Chapter 4. Fixed Service Systems

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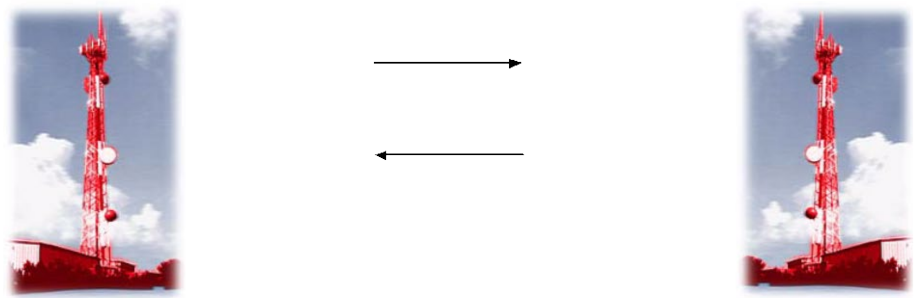
Dpt. Communication Engineering
Bilbao Faculty of Engineering

Contents

Introduction

- A radio link of the Fixed Service (FS as ITU-R terminology) is any radiocommunications link between two fixed stations based on the propagation of signals through the atmosphere at frequencies higher than 30 MHz, with a limit that has been set in 3000 GHz.

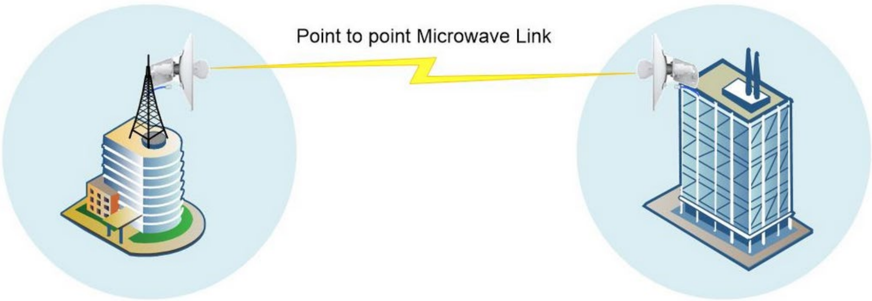


- Currently, there is a tendency to use more the generic term of Fixed Wireless System (FWS), which is used to identify the telecommunication systems operated for fixed services and that are used in access and transport application scenarios.

Introduction

Fixed Wireless System (FWS)

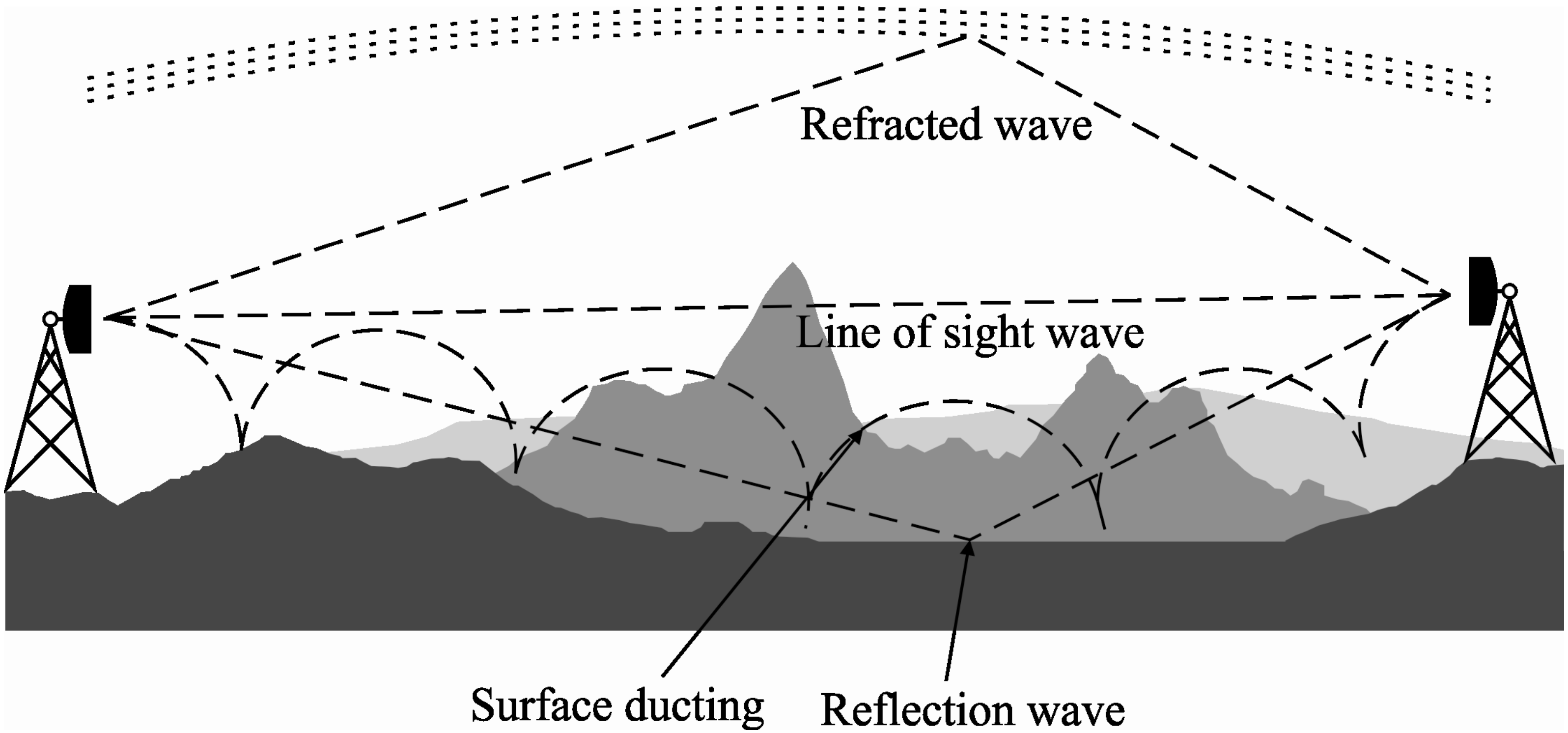
- Terrestrial point-to-multipoint
- HF systems
- High Altitude Platform Systems (HAPS)
- Free space optic links
- Terrestrial point-to-point. These systems are in practice referred as:
  - **Microwave Line of Sight Links (LOS Microwave)**
  - Microwave Links (MW links)
  - Fixed Service Radio Links
  - Simply Radio Links.



Introduction

Fixed Wireless System (FWS) **: Microwave Line of Sight Links (LOS Microwave)**

- LOS Microwave links operate in Line of Sight condition in frequencies from 400 MHz and 95 GHz under specified availability and quality conditions



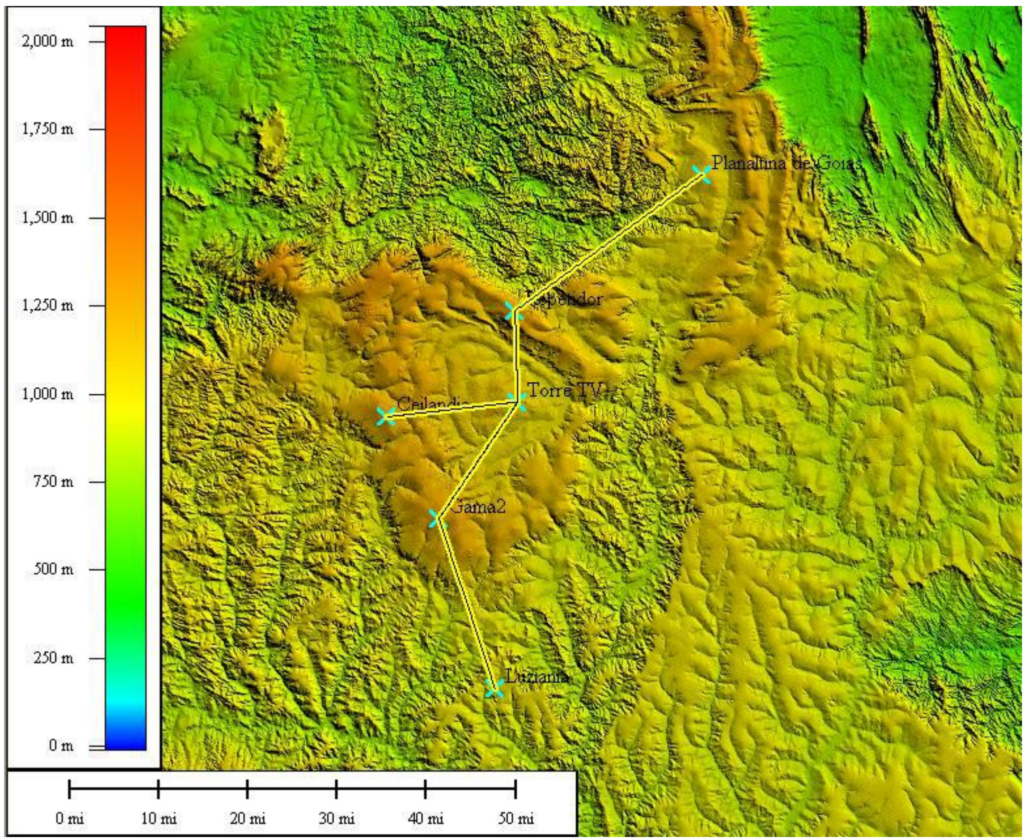
Introduction

LOS Microwave: Field of application and use cases

- Backhaul Networks
- Backhaul in Mobile Networks
- Metro and Edge Networks
- Fixed Access Networks
- Additional use cases

Introduction

LOS Microwave: Field of application and use cases: Backhaul Networks



- Traditional transport or backhaul Networks have used microwave LOS links that operate in frequency bands below 15 GHz.
- The typical hop length of these systems is in the range from 30 to 50 km and the associated bitrate capacity is equivalent to medium to high capacities in PDH, SDH or IP systems (usually above 34 Mbps).

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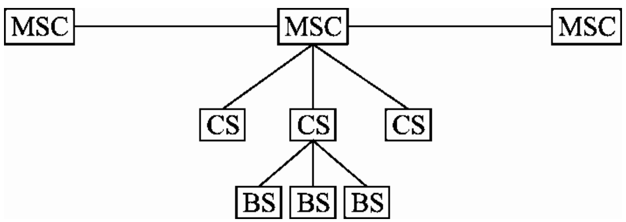
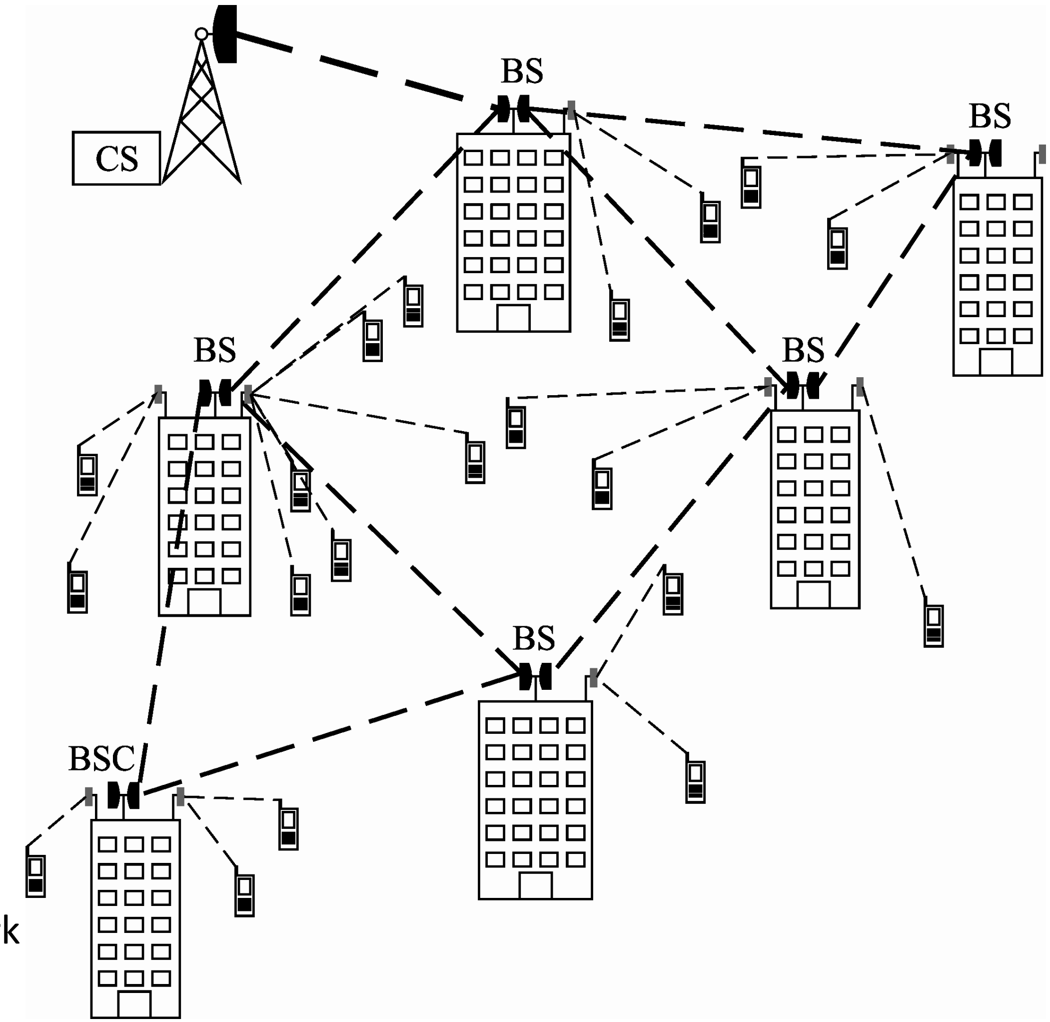
LOS Microwave: Field of application and use cases: Backhaul in Mobile Networks

