BEC701 - FIBRE OPTIC COMMUNICATION

UNIT-I
INTRODUCTION TO OPTICAL FIBER

- Evolution of fiber Optic system
- Element of an Optical Fiber Transmission link
- Ray Optics
- Optical Fiber Modes and Configurations
- Mode theory of Circular Wave guides
- Overview of Modes
- Key Modal concepts
- Linearly Polarized Modes
- Single Mode Fibers
- Graded Index fiber structure

Introduction

- An optical Fiber is a thin, flexible, transparent Fiber that acts as a waveguide, or "light pipe", to transmit light between the two ends of the Fiber.
- Optical fibers are widely used in Fiber-optic communications, which permits transmission over longer distances and at higher bandwidths (data rates) than other forms of communication.
- Fibers are used instead of metal wires because signals travel along them with less loss and are also immune to electromagnetic interference.

Evolution of fiber Optic system

First generation

- The first generation of light wave systems uses GaAs semiconductor laser and operating region was near 0.8 μm. Other specifications of this generation are as under:
- i) Bit rate : 45 Mb/s
- ii) Repeater spacing : 10 km

Second generation

i) Bit rate: 100 Mb/s to 1.7 Gb/s ii) Repeater spacing: 50 km

iii) Operation wavelength: 1.3 μm iv) Semiconductor: In GaAsP

Third generation

i) Bit rate : 10 Gb/s

ii) Repeater spacing: 100 km

iii) Operating wavelength: 1.55 μm

Evolution of fiber Optic system

Fourth generation

- Fourth generation uses WDM technique. i) Bit rate: 10 Tb/s
- ii) Repeater spacing: > 10,000 km
- Iii) Operating wavelength: 1.45 to 1.62 μm

Fifth generation

- Fifth generation uses Roman amplification technique and optical solitiors. i) Bit rate: 40 - 160 Gb/s
- ii) Repeater spacing: 24000 km - 35000 km iii) Operating wavelength: 1.53 to 1.57 μm

Element of an Optical Fiber Transmission link

Basic block diagram of optical fiber communication system consists of following important blocks.

1. Transmitter
2. Information channel
3. Receiver.

Block diagram of OFC system

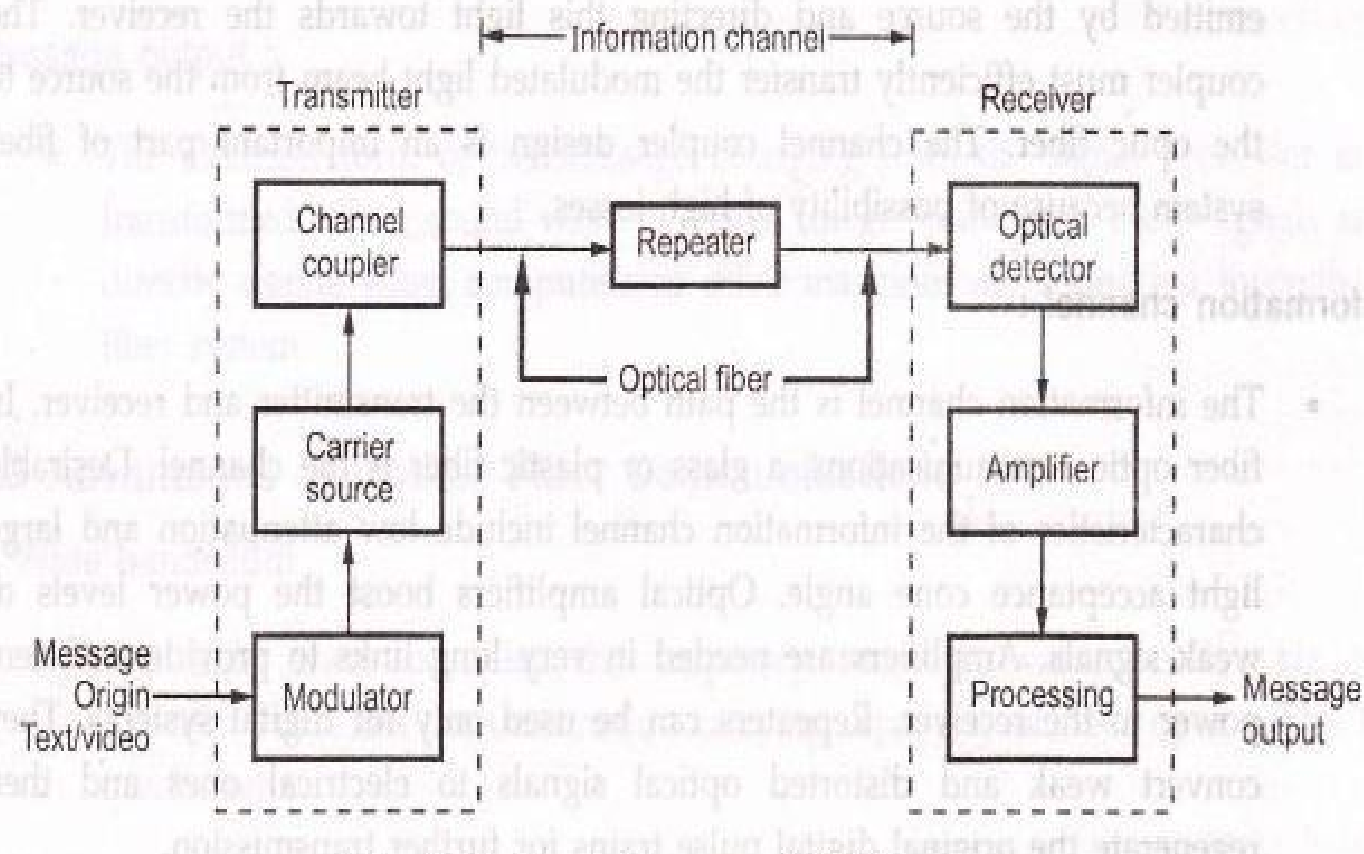


Fig. 1.2.1 Block diagram of OFC systems

- The light beam pulses are then fed into a fiber – optic cable where they are transmitted over long distances.
- At the receiving end, a light sensitive device known as a photocell or light detector is used to detect the light pulses.
- This photocell or photo detector converts the light pulses into an electrical signal.
- The electrical pulses are amplified and reshaped back into digital form.

Fiber optic Cable

Fiber Optic Cable consists of four parts.

- Core
- Cladding
- Buffer
- Jacket

Core. The core of a fiber cable is a cylinder of plastic that runs all along the fiber cable's length, and offers protection by cladding. The diameter of the core depends on the application used. Due to internal reflection, the light travelling within the core reflects from the core, the cladding boundary. The core cross section needs to be a circular one for most of the applications

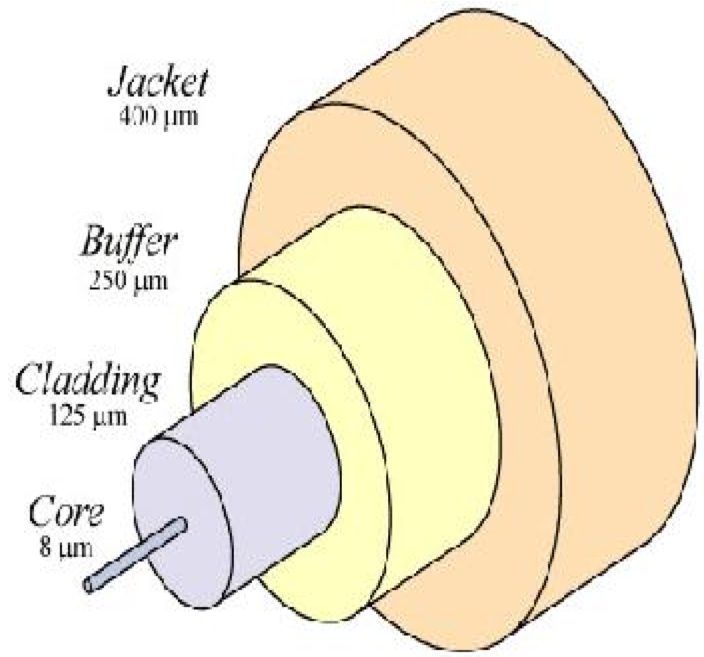
Cladding

Cladding is an outer optical material that protects the core. The main function of the cladding is that it reflects the light back into the core. When light enters through the core (dense material) into the cladding(less dense material), it changes its angle, and then reflects back to the core.

Fiber optic Cable

Buffer

- The main function of the buffer is to protect the fiber from damage and thousands of optical fibers arranged in hundreds of optical cables. These bundles are protected by the cable’s outer covering that is called jacket.



JACKET

Fiber optic cable's jackets are available in different colors that can easily make us recognize the exact color of the cable we are dealing with. The color yellow clearly signifies a single mode cable, and orange color indicates multimode.

- Both the light sources at the sending end and the light detectors on the receiving end must be capable of operating at the same data rate.
- The circuitry that drives the light source and the circuitry that amplifies and processes the detected light must both have suitable high-frequency response.
- The fiber itself must not distort the high-speed light pulses used in the data transmission.
- They are fed to a decoder, such as a Digital – to – Analog converter (D/A), where the original voice or video is recovered.

- In very long transmission systems, repeater units must be used along the way.
- Since the light is greatly attenuated when it travels over long distances, at some point it may be too weak to be received reliably.
- To overcome this problem, special relay stations are used to pick up light beam, convert it back into electrical pulses that are amplified and then retransmit the pulses on another beam.
- Several stages of repeaters may be needed over very long distances.
- But despite the attenuation problem, the loss is less than the loss that occurs with the electric cables.

Characteristics of fiber

1)Wider bandwidth: The optical carrier frequency is in the range 10^13 Hz to 10^15Hz.

2)Low transmission loss: The fibers having a transmission loss of 0.002dB/km.

3)Dielectric waveguide: Optical fibers are made from silica which is an electrical insulator. Therefore they do not pickup any electromagnetic wave or any high current lightning.

4)Signal security: The transmitted signal through the fibers does not radiate. Further the signal cannot be tapped from a Fiber in an easy manner.
5)Small size and weight: Fiber optic cables are developed with small radii, and they are flexible, compact and lightweight. The fiber cables can be bent or twisted without damage.

Operation of fiber

- A hair-thin Fiber consist of two concentric layers of high-purity silica glass the core and the cladding, which are enclosed by a protective sheath .
- Core and cladding have different refractive indices, with the core having a refractive index, n1, which is slightly higher than that of the cladding, n2.
- It is this difference in refractive indices that enables the Fiber to guide the light. Because of this guiding property, the Fiber is also referred to as an “optical waveguide.”

Advatages of optical fiber

1)WAVELENGTH : It is a characteristic of light that is emitted from the light source and is measures in nanometres (nm).

2)FREQUENCY : It is number of pulse per second emitted from a light source. Frequency is measured in units of hertz (Hz). In terms of optical pulse 1Hz = 1 pulse/ sec.

3)WINDOWS :A narrow window is defined as the range of wavelengths at which a fibre best operates.
4)ATTENUATION: Attenuation in optical fiber is caused by intrinsic factors, primarily scattering and absorption, and by extrinsic factors, including stress from the manufacturing process, the environment, and physical bending.
5)DISPERSION : Dispersion is the spreading of light pulse as its travels down the length of an optical fibre . Dispersion limits the bandwidth or information carrying capacity of a fibre.

Disadvantages of optical fiber

- High investment cost
- Need for more expensive optical transmitters and receivers
- More difficult and expensive to splice than wires
- Price
- Fragility
- Affected by chemicals
- Opaqueness
- Requires special skills

Ray Optics

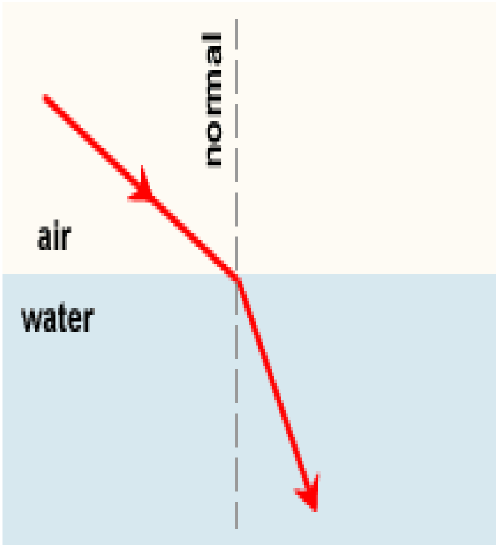
Basic laws of ray theory/geometric optics

- The basic laws of ray theory are quite self-explanatory
- In a homogeneous medium, light rays are straight lines.Light may be absorbed or reflected.
- Reflected ray lies in the plane of incidence and angle of incidence will be equal to the angle of reflection.
- At the boundary between two media of different refractive indices, the refracted ray will lie in the plane of incidence. Snell’s Law will give the relationship between the angles of incidence and refraction.

Ray Optics

Refraction of light

- As a light ray passes from one transparent medium to another, it changes direction; this phenomenon is called refraction of light. How much that light ray changes its direction depends on the refractive index of the mediums.



Ray Optics

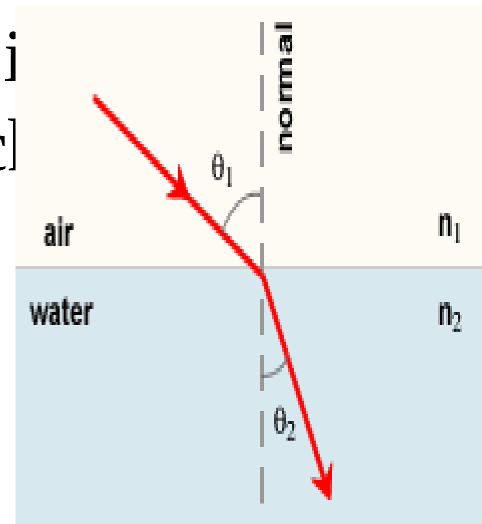
Refractive Index

- Refractive index is the speed of light in a vacuum (abbreviated **c**, **c**=299,792.458km/second) divided by the speed of light in a material (abbreviated **v**). Refractive index measures how much a material refracts light. Refractive index of a material, abbreviated as **n**, is defined as
- **n=c/v**

Ray Optics
Snells Law

- When light passes from one transparent material to another, i bends according to Snell's law which is defined as:

  $$n_1\sin(\theta_1) = n_2\sin(\theta_2)$$



where:

n_1 is the refractive index of the medium the light is leaving

$\boldsymbol{\theta_1}$ is the incident angle between the light beam and the normal (normal is 90° to the interface between two materials)

$\boldsymbol{n_2}$ is the refractive index of the material the light is entering

$\boldsymbol{\theta_2}$ is the refractive angle between the light ray and the normal

Ray Optics
Critical angle

- The critical angle can be calculated from Snell's law, putting in an angle of 90° for the angle of the refracted ray $\boldsymbol{\theta_2}$. This gives $\boldsymbol{\theta_1}$:

Since

$$\boldsymbol{\theta_2} = 90°$$

So

$$\mathbf{sin}(\boldsymbol{\theta_2}) = 1$$

Then

$$\boldsymbol{\theta_c = \theta_1} = \mathbf{arcsin}(\boldsymbol{n_2/n_1})$$

Numerical Aperture (NA) For step-index multimode fiber, the acceptance angle is determined only by the indices of refraction:

$$NA = n \sin\theta_{\max} = \sqrt{n_f^{\,2} - n_c^{\,2}}$$

Where

n is the refractive index of the medium light is traveling before entering the fiber

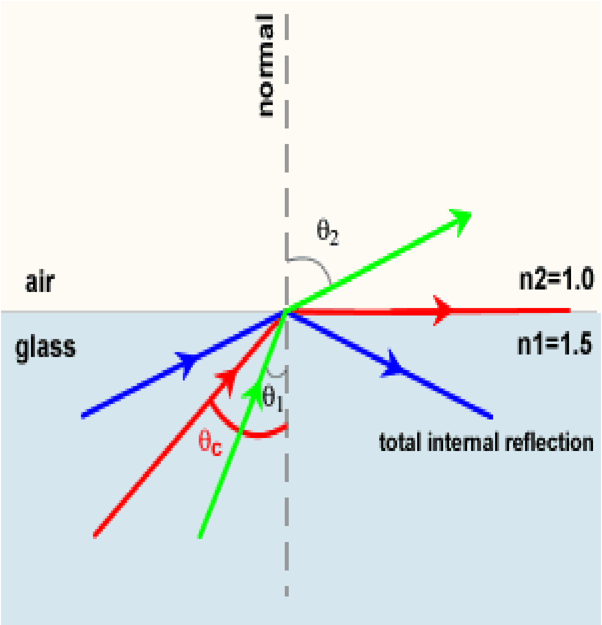
$\boldsymbol{n_f}$ is the refractive index of the fiber core

$\boldsymbol{n_c}$ is the refractive index of the cladding

Ray Optics

Total internal reflection

- If the light hits the interface at any angle larger than this critical angle, it will not pass through to the second medium at all. Instead, all of it will be reflected back into the first medium, a process known as **total internal reflection**.



Fiber Optic Modes

Mode is the one which describes the nature of propagation of electromagnetic waves in a wave guide.

i.e. it is the allowed direction whose associated angles satisfy the conditions for total internal reflection and constructive interference.

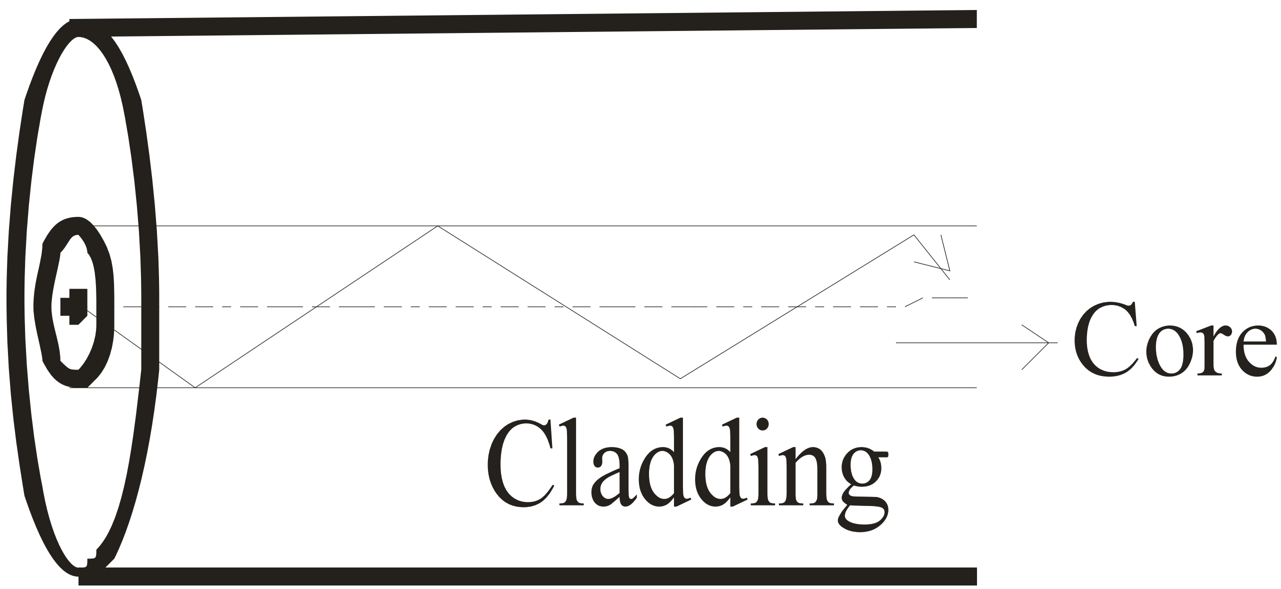
Based on the number of modes that propagates through the optical fiber, they are classified as:

- Single mode fibers
- Multi mode fibers

Single mode fibers

- In a fiber, if only one mode is transmitted through it, then it is said to be a single mode fiber.
- A typical single mode fiber may have a core radius of 3 μm and a numerical aperture of 0.1 at a wavelength of 0.8 μm.
- The condition for the single mode operation is given by the V number of the fiber which is defined as such that $V \leq 2.405$.
- Here, n_1 = refractive index of the core; a = radius of the core; λ = wavelength of the light propagating through the fiber; Δ = relative refractive indices difference.

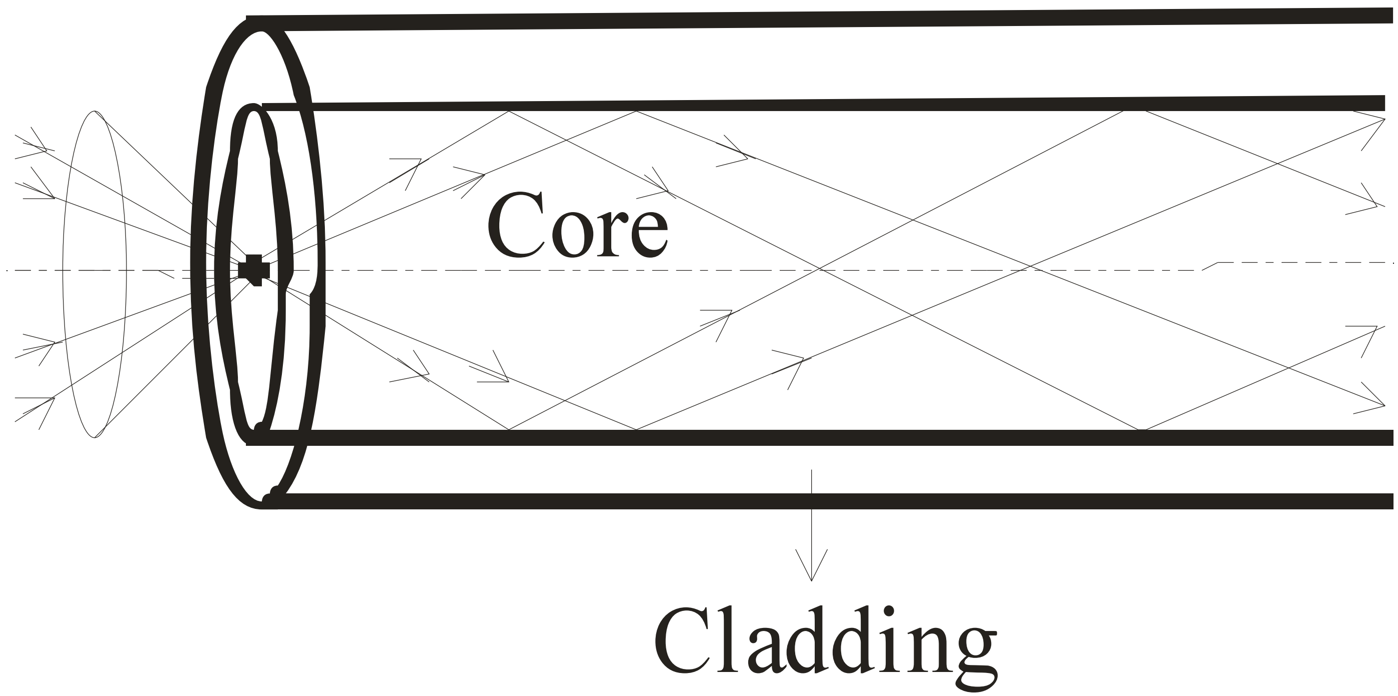
Single mode fibers



Single mode fibers

- Only one path is available.
- V-number is less than 2.405
- Core diameter is small
- No dispersion
- Higher band width (1000 MHz)
- Used for long haul communication
- Fabrication is difficult and costly

Multimode fibers



Multi mode fibers

- If more than one mode is transmitted through optical fiber, then it is said to be a multimode fiber.
- The larger core radii of multimode fibers make it easier to launch optical power into the fiber and facilitate the end to end connection of similar powers.

Some of the basic properties of multimode optical fibers are listed below :

- More than one path is available
- V-number is greater than 2.405

Types of fibers based on Refractive Index Profile

Based on the refractive index profile of the core and cladding, the optical fibers are classified into two types:

- Step index fiber
- Graded index fiber

Step index fiber

- In a step index fiber, the refractive index changes in a step fashion, from the centre of the fiber, the core, to the outer shell, the cladding.
- It is high in the core and lower in the cladding. The light in the fiber propagates by bouncing back and forth from core-cladding interface.
- The step index fibers propagate both single and multimode signals within the fiber core.
- The light rays propagating through it are in the form of meridinal rays which will cross the fiber core axis during every reflection at the core – cladding boundary and are propagating in a zig – zag manner.

Step index fiber

- With careful choice of material, dimensions and λ, the total dispersion can be made extremely small, less than 0.1 ps /(km $\times$ nm), making this fiber suitable for use with high data rates.
- In a single-mode fiber, a part of the light propagates in the cladding.
- The cladding is thick and has low loss.
- Typically, for a core diameter of 10 μm, the cladding diameter is about 120 μm.
- Handling and manufacturing of single mode step index fiber is more difficult.

Step index multimode fibers

- A multimode step index fiber is shown.
- In such fibers light propagates in many modes.
- The total number of modes *MN* increases with increase in the numerical aperture.
- For a larger number of modes, *MN* can be approximated by

$$M_N = \frac{V^2}{2} = 4.9\left[\frac{dn_1\sqrt{2\Delta}}{\lambda}\right]^2$$

Step index multimode fibers

where *d* = diameter of the core of the fiber and *V* = V – number or normalized frequency.
The normalized frequency *V* is a relation among the fiber size, the refractive indices and the wavelength. *V* is the normalized frequency or simply the *V* number and is given by

$$V = \left(\frac{2\pi a}{\lambda}\right) \times \mathrm{N.A} = \left(\frac{2\pi a}{\lambda}\right) \times n_1 \times (2\Delta)^{\frac{1}{2}}$$

where *a* is the fiber core radius, λ is the operating wavelength, *n1* the core refractive index and Δ the relative refractive index difference

Graded index fiber

- A graded index fiber is shown in Fig.3.27. Here, the refractive index n in the core varies as we move away from the centre.
- The refractive index of the core is made to vary in the form of parabolic manner such that the maximum refractive index is present at the centre of the core.
- The refractive index (n) profile with reference to the radial distance (r) from the fiber axis is given as:

Graded index fiber

when $r = 0, n(r) = n1$

$r < a, n(r) =$

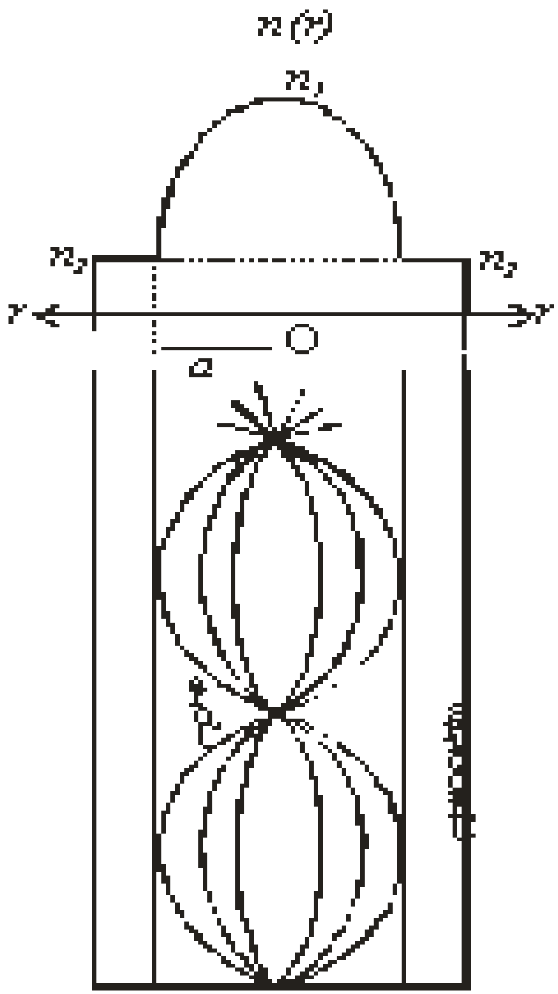
$$n_1\left[1-\left(2\Delta\left[\frac{r}{a}\right]^2\right)\right]^{\frac{1}{2}}$$

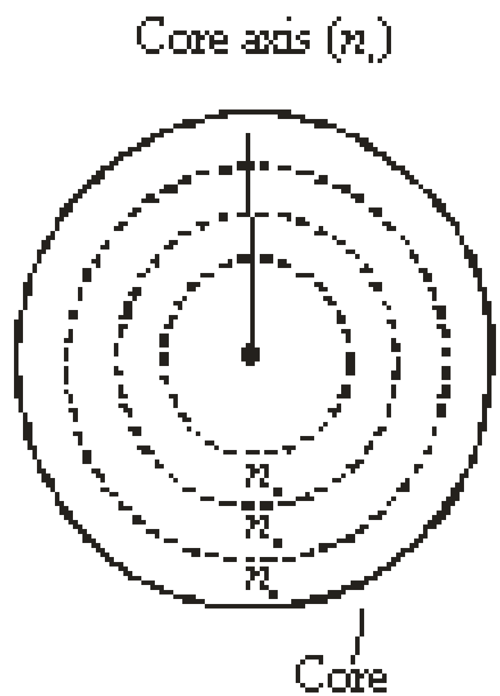
$r \geq a,\ n(r) = n2\ =$

$$n_1(1-2\Delta)^{\frac{1}{2}}$$

At the fiber centre we have *n1*; at the cladding we have *n2*; and in between we have *n(r)*, where n is the function of the particular radius as shown in Fig. simulates the change in *n* in a stepwise manner.

Graded index fiber





Graded index fiber

- Each dashed circle represents a different refractive index, decreasing as we move away from the fiber center.
- A ray incident on these boundaries between $n_a - n_b$, $n_b - n_c$ etc., is refracted.
- Eventually at n_2 the ray is turned around and totally reflected.
- This continuous refraction yields the ray tracings as shown in Fig.

Graded index fiber

- The light rays will be propagated in the form skew rays (or) helical rays which will not cross the fiber axis at any time and are propagating around the fiber axis in a helical or spiral manner.

- The effective acceptance angle of the graded-index fiber is somewhat less than that of an equivalent step-index fiber. This makes coupling fiber to the light source more difficult.

UNIT-II
SIGNAL DEGRADATION IN OPTICAL FIBER

- Attenuation – Absorption losses, Scattering losses, Bending Losses, Core and Cladding losses,
- Signal Distortion in Optical Wave guides – Information Capacity determination – Group Delay –
- Material Dispersion, Wave guide Dispersion,
- Signal distortion in SM fibers – Polarization Mode dispersion, Intermodal dispersion,
- Pulse Broadening in GI fibers
- Mode Coupling – Design Optimization of SM fibers – RI profile and cut-off wavelength.

Signal Attenuation & Distortion in Optical Fibers

- What are the loss or signal attenuation mechanism in a fiber?
- Why & to what degree do optical signals get distorted as they propagate down a fiber?
- Signal attenuation (fiber loss) largely determines the maximum repeaterless separation between optical transmitter & receiver.
- Signal distortion cause that optical pulses to broaden as they travel along a fiber, the overlap between neighboring pulses, creating errors in the receiver output, resulting in the limitation of information-carrying capacity of a fiber.

Attenuation (fiber loss)

- Power loss along a fiber:

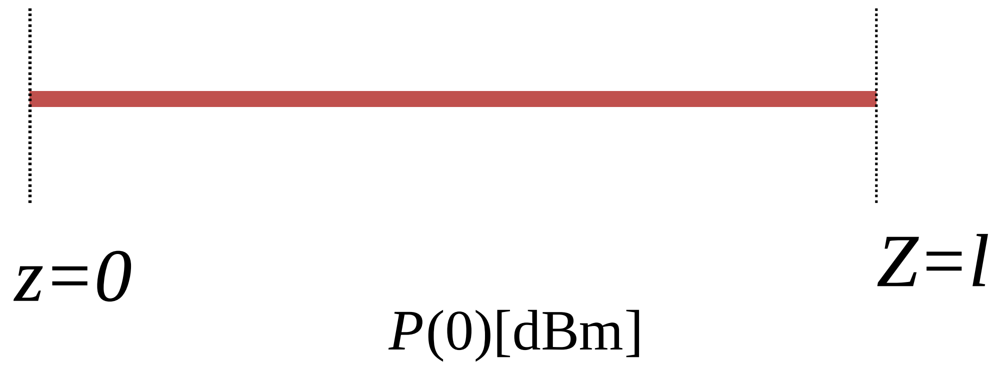
$$P(l) = P(0)e^{-\alpha_p l} \quad \text{mw}$$

$$P(z) = P(0)e^{-\alpha_p z} \qquad [3\text{-}1]$$

- The parameter α_p is called fiber attenuation coefficient in a units of for example [1/km] or [nepers/km]. A more common unit is [dB/km] that is defined by:

$$\alpha[\text{dB/km}] = \frac{10}{l}\log\left[\frac{P(0)}{P(l)}\right] = 4.343\alpha_p[1/\text{km}] \qquad [3\text{-}2]$$

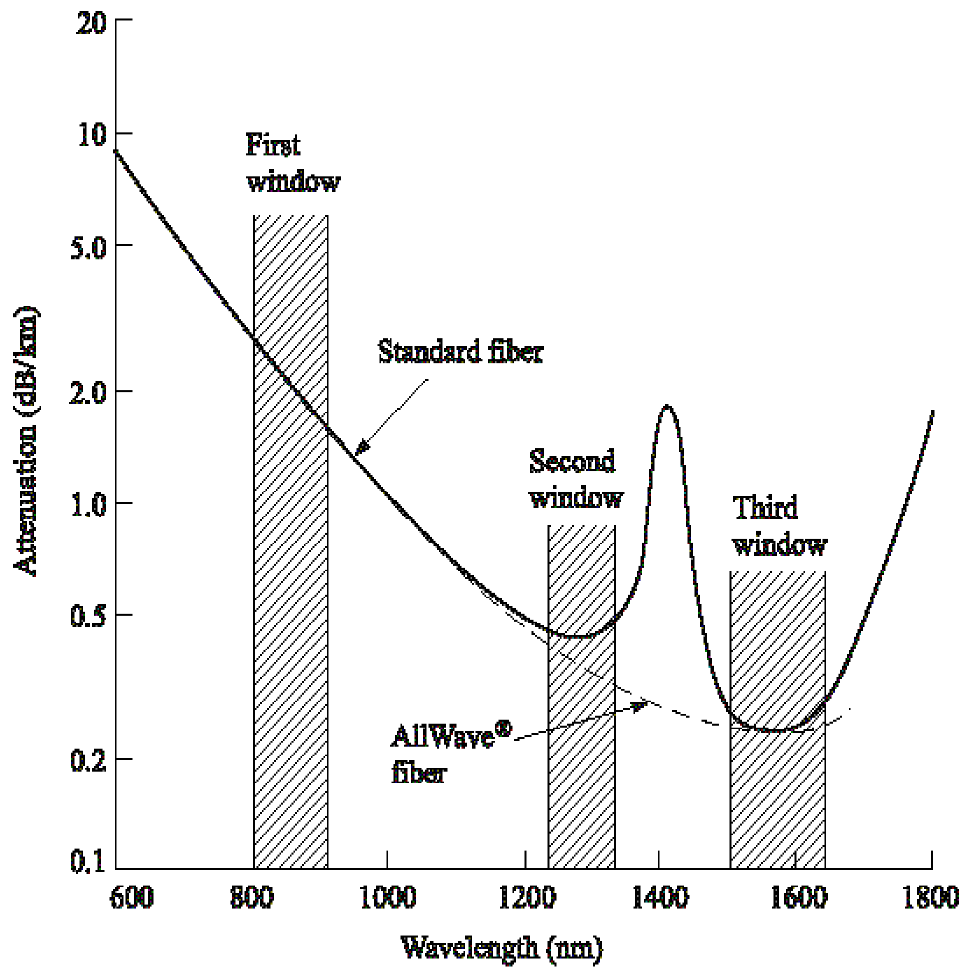
Fiber loss in dB/km



$$P(l)[\text{dBm}] = P(0)[\text{dBm}] - \alpha[\text{dB/km}] \times l[\text{km}] \qquad [3\text{-}3]$$

- Where [dBm] or dB milliwat is 10log(P [mW]).

Optical fiber attenuation vs. wavelength



Absorption

- Absorption is caused by three different mechanisms:

1- Impurities in fiber material: from transition metal ions (must be in order of ppb) & particularly from OH ions with absorption peaks at wavelengths 2700 nm, 400 nm, 950 nm & 725nm.

2- Intrinsic absorption (fundamental lower limit): electronic absorption band (UV region) & atomic bond vibration band (IR region) in basic SiO2.

3- Radiation defects

Scattering Loss

- Small (compared to wavelength) variation in material density, chemical composition, and structural inhomogeneity scatter light in other directions and absorb energy from guided optical wave.

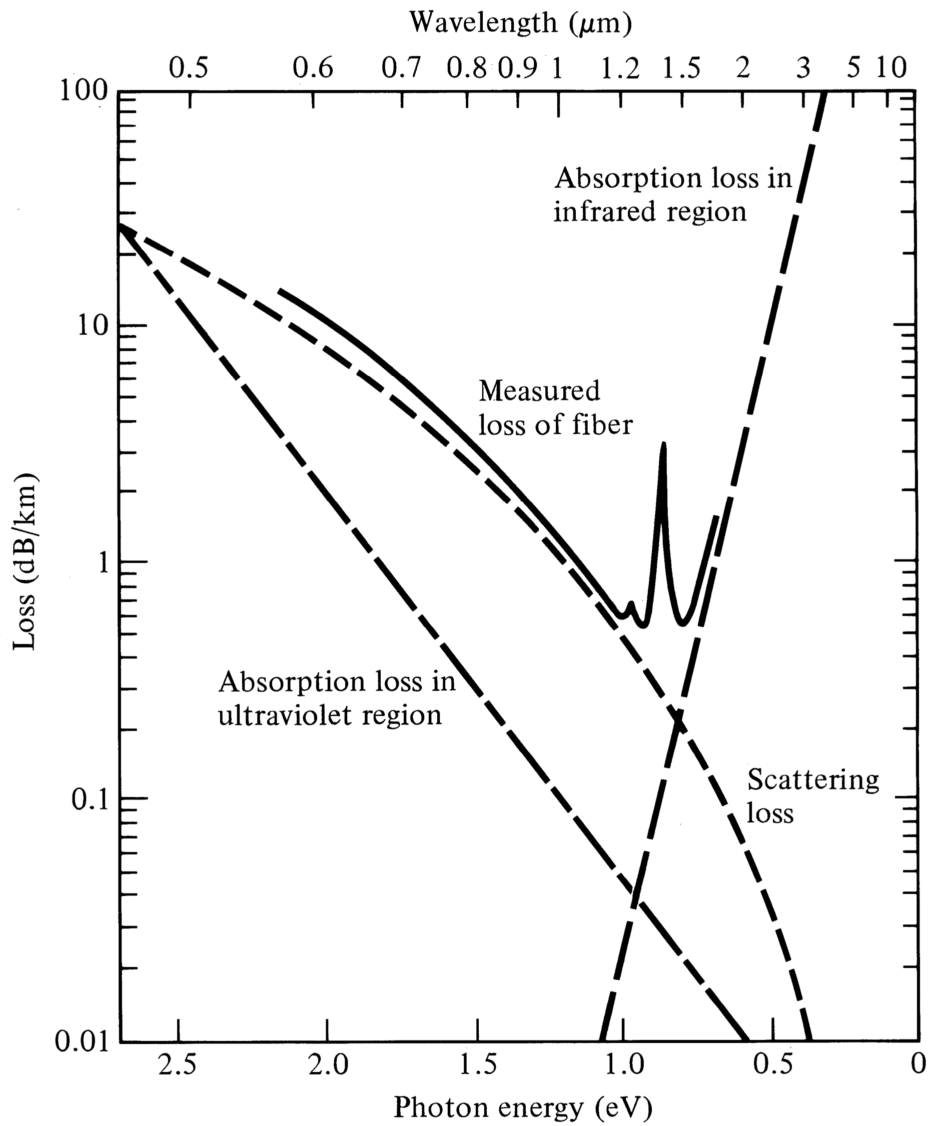
- The essential mechanism is the Rayleigh scattering. Since the black body radiation classically is proportional to λ^{-4} (this is true for wavelength typically greater than 5 micrometer), the attenuation coefficient due to Rayleigh scattering is approximately proportional to λ^{-4}.

This seems to me not precise, where the attenuation of fibers at 1.3 & 1.55 micrometer can be exactly predicted with Planck’s formula & can not be described with Rayleigh-Jeans law. Therefore I believe that the more accurate formula for scattering loss is

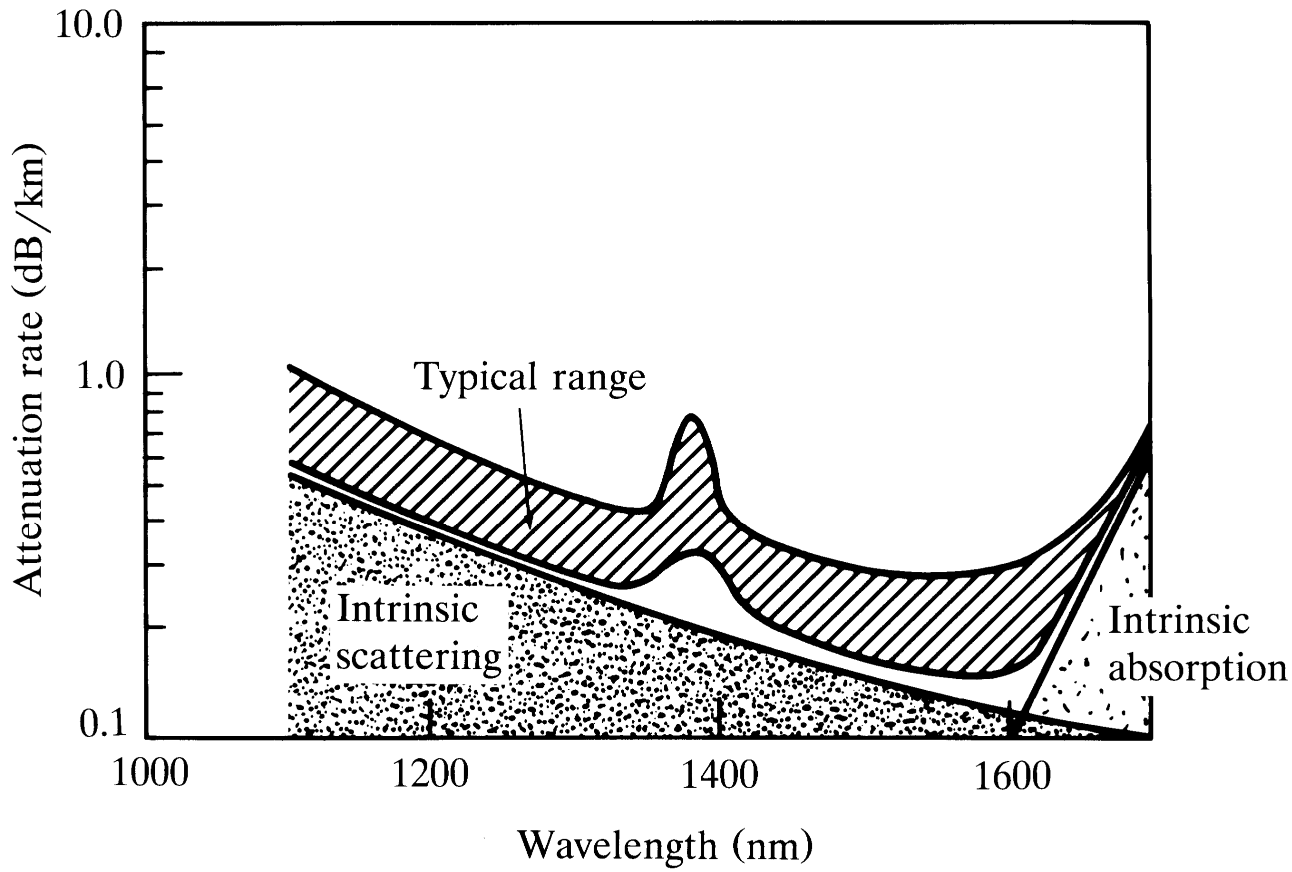
$$\alpha_{scat} \propto \lambda^{-5}\left[\exp\left(\frac{hc}{\lambda k_B T}\right)\right]^{-1}$$

$$h = 6.626\times10^{-34}\ \text{Js},\quad k_B = 1.3806\times10^{-23}\ \text{JK}^{-1},\ T:\text{Temperature}$$

Absorption & scattering losses in fibers

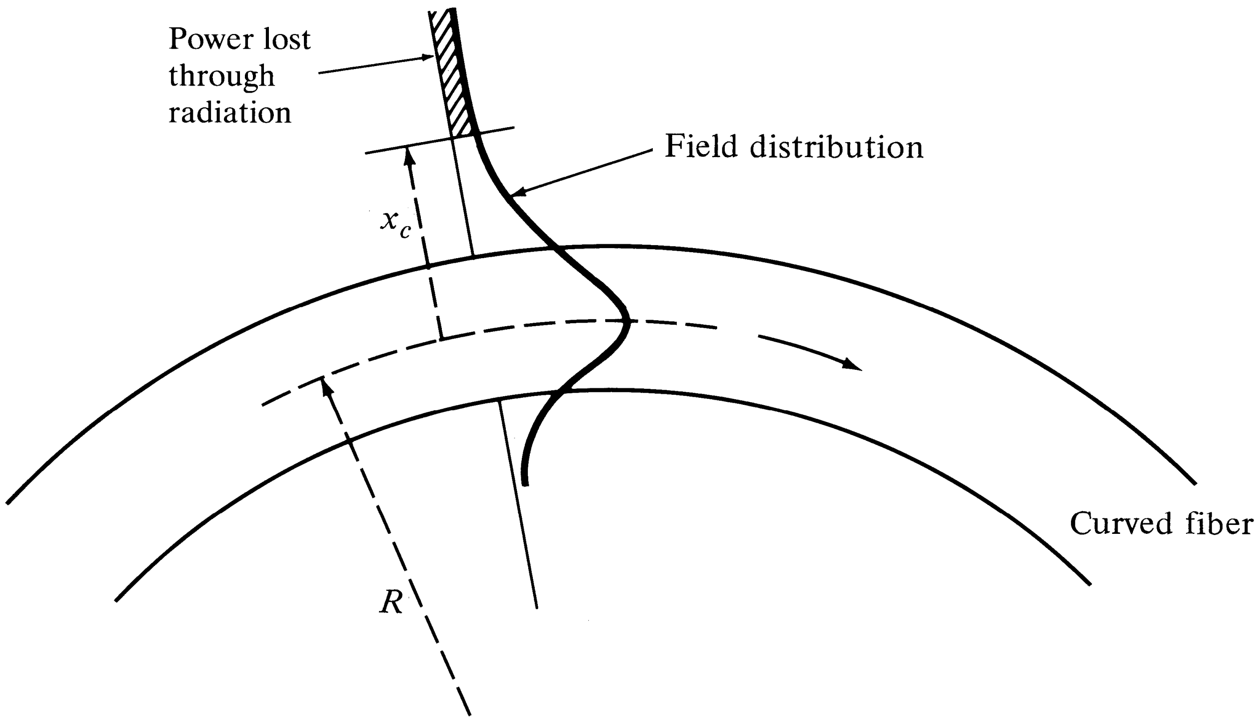


Typical spectral absorption & scattering attenuations for a single mode-fiber



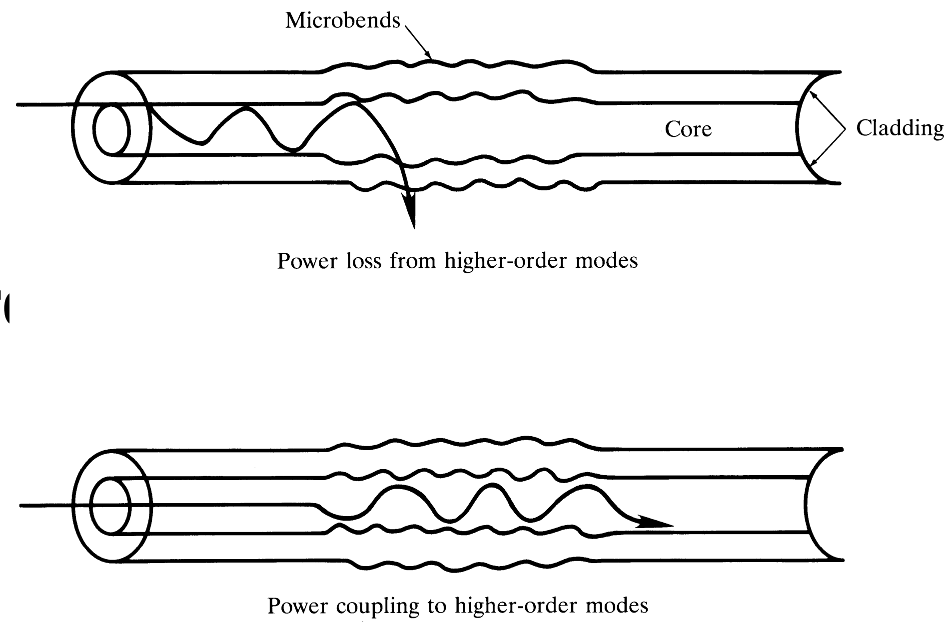
Bending Loss (Macrobending & Microbending)

- **Macrobending Loss**: The curvature of the bend is much larger than fiber diameter. Lightwave suffers sever loss due to radiation of the evanescent field in the cladding region. As the radius of the curvature decreases, the loss increases exponentially until it reaches at a certain critical radius. For any radius a bit smaller than this point, the losses suddenly becomes extremely large. Higher order modes radiate away faster than lower order modes.


Power lost
through
radiation
Field distribution
x_c
R
Curved fiber

Microbending Loss

Microbending Loss: microscopic bends of the fiber axis that can arise when the fibers ar incorporated into cables. The power is dissipated through the microbended fiber, because of the repetitive coupling of energy between guided modes & the leaky or radiation modes in the fiber.



Dispersion in Optical Fibers

- **Dispersion**: Any phenomenon in which the velocity of propagation of any electromagnetic wave is wavelength dependent.

- In communication, dispersion is used to describe any process by which any electromagnetic signal propagating in a physical medium is degraded because the various wave characteristics (i.e., frequencies) of the signal have different propagation velocities within the physical medium.

There are 3 dispersion types in the optical fibers, in general:

1- Material Dispersion
2- Waveguide Dispersion
3- Polarization-Mode

Dispersion

Material & waveguide dispersions are main causes of Intramodal Dispersion.

Group Velocity

- Wave Velocities:
- 1- **Plane wave velocity**: For a plane wave propagating along *z*-axis in an unbounded homogeneous region of refractive index n_1, which is represented by $\exp(j\omega t - jk_1 z)$, the velocity of constant phase plane is:

$$v = \frac{\omega}{k_1} = \frac{c}{n_1} \qquad [3\text{-}4]$$

$$v_p = \frac{\omega}{\beta} \qquad [3\text{-}5]$$

- 2- **Modal wave phase velocity**: For a modal wave propagating along *z*-axis represented by $\exp(j\omega t - jk_1 z)$, the velocity of constant phase plane is:

3- For transmission system operation the most important & useful type of velocity is the **group velocity,** V_g **.** This is the actual velocity which the signal information & energy is traveling down the fiber. It is always less than the speed of light in the medium. The observable delay experiences by the optical signal waveform & energy, when traveling a length of l along the fiber is commonly referred to as **group delay**.

Group Velocity & Group Delay

- The group velocity is given by:

$$V_g = \frac{d\omega}{d\beta} \qquad [3\text{-}6]$$

- The group delay is given by:

$$\tau_g = \frac{l}{V_g} = l\frac{d\beta}{d\omega} \qquad [3\text{-}7]$$

- It is important to note that all above quantities depend both on **frequency** & the **propagation mode**. In order to see the effect of these parameters on group velocity and delay, the following analysis would be helpful.

Input/Output signals in Fiber Transmission System

- The optical signal (complex) waveform at the input of fiber of length *l* is *f(t)*. The propagation constant of a particular modal wave carrying the signal is $\beta(\omega)$. Let us find the output signal waveform *g(t)*.

z-=0 $\Delta\omega$ is the optical signal bandwidth. *Z=l*

$$f(t) = \int_{\omega_c - \Delta\omega}^{\omega_c + \Delta\omega} \tilde{f}(\omega) e^{j\omega t} d\omega \qquad [3\text{-}8]$$

$$g(t) = \int_{\omega_c - \Delta\omega}^{\omega_c + \Delta\omega} \tilde{f}(\omega) e^{j\omega t - j\beta(\omega) l} d\omega \qquad [3\text{-}9]$$

If $\Delta\omega << \omega_c$

$$\beta(\omega) = \beta(\omega_c) + \left.\frac{d\beta}{d\omega}\right|_{\omega=\omega_c} (\omega - \omega_c) + \frac{1}{2}\left.\frac{d^2\beta}{d\omega^2}\right|_{\omega=\omega_c} (\omega - \omega_c)^2 + \ldots \qquad [3\text{-}10]$$

$$g(t) = \int_{\omega_c-\Delta\omega/2}^{\omega_c+\Delta\omega/2} \tilde{f}(\omega) e^{j\omega t - j\beta(\omega) l} d\omega \approx \int_{\omega_c-\Delta\omega/2}^{\omega_c+\Delta\omega/2} \tilde{f}(\omega) e^{j\omega t - j[\beta(\omega_c) + \left.\frac{d\beta}{d\omega}\right|_{\omega=\omega_c}(\omega-\omega_c)]l} d\omega$$

$$\approx e^{-j\beta(\omega_c)l} \int_{\omega_c-\Delta\omega/2}^{\omega_c+\Delta\omega/2} \tilde{f}(\omega) e^{j\omega(t - l\left.\frac{d\beta}{d\omega}\right|_{\omega=\omega_c})} d\omega$$

$$= e^{-j\beta(\omega_c)l} f(t - l\left.\frac{d\beta}{d\omega}\right|_{\omega=\omega_c}) = e^{-j\beta(\omega_c)l} f(t - \tau_g) \qquad [3\text{-}11]$$

$$\tau_g = l\left.\frac{d\beta}{d\omega}\right|_{\omega=\omega_c} = \frac{l}{V_g} \qquad [3\text{-}14]$$

Intramodal Dispersion

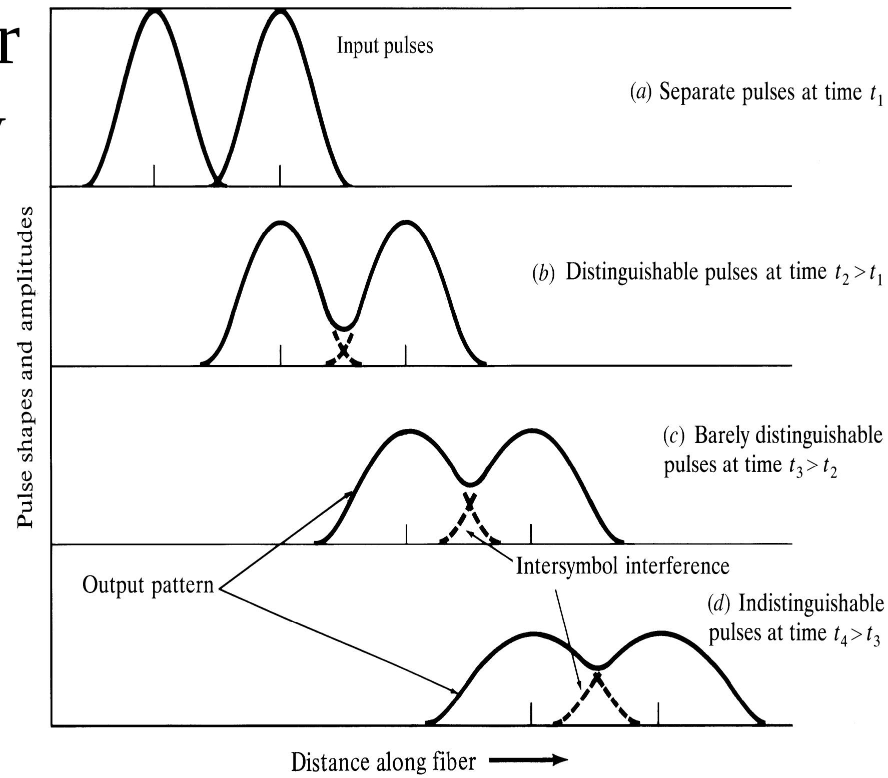
- As we have seen from Input/output signal relationship in optical fiber, the output is proportional to the delayed version of the input signal, and the delay is inversely proportional to the group velocity of the wave. Since the propagation constant, $\Delta\omega$, is frequency dependent over band width $\beta(\omega)$ sitting at the center frequency ω_c , at each frequency, we have one propagation constant resulting in a specific delay time.

As the output signal is collectively represented by group velocity & group delay this phenomenon is called intramodal dispersion or Group Velocity Dispersion (GVD). This phenomenon arises due to a finite bandwidth of the optical source, dependency of refractive index on the wavelength and the modal dependency of the group velocity.

In the case of optical pulse propagation down the fiber, GVD causes pulse broadening, leading to Inter Symbol Interference (ISI).

Dispersion & ISI

A measure of information capacity of an optical fiber for digital transmission is usually specified by the bandwidth distance product in GHz.km. For multi-mode step index fiber this quantity is about 20 MHz.km, for graded index fiber is about 2.5 GHz.km & for single mode fibers are higher than 10 GHz.km.



$$BW \times L$$

How to characterize dispersion?

- Group delay per unit length can be defined as:

$$\frac{\tau_g}{L} = \frac{d\beta}{d\omega} = \frac{1}{c}\frac{d\beta}{dk} = -\frac{\lambda^2}{2\pi c}\frac{d\beta}{d\lambda} \qquad [3\text{-}15]$$

- If the spectral width of the optical source is not too wide, then the delay difference per unit wavelength $\delta\lambda$ along the propagation path is approximately For spectral components which are $\delta\tau$ apart, symmetrical around center wavelength, the total delay difference over a distance L is: $\frac{d\tau_g}{d\lambda}$

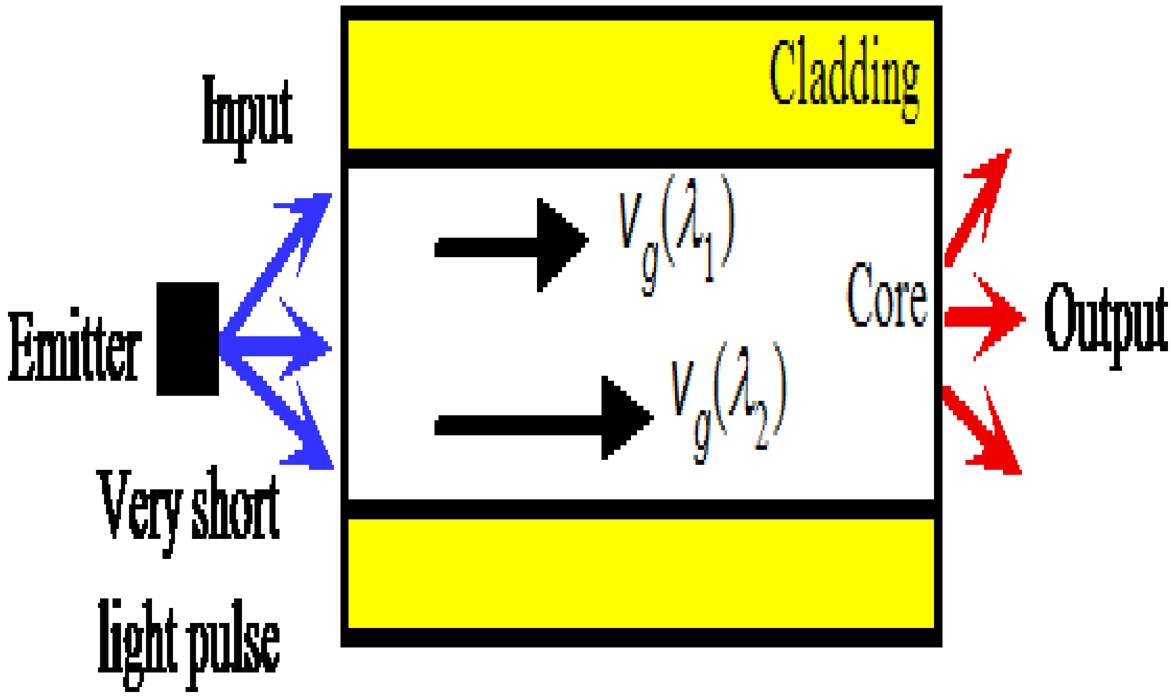
- $\beta_2 \equiv \frac{d^2\beta}{d\omega^2}$ is called GVD parameter, and shows how much a light pulse broadens as it travels along an optical fiber. The more common parameter is called Dispersion, and can be defined as the delay difference per unit length per unit wavelength as follows:

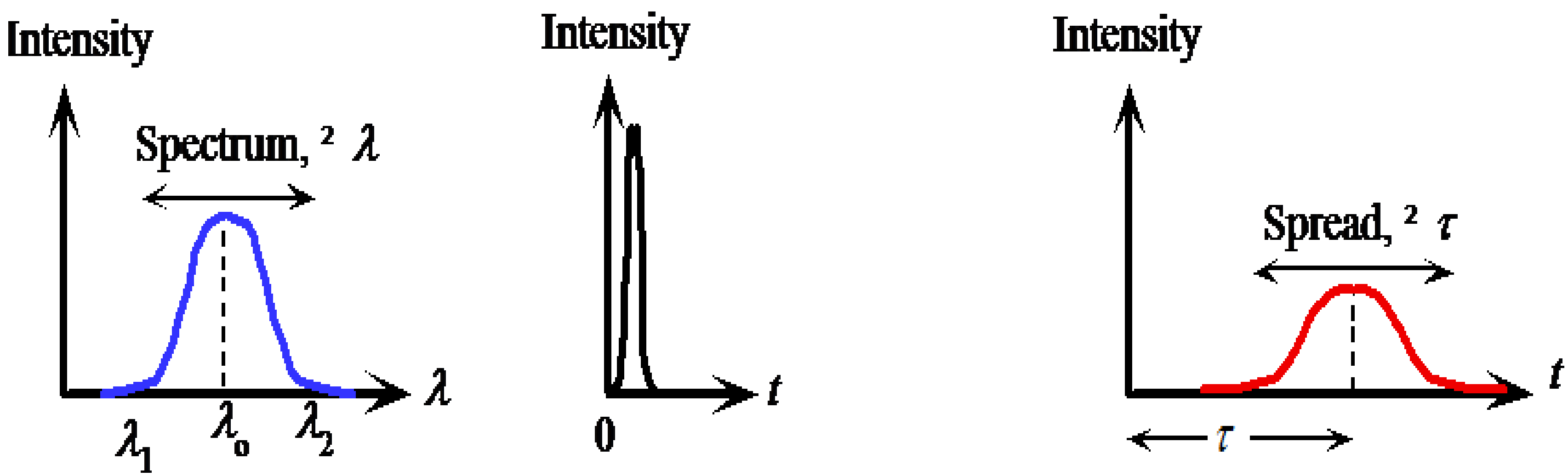
$$D = \frac{1}{L}\frac{d\tau_g}{d\lambda} = \frac{d}{d\lambda}\left(\frac{1}{V_g}\right) = -\frac{2\pi c}{\lambda^2}\beta_2 \qquad [3\text{-}17]$$

- In the case of optical pulse, if the spectral width of the optical source is characterized by its rms value of the Gaussian pulse σ_g , the pulse spreading over the length of L, σ_λ can be well approximated by:

$$\sigma_g \approx \left|\frac{d\tau_g}{d\lambda}\right|\sigma_\lambda = DL\sigma_\lambda \qquad [3\text{-}18]$$

Material Dispersion





All excitation sources are inherently non-monochromatic and emit within a spectrum, $^{2}\lambda$, of wavelengths. Waves in the guide with different free space wavelengths travel at different group velocities due to the wavelength dependence of n_1. The waves arrive at the end of the fiber at different times and hence result in a broadened output pulse.

Material Dispersion

- The refractive index of the material varies as a function of wavelength, $n(\lambda)$
- Material-induced dispersion for a plane wave propagation in homogeneous medium of refractive index *n*:

$$\tau_{mat} = L\frac{d\beta}{d\omega} = -\frac{\lambda^2}{2\pi c}L\frac{d\beta}{d\lambda} = -\frac{\lambda^2}{2\pi c}L\frac{d}{d\lambda}\left[\frac{2\pi}{\lambda}n(\lambda)\right]$$

$$= \frac{L}{c}\left(n - \lambda\frac{dn}{d\lambda}\right) \qquad [3\text{-}19]$$

- The pulse spread due to material dispersion is therefore:

$$\sigma_g \approx \left|\frac{d\tau_{mat}}{d\lambda}\right|\sigma_\lambda = \frac{L\sigma_\lambda}{c}\left|\lambda\frac{d^2n}{d\lambda^2}\right| = L\sigma_\lambda\left|D_{mat}(\lambda)\right| \qquad [3\text{-}20]$$

$D_{mat}(\lambda)$ is material dispersion

Material Dispersion Diagrams

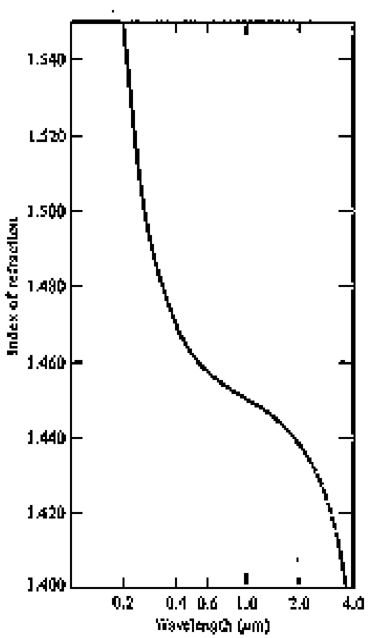


FIGURE 3-12
Variations in the index of refraction as a function of the optical wavelength for silica. (Reproduced with permission from I. H. Malitson, *J. Opt. Soc. Amer.*, vol. 55, pp. 1205–1209, Oct. 1965.)

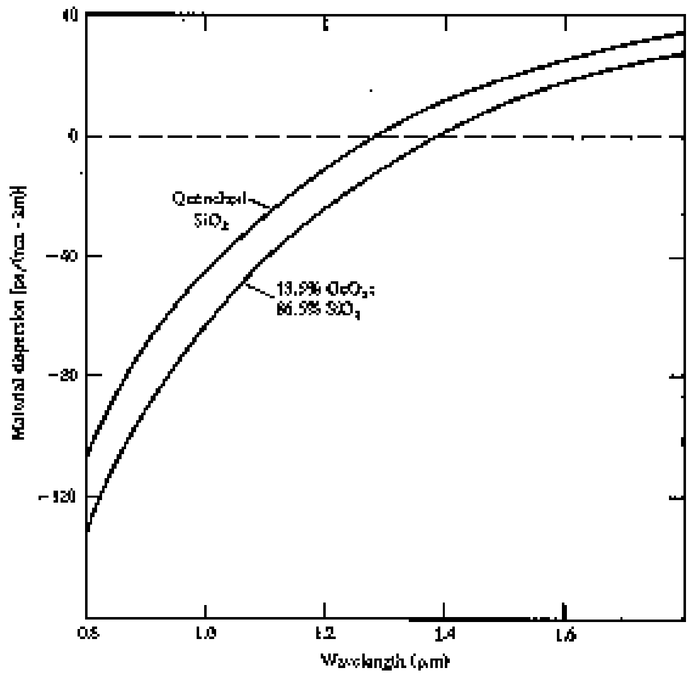


FIGURE 3-13
Material dispersion as a function of optical wavelength for pure silica and 13.5 percent GeO_2/86.5 percent SiO_2. (Reproduced with permission from J. W. Fleming, *Electron. Lett.*, vol. 14, pp. 326–328, May 1978.)

Waveguide Dispersion

- Waveguide dispersion is due to the dependency of the group velocity of the fundamental mode as well as other modes on the *V* number, (see Fig 2-18 of the textbook). In order to calculate waveguide dispersion, we consider that *n* is not dependent on wavelength. Defining the normalized propagation constant *b* as:

$$b = \frac{\beta^2 / k^2 - n_2^{\ 2}}{n_1^{\ 2} - n_2^{\ 2}} \approx \frac{\beta / k - n_2}{n_1 - n_2} \qquad \text{[3-21]}$$

- solving for propagation constant:

$$\beta \approx n_2 k(1 + b\Delta) \qquad \text{[3-22]}$$

- Using *V* number: $V = ka(n_1^{\ 2} - n_2^{\ 2})^{1/2} \approx kan_2\sqrt{2\Delta}$ [3-23]

Waveguide Dispersion

- Delay time due to waveguide dispersion can then be expressed as:

$$\tau_{wg} = \frac{L}{c}\left[n_2 + n_2 \Delta \frac{d(Vb)}{dV} \right] \quad [3\text{-}24]$$

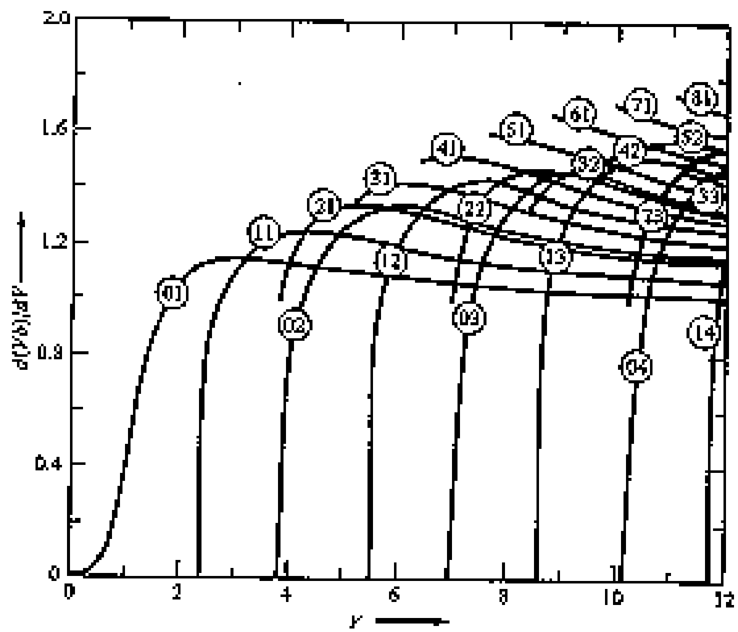


FIGURE 3-14
The group delay arising from waveguide dispersion as a function of the V number for a step-index optical fiber. The curve numbers jm designate the LP$_{jm}$ modes. (Reproduced with permission from Gloge.[37])

Waveguide dispersion in single mode fibers

- For single mode fibers, waveguide dispersion is in the same order of material dispersion. The pulse spread can be well approximated as:

$$\sigma_{wg} \approx \left|\frac{d\tau_{wg}}{d\lambda}\right|\sigma_\lambda = L\sigma_\lambda \left|D_{wg}(\lambda)\right| = \frac{n_2 L\Delta\sigma_\lambda}{c\lambda} V \frac{d^2(Vb)}{dV^2} \qquad [3\text{-}25]$$

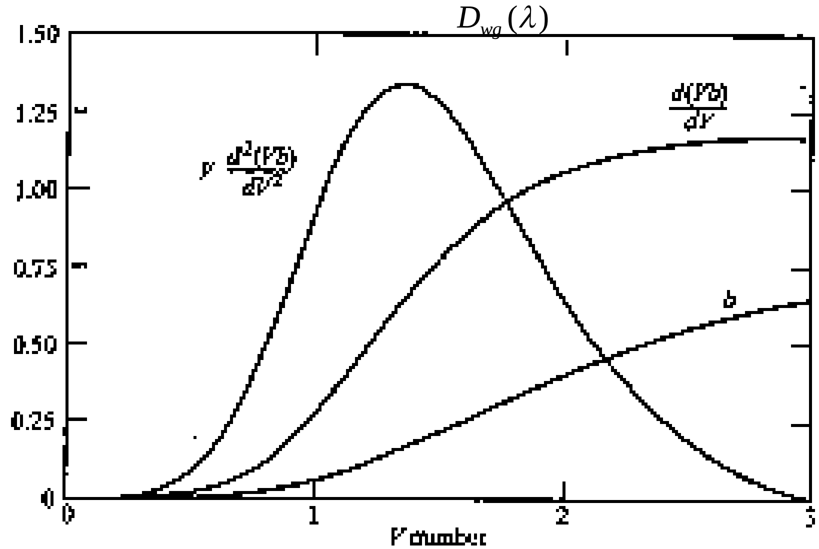
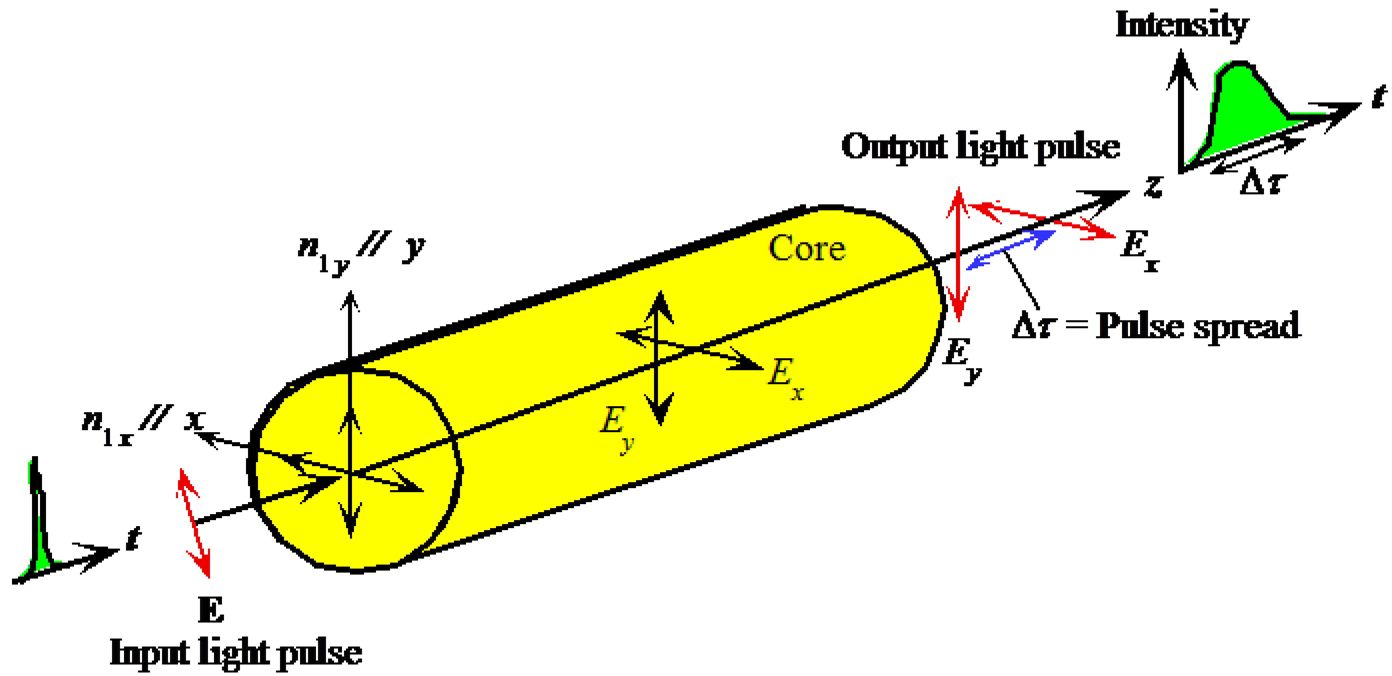


FIGURE 3-15
The waveguide parameter b and its derivatives $d(Vb)/dV$ and $V\,d^2(Vb)/dV^2$ plotted as a function of the V number for the HE_{11} mode.

Polarization Mode dispersion



Suppose that the core refractive index has different values along two orthogonal directions corresponding to electric field oscillation direction (polarizations). We can take x and y axes along these directions. An input light will travel along the fiber with and E_y polarizations having different group velocities and hence arrive at the output at different times

Polarization Mode dispersion

- The effects of fiber-birefringence on the polarization states of an optical are another source of pulse broadening. **Polarization mode dispersion** (PMD) is due to slightly different velocity for each polarization mode because of the lack of perfectly symmetric & anisotropicity of the fiber. If the group velocities of two orthogonal polarization modes are v_{gx} and v_{gy} then the differential time delay $\Delta\tau_{pol}$ between these two polarization over a distance L is

$$\Delta\tau_{pol} = \left| \frac{L}{v_{gx}} - \frac{L}{v_{gy}} \right| \quad [3\text{-}26]$$

- The rms value of the differential group delay can be approximated as:

$$\langle \Delta\tau_{pol} \rangle \approx D_{PMD}\sqrt{L} \quad [3\text{-}27]$$

Chromatic & Total Dispersion

- Chromatic dispersion includes the material & waveguide dispersions.

$$D_{ch}(\lambda) \approx \left| D_{mat} + D_{wg} \right|$$

$$\sigma_{ch} = D_{ch}(\lambda) L \sigma_{\lambda}$$

[3-28]

- Total dispersion is the sum of chromatic , polarization dispersion and other dispersion types and the total rms pulse spreading can be approximately written as:

$$D_{total} \approx \left| D_{ch} + D_{pol} + \ldots \right|$$

$$\sigma_{total} = D_{total} L \sigma_{\lambda}$$

[3-29]

Total Dispersion, zero Dispersion

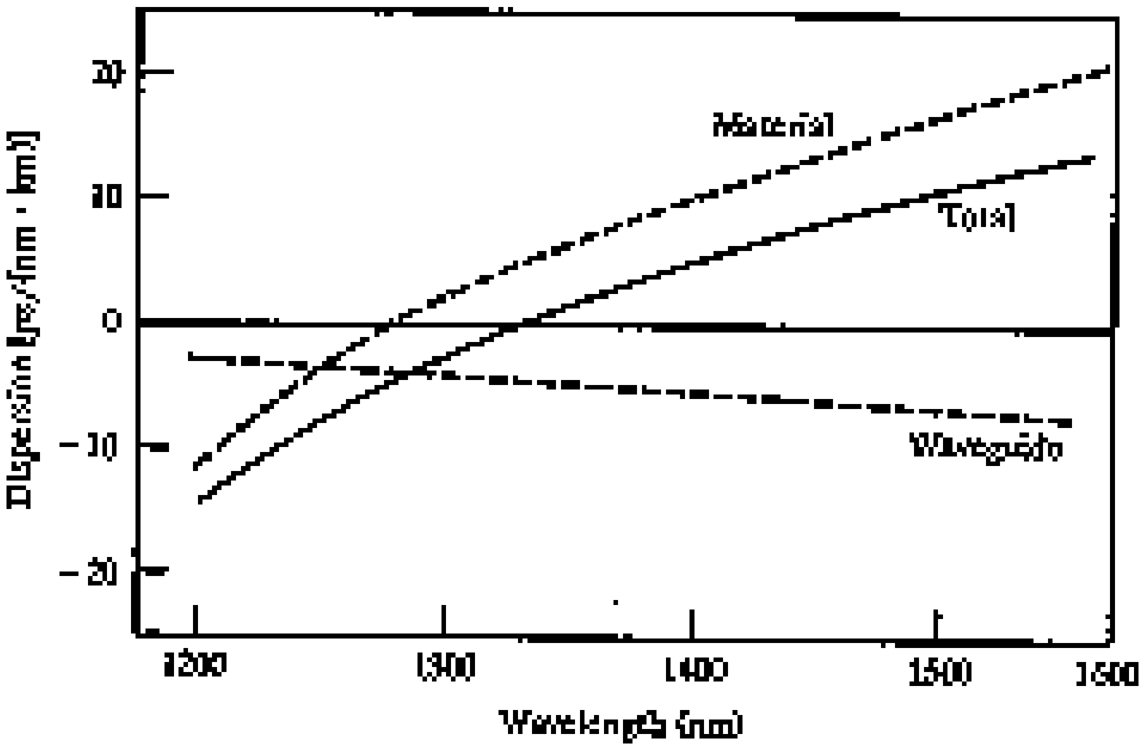


FIGURE 3-16
Examples of the magnitudes of material and waveguide dispersion as a function of optical wavelength for a single-mode fused-silica-core fiber. (Reproduced with permission from Keck,[16] © 1985, IEEE.)

Fact 1) Minimum distortion at wavelength about 1300 nm for single mode silica fiber.
Fact 2) Minimum attenuation is at 1550 nm for sinlge mode silica fiber.
Strategy: shifting the zero-dispersion to longer wavelength for minimum attenuation and dispersion.

Optimum single mode fiber & distortion/attenuation characteristics

Fact 1) Minimum distortion at wavelength about 1300 nm for single mode silica fiber.

Fact 2) Minimum attenuation is at 1550 nm for sinlge mode silica fiber.

Strategy: shifting the zero-dispersion to longer wavelength for minimum attenuation and dispersion by Modifying waveguide dispersion by changing from a simple step-index core profile to more complicated profiles.

There are four major categories to do that:

1- 1300 nm optimized single mode step-fibers: matched cladding (mode diameter 9.6 micrometer) and depressed-cladding (mode diameter about 9 micrometer)

2- Dispersion shifted fibers.

3- Dispersion-flattened fibers.

4- Large-effective area (LEA) fibers (less non linearities for fiber optical amplifier applications, effective cross section areas are typically greater than 100 μm^2).

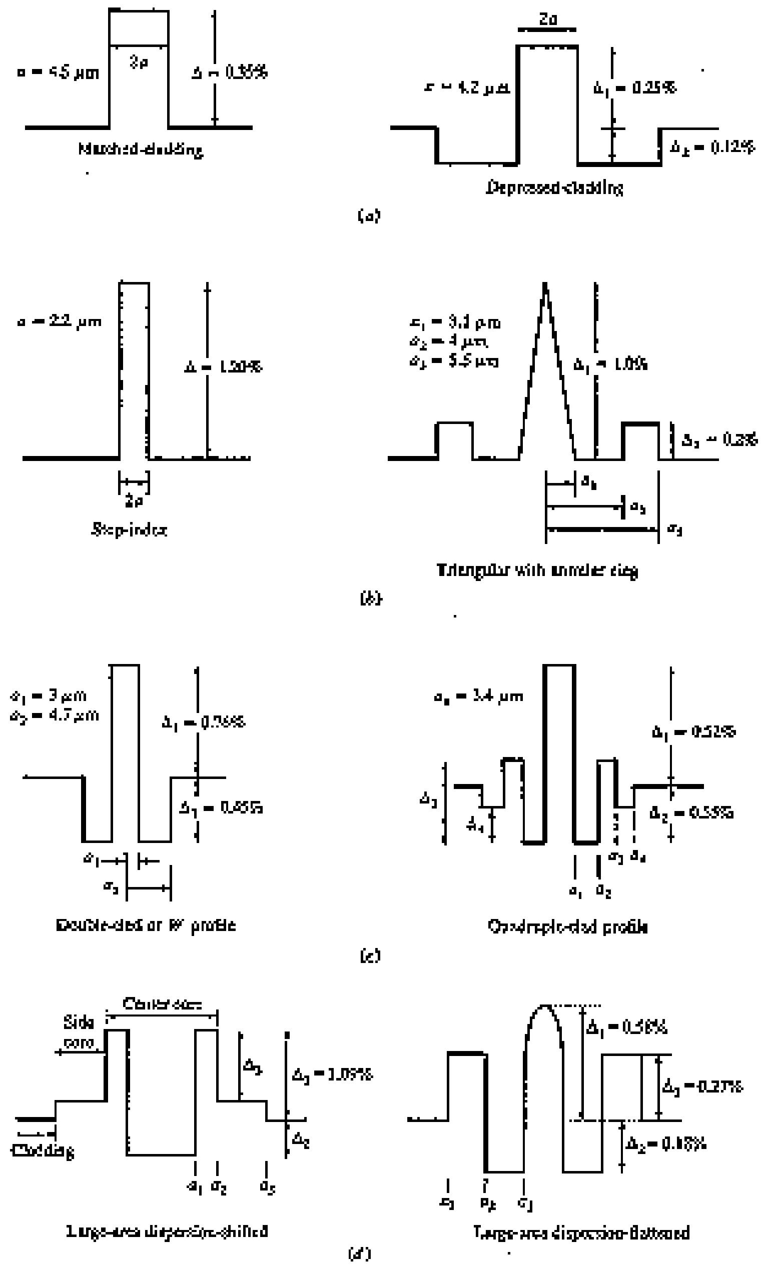
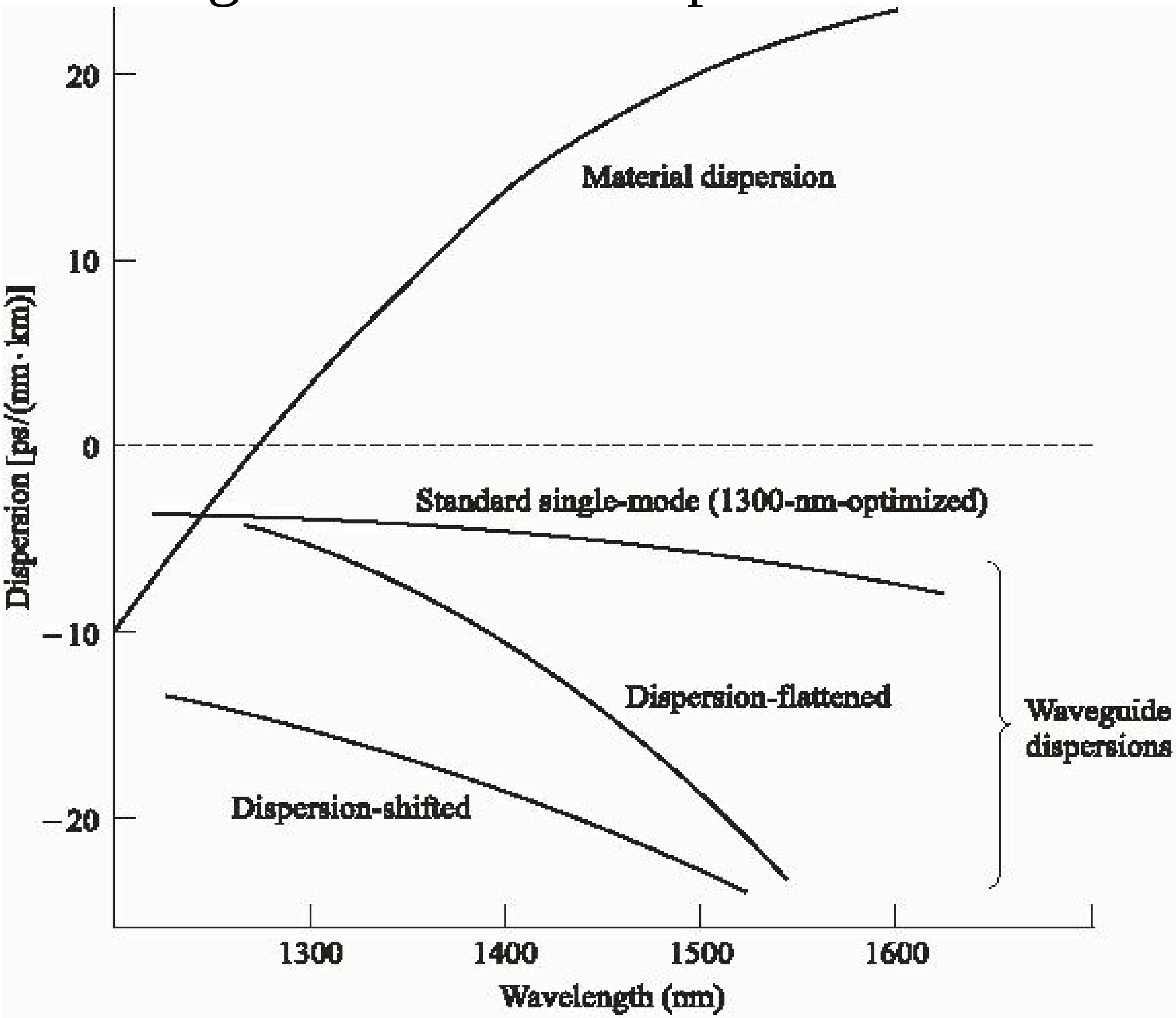


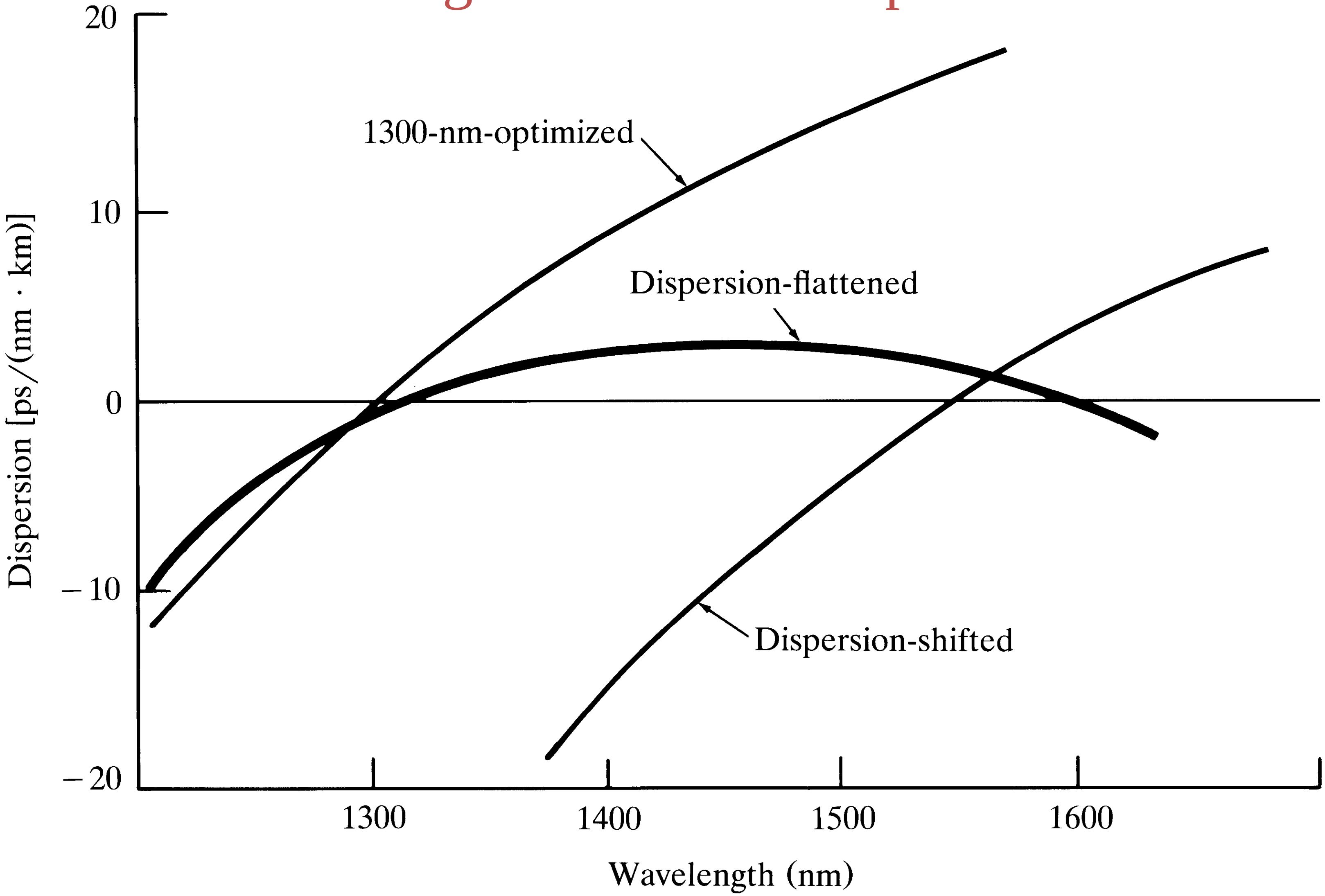
FIGURE 3-22
Representative cross sections of index profiles for (*a*) 1300-nm-optimized, (*b*) dispersion-shifted, (*c*) dispersion-flattened, and (*d*) large-effective-core-area fibers.

Single mode fiber dispersion



(*a*)

Single mode fiber dispersion



(*b*)

Single mode Cut-off wavelength & Dispersion

- Fundamental mode is HE_{11} or LP_{01}
- with V=2.405 and $\lambda_c = \frac{2\pi a}{V}\sqrt{n_1^2 - n_2^2}$ [3-30]
- Dispersion: [3-31]

$$D(\lambda) = \frac{d\tau}{d\lambda} \approx D_{mat}(\lambda) + D_{wg}(\lambda)$$

[3-32]

$$\sigma = D(\lambda) L \sigma_\lambda$$

- For non-dispersion-shifted fibers (1270 nm – 1340 nm)
- For dispersion shifted fibers (1500 nm- 1600 nm)

Dispersion for non-dispersion-shifted fibers (1270 nm – 1340 nm)

$$\tau(\lambda) = \tau_0 + \frac{S_0}{8}(\lambda - \frac{\lambda_0{}^2}{\lambda})^2$$ [3-33]

- τ_0 is relative delay minimum at the zero-dispersion wavelength λ_0, and S_0 is the value of the dispersion slope in $\text{ps/(nm}^2\text{.km)}$.

$$S_0 = S(\lambda_0) = \left.\frac{dD}{d\lambda}\right|_{\lambda=\lambda_0}$$ [3-34]

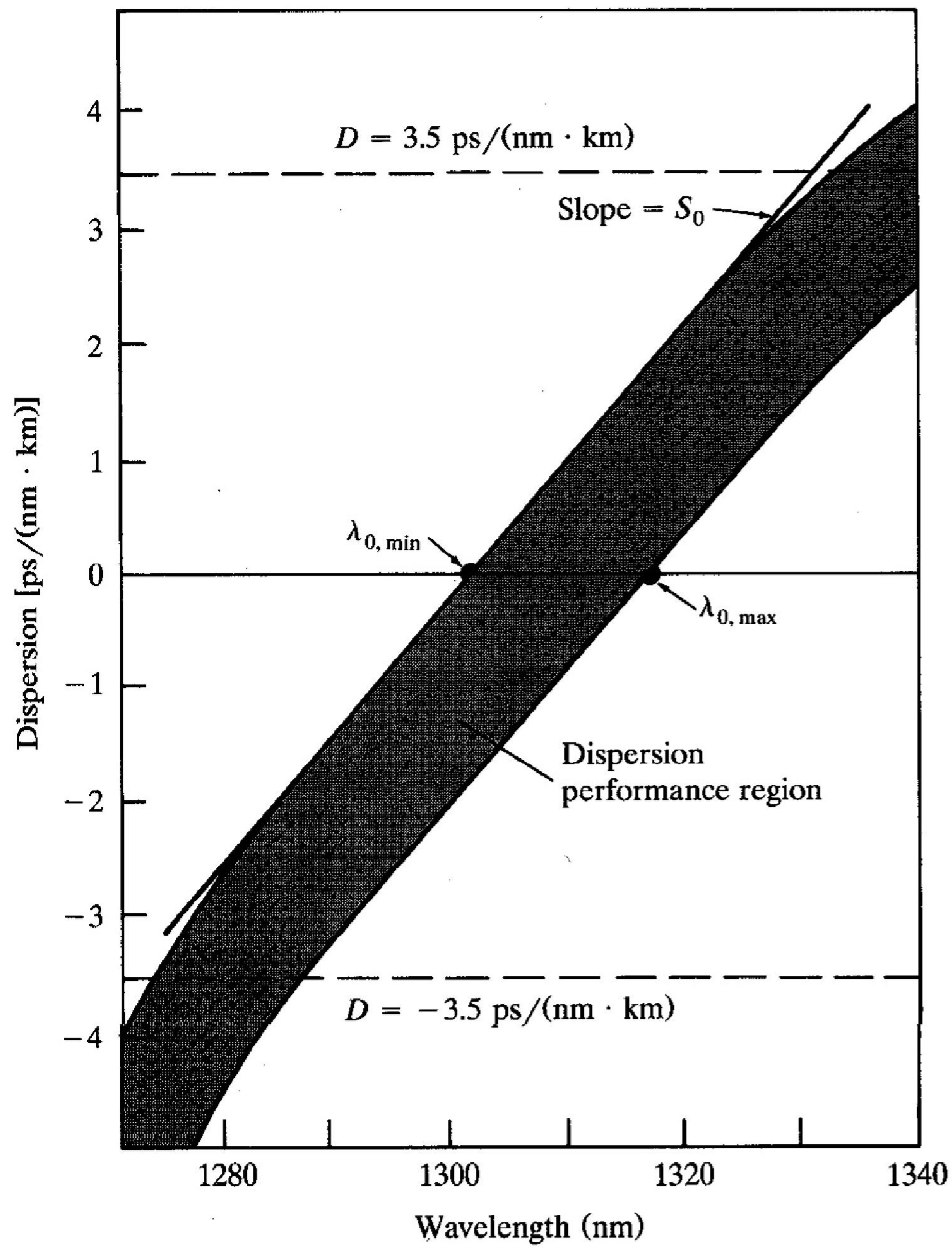
$$D(\lambda) = \frac{\lambda S_0}{4}\left[1 - (\frac{\lambda_0}{\lambda})^4\right]$$ [3-35]

Dispersion for dispersion shifted fibers(1500 nm- 1600 nm)

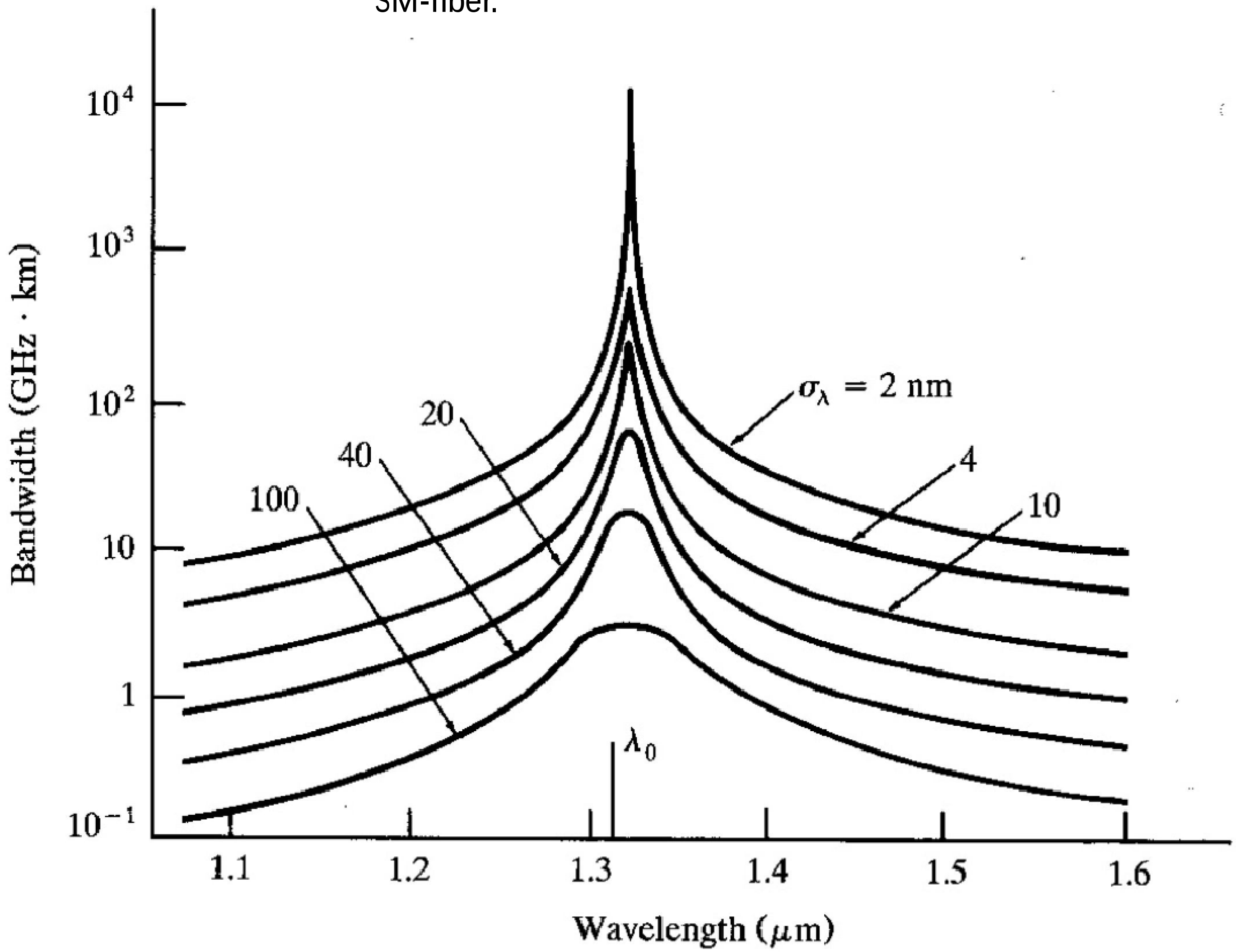
$$\tau(\lambda) = \tau_0 + \frac{S_0}{2}(\lambda - \lambda_0)^2 \qquad [3\text{-}36]$$

$$D(\lambda) = (\lambda - \lambda_0)S_0 \qquad [3\text{-}37]$$

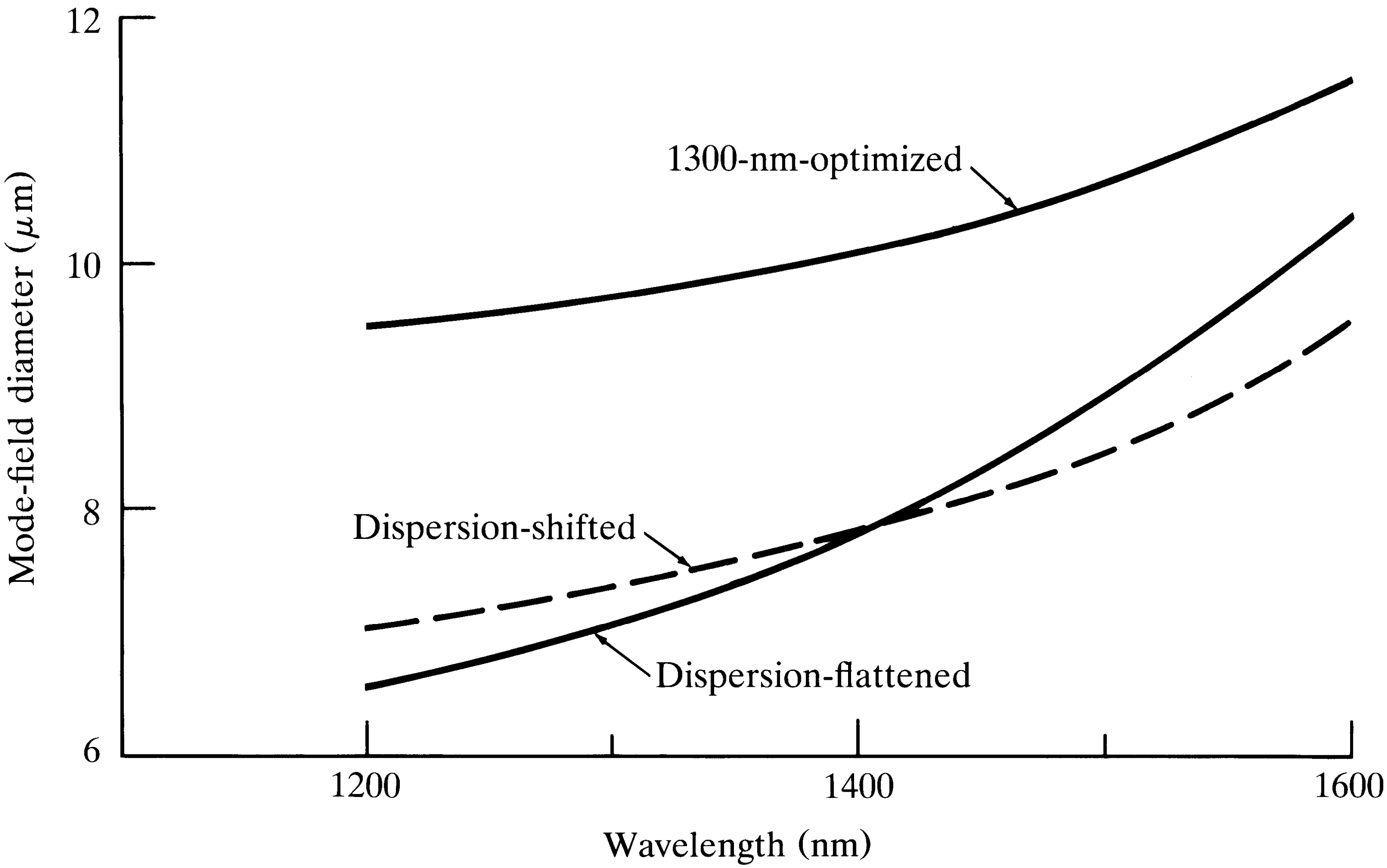
Example of dispersion
Performance curve for
Set of SM-fiber



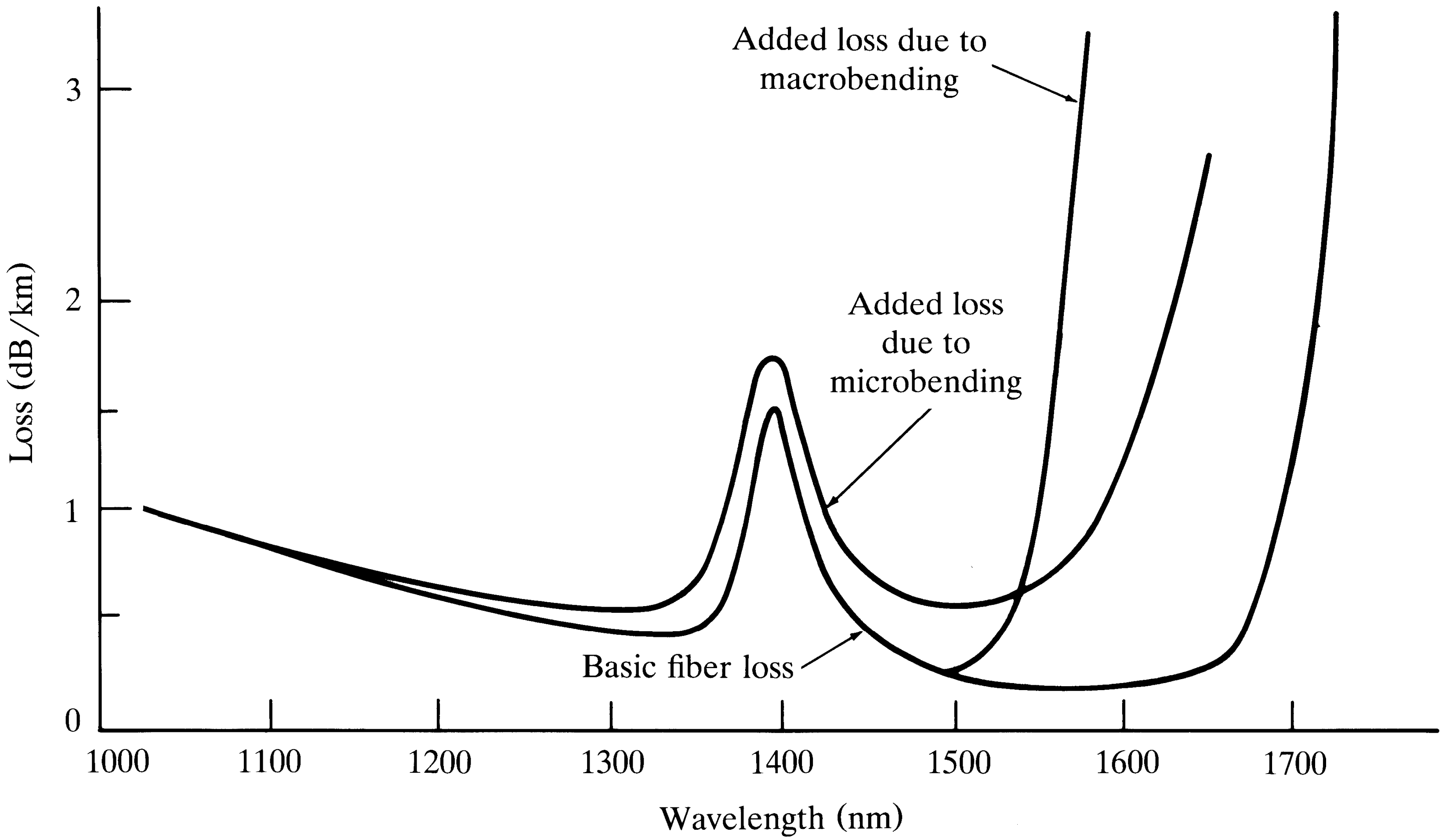
Example of BW vs wavelength for various optical sources for SM-fiber.



