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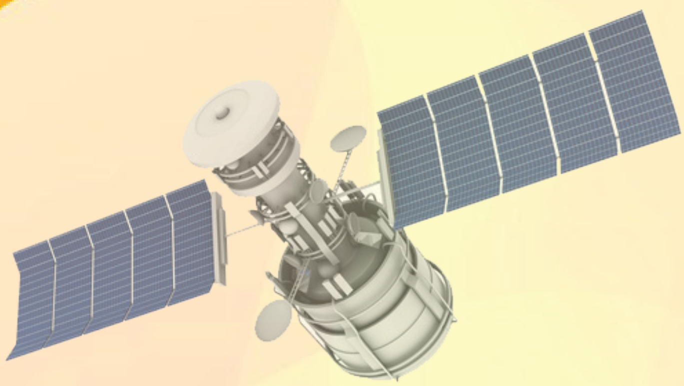

Satellite & Radar Communication System

NORLIA BT EMBONG

KEJURUTERAAN ELEKTRIK

Satellite & Radar Communication System

Declaration

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Author :
Norlia binti Embong

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Jalan Sultan Ismail,
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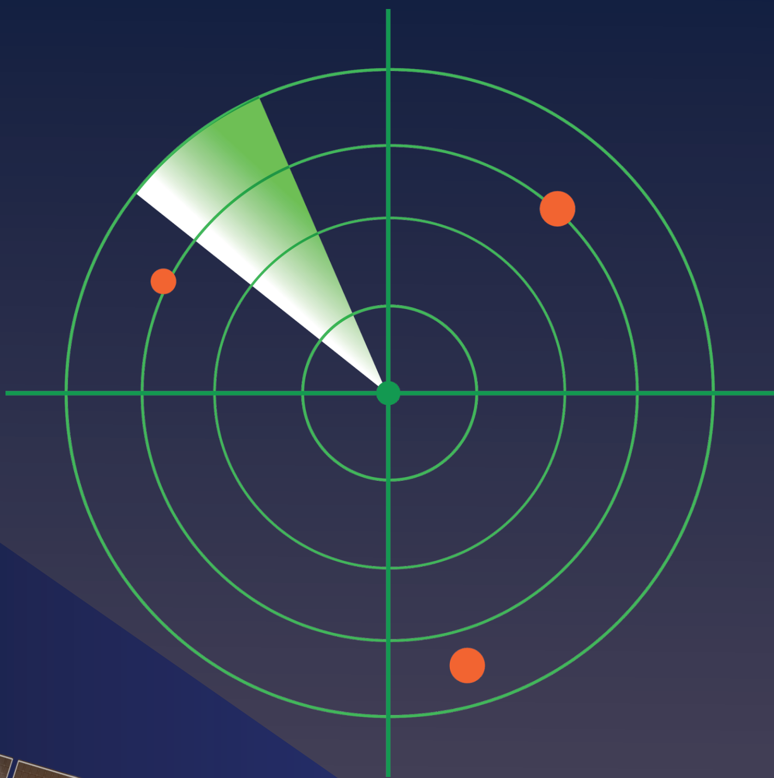

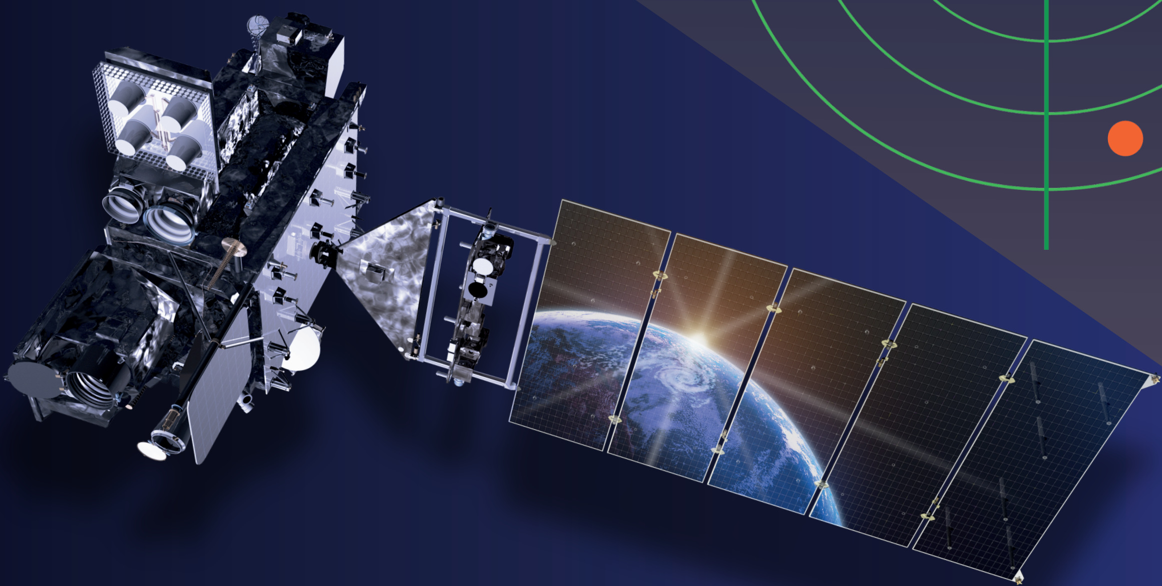

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“

Special thanks to my colleagues in giving me support and encouragement to completed this e-book. Thanks to my family for giving me motivation and enthusiasm.Finally I managed to complete this ebook for learning and training purposes

Norlia binti Embong

Abstract

SATELLITE AND RADAR COMMUNICATION SYSTEM introduces to students the concept of satellite and radar, satellite orbits, space satellite subsystem, satellite communication system, radar fundamentals and different types of radar system. It also covers end to end satellite and radar communication system in various generations and latest technologies.

CONTENTS

TOPIC 1

INTRODUCTION TO SATELLITE COMMUNICATION

1.1 Remember satellite communication system

1.2 Understand frequency allocations in satellite communication system

1.3 Apply the understanding of satellite orbital

1.4 Apply the understanding look angle of a satellite

1.5 Apply the understanding of earth coverage area (foot print)

What is Satellite?

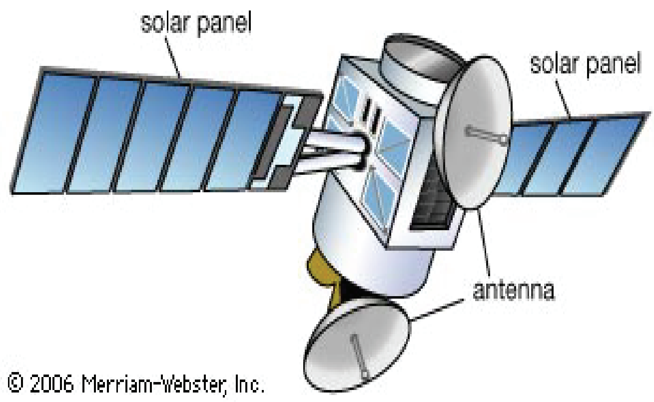
In general satellite is an artificial satellite stationed in space for the purposes of telecommunications, military, surveillance, ect

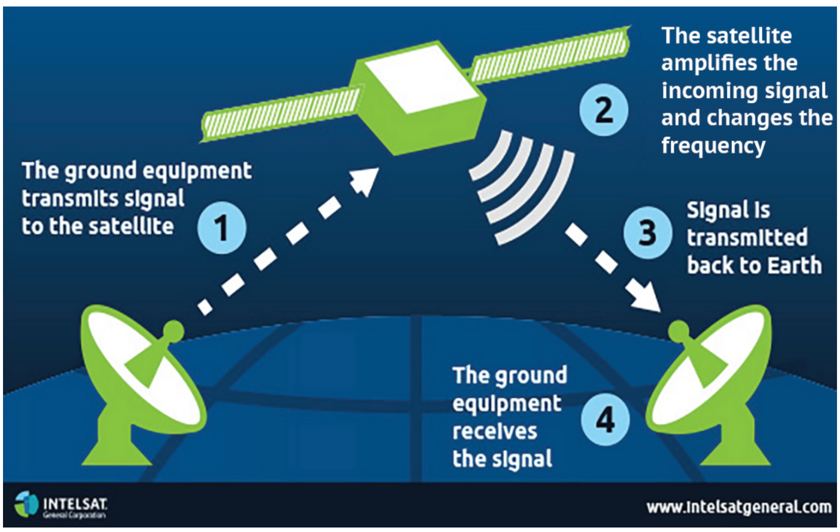
A communications satellite is an orbiting artificial earth satellite that receives a communications signal from a transmitting ground station, amplifies and possibly processes it, then transmits it back to the earth for reception by one or more receiving ground stations.

The satellite is an active transmission relay, similar in function to relay towers used in terrestrial microwave communications.

It contains several transponders which listens to some portion of the spectrum, amplifies the incoming signal and broadcasts it in another frequency to avoid interface with incoming signals

Structure of satellite

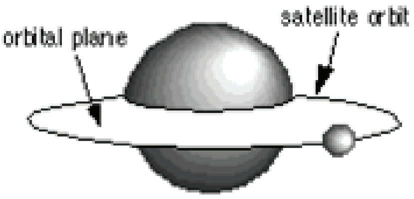




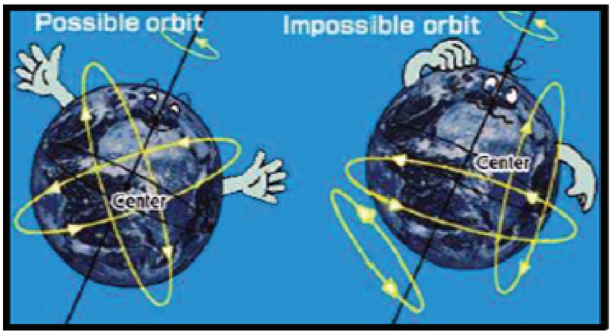
Satellites come in many shapes and sizes. But most have at least two parts in common an antenna and a power source.
The antenna sends and receives information, often to and from Earth.
The power source can be a solar panel or battery. Solar panels make power by turning sunlight into electricity.
Many NASA satellites carry cameras and scientific sensors.
Sometimes these instruments point toward Earth to gather information about its land, air and water.
Most satellites are launched into space on rockets.

Satellite Orbit

The path followed by a satellite is called an orbit



The orbit's plane always passes through the center of the Earth

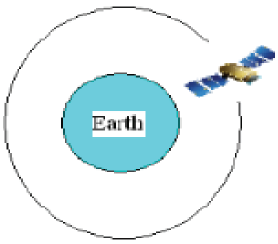


Types of Orbital shape

Two basic types of orbit:

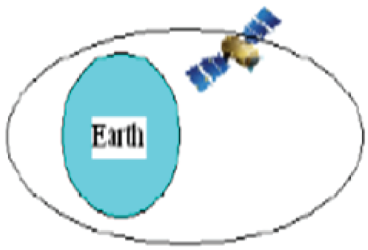
Circular orbit

The distance from the Earth remains the same at all times.



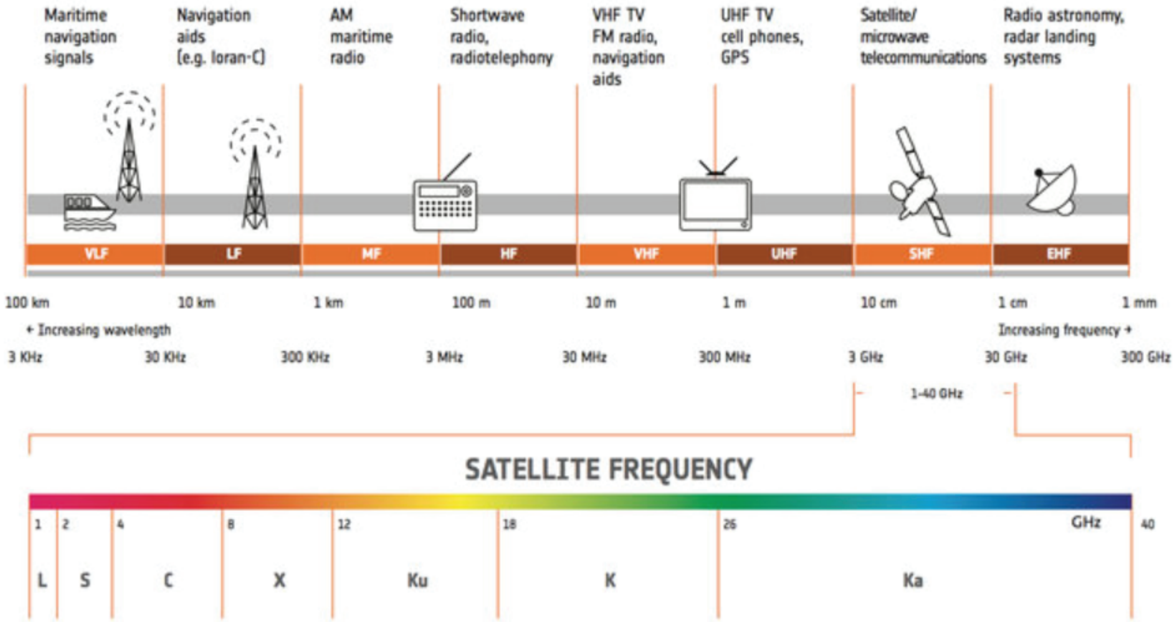
Elliptical orbit

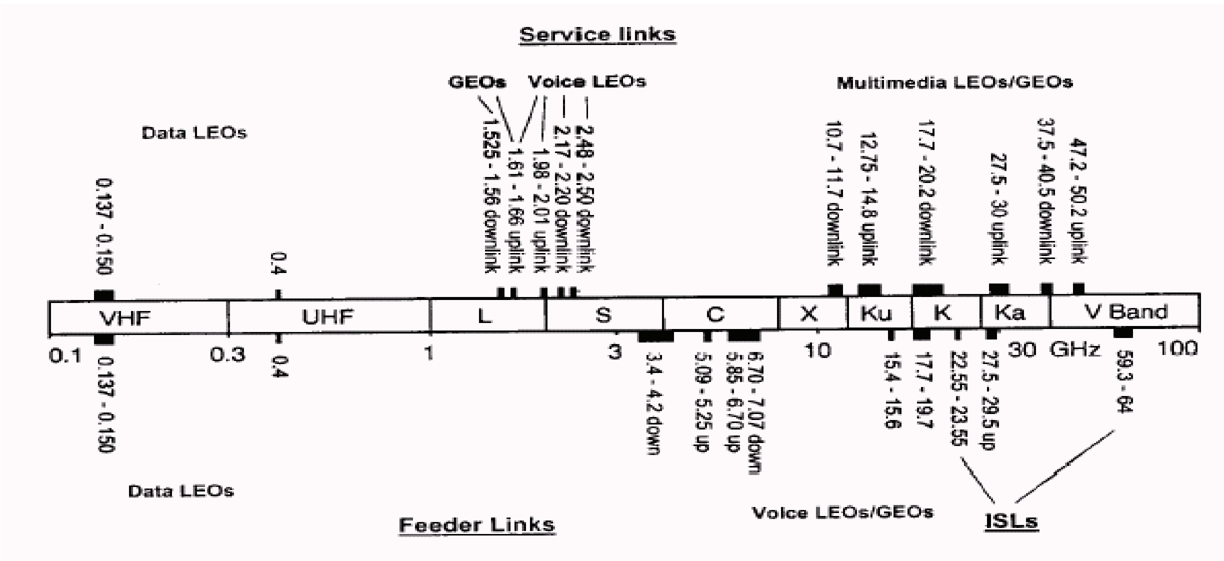
The elliptical orbit changes the distance to the Earth



1.2 Understand frequency allocations for satellite communication system

Satellite Frequency Band





Four different bands of operation are used for satellite communications. The lowest band is called the L-band. It operates with an uplink at 1.6 GHz and a downlink at 1.5 GHz using a narrow bandwidth. The next band is the C-band and operates around 6 GHz for the uplink to the satellite and 4 GHz for the down-link from the satellite to the ground station. The next band, which is generally used by the military, operates in the X-band and operates around 8 GHz for the uplink and 7 GHz for the down-link.

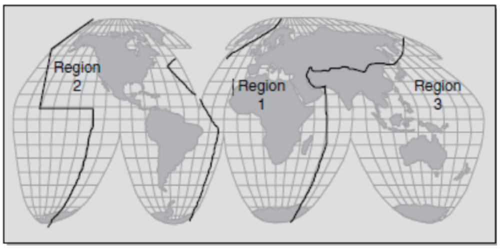
The next band, which has become popular for telecommunications, is the Ku-band and operates around 14 GHz for the uplink, and 11 to 12 GHz for the downlink. The highest band of operation, the Ka-band, is becoming popular for broadband communications and other applications. This band operates at 30 GHz for the uplink and 20 GHz for the downlink. The Ka band provides a much higher bandwidth for high-speed data and allows for more simultaneous end users.

Frequency allocation

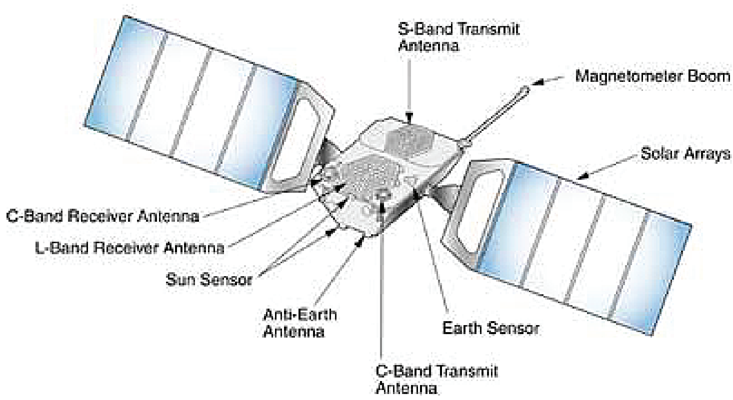
Frequency allocation planning based on the requirement of International Telecommunication Union (ITU) was divided by 3 region;

Region 1: Europe, Africa (was formerly the Soviet Union and Mongolia)
Region 2: North and South America and Greenland
Region 3: Asia, Australia and south-west Pacific

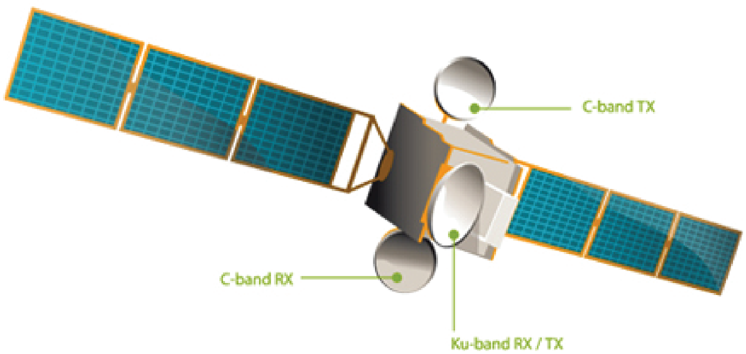
Each service region is treated as independent in terms of frequency allocations, because the general assumption is that systems operating in any one of the regions are protected by geographic separation from systems in the other service regions. International frequency allocations are provided for systems operating on a global



Example



Bands for satellite operation:
L(2GHz/1GHz), S(4GHz/2GHz), C(6GHz/4GHz). Ku(12-18GHz), Ka(27-40GHz)

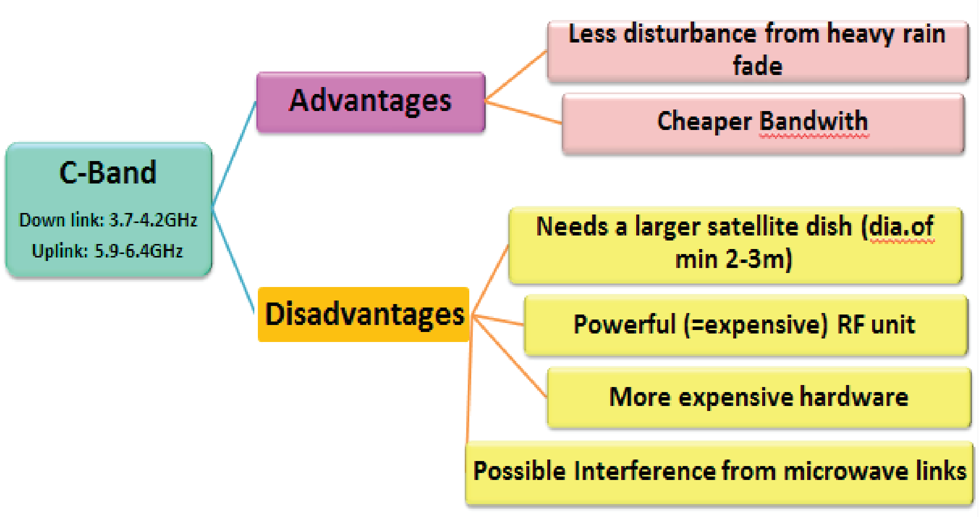


Advantage and Disadvantage
(C-Band, Ku-Band, Ka-Band)

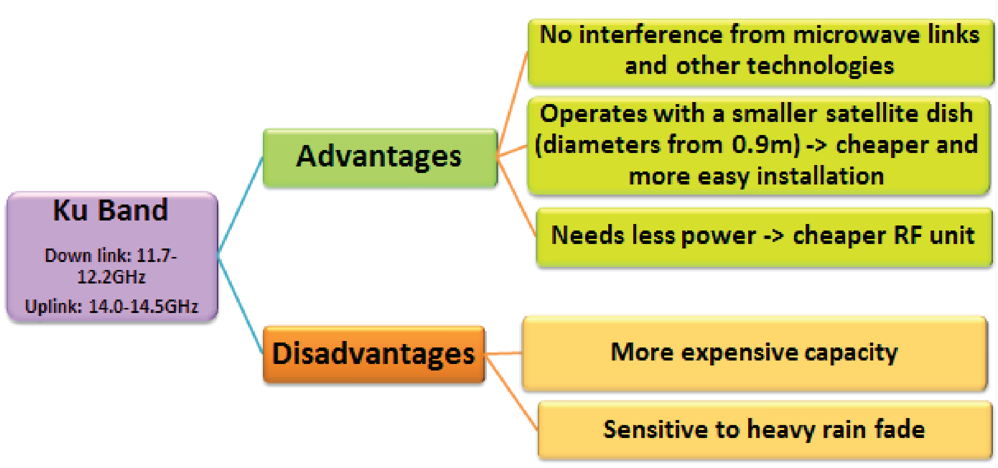
L C Ku Ka

The higher the frequency, the more bandwidth is available, but the equipment needs to be more sophisticated.

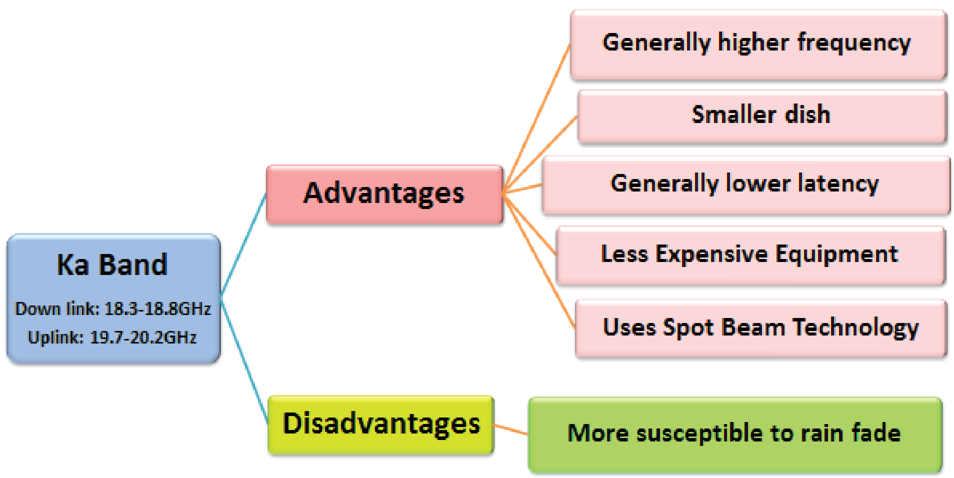
Advantage and Disadvantage (C-Band)



Advantage and Disadvantage (Ku-Band)



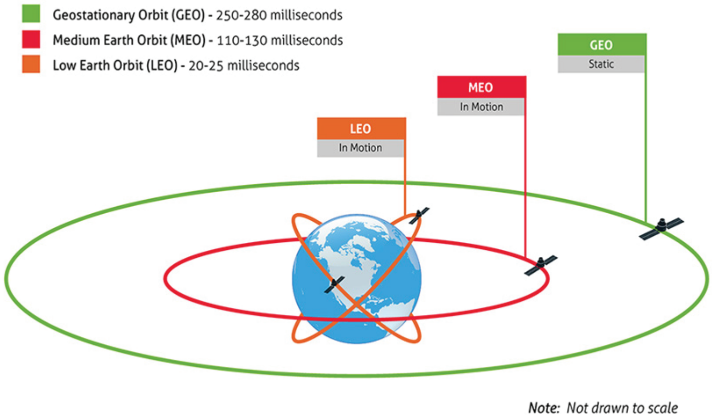
Advantage and Disadvantage (Ka-Band)



1.3 Apply the understanding of satellite orbital

Types of Circular Orbit

LEO : Low Earth Orbit
MEO : Medium Earth Orbit
GEO : Geostationary Earth Orbit



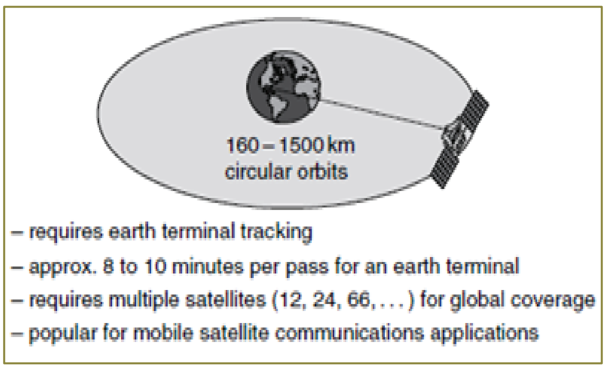
LEO satellites are much closer to the earth , ranging from 500 to 1,500 km above the surface.
LEO satellites must travel very fast so gravity does not pull them back into the atmosphere.
Rotation period is 90 min
shortest life (5-8 years)

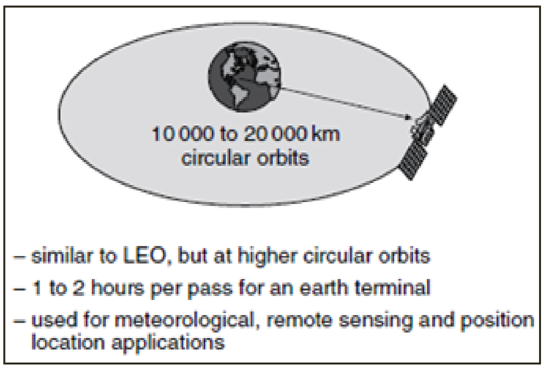
LEO satellites, with proper inclinations, can cover high latitude locations, including polar areas, which cannot be reached by GEO satellites
E.g. Satellite Telephones, ISS

Medium Earth Orbit (MEO)

Operate at a distance of about 8,000 km and 20,000 km above the earth's surface.
Rotation period 5-12 hour

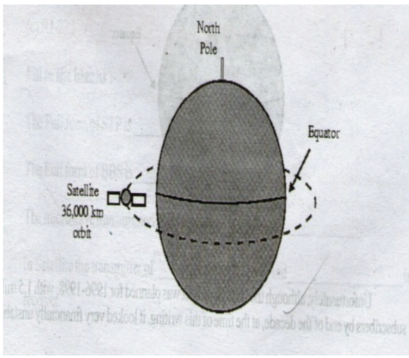
Difficult due to radiation belts
MEO satellites have a larger coverage area than LEO satellites.
Communications satellites that cover the North and South Pole are also put in MEO.
Telstar, one of the first and most famous experimental satellites, orbits in MEO.
E.g: Meteorological satellite, GPS





Geostationary Earth Orbit (GEO)

Satellite are paled above a equator at a distance of 35863km. 24 hour rotation Long life 10-15 years. Objects in Geostationary orbit revolve around the earth at the same speed as the earth rotates. This means GEO satellites remain in the same position relative to the surface of earth.



Because geostationary satellites circle the earth at the equator, they are not able to provide coverage at the Northern and Southern latitudes.
Geostationary orbits are ideal for weather satellites and communications satellites.

Advantages of geostationary satellite

1. A GEO satellite's distance from earth gives it a large coverage area, almost a fourth of the earth's surface.
2. GEO satellites have a 24 hour view of a particular area.
3. These factors make it ideal for satellite broadcast and other multipoint applications.
4. The geostationary orbit is useful for communications applications because ground based antennas, which must be directed toward the satellite, can operate effectively without the need for expensive equipment to track the satellite's motion.

Disadvantages of geostationary satellite

1. A GEO satellite's distance also cause it to have both a comparatively weak signal and a time delay in the signal, which is bad for point to point communication.
2. GEO satellites, centered above the equator, have difficulty broadcasting signals to near polar regions Require sophisticated and heavy propulsion devices on board to keep them in a fixed orbit

Differences between LEO, MEO, GEO

Parameter	LEO	MEO	GEO
Satellite Height	500 – 1500 km	2000 – 30000 km	35 800 km
Orbital Period	90 min	5 – 12 hours	24 hours
Number of Satellites	40 - 80	8 - 20	3
Satellite Life	Short	Long	Long
Number of Handoffs	High	Low	Least (none)
Propagation Loss	Least	High	Highest

1.4 Apply the understanding look angle of a satellite

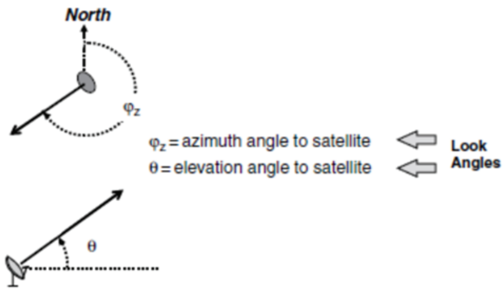
Show look angles of a satellite with an illustration:
a. elevation angle
b. azimuth angle

Look Angles

Look Angle: the coordinates to which earth station(ES) must point to communicate with a satellite. These are:

Azimuth angle (AZ)

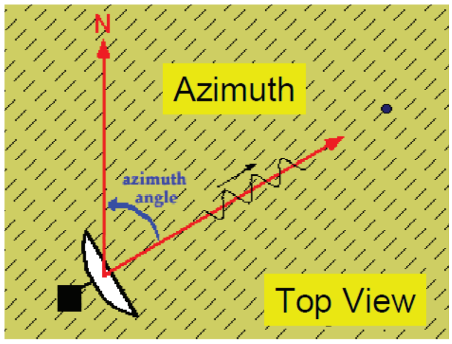
Elevation angle (EL)

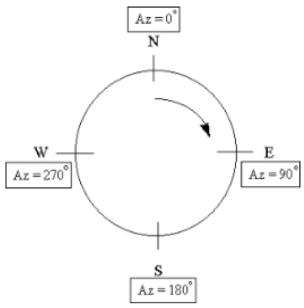


Azimuth Angle

Azimuth is defined as the horizontal pointing angle of an antenna (0° – 360°).