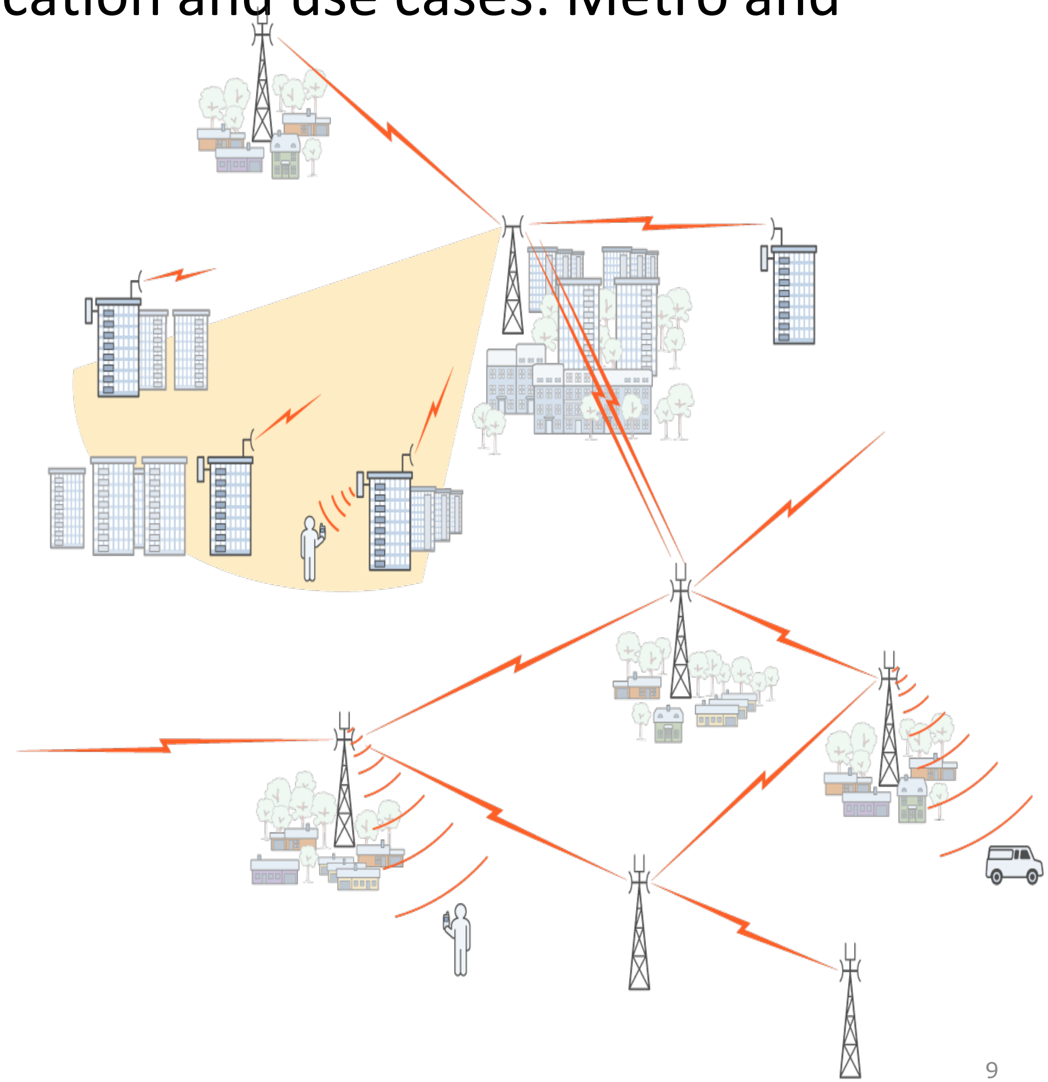




- Microwave LOS links are the usual communication system for transport functions between base stations BS (or equivalent in 3G and 4G networks), upper level control nodes (i.e. BSC, Base Station Controllers in GSM) and even with higher order nodes such as MSCs (Mobile Switching Centres) and packet switching nodes.
- When installed in Base Stations, microwave LOS links share infrastructure and towers with the cellular access network equipment.

Introduction

LOS Microwave: Field of application and use cases: Metro and Edge Networks



- Metro networks are transport networks in urban areas based on fiber optic rings with high capacities and usually based on SONET/SDH and Metro Ethernet standards, that transport voice, video, TV and data traffic flows.
- The application of microwave LOS link is:
  - Short term alternative solution to Fiber optic links.
  - Links that enable redundant paths that could reconfigure and carry traffic originally conveyed by the optic fiber ring in the cases of ring disruption.
  - Backbone extension to reach locations outsider the limits of urban areas

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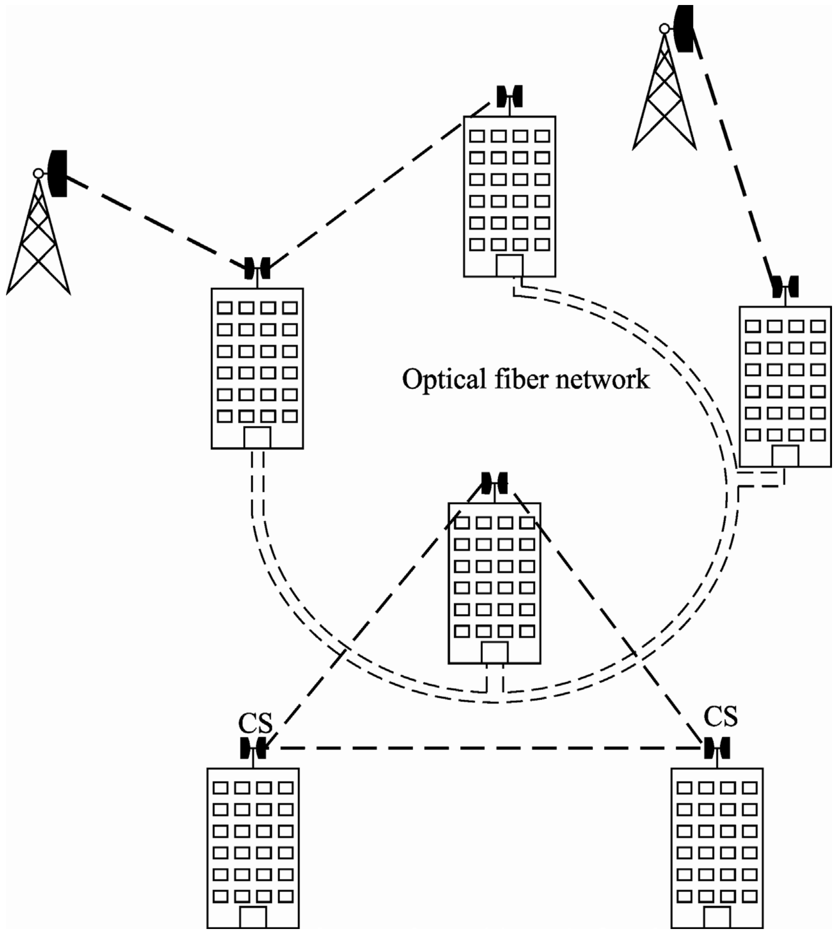
Introduction

LOS Microwave: Field of application and use cases: Fixed Access Networks

- The connection of customer premises CP to the wideband fixed access networks is usually carried out either by means of copper pair or fiber optic systems. This application includes also connections for LAN bridging or remote LAN connections.
- Microwave LOS links and high density point-to-multipoint systems are used as alternative or complementary choices.
- Microwave LOS links used in this environment are usually high capacity IP links, in line with the evolution tendency in access networks from ATM to IP.



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Introduction

LOS Microwave: Field of application and use cases

Additional use cases

- Physical support to corporate networks of private companies such as utilities (electricity, gas, etc), public security and other industries, that might require to connect buildings and other installation facilities within an area
- LAN or PAN (Personal Area Networks) in indoor environments, where radio links are used for high speed multimedia service connections between local devices in indoor areas, offices, etc.
- Temporary portable link installations for special events or for distress operation communications in the case of natural disasters.

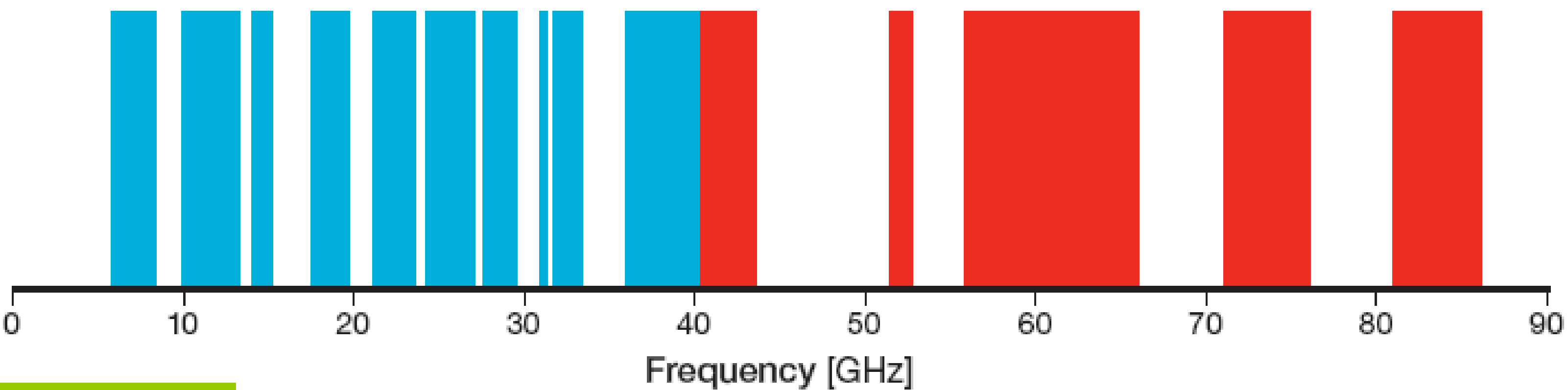
Contents

Frequency band and equipment choice

Frequency bands used for microwave LOS links

Traditional Commercial Bands

New bands and Experimental



Multipath

Rain

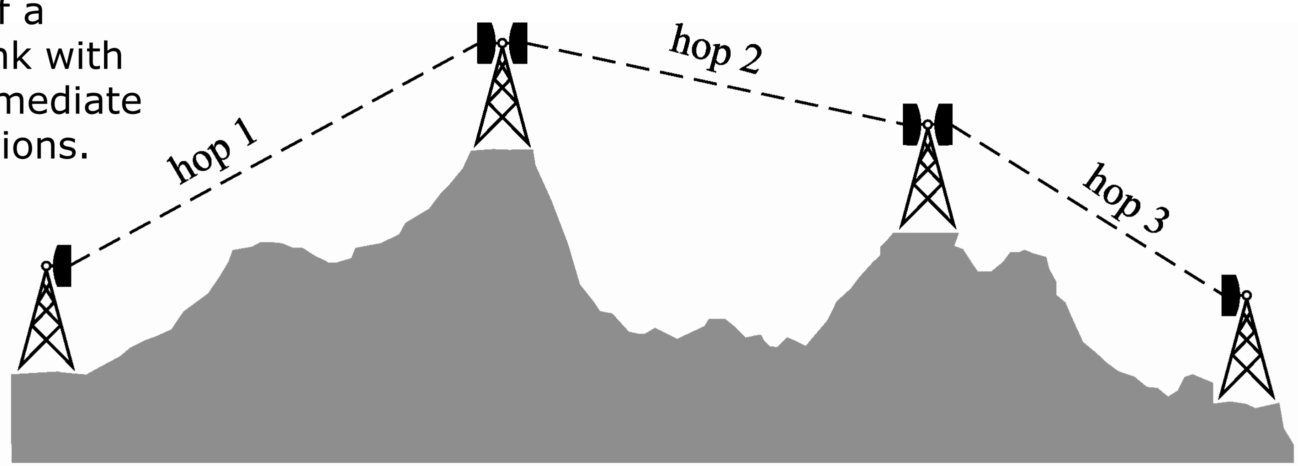
Fog, Clouds, Dust

Contents

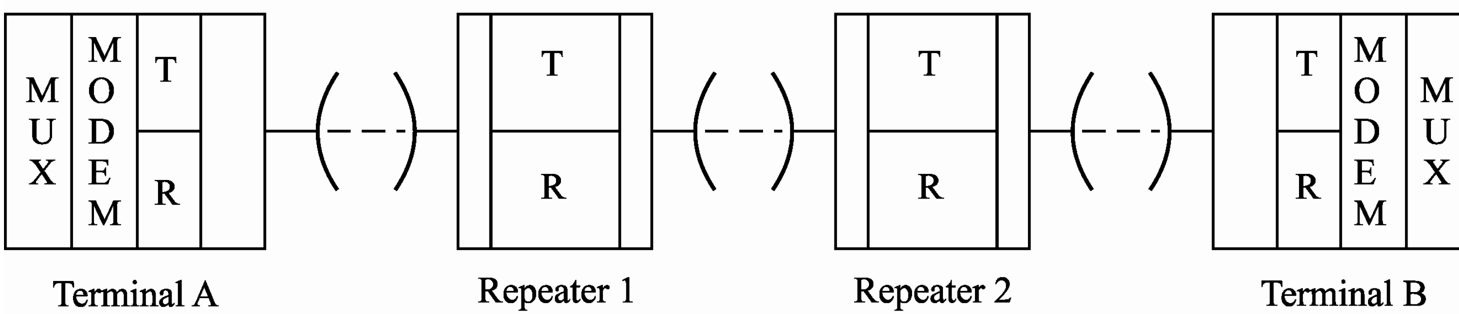
Basic Block Diagrams

LOS Microwave: Basic Structure.