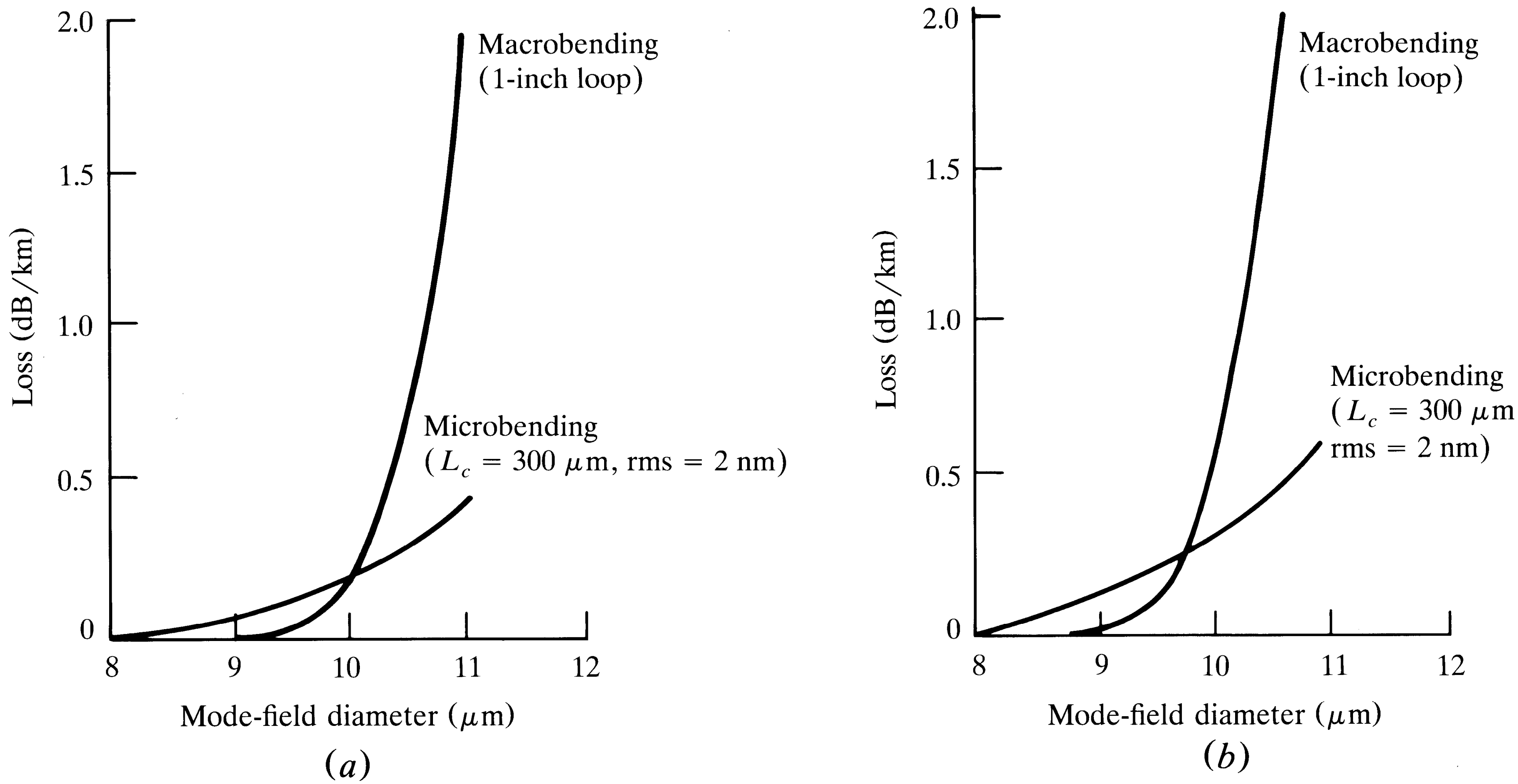
MFD


12
10
8
6
Mode-field diameter (μm)
1300-nm-optimized
Dispersion-shifted
Dispersion-flattened
1200
1400
1600
Wavelength (nm)

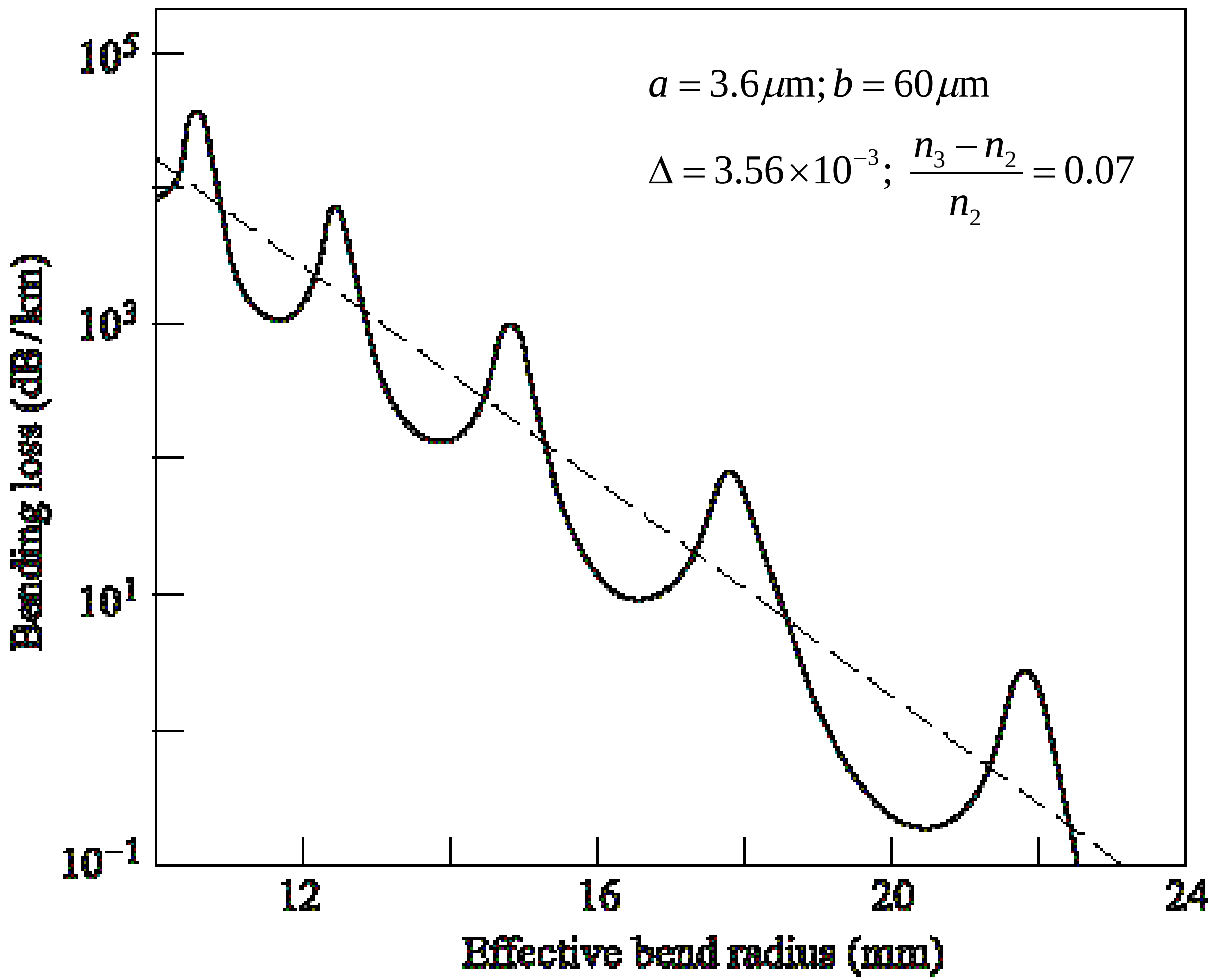
Bending Loss



Bending effects on loss vs MFD



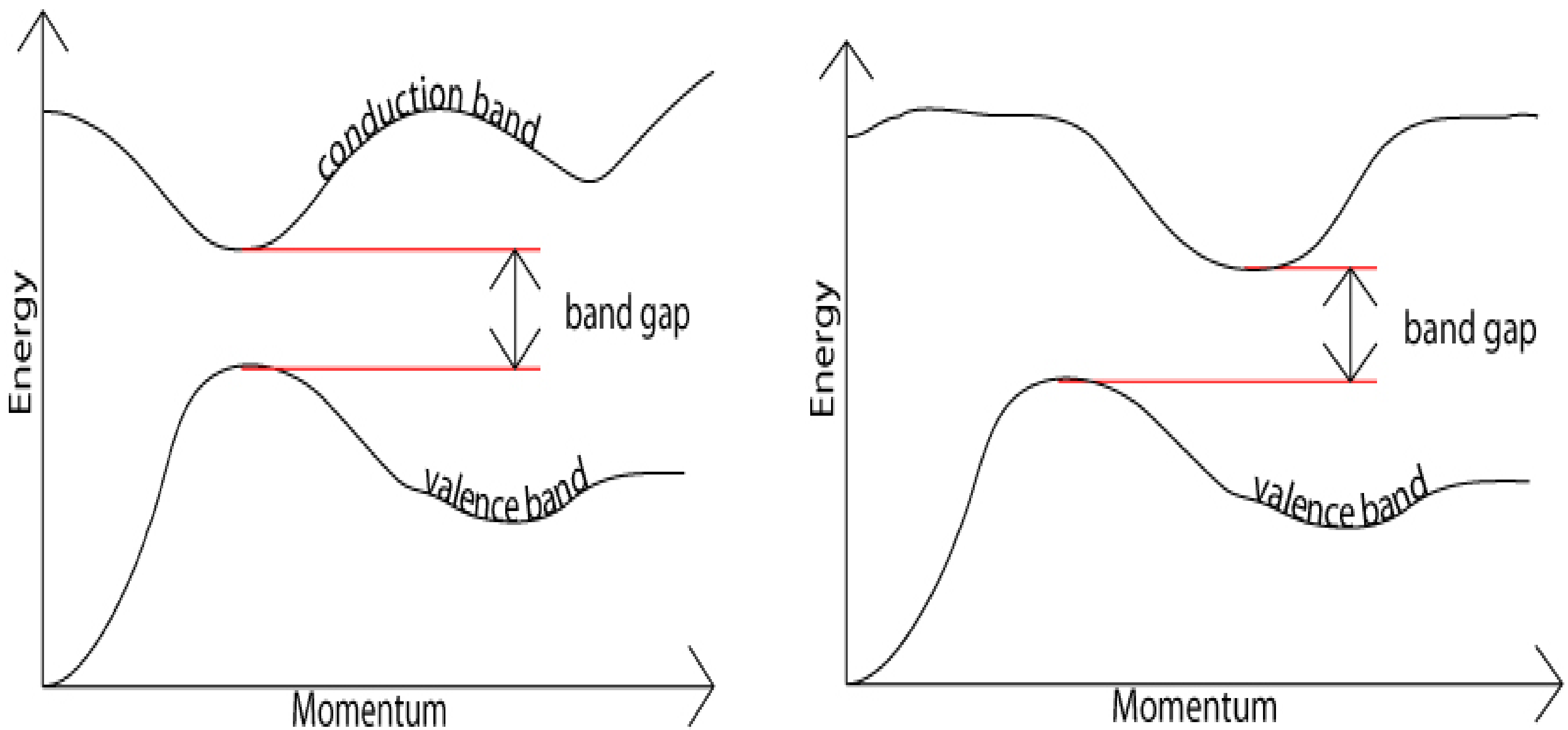
Bend loss versus bend radius



Unit-III
FIBER OPTICAL SOURCES

- Direct and indirect Band gap materials
- LED structures – Light source materials – Quantum efficiency and LED power, Modulation of a LED
- Laser Diodes – Modes and Threshold condition – Rate equations – External Quantum efficiency – Resonant frequencies – Laser Diodes structures and radiation patterns
- Single Mode lasers – Modulation of Laser Diodes, Temperature effects, Introduction to Quantum laser, Fiber amplifiers

Direct and indirect Band gap materials



Direct and indirect Band gap materials

- The band gap represents the minimum energy difference between the top of the valence band and the bottom of the conduction band.
- However, the top of the valence band and the bottom of the conduction band are not generally at the same value of the electron momentum.

Direct and indirect Band gap materials

- In a direct band gap semiconductor, the top of the valence band and the bottom of the conduction band occur at the same value of momentum.

- In an indirect band gap semiconductor, the maximum energy of the valence band occurs at a different value of momentum to the minimum in the conduction band energy:

A **light-emitting diode** (LED) is a semiconductor device that emits incoherent light, through spontaneous emission, when a current is passed through it. Typically LEDs for the 850-nm region are fabricated using GaAs and AlGaAs. LEDs for the 1300-nm and 1550-nm regions are fabricated using InGaAsP and InP.
The basic LED types used for fiber optic communication systems are the surface-emitting LED (SLED), the edge-emitting LED (ELED), and the superluminescent diode (SLD

LED performance differences help link designers decide which device is appropriate for the intended application. For short-distance (0 to 3 km), low-data-rate fiber optic systems, SLEDs and ELEDs are the preferred optical source.

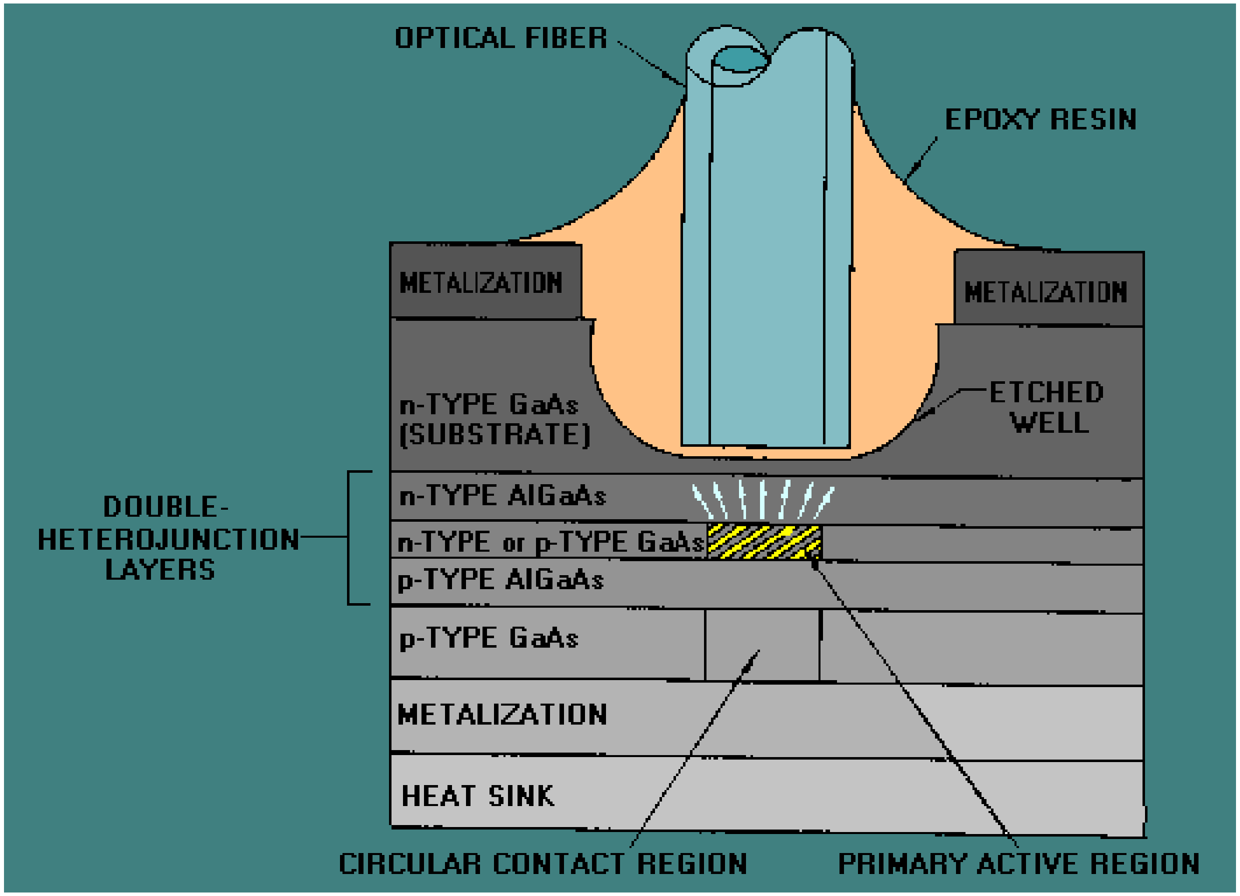
Typically, SLEDs operate efficiently for bit rates up to 250 megabits per second (Mb/s). Because SLEDs emit light over a wide area (wide far-field angle), they are almost exclusively used in multimode systems.

For medium-distance, medium-data-rate systems, ELEDs are preferred.
ELEDs may be modulated at rates up to 400 Mb/s. ELEDs may be used for both single mode and multimode fiber systems. Both SLDs and ELEDs are used in long-distance, high-data-rate systems. SLDs are ELED-based diodes designed to operate in the superluminescence mode. A further discussion on superluminescence is provided later in this chapter. SLDs may be modulated at bit rates of over 400 Mb/s.

Surface-Emitting LEDs

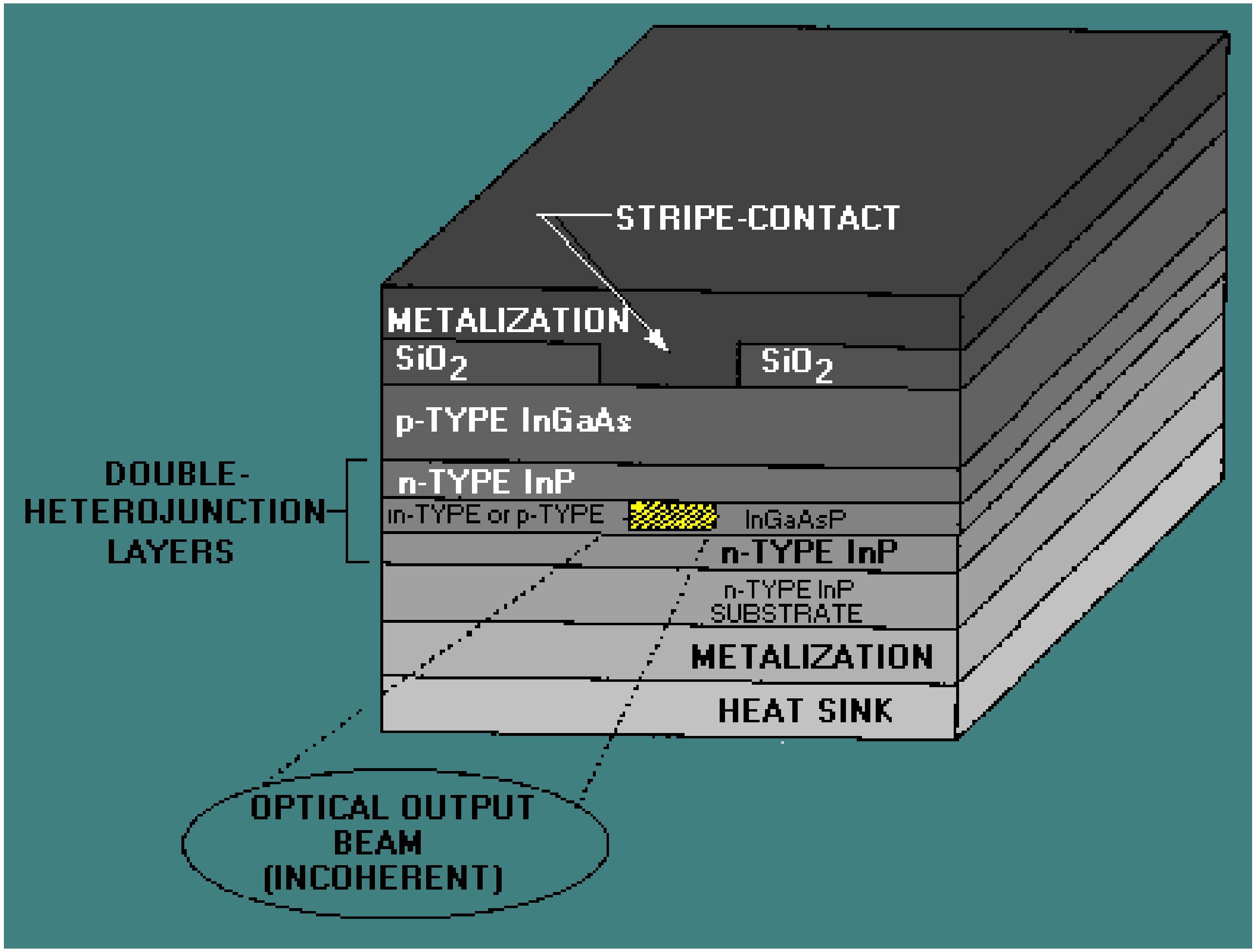
The surface-emitting LED (shown in figure 6-1) is also known as the Burrus LED in honor of C. A. Burrus, its developer. In SLEDs, the size of the primary active region is limited to a small circular area of 20 μm to 50 μm in diameter. The active region is the portion of the LED where photons are emitted. The primary active region is below the surface of the semiconductor substrate perpendicular to the axis of the fiber.

A **well** is etched into the substrate to allow direct coupling of the emitted light to the optical fiber. The etched well allows the optical fiber to come into close contact with the emitting surface.
In addition, the epoxy resin that binds the optical fiber to the SLED reduces the refractive index mismatch, increasing coupling efficiency.


OPTICAL FIBER
EPOXY RESIN
METALIZATION
METALIZATION
n-TYPE GaAs
(SUBSTRATE)
ETCHED
WELL
DOUBLE-
HETEROJUNCTION
LAYERS
n-TYPE AlGaAs
n-TYPE or p-TYPE GaAs
p-TYPE AlGaAs
p-TYPE GaAs
METALIZATION
HEAT SINK
CIRCULAR CONTACT REGION
PRIMARY ACTIVE REGION

Edge-Emitting LEDs

The demand for optical sources for longer distance, higher bandwidth systems operating at longer wavelengthsled to the development of edge-emitting LEDs. Figure 6-2 shows a typical ELED structure. It shows the different layers of semiconductor material used in the ELED. The primary active region of the ELED is a narrow stripe, which lies below the surface of the semiconductor substrate. The semiconductor substrate is cut or polished so that the stripe runs between the front and back of the device. The polished or cut surfaces at each end of the stripe are called facets.


STRIPE-CONTACT
METALIZATION
SiO2
SiO2
p-TYPE InGaAs
DOUBLE-
HETEROJUNCTION
LAYERS
n-TYPE InP
n-TYPE or p-TYPE
InGaAsP
n-TYPE InP
n-TYPE InP
SUBSTRATE
METALIZATION
HEAT SINK
OPTICAL OUTPUT
BEAM
(INCOHERENT)

In an ELED the rear facet is highly reflective and the front facet is antireflection-coated. The rear facet reflects the light propagating toward the rear end-face back toward the front facet. By coating the front facet with antireflection material, the front facet reduces optical feedback and allows light emission. ELEDs emit light only through the front facet. ELEDs emit light in a narrow emission angle allowing for better source-to-fiber coupling. They couple more power into small NA fibers than SLEDs. ELEDs can couple enough power into single mode fibers for some applications. ELEDs emit power over a narrower spectral range than SLEDs. However, ELEDs typically are more sensitive to temperature fluctuations than SLEDs.

In an ELED the rear facet is highly reflective and the front facet is antireflection-coated. The rear facet reflects the light propagating toward the rear end-face back toward the front facet. By coating the front facet with antireflection material, the front facet reduces optical feedback and allows light emission. ELEDs emit light only through the front facet. ELEDs emit light in a narrow emission angle allowing for better source-to-fiber coupling. They couple more power into small NA fibers than SLEDs. ELEDs can couple enough power into single mode fibers for some applications. ELEDs emit power over a narrower spectral range than SLEDs. However, ELEDs typically are more sensitive to temperature fluctuations than SLEDs.

Rate equations, Quantum Efficiency & Power of LEDs

- When there is no external carrier injection, the excess density decays exponentially due to electron-hole recombination.

$$n(t) = n_0 e^{-t/\tau} \qquad [4\text{-}4]$$

- *n* is the excess carrier density,

n_0 : initial injected excess electron density

τ : carrier lifetime.

- Bulk recombination rate *R*:

$$R = -\frac{dn}{dt} = \frac{n}{\tau} \qquad [4\text{-}5]$$

- Bulk recombination rate (*R*)=Radiative recombination rate + nonradiative recombination rate bulk recombination rate $(R = 1/\tau) =$

radiative recombination rate $(R_r = 1/\tau_r)$ + nonradiative recombination rate$(R_{nr} = 1/\tau_{nr})$

With an external supplied current density of J the rate equation for the electron-hole recombination is:

$$\frac{dn(t)}{dt} = \frac{J}{qd} - \frac{n}{\tau} \qquad [4\text{-}6]$$

q : charge of the electron; d : thickness of recombination region

In equilibrium condition: *dn/dt=0*

$$n = \frac{J\tau}{qd} \qquad [4\text{-}7]$$

Internal Quantum Efficiency & Optical Power

$$\eta_{\text{int}} = \frac{R_r}{R_r + R_{nr}} = \frac{\tau_{nr}}{\tau_r + \tau_{nr}} = \frac{\tau}{\tau_r} \qquad [4\text{-}8]$$

η_{int} : internal quantum efficiency in the active region

Optical power generated internally in the active region in the LED is:

$$P_{\text{int}} = \eta_{\text{int}} \frac{I}{q} h\nu = \eta_{\text{int}} \frac{hcI}{q\lambda} \qquad [4\text{-}9]$$

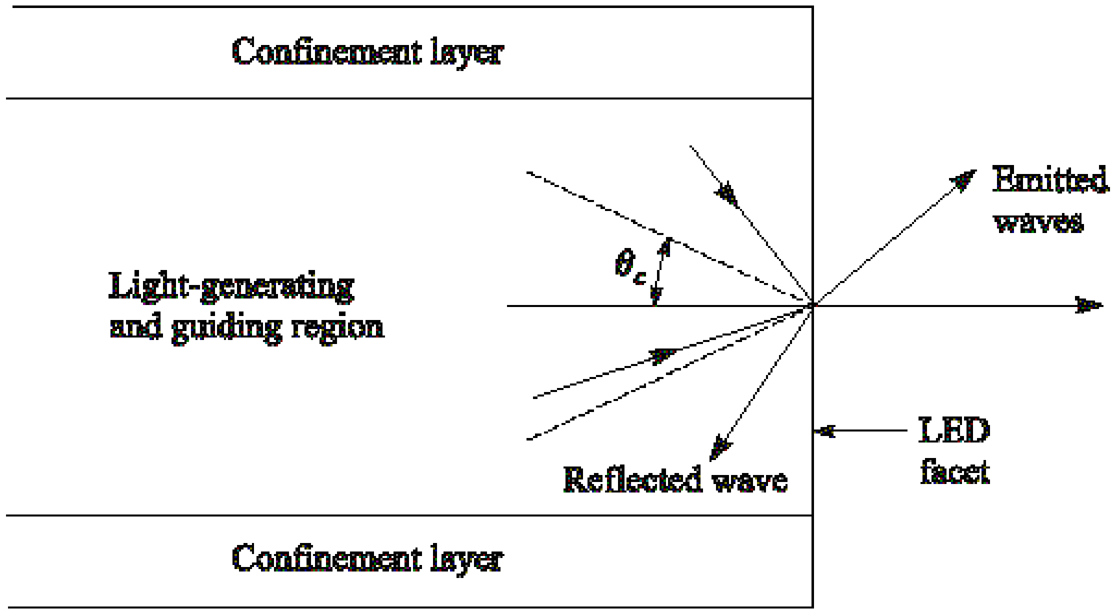
P_{int} : Internal optical power,

I : Injected current to active region

External Quantum Eficiency

$$\eta_{ext} = \frac{\#\text{ of photons emitted from LED}}{\#\text{ of LED internally generated photons}} \qquad [4\text{-}10]$$

- In order to calculate the external quantum efficiency, we need to consider the reflection effects at the surface of the LED. If we consider the LED structure as a simple 2D slab waveguide, only light falling within a cone defined by critical angle will be emitted from an LED.



$$\eta_{\text{ext}} = \frac{1}{4\pi}\int_0^{\phi_c} T(\phi)(2\pi \sin\phi)\,d\phi \qquad [4\text{-}11]$$

$$T(\phi): \text{Fresnel Transmission Coefficient} \approx T(0) = \frac{4n_1 n_2}{(n_1+n_2)^2} \qquad [4\text{-}12]$$

$$\text{If } n_2 = 1 \Rightarrow \eta_{\text{ext}} \approx \frac{1}{n_1(n_1+1)^2} \qquad [4\text{-}13]$$

$$\text{LED emitted optical powr, } P = \eta_{\text{ext}} P_{\text{int}} \approx \frac{P_{\text{int}}}{n_1(n_1+1)^2} \qquad [4\text{-}14]$$

Modulation of LED

- The frequency response of an LED depends on:

  1- Doping level in the active region

  2- Injected carrier lifetime in the recombination region, τ_i.

  3- Parasitic capacitance of the LED

- If the drive current of an LED is modulated at a frequency of ω the output optical power of the device will vary as:

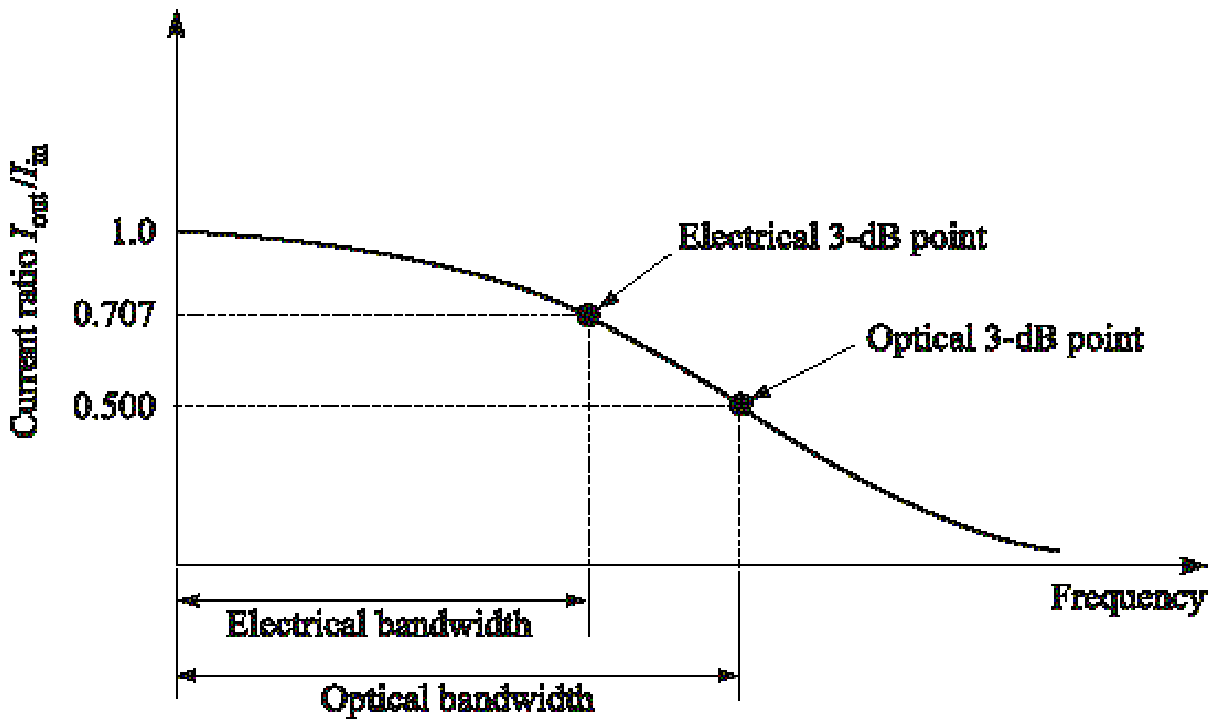
$$P(\omega) = \frac{P_0}{\sqrt{1 + (\omega\tau_i)^2}} \qquad [4\text{-}15]$$

- Electrical current is directly proportional to the optical power, thus we can define electrical bandwidth and optical bandwidth, separately.

$$\text{Electrical BW} = 10\log\left[\frac{p(\omega)}{p(0)}\right] = 20\log\left[\frac{I(\omega)}{I(0)}\right] \qquad [4\text{-}16]$$

p : electrical power, I : electrical current

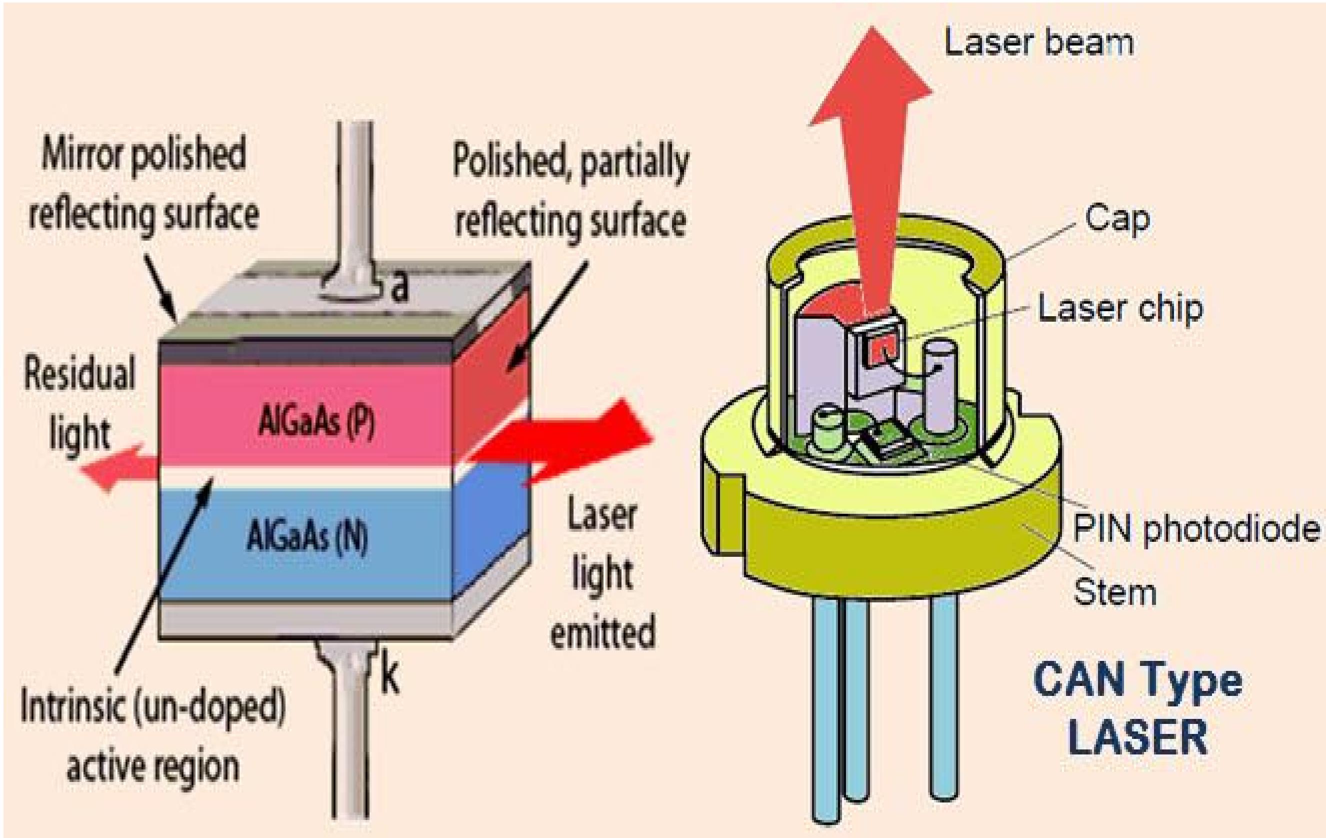
$$\text{Optical BW} = 10\log\left[\frac{P(\omega)}{P(0)}\right] = 10\log\left[\frac{I(\omega)}{I(0)}\right] \quad [4\text{-}17]$$



The laser diode light contains only a single frequency. Therefore, it can be focused by even a simple lens system to an extremely small point. There is no chromatic aberration since only one wavelength exists, also all of the energy from the light source is concentrated into a very small spot of light. LASER is an acronym for Light Amplification by the Stimulated Emission of Radiation.

Laser Diode Construction

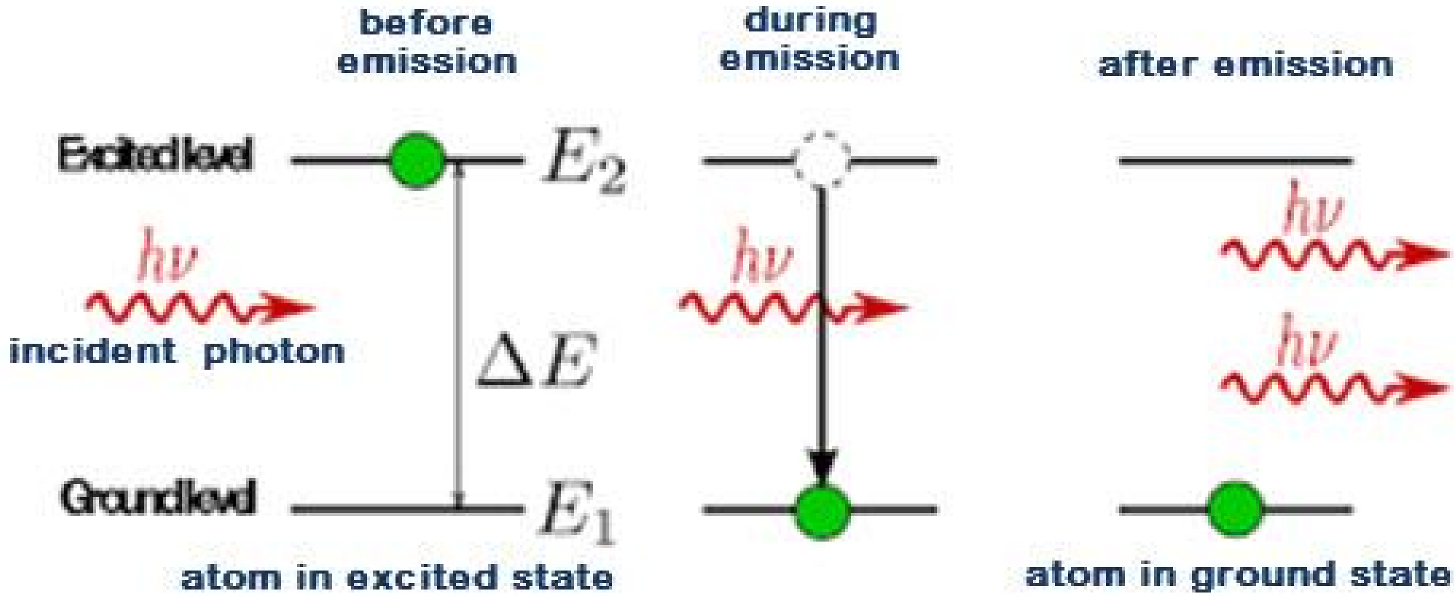
The above figure shows a simplified construction of a laser diode, which is similar to a light emitting diode (LED). It uses gallium arsenide doped with elements such as selenium, aluminium, or silicon to produce P type and N type semiconductor materials. While a laser diode has an additional active layer of undoped (intrinsic) gallium arsenide have the thickness only a few nanometers, sandwiched between the P and N layers, effectively creating a PIN diode (P type-Intrinsic-N type). It is in this layer that the laser light is produced.



Mirror polished reflecting surface
Polished, partially reflecting surface
a
Residual light
AlGaAs (P)
AlGaAs (N)
Laser light emitted
k
Intrinsic (un-doped) active region
Laser beam
Cap
Laser chip
PIN photodiode
Stem
CAN Type LASER

How Laser Diode Work?

Every atom according to the quantum theory, can energies only within a certain discrete energy level. Normally, the atoms are in the lowest energy state or ground state. When an energy source given to the atoms in the ground state can be excited to go to one of the higher levels. This process is called absorption. After staying at that level for a very short duration, the atom returns to its initial ground state, emitting a photon in the process, This process is called spontaneous emission. These two processes, absorption and spontaneous emission, take place in a conventional light source.



$$E_2 - E_1 = \Delta E = h\nu$$

Amplification and Population Inversion

When favourable conditions are created for the stimulated emission, more and more atoms are forced to emit photons thereby initiating a chain reaction and releasing an enormous amount of energy. This results in a rapid build up of energy of emitting one particular wavelength (monochromatic light), travelling coherently in a particular, fixed direction. This process is called amplification by stimulated emission.

The number of atoms in any level at a given time is called the population of that level. Normally, when the material is not excited externally, the population of the lower level or ground state is greater than that of the upper level. When the population of the upper level exceeds that of the lower level, which is a reversal of the normal occupancy, the process is called population inversion.

Main laser diode types

Some of the main types of laser diode include the following types:

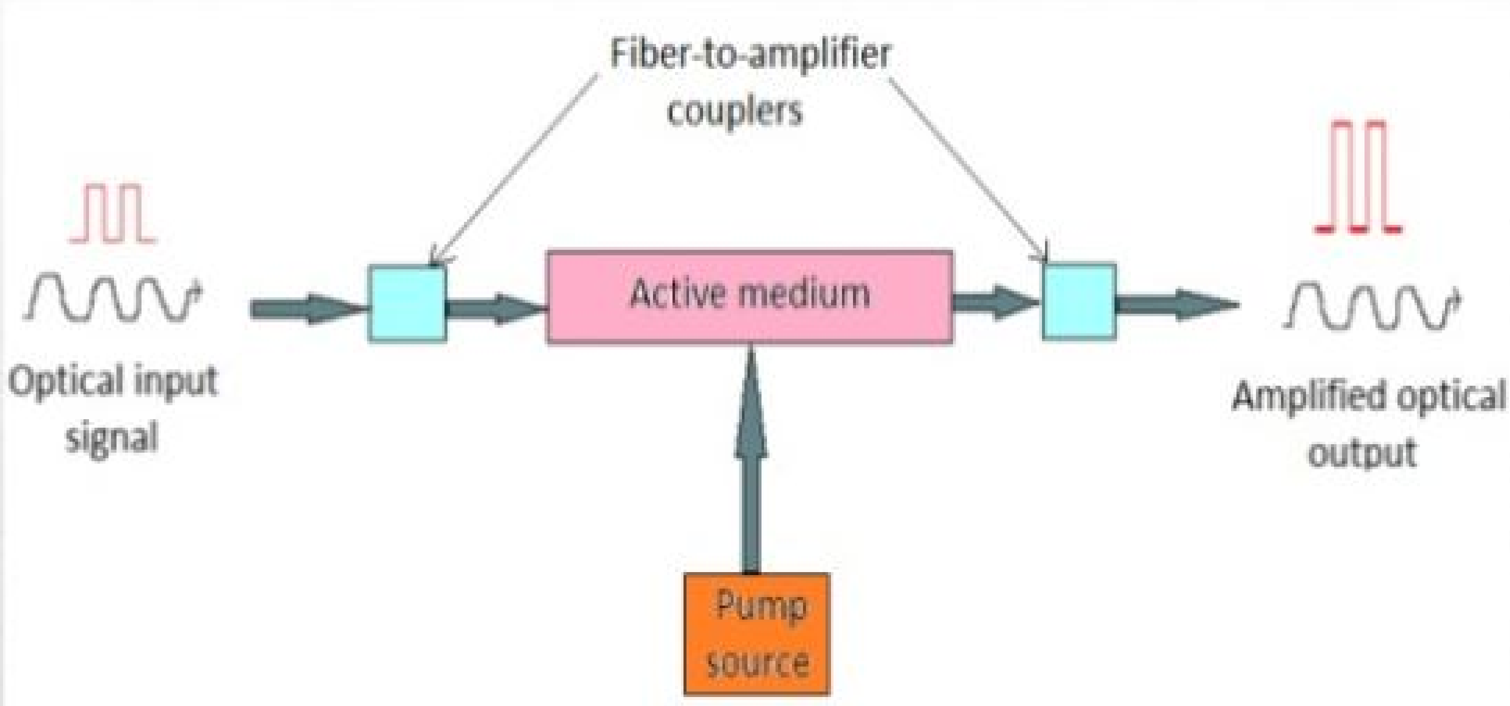
Double heterostructure laser diode : The double heterojunction laser diode is made up by sandwiching a layer of a low bandgap material with a layer on either side of high bandgap layers. This makes the two heterojunctions as the materials themselves are different and not just the same material with different types of doping. Common materials for the double heterojunction laser diode are Gallium Arsenide, GaAs, and aluminium gallium arsenide, AlGaAs.

The advantage of the double heterojunction laser diode over other types is that the holes and electrons are confined to the thin middle layer which acts as the active region. By containing the electrons and holes within this area more effectively, more electron-hole pairs are available for the laser optical amplification process. Additionally the change in material at the heterojunction helps contain the light within the active region providing additional benefit.

Quantum well laser diode: The quantum well laser diode uses a very thin middle layer - this acts as a quantum well where the vertical component of the electron wave function is quantised. As the quantum well has an abrupt edge, this concentrates electrons in energy states that contribute to laser action, and this increases the efficiency of the system.

In addition to the single quantum well laser diodes, multiple quantum well laser diodes also exist. The presence of multiple quantum wells improves the overlap between the gain region and the optical waveguide mode.

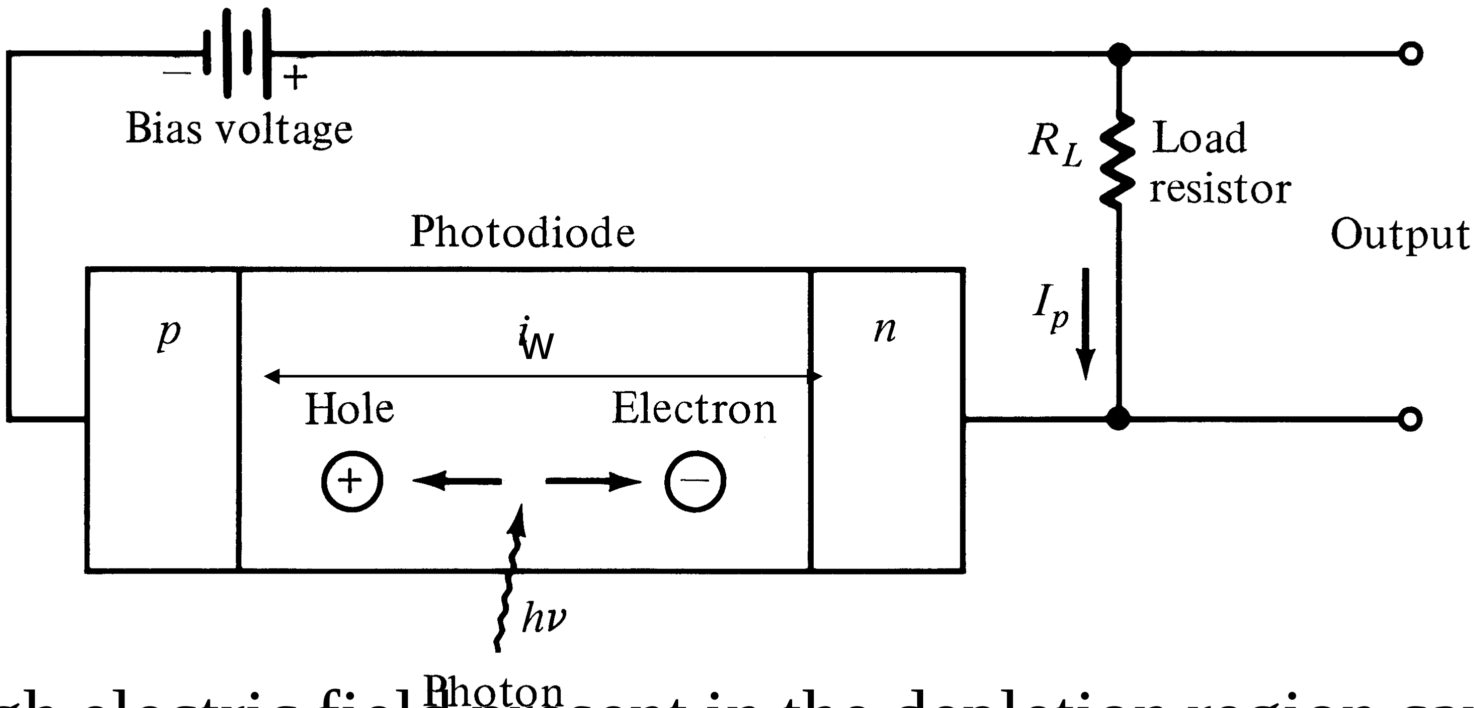
BASIC OPERATION OF OPTICAL AMPLIFIER.



Unit-IV
FIBER OPTICAL RECEIVERS

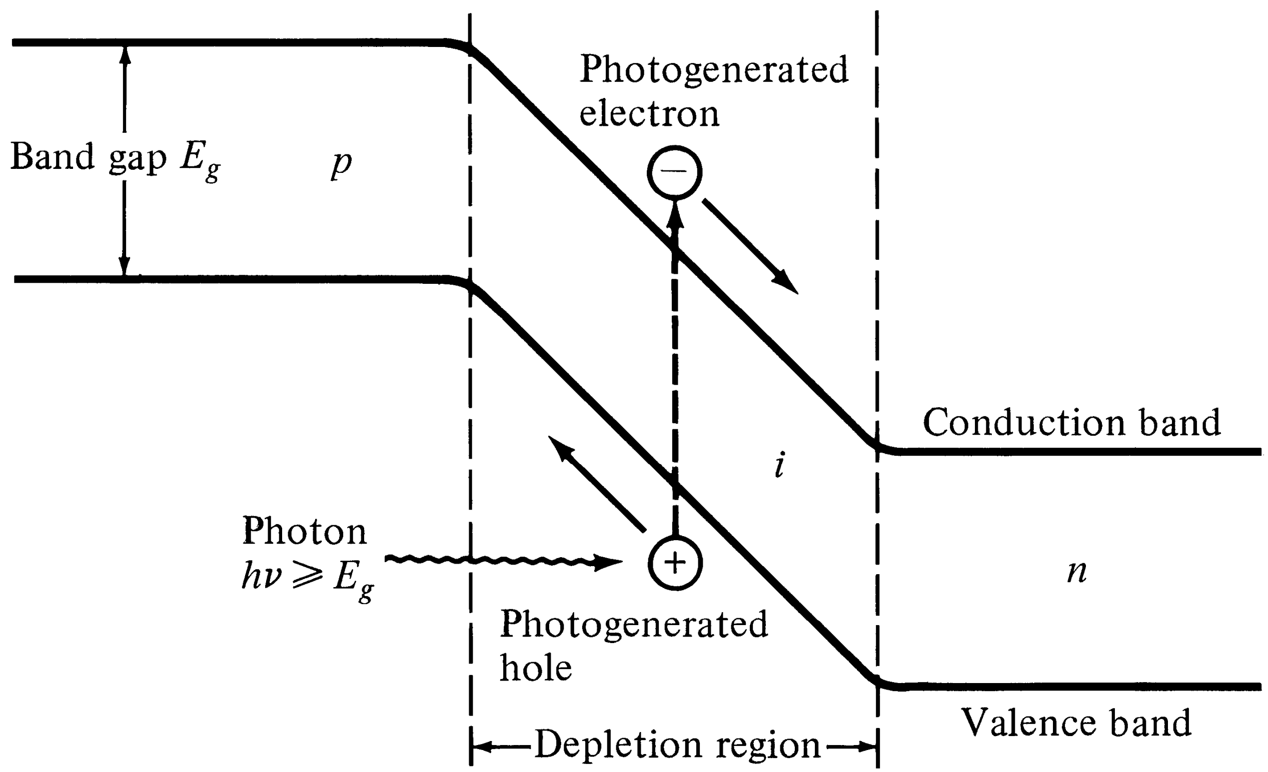
- PIN and APD diodes
- Photo detector noise, SNR, Detector Response time
- Avalanche multiplication Noise – Comparison of Photo detectors
- Fundamental Receiver Operation – pre-amplifiers
- Error Sources – Receiver Configuration – Probability of Error – The Quantum Limit

PIN Photodetector



The high electric field present in the depletion region causes photo-generated carriers to separate and be collected across the reverse –biased junction. This give rise to a current Flow in an external circuit, known as **photocurrent**.

Energy-Band diagram for a *pin* photodiode



Photocurrent

- Optical power absorbed, $P(x)$ in the depletion region can be written in terms of incident optical power, P_0 :

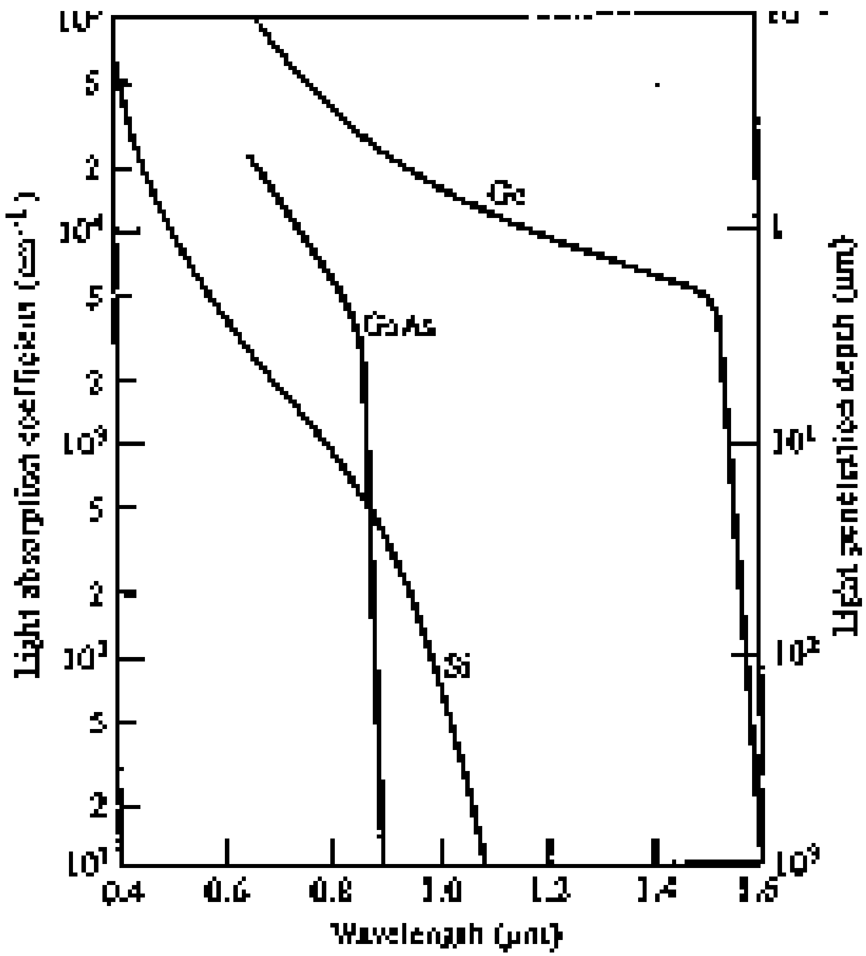
$$P(x) = P_0(1 - e^{-\alpha_s(\lambda)x}) \qquad [6\text{-}1]$$

- Absorption coefficient $\alpha_s(\lambda)$ strongly depends on wavelength. The upper wavelength cutoff for any semiconductor can be determined by its energy gap as follows:

$$\lambda_c(\mu\text{m}) = \frac{1.24}{E_g(\text{eV})} \qquad [6\text{-}2]$$

- Taking entrance face reflectivity into consideration, the absorbed power in the width of depletion region, w, becomes: $(1-R_f)P(w) = P_0(1-e^{-\alpha_s(\lambda)w})(1-R_f)$

Optical Absorption Coefficient



Responsivity

- The primary photocurrent resulting from absorption is:

$$I_p = \frac{q}{h\nu} P_0 \left(1 - e^{-\alpha_s(\lambda)w}\right)\left(1 - R_f\right) \qquad [6\text{-}3]$$

- Quantum Efficiency:

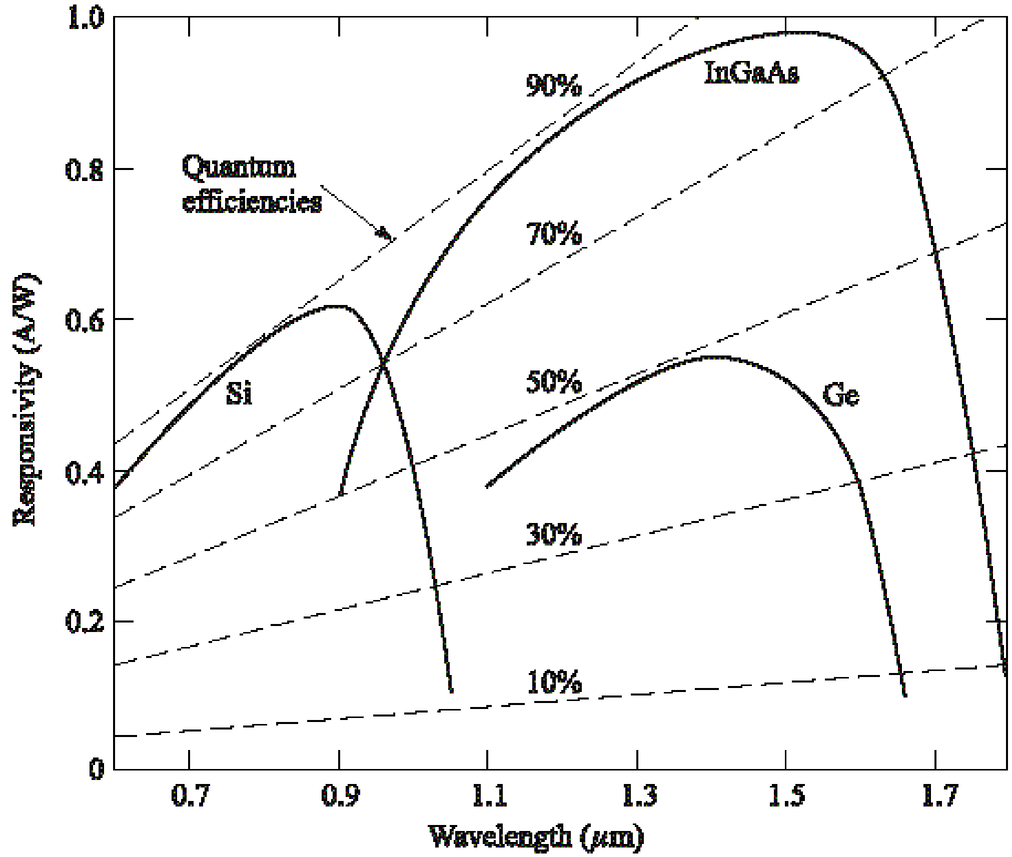
$$\eta = \frac{\#\text{ of electron - hole photogenerated pairs}}{\#\text{ of incident photons}}$$

$$\eta = \frac{I_P / q}{P_0 / h\nu} \qquad [6\text{-}4]$$

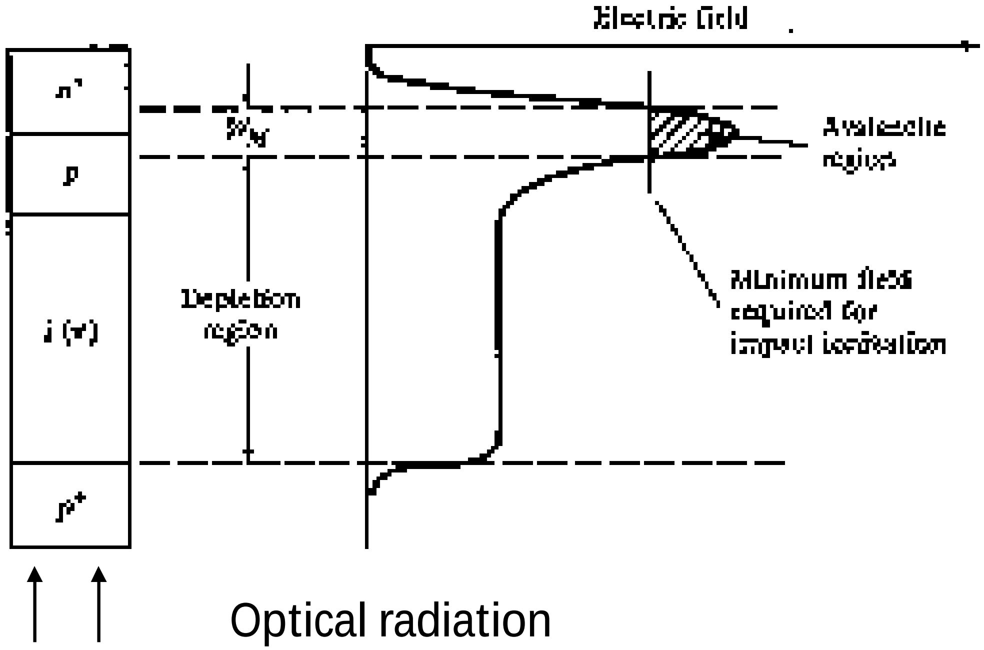
- Responsivity:

$$\Re = \frac{I_P}{P_0} = \frac{\eta q}{h\nu} \quad \text{[A/W]} \qquad [6\text{-}5]$$

Responsivity vs. wavelength



Avalanche Photodiode (APD)



Optical radiation

Reach-Through APD structure (RAPD) showing the electric fields in depletion region and multiplication region.

APDs internally multiply the primary photocurrent before it enters to following circuitry.

In order to carrier multiplication take place, the photogenerated carriers must traverse along a high field region. In this region, photogenerated electrons and holes gain enough energy to ionize bound electrons in VB upon colliding with them. This multiplication is known as **impact ionization**. The newly created carriers in the presence of high electric field result in more ionization called **avalanche effect**.

Responsivity of APD

- The multiplication factor (current gain) M for all carriers generated in the photodiode is defined as:

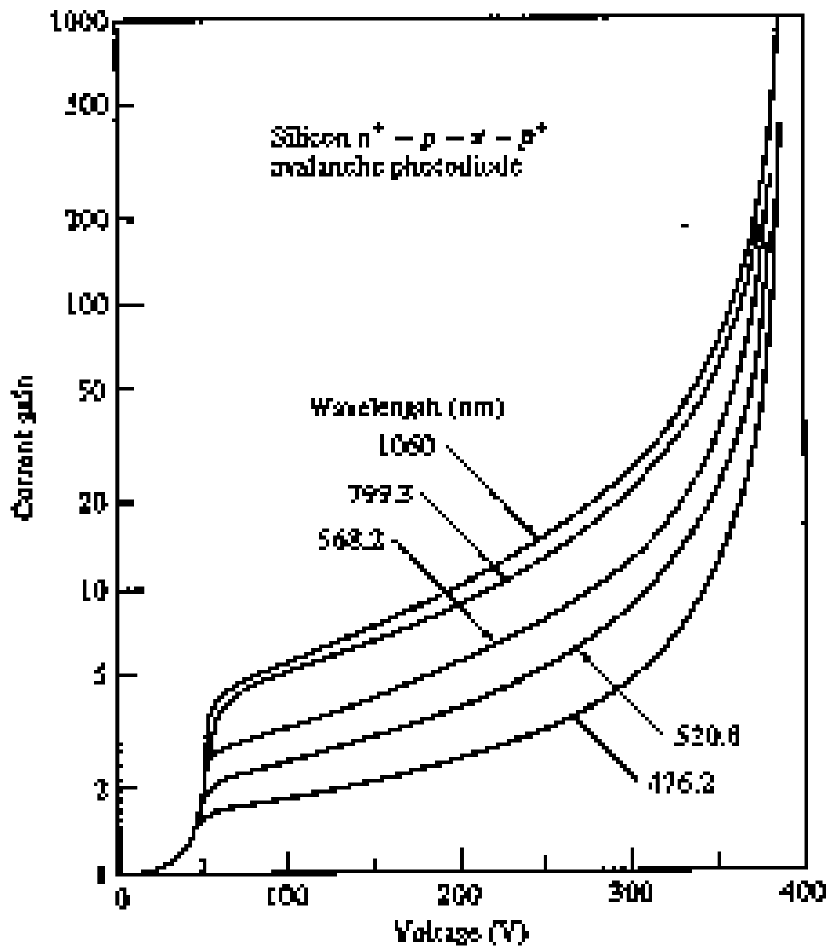
$$M = \frac{I_M}{I_p} \qquad [6\text{-}6]$$

- Where I_M is the average value of the total multiplied output current & I_P is the primary photocurrent.

$$\Re_{\text{APD}} = \frac{\eta q}{h\nu} M = \Re_0 M \qquad [6\text{-}7]$$

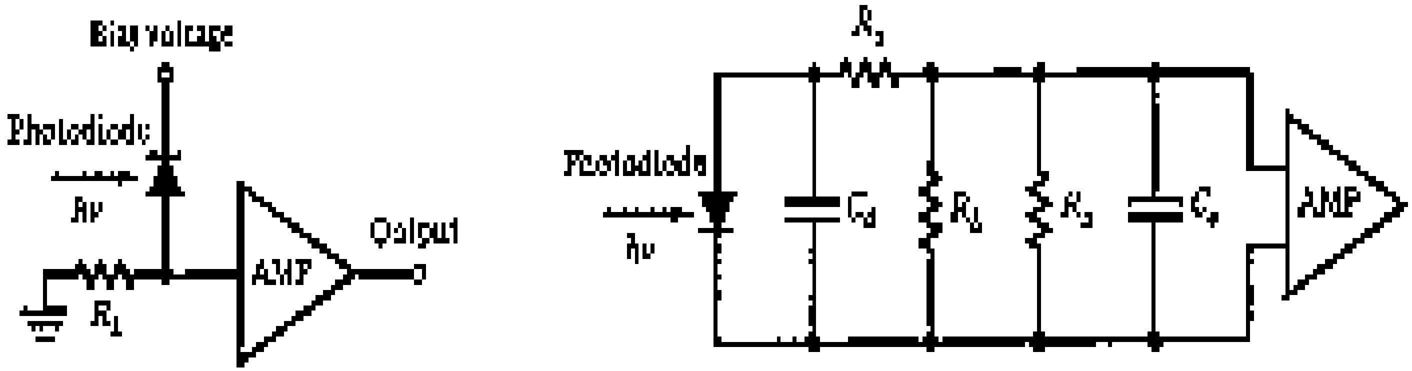
- The responsivity of APD can be calculated by considering the current gain as:

Current gain (M) vs. Voltage for different optical wavelengths



Photodetector Noise & S/N

- Detection of weak optical signal requires that the photodetector and its following amplification circuitry be optimized for a desired signal-to-noise ratio.
- It is the noise current which determines the minimum optical power level that can be detected. This minimum detectable optical power defines the **sensitivity** of photodetector. That is the optical power that generates a photocurrent with the amplitude equal to that of the total noise current ($S/N=1$)



(a) (b)

$$\frac{S}{N} = \frac{\text{signal power from photocurrent}}{\text{photodetector noise power} + \text{amplifier noise power}}$$

Signal Calculation

- Consider the modulated optical power signal *P(t)* falls on the photodetector with the form of:

$$P(t) = P_0[1 + ms(t)] \qquad [6\text{-}8]$$

- Where *s(t)* is message electrical signal and *m* is modulation index. Therefore the primary photocurrent is (for pin photodiode *M=1*):

$$i_{\text{ph}} = \frac{\eta q}{h\nu} MP(t) = I_P[\text{DC value}] + i_p(t)[\text{AC current}] \qquad [6\text{-}9]$$

- The root mean square signal current is then:

$$\langle i_s^2 \rangle = \langle i_p^2 \rangle M^2 = \sigma_s^2 \qquad [6\text{-}9]$$

$$\langle i_p^2 \rangle = \sigma_p^2 = \frac{m^2 I_P^2}{2} \quad \text{for sinusoidal signal} \qquad [6\text{-}10]$$

Noise Sources in Photodetecors

- The principal noises associated with photodetectors are :

  1- Quantum (Shot) noise: arises from statistical nature of the production and collection of photo-generated electrons upon optical illumination. It has been shown that the statistics follow a Poisson process.

  2- Dark current noise: is the current that continues to flow through the bias circuit in the absence of the light. This is the combination of **bulk dark current**, which is due to thermally generated e and h in the *pn* junction, and the **surface dark current**, due to surface defects, bias voltage and surface area.

In order to calculate the total noise presented in photodetector, we should sum up the root mean square of each noise current by assuming that those are uncorrelated.

Total photodetector noise current=quantum noise current +bulk dark current noise + surface current noise

Noise calculation (1)

- **Quantum noise current** (lower limit on the sensitivity):

$$\left\langle i_Q{}^2 \right\rangle = \sigma_Q{}^2 = 2qI_P BM^2 F(M) \qquad [6\text{-}11]$$

- B: Bandwidth, $F(M)$ is the noise figure and generally is $F(M) \approx M^x \quad 0 \le x \le 1.0$

- **Bulk dark current noise:**

$$\left\langle i_{DB}{}^2 \right\rangle = \sigma_{DB}^2 = 2qI_D BM^2 F(M) \qquad [6\text{-}12]$$

I_D is bulk dark current

Note that for *pin* photodiode

$$M^2 F(M) = 1$$

- **Surface dark current noise:** I_L is the surface current.

$$\left\langle i_{DS}{}^2 \right\rangle = \sigma_{DS}^2 = 2qI_L B \qquad [6\text{-}13]$$

Noise calculation (2)

- The total rms photodetector noise current is:

$$\left\langle i_N{}^2 \right\rangle = \sigma_N{}^2 = \left\langle i_Q{}^2 \right\rangle + \left\langle i_{DB}{}^2 \right\rangle + \left\langle i_{DS}{}^2 \right\rangle$$
$$= 2q(I_P + I_D)BM^2F(M) + 2qI_L B \qquad [6\text{-}14]$$

- The thermal noise of amplifier connected to the photodetector is:

$$\left\langle i_T{}^2 \right\rangle = \sigma_T{}^2 = \frac{4k_B TB}{R_L} \qquad [6\text{-}15]$$

R_L input resistance of amplifier, and $k_B = 1.38 \times 10^{-23}$ JK $^{-1}$ is Boltzmann cte.

S/N Calculation

- Having obtained the signal and total noise, the signal-to-noise-ratio can be written as:

$$\frac{S}{N} = \frac{\langle i_P{}^2 \rangle M^2}{2q(I_P + I_D)BM^2 F(M) + 2qI_L B + 4k_B TB / R_L} \quad [6\text{-}16]$$

- Since the noise figure *F(M)* increases with M, there always exists an optimum value of *M* that maximizes the S/N. For sinusoidally modulated signal with *m=1* and $F(M) \approx M^x$:

$$M_{\text{opt}}^{x+2} = \frac{2qI_L + 4k_B T / R_L}{xq(I_P + I_D)} \quad [6\text{-}17]$$

Photodetector Response Time

- The response time of a photodetector with its output circuit depends mainly on the following three factors:

  1- The transit time of the photocarriers in the depletion region. The transit time t_d depends on the carrier drift velocity v_d and the depletion layer width *w*, and is given by:

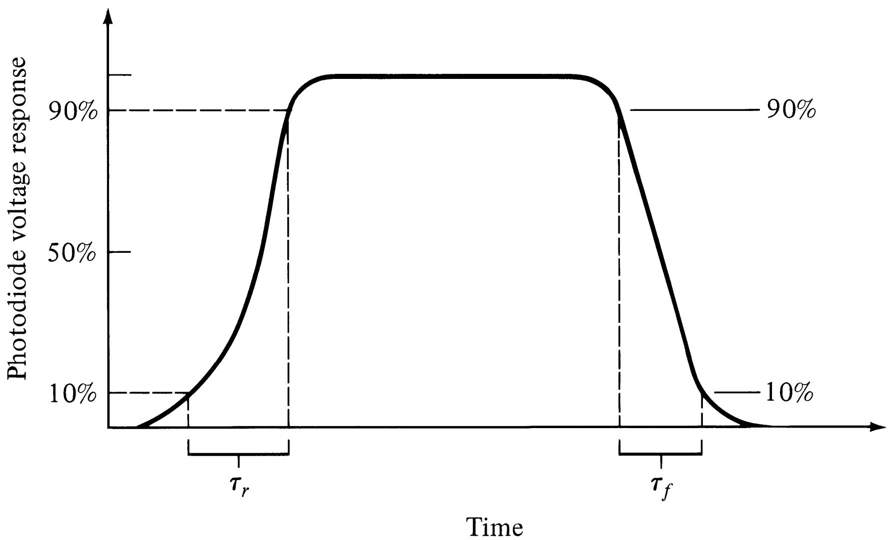
$$t_d = \frac{w}{v_d} \qquad [6\text{-}18]$$

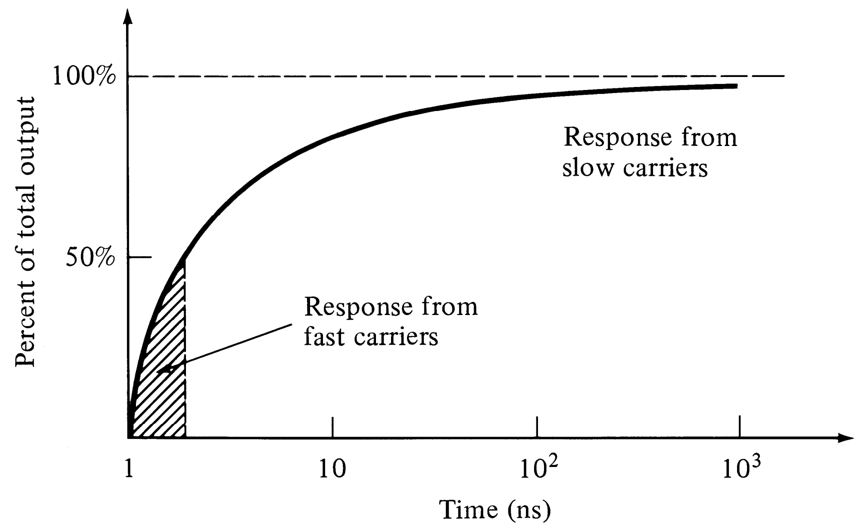
2- Diffusion time of photocarriers outside depletion region.

3- *RC* time constant of the circuit. The circuit after the photodetector acts like *RC* low pass filter with a passband given by:

$$B = \frac{1}{2\pi R_T C_T} \qquad R_T = R_s \parallel R_L \text{ and } C_T = C_a + C_d \qquad [6\text{-}19]$$

Photodiode response to optical pulse



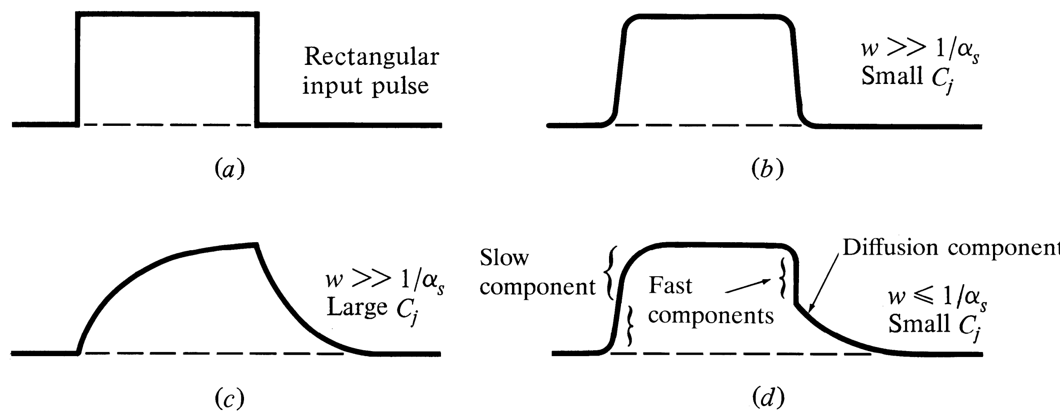


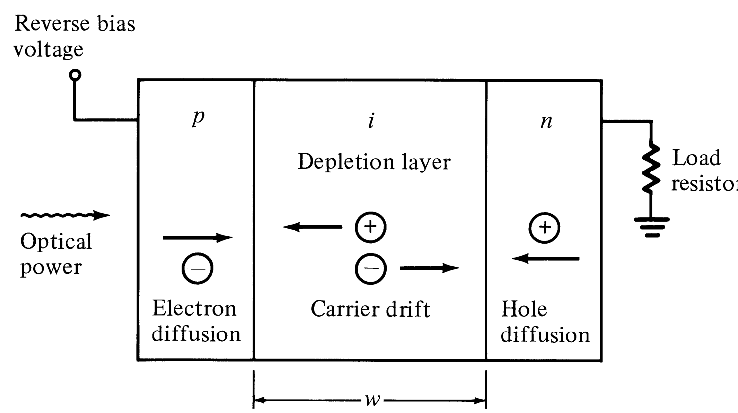
Typical response time of the photodiode that is not fully depleted

Various optical responses of photodetectors: Trade-off between quantum efficiency & response time

- To achieve a high quantum efficiency, the depletion layer width must be larger than $1/\alpha_s$ (the inverse of the absorption coefficient), so that most of the light will be absorbed. At the same time with large width, the capacitance is small and *RC* time constant getting smaller, leading to faster response, but wide width results in larger transit time in the depletion region. Therefore there is a trade-off between width and QE. It is shown that the best is:

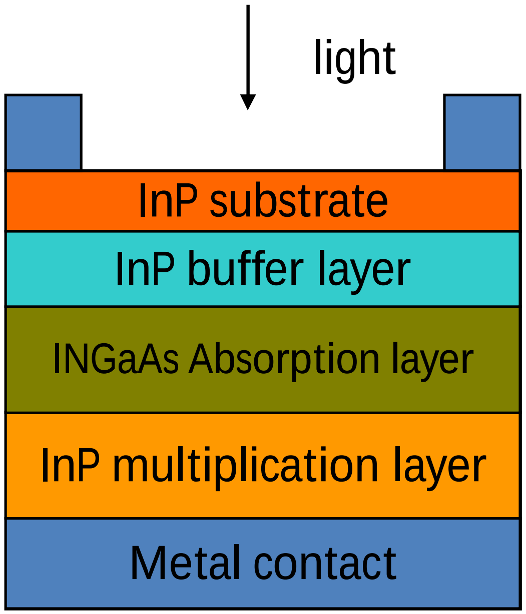
$$1/\alpha_s \le w \le 2/\alpha_s$$





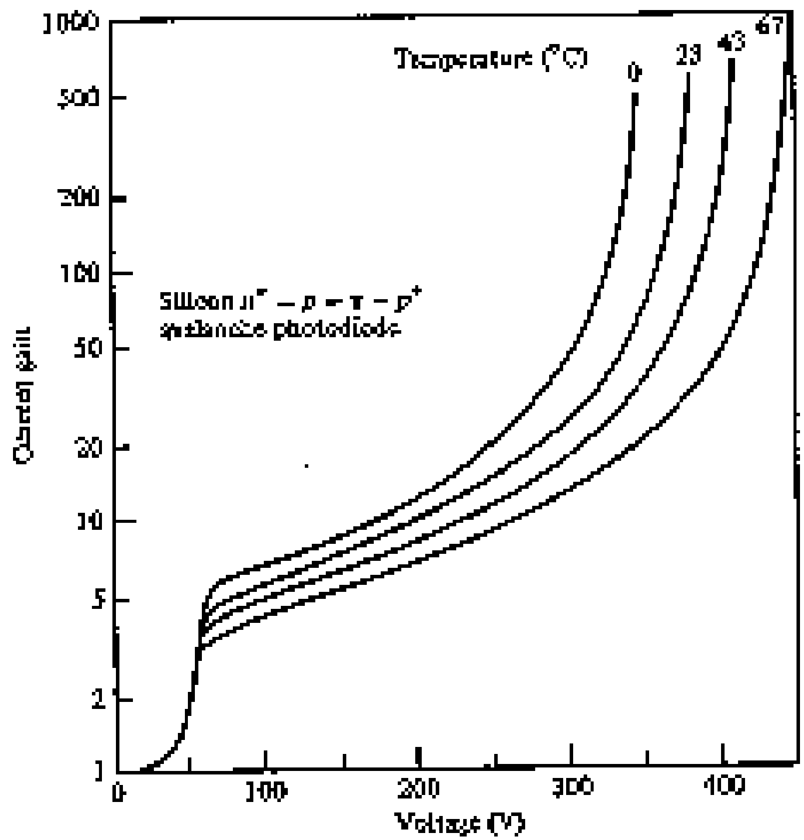
Structures for InGaAs APDs

- Separate-absorption-and multiplication (SAM) APD



- InGaAs APD superlattice structure (The multiplication region is composed of several layers of InAlGaAs quantum wells separated by InAlAs barrier layers.

Temperature effect on avalanche gain



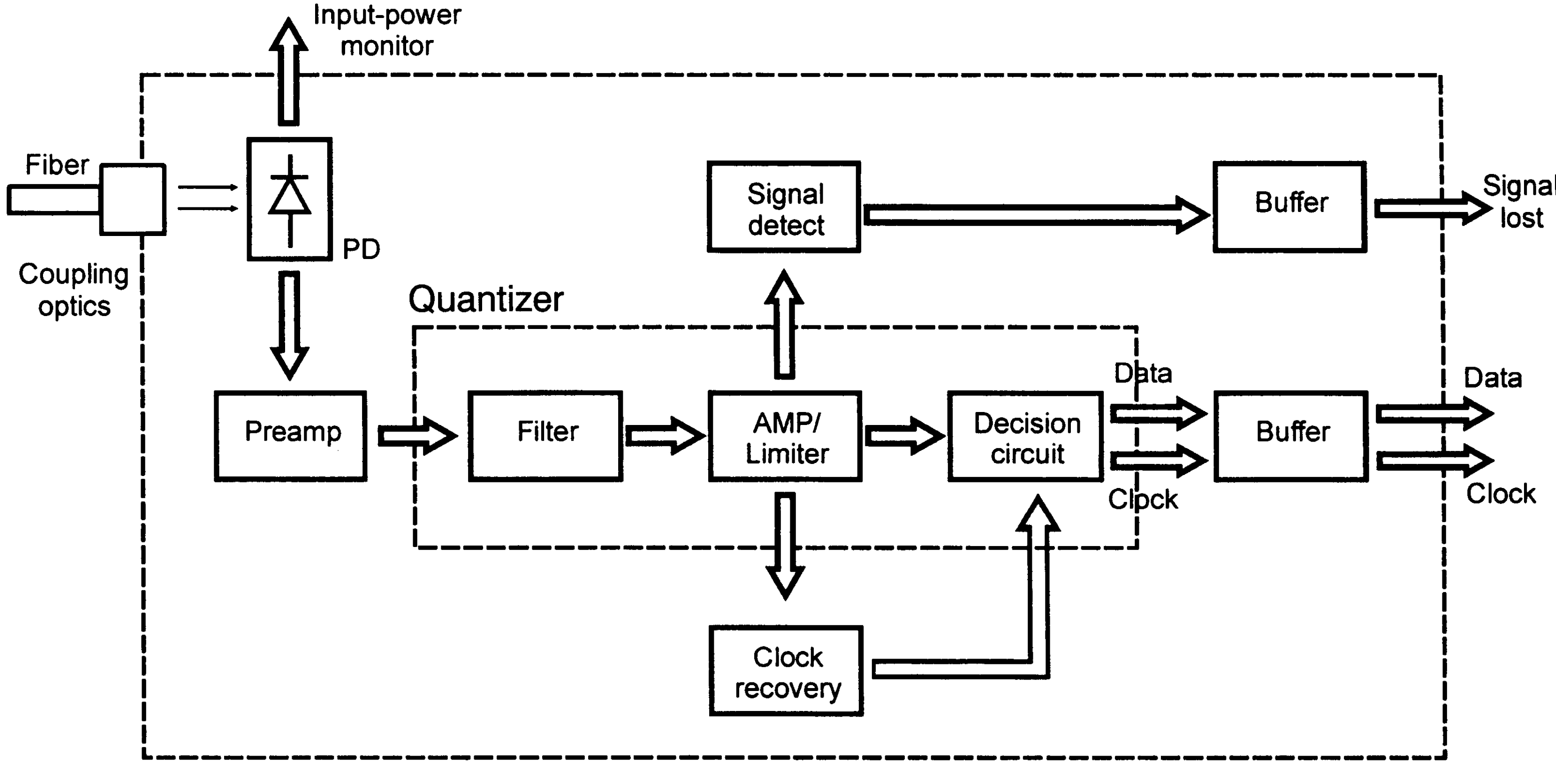
Comparison of photodetectors

Parameter	Symbol	Unit	Si	Ge	InGaAs
Wavelength range	λ	nm	400–1100	800–1650	1100–1700
Responsivity	$\mathcal{R}$	A/W	0.4–0.6	0.4–0.5	0.75–0.95
Dark current	I_D	nA	1–10	50–500	0.5–2.0
Rise time	τ_r	ns	0.5–1	0.1–0.5	0.05–0.5
Bandwidth	B	GHz	0.3–0.7	0.5–3	1–2
Bias voltage	V_B	V	5	5–10	5

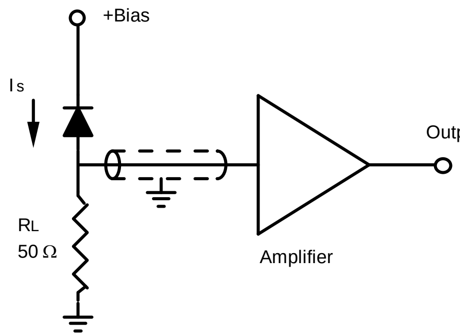
TABLE 6-2
Generic operating parameters of Si, Ge, and InGaAs avalanche photodiodes

Parameter	Symbol	Unit	Si	Ge	InGaAs
Wavelength range	λ	nm	400–1100	800–1650	1100–1700
Avalanche gain	M	—	20–400	50–200	10–40
Dark current	I_D	nA	0.1–1	50–500	10–50 @ $M = 10$
Rise time	τ_r	ns	0.1–2	0.5–0.8	0.1–0.5
Gain · bandwidth	$M \cdot B$	GHz	100–400	2–10	20–250
Bias voltage	V_B	V	150–400	20–40	20–30

Receiver Functional Block Diagram

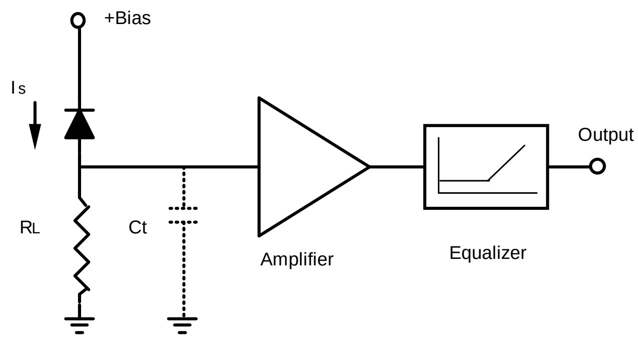


Receiver Types



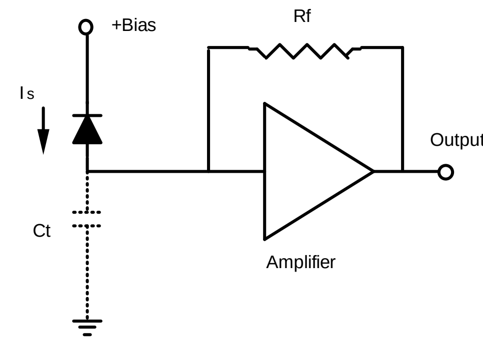
Low Impedance

Low Sensitivity
Easily Made
Wide Band



High Impedance

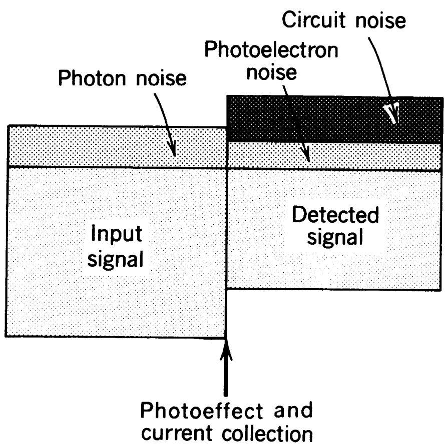
Requires Equalizer for high BW
High Sensitivity
Low Dynamic Range
Careful Equalizer Placement Required



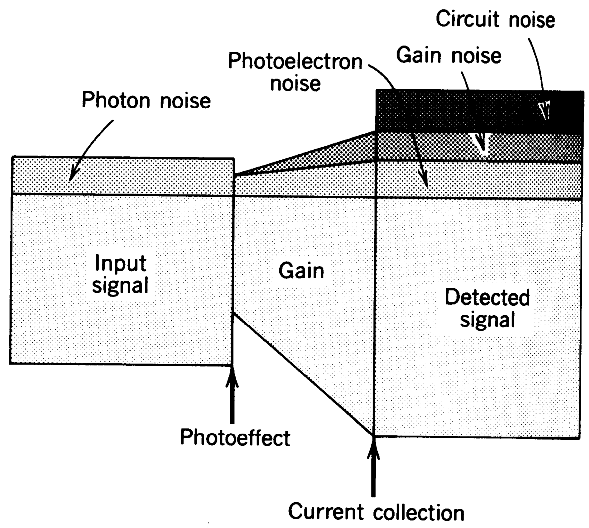
Transimpedance

High Dynamic Range
High Sensitivity
Stability Problems
Difficult to equalize

Receiver Noise Sources



Photodetector without gain



Photodetector with gain (APD)

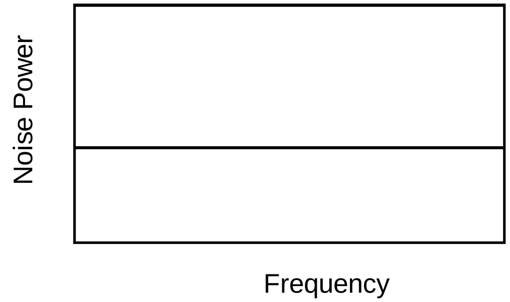
- Photon Noise
  - Also called shot noise or Quantum noise, described by poisson statistics
- Photoelectron Noise
  - Randomness of photodetection process leads to noise
- Gain Noise
  - eg. gain process in APDs or EDFAs is noisy
- Receiver Circuit noise
  - Resistors and transistors in the the electrical amplifier contribute to circuit noise

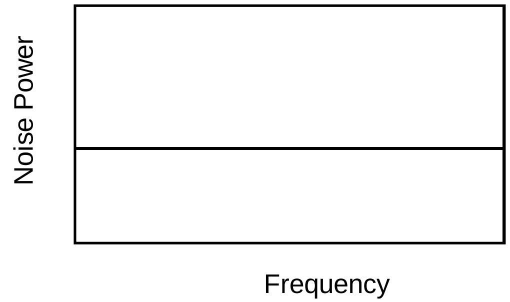
Noise

Johnson noise (Gaussian and white)

$$\text{Noise Power}=4kTB = \frac{\langle V_n \rangle^2}{R} = \langle i_n{}^2 \rangle R$$

$$i_{rms} = \sqrt{\frac{4kTB}{R}} \qquad V_{rms} = \sqrt{4kTRB}$$





Shot noise (Gaussian and white)

$$\text{rms noise current} = \langle i_n{}^2 \rangle^{1/2} = (2qIB)^{1/2}$$

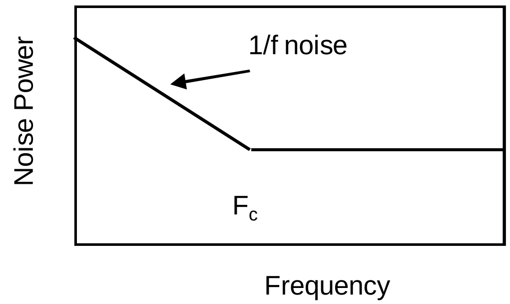
"1/f" noise

$$\text{spectral density}=\frac{K}{f} \quad V^2/\text{Hz}$$

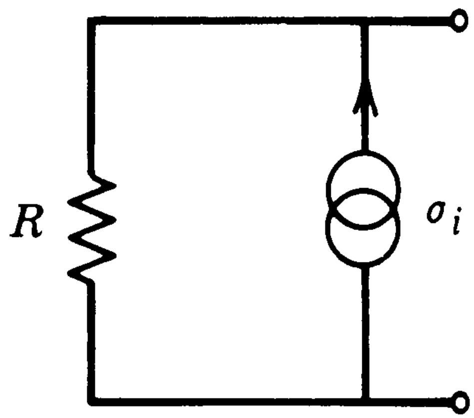
for FETs

$$K=\frac{4kT\Gamma}{g_m} f_c$$

where f_c is the FET corner frequency and Γ is the channel noise factor



Johnson (thermal) Noise



Noise in a resistor can be modeled as due to a noiseless resistor in parallel with a noise current source

The variance of the noise current source is given by:

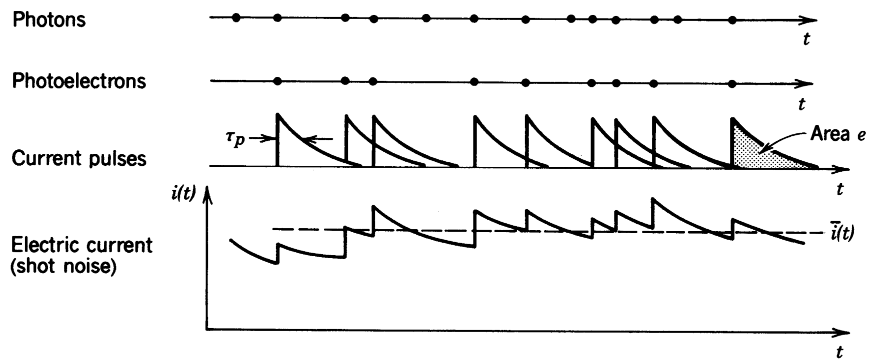
$$\sigma_i^2 = \langle i^2 \rangle \approx \frac{4k_B TB}{R}$$

Where k_B is Boltzman's constant

T is the Temperature in Kelvins

B is the bandwidth in Hz (not bits/sec)

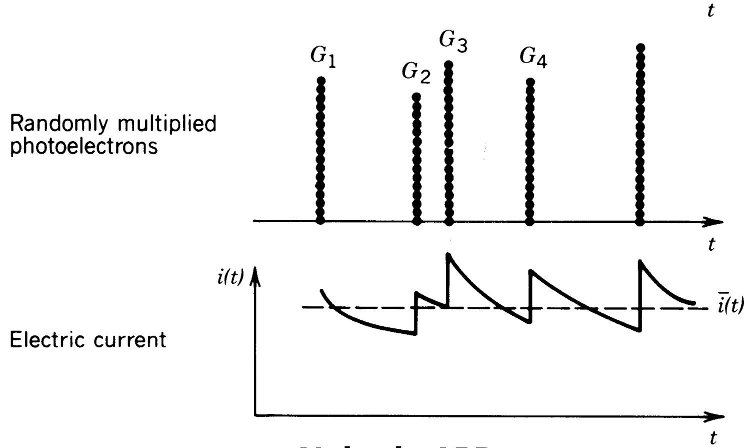
Photodetection noise



Noise in photodetector

The electric current in a photodetector circuit is composed of a superposition of the electrical pulses associated with each photoelectron

The variation of this current is called shot noise



Noise in APD

If the photoelectrons are multiplied by a gain mechanism then variations in the gain mechanism give rise to an additional variation in the current pulses. This variation provides an additional source of noise, gain noise

Circuit Noise

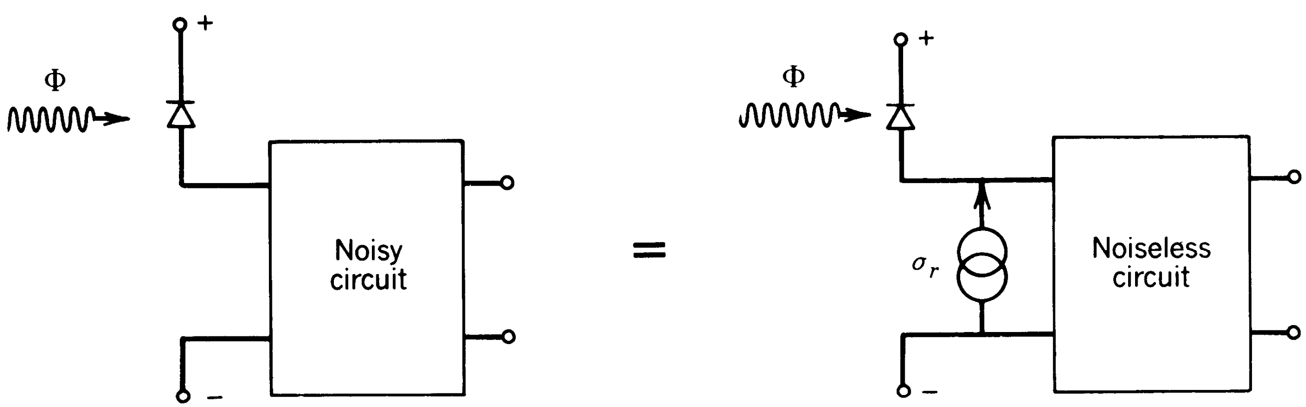
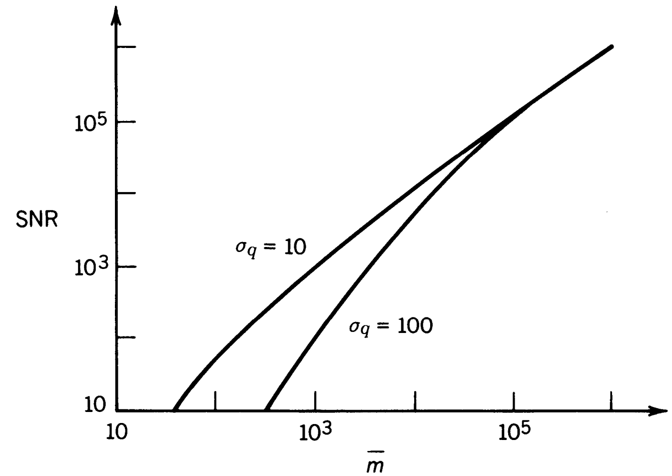
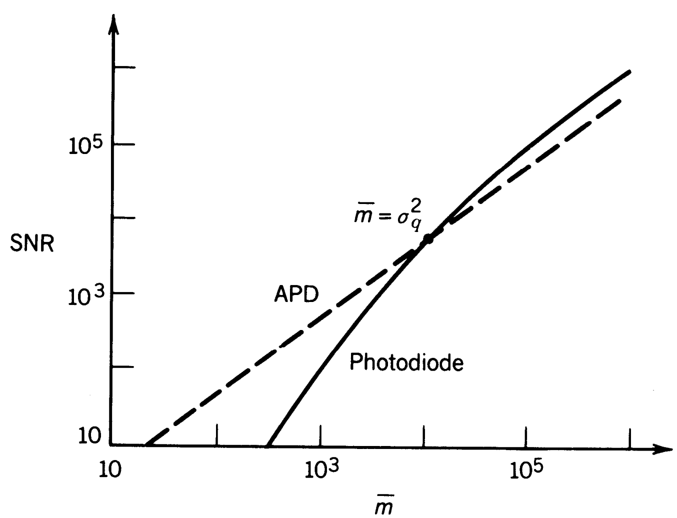


Figure 17.5-6 Noise in the receiver circuit can be replaced with a single random current source with rms value σ_r.

Signal to Noise Ratio



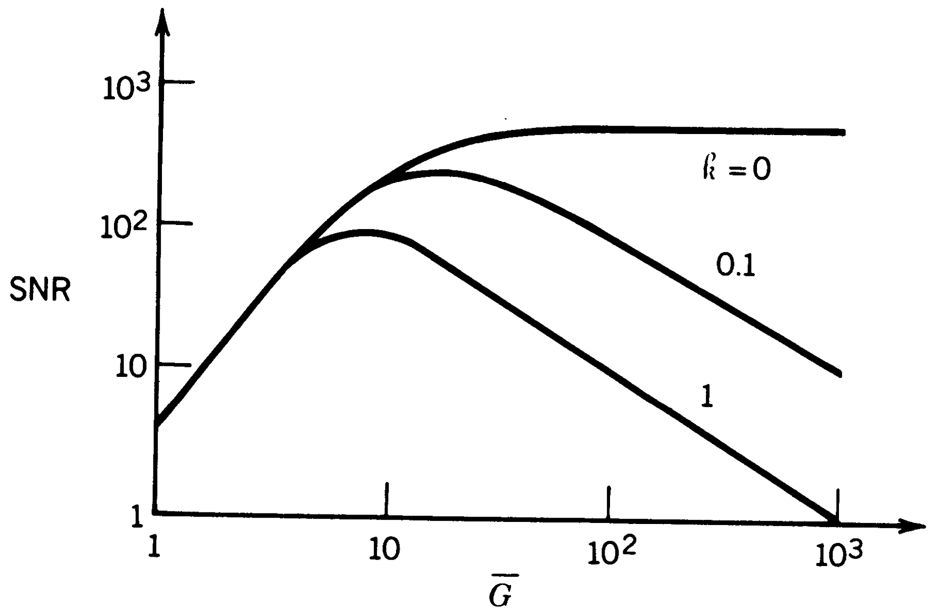
Signal to noise Ratio (SNR) as a function of the average number of photo electrons per receiver resolution time for a photo diode receiver at two different values of the circuit noise



Signal to noise Ratio (SNR) as a function of the average number of photoelectrons per receiver resolution time for a photo diode receiver and an APD receiver with mean gain G=100 and an excess noise factor F=2

At low photon fluxes the APD receiver has a better SNR. At high fluxes the photodiode receiver has lower noise

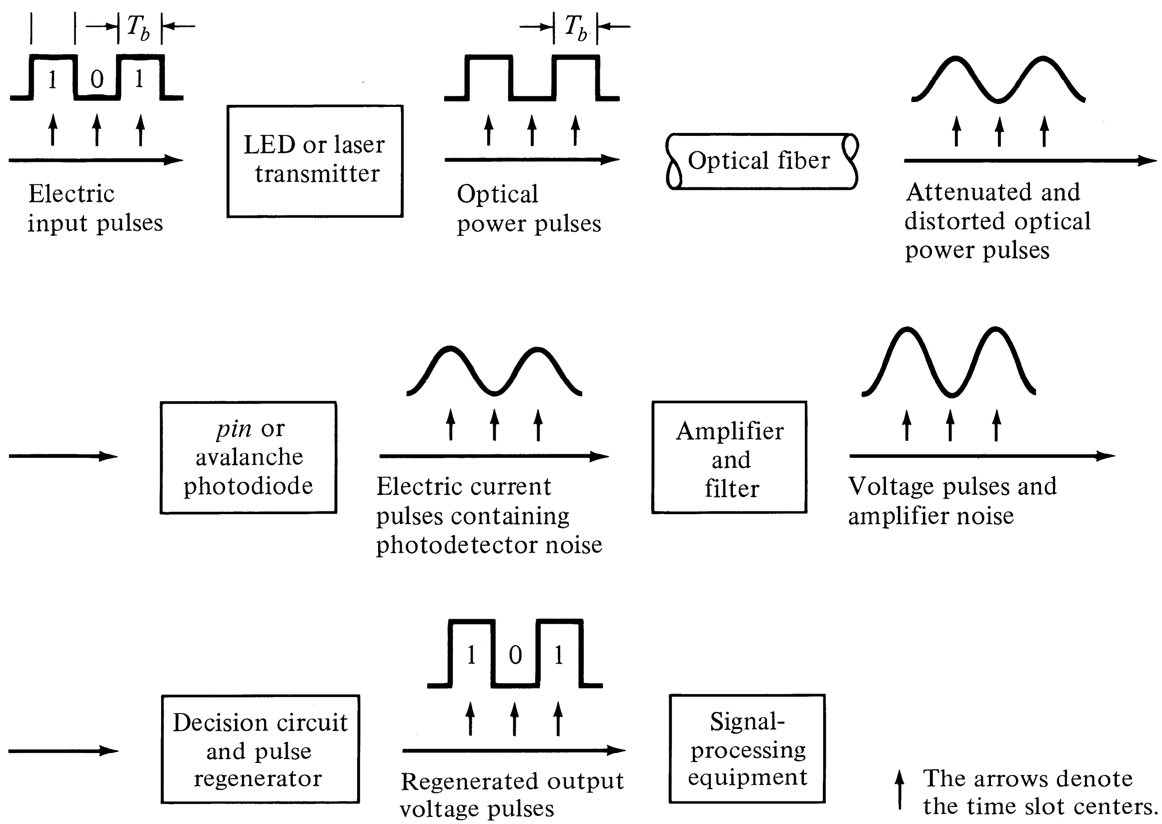
Dependence of SNR on APD Gain



Curves are parameterized by k, the ionization ratio between holes and electrons

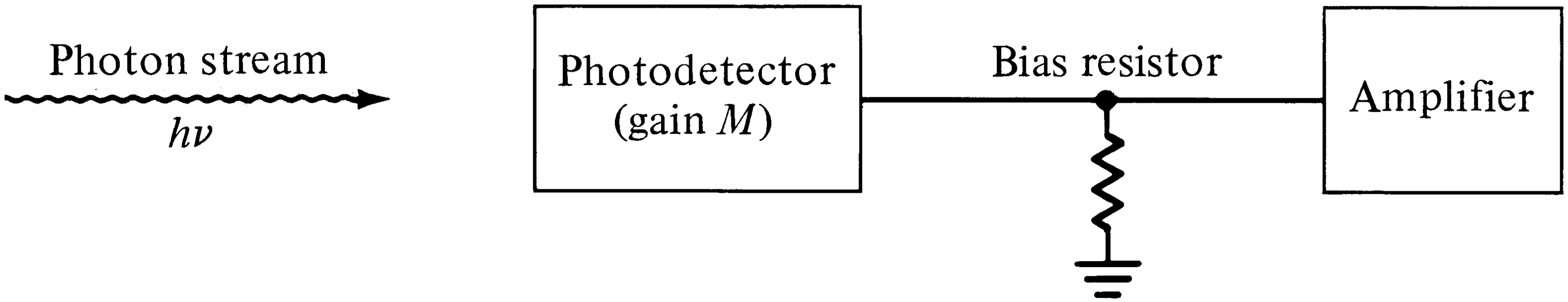
Plotted for an average detected photon flux of 1000
and constant circuit noise

Digital Transmission System (DTS)



- The design of optical receiver is much more complicated than that of optical transmitter because the receiver must first detect weak, distorted signals and the n make decisions on what type of data was sent.