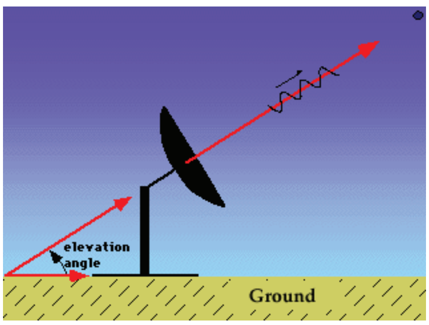
It is measured in a clockwise direction in degrees from true north (north pole 0°) which is used as reference.

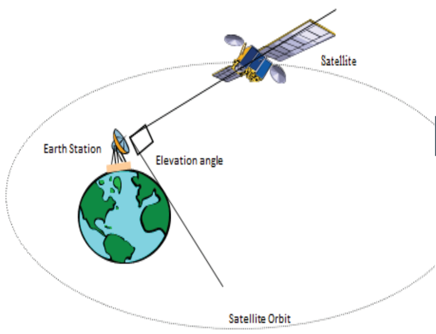


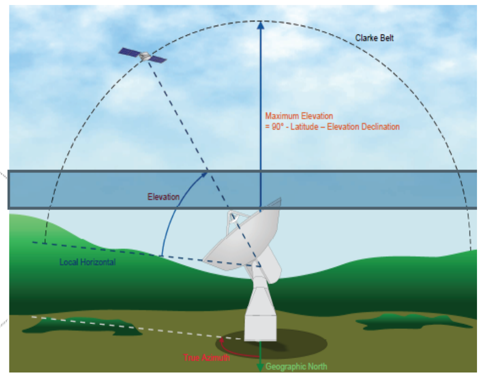


Elevation Angle

The angle of elevation is the angle between the horizontal plane and the pointing direction of the antenna.





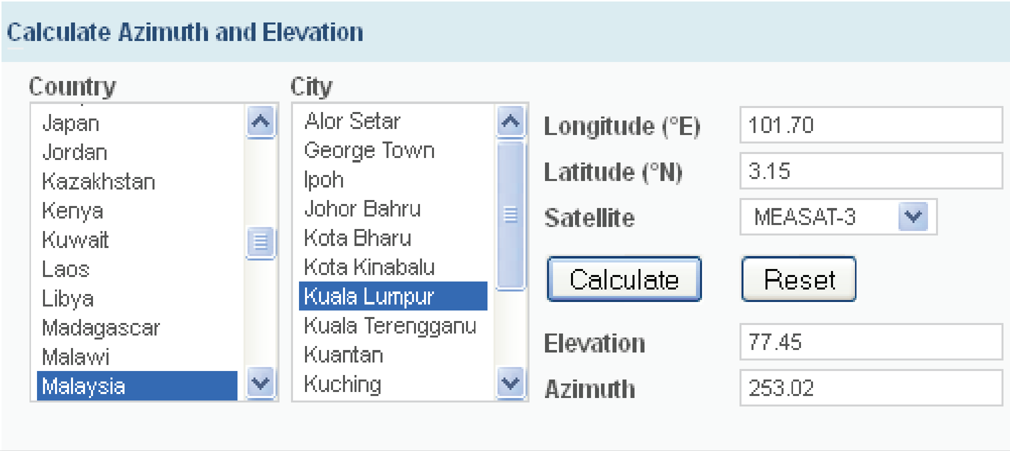


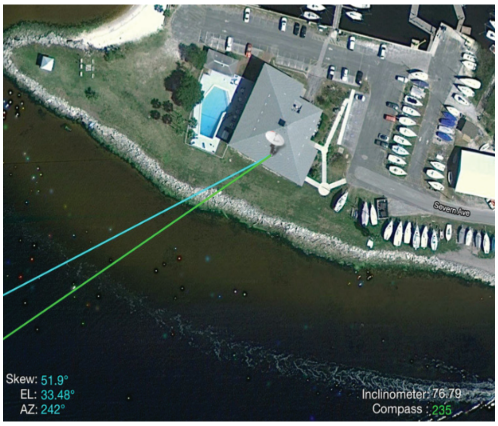
The smaller the angle of elevation, the greater the distance a propagated wave must pass through the earth's atmosphere.

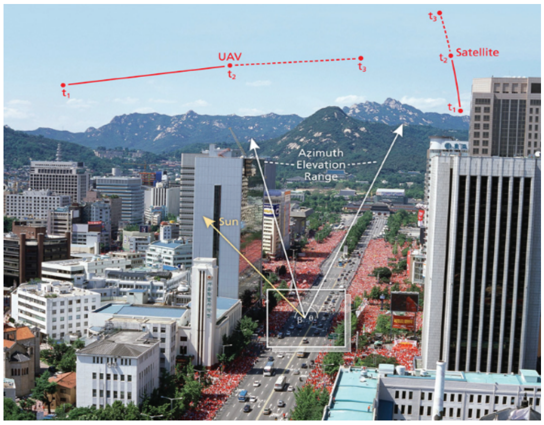
1.4 Apply the understanding look angle of a satellite

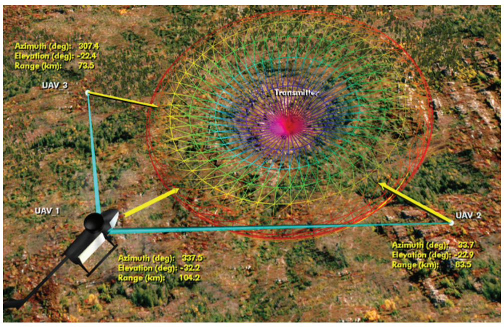
Azimuth & Elevation Angle

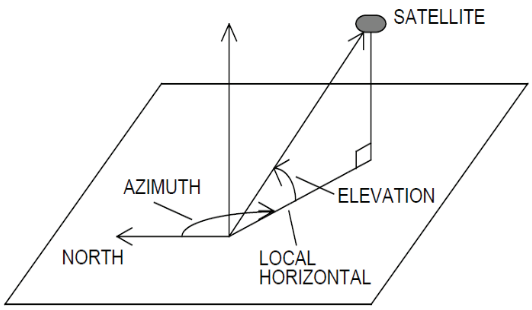
How to setting azimuth and elevation angle at earth station?











1.5 Apply the understanding of earth coverage area (foot print)

Satellite Altitude and Earth Coverage Area

Earth coverage also known as footprint, is the surface area of the earth that can possibly be covered by a given satellite. The effect of satellite altitude on earth coverage provided by the satellite.
Refer to figure below, it is evident that the coverage area increases with the height of the satellite above the surface of the earth.
It varies from 1.5% of the earths surface area for a low earth satellite orbit at 200km to about 43% of the earth surface area for a satellite at a geostationary height of 36000km.
The figure shows the variation of coverage area as a function of the satellite altitude.
The increase in coverage area with an increase in altitude is steeper in the beginning than it is as the altitude increase beyond 10000km.

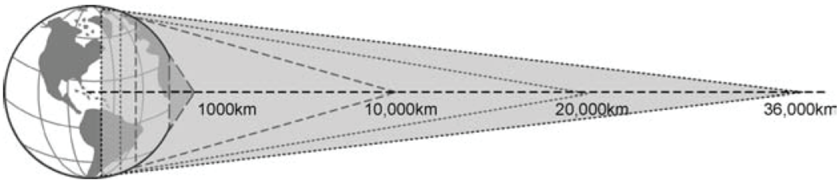


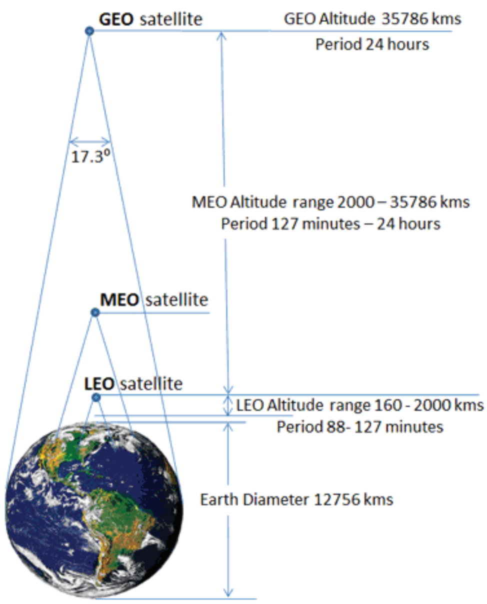
Figure 3.47 Satellite altitude and Earth coverage area

The higher the altitude of the satellite, the smaller is the angular velocity and the greater will be the displacement of the ground track towards the west due to the earth rotation.
Ground track is the path followed by the sub satellite point.

Table 3.1 Variation of the coverage area as a function of the satellite altitude

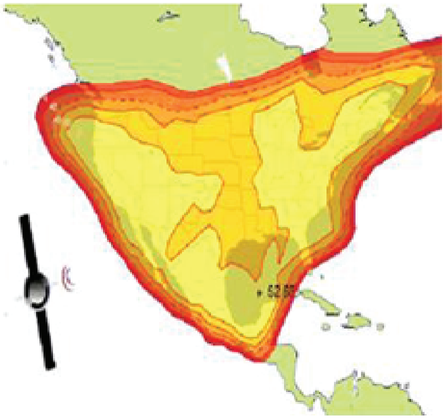
Satellite altitude (km)	Coverage area (% of Earth's surface area)
200	1.5
300	2.0
400	2.5
500	3.0
600	3.5
700	4.5
800	5.5
900	6.0
1 000	7.0
2 000	12.0
4 000	18.5
5 000	21.5
6 000	24.0
7 000	26.0
8 000	27.5
9 000	29.0
10 000	30.0
15 000	35.0
20 000	37.5
25 000	40.0
30 000	41.5
36 000	43.0

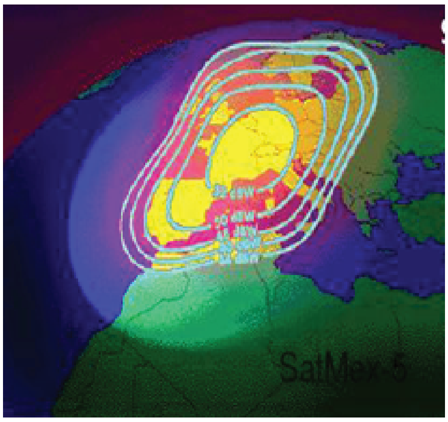
Satellite Orbits, Periods and Footprints

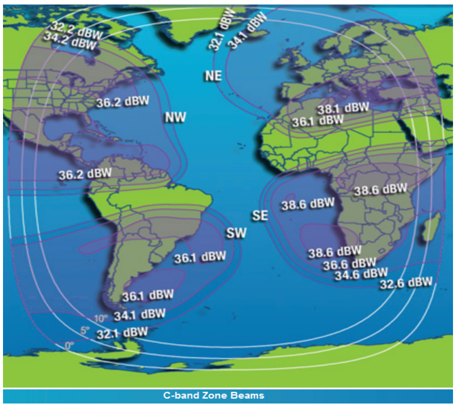


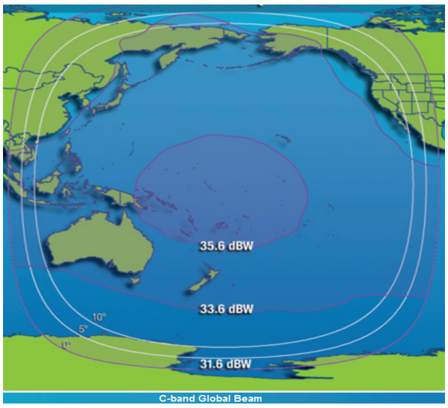
1.5 Apply the understanding of earth coverage area (foot print)

Satellite Antenna Radiation Patterns: Footprints









Footprint Categories

Spot and Zonal Beams:
–Concentrated power to very small geographical areas
–Have high EIRPs
–Blanket less than 10% of earth's surface

Hemispherical Beam
–Blanket 20% of Earth's surface
–Have EIRP that are 3dB lower than spot beams

Earth(Global)
– Beam width of approximately 17˚
–Coverage of up to 42% of earth's surface
–Power levels are considerably low
–Require large receive dishes for adequate signal detection

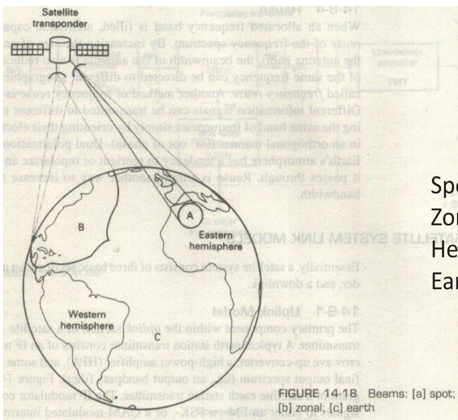


FIGURE 14-18 Beams: [a] spot; [b] zonal; [c] earth

Spot
Zonal
Hemispherical
Earth(Global)

Orbit Inclination and Latitude Coverage

Spot and Zonal Beams:
–Concentrated power to very small geographical areas
–Have high EIRPs
–Blanket less than 10% of earth's surface

Hemispherical Beam
–Blanket 20% of Earth's surface
–Have EIRP that are 3dB lower than spot beams

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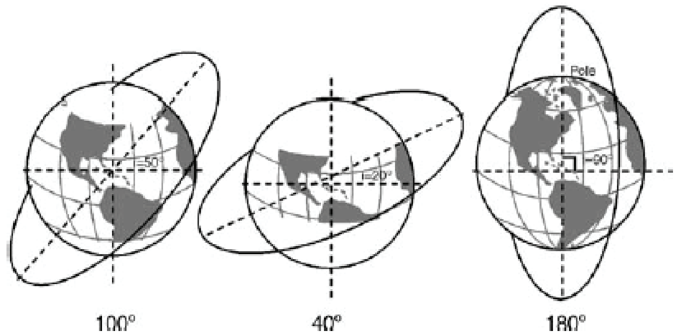


Figure 3.50 Effect of satellite orbital inclination on the latitude coverage

It can be seen that the latitude coverage is 100% only in the case of polar orbits.
The higher the orbit inclination, the greater is the latitude coverage.
This also explains why an equatorial orbit is not useful for higher latitude regions and also why a highly inclined Molniya orbit is more suitable for the territories of Russia and other republics of the former USSR.

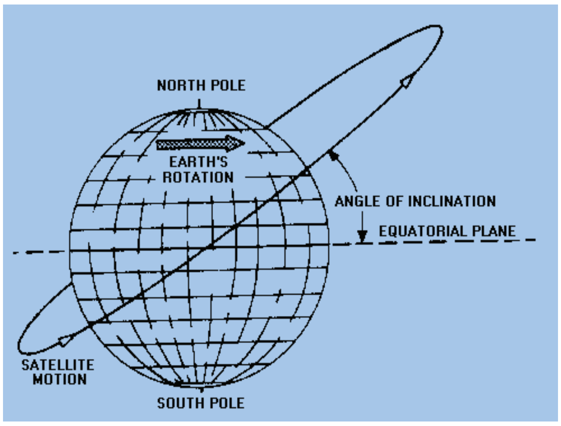
Angle of Inclination

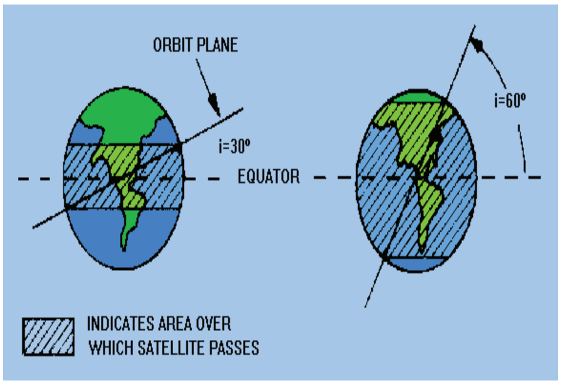
This figure show the angle of inclination between the equatorial plane and the orbital plane.

A satellite orbiting in any plane not identical with the equatorial plane is in an INCLINED ORBIT.

The inclination of the orbit determines the area covered by the path of the satellite.

The greater of inclination, the greater amount of surface area covered by the satellite.





SUMMARY / RECAP

At the end of the learning session the students has been taught about the:-

Satellite communication system
Satellite orbits
Types of circular orbit
Look angle
Earth coverage

TOPIC 2

SATELLITE SYSTEM ELEMENTS

2.1 Understand satellite system elements

2.2 Apply the understanding of satellite system element

2.3 Understand types of earth station

2.4 Apply the understanding of earth station

2.5 Understand satellite organizations

2.6 Apply the understanding of satellite services

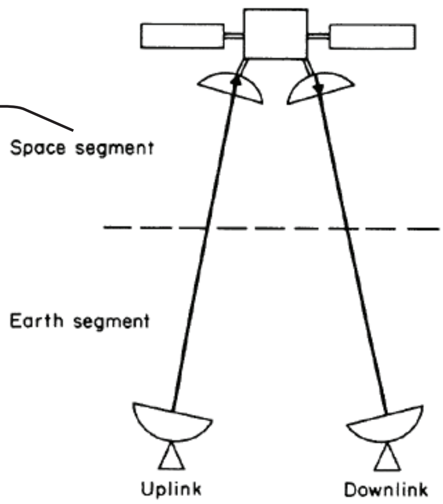
2.1 Understand satellite system elements

At the end of this learning session, students should be able to explain :

2.1.1 Explain the satellite subsystem

a. Power supply
b. Propulsion
c. Altitude and orbit control
d. Thermal control
e. Telemetry, Tracking and Command
f. Antenna
g. Transponder

Satellite System



Two basic elements:

1. Space segment
The satellites: receives, amplifies, and retransmits the signals back to earth.

2. Earth Segment
Uplink transmitter station : transmits signals to the satellite.
Downlink receiving station: receives the signals from satellite

Satellite System

a. Propulsion subsystem
b. Thermal control subsystem
c. Power supply subsystem
d. Telemetry, tracking and command (TT&C) subsystem
e. Attitude and orbit control subsystem
f. Payload subsystem
g. Antenna subsystem

Mechanical structural subsystem provides the framework for mounting other subsystems of the satellite and also an interface between the satellite and the launch vehicle.
Propulsion subsystem is used to provide the thrusts required to impart the necessary velocity changes and transfer orbit of the satellite, such as those required for station keeping.
Thermal control subsystem is essential to maintain the satellite platform within its operating temperature limits for the type of equipment on board the satellite.
The Power Subsystems consists of solar panels and backup batteries that generate power when the satellite passes into the Earth's shadow.

Satellite System

Mechanical structural subsystem provides the framework for mounting other subsystems of the satellite and also an interface between the satellite and the launch vehicle.

Propulsion subsystem is used to provide the thrusts required to impart the necessary velocity changes and transfer orbit of the satellite, such as those required for station keeping.

Thermal control subsystem is essential to maintain the satellite platform within its operating temperature limits for the type of equipment on board the satellite.

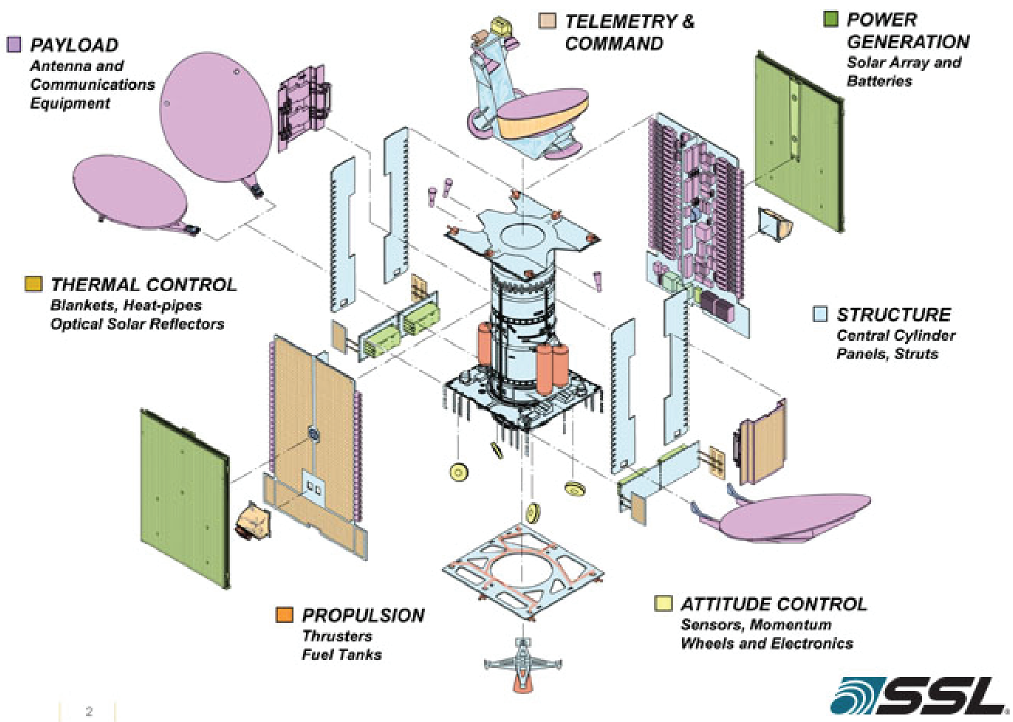
The Power Subsystems consists of solar panels and backup batteries that generate power when the satellite passes into the Earth's shadow.

Attitude and Orbit Control Subsystems: The attitude and orbit control subsystem consists of small rocket thrusters that keep the satellite in the correct orbital position and keep antennas positioning in the right directions.

Telemetry, tracking and command (TT&C) subsystem: Monitors the on-board equipment operations, transmits equipment operation data to the earth control station, and receives the earth control station's commands to perform equipment operation adjustments.

Payload subsystem :The basic payload in the case of a communication satellite is the transponder and antenna, which acts as a receiver, an amplifier and a transmitter.

Antennas : used for both receiving signals from ground stations as well as for transmitting signals towards them. There are a variety of antennas available for use on board a satellite. The final choice depends mainly upon the frequency of operation and required gain. Typical antenna types used on satellites include horn antennas, center-fed and offset-fed parabolic reflectors and lens antennas.

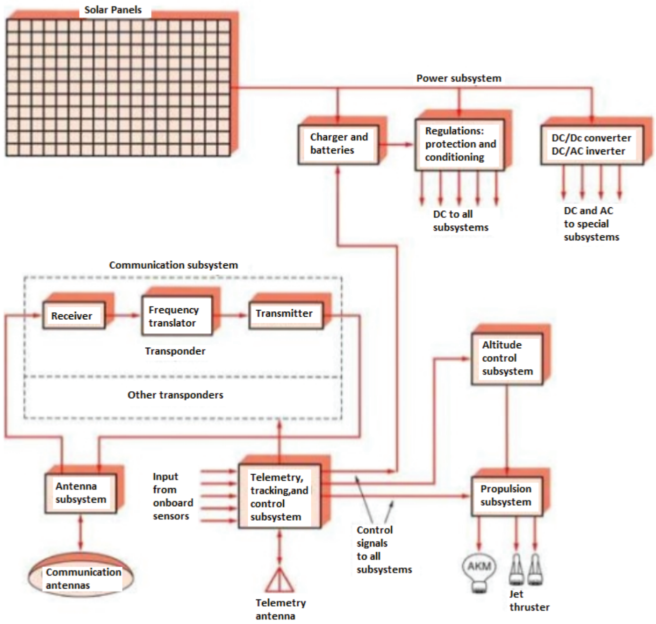


2.2 Apply the understanding of satellite system element

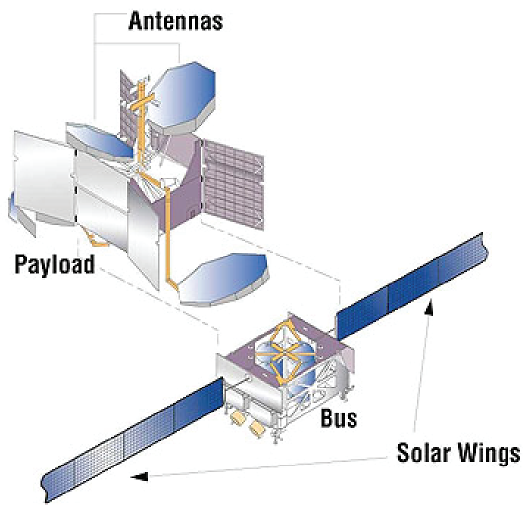
2.2.1 Draw the block diagram of satellite subsystem

2.2.2 Discover bus and payload subsystem in 2.2.1

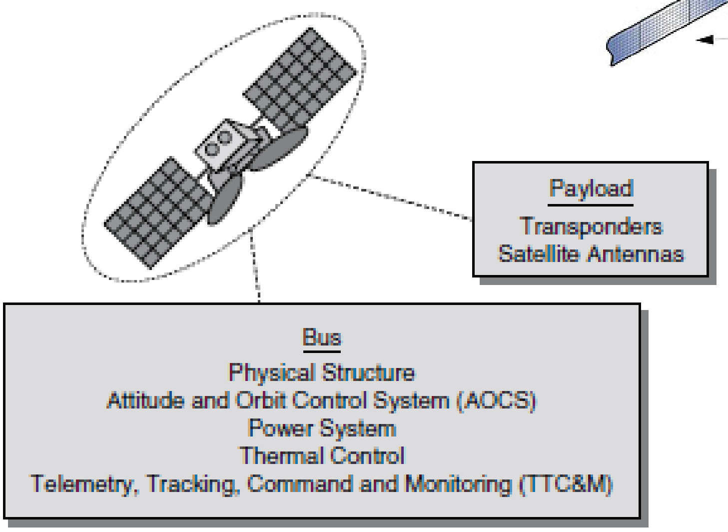
Basic Block Diagram Of Satellite Subsystem



Satellite Subsystem



A satellite system is composed of the spacecraft (bus) and payload(s)



Payload Subsystem

Is the main component of the communications satellite.

Includes: - Transponders
- Antennas

The main functions of the payload subsystem:

1. To capture the signal transmitted by the earth station.   Also capture as little interference as possible.

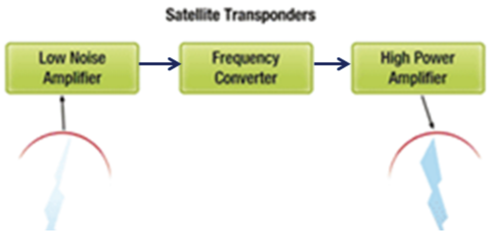
2. To amplify the received signal.

3. To change the frequency of the signal from the uplink to the down-link (e.g. 14 to 11 GHz).

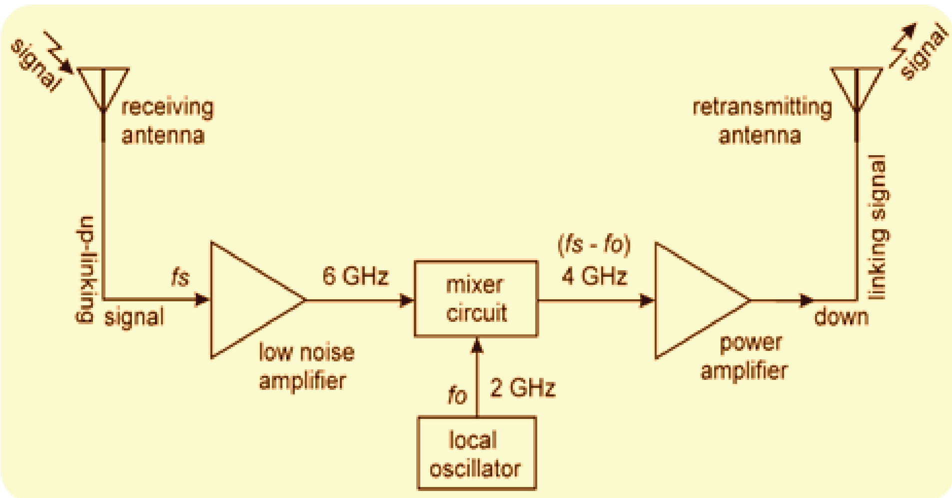
4. To provide the power required for down-link transmission.

Payload Subsystem

A satellite transponder is a circuit on a satellite that receives, modulates, amplifies and re-transmits an uplinked signal.
A satellite may consist of many transponders (i.e. a communication satellite has about 12 or more transponders) - operating on different frequencies and providing different services.



Block Diagram Of Transponder



Function at each blocks:
Receiving antenna- receive up link signal from earth station
1. LNA – choose and amplified uplink signal
2. Local oscillator – to produce LO, 2 GHz.
3. Mixer – combine the uplink signal and local oscillator to produce down link signal
4. HPA (power amplifier) – amplified down-link signal
5. Retransmitting antenna– transmitt down link signal to earth station
6. Up linking signal and down linking signal- as carrier signal from satellite in any information or data

Satellite Antenna

The antenna subsystem is one of the most critical components of the spacecraft design because of some problem:

1. Satellite antennas on board the spacecraft cannot be prohibitively large as large antennas are difficult to mount.

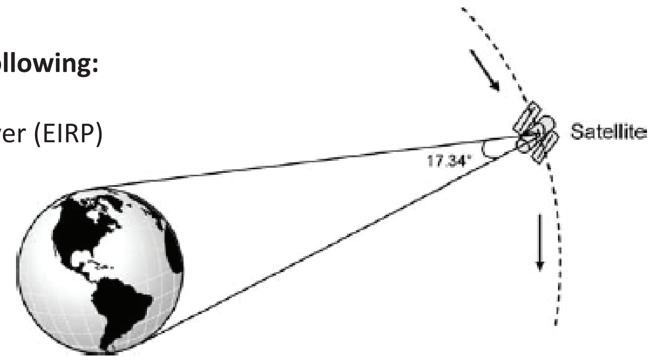
2. Large antennas also cause structural problems as they need to be folded inside the launch vehicle during the launch and orbital injection phase and are deployed only subsequent to the satellite reaching the desired orbit.