Diagram of a bidirectional link with nodal and intermediate repeater stations.



a) Path terrain profile



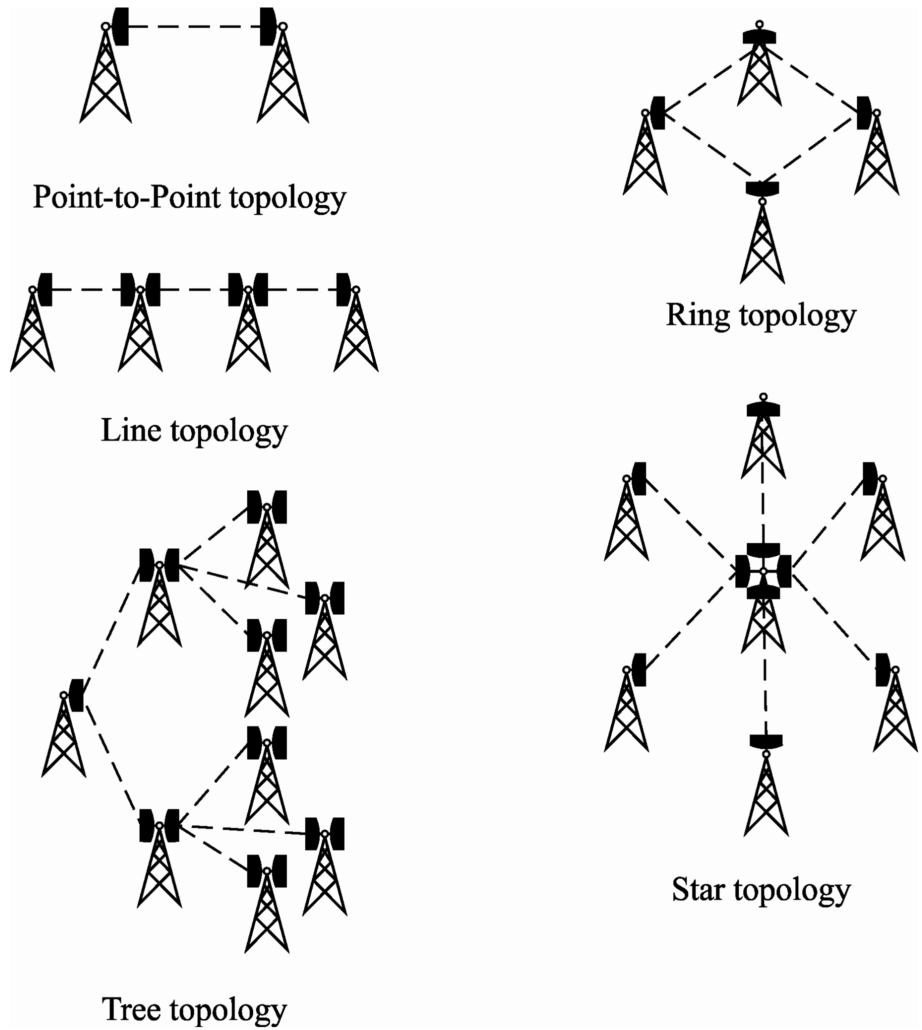
b) Functional equipment blocks of the link

LOS Microwave: Basic Structure

- In the most general case, a microwave LOS link is composed of terminal radio stations (transmitting station, a receiving station), and intermediate repeater stations.
- A terminal radioelectric station is a hub that manages incoming and outgoing traffic, and where there may be some kind of multiplexing-demultiplexing with the aim of aggregating or disaggregating different traffic sources.
- A repeater station has the function of enabling the line of sight characteristic along a specific path, usually to overcome a geographical obstacle or distance that is too large.
- There are two general types of intermediate repeater stations:
  - Passive Repeaters: These are either simple reflecting surfaces (radioelectric mirrors), or directive antennas installed back to back through a passive transmission line.
  - Active Repeaters: These are radio stations that use active elements, transmitters, receivers and radiating systems that receive, process, amplify, and transmit the signal arriving from one link hop to the next one. Depending on the processing involved these stations can be RF, IF and baseband repeaters.
- Nodal or Terminal Stations of a microwave LOS link are the radiocommunication stations where the baseband payload is originated and sent to.
- A hop (or link hop) is the link section between two radio stations, either between a nodal and a repeater station or between repeater stations.

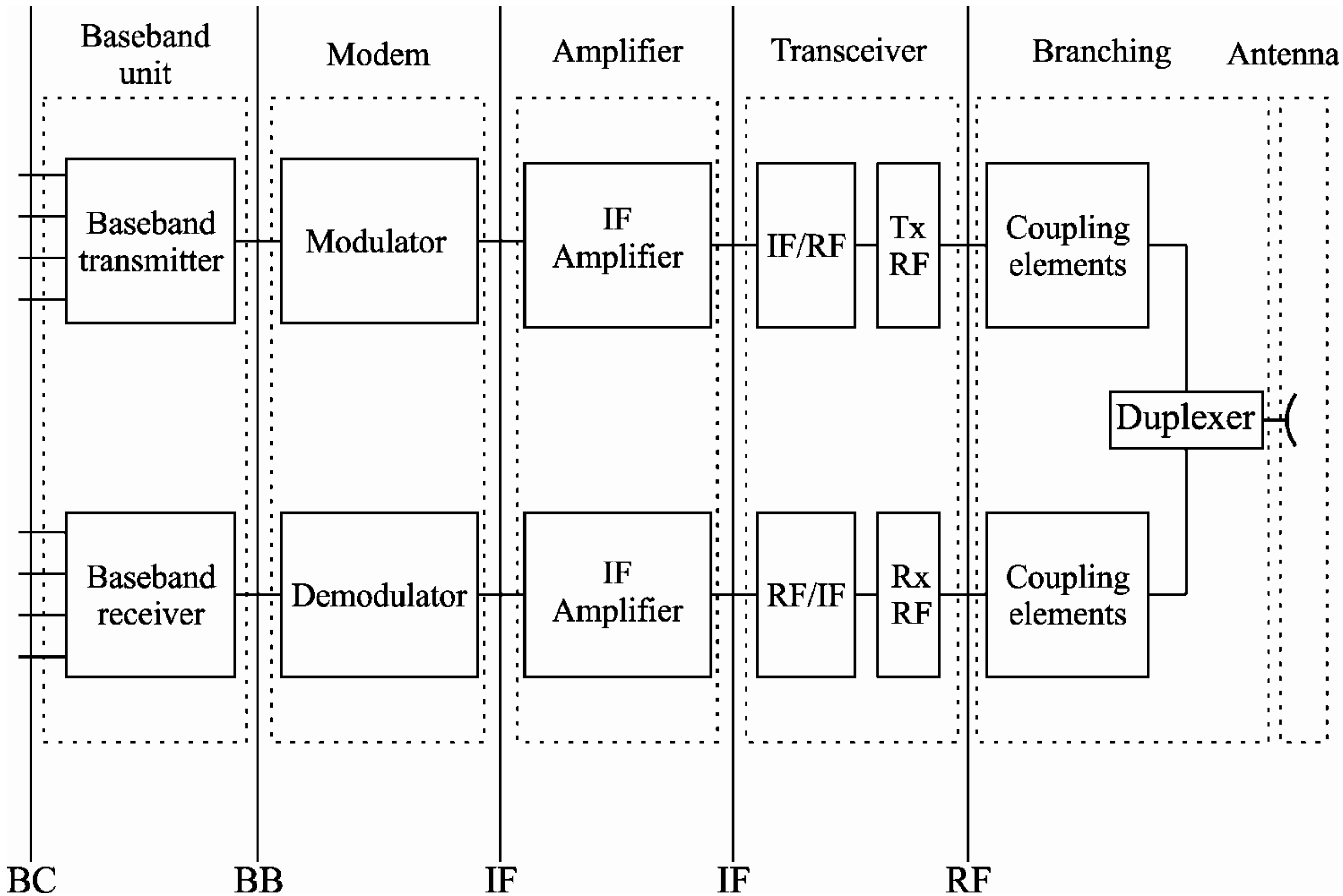
Basic Block Diagrams

Network Topologies



Basic Block Diagrams

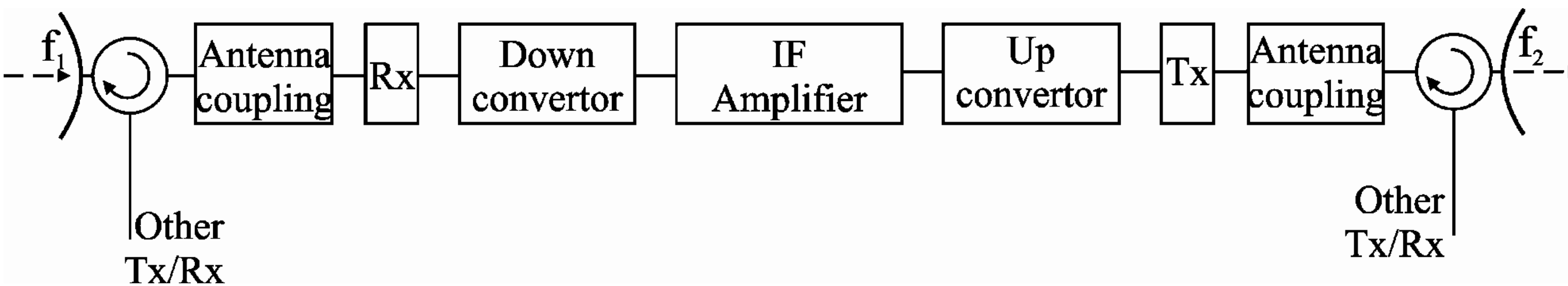
Block diagram of a terminal station of a radio-relay link



Basic Block Diagrams

Block diagram of a non-regenerative active repeater

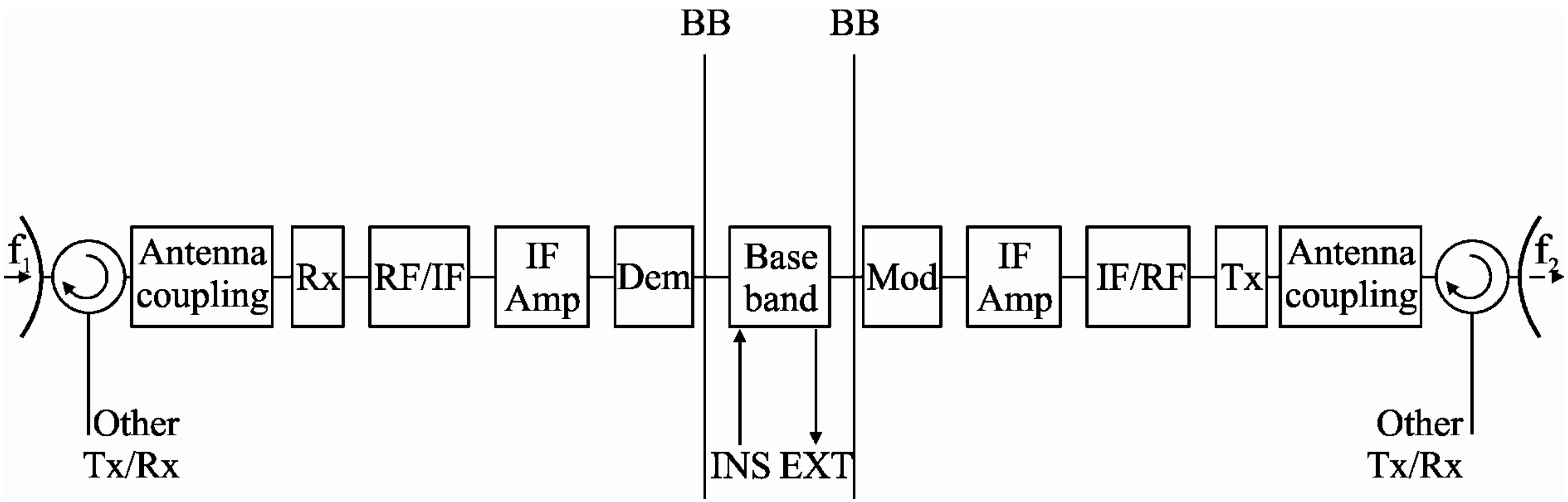
(only the branch associated to one of the directions of a radio channel)



Block diagram for one radio channel in a single transmission direction that is received in f1 frequency and retransmitted in f2 frequency, according to the same block and interface nomenclature that was used in the case of terminal stations.

Basic Block Diagrams

Block diagram of a nodal station for a single radio channel



Block diagram of a nodal station for a single radio channel (only the branch associated to one the directions of a radio channel is shown)

Block diagram of a nodal station for a single radio channel

- Intermediate Nodal Stations are similar to Regenerative Repeaters.
- In this case, the signal is down-converted to IF, demodulated and demultiplexed in Baseband.
- It is possible then to drop and insert channels to and from the overall traffic flow of the main link flow. Intermediate nodal stations permit to interconnect different sections of the network or different radio-relay link paths.
- If more than two paths are connected the radio station is called multi-directional node.
- Drop and insertion of channels can be made at radio channel level or at a higher frame level of the digital interface multiplexes.
- The path between a terminal station and an intermediate nodal station is called switching section, and will be considered a control, protection and monitoring unit. The switching section term is extended to the sections between nodal stations when there are several nodal stations in the same radio-relay link.

Basic Block Diagrams

Passive Repeater Stations

- Back to Back
- Reflectors

Basic Block Diagrams

- The physical location of the functional elements of the link will change depending on the application and integration degree of each manufacturer

- According to the exact installation place for each one
  - all indoor – (In-Door Unit) IDU
  - Split Unit (RF outdoor)
  - all outdoor (out-Door Unit) ODU.

Basic Block Diagrams

All Indoor – (In-Door Unit) IDU

- IDU configurations are typical of high capacity radio-relay links. Units are arranged on transmission rooms and located in frames of different types and sizes: 19 inches (ETSI) in Europe, 21 inches in the United States.
- Antennas are installed in outdoor towers and connected to the transmission shelter through coaxial cables or waveguides.

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Basic Block Diagrams

All Outdoor (out-Door Unit) ODU

- All the radio-relay link equipment are installed close to the antenna
- ODU are mainly used for transporting microcell signals in mobile communications, where base stations are also outdoor.
- Base stations are usually furnished with digital interfaces that are directly connected to the outdoor unit. Connections must be made using coaxial cables: traffic, power supply, alarms and management signals will share the transmission media.