Error Sources in DTS



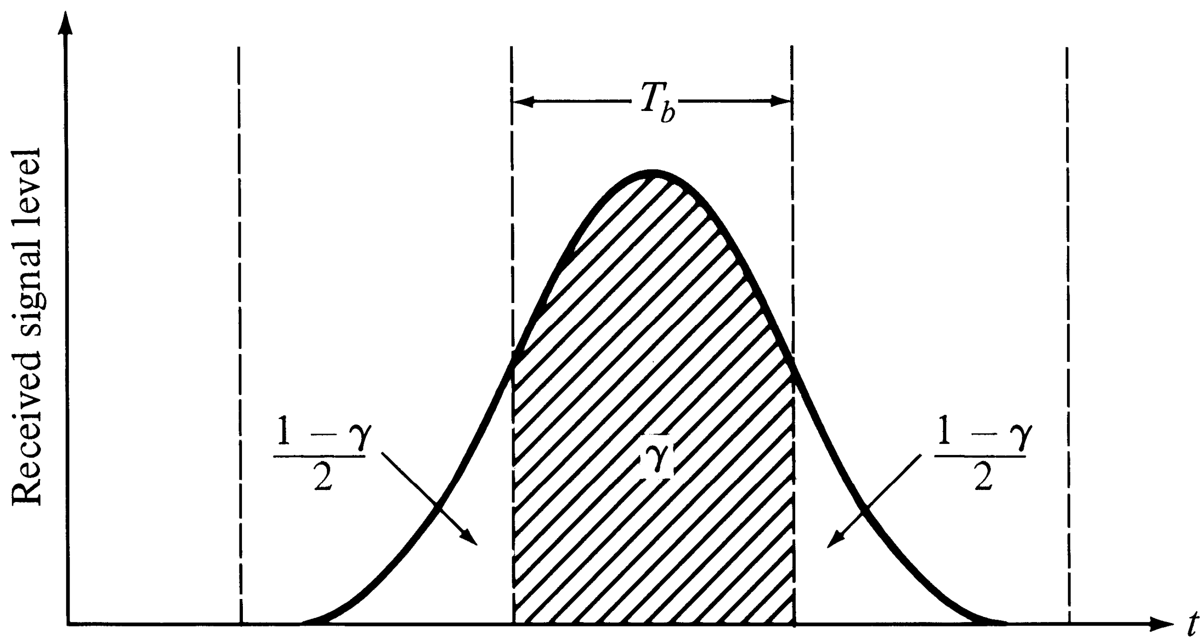
- Photon detection quantum noise (Poisson fluctuation)
- Bulk dark current
- Surface leakage current
- Statistical gain fluctuation (for avalanche photodiodes)
- Thermal noise
- Amplifier noise

$$\overline{N} = \frac{\eta}{h\nu}\int_0^{\tau} P(t)dt = \frac{\eta}{h\nu}E \qquad [7\text{-}1]$$

$$P_r(n) = \overline{N}^{\,n}\frac{e^{-\overline{N}}}{n!} \qquad [7\text{-}2]$$

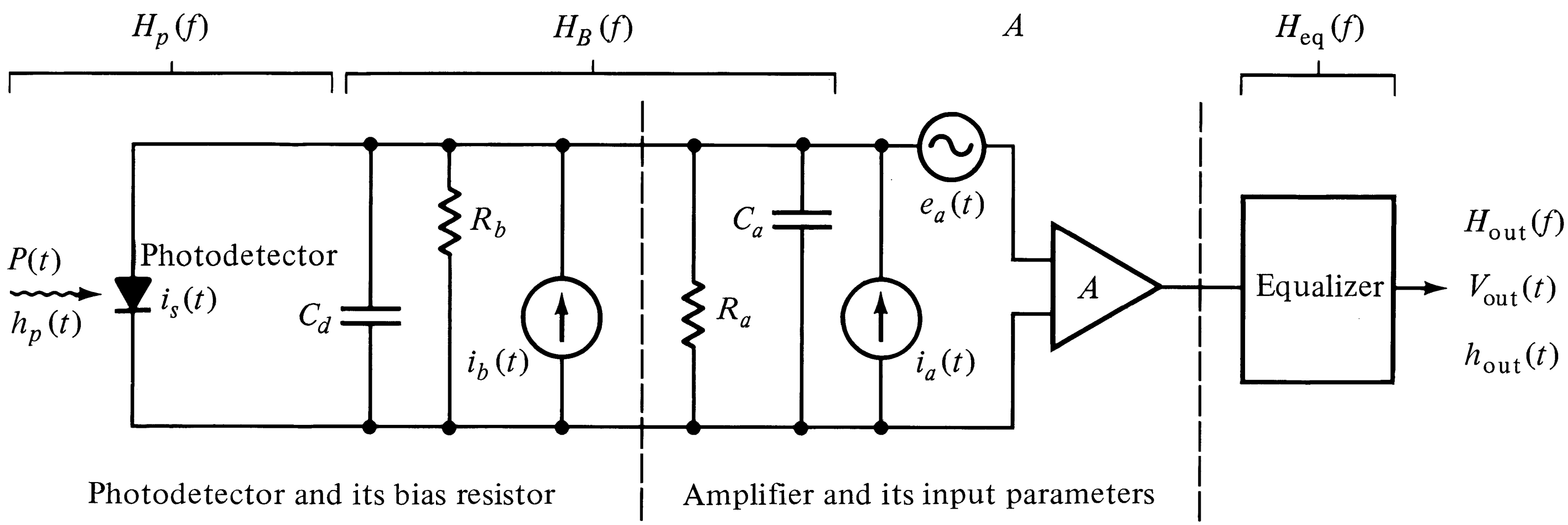
$\overline{N}$ is the average number of electron-hole pairs in photodetector, η is the detector quantum efficiency and E is energy received in a time interval τ and $h\nu$ is photon energy, where $P_r(n)$ is the probability that n electrons are emitted in an interval τ .

InterSymbol Interference (ISI)



Pulse spreading in an optical signal, after traversing along optical fiber, leads to ISI. Some fraction of energy remaining in appropriate time slot is designated by γ , so the rest is the fraction of energy that has spread Into adjacent time slots.

Receiver Configuration



The binary digital pulse train incident on the photodetector can be written in the following form:

$$P(t) = \sum_{n=-\infty}^{+\infty} b_n h_p(t - nT_b) \qquad [7\text{-}3]$$

where T_b is bit period, b_n is an amplitude parameter of the nth message digit and $h_p(t)$ is the received pulse shape which is positive for all t.

- In writing down eq. [7-3], we assume the digital pulses with amplitude *V* represents bit 1 and 0 represents bit 0. Thus b_n can take two values corresponding to each binary data. By normalizing the input pulse $h_p(t)$ to the photodiode to have unit area

$$\int_{-\infty}^{+\infty} h_p(t)dt = 1$$

- b_n represents the energy in the *n*th pulse.

The mean output current from the photodiode at time *t* resulting from pulse train given in eq. [7-3] is (neglecting the DC components arising from dark current noise):

$$\langle i(t)\rangle = \frac{\eta q}{h\nu} MP(t) = \Re_o M \sum_{n=-\infty}^{+\infty} b_n h_p(t - nT_b) \qquad \text{[7-4]}$$

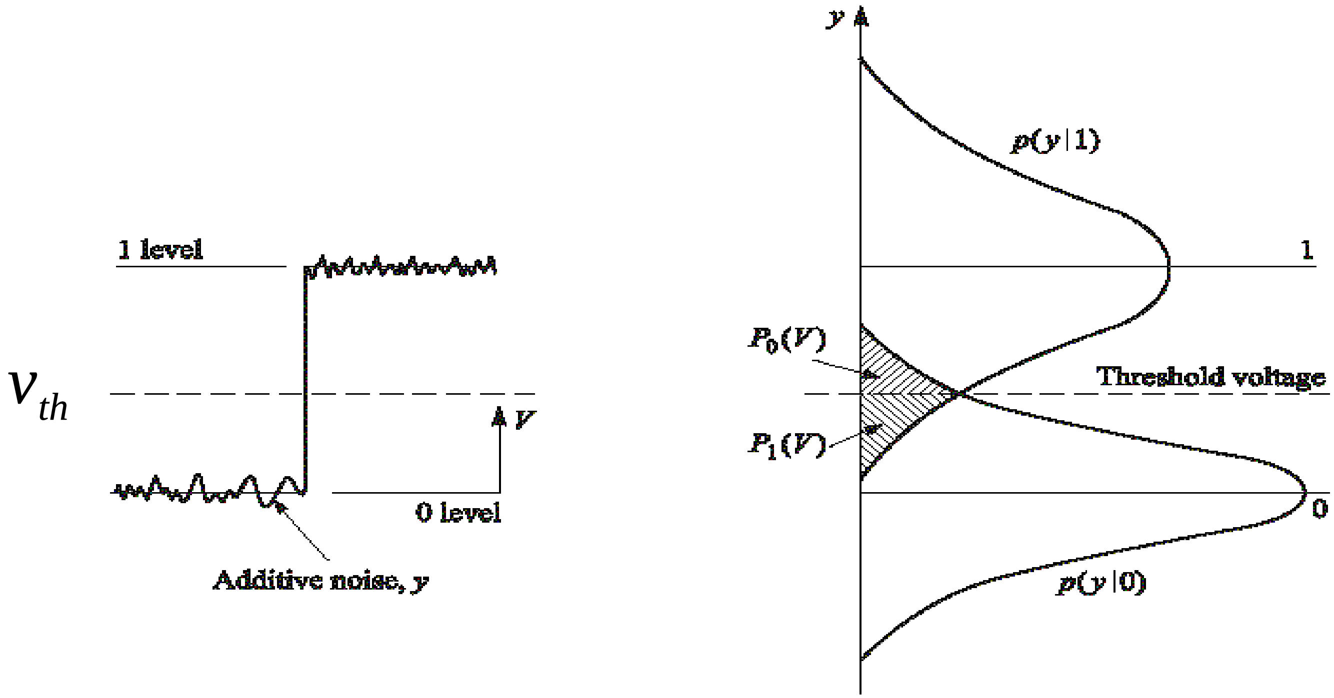
Bit Error Rate (BER)

$$\text{BER} = \text{Probability of Error} =$$

$$\frac{\#\text{ of error over a certain time interval } t}{\text{total }\#\text{ of pulses transmitted during } t} = \qquad [7\text{-}5]$$

$$\frac{N_e}{N_t} = \frac{N_e}{Bt} \qquad B = 1/T_b$$

- **Probability of Error**= probability that the output voltage is less than the threshold when a 1 is sent + probability that the output voltage is more than the threshold when a 0 has been sent.



Probability distributions for received logical 0 and 1 signal pulses.
the different widths of the two distributions are caused by various signal distortion effects.

$$P_1(v) = \int_{-\infty}^{v} p(y\,|\,1)dy \quad \text{probablity that the equalizer output voltage is less than } v, \text{if 1 transmitted}$$

[7-6]

$$P_0(v) = \int_{v}^{\infty} p(y\,|\,0)dy \quad \text{probablity that the equalizer output voltage exceeds } v, \text{if 0 transmitted}$$

$$P_e = q_1 P_1(v_{th}) + q_0 P_0(v_{th})$$

$$= q_1 \int_{-\infty}^{v_{th}} p(y\,|\,1)dy + q_0 \int_{v_{th}}^{\infty} p(y\,|\,1)dy \qquad [7\text{-}7]$$

- Where q_1 and q_0 are the probabilities that the transmitter sends 0 and 1 respectively.

$$q_0 = 1 - q_1 \qquad q_0 = q_1 = 0.5$$

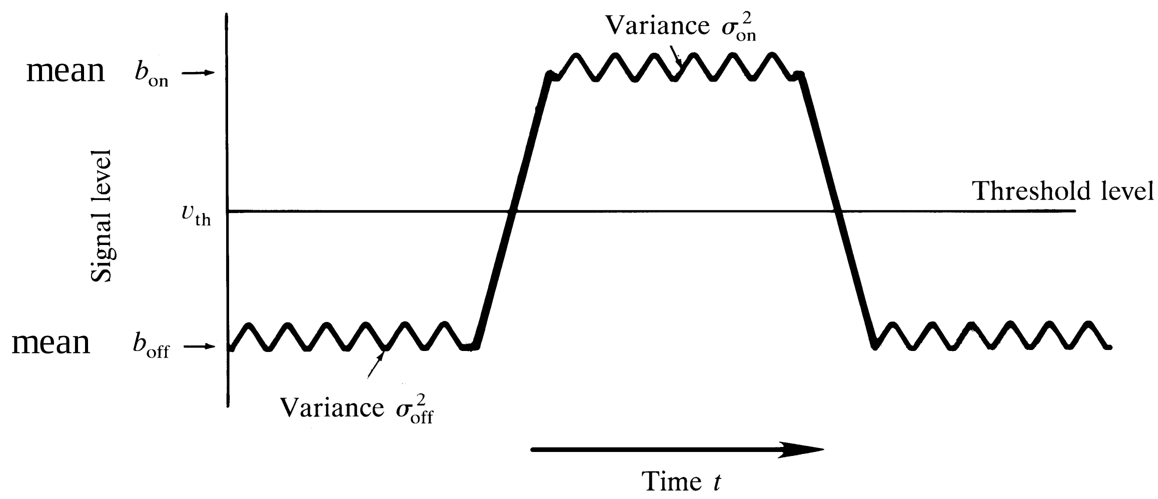
- For an unbiased transmitter

Gaussian Distribution

$$P_1(v_{th}) = \int_{-\infty}^{v_{th}} p(y\,|\,1)dy = \frac{1}{\sqrt{2\pi}\sigma_{\text{on}}} = \int_{-\infty}^{v_{th}} \exp\left[-\frac{(v-b_{on})^2}{2\sigma_{\text{on}}^2}\right]dv$$

$$P_0(v_{th}) = \int_{v_{th}}^{\infty} p(y\,|\,0)dy = \frac{1}{\sqrt{2\pi}\sigma_{\text{off}}} = \int_{v_{th}}^{\infty} \exp\left[-\frac{(v-b_{\text{off}})^2}{2\sigma_{\text{off}}^2}\right]dv$$

[7-8]



- If we assume that the probabilities of 0 and 1 pulses are equally likely, then using eq [7-7] and [7-8] , BER becomes:

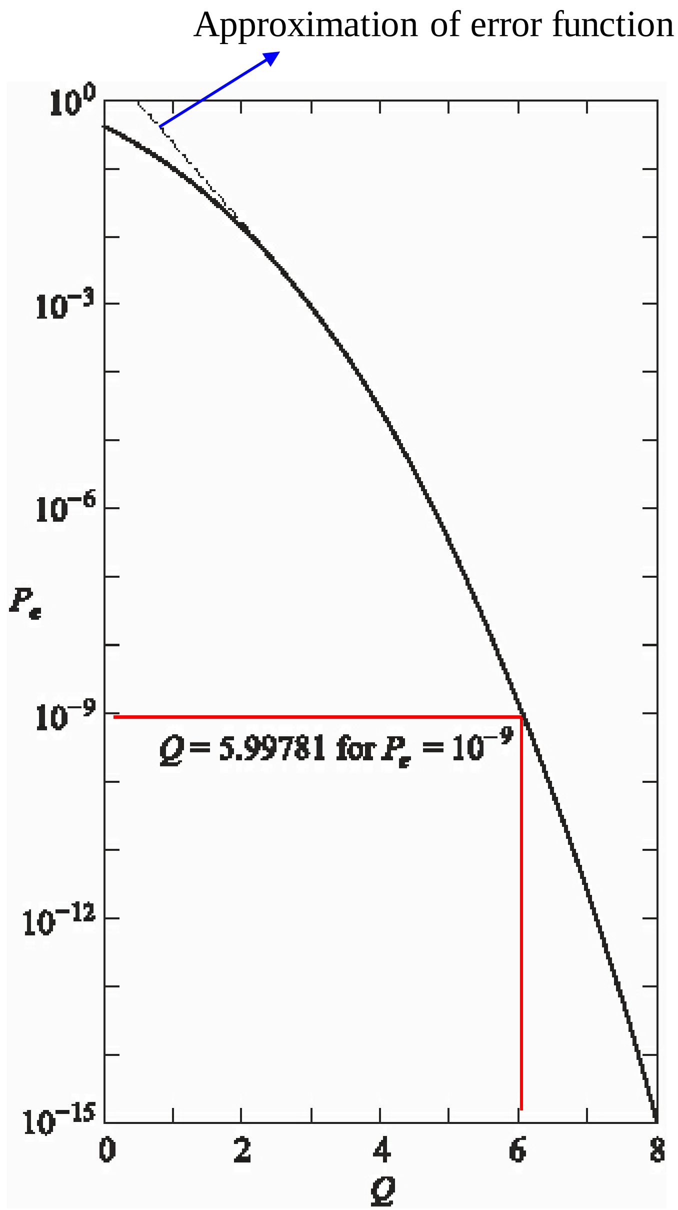
$$\mathrm{BER} = P_e(Q) = \frac{1}{\sqrt{\pi}} \int_{Q/\sqrt{2}}^{\infty} \exp(-x^2)dx = \frac{1}{2}\left[1 - \mathrm{erf}\left(\frac{Q}{\sqrt{2}}\right)\right]$$

$$\approx \frac{1}{\sqrt{2\pi}} \frac{\exp(-Q^2/2)}{Q} \qquad [7\text{-}9]$$

$$Q = \frac{v_{th} - b_{\mathrm{off}}}{\sigma_{\mathrm{off}}} = \frac{b_{\mathrm{on}} - v_{th}}{\sigma_{\mathrm{on}}} \qquad [7\text{-}9]$$

$$\mathrm{erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^x \exp(-y^2)dy \qquad [7\text{-}10]$$

Variation of BER vs Q, according to eq [7-9].



Special Case

In special case when:

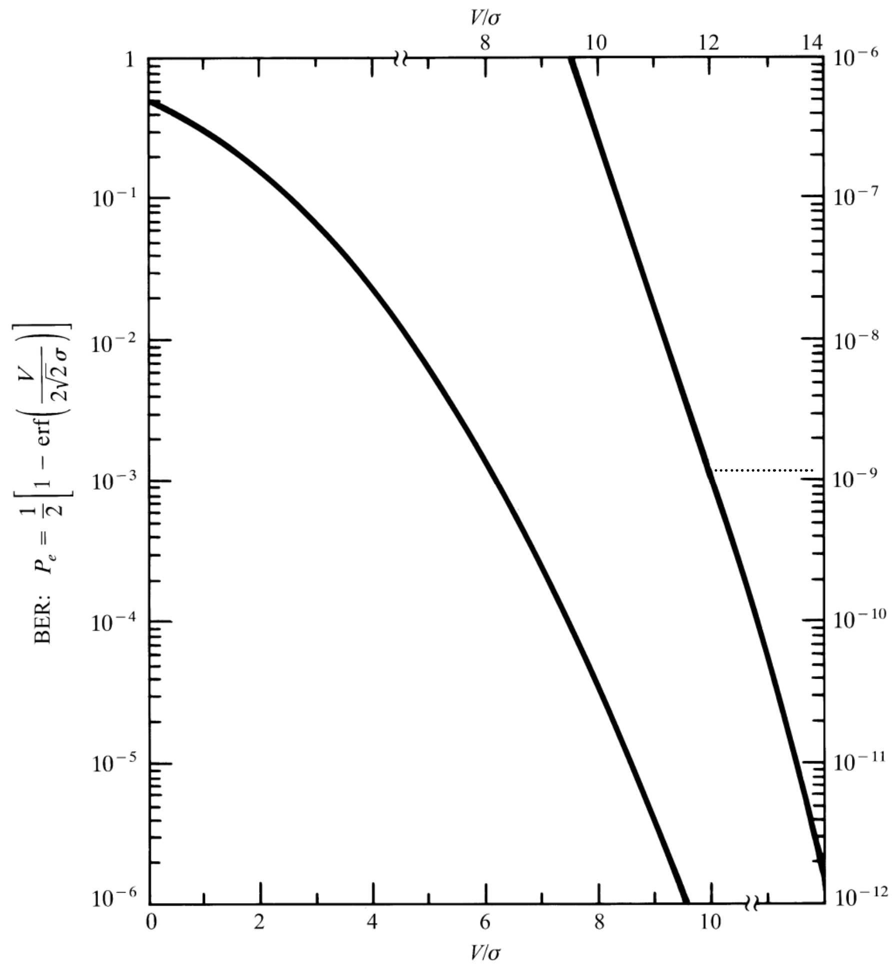
$$\sigma_{\text{off}} = \sigma_{\text{on}} = \sigma \ \& b_{\text{off}} = 0, b_{\text{on}} = V$$

From eq [7-29], we have: $v_{th} = V/2$

Eq [7-8] becomes:

$$P_e(\sigma) = \frac{1}{2}\left[1 - \text{erf}\,\left(\frac{V}{2\sqrt{2}\sigma}\right)\right] \qquad [7\text{-}11]$$

$\frac{V}{\sigma}$ is peak signal-to-rms-noise ratio.



Study example 7-1 pp. 286 of the textbook.

Quantum Limit

- Minimum received power required for a specific BER assuming that the photodetector has a 100% quantum efficiency and zero dark current. For such ideal photo-receiver,

$$P_e = P_1(0) = \exp(-\overline{N}) \qquad [7\text{-}12]$$

- Where $\overline{N}$ is the average number of electron-hole pairs, when the incident optical pulse energy is E and given by eq [7-1] with 100% quantum efficiency $(\eta = 1)$.

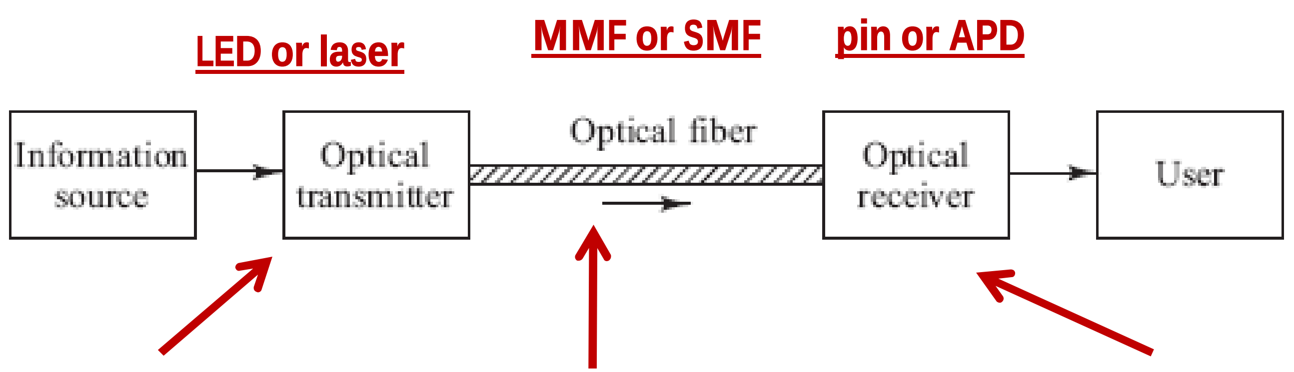
Unit -V
DIGITAL TRANMISSION SYSTEM

- Point-to-Point links – System considerations – Fiber Splicing and connectors – Link Power budget – Rise-time budget – Noise Effects on System Performance – Operational Principals of WDM, Solutions

Point-to-Point Links

Key system requirements needed to analyze optical fiber links:

1. The desired (or possible) transmission distance
2. The data rate or channel bandwidth
3. The desired bit-error rate (BER)



(a) Emission wavelength
(b) Spectral line width
(c) Output power
(d) Effective radiating area
(e) Emission pattern

(a) Core size
(b) Core index profile
(c) BW or dispersion
(d) Attenuation
(e) NA or MFD

(a) Responsivity
(b) Operating λ
(c) Speed
(d) Sensitivity

Selecting the Fiber

Bit rate and distance are the major factors

Other factors to consider: attenuation (depends on?) and distance-bandwidth product (depends on?) cost of the connectors, splicing etc.

Then decide

- Multimode or single mode
- Step or graded index fiber

Selecting the Optical Source

- Emission wavelength depends on acceptable attenuation and dispersion
- Spectral line width depends on acceptable ………… dispersion (LED → wide, LASER → narrow)
- Output power in to the fiber (LED → low, LASER → high)
- Stability, reliability and cost
- Driving circuit considerations

Selecting the detector

- Type of detector
  - APD: High sensitivity but complex, high bias voltage (40V or more) and expensive
  - PIN: Simpler, thermally stable, low bias voltage (5V or less) and less expensive
- Responsivity (that depends on the avalanche gain & quantum efficiency)
- Operating wavelength and spectral selectivity
- Speed (capacitance) and photosensitive area
- Sensitivity (depends on noise and gain)

Typical bit rates at different wavelengths

Wavelength	**LED** Systems	**LASER** Systems.
800-900 nm (Typically Multimode Fiber)	150 Mb/s.km	2500 Mb/s.km
1300 nm (Lowest dispersion)	1500 Mb/s.km	25 Gb/s.km (InGaAsP Laser)
1550 nm (Lowest Attenuation)	1200 Mb/s.km	Up to 500 Gb/s.km (Best demo)

Fusion Splicing Method

Fusion splicing is a permanent connection of two or more optical fibers by welding them together using an electronic arc. It is the most widely used method of splicing as it provides for the lowest loss, less reflectance, strongest and most reliable joint between two fibers. When adopting this method, fusion splicing machines are often used. Generally, there are four basic steps in fusion splicing process as illustrating in following one by one.

Step 1: strip the fiber

The splicing process begins with the preparation for both fibers ends to be fused. So you need to strip all protective coating, jackets, tubes, strength members and so on, just leaving the bare fiber showing. It is noted that the cables should be clean.

Step 2: cleave the fiber

A good fiber cleaver is crucial to a successful fusion splice. The cleaver merely nicks the fiber and then pulls or flexes it to cause a clean break rather than cut the fiber. The cleave end-face should be perfectly flat and perpendicular to the axis of the fiber for a proper splice.

Step 3: fuse the fiber

When fusing the fiber, there are two important steps: aligning and melting. Fist of all, aligning the ends of the fiber within the fiber optic splicer. Once proper alignment is achieved, utilizing an electrical arc to melt the fibers to permanently welding the two fiber ends together.

Step 4: protect the fiber

A typical fusion splice has a tensile strength between 0.5 and 1.5 lbs and it is not easy to break during normal handling. However, it still requires protection from excessive bending and pulling forces. By using heat shrink tubing, silicone gel and/or mechanical crimp protectors will keep the splice protected from outside elements and breakage.

Mechanical Splicing Method

A mechanical splice is a junction of two or more optical fibers that are aligned and held in place by a self-contained assembly. A typical example of this method is the use of connectors to link fibers. This method is most popular for fast, temporary restoration or for splicing multimode fibers in a premises installation. Like fusion splice, there are also four basic steps in mechanical splice.

Step 1: strip the fiber

Fiber preparation here is practically the same as for fusion splicing. Just removing the protective coatings, jackets, tubes, strength members to show the bare fiber. Then ensuring the cleanliness of the fiber.

Step 2: cleave the fiber

The process is the same as the cleaving for fusion splicing. It is necessary to obtain a cut on the fiber which is exactly at right angles to the axis of the fiber.

Step 3: mechanically join the fiber

In this step, heating is not used as in fusion splice. Simply connecting the fiber ends together inside the mechanical splice unit. The index matching gel inside the mechanical splice apparatus will help couple the light from one fiber end to the other.

Step 4: protect the fiber

Once fibers are spliced, they will be placed in a splice tray which is then placed in a splice closure. Outside plant closures without use of heat shrink tubing will be carefully sealed to prevent moisture damage to the splices.

Wavelength Division Multiplexing (WDM)

Why Is WDM Used?

With the exponential growth in communications, caused mainly by the wide acceptance of the Internet, many carriers are finding that their estimates of fiber needs have been highly underestimated. Although most cables included many spare fibers when installed, this growth has used many of them and new capacity is needed. Three methods exist for expanding capacity: 1) installing more cables, 2) increasing system bitrate to multiplex more signals or 3) wavelength division multiplexing.

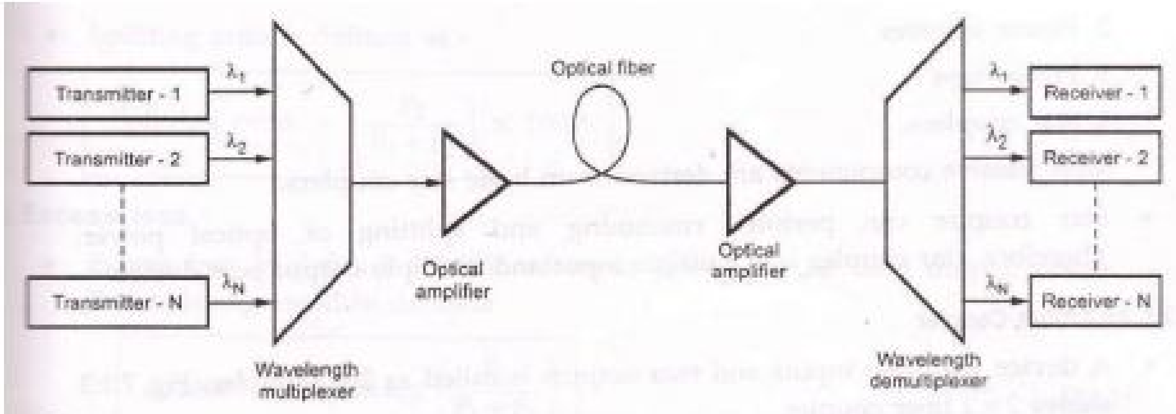


Fig. 7.1.1 WDM scheme

- To prevent spurious signals to enter into receiving channel, the demultiplexer must have narrow spectral operation with sharp wavelength cut-offs. The acceptable limit of crosstalk is – 30 dB.

Features of WDM

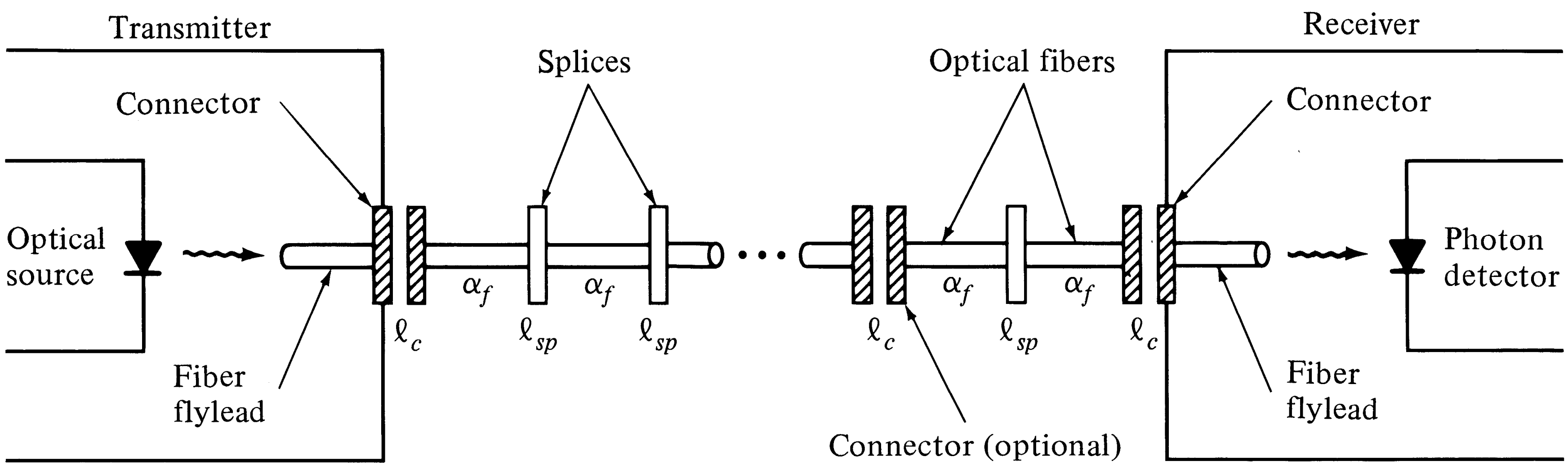
- Important advantages or features of WDM are as mentioned below –
  1. Capacity upgrade : Since each wavelength supports independent data rate in Gbps.
  2. Transparency : WDM can carry fast asynchronous, slow synchronous, synchronous analog and digital data.
  3. Wavelength routing : Link capacity and flexibility can be increased by using multiple wavelength.
  4. Wavelength switching : WDM can add or drop multiplexers, cross connects and wavelength converters.

Design Considerations

- Link Power Budget
  - There is enough power margin in the system to meet the given BER
- Rise Time Budget
  - Each element of the link is fast enough to meet the given bit rate

These two budgets give necessary conditions for satisfactory operation

Optical power-loss model



$$P_T = P_s - P_R = ml_c + nl_{sp} + \alpha_f L + \text{System Margin}$$

P_T: Total loss; P_s : Source power; P_R: Rx sensitivity

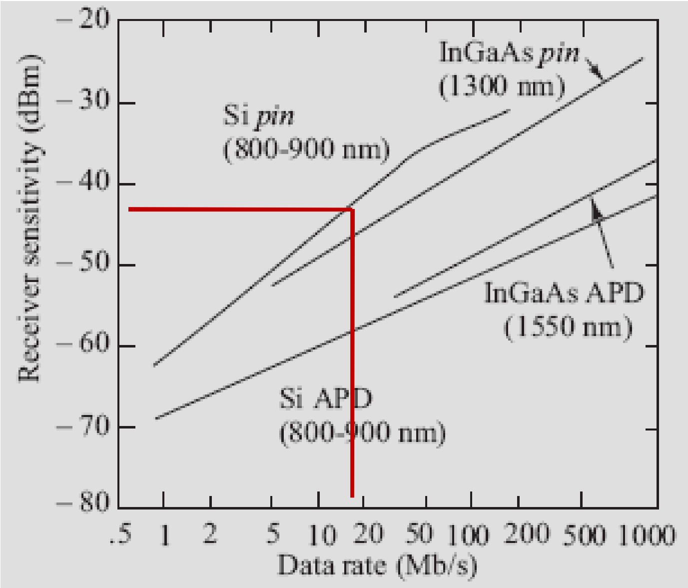
m connectors; n splices

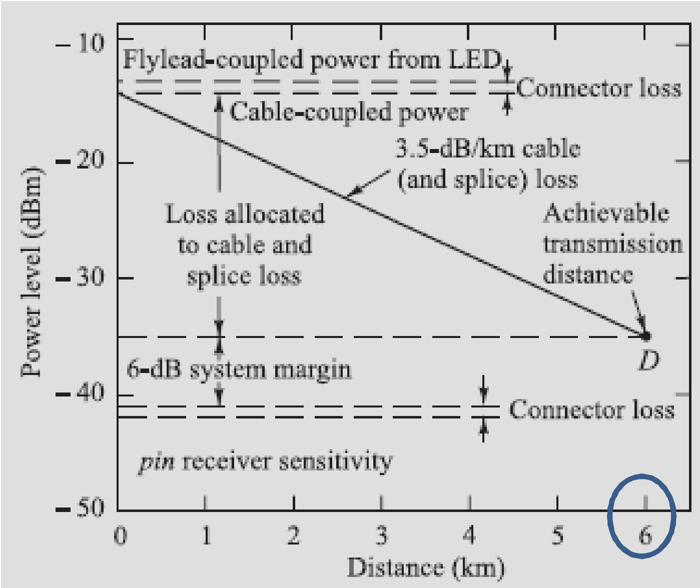
Power Budget Example

- Specify a 20-Mb/s data rate and a BER = 10^{-9}.
- With a Si *pin* photodiode at 850 nm, the required receiver input signal is –42 dBm.
- Select a GaAlAs LED that couples 50 mW into a 50-μm core diameter fiber flylead.
- Assume a 1-dB loss occurs at each cable interface and a 6-dB system margin.
- The possible transmission distance L = 6 km can be found from

$$P_T = P_S - P_R = 29\ dB = 2l_c + \alpha L + \text{system margin} = 2(1\text{ dB}) + \alpha\text{L} + 6\text{ dB}$$

- The link power budget can be represented graphically (see the right-hand figure).





Rise-Time Budget (1)

- A *rise-time budget analysis* determines the dispersion limitation of an optical fiber link.
- The total rise time t_{sys} is the root sum square of the rise times from each contributor t_i to the pulse rise-time degradation:
  - The transmitter rise time t_{tx}
  - The group-velocity dispersion (GVD) rise time t_{GVD} of the fiber

The modal dispersion rise time t_{mod} of the fiber

The receiver rise time t_{rx}

$$t_{sys} = \left[t_{tx}^2 + t_{mod}^2 + t_{GVD}^2 + t_{rx}^2 \right]^{1/2}$$

$$= \left[t_{tx}^2 + \left(\frac{440 L^q}{B_0} \right)^2 + D^2 \sigma_\lambda^2 L^2 + \left(\frac{350}{B_e} \right)^2 \right]^{1/2}$$

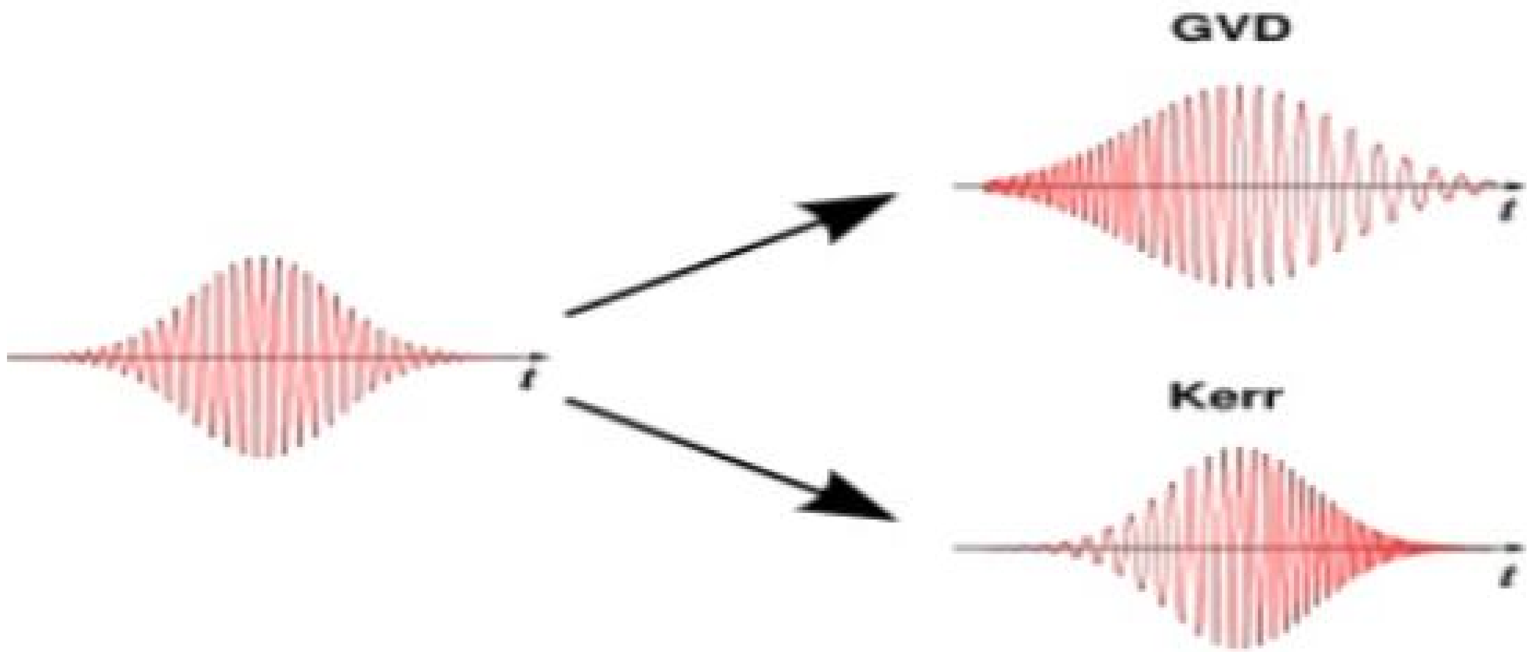
Here Be and B0 are given in MHz, so all times are in ns.

Solitons

- Soliton is very narrow, high intensity optical pulses.
- Retain their shape through the interaction of balancing pulse dispersion with non linear properties of an optical fiber.
- GVD causes most pulses to broaden in time, but soliton takes advantage of non-linear effects in silica (SPM) resulting from Kerr nonlinearity, to over come the pulse broadening effects of GVD

- Depending on the particular shape chosen, the pulse either does not change its shape as it propagate, or it undergoes periodically repeating change in shape.
- The family of pulse that do not change in shape are called **Fundamental Soliton**.
- The family of pulse that undergo periodic shape change are called **Higher order soliton.**

In OFC, Solitons



On the left there is a standard Gaussian pulse, that's the envelope of the field oscillating at a defined frequency. ***frequency remains perfectly constant*** during the pulse.

Soliton Pulses

1.Medium with Positive GVD

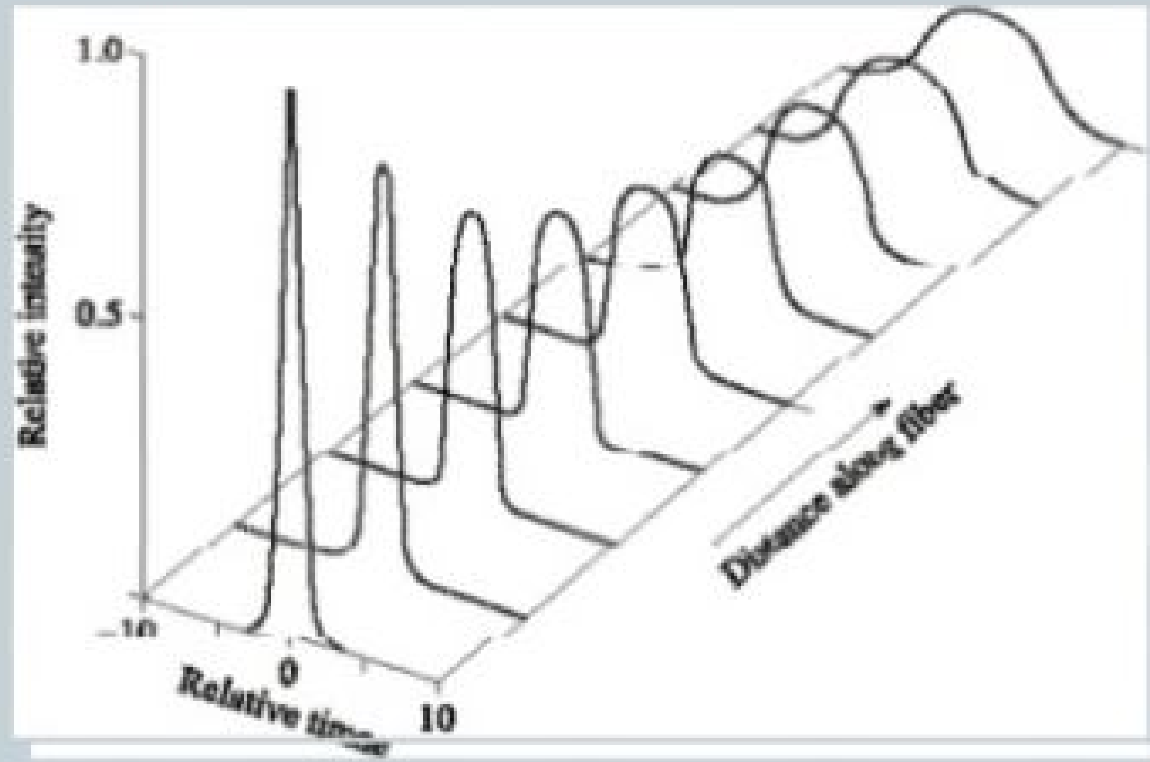
Leading part of the pulse is shifted toward lower frequencies , so the speed in that portion increases.

In trailing half, the frequency rises so the speed decreases. This causes trailing edge to be further delayed.

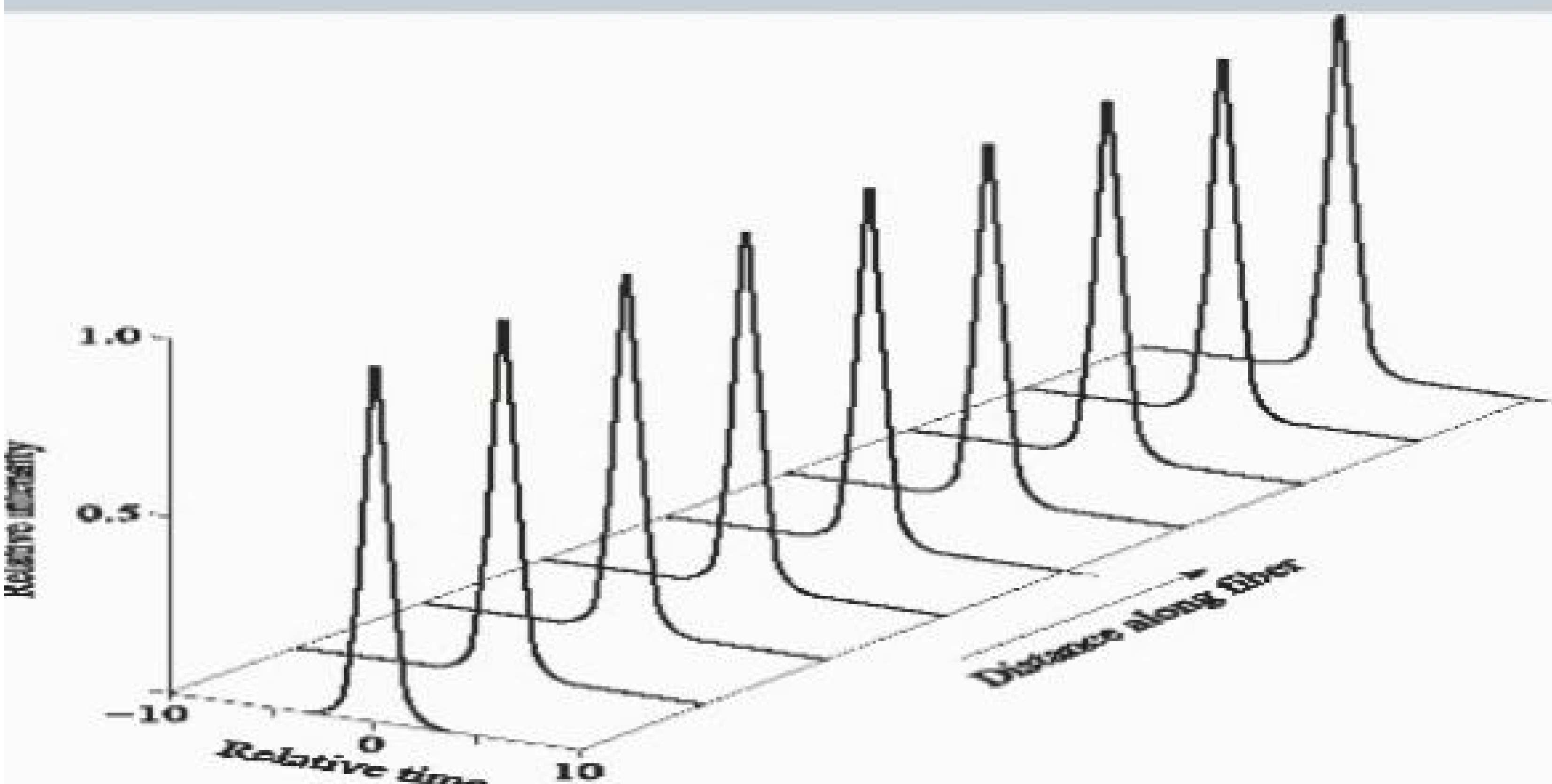
Also energy in the centre of pulse is dispersed to either side, and pulse takes on a rectangular wave shape.

These effects will severely limit high speed long distance transmission if the system is operated in this condition

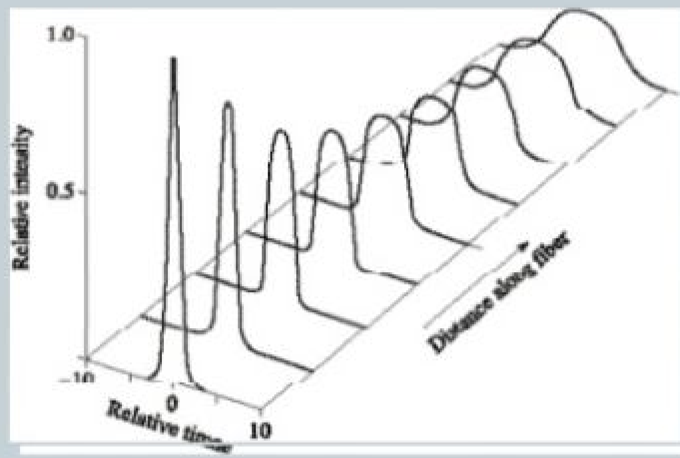
Soliton Pulses



Soliton Pulses



Soliton Pulses



A Course Material on

SATELLITE COMMUNICATION

By

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QUALITY CERTIFICATE

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Subject : **SATELLITE COMMUNICATION**

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Designation : Assistant Professor

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Signature of HD

N.RAMKUMAR

EC2045 SATELLITE COMMUNICATION

AIM

To enable the student to become familiar with satellites and satellite services.

OBJECTIVES

- Overview of satellite systems in relation to other terrestrial systems.
- Study of satellite orbits and launching.
- Study of earth segment and space segment components
- Study of satellite access by various users.
- Study of DTH and compression standards.

UNIT I SATELLITE ORBITS **8**

Kepler's Laws, Newton's law, orbital parameters, orbital perturbations, station keeping, geo stationary and non Geo-stationary orbits – Look Angle Determination- Limits of visibility –eclipse-Sub satellite point –Sun transit outage-Launching Procedures - launch vehicles and propulsion.

UNIT II SPACE SEGMENT AND SATELLITE LINK DESIGN **12**

Spacecraft Technology- Structure, Primary power, Attitude and Orbit control, Thermal control and Propulsion, communication Payload and supporting subsystems, Telemetry, Tracking and command. Satellite uplink and downlink Analysis and Design, link budget, E/N calculation- performance impairments-system noise, inter modulation and interference, Propagation Characteristics and Frequency considerations- System reliability and design lifetime.

UNIT III SATELLITE ACCESS: **10**

Modulation and Multiplexing: Voice, Data, Video, Analog – digital transmission system, Digital video Brocast, multiple access: FDMA, TDMA, CDMA, Assignment Methods, Spread Spectrum communication, compression – encryption

UNIT IV EARTH SEGMENT **5**

Earth Station Technology-- Terrestrial Interface, Transmitter and Receiver, Antenna Systems TVRO, MATV, CATV, Test Equipment Measurements on G/T, C/No, EIRP, Antenna Gain.

UNIT V SATELLITE APPLICATIONS **10**

INTELSAT Series, INSAT, VSAT, Mobile satellite services: GSM, GPS, INMARSAT, LEO, MEO, Satellite Navigational System. Direct Broadcast satellites (DBS)- Direct to home Broadcast (DTH), Digital audio broadcast (DAB)- Worldspace services, Business TV(BTV), GRAMSAT, Specialized services – E –mail, Video conferencing, Internet.

TOTAL = 45 PERIODS

TEXT BOOKS:

1. Dennis Roddy, 'Satellite Communication', McGraw Hill International, 4th Edition, 2006.
2. Wilbur L. Pritchard, Hendri G. Suyderhoud, Robert A. Nelson, 'Satellite Communication Systems Engineering', Prentice Hall/Pearson, 2007.

REFERENCES:

1. N.Agarwal, 'Design of Geosynchronous Space Craft, Prentice Hall, 1986.
2. Bruce R. Elbert, 'The Satellite Communication Applications' Hand Book, Artech HouseBostan London, 1997.

UNIT I SATELLITE ORBITS

1.1 Introduction to satellite communication:

Satellites are specifically made for telecommunication purpose. They are used for mobile applications such as communication to ships, vehicles, planes, hand -held terminals and for TV and radio broadcasting.

They are responsible for providing these services to an assigned region (area) on the earth. The power and bandwidth of these satellites depend upon the preferred size of the footprint, complexity of the traffic control protocol schemes and the cost of ground stations.

A satellite works most efficiently when the transmissions are focused with a desired area.

When the area is focused, then the emissions don‟t go outside that designated area and thus minimizing the interference to the other systems. This leads more efficient spectrum usage.

Satellite‟s antenna patterns play an important role and must be designed to best cover the designated geographical area (which is generally irregular in shape).

Satellites should be designed by keeping in mind its usability for short and long term effects throughout its life time.

The earth station should be in a position to control the satellite if it drifts from its orbit it is subjected to any kind of drag from the external forces.

Applications Of Satellites:

- Weather Forecasting
- Radio and TV Broadcast
- Military Satellites
- Navigation Satellites
- Global Telephone
- Connecting Remote Area
- Global Mobile Communication

1.2 Kepler's laws:

1.2.1 Kepler's law Introduction:

Satellites (spacecraft) orbiting the earth follow the same laws that govern the motion of the planets around the sun.

Kepler's laws apply quite generally to any two bodies in space which interact through gravitation. The more massive of the two bodies is referred to as the *primary,* the other, the *secondary* or *satellite*.

1.2.2 Kepler's First Law:

Kepler's first law states that the path followed by a satellite around the primary will be an ellipse. An ellipse hast Two focal points shown as $F1$ and $F2$in Fig. 2.1. The center of mass of the two-body system, termed the *bary center,* is always center of the foci.

The semi major axis of the ellipse is denoted by a, and the semi minor axis, by b. The eccentricity e is given by

$$e = \frac{\sqrt{a^2 - b^2}}{a}$$

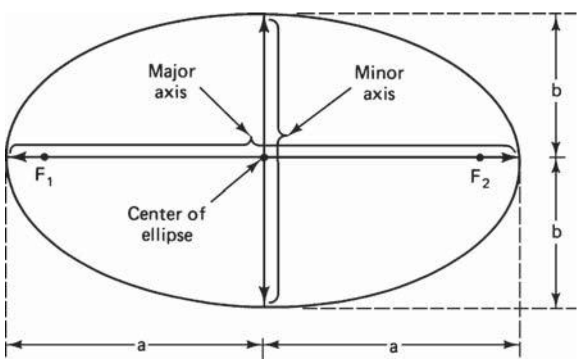


Figure 1.1 The foci $F1$ and $F2$, the semi major axis a, and the semi minor axis b of an ellipse.

1.2.3 Kepler's Second Law :

Kepler's second law states that, for equal time intervals, a satellite will sweep out equal areas in its orbital plane, focused at the barycenter. Referring to Fig. 2.2, assuming the satellite travels distances S_1 and S_2 meters in 1 s, then the areas A_1 and A_2 will be equal. The average velocity in each case is S_1 and S_2 m/s, and because of the equal area law, it follows that the velocity at S_2 is less than that at S_1.

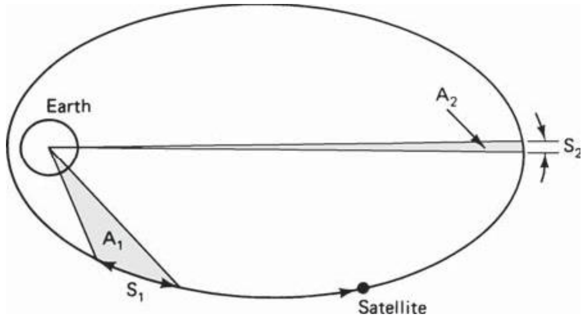


Figure 1.2 Kepler's second law. The areas A_1 and A_2 swept out in unit time are equal.

1.2.4 Kepler'sThird Law:

Kepler's third law states that the square of the periodic time of orbit is proportional to the cube of the mean distance between the two bodies. The mean distance is equal to the semi major axis a.

For the artificial satellites orbiting the earth, Kepler's third law can be written in the form

$$a^3 = \mu/n^2$$

Where n is the mean motion of the satellite in radians per second and is the earth's geocentric gravitational constant $\mu = 3.986005 \times 10^{14} m^3/s^2$

1.3. Newton's law:

1.3.1 Newton's first law:

An object at rest will remain at rest unless acted on by an unbalanced force. An object in motion continues in motion with the same speed and in the same direction unless acted upon by an unbalanced force. This law is often called "the law of inertia".

1.3.2 Newton's second law:

Acceleration is produced when a force acts on a mass. The greater the mass (of the object being accelerated) the greater the amount of force needed (to accelerate the object).

1.3.3 Newton's first law:

For every action there is an equal and opposite re-action. This means that for every force there is a reaction force that is equal in size, but opposite in direction. That is to say that whenever an object pushes another object it gets pushed back in the opposite direction equally hard.

1.4. orbital parameters:

Apogee: A point for a satellite farthest from the Earth. It is denoted as $\mathbf{h_a}$.

***Perigee*:** A point for a satellite closest from the Earth. It is denoted as $\mathbf{h_p}$.

Line of Apsides: Line joining perigee and apogee through centre of the Earth. It is the major axis of the orbit. One-half of this line‟s length is the semi-major axis equivalents to satellite‟s mean distance from the Earth.

Ascending Node: The point where the orbit crosses the equatorial plane going from north to south.

Descending Node: The point where the orbit crosses the equatorial plane going from south to north.

Inclination: the angle between the orbital plane and the Earth‟s equatorial plane. Its measured at the ascending node from the equator to the orbit, going from East to North. Also, this angle is commonly denoted as **i.**

Line of Nodes: the line joining the ascending and descending nodes through the centre of Earth.

Prograde Orbit: an orbit in which satellite moves in the same direction as the Earth‟s rotation. Its inclination is always between 0_0 to 90_0. Many satellites follow this path as Earth‟s velocity makes it easier to lunch these satellites.

Retrograde Orbit: an orbit in which satellite moves in the same direction counter to the Earth‟s rotation.

Argument of Perigee: An angle from the point of perigee measure in the orbital plane at the Earth‟s centre, in the direction of the satellite motion.

Right ascension of ascending node: The definition of an orbit in space, the position of ascending node is specified. But as the Earth spins, the longitude of ascending node changes and cannot be used for reference. Thus for practical determination of an orbit, the longitude and time of crossing the ascending node is used.For absolute measurement, a fixed reference point in space is required.

It could also be defined as "*right ascension of the ascending node; right ascension is the angular position measured eastward along the celestial equator from the vernal equinox vector to the hour circle of the object*".

Mean anamoly: It gives the average value to the angular position of the satellite with reference to the perigee.

True anamoly: It is the angle from point of perigee to the satellite‟s position, measure at the Earth‟s centre.

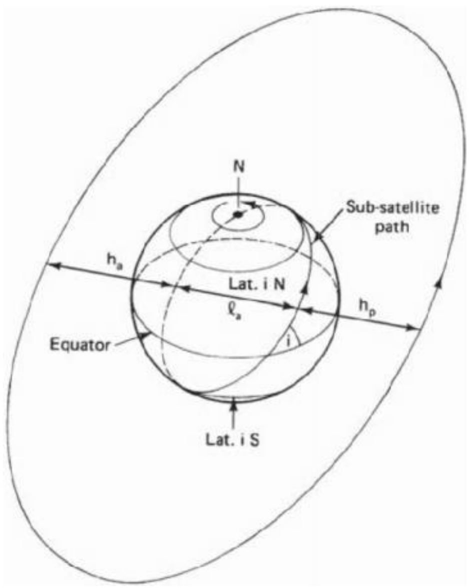


Figure1.2 Apogee height h_a, perigee height h_p, and inclination i. $L_a$is the line of apsides.

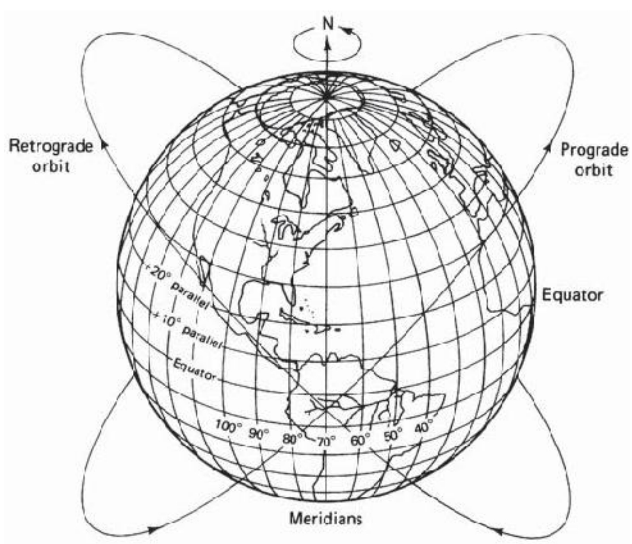


Figure 1.3(a) Prograde and retrograde orbits.

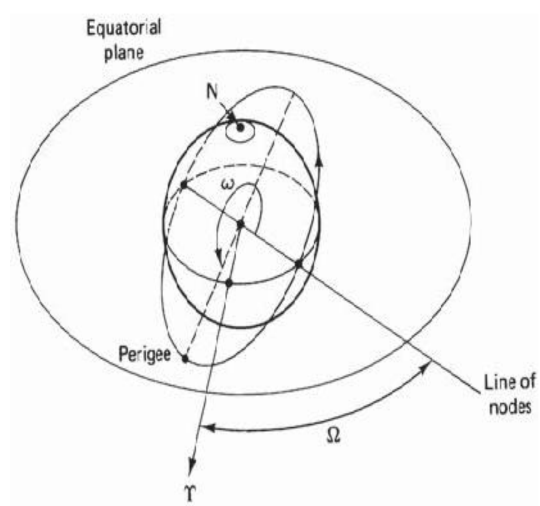


Figure.1.4 The argument of perigee *w* & right ascension of the ascending node Ω.

1.5. Orbital Perturbations:

Theoretically, an orbit described by Kepler is ideal as Earth is considered to be a perfect sphere and the force acting around the Earth is the centrifugal force. This force is supposed to balance the gravitational pull of the earth.

In reality, other forces also play an important role and affect the motion of the satellite. These forces are the gravitational forces of Sun and Moon along with the atmospheric drag.

Effect of Sun and Moon is more pronounced on geostationary earth satellites where as the atmospheric drag effect is more pronounced for low earth orbit satellites.

1.5.1 Effects of non-Spherical Earth :

As the shape of Earth is not a perfect sphere, it causes some variations in the path followed by the satellites around the primary. As the Earth is bulging from the equatorial belt, and keeping in mind that an orbit is not a physical entity, and it is the forces resulting from an oblate Earth which act on the satellite produce a change in the orbital parameters.

This causes the satellite to drift as a result of regression of the nodes and the latitude of the point of perigee (point closest to the Earth). This leads to rotation of the line of apsides. As the orbit itself is moving with respect to the Earth, the resultant changes are seen in the values of argument of perigee and right ascension of ascending node.

Due to the non-spherical shape of Earth, one more effect called as the "Satellite Graveyard" is seen. The non-spherical shape leads to the small value of eccentricity (10_{-5}) at the equatorial plane. This causes a gravity gradient on GEO satellite and makes them drift to one of the two stable points which coincide with minor axis of the equatorial ellipse.

1.5.2 Atmospheric Drag:

For Low Earth orbiting satellites, the effect of atmospheric drag is more pronounces. The impact of this drag is maximumat the point of perigee. Drag (pull towards the Earth) has an effect on velocity of Satellite (velocity reduces).

This causes the satellite to not reach the apogee height successive revolutions. This leads to a change in value of semi-major axis and eccentricity. Satellites in service are maneuvered by the earth station back to their original orbital position.

1.6 Station Keeping:

In addition to having its attitude controlled, it is important that a geo-stationary satellite be kept in its correct orbital slot. The equatorial ellipticity of the earth causes geostationary satel- lites to drift slowly along the orbit, to one of two stable points, at 75°E and 105°W.

To counter this drift, an oppositely directed velocity com-ponent is imparted to the satellite by means of jets, which are pulsed once every 2 or 3 weeks.

These maneuvers are termed *east-west station-keeping maneuvers*. Satellites in the 6/4-GHz band must be kept within 0.1° of the desig- nated longitude, and in the 14/12-GHz band, within 0.05°.

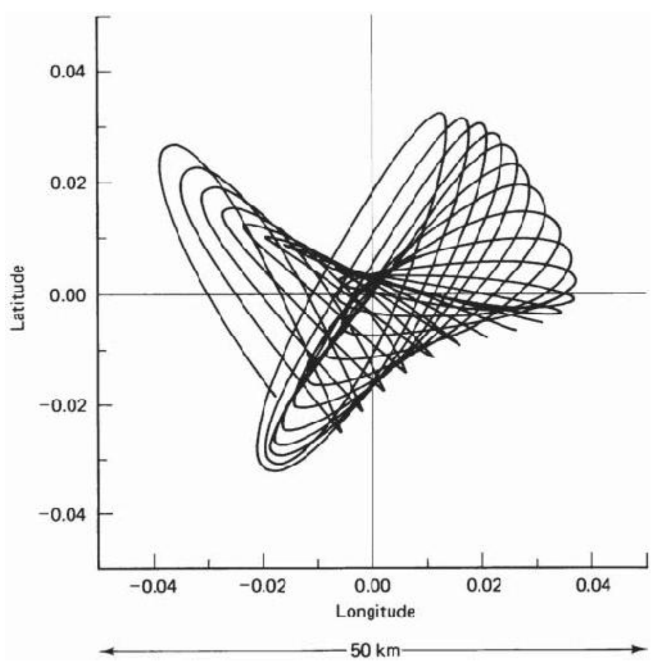


Figure 1.5 Typical satellite motion.(*CourtesyofTelesat,Canada,1983.*)

1.7. Geo stationary and Non Geo-stationary orbits:

1.7.1 Geo stationary:

A **geostationary** orbit is one in which a satellite orbits the earth at exactly the same speed as the earth turns and at the same latitude, specifically zero, the latitude of the equator. A satellite orbiting in a geostationary orbit appears to be hovering in the same spot in the sky, and is directly over the same patch of ground at all times.

A **geosynchronous** orbit is one in which the satellite is synchronized with the earth's rotation, but the orbit is tilted with respect to the plane of the equator. A satellite in a geosynchronous orbit will wander up and down in latitude, although it will stay over the same line of longitude. Although the terms 'geostationary' and 'geosynchronous' are sometimes used interchangeably, they are not the same technically; geostationary orbit is a subset of all possible geosynchronous orbits.

The person most widely credited with developing the concept of geostationary orbits is noted science fiction author Arthur C. Clarke (Islands in the Sky, Childhood's End, Rendezvous with Rama, and the movie 2001: a Space Odyssey). Others had earlier pointed out that bodies traveling a certain distance above the earth on the equatorial plane would remain motionless with respect to the earth's surface. But Clarke published an article in 1945's Wireless World that made the leap from the Germans' rocket research to suggest permanent manmade satellites that could serve as communication relays.

Geostationary objects in orbit must be at a certain distance above the earth; any closer and the orbit would decay, and farther out they would escape the earth's gravity altogether. This distance is 35,786 kilometers (22,236 miles) from the surface.

The first geosynchrous satellite was orbited in 1963, and the first geostationary one the following year. Since the only geostationary orbit is in a plane with the equator at 35,786 kilometers, there is only one circle around the world where these conditions obtain.

This means that geostationary 'real estate' is finite. While satellites are in no danger of bumping in to one another yet, they must be spaced around the circle so that their frequencies do not interfere with the functioning of their nearest neighbors.

Geostationary Satellites:

There are 2 kinds of manmade satellites in the heavens above: One kind of satellite ORBITS the earth once or twice a day, and the other kind is called a communications satellite and it is PARKED in a STATIONARY position 22,300 miles (35,900 km) above the equator of the STATIONARY earth.

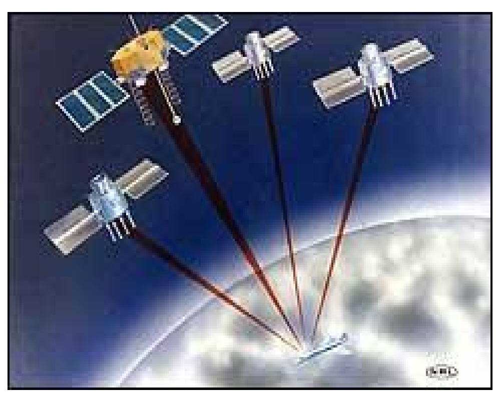
A type of the orbiting satellite includes the space shuttle and the international space station which keep a low earth orbit (LEO) to avoid the deadly Van Allen radiation belts.

The most prominent satellites in medium earth orbit (MEO) are the satellites which comprise the GLOBAL POSITIONING SYSTEM or GPS as it is called.

The Global Positioning System

The global positioning system was developed by the U.S. military and then opened to civilian use. It is used today to track planes, ships, trains, cars or literally anything that moves. Anyone can buy a receiver and track their exact location by using a GPS receiver.

GPS satellites orbit at a height of about 12,000 miles (19,300 km) and orbit the earth once every 12 hours.

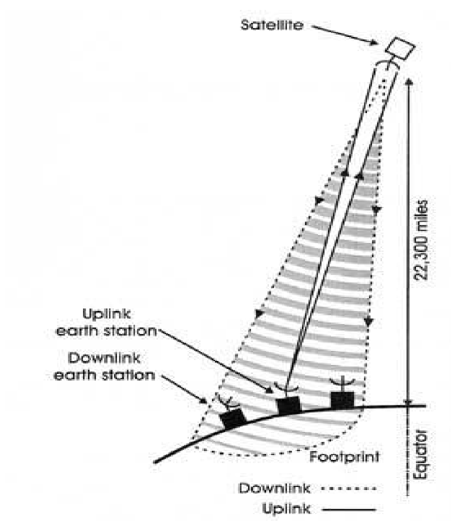


About 24 GPS satellites orbit the earth every 12 hours.

These satellites are traveling around the earth at speeds of about 7,000 mph (11,200 kph). GPS satellites are powered by solar energy. They have backup batteries onboard to keep them running in the event of a solar eclipse, when there's no solar power.

Small rocket boosters on each satellite keep them flying in the correct path. The satellites have a lifetime of about 10 years until all their fuel runs out.

At exactly 22,300 miles above the equator, the force of gravity is cancelled by the centrifugal force of the rotating universe. This is the ideal spot to park a stationary satellite.



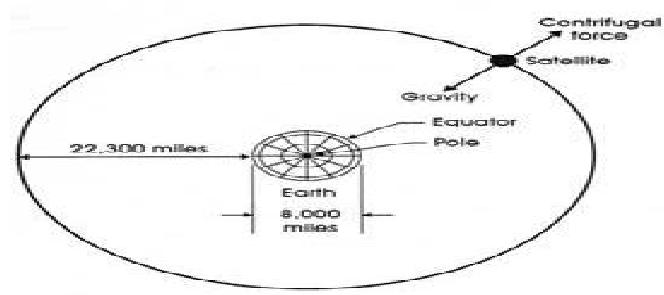


Figure. 1.6 & 1.7 At exactly 22,000 miles (35,900 km) above the equator, the earth's force of gravity is canceled by the centrifugal force of the rotating universe. .

1.7.2 Non Geo-Stationary Orbit:

For the geo- stationary case, the most important of these are the gravitational fields of the moon and the sun, and the nonspherical shape of the earth.

Other significant forces are solar radiation pressure and reaction of the satellite itself to motor movement within the satellite. As a result, station-keeping maneuvers must be carried out to maintain the satel- lite within set limits of its nominal geostationary position.

An exact geostationary orbit therefore is not attainable in practice, and the orbital parameters vary with time. The two-line orbital elements are published at regular intervals.

The period for a geostationary satellite is 23 h, 56 min, 4 s, or 86,164 s. The reciprocal of this is 1.00273896 rev/day, which is about the value tabulated for most of the satellites in Fig.

Thus these satellites are *geo- synchronous,* in that they rotate in synchronism with the rotation of the earth. However, they are not geostationary. The term *geosynchronous satellite* is used in many cases instead of *geostationary* to describe these near-geostationary satellites.

It should be noted, however, that in gen- eral a geosynchronous satellite does not have to be near-geostationary, and there are a number of geosynchronous satellites that are in highly elliptical orbits with comparatively large inclinations (e.g., the Tundra satellites).

The small inclination makes it difficult to locate the position of the ascending node, and the small eccentricity makes it difficult to locate the position of the perigee.

However, because of the small inclination, the angles *w* and Ω can be assumed to be in the same plane.The longitude of the subsatellite point (thesatellitelongitude) is the east early rotation from the Greenwich meridian.

$$\phi_{SS} = \omega + \Omega + v - \mathrm{GST}$$

The *Greenwich sidereal time* (GST) gives the eastward position of the Greenwich meridian relative to the line of Aries, and hence the subsatellite point is at longitudeand the mean longitude of the satellite is given by

$$\phi_{SSmean} = \omega + \Omega + M - \mathrm{GST}$$

Equation(2.31)can be used to calculate the trueanomaly, and because of the small eccentricity, this can be approximated as v= $M + 2e\sin M$.

1.8 Look Angle Determination:

The look angles for the ground station antenna are Azimuth and Elevation angles. They are required at the antenna so that it points directly at the satellite. Look angles are calculated by considering the elliptical orbit. These angles change in order to track the satellite.

For geostationary orbit, these angels values does not change as the satellites are stationary with respect to earth. Thus large earth stations are used for commercial communications.

For home antennas, antenna beamwidth is quite broad and hence no tracking is essential. This leads to a fixed position for these antennas.

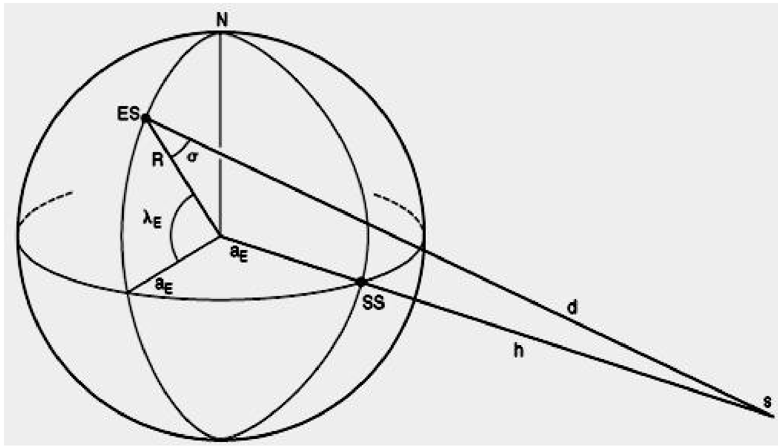


Figure 1.8: The geometry used in determining the look angles for Geostationary Satellites.

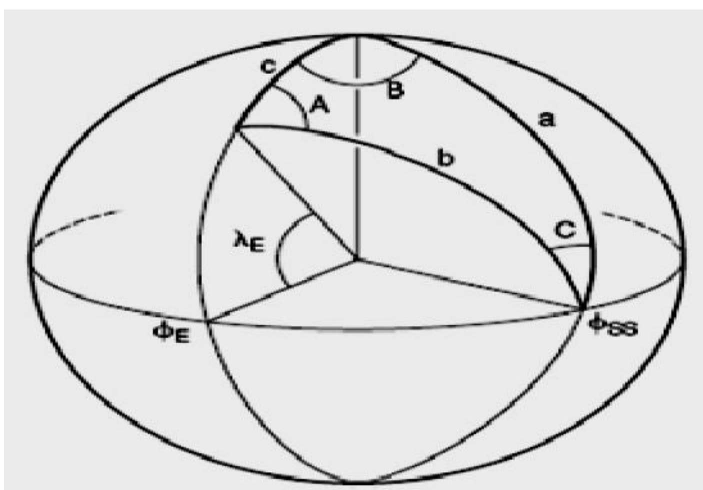


Figure 1.9: The spherical geometry related to figure 1.8

With respect to the figure 1.8 and 1.9, the following information is needed to determine the look angles of geostationary orbit.

1. Earth Station Latitude: λ_E
2. Earth Station Longitude: Φ_E

3. Sub-Satellite Point‟s Longitude: Φ_{SS}
4. ES: Position of Earth Station
5. SS: Sub-Satellite Point
6. S: Satellite
7. d: Range from ES to S
8. ζ: angle to be determined

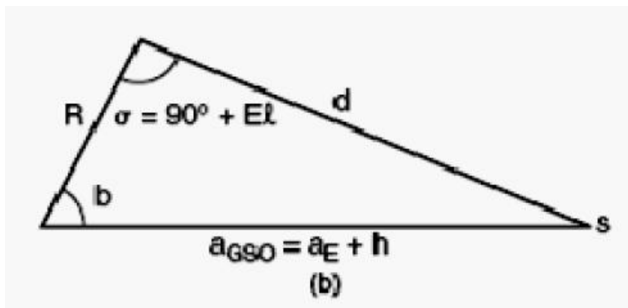


Figure 1.10: A plane triangle obtained from figure 1.8

Considering figure 3.3, it‟s a spherical triangle. All sides are the arcs of a great circle. Three sides of this triangle are defined by the angles subtended by the centre of the earth.

- Side a: angle between North Pole and radius of the sub-satellite point.

- Side b: angle between radius of Earth and radius of the sub-satellite point.

- Side c: angle between radius of Earth and the North Pole.

$a = 90^0$ and such a spherical triangle is called quadrantal triangle. $c = 90^0 - \lambda$

Angle B is the angle between the plane containing c and the plane containing a.

Thus, $B = \Phi_E - \Phi_{SS}$

Angle A is the angle between the plane containing b and the plane containing c.

Angle C is the angle between the plane containing a and the plane containing b.

Thus, $a = 90^0$

$c = 90^0 - \lambda_E$

$B = \Phi_E - \Phi_{SS}$

Thus, $b = \arccos(\cos B \cos \lambda_E)$

And $A = \arcsin(\sin |B| / \sin b)$

Applying the cosine rule for plane triangle to the triangle of figure

$$d = \sqrt{R^2 + a_{GSO}^2 - 2Ra_{GSO} \cos b}$$

Applying the sine rule for plane triangles to the triangle of figure 3.3 allows the angle of elevation to be found:

$$El = \arccos\left(\frac{a_{GSO}}{d} \sin b\right)$$

1.9. Limits of visibility:

The east and west limits of geostationary are visible from any given Earth station. These limits are set by the geographic coordinates of the Earth station and antenna elevation.

The lowest elevation is zero (in theory) but in practice, to avoid reception of excess noise from Earth. Some finite minimum value of elevation is issued. The earth station can see a satellite over a geostationary arc bounded by **+- (81.30)** about the earth station‟s longitude.

1.10. Eclipse:

It occurs when Earth‟s equatorial plane coincides with the plane f he Earth‟s orbit around the sun.

Near the time of spring and autumnal equinoxes, when the sun is crossing the equator, the satellite passes into sun‟s shadow. This happens for some duration of time every day.

These eclipses begin 23 days before the equinox and end 23 days after the equinox. They last for almost 10 minutes at the beginning and end of equinox and increase for a maximum period of 72 minutes at a full eclipse.

The solar cells of the satellite become non-functional during the eclipse period and the satellite is made to operate with the help of power supplied from the batteries.

A satellite will have the eclipse duration symmetric around the time t=Satellite Longitude/15 + 12 hours. A satellite at Greenwich longitude 0 will have the eclipse duration symmetric around 0/15

UTC +12hours = 00:00 UTC.

The eclipse will happen at night but for satellites in the east it will happen late evening local time.

For satellites in the west eclipse will happen in the early morning hour’s local time.

An earth caused eclipse will normally not happen during peak viewing hours if the satellite is located near the longitude of the coverage area. Modern satellites are well equipped with batteries for operation during eclipse.

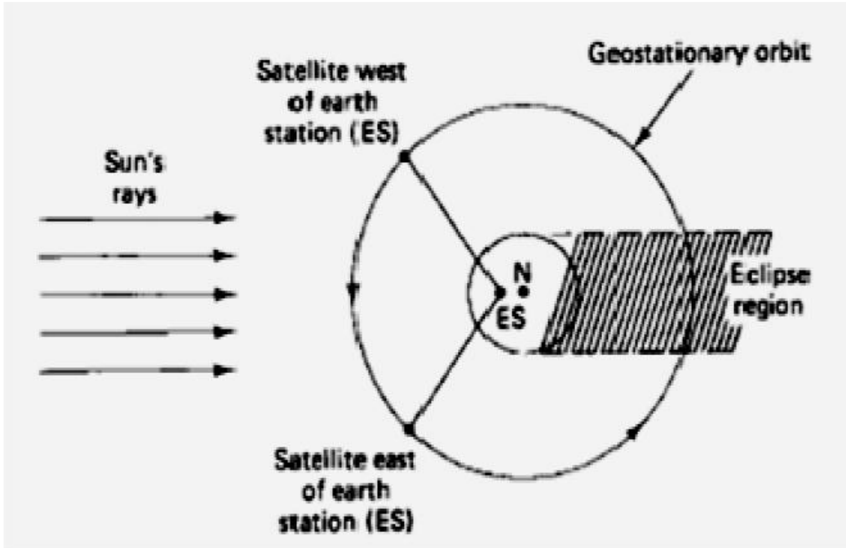


Figure 1.11(i): A satellite east of the earth station enters eclipse during daylight busy) hours at the earth station. A Satellite west of earth station enters eclipse during night and early morning hours (non busy time).

1.11. Sub satellite Point:

- ✓ Point at which a line between the satellite and the center of the Earth intersects the Earth's surface
- ✓ Location of the point expressed in terms of latitude and longitude
- ✓ If one is in the US it is common to use
  - o Latitude – degrees north from equator
  - o Longitude – degrees west of the Greenwich meridian
- ✓ Location of the sub satellite point may be calculated from coordinates of the rotating system as:

$$L_s = \frac{®}{2} - \cos^{-1}\left(\frac{z_r}{\sqrt{x_r^2 + y_r^2 + z_r^2}}\right)$$

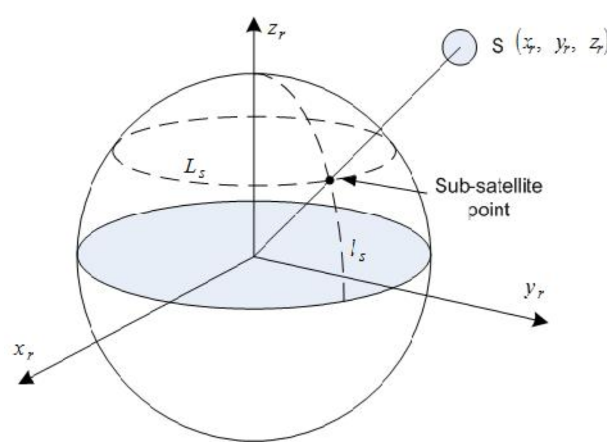


Figure 1.11(ii) **Sub satellite Point**

1.12. Sun Transit Outage :

Sun transit outage is an interruption in or distortion of geostationary satellite signals caused by interference from solar radiation.

Sun appears to be an extremely noisy source which completely blanks out the signal from satellite. This effect lasts for 6 days around the equinoxes. They occur for a maximum period of 10 minutes.

Generally, sun outages occur in February, March, September and October, that is, around the time of the equinoxes.

At these times, the apparent path of the sun across the sky takes it directly behind the line of sight between an earth station and a satellite.

As the sun radiates strongly at the microwave frequencies used to communicate with satellites (C-band, Ka band and Ku band) the sun swamps the signal from the satellite.

The effects of a sun outage can include partial degradation, that is, an increase in the error rate, or total destruction of the signal.

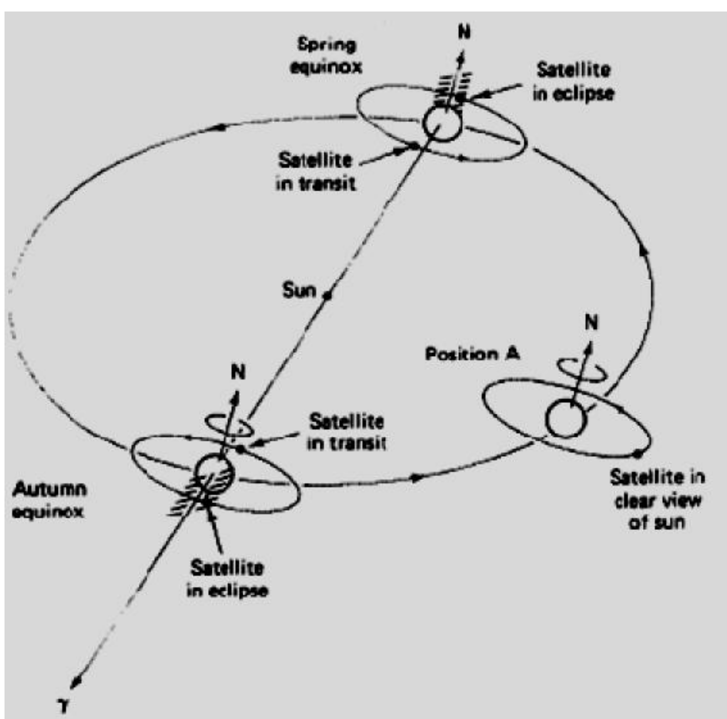


Figure 1.12 : Earth Eclipse of a Satellite and Sun transit Outage

1.13. Launching Procedures :

1.13.1 Intoduction:

Low Earth Orbiting satellites are directly injected into their orbits. This cannot be done incase of GEOs as they have to be positioned 36,000kms above the Earth‟s surface.

Launch vehicles are hence used to set these satellites in their orbits. These vehicles are reusable. They are also known as „Space Transportation System‟ (STS).

When the orbital altitude is greater than 1,200 km it becomes expensive to directly inject the satellite in its orbit.

For this purpose, a satellite must be placed in to a transfer orbit between the initial lower orbit and destination orbit. The transfer orbit is commonly known as *Hohmann-Transfer Orbit.

1.13.2 Orbit Transfer:

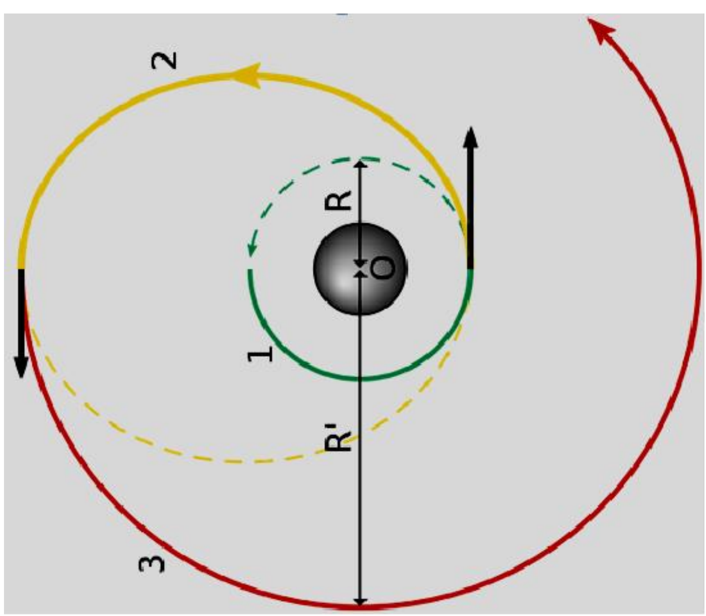


Figure 1.13: *Orbit Transfer positions*

(*About Hohmann Transfer Orbit: This manoeuvre is named for the German civil engineer who first proposed it, Walter Hohmann, who was born in 1880. He didn't work in rocketry professionally (and wasn't associated with military rocketry), but was a key member of Germany's pioneering Society for Space

Travel that included people such as Willy Ley, Hermann, and Werner von Braun. He published his concept of how to transfer between orbits in his 1925 book, The Attainability of Celestial Bodies.)

The transfer orbit is selected to minimize the energy required for the transfer. This orbit forms a tangent to the low attitude orbit at the point of its perigee and tangent to high altitude orbit at the point of its apogee.

1.14 Launch vehicles and propulsion:

The rocket injects the satellite with the required thrust** into the transfer orbit. With the STS, the satellite carries a perigee kick motor*** which imparts the required thrust to inject the satellite in its transfer orbit. Similarly, an apogee kick motor (AKM) is used to inject the satellite in its destination orbit.

Generally it takes 1-2 months for the satellite to become fully functional. The Earth Station performs the Telemetry Tracking and Command**** function to control the satellite transits and functionalities.

(**Thrust: It is a reaction force described quantitatively by Newton's second and third laws. When a system expels or accelerates mass in one direction the accelerated mass will cause a force of equal magnitude but opposite direction on that system.)

Kick Motor refers to a rocket motor that is regularly employed on artificial satellites destined for a geostationary orbit. As the vast majority of geostationary satellite launches are carried out from spaceports at a significant distance away from Earth's equator.

The carrier rocket would only be able to launch the satellite into an elliptical orbit of maximum apogee 35,784-kilometres and with a non-zero inclination approximately equal to the latitude of the launch site.

TT&C: it‟s a sub-system where the functions performed by the satellite control network to maintain health and status, measure specific mission parameters and processing over time a sequence of these measurement to refine parameter knowledge, and transmit mission commands to the satellite. Detailed study of TT&C in the upcoming units.

1.14.1 Transfer Orbit :

It is better to launch rockets closer to the equator because the Earth rotates at a greater speed here than that at either pole. This extra speed at the equator means a rocket needs less thrust (and therefore less fuel) to launch into orbit.

In addition, launching at the equator provides an additional 1,036 mph (1,667 km/h) of speed once the vehicle reaches orbit. This speed bonus means the vehicle needs less fuel, and that freed space can be used to carry more pay load.

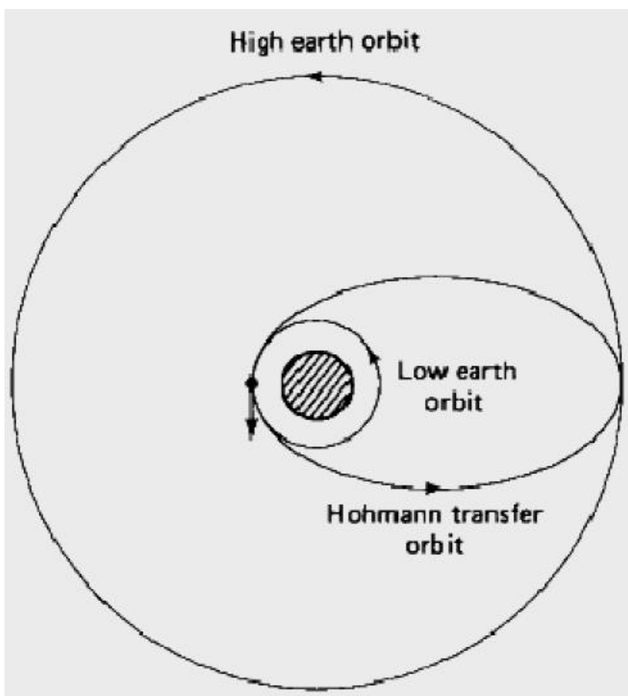


***Figure 1.14**: Hohmann Transfer Orbit*

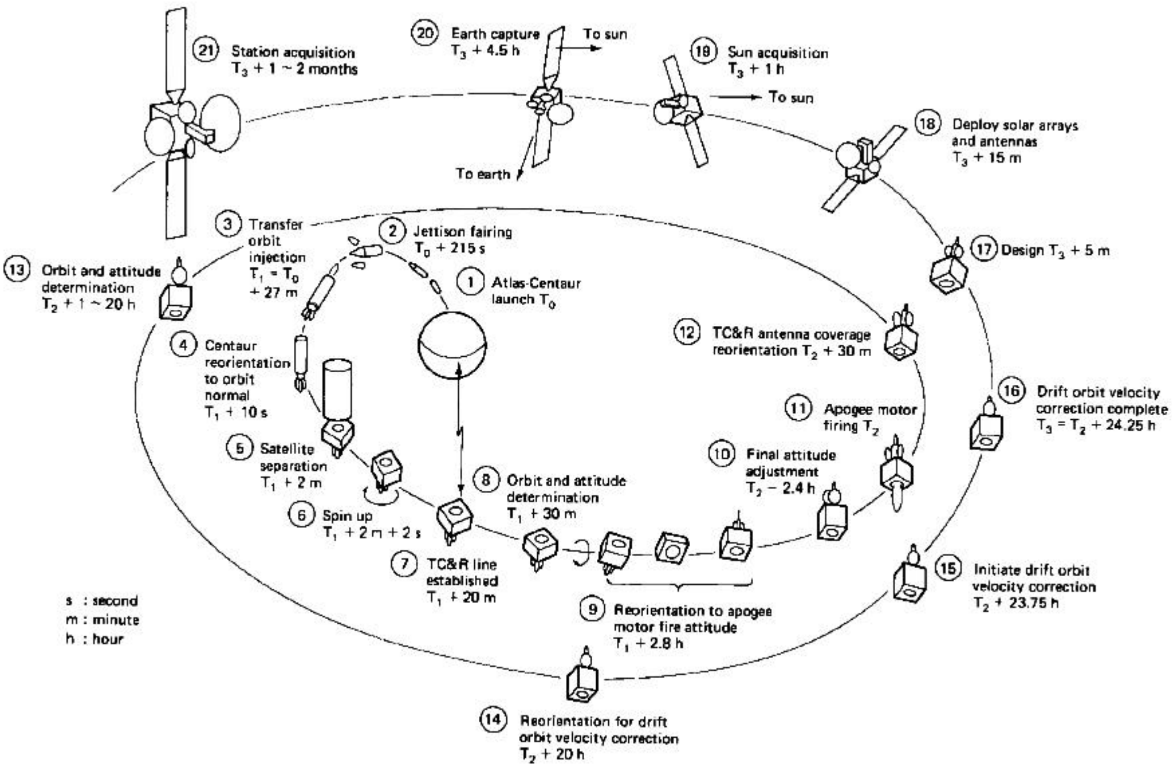


***Figure 1.15**: Launching stages of a GEO (example INTELSAT)*

Rocket launch:

A **rocket launch** is the takeoff phase of the flight of a rocket. Launches for orbital spaceflights, or launches into interplanetary space, are usually from a fixed location on the ground, but may also be from a floating platform (such as the Sea Launch vessel) or, potentially, from a superheavy An-225-class airplane[1]

Launches of suborbital flights (including missile launches), can also be from:

- a missile silo
- a mobile launcher vehicle
- a submarine
- air launch:
  - from a plane (e.g. Scaled Composites Space Ship One, Pegasus Rocket, X-15)
  - from a balloon (Rockoon, da Vinci Project (under development))
- a surface ship (Aegis Ballistic Missile Defense System)
- an inclined rail (e.g. rocket sled launch)

"Rocket launch technologies" generally refers to the entire set of systems needed to successfully launch a vehicle, not just the vehicle itself, but also the firing control systems, ground control station, launch pad, and tracking stations needed for a successful launch and/or recovery.

Orbital launch vehicles commonly take off vertically, and then begin to progressively lean over, usually following a gravity turn trajectory.

Once above the majority of the atmosphere, the vehicle then angles the rocket jet, pointing it largely horizontally but somewhat downwards, which permits the vehicle to gain and then maintain altitude while increasing horizontal speed. As the speed grows, the vehicle will become more and more horizontal until at orbital speed, the engine will cut off.

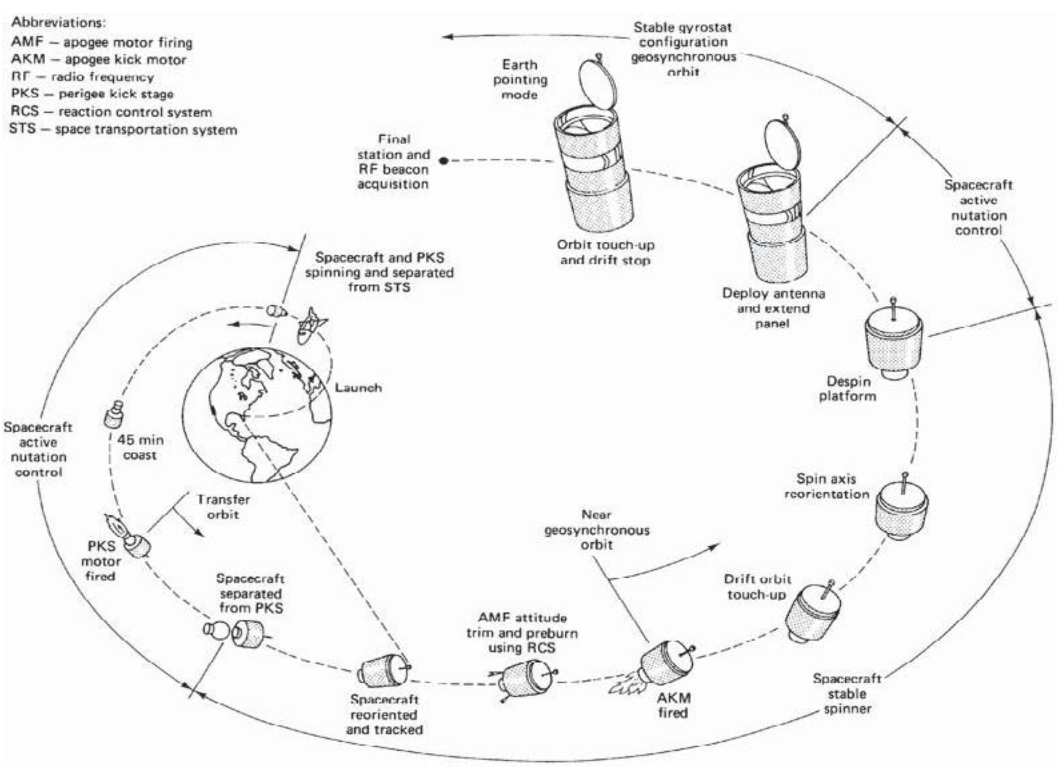


Figure 1.16 STS-7/Anik C2 mission scenario. (*From Anik C2 Launch Handbook; courtesy of Telesat, Canada.*)

UNIT II SPACE SEGMENT AND SATELLITE LINK DESIGN

2.1 Spacecraft Technology- Structure:

A satellite communications system can be broadly divided into two segments—a ground segment and a space segment.

The space segment will obviously include the satellites, but it also includes the ground facilities needed to keep the satellites operational, these being referred to as the *tracking, telemetry, and command* (TT&C) facilities. In many networks it is common practice to employ a ground station solely for the purpose of TT&C.

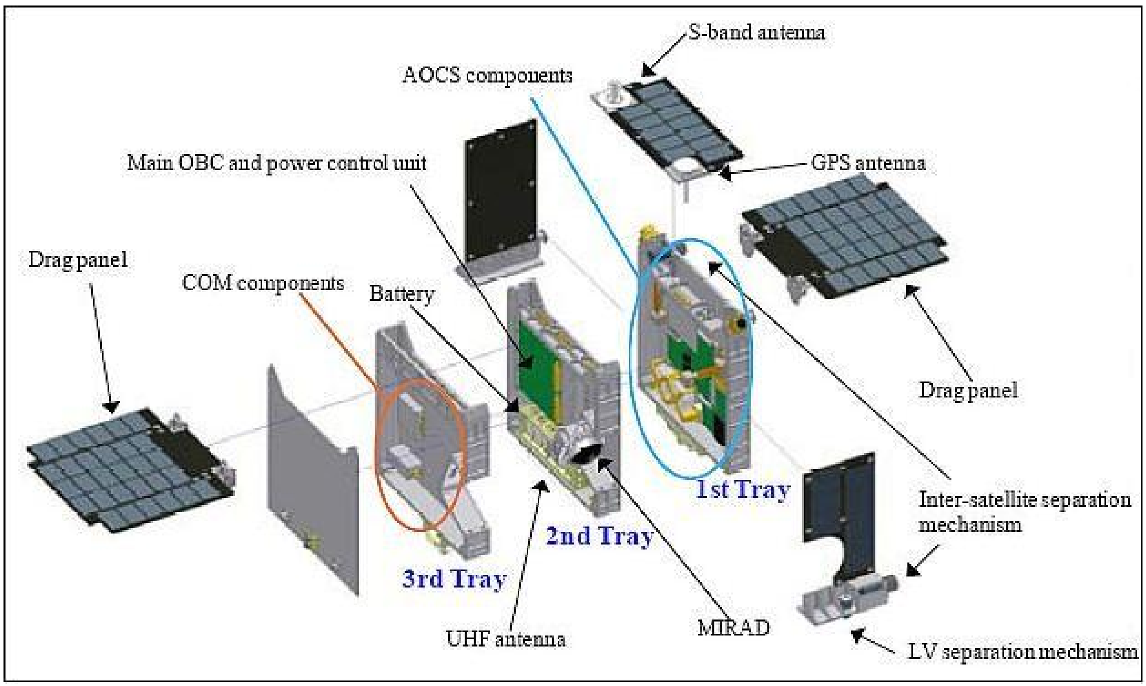


Figure 2.1 (a) Satellite Structure

The equipment carried aboard the satellite also can be classified according to function. The *payload* refers to the equipment used to pro- vide the service for which the satellite has been launched.

In a communications satellite, the equipment which provides the con- necting link between the satellite's transmit and receive antennas is referred to as the *transponder*. The transponder forms one of the main sections of the payload, the other being the antenna subsystems.In this chapter the main characteristics of certain bus systems and payloads are described.

2.2 The Power Supply:

The primary electrical power for operating the electronic equipment is obtained from solar cells. Individual cells can generate only small amounts of power, and therefore, arrays of cells in series-parallel connection are required.

Figure shows the solar cell panels for the HS 376 satellite manufactured by Hughes Space and Communications Company.

In geostationary orbit the telescoped panel is fully extended so that both are exposed to sun- light. At the beginning of life, the panels produce 940 W dc power, which may drop to 760 W at the end of 10 years.

During eclipse, power is provided by two nickel-cadmium (Ni-Cd) long-life batteries, which will deliver 830 W. At the end of life, battery recharge time is less than 16 h.