3. All satellites need a variety of antennas. These include an omnidirectional antenna, which is an isotropic radiator, a global or Earth coverage antenna, a zone coverage antenna and antennas that produce spot beams.

4. The omnidirectional antenna is used for TT & C operations during the phase when the satellite has been injected into its parking orbit until it reaches its final position. Unless the high gain directional antennas are fully deployed and oriented properly, the omnidirectional antenna is the only practicable means of establishing a communication channel for tracking, telemetry and command operations.

5. The global or Earth coverage antenna has a beam width of 17.34°, which is the angle subtended by Earth at a geostationary satellite, as shown in Figure 4.23. Any beam width lower than that would have a smaller coverage area while a beam width larger than that would lead to loss of power.

The antenna parameter are following:
Gain
Effective isotropic radiated power (EIRP)
Beam width
Bandwidth
Polarization
Aperture



The antenna parameter are following:
There is a large variety of antennas having varied features and characteristics. Those types that are relevant to satellite applications will be described before.
Four main types of antennas are used on spacecraft.

- Wire antennas (monopoles and dipoles).
- Horn antennas.
- Reflector antennas.
- Array antennas.

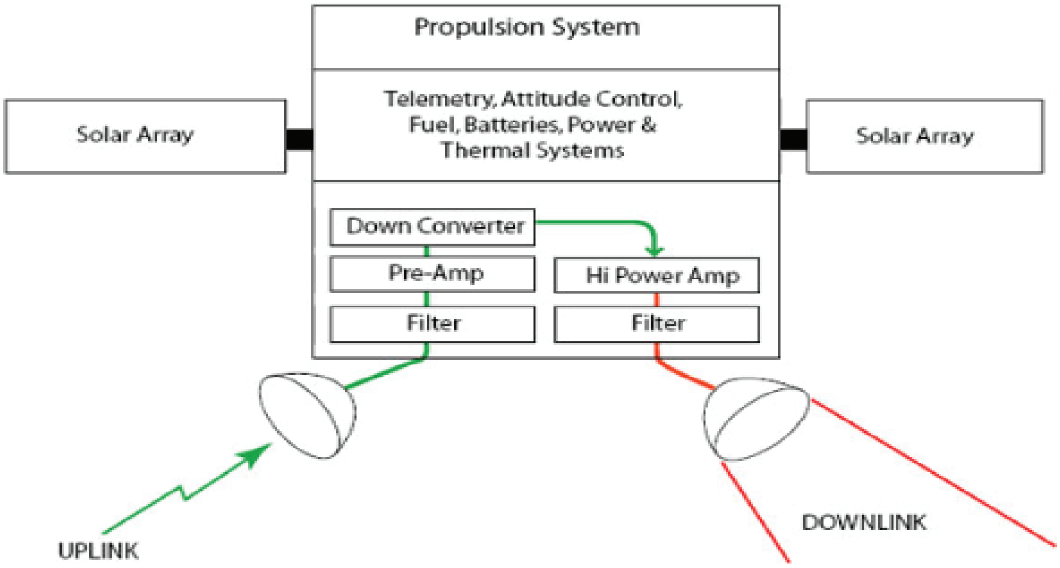
Types of satellite antenna
i - Wire antennas
ii - Horn antennas

Wire antennas
Used primarily at VHF and UHF to provide communications for the TTC&M systems.
Great to provide omnidirectional coverage
Difficult to get the required antenna patterns

Horn antennas
Antenna that contains an opening which electromagnetic wave are transmitted and received through.Aperture antennas can be many different shapes
Most popular antenna are waveguide and horns. Aperture antennas are use widely in aircrafts because can covered with a dielectric. This electric protects the antenna from the environments that an aircraft is exposed to. A waveguide antenna guides an electromagnetic wave.

EXERCISE 1

Identify each subsystem is bus module or payload module:



2.3 Understand Types Of Earth Station

At the end of this learning session, students should be able to explain :

2.3.1 Explain types of earth station:
- a. Transmit only
- b. Receive only
- c. Transmit and received

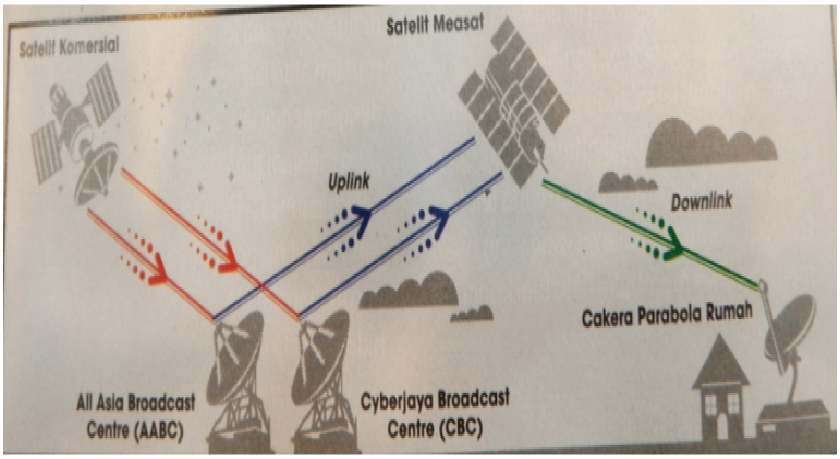
2.4.1 Show the application of 2.3.1

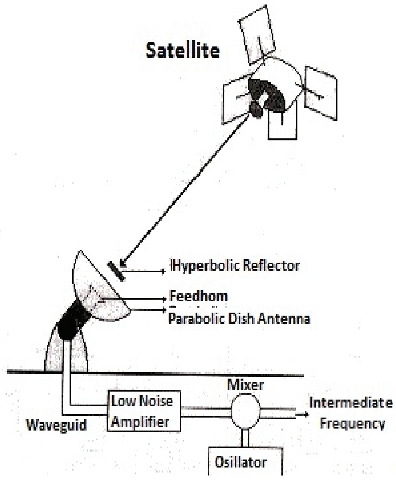
2.4.2 Sketch the block diagram of the earth station:
- a. Earth station transmitter
- b. Earth station receiver

Types Of Earth Station

TRANSMIT ONLY	RECEIVE ONLY	TRANSMIT & RECEIVED
•The Earth Station can transmit signal only towards the satellite. • These stations is used in data collection systems.	•The Earth Station can only receive the signal from a satellite but not transmit anything towards the satellite. •These stations are mostly used in CATV (community antenna TV systems) •astro	•The Earth Station can transmit signal for satellite as well as can receive the signal from the satellite. •These stations are used for two way communication like telephony. •Ground station

Astro Earth Station



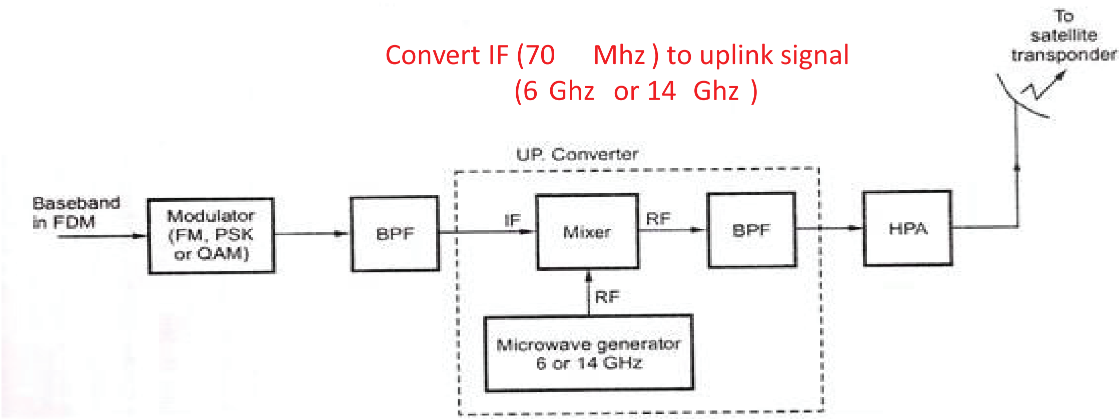


some earth stations also called ground station

A high directive and a high gain antenna is necessary at the earth station , because the losses over the long path is very high the signals power reaching back to the earth station from satellite is very small, therefore at receiving end a parabolic dish antenna with 61m diameter provides a high gain and thus amplify the signal power.

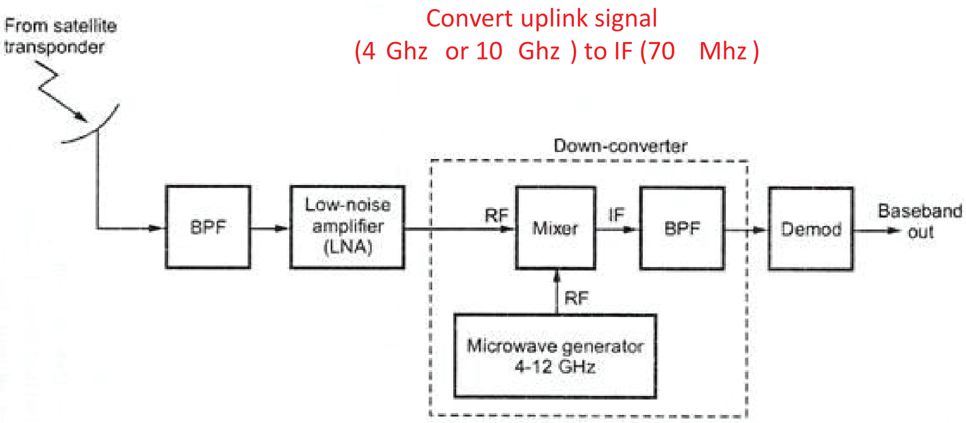
Earth Station Transmitter

1. IF modulator
2. IF-to-RF microwave up-converter
3. High Power Amplifier(Klystrons or Travelling-wave tubes)
4. Band pass filter



Earth Station Receivers

1. Input BPF
2. LNA (tunnel diode)
3. RF-to-IF down-converter (mixer + BPF)



2.5 Understand Satellite Organizations

At the end of this learning session, students should be able to :

Explain satellite organization:
a. International
b. Regional
c. Domestic

Satellite Organizations

a. International Satellite Organizations
b. Regional Satellite Organizations
c. Domestic Satellite Organizations

International Satellite Organizations

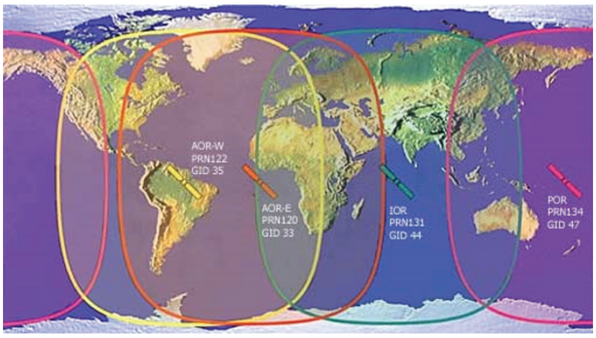
Two major international satellite organizations:
i. International Telecommunications Satellite Organizations (INTELSAT)
ii International Maritime Satellite Organizations (INMARSAT)

Examples of various international satellite systems are New Skies Satellites, PanAmSaT, INTERSPUTNIK and COSPAS-SARSAT

Satellite Organizations

The INTELSAT Organization was established in 1964 to handle the myriad of technical and administrative problems associated with a world wide telecommunication system.

The international regions served by INTELSAT are divided into :
the Atlantic Ocean region (AOR),
the Pacific Ocean Region (POR), and
the Indian Ocean region (IOR).



The international regions served by INTELSAT

Intelsat

For each region, satellites are positioned in geo-stationary orbit above the particular Ocean, where they provide a transoceanic telecommunication route.

In addition to providing trans oceanic routes, the INTELSAT satellites are used for domestic services within any given country and regional services between countries. Two such services are vista for telephony and Intelnet for data exchange.

INTELSAT provides telecommunication services in the space segment only. It also approves and sets standards for the earth station terminals

Space segment is defined as 'the telecommunications satellites, and the tracking, telemetry, command, control, monitoring and related facilities and equipment required to support the operation of these satellites.'

The telecommunication services is defined :
a. telephone and telegram exchange;
b. information services; and
c. broadcasting of radio and television.

Regional Satellite Organizations

to deliver telecommunications and broadcasting services **to a number of countries in a region** for meeting their domestic and regional telecommunications and broadcasting requirements rather than having separate domestic system for each of these countries.
Some of the regional Satellite Systems include :

EUTELSAT - providing video & data services to Europe, Middle East, Africa and large parts of Asian & American continents ,

ARABSAT – provide satellite comm. Services to the Middle East, Africa and large parts of Europe,

ASIASAT, MEASAT– providing satellite services to the Asia Pacific region

ACeS (asia celular satellite) – providing services to Asia. Provide fully digital and optional data services throughout Asia

Thuraya – provides mobile comm. Services to the Middle East, North & central Africa, Europe, Central Asia and the Indian subcontinent

Domestic Satellite (DOMSAT)

Domestic satellites are used to provide various telecommunication services with in a country.

Some countries with their own domestic satellite communications systems are:
a. Canada (Anik F series)
b. United States of America (Wester, SBS, Etc.)
c. USSR (a series of Molniya Satellites)
d. India (INSAT)
e. Brazil (Brazilsat)
f. Mexico (Morelos)
h. China (Chinasat)
i. Japan (CS, BS)

2.6 Apply the understanding of satellite services

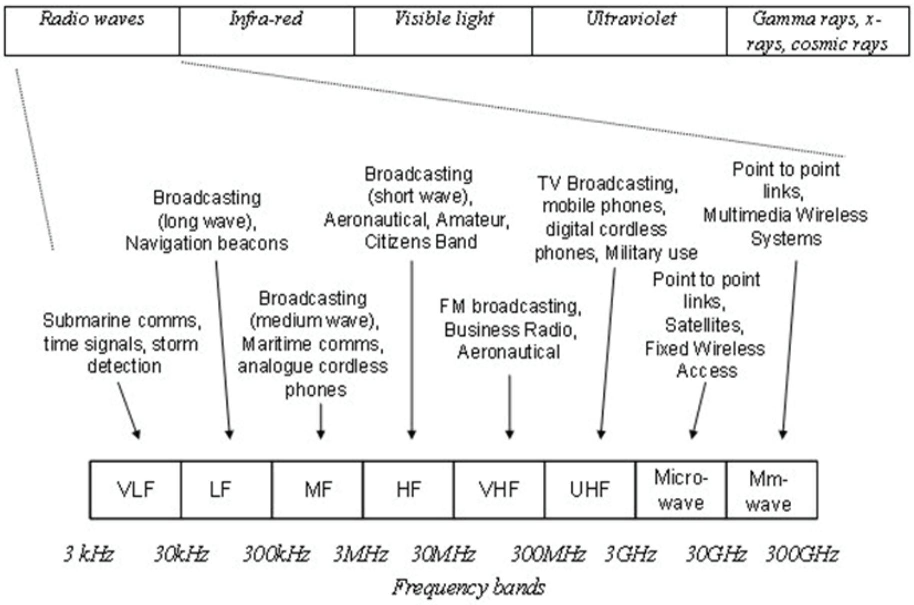
At the end of this learning session, students should be able to :

2.6.1 Show types of satellite services:
- a. Fixed satellite service
- b. Broadcast satellite service
- c. Mobile satellite service
- d. Navigational satellite service
- e. Meteorological satellite service

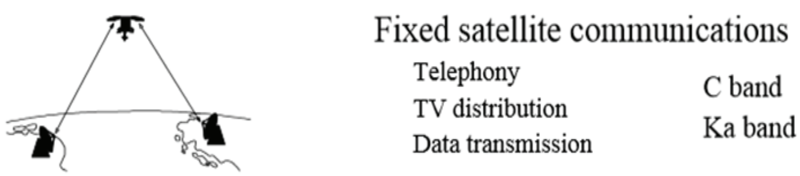
2.6.2 Show the specification of MEASAT satellite in term of:
- Frequency allocation
- Coverage area
- Satellite orbital

Operational Frequencies

Radio communication services	Typical frequency bands for uplink/downlink	Usual terminology
Fixed satellite service (FSS)	6/4GHz	C band
	8/7GHz	X band
	14/12-11GHz	Ku band
	30/20GHz	Ka band
	50/40GHz	V band
Mobile satellite service (MSS)	1.6/1.5GHz	L band
	30/20GHz	Ka band
Broadcasting satellite service (BSS)	2/2.2GHz	S band
	12GHz	Ku band
	2.6/2.5GHz	S band



Operational Frequencies



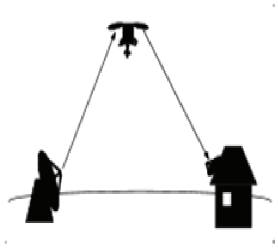
Fixed-Satellite Services (FSS)

Satellites providing Fixed-Satellite Services (FSS) transmit radio communications between ground Earth stations at fixed locations.

Satellite-transmitted information is carried in the form of radio-frequency signals. Any number of satellites may be used to link these stations. Earth stations that are part of fixed-satellite services networks also use satellite news gathering vehicles to broadcast from media events, such as sporting events or news conferences.

In addition, FSS satellites provide a wide variety of services including paging networks and point-of-sale support, such as credit card transactions and inventory control.

Broadcasting satellite service (BSS)



Direct satellite broadcasting

TV (analog and digital)
Digital radio

Ku band

A **radiocommunication** service in which signals transmitted or retransmitted by space stations are intended for direct reception by the general public. In the broadcasting-**satellite** service, the term "direct reception" shall encompass both **individual reception** and **community reception.**

Mobile satellite service (MSS)

Mobile satellite communications

Telephony Multimedia	L, S + Ku band*
Broadband	Ku-Ka band
	* Link to ground station

Mobile satellite services (MSS) refers to networks of communications satellites intended for use with mobile and portable wireless telephones.
There are three major types: AMSS (aeronautical MSS), LMSS (land MSS), and MMSS (maritime MSS).

Navigational satellite

Navigational satellite service
A satellite navigation or satnav system is a system that uses satellites to provide autonomous geo-spatial positioning. It allows small electronic receivers to determine their location (longitude, latitude, and altitude/elevation) to high precision (within a few metres) using time signals transmitted along a line of sight by radio from satellites.
The system can be used for navigation or for tracking the position of something fitted with a receiver (satellite tracking).

The signals also allow the electronic receiver to calculate the current local time to high precision, which allows time synchronization.
Satnav systems operate independently of any telephonic or internet reception, though these technologies can enhance the usefulness of the positioning information generated.
A satellite navigation system with global coverage may be termed a global navigation satellite system (GNSS), oldest US Global Positioning System (GPS), the Russian GLObal Navigation Satellite System(GLONASS) and the European GALILEO system.

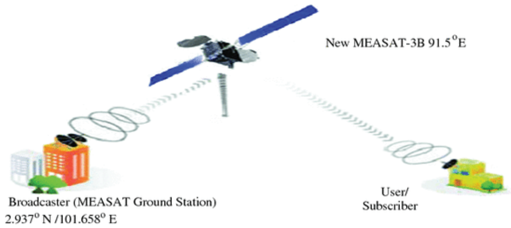
Meteorological satellite

Meteorological satellite service
The weather satellite is a type of satellite that is primarily used to monitor the weather and climate of the Earth. Satellites can be polar orbiting, covering the entire Earth asynchronously, or geostationary, hovering over the same spot on the equator.

Meteorological satellites see more than clouds and cloud systems. City lights, fires, effects of pollution, auroras, sand and dust storms, snow cover, ice mapping, boundaries of ocean currents, energy flows, etc., and other types of environmental information are collected using weather satellites.
Weather satellite images helped in monitoring the volcanic ash cloud from Mount St. Helens and activity from other volcanoes such as Mount Etna. Smoke from fires in the western United States such as Colorado and Utah have also been monitored.
Other environmental satellites can detect changes in the Earth's vegetation, sea state, ocean color, and ice fields.

Measat 3a/3b/5

http://www.measat.com/measat-fleet/



MEASAT (Malaysia East Asia Satellite) is the name of a line of Malaysian communications satellites owned and operated by MEASAT Satellite Systems Sdn. Bhd. (formerly Binariang Satellite Systems Sdn. Bhd.).

In 2006, the MEASAT satellite network consists of three geostationary satellites designed and built by Boeing Satellite Development Center (formerly Boeing Satellite Systems). MEASAT-1 and MEASAT-2 were launched in 1996 and MEASAT-3 in 2006.

The MEASAT-1 and 2 satellites were designed to provide 12 years of both direct to user television service in Malaysia and general communications services in the region from Malaysia to the Philippines and from Beijing to Indonesia.

With the launch of MEASAT-3, the coverage extends to 70% of the world's population . With the two high-powered Boeing 376HP communications satellites provided regional C-Band coverage and pioneered the use of Ku-Band in the high rain fall South East Asia region.

The communication satellite used consist of several applications which is telephony, satellite television and radio, mobile satellite technology, amateur radio, satellite broadband and also military communications. Another function is satellite broadband. It has been used to connect to the Internet via broadband data connections in Malaysia.

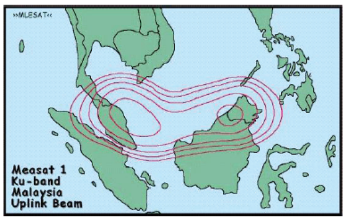
Frequency allocation

Main transponders	12
Backup transponders	3
Power	12 W (SSPA)
Bandwidth	36 MHz
Coverage	Malaysia, Philippines & South-India
EIRP max	39 dBW
G/T max	+3 dB/K
Polarization	Linear
Frequencies	Uplink : 5.925 – 6.425 GHz Downlink : 3.700 – 4200 GHz

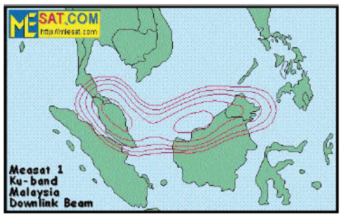
C band

Main transponders	5
Backup transponders	1
Power	112 W (TWTA)
Bandwidth	54 MHz
Coverage	Narrow spots :Malaysia, Philippines & South-India
EIRP max	57 dBW
G/T max	+11 dB/K
Polarization	Linear
Frequencies	Uplink : 14.000 – 14.250 GHz
	Downlink : 10.950 – 11.200 GHz to 11.45 – 11.7 or 12.2 – 12.75 GHz

Ku band



MEASAT 1 K_U-Band Uplink Beam



MEASAT 1 K_U-Band Downlink Beam

SUMMARY / RECAP

At the end of the learning session the students has been taught about the:-

1. Satellite system elements
2. Types of earth station
3. Satellite organizations
4. Satellite services
4. MEASAT satellite

TOPIC 3

SATELLITE AND RADAR COMMUNICATION SYSTEM

3.1 Understand multiple access methods in satellite communication system.

3.2 Understand satellite system links.

3.3 Apply satellite link parameter in link budget.

3.4 Investigate satellite link budget.

3.5 Understand Very Small Aperture Terminal (VSAT) network.

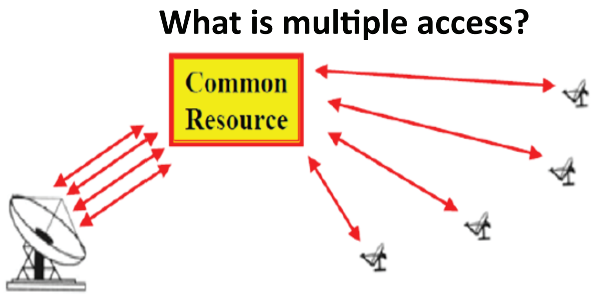
3.6 Apply the understanding of VSAT network.

3.1 Multiple Access Methods

Upon completion of this learning session, the student should be able to:

Explain multiple access
Explain types of multiple access in satellite communication system:
Frequency Division Multiple Access (FDMA)
Time Division Multiple Access (TDMA)
Code Division Multiple Access (CDMA

Satellite Multiple Access?



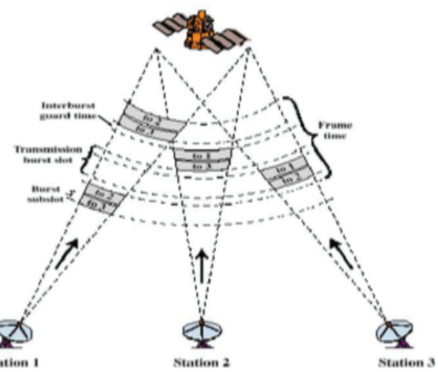
Multiple access is a technique whereby multiple users can access a common resource/facility for the purpose of communications.

In the context of satellite communication, the facility is the transponder and the multiple users are various terrestrial terminals under the footprint of the satellite.

The transponder provides the communication channels that receives the signals beamed at it via the uplink and then retransmits the same back to Earth for intended users via the downlink.

In telecommunications multiple access method allows several terminals connected to the same multipoint transmission medium to transmit over it and to share its capacity.

Examples of shared physical media are wireless networks, bus networks, ring networks, star networks and half-duplex point-to-point links.



There are three types of Multiple Access Methods:
Frequency Division Multiple Access (FDMA) – flexible and simple
Time Division Multiple Access (TDMA) – popular
Code Division Multiple Access (CDMA Spread Spectrum) – highly secure

Frequency Division Multiple Access

Is the oldest and still one of the most common method for channel allocation.

In this scheme, the available satellite system bandwidth is divided into frequency/channel bands of equal bandwidth for different Earth Stations (ES). All ES are able to transmit continuously.

The channel bands are assigned on demand to users who request service. During the period of service, no other user can share the same frequency band.

When the user terminates the service, the frequency band may by reassigned to another user (frequency reuse).

Frequency Division Multiple Access

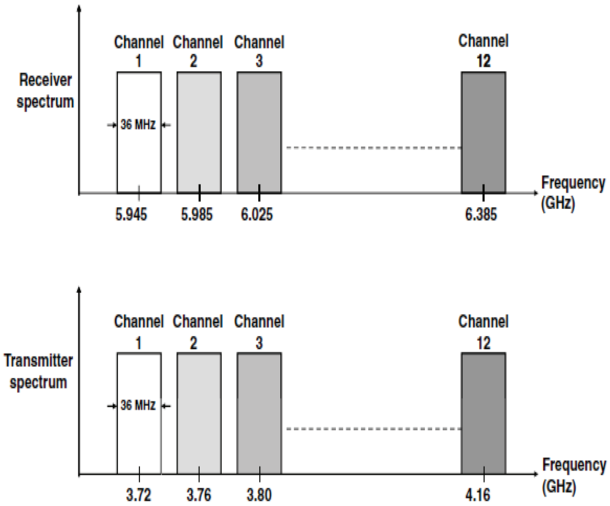


Figure 1: Carrier frequencies for a C band transponder for both uplink and downlink channels

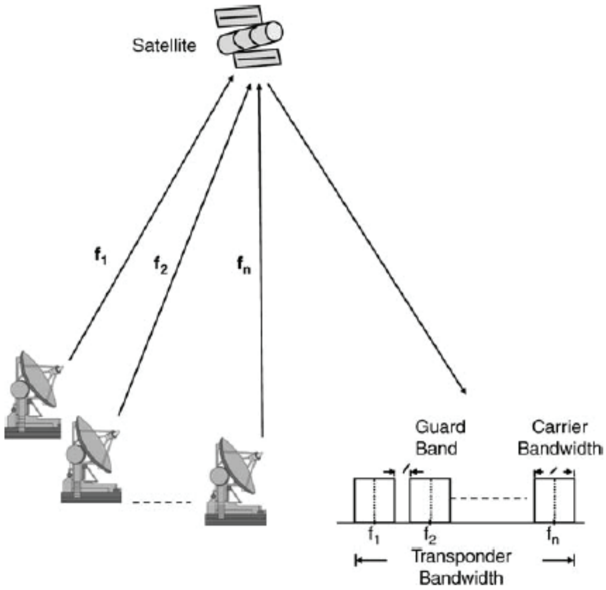


Figure 2: Basic concept of FDMA

In FDMA different Earth stations are able to access the total available bandwidth of satellite transponder by virtue of their different carrier frequencies, thus avoiding interference among multiple signals.

Typical arrangement for carrier frequencies for a C band transponder for both uplink and downlink.

The transponder receives transmissions at around 6 GHz and retransmits them at around 4 GHz.

Figure 1 shows the case of a satellite with 12 transponders, with each transponder having a bandwidth of 36MHz and a guard band of 4MHz between next to transponders to avoid interference.

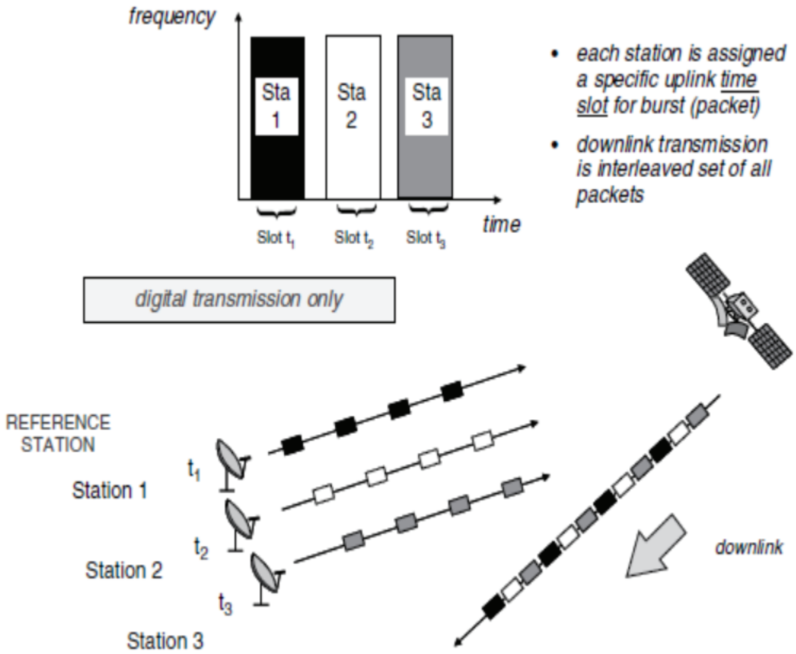
Each of the Earth stations within the satellite's footprint transmits one or more message signals at different carrier frequencies.