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Basic Block Diagrams

Split Unit (RF outdoor)

- Baseband and modem blocks are located indoor, usually in shelter buildings designed specifically for this purpose
- The radio-frequency unit is arranged outdoor, close to the antenna.
- The IF connection between both units is done with coaxial cables, which also transmit necessary power supply to the RF units.
- This configuration has lower transmission loss on lines than IDU configurations, particularly for higher frequencies.
- This arrangement is widely used in access or transport networks for mobile communications, at higher frequencies

Contents

Baseband Unit

Typical Digital interfaces

	Interface
Ethernet	IEEE 802.3 -10/100/1000 BaseT
PDH	E1/2048 kbps - T1/1544 kbps
PDH	E3/34368 kbps – T3/44736 kbps
PDH	E4/139264 kbps
SDH	STM-1/155.520 kbps
SONET	OC-3/STS-3
Packet based networks	IP

Baseband Unit

Additional Functions of the Baseband Unit

- Error Correction and Coding (CR)
- Base Band Processing: The objective of the baseband signal processing stages is the conversion of input signals of digital channel interfaces into other properly formatted flows that will be handled by the radio unit.
  - Line Code Conversion
  - Equalization
  - Clock recovery
  - Carrier recovery
  - Jitter reduction
  - Signal quality monitoring

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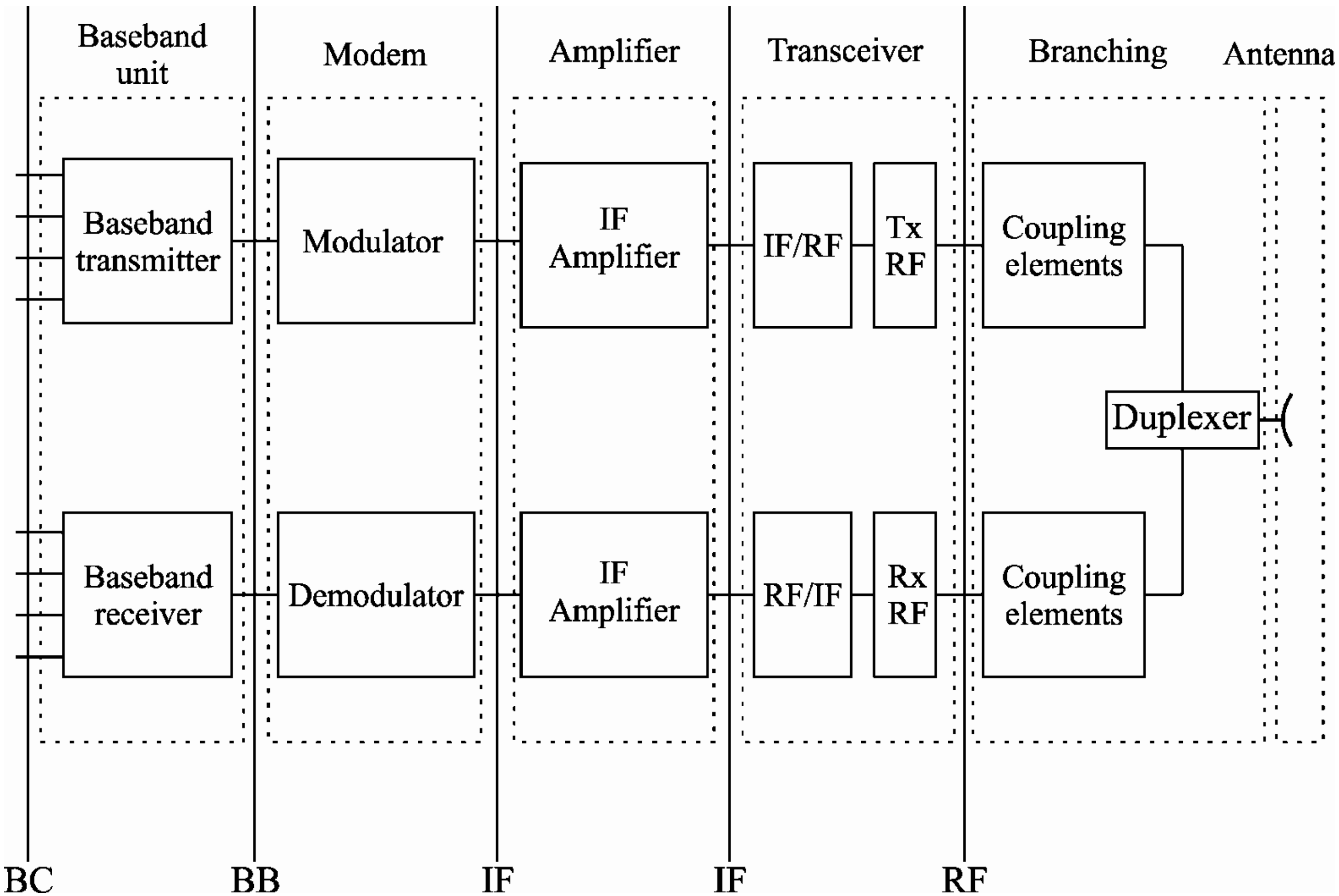
Basic Block Diagrams

Block diagram of a terminal station of a radio-relay link



Modulation and Demodulation

Modulations used in radio-relay links

<table>
<tr><th>Coding</th><th colspan="2">Type</th></tr>
<tr><td rowspan="4">Uncoded</td><td rowspan="3">PSK, Phase-shift keying</td><td>Quadrature PSK (QPSK - 4PSK)</td></tr>
<tr><td>Differential QPSK (DQPSK),</td></tr>
<tr><td>Offset QPSK (O-QPSK)</td></tr>
<tr><td>QAM, Quadrature amplitude modulation</td><td>16, 32, 64, 128, 256, 512, 1024, 2048 and 4096QAM</td></tr>
<tr><td rowspan="3">Coded</td><td colspan="2">BCM, Block Coded Modulation</td></tr>
<tr><td colspan="2">TCM, Trellis Coded Modulation</td></tr>
<tr><td colspan="2">MLCM, Multi Level Coded Modulation</td></tr>
</table>

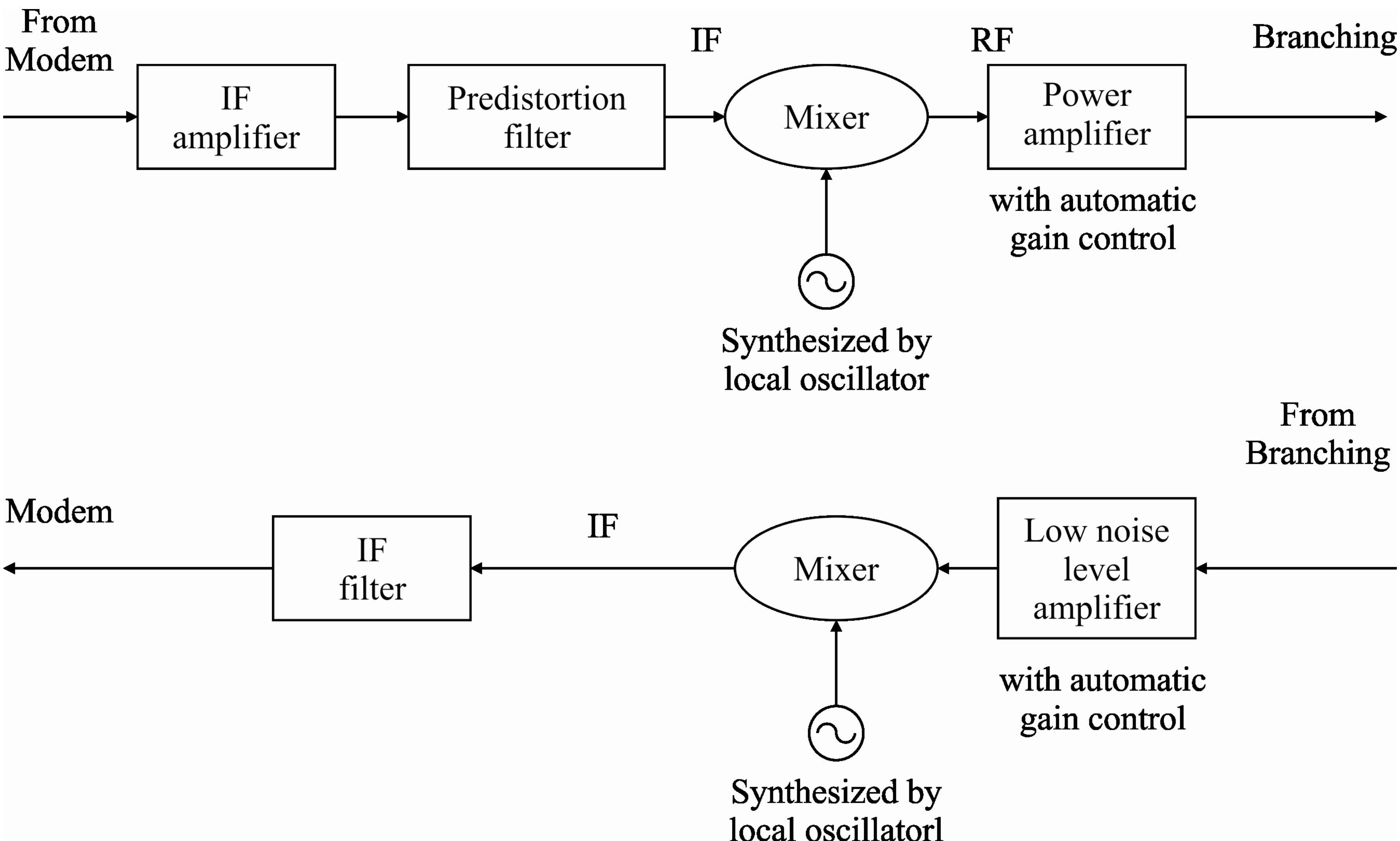
Modulation and Demodulation

Error probability - Bit error rates for different modulations and thresholds.

Modulation scheme	*$W = 10 \log e_b/n_o$*	
	$P_{eb} = 10^{-3}$	*$P_{eb} = 10^{-6}$*
2 PSK	6.8	10.5
4 PSK	6.8	10.5
8 PSK	10.0	13.8
4 DPSK	9.1	12.8
16 QAM	10.5	14.4
64 QAM	14.7	18.8
256 QAM	19.3	23.5

Transceiver

Block diagram of a transmitter-receiver (transceiver)



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Contents

Antenna Coupling

Antenna Coupling Elements

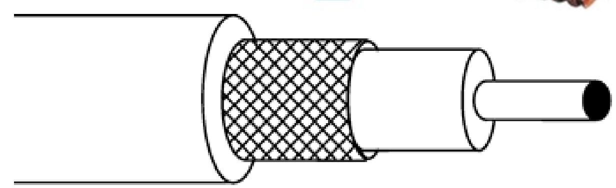
- RF TRANSMISSION LINES
  - Coaxial Cables
  - Wave Guides

- BRANCHING CIRCUITS
  - Filters
  - Circulators
  - RF isolators
  - Duplexers

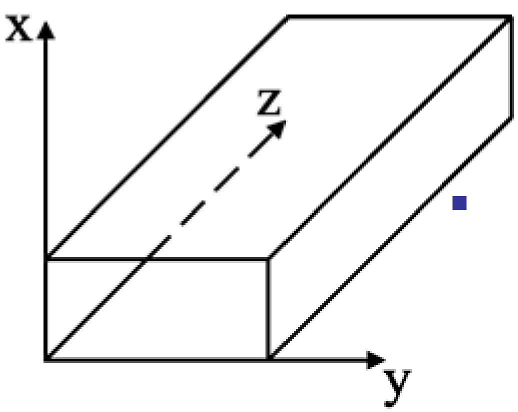
Antenna Coupling

RF Transmission Lines: Coaxial Cables

- Losses in coaxial cables increase with frequency, so its use is commonly limited to 3 GHz for large connection distances between the antenna of indoor units. For higher frequencies, coaxial cable is only used for short distance connections, such as feeder connections to the outdoor transceiver units.



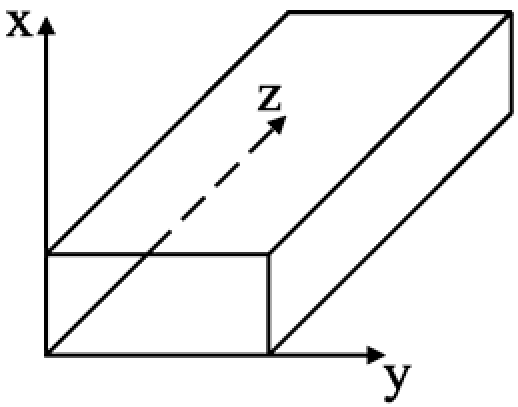
RF Transmission Lines: Wave Guides

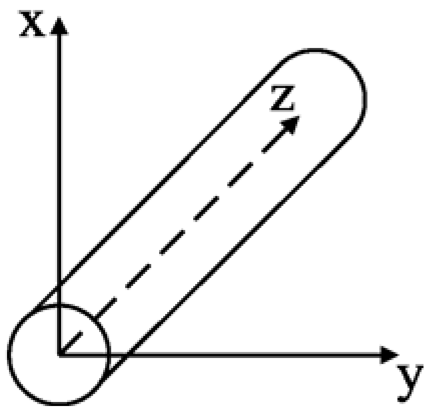


- In practice, wave guides are used for frequencies above 3 GHz and below 10 GHz. They can deliver high power with less attenuation at higher frequencies than coaxial transmission lines. The disadvantages of waveguides are the complexity of the installations. Despite the lower attenuation values, the overall loss might be too large in IDU installations.