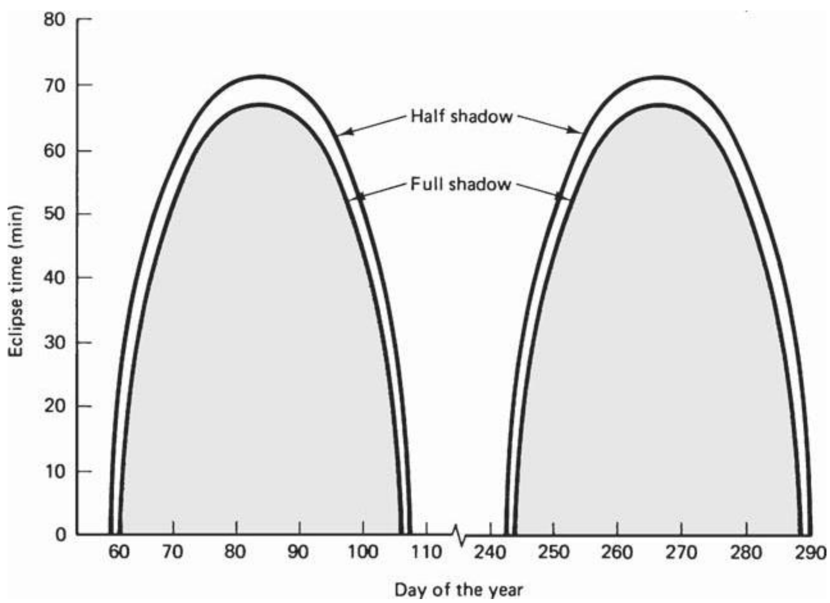


Figure 2.1.(b) Satellite eclipse time as a function of the current day of the year. (*Courtesy of Spilker, 1977. Reprinted by permission of Prentice-Hall, Englewood Cliffs, NJ.*)

capacity of cylindrical and solar-sail satellites, the cross-over point is esti- mated to be about 2 kW, where the solar-sail type is more economical than the cylindrical type (Hyndman, 1991).

2.3 Attitude Control & Orbit Control:

The *attitude* of a satellite refers to its orientation in space. Much of the equipment carried aboard a satellite is there for the purpose of control- ling its attitude. Attitude control is necessary, for example, to ensure that directional antennas point in the proper directions.

In the case of earth environmental satellites, the earth-sensing instruments must cover the required regions of the earth, which also requires attitude control. A number of forces, referred to as *disturbance torques*, can alter the attitude, some examples being the gravitational fields of the earth and the moon, solar radiation, and meteorite impacts.

Attitude control must not be con- fused with station keeping, which is the term used for maintaining a satellite in its correct orbital position, although the two are closely related.

To exercise attitude control, there must be available some measure of a satellite's orientation in space and of any tendency for this to shift. In one method, infrared sensors, referred to as *horizon detectors*, are used to detect the rim of the earth against the background of space.

With the use of four such sensors, one for each quadrant, the center of the earth can be readily established as a reference point.

Usually, the attitude-control process takes place aboard the satellite, but it is also possible for control signals to be transmitted from earth, based on attitude data obtained from the satellite.

Also, where a shift in attitude is desired, an *attitude maneuver* is executed. The control signals needed to achieve this maneuver may be transmitted from an earth station.

Controlling torques may be generated in a number of ways. *Passive attitude control* refers to the use of mechanisms which stabilize the satellite without putting a drain on the satellite's energy supplies; at most, infrequent use is made of these supplies, for example, when thruster jets are impulsed to provide corrective torque. Examples of passive attitude control are *spin stabilization* and *gravity gradient sta- bilization*.

The other form of attitude control is *active control*. With active attitude control, there is no overall stabilizing torque present to resist the disturbance torques. Instead, corrective torques are applied as required in response to disturbance torques. Methods used to generate active control torques include momentum wheels, electromagnetic coils, and mass expulsion devices, such as gas jets and ion thrusters.

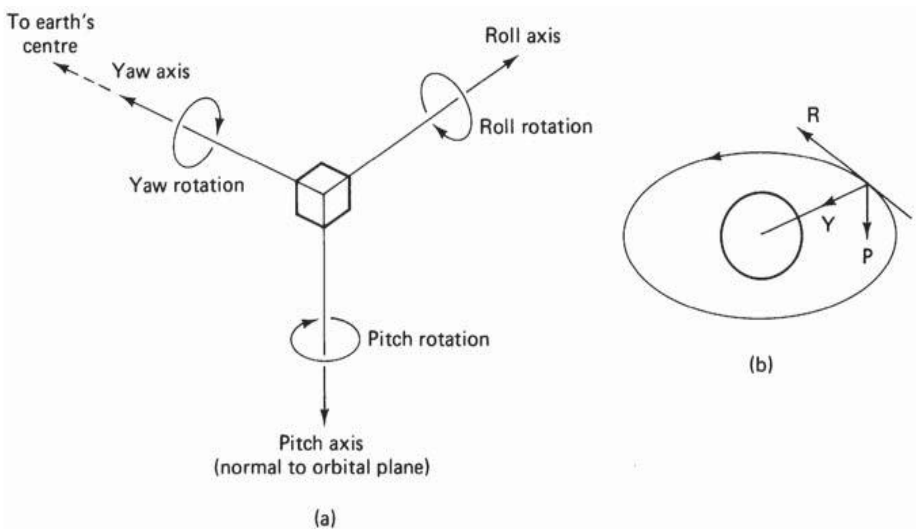


Figure 2.2 (*a*) Roll, pitch, and yaw axes. The yaw axis is directed toward the earth's center, the pitch axis is normal to the orbital plane, and the roll axis is perpendicular to the other two. (*b*) RPY axes for the geostationary orbit. Here, the roll axis is tangential to the orbit and lies along the satellite velocity vector.

The three axes which define a satellite's attitude are its *roll, pitch*, and *yaw* (RPY) axes. These are shown relative to the earth in Fig. 7.4. All three axes pass through the center of gravity of the satellite. For an equatorial orbit, movement of the satellite about the roll axis moves the antenna footprint north and south; movement about the pitch axis moves the footprint east and west; and movement about the yaw axis rotates the antenna footprint.

2.3.1 Spinning satellite stabilization:

Spin stabilization may be achieved with cylindrical satellites. The satellite is constructed so that it is mechanically balanced about one partic- ular axis and is then set spinning around this axis. For geostationary satellites, the spin axis is adjusted to be parallel to the N-S axis of the earth, as illustrated in Fig. 7.5. Spin rate is typically in the range of 50 to 100 rev/min. Spin is initiated during the launch phase by means of small gas jets.

In the absence of disturbance torques, the spinning satellite would maintain its correct attitude relative to the earth. Disturbance torques are generated in a number of ways, both external and internal to the satellite.

Solar radiation, gravitational gradients, and meteorite impacts are all examples of external forces which can give rise to disturbance torques. Motor-bearing friction and the movement of satellite elements such as the antennas also can give rise to disturbance torques. The

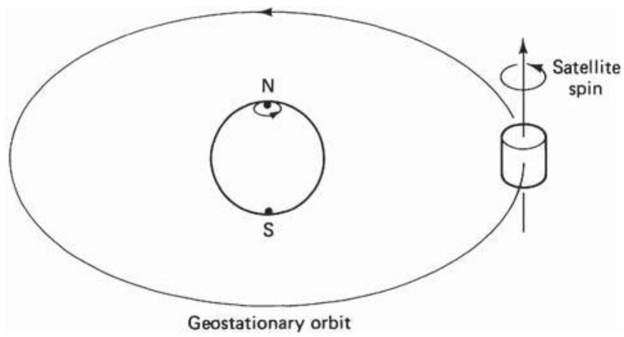


Figure 2.3 Spin stabilization in the geostationary orbit. The spin axis lies along the pitch axis, parallel to the earth's N-S axis.

overall effect is that the spin rate will decrease, and the direction of the angular spin axis will change. Impulse-type thrusters, or jets, can be used to increase the spin rate again and to shift the axis back to its cor- rect N-S orientation.

Nutation, which is a form of wobbling, can occur as a result of the disturbance torques and/or from misalignment or unbalance of the control jets. This nutation must be damped out by means of energy absorbers known as *nutation dampers*.

The antenna feeds can therefore be connected directly to the transponders without the need for radiofrequency (rf) rotary joints, while the complete platform is despun. Of course, control signals and power must be transferred to the despun section, and a mechanical bearing must be provided.

The complete assembly for this is known as the *bearing and power transfer assembly* (BAPTA). Figure 2.4 shows a photograph of the internal structure of the HS 376.

Certain dual-spin spacecraft obtain spin stabilization from a spinning fly-wheel rather than by spinning the satellite itself. These flywheels are termed *momentum wheels*, and their average momentum is referred to as *momentum bias*

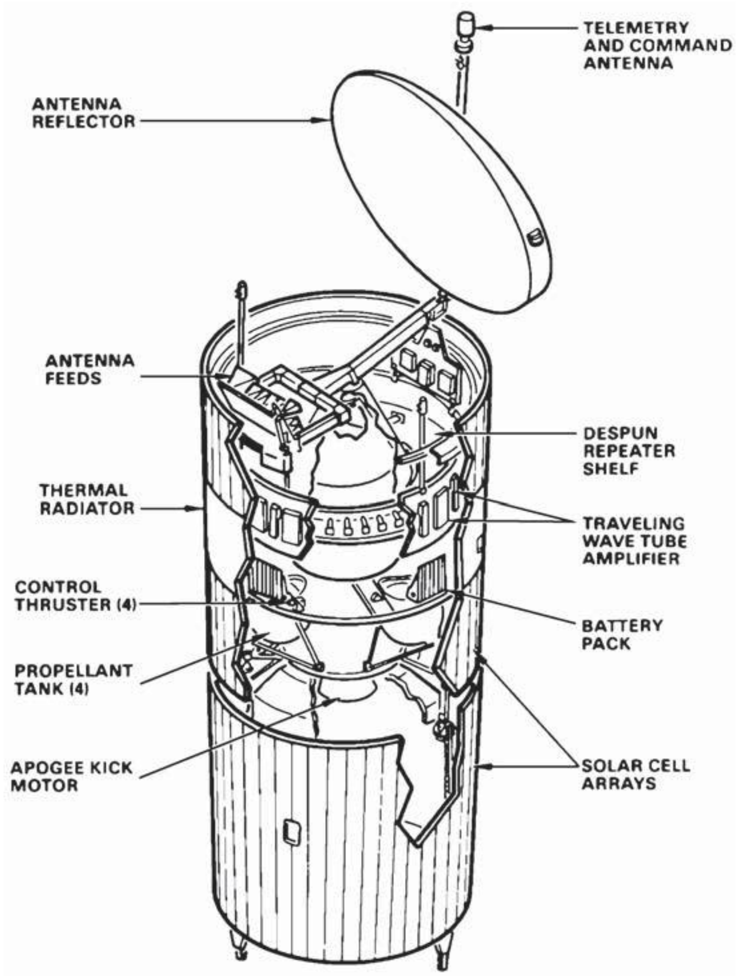


Figure 2.4 HS 376 spacecraft. (*Courtesy of Hughes Aircraft Company Space and Communications*

Group.)

2.3.2 Momentum wheel stabilization

In the previous section the gyroscopic effect of a spinning satellite was shown to provide stability for the satellite attitude.

Stability also can be achieved by utilizing the gyroscopic effect of a spinning flywheel, and this approach is used in satellites with cube-like bodies (such as shown in Fig. and the INTELSAT V type satellites shown in Fig. These are known as *body-stabilized* satellites.

The complete unit, termed a momentum wheel, consists of a flywheel, the bearing assembly, the casing, and an electric drive motor with associated electronic con- trol circuitry.

The flywheel is attached to the rotor, which consists of a permanent magnet providing the magnetic field for motor action. The stator of the motor is attached to the body of the satellite.

Thus the motor provides the coupling between the flywheel and the satellite structure. Speed and torque control of the motor is exercised through the currents fed to the stator.

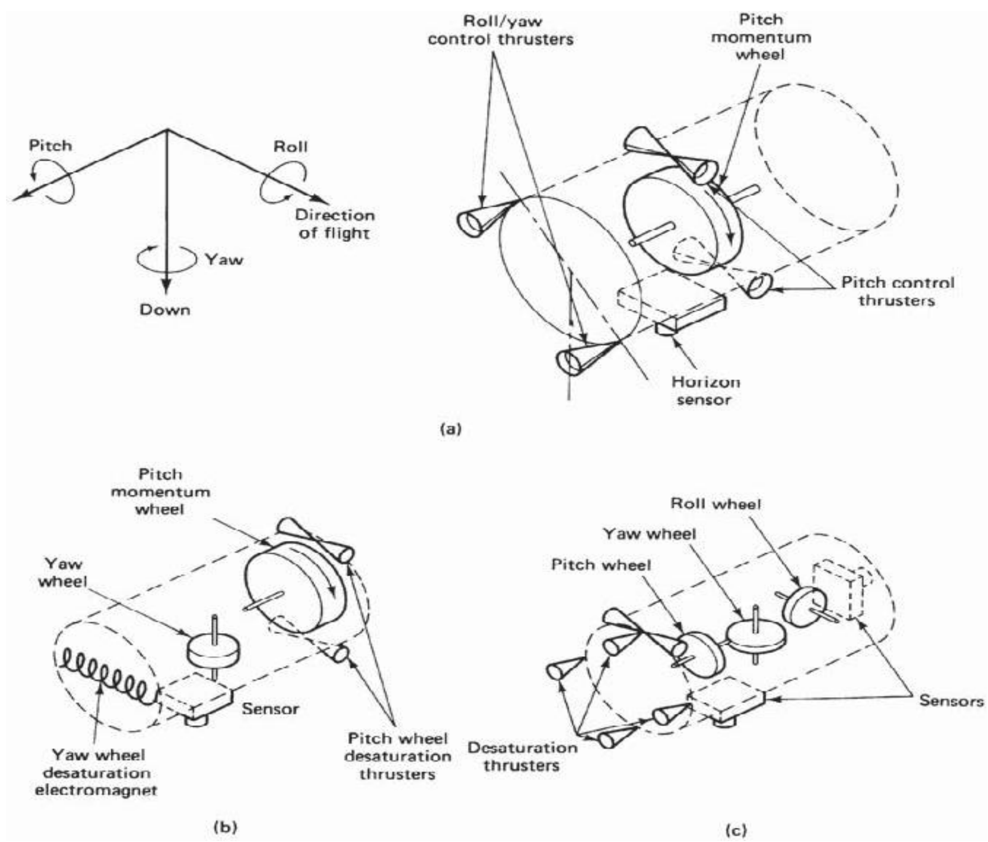


Figure 2.5 Alternative momentum wheel stabilization systems: (*a*) one-wheel, (*b*) two- wheel, (*c*) three-wheel.

When a momentum wheel is operated with zero momentum bias, it is generally referred to as a *reaction wheel*. Reaction wheels are used in three-axis stabilized systems. Here, as the name suggests, each axis is stabilized by a reaction wheel, as shown in Fig. 7.8*c*. Reaction wheels can also be combined with a momentum wheel to provide the control needed (Chetty, 1991).

Random and cyclic disturbance torques tends to produce zero momentum on average. However, there will always be some disturbance torques that causes a cumulative increase in wheel momentum, and eventually at some point the wheel *saturates*.

In effect, it reaches its maximum allowable angular velocity and can no longer take in any more momentum. Mass expulsion devices are then used to unload the wheel, that is, remove momentum from it (in the same way a brake removes energy from a moving vehicle). Of course, operation of the mass expulsion devices consumes part of the satellite's fuel supply.

2.4 Thermal Control and Propulsion:

Satellites are subject to large thermal gradients, receiving the sun's radiation on one side while the other side faces into space. In addition, thermal radiation from the earth and the earth's *albedo*, which is the fraction of the radiation falling on earth which is reflected, can be sig- nificant for low-altitude earth-orbiting satellites, although it is negligi- ble for geostationary satellites.

Equipment in the satellite also generates heat which has to be removed. The most important consideration is that the satellite's equipment should operate as nearly as possible in a stable temperature environment. Various steps are taken to achieve this. Thermal blankets and shields may be used to provide insulation. Radiation mirrors are often used to remove heat from the communications payload.

The mirrored thermal radiator for the Hughes HS 376 satellite can be seen in Fig. These mirrored drums surround the communications equipment shelves in each case and pro- vide good radiation paths for the generated heat to escape into the surrounding space.

One advantage of spinning satellites compared with body-stabilized is that the spinning body provides an averaging of the temperature extremes experienced from solar flux and the cold back- ground of deep space.

In order to maintain constant temperature conditions, heaters may be switched on (usually on command from ground) to make up for the heat reduction which occurs when transponders are switched off. The INTELSAT VI satellite used heaters to maintain propulsion thrusters and line temperatures (Pilcher, 1982).

2.5 Communication Payload & Supporting Subsystems:

The physical principle of establishing communication connections between remote communication devices dates back to the late 1800s when scientists were beginning to understand electromagnetism and discovered that electromagnetic (EM) radiation (also called EM waves) generated by one device can be detected by another located at some distance away.

By controlling certain aspect s of the radiation (through a process called modulation , explained in Section 4.4), useful information can be embedded in the EM waves and transmitted from one device to another.

The second major module is the communication payload, which is made up of transponders. A transponder is capable of :

- ✓ Receiving uplinked radio signals from earth satellite transmission stations (antennas).
- ✓ Amplifying received radio signals
- ✓ Sorting the input signals and directing the output signals through input/output signal multiplexers to the proper downlink antennas for retransmission to earth satellite receiving stations (antennas).

2.6 TT&C Subsystem

The TT&C subsystem performs several routine functions aboard the spacecraft. The telemetry, or telemetering, function could be interpreted as *measurement at a distance*. Specifically, it refers to the overall oper- ation of generating an electrical signal proportional to the quantity being measured and encoding and transmitting this to a distant station, which for the satellite is one of the earth stations.

Data which are trans- mitted as telemetry signals include attitude information such as that obtained from sun and earth sensors; environmental information such as the magnetic field intensity and direction, the frequency of meteorite impact, and so on; and spacecraft information such as temperatures, power supply voltages, and stored-fuel pressure.

Telemetry and command may be thought of as complementary func- tions. The telemetry subsystem transmits information about the satellite to the earth station, while the command subsystem receives command sig- nals from the earth station, often in response to telemetered information. The command subsystem demodulates and, if necessary, decodes the com- mand signals and routes these to the appropriate equipment needed to exe- cute the necessary action.

Thus attitude changes may be made, communication transponders switched in and out of circuits, antennas redirected, and station-keeping maneuvers carried out on command. It is clearly important to prevent unauthorized commands from being received and decoded, and for this reason, the command signals are often encrypted.

Encrypt is derived from a Greek word *kryptein*, meaning *to hide*, and represents the process of concealing the command signals in a secure code. This differs from the normal process of encoding which converts characters in the command signal into a code suitable for transmission.

Tracking of the satellite is accomplished by having the satellite transmit beacon signals which are received at the TT&C earth stations.

Tracking is obviously important during the transfer and drift orbital phases of the satellite launch. Once it is on station, the position of a geostationary satellite will tend to be shifted as a result of the various dis- turbing forces, as described previously.

Therefore, it is necessary to be able to track the satellite's movement and send correction signals as required.

2.6.1 Transponders:

A transponder is the series of interconnected units which forms a single communications channel between the receive and transmit antennas in a communications satellite.

Some of the units utilized by a transponder in a given channel may be common to a number of transponders. Thus, although reference may be made to a specific transponder, this must be thought of as an equipment *channel* rather than a single item of equipment.

Before describing in detail the various units of a transponder, the overall frequency arrangement of a typical C-band communications satellite will be examined briefly. The bandwidth allocated for C-band service is 500 MHz, and this is divided into subbands, one transponder.

A typical transponder bandwidth is 36 MHz, and allowing for a 4-MHz guardband between transponders, 12 such transponders can be accommodated in the 500-MHz bandwidth.

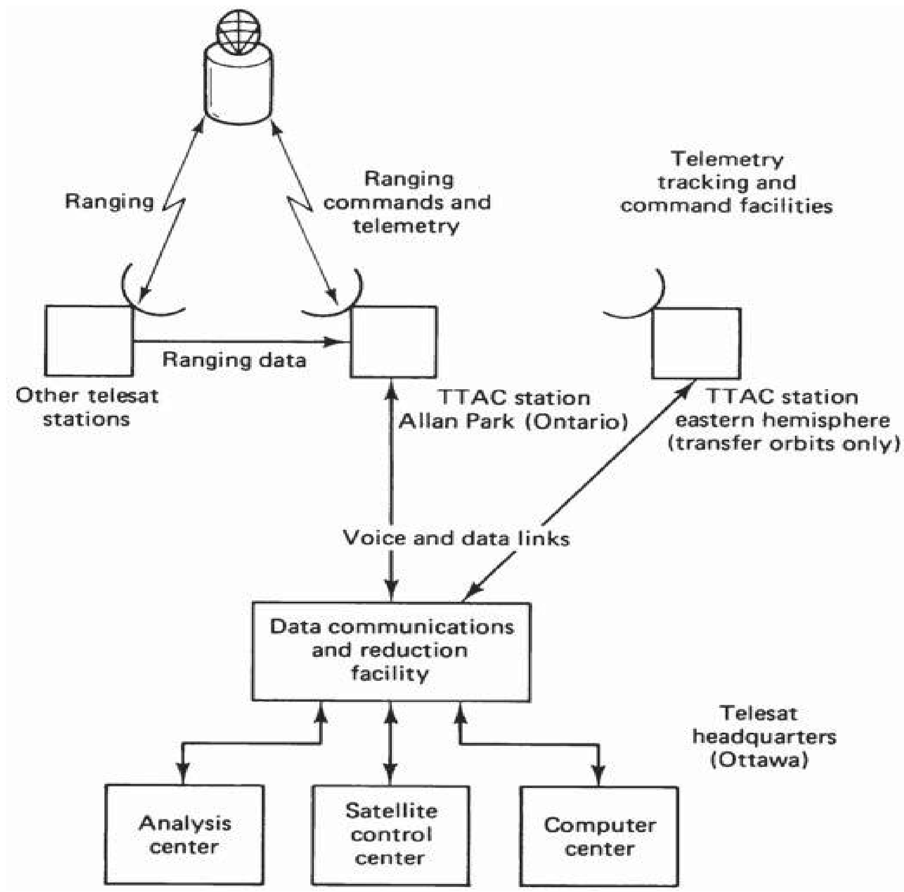
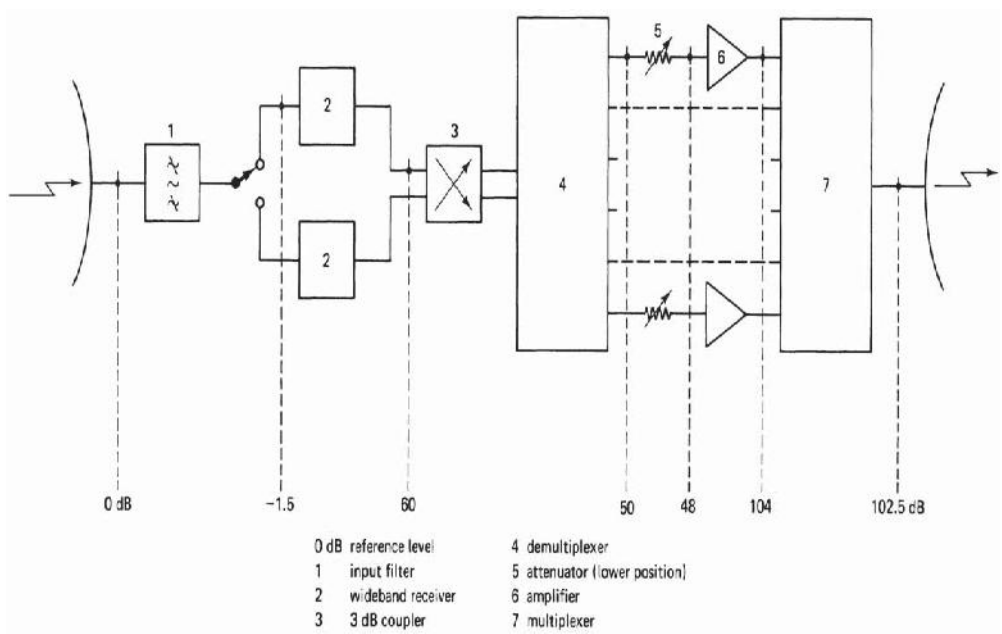


Figure 2.8 Satellite control system. (*Courtesy of Telesat Canada, 1983.*)

By making use of *polar- ization isolation*, this number can be doubled. Polarization isolation refers to the fact that carriers, which may be on the same frequency but with opposite senses of polarization, can be isolated from one another by receiving antennas matched to the incoming polarization.

With linear polarization, vertically and horizontally polarized carriers can be sep- arated in this way, and with circular polarization, left-hand circular and right-hand circular polarizations can be separated.

Because the carriers with opposite senses of polarization may overlap in frequency, this technique is referred to as *frequency reuse*. Figure 2.9 shows part of the frequency and polarization plan for a C-band communications satellite.



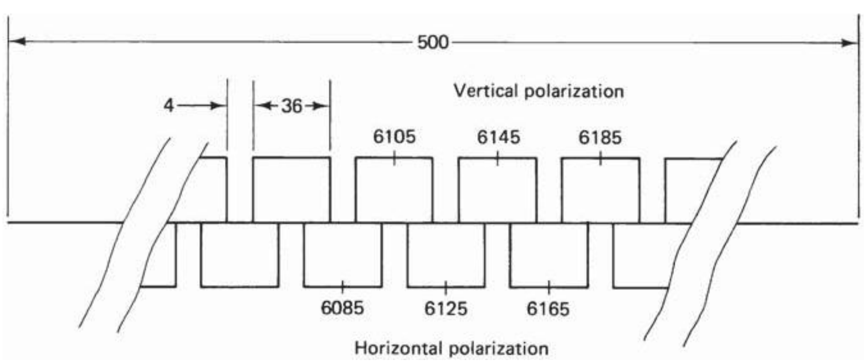


Figure 2.9 Section of an uplink frequency and polarization plan. Numbers refer to frequency in megahertz.

Frequency reuse also may be achieved with spot-beam antennas, and these may be combined with polarization reuse to provide an effective bandwidth of 2000 MHz from the actual bandwidth of 500 MHz.

For one of the polarization groups, Fig. 2.9 shows the channeling scheme for the 12 transponders in more detail. The incoming, or uplink, frequency range is 5.925 to 6.425 GHz.

The frequency conversion shifts the carriers to the downlink frequency band, which is also 500 MHz wide, extending from 3.7 to 4.2 GHz. At this point the signals are channelized into frequency bands which represent the individual transponder bandwidths.

2.6.2 The wideband receiver

The wideband receiver is shown in more detail in Fig. 2.10. A duplicate receiver is provided so that if one fails, the other is automatically switched in. The combination is referred to as a *redundant receiver*, meaning that although two are provided, only one is in use at a given time.

The first stage in the receiver is a *low-noise amplifier* (LNA). This amplifier adds little noise to the carrier being amplified, and at the same time it provides sufficient amplification for the carrier to override the higher noise level present in the following mixer stage.

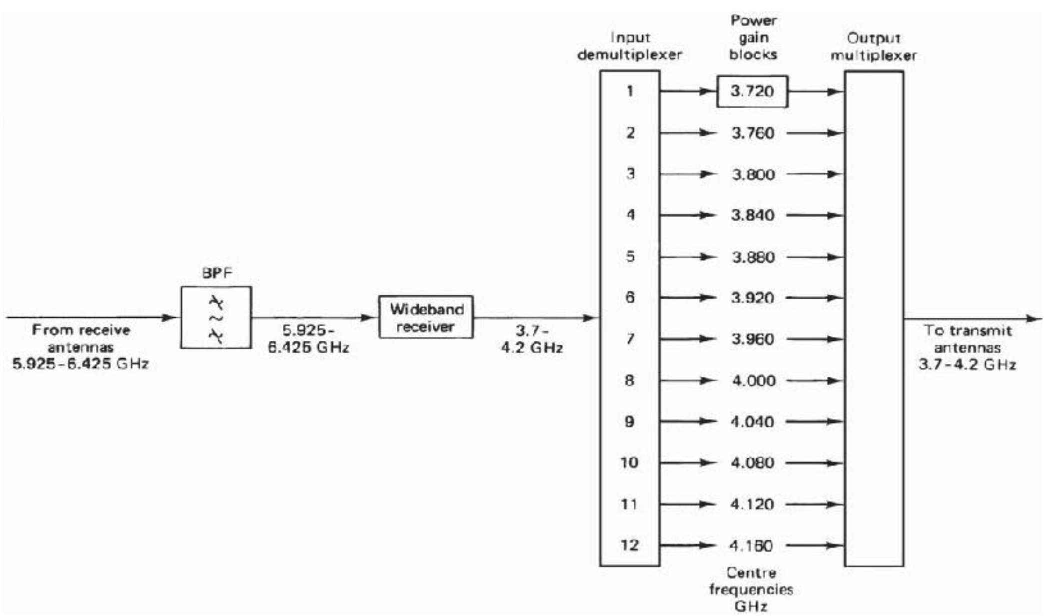


Figure 2.10 Satellite transponder channels

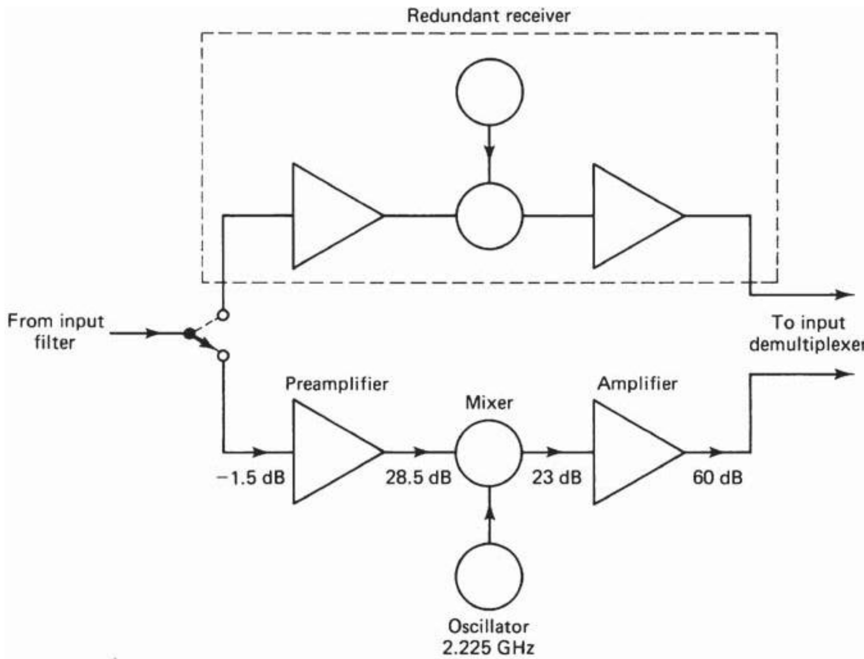


Figure 2.11 Satellite wideband receiver. (*Courtesy of CCIR, CCIR Fixed Satellite Services Handbook, final draft 1984.*)

involving noise, it is usually more convenient to refer all noise levels to the LNA input, where the total receiver noise may be expressed in terms of an equivalent noise temperature.

In a well-designed receiver, the equivalent noise temperature referred to the LNA input is basically that of the LNA alone. The overall noise temperature must take into account the noise added from the antenna, and these calculations are presented in detail in Chap. 12. The equivalent noise temperature of a satellite receiver may be on the order of a few hundred kelvins.

The LNA feeds into a mixer stage, which also requires a *local oscillator* (LO) signal for the frequency-conversion process.

With advances in *field-effect transistor* (FET) technology, FET amplifiers, which offer equal or better performance, are now available for both bands. Diode mixer stages are used.

The amplifier following the mixer may utilize *bipolar junction transistors* (BJTs) at 4 GHz and FETs at 12 GHz, or FETs may in fact be used in both bands.

2.6.3 The input demultiplexer

The input demultiplexer separates the broadband input, covering the frequency range 3.7 to 4.2 GHz, into the transponder frequency channels.

This provides greater frequency separation between adjacent channels in a group, which reduces adjacent channel interference.

The output from the receiver is fed to a power splitter, which in turn feeds the two separate chains of circulators.

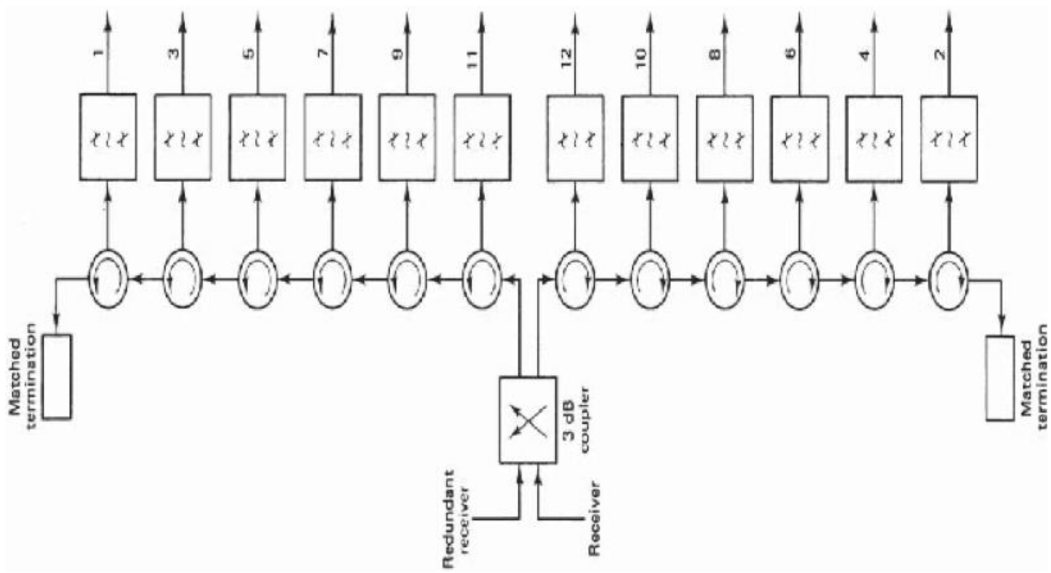


Figure 2.12 Satellite input multiplexer

The full broadband signal is transmitted along each chain, and the channelizing is achieved by means of channel filters con- nected to each circulator,

Each filter has a bandwidth of 36 MHz and is tuned to the appropriate center frequency, as shown in Fig. 2.11.

Although there are considerable losses in the demultiplexer, these are easily made up in the overall gain for the transponder channels.

2.6.4 The power amplifier

The fixed attenuation is needed to balance out variations in the input attenuation so that each transpon- der channel has the same nominal attenuation, the necessary adjust- ments being made during assembly.

The variable attenuation is needed to set the level as required for different types of service (an example being the requirement for input power backoff discussed later). Because this variable attenuator adjustment is an operational requirement, it must be under the control of the ground TT&C station.

Traveling-wave tube amplifiers (TWTAs) are widely used in transpon- ders to provide the final output power required to the transmit antenna. Figure 2.13 shows the schematic of a *traveling wave tube* (TWT) and its power supplies.

In the TWT, an electron-beam gun assembly consisting of a heater, a cathode, and focusing electrodes is used to form an elec- tron beam. A magnetic field is required to confine the beam to travel along the inside of a wire helix.

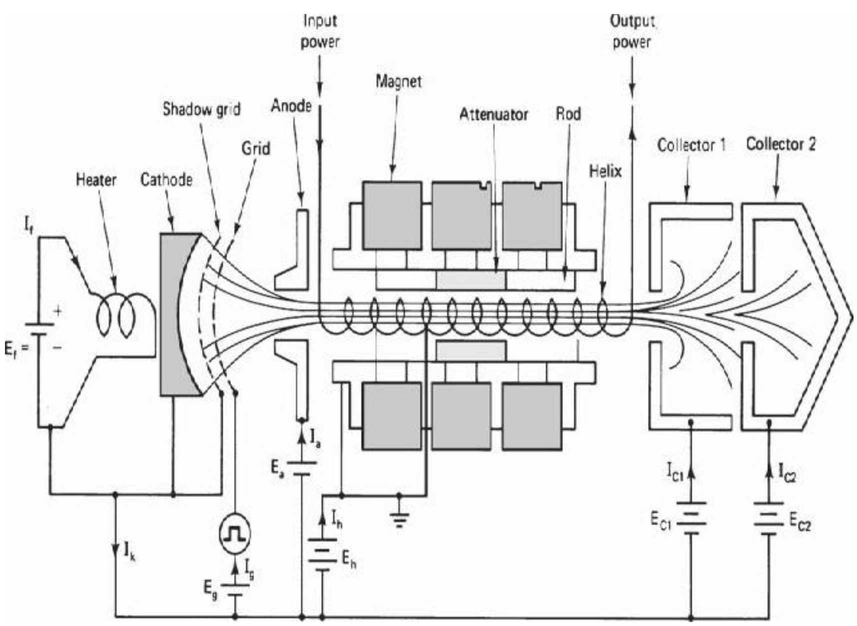


Figure 2.13 Satellite TWTA

used in ground stations, the magnetic field can be provided by means of a solenoid and dc power supply. The comparatively large size and high power consumption of solenoids make them unsuitable for use aboard satellites, and lower-power TWTs are used which employ permanent- magnet focusing.

The wave actually will travel around the helical path at close to the speed of light, but it is the axial component of wave velocity which interacts with the electron beam.

This component is less than the velocity of light approximately in the ratio of helix pitch to circumference. Because of this effective reduction in phase velocity, the helix is referred to as a *slowwave structure*.

The advantage of the TWT over other types of tube amplifiers is that it can provide amplification over a very wide bandwidth. Input levels to the TWT must be carefully controlled, however, to minimize the effects of certain forms of distortion.

The worst of these result from the nonlinear transfer characteristic of the TWT, illustrated in Fig. 2.14.

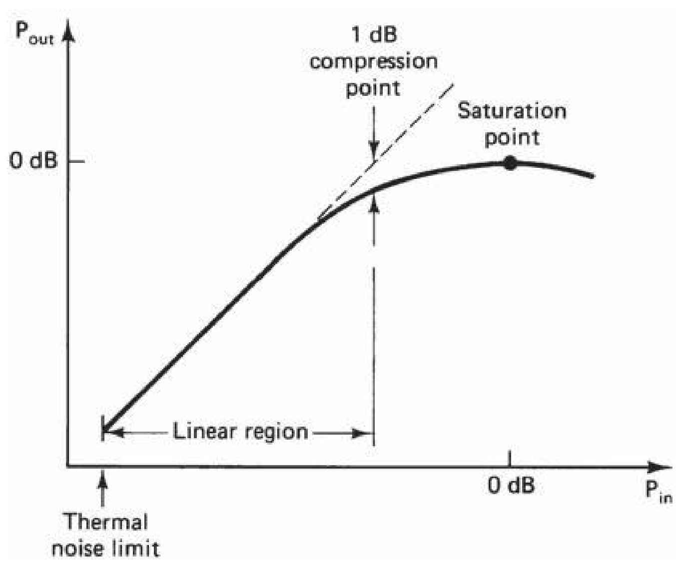


Figure 2.14 Power transfer characteristics of a TWT. The saturation point is used as 0-dB reference for both input and output.

At low-input powers, the output-input power relationship is linear; that is, a given decibel change in input power will produce the same decibel change in output power. At higher power inputs, the output power sat- urates, the point of maximum power output being known as the *satu- ration point*.

The saturation point is a very convenient reference point, and input and output quantities are usually referred to it. The linear region of the TWT is defined as the region bound by the thermal noise limit at the low end and by what is termed the *1-dB compression point* at the upper end. This is the point where the actual transfer curve drops

2.7. Satellite uplink and downlink Analysis and Design:

2.7.1 Introduction

This chapter describes how the link-power budget calculations are made. These calculations basically relate two quantities, the transmit power and the receive power, and show in detail how the difference between these two powers is accounted for.

Link-budget calculations are usually made using decibel or decilog quantities. These are explained in App. G. In this text [square] brackets are used to denote decibel quantities using the basic power definition.

Where no ambiguity arises regarding the units, the abbreviation dB is used. For example, Boltzmann's constant is given as 228.6 dB, although, strictly speaking, this should be given as 228.6 deci logs relative to 1 J/K.

2.7.2 Equivalent Isotropic Radiated Power

A key parameter in link-budget calculations is the *equivalent isotropic radiated power*, conventionally denoted as EIRP. From Eqs, the maximum power flux density at some distance *r* from a transmitting antenna of gain *G* i

$$Pr= \frac{GP}{4\pi^2}$$

An isotropic radiator with an input power equal to GP_S would produce the same flux density. Hence, this product is referred to as the EIRP, or EIRP is often expressed in decibels relative to 1 W, or dBW. Let P_S be in watts; then [EIRP] = [P_S] x [G] dB ,where [P_S] is also in dBW and [G] is in dB.

2.7.3 Transmission Losses

The [EIRP] may be thought of as the power input to one end of the transmission link, and the problem is to find the power received at the other end. Losses will occur along the way, some of which are constant.

Other losses can only be estimated from statistical data, and some of these are dependent on weather conditions, especially on rainfall.

The first step in the calculations is to determine the losses for *clear- weather* or *clear-sky conditions*. These calculations take into account the losses, including those calculated on a statistical basis, which do not vary significantly with time. Losses which are weather-related, and other losses which fluctuate with time, are then allowed for by introducing appropriate *fade margins* into the transmission equation.

Free-space transmission:

As a first step in the loss calculations, the power loss resulting from the spreading of the signal in space must be determined.

Feeder losses:

Losses will occur in the connection between the receive antenna and the receiver proper. Such losses will occur in the connecting waveguides, filters, and couplers. These will be denoted by RFL, or [RFL] dB, for *receiver feeder losses*.

Antenna misalignment losses:

When a satellite link is established, the ideal situation is to have the earth station and satellite antennas aligned for maximum gain, as shown in Fig. There are two possible sources of off-axis loss, one at the satellite and one at the earth station, as shown in Fig.

The off-axis loss at the satellite is taken into account by designing the link for operation on the actual satellite antenna contour; this is described in more detail in later sections. The off-axis loss at the earth station is referred to as the *antenna pointing loss*. Antenna pointing losses are usually only a few tenths of a decibel;

In addition to pointing losses, losses may result at the antenna from misalignment of the polarization direction (these are in addition to the polarization losses described in Chap. 5). The polarization misalign- ment losses are usually small, and it will be assumed that the antenna misalignment losses, denoted by [AML], include both pointing and polar- ization losses resulting from antenna misalignment. It should be noted

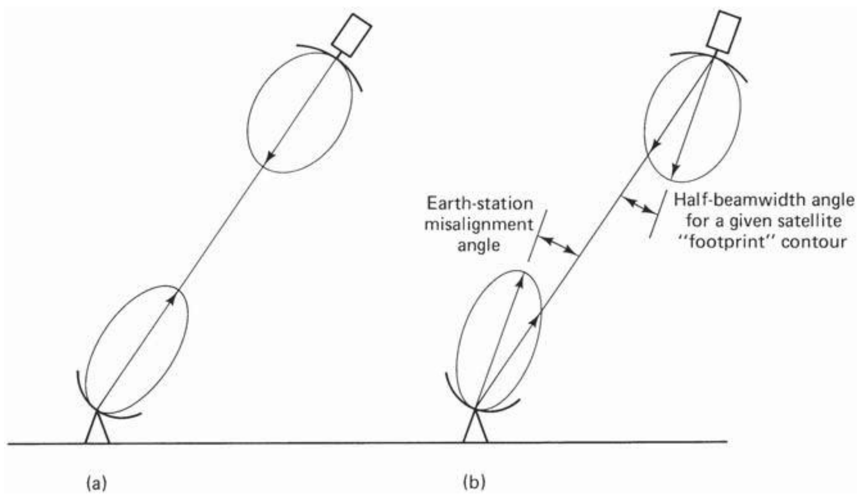


Figure 2.15 (*a*) Satellite and earth-station antennas aligned for maximum gain; (*b*) earth station situated on a given satellite "footprint," and earth-station antenna misaligned.

2.8 The Link-Power Budget Equation:

Now that the losses for the link have been identified, the power at the receiver, which is the power output of the link, may be calculated simply as [EIRP] [LOSSES] [G_R], where the last quantity is the receiver antenna gain. Note carefully that decibel addition must be used.

The major source of loss in any ground-satellite link is the free-space spreading loss [FSL], the basic link-power budget equation taking into account this loss only. However, the other losses also must be taken into account, and these are simply added to [FSL]. The losses for clear-sky conditions are

[LOSSES] = [FSL] + [RFL] + [AML] + [AA] - [PL] equation for the received power is then

$$[P_R] = [EIRP] \times [G_R] - [LOSSES]$$

where [PR] received power, dBW

[EIRP] → equivalent isotropic radiated power, dBW [FSL] free-space spreading loss, dB

[RFL] → receiver feeder loss, dB

[AML] → antenna misalignment loss, dB

[AA] → atmospheric absorption loss, dB [PL] polarization mismatch loss, dB

2.9 Amplifier noise temperature

Consider first the noise representation of the antenna and the *low noise amplifier* (LNA) shown in Fig. 2.15.

The available power gain of the amplifier is denoted as G, and the noise power output, as P_{no}.

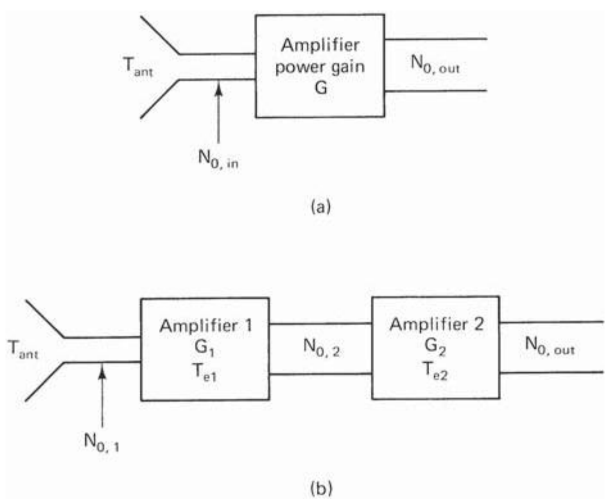


Figure 2.15 LNA Amplifier gain

For the moment we will work with the noise power per unit bandwidth, which is simply noise energy in joules as shown by Eq.

The input noise energy coming from the antenna is

$$N_{0,\text{ant}} = kT_{\text{ant}}$$

2.10 The Uplink

The uplink of a satellite circuit is the one in which the earth station is transmitting the signal and the satellite is receiving it specifically that the uplink is being considered.

$$\frac{C}{N} = [EIRP] - [LOSSES] + [k]$$

In this Eq the values to be used are the earth station EIRP, the satellite receiver feeder losses, and satellite receiver *G*/*T*. The free-space loss and other losses which are frequency-dependent are calculated for the uplink frequency.

2.10.1 Input backoff

Number of carriers are present simultaneously in a TWTA, the operating point must be backed off to a linear portion of the transfer characteristic to reduce the effects of inter modulation distortion. Such multiple carrier operation occurs with *frequency- division multiple access* (FDMA), which is described in Chap. 14. The point to be made here is that *backoff* (BO) must be allowed for in the link- budget calculations.

Suppose that the saturation flux density for single-carrier operation is known. Input BO will be specified for multiple-carrier operation, referred to the single-carrier saturation level. The earth-station EIRP will have to be reduced by the specified BO, resulting in an uplink value of

$$[EIRP]_U = [EIRP_S]_U + [BO]_i$$

2.10.2 The earth station HPA

The earth station HPA has to supply the radiated power plus the transmit feeder losses, denoted here by TFL, or [TFL] dB. These include waveguide, filter, and coupler losses between the HPA output and the transmit antenna. Referring back to Eq. (12.3), the power output of

The earth station itself may have to transmit multiple carriers, and its output also will require back off, denoted by $[BO]_{HPA}$. The earth station HPA must be rated for a saturation power output given by

$$[P_{HPA,sat}] = [P_{HPA}] + [BO]_{HPA}$$

2.11 Downlink

The downlink of a satellite circuit is the one in which the satellite is transmitting the signal and the earth station is receiving it. Equation can be applied to the downlink, but subscript D will be used to denote specifically that the downlink is being considered. Thus Eq. becomes

$$\frac{C}{N} = [EIRP] - [LOSSES] + [k]$$

In Eq. the values to be used are the satellite EIRP, the earth- station receiver feeder losses, and the earth-station receiver G/T. The free space and other losses are calculated for the downlink frequency. The resulting carrier-to-noise density ratio given by Eq. is that which appears at the detector of the earth station receiver.

2.11.1 Output back-off

Where input BO is employed as described in a corresponding output BO must be allowed for in the satellite EIRP. As the curve of Fig. 2.16 shows, output BO is not linearly related to input BO. A rule of thumb, frequently used, is to take the output BO as the point on the curve which is 5 dB below the extrapolated linear portion, as shown in Fig. 12.7. Since the linear portion gives a 1:1 change in decibels, the relationship between input and output BO is $[BO]_0$ $[BO]_i$ 5 dB. For example, with an input BO of $[BO]_i$ 11 dB, the corresponding output BO is $[BO]_0$

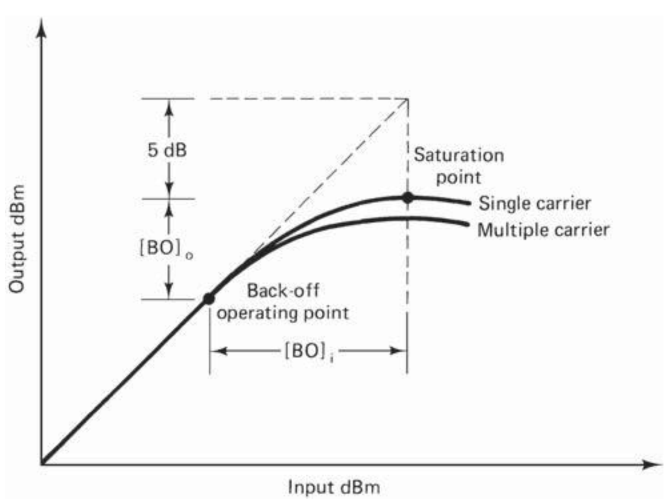


Figure 2.16 Input and output back-off relationship for the satellite traveling-wave-tube amplifier; $[BO]_i$ $[BO]_0$ 5 dB.

2.11.2 Effects of Rain

In the C band and, more especially, the Ku band, rainfall is the most significant cause of signal fading. Rainfall results in attenuation of radio waves by scattering and by absorption of energy from the wave.

Rain attenuation increases with increasing frequency and is worse in the Ku band compared with the C band.

This produces a depolarization of the wave; in effect, the wave becomes elliptically polarized. This is true for both linear and circular polar- izations, and the effect seems to be much worse for circular polarization (Freeman, 1981).

The C/N_0 ratio for the downlink alone, not counting the P_{NU} contri- bution, is P_R/P_{ND}, and the combined C/N_0 ratio at the ground receiver is

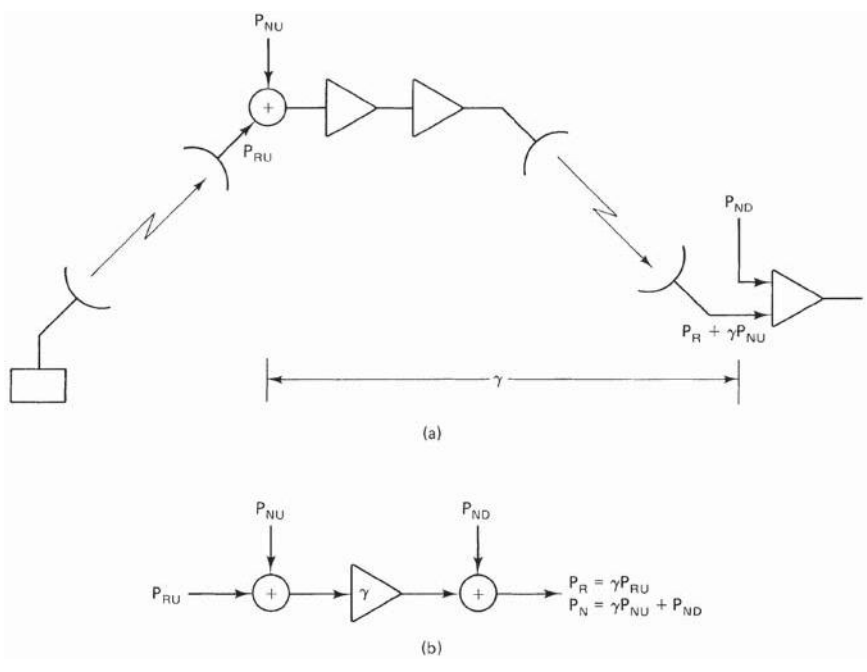


Figure 2.17 (*a*) Combined uplink and downlink; (*b*) power flow diagram

The reason for this reciprocal of the sum of the reciprocals method is that a single signal power is being transferred through the system, while the various noise powers, which are present are additive. Similar reasoning applies to the carrier-to-noise ratio, C/N.

2.12. inter modulation and interference:

Intermodulation interference is the undesired combining of several signals in a nonlinear device, producing new, unwanted frequencies, which can cause interference in adjacent receivers located at repeater sites.

Not all interference is a result of intermodulation distortion. It can come from co-channel interference, atmospheric conditions as well as man-made noise generated by medical, welding and heating equipment.

Most intermodulation occurs in a transmitter's nonlinear power amplifier (PA). The next most common mixing point is in the front end of a receiver. Usually it occurs in the unprotected first mixer of older model radios or in some cases an overdriven RF front-end amp.

Intermodulation can also be produced in rusty or corroded tower joints, guy wires, turnbuckles and anchor rods or any nearby metallic object, which can act as a nonlinear "mixer/rectifier" device.

2.13. Propagation Characteristics and Frequency considerations:

2.13.1 Introduction

A number of factors resulting from changes in the atmosphere have to be taken into account when designing a satellite communications system in order to avoid impairment of the wanted signal.

Generally, a margin in the required carrier-to-noise ratio is incorporated to accommodate such effects.

2.13.2 Radio Noise

Radio noise emitted by matter is used as a source of information in radioastronomy and in remote sensing. Noise of a thermal origin has a continuous spectrum, but several other radiation mechanisms cause the emission to have a spectral-line structure. Atoms and molecules are distinguished by their different spectral lines.

For other services such as satellite communications noise is a limiting factor for the receiving system; generally, it is inappropriate to use receiving systems with noise temperatures which are much less than those specified by the minimum external noise.

From about 30 MHz to about 1 GHz cosmic noise predominates over atmospheric noise except during local thunderstorms, but will generally be exceeded by man-made noise in populated areas.

In the bands of strong gaseous absorption, the noise temperature reaches maximum values of some 290 K. At times, precipitation will also increase the noise temperature at frequencies above 5 GHz.

Figure 6.1 gives an indication of sky noise at various elevation angles and frequencies.

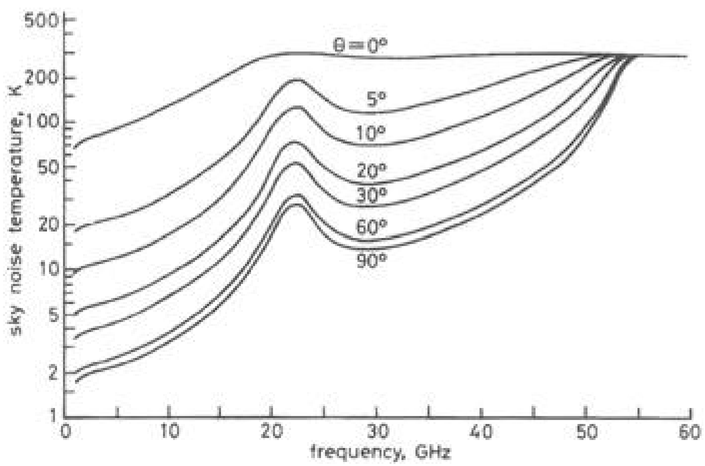


Figure 2.18 Sky-Noise Temperature for Clear Air

2.14. System reliability and design lifetime:

2.14.1 System reliability:

Satellites are designed to operate dependably throughout their operational life, usually a number of years.

This is achieved through stringent quality control and testing of parts and subsystems before they are used in the construction of the satellite.

Redundancy of key components is often built in so that if a particular part or subassembly fails, another can perform its functions.

In addition, hardware and software on the satellite are often designed so that ground controllers can reconfigure the satellite to work around a part that has failed.

2.14.2. Design lifetime:

The Milstar constellation has demonstrated exceptional reliability and capability, providing vital protected communications to the warfighter," said Kevin Bilger, vice president and general manager, Global Communications Systems, Lockheed Martin Space Systems in Sunnyvale.

"Milstar's robust system offers our nation worldwide connectivity with flexible, dependable and highly secure satellite communications."

The five-satellite Milstar constellation has surpassed 63 years of combined successful operations, and provides a protected, global communication network for the joint forces of the U.S. military. In addition, it can transmit voice, data, and imagery, and offers video teleconferencing capabilities.

The system is the principal survivable, endurable communications structure that the President, the Secretary of Defense and the Commander, U.S. Strategic Command use to maintain positive command and control of the nation's strategic forces.

In addition to this 10-year milestone for Flight-5, each of the first two Milstar satellites have been on orbit for over 16 years – far exceeding their 10-year design life.

The next-generation Lockheed Martin-built Advanced EHF satellites, joining the Milstar constellation, provide five times faster data rates and twice as many connections, permitting transmission of strategic and tactical military communications, such as real-time video, battlefield maps and targeting data. Advanced EHF satellites are designed to be fully interoperable and backward compatible with Milstar.

Headquartered in Bethesda, Md., Lockheed Martin is a global security company that employs about 123,000 people worldwide and is principally engaged in the research, design, development, manufacture, integration and sustainment of advanced technology systems, products and services. The Corporation's net sales for 2011 were $46.5 billion.

UNIT III SATELLITE ACCESS

3.1 Modulation and Multiplexing: Voice, Data, Video :

Communications satellites are used to carry telephone, video, and data signals, and can use both analog and digital modulation techniques.

Modulation:

Modification of a carrier's parameters (amplitude, frequency, phase, or a combination of them) in dependence on the symbol to be sent.

Multiplexing:

Task of multiplexing is to assign space, time, frequency, and code to each communication channel with a minimum of interference and a maximum of medium utilization Communication channel refers to an association of sender(s) and receiver(s) that want to exchange data One of several constellations of a carrier's parameters defined by the used modulation scheme.

3.1.1 Voice, Data, Video :

The modulation and multiplexing techniques that were used at this time were analog, adapted from the technology developed for The change to digital voice signals made it easier for long-distance.

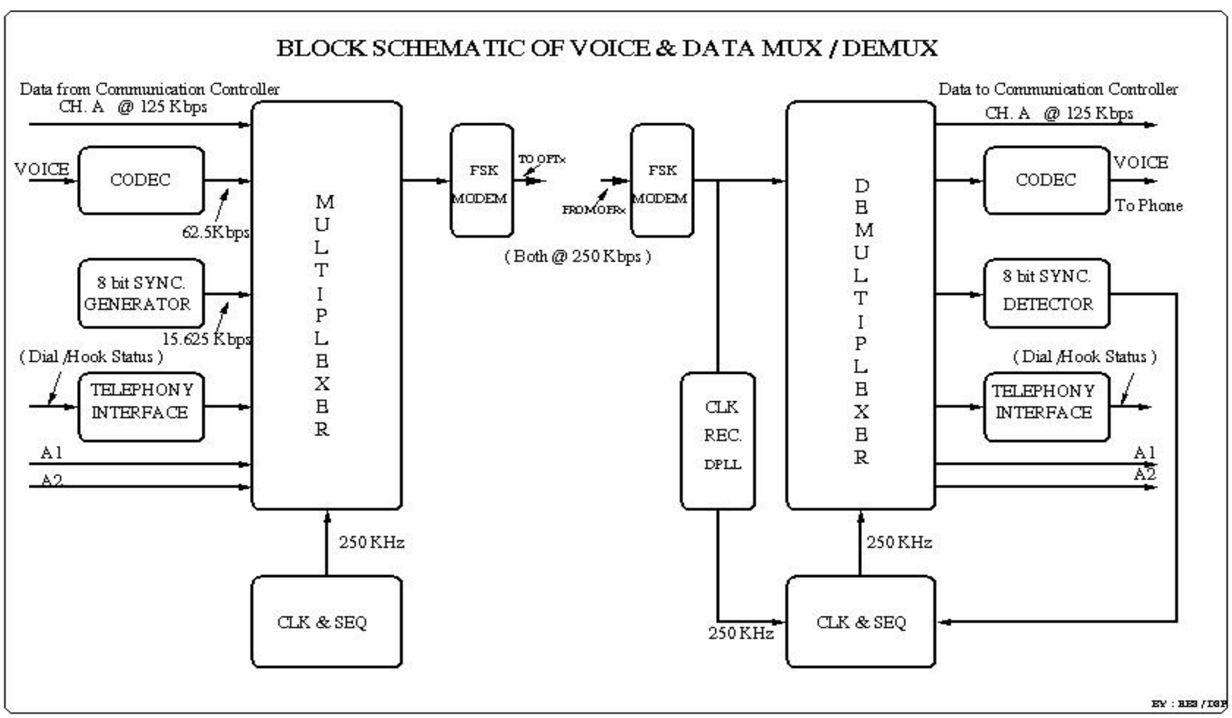


Figure 3.1 Modulation and Multiplexing: Voice/Data/Video

Communication carriers to mix digital data and telephone Fiber-optic Cable Transmission Standards System Bit rate (Mbps) 64- kbps Voice channel capacity Stuffing bits and words are added to the satellite data stream as needed to fill empty bit and word spaces.

Primarily for video provided that a satellite link's overall carrier-to-noise but in to older receiving equipment at System and Satellite Specification Ku-band satellite parameters.

3.1.2 Modulation And Multiplexing:

In analog television (TV) transmission by satellite, the baseband video signal and one or two audio subcarriers constitute a composite video signal.

Digital modulation is obviously the modulation of choice for transmitting digital data are digitized analog signals may conveniently share a channel with digital data, allowing a link to carry a varying mix of voice and data traffic.

Digital signals from different channels are interleaved for transmission through time division multiplexing TDM carry any type of traffic â€” the bent pipe transponder that can carry voice, video, or data as the marketplace demands.

Hybrid multiple access schemes can use time division multiplexing of baseband channels which are then modulate.

3.2 Analog – digital transmission system :

3.2.1 Analog vs. Digital Transmission:

Compare at two levels:

1. Data—continuous (audio) vs. discrete (text)
2. Signaling—continuously varying electromagnetic wave vs. sequence of voltage pulses.

Also Transmission—transmit without regard to signal content vs. being concerned with signal content. Difference in how attenuation is handled, but not focus on this.Seeing a shift towards digital transmission despite large analog base. Why?

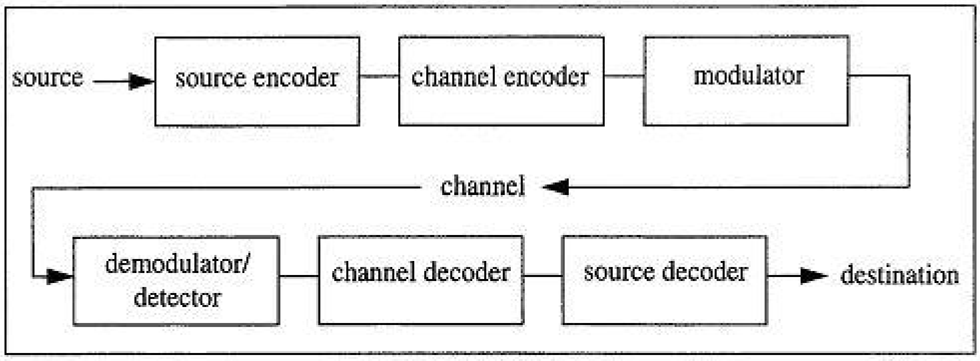


Figure 3.2 basic communication systems

- Improving digital technology
- Data integrity. Repeaters take out cumulative problems in transmission. Can thus transmit longer distances.
- Easier to multiplex large channel capacities with digital
- Easy to apply encryption to digital data
- Better integration if all signals are in one form. Can integrate voice, video and digital data.

3.2.2 Digital Data/Analog Signals:

Must convert digital data to analog signal such device is a modem to translate between bit-serial and modulated carrier signals?

To send digital data using analog technology, the sender generates a carrier signal at some continuous tone (e.g. 1-2 kHz in phone circuits) that looks like a sine wave. The following techniques are used to encode digital data into analog signals.

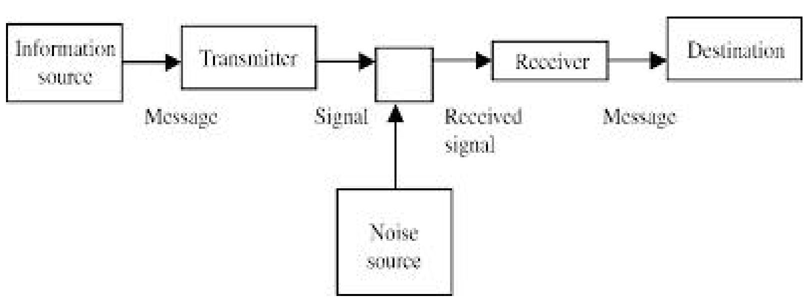


Figure 3.3 Digital /Analog Transmitter & receiver

Resulting bandwidth is centered on the carrier frequency.

- Amplitude-shift modulation (keying): vary the amplitude (e.g. voltage) of the signal. Used to transmit digital data over optical fiber.
- Frequency-shift modulation: two (or more tones) are used, which are near the carrier frequency. Used in a full-duplex modem (signals in both directions).
- Phase-shift modulation: systematically shift the carrier wave at uniformly spaced intervals.

For instance, the wave could be shifted by 45, 135, 225, 315 degree at each timing mark. In this case, each timing interval carries 2 bits of information.

Why not shift by 0, 90, 180, 270? Shifting zero degrees means no shift, and an extended set of no shifts leads to clock synchronization difficulties.

Frequency division multiplexing (FDM): Divide the frequency spectrum into smaller subchannels, giving each user exclusive use of a subchannel (e.g., radio and TV). One problem with FDM is that a user is given all of the frequency to use, and if the user has no data to send, bandwidth is wasted — it cannot be used by another user.

Time division multiplexing (TDM): Use time slicing to give each user the full bandwidth, but for only a fraction of a second at a time (analogous to time sharing in operating systems). Again, if the user doesn’t have data to sent during his timeslice, the bandwidth is not used (e.g., wasted).

Statistical multiplexing: Allocate bandwidth to arriving packets on demand. This leads to the most efficient use of channel bandwidth because it only carries useful data.That is, channel bandwidth is allocated to packets that are waiting for transmission, and a user generating no packets doesn’t use any of the channel resources.

3.3. Digital Video Broadcasting (DVB):

- Digital Video Broadcasting (DVB) has become the synonym for digital television and for data broadcasting world-wide.

- DVB services have recently been introduced in Europe, in North- and South America, in Asia, Africa and Australia.

- This article aims at describing what DVB is all about and at introducing some of the technical background of a technology that makes possible the broadcasting.

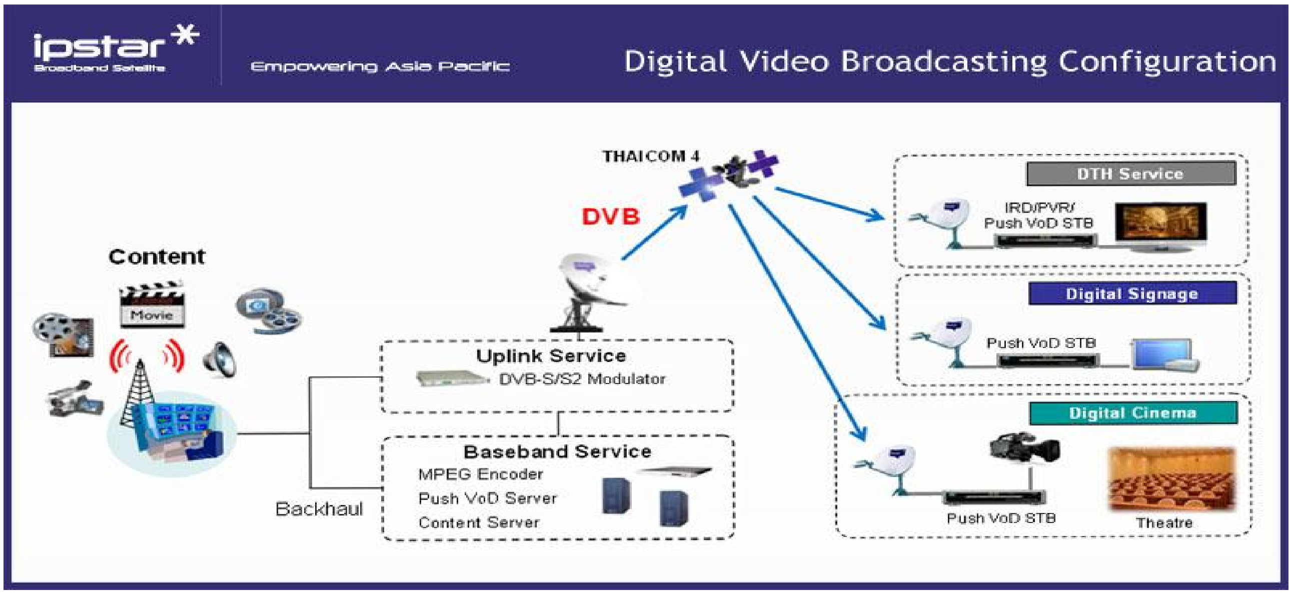


Figure 3.4 Digital Video Broadcasting systems

3.4 Multiple Access Techniques:

- The transmission from the BS in the downlink can be heard by each and every mobile user in the cell, and is referred as *broadcasting*. Transmission from the mobile users in the uplink to the BS is many-to-one, and is referred to as multiple access.

- Multiple access schemes to allow many users to share simultaneously a finite amount of radio spectrum resources.
  - Should not result in severe degradation in the performance of the system as compared to a single user scenario.
  - Approaches can be broadly grouped into two categories: narrowband and wideband.

- Multiple Accessing Techniques : with possible conflict and conflict- free

- Random access
- Frequency division multiple access (FDMA)
- Time division multiple access (TDMA)
- Spread spectrum multiple access (SSMA) : an example is Code division multiple access (CDMA)
- Space division multiple access (SDMA)

Duplexing:

- For voice or data communications, must assure two way communication (duplexing, it is possible to talk and listen simultaneously). Duplexing may be done using frequency or time domain techniques.
  - Forward (downlink) band provides traffic from the BS to the mobile
  - Reverse (uplink) band provides traffic from the mobile to the BS.

3.4.1 Frequency division duplexing (FDD):

- Provides two distinct bands of frequencies for every user, one for downlink and one for uplink.

- A large interval between these frequency bands must be allowed so that interference is minimized.

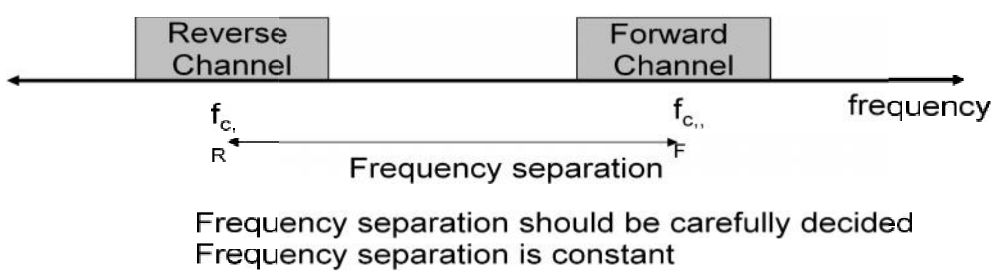


Figure 3.5 Frequency Separation

3.4.2. Time division duplexing (TDD):

- In TDD communications, both directions of transmission use one contiguous frequency allocation, but two separate time slots to provide both a forward and reverse link.

- Because transmission from mobile to BS and from BS to mobile alternates in time, this scheme is also known as "ping pong".
- As a consequence of the use of the same frequency band, the communication quality in both directions is the same. This is different from FDD.

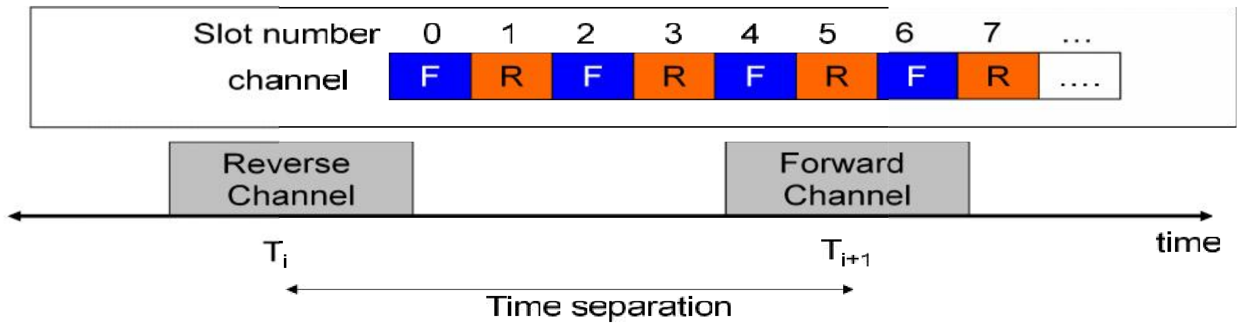


Figure 3.6 Time Slot

3.4.3 FDMA:

- In FDMA, each user is allocated a unique frequency band or channel. During the period of the call, no other user can share the same frequency band.

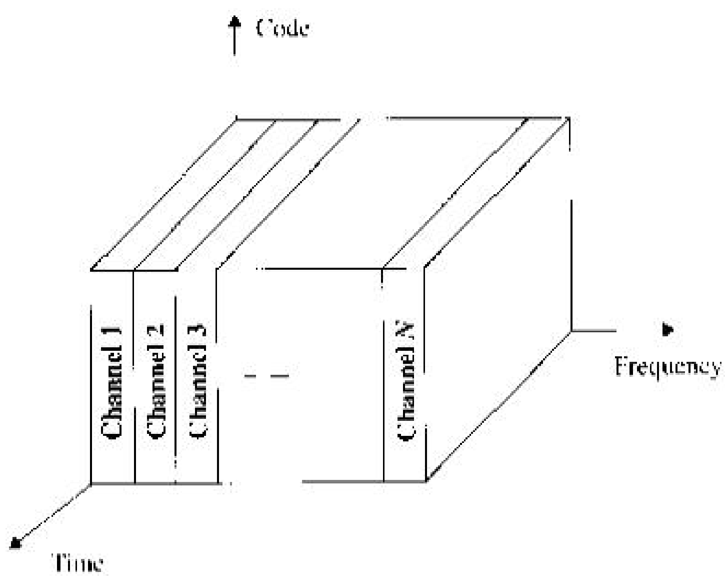


Figure 3.7 FDMA Channels

- All channels in a cell are available to all the mobiles. Channel assignment is carried out on a first-come first- served basis.

- The number of channels, given a frequency spectrum *BT* , depends on the modulation technique (hence *Bw* or *Bc*) and the guard bands between the channels 2*Bguard* .

- These guard bands allow for imperfect filters and oscillators and can be used to minimize adjacent channel interference.
- FDMA is usually implemented in narrowband systems.

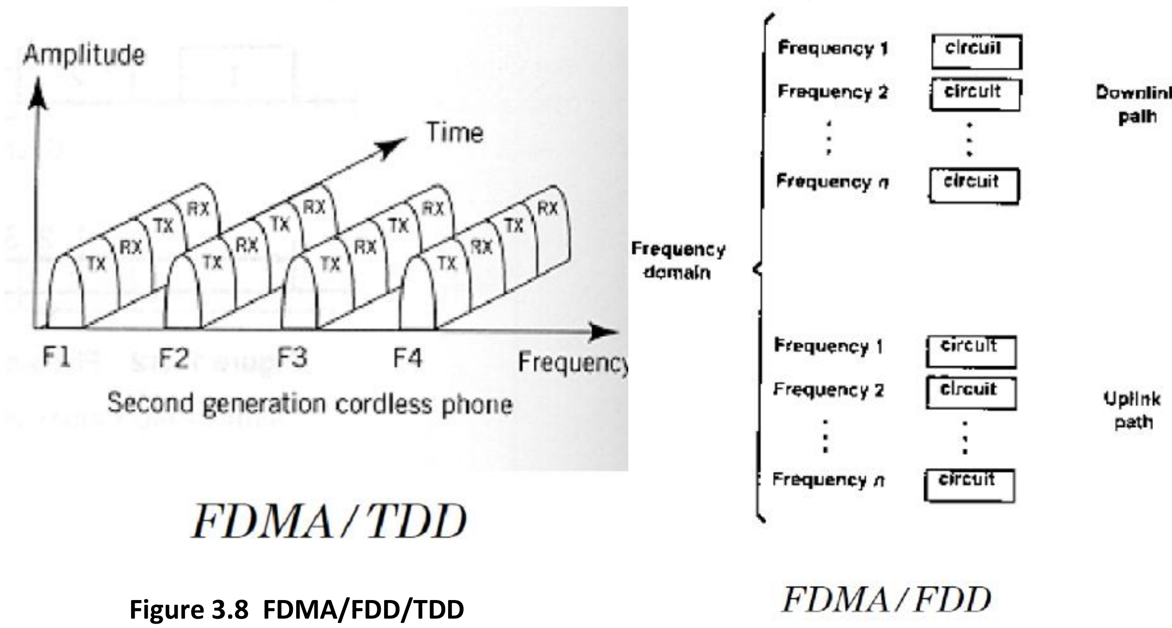


Figure 3.8 FDMA/FDD/TDD

Nonlinear effects in FDMA:

- In a FDMA system, many channels share the same antenna at the BS. The power amplifiers or the power combiners, when operated at or near saturation are nonlinear.

- The nonlinear ties generate inter-modulation frequencies.

- Undesirable harmonics generated outside the mobile radio band cause interference to adjacent services.

- Undesirable harmonics present inside the band cause interference to other users in the mobile system.

3.4.4 TDMA:

- TDMA systems divide the channel time into frames. Each frame is further partitioned into time slots. In each slot only one user is allowed to either transmit or receive.
- Unlike FDMA, only digital data and digital modulation must be used.
- Each user occupies a cyclically repeating time slot, so a channel may be thought of as a particular time slot of every frame, where *N* time slots comprise a frame.

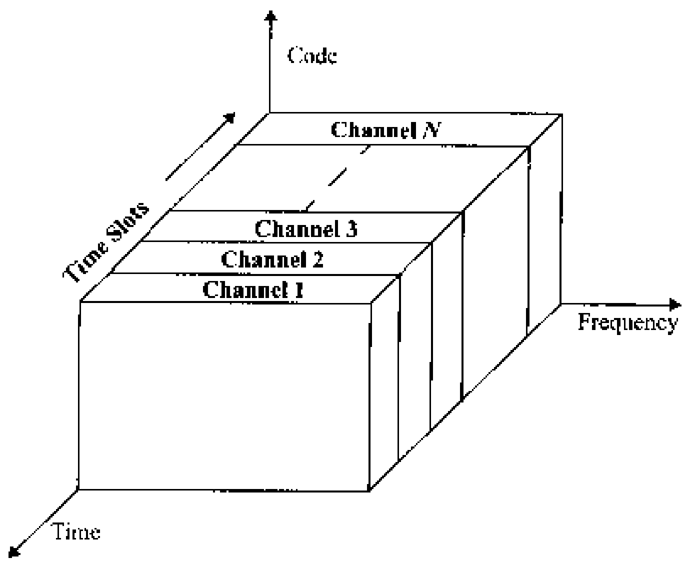


Figure 3.9 TDMA Channels

Features:

- Multiple channels per carrier or RF channels.
- Burst transmission since channels are used on a timesharing basis. Transmitter can be turned off during idle periods.
- Narrow or wide bandwidth – depends on factors such as modulation scheme, number of voice channels per carrier channel.
- High ISI – Higher transmission symbol rate, hence resulting in high ISI. Adaptive equalizer required.

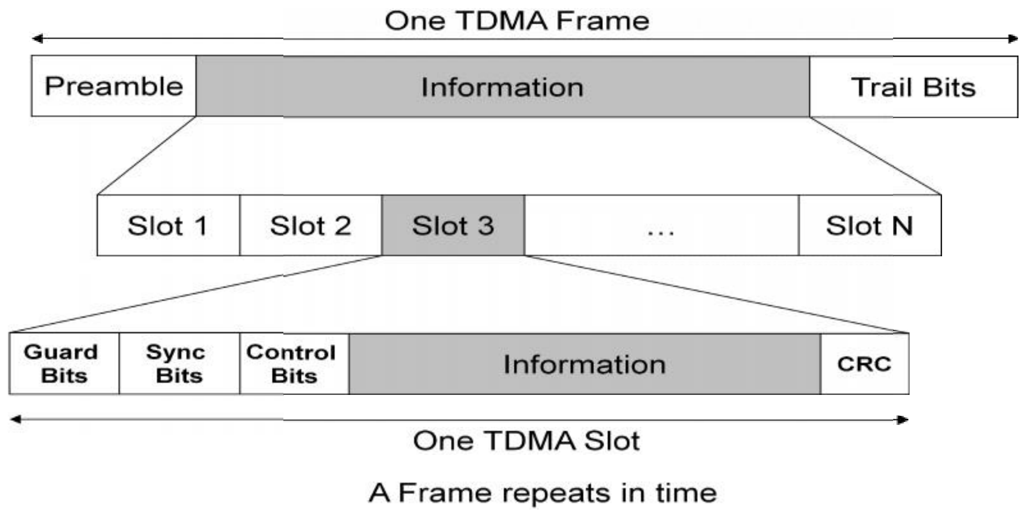


Figure 3.10 TDMA Channels time slot

- A guard time between the two time slots must be allowed in order to avoid interference, especially in the uplink direction. All mobiles should synchronize with BS to minimize interference.
- Efficient power utilization : FDMA systems require a 3- to 6-dB power back off in order to compensate for inter-modulation effects.
- Efficient handoff : TDMA systems can take advantage of the fact that the transmitter is switched off during idle time slots to improve the handoff procedure. An enhanced link control, such as that provided by mobile assisted handoff (MAHO) can be carried out by a subscriber by listening to neighboring base station during the idle slot of the TDMA frame.
- Efficiency of TDMA
- Efficiency of TDMA is a measure of the percentage of bits per frame which contain transmitted data. The transmitted data include source and channel coding bits.

$$\eta_f = \frac{b_T - b_{OH}}{b_T} \cdot 100\%$$

- b_{OH} includes all overhead bits such as preamble, guard bits, etc.

3.4.5 Code Division Multiple Access (CDMA):

- Spreading signal (code) consists of chips
  - Has Chip period and and hence, chip rate
  - Spreading signal use a pseudo-noise (PN) sequence (a pseudo-random sequence)
  - PN sequence is called a codeword
  - Each user has its own cordword
  - Codewords are orthogonal. (low autocorrelation)
  - Chip rate is oder of magnitude larger than the symbol rate.
- The receiver correlator distinguishes the senders signal by examining the wideband signal with the same time-synchronized spreading code
- The sent signal is recovered by despreading process at the receiver.

CDMA Advantages:

- Low power spectral density.
  - Signal is spread over a larger frequency band
  - Other systems suffer less from the transmitter
- Interference limited operation
  - All frequency spectrum is used
- Privacy
  - The codeword is known only between the sender and receiver. Hence other users can not decode the messages that are in transit
- Reduction of multipath affects by using a larger spectrum

CDMA data:

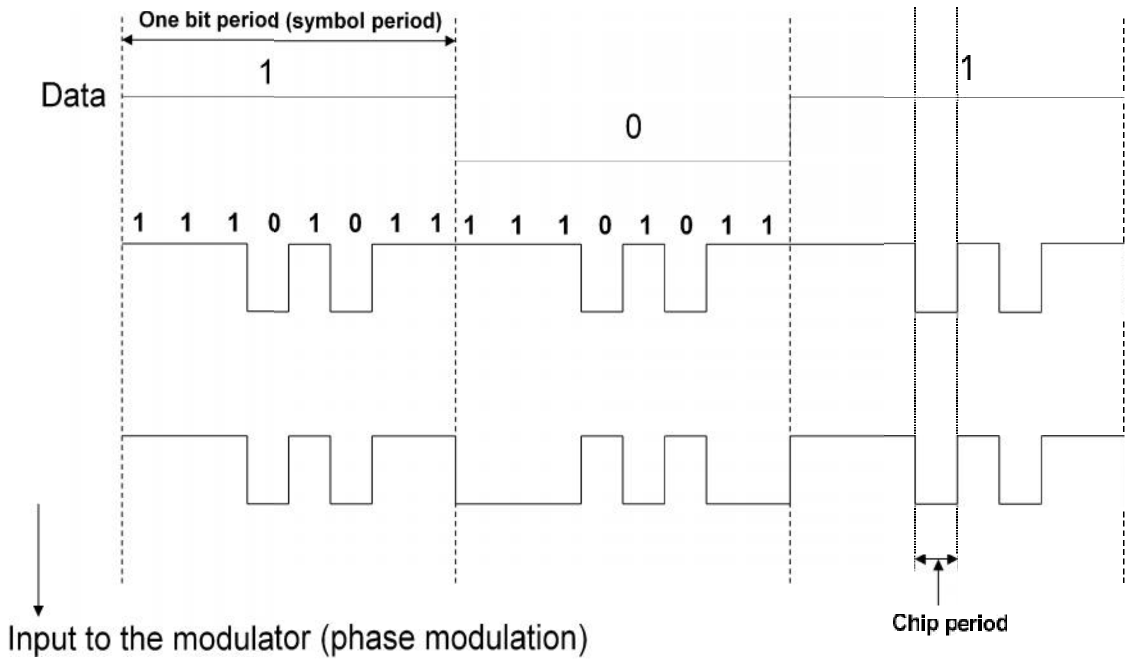
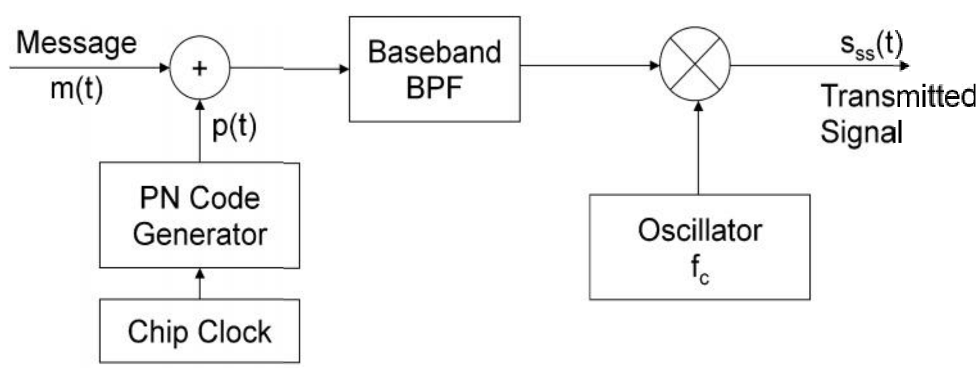


Figure 3.11 CDMA Channels transmission

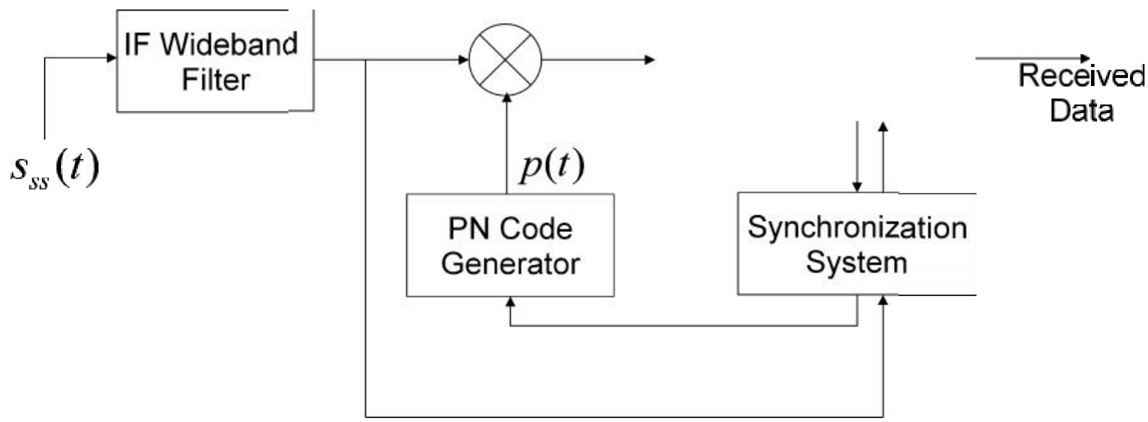
DSSS Transmitter:



$$s_{ss}(t) = \sqrt{\frac{2E_s}{T_s}} m(t) p(t) \cos(2\pi f_c t + \theta)$$

Figure 3.12 CDMA Transmitter

DSSS Receiver



$$s_1(t) = \sqrt{\frac{2E_s}{T_s}} m(t) \cos(2\pi f_c t + \theta)$$

Figure 3.13 CDMA Receiver

- FDMA/CDMA
  - Available wideband spectrum is frequency divided into number narrowband radio channels. CDMA is employed inside each channel.
- DS/FHMA
  - The signals are spread using spreading codes (direct sequence signals are obtained), but these signal are not transmitted over a constant carrier frequency; they are transmitted over a frequency hopping carrier frequency.
- Time Division CDMA (TCDMA)
  - Each cell is using a different spreading code (CDMA employed between cells) that is conveyed to the mobiles in its range.
  - Inside each cell (inside a CDMA channel), TDMA is employed to multiplex multiple users.

- Time Division Frequency Hopping
    - At each time slot, the user is hopped to a new frequency according to a pseudo-random hopping sequence.
    - Employed in severe co-interference and multi-path environments.

Bluetooth and GSM are using this technique

- A large number of independently steered high-gain beams can be formed without any resulting degradation in SNR ratio.
- Beams can be assigned to individual users, thereby assuring that all links operate with maximum gain.
- Adaptive beam forming can be easily implemented to improve the system capacity by suppressing co channel interference.

Advantage of CDMA

- It is recognized that CDMA's capacity gains over TDMA
- FDMA are entirely due to Its tighter, dynamic control over the use of the power domain.
- Choosing a new non-orthogonal PN sequence a CDMA system does not encounter the difficulties of choosing a spare carrier frequency or time slot to carry a Traffic Channel
- Ensure that interference will not be too great if it begins to transmit -that there is still enough space left in the power domain.

Disadvantages of CDMA:

- Satellite transponders are channelized too narrowly for roadband CDMA, which is the most attractive form of CDMA.
- Power control cannot be as tight as it is in a terrestrial system because of long round-trip delay.

3.5. Channel allocation schemes:

In radio resource management for wireless and cellular network, channel allocation schemes are required to allocate bandwidth and communication channels to base stations, access points and terminal equipment.

The objective is to achieve maximum system spectral efficiency in bit/s/Hz/site by means of frequency reuse, but still assure a certain grade of service by avoiding co-channel interference and adjacent channel interference among nearby cells or networks that share the bandwidth. There are two types of strategies that are followed:-

- Fixed: FCA, fixed channel allocation: Manually assigned by the network operator
- Dynamic:
    - DCA, dynamic channel allocation,
    - DFS, dynamic frequency selection
    - Spread spectrum

3.5.1 FCA:

In **Fixed Channel Allocation** or **Fixed Channel Assignment** (FCA) each cell is given a predetermined set of frequency channels.

FCA requires manual frequency planning, which is an arduous task in TDMA and FDMA based systems, since such systems are highly sensitive to co-channel interference from nearby cells that are reusing the same channel.

This results in traffic congestion and some calls being lost when traffic gets heavy in some cells, and idle capacity in other cells.

3.5.2. DCA and DFS:

Dynamic Frequency Selection (DFS) may be applied in wireless networks with several adjacent non-centrally controlled access points.

A more efficient way of channel allocation would be **Dynamic Channel Allocation** or **Dynamic Channel Assignment** (DCA) in which voice channel are not allocated to cell permanently, instead for every call request base station request channel from MSC.

3.6 Spread spectrum:

Spread spectrum can be considered as an alternative to complex DCA algorithms. Spread spectrum avoids cochannel interference between adjacent cells, since the probability that users in nearby cells use the same spreading code is insignificant.

Thus the frequency channel allocation problem is relaxed in cellular networks based on a combination of Spread spectrum and FDMA, for example IS95 and 3G systems.

In packet based data communication services, the communication is bursty and the traffic load rapidly changing. For high system spectrum efficiency, DCA should be performed on a packet-by-packet basis.

Examples of algorithms for packet-by-packet DCA are **Dynamic Packet Assignment** (DPA), Dynamic Single Frequency Networks (DSFN) and **Packet and resource plan scheduling** (PARPS).

3.6.1 Spread spectrum Techniques:

1 In telecommunication and radio communication, spread-spectrum techniques are methods by which a signal (e.g. an electrical, electromagnetic, or acoustic signal) generated with a particular bandwidth is deliberately spread in the frequency domain, resulting in a signal with a wider bandwidth.

2 These techniques are used for a variety of reasons, including the establishment of secure communications, increasing resistance to natural interference, noise and jamming, to prevent detection, and to limit power flux density (e.g. in satellite downlinks).

3 Spread-spectrum telecommunications this is a technique in which a telecommunication signal is transmitted on a bandwidth considerably larger than the frequency content of the original information.

4 Spread-spectrum telecommunications is a signal structuring technique that employs direct sequence, frequency hopping, or a hybrid of these, which can be used for multiple access and/or multiple functions.

5 Frequency-hopping spread spectrum (FHSS), direct-sequence spread spectrum (DSSS), time-hopping spread spectrum (THSS), chirp spread spectrum (CSS).

6 Techniques known since the 1940s and used in military communication systems since the 1950s "spread" a radio signal over a wide frequency range several magnitudes higher than minimum requirement.

7 Resistance to jamming (interference). DS (direct sequence) is good at resisting continuous-time narrowband jamming, while FH (frequency hopping) is better at resisting pulse jamming.

8 Resistance to fading. The high bandwidth occupied by spread-spectrum signals offer some frequency diversity, i.e. it is unlikely that the

signal will encounter severe multipath fading over its whole bandwidth, and in other cases the signal can be detected using e.g. a Rake receiver.

9 Multiple access capability, known as code-division multiple access (CDMA) or code-division multiplexing (CDM). Multiple users can transmit simultaneously in the same frequency band as long as they use different spreading codes.

3.7 Compression – Encryption:

At the broadcast center, the high-quality digital stream of video goes through an MPEG encoder, which converts the programming to MPEG-4 video of the correct size and format for the satellite receiver in your house.

Encoding works in conjunction with compression to analyze each video frame and eliminate redundant or irrelevant data and extrapolate information from other frames. This process reduces the overall size of the file. Each frame can be encoded in one of three ways:

- As an **intraframe**, which contains the complete image data for that frame. This method provides the least compression.
- As a **predicted** frame, which contains just enough information to tell the satellite receiver how to display the frame based on the most recently displayed intraframe or predicted frame.
- As a **bidirectional** frame, which displays information from the surrounding intraframe or predicted frames. Using data from the closest surrounding frames, the receiver **interpolates** the position and color of each pixel.

This process occasionally produces **artifacts --** glitches in the video image. One artifact is **macroblocking,** in which the fluid picture temporarily dissolves into blocks. Macroblocking is often mistakenly called **pixilating,** a technically incorrect term which has been accepted as slang for this annoying artifact.

There really are pixels on your TV screen, but they're too small for your human eye to perceive them individually -- they're tiny squares of video data that make up the image you see. (For more information about pixels and perception, see How TV Works.)

The rate of compression depends on the nature of the programming. If the encoder is converting a newscast, it can use a lot more predicted frames because most of the scene stays the same from one frame to the next.

In more fast-paced programming, things change very quickly from one frame to the next, so the encoder has to create more intraframes. As a result, a newscast generally compresses to a smaller size than something like a car race.

3.7.1 Encryption and Transmission:

After the video is compressed, the provider encrypts it to keep people from accessing it for free. Encryption scrambles the digital data in such a way that it can only be **decrypted** (converted back into usable data) if the receiver has the correct decryption algorithm and security keys.

Once the signal is compressed and encrypted, the broadcast center beams it directly to one of its satellites. The satellite picks up the signal with an onboard dish, amplifies the signal and uses another dish to beam the signal back to Earth, where viewers can pick it up.

In the next section, we'll see what happens when the signal reaches a viewer's house.

3.7.2 Video and Audio Compression:

Video and Audio files are very large beasts. Unless we develop and maintain very high bandwidth networks (Gigabytes per second or more) we have to compress to data.

Relying on higher bandwidths is not a good option -- M25 Syndrome: Traffic needs ever increases and will adapt to swamp current limit whatever this is.

As we will compression becomes part of the representation or *coding* scheme which have become popular audio, image and video formats.

We will first study basic compression algorithms and then go on to study some actual coding formats.

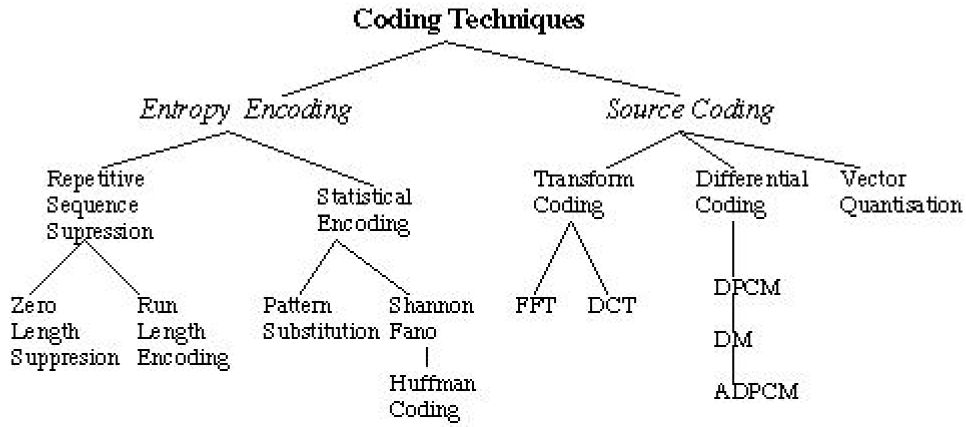


Figure 3.14 *coding* scheme

What is Compression?

Compression basically employs redundancy in the data:

- Temporal -- in 1D data, 1D signals, Audio etc.
- Spatial -- correlation between neighbouring pixels or data items
- Spectral -- correlation between colour or luminescence components. This uses the frequency domain to exploit relationships between frequency of change in data.
- psycho-visual -- exploit perceptual properties of the human visual system.

Compression can be categorised in two broad ways:

Lossless Compression :

-- where data is compressed and can be reconstituted (uncompressed) without loss of detail or information. These are referred to as bit-preserving or reversible compression systems also.

Lossy Compression :

-- where the aim is to obtain the best possible *fidelity* for a given bit-rate or minimizing the bit-rate to achieve a given fidelity measure. Video and audio compression techniques are most suited to this form of compression.

If an image is compressed it clearly needs to uncompressed (decoded) before it can viewed/listened to. Some processing of data may be possible in encoded form however. Lossless compression frequently involves some form of *entropy encoding* and are based in information theoretic techniques.

Lossy compression use source encoding techniques that may involve transform encoding, differential encoding or vector quantization.

3.7.3 MPEG Standards :

All MPEG standards exist to promote system interoperability among your computer, television and handheld video and audio devices. They are:

- **MPEG-1:** the original standard for encoding and decoding streaming video and audio files.
- **MPEG-2:** the standard for digital television, this compresses files for transmission of high-quality video.
- **MPEG-4:** the standard for compressing high-definition video into smaller-scale files that stream to computers, cell phones and PDAs (personal digital assistants).
- **MPEG-21:** also referred to as the Multimedia Framework. The standard that interprets what digital content to provide to which individual user so that media plays flawlessly under any language, machine or user conditions.

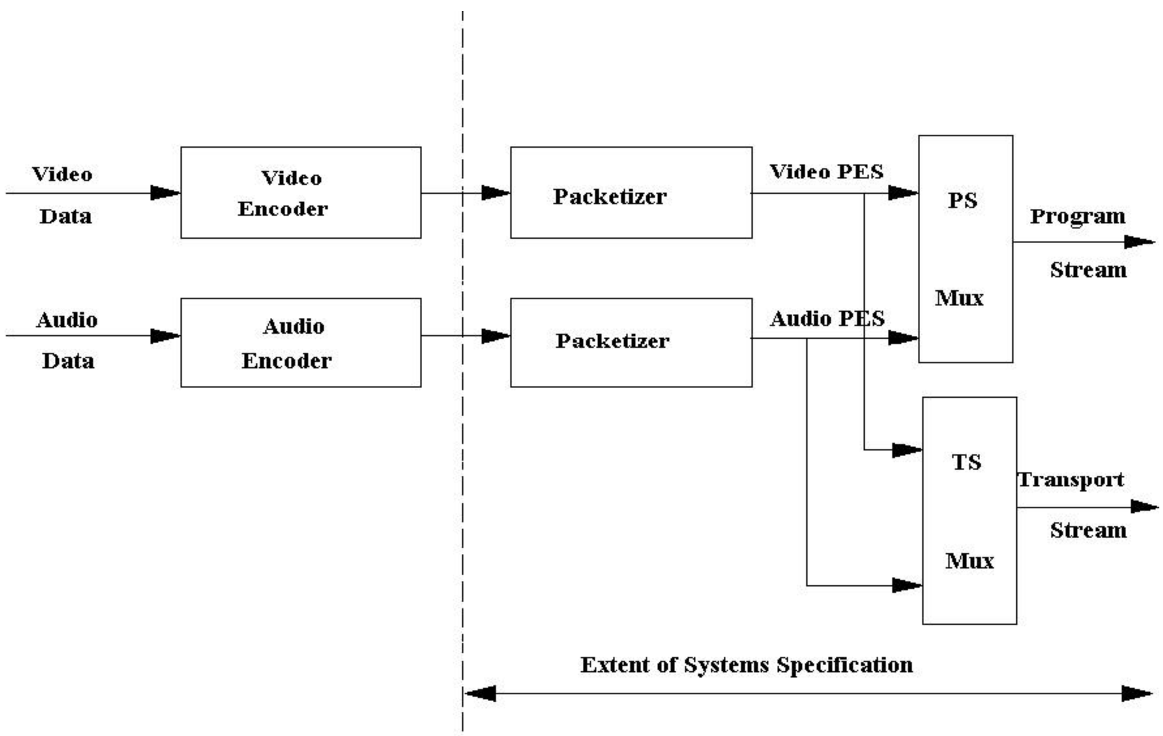


Figure 3.15 MPEG scheme

3.8 Encryption:

It is the most effective way to achieve data security. To read an **encrypted** file, you must have access to a secret key or password that enables you to decrypt it. Unencrypted data is called **plain text** ; **encrypted** data is referred to as **cipher text.**

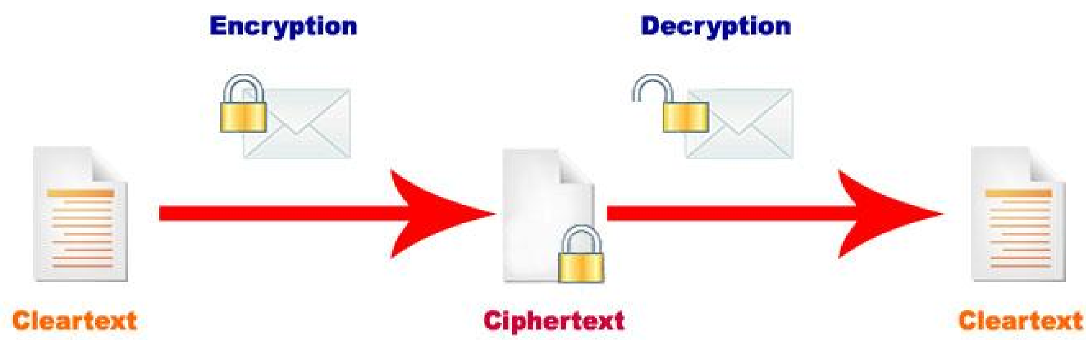


Figure 3.16 Encryption methods

9.1.1 Symmetric key encryption:

In symmetric-key schemes, the encryption and decryption keys are the same. Thus communicating parties must have the same key before they can achieve secret communication.

In public-key encryption schemes, the encryption key is published for anyone to use and encrypt messages. However, only the receiving party has access to the decryption key that enables messages to be read.

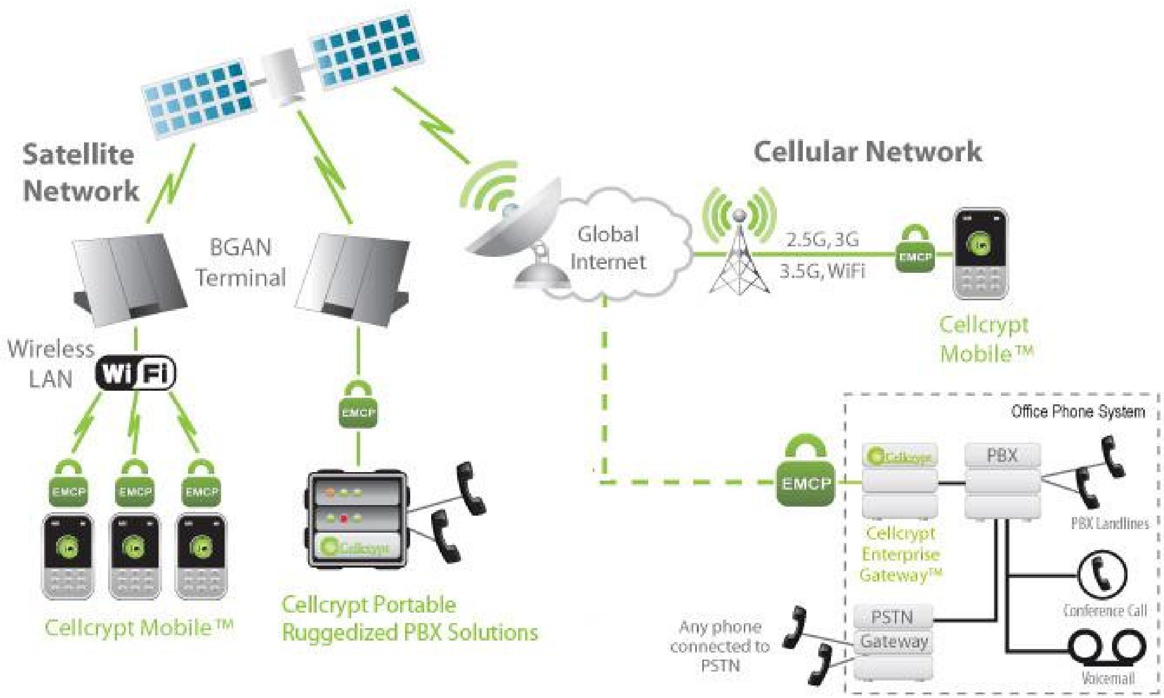


Figure 3.16 General block diagram Encryption methods

Decryption:

It is the process of taking encoded or encrypted text or other data and converting it back into text that you or the computer are able to read and understand.