Each carrier is assigned a small guard band, as mentioned above, to avoid overlapping of adjacent carriers.

The satellite transponder receives all carrier frequencies within its bandwidth, does the necessary frequency translation and amplification and then retransmits them back towards Earth.

Figure 2 illustrates the basic concept of FDMA in satellite communications. Different Earth stations are capable of selecting the carrier frequency containing messages of their interest.

Time Division Multiple Access



3 ground stations accessing a single frequency transponder.
Each station is assigned a specific time slot, t1, t2, and t3, for its
uplink transmission of a burst (or packet) of data.

The frequency/time plot of the figure shows that each ground station has exclusive use of the full transponder bandwidth during its time slot.

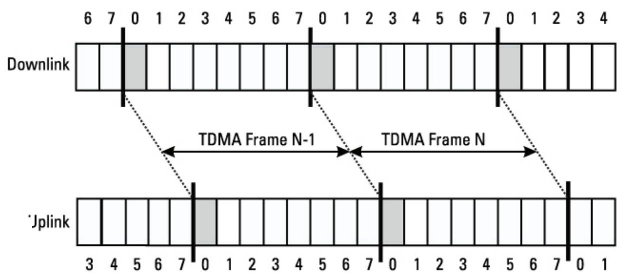
The time slot is pre-assigned or can be changed on demand. Guard times are used between the time slots to avoid interference.

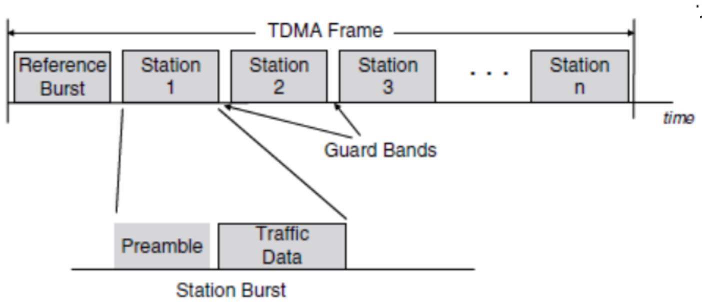
TDMA is most practical for digital data only, because of the burst nature of the transmissions. Downlink transmission consists of interleaved set of packets from all the ground stations.

The disadvantages of TDMA include a requirement for complex and expensive Earth station equipment.

TDMA Frame Structure

A basic channel is formed by a particular time slot inside every frame.





In TDMA, the preamble contains the address and synchronization information that both the base station and the mobiles use to identify

Code Division Multiple Access

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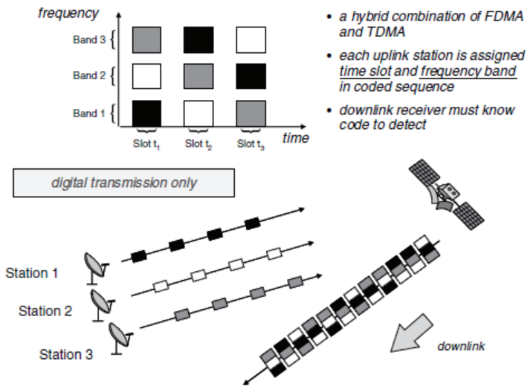
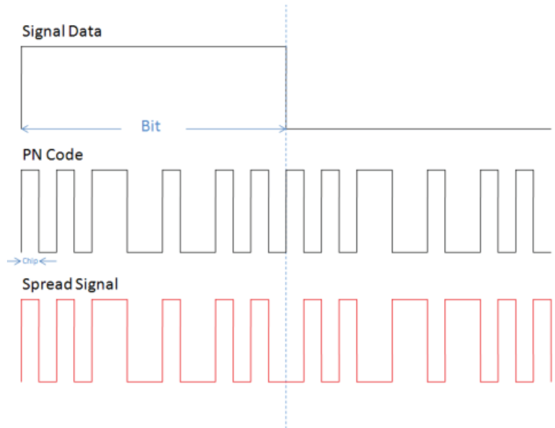


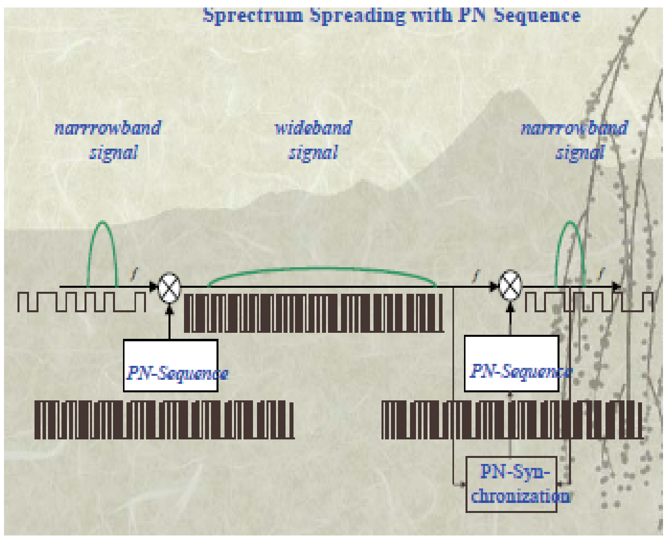
Example of CDMA Process



The codes (one/zero sequences) used to differentiate signals are designed and generated at a much higher rate than the baseband information.

A transmitting station spreads the signal in a bandwidth wider than actually needed.

Narrowband message signal multiplied by wideband spreading signal, or codeword
Each user has its own Pseudorandom Noise (PN) or pseudo-codeword (orthogonal to others).
Each authorized receiving station must have a matching PN code to retrieve the information.
Receivers detect only the desired PN. All others appear as noise.
Other channels may operate simultaneously within the same frequency spectrum as long as different, orthogonal codes are used.



3.2 Understand satellite system links

Upon completion of this learning session, the student should be able to:

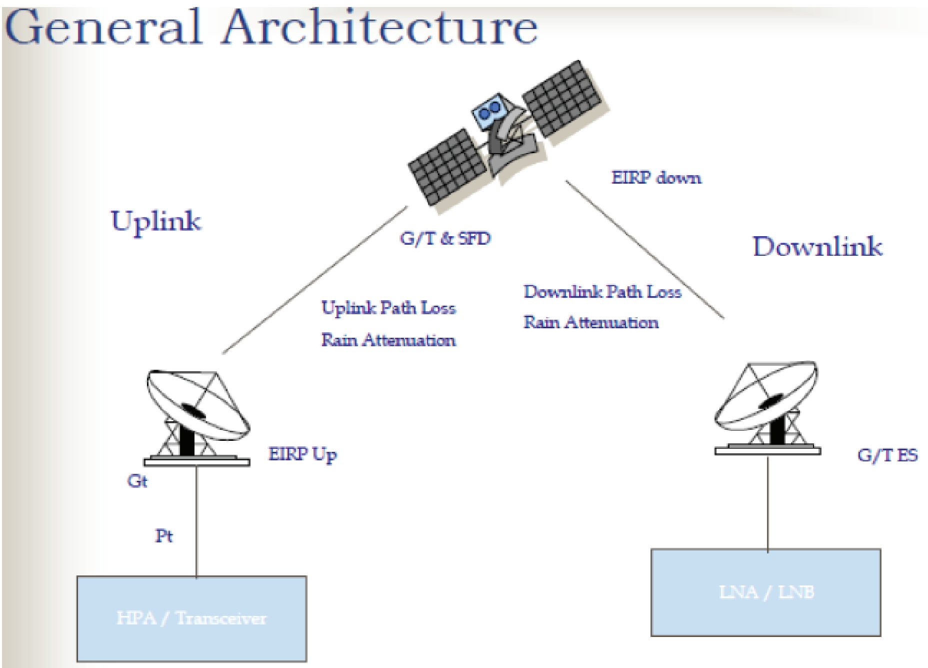
3.2.1 Explain basic terminology in satellite system links with an illustration of:

- Up link
- Down link
- Cross-link

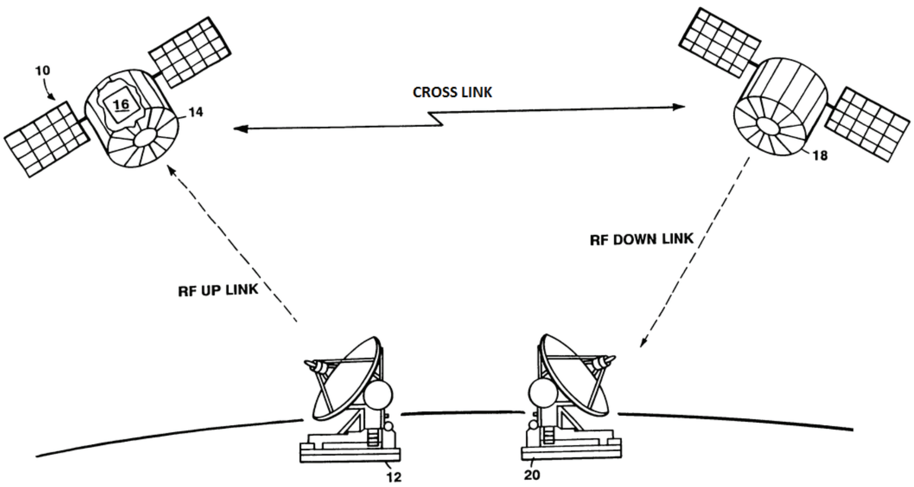
3.2.2 Discuss satellite link budget with an illustration

3.2.3 Explain the importance of link budget

Satellite System Link



Terminology in satellite system links



Satellite System Link

Satellite link design involved two communication link;

The Uplink – transmission involves communication from the Earth to the satellite

The Downlink – involves communication from the satellite back to the Earth.

Cross link/ISL- communicate between satellite

The four factors related to satellite system design:

1. The weight of satellite
2. The choice frequency band
3. Atmospheric propagation effects
4. Multiple access technique

Satellite System Link

Cross-Links

Occasionally, there is an application where it is necessary to communicate between satellites.
This is done using *satellite cross-links or intersatellite links* (ISLs).
A disadvantage of using an ISL is that both the transmitter and receiver are spacebound.
Consequently, both the transmitter's output power and the receiver's input sensitivity are limited.

Importance Of Link Budget

A **link budget** is accounting of all of the gains and losses from the transmitter, through the medium (free space, cable, waveguide, fiber, etc.) to the receiver in a satellite communication system.

A link budget is a tabular method for evaluating the power received and the noise ratio in a radio link.
It simplifies C/N ratio calculations.

If that power, minus the free space loss of the link path, is greater than the minimum received signal level of the receiving radio, then a link is possible.

The difference between the minimum received signal level and the actual received power is called the link margin

The link margin must be positive, and should be maximized (should be at least 10dB or more for reliable links)

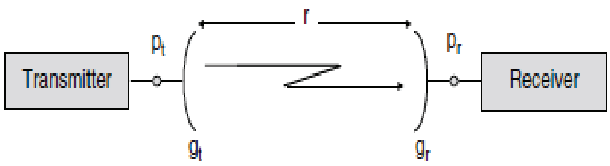
3.3 Apply Satellite Link Parameter In Link Budget

Upon completion of this learning session, the student should be able to:

3.3.1 Describe the parameter in link budget with the aid of a diagram:

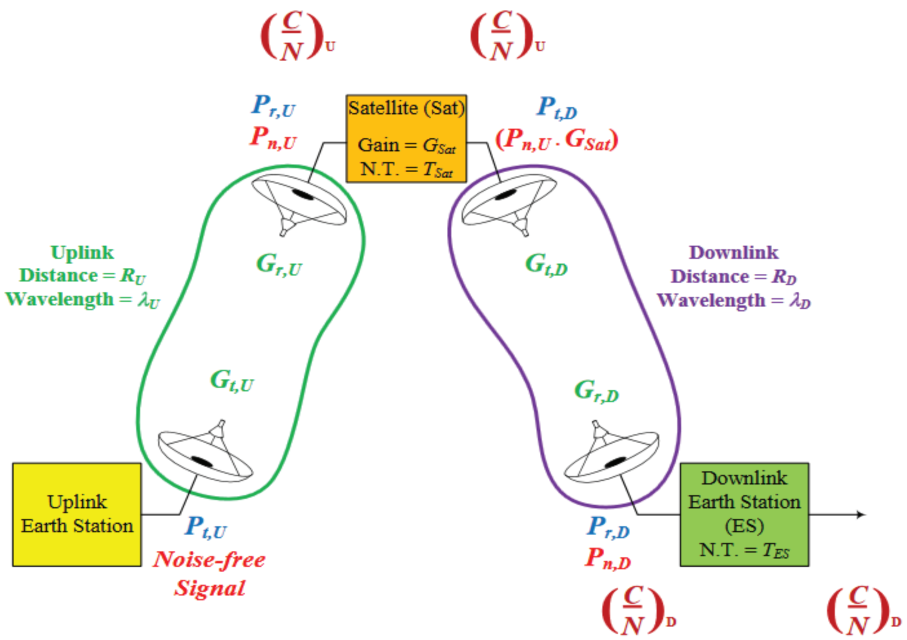
a. Effective Isotropic Radiated Power (EIRPu/ EIRPD)
b. Power flux density, (Φ)
c. Path loss, (Lp)
d. Antenna gain, (Gt/ Gr)
e. Antenna gain to noise temperature (G/T)u /(G/T)D
f. Trasmitted power, (Pt)
g. Received power, (Pr)
h. Carrier per noise (C/N)u/ (C/N)D

Basic Communication Link



$$P_t - Transmitted\ \ power$$
$$g_t - Transmitted\ \ Antenna\ Gain$$
$$P_r - \mathrm{Re}\,ceived\ \ Power$$
$$G_r - \mathrm{Re}\,ceived\ \ Antenna\ Gain$$
$$r - Antenna\ dis\,\tan ce$$

Satellite Link Budget



Link Budget Parameter

1. Antenna gain communication systems employ parabolic (dish) antennas for transmitting and receiving satellite signals. Then gain expression for parabolic antennas is given by:

$$G = \eta \left(\frac{\pi \text{ D}}{\lambda} \right)^2$$

Where η = antenna efficiency (typically 55-75 percent)
D = antenna diameter
λ = wavelength of radio wave = c/f
c = velocity of light = 3x10^8 m/s
f = radio wave frequency.

OR In decibels as:
G (dB) = 20.4 + 20 log f (GHz) + 20 log D (m) + 10 log η .

2. Free-space path loss (spreading loss), Lp or Ls:

The free space loss takes into account that electromagnetic waves spread out into spherical wavefronts as they propagate through space due to diffraction.

$$L_s = \left(\frac{4\pi d}{\lambda} \right)^2 = \left(\frac{4\pi d f}{c} \right)^2$$

$$[L_s] = 10 \log_{10} \left(\frac{4\pi d}{\lambda} \right)^2 = 20 \log_{10} \left(\frac{4\pi d}{\lambda} \right)$$

For a geostationary satellite, the free space loss is on the order of 200 dB (or a factor of 10^{20}).

The received power at the earth terminal is typically on the order of tens of *pico*watts.

Where R/d is the distance travelled in free-space (path length).
OR In decibels as:
Lp (dB) = 92.4 + 20 log R (km) + 20 log f (GHz) .

Example

What is the Free Space Path Loss to a geostationary satellite at a range of 40,000 km, operating at 15 GHz?

Lp (dB) = 92.4 + 20 log R (km) + 20 log f (GHz)
= 92.4 + 20 log(40000)+20 log(15)
= 208dB

3. **Effective isotropic radiated power (EIRP)** is defined as an equivalent transmit power

EIRP of an earth-station or of a transponder can be expressed as:

$$EIRP\ (dBW) = Pt\ (dBW) + Gt\ (dB)$$

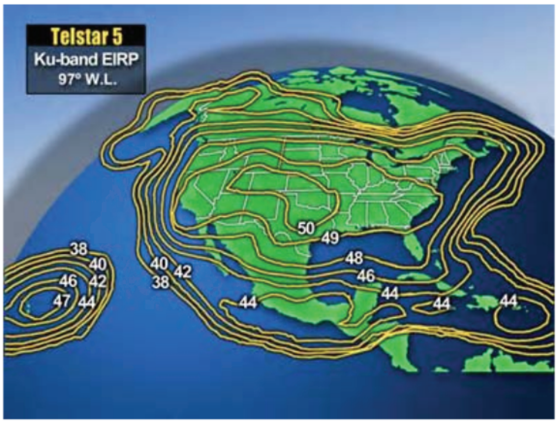
Pt = transmitted power including back-off and any losses at the output of the HPA (e.g. combining losses)

Gt = transmitter antenna gain.

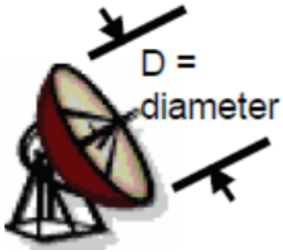
> Effective isotropic radiated power(EIRP) from the transmitting side and is the product of the antenna gain and the transmitting power, expressed as:

$$EIRP(dBw) = Pt - Lbo - Lbf + Gt$$

Where
Lbo = back-off losses of HPA (decibels)
Lbf = total branching and feeder loss (decibels)
Gt = transmit antenna gain (decibels)
Pt = saturated amplifier output power (dBW per watt)



The EIRP coverage of a satellite determines the size of receiving dishes required. The higher the EIRP, the smaller the antenna needed.



P = 100 W $[P]$ = 20 dBW $[G]$ = 30 dB

$$[EIRP] = [G] + [P] = 30\ dB + 20\ dBW = 50\ dBW$$

Link Budget Parameter

Example 1

For an earth station transmitter with an antenna output power of 40dBW (10,000W), a back-off loss of 3 dB, a total branching and feeder loss of 3 dB and a transmit antenna gain of 40 dB. Determine the EIRP.

Solution:

dBm= 10 * log (P/1mW)

EIRP(dBw) = Pt - Lbo - Lbf + Gt

= 40 dBW – 3 dB – 3 dB + 40 dB

= 74 dBW

Example 2

A satellite downlink at 12 GHz operates with a transmit power of 6W and an antenna gain of 48.2 dB. Calculate the EIRP in dBW.:

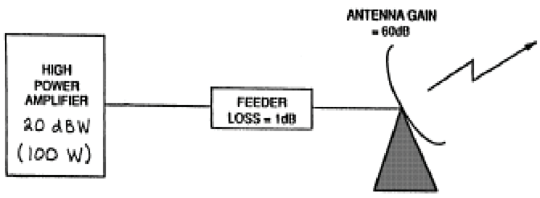
Solution:

EIRP(dBw) = Pt (dBW)+ Gt

= 10 log (6W) + 48.2

= 56 dBW

Example 3



$[P_{HPA}] = 10 \log_{10}(100 \text{ W}) = 20 \text{ dBW}$

$[P_{in}] = [P_{HPA}] - [L] = 20 \text{ dBW} - 1 \text{ dB} = 19 \text{ dBW}$

$[\text{EIRP}] = [G_t] + [P_{in}] = 60 \text{ dB} + 19 \text{ dBW} = 79 \text{ dBW}$

4. The received power PR is commonly referred to as the carrier power. The product of the gain Gt and power Pt of the transmitting antenna is called the effective isotropic radiated power (EIRP) and write the received power as
The decibel equation for the received power;

$$[P_R] = [EIRP] + [G_R] - [LOSSES]$$

Received power is very small (in picowatts)

Where; [PR] = received power, dBW
[GR] = receiver antenna gain
[EIRP] = Effective radiated power.
[LOSSES] = the losses for clear-sky

Problem: Determine the received carrier power for the Ku band downlink between Telstar 5 and an Earth terminal in Los Angeles if the frequency is 12 GHz and the antenna has an efficiency of 0.60 and a diameter of 5.0 m. Allow a rain attenuation loss of 1.9 dB, a gaseous atmospheric loss of 0.1 dB, and a pointing loss of 0.2 dB.

Solution: The satellite EIRP in Los Angeles is 49.2 dBW. At 12 GHz, the antenna gain is 53.7 dB and the free space loss is 205.5 dB. Therefore, the received carrier power is

$$P_R] = [EIRP] + [G_R] - [LOSSES]$$

$$[P_R] = [\mathrm{EIRP}] + [G_r] - [L_s] - [L_r] - [L_a] - [L_p]$$

$$= 49.2\ \mathrm{dBW} + 53.7\ \mathrm{dB} - 205.5\ \mathrm{dB}$$

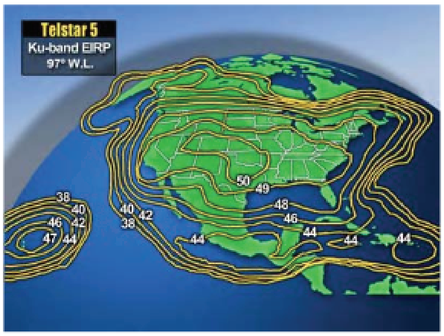
$$- 1.9\ \mathrm{dB} - 0.1\ \mathrm{dB} - 0.2\ \mathrm{dB}$$

$$= -104.8\ \mathrm{dBW}$$

Therefore,

$$P_R = 10^{-10.48}\ \mathrm{W} = 3.3 \times 10^{-11}\ \mathrm{W} = 33\ \mathrm{pW}$$

$$P_R] = [EIRP] + [G_R] - [LOSSES]$$



$$G\ (\mathrm{dB}) = 20.4 + 20 \log f\ (\mathrm{GHz}) + 20 \log D\ (\mathrm{m}) + 10 \log \eta\ .$$

$$L_p\ (\mathrm{dB}) = 92.4 + 20 \log d\ (\mathrm{km}) + 20 \log f\ (\mathrm{GHz})$$

Link Budget Parameter

5. Figure of merit, (G/T)
   The ratio of the receive antenna gain G to the total system temperature T.

$$[G/T] = [G] - [T] \quad \text{(dB/K)}$$

where

$[G]$ = receive antenna gain (dB)

$[T]$ = total system temperature (dBK)

The figure of merit is independent of the point where it is calculated. However, the gain and system temperature must be specified at the same point.

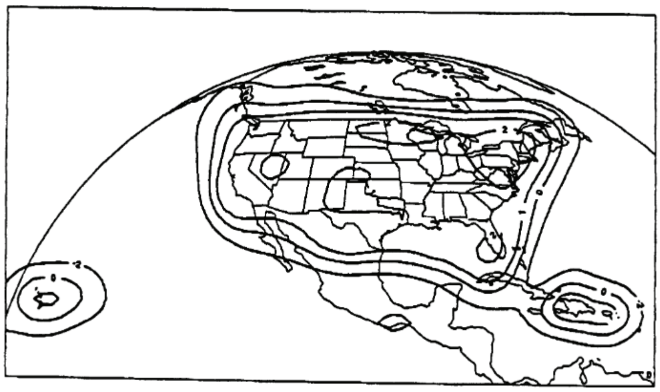
Example: Suppose the antenna gain is 53.7 dB and the system temperature is 150 K. Then

$$[T] = 10\log_{10}(150\text{ K}) = 21.7\text{ dBK}$$

$$[G/T] = [G] - [T] = 53.7\text{ dB} - 21.7\text{ dBK} = 32.0\text{ dB/K}$$

Satellite Figure of Merit G/ T

5. Figure of merit, (G/T)
   The ratio of the receive antenna gain G to the total system temperature T.



$T = 630$ K $\quad [T] = 28$ dBK $\quad [G] = 30$ dB

$$[G/T] = [G] - [T] = 30\text{ dB} - 28\text{ dBK} = 2\text{ dB/K (COC)}$$

Carrier-To-Noise Ratio (C/N)

C/N = PR / PN (in Watt)

= PR – PN (in dB)

Noise power, PN = k TN BN (in Watt)

$C/N = EIRP + G_R - Losses - k - T_N - B_N$

$C/N = EIRP + G/T - Losses - k - B_N$

(in dB)

$$\begin{aligned} k &= \text{Boltzmann's Constant} \\ &= 1.39 \times 10^{-23}\ \text{Joules/K} \\ &= -198\ \text{dBm/K/Hz} \\ &= -228.6\ \text{dBw/K/Hz} \end{aligned}$$

where:

TN – equivalent noise temperature,

BN – equivalent noise bandwidth

Power Flux Density

The EIRP of the uplink Earth station antenna must be adjusted to match an acceptable power flux density (PFD) at the satellite.

$$PFD = \Phi = \frac{EIRP}{4\pi d^2}\frac{1}{L_r}\frac{1}{L} = \frac{EIRP}{L_s\,(\lambda^2/4\pi)}\frac{1}{L_r}\frac{1}{L}$$

$$[\Phi] = [EIRP] - [4\pi d^2] - [L_r] - [L]$$

or

Φ = EIRP – 10 log4πd^2- Losses

Power Flux Density

Example 4a

Problem: For an uplink between an Earth station in Washington, DC and Telstar 5, the EIRP is 79.0 dBW, the slant range is 37,722 km, the rain attenuation is 5.9 dB, and the antenna pointing loss is 0.2 dB. Determine the power flux density incident on the satellite.

Solution:

$$[\Phi] = [\mathrm{EIRP}] - [4\pi d^2] - [L_r] - [L]$$

$$= 79.0\ \mathrm{dBW} - 10\log_{10}\left\{4\pi\,(37{,}722{,}000\ \mathrm{m})^2\right\} - 5.9\ \mathrm{dB} - 0.2\ \mathrm{dB}$$

$$= -89.6\ \mathrm{dBW/m^2}$$

This PFD is within the specifications for Telstar 5.

Saturation Flux Density - Typical CONUS

-75 to -96 (dBW/m²) at Ku-band adjustable in 1 dB steps

Ku-band Optional "Automatic Level Control" Mode
Mitigates the effects of uplink rain fade by maintaining the transponder at a specific fixed operating point between saturation and 8 dB input backoff.

Example 4b

Power flux density (PDF) measure the required density of the satellite input. Calculate the EIRP and PFD if the GEO satellite is at a distance 36000KM from surface of the earth radiating a power of 10watta in a desired direction through an antenna with a gain of 20 dBi

Solution:

EIRP = Pt + Gt
= 10log(10) +20
= 30dB
PFD = 10log (PtGt/4PHIR2)
= 10log(Pt) + 10log (Gt) – 20log (R) – 10log (4PHI)
= -72.11dB(w2/m)

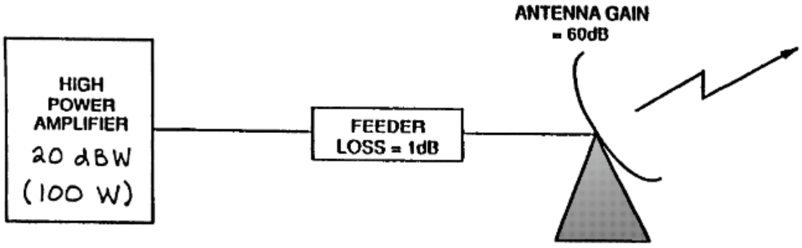
Example 5

numeric form	*logarithmic (dB) form*
$G_t = 100$	$[G_t] = 10\log_{10}(100) = 20.0$ dB
$P_{in} = 50$ W	$[P_{in}] = 10\log_{10}(50\ \mathrm{W}) = 17.0$ dBW
EIRP = $G_t P_{in}$	[EIRP] = $[G_t] + [P_{in}]$
= (100)(50 W)	= 20.0 dB + 17.0 dBW
= 5000 W	= 37.0 dBW

$10\log_{10}(5000\ \mathrm{W}) = 37.0$ dBW

Power Flux Density

Example 6



$$[P_{HPA}] = 10 \log_{10}(100\ W) = 20\ dBW$$

$$[P_{in}] = [P_{HPA}] - [L] = 20\ dBW - 1\ dB = 19\ dBW$$

$$[EIRP] = [G_t] + [P_{in}] = 60\ dB + 19\ dBW = 79\ dBW$$

Example 7

A satellite transponder has a bandwidth of 36 MHz and a saturation EIRP of 27 dBW. The earth station receiver has a [G/T] of 30 dB/K, and the total link losses are 196dB. The transponder is accessed by FDMA carriers each of 3MHz bandwidth and 6dB output backoff is employed. Calculate the downlink carrier-to-noise ratio.

Solution:

$[C/N]_D = [EIRP]_D + [G/T]_D - [LOSSES]_D - [K] - [B]$

$= 27\ dBW + 30\ dB/K - 196\ dB + 228.6 - 75.56\ dBHz$

$= 14\ dB$

Power Flux Density - Exercise

1. A satellite link operating at 14GHz has receiver feeder losses of 1.5 dB and a free-space loss of 207 dB. The atmospheric absorption loss is 0.5 dB, and the antenna pointing loss is 0.5dB. Calculate

i - The total link loss for clear sky condition

ii - The received power if an earth station radiates an [EIRP] of 54dBW and an antenna gain of 48.2 dB.

2. A satellite carrying a 9.8-GHz continuous-wave beacon transmitter is located in geosynchronous orbit 37,586 km from an earth station. The beacon's output power is 0.3W and feeds antenna of 19-dB gain toward the earth station. The antenna is 3.65m in diameter with an aperture efficiency of 62.5%.

(i) Calculate the satellite EIRP.
(ii) Calculate the receiving antenna gain.
(iii) Calculate the path loss.
(iv) Calculate the received power.
(v) If the overall system noise of the earth station is 1189 K, calculate the earth station G/T.
(vii) The receiver carrier-to-noise ratio in a 115-Hz noise bandwidth.

3. A C band satellite transmits with an EIRP of 46dBW. Calculate the received carrier-to-noise ratio if the bandwidth is 35MHz and the receiver has a G/T of 25 dB/K. Assume the distance between the earth and the satellite is 35,786 km.

4. The following parameters apply to a satellite downlink of C band saturation [EIRP] 22.5 dBW, free-space loss 195 dB, other losses and margins 1.5 dB, earth station [G/T] 37.5 dB/K. Calculate the [C/N0] at the earth station.