Antenna Coupling

RF Transmission Lines: Wave Guides

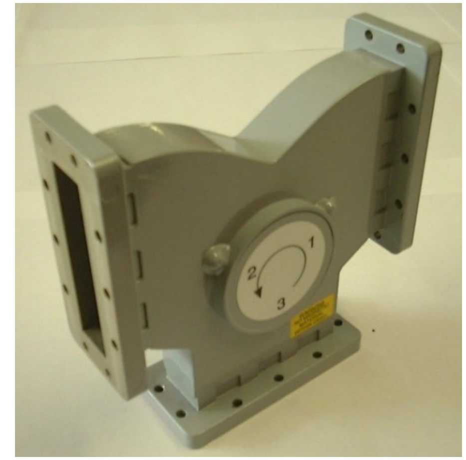




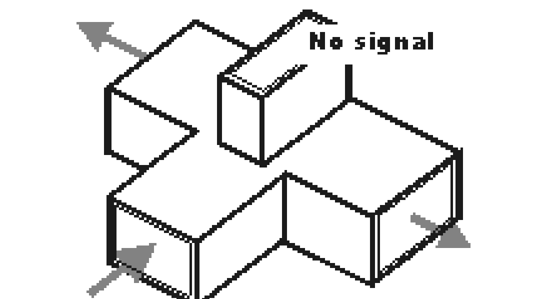
- Above 10 GHz and if the branching network is long, equipment manufacturers offer alternative solutions based on ODU or split unit arrangements. The IDU section will be connected to a transceiver close to the antenna by a coaxial cable. The signals will travel on IF through the coaxial to and from the transceiver to/from the IDU modules. In summary the path travelled by the RF high frequency signals will be much shorter (antenna – transceiver path)

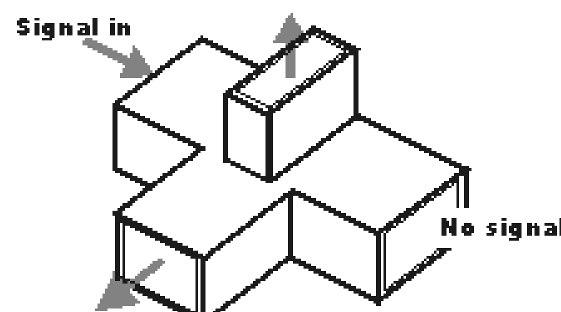
Antenna Coupling

Branching circuits



- All passive circuits and devices between the transceiver and the antenna are integrated in the branching unit.
- **Filters, circulators, isolators and duplexers** are included in this category.
- **Insertion loss** is the most important parameter to consider for all of them.
- **RF Filters**:
  - Branching RF filters ensure that signal spectrum is kept within the limits of the allowed frequency band, reducing the possible interference to adjacent channels in transmission. At the receiver side, their function is to reduce the influence of undesired signals and keep the influence of thermal noise within the minimum required bandwidth.

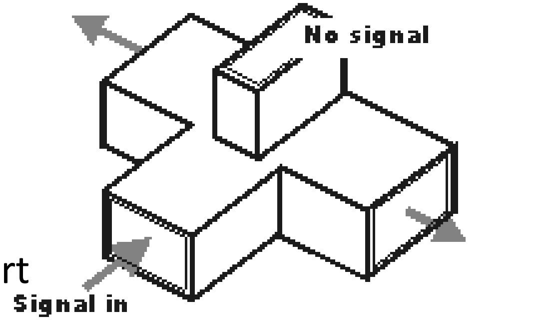


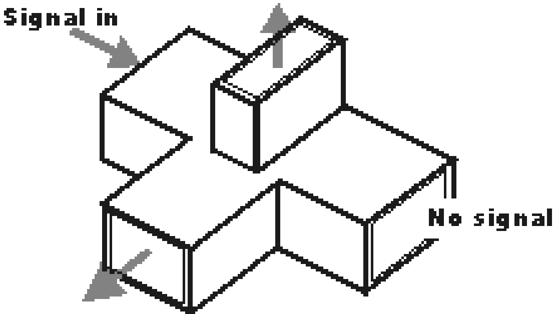


Antenna Coupling

Branching circuits

- **Circulators**:
  - Circulators are devices with three ports. Each port is associated to one of the other two and the resulting pair will be called coupled ports. The signal entering one port of the circulator will be delivered entirely to the coupled port, whereas the third port will be completely isolated. The third port is called the isolated gate. Circulators are the most widely used devices to enable sharing a single antenna by multiple radio channels.
- **RF Isolators**:
  - Isolators are two port devices that have low insertion losses when the signal travels from the first to the second port, and high isolation, or high losses, when power enters the second port towards the first one. In this case, the power will be totally dissipated on the device. They are used in radio-relay links in order to protect the radio-frequency equipment from possible reflections that may damage transmission units.



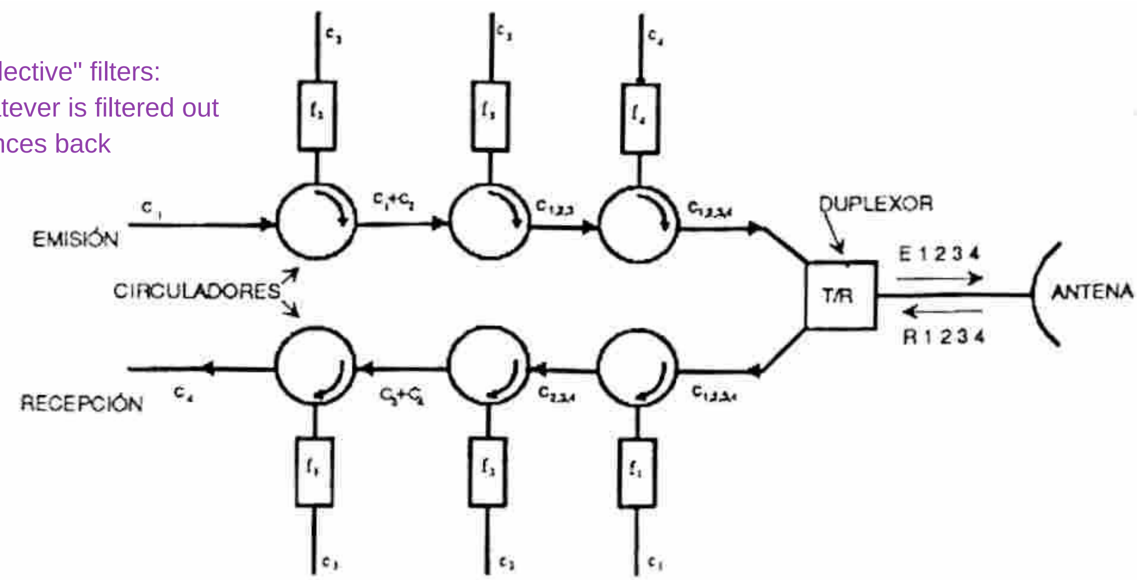


Antenna Coupling

Branching circuits

- Duplexers

"Reflective" filters:
Whatever is filtered out
bounces back



- Duplexers are passive devices that allow to share a single antenna for bidirectional radio channels, by conveniently isolating the transmission and reception radio channels.
- They are usually formed by a combination of circulators and band-pass filters with cut-off frequencies equivalent to the frequency band limits of the transmission and reception channels. They have reduced insertion losses.

Contents

Antennas used in radio-relay links

- Transfer as much power as possible to the desired receiver in the direction of the antenna axis
- The transmission should avoid energy dispersion in other directions that could create interferences to other systems.
- Radiation patterns must have a narrow main lobe and a high directivity in the maximum radiation direction.
- Small secondary, side and back lobes.
- Wide range of possible radio channel arrangement plans and bandwidths: stable over a considerable bandwidth
- High cross-polar discrimination (XPD).

Antennas

Antennas used in radio-relay links

- Yagi
- Flat-plane (Flat panel Array)
- **Parabolic reflector antennas**

Flat Panel Array Antenna

Low Back Lobe Antenna

Focal Plane High Performance Antenna

Dual Beam Angle Diversity Antenna

Antennas

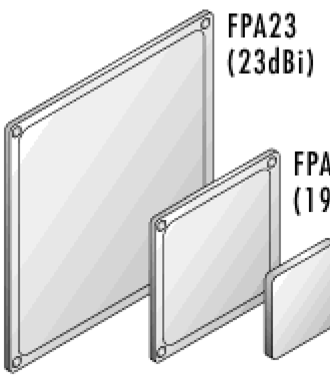
Antennas used in radio-relay links: Yagi antennas

- Lowest frequency bands, below 2.5 GHz
- Low cost
- Small bandwidth

Antennas

Antennas used in radio-relay links: Flat-plane Antennas

- Multi-layered microstrip technology
- Small size, profile and weigth. Typically sizes of shielded antennas from 0.15 m up to 1m with a thickness about 25 mm – 50 mm and weighing less than 4 kg.
- Products are available in the 23 GHz, 27 GHz and 38 GHz



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Antennas

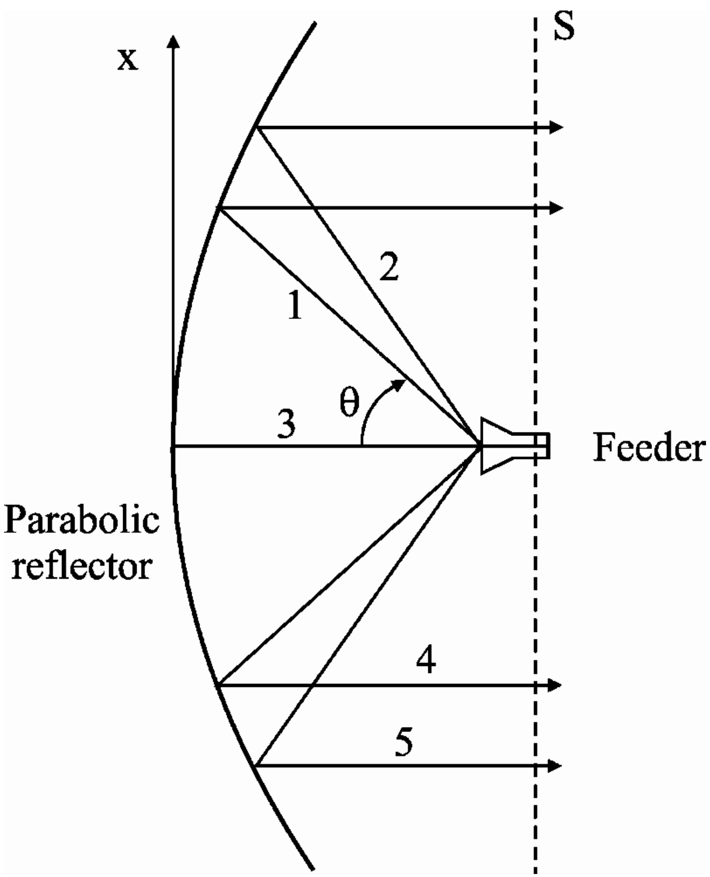
Antennas used in radio-relay links: Parabolic Reflector Antennas

Standard Focal Plane Antenna

GRIDPAK® Antenna (KP F- , KPR F-Series)

Unshielded Antenna (PAR Series)

Parabolic Reflector Antenna



- The geometric characteristics of revolution paraboloid, allow transforming the spherical wave radiation (almost omnidirectional) that emerges from feeder and is reflected on the surface of the paraboloid into a planar (flat) wave front, with parallel reflected components that will be in-phase when arriving to the focal plane (perpendicular to the antenna revolution axis).
- The resulting wave front will be a collimated beam of high directivity.
- In reception, by reciprocity, the plane wave that falls into the reflective surface is reflected in order to focus the received power on the feeder.

Parameters of Parabolic Reflector Antenna

- Antenna Gain
  - Directivity
  - Gain
  - Aperture Efficiency
- Equivalent Isotropic Radiated Power (EIRP)
- Radiation Pattern
  - Beamwidth
  - Minor or Secondary Lobes
- Mismatch, VSWR and Returning Losses
- Polarization

Parameters of Parabolic Reflector: Antenna Gain

- Gain (dBi, dBd, $dB_{\lambda/2}$): The gain of an antenna, traditionally called absolute gain, is a concept that includes the losses of the antenna.
- It is defined as the relationship between the radiation intensity in a specified direction, and the intensity produced by an isotropic radiator fed with the same power.
- As the radiation intensity associated to an isotropic radiator is equal to the input power, P_{in}, divided by 4π

$$G = \frac{4\pi U(\theta,\varphi)}{P_{in}}$$

- Gain of a parabolic antenna can be approximated by the following equation, in dBi:

$$G = 10\log\left(\eta A \frac{4\pi}{\lambda^2}\right)$$

A	of physical aperture area of the antenna(m^2)
η	efficiency of the antenna aperture
λ	wavelength(m)