This term could be used to describe a method of un-encrypting the data manually or with un-encrypting the data using the proper codes or keys.

Data may be encrypted to make it difficult for someone to steal the information. Some companies also encrypt data for general protection of company data and trade secrets. If this data needs to be viewable, it may require decryption.

UNIT IV EARTH SEGMENT

4.1 Earth Station Technology:

The earth segment of a satellite communications system consists of the transmit and receive earth stations. The simplest of these are the home *TV receive-only* (TVRO) systems, and the most complex are the terminal stations used for international communications networks. Also included in the earth segment are those stations which are on ships at sea, and commercial and military land and aeronautical mobile stations.

As mentioned in earth stations that are used for logistic sup- port of satellites, such as providing the *telemetry, tracking, and command* (TT&C) functions, are considered as part of the space segment.

4.1.1 Terrestrial Interface:

Earth station is a vital element in any satellite communication network. The function of an earth station is to receive information from or transmit information to, the satellite network in the most cost-effective and reliable manner while retaining the desired signal quality. The design of earth station configuration depends upon many factors and its location. But it is fundamentally governed by its

Location which are listed below,

- In land
- On a ship at sea
- Onboard aircraft

The factors are

- Type of services
- Frequency bands used
- Function of the transmitter
- Function of the receiver
- Antenna characteristics

4.1.2 Transmitter and Receiver

Any earth station consists of four major subsystems

- Transmitter
- Receiver
- Antenna • Tracking equipment

Two other important subsystems are

- Terrestrial interface equipment
- Power supply

The earth station depends on the following parameters

- Transmitter power
- Choice of frequency
- Gain of antenna
- Antenna efficiency
- Antenna pointing accuracy
- Noise temperature

The functional elements of a basic digital earth station are shown in the below figure

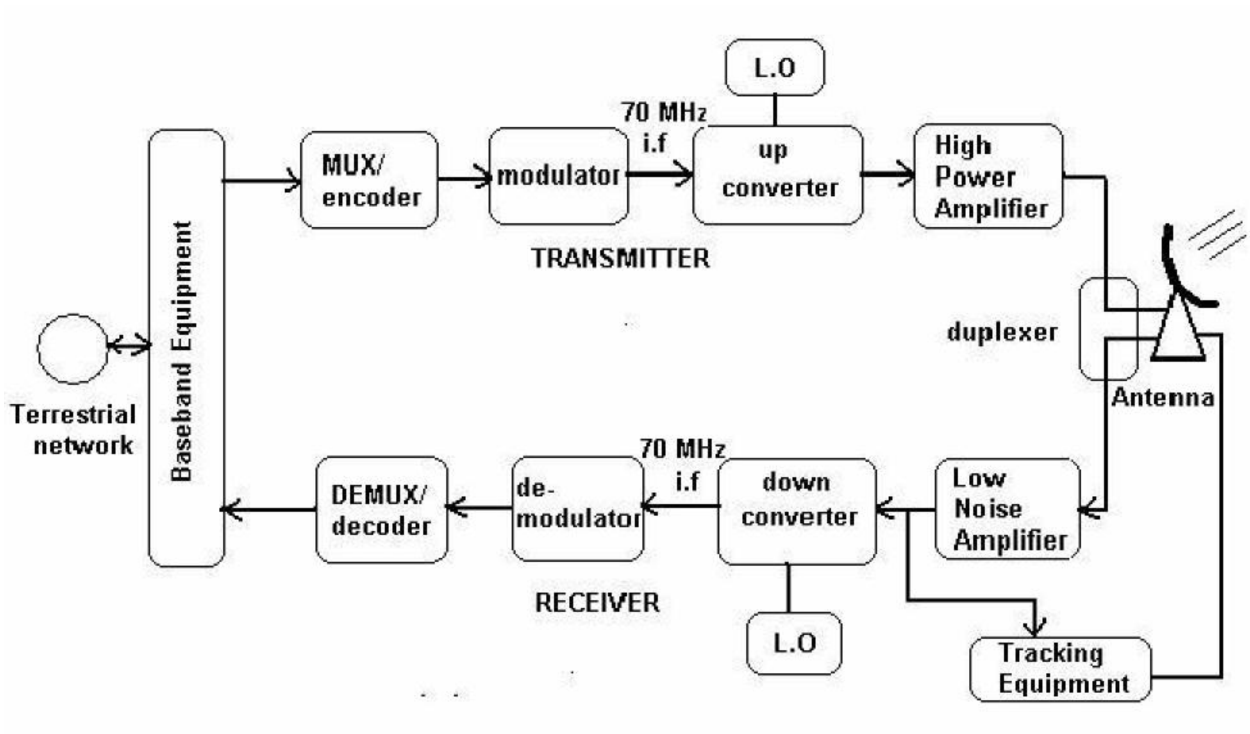


Figure 4.1 Transmitter- Receiver

Digital information in the form of binary digits from terrestrial networks enters earth station and is then processed (filtered, multiplexed, formatted etc.) by the base band equipment.

- The encoder performs error correction coding to reduce the error rate, by introducing extra digits into digital stream generated by the base band equipment. The extra digits carry information.

• In satellite communication, I.F carrier frequency is chosen at 70 MHz for communication using a 36 MHz transponder bandwidth and at 140 MHz for a transponder bandwidth of 54 or 72 MHz.

• On the receive side, the earth station antenna receives the low-level modulated R.F carrier in the downlink frequency spectrum.

• The low noise amplifier (LNA) is used to amplify the weak received signals and improve the signal to Noise ratio (SNR). The error rate requirements can be met more easily.

• R.F is to be reconverted to I.F at 70 or 140 MHz because it is easier design a demodulation to work at these frequencies than 4 or 12 GHz.

• The demodulator estimate which of the possible symbols was transmitted based on observation of the received if carrier.

• The decoder performs a function opposite that of the encoder. Because the sequence of symbols recovered by the demodulator may contain errors, the decoder must use the uniqueness of the redundant digits introduced by the encoder to correct the errors and recover information-bearing digits.

• The information stream is fed to the base-band equipment for processing for delivery to the terrestrial network.

• The tracking equipments track the satellite and align the beam towards it to facilitate communication.

4.1.3. Earth Station Tracking System:

Tracking is essential when the satellite drift, as seen by an earth station antenna is a significant fraction of an earth station's antenna beam width.

An earth station's tracking system is required to perform some of the functions such as

i)Satellite acquisition
ii)Automatic tracking
iii)Manual tracking
iv)Program tracking.

4.2 Antenna Systems :

The antenna system consist of

- ✓ Feed System
- ✓ Antenna Reflector
- ✓ Mount
- ✓ Antenna tracking System

4.2.1 FEED SYSTEM

The feed along with the reflector is the radiating/receiving element of electromagnetic waves. The reciprocity property of the feed element makes the earth station antenna system suitable for transmission and reception of electromagnetic waves.

The way the waves coming in and going out is called feed configuration Earth Station feed systems most commonly used in satellite communication are:

i)Axi-Symmetric Configuration

ii)Asymmetric Configuration

i)Axi-Symmetric Configuration

In an axi-symmetric configuration the antenna axes are symmetrical with respect to the reflector ,which results in a relatively simple mechanical structure and antenna mount.

- **Primary Feed :**

In primary, feed is located at the focal point of the parabolic reflector. Many dishes use only a single bounce, with incoming waves reflecting off the dish surface to the focus in front of the dish, where the antenna is located. when the dish is used to transmit ,the transmitting antenna at the focus beams waves toward the dish, bouncing them off to space. This is the simplest arrangement.

- **Cassegrain :**

Many dishes have the waves make more than one bounce .This is generally called as folded systems. The advantage is that the whole dish and feed system is more compact. There are several folded configurations, but all have at least one secondary reflector also called a sub reflector, located out in front of the dish to redirect the waves.

A common dual reflector antenna called Cassegrain has a convex sub reflector positioned in front of the main dish, closer to the dish than the focus. This sub reflector bounces back the waves back toward a feed located on the main dish's center, sometimes behind a hole at the center of the main dish. Sometimes there are even more sub reflectors behind the dish to direct the waves to the fed for convenience or compactness.

- **Gregorian**

This system has a concave secondary reflector located just beyond the primary focus. This also bounces the waves back toward the dish.

ii)Asymmetric Configuration

- **Offset or Off-axis feed**

The performance of tan axi-symmetric configuration is affected by the blockage of the aperture by the feed and the sub reflector assembly. The result is a reduction in the antenna efficiency and an increase in the side lobe levels. The asymmetric configuration can remove this limitation..This is achieved by off-setting the mounting arrangement of the feed so that it does not obstruct the main beam.As a result ,the efficiency and side lobe level performance are improved.

4.2.2 ANTENNA REFLECTOR :

Mostly parabolic reflectors are used as the main antenna for the earth stations because of the high gain available from the reflector and the ability of focusing a parallel beam into a point at the focus where the feed,i.e., the receiving/radiating element is located .For large antenna system more than one reflector surfaces may be used in as in the cassegrain antenna system.

Earth stations are also classified on the basis of services for example:

1.Two way TV ,Telephony and data

2. Two way TV

3.TV receive only and two way telephony and data

4.Two way data

From the classifications it is obvious that the technology of earth station will vary considerably on the performance and the service requirements of earth station

For mechanical design of parabolic reflector the following parameters are required to be considered:

- ✓ Size of the reflector
- ✓ Focal Length /diameter ratio
- ✓ RMS error of main and sub reflector
- ✓ Pointing and tracking accuracies
- ✓ Speed and acceleration
- ✓ Type of mount
- ✓ Coverage Requirement

- **Wind Speeed**

The size of the reflector depends on transmit and receive gain requirement and beamwidth of the antenna.Gain is directly proportional to the antenna diameter whereas the beamwidth is inversely proportional to the antenna diameter .for high inclination angle of the satellite ,the tracking of the earth station becomes necessary when the beamwidth is too narrow.

The gain of the antenna is given by

$$\text{Gain} = (\eta 4\Pi A_{eff})/ \lambda^2$$

Where Aeff is the aperture

Λ is wave length

H is efficiency of antenna system

For a parabolic antenna with circular aperture diameter D, the gain of the antenna is :

$$\text{Gain} = (\eta 4\Pi/ \lambda^2)(\Pi D^2/4)$$

$$= \eta (\Pi D/ \lambda)^2$$

The overall efficiency of the antenna is the net product of various factors such as

1. Cross Polarization
2. Spill over
3. Diffraction
4. Blockage
5. Surface accuracy
6. Phase error
7. Illumination

In the design of feed ,the ratio of focal length F to the diameter of the reflector D of the antenna system control the maximum angle subtended by the reflector surface on the focal point. Larger the F/D ratio larger is the aperture illumination efficiency and lower the cross polarization.

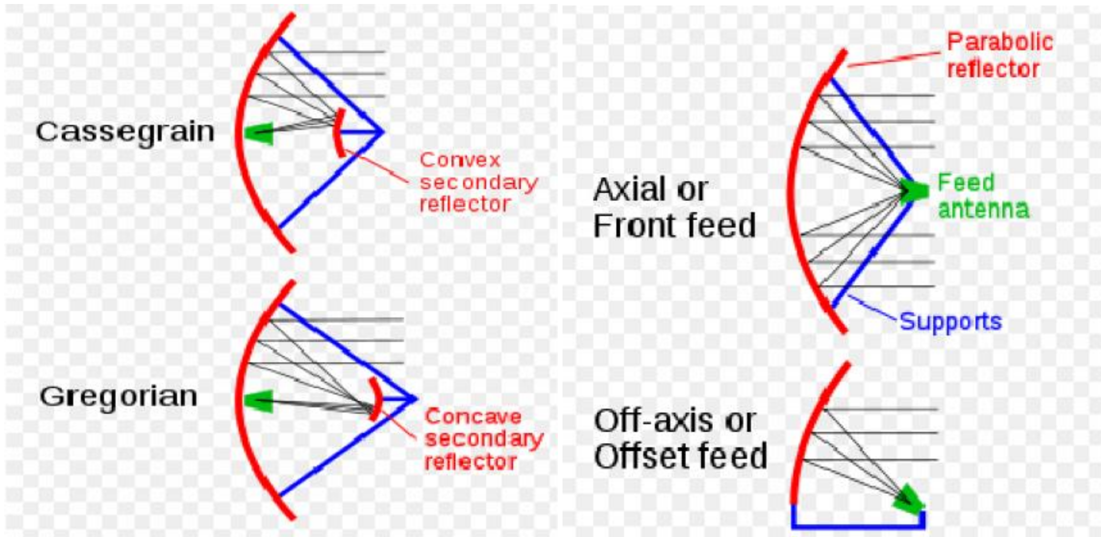


Figure 4.2 Antenna sub systems

4.2.3 ANTENNA MOUNT:

Type of antenna mount is determined mainly by the coverage requirement and tracking requirements of the antenna systems. Different types of mounts used for earth station antenna are:

i) The Azimuth –elevation mount :

This mount consists of a primary vertical axis. Rotation around this axis controls the azimuth angle. The horizontal axis is mounted over the primary axis, providing the elevation angle control.

ii) **The X-Y mount**.

It consists of a horizontal primary axis (X-axis) and a secondary axis (Y-axis) and at right angles to it. Movement around these axes provides necessary steering.

4.2.4 ANTENNA TRACKING SYSTEM :

Tracking is essential when the satellite drift, as seen by an earth station antenna is a significant fraction of an earth station's antenna beam width.

An earth station's tracking system is required to perform some of the functions such as

i)Satellite acquisition
ii)Automatic tracking
iii)Manual tracking
iv)Program tracking.

RecentTrackingTechniques:

There have been some interesting recent developments in auto-track techniques which can potentially provide high accuracies at a low cost.

In one proposed technique the sequential lobing technique has been I implemented by using rapid electronic switching of a s single beam which effectively approximates simultaneous lobbing.

4.3 Receive-Only Home TV Systems:

Planned broadcasting directly to home TV receivers takes place in the Ku (12-GHz) band. This service is known as *direct broadcast satellite* (DBS) service.

There is some variation in the frequency bands assigned to different geographic regions. In the Americas, for example, the down- link band is 12.2 to 12.7 GHz.

The comparatively large satellite receiving dishes [ranging in diame- ter from about 1.83 m (6 ft) to about 3-m (10 ft) in some locations], which may be seen in some "backyards" are used to receive downlink TV signals at C band (4 GHz).

Originally such downlink signals were never intended for home reception but for network relay to commercial TV outlets (VHF and UHF TV broadcast stations and cable TV "head-end" studios).

4.3.1 The Indoor unit:

Equipment is now marketed for home reception of C-band signals, and some manufacturers provide dual C-band/Ku-band equipment. A single mesh type reflector may be used which focuses the signals into a dual feed- horn, which has two separate outputs, one for the C-band signals and onefor the Ku-band signals.

Much of television programming originates as *first generation signals*, also known as *master broadcast quality signals*.

These are transmitted via satellite in the C band to the network head- end stations, where they are retransmitted as compressed digital signals to cable and direct broadcast satellite providers.

- Another of the advantages, claimed for home C-band systems, is the larger number of satellites available for reception compared to what is available for direct broadcast satellite sys- terms.
- Although many of the C-band transmissions are scrambled, there are free channels that can be received, and what are termed “wild feeds.”
- These are also free, but unannounced programs, of which details can be found in advance from various publications and Internet sources.
- C-band users can also subscribe to pay TV channels, and another advantage claimed is that subscription services are cheaper than DBS or cable because of the multiple-source programming available.
- The most widely advertised receiving system for C-band system appears to be 4DTV manufactured by Motorola.

This enables reception of:

- ✓ Free, analog signals and “wild feeds”
- ✓ VideoCipher ll plus subscription services
- ✓ Free DigiCipher 2 services
- ✓ Subscription DigiCipher 2 services

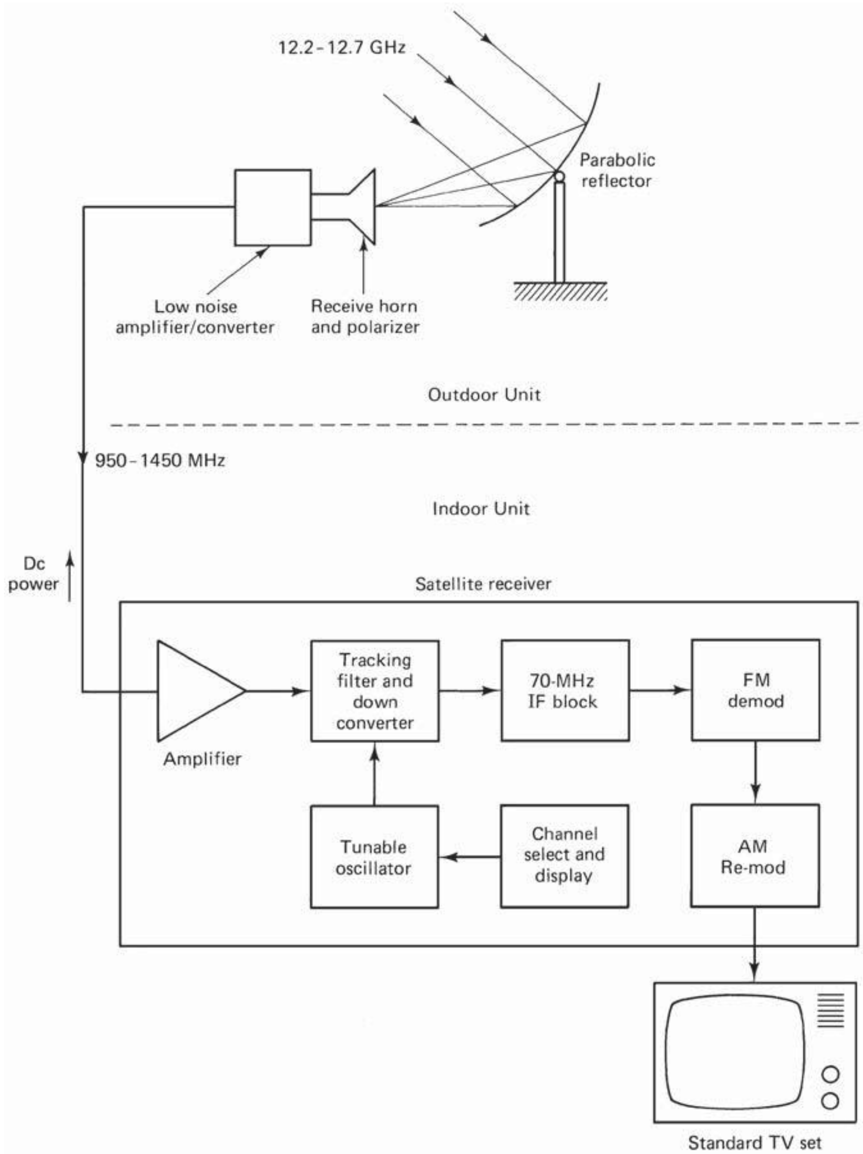


Figure 4.3 TVRO System block diagrams

4.3.2 The outdoor unit:

This consists of a receiving antenna feeding directly into a low-noise amplifier/converter combination. A parabolic reflector is generally used, with the receiving horn mounted at the focus. A common design is to have the focus directly in front of the reflector, but for better interference rejection, an offset feed may be used as shown.

Comparing the gain of a 3-m dish at 4 GHz with a 1-m dish at 12 GHz, the ratio ***D/λ*** equals 40 in each case, so the gains will be about equal. Although the free-space losses are much higher at 12 GHz compared with 4 GHz.

The downlink frequency band of 12.2 to 12.7 GHz spans a range of 500 MHz, which accommodates 32 TV/FM channels, each of which is 24-MHz wide. Obviously, some overlap occurs between channels, but these are alternately polarized *left-hand circular* (LHC) and *right-hand circular* (RHC) or vertical/horizontal, to reduce interference to accept- able levels. This is referred to as *polarization interleaving*. A polarizer that may be switched to the desired polarization from the indoor con- trol unit is required at the receiving horn.

The receiving horn feeds into a *low-noise converter* (LNC) or possibly a combination unit consisting of a *low-noise amplifier* (LNA) followed by a converter.

The combination is referred to as an LNB, for *low-noise block*. The LNB provides gain for the broadband 12-GHz signal and then converts the signal to a lower frequency range so that a low-cost coaxial cable can be used as feeder to the indoor unit.

The signal fed to the indoor unit is normally a wideband signal cov- ering the range 950 to 1450 MHz. This is amplified and passed to a tracking filter which selects the desired channel, as shown in Fig.

As previously mentioned, polarization interleaving is used, and only half the 32 channels will be present at the input of the indoor unit for any one setting of the antenna polarizer. This eases the job of the tracking filter, since alternate channels are well separated in frequency.

The selected channel is again down converted, this time from the 950- to 1450-MHz range to a fixed intermediate frequency, usually 70 MHz although other values in the *very high frequency* (VHF) range are also used.

The 70-MHz amplifier amplifies the signal up to the levels required for demodulation. A major difference between DBS TV and conventional TV is that with DBS, frequency modulation is used, whereas with conventional TV, amplitude modulation in the form of *vestigial single side- band* (VSSB) is used.

The 70-MHz, FM *intermediate frequency* (IF) carrier therefore must be demodulated, and the baseband information used to generate a VSSB signal which is fed into one of the VHF/UHF channels of a standard TV set.

4.4 Master Antenna TV System:

A *master antenna TV* (MATV) system is used to provide reception of DBS TV/FM channels to a small group of users, for example, to the tenants in an apartment building. It consists of a single outdoor unit (antenna and LNA/C) feeding a number of indoor units, as shown in Fig.

It is basically similar to the home system already described, but with each user having access to all the channels independently of the other users. The advantage is that only one outdoor unit is required, but as shown, separate LNA/Cs and feeder cables are required for each sense of polarization.

Compared with the single- user system, a larger antenna is also required (2- to 3-m diameter) in order to maintain a good signal-to-noise ratio at all the indoor units.

Where more than a few subscribers are involved, the distribution system used is similar to the *community antenna* (CATV) system described in the following section.

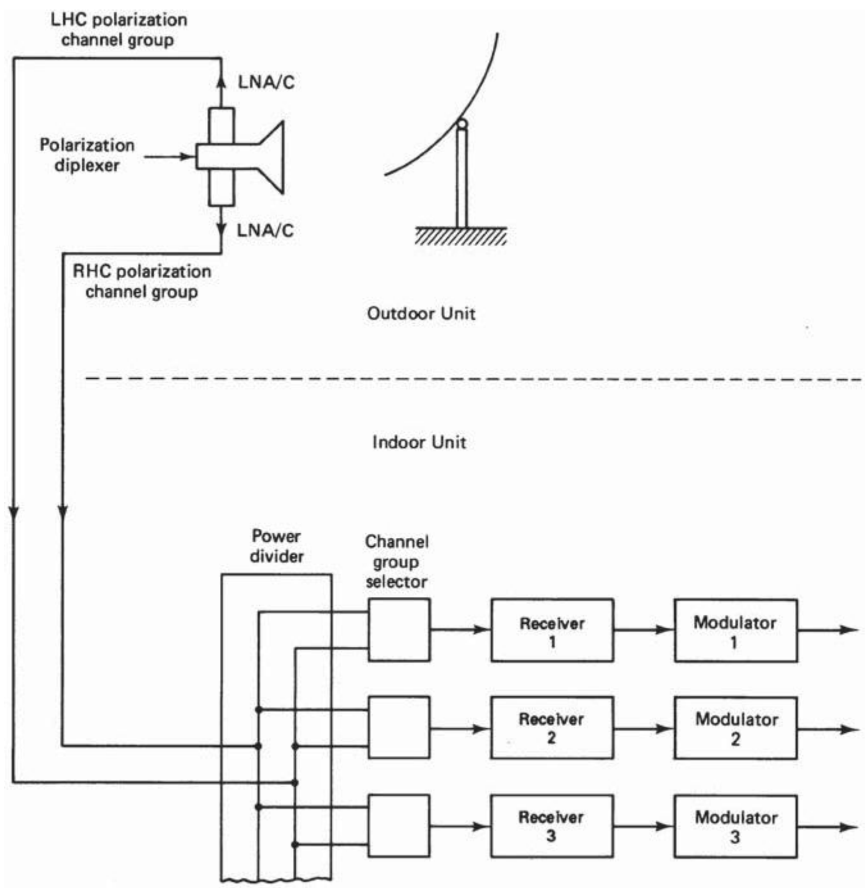


Figure 4.4 CATV System block diagrams

4.5 Community Antenna TV System:

The CATV system employs a single outdoor unit, with separate feeds available for each sense of polarization, like the MATV system, so that all channels are made available simultaneously at the indoor receiver.

Instead of having a separate receiver for each user, all the carriers are demodulated in a common receiver-filter system, as shown in Fig. The channels are then combined into a standard multiplexed signal for transmission over cable to the subscribers.

In remote areas where a cable distribution system may not be installed, the signal can be rebroadcast from a low-power VHF TV transmitter.

Figure shows a remote TV station which employs an 8-m (26.2-ft) antenna for reception of the satellite TV signal in the C band.

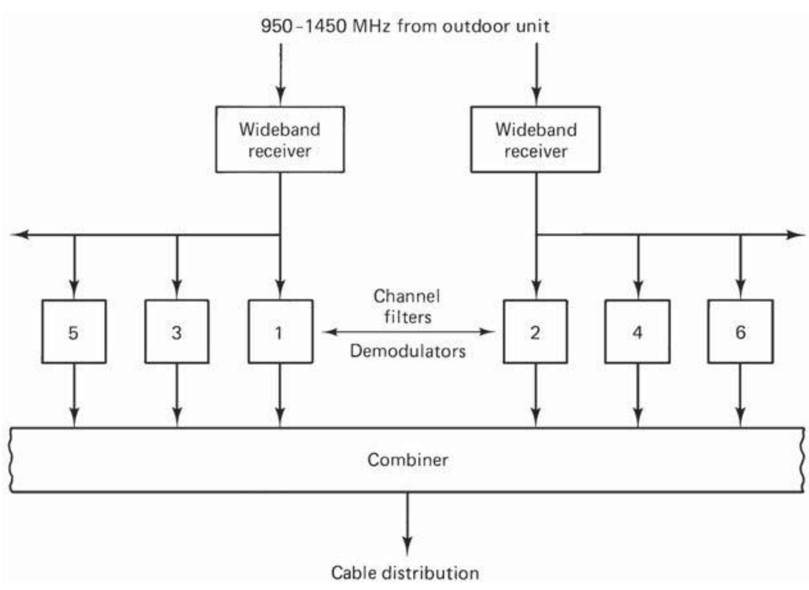


Figure 4.5 One possible arrangement for the indoor unit of a community antenna TV (CATV) system.

With the CATV system, local programming material also may be distributed to subscribers, an option which is not permitted in the MATV system.

4.6 Test Equipment Measurements on G/T, C/No, EIRP:

Measurement of G/T of small antennas is easily and simply measured using the spectrum analyser method. For antennas with a diameter of less than 4.5 meters it is not normally necessary to point off from the satellite.

A step in frequency would be required into one of the satellite transponder guard bands.

However antennas with a G/T sufficiently large to enable the station to see the transponder noise floor either a step in frequency into one of the satellite transponder guard bands and/or in azimuth movement would be required.

The test signal can be provided from an SES WORLD SKIES beacon.

Procedure :

(a) Set up the test equipment as shown below. Allow half an hour to warm up,
and then calibrate in accordance with the manufacturer's procedures.

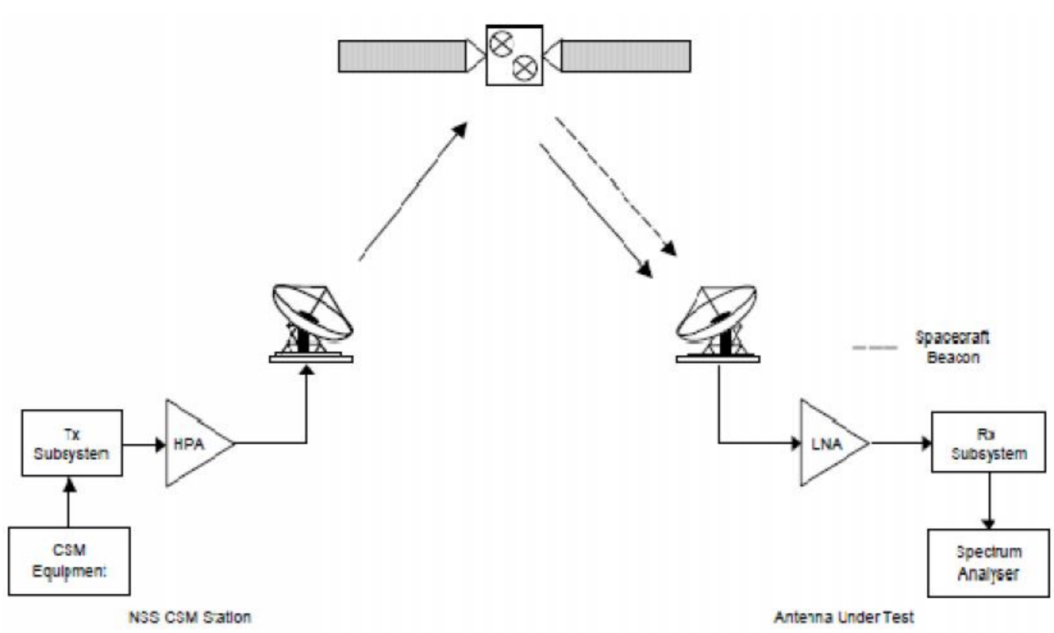


Figure 4.6 One possible arrangement for Measurement of G/T

(b) Adjust the centre frequency of your spectrum analyzer to receive the SES WORLD SKIES beacon (data to be provided on the satellite used for testing)

(c) Carefully peak the antenna pointing and adjust the polarizer by nulling the
cross polarized signal. You cannot adjust polarization when using the circularly polarized SES WORLD SKIES beacon.

(d) Configure the spectrum analyser as follows:

Centre Frequency: Adjust for beacon or test signal frequency (to be advised).
Use marker to peak and marker to centre functions.

- ✓ Frequency Span: 100 KHz
- ✓ Resolution Bandwidth: 1 KHz
- ✓ Video Bandwidth: 10 Hz (or sufficiently small to limit noise variance)
- ✓ Scale: 5 dB/div
- ✓ Sweep Time: Automatic
- ✓ Attenuator Adjust to ensure linear operation. Adjust to provide the "Noise floor delta" described in steps 7 and 8.

(e) To insure the best measurement accuracy during the following steps, adjust the spectrum analyser amplitude (reference level) so that the measured signal, carrier or noise, is approximately one division below the top line of the spectrum analyser display.

(f) Record the frequency and frequency offset of the test signal from the nominal frequency:
For example, assume the nominal test frequency is 11750 MHz but the spectrum analyser shows the peak at 11749 MHz. The frequency offset in this case is -1 MHz.

(g) Change the spectrum analyser centre frequency as specified by SES WORLD SKIES so that the measurement is performed in a transponder guard band so that only system noise power of the earth station and no satellite signals are received. Set the spectrum analyser frequency as follows:
Centre Frequency = Noise slot frequency provided by the PMOC

(h) Disconnect the input cable to the spectrum analyser and confirm that the noise floor drops by at least 15 dB but no more than 25dB. This confirms that the spectrum analyser's noise contribution has an insignificant effect on the measurement. An input attenuation value allowing a "Noise floor Delta" in excess of 25 dB may cause overloading of the spectrum analyser input. (i) Reconnect the input cable to the spectrum analyser.

(j) Activate the display line on the spectrum analyser.

(k) Carefully adjust the display line to the noise level shown on the spectrum analyser. Record the display line level.

(l) Adjust the spectrum analyser centre frequency to the test carrier frequency
recorded in step (e).

(m) Carefully adjust the display line to the peak level of the test carrier on the
spectrum analyser. Record the display line level.

(n) Determine the difference in reference levels between steps (l) and (j) which is the (C+N)/N.

(o) Change the (C+N)/N to C/N by the following conversion:

This step is not necessary if the (C+N)/N ratio is more than 20 dB because the resulting correction is less than 0.1 dB.

$$\left(\frac{C}{N}\right) = 10\log_{10}\left(10^{\frac{\left(\frac{C+N}{N}\right)}{10}} - 1\right) \quad \text{dB}$$

(p) Calculate the carrier to noise power density ratio (C/No) using:

$$\left(\frac{C}{No}\right) = \left(\frac{C}{N}\right) - 2.5 + 10\log_{10}(RBW \quad x \quad SA_{corr}) \quad \text{dB}$$

The 2.5 dB figure corrects the noise power value measured by the log converters in the spectrum analyser to a true RMS power level, and the SA_{corr}

factor takes into account the actual resolution filter bandwidth.

(q) Calculate the G/T using the following:

$$\left(\frac{G}{T}\right) - \left(\frac{C}{No}\right) - (EIRP_{SC} - A_{corr}) + (FSL + L_a) - 228.6 \quad dB/K$$

where,

$EIRP_{SC}$ – Downlink EIRP measured by the PMOC (dBW)

A_{corr} – Aspect correction supplied by the PMOC (dB)

FSL – Free Space Loss to the AUT supplied by the PMOC (dB)

L_a – Atmospheric attenuation supplied by the PMOC (dB)

(r) Repeat the measurement several times to check consistency of the result.

4.7 Antenna Gain:

Antenna gain is usually **defined** as the ratio of the power produced by the **antenna** from a far-field source on the **antenna's** beam axis to the power produced by a hypothetical lossless isotropic **antenna**, which is equally sensitive to signals from all directions.

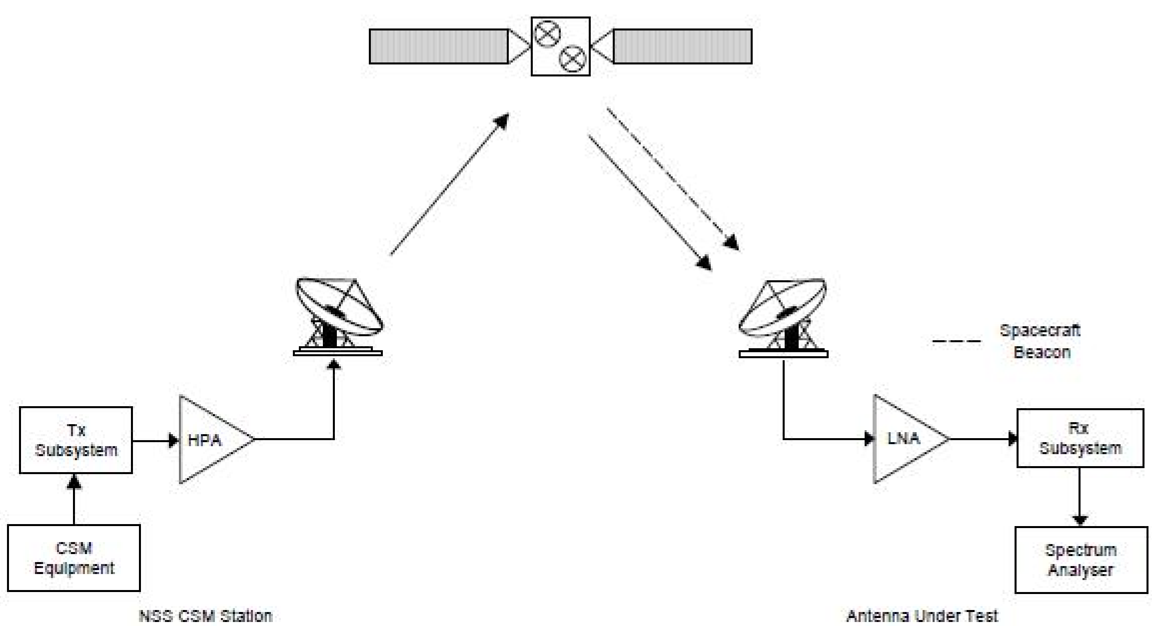


Figure 4.6 One possible arrangement for Measurement of Antenna Gain

Two direct methods of measuring the Rx gain can be used; integration of the Rx sidelobe pattern or by determination of the 3dB and 10dB beamwidths.

The use of pattern integration will produce the more accurate results but would require the AUT to have a tracking system. In both cases the test configurations for measuring Rx gain are identical, and are illustrated in Figure.

In order to measure the Rx gain using pattern integration the AUT measures the elevation and azimuth narrowband (±5° corrected) sidelobe patterns.

The AUT then calculates the directive gain of the antenna through integration of the sidelobe patterns. The Rx gain is then determined by reducing the directive gain by the antenna inefficiencies.

In order to measure the Rx gain using the beamwidth method, the AUT measures the corrected azimuth and elevation 3dB/10dB beamwidths. From these results the Rx gain of the antenna can be directly calculated using the formula below.

$$G = 10\mathrm{Log}_{10}\left[\frac{1}{2}\left(\frac{31000}{(Az_3)(El_3)} + \frac{91000}{(Az_{10})(El_{10})}\right)\right] - F_{Loss} - R_{Loss}$$

where:

G is the effective antenna gain (dBi)

Az_3 is the corrected azimuth 3dB beamwidth (°)

El_3 is the elevation 3dB beamwidth (°)

Az_{10} is the corrected azimuth 10dB beamwidth (°)

El_{10} is the elevation 10dB beamwidth (°)

F_{Loss} is the insertion loss of the feed (dB)

R_{Loss} is the reduction in antenna gain due to reflector inaccuracies, and is given by:

$$R_{Loss} = 4.922998677(S_{dev}\, f)^2 \text{ dB}$$

where: S_{dev} is the standard deviation of the actual reflector surface (inches)
f is the frequency (GHz)

UNIT V SATELLITE APPLICATIONS

5.1 INTELSAT Series:

INTELSAT stands for *International Telecommunications Satellite*. The organization was created in 1964 and currently has over 140 member countries and more than 40 investing entities (see http://www.intelsat.com/ for more details).

In July 2001 INTELSAT became a private company and in May 2002 the company began providing end-to-end solutions through a network of teleports, leased fiber, and *points of presence* (PoPs) around the globe.

Starting with the Early Bird satellite in 1965, a succes- sion of satellites has been launched at intervals of a few years. Figure 1.1 illustrates the evolution of some of the INTELSAT satellites. As the figure shows, the capacity, in terms of number of voice channels, increased dramatically with each succeeding launch, as well as the design lifetime.

These satellites are in *geostationary orbit,* meaning that they appear to be stationary in relation to the earth. At this point it may be noted that geosta- tionary satellites orbit in the earth's equatorial plane and their position is specified by their longitude.

For international traffic, INTELSAT covers three main regions—the *Atlantic Ocean Region* (AOR), the *Indian Ocean Region* (IOR), and the *Pacific Ocean Region* (POR) and what is termed *Intelsat America's Region*.

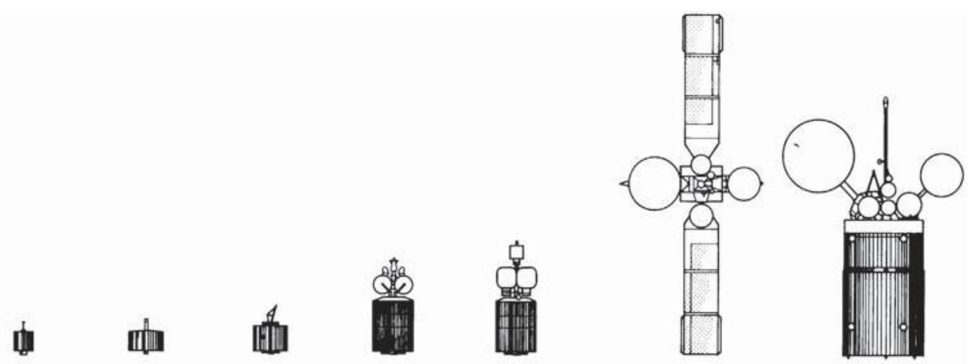
For the ocean regions the satellites are positioned in geostationary orbit above the particular ocean, where they provide a transoceanic telecommunications route. For example, INTELSAT satellite 905 is positioned at 335.5° east longitude.

The INTELSAT VII-VII/A series was launched over a period from October 1993 to June 1996. The construction is similar to that for the V and VA/VB series, shown in Fig. in that the VII series has solar sails rather than a cylindrical body.

The VII series was planned for service in the POR and also for some of the less demanding services in the AOR. The antenna beam coverage is appropriate for that of the POR. Figure 1.3 shows the antenna beam footprints for the C-band hemispheric cover- age and zone coverage, as well as the spot beam coverage possible with the Ku-band antennas (Lilly, 1990; Sachdev et al., 1990). When used in the AOR, the VII series satellite is inverted north for south (Lilly, 1990), minor adjustments then being needed only to optimize the antenna pat- terns for this region. The lifetime of these satellites ranges from 10 to 15 years depending on the launch vehicle.

Recent figures from the INTELSAT Web site give the capacity for the INTELSAT VII as 18,000 two-way telephone circuits and three TV channels; up to 90,000 two-way telephone circuits can be achieved with the use of “digital circuit mul- tiplication.”

The INTELSAT VII/A has a capacity of 22,500 two-way telephone circuits and three TV channels; up to 112,500 two-way tele- phone circuits can be achieved with the use of digital circuit multipli- cation. As of May 1999, four satellites were in service over the AOR, one in the IOR, and two in the POR.



Designation: Intelsat	I	II	III	IV	IV A	V	V A/V B	VI
Year of first launch	1965	1966	1968	1971	1975	1980	1984/85	1986/87
Prime contractor	Hughes	Hughes	TRW	Hughes	Hughes	Ford Aerospace	Ford Aerospace	Hughes
Width (m)	0.7	1.4	1.4	2.4	2.4	2.0	2.0	3.6
Height (m)	0.6	0.7	1.0	5.3	6.8	6.4	6.4	6.4
Launch vehicles		Thor Delta		Atlas-Centaur		Atlas-Centaur and Ariane	Atlas-Centaur and Ariane	STS and Ariane
Spacecraft mass in transfer orbit (kg)	68	182	293	1385	1489	1946	2140	12,100/3720
Communications payload mass (kg)	13	36	56	185	190	235	280	800
End-of-life (EOL) power of equinox (W)	40	75	134	480	800	1270	1270	2200
Design lifetime (years)	1.5	3	5	7	7	7	7	10
Capacity (number of voice channels)	480	480	2400	8000	12,000	25,000	30,000	80,000
Bandwidth (MHz)	50	130	300	500	800	2137	2480	3520

Figure 5.1 INTELSAT Series

The INTELSAT VIII-VII/A series of satellites was launched over the period February 1997 to June 1998. Satellites in this series have similar capacity as the VII/A series, and the lifetime is 14 to 17 years.

It is standard practice to have a spare satellite in orbit on high-reliability routes (which can carry preemptible traffic) and to have a ground spare in case of launch failure.

Thus the cost for large international schemes can be high; for example, series IX, described later, represents a total investment of approximately $1 billion.

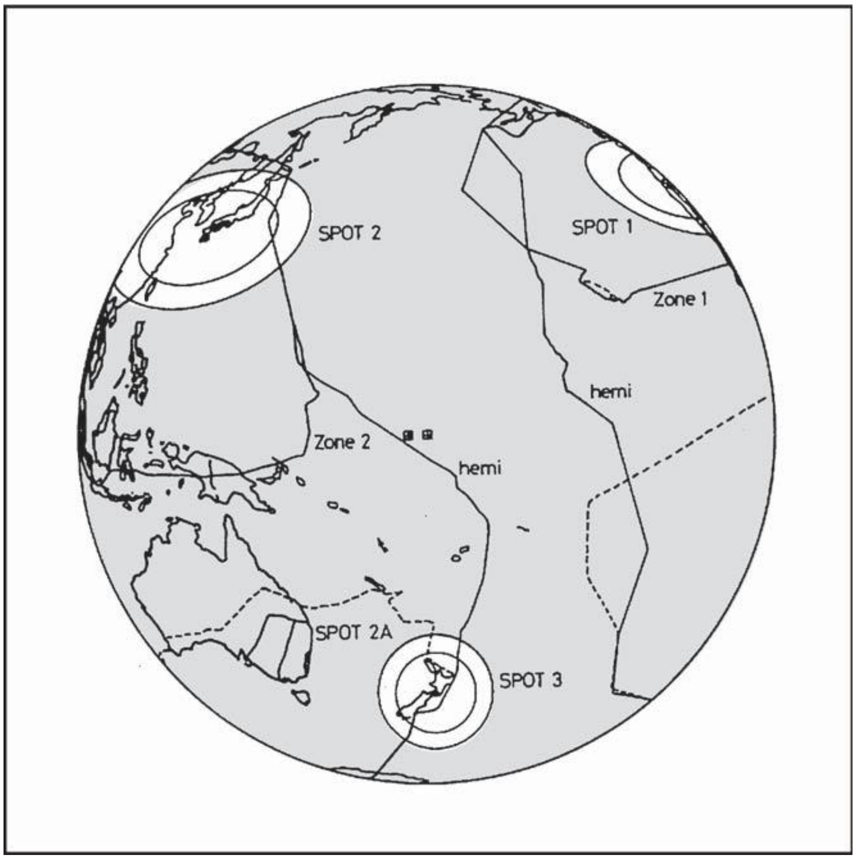


Figure 5.2 Region of glob

5.2 INSAT:

INSAT or the ***Indian National Satellite System*** is a series of multipurpose geo-stationary satellites launched by ISRO to satisfy the telecommunications, broadcasting, meteorology, and search and rescue operations.

Commissioned in 1983, INSAT is the largest domestic communication system in the Asia Pacific Region. It is a joint venture of the Department of Space, Department of Telecommunications, India Meteorological Department, All India Radio and Doordarshan. The overall coordination and management of INSAT system rests with the Secretary-level INSAT Coordination Committee.

INSAT satellites provide transponders in various bands (C, S, Extended C and K_u) to serve the television and communication needs of India. Some of the satellites also have the Very High Resolution Radiometer (VHRR), CCD cameras for metrological imaging.

The satellites also incorporate transponder(s) for receiving distress alert signals for search and rescue missions in the South Asian and Indian Ocean Region, as ISRO is a member of the Cospas-Sarsat programme.

5.2.1 INSAT System:.

The Indian National Satellite (INSAT) System Was Commissioned With The Launch Of INSAT-1B In August 1983 (INSAT-1A, The First Satellite Was Launched In April 1982 But Could Not Fulfil The Mission).

INSAT System Ushered In A Revolution In India's Television And Radio Broadcasting, Telecommunications And Meteorological Sectors. It Enabled The Rapid Expansion Of TV And Modern Telecommunication Facilities To Even The Remote Areas And Off-Shore Islands.

5.2.2 Satellites In Service:

Of The 24 Satellites Launched In The Course Of The INSAT Program, 10 Are Still In Operation.INSAT-2E

It Is The Last Of The Five Satellites In INSAT-2 Series{Prateek }. It Carries Seventeen C-Band And Lower Extended C-Band Transponders Providing Zonal And Global Coverage With An Effective Isotropic Radiated Power (EIRP) Of 36 Dbw.

It Also Carries A Very High Resolution Radiometer (VHRR) With Imaging Capacity In The Visible (0.55-0.75 µm), Thermal Infrared (10.5-12.5 µm) And Water Vapour (5.7-7.1 µm) Channels And Provides 2x2 Km, 8x8 Km And 8x8 Km Ground Resolution Respectively.

INSAT-3A

The Multipurpose Satellite, INSAT-3A, Was Launched By Ariane In April 2003. It Is Located At 93.5 Degree East Longitude. The Payloads On INSAT-3A Are As Follows:

12 Normal C-Band Transponders (9 Channels Provide Expanded Coverage From Middle East To South East Asia With An EIRP Of 38 Dbw, 3 Channels Provide India Coverage With An EIRP Of 36 Dbw And 6 Extended C-Band Transponders Provide India Coverage With An EIRP Of 36 Dbw).

A CCD Camera Provides 1x1 Km Ground Resolution, In The Visible (0.63-0.69 μm), Near Infrared (0.77-0.86 μm) And Shortwave Infrared (1.55-1.70 μm) Bands.

INSAT-3D

Launched In July 2013, INSAT-3D Is Positioned At 82 Degree East Longitude. INSAT-3D Payloads Include Imager, Sounder, Data Relay Transponder And Search & Rescue Transponder. All The Transponders Provide Coverage Over Large Part Of The Indian Ocean Region Covering India, Bangladesh, Bhutan,Maldives, Nepal, Seychelles, Sri Lanka And Tanzania For Rendering Distress Alert Services

INSAT-3E

Launched In September 2003, INSAT-3E Is Positioned At 55 Degree East Longitude And Carries 24 Normal C-Band Transponders Provide An Edge Of Coverage EIRP Of 37 Dbw Over India And 12 Extended C-Band Transponders Provide An Edge Of Coverage EIRP Of 38 Dbw Over India.

KALPANA-1

KALPANA-1 Is An Exclusive Meteorological Satellite Launched By PSLV In September 2002. It Carries Very High Resolution Radiometer And DRT Payloads To Provide Meteorological Services. It Is Located At 74 Degree East Longitude. Its First Name Was METSAT. It Was Later Renamed As KALPANA-1 To Commemorate Kalpana Chawla.

Edusat

Configured For Audio-Visual Medium Employing Digital Interactive Classroom Lessons And Multimedia Content, EDUSAT Was Launched By GSLV In September 2004. Its Transponders And Their Ground Coverage Are Specially Configured To Cater To The Educational Requirements.

GSAT-2

Launched By The Second Flight Of GSLV In May 2003, GSAT-2 Is Located At 48 Degree East Longitude And Carries Four Normal C-Band Transponders To Provide 36 Dbw EIRP With India Coverage, Two K_u Band Transponders With 42 Dbw EIRP Over India And An MSS Payload Similar To Those On INSAT-3B And INSAT-3C.

INSAT-4 Series:

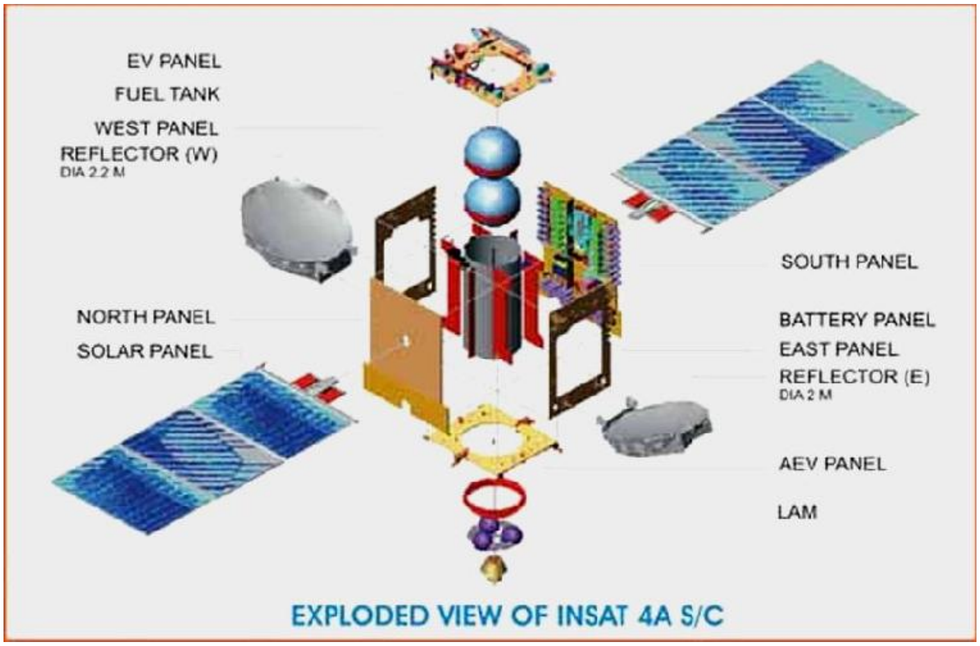


Figure 5.3 INSAT 4A

INSAT-4A is positioned at 83 degree East longitude along with INSAT-2E and INSAT-3B. It carries 12 K_u band 36 MHz bandwidth transponders employing 140 W TWTAs to provide an EIRP of 52 dBW at the edge of coverage polygon with footprint covering Indian main land and 12 C-band 36 MHz bandwidth transponders provide an EIRP of 39 dBW at the edge of coverage with expanded radiation patterns encompassing Indian geographical boundary, area beyond India in southeast and northwest regions.[8] Tata Sky, a joint venture between the TATA Group and STAR uses INSAT-4A for distributing their DTH service.

- INSAT-4A
- INSAT-4B
- Glitch In INSAT 4B
- China-Stuxnet Connection
- INSAT-4CR
- GSAT-8 / INSAT-4G
- GSAT-12 /GSAT-10

5.3 VSAT:

VSAT stands for *very small aperture terminal* system. This is the distinguishing feature of a VSAT system, the earth-station antennas being typically less than 2.4 m in diameter (Rana et al., 1990). The trend is toward even smaller dishes, not more than 1.5 m in diameter (Hughes et al., 1993).

In this sense, the small TVRO terminals for direct broadcast satellites could be labeled as VSATs, but the appellation is usually reserved for private networks, mostly providing two-way communications facilities.

Typical user groups include bank- ing and financial institutions, airline and hotel booking agencies, and large retail stores with geographically dispersed outlets.

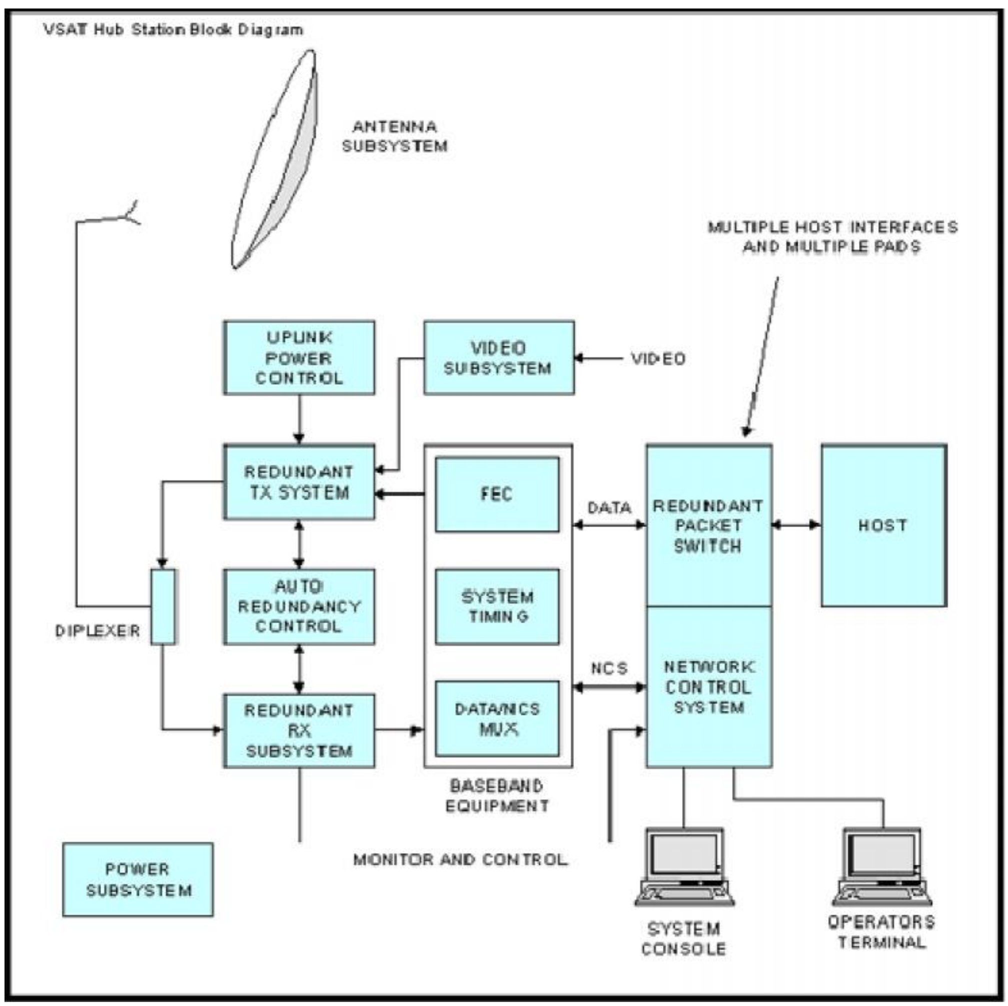


Figure 5.4 VSAT Block Diagrams

5.3.1 VSAT network :

The basic structure of a VSAT network consists of a hub station which provides a broadcast facility to all the VSATs in the network and the VSATs themselves which access the satellite in some form of multiple- access mode.

The hub station is operated by the service provider, and it may be shared among a number of users, but of course, each user organ- ization has exclusive access to its own VSAT network.

Time division mul- tiplex is the normal downlink mode of transmission from hub to the VSATs, and the transmission can be broadcast for reception by all the VSATs in a network, or address coding can be used to direct messages to selected VSATs.

A form of *demand assigned multiple access* (DAMA) is employed in some systems in which channel capacity is assigned in response to the fluctuating demands of the VSATs in the network.

Most VSAT systems operate in the Ku band, although there are some C-band systems in existence (Rana et al., 1990).

5.3.2 Applications:

- ✓ Supermarket shops (tills, ATM machines, stock sale updates and stock ordering).
- ✓ Chemist shops - Shoppers Drug Mart - Pharmaprix. Broadband direct to the home. e.g. Downloading MP3 audio to audio players.
- ✓ Broadband direct small business, office etc, sharing local use with many PCs.
- ✓ Internet access from on board ship Cruise ships with internet cafes, commercial shipping communications.

9.4 Mobile satellite services:

5.4.1 GSM:

5.4.1.1 Services and Architecture:

If your work involves (or is likely to involve) some form of wireless public communications, you are likely to encounter the GSM standards. Initially developed to support a standardized approach to digital cellular communications in Europe, the "Global System for Mobile Communications" (GSM) protocols are rapidly being adopted to the next generation of wireless telecommunications systems.

In the US, its main competition appears to be the cellular TDMA systems based on the IS-54 standards. Since the GSM systems consist of a wide range of components, standards, and protocols.

The GSM and its companion standard DCS1800 (for the UK, where the 900 MHz frequencies are not available for GSM) have been developed over the last decade to allow cellular communications systems to move beyond the limitations posed by the older analog systems.

Analog system capacities are being stressed with more users that can be effectively supported by the available frequency allocations. Compatibility between types of systems had been limited, if non-existent.

By using digital encoding techniques, more users can share the same frequencies than had been available in the analog systems. As compared to the digital cellular systems in the US (CDMA [IS-95] and TDMA [IS-54]), the GSM market has had impressive success. Estimates of the numbers of telephones run from 7.5 million GSM phones to .5 million IS54 phones to .3 million for IS95.

GSM has gained in acceptance from its initial beginnings in Europe to other parts of the world including Australia, New Zealand, countries in the Middle East and the far east. Beyond its use in cellular frequencies (900 MHz for GSM, 1800 MHz for DCS1800), portions of the GSM signaling protocols are finding their way into the newly developing PCS and LEO Satellite communications systems.

While the frequencies and link characteristics of these systems differ from the standard GSM air interface, all of these systems must deal with users roaming from one cell (or satellite beam) to another, and bridge services to public communication networks including the Public Switched Telephone Network (PSTN), and public data networks (PDN).

The GSM architecture includes several subsystems:

The Mobile Station (MS) -- These digital telephones include vehicle, portable and hand-held terminals. A device called the Subscriber Identity Module (SIM) that is basically a smart-card provides custom information about users such as the services they've subscribed to and their identification in the network

The Base Station Sub-System (BSS) -- The BSS is the collection of devices that support the switching networks radio interface. Major components of the BSS include the Base Transceiver Station (BTS) that consists of the radio modems and antenna equipment.

In OSI terms, the BTS provides the physical interface to the MS where the BSC is responsible for the link layer services to the MS. Logically the transcoding equipment is in the BTS, however, an additional component.

The Network and Switching Sub-System (NSS) -- The NSS provides the switching between the GSM subsystem and external networks along with the databases used for additional subscriber and mobility management.

Major components in the NSS include the Mobile Services Switching Center (MSC), Home and Visiting Location Registers (HLR, VLR). The HLR and VLR databases are interconnected through the telecomm standard Signaling System 7 (SS7) control network.

The Operation Sub-System (OSS) -- The OSS provides the support functions responsible for the management of network maintenance and services. Components of the OSS are responsible for network operation and maintenance, mobile equipment management, and subscription management and charging.

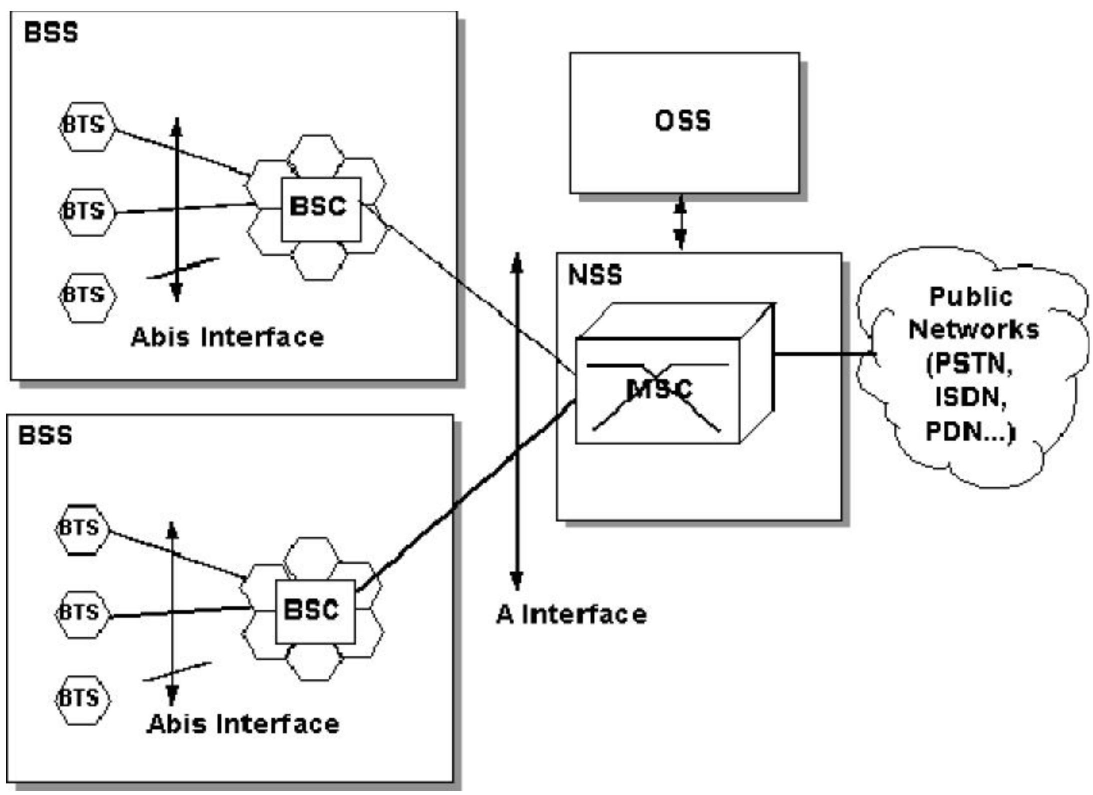


Figure 5.5 GSM Block Diagrams

Several channels are used in the air interface:

- ✓ **FCCH** - the frequency correction channel - provides frequency synchronization information in a burst
- ✓ **SCH** - Synchronization Channel - shortly following the FCCH burst (8 bits later), provides a reference to all slots on a given frequency
- ✓ **PAGCH** - Paging and Access Grant Channel used for the transmission of paging information requesting the setup of a call to a MS.
- ✓ **RACH** - Random Access Channel - an inbound channel used by the MS to request connections from the ground network. Since this is used for the first access attempt by users of the network, a random access scheme is used to aid in avoiding collisions.
- ✓ **CBCH -** Cell Broadcast Channel - used for infrequent transmission of broadcasts by the ground network.
- ✓ **BCCH** - Broadcast Control Channel - provides access status information to the MS. The information provided on this channel is used by the MS to determine whether or not to request a transition to a new cell

- ✓ **FACCH -** Fast Associated Control Channel for the control of handovers
- ✓ **TCH/F** - Traffic Channel, Full Rate for speech at 13 kbps or data at 12, 6, or 3.6 kbps
- ✓ **TCH/H** - Traffic Channel, Half Rate for speech at 7 kbps, or data at 6 or 3.6 kbps

9.5 **Mobility Management:**

One of the major features used in all classes of GSM networks (cellular, PCS and Satellite) is the ability to support roaming users. Through the control signaling network, the MSCs interact to locate and connect to users throughout the network.

"Location Registers" are included in the MSC databases to assist in the role of determining how, and whether connections are to be made to roaming users. Each user of a GSM MS is assigned a Home Location Register (HLR) that is used to contain the user's location and subscribed services.

Difficulties facing the operators can include;

a. Remote/Rural Areas. To service remote areas, it is often economically unfeasible to provide backhaul facilities (BTS to BSC) via terrestrial lines (fiber/microwave).

b. Time to deploy. Terrestrial build-outs can take years to plan and implement.
c. Areas of 'minor' interest. These can include small isolated centers such as tourist resorts, islands, mines, oil exploration sites, hydro-electric facilities.
d. Temporary Coverage. Special events, even in urban areas, can overload the existing infrastructure.

9.5.1 GSM service security:

GSM was designed with a moderate level of service security. GSM uses several cryptographic algorithms for security. The A5/1, A5/2, and A5/3 stream ciphers are used for ensuring over-the-air voice privacy.

GSM uses General Packet Radio Service (GPRS) for data transmissions like browsing the web. The most commonly deployed GPRS ciphers were publicly broken in 2011The researchers revealed flaws in the commonly used GEA/1.

5.4.2 Global Positioning System (GPS) :

The Global Positioning System (GPS) is a satellite based navigation system that can be used to locate positions anywhere on earth. Designed and operated by the U.S. Department of Defense, it consists of satellites, control and monitor stations, and receivers. GPS receivers take information transmitted from the satellites and uses triangulation to calculate a user's exact location. GPS is used on incidents in a variety of ways, such as:

- ✓ To determine position locations; for example, you need to radio a helicopter pilot the coordinates of your position location so the pilot can pick you up.
- ✓ To navigate from one location to another; for example, you need to travel from a lookout to the fire perimeter.
- ✓ To create digitized maps; for example, you are assigned to plot the fire perimeter and hot spots.
- ✓ To determine distance between two points or how far you are from another location.

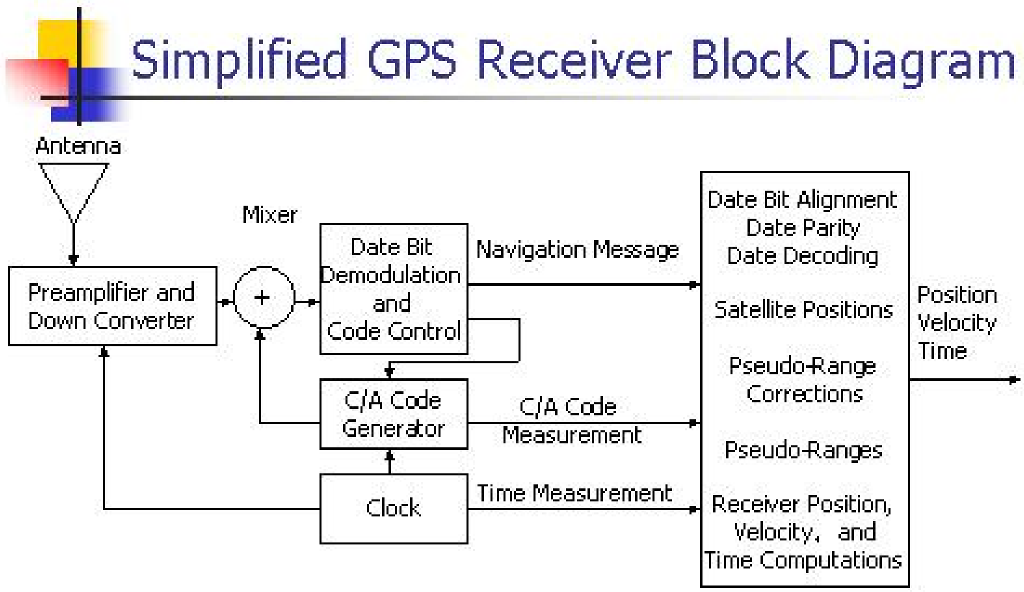


Figure 5.6 GPS Block Diagrams

The purpose of this chapter is to give a general overview of the Global Positioning System, not to teach proficiency in the use of a GPS receiver. To become proficient with a specific GPS receiver, study the owner's manual and practice using the receiver.

The chapter starts with a general introduction on how the global positioning system works. Then it discusses some basics on using a GPS receiver.

Three Segments of GPS:

Space Segment — Satellites orbiting the earth

The space segment consists of 29 satellites circling the earth every 12 hours at 12,000 miles in altitude. This high altitude allows the signals to cover a greater area. The satellites are arranged in their orbits so a GPS receiver on earth can receive a signal from at least four satellites at any given time. Each satellite contains several atomic clocks.

Control Segment — The control and monitoring stations

The control segment tracks the satellites and then provides them with corrected orbital and time information. The control segment consists of five unmanned monitor stations and one Master Control Station. The five unmanned stations monitor GPS satellite signals and then send that information to the Master Control Station where anomalies are corrected and sent back to the GPS satellites through ground antennas.

User Segment — The GPS receivers owned by civilians and military

The user segment consists of the users and their GPS receivers. The number of simultaneous users is limitless.

How GPS Determines a Position:

The GPS receiver uses the following information to determine a position.

- ✓ Precise location of satellites
- ✓

When a GPS receiver is first turned on, it downloads orbit information from all the satellites called an almanac. This process, the first time, can take as long as 12 minutes; but once this information is downloaded, it is stored in the receiver's memory for future use.

- ✓ Distance from each satellite

The GPS receiver calculates the distance from each satellite to the receiver by using the distance formula: distance = velocity x time. The receiver already knows the velocity, which is the speed of a radio wave or 186,000 miles per second (the speed of light).

- ✓ Triangulation to determine position

The receiver determines position by using triangulation. When it receives signals from at least three satellites the receiver should be able to calculate its approximate position (a 2D position). The receiver needs at least four or more satellites to calculate a more accurate 3D position.

Using a GPS Receiver :

There are several different models and types of GPS receivers. Refer to the owner's manual for your GPS receiver and practice using it to become proficient.

- ✓ When working on an incident with a GPS receiver it is important to:
- ✓ Always have a compass and a map.
- ✓ Have a GPS download cable.
- ✓ Have extra batteries.
- ✓ Know memory capacity of the GPS receiver to prevent loss of data, decrease in accuracy of data,or other problems.
- ✓ Use an external antennae whenever possible, especially under tree canopy, in canyons, or while flying or driving.
- ✓ Set up GPS receiver according to incident or agency standard regulation; coordinate system.
- ✓ Take notes that describe what you are saving in the receiver.

5.5. INMARSAT:

Inmarsat-Indian Maritime SATellite is still the sole IMO-mandated provider of satellite communications for the GMDSS.

- Availability for GMDSS is a minimum of 99.9%

Inmarsat has constantly and consistently exceeded this figure & Independently audited by IMSO and reported on to IMO.

Now Inmarsat commercial services use the same satellites and network &Inmarsat A closes at midnight on 31 December 2007 Agreed by IMO – MSC/Circ.1076. Successful closure programme almost concluded Overseen throughout by IMSO.

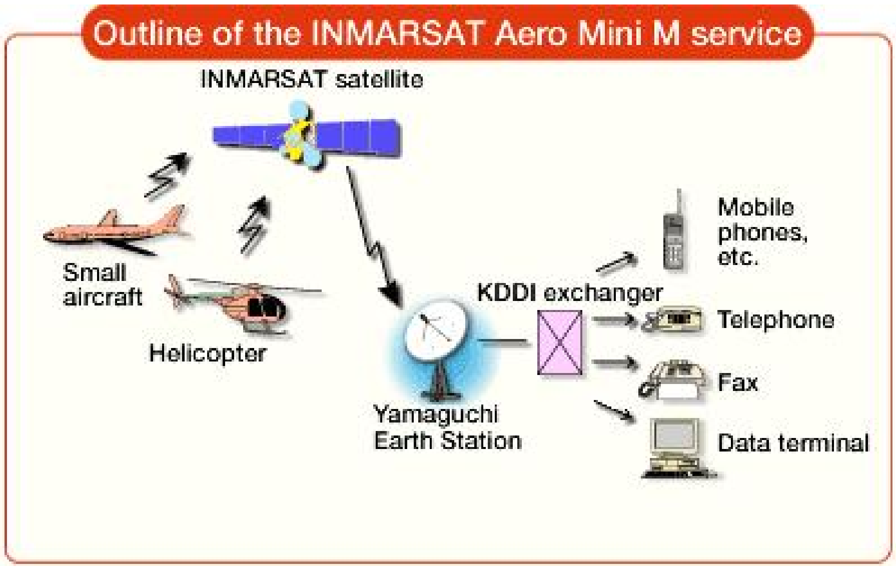


Figure 5.7 INMARSAT Satellite Service

GMDSS services continue to be provided by:

- Inmarsat B, Inmarsat C/mini-C and Inmarsat Fleet F77
- Potential for GMDSS on FleetBroadband being assessed

- The IMO Criteria for the Provision of Mobile Satellite Communications Systems in the Global Maritime Distress and Safety System (GMDSS)

- Amendments were proposed; potentially to make it simpler for other satellite systems to be approved

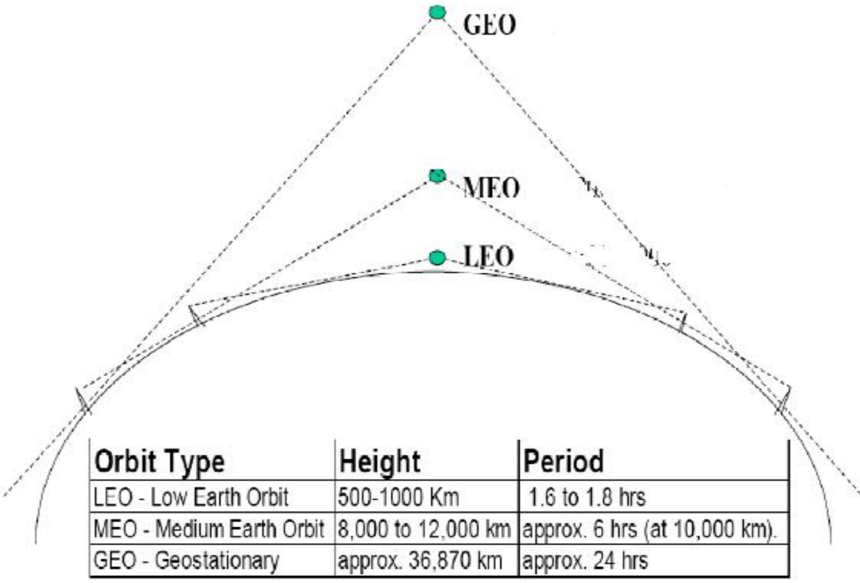
- The original requirements remain and were approved by MSC 83
  - No dilution of standards

- Minor amendments only; replacement Resolution expected to be approved by the IMO 25th Assembly

- Inmarsat remains the sole, approved satcom provider for the GMDSS

5.6 LEO: Low Earth Orbit satellites have a small area of coverage. They are positioned in an orbit approximately 3000km from the surface of the earth

- They complete one orbit every 90 minutes
- The large majority of satellites are in low earth orbit
- The Iridium system utilizes LEO satellites (780km high)
- The satellite in LEO orbit is visible to a point on the earth for a very short time



Orbit Type	Height	Period
LEO - Low Earth Orbit	500-1000 Km	1.6 to 1.8 hrs
MEO - Medium Earth Orbit	8,000 to 12,000 km	approx. 6 hrs (at 10,000 km).
GEO - Geostationary	approx. 36,870 km	approx. 24 hrs

Figure 5.8 LEO, MEO & GEO range

5.7 MEO: *Medium Earth Orbit* satellites have orbital altitudes between 3,000 and 30,000 km.

- They are commonly used used in navigation systems such as GPS

5.8 GEO: *Geosynchronous (Geostationary) Earth Orbit* satellites are positioned over the equator. The orbital altitude is around 30,000-40,000 km

- There is only one geostationary orbit possible around the earth
  - Lying on the earth's equatorial plane.
  - The satellite orbiting at the same speed as the rotational speed of the earth on its axis.
  - They complete one orbit every 24 hours. This causes the satellite to appear stationary with respect to a point on the earth, allowing one satellite to provide continual coverage to a given area on the earth's surface
  - One GEO satellite can cover approximately 1/3 of the world's surface

They are commonly used in communication systems

- Advantages:
  - Simple ground station tracking.
  - Nearly constant range
  - Very small frequency shift
- Disadvantages:

- Transmission delay of the order of 250 msec.
- Large free space loss.
- No polar coverage

⦿ Satellite orbits in terms of the orbital height:

⦿ According to distance from earth:

- Geosynchronous Earth Orbit (GEO) ,
- Medium Earth Orbit (MEO),
- Low Earth Orbit (LEO)

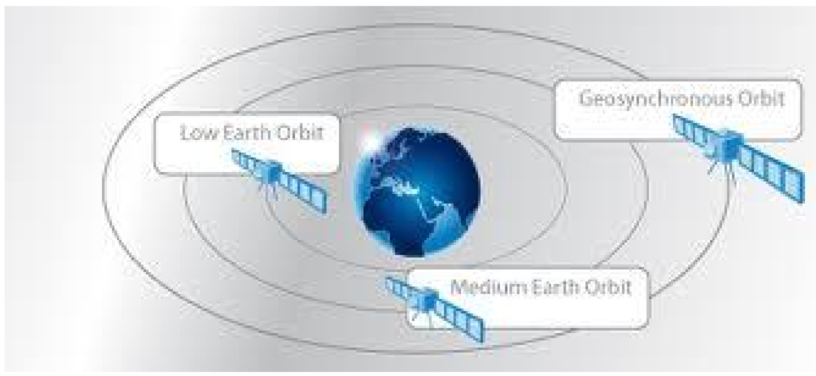


Figure 5.9 LEO, MEO & GEO Orbits

LEO / MEO / GEO / HEO (cont.)

	Name	Number	Panel	No./Panel	altitude	deg.
LEO	STARSYS	24	6	4	1300km	60
	ORBCOMM	24	4	6	785km	45
	GLOBALSTAR	48	8	6	1400km	52
	IRIDIUM	66	6	11	765km	86
MEO	**Name**	**Number**	**Panel**	**No./Panel**	**altitude**	**deg.**
	INMARSAT P	10	2	5	10300km	45
	ODYSEEY	12	3	4	10370km	55
	GPS	24	6	4	20200km	55
	GLONASS	24	3	8	19132km	64.8
HEO	**Name**	**Number**	**Panel**	**No./Panel**	**altitude**	**deg.**
	ELLIPSO	24	4	6	A:7800km P:520km	63.4
	MOLNIYA	4	1	4	A:39863km P:504km	63.4
	ARCHIMEDES	4	4	1	A:39447km P:926km	63.4

9

Figure 5.10 Diff b/w LEO, MEO & GEO Orbits

GEO: 35,786 km above the earth, MEO: 8,000-20,000 km above the earth & LEO: 500-2,000 km above the earth.

5.9 Satellite Navigational System:

Benefits:

- Enhanced Safety
- Increased Capacity
- Reduced Delays

Advantage:

- Increased Flight Efficiencies
- Increased Schedule Predictability
- Environmentally Beneficial Procedures

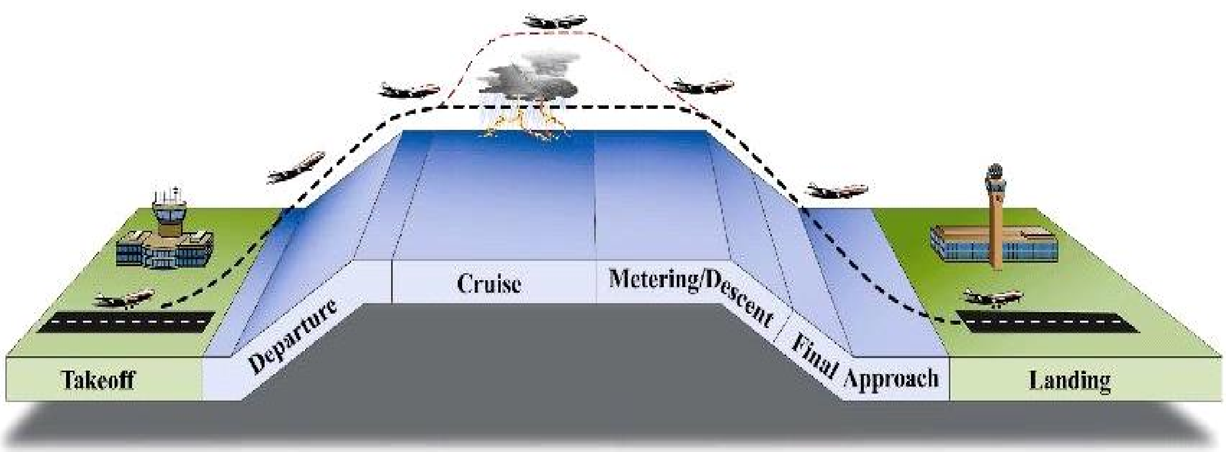


Figure 5.11 LEO, MEO & GEO Orbits

- Using ICAO GNSS Implementation Strategy and ICAO Standards and Recommended Practices
- GPS Aviation Use Approved for Over a Decade
  - Aircraft Based Augmentation Systems (ABAS) – (e.g. RAIM)
- Space Based Augmentation System (SBAS) since 2003
  - Wide Area Augmentation System (WAAS) augmenting GPS

- Development of GNSS Ground Based Augmentation System (GBAS) Continues
  - Local Area Augmentation System (LAAS)
- GNSS is Cornerstone for National Airspace System

5.10 Direct Broadcast satellites (DBS):

Satellites provide *broadcast* transmissions in the fullest sense of the word, because antenna footprints can be made to cover large areas of the earth.

The idea of using satellites to provide direct transmissions into the home has been around for many years, and the services pro- vided are known generally as *direct broadcast satellite* (DBS) services.

Broadcast services include audio, television, and Internet services.

5.10.1 Power Rating and Number of Transponders:

From Table 1.4 it will be seen that satellites primarily intended for DBS have a higher [EIRP] than for the other categories, being in the range 51 to 60 dBW. At a *Regional Administrative Radio Council* (RARC) meeting in 1983, the value established for DBS was 57 dBW (Mead,2000). Transponders are rated by the power output of their high-power amplifiers.

Typically, a satellite may carry 32 transponders. If all 32 are in use, each will operate at the lower power rating of 120 W.

The available bandwidth (uplink and downlink) is seen to be 500 MHz. A total number of 32 transponder channels, each of bandwidth 24 MHz, can be accommodated.

The bandwidth is sometimes specified as 27 MHz, but this includes a 3-MHz guardband allowance. Therefore, when calculating bit-rate capacity, the 24 MHz value is used.

The total of 32 transponders requires the use of both *right- hand circular polarization* (RHCP) and *left-hand circular polarization* (LHCP) in order to permit frequency reuse, and guard bands are inserted between channels of a given polarization.

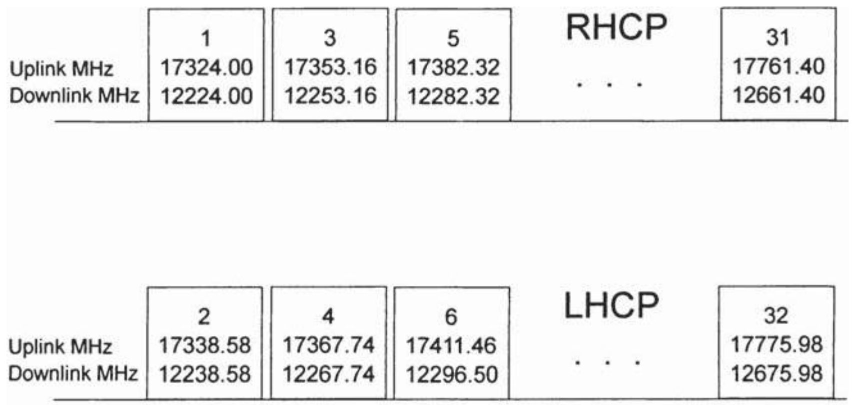


Figure 5.12 DBS Service

5.10.2 Bit Rates for Digital Television:

The bit rate for digital television depends very much on the picture format. One way of estimating the uncompressed bit rate is to multiply the number of pixels in a frame by the number of frames per second, and multiply this by the number of bits used to encode each pixel.

5.10.3 MPEG Compression Standards:

MPEG is a group within the *International Standards Organization and the International Electrochemical Commission* (ISO/IEC) that undertook the job of defining standards for the transmission and storage of moving pictures and sound.

The MPEG standards currently available are MPEG-1, MPEG-2, MPEG-4, and MPEG-7.

5.11 Direct to home Broadcast (DTH):

DTH stands for Direct-To-Home television. DTH is defined as the reception of satellite programmes with a personal dish in an individual home.

- ✓ DTH Broadcasting to home TV receivers take place in the ku band(12 GHz). This service is known as Direct To Home service.
- ✓ DTH services were first proposed in India in 1996.
- ✓ Finally in 2000, DTH was allowed.
- ✓ The new policy requires all operators to set up earth stations in India

within 12 months of getting a license. DTH licenses in India will cost $2.14 million and will be valid for 10 years.

Working principal of DTH is the satellite communication. Broadcaster modulates the received signal and transmit it to the satellite in KU Band and from satellite one can receive signal by dish and set top box.

5.11.1 DTH Block Diagram:

- ✓ A DTH network consists of a broadcasting centre, satellites, encoders, multiplexers, modulators and DTH receivers
- ✓ The encoder converts the audio, video and data signals into the digital format and the multiplexer mixes these signals.

It is used to provide the DTH service in high populated area A Multi Switch is basically a box that contains signal splitters and A/B switches. A outputs of group of DTH LNBs are connected to the A and B inputs of the Multi Switch.

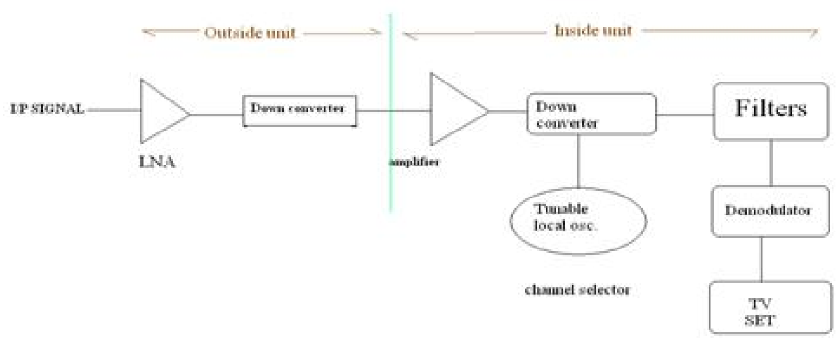


Figure 5.13 DTH Service

5.11.2 Advantage:

- ✓ DTH also offers digital quality signals which do not degrade the picture or sound quality.
- ✓ It also offers interactive channels and program guides with customers having the choice to block out programming which they consider undesirable
- ✓ One of the great advantages of the cable industry has been the ability to provide local channels, but this handicap has been overcome by many

DTH providers using other local channels or local feeds.

- ✓ The other advantage of DTH is the availability of satellite broadcast in rural and semi-urban areas where cable is difficult to install.

5.12 Digital audio broadcast (DAB):

DAB Project is an industry-led consortium of over 300 companies

- ✓ The DAB Project was launched on 10th September, 1993
- ✓ In 1995 it was basically finished and became operational
- ✓ There are several sub-standards of the DAB standard
  - DAB-S (Satellite) – using QPSK – 40 Mb/s
  - DAB-T (Terrestrial) – using QAM – 50 Mb/s
  - DAB-C (Cable) – using OFDM – 24 Mb/s
- ✓ These three sub-standards basically differ only in the specifications to the physical representation, modulation, transmission and reception of the signal.
- ✓ The DAB stream consists of a series of fixed length packets which make up a Transport Stream (TS). The packets support 'streams' or 'data sections'.
- ✓ Streams carry higher layer packets derived from an MPEG stream & Data sections are blocks of data carrying signaling and control data.
- ✓ DAB is actually a support mechanism for MPEG.& One MPEG stream needing higher instantaneous data can 'steal' capacity from another with spare capacity.

5.13 Worldspace services:

WorldSpace (Nasdaq: WRSP) is the world's only global media and entertainment company positioned to offer a satellite radio experience to consumers in more than 130 countries with five billion people, driving 300 million cars. WorldSpace delivers the latest tunes, trends and information from around the world and around the corner.

WorldSpace subscribers benefit from a unique combination of local programming, original WorldSpace content and content from leading brands around the globe, including the BBC, CNN, Virgin Radio, NDTV and RFI. WorldSpace's satellites cover two-thirds of the globe with six beams.

Each beam is capable of delivering up to 80 channels of high quality digital audio and multimedia programming directly to WorldSpace Satellite Radios anytime and virtually anywhere in its coverage area. WorldSpace is a pioneer of satellite-based digital radio services (DARS) and was instrumental in the development of the technology infrastructure used today by XM Satellite Radio. For more information, visit http://www.worldspace.com.

5.14 Business Television (BTV) - Adaptations for Education:

Business television (BTV) is the production and distribution, via satellite, of video programs for closed user group audiences. It often has two-way audio interaction component made through a simple telephone line. It is being used by many industries including brokerage firms, pizza houses, car dealers and delivery services.

BTV is an increasingly popular method of information delivery for corporations and institutions. Private networks, account for about 70 percent of all BTV networks. It is estimated that by the mid-1990s BTV has the potential to grow to a $1.6 billion market in North America with more and more Fortune 1,000 companies getting involved. The increase in use of BTV has been dramatic.

Institution updates, news, training, meetings and other events can be broadcast live to multiple locations. The expertise of the best instructors can be delivered to thousands of people without requiring trainers to go to the site. Information can be disseminated to all employees at once, not just a few at a time. Delivery to the workplace at low cost provides the access to training that has been denied lower level employees. It may be the key to re-training America's work force.

Television has been used to deliver training and information within businesses for more than 40 years. Its recent growth began with the introduction of the video cassette in the early 1970s. Even though most programming is produced for video cassette distribution, business is using BTV to provide efficient delivery of specialized programs via satellite.

The advent of smaller receiving stations - called very small aperture terminals (VSATs) has made private communication networks much more economical to operate. BTV has a number of tangible benefits, such as reducing travel, immediate delivery of time-critical messages, and eliminating cassette duplication and distribution hassles.

The programming on BTV networks is extremely cost-effective compared to seminar fees and downtime for travel. It is an excellent way to get solid and current information very fast. Some people prefer to attend seminars and conferences where they can read, see, hear and ask questions in person. BTV provides yet another piece of the education menu and is another way to provide professional development.

A key advantage is that its format allows viewers to interact with presenters by telephone, enabling viewers to become a part of the program. The satellite effectively places people in the same room, so that sales personnel in the field can learn about new products at the same time.

Speed of transmission may well be the competitive edge which some firms need as they introduce new products and services. BTV enables employees in many locations to focus on common problems or issues that might develop into crises without quick communication and resolution.

BTV networks transmit information every business day on a broad range of topics, and provide instructional courses on various products, market trends, selling and motivation. Networks give subscribers the tools to apply the information they have to real world situations.

5.15 GRAMSAT:

ISRO has come up with the concept of dedicated GRAMSAT satellites, keeping in mind the urgent need to eradicate illiteracy in the rural belt which is necessary for the all round development of the nation.

This Gramsat satellite is carrying six to eight high powered C-band transponders, which together with video compression techniques can disseminate regional and cultural specific audio-visual programmes of relevance in each of the regional languages through rebroadcast mode on an ordinary TV set.

The high power in C-band has enabled even remote area viewers outside the reach of the TV transmitters to receive programmers of their choice in a direct reception mode with a simple .dish antenna.

The salient features of GRAMSAT projects are:

i. Its communications networks are at the state level connecting the state capital to districts, blocks and enabling a reach to villages.

ii. It is also providing computer connectivity data broadcasting, TV-broadcasting facilities having applications like e- governance, development information, teleconferencing, helping disaster management.

iii. Providing rural-education broadcasting.

However, the Gramsat projects have an appropriate combination of following activities.

(i) Interactive training at district and block levels employing suitable configuration

(ii) Broadcasting services for rural development

(iii) Computer interconnectivity and data exchange services

(iv) Tele-health and tele-medicine services.

5.16 Specialized services:

5.16.1 Satellite-email services:

The addition of Internet Access enables Astrium to act as an Internet Service Provider (ISP) capable of offering Inmarsat users a tailor-made Internet connection.

With Internet services added to our range of terrestrial networks, you will no longer need to subscribe to a third party for Internet access (available for Inmarsat A, B, M, mini-M, Fleet, GAN, Regional BGAN & SWIFT networks).

We treat Internet in the same way as the other terrestrial networks we provide, and thus offer unrestricted access to this service. There is no time-consuming log-on procedure, as users are not required to submit a user-ID or password.

Description of E-mail Service:

Astrium's E-Mail service allows Inmarsat users to send and receive e-mail directly through the Internet without accessing a public telephone network.

Features and Benefits

- ✓ No need to configure an e-mail client to access a Astrium e-mail account
- ✓ Service optimized for use with low bandwidth Inmarsat terminals
- ✓ Filter e-mail by previewing the Inbox and deleting any unwanted e-mails prior to downloading
- ✓ No surcharge or monthly subscription fees
- ✓ Service billed according to standard airtime prices for Inmarsat service used

5.16.2 Video Conferencing (medium resolution):

Video conferencing technology can be used to provide the same full, two-way interactivity of satellite broadcast at much lower cost. For Multi-Site meetings, video conferencing uses bridging systems to connect each site to the others.

It is possible to configure a video conference bridge to show all sites at the same time on a projection screen or monitor. Or, as is more typical, a bridge can show just the site from which a person is speaking or making a presentation.

The technology that makes interactive video conferencing possible, compresses video and audio signals, thus creating an image quality lower than that of satellite broadcasts.

5.16.3. Satellite Internet access:

Satellite Internet access is Internet access provided through communications satellites. Modern satellite Internet service is typically provided to users through geostationary satellites that can offer high data speeds, with newer satellites using Ka band to achieve downstream data speeds up to 50 Mbps.

Satellite Internet generally relies on three primary components: a satellite in geostationary orbit (sometimes referred to as a geosynchronous Earth orbit, or GEO), a number of ground stations known as gateways that relay Internet data to and from the satellite via radio waves (microwave), and a VSAT (very-small-aperture terminal) dish antenna with a transceiver, located at the subscriber's premises.

Other components of a satellite Internet system include a modem at the user end which links the user's network with the transceiver, and a centralized network operations center (NOC) for monitoring the entire system.

Satellite Communication **Two Marks (Q&A)**

UNIT – I

SATELLITE ORBITS

1. What is Satellite?

An artificial body that is projected from earth to orbit either earth (or) another body of solar systems.
Types: Information satellites and Communication Satellites

2. Define Satellite Communication.

It is defined as the use of orbiting satellites to receive, amplify and retransmit data to earth stations.

3. State Kepler's first law.

It states that the path followed by the satellite around the primary will be an ellipse.
An ellipse has two focal points F1 and F2. The center of mass of the two body system,
termed the barycenter is always centered on one of the foci.

e = [square root of (a2– b2)] / a

4. State Kepler's second law.

It states that for equal time intervals, the satellite will sweep out equal areas in its orbital plane, focused at the barycenter
.

5. State Kepler's third law.

It states that the square of the periodic time of orbit is perpendicular to the cube of the mean distance between the two bodies.

$$a^3 = \frac{\mu}{n^2}$$

Where, n = Mean motion of the satellite in rad/sec.

μ= Earth's geocentric gravitational constant. With the n in radians per sec. the orbital period in second is given by,

$$P = \frac{2\pi}{n}$$

6. Define apogee.

The point farthest from the earth.

7. Define Perigee.

The point closest from the earth.

8. What is line of apsides?

The line joining the perigee and apogee through the center of the earth.

9. Define ascending node.

The point where the orbit crosses the equatorial plane going from south to north.

10. Define descending node.

The point where the orbit crosses the equatorial plane going from north to south.

11. Define Inclination.

The angle between the orbital plane and the earth's equatorial plane. It is measured at the ascending node from the equator to the orbit going from east to north.

12. Define mean anomaly.

It gives an average bvalue of the angular position of the satellite with reference to the perigee.

13. Define true anomaly.

It is the angle from perigee to the satellite position, measured at the earth's center.

15. What is meant by azimuth angle?

It is defined as the angle produced by intersection of local horizontal plane and the plane passing through the earth station, the satellite and center of earth.

16. Give the 3 different types of applications with respect to satellite systems.

- The largest international system (Intelsat)
- The domestic satellite system (Dom sat) in U.S.
- U.S. National oceanographic and atmospheric administrations (NOAA)

17. Mention the 3 regions to allocate the frequency for satellite services.

- Region1: It covers Europe, Africa and Mangolia
- Region2: It covers North & South Ameriaca and Greenland.
- Region3: It covers Asia, Australia and South West Pacific.

18. Give the types of satellite services.

- Fixed satellite service
- Broadcasting satellite service
- Mobile satellite service
- Navigational satellite services
- Meteorological satellite services

19. What is mean by Dom sat?

Domestic Satellites. These are used for voice, data and video transmissions within the country.

20. What is mean by INTELSAT & SARSAT ?

- International Telecommunication Satellite.
- Search and rescue satellite.

21. Define polar-orbiting satellites.

Polar orbiting satellites orbit the earth in such a way as to cover the north and south polar regions.

22. Give the advantage of geostationary orbit.
There is no necessity for tracking antennas to find the satellite positions.

23. Define look angles.

The azimuth and elevation angles of the ground station antenna are termed as look angles.

24. Write short notes on station keeping.

It is the process of maintenance of satellite's attitude against different factors that can cause drift with time. Satellites need to have their orbits adjusted from time to time, because the satellite is initially placed in the correct orbit, natural forces induce a progressive drift.

25. What are the geostationary satellites?

The satellites present in the geostationary orbit are called geostationary satellite. The geostationary orbit is one in which the satellite appears stationary relative to the earth. It lies in equatorial plane and inclination is '0'. The satellite must orbit the earth in the same direction as the earth spin. The orbit is circular.

26. What is sun transit outage.

The sun transit is nothing but the sun comes within the beam width of the earth station antenna. During this period the sun behaves like an extremely noisy source and it blanks out all the signal from the satellite. This effect is termed as sun transit outage.

UNIT – II
SPACE SEGMENT AND LINK DESIGN

1. Give the two segments of basic satellite communication.

a. Earth segment (or) ground segment
b. Space segment

2. Write short notes on attitude control system.

It is the system that achieves and maintains the required attitudes. The main functions of attitude control system include maintaining accurate satellite position throughout the life span of the system.

3. What is declination?

The angle of tilt is often referred to as the declination which must not be confused with the magnetic declination used in correcting compass readings.

4. What is meant by payload?

It refers to the equipment used to provide the service for which the satellite has been launched.

5. What is meant by transponder?

In a communication satellite, the equipment which provides the connecting link between the satellite's transmit and receive antennas is referred to as the transponder.

6. Write short notes on station keeping.

It is the process of maintenance of satellite's attitude against different factors that can cause drift with time. Satellites need to have their orbits adjusted from time to time, because the satellite is initially placed in the correct orbit, natural forces induce a progressive drift.

7. What is meant by Pitch angle?

Movement of a spacecraft about an axis which is perpendicular to its longitudinal axis. It is the degree of elevation or depression.

8. What is an propellant?

A solid or liquid substance burnt in a rocket for the purpose of producing thrust.

9. What is an Yaw?

Yaw is the rotation of a vehicle about its vertical axis.

10. What is an zero 'g'?

Zero ‘g’ is a state when the gravitational attraction is opposed by equal and opposite inertial forces and the body experiences no mechanical stress.

11. Describe the spin stabilized satellites.

In a spin stabilized satellites, the body of the satellite spins at about 30 to 100 rpm about the axis perpendicular to the orbital plane. The satellites arem normally dual spin satellites with a spinning section and a despun section on which antennas are mounted. These are kept stationary with respect to earth by counter rotating the despun section.

12. What is meant by frequency reuse?

The carrier with opposite senses of polarization may overlap in frequency. This technique is known as frequency reuse.

13. What is meant by spot beam antenna?

A beam generated by a communication satellite antenna of sufficient size that the angular spread of sufficient size that the angular spread of the energy in the beam is very small with the result that a region that is only a few hundred km in diameter is illuminated on earth.

14. What is meant by momentum wheel stabilization?

During the spin stabilization, flywheels may be used rather than spinning the satellite. These flywheels are termed as momentum wheels.

15. What is polarization interleaving?

Overlap occurs between channels, but these are alternatively polarized left hand circular and right hand circular to reduce interference to acceptable levels. This is referred to as polarization interleaving.

16. Define S/N ratio.

The S/N introduced in the preceding section is used to refer to the ratio of signal power to noise power at the receiver output. This is known as S/N ratio.

17. What is an intermodulation noise?

Intermodulation distortion in high power amplifier can result in signal product which appear as noise and it is referred to as intermodulation noise.

18. What is an antenna loss?

It is added to noise received as radiation and the total antenna noise temperature is the sum of the equivalent noise temperature of all these sources.

19. Define sky noise.

It is a term used to describe the microwave radiation which is present throughout universe and which appears to originate from matter in any form, at finite temperature.

20. Define noise factor.

An alternative way of representing amplifier noise is by means of its noise factor. In
defining the noise factor of an amplifiers, usually taken as 290 k.

21. What is TWTA?

TWTA means Traveling Wave Tube Amplifier. The TWTA is widely used in transponder to provide the final output power required to the transtube and its power supplies.

22.What is meant by thermal control and why this is necessary in a satellite?

Equipment in the satellite generates heat which has to be removed. The element used in the satellite to control thermal heat is called thermal conrol. The most important consideration is that the satellite's equipment should operate as nearly as possible in a stable temperature environment

23.What are the functions carried out in TT&C?

Telemetry- *Gathering or measure information about satellite*.
Tracking- track the satellite's movement and send correction signals as Required
Comment- send information about the satellite to earth station.

24.What is meant by redundant receiver?

A duplicate receiver is provided so that if one fails, the other is automatically switched in. The combination is referred to as a *redundant receiver*, meaning that although two are provided, only one is in use at a given time.

25.List out the advantages of TWT.

The advantage of the TWT over other types of tube amplifiers is that it can provide amplification over a very wide bandwidth. Input levels to the TWT must be carefully controlled, however, to minimize the effects of certain forms of distortion

26.Define input back off.

In a TWTA, the operating point must be backed off to a linear portion of the transfer characteristic to reduce the effects of intermodulation distortion.The point from the saturation point to linear region at the input is called input backoff.

27.Define diplexer & *orthocoupler*.

The same feed horn may be used to transmit and receive carriers with the same polarization. The transmit and receive signals are separated in a device known as a *diplexer*,

The polarization separation takes place in a device known as an *orthocoupler*, or *orthogonal mode transducer* (OMT). Separate horns also may be used for the transmit and receive functions, with both horns using the same reflector.

UNIT – III

SATELLITE ACCESS

1. What is a single mode of operation?

A transponder channel abroad a satellite may be fully loaded by a single transmission from an earth station. This is referred to as a single access mode of operation.

2. What are the methods of multiple access techniques?
FDMA – Frequency Division Multiple Access Techniques
TDMA – Time Division Multiple Access Techniques

2. What is an CDMA?

CDMA – Code Division Multiple Access Techniques
In this method, each signal is associated with a particular code that is used to spread the signal in frequency and time.

4. Give the types of CDMA.
- Spread spectrum multiple access
- Pulse address multiple access

5. What is SCPC?
SCPC means Single Channel Per Carrier. In a thin route circuit, a transponder channel (36 MHz) may be occupied by a number of single carriers, each associated with its own voice circuit.

6. What is a thin route service?
SCPC systems are widely used on lightly loaded routes, this type of service being referred to as a thin route service.

7. What is an important feature of Intelsat SCPC system?
The system is that each channel is voice activated. This means that on a two way telephone conversation only one carriers is operative at any one time.

8. What is an TDMA? What are the advantages?

TDMA – Time Division Multiple Access Techniques

Only one carrier uses the transponder at any one time, and therefore Inter modulation products, which results from the non-linear amplification of multiple carriers are absent. Advantages : The transponder traveling wave tube can be operated at maximum power output.

9. What is preamble?

Certain time slots at the beginning of each burst are used to carry timing and synchronizing information. These time slots collectively are referred to as preamble.

10. Define guard time.

It is necessary to prevent the bursts from overlapping. The guard time will vary from burst to burst depending on the accuracy with which the various bursts can be positioned within each frame.

11. What is meant by decoding quenching?

In certain phase detection systems, the phase detector must be allowed for some time to recover from one burst before the next burst is received by it. This is known as decoding quenching.

12. What is meant by direct closed loop feedback?

The timing positions are reckoned from the last bit of the unique word in the preamble. The loop method is also known as direct closed loop feedback.

13. What is meant by feedback closed loop control?

The synchronization information is transmitted back to an earth station from a distant, that is termed feedback closed loop control.

14. Define frame efficiency.

It is measure of the fraction of frame time used for the transmission of traffic.

15. What is meant by digital speech interpolation?

The point is that for a significant fraction of the time, the channel is available for other transmission and advantages are taken of this in a form of demand assignment known as digital speech interpolation.