FORMULA

Gain transmit and receive

$G\ (dB) = 20.4 + 20 \log f\ (GHz) + 20 \log D\ (m) + 10 \log \eta$

EIRP transmit or receive

$EIRP\ (dBW) = Pt\ (dBW) + Gt\ (dB)$ *or*

$EIRP(dBw) = Pt - Lbo - Lbf + Gt$

Path loss uplink or downlink

$Lp\ (dB) = 92.4 + 20 \log R\ (km) + 20 \log f\ (GHz)$

Power receive

$Pr = EIRP + Gr - Losses$

$Losses = Lp + Lbo + Lbf + La$

Carrier to noise uplink and downlink

$C/N = EIRP + G_R - Losses - k - T_N - B_N$ or

$C/N = EIRP + G/T - Losses - k - B_N$

3.4 Investigate Satellite Link Budget

Upon completion of this learning session, the student should be able to:

3.4.1 Investigate the reliability of satellite performance/ link margin

If the link margin is too big or too small, corrective action can be applied to ensure the system will operate satisfactorily.

The margin must be positive (Received power > Receiver sensitivity) and should be at least a few dB for the receiver to successfully demodulated signal.

Exercise

A certain 6/4 GHZ satellite has the following data on various gains and losses:

1. ES EIRP = 80dBW
2. ES satellite distance = 35780km
3. Atmospheric losses= 2 dB
4. Satellite antenna efficiency = 0.8
5. Diameter Satellite antenna = 0.8m
6. Satellite receiver noise temperature = 190K
7. Satellite receiver bandwidth = 20MHz

Determine the link margin for satisfactory quality of services if the threshold value of the receiver carrier to noise ratio is 25dB

Solution

A certain 6/4 GHZ satellite has the following data on various gains and losses:

1. ES EIRP = 80dBW
2. ES satellite distance = 35780km
3. Atmospheric losses= 2 dB
4. Satellite antenna efficiency = 0.8
5. Diameter Satellite antenna = 0.8m
6. Satellite receiver noise temperature = 190K
7. Satellite receiver bandwidth = 20MHz

Determine the link margin for satisfactory quality of services if the threshold value of the receiver carrier to noise ratio is 25dB

Solution:

Satellite antenna gain, Gr

Gr(dB) = 20.4 + 20 log f (GHz) + 20 log D (m) + 10 log η .

= 20.4 + 20log6 + 20log 0.8+ 10log0.8

= 20.4+ 15.56-1.94-0.97

= 33.05dB

Uplink losses, Lp

Lp (dB) = 92.4 + 20 log R (km) + 20 log f (GHz)

= 92.4 +20log(35780)+ 20l0g(6)

= 92.4 + 91.07+15.56

= 199.03

Carrier to noise, C/N

C/N = EIRP + GR - Losses - k - TN – BN

= 80 + 33.05 – (199.03 +2) – (- 228.6) – 10log 190 – l0log 20M

= 80 +33.05-201.03+228.6-22.79-73.01

= 44.82 dB

Thus the receiver carrier is 44.82 stronger than the noise. It is (44.82 – 25) = 19.82 dB more than the required threshold value. Therefore the link margin = 19.82dB.

3.4 Investigate Satellite Link Budget - Exercise

Exercise

Given the link budget of Ku band satellite to DTH receiver downlink have a parameter as below:
Transmit power = 35dB
Free space path loss = 199 dB
Transmit antenna gain = 32 dB
Receive antenna gain = 39.12dB
Atmospheric losses= 1dB
Receiver Sensitivity Threshold = -110dBW

Solution

The Received Power Pr is given by:
[Pr] = [EIRP] + [Gr] – [LOSSES]
= 35 + 32 + 39.12 – (199+1)
= -93.88dBW
Pr is well above the required (-93.88+110)= 16.12dB for communication at the maximum data rate so link should be work fine.

The difference between the minimum received signal level and the actual received power is called the link margin
The link margin must be positive, and should be maximized (should be at least 10dB or more for reliable links)

3.5 VSAT

Upon completion of this learning session, the student should be able to:

1. Explain VSAT
2. Explain the element in VSAT network:
    a. Hub Station
    b. Satellite
    c. Remote Site
3. Show the topology of VSAT network for star, star mesh and SCPC
4. Tabulate the advantages and disadvantages of VSAT

VSAT - "Very Small Aperture Terminal"

VSAT is a small satellite dish that is capable of both receiving and sending satellite signals. It can be used for two-way communications via satellite. VSATs can support any communication requirement be it voice, data, or video conferencing

VSAT is a satellite-based service and used widely in telephony communication, broadband and internet services, and military communication.

Typical examples are small and medium businesses with a central office, Banking institutions with branches all over the country, backbone links for an ISP and Airline ticketing system.
A VSAT consists of two parts, a transceiver that is placed outdoors in direct line of sight to the satellite and a device that is placed indoors to interface the transceiver with the end user's communications device, such as a PC.
The transceiver receives or sends a signal to a satellite transponder in the sky. The satellite sends and receives signals from a ground station computer that acts as a hub for the system.

Each end user is interconnected with the hub station via the satellite, forming a star topology. Transmissions and network operations are via C-band or Ku-band satellite frequencies.

VSAT refers to receive/transmit terminals, installed at remote sites (without terrestrial connectivity) and connecting to a central hub via satellite using small diameter antenna dishes (0.75 to 3.8 meter).

The second component of VSAT earth station is the indoor unit (IDU). The indoor unit is a small desktop box or PC that contains receiver and transmitter boards and an interface to communicate with the user's existing in-house equipment - LANs, servers, PCs, TVs, kiosks, etc. The indoor unit is connected to the outdoor unit with a pair of cables.

3.5 VSAT

VSAT - "Very Small Aperture Terminal"

A VSAT system consists of a satellite transponder, central hub/ master earth station (hub station), and remote VSATs (remote site).

The VSAT terminal has the capability to receive as well as transmit signals via the satellite to other VSATs in the network.

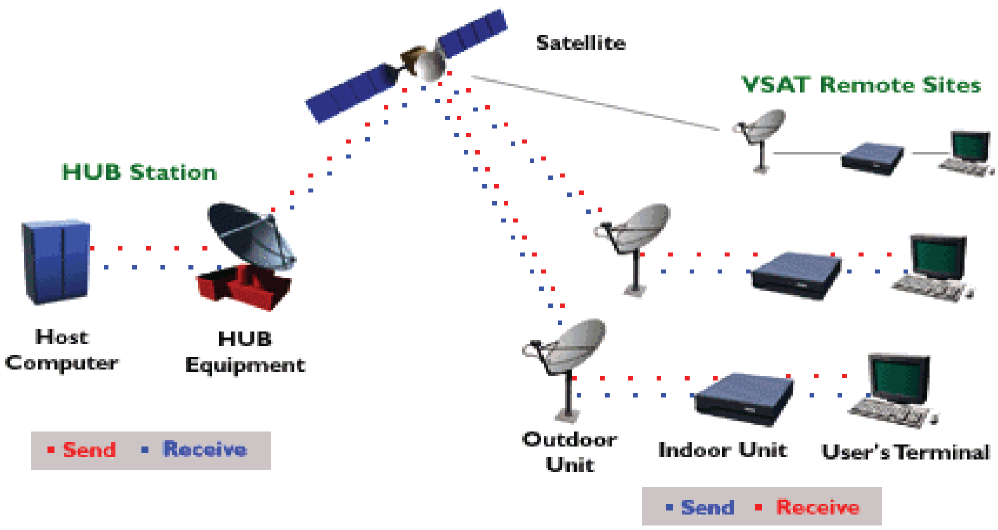
VSAT networks are typically arranged in a star based topology, where each remote user is supported by a VSAT.

The Earth hub station acts as the central node and employs a large size dish antenna with a high quality transceiver.

The satellite provides a broadcast medium acting as a common connection point for all the remote VSAT earth stations.

Elements in VSAT Network

The hub controls the entire operation of the network. For one end user to communicate with another , each transmission has to first go to the hub station that then retransmits it via the satellite to the other end user's VSAT.



VSAT Network

Topologies

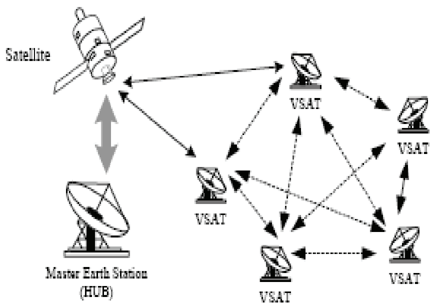
Network topologies define how remote locations connect to each other and to the hub. The link over the satellite from the hub to the remote is called the outbound or downlink transmission, whereas the link from the remote to the hub is referred to as inbound or uplink.

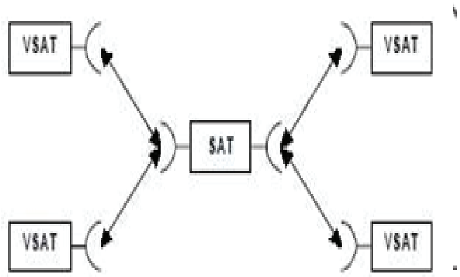
1. Mesh Networks
A Mesh Network topology allows several remote sites (VSATs) to communicate with each other via a single link through the satellite. The "single hop" nature of this network design leads to a minimal time delay between signal transmission and reception.

Historically, mesh networks have been an expensive application to provide dedicated satellite communications. However, modulation and compression improvements have helped to make this service more cost efficient.

Mesh technology is best used for a group of VSAT systems which require real time applications (Voice, Video) between every site without the latency created by a double satellite hop with communications via a teleport.

VSATs are link together without going through a hub



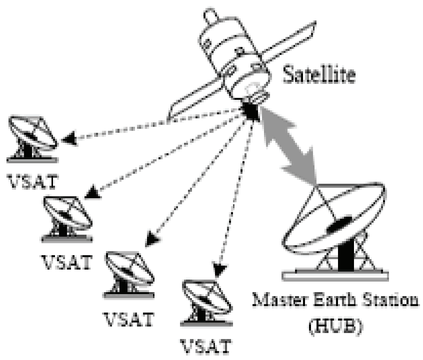


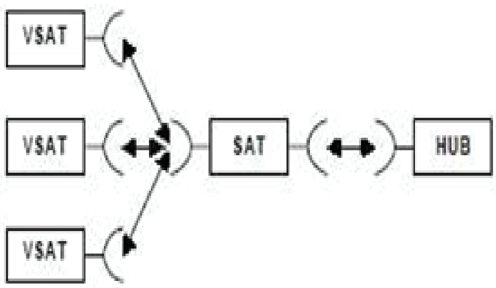
Mesh Networks

2. Star Networks
A Star Network is typically used for a Main Office - Branch Office scenario, where all the branch offices only communicate with the Main Office - not with other remotes.

An interbranch office communication is possible, but the signal (data/voice) runs from the branch remote site to the central site - and then to the other branch remote site. Typical applications for a Star-Network are Corporate Networks with a headquarter and remote offices.

VSATs are linked via hub





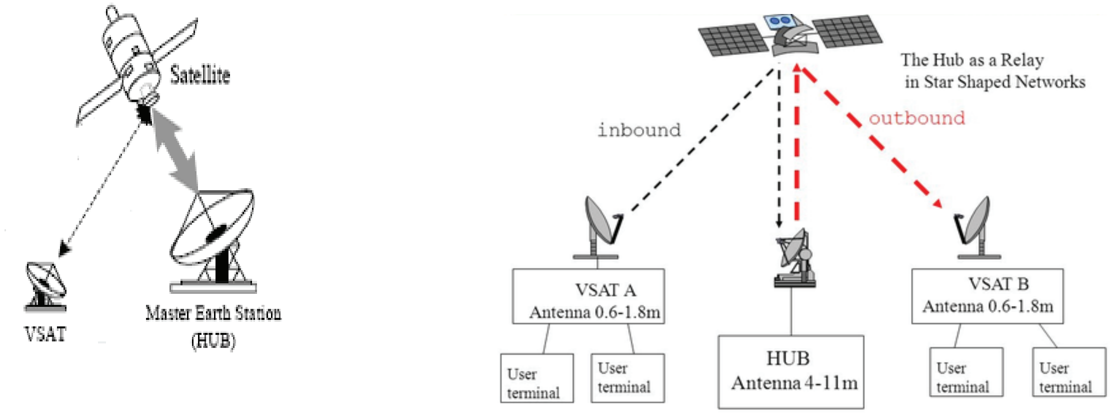
Star Networks

3. SCPC (single carrier per channel)
A point-to-point satellite link provides a direct link between two sites, which are located within the same satellite footprint.

These networks easily support voice, video, and data transmissions using a standard data/voice multiplexer, an SCPC satellite modem and a VSAT terminal at every site.

It is a very simple approach for point-to-point networks as communications takes place only between the two sites.

This type of connection is very often used to provide standard internet services through our teleport.



SCPC (single carrier per channel)

Advantages of VSAT

1. Wide geographic coverage.
2. Independence from terrestrial communication infrastructure.
3. High availability.
4. Communication costs independent of transmission distance.
5. Flexible network configuration.
6. Rapid network deployment.
7. Centralized control and monitoring.
8. Any service can be provided from telephony through to ATM, Frame Relay,

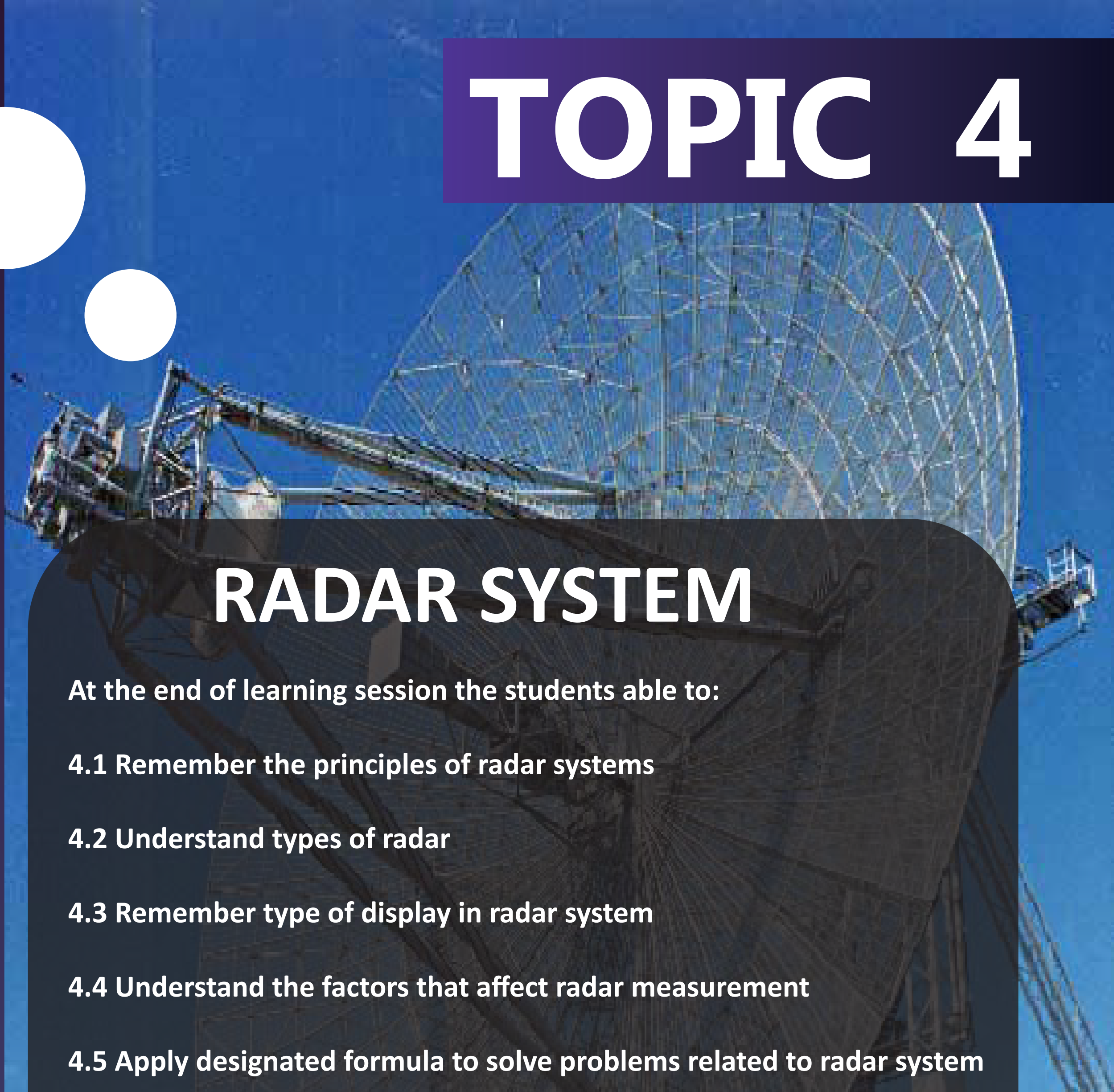
Disdvantages of VSAT

1. VSAT services are generally expensive.
2. VSAT services are not available for single site users, but only to multiple site networks.
3. The ODU (outdoor unit, antenna) may be prone to vandalism or adverse weather conditions (lightning, storm, etc).
4. Requires professional installation, management, monitoring and maintenance.
5. In some countries VSAT are heavily regulated.
6. As with all satellite solutions, there is latency (delay) in the signal, making telephone and videoconferencing

SUMMARY / RECAP

At the end of the learning session the students has been taught about the:-

1. Multiple access techniques
2. Link budget calculation for uplink and downlink
3. VSAT



TOPIC 4

RADAR SYSTEM

At the end of learning session the students able to:

4.1 Remember the principles of radar systems

4.2 Understand types of radar

4.3 Remember type of display in radar system

4.4 Understand the factors that affect radar measurement

4.5 Apply designated formula to solve problems related to radar system

4.6 Investigate performance of CW radar

4.7 Apply the designated formula to solve problem related to Pulse radar

4.8 Understand radar system

4.9 Apply the principle of Doppler effect

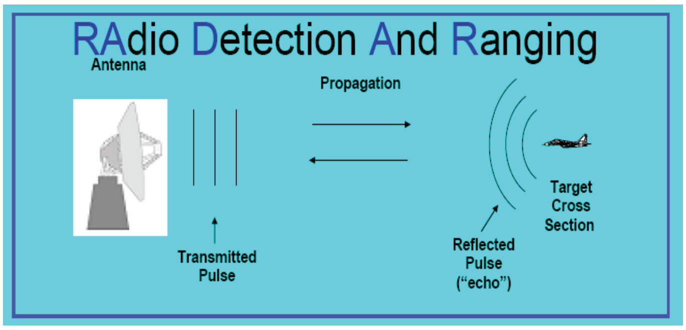
4.1 Remember The Principles Of Radar Systems

Upon completion of this learning session, the student should be able to:

1. Describe basic principles of radar
2. List the application of radar system
3. Describe types of radar
4. Recognize types of radar signal
5. Describe Line of Sight (LOS) range limitation radar

Radar Definition

Radar is stand for Radio Detection And Ranging."
Radar is an object detection system that uses electromagnetic waves to identify the range, altitude, direction or speed of both moving and fixed objects such as aircraft, ships, motor vehicles, weather formations and obstacles (mountain, trees, etc.)



Basic principles radar

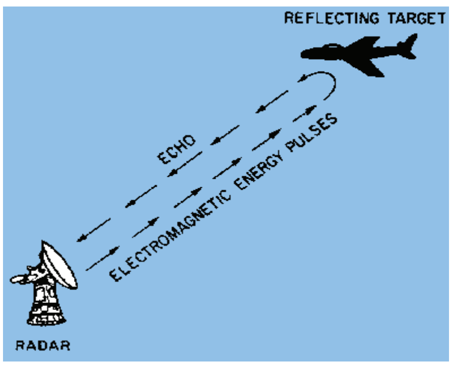
Operation of radar is very similar to the principle of sound-wave reflection. If you shout in the direction of a sound-reflecting object (like a rocky canyon or cave), you will hear an echo.

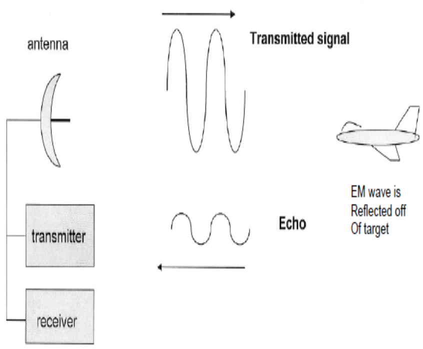
If you know the speed of sound in air, you can then estimate the distance and general direction of the object. The time required for a return echo can be roughly converted to distance if the speed of sound is known.

Radar uses electromagnetic energy pulses in much the same way, as shown below.

The radio-frequency (RF) energy is transmitted to and reflects from the reflecting object. A small portion of the energy is reflected and returns to the radar set. This returned energy is called an ECHO, just as it is in sound terminology.

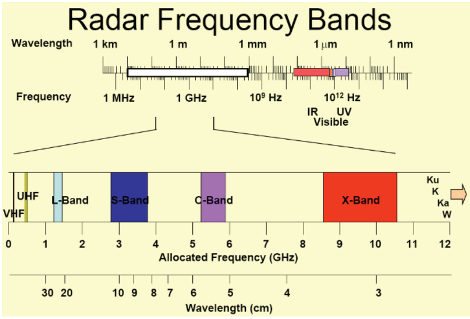
Radar sets use the echo to determine the direction and distance of the reflecting object.



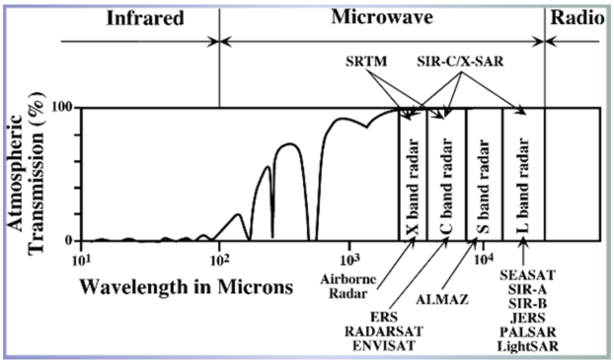


Radar Frequency Band

Radars operate in the radio frequency band of the energy spectrum between about 100 MHz (VHF) and 100 GHz (Ka or millimeter wave (mmw)).



Search radars operate at VHF to C band
Track radars operate in X and Ku bands, and sometimes in K band
Instrumentation radars and short range radars sometimes operate in the Ka band.



Frequency Band	Primary Application
HF, VHF	Primarily used for early warning and over-the-horizon radars
UHF(300 M -1 G)	Used for Early warning radars, Wind profilers
L-band(1G -2G)	Used for Air Route Surveillance Radars. Used by first civilian remote sensing American satellite carrying SAR (SEASAT) and Japanese JERS-1 satellites (L band SAR) and NASA airborne system.
S-band	Used on board the Russian ALMAZ satellite, Magellan mapped Venus
C-band	Commonly used on airborne (CCRS Convair-580 and NASA AirSAR) and spaceborne systems (including ERS-1 and 2(SAR & radar altimeter) and RADARSAT.
X-Band	Used on airborne systems for military reconnaissance and terrain mapping
Ka, K, and Ku bands	Used in early airborne radar systems but uncommon today.

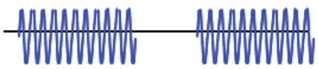
Applications of Radar

- Navigational aid on ground and sea
- Radar altimeters (height measurement)
- Radar blind lander (aircraft landing during poor visibility
- Airborne radar for satellite surveillance
- Space applications like planetary observations
- Police radars (Law enforcement and Highway safety)
- Radars for determining speed of moving targets
- Remote sensing (weather monitoring)
- Air traffic control (ATC) and Aircraft safety
- Ship safety
- Non-contact method of speed and distance in industry

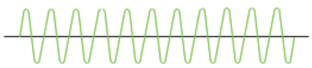
Types of Radar Signal

There are two typess of radar signal

- Pulse Transmission



- Continuous Wave



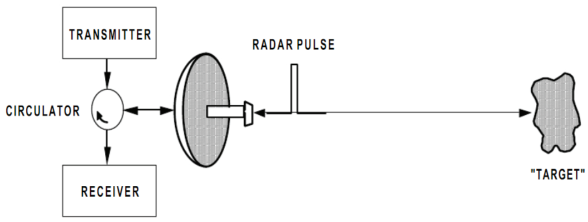
Radar technology is not only used in aviation but is also used in detecting velocity as speed traps, detect wind speed and direction, angles and so on.

Pulse Radar

Pulsed radar transmits high power, high-frequency pulses toward the target. Then it waits for the echo of the transmitted signal for sometime before it transmits a new pulse.

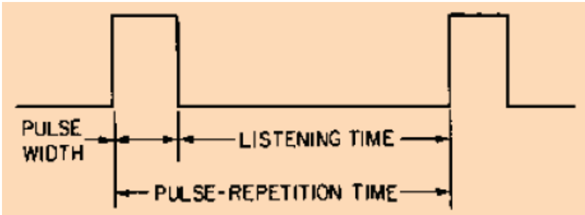
Direction, distance and sometimes if necessary the height or altitude of the target can be determined from the measured antenna position and propagation time of the pulse-signal.

These classically radars transmit a very short pulse (to get a good range resolution) with an extremely high pulse-power (to get a good maximum range). Choice of pulse repetition frequency (PRF) decides the range and resolution of the radar.



Sends out signals in short but powerful bursts or pulses

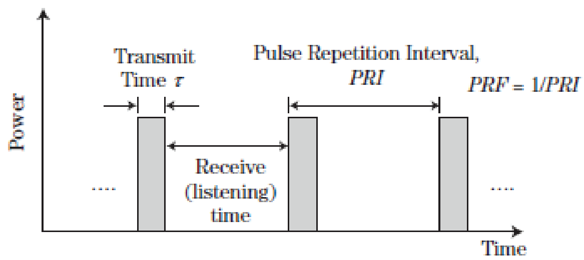
Pulse Radar

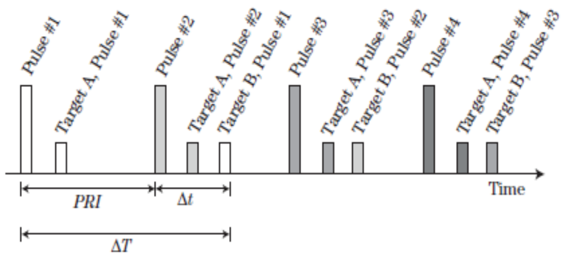


Pulsed radars transmit signal during a very short time duration, or pulse width τ , typically 0.1 to 10 µs, but sometimes ns or ms.

During the time between transmitted pulses, typically from 1 µs to 10ms, the receiver is connected to the antenna, allowing it to receive echoes that may have been reflected from objects in the environment.

This "listening" time plus the pulse width represents one pulsed radar cycle time, normally called the inter-pulse period (IPP) or pulse repetition interval (PRI)/ PRT. The pulsed waveform show below.





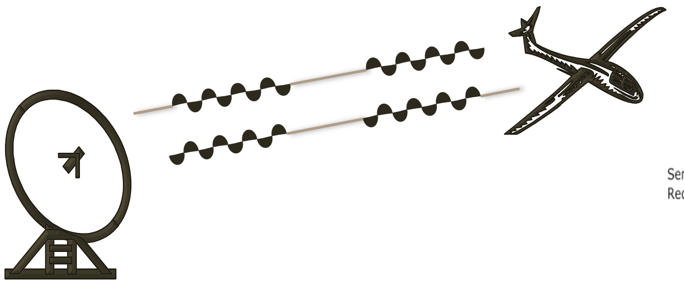
Unambiguous Range Measurement
Range is determined by measuring the delay time from transmission of a pulse to reception of the reflected signal.

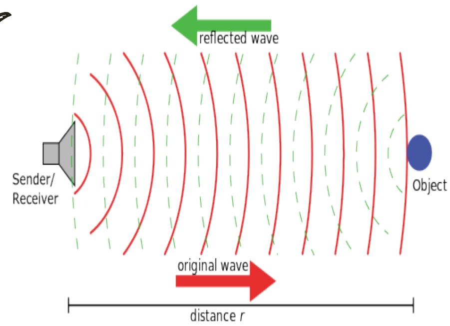
Problems can occur in a pulsed radar when determine the range to targets if the pulse round-trip travel time, ΔT , between the radar and the distant target is greater than the interpulse period, IPP. The round-trip time for the radar wave $\Delta T = 2R/c$.

The distance of the target can be calculated from the total time (t)/ ΔT taken by the pulse to travel to the target and return to its original initial point.

Assuming "c" to be the velocity of light in free space, the distance traversed by pulse is "ct" meters. Now this is 2 times the target distance, hence the distance to the target.

Continuous Wave Radar (CW)





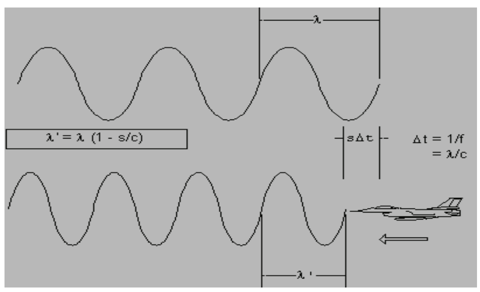
The signal transmitted in the form of a sine wave (microwave) with a constant amplitude and constant.

Echoes produced also in the form of waves sinus but with changes in frequency. Fixed echo wave amplitude but smaller.

CW radars have the disadvantage that they cannot measure distance, because there are no pulses to time.

In order to correct for this problem, frequency shifting methods can be used. In the frequency shifting method, a signal that constantly changes in frequency around a fixed reference is used to detect stationary objects.

When a reflection is received the frequencies can be examined, and by knowing when in the past that particular frequency was sent out, a range calculation can be done similar to using a pulse.



Doppler shift from moving transmitter

High frequency will be accepted if the target / moving objects and low-frequency radar approach would be acceptable if the target / object moving away from the radar.

Changes in frequency between the transmitted signal and the reflected signal is used to determine the speed of the target.

Advantage of CW radar is to measure the speed of the target object. It is commonly used by the policy to measure the speed of the car and lorry (speed trap).

Pulse Radar vs CW Radar

Pulse Radar	CW Radar
Single antenna	Required 2 antenna
Gives Range & Altitude	No Range & Alt. Info
Susceptible to Jamming	More difficult to Jam but easily Deceived
Physical Range determined by PW and PRF	Amp can be tuned to look for expected Frequencies

Line Of Sight

There are limits to the reach of radar signals. At the frequencies normally used for radar, radio waves usually travel in a straight line.

When radar uses microwave frequencies, line of sight communication will appear.

In other words, radar cannot detect target which are beyond the horizon.