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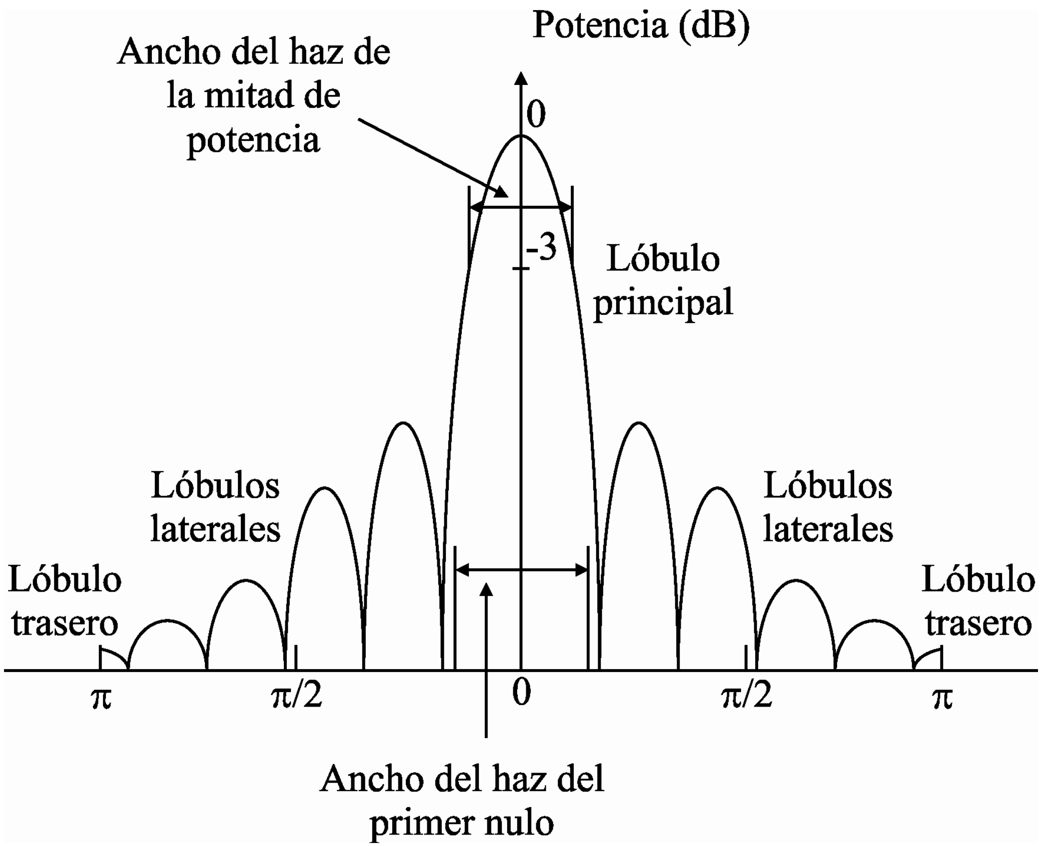
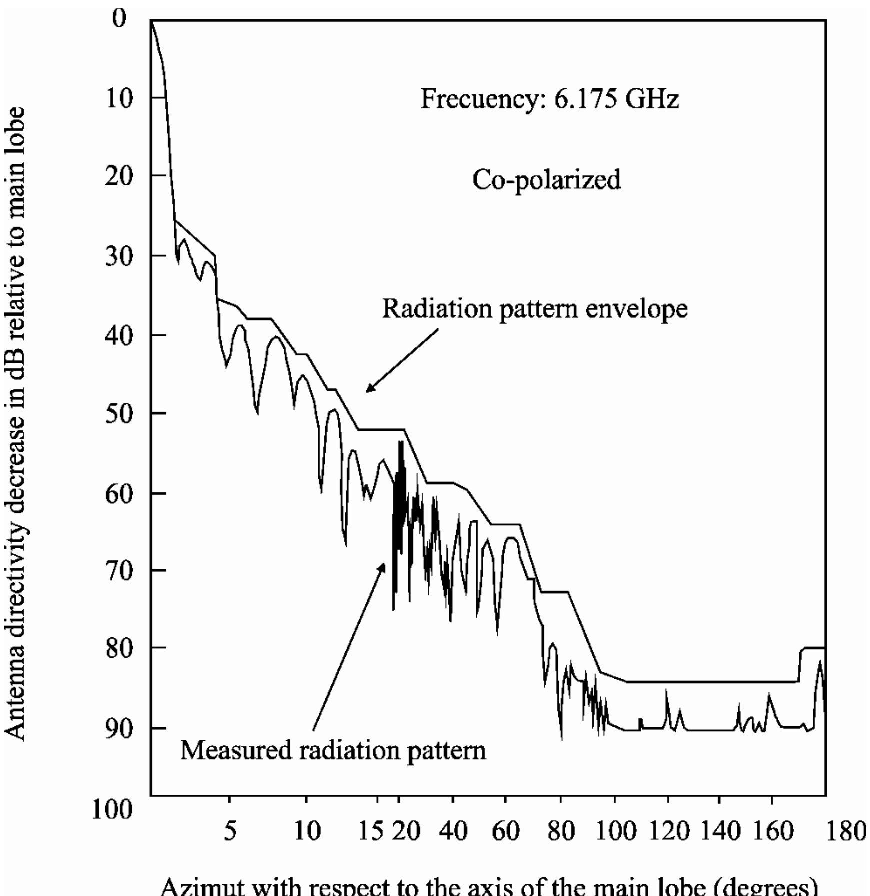
Parameters of Parabolic Reflector: Radiation Pattern



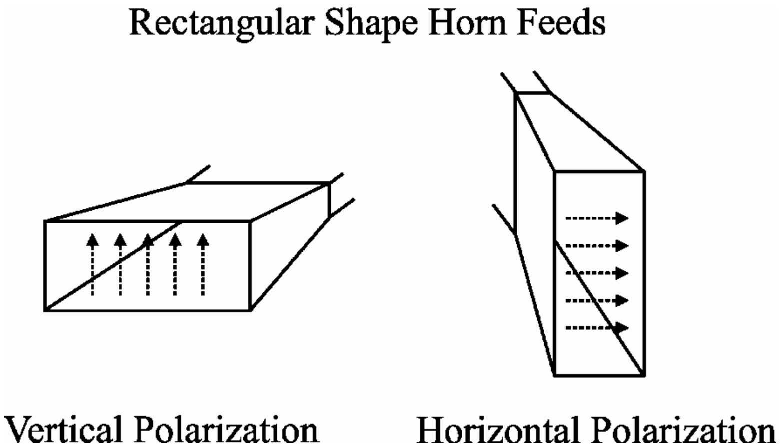
Parameters of Parabolic Reflector: Radiation Pattern

Radiation Pattern Envelope (RPE)



- Antennas of the same series will show a dispersion of their radiation pattern characteristics, simply because of tolerances associated to the manufacturing process and material characteristics.
- Radiation pattern envelopes (RPEs) are regular and simplified patterns obtained as envelopes of real diagrams measured at different frequencies in antennas of a specific series.

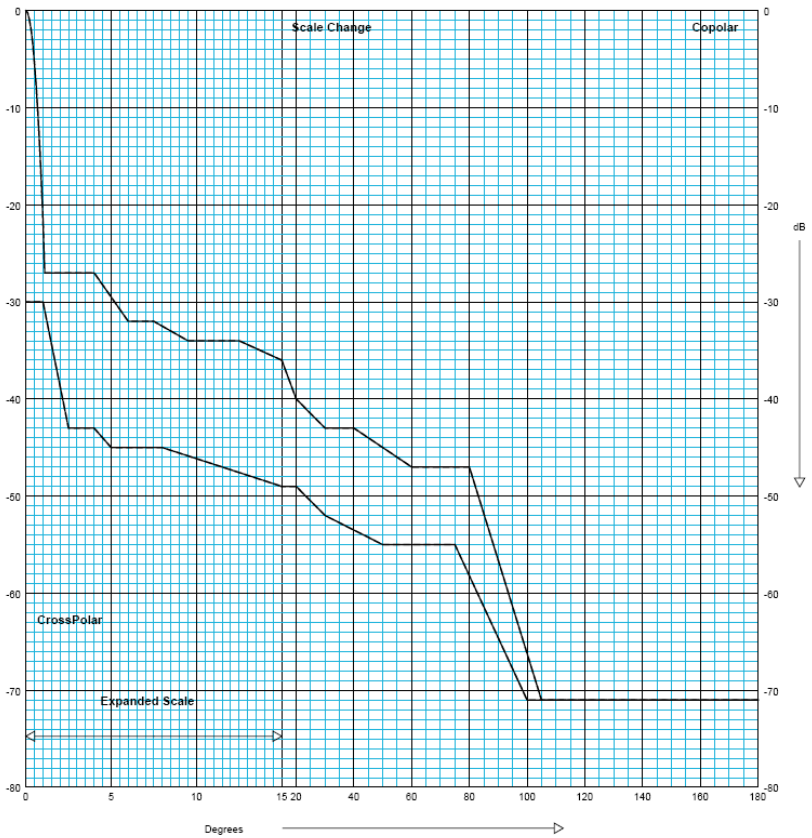
Parameters of Parabolic Reflector: Polarization



- Polarization of an antenna in a defined direction is the polarization of the wave radiated by that antenna, thus, the time varying shape that direction and relative amplitude of the electric field vector describe.
- Polarization can be classified into linear, circular or elliptical.
- Polarization can be separated into two orthogonal components that represent the horizontal and vertical polarization components that are orthogonal.

- For a parabolic antenna, polarization is defined by the polarization of the feeder.
- Discrimination between the orthogonal components of the polarization (usually one desired and the other one interfering) is called cross-polar discrimination (XPD)

Parameters of Parabolic Reflector: Polarization



Manufacturers of antennas usually give radiation patterns for the co-polar and cross-polar polarization.

In the special case of dual polarized antennas, the patterns provided are more complex than the general single polarized case.

The patterns required will be co-polar HH (response of a horizontally polarized antenna to a horizontally polarized signal) and VV (response of a vertically polarized antenna to a vertically polarized signal) as well as cross-polar HV (response of a horizontally polarized antenna to a vertically polarized signal) and VH (response of a vertically polarized antenna to a horizontally polarized signal).

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Antennas

- Grid Antennas
  - reflector is a metallic grid
  - 300 MHz and 3.5 GHz
  - 1.2 m to 4 m

Mini-GRIDPAK® Antenna (MKP Series)

GRIDPAK® Antenna (KP F- , KPR F-Series)

- Standard Antennas
  - Cheap
  - Solid parabolic reflector
  - Low interference environments
  - Spun aluminum reflector
  - without any kind of coating

Standard Parabolic Antenna

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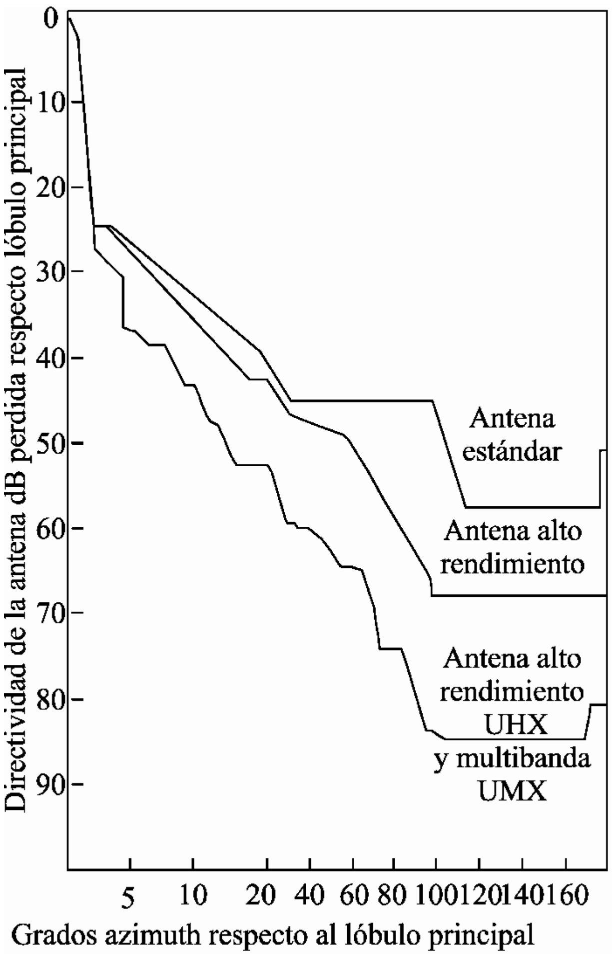
Antennas

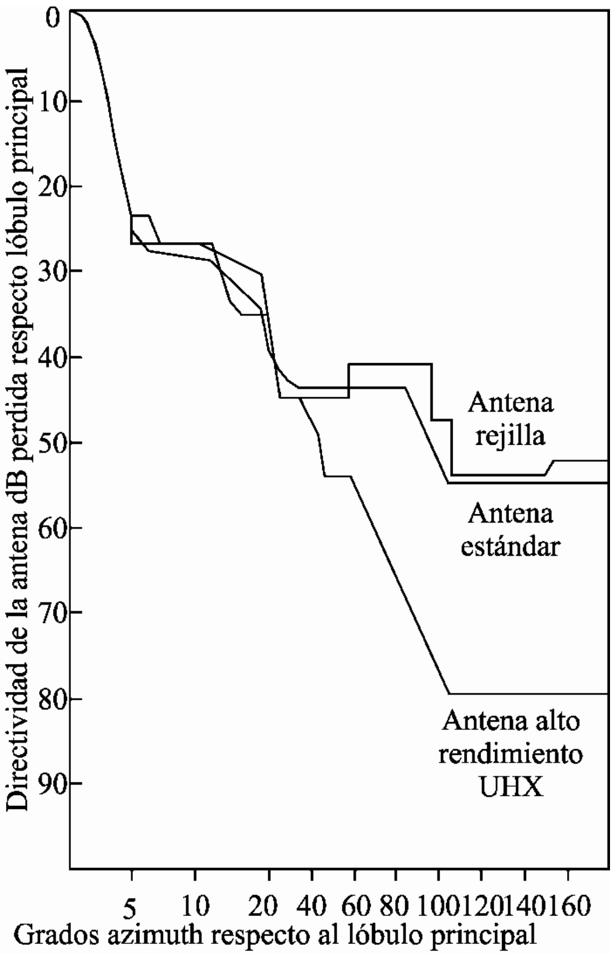
- Focal Plane Antenna
  - The effective aperture area of these antennas is increased making the focus plane of the parabolic surface spread towards the focal plane.