16. What is meant by telephone load activity factor?

The fraction of time a transmission channel is active is known as the telephone load activity factor.

17. What are the types of digital speech interpolation?
- Digital time assignment speech interpolation
- Speech predictive encoded communications

18. What is meant by freeze out?

It has assumed that a free satellite channel will be found for any incoming speed spurt, but there is a finite probability that all channels will be occupied and the speech spurt lost. Losing a speech spurt in this manner is referred to as freeze out.

19. What are the advantages of SPEC method over DSI method?

Freeze out does not occur during overload conditions.

20. Define satellite switched TDMA?

Space Division Multiplexing can be realized by switching the antenna interconnections in synchronism with the TDMA frame rate, this being known as satellite switched TDMA.

21. What is SS / TDMA?

A repetitive sequence of satellite switch modes, also referred to as SS /TDMA.

22. What is processing gain?

The jamming or interference signal energy is reduced by a factor known as the processing gain.

23. What is burst code word?

It is a binary word, a copy of which is stored at each earth station.

24. What is meant by burst position acquisition?

A station just entering, or reentering after a long delay to acquire its correct slot position is known as burst position acquisition.

25. What is an single access?

A transponder channel aboard a satellite may be fully loaded by a single transmission from earth station.

26. What is an multiple access technique?

A transponder to be loaded by a number of carriers. These may originate from a number of earth station may transmit one or more of the carriers. This mode of operation known as multiple access technique.

27. What is meant by space division multiple access?

The satellite as a whole to be accessed by earth stations widely separated geographically but transmitting on the same frequency that is known as frequency reuse. This method of access known as space division multiple access..

28. What are the limitations of FDMA-satellite access?

a. If the traffic in the downlink is much heavier than that in the uplink, then FDMA is relatively inefficient.

b. Compared with TDMA, FDMA has less flexibility in reassigning channels.

c. Carrier frequency assignments are hardware controlled..

29. Write about pre-assigned TDMA satellite access.

Example for pre-assigned TDMA is CSC for the SPADE network. CSC can accommodate upto 49 earth stations in the network and 1 reference station. All bursts are of equal length. Each burst contains 128 bits. The bit rate is 128 Kb / s.

30. Write about demand assigned TDMA satellite access.

The burst length may be kept constant and the number of bursts per frame used by the given station is varied when the demand is varied.

UNIT – IV
EARTH SEGMENT

1. Define earth segment.

Earth segment of a satellite communication system consists of transmit earth station and receive earth station.
Example : TV Receive Only systems (TVRO systems)

2. Give the difference between KU-band and the C-band receive only systems.

Operating frequency of outdoor unit.

3. What is mean by ODU and IDU.

ODU – The Home Receiver Outdoor Unit
IDU – The Home Receiver Indoor Unit

4. Explain about MATV system.

MATV – Master Antenna TV system.

It is used to provide reception of DBS TV channels to the user group.
Example : Apartment users It consists of one outdoor unit and various indoor units. Each user can independently access all the channels.

5. Write about CATV system.

CATV – Community Antenna TV system.
As in MATV system, it consists of oneoutdoor unit and separate feeds for each sense of polarization.

6. Define S/N ratio.

The S/N introduced in the preceding section is used to refer to the ratio of signal power to noise power at the receiver output. This is known as S/N ratio.

7. What is noise weighting?

The method used to improve the post detection signal to noise ratio is referred to as noise weighting.

8. What is an EIRP?

EIRP means Equivalent Isotropic Radiated Power. It is a measure of radiated or
transmitted power of an antenna.

9. What is noise power spectral density?

Noise power per unit Bandwidth is termed as the noise power spectral density.

10. What is an inter modulation noise?

Inter modulation distortion in high power amplifier can result in signal product which appear as noise and it is referred to as inter modulation noise.

11. What is an antenna loss?

It is added to noise received as radiation and the total antenna noise temperature is the sum of the equivalent noise temperature of all these sources.

12. Define noise factor.

An alternative way of representing amplifier noise is by means of its noise factor. In
defining the noise factor of an amplifiers, usually taken as 290 k.

13. A satellite downlink at 12 GHz operates with a transmit power of 6 W and an antenna gain of 48.2 dB. Calculate the EIRP in dBW.

EIRP = 10 log 6 + 48.2 = 56 dBW

14. The range between a ground station and a satellite is 42000 km. Calculate the free space loss a frequency of 6 GHz.

[Free space loss] = 32.4 + 20 log 42000 + 20 log 6000 = 200.4 dB

15. Define Saturation flux density.

The flux density required at the receiving antenna to produce saturation of TWTA is termed the saturation flux density.

UNIT – V
SATELLITE APPLICATIONS

1. Give the 3 different types of applications with respect to satellite systems.
   - The largest international system (Intelsat)
   - The domestic satellite system (Dom sat) in U.S.
   - U.S. National oceanographic and atmospheric administrations (NOAA)

2. Mention the 3 regions to allocate the frequency for satellite services.

   a. Region1: It covers Europe, Africa and Mangolia
   b. Region2: It covers North & South Ameriaca and Greenland.
   c. Region3: It covers Asia, Australia and South West Pacific.

3. Give the types of satellite services.

   a. Fixed satellite service
   b. Broadcasting satellite service
   c. Mobile satellite service
   d. Navigational satellite services
   e. Meteorological satellite services

4. What is mean by Dom sat?

Domestic Satellites. These are used for voice, data and video transmissions within the country.

5. What is mean by INTELSAT?
International Telecommunication Satellite.

6. What is mean by SARSAT?
Search and rescue satellite.

7. What are the applications of Radarsat?
   a. Shipping and fisheries.
   b. Ocean feature mapping
   d. Iceberg detection
   e. Crop monitoring

8. What is ECEF?
The geocentric equatorial coordinate system is used with the GPS system.It is called as earth centered, earth fixed coordinate system.

9. What is dilution of precision?
Position calculations involve range differences and where the ranges are nearly equal, any error is greatly magnified in the difference. This effect, brought a result of the satellite geometry is known as dilution of precision.

10. What is PDOP?

With the GPS system, dilution of position is taken into account through a factor known as the position dilution of precision.

11. What is DBS?

Satellites are used to provide the broadcast transmissions. It is used to provide direct transmissions into the home. The service provided is known as Direct Broadcast Satellite services.
Example : Audio, TV and internet services.

12. Give the frequency range of US DBS systems with high power satellites.

a. Uplink frequency range is 17.3 GHz to 17.8 GHz
b. Downlink frequency range is 12.2 GHz to 12.7 GHz

13. Give the frequency range of US DBS systems with medium power satellites.

a. Uplink frequency range is 14 GHz to 14.5 GHz
b. Downlink frequency range is 11.7 GHz to 12.2 GHz

14. What is DTH?

DBS television is also known as Direct To Home (DTH).

- DTH stands for Direct-To-Home television. DTH is defined as the reception of satellite programmes with a personal dish in an individual home.
- DTH Broadcasting to home TV receivers take place in the ku band(12 GHz). This service is known as Direct To Home service.

15. Write about bit rates for digital television.

It depends format of the picture.

Uncompressed Bit rate = (Number of pixels in a frame) * (Number of pixels per second) * (Number of bits used to encode each pixel)

16. Give the satellite mobile services.

a. DBS – Direct Broadcast satellite
b. VSATS – Very Small Aperture Terminals
c. MSATS – Mobile Satellite Service
d. GPS – Global Positioning Systems
e. Micro Sats
f. Orb Comm – Orbital Communications Corporation
g. Iridium

17. What is GCC and GEC?

GCC - Gateway Control Centers
GEC – Gateway Earth Stations

18. What is INMARSAT?

It is the first global mobile satellite communication system operated at Lband and internationally used by 67 countries for communication between ships and coast so that emergency life saving may be provided. Also it provides modern communication services to maritime, land mobile, aeronautical and other users.

19. List out the regions covered by INMARSAT.
 • Atlantic ocean region, east (AOR-E)
 • Atlantic ocean region, west (AOR-W)
 • Indian ocean region (IOR)\• Pacific ocean region (POR)

20.What is INSAT?

INSAT – Indian National Satellite System.

INSAT is a Indian National Satellite System for telecommunications, broadcasting, meteorology and search and rescue services. It was commissioned in 1983. INSAT was the largest domestic communication system in the Asia-Pacific region.

20. List out the INSAT series.
 • INSAT-1 • INSAT-2 • INSAt-2A
 • INSAT-2E • INSAT-3

21.What is GSM?

GSM (Global System for Mobile communications: originally from Groupe Spécial Mobile) is the most popular standard for mobile phones in the world. GSM differs from its predecessors in that both signaling and speech channels are digital, and thus is considered a second generation (2G) mobile phone system. This has also meant that data communication was easy to build into the system.

22.What is GPRS?

General packet radio service (GPRS) is a packet oriented mobile data service available to users of the 2G cellular communication systems global system for mobile communications (GSM), as well as in the 3G systems. In the 2G systems, GPRS provides data rates of 56-114 kbit/s.

23. What is GPS?

In the GPS system, a constellation of 24 satellites circles the earth in near-circular inclined orbits. By receiving signals from at least four of these satellites, the receiver position (latitude, longitude, and altitude) can be determined accurately. In effect, the satellites substitute for the geodetic position markers used in terrestrial surveying. In terrestrial the GPS system uses one-way transmissions, from satellites to users, so that the user does not require a transmitter, only a GPS receiver.

QUESTION BANK
UNIT-I

PART-A (2 Marks)

1. What are the major regions are classified the world for frequency planning?
2. How many broadcasting services provided in satellite?
3. What is meant by distance insensitive?
4. List out the coverage area for INTELSAT?
5. What are the classify the Domsats in terms of power?
6. State Kepler's first law.
7. State Kepler's second law.
8. State Kepler's third law.
9. Define apogee and perigee.
10. Define prograde orbit and retrograde orbit.
11. Define ascending node and descending node.
12. Explain right ascension of ascending node.
13. Define true anomaly and mean anomaly.
14. What is meant by argument of perigee?
15. List out the keplerian elements.
16. What are the quantities involved for determination of look angles?
17. Define sidereal time.

PART-B

1. (a) Explain about frequency allocations for satellite services. **(10)**
(b) Explain about U.S Domsats. **(6)**
2. Discuss briefly the development of INTELSAT starting from the 1960s through the Present. **(16)**
3. What is meant by polar orbiting and explain in details. **(16)**
4. State Kepler's three laws of planetary motion. Illustrate in each case their relevance to artificial satellites orbiting the earth. **(16)**
5. Explain in detail about geocentric-equatorial coordinate system which is based on the earth's equatorial plane. **(16)**
6. Explain in detail about topocentric-horizon coordinate system which is based on the observer's horizon plane. **(16)**
7. Explain in detail about various measure of time. **(16)**

UNIT-II

PART-A (2 Marks)

1. What are the three conditions are required for an orbit to be geostationary?
2. Find height of geostationary orbit based on aE and aGSO.
3. What is meant by look angles how to classify it.
4. Define elevation angle.
5. Define azimuth angle.
6. What are the three pieces of information needed to determine the look angles for the geostationary orbit?
7. What is meant by polar mount antenna?
8. Define geosynchronous.
9. What is meant by the geostationary orbit? How do the geostationary orbit and a Geosynchronous orbit differ?
10. Why satellites to carry batteries in addition to solar-cell arrays?
11. What is meant by satellite attitude?
12. Define the terms roll, pitch and yaw.
13. What is meant by the term despun antenna?
14. Define nutation dampers.
15. Define momentum bias and reaction wheel.
16. Describe the east-west and north-south station keeping maneuvers required in Satellite station keeping.
17. What is meant by thermal control and why this is necessary in a satellite?
18. What are the functions carried out in TT&C?
19. What is meant by transponder?
20. What is meant by frequency reuse?
21. What is meant by redundant receiver?
22. Define attenuators and explain its classification.
23. Describe the function of the input demultiplexer used aboard a communication satellite.
24. Why TWTAs widely used?
25. What is meant by slow wave structure?
26. List out the advantages of TWT.
27. Define saturation and compression point.
28. What is meant by intermodulation distortion?
29. Define input back off.
30. Define diplexer and orthocoupler.

PART-B

1. Explain in detail about antenna look angles and the polar mount antenna. **(16)**
1. Explain about Earth eclipse of satellite and sun transit outage. **(16)**
2. Explain about launching orbits. **(16)**
3. Explain what is meant by satellite attitude, and briefly describe two forms of attitude control. **(16)**
4. Draw the block diagram of TT&C and explain each and individual blocks. **(16)**
5. Describe briefly the most common type of high-power amplifying device(TWTA) used aboard a communication satellite. **(16)**
6. Explain about wideband receiver and advanced Tiros-N spacecraft. **(16)**
7. Describe briefly the antenna subsystem and Anik-E. **(16)**
8. Explain in detail about thermal control and Morelos. **(16)**

UNIT-III

PART-A (2 Marks)

1. What is meant by DBS service? How does differ from the home reception of satellite TV signals in the C band?
2. What is meant by polarization interleaving?
3. What is meant by master broadcast quality signals?
4. What are the difference between DBS TV and conventional TV?
5. Why the LNA in a satellite receiving system is placed at the antenna end of the feeder cable.
6. What is meant by single carrier per channel?
7. In most satellite TV receivers the first IF band is converted to a second, fixed IF. Why is this second frequency conversion required?
8. What is meant by the term redundant earth station?
9. List out the comparison between MATV and CATV.
10. Define EIRP.
11. Define receiver feeder losses.
12. What is meant by antenna pointing loss?
13. Write the equation for clear-sky losses and explain each term.
14. What is meant by noise power spectral density?
15. What is meant by intermodulation noise?
16. How to broadly classify the antenna noise and explain.
17. What is meant by antenna noise temperature?
18. What is meant by amplifier noise temperature?
19. What is meant by system noise temperature?

20. What is meant by noise factor?
21. Write the equation for system noise temperature.
22. Define saturation flux density.
23. Define apparent absorber temperature.
24. Define quantum efficiency and responsivity.
25. What is meant by excess noise factor?

PART-B

1. Describe and compare the MATV and CATV systems. **(16)**
2. Write the relevant expression & explain in detail about transmission losses. **(16)**
3. How to classify the system noise temperature & explain in detail about all. **(16)**
4. Explain about uplink satellite circuit**.** **(16)**
5. Explain about downlink satellite circuit. **(16)**
6. Describe briefly about the rains effects. **(16)**
7. Explain about inter-satellite link. **(16)**
8. With the aid of a block schematic, briefly describe the functioning of the receive only home TV systems **(16)**

UNIT-IV

PART-A (2Marks)

1. What is meant by single access?
2. Distinguish between preassigned and demand assigned traffic in relation to a satellite communications network.
3. What is meant by thin route service?
4. What is meant by centrally controlled random access and distributed control random access?
5. Explain the word spade.
6. Define the term power-limited and bandwidth limited operation.
7. What is meant by demand assignment signaling and switching?
8. What are the advantages of TDMA over FDMA?
9. Define the term burst and frame.
10. Define burst rate and average bit rate.
11. What do you meant by guard time?
12. Explain carrier and bit-timing recovery.
13. Explain burst code word.
14. Define the term preamble and postamble.
15. What is meant by burst position acquisition and burst position synchronization?
16. What is meant by adaptive open loop timing?

17. Explain the term look back.
18. Define the terms miss probability and probability of false alarm.
19. Define satellite channel and satellite channels.
20. What is meant by digital speech interpolation and digital Noninterpolated?
21. What is meant by telephone load activity factor and digital speech interpolation?
22. What is meant by spread spectrum multiple access?
23. What is meant by direct sequence spread spectrum?
24. Define maximal sequence?
25. List out the advantages of CDMA over FDMA and TDMA.
26. List out the advantages of CDMA in terms of VSAT.
27. Define throughput efficiency.

PART-B

1. Explain what is meant by single access in relation to a satellite communications Network. **(16)**
2. Explain in detail about FDMA, and show how this differs from FDM. **(16)**
3. Explain what the abbreviation SCPC stands for. Explain in detail the operation of a Preassigned SCPC network. **(16)**
4. Explain in detail the operation of the spade system of demand assignment. What is the function of the function of the common signaling channel? **(16)**
5. Describe the general operating principles of a TDMA network. Show how the Transmission bit rate is related to the input bit rate. **(16)**
6. Explain the need for reference burst and preamble and postamble in a TDMA System. **(16)**
7. Explain in detail about network synchronization with neat sketch. **(16)**
8. Define and explain the terms carrier recovery, traffic data, frame efficiency and Channel capacity. **(16)**
9. Describe in your own words how signal acquisition and tracking are achieved in a DS/SS system. And also derive the expression for maximal sequence. **(16)**
10. Explain in the principle behind spectrum spreading and dispreading and how this is used to minimize interference in a CDMA system. And also determine the throughput efficiency of the system. **(16)**

UNIT-V

PART-A (2Marks)

1. What do you mean by direct broadcasting satellite services?
2. Define DTH.
3. Expand the term RARC and ISO/IEC.
4. How many MPEG standards available now.
5. What is meant by chroma sub sampling?
6. Draw the diagram of MPEG-2 sub sampling.
7. What is meant by spatial frequency?
8. What is meant by masking in the context of audio compression?
9. Define temporal masking and frequency masking?
10. Expand the terms MPEG, ITU, AVC and CCIR?
11. What is meant by fidelity range extension?
12. Define ideal parabolic surface in terms of rms.
13. What is meant by microsat?
14. List out the modes of operation in Radarsat-2.
15. What is meant by earth-centered, earth-fixed coordinate system?
16. What does the term dilution of precision refer to?
17. What does the term position dilution of precision factor of refer to?
18. Define GPS time.
19. Expand the terms GSM, GPS, orbcomm, GCC, NCC, GES, and OSC.

PART-B

1. Describe briefly the video compression process used in MPEG-2. **(16)**
2. Explain about indoor and outdoor unit of home receiver. **(16)**
3. Explain about frequencies and polarization, transponder capacity and bit rates for Digital television. **(16)**
4. Explain in detail about satellite mobile services. **(16)**
5. Describe the operation of typical VSAT system. State briefly where VSAT systems find widest application. **(16)**
6. Describe the main features of Radarsat. Explain what is meant by dawn to dusk orbit and why the Radarsat follows such on orbit. **(16)**
7. Explain why a minimum of four satellites must be visible at an earth location utilizing the GPS system for position determination. What does the term dilution of precision refer to? **(16)**
8. Describe the main features and services offered by the orbcomm satellite system. **(16)**

Reg. No. :

Question Paper Code : 51385

B.E./B.Tech. DEGREE EXAMINATION, APRIL 2014.

Eighth Semester

Electronics and Communication Engineering

EC 2045/EC 810/10144 ECE 52 — SATELLITE COMMUNICATION

(Regulation 2008)

Time : Three hours | Maximum : 100 marks

Answer ALL questions.

PART A — (10 × 2 = 20 marks)

1. Define geostationary orbit.

2. What do you mean by apogee?

3. Why is noise temperature a useful concept in communication receivers?

4. Write the objectives with which the downlink of any satellite communication system must be designed.

5. Define multiplexing.

6. Write the two basic problems in satellite digital transmission.

7. For a given satellite and signal transmission, what are the earth station parameters affecting the C/N ratio?

8. Why is the cassegrain antenna popular for large earth stations?

9. Write the four kinds of communications that the network structure of MSAT can accommodate.

10. Write the two areas of satellite communications which are gaining major thrust from leading satellite industries and organisations in recent years.

PART B — (5 × 16 = 80 marks)

11. (a) Explain how Kepler's and Newton's laws are used to describe the orbit. (16)

Or

(b) Explain the following :

(i) Orbital perturbations. (8)

(ii) Launching vehicles. (8)

12. (a) From the calculation of system noise temperature prove that C/N ratio is directly proportional to G/T ratio. (16)

Or

(b) (i) List and explain the factors governing the design of satellite links. (10)

(ii) What are the factors contributing to noise in an earth station receiving channel? (6)

13. (a) Briefly discuss about analog voice transmission. (16)

Or

(b) Compare the salient features of FDMA, TDMA and CDMA. (16)

14. (a) Briefly explain about the test equipments for earth stations. (16)

Or

(b) (i) Briefly discuss on TVRO systems. (8)

(ii) Describe how the gain of large antennas can be optimized. (8)

15. (a) Explain the types of INTELSAT satellites with respect to basic space craft characteristics and vehicle type. (16)

Or

(b) (i) Explain the block diagram of an outdoor unit for a DBS home receiver. (8)

(ii) With a block schematic explain about DTH system. (8)

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Reg. No. : [redacted]

Question Paper Code : 21343

B.E./B.Tech. DEGREE EXAMINATION, MAY/JUNE 2013.

Eighth Semester

Electronics and Communication Engineering

EC 2045/EC 810 — SATELLITE COMMUNICATION

(Regulation 2008)

(Common to PTEC 2045 — Satellite Communication for B.E. (Part-Time) Seventh Semester — Electronics and Communication Engineering — Regulation 2009)

Time : Three hours　　　　Maximum : 100 marks

Answer ALL questions.

PART A — (10 × 2 = 20 marks)

1. Given the geostationary orbital radius 'r', the Earth's radius 'R' and speed of light 'C' how will you compute the time taken for a signal to pass from Earth to the Satellite and back again?

2. Enlist the traditional orbital Keplerian elements.

3. How is the attitude of a satellite controlled through active control?

4. Why the operation near the saturation point of a TWTA is to be avoided when multiple carriers are being amplified simultaneously?

5. When VSAT-type terminals involved CDMA offers several advantages for satellite networking. What are they?

6. Point out the function of (a) the burst code word and (b) the carrier and bit-timing recovery channel in a TDMA burst.

7. Give the reason for deploying a demodulator/remodulator unit in our home television set when we want to function in a satellite TV/FM receiving system.

8. What is known as polarization interleaving with reference to the Down link frequency?

9. When the available bandwidth is 500 MHZ, how many transponder each of bandwidth 24 MHZ can be accomodated.

10. What is meant by conjestion and slowstart with reference to Internet traffic.

PART B — (5 × 16 = 80 marks)

11. (a) (i) A satellite is orbiting the equatorial plane with a period from perigee to perigee of 10h. Given that the eccentricity is 0.002 and the earth's equatorial radius is 6378.1414 km how will you calculate the semi major axis.

(ii) Summarise how you will determine the look angles for the geostationary orbit? What are known as sun-synchronous orbits.

Or

(b) (i) How will you determine the sub satellite point?

(ii) Write a brief note on launch vehicles and propulsion.

12. (a) How do the TT and C subsystem perform aboard the spacecraft? Also explain the working of a transponder unit.

Or

(b) How is the performance of a satellite impaired due to external factors? Also suggest suitable methods to overcome the same.

13. (a) (i) Describe the ways in which demand assignment may be carried out in FDMA.

(ii) What is known as pre-assigned traffic?

Or

(b) (i) Calculate the probability of false detection, when N = 10 and d = 4.

(ii) For digital video broadcast what type of multiple access is best suited. Justify your answer.

14. (a) Show how MATV is used to provide reception of DDS to a small group of users. When this group is large what type of antenna should be used? Explain.

Or

(b) Analyse the functioning of Transmit — Receive Earth stations. With a block diagram explain how the redundant earth station functions.

15. (a) Enumerate how GSM and GPS deploying Satellites have improved the mobility of the customers.

Or

(b) Write short notes on the specialized services offered by satellites for video conferencing e-mail and internet.

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Reg. No. : [ ]

Question Paper Code : 20258

B.E./B.Tech. DEGREE EXAMINATION, MAY/JUNE 2012.

Eighth Semester

Electronics and Communication Engineering

EC 2045/EC 810 — SATELLITE COMMUNICATION

(Regulation 2008)

Time : Three hours

Maximum : 100 marks

Answer ALL questions.

PART A — (10 × 2 = 20 marks)

1. State Kepler's 2nd law of planetary motion.

2. State the condition for visibility of satellite to an observer standing on earth surface.

3. List some antennas used in communication sub-system of spacecrafts.

4. Define the term "Figure of Merit".

5. What are spreading sequences?

6. What is meant by encryption?

7. What is the role played by duplexers?

8. State the functions of a LNA. Where is it employed?

9. List out the popular 'INTELSAT' – series.

10. Mention the application of INMARSAT systems.

PART B — ($5 \times 16 = 80$ marks)

11. (a) What are look angles? Explain how look angles are determined using sub-satellite points? Derive the necessary expressions for look angles. (16)

Or

(b) Give a detailed note on launching vehicles and the procedures employed for launching spacecraft in GEO orbits. (16)

12. (a) (i) With a neat sketch, explain the various modules of Attitude and Orbit Control (AOCS) subsystem. (10)

(ii) Derive the analytical expression for uplink CNR. (6)

Or

(b) In detail, explain the various sub-modules and their functions of a Telemetry, Tracking and Command (TT & C) subsystem. Draw required diagrams. (16)

13. (a) (i) In detail, explain the satellite TDMA frame structure with neat diagrams. Emphasize on all the important fields in the TDMA frame and its associated function. (10)

(ii) Give a broad outline on digital satellite links. (6)

Or

(b) (i) Elaborate on FDMA satellite networks. Putforth its advantages and limitations with justification. Draw all required diagrams to substantiate your argument. (11)

(ii) Explain the concept of compression in satellite links. (5)

14. (a) With neat diagrams, explain the procedure for measuring critical satellite parameters like C/N_0 and G/T. Emphasise on the significance of these parameters. (16)

Or

(b) In detail, explain the block diagram representation of a typical digital earth station (Transmitter and Receiver). Give the block diagrams. (16)

15. (a) In detail, discuss on a complete and detailed overview on various mobile satellite services. Provide all required diagrams. (16)

Or

(b) Give a detailed note on :

(i) DTH and world space receivers. (10)

(ii) Satellite Navigation System. (6)

Reg. No. : | | | | | | | | | | | |

V 4149

B.E./B.Tech. DEGREE EXAMINATION, APRIL/MAY 2008.

Eighth Semester

Electronics and Communication Engineering

EC 1015 — SATELLITE COMMUNICATION

(Regulation 2004)

Time : Three hours Maximum : 100 marks

Answer ALL questions.

PART A — (10 × 2 = 20 marks)

1. List out the frequency bands used for satellite services.

2. State Kepler's second law of planetary motion.

3. What is meant by momentum wheel stabilisation?

4. What are geostationary satellites?

5. What is meant by input back off of a transponder?

6. Give the formulae to compute the uplink carrier to noise ratio.

7. What are the limitations of FDMA-satellite access?

8. Distinguish between pre-assigned and demand-assigned TDMA satellite access.

9. Give the applications of satellites.

10. What are the various compression standards used in satellite applications?

PART B — (5 × 16 = 80 marks)

11. (a) What are orbital elements? Derive the six orbital elements of satellite from Newton's law of motion. (16)

Or

(b) How are the satellites positions estimated using the sub-satellite points? (16)

12. (a) What are look angles and derive the expressions for azimuth and elevation? (16)

Or

(b) With a neat block diagram, explain the attitude and orbit control system present in the space segment. (16)

13. (a) With a neat sketch, explain the power budget for a satellite link considering back off and rain fade margin. (16)

Or

(b) How does the system noise temperature affect the performance? Derive the expression for overall system noise temperature at the receiving earth station. (16)

14. (a) With a neat block diagram, explain the functioning of a SPADE system. (16)

Or

(b) Explain the TDMA burst and frame structure of satellite system. Draw the necessary diagrams. (16)

15. (a) In detail, give an account of various compression standards used in the satellite context. (16)

Or

(b) What is meant by DTH? What are the design issues to be considered for launching DTH systems? (16)

Reg. No. : | | | | | | | | | | | | |

Question Paper Code : 21293

B.E./B.Tech. DEGREE EXAMINATION, NOVEMBER/DECEMBER 2012.

Eighth Semester

Electronics and Communication Engineering

080290077 – SATELLITE COMMUNICATION

(Regulation 2008)

Time : Three hours — Maximum : 100 marks

Answer ALL questions.

PART A — (10 × 2 = 20 marks)

1. Mention the various types of satellite orbits.
2. Define the term 'azimuth'.
3. Mention the various mechanisms through which attitude control is attained.
4. What are transponders?
5. List out the types of modulation schemes employed in satellite communication.
6. Define the term 'beam switching'.
7. Give the significance of EIRP.
8. Define the term 'antenna gain'.
9. What are satellite phones?
10. What is meant by DAB? Give its significance.

PART B — (5 × 16 = 80 marks)

11. (a) (i) What are orbital elements? How are they helpful in locating satellites in orbital planes? (10)

(ii) Explain the launching procedure of geo-stationary satellites using launch vehicles. Give diagrams. (6)

Or

(b) State and derive the expressions for the look angles. Give necessary diagrams. (16)

12. (a) Explain how attitude control is established through various satellite stabilization techniques. (16)

Or

(b) Deduce the expression for overall carrier to noise ratio starting from received power flux. Indicate the power margin assigned to accommodate various losses excluding atmospheric losses. (16)

13. (a) With a neat block diagram, explain the working of a FDMA based satellite network. Analyse its merits and demerits. (16)

Or

(b) (i) In detail, explain the format structure of TDMA frame. Comment on the significance of each field. (10)

(ii) Explain satellite switched TDMA. (6)

14. (a) Give a detailed note on

(i) TVRO (5)

(ii) MATV (5)

(iii) Earth station antennas. (6)

Or

(b) With neat diagrams, explain how measurements on $\frac{G}{T}$ and $\frac{C}{N_0}$ are made. (16)

15. (a) In detail, explain the various mobile satellite services and their impact on society. (16)

Or

(b) Give a detailed note on

(i) DBS and DTH (8)

(ii) GRAMSAT and Business TV. (8)

Reg. No. : | | | | | | | | | | | |

Question Paper Code : 20258

B.E./B.Tech. DEGREE EXAMINATION, MAY/JUNE 2012.

Eighth Semester

Electronics and Communication Engineering

EC 2045/EC 810 — SATELLITE COMMUNICATION

(Regulation 2008)

Time : Three hours

Maximum : 100 marks

Answer ALL questions.

PART A — ($10 \times 2 = 20$ marks)

1. State Kepler's 2nd law of planetary motion.

2. State the condition for visibility of satellite to an observer standing on earth surface.

3. List some antennas used in communication sub-system of spacecrafts.

4. Define the term "Figure of Merit".

5. What are spreading sequences?

6. What is meant by encryption?

7. What is the role played by duplexers?

8. State the functions of a LNA. Where is it employed?

9. List out the popular 'INTELSAT' – series.

10. Mention the application of INMARSAT systems.

PART B — ($5 \times 16 = 80$ marks)

11. (a) What are look angles? Explain how look angles are determined using sub-satellite points? Derive the necessary expressions for look angles. (16)

Or

(b) Give a detailed note on launching vehicles and the procedures employed for launching spacecraft in GEO orbits. (16)

12. (a) (i) With a neat sketch, explain the various modules of Attitude and Orbit Control (AOCS) subsystem. (10)

(ii) Derive the analytical expression for uplink CNR. (6)

Or

(b) In detail, explain the various sub-modules and their functions of a Telemetry, Tracking and Command (TT & C) subsystem. Draw required diagrams. (16)

13. (a) (i) In detail, explain the satellite TDMA frame structure with neat diagrams. Emphasize on all the important fields in the TDMA frame and its associated function. (10)

(ii) Give a broad outline on digital satellite links. (6)

Or

(b) (i) Elaborate on FDMA satellite networks. Putforth its advantages and limitations with justification. Draw all required diagrams to substantiate your argument. (11)

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14. (a) With neat diagrams, explain the procedure for measuring critical satellite parameters like C/N_0 and G/T. Emphasise on the significance of these parameters. (16)

Or

(b) In detail, explain the block diagram representation of a typical digital earth station (Transmitter and Receiver). Give the block diagrams. (16)

15. (a) In detail, discuss on a complete and detailed overview on various mobile satellite services. Provide all required diagrams. (16)

Or

(b) Give a detailed note on :

(i) DTH and world space receivers. (10)

(ii) Satellite Navigation System. (6)

Reg. No. : | | | | | | | | | | | | |

Question Paper Code : 21293

B.E./B.Tech. DEGREE EXAMINATION, NOVEMBER/DECEMBER 2012.

Eighth Semester

Electronics and Communication Engineering

080290077 – SATELLITE COMMUNICATION

(Regulation 2008)

Time : Three hours Maximum : 100 marks

Answer ALL questions.

PART A — (10 × 2 = 20 marks)

1. Mention the various types of satellite orbits.
2. Define the term 'azimuth'.
3. Mention the various mechanisms through which attitude control is attained.
4. What are transponders?
5. List out the types of modulation schemes employed in satellite communication.
6. Define the term 'beam switching'.
7. Give the significance of EIRP.
8. Define the term 'antenna gain'.
9. What are satellite phones?
10. What is meant by DAB? Give its significance.

PART B — (5 × 16 = 80 marks)

11. (a) (i) What are orbital elements? How are they helpful in locating satellites in orbital planes? (10)

(ii) Explain the launching procedure of geo-stationary satellites using launch vehicles. Give diagrams. (6)

Or

(b) State and derive the expressions for the look angles. Give necessary diagrams. (16)

12. (a) Explain how attitude control is established through various satellite stabilization techniques. (16)

Or

(b) Deduce the expression for overall carrier to noise ratio starting from received power flux. Indicate the power margin assigned to accommodate various losses excluding atmospheric losses. (16)

13. (a) With a neat block diagram, explain the working of a FDMA based satellite network. Analyse its merits and demerits. (16)

Or

(b) (i) In detail, explain the format structure of TDMA frame. Comment on the significance of each field. (10)

(ii) Explain satellite switched TDMA. (6)

14. (a) Give a detailed note on

(i) TVRO (5)

(ii) MATV (5)

(iii) Earth station antennas. (6)

Or

(b) With neat diagrams, explain how measurements on $\frac{G}{T}$ and $\frac{C}{N_0}$ are made. (16)

15. (a) In detail, explain the various mobile satellite services and their impact on society. (16)

Or

(b) Give a detailed note on

(i) DBS and DTH (8)

(ii) GRAMSAT and Business TV. (8)

Reg. No. : [redacted]

Question Paper Code : 21343

B.E./B.Tech. DEGREE EXAMINATION, MAY/JUNE 2013.

Eighth Semester

Electronics and Communication Engineering

EC 2045/EC 810 — SATELLITE COMMUNICATION

(Regulation 2008)

(Common to PTEC 2045 — Satellite Communication for B.E. (Part-Time) Seventh Semester — Electronics and Communication Engineering — Regulation 2009)

Time : Three hours | Maximum : 100 marks

Answer ALL questions.

PART A — (10 × 2 = 20 marks)

1. Given the geostationary orbital radius 'r', the Earth's radius 'R' and speed of light 'C' how will you compute the time taken for a signal to pass from Earth to the Satellite and back again?

2. Enlist the traditional orbital Keplerian elements.

3. How is the attitude of a satellite controlled through active control?

4. Why the operation near the saturation point of a TWTA is to be avoided when multiple carriers are being amplified simultaneously?

5. When VSAT-type terminals involved CDMA offers several advantages for satellite networking. What are they?

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7. Give the reason for deploying a demodulator/remodulator unit in our home television set when we want to function in a satellite TV/FM receiving system.

8. What is known as polarization interleaving with reference to the Down link frequency?

9. When the available bandwidth is 500 MHZ, how many transponder each of bandwidth 24 MHZ can be accomodated.

10. What is meant by conjestion and slowstart with reference to Internet traffic.

PART B — (5 × 16 = 80 marks)

11. (a) (i) A satellite is orbiting the equatorial plane with a period from perigee to perigee of 10h. Given that the eccentricity is 0.002 and the earth's equatorial radius is 6378.1414 km how will you calculate the semi major axis.

(ii) Summarise how you will determine the look angles for the geostationary orbit? What are known as sun-synchronous orbits.

Or

(b) (i) How will you determine the sub satellite point?

(ii) Write a brief note on launch vehicles and propulsion.

12. (a) How do the TT and C subsystem perform aboard the spacecraft? Also explain the working of a transponder unit.

Or

(b) How is the performance of a satellite impaired due to external factors? Also suggest suitable methods to overcome the same.

13. (a) (i) Describe the ways in which demand assignment may be carried out in FDMA.

(ii) What is known as pre-assigned traffic?

Or

(b) (i) Calculate the probability of false detection, when N = 10 and d = 4.

(ii) For digital video broadcast what type of multiple access is best suited. Justify your answer.

14. (a) Show how MATV is used to provide reception of DDS to a small group of users. When this group is large what type of antenna should be used? Explain.

Or

(b) Analyse the functioning of Transmit — Receive Earth stations. With a block diagram explain how the redundant earth station functions.

15. (a) Enumerate how GSM and GPS deploying Satellites have improved the mobility of the customers.

Or

(b) Write short notes on the specialized services offered by satellites for video conferencing e-mail and internet.

———————

Reg. No. :

Question Paper Code : 51385

B.E./B.Tech. DEGREE EXAMINATION, APRIL 2014.

Eighth Semester

Electronics and Communication Engineering

EC 2045/EC 810/10144 ECE 52 — SATELLITE COMMUNICATION

(Regulation 2008)

Time : Three hours | Maximum : 100 marks

Answer ALL questions.

PART A — (10 × 2 = 20 marks)

1. Define geostationary orbit.

2. What do you mean by apogee?

3. Why is noise temperature a useful concept in communication receivers?

4. Write the objectives with which the downlink of any satellite communication system must be designed.

5. Define multiplexing.

6. Write the two basic problems in satellite digital transmission.

7. For a given satellite and signal transmission, what are the earth station parameters affecting the C/N ratio?

8. Why is the cassegrain antenna popular for large earth stations?

9. Write the four kinds of communications that the network structure of MSAT can accommodate.

10. Write the two areas of satellite communications which are gaining major thrust from leading satellite industries and organisations in recent years.

PART B — (5 × 16 = 80 marks)

11. (a) Explain how Kepler's and Newton's laws are used to describe the orbit. (16)

Or

(b) Explain the following :

(i) Orbital perturbations. (8)

(ii) Launching vehicles. (8)

12. (a) From the calculation of system noise temperature prove that C/N ratio is directly proportional to G/T ratio. (16)

Or

(b) (i) List and explain the factors governing the design of satellite links. (10)

(ii) What are the factors contributing to noise in an earth station receiving channel? (6)

13. (a) Briefly discuss about analog voice transmission. (16)

Or

(b) Compare the salient features of FDMA, TDMA and CDMA. (16)

14. (a) Briefly explain about the test equipments for earth stations. (16)

Or

(b) (i) Briefly discuss on TVRO systems. (8)

(ii) Describe how the gain of large antennas can be optimized. (8)

15. (a) Explain the types of INTELSAT satellites with respect to basic space craft characteristics and vehicle type. (16)

Or

(b) (i) Explain the block diagram of an outdoor unit for a DBS home receiver. (8)

(ii) With a block schematic explain about DTH system. (8)

———————

Reg. No. :

V 4149

B.E./B.Tech. DEGREE EXAMINATION, APRIL/MAY 2008.

Eighth Semester

Electronics and Communication Engineering

EC 1015 — SATELLITE COMMUNICATION

(Regulation 2004)

Time : Three hours　　　　Maximum : 100 marks

Answer ALL questions.

PART A — (10 × 2 = 20 marks)

1. List out the frequency bands used for satellite services.

2. State Kepler's second law of planetary motion.

3. What is meant by momentum wheel stabilisation?

4. What are geostationary satellites?

5. What is meant by input back off of a transponder?

6. Give the formulae to compute the uplink carrier to noise ratio.

7. What are the limitations of FDMA-satellite access?

8. Distinguish between pre-assigned and demand-assigned TDMA satellite access.

9. Give the applications of satellites.

10. What are the various compression standards used in satellite applications?

PART B — (5 × 16 = 80 marks)

11. (a) What are orbital elements? Derive the six orbital elements of satellite from Newton's law of motion. (16)

Or

(b) How are the satellites positions estimated using the sub-satellite points? (16)

12. (a) What are look angles and derive the expressions for azimuth and elevation? (16)

Or

(b) With a neat block diagram, explain the attitude and orbit control system present in the space segment. (16)

13. (a) With a neat sketch, explain the power budget for a satellite link considering back off and rain fade margin. (16)

Or

(b) How does the system noise temperature affect the performance? Derive the expression for overall system noise temperature at the receiving earth station. (16)

14. (a) With a neat block diagram, explain the functioning of a SPADE system. (16)

Or

(b) Explain the TDMA burst and frame structure of satellite system. Draw the necessary diagrams. (16)

15. (a) In detail, give an account of various compression standards used in the satellite context. (16)

Or

(b) What is meant by DTH? What are the design issues to be considered for launching DTH systems? (16)

———————

CELLULAR MOBILE COMMUNICATION

UNIT I

INTRODUCTION TO WIRELESS MOBILE COMMUNICATION

Introduction:

- In 1897, Guglielmo Marconi first demonstrated radio's ability to provide continuous contact with ships sailing the English channel.

- During the past 10 years, fueled by
  - Digital and RF circuit fabrication improvements
  - New VLSI technologies
  - Other miniaturization technologies
    (e.g., passive components)
  - The mobile communications industry has grown by orders of magnitude.

- The trends will continue at an even greater pace during the next decade.

Evolution of Mobile Radio Communications

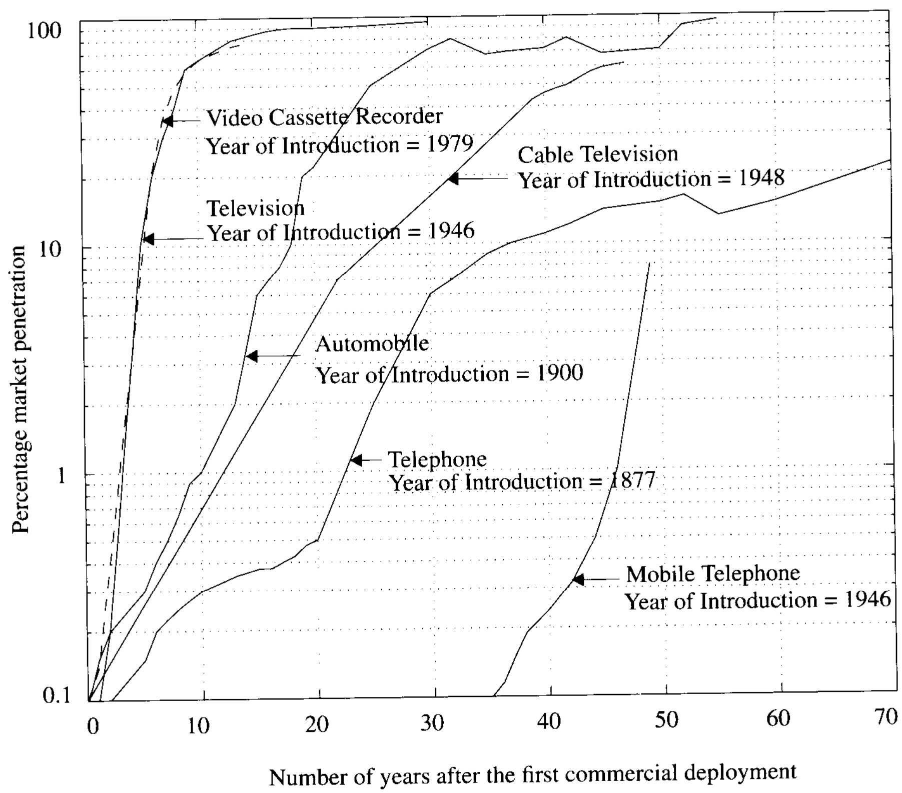
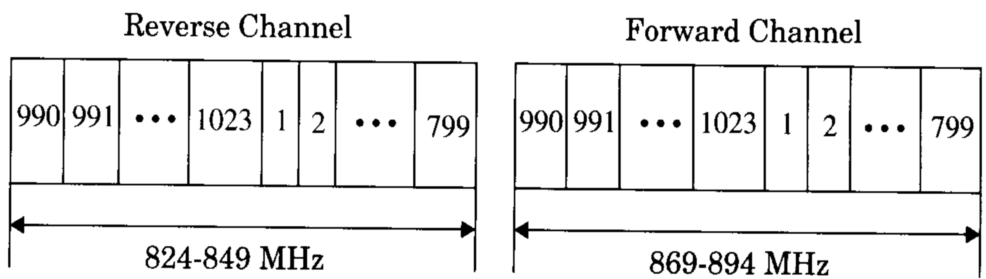


Figure 1.1
Figure illustrating the growth of mobile telephony as compared to other popular inventions of this century.

- In 1934, AM mobile communication systems for municipal police radio systems.
  - Vehicle ignition noise was a major problem.
- In 1946, FM mobile communications for the first public mobile telephone service
  - Each system used a single, high-powered transmitter and large tower to cover distances of over 50 km.
  - Used 120 kHz of RF bandwidth in a half-duplex mode. (push-to-talk release-to-listen systems.)
  - Large RF bandwidth was largely due to the technology difficulty (in mass-producing tight RF filter and low-noise, front-end receiver amplifiers.)
- In 1950, the channel bandwidth was cut in half to 60kHZ due to improved technology.
- By the mid 1960s, the channel bandwidth again was cut to 30 kHZ.
- Thus, from WWII to the mid 1960s, the spectrum efficiency was improved only a factor of 4 due to the technology advancements.

- Also in 1950s and 1960s, automatic channel truncking was introduced in IMTS(Improved Mobile Telephone Service.)
  - offering full duplex, auto-dial, auto-trunking
  - became saturated quickly
  - By 1976, has only twelve channels and could only serve 543 customers in New York City of 10 millions populations.
- Cellular radiotelephone
  - Developed in 1960s by Bell Lab and others
  - The basic idea is to reuse the channel frequency at a sufficient distance to increase the spectrum efficiency.
  - But the technology was not available to implement until the late 1970s. (mainly the microprocessor and DSP technologies.)

- In 1983, AMPS (Advanced Mobile Phone System, IS-41) deployed by Ameritech in Chicago.
  - 40 MHz spectrum in 800 MHz band
  - 666 channels (+ 166 channels), per Fig 1.2.
  - Each duplex channel occupies > 60 kHz (30+30) FDMA to maximize capacity.
  - Two cellular providers in each market.



	Channel Number	Center Frequency (MHz)
Reverse Channel	$1 \le N \le 799$	$0.030N + 825.0$
	$990 \le N \le 1023$	$0.030(N - 1023) + 825.0$
Forward Channel	$1 \le N \le 799$	$0.030N + 870.0$
	$990 \le N \le 1023$	$0.030(N - 1023) + 870.0$

(Channels 800 - 989 are unused)

Figure 1.2
Frequency spectrum allocation for the U.S. cellular radio service. Identically labeled channels in the two bands form a forward and reverse channel pair used for duplex communication between the base station and mobile. Note that the forward and reverse channels in each pair are separated by 45 MHz.

- In late 1991, U.S. Digital Cellular (USDC, IS-54) was introduced.
  - to replace AMPS analog channels
  - 3 times of capacity due to the use of digital modulation ($\frac{\pi}{4}$ DQPSK), speech coding, and TDMA technologies.
  - could further increase up to 6 times of capacity given the advancements of DSP and speech coding technologies.
- In mid 1990s, Code Division Multiple Access (CDMA, IS-95) was introduced by Qualcomm.
  - based on spread spectrum technology.
  - supports 6-20 times of users in 1.25 MHz shared by all the channels.
  - each associated with a unique code sequence.
  - operate at much smaller SNR.(FdB)

Table 1.1 Major Mobile Radio Standards in North America

Standard	Type	Year of Introduction	Multiple Access	Frequency Band	Modulation	Channel Bandwidth
AMPS	Cellular	1983	FDMA	824-894 MHz	FM	30 kHz
NAMPS	Cellular	1992	FDMA	824-894 MHz	FM	10 kHz
USDC	Cellular	1991	TDMA	824-894 MHz	$\pi/4$-DQPSK	30 kHz
CDPD	Cellular	1993	FH/ Packet	824-894 MHz	GMSK	30 kHz
IS-95	Cellular/ PCS	1993	CDMA	824-894 MHz 1.8-2.0 GHz	QPSK/ BPSK	1.25 MHz
GSC	Paging	1970s	Simplex	Several	FSK	12.5 kHz
POCSAG	Paging	1970s	Simplex	Several	FSK	12.5 kHz
FLEX	Paging	1993	Simplex	Several	4-FSK	15 kHz
DCS-1900 (GSM)	PCS	1994	TDMA	1.85-1.99 GHz	GMSK	200 kHz
PACS	Cordless/ PCS	1994	TDMA/ FDMA	1.85-1.99 GHz	$\pi/4$-DQPSK	300 kHz
MIRS	SMR/PCS	1994	TDMA	Several	16-QAM	25 kHz
iDen	SMR/PCS	1995	TDMA	Several	16-QAM	25 kHz

users. In the U.S., the PACS standard, developed by Bellcore and Motorola, is likely to be used inside office buildings as a wireless voice and data telephone system or radio local loop. The Personal Handyphone System (PHS) standard supports indoor and local loop applications in Japan. Local loop concepts are explained in Chapter 10.

The world's first cellular system was implemented by the Nippon Telephone and Telegraph company (NTT) in Japan. The system, deployed in 1979, uses 600 FM duplex channels (25 kHz for each one-way link) in the 800 MHz band. In Europe, the Nordic Mobile Telephone system

Table 1.2 Major Mobile Radio Standards in Europe

Standard	Type	Year of Introduction	Multiple Access	Frequency Band	Modulation	Channel Bandwidth
E-TACS	Cellular	1985	FDMA	900 MHz	FM	25 kHz
NMT-450	Cellular	1981	FDMA	450-470 MHz	FM	25 kHz
NMT-900	Cellular	1986	FDMA	890-960 MHz	FM	12.5 kHz
GSM	Cellular /PCS	1990	TDMA	890-960 MHz	GMSK	200 kHz
C-450	Cellular	1985	FDMA	450-465 MHz	FM	20 kHz/ 10 kHz
ERMES	Paging	1993	FDMA	Several	4-FSK	25 kHz
CT2	Cordless	1989	FDMA	864-868 MHz	GFSK	100 kHz
DECT	Cordless	1993	TDMA	1880-1900 MHz	GFSK	1.728 MHz
DCS-1800	Cordless /PCS	1993	TDMA	1710-1880 MHz	GMSK	200 kHz

Table 1.3 Major Mobile Radio Standards in Japan

Standard	Type	Year of Introduction	Multiple Access	Frequency Band	Modulation	Channel Bandwidth
JTACS	Cellular	1988	FDMA	860-925 MHz	FM	25 kHz
PDC	Cellular	1993	TDMA	810-1501 MHz	$\pi/4$-DQPSK	25 kHz
NTT	Cellular	1979	FDMA	400/800 MHz	FM	25 kHz
NTACS	Cellular	1993	FDMA	843-925 MHz	FM	12.5 kHz
NTT	Paging	1979	FDMA	280 MHz	FSK	12.5 kHz
NEC	Paging	1979	FDMA	Several	FSK	10 kHz
PHS	Cordless	1993	TDMA	1895-1907 MHz	$\pi/4$-DQPSK	300 kHz

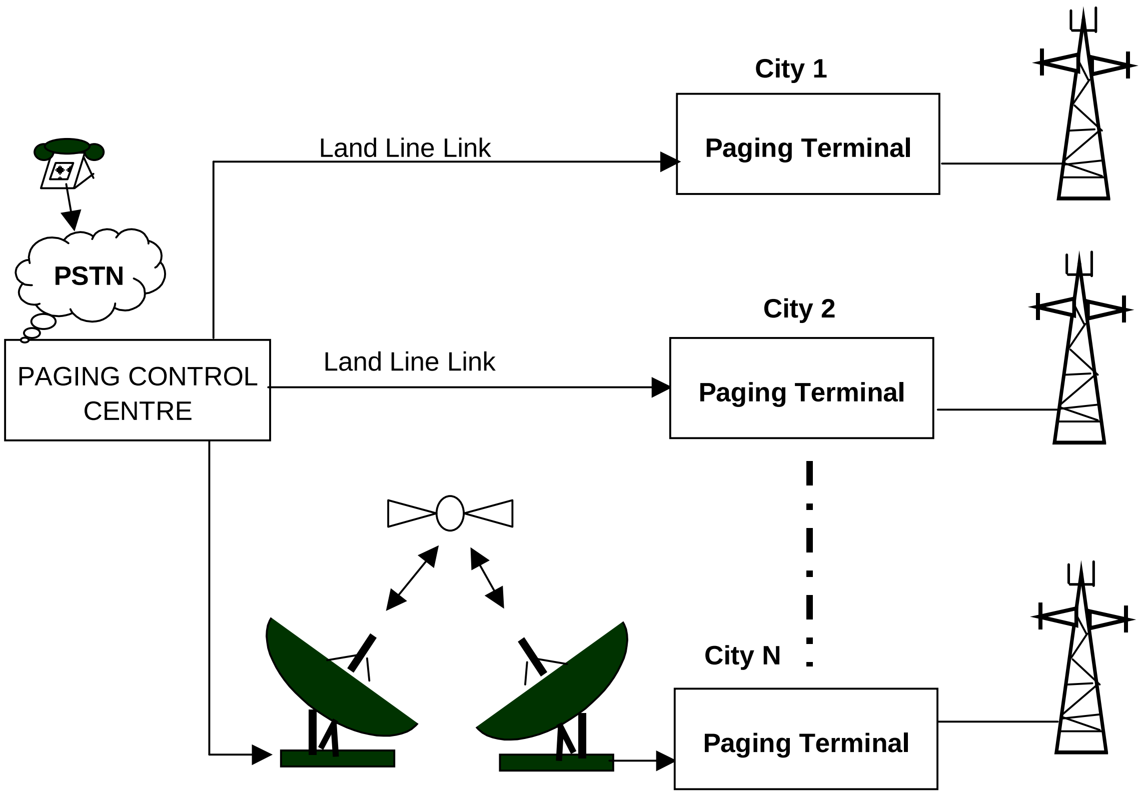
Examples of Mobile Radio Systems

Table 1.4 Wireless Communications System Definitions

Base Station	A fixed station in a mobile radio system used for radio communication with mobile stations. Base stations are located at the center or on the edge of a coverage region and consist of radio channels and transmitter and receiver antennas mounted on a tower.
Control Channel	Radio channels used for transmission of call setup, call request, call initiation, and other beacon or control purposes.
Forward Channel	Radio channel used for transmission of information from the base station to the mobile.
Full Duplex Systems	Communication systems which allow simultaneous two-way communication. Transmission and reception is typically on two different channels (FDD) although new cordless/PCS systems are using TDD.
Half Duplex Systems	Communication systems which allow two-way communication by using the same radio channel for both transmission and reception. At any given time, the user can only either transmit or receive information.
Handoff	The process of transferring a mobile station from one channel or base station to another.
Mobile Station	A station in the cellular radio service intended for use while in motion at unspecified locations. Mobile stations may be hand-held personal units (portables) or installed in vehicles (mobiles).
Mobile Switching Center	Switching center which coordinates the routing of calls in a large service area. In a cellular radio system, the MSC connects the cellular base stations and the mobiles to the PSTN. An MSC is also called a mobile telephone switching office (MTSO).
Page	A brief message which is broadcast over the entire service area, usually in a simulcast fashion by many base stations at the same time.
Reverse Channel	Radio channel used for transmission of information from the mobile to base station.
Roamer	A mobile station which operates in a service area (market) other than that from which service has been subscribed.
Simplex Systems	Communication systems which provide only one-way communication.
Subscriber	A user who pays subscription charges for using a mobile communications system.
Transceiver	A device capable of simultaneously transmitting and receiving radio signals.

- In FDD,
  - A device, called a duplexer, is used inside the subscriber unit to enable the same antenna to be used for simultaneous transmission and reception.
  - To facilitate FDD, it is necessary to separate the XMIT and RCVD frequencies by about 5% of the nominal RF frequency, so that the duplexer can provide sufficient isolation while being inexpensively manufactured.
- In TDD,
  - Only possible with digital transmission format and digital modulation.
  - Very sensitive to timing. Consequently, only used for indoor or small area wireless applications.

Paging Systems



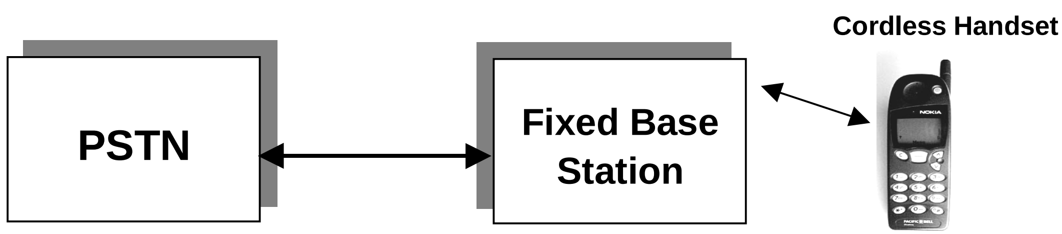
- Paging receivers are simple and inexpensive, but the transmission system required is quite sophisticated. (simulcasting)
- designed to provide ultra-reliable coverage, even inside buildings
- Buildings can attenuate radio signals by 20 or 30 dB, making the choice of base station locations difficult for the paging companies.
- Small RF bandwidths are used to maximize the signal-to-noise ratio at each paging receiver, so low data rates (6400 bps or less) are used.

Wireless Local Loop

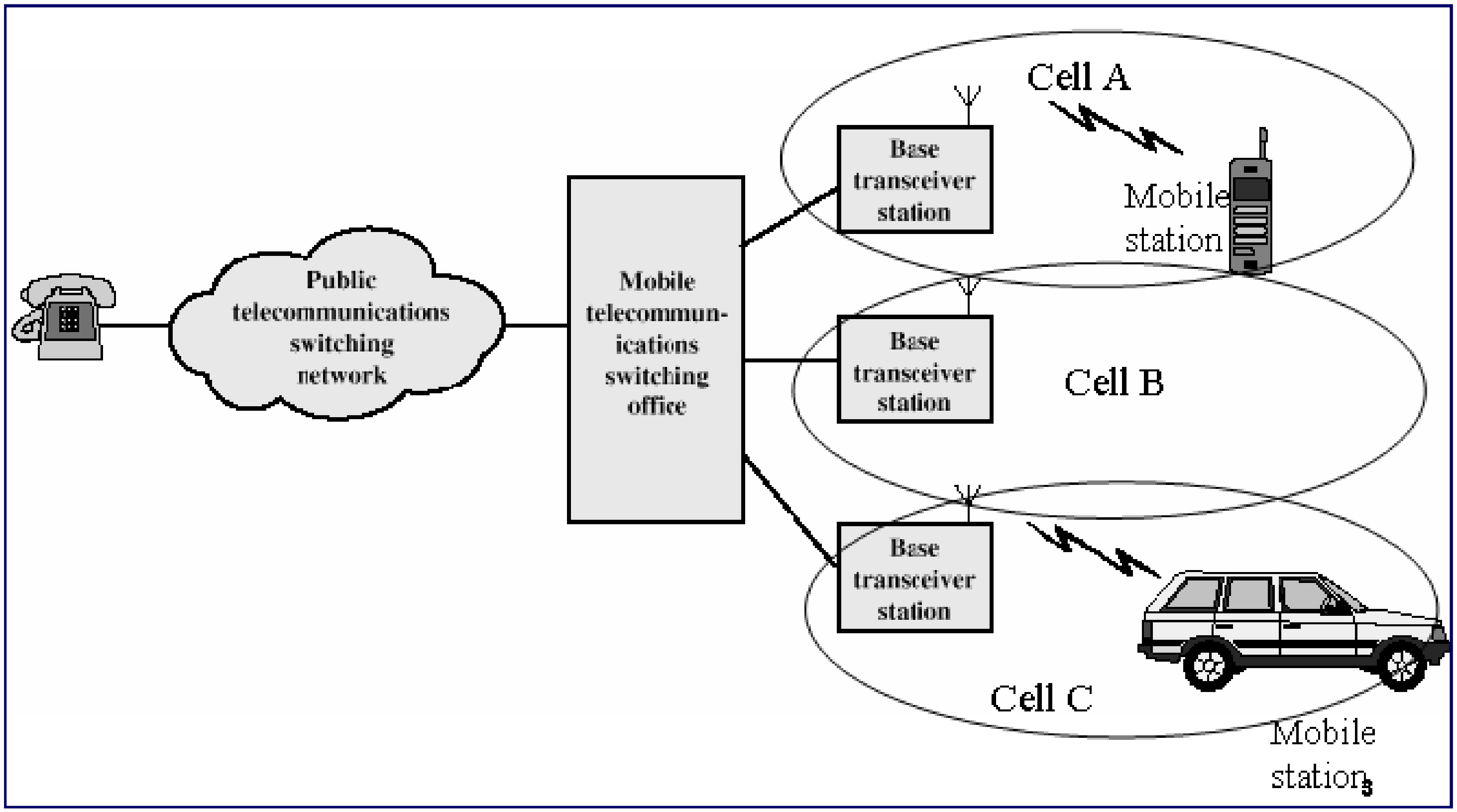
- In the telephone networks, the circuit between the subscriber's equipment (e.g. telephone set) and the local exchange is called the subscriber loop or local loop.
- Copper wire has been used as the medium for local loop to provide voice and voice-band data services.
- Since 1980s, the demand for communications services has increased explosively. There has been a great need for the basic telephone service, i.e. the plain old telephone service (POTS) in developing countries.
- Wireless local loop provides two-ways a telephone system…………..
- Wireless local loop includes cordless access system, proprietary fixed radio access system and fixed cellular system. It is also known as fixed radio wireless. This can be in an office or home.
- Broadband Wireless Access (BWA), Radio In The Loop (RITL), Fixed-Radio Access (FRA) and Fixed Wireless Access (FWA).

Cordless Telephone System

- To Connect a Fixed Base Station to a Portable Cordless Handset
- Early Systems (1980s) have very limited range of few tens of meters [within a House Premises]
- Modern Systems [PACS, DECT, PHS, PCS] can provide a limited range & mobility within Urban Centers



- Limitations of Simple Mobile Radio Systems
- The Cellular Approach
  - Divides the Entire Service Area into Several Small Cells
  - Reuse the Frequency
- Basic Components of a Cellular Telephone System
  - **Cellular Mobile Phone**: A light-weight hand-held set which is an outcome of the marriage of Graham Bell's Plain Old Telephone Technology [1876] and Marconi's Radio Technology [1894] [although a very late delivery but very cute]
  - **Base Station**: A Low Power Transmitter, other Radio Equipment [Transceivers] plus a small Tower
  - **Mobile Switching Center [MSC] /Mobile Telephone Switching Office[MTSO]**
    - An Interface between Base Stations and the PSTN
    - Controls all the Base Stations in the Region and Processes User ID and other Call Parameters
    - A typical MSC can handle up to 100,000 Mobiles, and 5000 Simultaneous Calls
    - Handles Handoff Requests, Call Initiation Requests, and all Billing & System Maintenance Functions

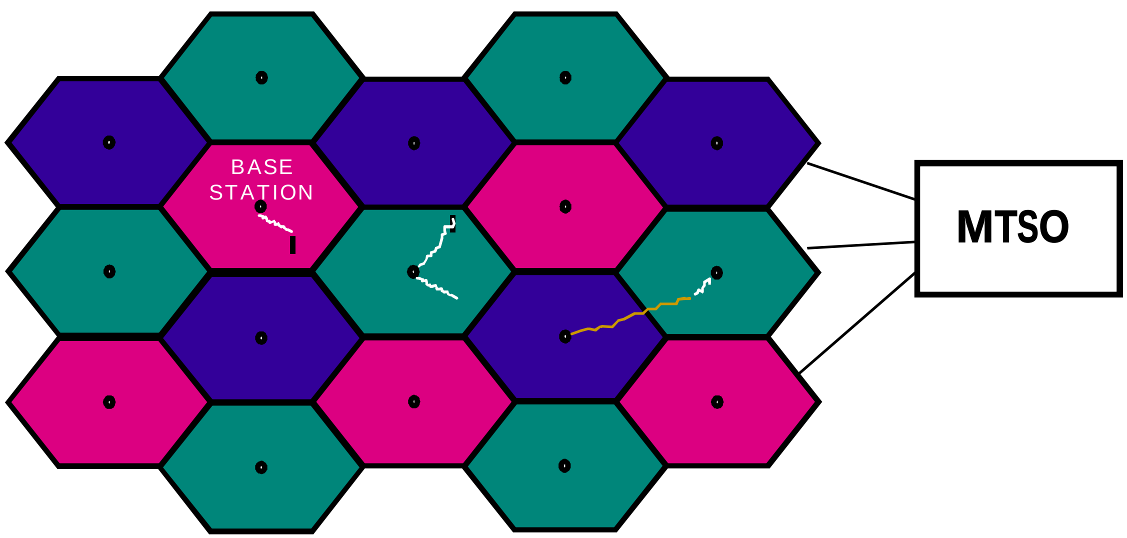


Public telecommunications switching network
Mobile telecommun- ications switching office
Base transceiver station
Base transceiver station
Base transceiver station
Cell A
Cell B
Cell C
Mobile station
Mobile station

- The Cellular Concept
  - RF spectrum is a valuable and scarce commodity
  - RF signals attenuate over distance
  - Cellular network divides coverage area into cells, each served by its own base station transceiver and antenna
  - Low (er) power transmitters used by BSs; transmission range determines cell boundary
  - RF spectrum divided into distinct groups of channels
  - Adjacent cells are (usually) assigned different channel groups to avoid interference
  - Cells separated by a sufficiently large distance to avoid mutual interference can be assigned the same channel group $\Rightarrow$ frequency reuse among co-channel cells

Cellular Systems: Reuse channels to maximize capacity

- Geographic region divided into cells
- Frequencies/timeslots/codes reused at spatially-separated locations.
- Co-channel interference between same color cells.
- Base stations/MTSOs coordinate handoff and control functions
- Shrinking cell size increases capacity, as well as networking burden



Trends in Cellular radio and Personal Communications

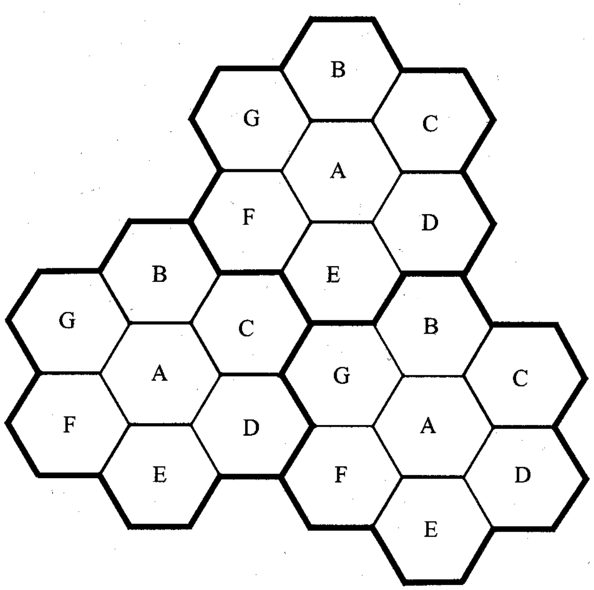
- PCS/PCN: PCS calls for more personalized services whereas PCN refers to Wireless Networking Concept-any person, anywhere, anytime can make a call using PC. PCS and PCN terms are sometime used interchangeably
- IEEE 802.11: A standard for computer communications using wireless links[inside building].
- ETSI's 20 Mbps HIPER LAN: Standard for indoor Wireless Networks
- IMT-2000 [International Mobile Telephone-2000 Standard]: A 3G universal, multi-function, globally compatible Digital Mobile Radio Standard is in making
- Satellite-based Cellular Phone Systems
- A very good Chance for Developing Nations to Improve their Communication Networks

UNIT II

CELLULAR CONCEPT AND SYSTEM DESIGN FUNDAMENTALS

2.1 Introduction to Cellular Systems

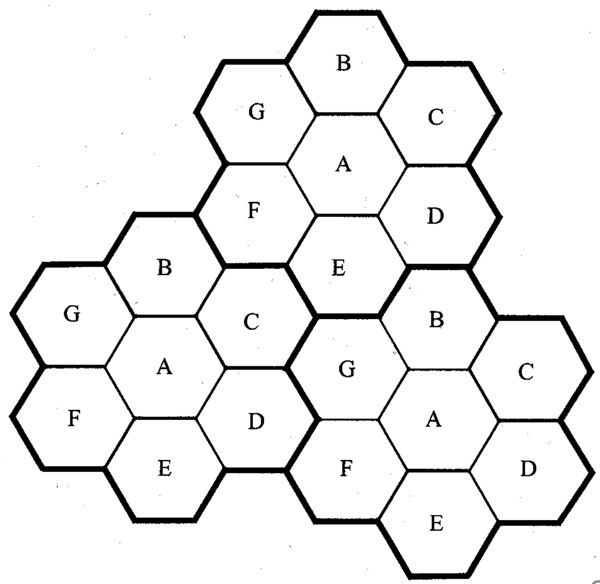
- Solves the problem of spectral congestion and user capacity.
- Offer very high capacity in a limited spectrum without major technological changes.
- Reuse of radio channel in different cells.
- Enable a fix number of channels to serve an arbitrarily large number of users by reusing the channel throughout the coverage region.



Frequency Reuse

- Each cellular base station is allocated a group of radio channels within a small geographic area called a *cell*.
- Neighboring cells are assigned different channel groups.
- By limiting the coverage area to within the boundary of the cell, the channel groups may be reused to cover different cells.
- Keep interference levels within tolerable limits.
- Frequency reuse or frequency planning

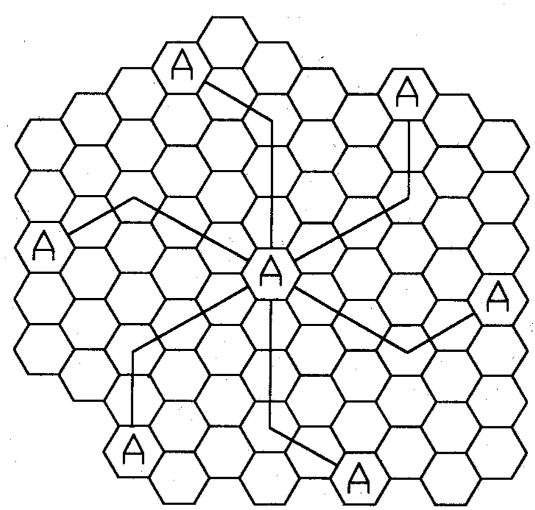
  - seven groups of channel from A to G
  - footprint of a cell - actual radio coverage
  - omni-directional antenna v.s. directional antenna



- Hexagonal geometry has
  - exactly six equidistance neighbors
  - the lines joining the centers of any cell and each of its neighbors are separated by multiples of 60 degrees.
- Only certain cluster sizes and cell layout are possible.
- The number of cells per cluster, *N*, can only have values which satisfy

$$N = i^2 + ij + j^2$$

- Co-channel neighbors of a particular cell, ex, *i=3* and *j=2*.

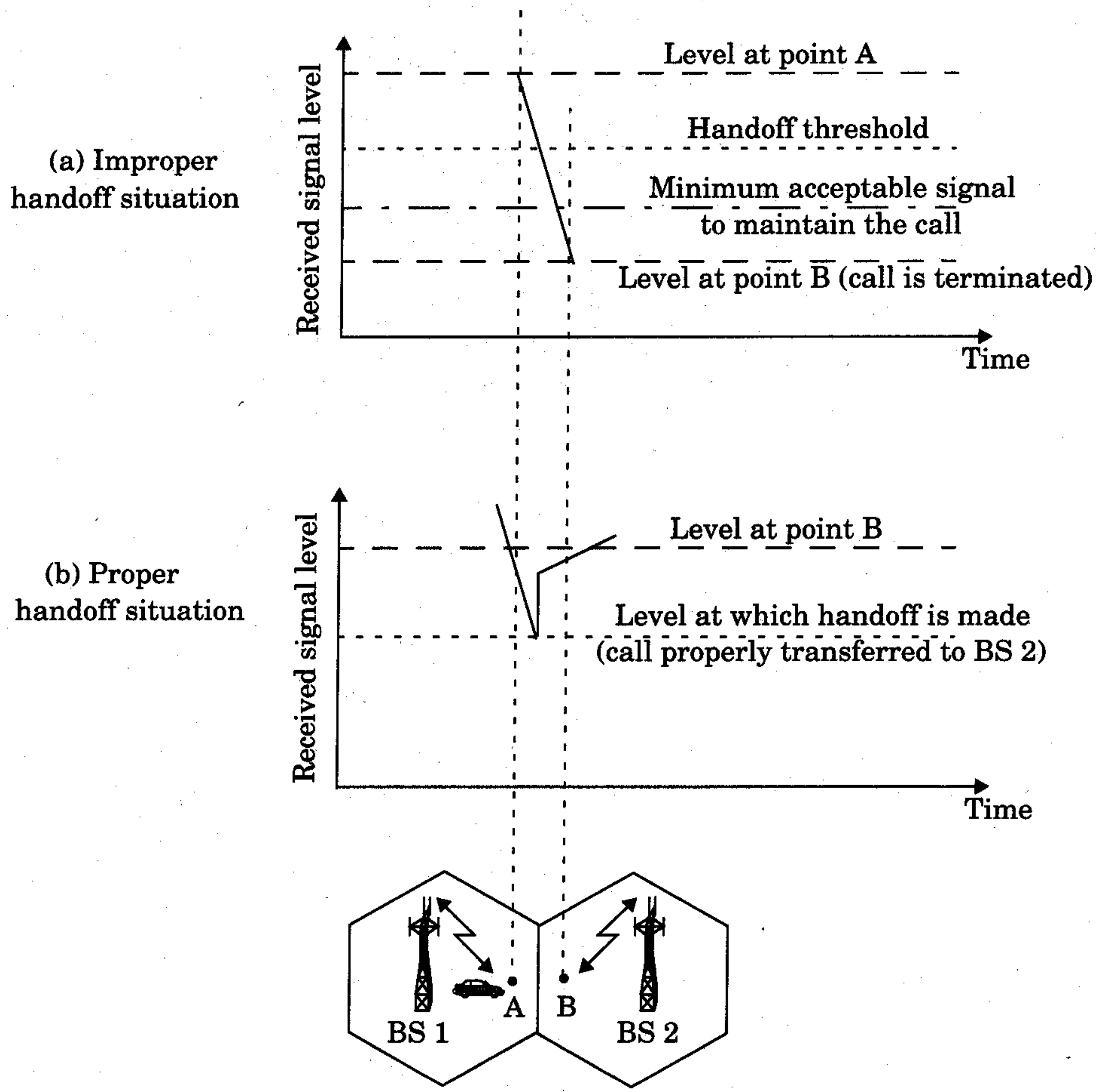


Channel Assignment Strategies

- Frequency reuse scheme
  - increases capacity
  - minimize interference
- Channel assignment strategy
  - fixed channel assignment
  - dynamic channel assignment
- Fixed channel assignment
  - each cell is allocated a predetermined set of voice channel
  - any new call attempt can only be served by the unused channels
  - the call will be *blocked* if all channels in that cell are occupied
- Dynamic channel assignment
  - channels are not allocated to cells permanently.
  - allocate channels based on request.
  - reduce the likelihood of blocking, increase capacity.

2.4 Handoff Strategies

- When a mobile moves into a different cell while a conversation is in progress, the MSC automatically transfers the call to a new channel belonging to the new base station.
- Handoff operation
  - identifying a new base station
  - re-allocating the voice and control channels with the new base station.
- Handoff Threshold
  - Minimum usable signal for acceptable voice quality (-90dBm to -100dBm)
  - Handoff margin $\Delta = P_{r,handoff} - P_{r,minimum\ usable}$ cannot be too large or too small.
  - If Δ is too large, unnecessary handoffs burden the MSC
  - If Δ is too small, there may be insufficient time to complete handoff before a call is lost.



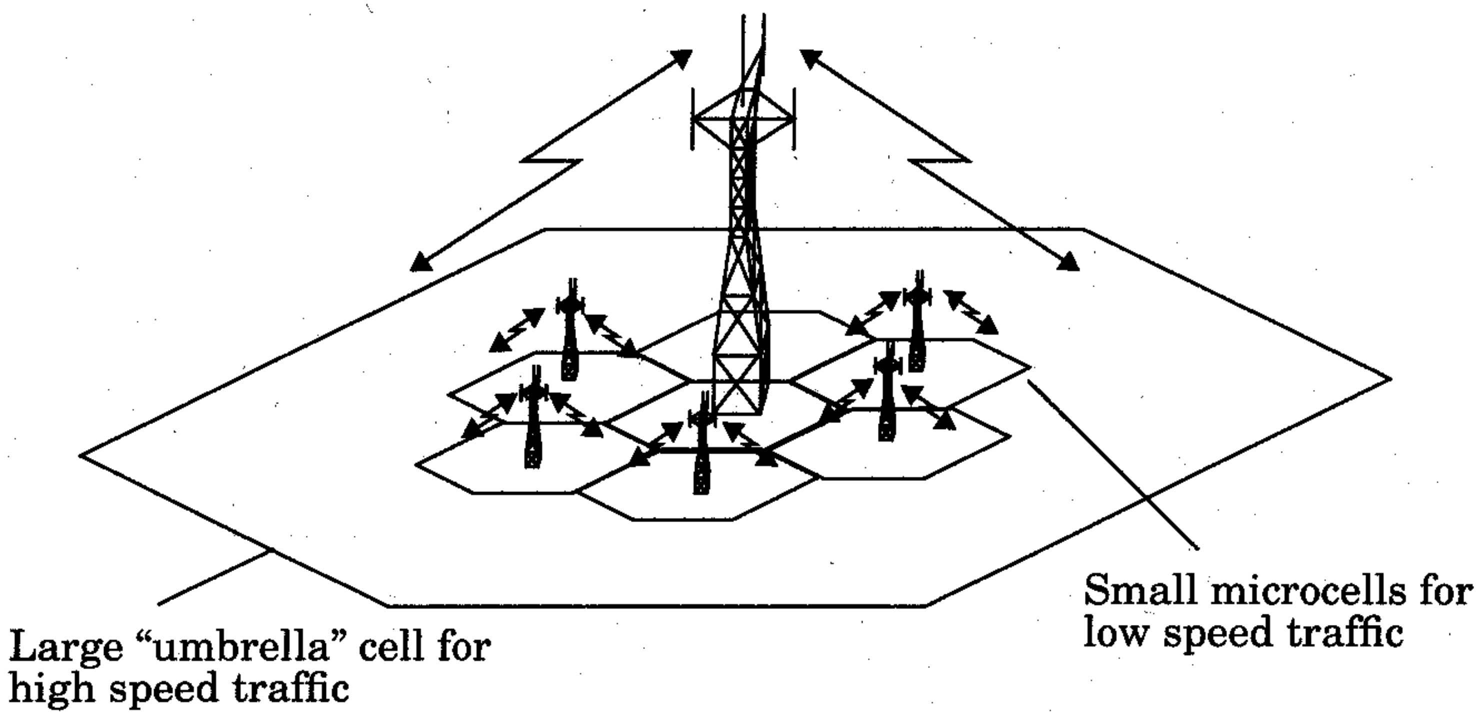
(a) Improper
handoff situation
Received signal level
Level at point A
Handoff threshold
Minimum acceptable signal
to maintain the call
Level at point B (call is terminated)
Time
(b) Proper
handoff situation
Received signal level
Level at point B
Level at which handoff is made
(call properly transferred to BS 2)
Time
BS 1
A
B
BS 2

- Handoff must ensure that the drop in the measured signal is not due to momentary fading and that the mobile is actually moving away from the serving base station.
- Running average measurement of signal strength should be optimized so that unnecessary handoffs are avoided.
  - Depends on the speed at which the vehicle is moving.
  - Steep short term average -> the hand off should be made quickly
  - The speed can be estimated from the statistics of the received short-term fading signal at the base station
- Dwell time: the time over which a call may be maintained within a cell without handoff.
- Dwell time depends on
  - propagation
  - interference
  - distance
  - speed

- Handoff measurement
  - In first generation analog cellular systems, signal strength measurements are made by the base station and supervised by the MSC.
  - In second generation systems (TDMA), handoff decisions are mobile assisted, called mobile assisted handoff (MAHO)
- Intersystem handoff: If a mobile moves from one cellular system to a different cellular system controlled by a different MSC.
- Handoff requests is much important than handling a new call.

Practical Handoff Consideration

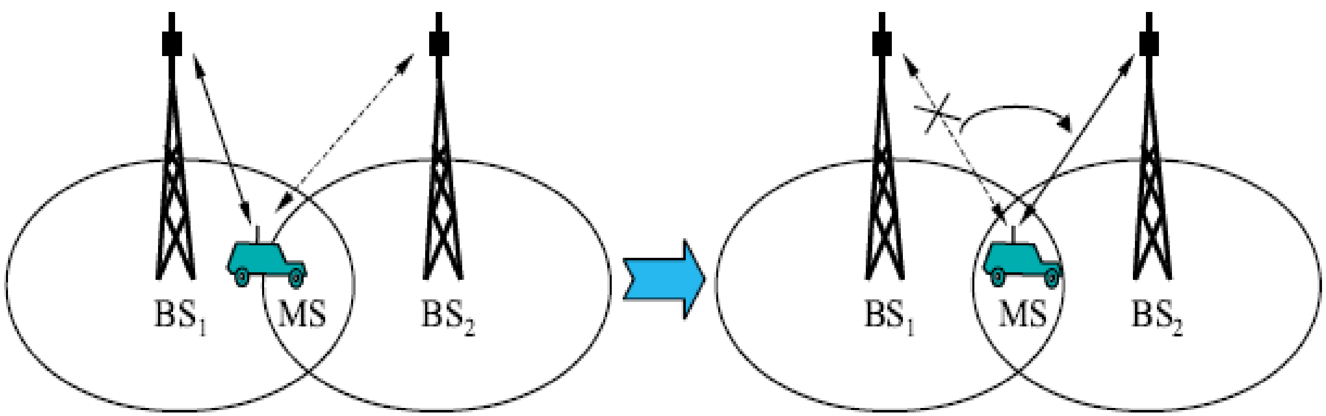
- Different type of users
  - High speed users need frequent handoff during a call.
  - Low speed users may never need a handoff during a call.
- Microcells to provide capacity, the MSC can become burdened if high speed users are constantly being passed between very small cells.
- Minimize handoff intervention
  - handle the simultaneous traffic of high speed and low speed users.
- Large and small cells can be located at a single location (umbrella cell)
  - different antenna height
  - different power level
- Cell dragging problem: pedestrian users provide a very strong signal to the base station
  - The user may travel deep within a neighboring cell


Large “umbrella” cell for
high speed traffic
Small microcells for
low speed traffic

- Handoff for first generation analog cellular systems
  - 10 secs handoff time
  - Δ is in the order of 6 dB to 12 dB
- Handoff for second generation cellular systems, e.g., GSM
  - 1 to 2 seconds handoff time
  - mobile assists handoff
  - Δ is in the order of 0 dB to 6 dB
  - Handoff decisions based on signal strength, co-channel interference, and adjacent channel interference.
- IS-95 CDMA spread spectrum cellular system
  - Mobiles share the channel in every cell.
  - No physical change of channel during handoff
  - MSC decides the base station with the best receiving signal as the service station
-

Types of Handoffs:

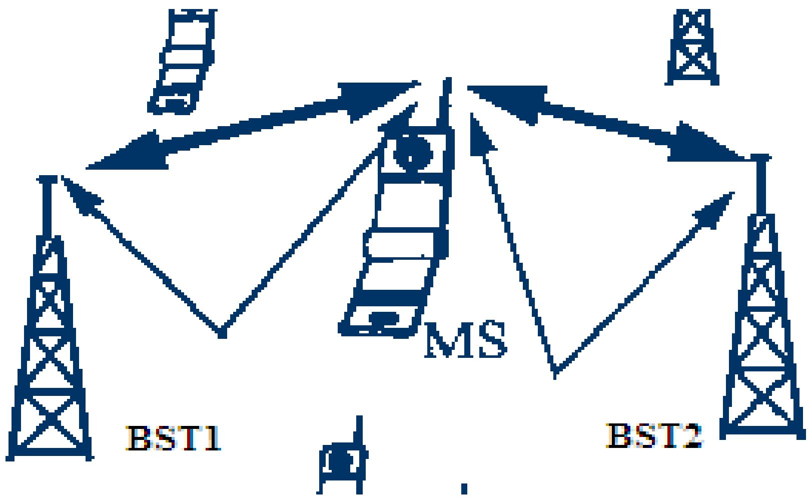
- Hard handoff: “break before make” connection
- Intra and inter-cell handoffs



Hard Handoff between the MS and BSs

Cont.

- Soft handoff: “make-before-break” connection.
- Mobile directed handoff.
- Multiways and softer handoffs



Soft Handoff between MS and BSTs

Handoff Prioritization:

Two basic methods of handoff prioritization are :

- Guard Channels
- Queuing of Handoff

2.5 Interference and System Capacity

- Sources of interference
  - another mobile in the same cell
  - a call in progress in the neighboring cell
  - other base stations operating in the same frequency band
  - noncellular system leaks energy into the cellular frequency band
- Two major cellular interference
  - co-channel interference
  - adjacent channel interference

2.5.1 Co-channel Interference and System Capacity

- Frequency reuse - there are several cells that use the same set of frequencies
  - co-channel cells
  - co-channel interference
- To reduce co-channel interference, co-channel cell must be separated by a minimum distance.
- When the size of the cell is approximately the same
  - co-channel interference is independent of the transmitted power
  - co-channel interference is a function of
    - *R*: Radius of the cell
    - *D*: distance to the center of the nearest co-channel cell
- Increasing the ratio $Q=D/R$, the interference is reduced.
- *Q* is called the co-channel reuse ratio

- For a hexagonal geometry

$$Q = \frac{D}{R} = \sqrt{3N}$$

- A small value of Q provides large capacity
- A large value of Q improves the transmission quality - smaller level of co-channel interference
- A tradeoff must be made between these two objectives

Table 2.1 Co-channel Reuse Ratio for Some Values of N

	Cluster Size (N)	Co-channel Reuse Ratio(Q)
$i = 1, j = 1$	3	3
$i = 1, j = 2$	7	4.58
$i = 2, j = 2$	12	6
$i = 1, j = 3$	13	6.24

- Let i_0 be the number of co-channel interfering cells. The signal-to-interference ratio (SIR) for a mobile receiver can be expressed as

$$\frac{S}{I} = \frac{S}{\sum_{i=1}^{i_0} I_i}$$

S: the desired signal power

I_i: interference power caused by the *i*th interfering co-channel cell base station

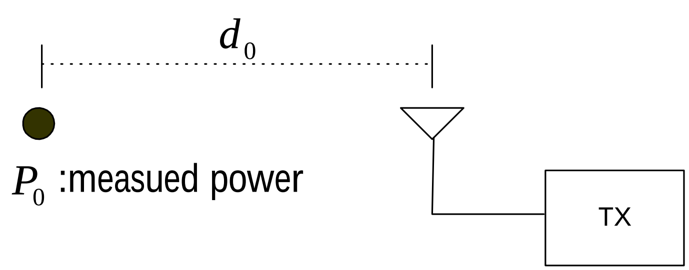
- The average received power at a distance *d* from the transmitting antenna is approximated by

$$P_r = P_0 \left(\frac{d}{d_0} \right)^{-n}$$

or

$$P_r(\text{dBm}) = P_0(\text{dBm}) - 10n \log\left(\frac{d}{d_0} \right)$$

close-in reference point



n is the path loss exponent which ranges between 2 and 4.

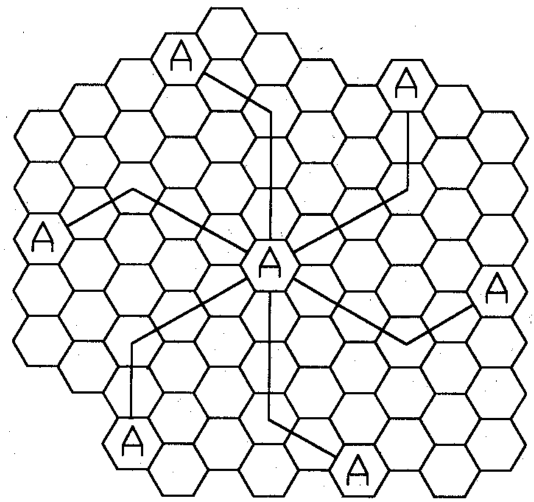
- When the transmission power of each base station is equal, SIR for a mobile can be approximated as

$$\frac{S}{I} = \frac{R^{-n}}{\sum_{i=1}^{i_0} (D_i)^{-n}}$$

- Consider only the first layer of interfering cells

$$\frac{S}{I} = \frac{(D/R)^n}{i_0} = \frac{\left(\sqrt{3N}\right)^n}{i_0}$$

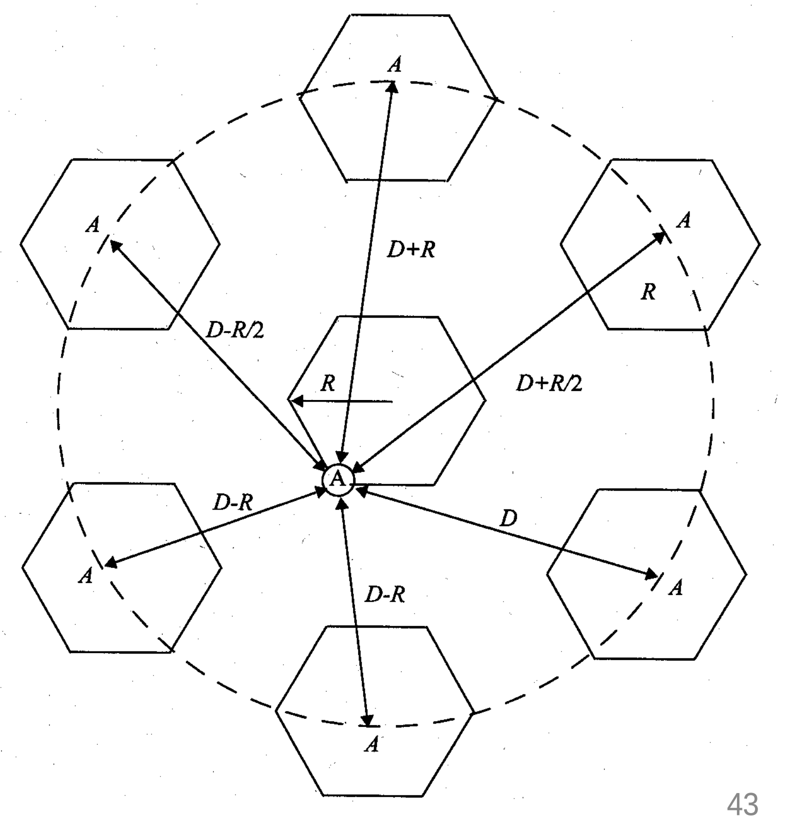
$i_0 = 6$



- Example: AMPS requires that SIR be greater than 18dB
  - *N* should be at least 6.49 for *n=4*.
  - Minimum cluster size is 7

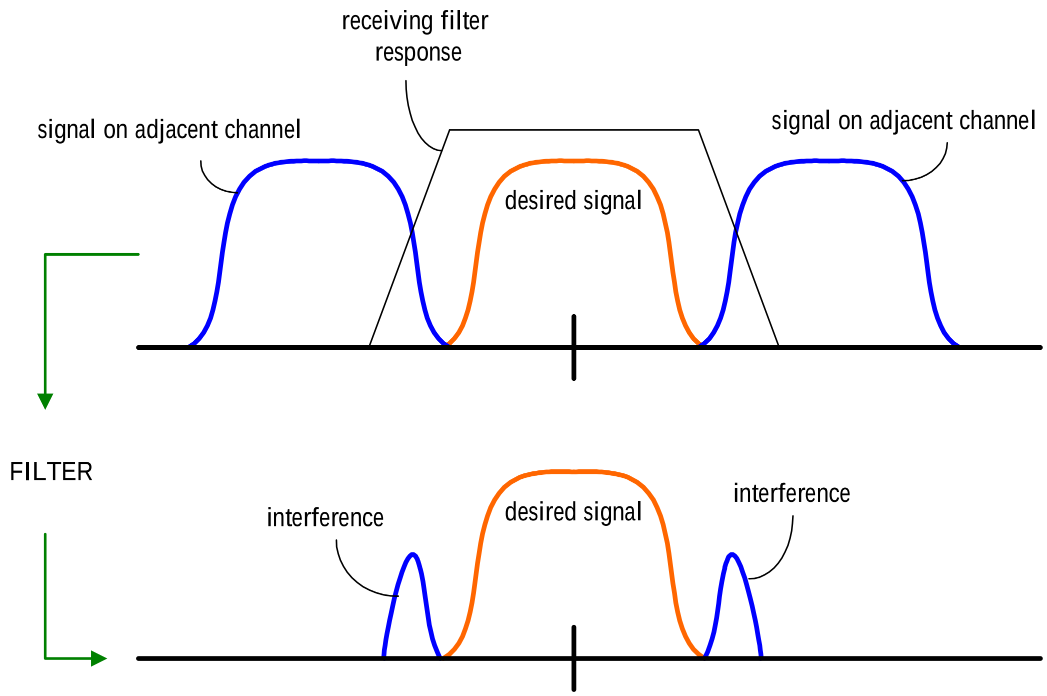
- For hexagonal geometry with 7-cell cluster, with the mobile unit being at the cell boundary, the signal-to-interference ratio for the worst case can be approximated as

$$\frac{S}{I} = \frac{R^{-4}}{2(D-R)^{-4} + (D-R/2)^{-4} + (D+R/2)^{-4} + (D+R)^{-4} + D^{-4}}$$



2.5.2 Adjacent Channel Interference

- Adjacent channel interference: interference from adjacent in frequency to the desired signal.
  - Imperfect receiver filters allow nearby frequencies to leak into the passband
  - Performance degrade seriously due to *near-far* effect.



- Adjacent channel interference can be minimized through careful filtering and *channel assignment*.
- Keep the frequency separation between each channel in a given cell as large as possible
- A channel separation greater than six is needed to bring the adjacent channel interference to an acceptable level.
- Ensure each mobile transmits the smallest power necessary to maintain a good quality link on the reverse channel
  - long battery life
  - increase SIR
  - solve the near-far problem

Trunking and Grade of Service

- A means for providing access to users on demand from available pool of channels.
- With trunking, a small number of channels can accommodate large number of random users.
- Telephone companies use trunking theory to determine number of circuits required.
- Trunking theory is about how a population can be handled by a limited number of servers.

Terminology:

- Traffic intensity is measured in Erlangs:
- One Erlang: traffic in a channel completely occupied. 0.5 Erlang: channel occupied 30 minutes in an hour.
- Grade of Service (GOS): probability that a call is blocked (or delayed).
- Set-Up Time: time to allocate a channel.
- Blocked Call: Call that cannot be completed at time of request due to congestion. Also referred to as Lost Call.
- Holding Time: (H) average duration of typical call.
- Load: Traffic intensity across the whole system.
- Request Rate: (λ) average number of call requests per unit time.

Traffic Measurement (Erlangs)

- Traffic per user $A_u = \lambda H$ where λ is the request rate and H is the holding time.
- For U users the load is $A = UA_u$
- If traffic is trunked in C channels, then the traffic intensity per channel is $A_c = UA_u / C$

Erlang B: If blocked calls are cleared (i.e. not queued), then under some model assumptions, the probability of a blocked call is given by the Erlang B model:

$$\Pr[blocking] = \frac{\frac{A^C}{C!}}{\sum_{k=0}^{C} \frac{A^k}{k!}} = GOS$$

Number of Channels C	Capacity (Erlangs) for GOS = 0.01	= 0.005	= 0.002	= 0.001
2	0.153	0.105	0.065	0.046
4	0.869	0.701	0.535	0.439
5	1.36	1.13	0.900	0.762
10	4.46	3.96	3.43	3.09
20	12.0	11.1	10.1	9.41
24	15.3	14.2	13.0	12.2
40	29.0	27.3	25.7	24.5
70	56.1	53.7	51.0	49.2
100	84.1	80.9	77.4	75.2

Table 3.4: Capacity of Erlang B System

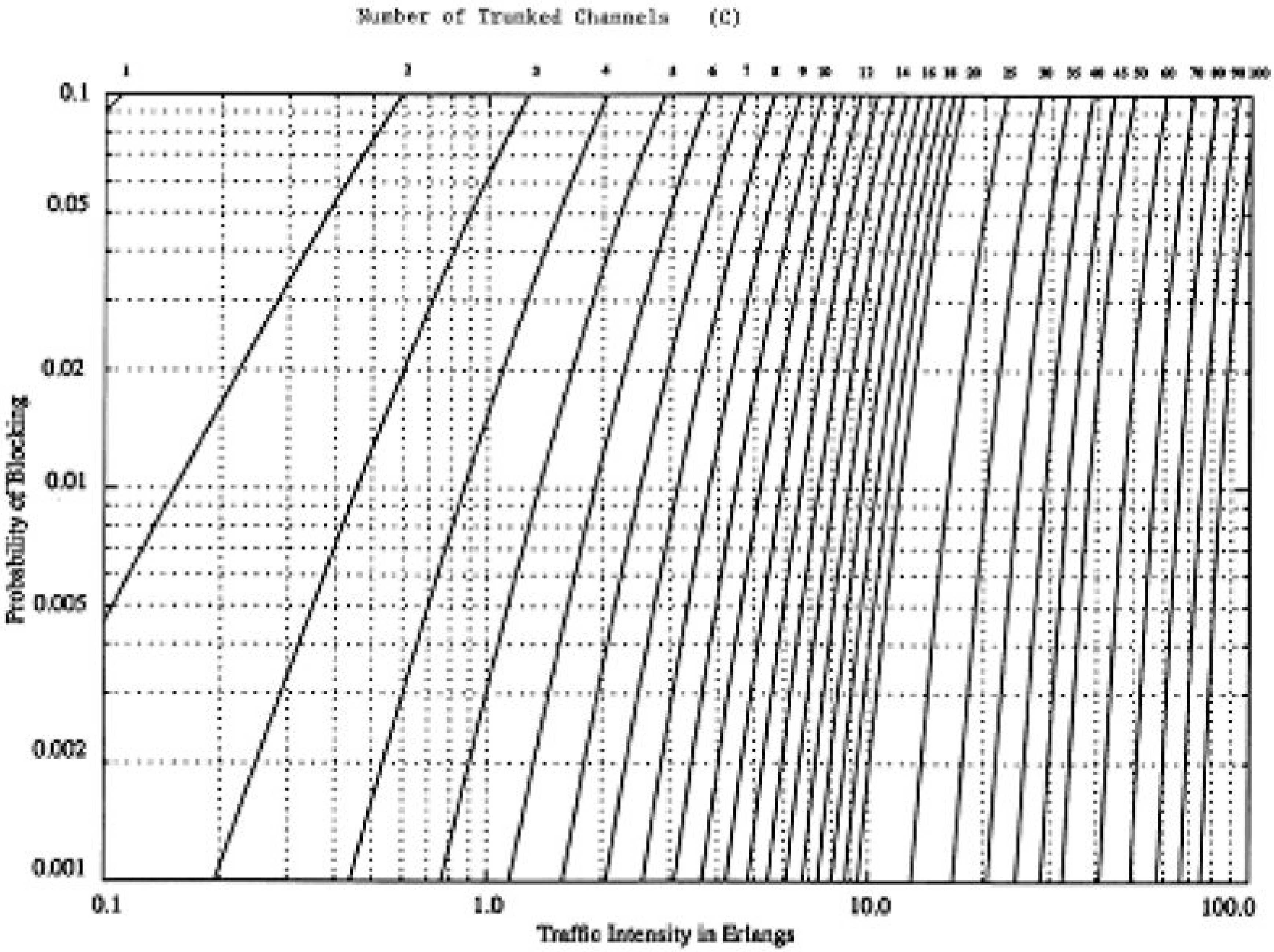


Figure 3.6: The Erlang B chart showing the probability of blocking vs. traffic intensity

Example 3.4

How many users can be supported for 0.5% blocking probability for the following number of trunked channels in a blocked calls cleared system? (a) 1, (b) 5, (c) 10, (d) 20, (e) 100. Assume each user generates 0.1 Erlangs of traffic.

The required GOS = 0.5%. Each user generates 0.1 Erlangs of traffic.How many users in a blocked channels cleared system for C =5 channels?

From the chart, with GOS=0.005 and the number of channels (C) = 5:

A (capacity in Erlangs) = 1.13

=> U = A/A_u = 1.13/0.1 ~ 11 users.

Example 3.5

An urban area has a population of two million residents. Three competing trunked mobile networks (systems A, B, and C) provide cellular service in this area. System A has 394 cells with 19 channels each, system B has 98 cells with 57 channels each, and system C has 49 cells, each with 100 channels. Find the number of users that can be supported at 2% blocking if each user averages two calls per hour at an average call duration of three minutes. Assuming that all three trunked systems are operated at maximum capacity, compute the percentage market penetration of each cellular provider.

Solution

System A

Given:

Probability of blocking = 2% = 0.02

Number of channels per cell used in the system, $C = 19$

Traffic intensity per user, $A_u = \lambda H = 2 \times (3/60) = 0.1$ Erlangs

For $GOS = 0.02$ and $C = 19$, from the Erlang B chart, the total carried traffic, A, is obtained as 12 Erlangs.

Therefore, the number of users that can be supported per cell is

$$U = A/A_u = 12/0.1 = 120$$

Since there are 394 cells, the total number of subscribers that can be supported by System A is equal to $120 \times 394 = 47280$

System B

Given:

Probability of blocking = 2% = 0.02

Number of channels per cell used in the system, $C = 57$

Traffic intensity per user, $A_u = \lambda H = 2 \times (3/60) = 0.1$ Erlangs

For $GOS = 0.02$ and $C = 57$, from the Erlang B chart, the total carried traffic, A, is obtained as 45 Erlangs.

Therefore, the number of users that can be supported per cell is

$$U = A/A_u = 45/0.1 = 450$$

Since there are 98 cells, the total number of subscribers that can be supported by System B is equal to $450 \times 98 = 44{,}100$

System C

Given:

Probability of blocking = 2% = 0.02

Number of channels per cell used in the system, $C = 100$

Traffic intensity per user, $A_u = \lambda H = 2 \times (3/60) = 0.1$ Erlangs

For $GOS = 0.02$ and $C = 100$, from the Erlang B chart, the total carried traffic, A, is obtained as 88 Erlangs.

Therefore, the number of users that can be supported per cell is

$$U = A/A_u = 88/0.1 = 880$$

Since there are 49 cells, the total number of subscribers that can be supported by System C is equal to $880 \times 49 = 43{,}120$

Therefore, total number of cellular subscribers that can be supported by these three systems are 47,280 + 44,100 + 43,120 = 134,500 users.

Since there are two million residents in the given urban area and the total number of cellular subscribers in System A is equal to 47280, the percentage market penetration is equal to

47,280/2,000,000 = 2.36%

Similarly, market penetration of System B is equal to

44,100/2,000,000 = 2.205%

and the market penetration of System C is equal to

43,120/2,000,000 = 2.156%

The market penetration of the three systems combined is equal to

134,500/2,000,000 = 6.725%

Erlang C Model –Blocked calls cleared

- A different type of trunked system queues blocked calls –Blocked Calls Delayed. This is known as an Erlang C model.

- Procedure:

  - Determine Pr[delay> 0] = probability of a delay from the chart.
  - Pr[delay □> t | delay □ > 0] = probability that the delay is longer than t, given that there is a delay
  - Pr[delay □ > t | delay □> 0] =exp[-(C-A)t /H]
  - Unconditional Probability of delay □ > t :
  - Pr[delay □> t] = Pr[delay □> 0] Pr[delay □> t | delay □ > 0]
  - Average delay time D = Pr[delay□> 0] H/ (C-A)

Erlang C Formula

- The likelihood of a call not having immediate access to a channel is determined by Erlang C formula:

$$\Pr[delay > 0] = \frac{A^C}{A^C + C!\left(1 - \frac{A}{C}\right)\sum_{k=0}^{C-1} \frac{A^k}{k!}}$$

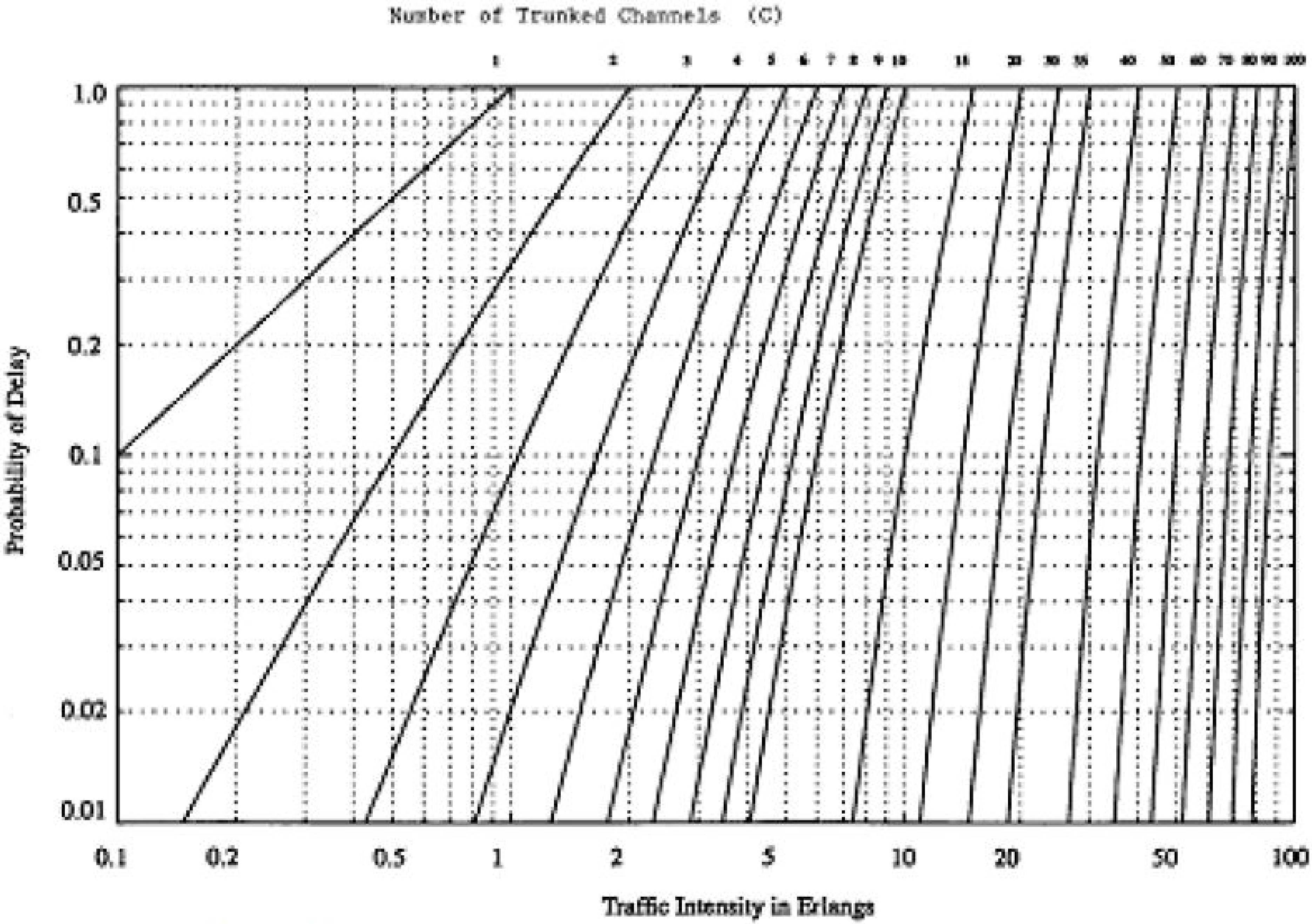


Figure 3.7: The Erlang C chart showing the probability of delay vs. traffic intensity

Example 3.7

A hexagonal cell within a four-cell system has a radius of 1.387 km. A total of 60 channels are used within the entire system. If the load per user is 0.029 Erlangs, and $\lambda = 1$ call/hour, compute the following for an Erlang C system that has a 5% probability of a delayed call:

(a) How many users per square kilometer will this system support?