Target not be physically visible, but they must be within line of sight radio distance in order for detection to occur.

The waves may be obstructed by weather or shadowing, and interference may come from other aircraft or from reflections from ground objects (Figure 1).

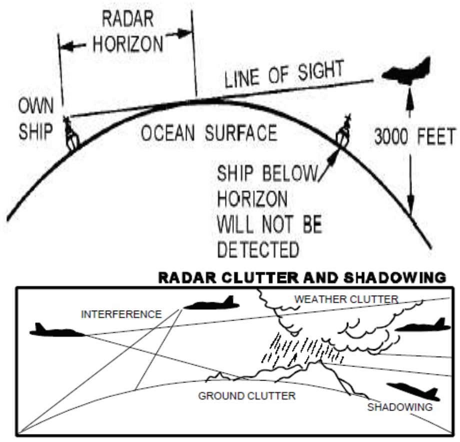


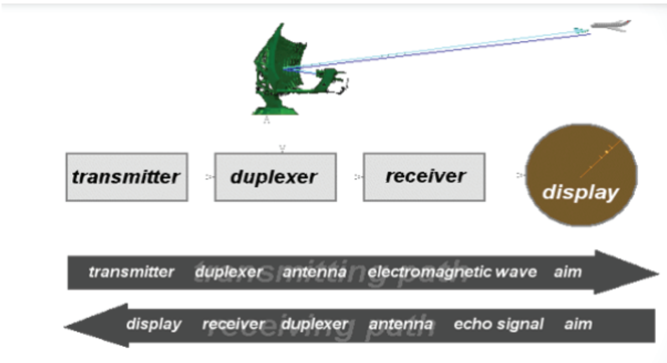
Figure 1. Radar Horizon and Shadowing

4.2 understand types of radar

Upon completion of this learning session, the student should be able to:

1. Visualize the operation of each block in 1:
    a. Transmitter.
    b. Duplexer.
    c. Antenna.
    d. Receiver.
2. Describe types of radar:
    a. Primary.
    b. Secondary.
4. Explain the operation of each block

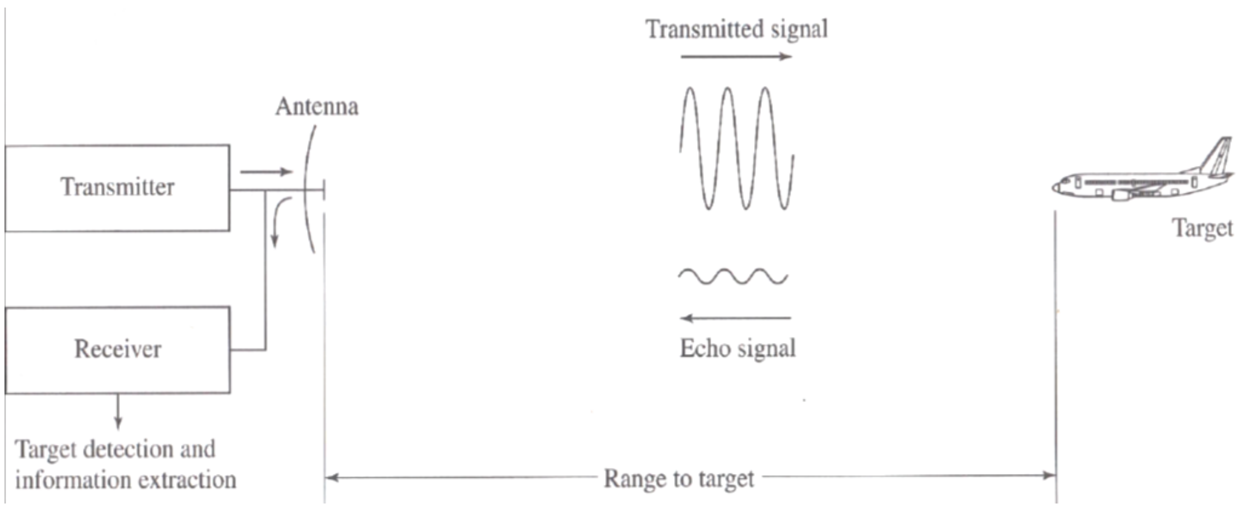
Typical Radar System



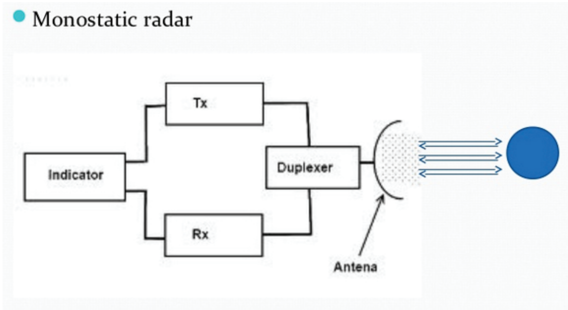
• Figure 1: Block diagram of typical radar system

Radar Operation

1. Transmitting antenna sends an electromagnetic signal.
2. Target reflects some energy back to source.
3. Receiving antenna receives reflected signal
4. Signal is processed and image produced



Block Diagram of Basic Radar System



TRANSMITTER generates electromagnetic energy in the form of short, powerful pulses.

DUPLEXER allows the same antenna to be used for transmitting and receiving.

NTENNA SYSTEM routes the electromagnetic energy from the transmitter, radiates it in a highly directional beam, receives any returning echoes, and routes those echoes to the receiver.

RECEIVER amplifies the weak, electromagnetic pulses returned from the reflecting object and reproduces them as video pulses that are sent to the indicator.

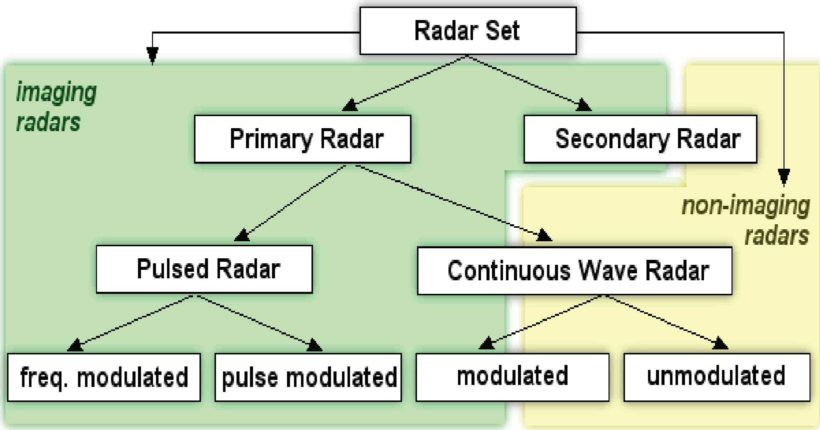
NDICATOR produces a visual indication of the echo pulses in a manner that, at a minimum, furnishes range and bearing information.

Exercise 1

What information RADAR can give?

Target range (distance)
Target height (altitude)
Target speed
Target identity
Target features (imaging)
Target size

Radar Classification



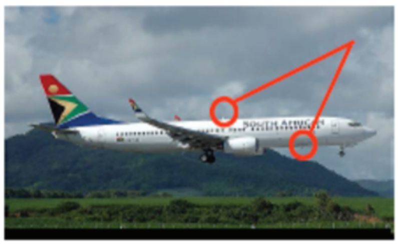
Radar Classification

Type of Radar

1. Primary Radar
radiates an EM wave and receives the echo reflected from any objects detecting the presence, distance and azimuth, but not the identity.

primary radar (PSR) ➡ plane is a passiv element
Reflects part of the electromagnetic energy that invests itself

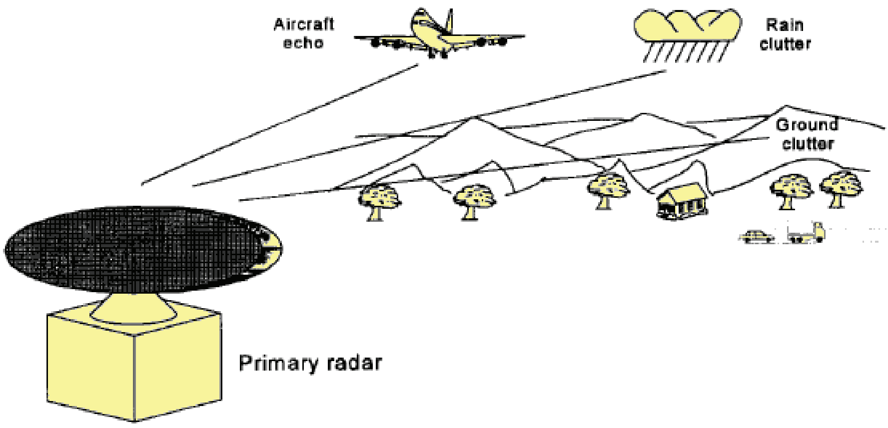
2. Secondary Radar
relies on a piece of equipment aboard the aircraft known as a 'transponder'. The transponder is a radio receiver and transmitter operating on the radar frequency. The target aircraft's transponder responds to interrogation by the ground station by transmitting a coded reply signal.



Secondary radar (SSR) ➡ plane is as active element
answers to the solicitation raised by the radar

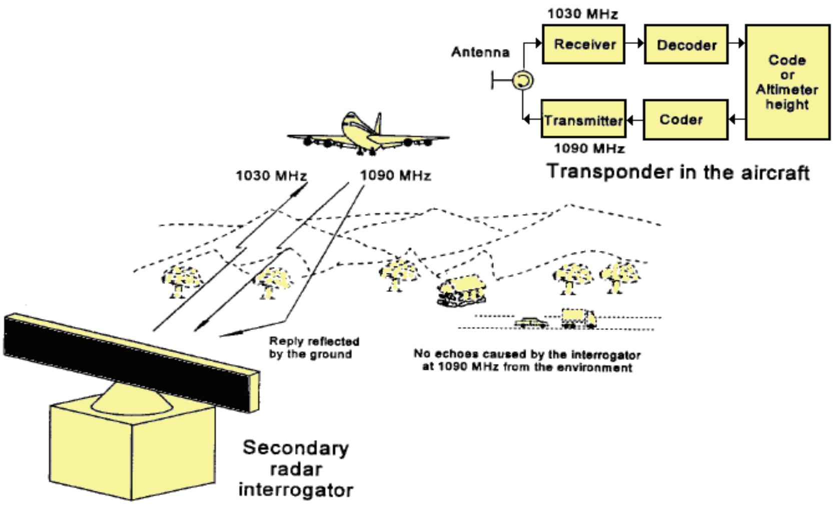
Primary Radar

A Primary Radar transmits high-frequency signals toward the targets.
The transmitted pulses are reflected by the target and then received by the same radar.
The reflected energy or the echoes are further processed to extract target information.
Only provide range & direction information



Secondary Radar

Secondary radar units work with active answer signals.
In addition to primary radar, this type of radar uses a transponder on the airborne target/object.



The secondary radar unit transmits and also receives high-frequency impulses, the so-called interrogation. This isn't simply reflected, but received by the target by means of a transponder which receives and processes. After this the target answers at another frequency.

Various kinds of information like, the identity of aircraft, position of aircraft, etc. are interrogated using the secondary radar. The type of information required defines the MODE of the secondary radar.

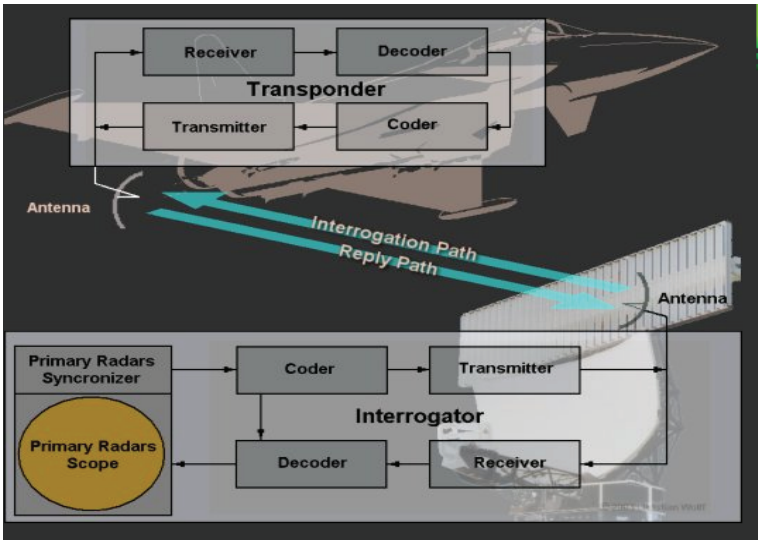
Information will be sent back in the form of a code to the radar antenna on Earth.

To avoid collisions between signals transmitter from the antenna and transmitter signal from transponder then both signals are distinguished by using the frequency signal different.

Examples of secondary radar use is between military helicopters and military vessels in which it can communicate with each other to feedback.

Secondary Surveillance Radar - SSR

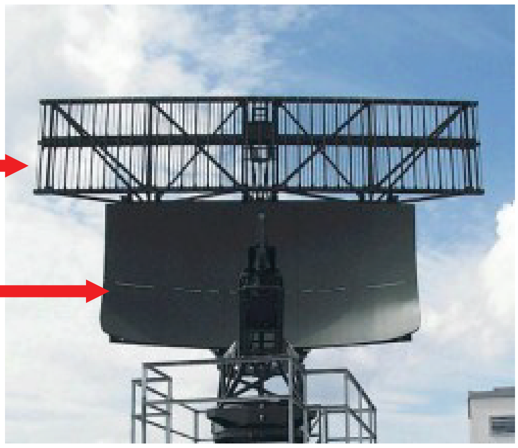
Secondary Surveillance Radar - SSR



Block diagram of secondary radar

Example
Primary radar sets are fitted with an additional interrogator as secondary radar mostly, to combine the advantages of both systems.

A monopulse **secondary surveillance radar** antenna (looks like a lattice fence) mounted on top of an antenna of a **primary radar** (parabolic reflector)



Differentiate between primary and Secondary radar

Primary radar	Secondary radar
• Using an antenna for transmitting and receiving signals.	• Using more than two antennas at the transmitter and receiver for transmitting and receiving signals.
• Using duplex switches as switching between the transmitter and receiver.	• Using synchronous online as an intermediary between the sender and receiver
• The system is simple and easy to control.	• System more complex and only an expert in the field capable of handling.
• Targets reflect signals and detected by the antenna and received via the same antenna. • Only detect the target in the control area only.	• Targets act as transponders that receive and transmit signals. Signal transmitted by the transmitting antenna to be received by the inner antenna receiver. •Can detect and communicate with target up to thousands of kilometers.

4.3 Remember Type Of Display In Radar System

Upon completion of this learning session, the student should be able to:

Recognize the following types of display in radar system:

a. A scan (A scope)
b. Height Positioning Indicator (HPI)
c. Plan Positioning indicator (PPI)

Radar Display

A radar display is an electronic instrument for visual representation of radar data. Radar displays can be classified from the standpoint of their functions, the physical principles of their implementation, type of information displayed, and so forth.

From the viewpoint of function, they can be detection displays, measurement displays, or special displays. From the viewpoint of number of displayed coordinates, they can be one dimensional (1D), two dimensional (2D), or three dimensional (3D).

An example of a 1D display is the range display (A-scope). Most widely used are 2D displays, represented by the altitude range display (range-height indicator, or RHI), azimuth elevation display (C-scope), azimuth range display (B-scope), elevation range display (E-scope), and plan position indicator (PPI).

Types of Radar Display

The fundamental geometrical quantities involved in radar displays are the RANGE, AZIMUTH ANGLE (or BEARING), and ELEVATION ANGLE.

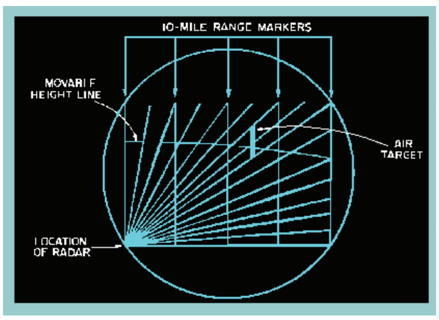
These displays relate the position of a radar target to the origin at the antenna. Most radar displays include one or two of these quantities as coordinates of the CRT face.

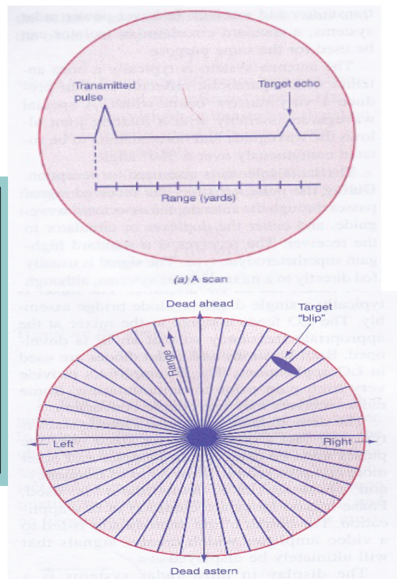
The three most common types of displays, called scopes, are the A SCOPE, the HEIGHT POSITIONING INDICATOR (HPI) , and the PLAN POSITION INDICATOR (PPI) .

A Scan/scope

Height Positioning Indicator (HPI)

Plan Positioning Indicator (PPI)





(a) A scan

(b) PPI

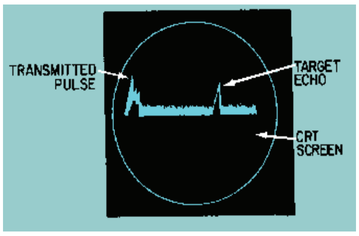
The A- scope

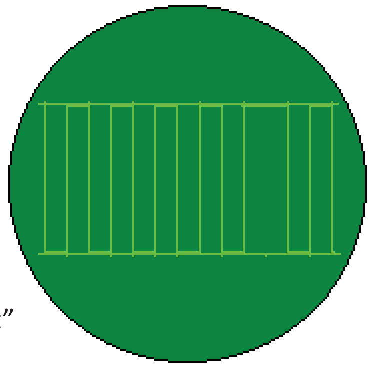
The simplest form of display

Simply displays the transmitted and received pulses.

Presents only the range to the target and the relative strength of the echo. Such a display is normally used in weapons control radar systems.

The horizontal sweep on the oscilloscope is calibrated in yards or miles.





A control-pulse shown at an A-scope of the russian VHF-radar „Spoon Rest”

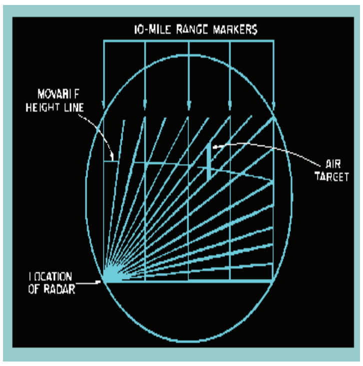
Height Positioning Indicator (HPI)

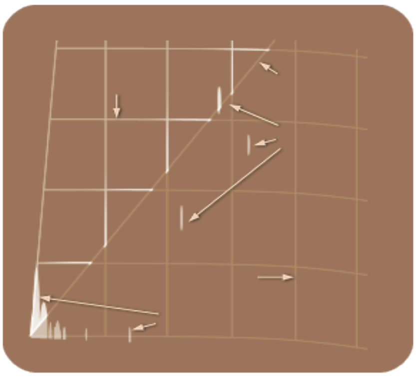
The RHI is a two-dimensional presentation indicating target range and height.

Target echoes are displayed as vertical BLIPS (spots of increased intensity that indicate a target location).

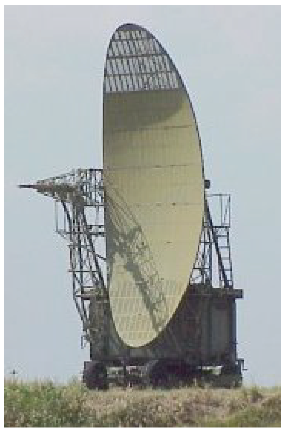
The operator determines altitude by adjusting a movable height line to the point where it bisects the center of the blip.

Target height is then read directly from an altitude dial or digital readout. Vertical range markers are also provided to estimate target range.





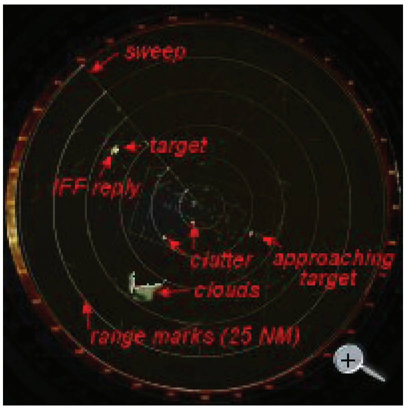
View of a RHI-scope



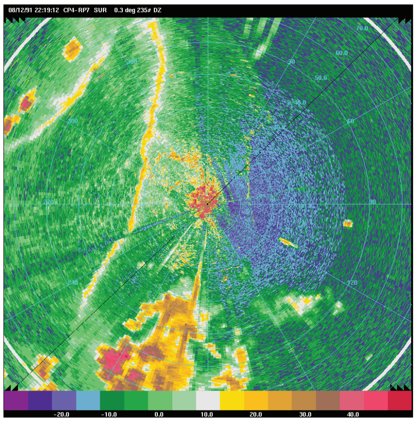
Russian height-finding Radar with nodding antenna “Odd Group”

Plan Positioning Indicator (PPI)

A Primary Radar transmits high-frequency signals toward the targets.
The transmitted pulses are reflected by the target and then received by the same radar.
The reflected energy or the echoes are further processed to extract target information.
Only provide range & direction information

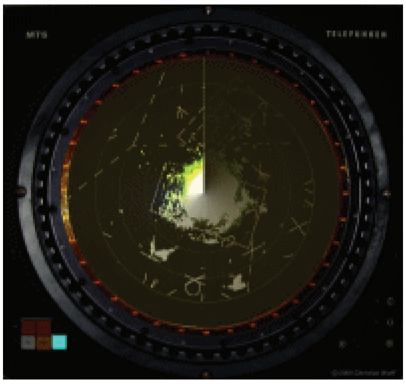


View of a PPI-screen



Good surveilance scan - good in operational setting

Airtraffic- Controllers with PPI-scopes



Historical PPI-scope,
manufactured by Telefunken AG in 1980

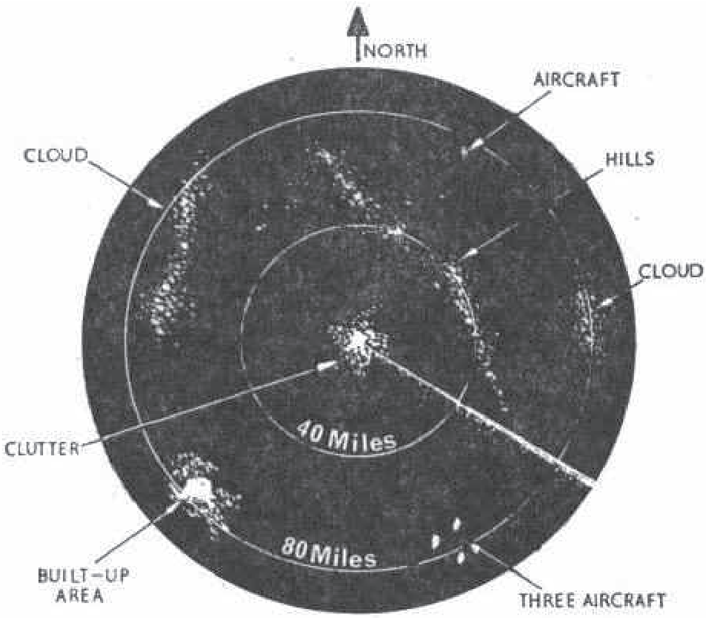


FIG 20. TYPICAL PPI DISPLAY

4.4 Understand The Factors That Affect Radar Measurement

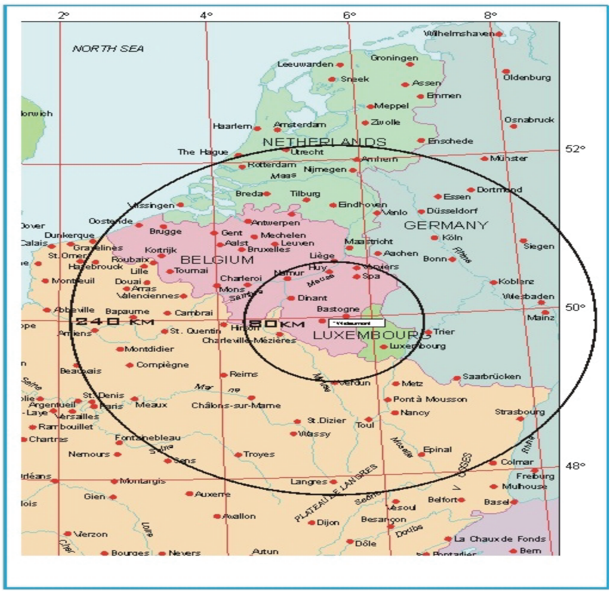
Upon completion of this learning session, the student should be able to:

1. Explain range of object.

2. Discuss the factors that effect echo:

    a. Material of the target.
    b. Surface area of the target.
    c. Types of surface of the target.
    d. Distance of the target.

3. Explain the following factor that affect the transmitted power:
    a. Maximum range, R
    b. Object reflection coefficient
    c. Radar sensitivity
    d. Atmospheric absorption

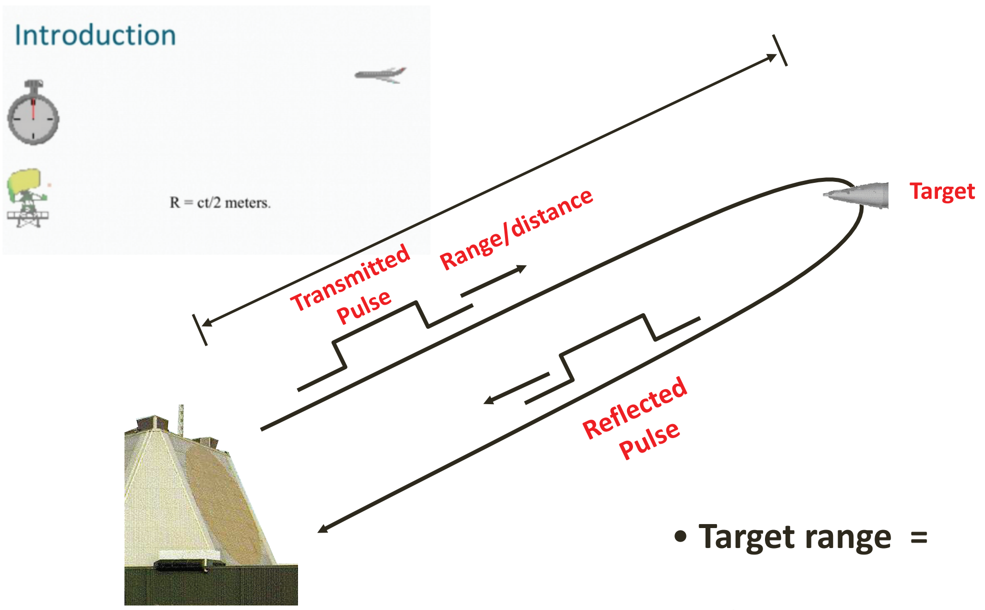


Range of Object

Distance from the radar
Measured from time delay between transmitted pulse and returned signal received

Radar Range Measurement

The common way to measure range with a radar is to measure the time delay Between transmission and reception of a pulse as figure below.



- **Target range** $= \dfrac{c\tau}{2}$

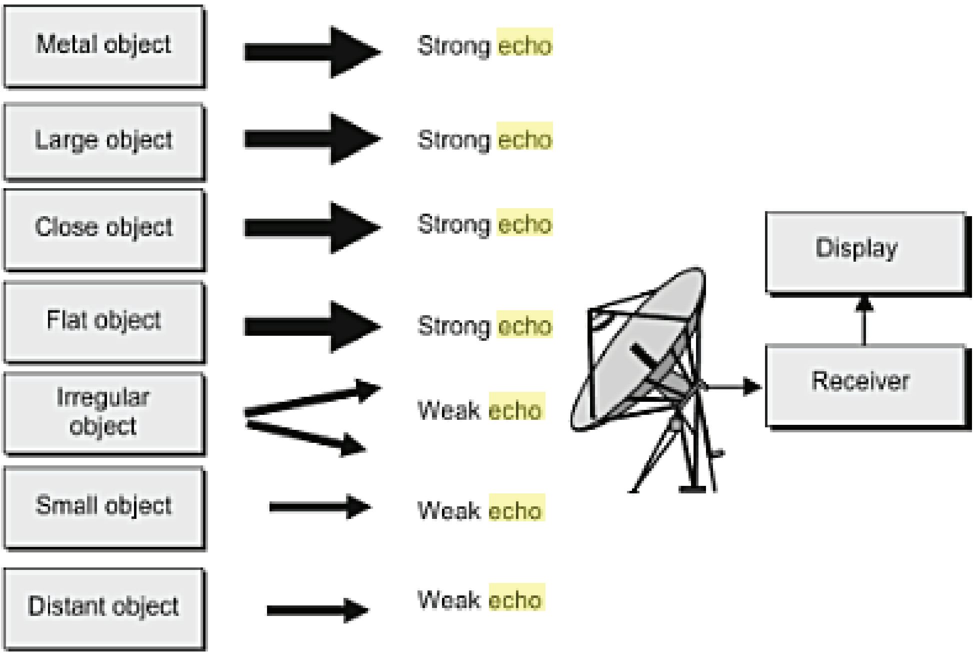
where c = **speed of light**
τ = **round trip time**

Factors that effect echo

1. **Material of the target**
2. **Surface area of the target.**
3. **Types of surface of the target.**
4. **Distance of the target.**

Factors that effect echo

The echo signal from radar are reflected from all object in path. But the strange of the reflected signal depends on size, shape of object and the material with which it is make up of.
The reflected signal is strong from metal, and from large, close and flat objects. Echoes from different objects are show below



The amount reflected depends upon the material of which the object is made, the shape of the object and its size (Fig 6).

Two identical objects at different distances from the radar the one nearer the radar reflects more energy.

A metal object will reflect more energy than an object of the same size and shape made of wood or plastic. The better the conductor the greater is the reflection.