- Shielded Antenna
  - Radomes
  - Shields
- High Performance Antennas
  - Standard Antenna
  - High-Performance Antennas
  - Ultra-High-Performance Antennas

Antennas



Comparación RPE a 6 GHz



Comparación RPE a 2GHz

Standard Antenna

High-Performance Antennas

UHX: Ultra-High-Performance Antennas

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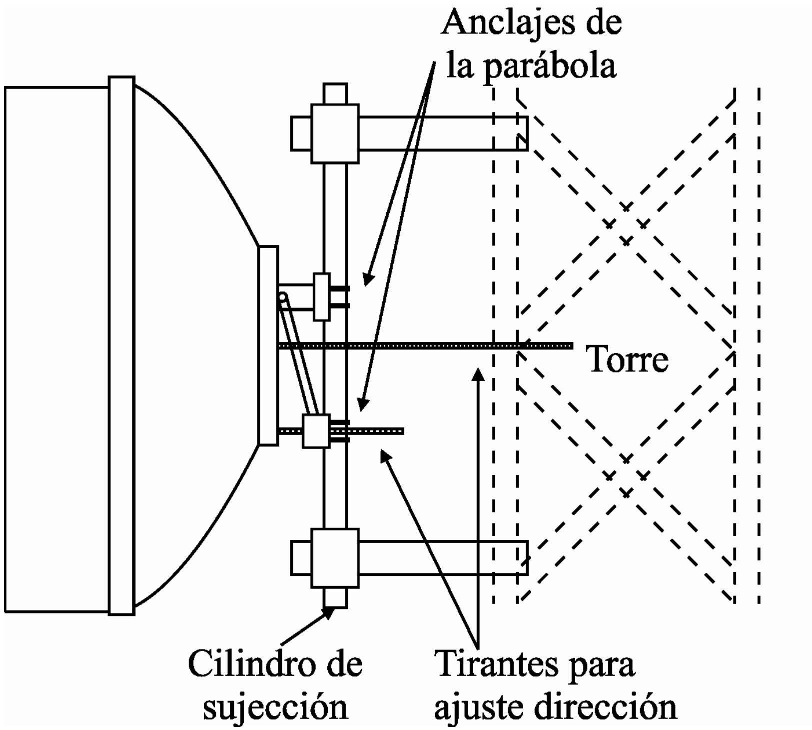
Antennas


Anclajes de
la parábola
Torre
Cilindro de
sujección
Tirantes para
ajuste dirección

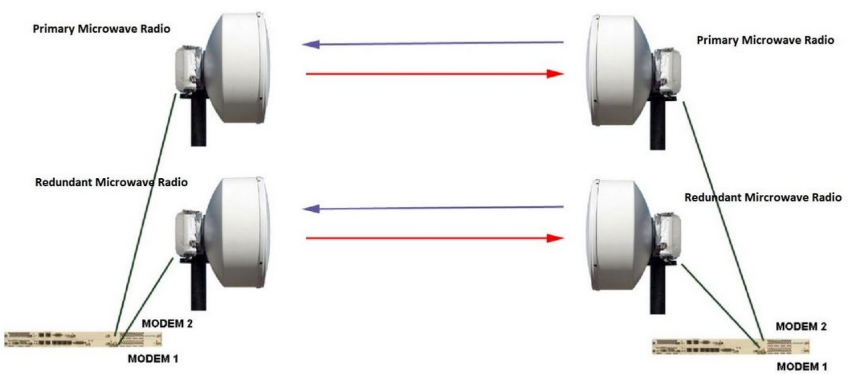
Contents

Availability

- Availability (or Reliability):
  - The availability is the proportion of time that a link connection is fully functional.
  - Link Availability is expressed in % and determines for what % of time the link has been established over a certain period of time, usually referred to one year period
  - Causes of Unavailability (U): Equipment Failure and Propagation (Rain Absorption).
    - Any time when a connection is not available (Unavailability) is referred to as an outage.
      - $U_{LINLK} = U_{EQUIPMENT\ FAILURE} + U_{PROPAGATION}$
  - Resiliency is the ability of a connection to recover quickly from outages or avoid them altogether.
  - Availability improvement techniques:
    - Redundancy
    - Frequency diversity
    - Space diversity
    - ATPC, Automatic Transmit Power Control
    - ACM, Adaptative Code Modulation

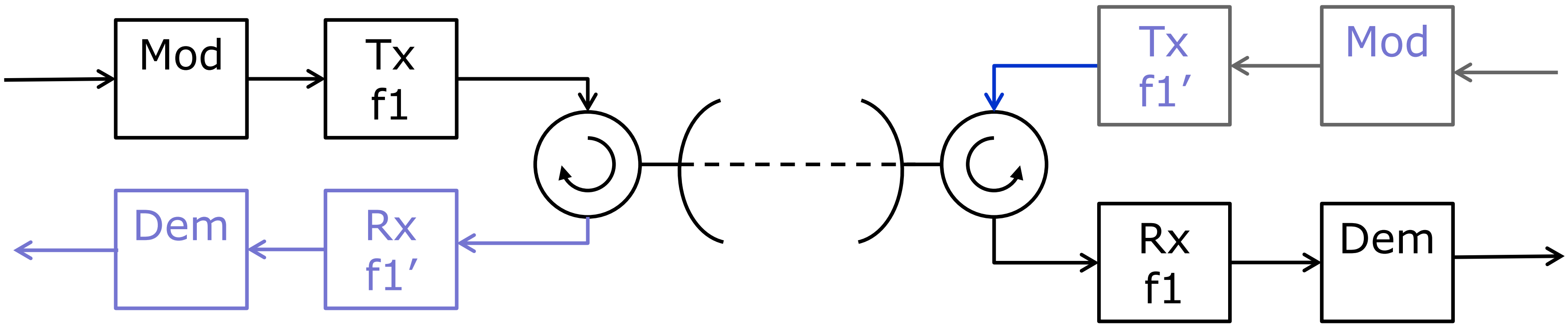
Redundancy

- Redundancy
  - The reliability of the link can be greatly increased by applying redundancy.
  - Dual redundant radios can be connected to the same antenna.

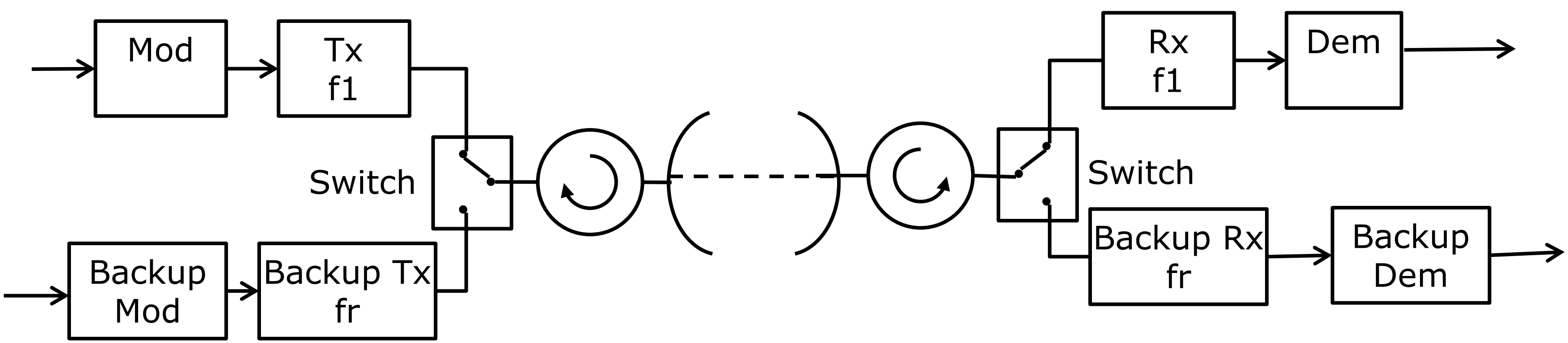


Redundancy Arrangements

- Unprotected Configurations: 1 + 0 Model (bidirectional)

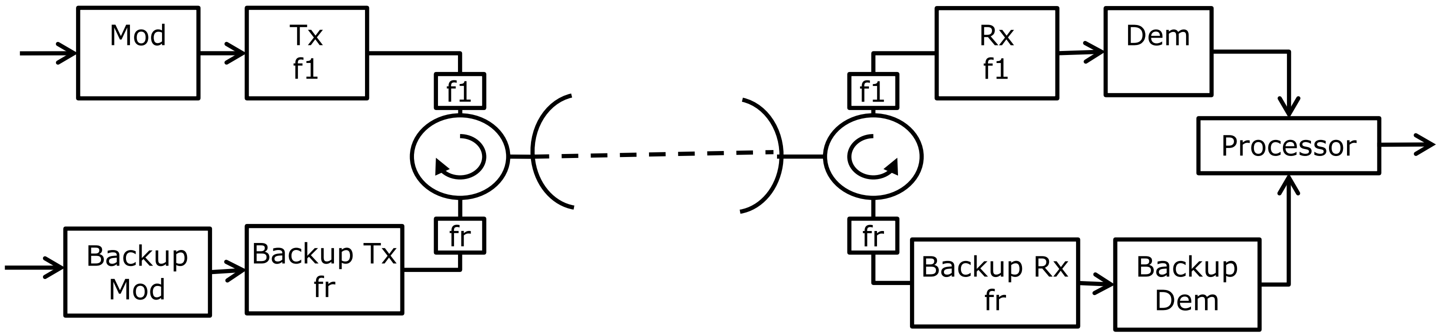


- Hot Standby Configuration, 1+1 configuration (unidirectional)

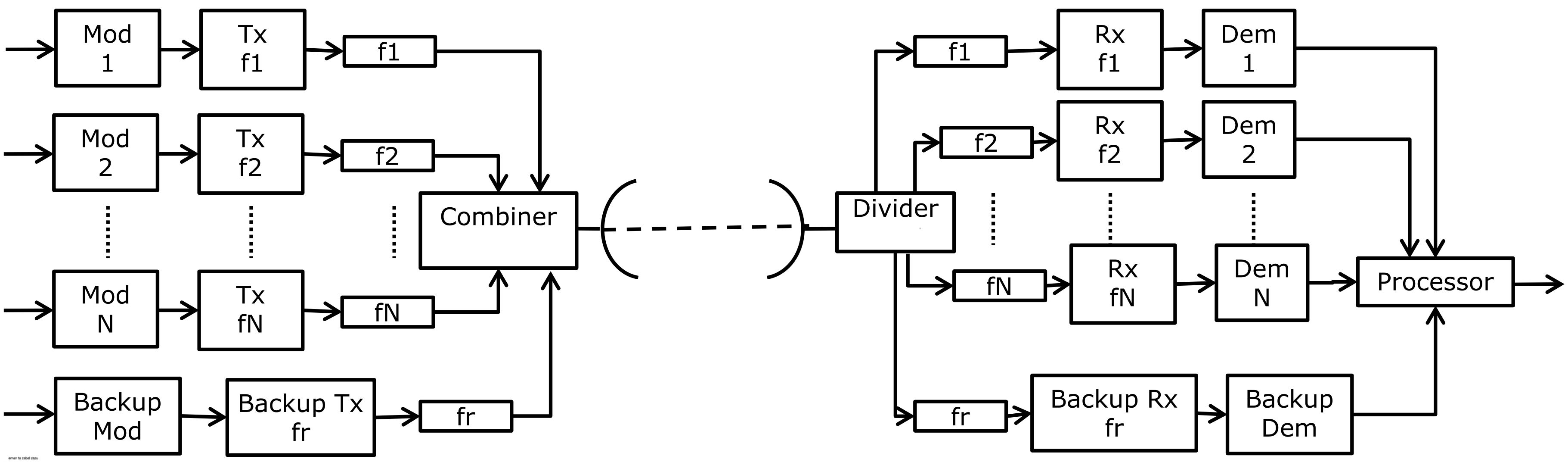


Redundancy Arrangements

- Frequency Diversity Configuration
  - 1+1 configuration (unidirectional)



  - N+1 Model (unidirectional)

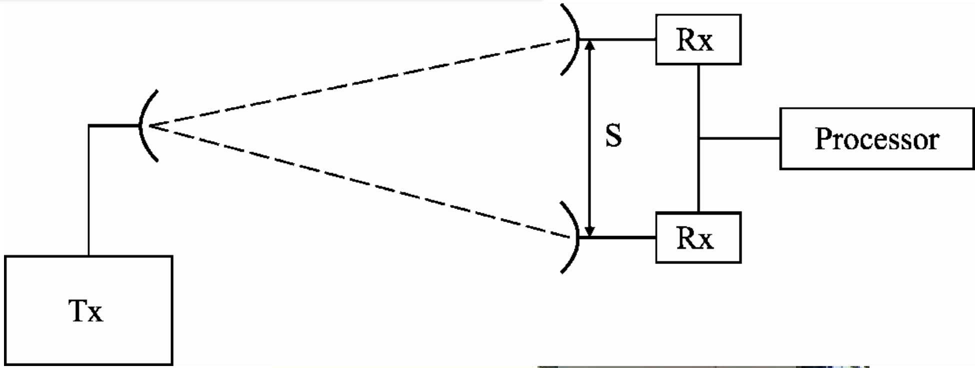


ATPC

- ATPC, Automatic Transmit Power Control techniques are utilized in microwave radio links in order to combat rain fading (attenuation).
- This is also sometimes referred to as power diversity.
- Initially, the link is designed such that the transmitter power is sufficiently large to achieve a given B.E.R., under clear sky conditions.
- When the link experiences an attenuation due to rain, the transmit power is increased gradually and up to the maximum transmission power limit set by a government authority

Spatial Diversity

- Spatial diversity (or MIMO, Multiple-Input, Multiple-Output): Sending and/or receiving redundant streams of information in parallel along multiple spatial paths
- If all paths are uncorrelated, they will not be degraded simultaneously, increasing reliability and range
- Channels are uncorrelated when s >≈ 1,5 λ
- Channels correlated, fade together when s <≈ 1,5 λ)



Receive diversity, or Single-Input, Multi-Output (SIMO):
Simplified diagram of the equipment in a Hop with Spatial diversity