(b) What is the probability that a delayed call will have to wait for more than 10 s?

(c) What is the probability that a call will be delayed for more than 10 seconds?

Solution

Given:

Cell radius, $R = 1.387$ km

Area covered per cell is $2.598 \times (1.387)^2 = 5$ sq km

Number of cells per cluster = 4

Total number of channels = 60

Therefore, number of channels per cell = 60 / 4 = 15 channels.

(a) From Erlang C chart, for 5% probability of delay with $C = 15$, traffic intensity = 9.0 Erlangs.

Therefore, number of users = total traffic intensity / traffic per user
= 9.0/0.029 = 310 users
= 310 users/5 sq km = 62 users/sq km

(b) Given $\lambda = 1$, holding time
$H = A_u/\lambda$ = 0.029 hour = 104.4 seconds.
The probability that a delayed call will have to wait longer than 10 s is
$Pr[delay > t | delay] = \exp(-(C - A)t/H)$
$= \exp(-(15 - 9.0)10/104.4) = 56.29\%$

(c) Given $Pr[delay > 0] = 5\% = 0.05$
Probability that a call is delayed more than 10 seconds,
$Pr[delay > 10] = Pr[delay > 0]Pr[delay > t | delay]$
$= 0.05 \times 0.5629 = 2.81\%$

2.7 Improving Capacity in Cellular Systems

- Methods for improving capacity in cellular systems
  - Cell Splitting: subdividing a congested cell into smaller cells.
  - Sectoring: directional antennas to control the interference and frequency reuse.
  - Coverage zone : Distributing the coverage of a cell and extends the cell boundary to hard-to-reach place.

Cell Splitting

- Cell Splitting is the process of subdividing the congested cell into smaller cells (microcells),Each with its own base station and a corresponding reduction in antenna height and transmitter power.

- Cell Splitting increases the capacity since it increases the number of times the channels are reused.

2.7.1 Cell Splitting

- Split congested cell into smaller cells.
  - Preserve frequency reuse plan.
  - Reduce transmission power.

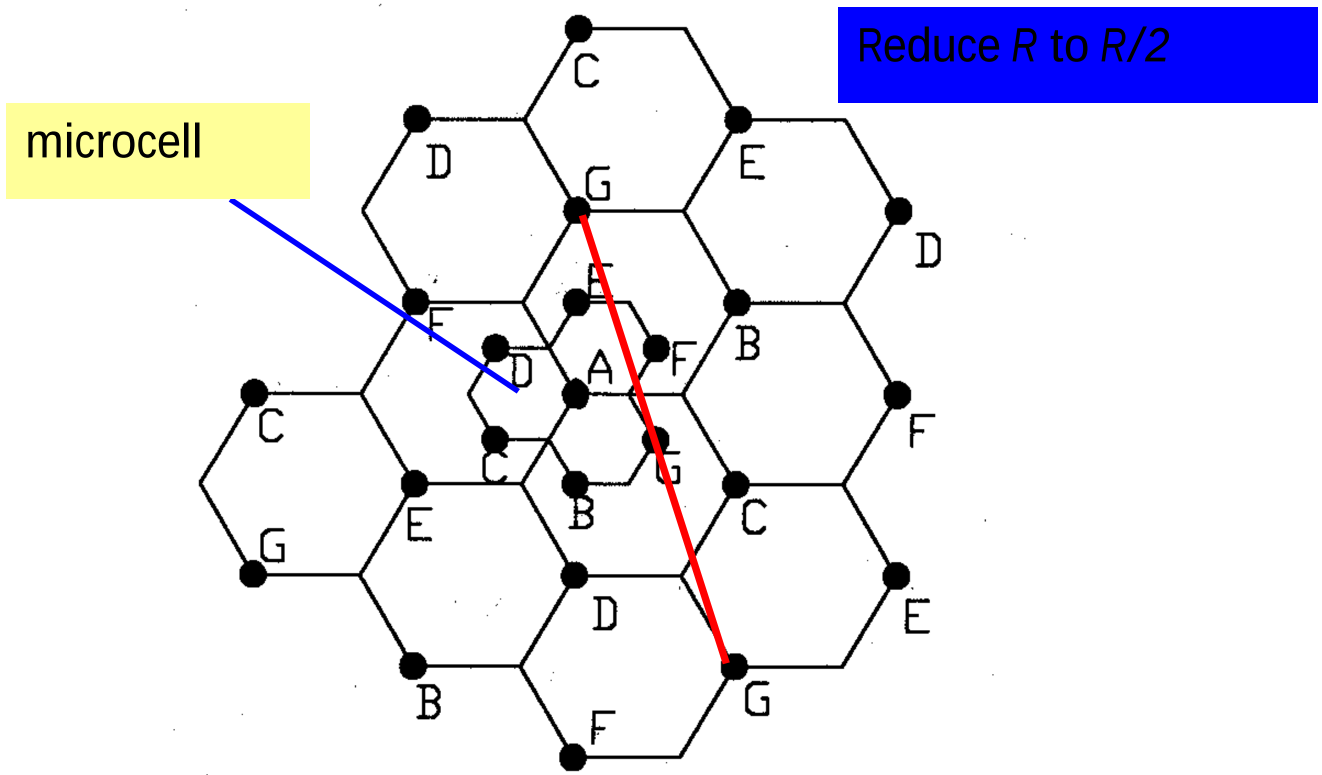
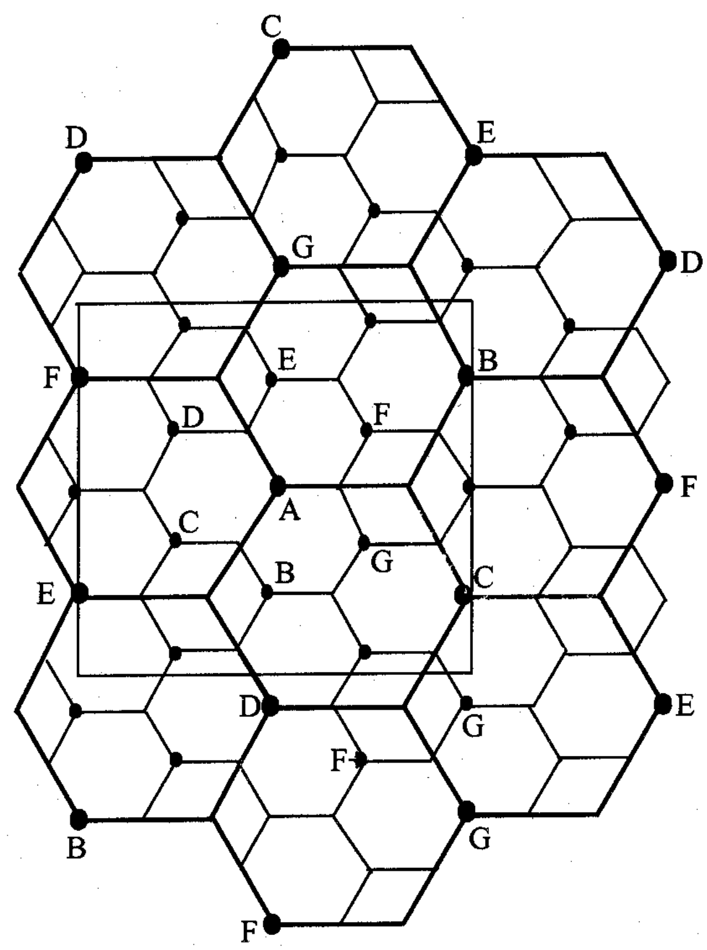


Illustration of cell splitting within a 3 km by 3 km square



- Transmission power reduction from P_{t1} to P_{t2}
- Examining the receiving power at the new and old cell boundary

$$P_r[\text{at old cell boundary}] \propto P_{t1} R^{-n}$$

$$P_r[\text{at new cell boundary}] \propto P_{t2} (R/2)^{-n}$$

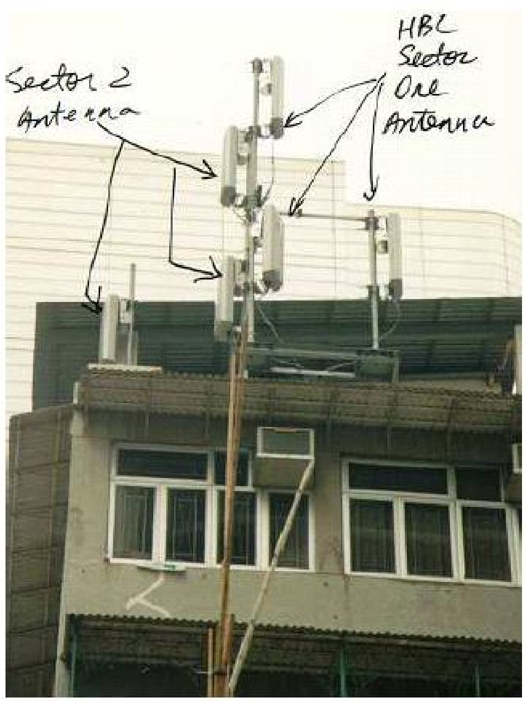
- If we take *n = 4* and set the received power equal to each other

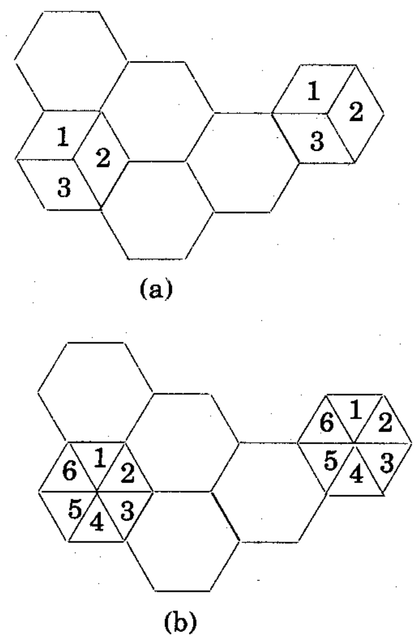
$$P_{t2} = \frac{P_{t1}}{16}$$

- The transmit power must be reduced by 12 dB in order to fill in the original coverage area.
- Problem: if only part of the cells are splited
  - Different cell sizes will exist simultaneously
- Handoff issues - high speed and low speed traffic can be simultaneously accommodated

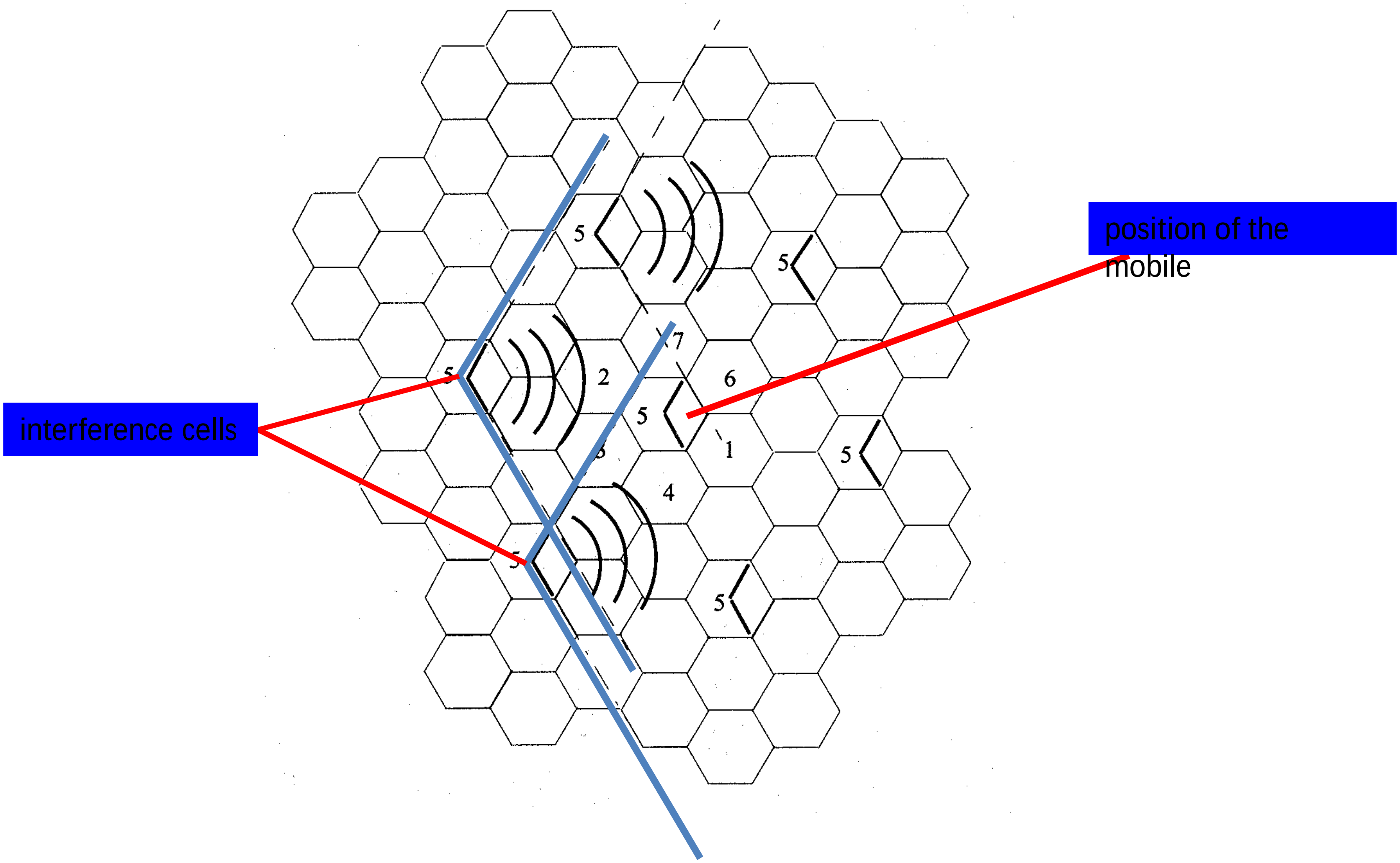
2.7.2 Sectoring

- Decrease the *co-channel interference* and keep the cell radius *R* unchanged
  - Replacing single omni-directional antenna by several directional antennas
  - Radiating within a specified sector





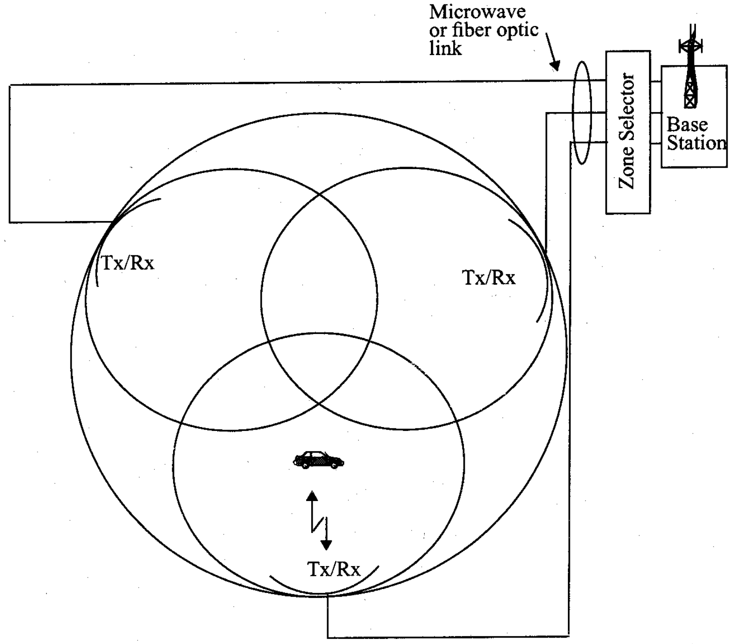
- Interference Reduction



2.7.3 Microcell Zone Concept

- Antennas are placed at the outer edges of the cell
- Any channel may be assigned to any zone by the base station
- Mobile is served by the zone with the strongest signal.

- Handoff within a cell
  - No channel re-assignment
  - Switch the channel to a different zone site
- Reduce interference
  - Low power transmitters are employed



Multiple Access Techniques for Wireless Communication:

Many users can access the at same time, share a finite amount of radio spectrum with high performance duplexing generally required frequency domain time domain. They accessing techniques are,

- FDMA
- TDMA
- SDMA
- PDMA

Frequency division multiple access FDMA

- One phone circuit per channel
- Idle time causes wasting of resources
- Simultaneously and continuously transmitting
- Usually implemented in narrowband systems
- For example: in AMPS is a FDMA bandwidth of 30 kHz implemented

Time Division Multiple Access

- Time slots
- One user per slot
- Buffer and burst method
- Noncontinuous transmission
- Digital data
- Digital modulation

Features of TDMA

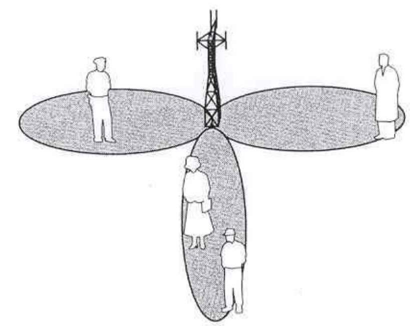
- A single carrier frequency for several users
- Transmission in bursts
- Low battery consumption
- Handoff process much simpler
- FDD : switch instead of duplexer
- Very high transmission rate
- High synchronization overhead
- Guard slots necessary

Space Division Multiple Access

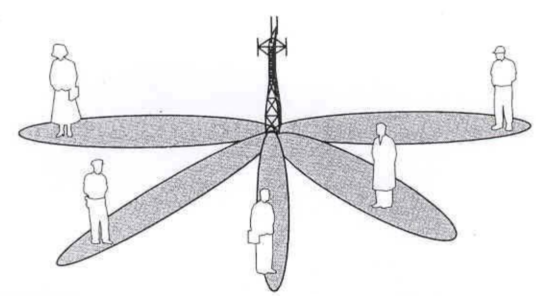
- Controls radiated energy for each user in space
- using spot beam antennas
- base station tracks user when moving
- cover areas with same frequency:
- TDMA or CDMA systems
- cover areas with same frequency:
- FDMA systems

Space Division Multiple Access

- primitive applications are "Sectorized antennas"



- In future adaptive antennas simultaneously steer energy in the direction of many users at once



UNIT III

MOBILE RADIO PROPAGATION

. **Mobile Radio Propagation**

- RF channels are random – do not offer easy analysis
- difficult to model – typically done statistically for a specific system

Introduction to Radio Wave Propagation: diverse mechanisms of electromagnetic (EM) wave propagation generally attributed to

(i) diffraction

(ii) reflection

(iii) scattering

- non-line of sight (**NLOS – obstructed**) paths rely on reflections
- **obstacles** cause diffraction
- **multi-path**: EM waves travel on different paths to a destination – interaction of paths causes fades at specific locations

traditional **Propagation Models** focus on

(i) transmit model - **average** received signal strength at given distance

(ii) receive model - **variability** in signal strength near a given location

(1) Large Scale Propagation Models: predict mean signal strength for TX-RX pair with arbitrary separation

- useful for estimating coverage area of a transmitter
- characterizes signal strength over large distances (10^2-10^3 m)
- predict local average signal strength that decreases with distance

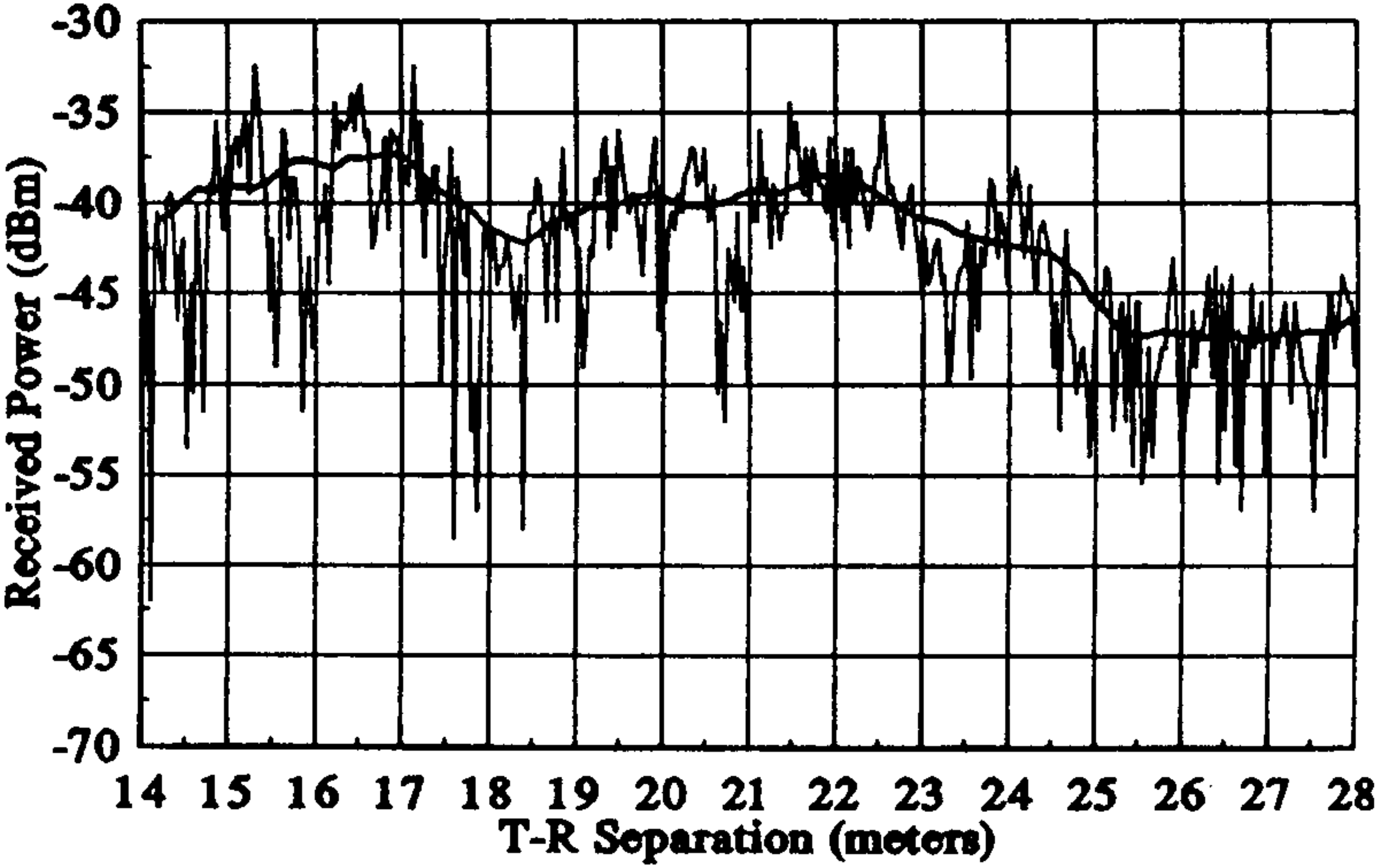
(2) Small Scale or Fading Models: characterize rapid fluctuations of received signal over

- short distances (*few* λ) or
- short durations (*few seconds*)

with **mobility** over short distances

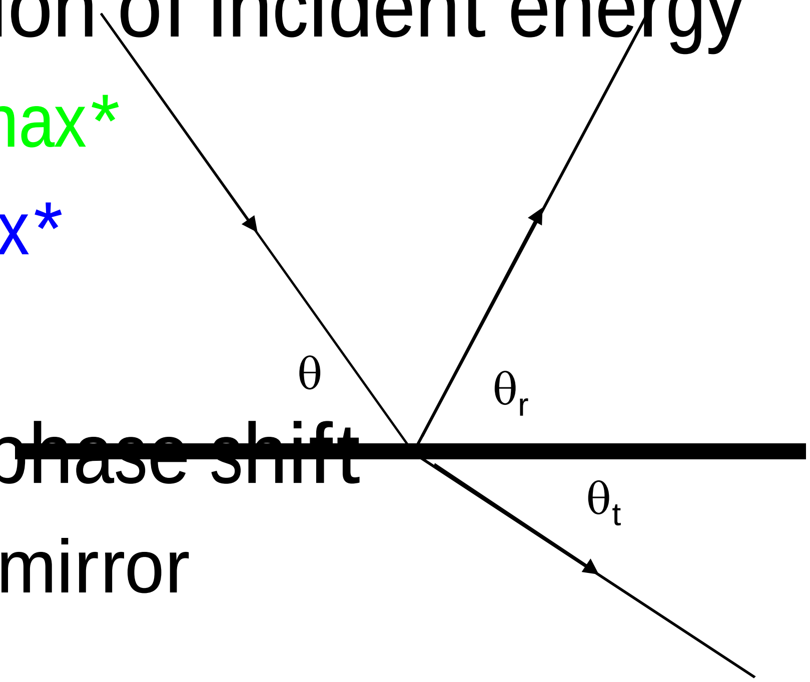
- instantaneous signal strength fluctuates
- received signal = sum of many components from different directions
- phases are random → sum of contributions varies widely
- received signal may fluctuate 30-40 dB by moving a fraction of λ

Large-scale small-scale propagation



Reflection

- Perfect conductors reflect with no attenuation
  - Like light to the mirror
- Dielectrics reflect a fraction of incident energy
  - "Grazing angles" reflect max*
  - Steep angles transmit max*
  - Like light to the water
- Reflection induces 180° phase shift
  - Why? See yourself in the mirror



Classical 2-ray ground bounce model

- One line of sight and one ground bound

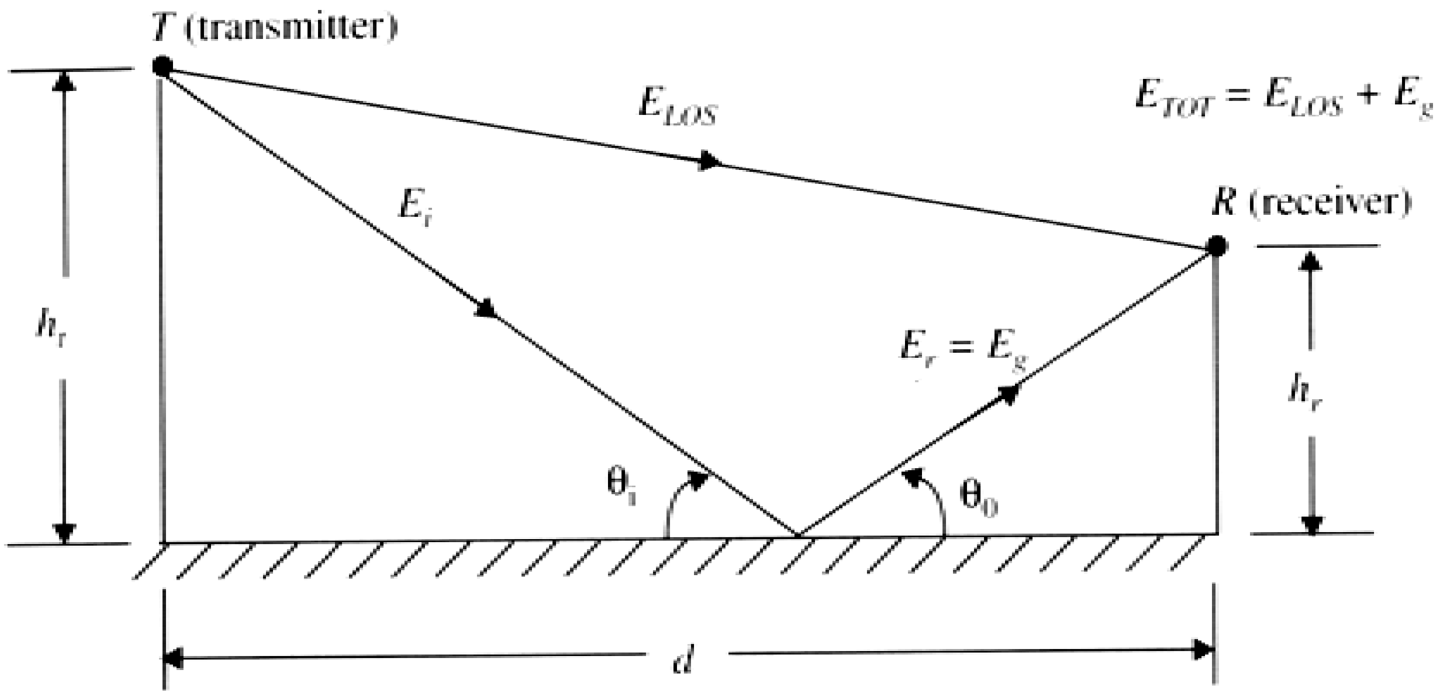


Figure 4.7 Two-ray ground reflection model.

Method of image

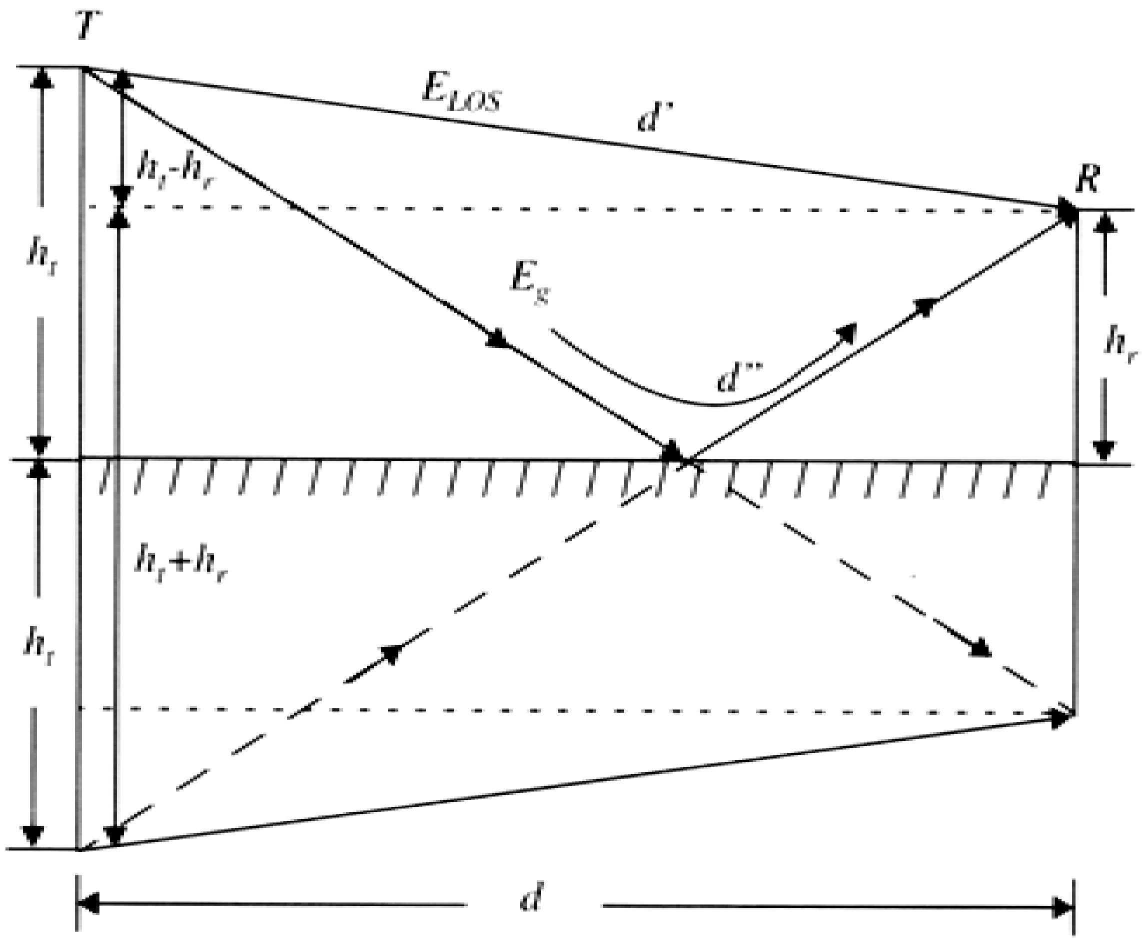


Figure 4.8 The method of images is used to find the path difference between the line-of-sight and the ground reflected paths.

Vector addition of 2 rays

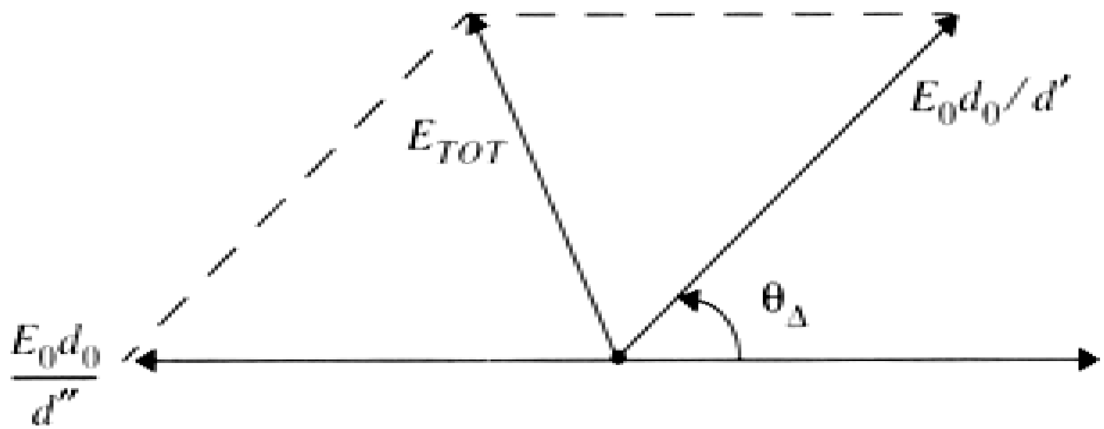


Figure 4.9 Phasor diagram showing the electric field components of the line-of-sight, ground reflected, and total received E-fields, derived from Equation (4.45).

Simplified model

$$P_r = P_t G_t G_r \frac{h_t^2 h_r^2}{d^4}$$

Path loss is due to the decay of the intensity of a propagating radio wave. In the simulations, we use the two-slope path-loss model [32], [33] to obtain the average received power as a function of distance. According to this model, the average path loss is given by

$$G = \frac{K_0}{r^{b_1}\left(1 + \frac{r\lambda_c}{(4h_b h_m)}\right)^{b_2}} \quad (31)$$

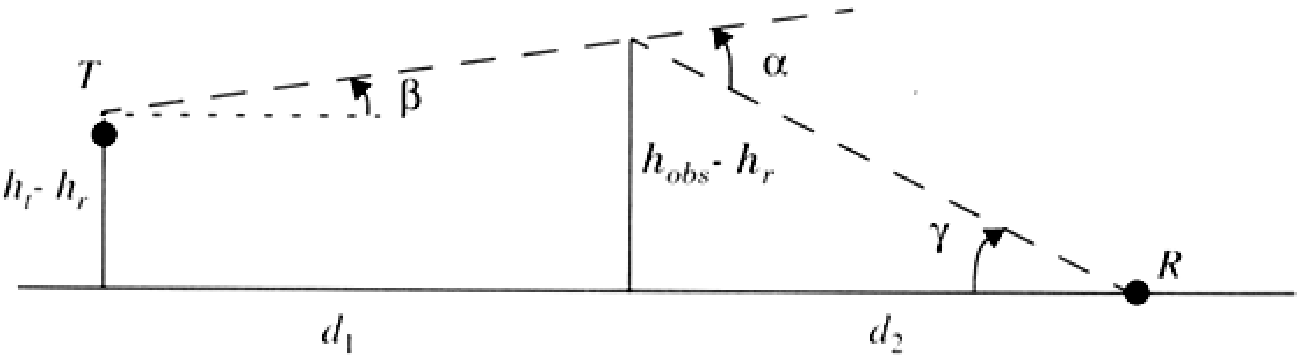
where K_0 is a constant, r is the distance between the mobile user and the base station, $b_1 = 2$ is the basic path-loss exponent, $b_2 = 2$ is the additional path loss component, h_b is the base station antenna height, h_m is the mobile antenna height, and λ_c is the wavelength of the carrier frequency. We assume that the

Diffraction

- Diffraction occurs when waves hit the edge of an obstacle
  - “Secondary” waves propagated into the shadowed region
  - Water wave example
  - Diffraction is caused by the propagation of secondary wavelets into a shadowed region.
  - Excess path length results in a phase shift
  - The field strength of a diffracted wave in the shadowed region is the vector sum of the electric field components of all the secondary wavelets in the space around the obstacle.
  - Huygen’s principle: all points on a wavefront can be considered as point sources for the production of secondary wavelets, and that these wavelets combine to produce a new wavefront in the direction of propagation.

Diffraction geometry

- Fresnel-Kirchoff distraction parameters,



(c) Equivalent knife-edge geometry where the smallest height (in this case h_r) is subtracted from all other heights.

Fresnel Screens

- Fresnel zones relate phase shifts to the positions of obstacles
- A rule of thumb used for line-of-sight

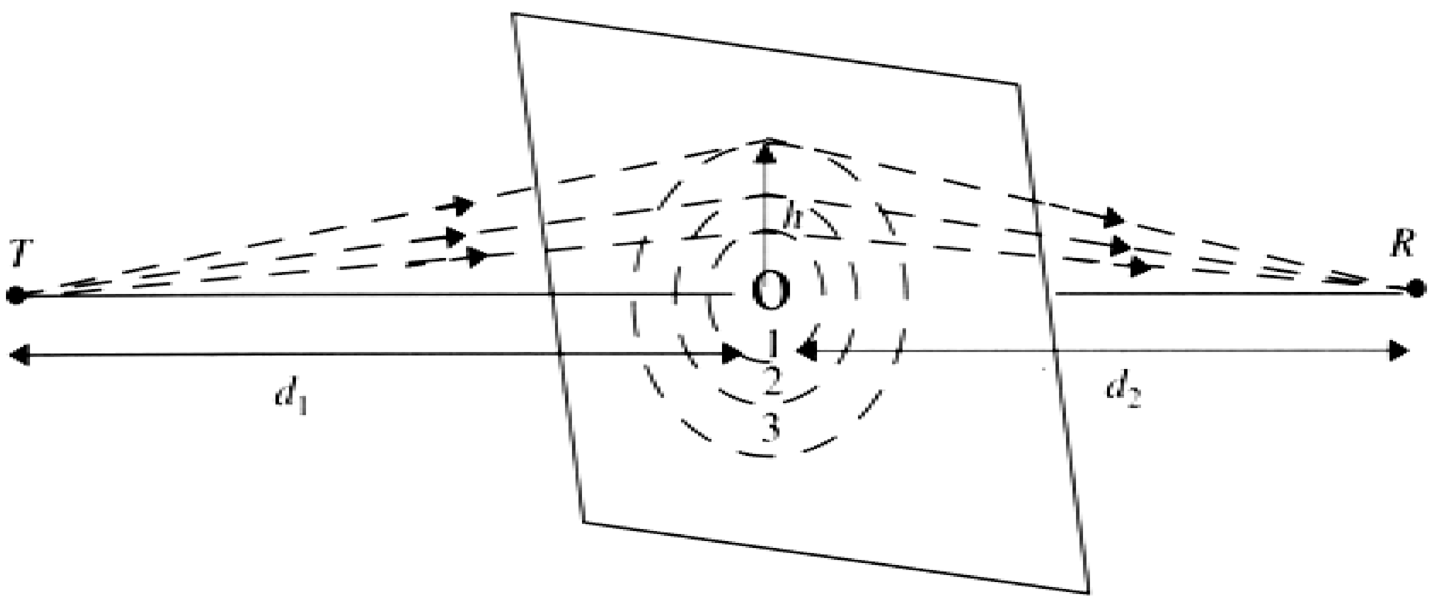


Figure 4.11 Concentric circles which define the boundaries of successive Fresnel zones.

Knife-edge diffraction loss

- Gain

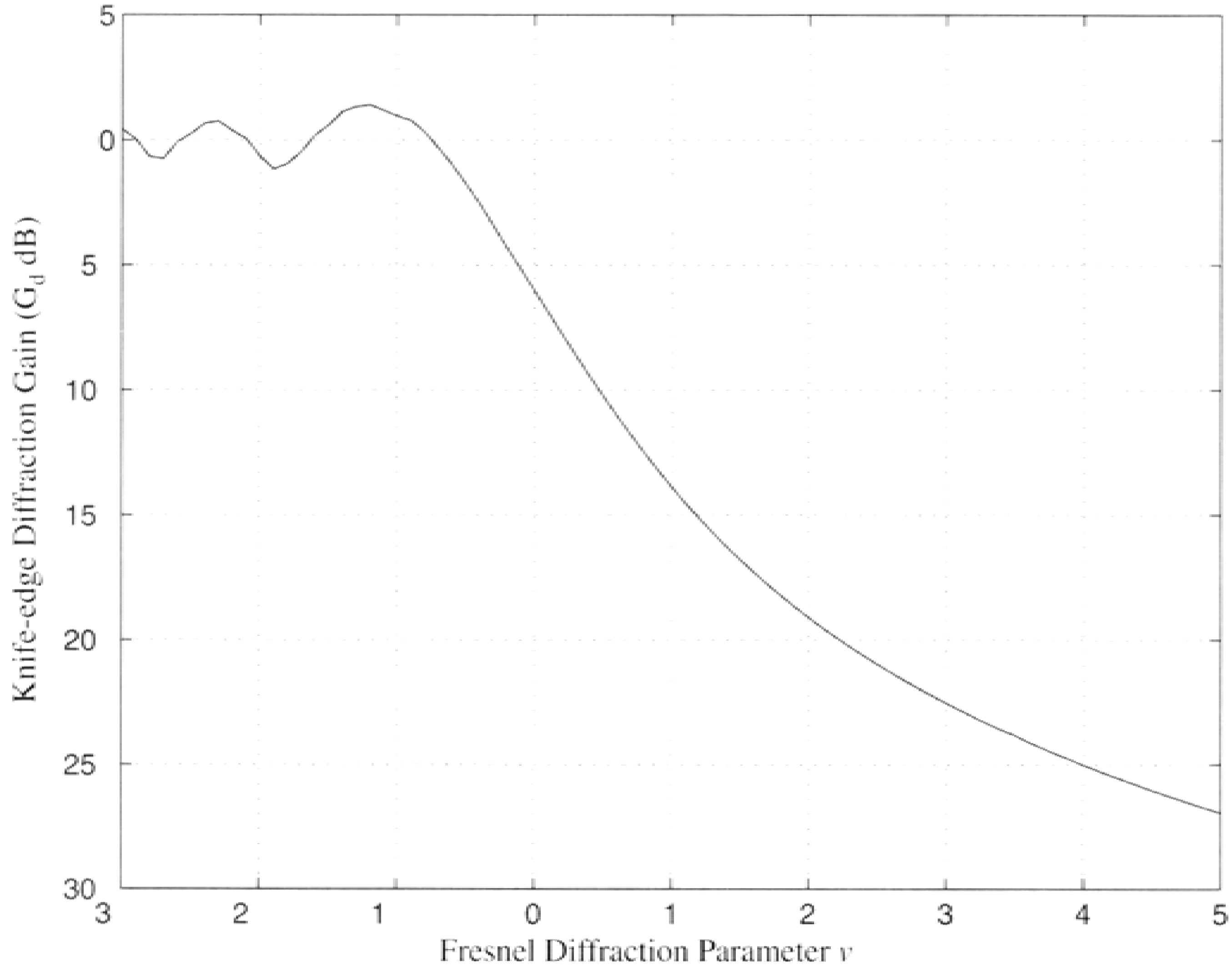


Figure 4.14 Knife-edge diffraction gain as a function of Fresnel diffraction parameter v.

Scattering

- Rough surfaces
  - Lamp posts and trees, scatter all directions
  - Critical height for bumps is f(λ,incident angle),
  - Smooth if its minimum to maximum protuberance h is less than critical height.
  - Scattering loss factor modeled with Gaussian distribution,
- Nearby metal objects (street signs, etc.)
  - Usually modeled statistically
- Large distant objects
  - Analytical model: Radar Cross Section (RCS)
  - Bistatic radar equation,

Impulse Response Model of a Time Variant Multipath Channel

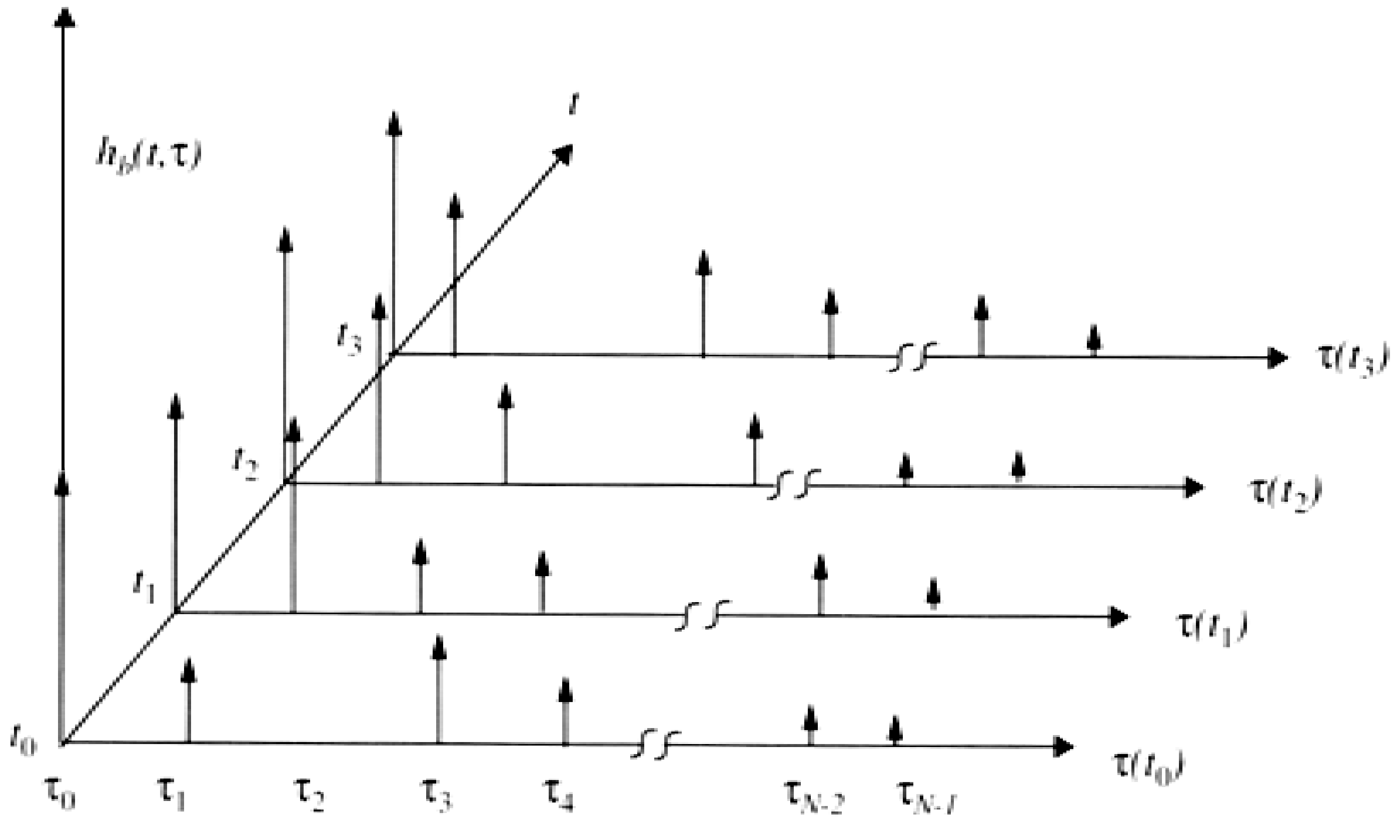


Figure 5.4 An example of the time varying discrete-time impulse response model for a multipath radio channel. Discrete models are useful in simulation where modulation data must be convolved with the channel impulse response [Tra02].

3.2 Free Space Propagation Model

used to predict signal strength for LOS path

- satellites
- LOS *uwave*
- power decay $\propto d^{-n}$ *(d = separation)*

Subsections

(1) Friis Equation

(2) Radiated Power

(3) Path Loss

(4) Far Field Region

(1) Friis free space equation: receive power at antenna separated by distance d from transmitter

$$P_r(d) = \left(\frac{G_t G_r \lambda^2}{(4\pi)^2 L}\right)\frac{P_t}{d^2} \qquad (3.1)$$

P_r & P_t = received & transmitted power

G_t & G_r = gain of transmit & receive antenna

λ = wavelength

d = separation

L = *system losses* (line attenuation, filters, antenna)

- not from propagation
- practically, $L \geq 1$, if $L = 1$ → ideal system with no losses

- **power decays** by d^2 → decay rate = 20dB/decade

Antenna Gain

$$G = \frac{4\pi}{\lambda^2} A_e \qquad (3.2)$$

- A_e = effective area of absorption– related to antenna size

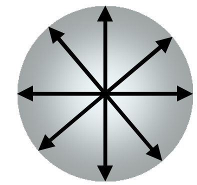
Antenna Efficiency $\eta = A_e/A$

A = antenna's physical area (cross sectional)

- for **parabolic** antenna $\eta \approx$ 45% - 50%
- for **horn** antenna $\eta \approx$ 50% - 80%

(2) Radiated Power

Isotropic Radiator: ideal antenna (*used as a reference antenna*)



- radiates power with unit gain uniformly in all directions
- **surface area** of a sphere = $4\pi d^2$

Effective Area of isotropic antennae given by $A_{iso} = \dfrac{\lambda^2}{4\pi}$

Isotropic Received Power $P_R = \left(\dfrac{\lambda^2}{4\pi}\right)\left(\dfrac{1}{4\pi d^2}\right)P_T = \dfrac{\lambda^2}{(4\pi d)^2} P_T$

- d = transmitter-receiver separation

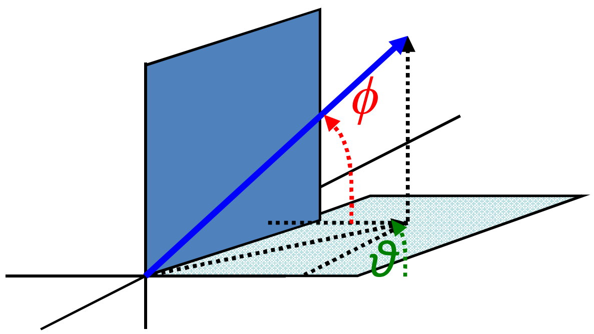
Isotropic free space path loss $L_p = \dfrac{P_T}{P_R} = \dfrac{(4\pi d)^2}{\lambda^2}$

- f^2 relationship with antenna size results from dependence of A_{iso} on λ

Directional Radiation

practical antennas have *gain* or *directivity* that is a function of

- ϑ = **azimuth**: look angle of the antenna in the horizontal plane
- ϕ = **elevation**: look angle of the antenna above the horizontal plane



Let Φ = power flux desnity

transmit antenna gain is given by:

$$G_T(\vartheta, \phi) = \frac{\Phi \text{ in the direction of } (\vartheta, \phi)}{\Phi \text{ of isotropic antenna}}$$

receive antenna gain is given by:

$$G_R(\vartheta, \phi) = \frac{A_e \text{ in the direction of } (\vartheta, \phi)}{A_e \text{ of isotropic antenna}}$$

Principal Of Reciprocity:

- signal transmission over a radio path is reciprocal
- the locations of TX & RX can be interchanged without changing transmission characteristics

signals suffers exact same effects over a path in either direction in a consistent order → implies that $G_T(\vartheta, \phi) = G_R(\vartheta, \phi)$

thus **maximum antenna gain** in either direction is given by

$$G = \frac{A_e}{A_{iso}} = \frac{4\pi}{\lambda^2} A_e$$

EIRP: effective isotropic radiated power

- represents maximum radiated power available from a transmitter
- measured in the direction of maximum antenna gain as compared to isotropic radiator

$$\text{EIRP} = P_t G_{iso} \tag{3.4}$$

ERP: effective radiated power - often used in practice

- denotes maximum radiated power compared to ½ wave dipole antenna
- dipole antenna gain = 1.64 (2.15dB) > isotropic antenna
- thus EIRP will be 2.15dB smaller than ERP for same system

$$\text{ERP} = P_t G_{dipole}$$

- 1. Outdoor Propagation Models
  - 1.1 Longley-Rice Model
  - 1.2 Okumura Model
  - 1.3. Hata Model
  - 1.4. PCS Extension to Hata Model
  - 1.5. Walfisch and Bertoni Model

Outdoor Propagation Models

- Propagation over irregular terrain.
- The propagation models available for predicting signal strength vary very widely in their capacity, approach, and accuracy.

Longley-Rice Model

- also referred to as the **ITS** *irregular terrain model*
- frequency range from 40 MHz to 100 GHz
- *Two version:*
- *point-to-point* using terrain profile.
- *area mode* estimate the path-specific parameters

Okumura Model

- Frequency range from150 MHz to 1920 MHz
- BS-MS distance of 1 km to 100 km.
- BS antenna heights ranging from 30 m 1000 m.

$$L_{50}(dB) = L_f + A_{mu}(f,d) - G(h_{te}) - G(h_{re}) - G_{AREA}$$

- L_f is the free space propagation loss,
- A_{mu} is the median attenuation relative to free space,
- $G(t_{te})$ is the base station antenna height gain factor, $G(t_{re})$ is the mobile antenna height gain factor,
- G_{AREA} is the gain due to the type of environment.

Hata Model

- Frequency range from150 MHz to 1500 MHz
- BS-MS distance of 1 km to 100 km.
- BS antenna heights ranging from 30 m 200 m.

$$L_{50}(urban)(dB) = 69.55 + 26.16\log f_c - 13.82\log h_{te} - a(h_{re}) + (44.9 - 6.55\log h_{te})\log d$$

- f_c is the frequency (in MHz) from 150 MHz to 1500 MHz,
- h_{te} is the effective transmitter antenna height (in meters)
- h_{re} is the effective receiver (mobile) antenna height (1..10 m)
- d is the **T-R** separation distance (in km),
- $a(h_{re})$ is the correction factor for effective mobile antenna height (large city, small to medium size city, suburban, open rural)

PCS Extension to Hata Model

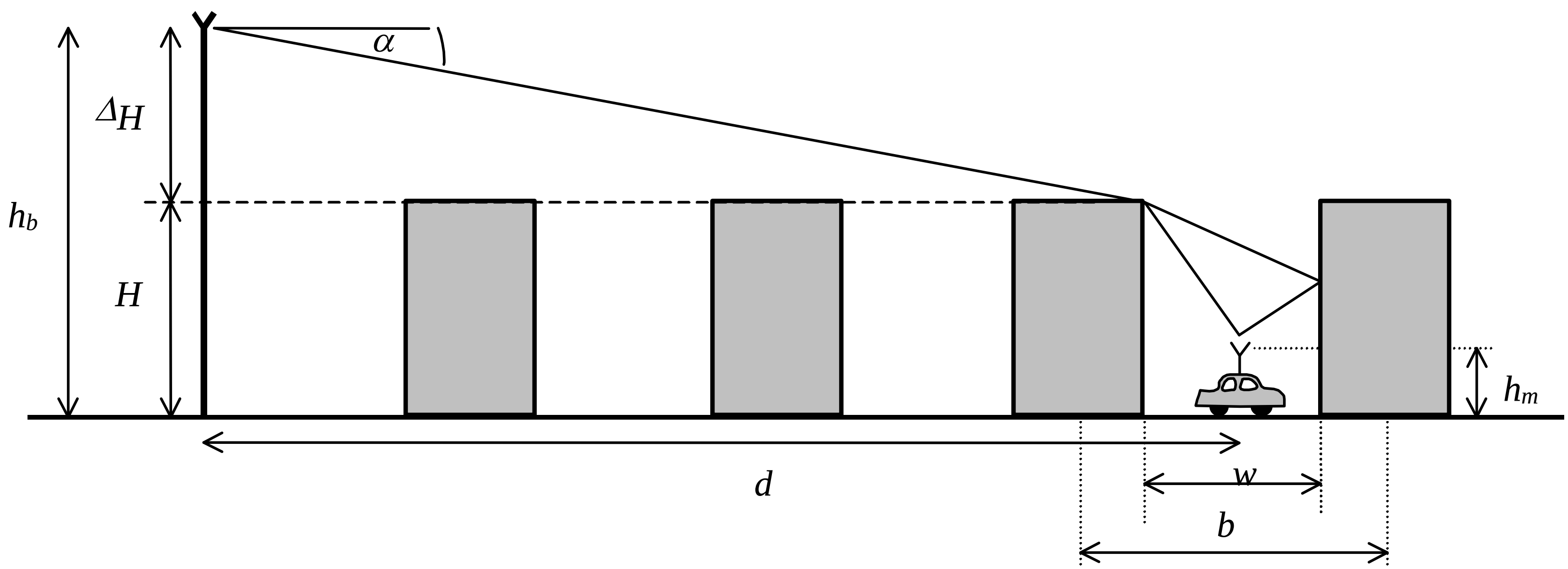
- Frequency range from1500 MHz to 2000 MHz
- BS-MS distance of 1 km to 20 km.
- BS antenna heights ranging from 30 m 200 m.

$$L_{50}(urban) = 46.3 + 33.9 \log f_c - 13.82 \log h_{te} - a(h_{re}) + (44.9 - 6.55 \log h_{te}) \log d + C_M$$

- f_c is the frequency (in MHz) from 1500 MHz to 2000 MHz,
- h_{te} is the effective transmitter antenna height (in meters)
- h_{re} is the effective receiver (mobile) antenna height (1..10 m)
- d is the **T-R** separation distance (in km),
- $a(h_{re})$ is the correction factor for effective mobile antenna height (large city, small to medium size city, suburban, open rural)
- C_M 0 dB for medium sized city and suburban areas,
- 3 dB for metropolitan centers

Walfisch and Bertoni Model

- considered the impact of the rooftops and building height by using diffraction to predict average signal strength at street level



Indoor Propagation Models

- The distances covered are much smaller
- The variability of the environment is much greater
- Key variables: layout of the building, construction materials, building type, where the antenna mounted, ...etc.
- In general, indoor channels may be classified either as LOS or OBS with varying degree of clutter
- The losses between floors of a building are determined by the external dimensions and materials of the building, as well as the type of construction used to create the floors and the external surroundings.
- Floor attenuation factor (FAF)

Partition losses between floors

Table 4.4 Total Floor Attenuation Factor and Standard Deviation σ (dB) for Three Buildings. Each Point Represents the Average Path Loss Over a 20λ Measurement Track [Sei92a]

Building	915 MHz FAF (dB)	σ (dB)	Number of locations	1900 MHz FAF (dB)	σ (dB)	Number of locations
Walnut Creek						
One Floor	33.6	3.2	25	31.3	4.6	110
Two Floors	44.0	4.8	39	38.5	4.0	29
SF PacBell						
One Floor	13.2	9.2	16	26.2	10.5	21
Two Floors	18.1	8.0	10	33.4	9.9	21
Three Floors	24.0	5.6	10	35.2	5.9	20
Four Floors	27.0	6.8	10	38.4	3.4	20
Five Floors	27.1	6.3	10	46.4	3.9	17
San Ramon						
One Floor	29.1	5.8	93	35.4	6.4	74
Two Floors	36.6	6.0	81	35.6	5.9	41
Three Floors	39.6	6.0	70	35.2	3.9	27

Partition losses between floors

Table 4.5 Average Floor Attenuation Factor in dB for One, Two, Three, and Four Floors in Two Office Buildings [Sei92b]

Building	FAF (dB)	σ (dB)	Number of locations
Office Building 1:			
Through One Floor	12.9	7.0	52
Through Two Floors	18.7	2.8	9
Through Three Floors	24.4	1.7	9
Through Four Floors	27.0	1.5	9
Office Building 2:			
Through One Floor	16.2	2.9	21
Through Two Floors	27.5	5.4	21
Through Three Floors	31.6	7.2	21

Log-distance Path Loss Model

- The exponent n depends on the surroundings and building type
  – X_σ is the variable in dB having a standard deviation σ.

Table 4.6 Path Loss Exponent and Standard Deviation Measured in Different Buildings [And94]

Building	Frequency (MHz)	*n*	σ (dB)
Retail Stores	914	2.2	8.7
Grocery Store	914	1.8	5.2
Office, hard partition	1500	3.0	7.0
Office, soft partition	900	2.4	9.6
Office, soft partition	1900	2.6	14.1
Factory LOS			
Textile/Chemical	1300	2.0	3.0
Textile/Chemical	4000	2.1	7.0
Paper/Cereals	1300	1.8	6.0
Metalworking	1300	1.6	5.8
Suburban Home			
Indoor Street	900	3.0	7.0
Factory OBS			
Textile/Chemical	4000	2.1	9.7
Metalworking	1300	3.3	6.8

$$PL(d) = PL(d_0) + 10n\log(d/d_0) + X_\sigma$$

Ericsson Multiple Breakpoint Model

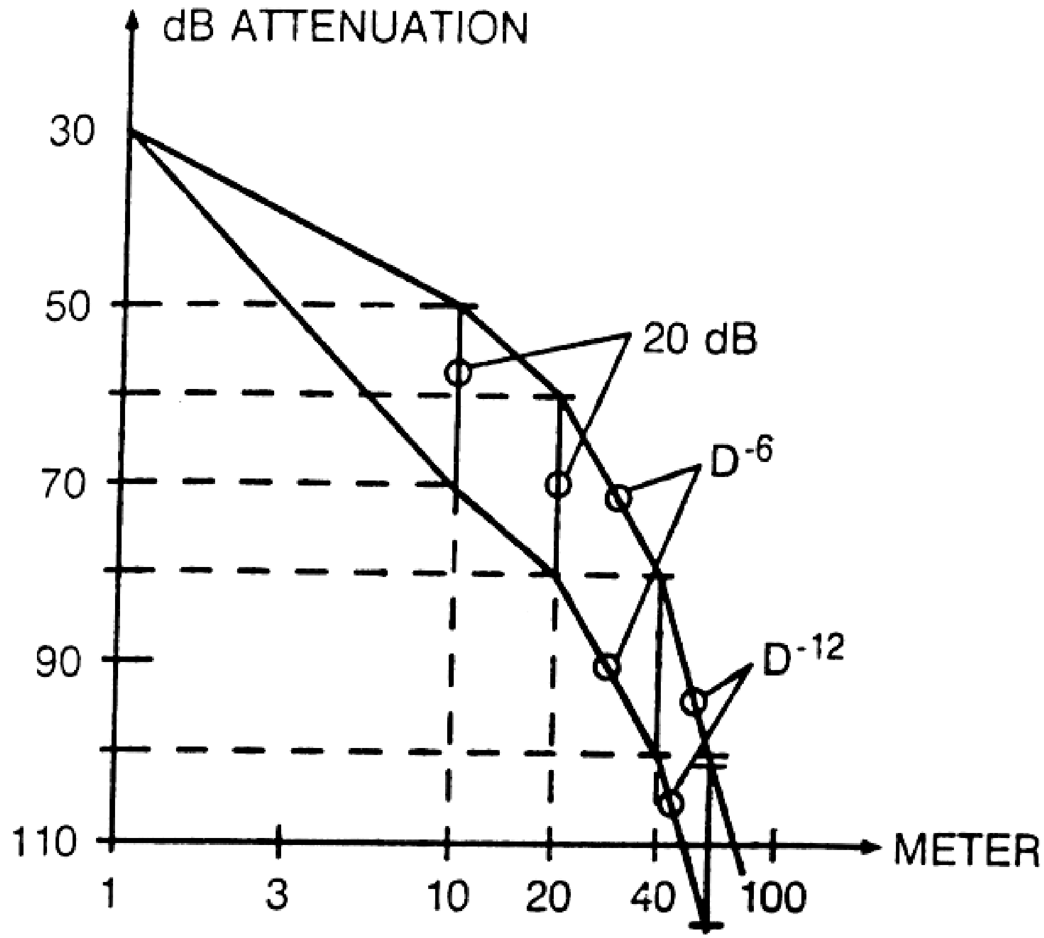


Figure 4.27 Ericsson in-building path loss model [from [Ake88] © IEEE].

Attenuation Factor Model

- FAF represents a floor attenuation factor for a specified number of building floors.
- PAF represents the partition attenuation factor for a specific obstruction encountered by a ray drawn between the transmitter and receiver in 3-D
- α is the attenuation constant for the channel with units of dB per meter.

$$PL(d) = PL(d_0) + 10 n_{SF} \log(d/d_0) + FAF + \sum PAF$$

$$PL(d) = PL(d_0) + 10 n_{MF} \log(d/d_0) + \sum PAF$$

$$PL(d) = PL(d_0) + 10 \log(d/d_0) + \alpha d + FAF + \sum PAF$$

Measured indoor path loss

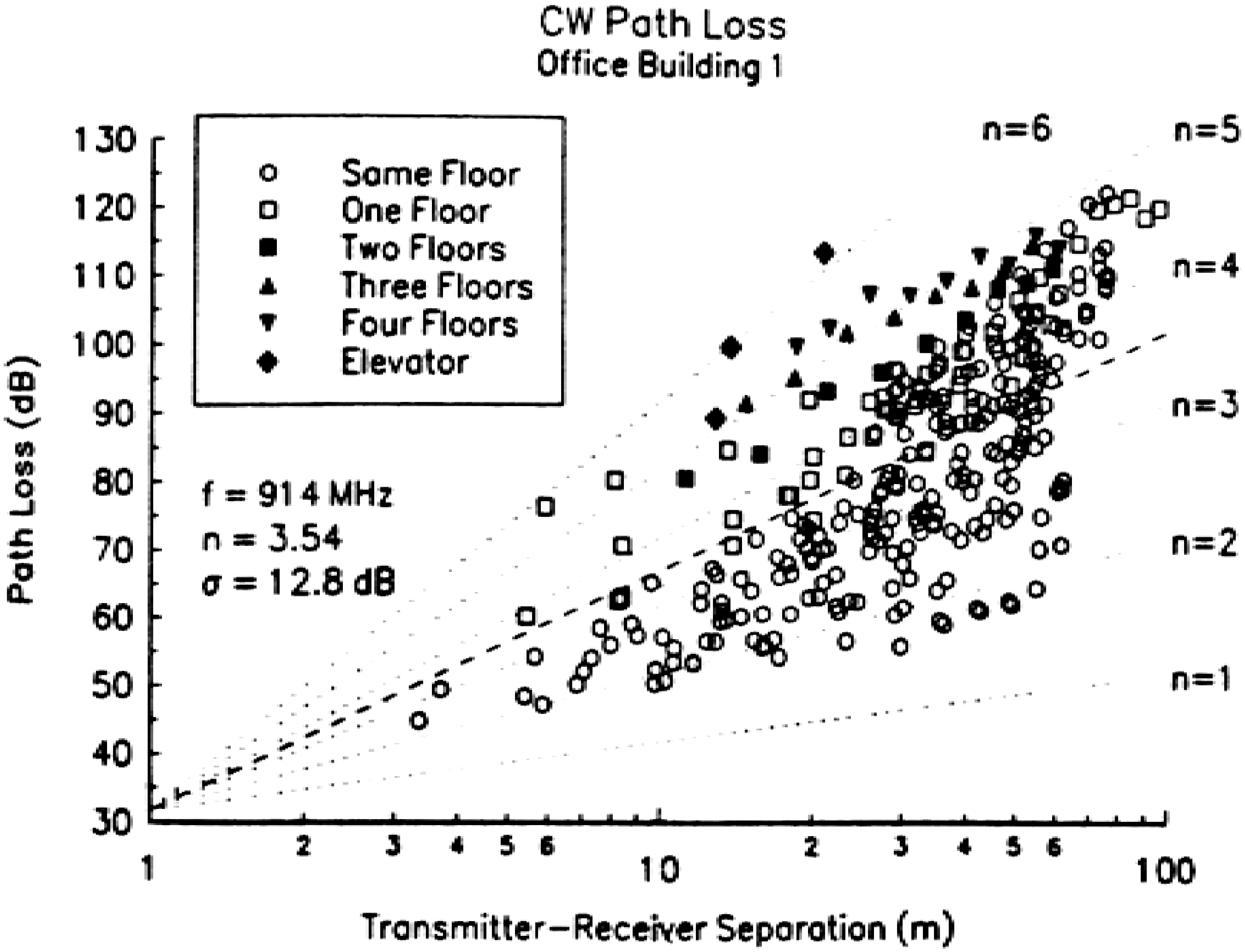


Figure 4.28 Scatter plot of path loss as a function of distance in Office Building 1 [from [Sei92b] © IEEE].

Measured indoor path loss

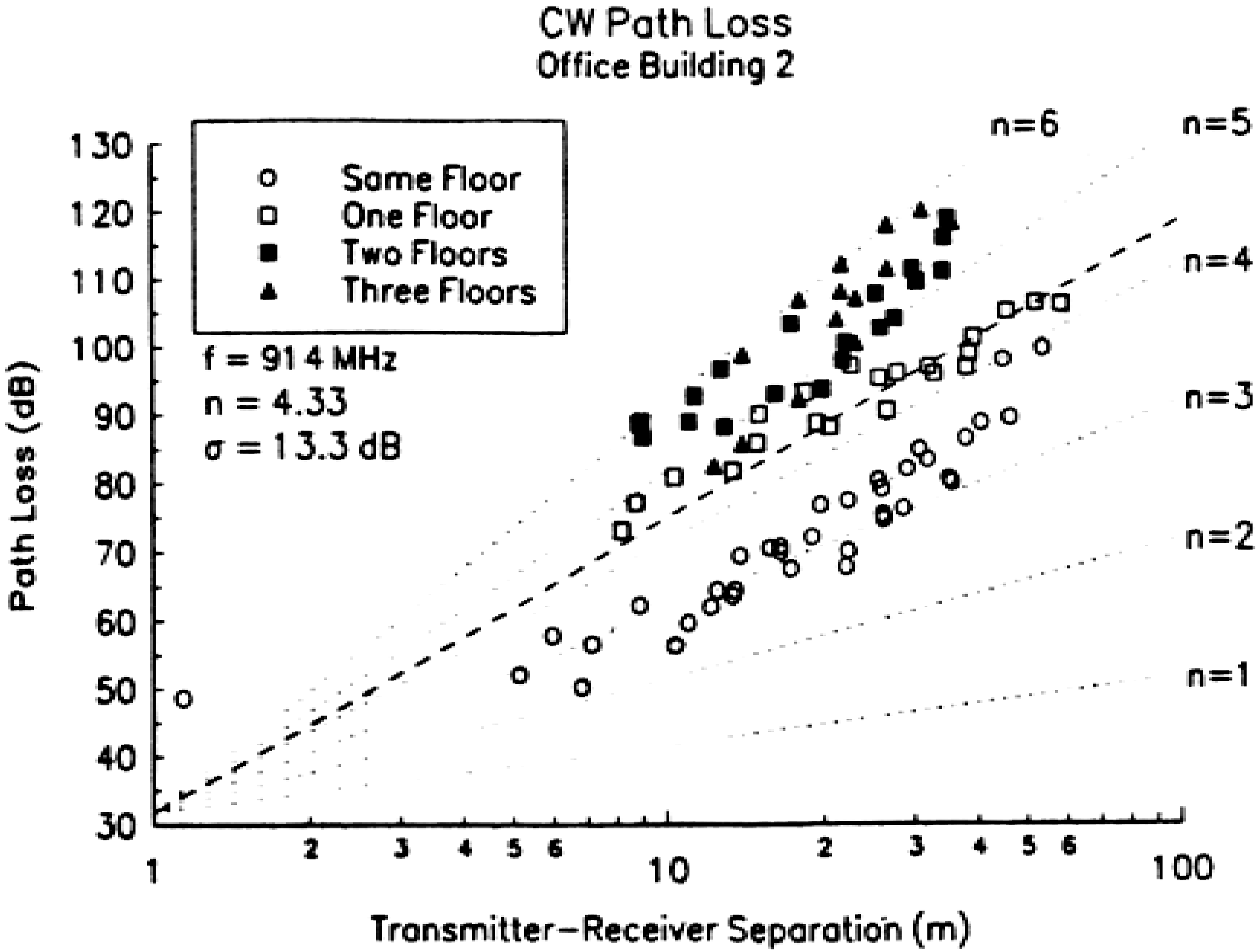


Figure 4.29 Scatter plot of path loss as a function of distance in Office Building 2 [from [Sei92b] © IEEE].

Measured indoor path loss

Table 4.7 Path Loss Exponent and Standard Deviation for Various Types of Buildings [Sei92b]

	n	σ (dB)	Number of locations
All Buildings:			
All locations	3.14	16.3	634
Same Floor	2.76	12.9	501
Through One Floor	4.19	5.1	73
Through Two Floors	5.04	6.5	30
Through Three Floors	5.22	6.7	30
Grocery Store	1.81	5.2	89
Retail Store	2.18	8.7	137
Office Building 1:			
Entire Building	3.54	12.8	320
Same Floor	3.27	11.2	238
West Wing 5th Floor	2.68	8.1	104
Central Wing 5th Floor	4.01	4.3	118
West Wing 4th Floor	3.18	4.4	120
Office Building 2:			
Entire Building	4.33	13.3	100
Same Floor	3.25	5.2	37

Parameters of Mobile Multipath Channels

- Time Dispersion Parameters
  - Grossly quantifies the multipath channel
  - Determined from Power Delay Profile
  - Parameters include
    - Mean Access Delay
    - RMS Delay Spread
    - Excess Delay Spread (X dB)
- Coherence Bandwidth
- Doppler Spread and Coherence Time

Measuring PDPs

- Power Delay Profiles
  - Are measured by channel sounding techniques
  - Plots of relative received power as a function of excess delay
  - They are found by averaging *intantenous* power delay measurements over a local area
    - Local area: no greater than 6m outdoor
    - Local area: no greater than 2m indoor
      - » Samples taken at $\lambda/4$ meters approximately
      - » For 450MHz – 6 GHz frequency range.

Timer Dispersion Parameters

Determined from a power delay profile.

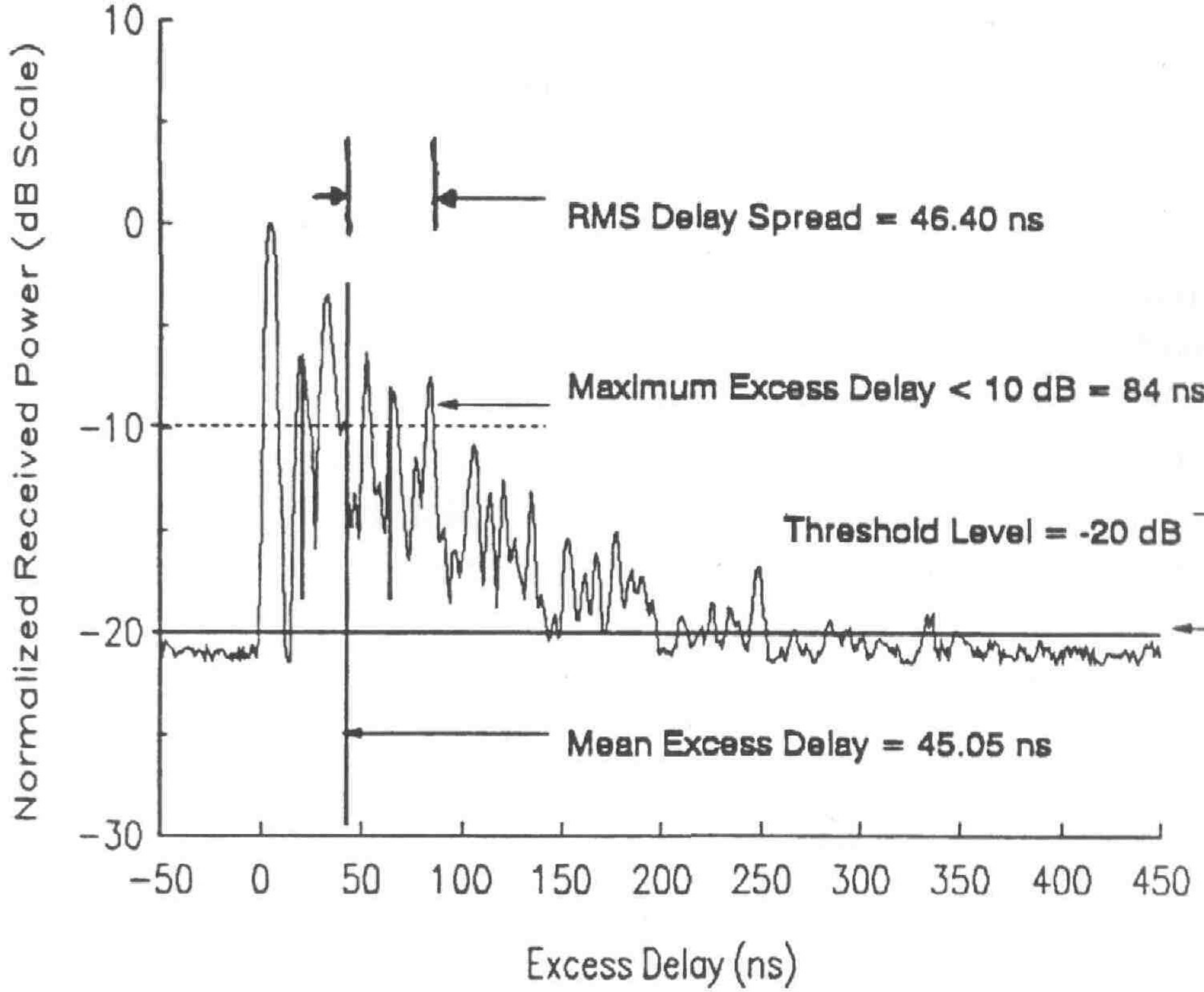
Mean excess delay( ): $\bar{\tau}$

$=$

Rms delay spread (σ_τ)**:**

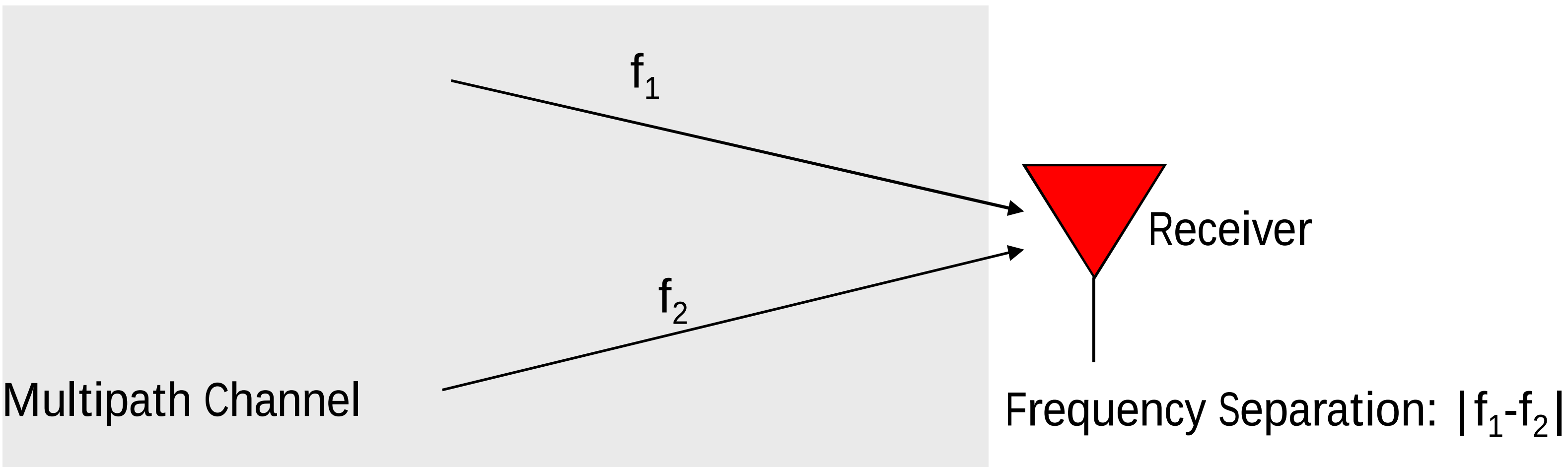
$$\overline{\tau^2} = \frac{\sum_k a_k^2 \tau_k^2}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k)(\tau_k^2)}{\sum_k P(\tau_k)}$$

RMS Delay Spread



Coherence Bandwidth (B_C)

- Range of frequencies over which the channel can be considered flat (i.e. channel passes all spectral components with equal gain and linear phase).
  - It is a definition that depends on RMS Delay Spread.
- Two sinusoids with frequency separation greater than B_c are affected quite differently by the channel.



Coherence Bandwidth

Frequency correlation between two sinusoids: 0 <= $C_{r1,\, r2}$ <= 1.

If we define Coherence Bandwidth (B_C) as the range of frequencies over which the frequency correlation is above 0.9, then

$$B_C = \frac{1}{50\sigma}$$

σ is rms delay spread.

If we define Coherence Bandwidth as the range of frequencies over which the frequency correlation is above 0.5, then

This is called 50% coherence bandwidth.

Coherence Time

- Delay spread and Coherence bandwidth describe the time dispersive nature of the channel in a local area.
  - They don't offer information about the time varying nature of the channel caused by relative motion of transmitter and receiver.
- Doppler Spread and Coherence time are parameters which describe the time varying nature of the channel in a small-scale region.

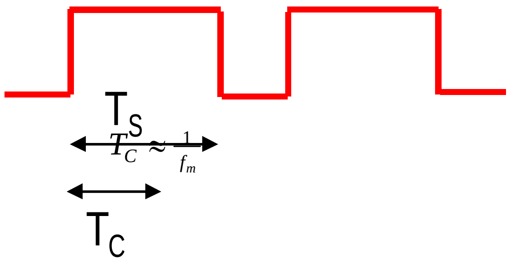
Doppler Spread

- Measure of spectral broadening caused by motion
- We know how to compute Doppler shift: f_d
- Doppler spread, B_D, is defined as the maximum Doppler shift: $f_m = v/\lambda$
- If the baseband signal bandwidth is much greater than B_D then effect of Doppler spread is negligible at the receiver.

Coherence Time

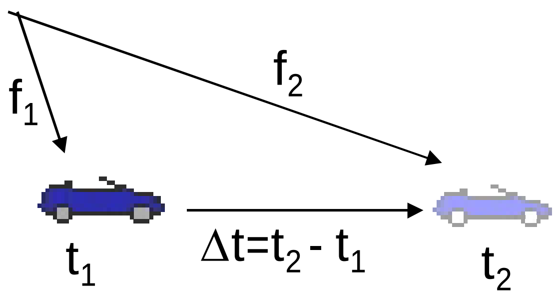
Coherence time is the time duration over which the channel impulse response is essentially invariant.

If the symbol period of the baseband signal (reciprocal of the baseband signal bandwidth) is greater the coherence time, than the signal will distort, since channel will change during the transmission of the signal .



Coherence time (T_C) is defined as:

$$T_C \approx \frac{1}{f_m}$$



Coherence Time

Coherence time is also defined as:

$$T_C \approx \sqrt{\frac{9}{16\pi f_m^2}} = \frac{0.423}{f_m}$$

Coherence time definition implies that two signals arriving with a time separation greater than T_C are affected differently by the channel.

Types of Small-scale Fading

Small-scale Fading
(Based on Multipath Time Delay Spread)

Flat Fading

1. BW Signal < BW of Channel
2. Delay Spread < Symbol Period

Frequency Selective Fading

1. BW Signal > Bw of Channel
2. Delay Spread > Symbol Period

Small-scale Fading
(Based on Doppler Spread)

Fast Fading

1. High Doppler Spread
2. Coherence Time < Symbol Period
3. Channel variations faster than baseband signal variations

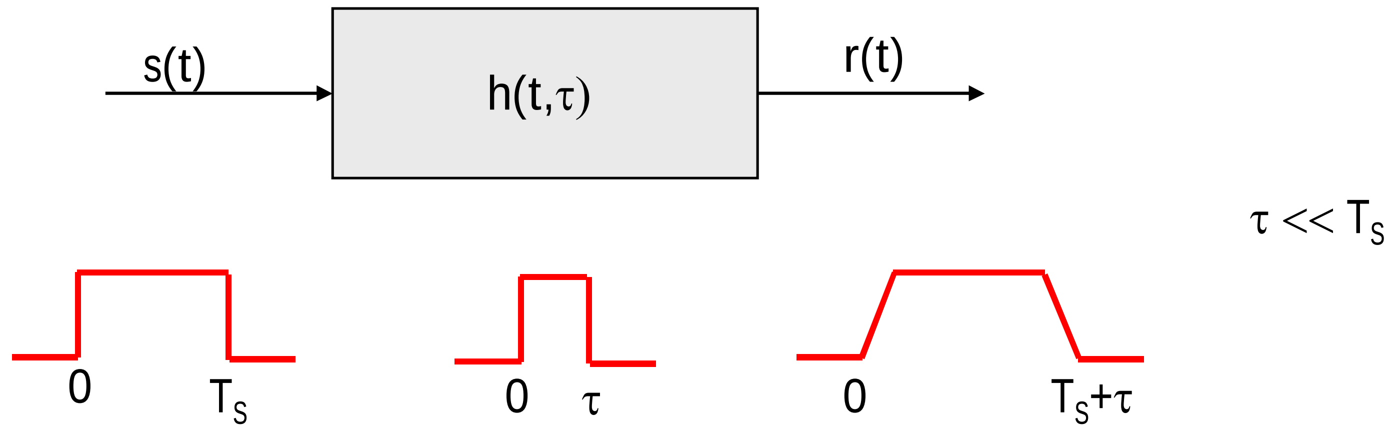
Slow Fading

1. Low Doppler Spread
2. Coherence Time > Symbol P
3. Channel variations smaller th signal variations

Flat Fading

- Occurs when the amplitude of the received signal changes with time
    - For example according to Rayleigh Distribution
- Occurs when symbol period of the transmitted signal is much larger than the Delay Spread of the channel
    - Bandwidth of the applied signal is narrow.
- May cause deep fades.
    - Increase the transmit power to combat this situation.

Flat Fading



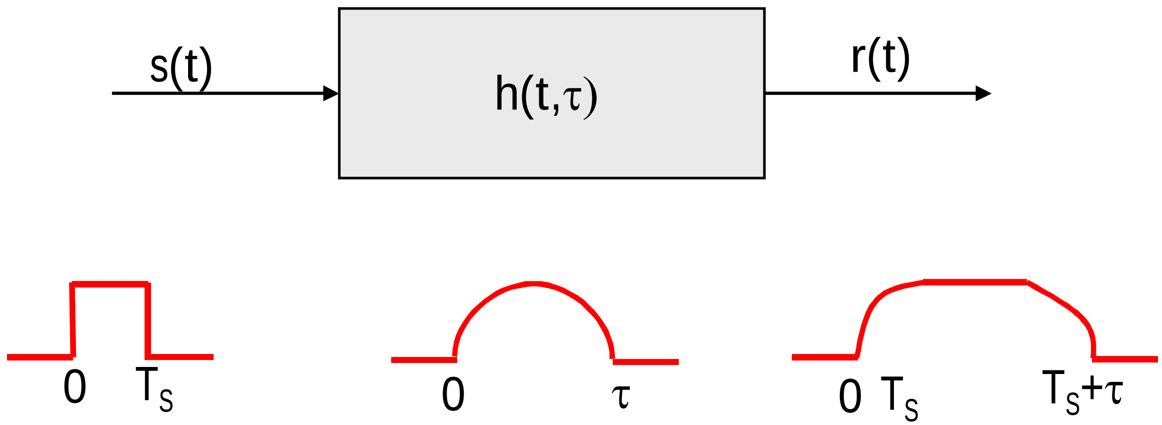
Occurs when:
$B_S << B_C$
and
$T_S >> \sigma_\tau$

B_C: Coherence bandwidth
B_S: Signal bandwidth
T_S: Symbol period
σ_τ: Delay Spread

Frequency Selective Fading

- Occurs when channel multipath delay spread is greater than the symbol period.
  - Symbols face time dispersion
  - Channel induces Intersymbol Interference (ISI)
- Bandwidth of the signal s(t) is wider than the channel impulse response.

Frequency Selective Fading



$\tau >> T_S$

Causes distortion of the received baseband signal

Causes Inter-Symbol Interference (ISI)

Occurs when:
$B_S > B_C$
and
$T_S < \sigma_\tau$

As a rule of thumb: $T_S < \sigma_\tau$

Fast Fading

- Due to Doppler Spread
  - Rate of change of the <u>channel characteristics</u>
    is **larger** than the
    Rate of change of the <u>transmitted signal</u>
  - The channel changes during a symbol period.
  - The channel changes because of receiver motion.
  - <u>Coherence time</u> of the channel is smaller than the <u>symbol period</u> of the transmitter signal

Occurs when:
$B_S < B_D$
and
$T_S > T_C$

B_S: Bandwidth of the signal
B_D: Doppler Spread
T_S: Symbol Period
T_C: Coherence Bandwidth

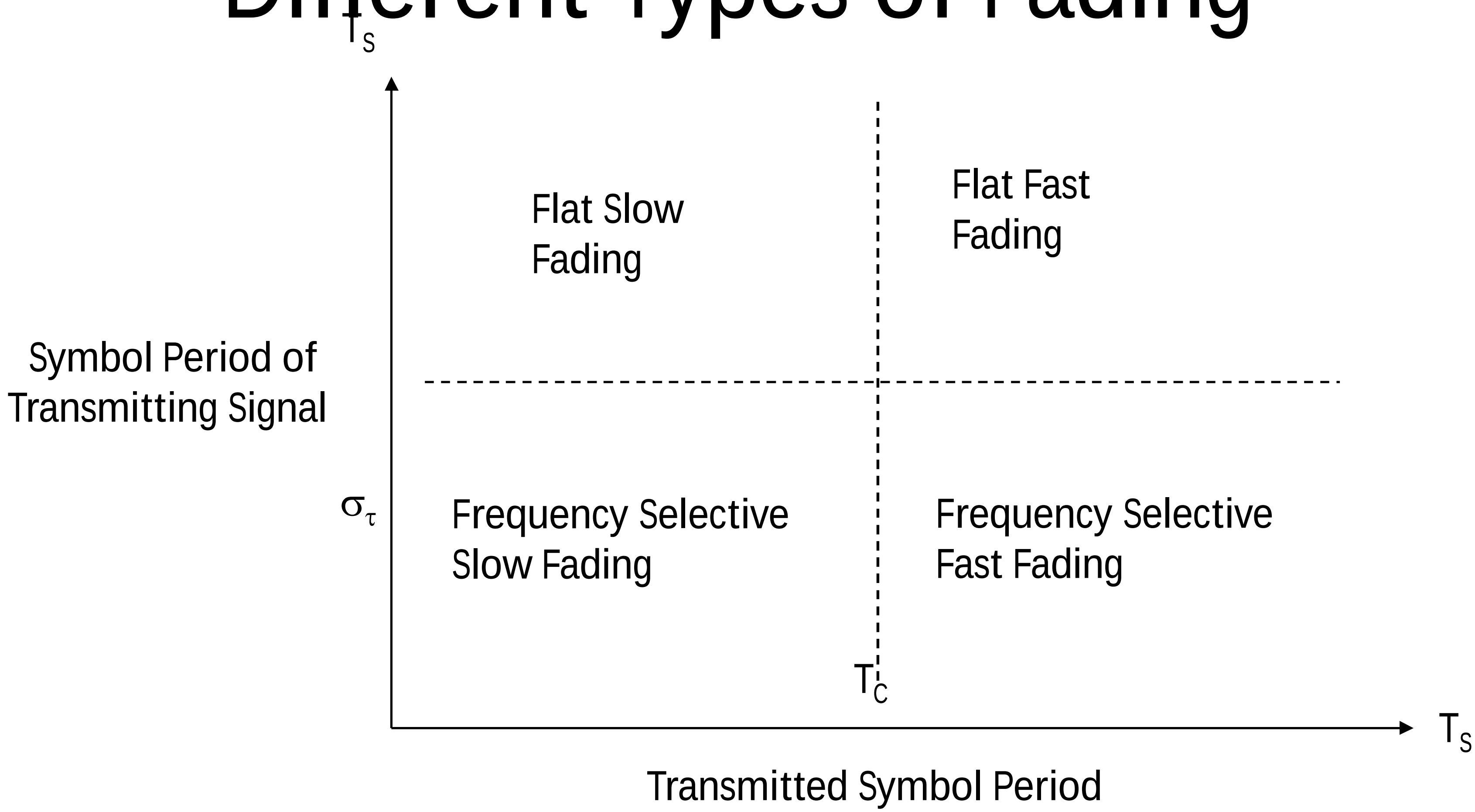
Slow Fading

- Due to Doppler Spread
  - Rate of change of the channel characteristics is **much smaller** than the Rate of change of the transmitted signal

Occurs when: $B_S >> B_D$ and $T_S << T_C$

B_S: Bandwidth of the signal
B_D: Doppler Spread
T_S: Symbol Period
T_C: Coherence Bandwidth

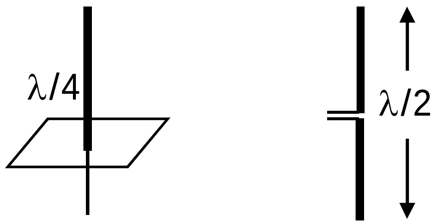
Different Types of Fading



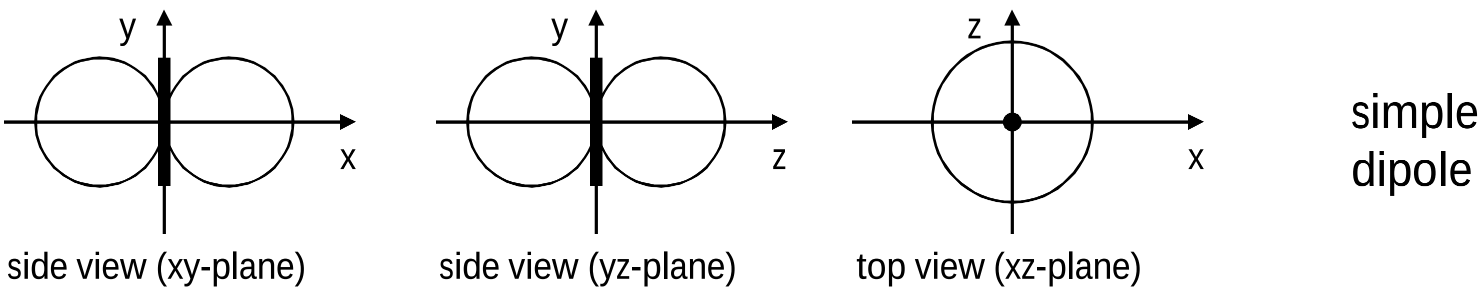
With Respect To SYMBOL PERIOD

Antennas: simple dipoles

- Real antennas are not isotropic radiators but, e.g., dipoles with lengths λ/4 on car roofs or λ/2 as Hertzian dipole
  ➔ shape of antenna proportional to wavelength



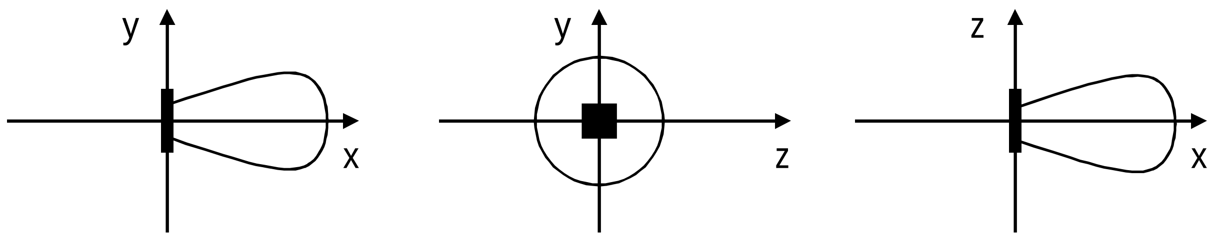
- Example: Radiation pattern of a simple Hertzian dipole



- Gain: maximum power in the direction of the main lobe compared to the power of an isotropic radiator (with the same average power)

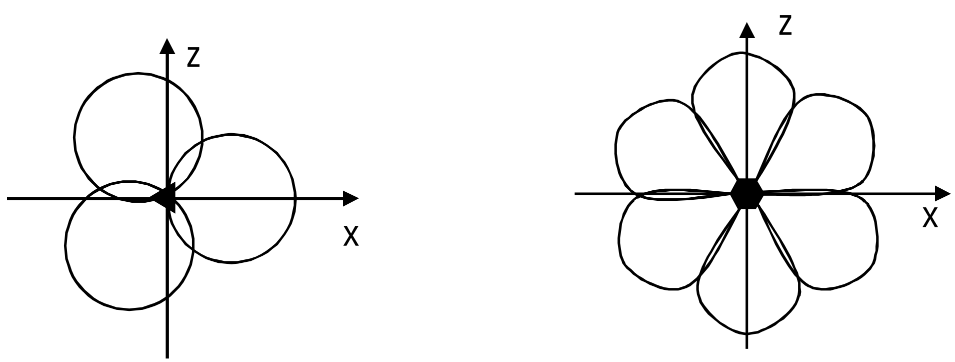
Antennas: Directed and Sectorized

- Often used for microwave connections or base stations for mobile phones (e.g., radio coverage of a valley)



side view (xy-plane) side view (yz-plane) top view (xz-plane)

directed antenna



top view, 3 sector top view, 6 sector

sectorized antenna

UNIT IV

MODULATION AND SIGNAL PROCESSING

Modulation Techniques

- Modulation can be done by varying the
  - Amplitude
  - Phase, or
  - Frequency of a high frequency carrier in accordance with the amplitude of the message signal.
- Demodulation is the inverse operation: extracting the baseband message from the carrier so that it may be processed at the receiver.

Analog/Digital Modulation

- Analog Modulation
  - The input is continues signal
  - Used in first generation mobile radio systems such as AMPS in USA.
- Digital Modulation
  - The input is time sequence of symbols or pulses.
  - Are used in current and future mobile radio systems

Goal of Modulation Techniques

- Modulation is difficult task given the hostile mobile radio channels
  - Small-scale fading and multipath conditions.
- The goal of a modulation scheme is:
  - Transport the message signal through the radio channel with best possible quality
  - Occupy least amount of radio (RF) spectrum.

Amplitude Modulation

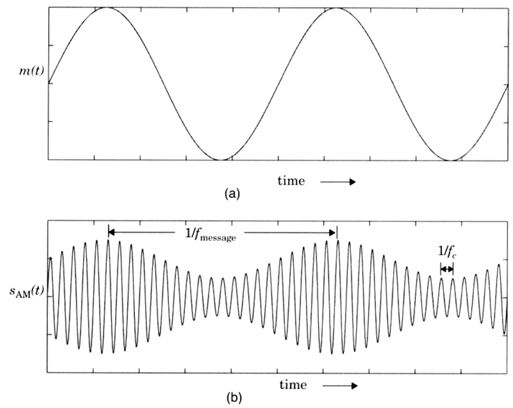


Figure 6.1 (a) A sinusoidal modulating signal and (b) the corresponding AM signal with modulation index 0.5.

Double Sideband Spectrum

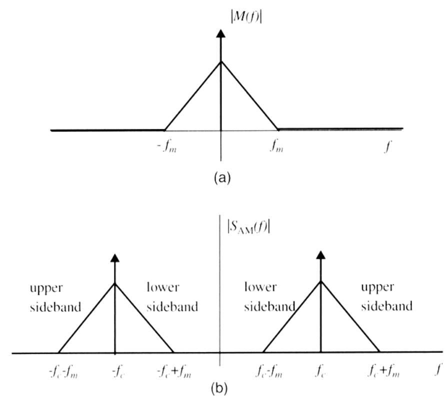


Figure 6.2 (a) Spectrum of a message signal; (b) spectrum of the corresponding AM signal.

SSB Modulators

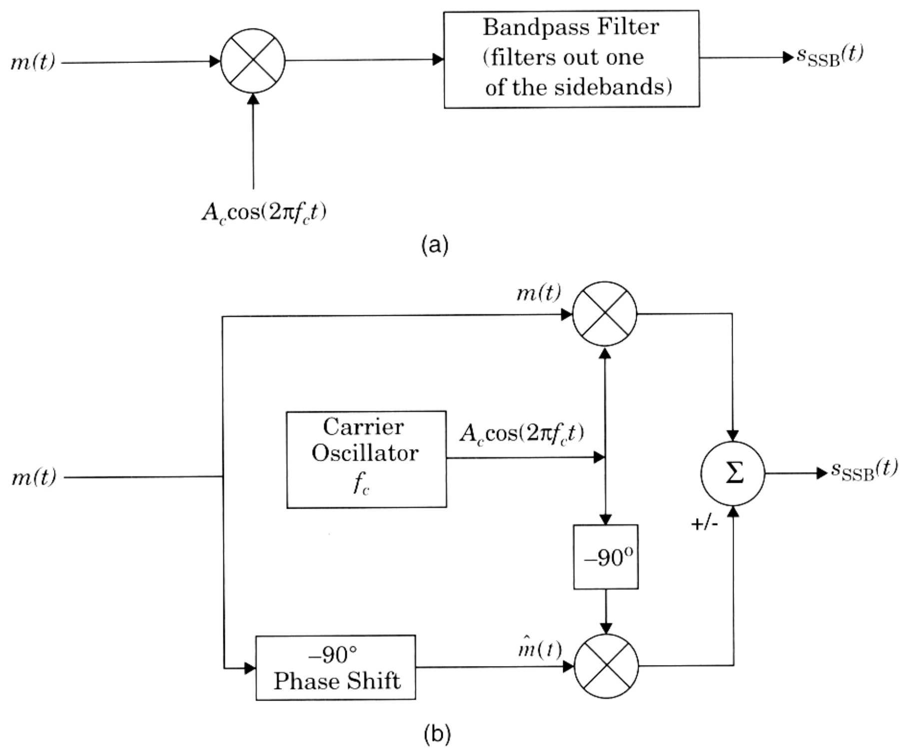


Figure 6.3 Generation of SSB using (a) a sideband filter and (b) a balanced modulator.

Wideband FM generation

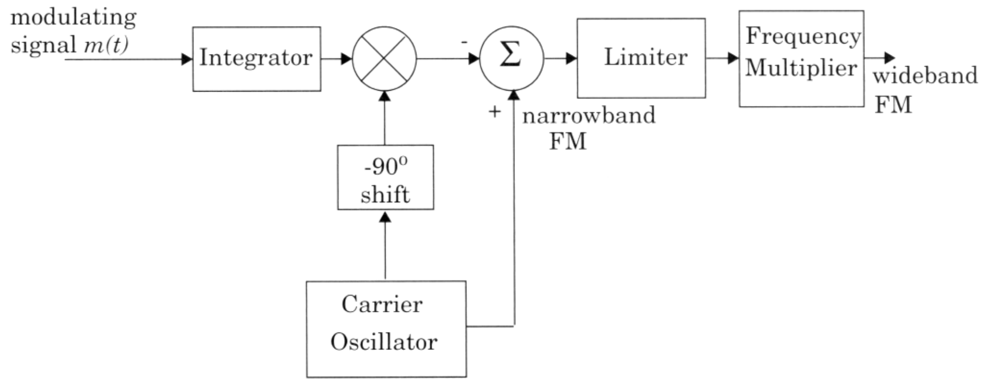


Figure 6.7 Indirect method for generating a wideband FM signal. A narrowband FM signal is generated using a balanced modulator and then frequency multiplied to generate a wideband FM signal.

Slope Detector for FM

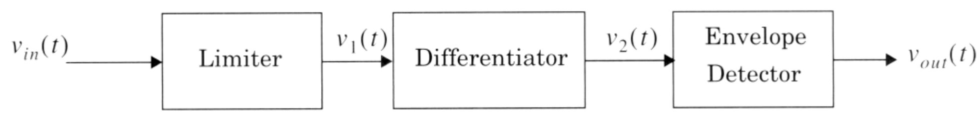


Figure 6.8 Block diagram of a slope detector type FM demodulator.