Factors that effect echo

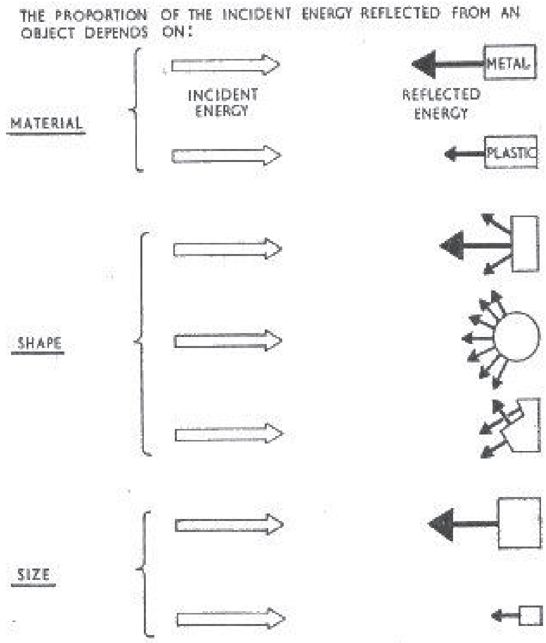
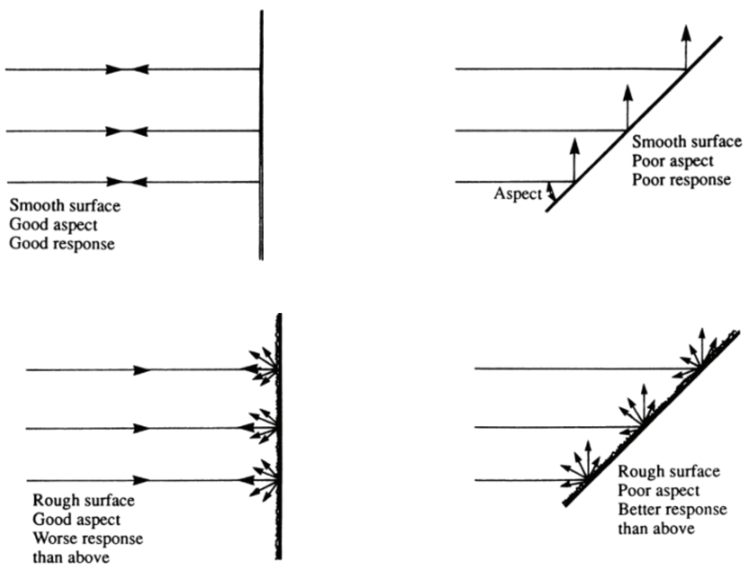


FIG 6. CHARACTERISTICS OF TARGETS

The shape of the object will deter-mine how the energy is reflected. If the object has a flat side facing the radar transmitter it will reflect more of the energy back towards the radar than an object of any other shape.

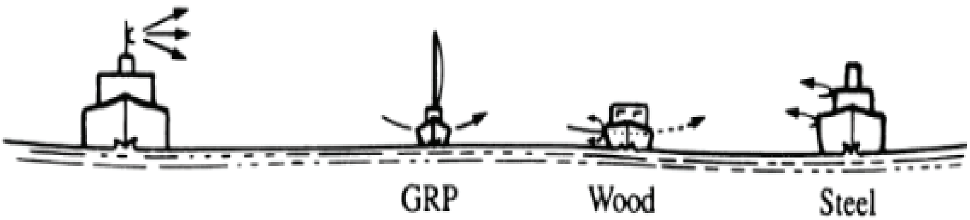
Large objects will reflect more energy than small objects of the same material and shape at the same distance from the transmitter. The object however must be greater than a certain minimum size, in terms of wavelength of the radiated energy, to produce a reasonable reflection of energy.

Generally targets must have a size greater than about a quarter of the radar wavelength being used before a detectable echo is received. Thus for the detection of small objects the radar wavelength must also be small, i.e. the frequency must be very high. This is one reason for the use of high frequencies in radar.

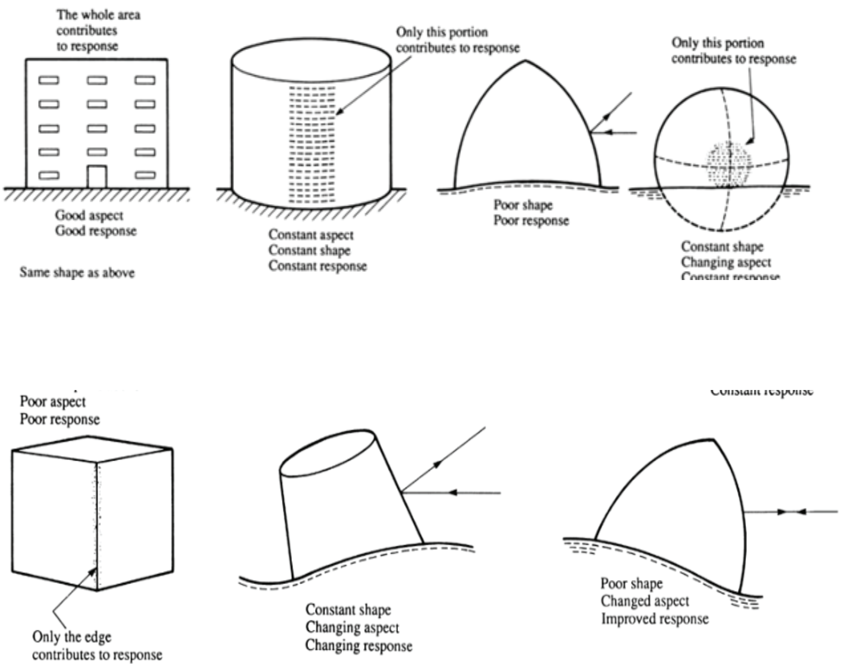


The Effects on Target Response of Aspect and Surface Texture

Material of the target

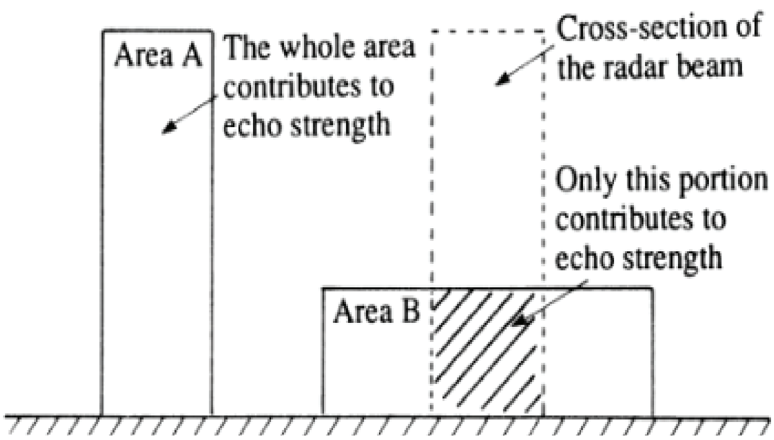


Some Effects of Material on Target Response



The Effect of Target Shape on Target Response

Size of target



Factors that affect the transmitter power requirement

A Primary Radar transmits high-frequency signals toward the targets.
The transmitted pulses are reflected by the target and then received by the same radar.
The reflected energy or the echoes are further processed to extract target information.
Only provide range & direction information

Maximum Range
The maximum range that the system can achieve when the transmitter transmits the greater power (more costly equipment and more power must be provided)

Antenna Gain
The antenna gain of the radar is a known value. This is a measure of the antenna's ability to focus outgoing energy into the directed beam.
The power received from a given target is directly related to the square of the antenna gain, while the antenna is used both for transmitting and receiving.

Object Reflection Coefficient
The reflection coefficient is used when wave propagation in a medium containing discontinuities is considered.
A reflection coefficient describes either the amplitude or the intensity of a reflected wave relative to an incident wave.

Radar Sensitivity
Changing the radar transmitter's pulse width changes the radar's sensitivity.
Wider pulses effectively increase the radar's sensitivity to weak atmospheric events, and increase the radar's ability to enter heavy rain.

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A Primary Radar transmits high-frequency signals toward the targets.
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4.5 Apply designated formula to solve problems related to radar system

Upon completion of this learning session, the student should be able to:

1. Calculate the parameters in target measurement of:
    a. Range/distance.
    b. time.
    c. velocity.
    d. height.
    e. bearing.
2. Use related formula to calculate CW radar, Pt and Pr

Range Of Object

- Formula range, R=ct/2, R in meter, m (t in s)

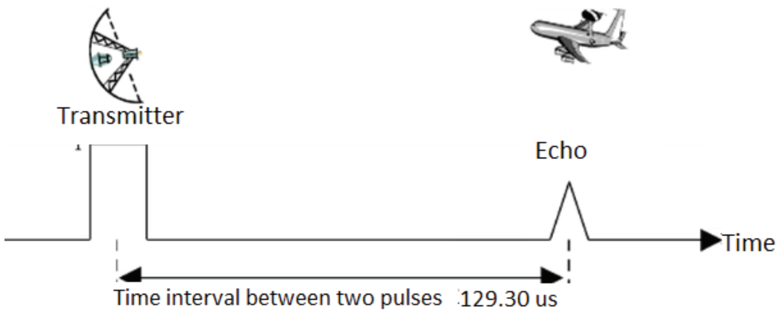
- The distance, D in nautical mile to the remote target also can be calculated using simple expression:

  D= T/12.36 (T in µs)
- D in yard (yd) is the common unit of distance measurement. Radio signal travels 328 yd/µs and can be compute as

  D = 164T (T in µs)
- The distances are expressed in kilometers or nautical miles (1 NM = 1.852 km).

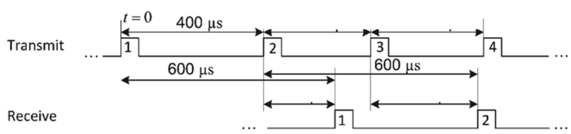
Example 1

1. The target is found at 129.30 µs after transmitting the signal from the radar. Calculate the distance from the radar to the target in nautical miles and meter (Answer: 19395 meter / 10.46 nmi)

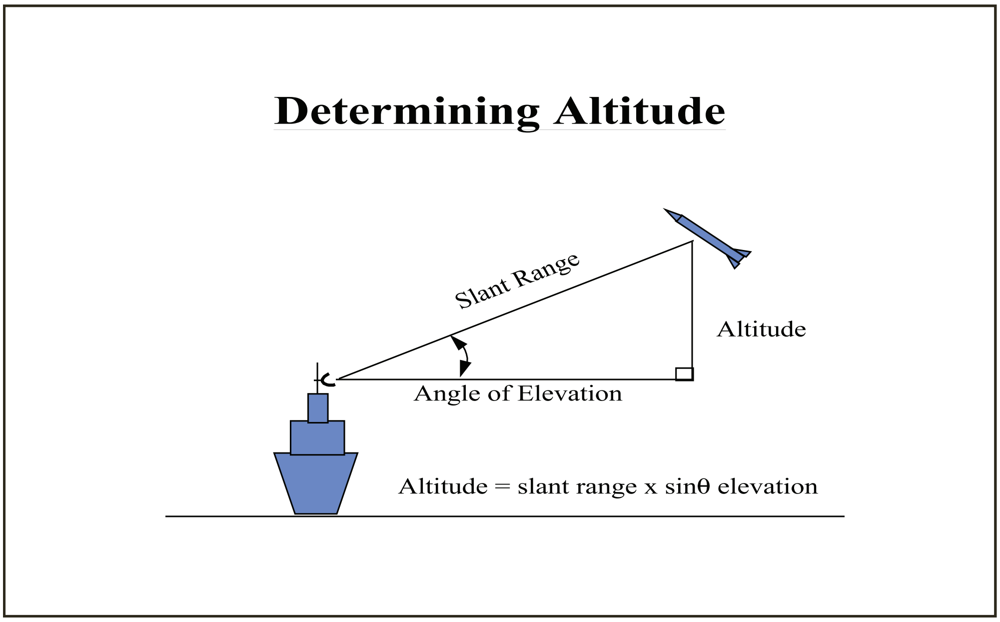


2. Calculate range delay time to target if transmit pulses are spaced 400 µs apart. And the target range 90km

$$\tau_R = \frac{2R}{c} = \frac{2\times 90\times 10^3}{3\times 10^8} = 60\times 10^{-5}\ \text{s} = 600\ \mu\text{s}.$$



Height /altitude or elevation



Trigonometric formula
Sin θ = altitude/range

The distance or range between the radar unit and the remote airplane is the hypotenuse of the right triangle.

The angle of elevation is the angle between the hypotenuse and the base line which is a line tangent to the surface of the earth at the radar location.

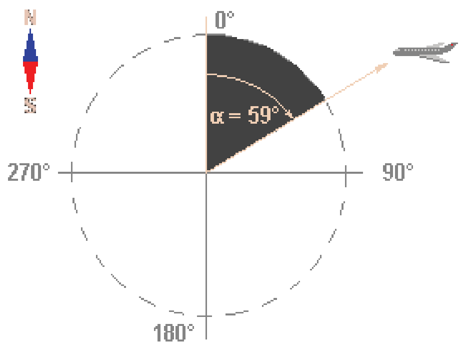
The altitude is defined by the angle of elevation.

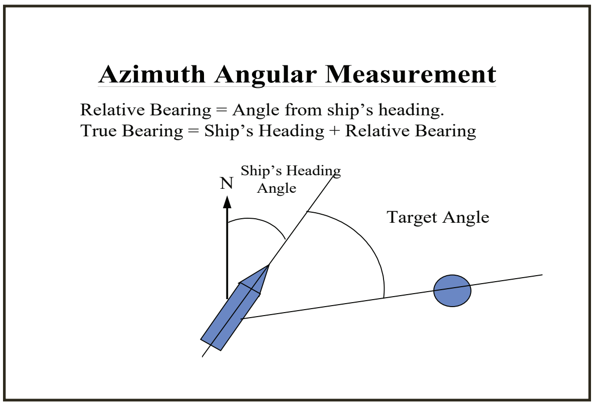
The greater angle of elevation, altitude also greater. By knowing the range and the angle of elevation, the altitude can be compute using trigonometric techniques.

Bearing (azimuth)

The direction or bearing of the target is usually given in degrees. Recall that true north is 0° or 360 °, east is 90 °, south 180 ° and west 270 °.

If the radar unit is located in a moving vehicle such as an airplane or ship, the azimuth or bearing is given as a relative bearing with respect to the forward direction of the vehicle.



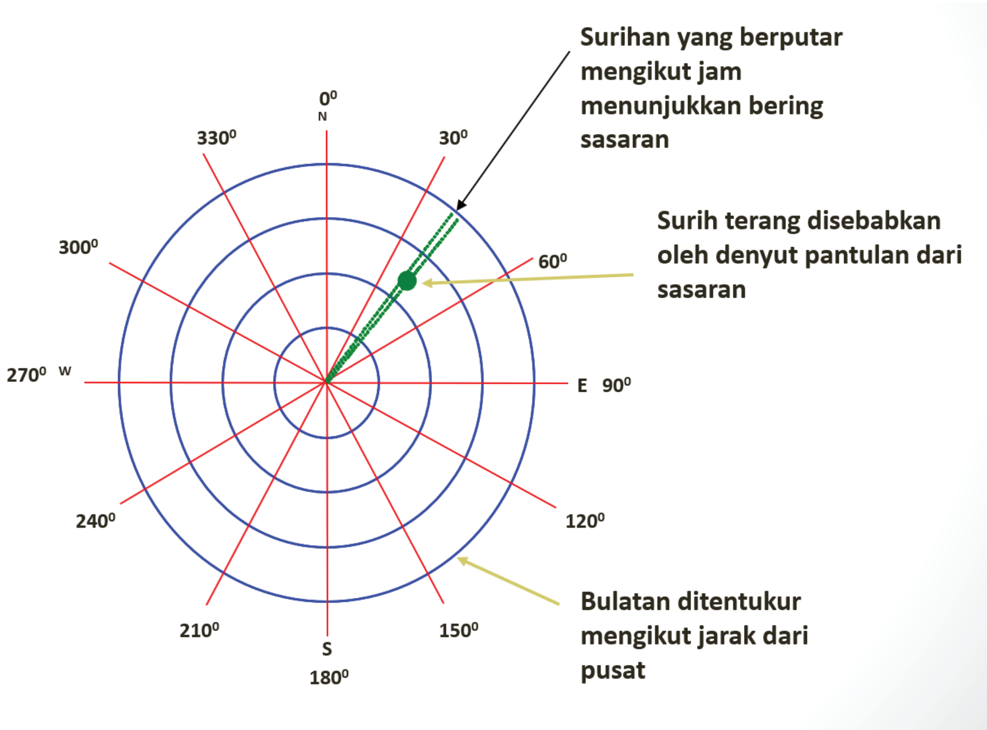


Bearing (azimuth)

Straight ahead is o ° or 360 °, directly to the right is 90°, direct behind is 180 °, and directly to the left is 270 °.

The ability of a radar unit to determine the direction of target is directly dependent with a highly directional antenna.

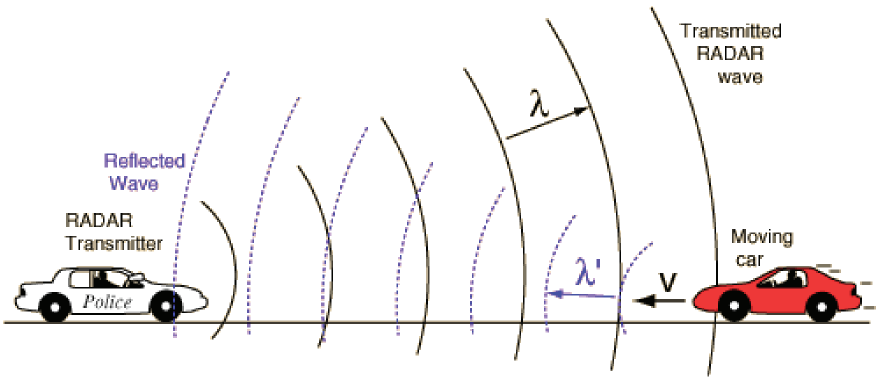
By using an antenna with an extremely narrow beam width, radar unit will be receive signals from only a narrow angle. Narrow beam width antenna get more precisely actual azimuth or bearing can be determined.



Velocity/speed (CW radar)

Example : Police Radar unit use CW Doppler radar to measuring the speed

RADAR speed detectors bounce microwave radiation off of moving vehicles and detect the reflected waves. These waves are shifted in frequency by the Doppler effect, and the beat frequency between the directed and reflected waves provides a measure of the vehicle speed.



Velocity/speed (CW radar)

- Speed can be compute using the following formula:

$$V = f_d * \lambda / 2$$

Where, f_d = frequency difference between transmitted and reflected signal, Hz

λ = wavelength of transmitted signal, m

V = speed between two objects, m/s

TRY : Calculate the velocity of the vehicle if the frequency difference between the transmitted signal and received signal is 4700Hz and use the 15GHz frequency signal for the antenna. (ans : 47ms -1)

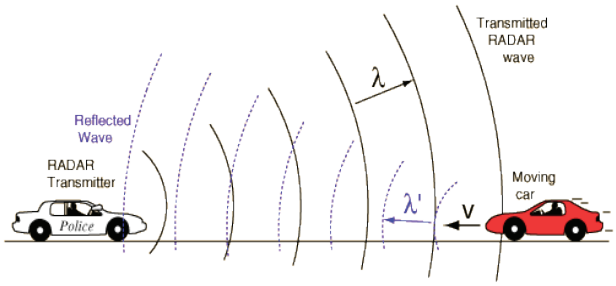
The radar shown in Figure below is used to determine the velocity, V of an approaching vehicle using an 18 GHz microwave signal. Determine the frequency difference between the transmitted signal and received signal if the vehicle is travelling at 140 km/h .

$$V = \frac{140 x1000 \; m}{(60 x 60)} = 38.89 \, m/s$$

$$\lambda = \frac{c}{f} = \frac{3x10^8}{18x10^9} = 0.0167 \; m$$

$$f_d = \frac{2V}{\lambda}$$

$$f_d = \frac{2(38.89)}{0.0167} = 4657.49 \, Hz$$



In CW radar, it is the Doppler radar effect that provides frequency modulation of the carrier.

In order for there to be a frequency change, the observed object must be moving toward or always from the radar unit. If the target move parallel to the radar unit, there is no relative motion between two object, and no frequency modulation occur. The greatest value of CW radar is its ability to measure the speed of distant object

Radar requirement

TRANSMITTER POWER is the peak power transmitted by the radar. This is a known value of the radar. It is important to know because the power returned is directly related to the transmitted power.

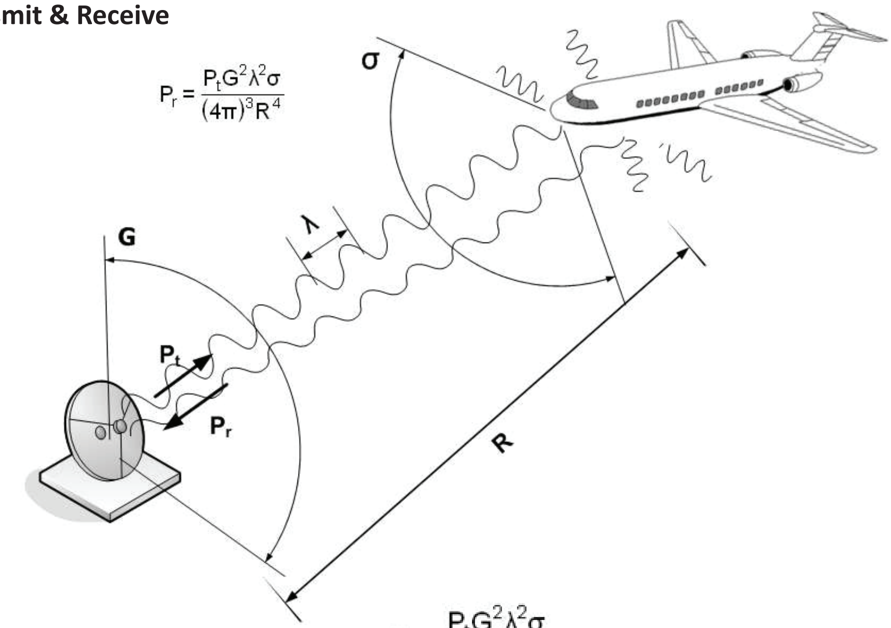
RECEIVER POWER is the power returned to the radar from a target. This is an unknown value of the radar, but it is one that is directly calculated. To detect a target, this power must be greater than the minimum detectable signal of the receiver.

4.6 Investigate performance of CW radar

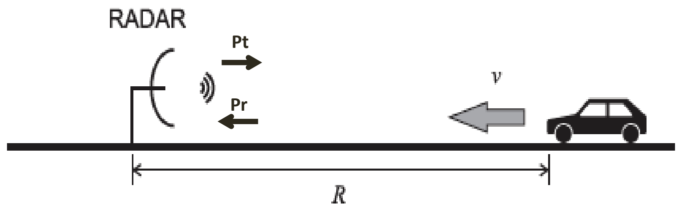
Upon completion of this learning session, the student should be able to:

1. Determine transmitted power, Pt and received power, Pr by referring to radar communication diagram or scenario

Power Transmit & Receive



$$P_r = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 R^4}$$



The minimum receivable power (Prmin) for a given receiver is important because the minimum receivable power is one of the factors which determine the maximum range performance of the radar. The sensitivity level MDS has got a value of 10 -13 Watts (-100 dBm) for a typical radar receiver.
All receivers are designed for a certain sensitivity level based on requirements. One would not design a receiver with more sensitivity than required because it limits the receiver bandwidth and will require the receiver to process signals it is not interested in.
In general, while processing signals, the higher the power level at which the sensitivity is set, the fewer the number of false alarms which will be processed. Simultaneously, the probability of detection of a "good" (low-noise) signal will be decreased.

$$P_r = \frac{P_t G_t G_r \lambda^2 \sigma}{(4\pi)^3 R^4}$$

In this expression,

P_t is the peak transmitted power in watts.
G_t is the gain of the transmit antenna.
G_r is the gain of the receive antenna.
λ is the carrier wavelength in meters.
σ is the mean[3] RCS of the target in square meters.
R is the range from the radar to the target in meters.

Power Transmit & Receive

For many monostatic radar systems, particularly those using mechanically scanned antennas, the transmit and receive antennas gains are the same, so in those cases the two gain terms in are replaced by G2.

For a bistatic radar, one for which the receive antenna is not collocated with the transmit antenna, the range between the transmitter and target, Rt , may be different from the range between the target and the receiver, Rr . In this case, the two different range values must be independently specified, leading to the bistatic form of the equation

$$P_r = \frac{P_t G_t G_r \lambda^2 \sigma_{bistatic}}{(4\pi)^3 R_t^2 R_r^2}$$

Example

A pulsed radar operating at 10 GHz has an antenna with a gain of 28dB and a total peak power developed by the radar transmitter of 100KW. If it is defined to detect a target with a radar cross section of 12 m2 at the target range of 50Km, Calculate the power reflected by the target back toward the radar.

$$P_r = \frac{P_t G_t G_r \lambda^2 \sigma}{(4\pi)^3 R^4}$$

$$G = 28dB$$
$$G = 10\log(x)$$
$$x = anti\log 2.8$$
$$x = 630$$
$$G = 28dB / 630$$
$$c = 3x10^8$$

$$\lambda = \frac{3x10^8}{10x10^9} = 0.03m$$

$$P_r = \frac{(100k)(630)(630)(0.03)^2(12)}{(4\pi)^3(50000)^4}$$

$$= \frac{428652000}{1.24x10^{22}} = 3.46x10^{-14} @ 0.0346 pW$$

Exercises

1. Compute the maximum range of radar which operates at a frequency of 10 GHz, Transmitter pulse peak power of 600W, the antenna gain 300, the target area of 20m2 minimum receivable power of 1 pW. (Answer:5.344km)

2. Consider a radar system having the following specifications:
Transmit and receive gain : 33dB
Receive power : 10-14W
Operating frequency : 2.5GHz
Calculate the peak transmitter power required in pulsed radar to detect a target of 15m2 radar cross section at a range of 250Km. (answer:96Kw)

Calculate power received Pr, if :

Radar center frequency, f = 9.5 GHz
Transmit power, PT = 100 kW
G = 12,600
Range to target, R = 20 km
Target RCS, = 1 m2 (small aircraft or boat)

Answer : P_r= 50 pW

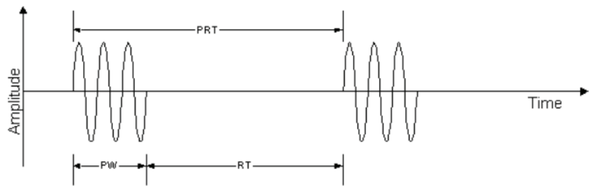
https://www.pasternack.com/t-calculator-radar-range.aspx

4.7 Apply the designated formula to solve problem related to Pulse radar

Upon completion of this learning session, the student should be able to:

1. Show the formula related to Pulse Repetition Frequency (PRF)
2. Show the relationship between peaks power (Ppk) to average power(Pavg)
3. Calculate:
    a. Pulse Repetition Frequency, PRF
    b. Peak power, Ppk
    c. Average power, Pavg
    d. Duty Cycle

Pulse Repetition Frequency (PRF)



Pulse Width (PW) is length or duration of a pulse
PFT is time from begining of one pulse to the begining of the next.
Pulse Repetition Time (PRT = PW + RT)
Pulse Repetition Frequency (PRF = 1/PRT) is frequency at which consecutive pulses are transmitted .
PW can determine the radar's minimum detection range
PRF can determine the radar's maximum detection range

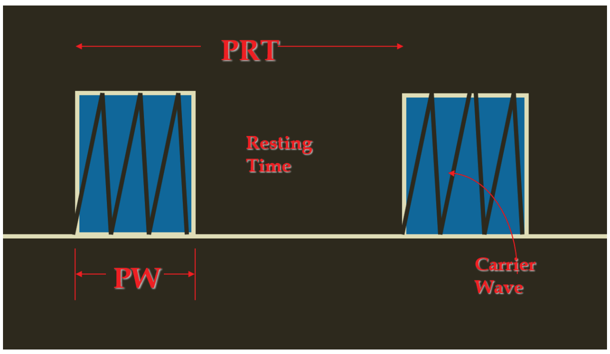


Figure 5.3:Pulse diagram

Pulse Repetition Frequency, PRF is the number of pulses transmitted in one second (PPS).

PRF=1/PRT

- Pulse Width (PW) is Length or duration of a given pulse.
- PW can determine the radar's minimum range resolution.
- PRT is the time interval between two pulses.
- PRF can determine the radar's maximum detection range.

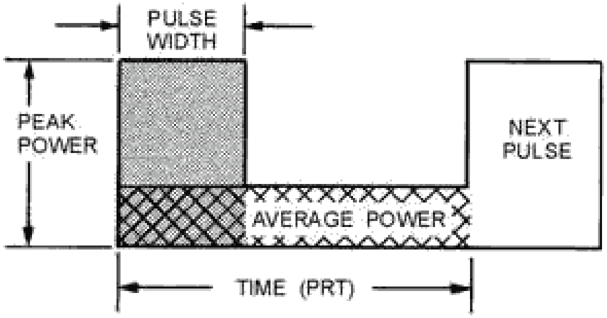
Duty cycle = PW / PRT x 100%

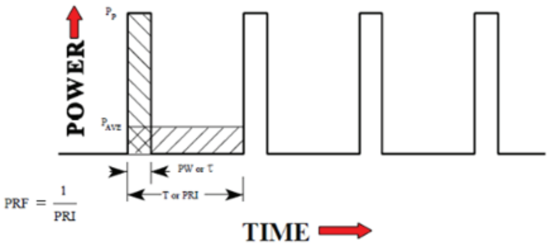
Example

If the PRF is 250 PPS, what is the PRT of the transmission?
Answer: 4000µs

Peak Power & Average Power

Peak power is the maximum power level.
Power measured over such a period of time (PRT) is referred to as AVERAGE POWER.



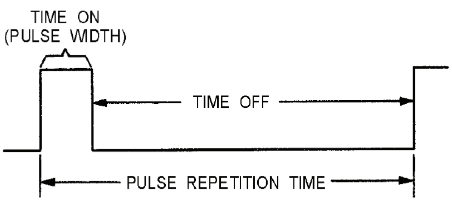


$$P_{avg} = P_{pk} \times \frac{pw}{PRT}$$

Where:

- P_{avg} = average power
- P_{pk} = peak power
- pw = pulse width
- prt = pulse repetition time

Relationship between Peak Power, Average Power & Duty Cycle



$$P_{avg} = P_{pk} \times \frac{pw}{PRT}$$

- The duty cycle is a ratio of the time on to the time off of the transmitter.
- Because 1/PRT is equal to PRF, the formula may be written as follows:

$$P_{avg} = P_{pk} \times pw \times PRF$$

- The product of pulse width (pw) and pulse-repetition frequency (prf) is called the DUTY CYCLE of a radar system. The formula for duty cycle:

$$Duty\_Cycle = pw \times PRF$$

Relationship between Peak Power, Average Power & Duty Cycle

The most common formula for average power is expressed as:

$$P_{avg} = P_{pk} \times Duty\_cycle$$

The amount of energy in the waveform is important because maximum range is directly related to transmitter output power. The more energy the radar system transmits, the greater the target detection range will be.

Peak Power & Average Power

Peak power must be calculated more often than average power. This is because, as previously mentioned, most measurement instruments measure average power directly. An example is shown below:

$$P_{avg} = 20,000 \text{ watts}$$
$$pw = 20 \text{ microseconds } (20 \times 10^{-6})$$
$$prf = 1,000 \text{ or } 10^{3} \text{ pulses per second}$$

Before figuring Ppk, you must figure duty cycle as follows:

$$\begin{aligned} \text{duty cycle} &= pw \times prf \\ &= 20 \times 10^{-6} \times 10^{3} \\ &= .02 \end{aligned}$$

Now that you have duty cycle, Ppk may be calculated as follows

$$\begin{aligned} P_{pk} &= \frac{P_{avg}}{\text{duty cycle}} \\ &= \frac{20,000}{.02} \\ &= 1,000,000 \text{ or } 10^{6} \text{ watts} \end{aligned}$$

Exercise 1

1. An airborne pulsed radar has peak power, P_t= 10 kW and uses a PRF of 10 kHz. What is the required pulse width so that the average transmitted power is equal to 1.5 kW?

2. A Pulse Radar transmits a peak power of 1 Mega Watt. It has a PRT equal to 1000 micro sec and the transmitted pulse width is 1 micro sec. Calculate

(i)Range = c.t/2 = (3x10^8x1000x10^-6)/2 = 150Kms
(ii)Average Power = PPx τ / TP= 1x1061x10-6/1000x10-6= 1000 watts = 1kw
(iii)Duty Cycle = τ/TP=1x10-6/1000x10-6= 0.001

FORMULA TO REMEMBER

PRF=1/PRT

$$Duty\_Cycle = pw \times PRF$$

$$P_{avg} = P_{pk} \times pw \times PRF$$

$$P_{avg} = P_{pk} \times \frac{pw}{PRT}$$

$$P_{avg} = P_{pk} \times Duty\_cycle$$

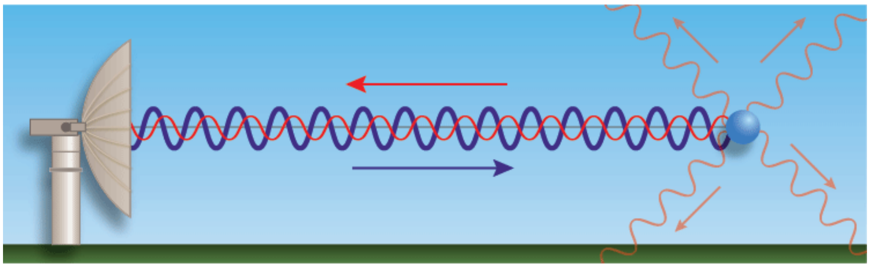
4.8 Understand radar system

Upon completion of this learning session, the student should be able to:

1. Explain Doppler Effect
2. Elaborate type of interference in radar system
    a. Noise – internal and external
    b. Clutter – volume, surface, point
    c. Jamming

Doppler Radar

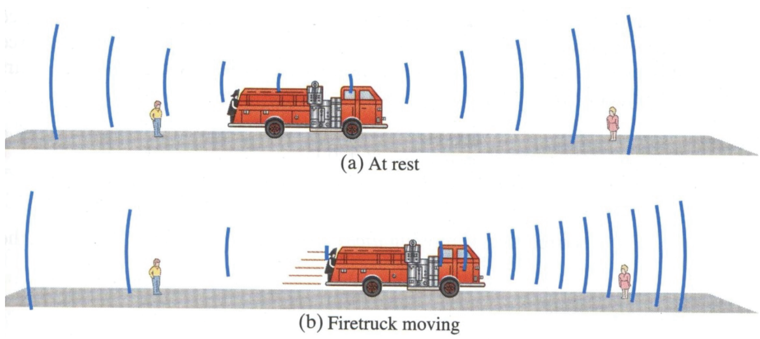
Doppler radar: A radar that can determine the frequency shift through measurement of the phase change that occurs in electromagnetic waves during a series of pulses.
Doppler Shift: A frequency shift that occurs in electromagnetic waves due to the motion of scatters toward or away from the observer.

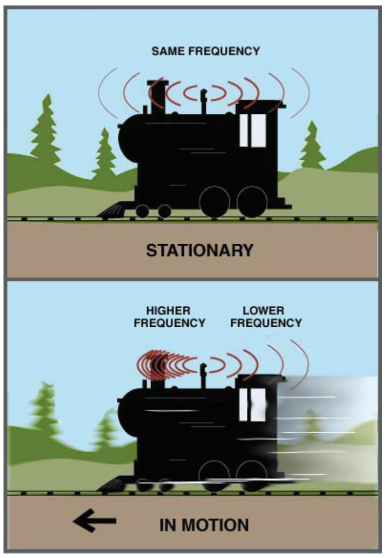


A Doppler radar is a specialized radar that makes use of the Doppler effect to produce velocity data about objects at a distance. Doppler radar works by sending a microwave signal towards a desired target and listening for its reflection, then analyzing how the frequency of the returned signal has been altered by the object's motion. The frequency variation gives direct and highly accurate measurements of a target's velocity relative to the radar. Doppler radars are used in aviation, sounding satellites, meteorology, police speed guns, and bistatic radar (surface to air missile).

Doppler Radar

Doppler effect: Changes of wavelength and frequency of electromagnetic waves caused by motion of the object. To realize Doppler Effect there should be a speed difference between the source of the electromagnetic wave and the target of the electromagnetic wave. Doppler Effect is observed and measured on the target side.

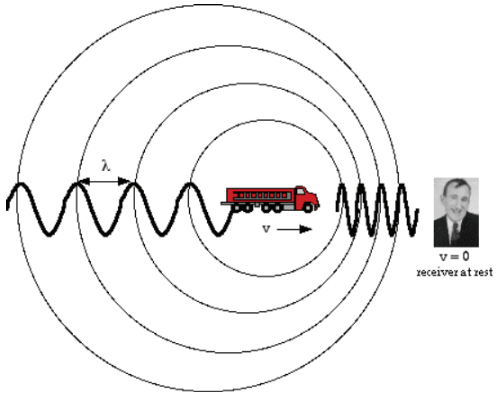




Doppler Frequency

The Doppler effect causes the received frequency of a source (how it is perceived when it gets to its destination) to differ from the sent frequency if there is motion that is increasing or decreasing the distance between the source and the receiver.

In radar technology the Doppler Effect is using for :
- Speed measuring;
- MTI - Moving Target Indication;
- in air-or space-based radar systems
- for precise determination of lateral distances.



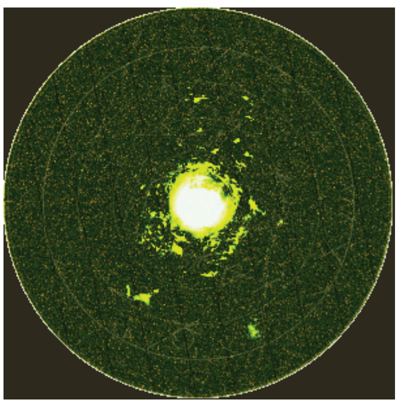
Radar Interference

Interference occurs when two waves move at the same time through a medium.
They can interfere constructively, destructively, or produce a resultant of zero
Radar systems must overcome unwanted signals in order to focus only on the actual targets of interest.
These unwanted signals may originate from internal and external sources, both passive and active.
The ability of the radar system to overcome these unwanted signals defines its signal-to-noise ratio (SNR).
SNR is defined as the ratio of a signal power to the noise power within the desired signal.
The higher a system's SNR, the better it is in isolating actual targets from the surrounding noise signals.

1. Noise
2. Clutter
3. Jamming

Noise

Is random variations superimposed on the desired echo signal received in the radar receiver.
Noise is most apparent in regions with low signal level, such as the weak received echo-signal in a radar receiver. The lower the power of the desired signal, the more difficult it is to discern it from the noise.



Background noise at a PPI scope

Clutter

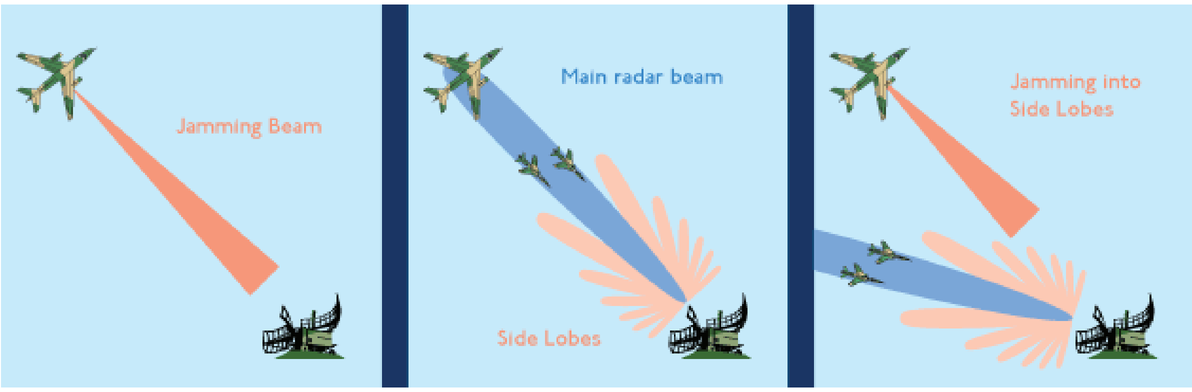
Clutter is a term used to describe any object that may generate unwanted radar echoes that may interfere with normal radar operation.
The output of the undesired echoes tends to clutter the radar display.
Such echoes are typically returned from ground, sea, rain, animals/insects, chaff (small pieces of metal foil) and atmospheric turbulences.
Can cause decrease of radar performance
Clutter can be classified into three main categories, surface clutter , volume clutter and pointer clutter.

Types Of Radar Clutter

Surface Clutter – Ground or sea returns are typical surface clutter. Returns from geographical land masses are generally stationary, however, the effect of wind on trees means that the target can introduce a Doppler Shift to the radar return. This Doppler shift is an important method of removing unwanted signals in the signal processing part of a radar system. Clutter returned from the sea generally also has movement associated with the waves.
Volume Clutter – Weather or chaff are typical volume clutter. In the air, the most significant problem is weather clutter. This can be produced from rain or snow and can have a significant Doppler content.
Point Clutter – Birds, windmills and individual tall buildings are typical point clutter and are not extended in nature. Moving point clutter is sometimes described as angels. Birds and insects produce clutter, which can be very difficult to remove because the characteristics are very much like aircraft.

Types Of Radar Clutter

Radar jamming is the intentional emission of radio frequency signals to interfere with the operation of a radar by saturating its receiver with noise or false information.



Jamming Principle

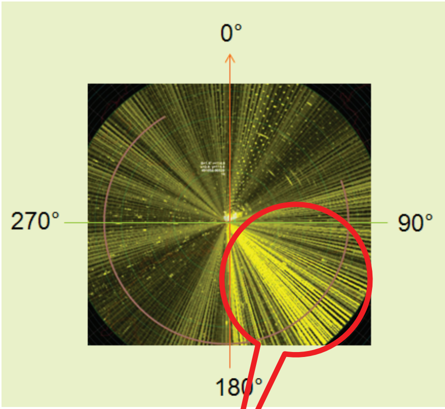
A radar jammer may aim simply to swamp the radar receiver to prevent it from receiving the returns from targets.
Alternatively, a more sophisticated radar jammer may attempt to transmit a signal that will cause false targets to be detected by the radar.
Jamming can be achieved by two principles:

1. Reflect or re-reflect radar energy back to the radar to produce false target returns on the operator’s scope.
2. Radiate interfering signals toward an enemy’s radar, blocking the receiver with highly concentrated energy signals

Noise Jamming

There are several different methods of jamming available, all with their own strengths and weaknesses. One of these is active noise jamming.

Noise jamming floods the radar with noise and therefore decreases the SNR. A powerful jammer can hide the targets completely.



- Example: Figure noise-modulated jamming, **the jammer in 150°** (VHF-Band radar)

4.9 Apply the principle of Doppler effect

Upon completion of this learning session, the student should be able to:

Apply the Doppler effect in explaining the operation of the following radar system:

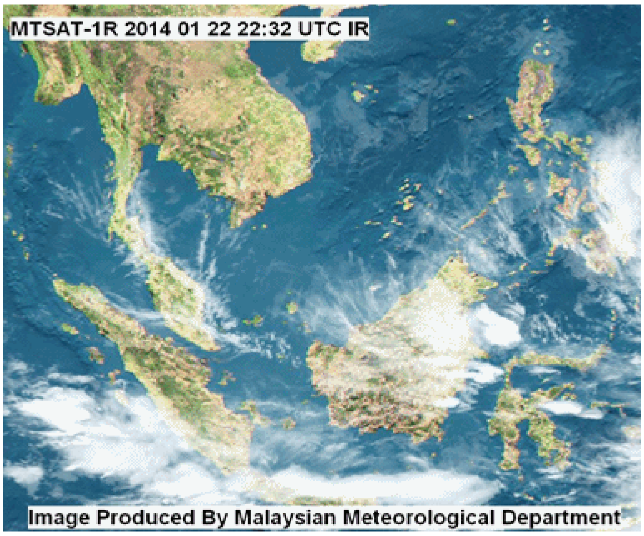
a. Weather radar
b. Air Traffic Control (ATC) radar
c. Radar altimeters

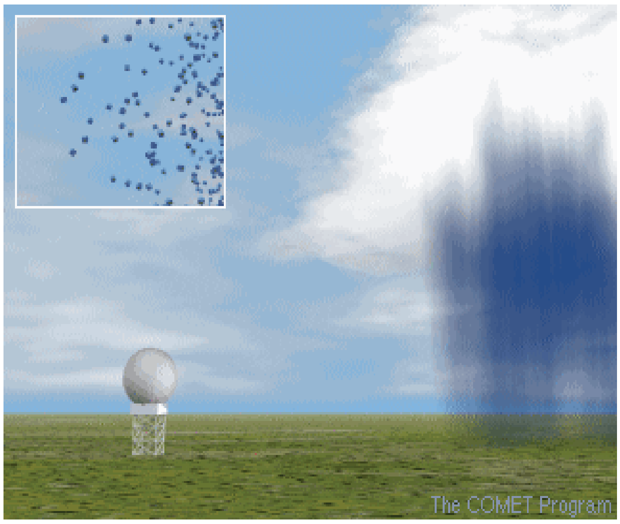
Weather Radar

Weather radar, also called weather surveillance radar (WSR) and Doppler weather radar. This radar using the Doppler effect to determine the location and velocity of a storm, clouds, precipitation, etc.
The Doppler weather radar – the faster the raindrops move towards the radar, the higher will be the frequency (i.e. pitch) of the microwave reflected from raindrops.
The raindrops' approach speed is determined by the frequency shift, and provides a good estimation of the winds, which carry the raindrops.

Weather Radar

In Weather radars, the Doppler frequency shift, is caused by the motion of the cloud and precipitation particles





In Weather radars, the Doppler frequency shift, is caused by the motion of the cloud and precipitation particles

Weather Radar Operation

A weather radar detects rain in the atmosphere by emitting pulses of microwave and measuring the reflected signals from the raindrops.

In general, the more intense the reflected signals, the higher will be the rain intensity.

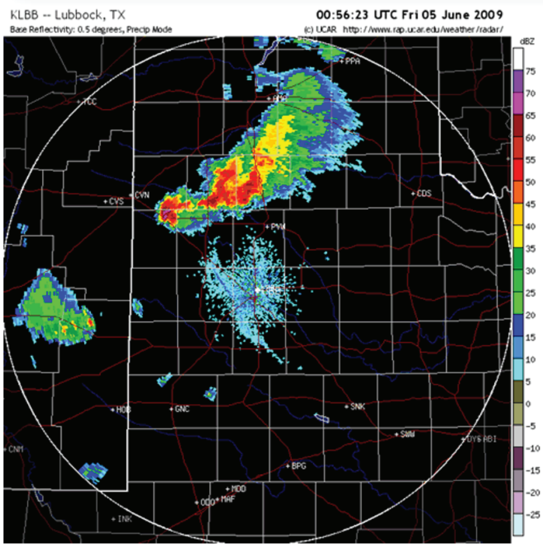
The distance of the rain is determined from the time it takes for the microwave to travel to and from the rain.

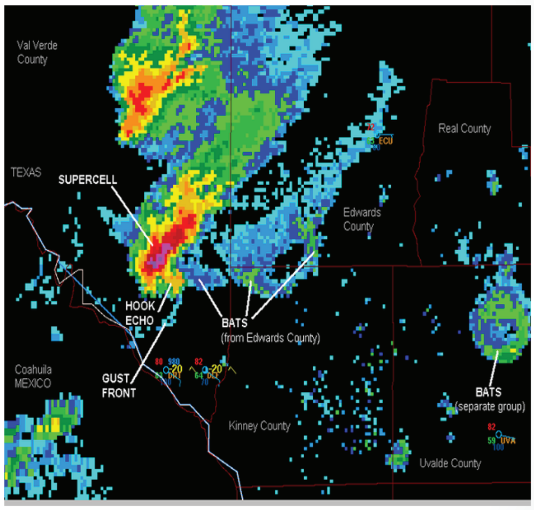
Example Of Weather Radar Amazing Hi-Tech Radar Umbrella (Radome)

Weather Radar

The expensive radar equipment is protected by the sphere shaped cover.

On the inside it looks similar to this:



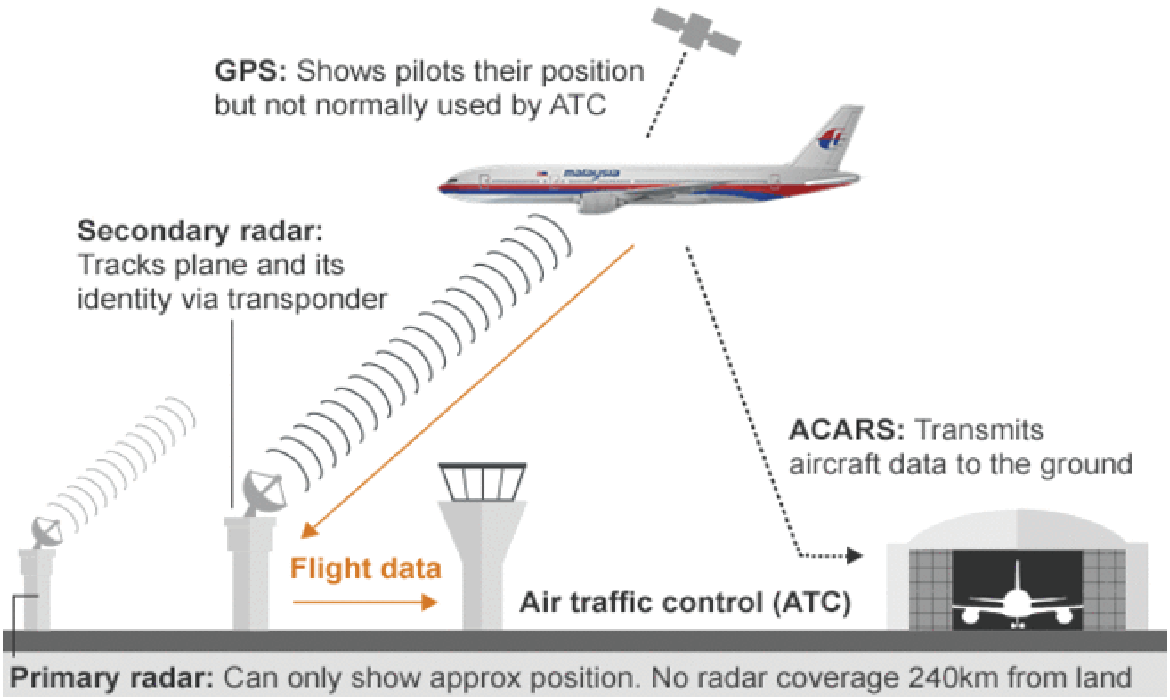


Radar Beacon / Atc Radar

Air Traffic Control (ATC) Radar is a very important equipment in avoiding aircraft collisions.
The international air traffic control system uses both primary and secondary radar.
A network of long-range radar systems called Air Route Surveillance Radar (ARSR) tracks aircraft as they fly between airports. Airports use medium-range radar systems called Airport Surveillance Radar to track aircraft more accurately while they are near the airport.

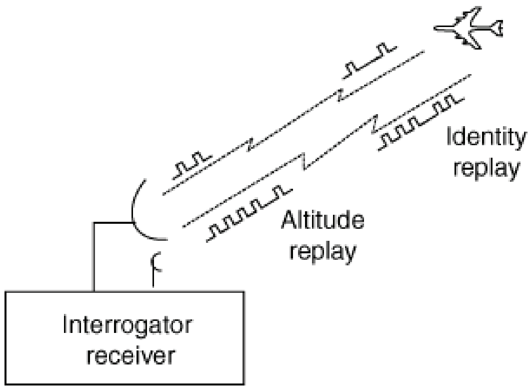
The air traffic control radar beacon system (ATCRBS) is a modern system used in air traffic control (ATC) to enhance surveillance radar monitoring and separation of air traffic.

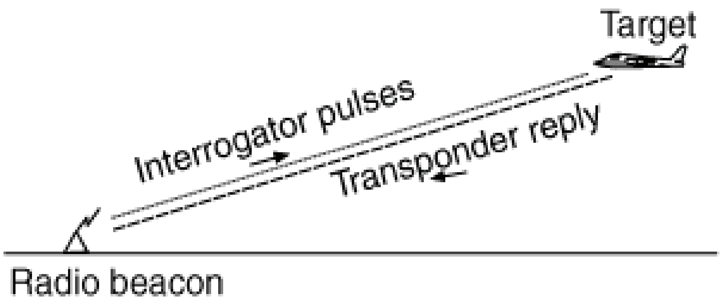
ATCRBS is a secondary surveillance radar system (SSR) developed for use within the air traffic control system for more precise position reporting of planes. It is used in conjunction with the primary radar, which is used to determine the presence of planes in the airspace.



Radar Beacon Operation

ATC radar beacon system utilizes a transponder in the aircraft. The ground equipment is an interrogating unit, in which the beacon antenna is mounted so it rotates with the surveillance antenna.
The interrogating unit transmits a coded pulse sequence that actuates the aircraft transponder.
The transponder answers the coded sequence by transmitting a preselected coded sequence back to the ground equipment, providing a strong return signal and positive aircraft identification, as well as other special data.





Example : Atc Radar Screen

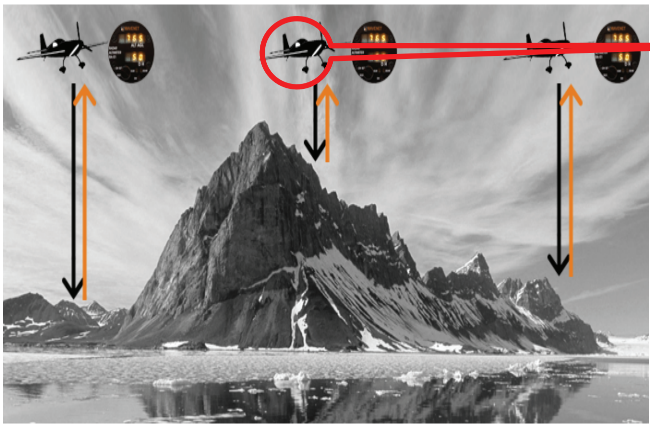
Radar Altimeter

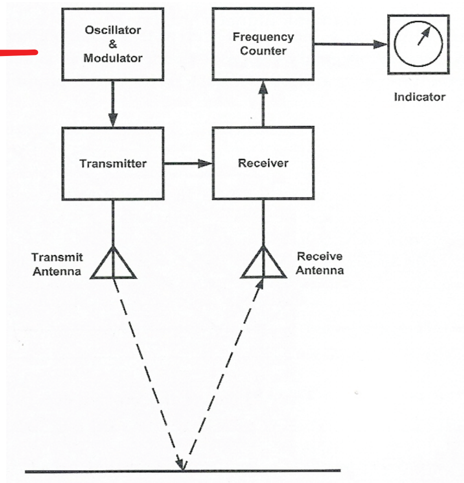
A radar altimeter, radio altimeter, low range radio altimeter (LRRA) or simply RA measures altitude above the terrain. This type of altimeter provides the distance between the plane and the ground directly below it. Differs from barometric or air data altimeter, which commonly reference sea level altitude (altimeter measures altitude above ground level)

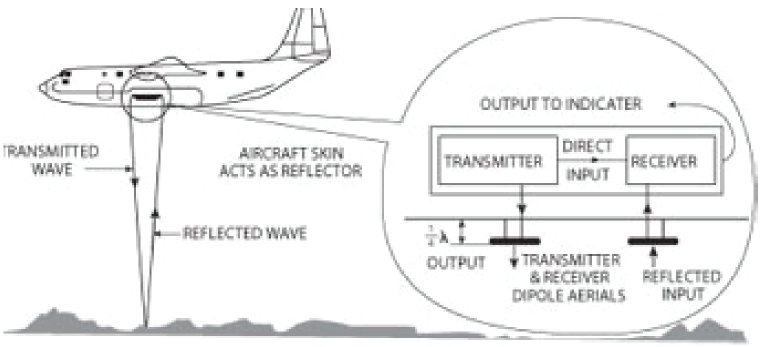
Operates over a max range of 0 – 5000 ft

Display shown has a max reading of 2000 ft

How An Altimeter Works

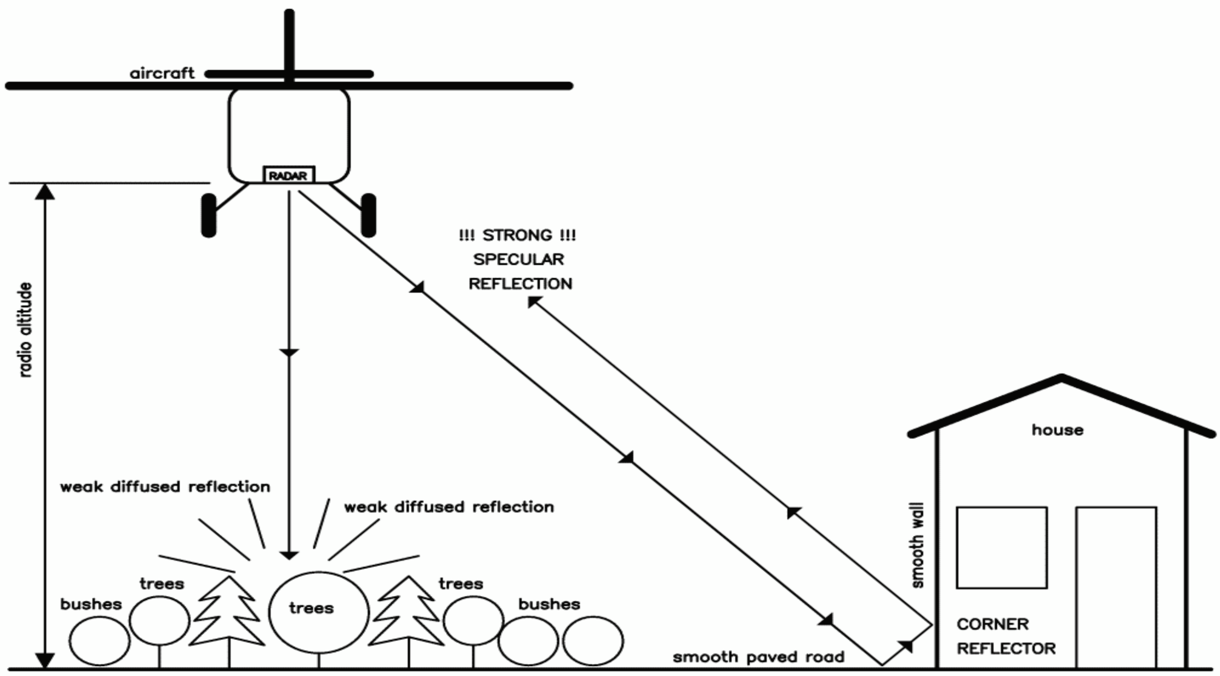






Radar altimeter measures the exact height during the landing procedure of aircraft and is a component of terrain avoidance warning systems (telling the pilot that the aircraft is flying too low or that terrain is rising to meet the aircraft).

Radar Altimeter Operation



Different targets reflect radio waves in different ways :

1. Smooth targets like lakes, sea, smooth roads and smooth runways provide specular reflections. Specular reflections are very strong and are always at right angle. The shape and tip of the antenna beam does not affect a specular reflection. In the case of a specular reflection it is relatively simple to measure the altitude of the aircraft above ground.

2. Rough targets like bushes, trees, mountains and unpaved runways provide diffused reflections. Diffused reflections are rather weak since the radio signal is scattered in many directions. Tilting the antenna changes the reflection area. In the case of a diffused reflection, the first radar return comes from the area just under the aircraft and this is a good estimate for the aircraft altitude.

This type of radar frequently used by commercial aircraft for approach and landing, especially in low-visibility conditions and also automatic landings. It also used in military aircraft flying extremely low over ground to avoid radar detection and targeting by anti-aircraft weapons. Gives the pilot an indication of the aircrafts absolute altitude above the surface. Determines height by measuring the time delay between transmission and reflection of downward directed radio waves.

SUMMARY/RECAP

At the end of the learning session the students has been taught about the:-

1. Principles of radar system
2. Types of radar
3. Block diagram of radar system
4. Radar display
5. Radar measurement
6. Radar requirement
7. Transmitter power requirement
8. Radar interference

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