Digital Modulation

- The input is discrete signals
  - Time sequence of pulses or symbols
- Offers many advantages
  - Robustness to channel impairments
  - Easier multiplexing of variuous sources of information: voice, data, video.
  - Can accommodate digital error-control codes
  - Enables encryption of the transferred signals
    - More secure link

Factors that Influence Choice of Digital Modulation Techniques

- A desired modulation scheme
  - Provides low bit-error rates at low SNRs
    - Power efficiency
  - Performs well in multipath and fading conditions
  - Occupies minimum RF channel bandwidth
    - Bandwidth efficiency
  - Is easy and cost-effective to implement
- Depending on the demands of a particular system or application, tradeoffs are made when selecting a digital modulation scheme.

Power Efficiency of Modulation

- Power efficiency is the ability of the modulation technique to preserve fidelity of the message at low power levels.
- Usually in order to obtain good fidelity, the signal power needs to be increased.
    - Tradeoff between fidelity and signal power
    - Power efficiency describes how efficient this tradeoff is made

- Eb: signal energy per bit
- N0: noise power spectral density
- PER: probability of error

Bandwidth Efficiency of Modulation

- Ability of a modulation scheme to accommodate data within a limited bandwidth.
- Bandwidth efficiency reflect how efficiently the allocated bandwidth is utilized

R: the data rate (bps)
B: bandwidth occupied by the modulated RF signal

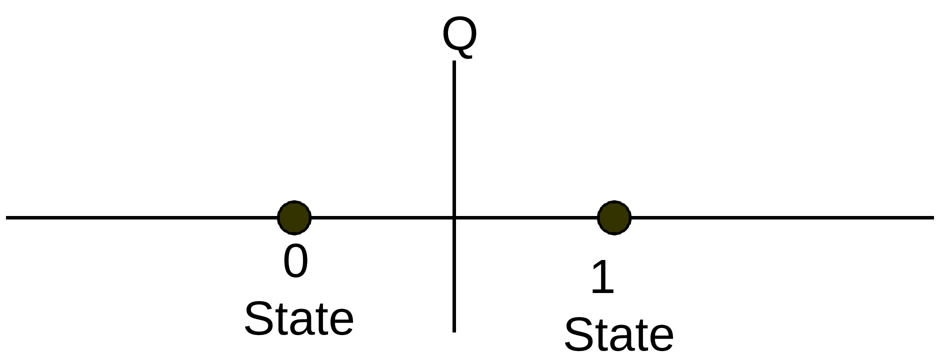
Linear Modulation Techniques

- Classify digital modulation techniques as:
  - Linear
    - The amplitude of the transmitted signal varies linearly with the modulating digital signal, m(t).
    - They usually do not have constant envelope.
    - More spectral efficient.
    - Poor power efficiency
    - Example: QPSK.
  - Non-linear

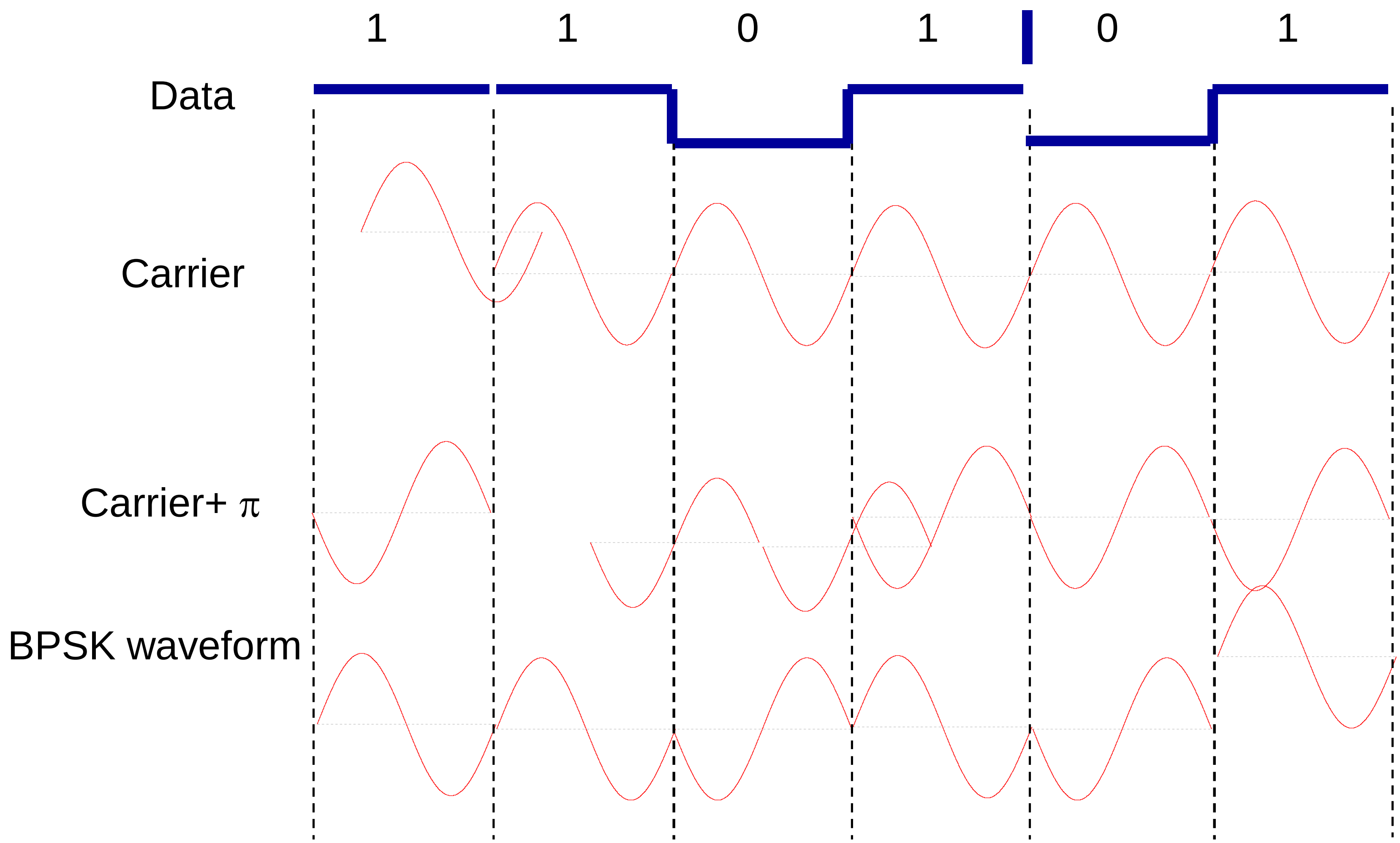
Binary Phase Shift Keying

- Use alternative sine wave phase to encode bits
  - Phases are separated by 180 degrees.
  - Simple to implement, inefficient use of bandwidth.
  - Very robust, used extensively in satellite communication.

$$s_1(t) = A_c \cos(2\pi f_c + \theta_c) \quad \text{binary } 1$$
$$s_2(t) = A_c \cos(2\pi f_c + \theta_c + \pi) \quad \text{binary } 0$$

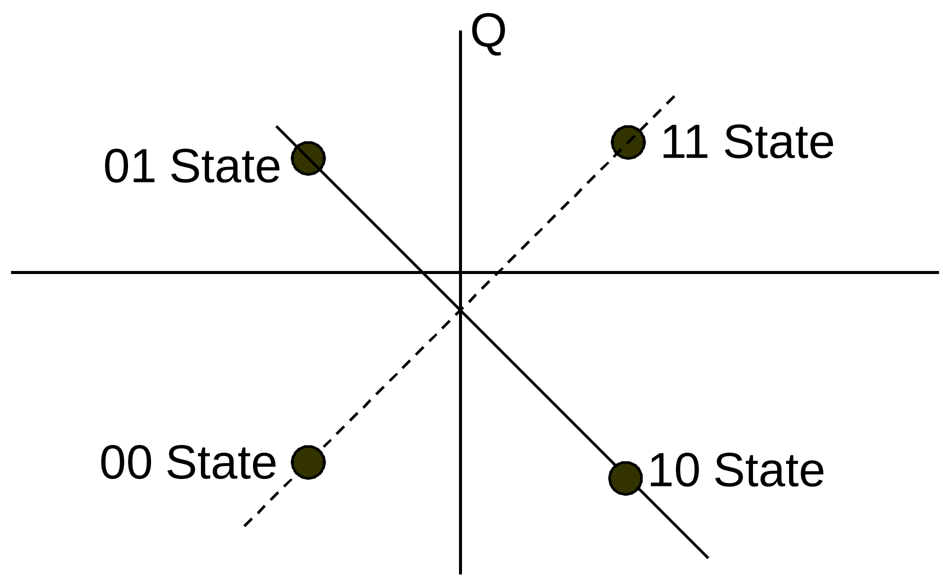


BPSK Example



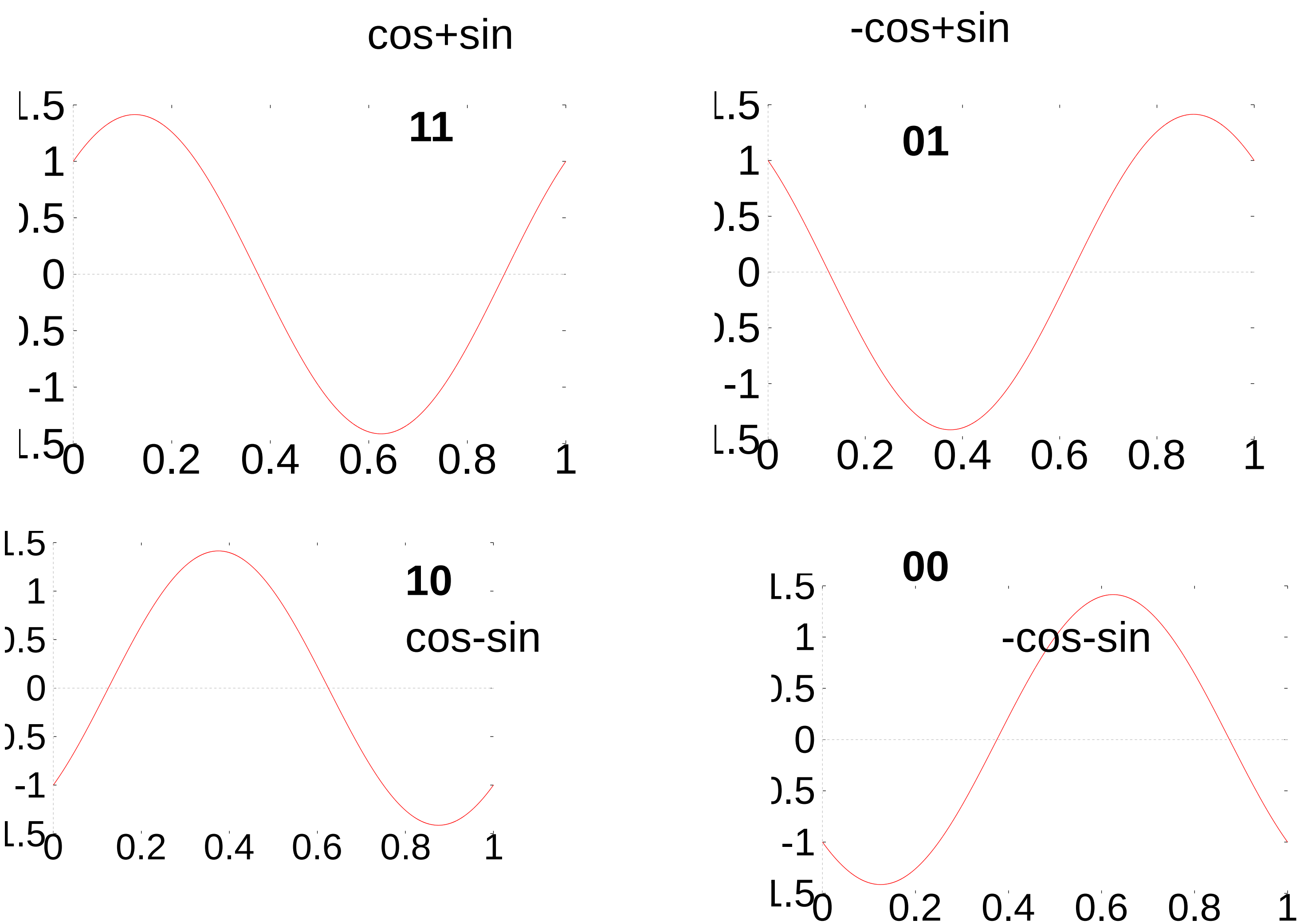
Quadrature Phase Shift Keying

- Multilevel Modulation Technique: 2 bits per symbol
- More spectrally efficient, more complex receiver.
- Two times more bandwidth efficient than BPSK



Phase of Carrier: $\pi/4$, $2\pi/4$, $5\pi/4$, $7\pi/4$

4 different waveforms



Constant Envelope Modulation

- Amplitude of the carrier is constant, regardless of the variation in the modulating signal
  - Better immunity to fluctuations due to fading.
  - Better random noise immunity
  - Power efficient
- They occupy larger bandwidth

Frequency Shift Keying (FSK)

- The frequency of the carrier is changed according to the message state (high (1) or low (0)).

$$s_1(t) = A\cos(2\pi f_c + 2\pi\Delta f)t \quad 0 \le \mathrm{t} \le \mathrm{T_b} \ (\mathrm{bit} = 1)$$
$$s_2(t) = A\cos(2\pi f_c - 2\pi\Delta f)t \quad 0 \le \mathrm{t} \le \mathrm{T_b} \ (\mathrm{bit} = 0)$$

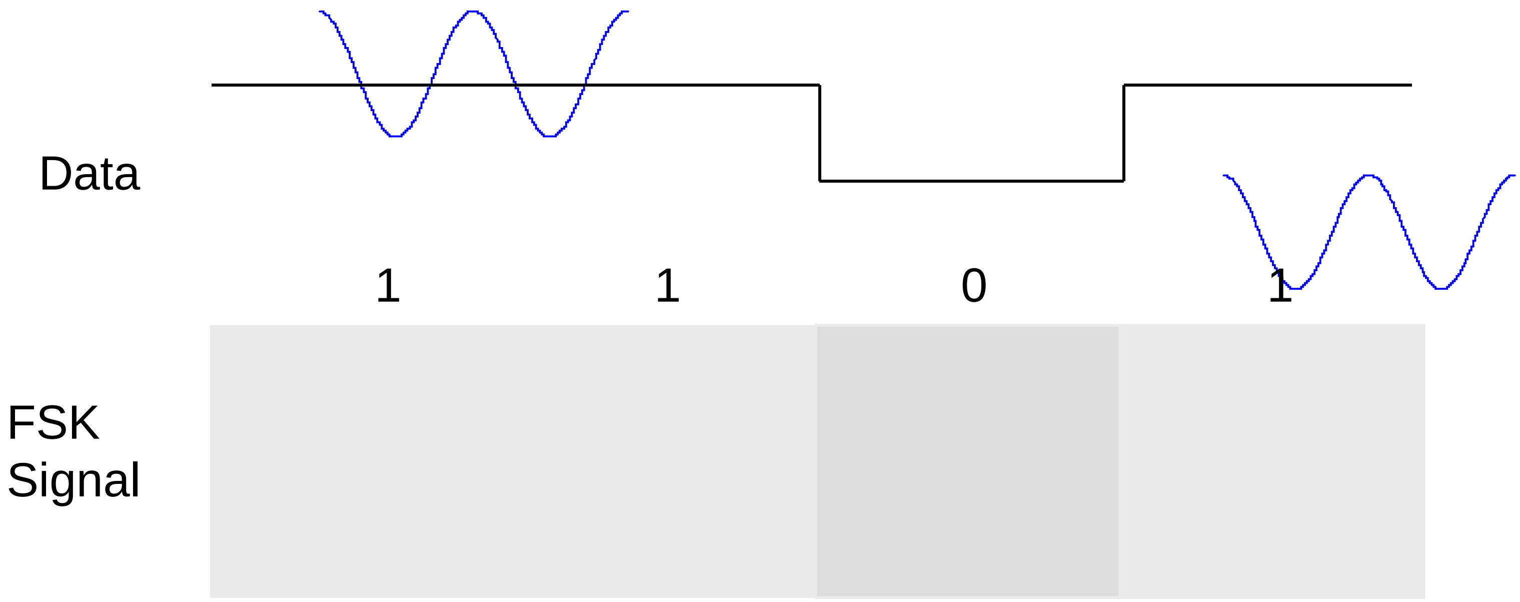
Continues FSK

$$s(t) = A\cos(2\pi f_c + \theta(t))$$

$$s(t) = A\cos(2\pi f_c t + 2\pi k_f \int_{-\infty}^{t} m(x)dx)$$

Integral of m(x) is continues.

FSK Example



BPSK constellation

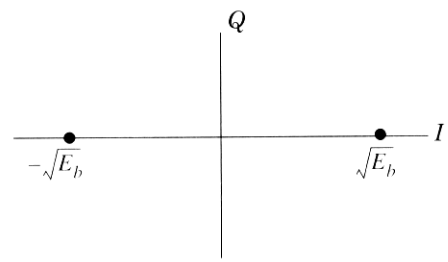


Figure 6.21 BPSK constellation diagram.

Virtue of pulse shaping

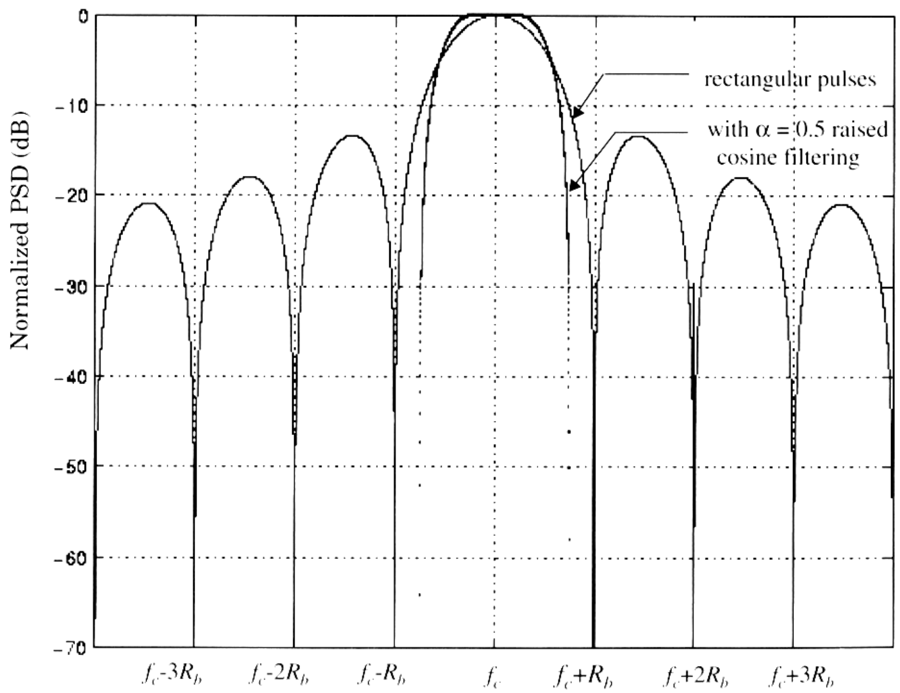


Figure 6.22 Power spectral density (PSD) of a BPSK signal.

BPSK Coherent demodulator

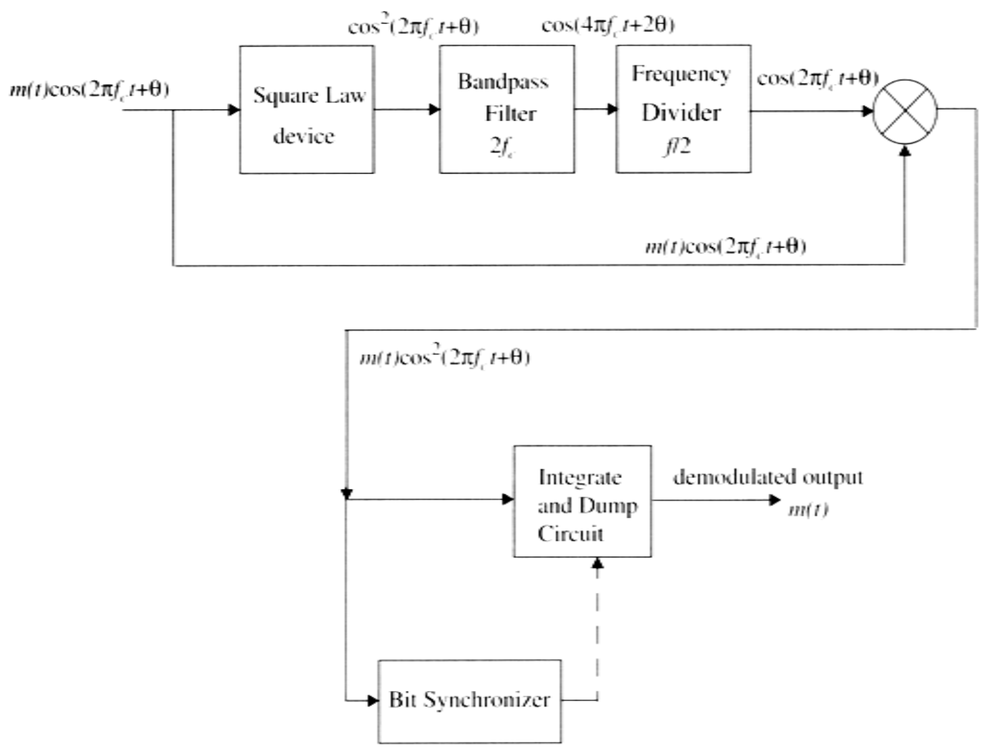


Figure 6.23 BPSK receiver with carrier recovery circuits.

Equalization,Diversity and Channel coding

- Three techniques are used to improve Rx signal quality and lower BER:

  1) Equalization
  2) Diversity
  3) Channel Coding

  – Used independently or together
  – We will consider Diversity and Channel Coding

III. Diversity Techniques

- Diversity : Primary goal is to reduce depth & duration of small-scale fades
  - Spatial or antenna diversity → most common
    - Use **multiple** Rx antennas in mobile or base station
    - Why would this be helpful?
    - Even small antenna separation ($\propto \lambda$) changes phase of signal → constructive /destructive nature is changed
  - Other diversity types → polarization, frequency, & time

- Exploits random behavior of MRC
  - Goal is to make use of several independent (uncorrelated) received signal paths
  - Why is this necessary?

- **Select** path with best *SNR* or **combine** multiple paths → improve overall *SNR* performance

- Microscopic diversity → combat **small-scale** fading
  - Most widely used
  - Use multiple antennas separated in space
    - At a **mobile**, signals are independent if separation > λ / 2
    - But it is not practical to have a mobile with multiple antennas separated by λ / 2 (7.5 cm apart at 2 GHz)
    - Can have multiple receiving antennas at base stations, but must be separated on the order of ten wavelengths (1 to 5 meters).

- Since reflections occur near receiver, independent signals spread out a lot before they reach the base station.
- a typical antenna configuration for 120 degree sectoring.
- For each sector, a transmit antenna is in the center, with two diversity receiving antennas on each side.
- If one radio path undergoes a deep fade, another independent path may have a strong signal.
- By having more than one path one select from, both the instantaneous and average SNRs at the receiver may be improved

- **Spatial** or Antenna Diversity → 4 basic types
  - *M* independent branches
  - Variable gain & phase at each branch → $G\angle\theta$
  - Each branch has same average *SNR*:

$$SNR = \Gamma = \frac{E_b}{N_0}$$

  - Instantaneous $SNR = \gamma_i$, the pdf of γ_i

$$p(\gamma_i) = \frac{1}{\Gamma} e^{\frac{-\gamma_i}{\Gamma}} \quad \gamma_i \geq 0 \quad (6.155)$$

$$\Pr\left[\gamma_i \leq \gamma\right] = \int_0^{\gamma} p(\gamma_i)\, d\gamma_i = \int_0^{\gamma} \frac{1}{\Gamma} e^{\frac{-\gamma_i}{\Gamma}} d\gamma_i = 1 - e^{\frac{-\gamma}{\Gamma}}$$

– The probability that all M independent diversity branches Rx signal which are simultaneously less than some specific SNR threshold γ

$$\Pr\left[\gamma_1,\ldots\gamma_M \le \gamma\right] = (1-e^{-\gamma/\Gamma})^M = P_M(\gamma)$$

$$\Pr\left[\gamma_i > \gamma\right] = 1 - P_M(\gamma) = 1-(1-e^{-\gamma/\Gamma})^M$$

– The pdf of γ $\quad p_M(\gamma) = \frac{d}{d\gamma} P_M(\gamma) = \frac{M}{\Gamma}\left(1-e^{-\gamma/\Gamma}\right)^{M-1} e^{-\gamma/\Gamma}$

– Average SNR improvement offered by selection diversity

$$\bar{\gamma} = \int_0^{\infty} \gamma\, p_M(\gamma) d\gamma = \Gamma \int_0^{\infty} Mx\left(1-e^{-x}\right)^{M-1} e^{-x} dx, \quad x = \gamma/\Gamma$$

$$\frac{\bar{\gamma}}{\Gamma} = \sum_{k=1}^{M} \frac{1}{k}$$

1) Selection Diversity → simple & cheap

- Rx selects branch with highest **instantaneous** *SNR*
  - new selection made at a time that is the reciprocal of the fading rate
  - this will cause the system to stay with the current signal until it is likely the signal has faded
- *SNR* improvement :
  - $\bar{\gamma}$ is new avg. *SNR*
  - Γ : avg. *SNR* in each branch

$$\bar{\gamma} = \Gamma \sum_{k=1}^{m} \frac{1}{k} = \Gamma\left(1 + \frac{1}{2} + \frac{1}{3} + \frac{1}{4} + \cdots + \frac{1}{m}\right) > \Gamma$$

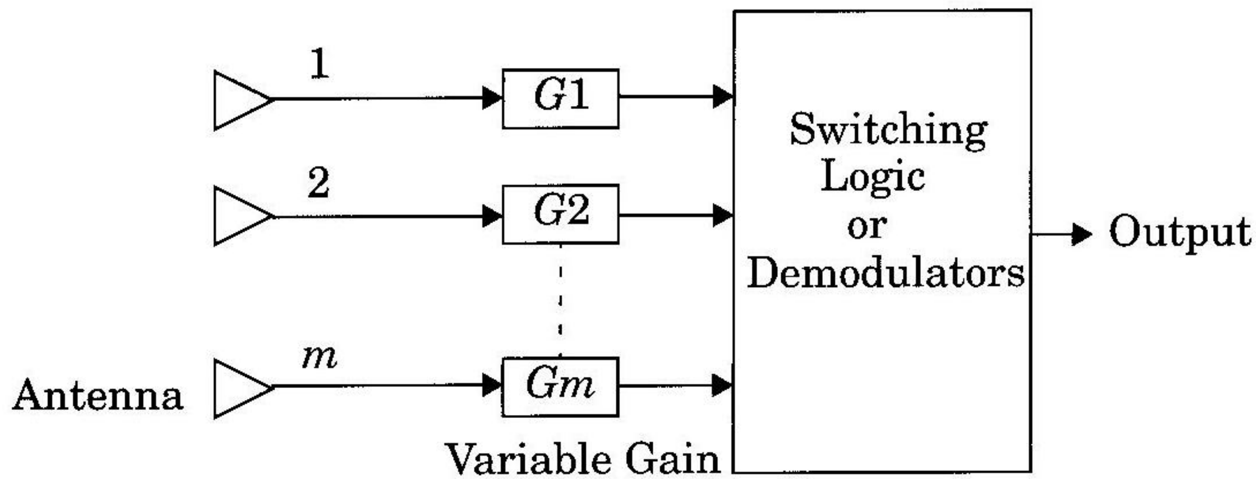


Figure 7.12 Generalized block diagram for space diversity.

2) Scanning Diversity

- scan each antenna until a signal is found that is above predetermined threshold
- if signal drops below threshold → rescan
- o[illegible]t a ti[illegible]

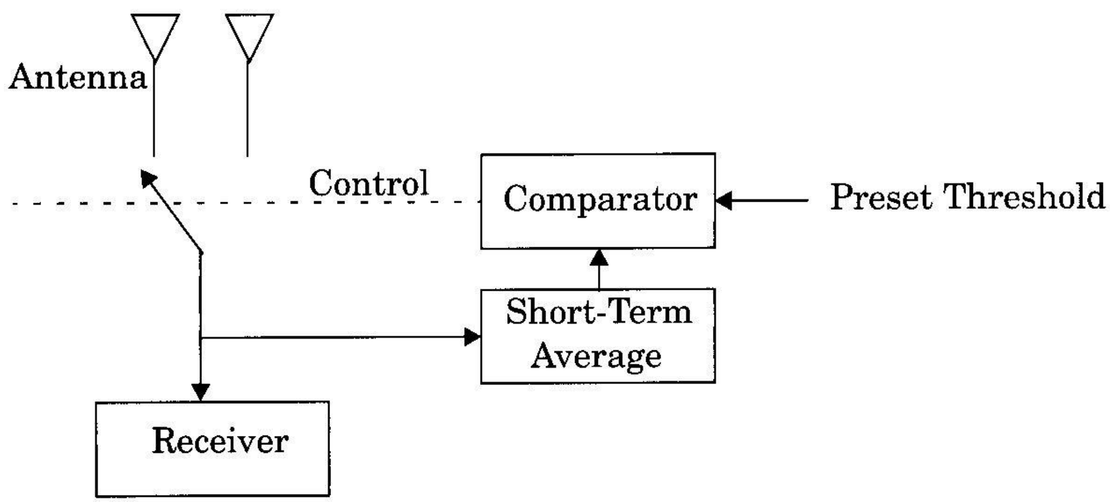


Figure 7.13 Basic form of scanning diversity.

3) Maximal Ratio Diversity

- signal amplitudes are weighted according to each *SNR*
- summed **in-phase**
- most complex of all types
- a complicated mechanism, but modern DSP makes this more practical → especially in the base station Rx where battery power to perform computations is not an issue

- The resulting signal envelop applied to detector:

$$r_M = \sum_{i=1}^{M} G_i r_i$$

- Total noise power:

$$N_T = N \sum_{i=1}^{M} G_i^2$$

- SNR applied to detector:

$$\gamma_M = \frac{r_M^2}{2N_T}$$

– The voltage signals γ_i from each of the M diversity branches are co-phased to provide coherent voltage addition and are individually weighted to provide optimal SNR

$$\gamma_M = \frac{1}{2}\frac{\sum (r_i^2/N)^2}{N\sum (r_i^2/N^2)} = \frac{1}{2}\sum_{i=1}^{M}\frac{r_i^2}{N} = \sum_{i=1}^{M}\gamma_i$$

(r_M is maximized when $G_i = r_i / N$)

– The SNR out of the diversity combiner is the sum of the SNRs in each branch.

– The probability that γ_M less than some specific SNR threshold γ

$$p(\gamma_M) = \frac{\gamma_M^{M-1} e^{-\gamma_M/\Gamma}}{\Gamma^M (M-1)!} \quad \text{for } \gamma_M \geq 0$$

$$Pr\{\gamma_M \leq \gamma\} = \int_0^{\gamma} p(\gamma_M) d\gamma_M = 1 - e^{-\gamma/\Gamma} \sum_{k=1}^{M} \frac{(\gamma/\Gamma)^{k-1}}{(k-1)!}$$

– gives **optimal** *SNR* improvement :

- Γ_i: avg. *SNR* of each individual branch
- $\Gamma_i = \Gamma$ if the avg. *SNR* is the same for each branch

$$\overline{\gamma_M} = \sum_{i=1}^{M} \overline{\gamma_i} = \sum_{i=1}^{M} \Gamma_i = M\Gamma$$

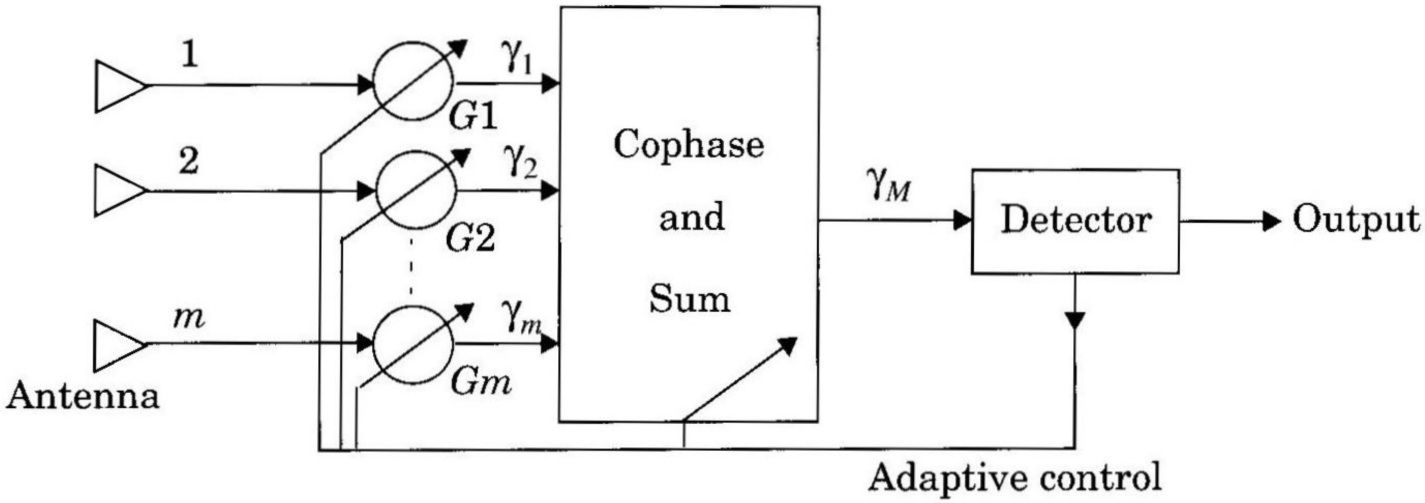


Figure 7.14 Maximal ratio combiner.

4) Equal Gain Diversity

– combine multiple signals into one
– $G = 1$, but the phase is adjusted for each received signal so that
  - The signal from each branch are co-phased
  - vectors add in-phase
– better performance than selection diversity

IV. Time Diversity

- Time Diversity → transmit repeatedly the information at different time spacings
  - Time spacing > coherence time (coherence time is the time over which a fading signal can be considered to have similar characteristics)
  - So signals can be considered independent
  - Main disadvantage is that BW efficiency is significantly worsened – signal is transmitted more than once
    - BW must ↑ to obtain the **same** R_d (data rate)

RAKE Receiver

- Powerful form of time diversity available in spread spectrum (DS) systems → CDMA
- Signal is only transmitted once
- Propagation delays in the MRC provide multiple copies of Tx signals delayed in time
- Attempts to collect the time-shifted versions of the original signal by providing a separate correlation receiver for each of the multipath signals.
- Each correlation receiver may be adjusted in time delay, so that a microprocessor controller can cause different correlation receivers to search in different time windows for significant multipath.
- The range of time delays that a particular correlator can search is called a search window.

- If time delay between multiple signals > chip period of spreading sequence (Tc) → multipath signals can be considered uncorrelated (independent)
  - In a basic system, these delayed signals only appear as noise, since they are delayed by more than a chip duration. And ignored.
  - Multiplying by the chip code results in noise because of the time shift.
  - But this can also be used to our advantage, by shifting the chip sequence to receive that delayed signal separately from the other signals.

- The RAKE Rx is a time diversity Rx that collects time-shifted versions of the original Tx signal

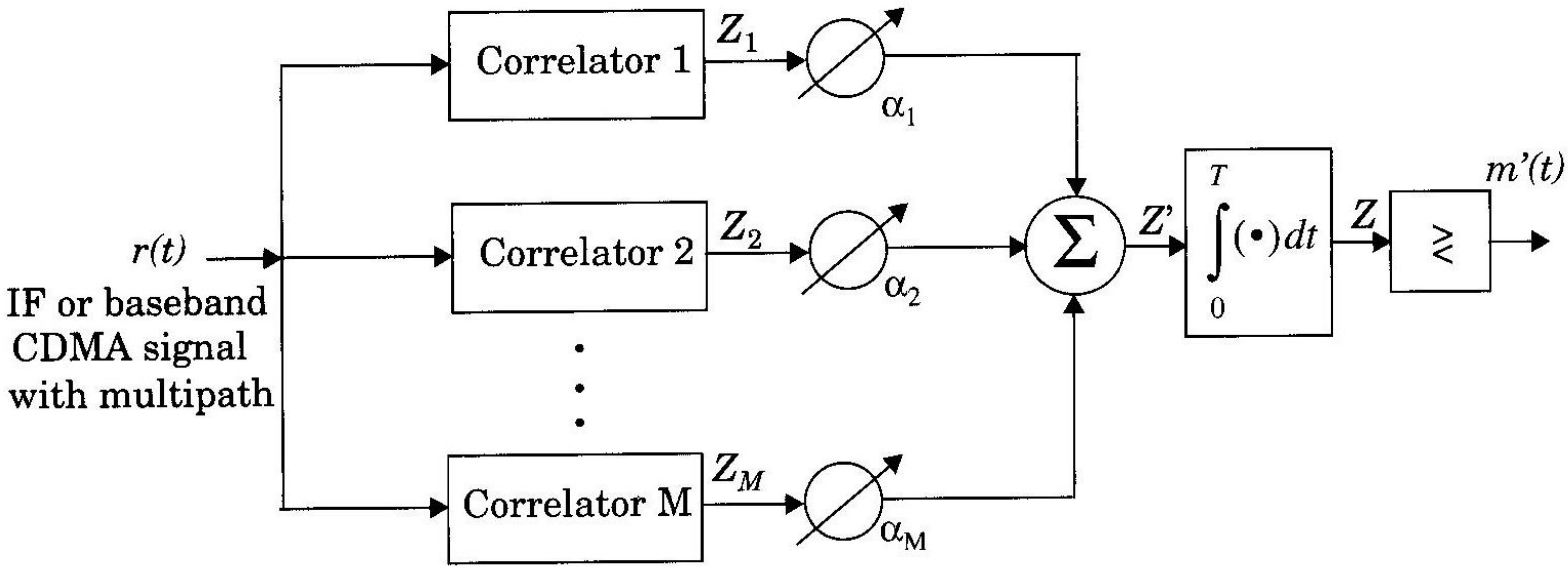


Figure 7.16 An *M*-branch (*M*-finger) RAKE receiver implementation. Each correlator detects a time shifted version of the original CDMA transmission, and each finger of the RAKE correlates to a portion of the signal which is delayed by at least one chip in time from the other fingers.

Cont.

- M branches or “fingers” = # of correlation Rx’s
- Separately detect the M strongest signals
- Weighted sum computed from M branches
  - Faded signal → low weight
  - Strong signal → high weight
  - Overcomes fading of a signal in a single branch

In indoor environments:

- The delay between multipath components is usually large, the low autocorrelation properties of a CDMA spreading sequence can assure that multipath components will appear nearly uncorrelated with each other.

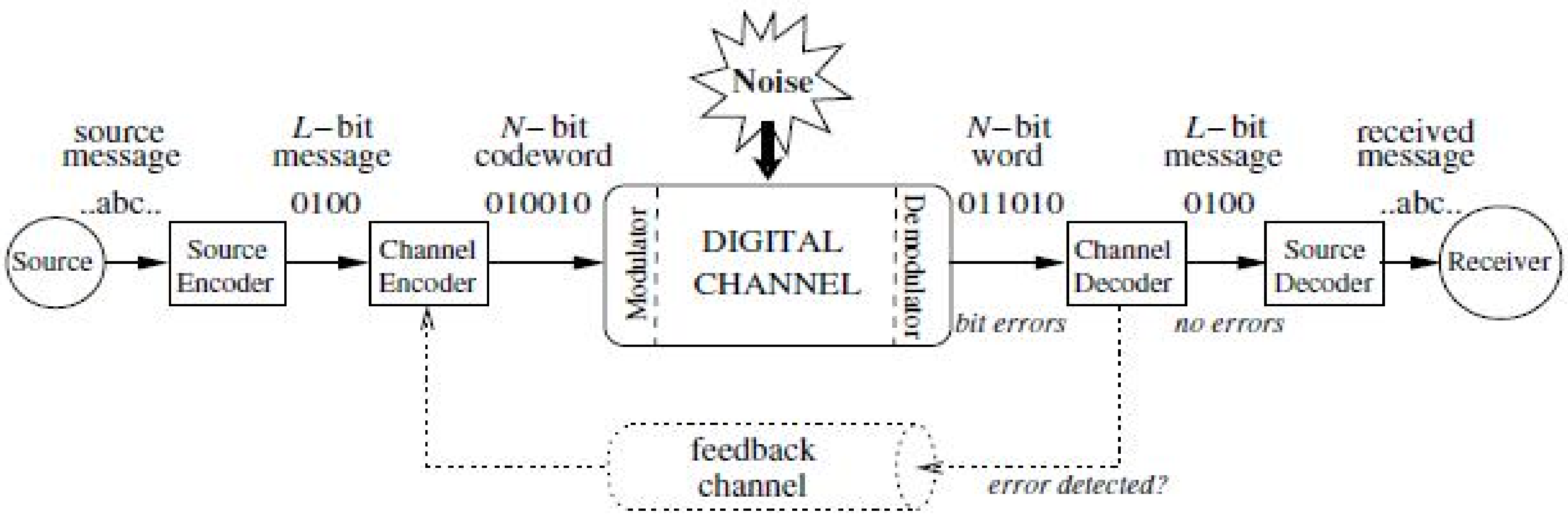
- RAKE receiver in IS-95 CDMA has been found to perform poorly

  - Since the multipath delay spreads in indoor channels (≈100 ns) are much smaller than an IS-95 chip duration (≈ 800 ns).
  - In such cases, a rake will not work since multipath is unresolveable
  - Rayleigh flat-fading typically occurs within a single chip period.

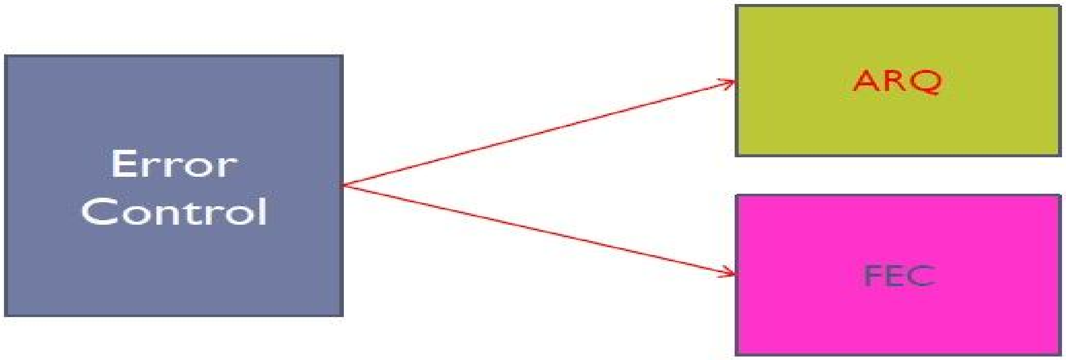
Channel Coding :

- Error control coding ,detect, and often correct, symbols which are received in error
- The channel encoder separates or segments the incoming bit stream into equal length blocks of L binary digits and maps each L-bit message block into an N-bit code word where N > L

There are $M=2^L$ messages and 2^L code words of length N bits



The channel decoder has the task of detecting that there has been a bit error and • (if possible) correcting the bit error



ARQ (Automatic-Repeat-Request) If the channel decoder performs error detection then errors can be detected and a feedback channel from the channel decoder to the channel encoder can be used to control the retransmission of the code word until the code word is received without detectable errors.

There are two major ARQ techniques stop and wait continuous ARQ

FEC (Forward Error Correction) If the channel decoder performs error correction then errors are not only detected but the bits in error can be identified and corrected (by bit inversion)

There are two major ARQ techniques.

- Stop and wait, in which each block of data is positively, or negatively, acknowledged by the receiving terminal as being error free before the next data block is transmitted,
- Continuous ARQ, in which blocks of data continue to be transmitted without waiting for each previous block to be acknowledged

Companding for ‘narrow-band’ speech

- ‘Narrow-band’ speech is what we hear over telephones.
- Normally band-limited from 300 Hz to about 3500 Hz.
- May be sampled at 8 kHz.
- 8-bits per sample not sufficient for good ‘narrow-band’ speech encoding with uniform quantisation.
- Problem lies with setting a suitable quantisation step-size □.
- One solution is to use instantaneous companding.
- Step-size adjusted according to amplitude of sample.
- For larger amplitudes, larger step-sizes used as illustrated next.
- ‘Instantaneous’ because step-size changes from sample to sample.

UNIT V

SYSTEM EXAMPLES AND DESIGN ISSUES

Multiple Access Techniques for Wireless Communication:

Many users can access the at same time, share a finite amount of radio spectrum with high performance duplexing generally required frequency domain time domain. They accessing techniques are,

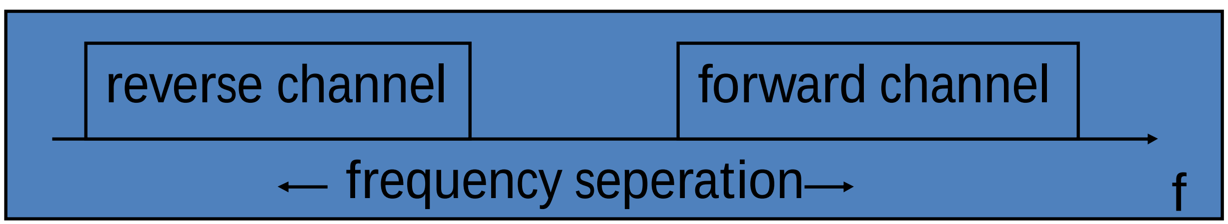
- FDMA
- TDMA
- SDMA
- PDMA

Introduction

- many users at same time
- share a finite amount of radio spectrum
- high performance
- duplexing generally required
- frequency domain
- time domain

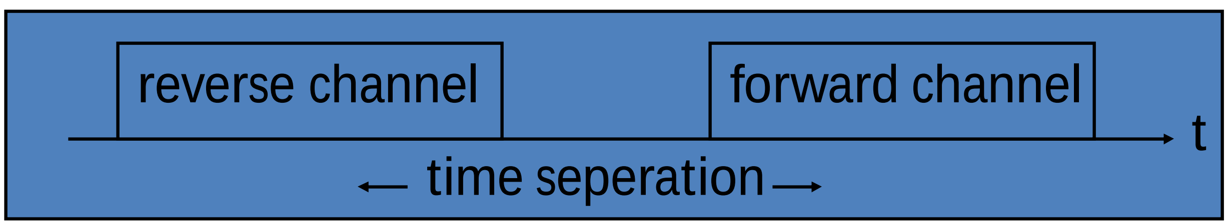
Frequency division duplexing (FDD)

- two bands of frequencies for every user
- forward band
- reverse band
- duplexer needed
- frequency seperation between forward band and reverse band is constant



Time division duplexing (TDD)

- uses time for forward and reverse link
- multiple users share a single radio channel
- forward time slot
- reverse time slot
- no duplexer is required



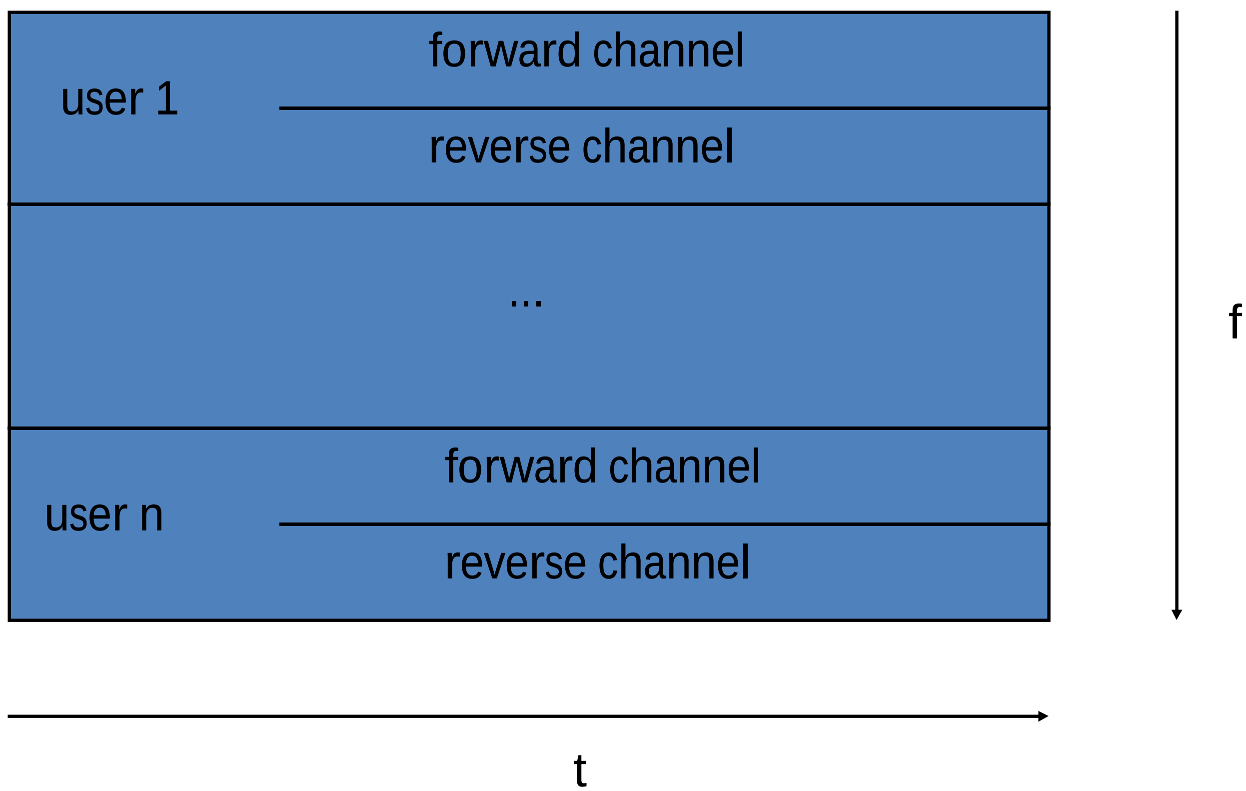
Multiple Access Techniques

- Frequency division multiple access (FDMA)
- Time division multiple access (TDMA)
- Code division multiple access (CDMA)
- Space division multiple access (SDMA)
- grouped as:
- narrowband systems
- wideband systems

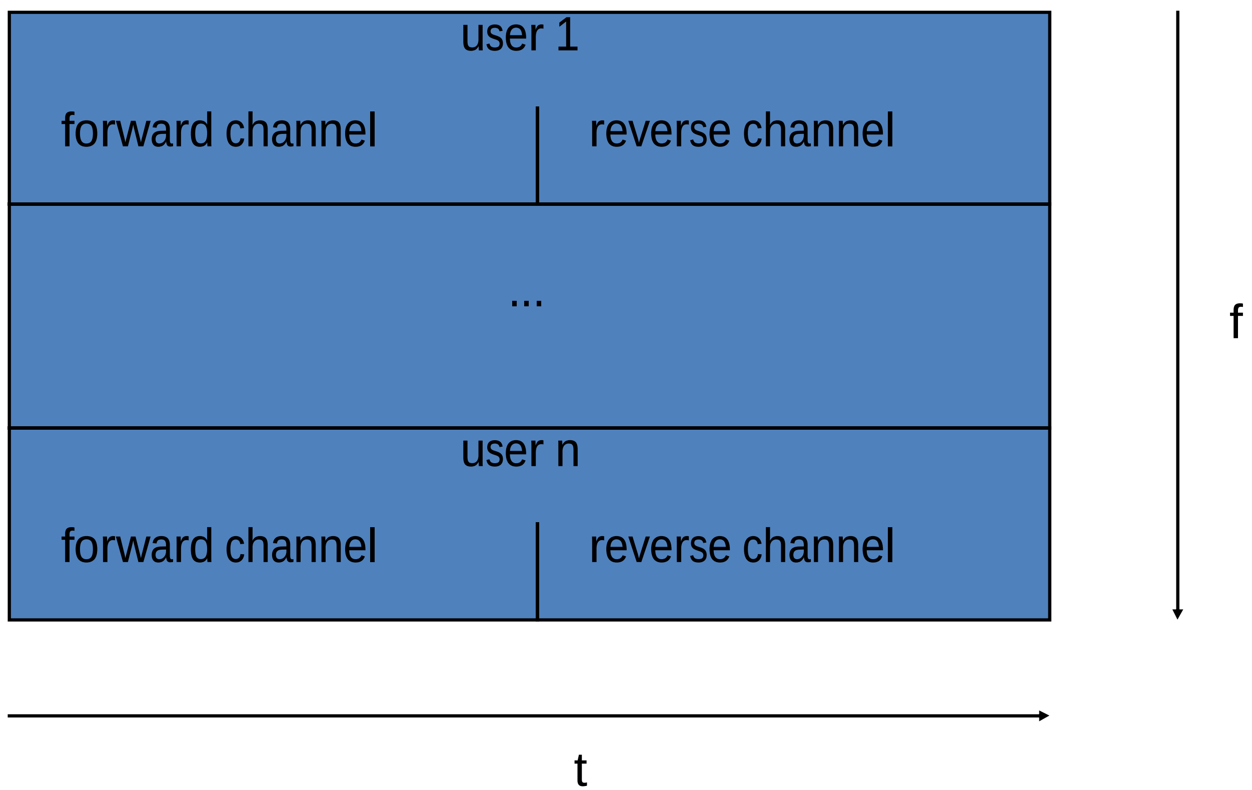
Narrowband systems

- large number of narrowband channels
- usually FDD
- Narrowband FDMA
- Narrowband TDMA
- FDMA/FDD
- FDMA/TDD
- TDMA/FDD
- TDMA/TDD

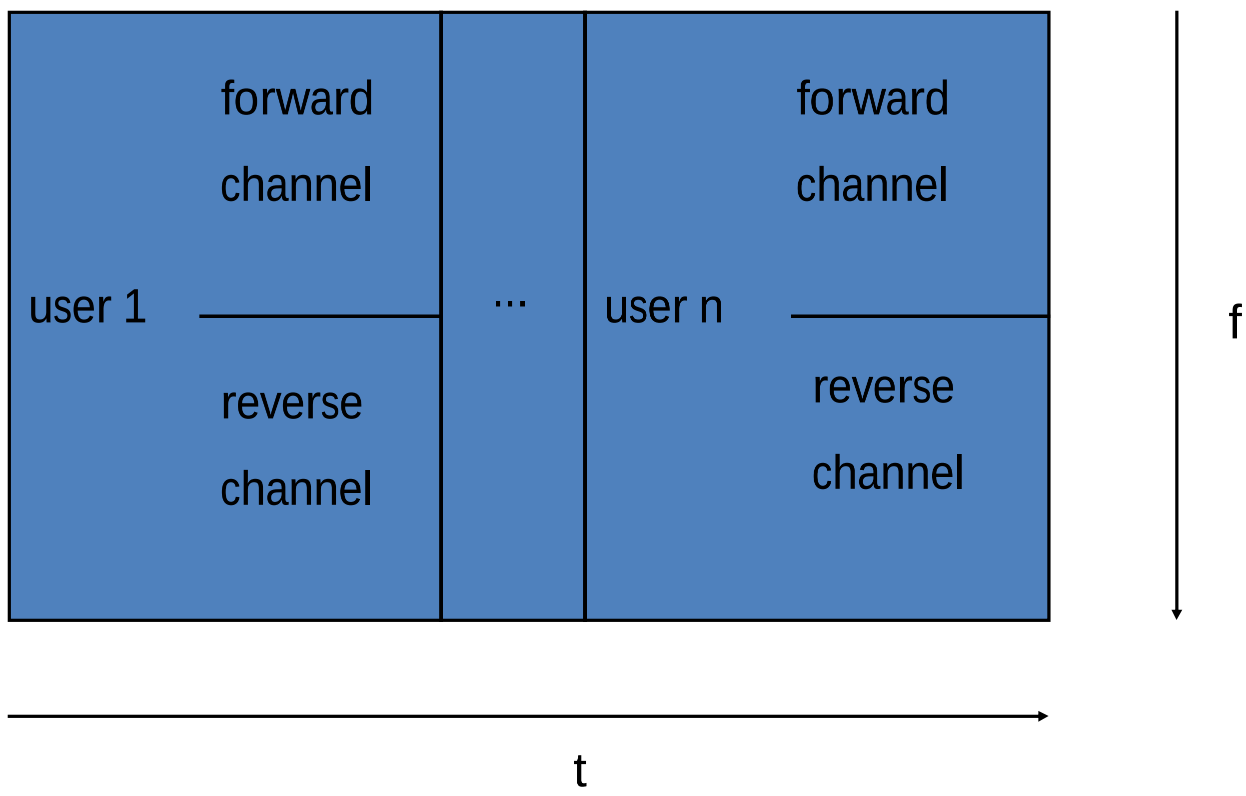
Logical separation FDMA/FDD



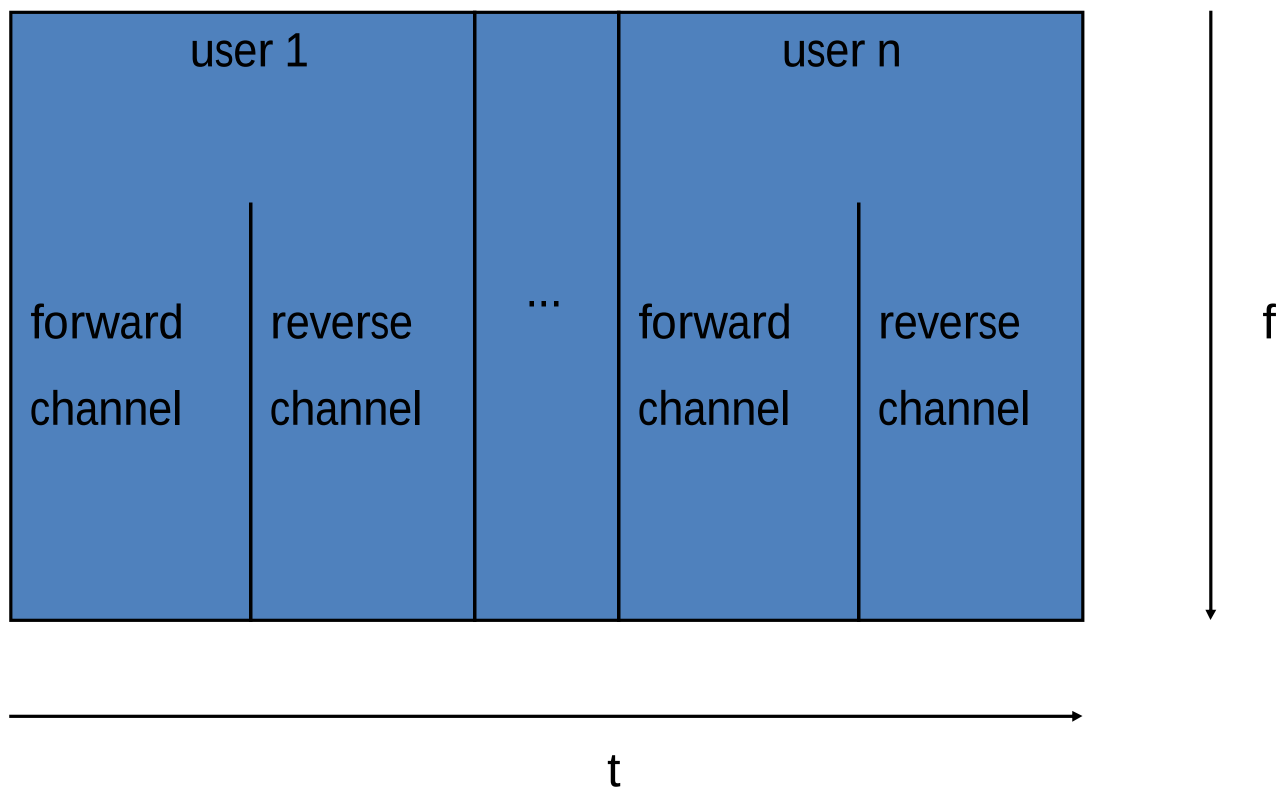
Logical separation FDMA/TDD



Logical separation TDMA/FDD



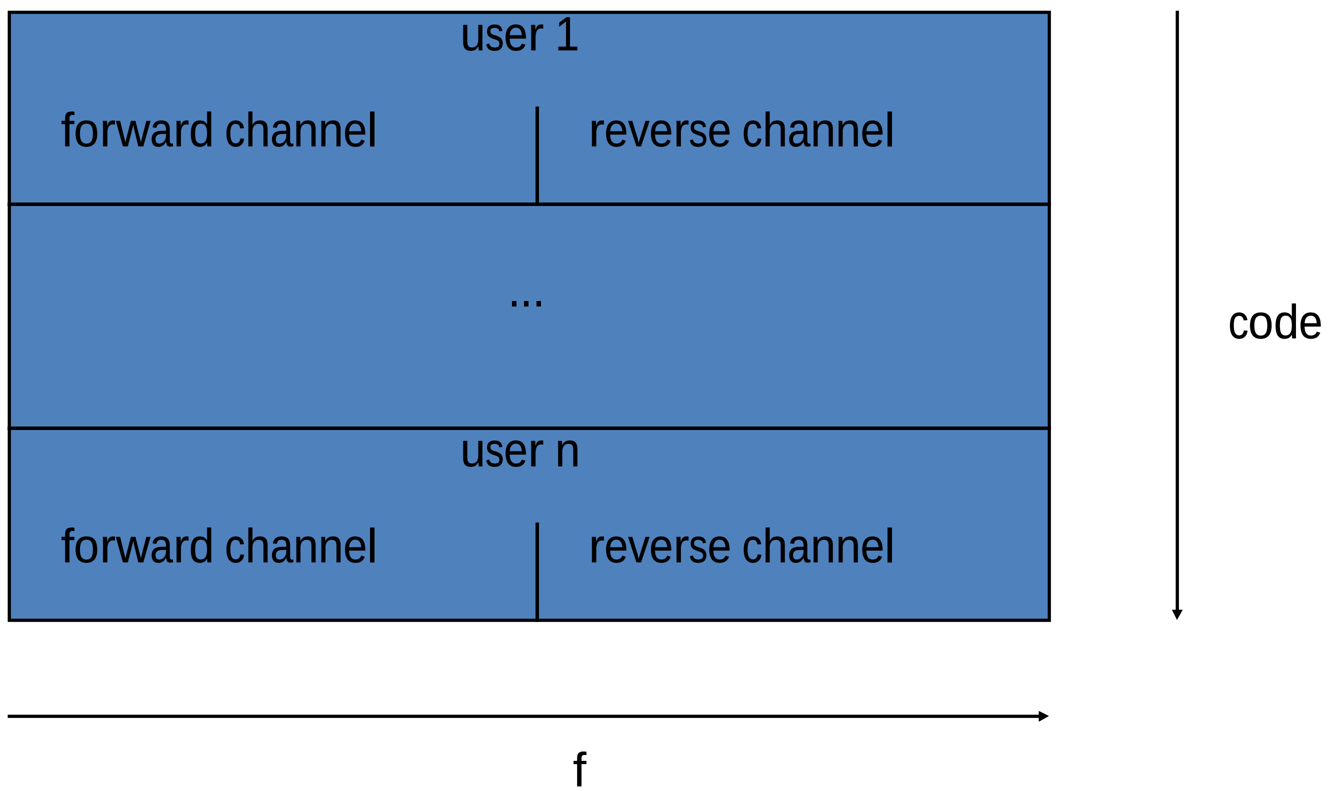
Logical separation TDMA/TDD



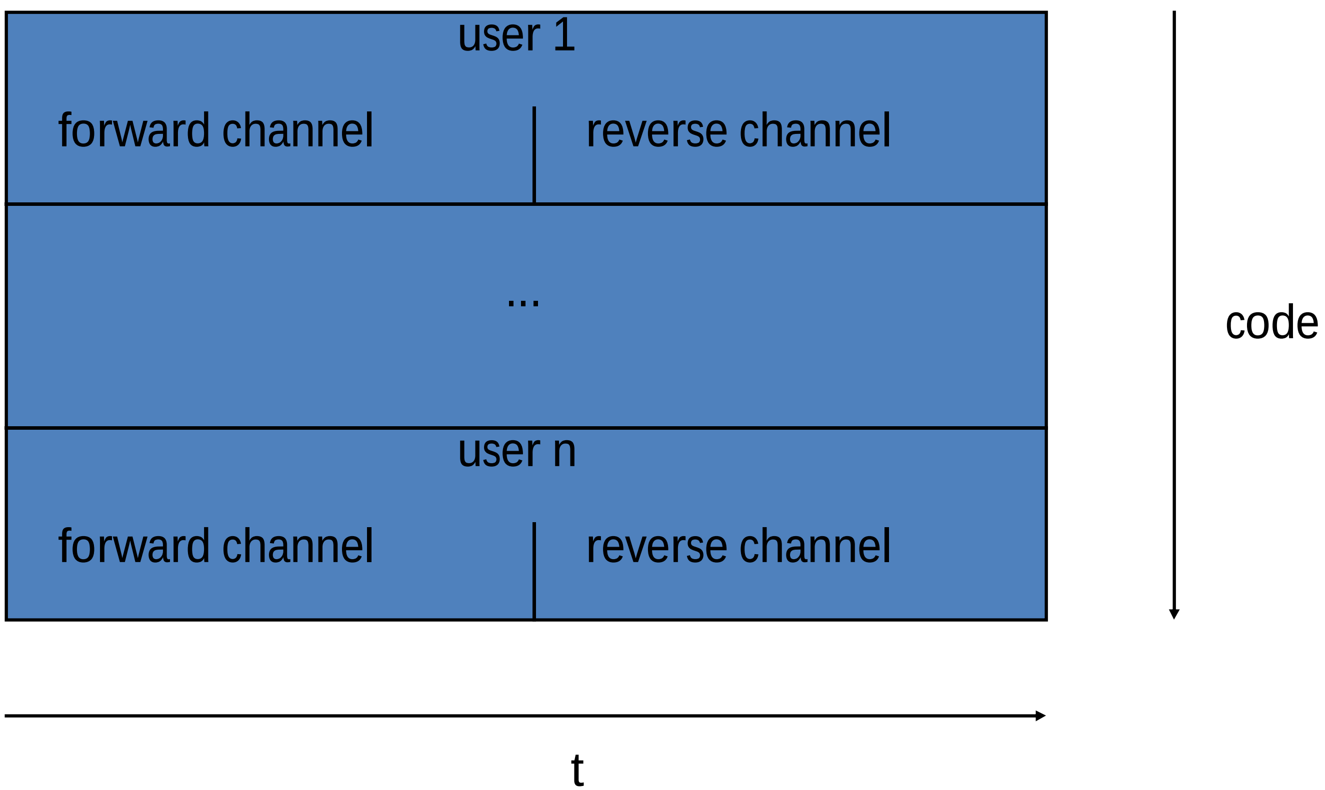
Wideband systems

- large number of transmitters on one channel
- TDMA techniques
- CDMA techniques
- FDD or TDD multiplexing techniques
- TDMA/FDD
- TDMA/TDD
- CDMA/FDD
- CDMA/TDD

Logical separation CDMA/FDD



Logical separation CDMA/TDD



Multiple Access Techniques in use

Cellular System	Multiple Access Technique
Advanced Mobile Phone System (AMPS)	FDMA/FDD
Global System for Mobile (GSM)	TDMA/FDD
US Digital Cellular (USDC)	TDMA/FDD
Digital European Cordless Telephone (DECT)	FDMA/TDD
US Narrowband Spread Spectrum (IS-95)	CDMA/FDD

Frequency division multiple access FDMA

- One phone circuit per channel
- Idle time causes wasting of resources
- Simultaneously and continuously transmitting
- Usually implemented in narrowband systems
- For example: in AMPS is a FDMA bandwidth of 30 kHz implemented

FDMA compared to TDMA

- Fewer bits for synchronization
- Fewer bits for framing
- Higher cell site system costs
- Higher costs for duplexer used in base station and subscriber units
- FDMA requires RF filtering to minimize adjacent channel interference

Nonlinear Effects in FDMA

- Many channels - same antenna
- For maximum power efficiency operate near saturation
- Near saturation power amplifiers are nonlinear
- Nonlinearities causes signal spreading
- Intermodulation frequencies

Nonlinear Effects in FDMA

- IM are undesired harmonics
- Interference with other channels in the FDMA system
- Decreases user C/I - decreases performance
- Interference outside the mobile radio band: adjacent-channel interference
- RF filters needed - higher costs

Number of channels in a FDMA system

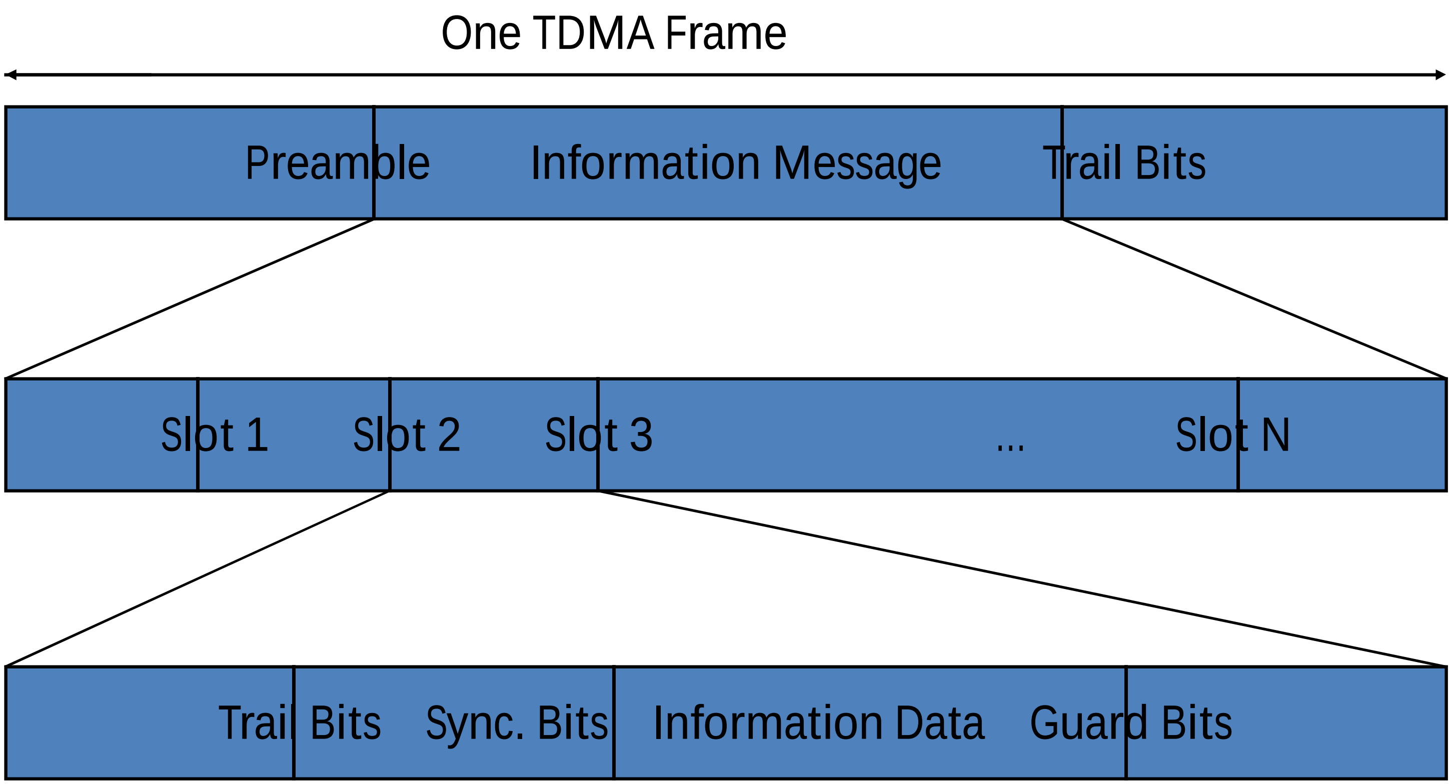
$$N = \frac{B_t - B_{guard}}{B_c}$$

- N … number of channels
- Bt … total spectrum allocation
- Bguard … guard band
- Bc … channel bandwidth

Time Division Multiple Access

- Time slots
- One user per slot
- Buffer and burst method
- Noncontinuous transmission
- Digital data
- Digital modulation

Repeating Frame Structure



The frame is cyclically repeated over time.

Features of TDMA

- A single carrier frequency for several users
- Transmission in bursts
- Low battery consumption
- Handoff process much simpler
- FDD : switch instead of duplexer
- Very high transmission rate
- High synchronization overhead
- Guard slots necessary

Number of channels in a TDMA system

$$N = \frac{m*(B_{tot} - 2*B_{guard})}{B_c}$$

- N … number of channels
- m … number of TDMA users per radio channel
- Btot … total spectrum allocation
- Bguard … Guard Band
- Bc … channel bandwidth

Example: Global System for Mobile (GSM)

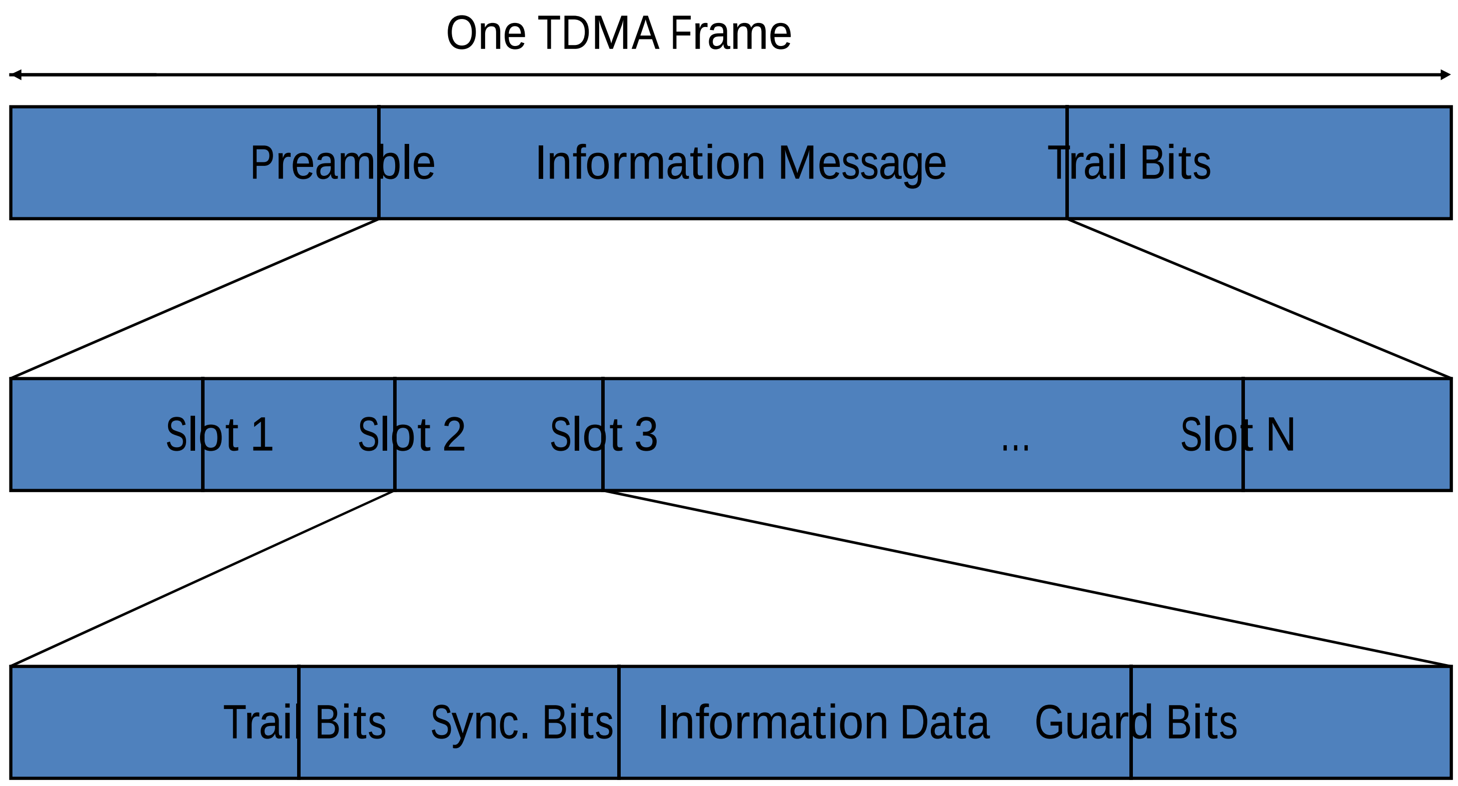
- TDMA/FDD
- forward link at Btot = 25 MHz
- radio channels of Bc = 200 kHz
- if m = 8 speech channels supported, and
- if no guard band is assumed :

$$N = \frac{8*25E6}{200E3} = 1000 \text{ simultaneous users}$$

Efficiency of TDMA

- Percentage of transmitted data that contain information
- Frame efficiency ηf
- Usually end user efficiency < ηf ,
- Because of source and channel coding

Repeating Frame Structure



The frame is cyclically repeated over time.

Efficiency of TDMA

$$b_{OH} = N_r * b_r + N_t * b_p + N_t * b_g + N_r * b_g$$

- bOH … number of overhead bits
- Nr … number of reference bursts per frame
- br … reference bits per reference burst
- Nt … number of traffic bursts per frame
- bp … overhead bits per preamble in each slot
- bg … equivalent bits in each guard time intervall

Efficiency of TDMA

$$b_T = T_f * R$$

- bT … total number of bits per frame
- Tf … frame duration
- R … channel bit rate

Efficiency of TDMA

$$\eta_f = (1-b_{OH}/b_T)*100\%$$

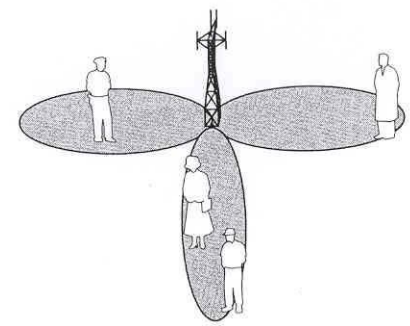
- η_f … frame efficiency
- b_{OH} … number of overhead bits per frame
- b_T … total number of bits per frame

Space Division Multiple Access

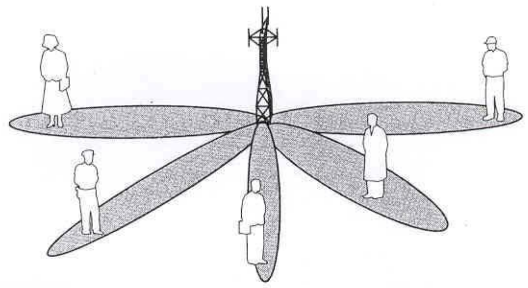
- Controls radiated energy for each user in space
- using spot beam antennas
- base station tracks user when moving
- cover areas with same frequency:
- TDMA or CDMA systems
- cover areas with same frequency:
- FDMA systems

Space Division Multiple Access

- primitive applications are "Sectorized antennas"



- In future adaptive antennas simultaneously steer energy in the direction of many users at once



Reverse link problems

- General problem
- Different propagation path from user to base
- Dynamic control of transmitting power from each user to the base station required
- Limits by battery consumption of subscriber units
- Possible solution is a filter for each user

Solution by SDMA systems

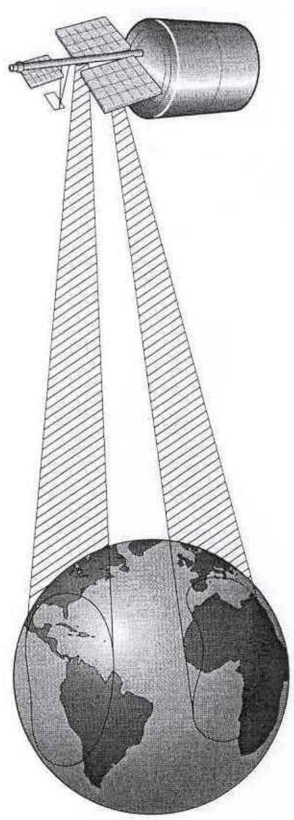
- Adaptive antennas promise to mitigate reverse link problems
- Limiting case of infinitesimal beamwidth
- Limiting case of infinitely fast track ability
- Thereby unique channel that is free from interference
- All user communicate at same time using the same channel

Disadvantage of SDMA

- Perfect adaptive antenna system: infinitely large antenna needed
- Compromise needed

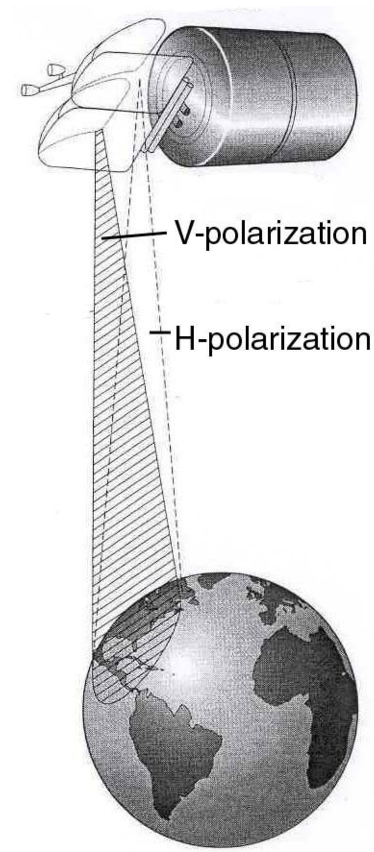
SDMA and PDMA in satellites

- INTELSAT IVA
- SDMA dual-beam receive antenna
- Simultaneously access from two different regions of the earth



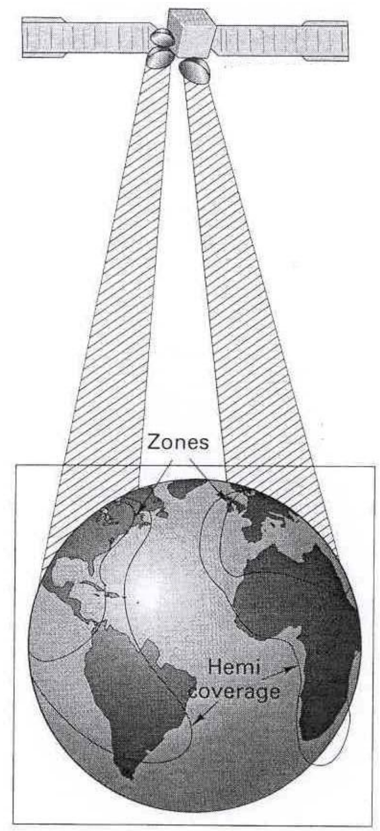
SDMA and PDMA in satellites

- COMSTAR 1
- PDMA
- separate antennas
- simultaneously access from same region



SDMA and PDMA in satellites

- INTELSAT V
- PDMA and SDMA
- Two hemispheric coverage by SDMA
- Two smaller beam zones by PDMA
- Orthogonal polarization



Capacity of Cellular Systems

- Channel capacity: maximum number of users in a fixed frequency band
- Radio capacity : value for spectrum efficiency
- Reverse channel interference
- Forward channel interference
- How determine the radio capacity?

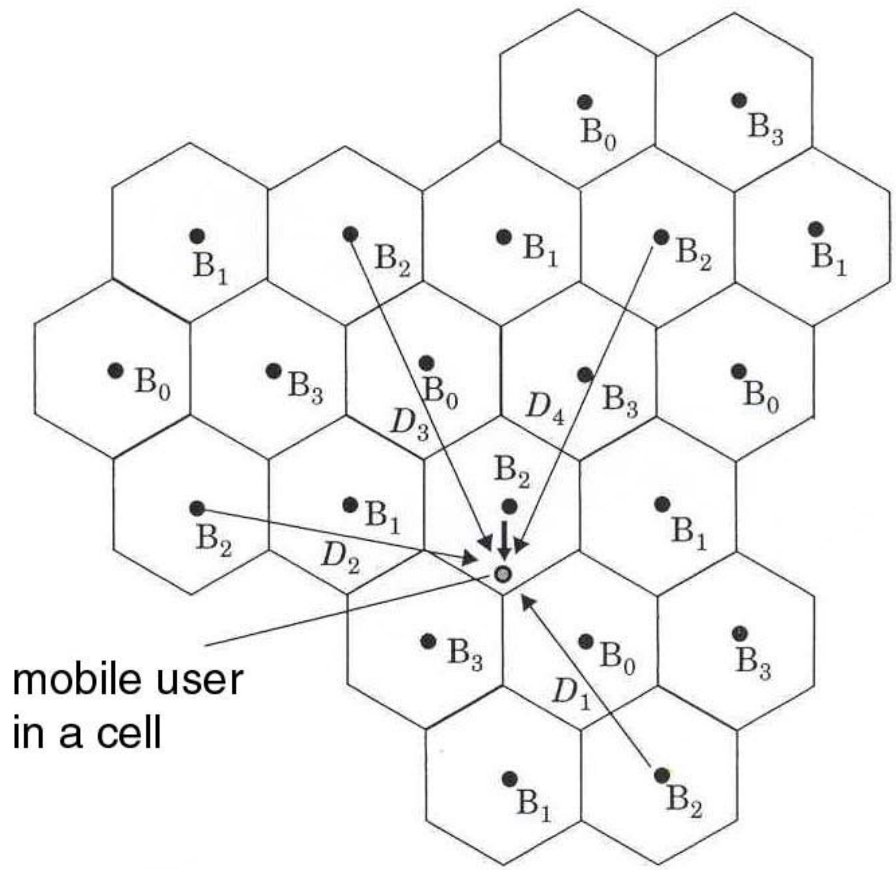
Co-Channel Reuse Ratio Q

$$Q = D/R$$

- Q … co-channel reuse ratio
- D … distance between two co-channel cells
- R … cell radius

Forward channel interference

- cluster size of 4
- D0 … distance serving station to user
- DK … distance co-channel base station to user



Cellular Wireless Network Evolution

- **First Generation**: Analog
  - AMPS: Advance Mobile Phone Systems
  - Residential cordless phones
- **Second Generation**: Digital
  - IS-54: North American Standard - TDMA
  - IS-95: CDMA (Qualcomm)
  - GSM: Pan-European Digital Cellular
  - DECT: Digital European Cordless Telephone

Cellular Evolution (cont)

- **Third Generation: T/CDMA**
  - combines the functions of: cellular, cordless, wireless LANs, paging etc.
  - supports multimedia services (data, voice, video, image)
  - a progression of integrated, high performance systems:

(a) GPRS (for GSM)

(b) EDGE (for GSM)

(c) 1xRTT (for CDMA)

(d) UMTS

Cellular systems around the world

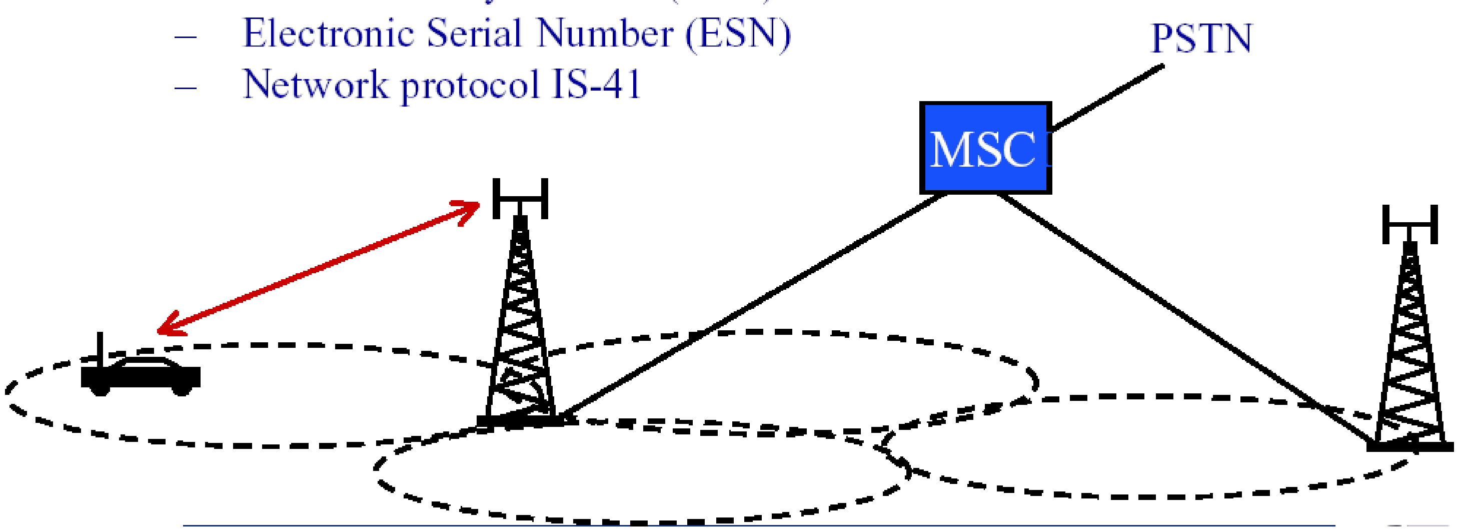
- **US systems (cont'd)**
  - **PCS1900:** Personal Communications System, 1900 MHz band
    Based on GSM and DCS1800
  - **CDMA2000:**
    Third-generation, digital system
    Evolution of IS-95
  - **General:** Dual-mode terminals AMPS/xxxx
    Network protocol IS-41
    Only AMPS national coverage, rest local

Advance Mobile Phone System

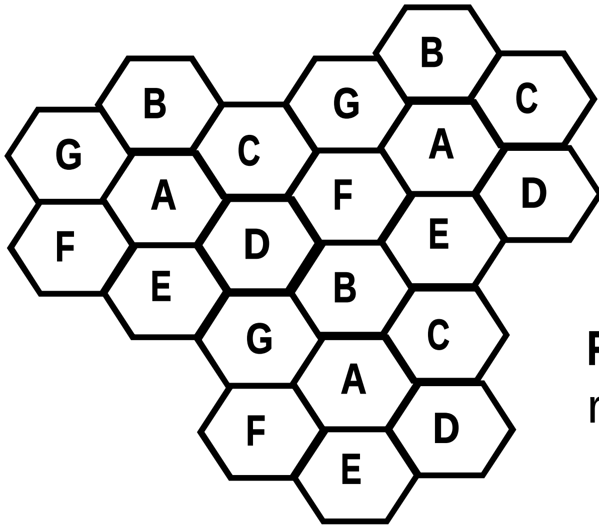
Invented by Bell Labs; installed
In US in 1982; in Europe as TACS

Architecture

- 7/21 site/sector reuse
- 18 dB C/I
- Mobile Identity Number (MIN)
- Electronic Serial Number (ESN)
- Network protocol IS-41



AMPS (Advance Mobile Phone System):

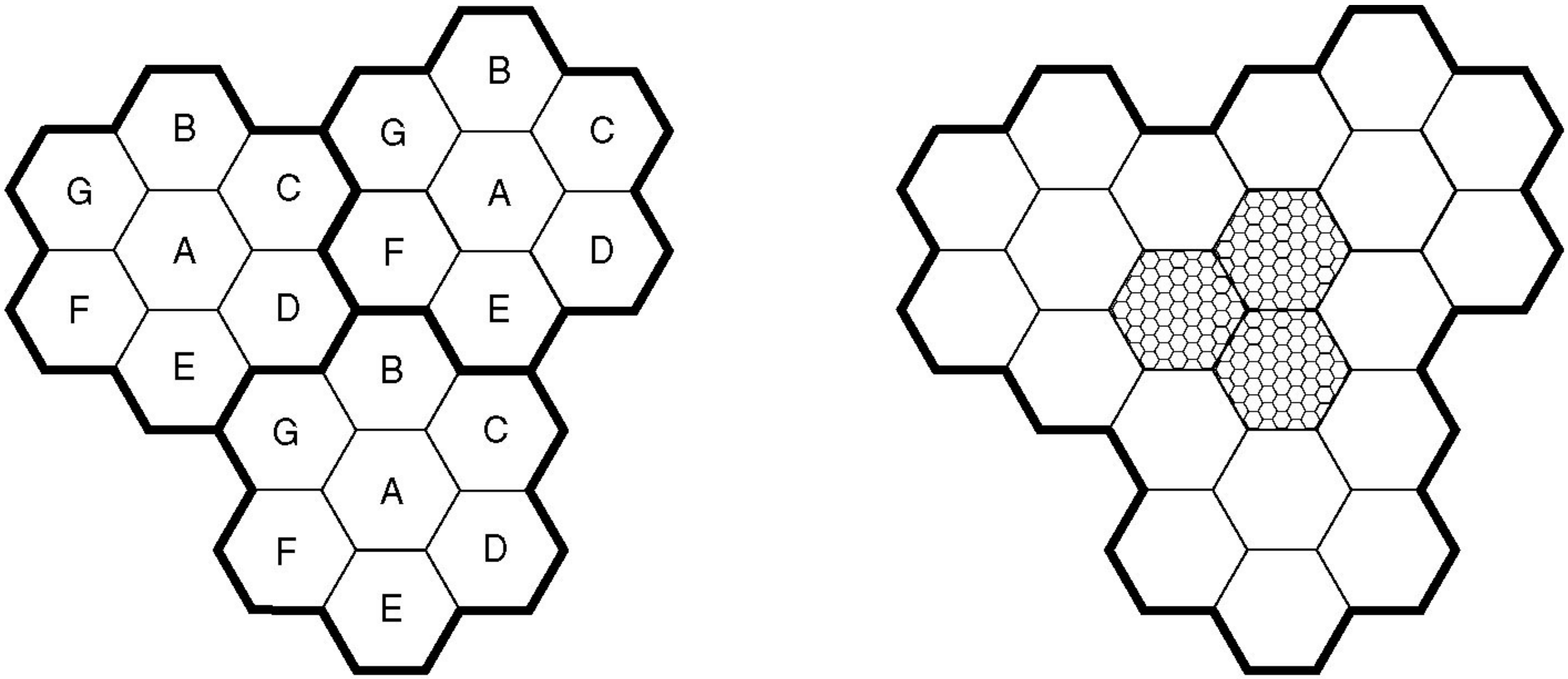


FDMA (Frequency Div Multiple Access): one frequency per user channel

Frequency Reuse: Frequencies are not reused in a group of 7 adjacent cells

In each cell, 57 channels each for A-side and B -side carrier respectively; about 800 channels total (across the entire AMPS system)

Advanced Mobile Phone System



(a) (b)

(a) Frequencies are not reused in adjacent cells.

(b) To add more users, smaller cells can be used.

Channel Categories

The channels are divided into four categories:

- **Control** (base to mobile) to manage the system
- **Paging** (base to mobile) to alert users to calls for them
- **Access** (bidirectional) for call setup and channel assignment
- **Data** (bidirectional) for voice, fax, or data

Handoff

- **Handoff**: Transfer of a mobile from one cell to another
- Each base station constantly monitors the received power from each mobile.
- When power drops below given threshold, base station asks neighbor station (with stronger received power) to pick up the mobile, on a new channel.
- In APMS the handoff process takes about 300 msec.
- **Hard handoff**: user must switch from one frequency to another (noticeable disruption)
- **Soft Handoff** (available only with CDMA): no change in frequency.

To register and make a phone call

- When phone is switched on , it scans a preprogrammed list of 21 **control** channels, to find the most powerful signal.
- It transmits its ID number on it to the MSC – which informs the home MSC (registration is done every 15 min)
- To make a call, user transmits dest Ph # on random **access** channel; MSC will assign a **data** channel
- At the same time MSC **pages** the destination cell for the other party (idle phone **listens** on all page channels)

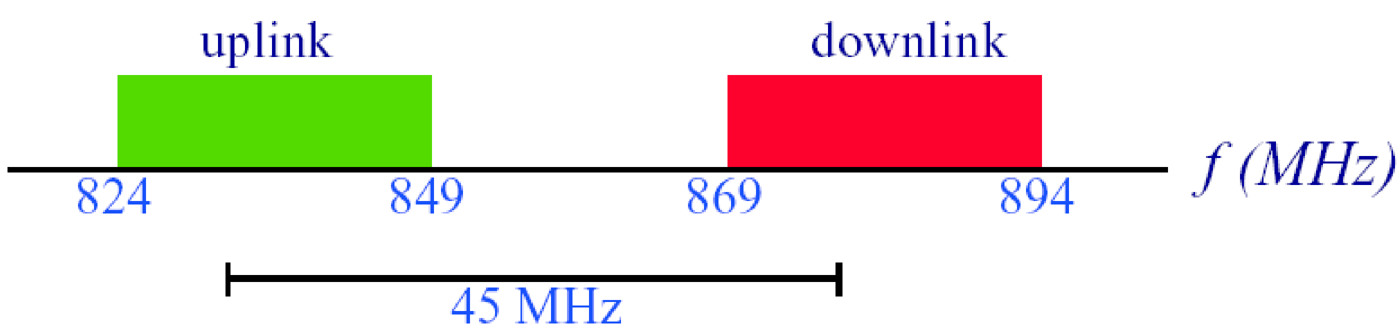
AMPS: physical layer

Radio bands

– 832 duplex (paired) channels
– A/B separation: 416 channels each
– channel spacing 30 kHz

FDD

(Freq Division Duplex)



AMPS: physical layer

Modulation

- traffic (voice): analog FM
  peak deviation $\Delta f = \pm 12$ kHz
  companding / expanding
  pre-emphasis / de-emphasis

- control (data): binary FSK ("0" → -8 kHz, "1" → +8 kHz)
  10 kb/s data rate
  Manchester NRZ coding
  BCH(40,28) downlink, BCH(48,36) uplink
  blank-and-burst

- Supervisory Audio Tone (SAT)
  5970 / 6000 / 6030 tone
  co-channel separation

Digital Cellular: IS-54 TDMA System

- Second generation: **digital** (as opposed to analog as in AMPS)
- Same frequency as AMPS
- Each 30 kHz RF channel is used at a rate of 48.6 kbps
  - 6 TDM slots/RF band (2 slots per user)
  - 8 kbps voice coding
  - 16.2 kbps TDM digital channel (3 channels fit in 30kHz)
- 4 cell frequency reuse (instead of 7 as in AMPS)
- Capacity increase per cell per carrier
  - 3 x 416 / 4 = 312 (instead of 57 in AMPS)
  - Additional factor of two with speech activity detection.

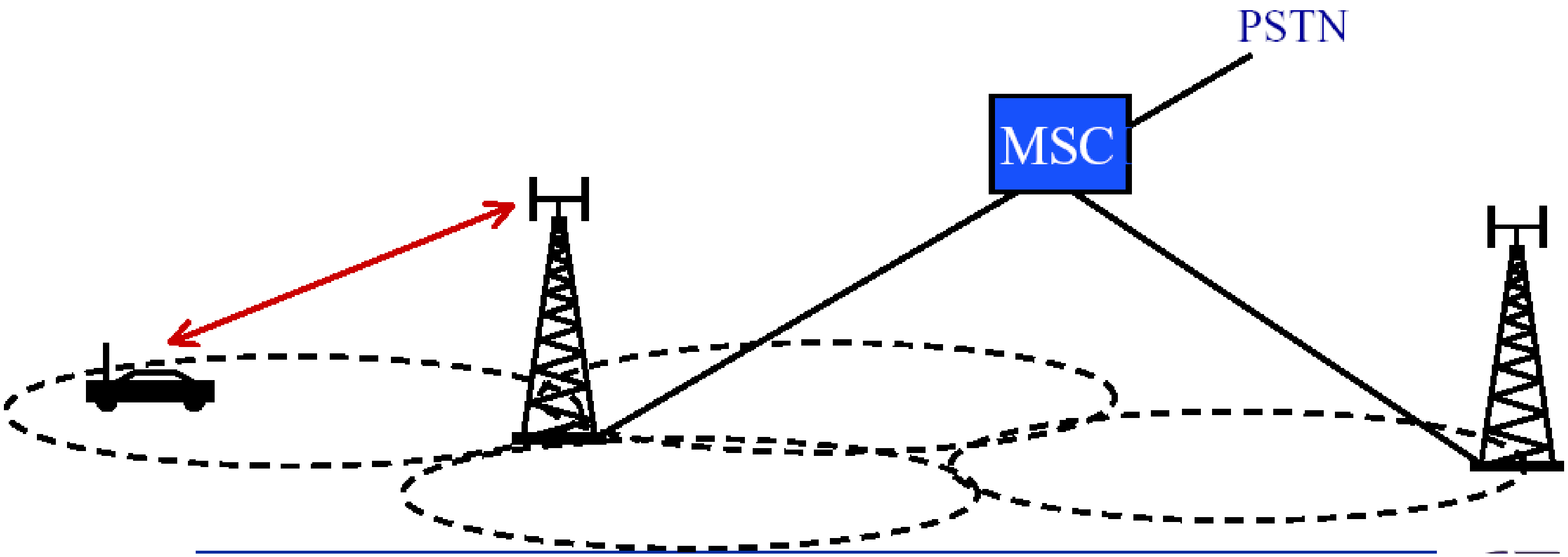
US Digital Cellular

- Standard: USDC = D-AMPS = IS-54 = IS-136 (EIA/TIA)
- TDMA/AMPS dual-mode terminals
- Split each AMPS FDMA channel into six TDMA channels
- Reuse of AMPS analog control channels: IS-54

  ⬇
- New digital control channels: IS-136

USDC: architecture

- 7/21 site/sector reuse
- 18 dB C/I
- Mobile Identity Number (MIN)
- Electronic Serial Number (ESN)
- Network protocol IS-41



GSM (Group Speciale Mobile)

Pan European Cellular Standard
Second Generation: **Digital**
Frequency Division Duplex (890-915 MHz Upstream; 935-960 MHz Downstream)
125 frequency carriers

Carrier spacing: 200 Khz
8 channels per carrier (Narrowband Time Division)

Speech coder: linear predictive coding (Source rate = 13 Kbps)

Modulation: phase shift keying (Gaussian minimum shift keying)

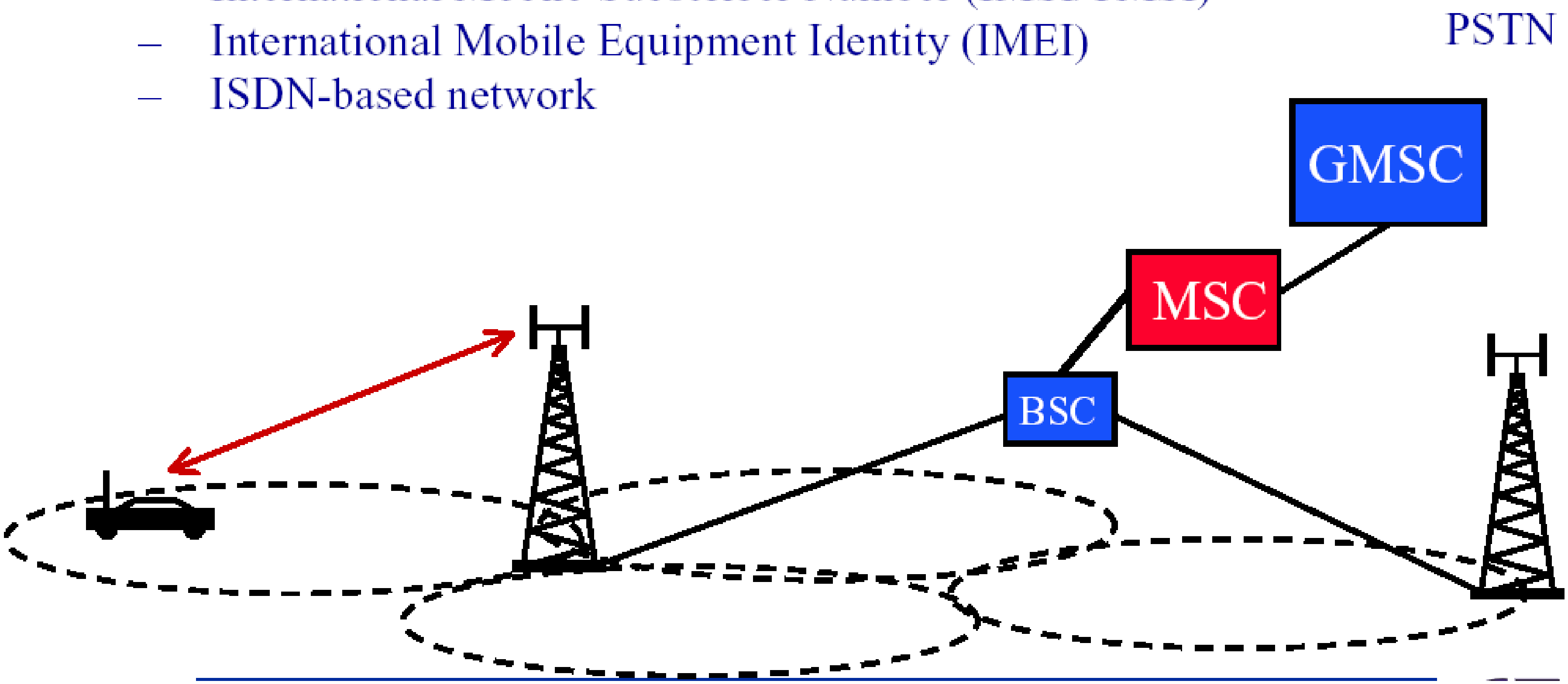
Slow frequency hopping to overcome multipath fading

GSM

- **Groupe Spéciale Mobile**
- **Standard: GSM - DSC1800 - PCS1900 (ETSI)**
- **Pan-European system**

GSM: architecture

- 3/9 site/sector reuse
- 11 dB C/I
- International Mobile Subscriber Number (IMSI/TMSI)
- International Mobile Equipment Identity (IMEI)
- ISDN-based network



IS-95

- Interim Standard 95; (TIA)
- CDMA/AMPS dual-mode terminals
- Narrowband CMDA (BW ≈ 1.25 MHz)
- Qualcomm (1994)

IS-95: architecture

- 1/1 reuse
- Mobile Identity Number (MIN)
- Electronic Serial Number (ESN)
- Network protocol IS-41