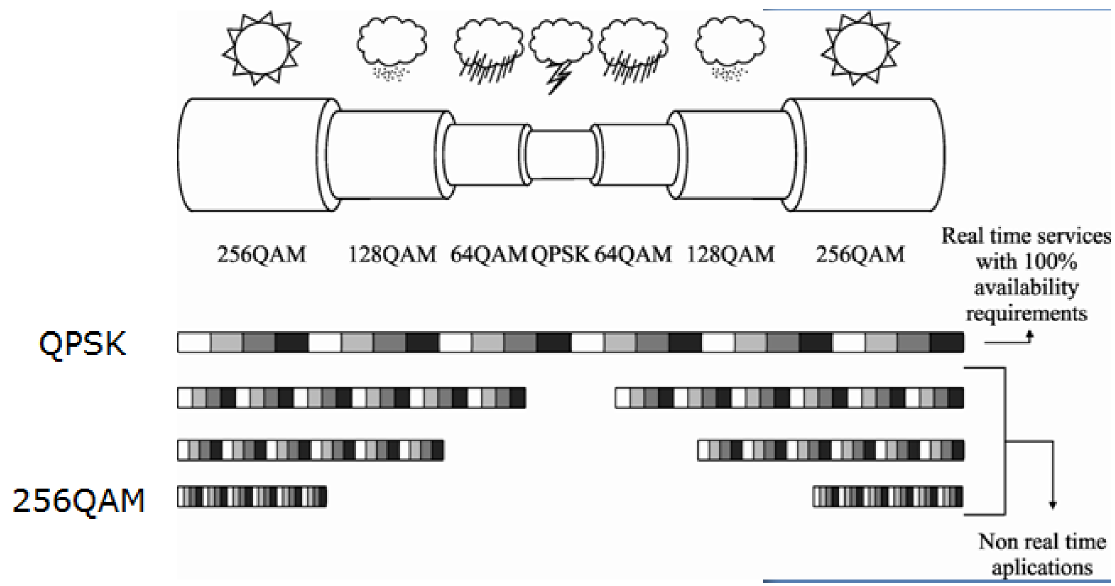
Frequency Diversity

- Frequency diversity allows the transmission of the same message signal at different carrier frequencies.
- In order for the received signals to be statistically independent or at least uncorrelated, the carrier frequencies must have a separation that is greater than the coherence bandwidth of the radio channel.
  - The coherence bandwidth depends on the multipath delay spread of the channel.
- Frequency diversity is utilized to adapt to severe signal fading in which identical information is transmitted by two frequencies, one is lower, the other is higher frequency.
  - Higher frequency:
    - Higher Bandwidth
    - Higher Throughput
    - Higher attenuation - Lower distance
    - Higher required Threshold at a given distance

ACM

ACM: Adaptive Coding and Modulation

- ACM adapts dynamically the modulation and coding scheme (MCS) according to the quality of the radio channel (propagation conditions) and thus the bit rate and robustness of data transmission.
- The link is designed to operate at its maximum throughput under clear sky conditions (highest CR and modulation order) to achieve a given B.E.R.
- Under rain fade, CR and modulation order decrease gradually, matching the required threshold at a given B.E.R., to path loss under rain.

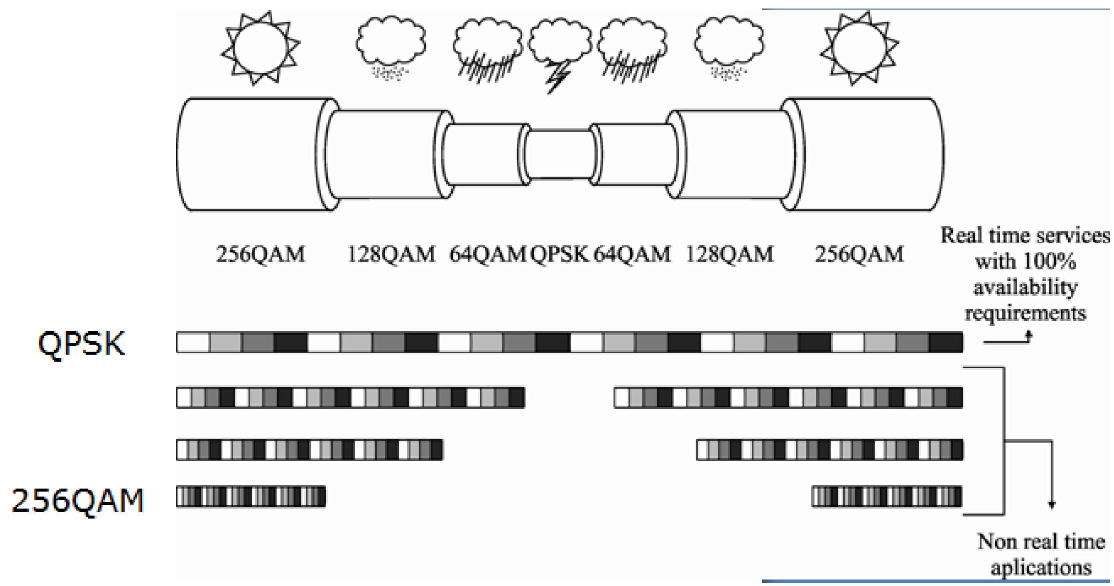


- Higher modulation order:
  - Higher Throughput
  - Higher required Threshold:
    - Lower Margin
    - Lower Path Loss
    - Lower rain attenuation
    - Lower rain rates
- Higher CR:
  - Higher Throughput
  - Higher required Threshold:
    - Lower Margin
    - Lower Path Loss
    - Lower rain attenuation
    - Lower rain rates

ACM

ACM: Adaptive Coding and Modulation

- Prior to the development of Automatic Coding and Modulation, microwave designers had to design for “worst case” conditions to avoid link outage
- For example a link can change from 256QAM down to QPSK to keep “link alive” without losing connection.



- The benefits of using ACM include:
  - Longer link lengths (distance)
  - Using smaller antennas (saves on mast space, also often required in residential areas) • Higher Availability (link reliability)

Contents

System Monitoring and Management

- The **aim of monitoring** and management tools is to obtain as much information as possible about the **state of the radio-relay link** at a specific moment as well as make maintaining operations easier.
- The management systems demand **a continuous stream of telemetry information** with access to the different monitored remote elements from the control system.
- **Integration with other superior management systems is made through interfaces with standardized protocols**.
- Operation and maintenance applications include different functions that are organized in modules: **failure management, performance management, configuration management and BER verification**.

System Monitoring and Management

- The system **performance management** function collects, stores and processes performance data of every element of the radio-relay link transmission network and produces quality reports adapted to the operation, maintenance and planning functions. The Bit Error Rate Testers are used to manage the performance quality.
- The **configuration management** function allows configuring network elements remotely, giving a permanent inventory of the network equipment.
- All these management functions can be integrated in an embedded application to control elements on a local basis. The access to this embedded application could be done directly from a PC with Ethernet or USB connections. Modern radio-relay links use remote access based on IP technology.

Contents

Propagation

Cause	*Effect*	*Description*	*Statistics*	*Degradation*
Refraction	Ray Bending	Curvature in the propagation path followed by the signal between transmitter and receiver	Depends on the statistics of the refractive index gradient along the transmitter receiver path	Fading by diffraction in terrain obstacles during extreme bending periods
	Ducting	Propagation confined between troposphere layers (ducts) or between layers and the Earth's surface	Depends on the probability of super-refractive troposphere occurrences	Flat Fading Selective Fading Long Distance Interference
	Troposphere Multipath	Propagation through multiple components that refract over different troposphere layers. The reflected component in the Earth's surface is sometimes also considered in the multipath ensemble.	Depends on the statistics of the refractive index gradient	Selective fading (distortion) in broadband systems (medium and high capacity links). Flat Fading in narrowband systems (low capacity links)
	Beam Spreading	Divergence (defocusing) of the radio signal. Caused because different components of the beam suffer different bending effects.	Depends on the statistics of the refractive index gradient	Enhancement Flat Fading

Propagation

Cause	*Effect*	*Description*	*Statistics*	*Degradation*
Refraction	Launch and arrival angle variation. (Beam misalignment effect)	Variation of the launch and arrival angle due to anomalous refraction values. The effect is a virtual pointing error between transmitting and receiving antennas.	Depends on the statistics of the refractive index gradient	Flat Fading
Terrain Diffraction	Attenuation	Diffraction on one or several terrain obstacles or artificial structures	Associated to the same statistics of the refractive index gradient. Under standard conditions diffraction should not occur in a FWS	Flat Fading
Vegetation Effects	Attenuation Depolarization	Absorption associated to the leaves and branches of vegetation, usually trees.	Variable as a function of the foliage cycles and wind	Flat Fading, Scintillation and depolarization
Troposphere Absorption	Attenuation	Energy Absorption of molecules forming the lower troposphere: Oxygen and Water Vapor	Depending mostly on water vapor density statistics, as oxygen concentration is assumed to be constant.	Attenuation

Propagation

Cause	*Effect*	*Description*	*Statistics*	*Degradation*
Hydrometeors	Absorption	Energy absorption by rain drops, mist/clouds water particles and snow flakes	Hydrometeor statistics. Specific models provided by the ITU-R	Attenuation
	Depolarization	Change in the polarization of the wave front caused by the non-spherical shape of rain drops, snow flakes or ice particles	Hydrometeor statistics (ITU-R)	Fading due to coupling losses in the antenna (gain) associated to depolarization Intra-system interference in dense reuse scenarios, both in the same or in different links

Contents

Frequency band and equipment choice

Capacity of a Microwave LOS Link

$$B_{RF} = (1+\alpha)\ V_b \frac{1}{\log_2 M}$$

α	Roll-off factor of the channel filter ($0 < \alpha < 1$)
V_b	Gross bit rate of the modulated signal in bit/s
M	Number of modulation levels

- The net bitrate is increased 5% over gross bitrate.
- This increase is produced in information processing stages and baseband data aggregation
  - Forward error correction (FEC)
  - Additional overhead bits for maintenance, supervision or internal service of the system
  - Internal multiplexing of several standardized bit streams

Frequency band and equipment choice

- Frequency Selection and Calculating Capacity
  - Microwave links range from 2.4 GHz to 90 GHz spectrum.
  - The higher the frequency, the higher the available capacity but at the same time, the effective range is lowered and the link would be more susceptible to rain or high humidity.
  - To use a frequency, a license should usually be obtained from the legal authorities of the country. There are also a few frequency bands that are “license-free” – mainly 2.4GHz, 5GHz and 24GHz.
  - As the capacity increases, you would need to design the link for a higher C/N, resulting the need for stronger equipment and antennas.

- Most frequency bands used by Point-to-Point Fixed links rely on a licensed, mostly link by link coordinated regime.

Frequency band and equipment choice

- Frequency Bands

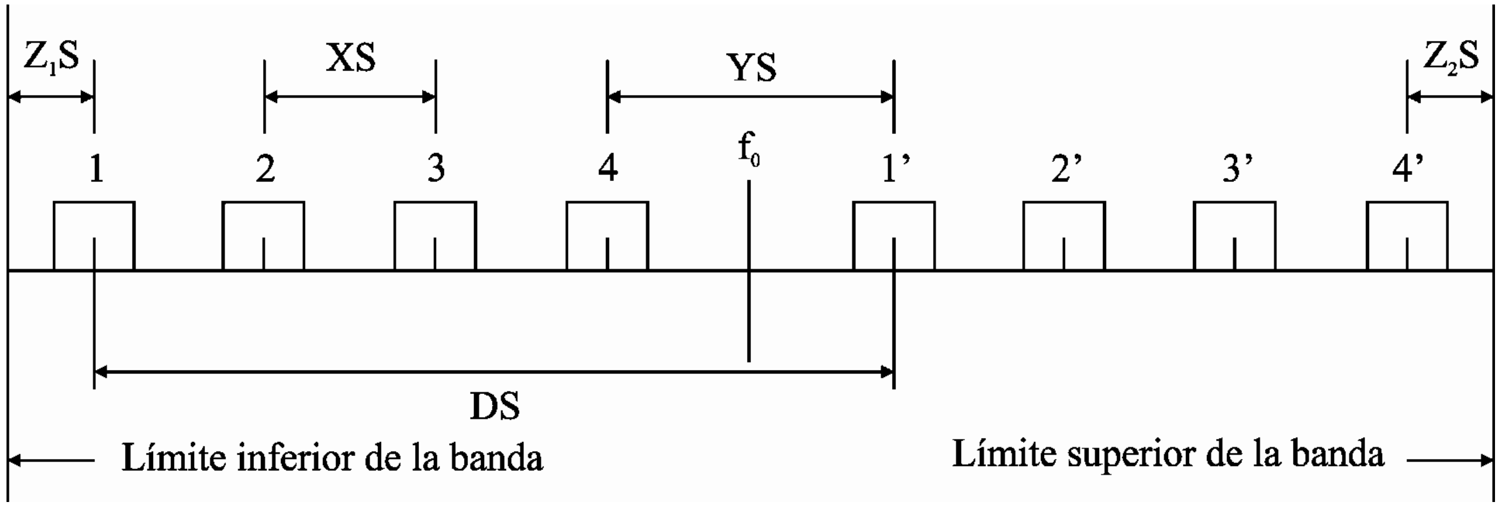
Band (GHz)	Frequency range (GHz)	Channel separation (MHz)	ECC (CEPT/ERC) Recommendations	ITU-R Recommendations
3,5	3,410 to 3,600	1,75 to 14	14-03 [i.12]	-
4	3,600 to 4,200	1,75 to 60	(12)08 [i.13]	F.635-6 [i.32] F.382-8 [i.33]
U4	4,400 to 5,000	28, 56, 60	-	F.1099-4 [i.34]
L6	5,925 to 6,425	3.5 to 59,3	(14)01 [i.14]	F.383-8 [i.35]
U6	6,425 to 7,100	3.5 to 60	14-02 [i.15]	F.384-11 [i.36]
7	7,125 to 7,725	1,75 to 56	(02)06 [i.16]	F.385-10 [i.37]
8	7,725 to 8,500	1,75 to 59,3	(02)06 [i.16]	F.386-8 [i.38]
10,5	10,000 to 10,680	3,5 to 56	12-05 [i.17]	F.747-1 [i.39]
11	10,700 to 11,700	7 to 56	12-06 [i.18]	F.387-12 [i.40]
13	12,75 to 13,25	1,75 to 56	12-02 [i.19]	F.497-7 [i.41]
15	14,5 to 15,35	1,75 to 56	12-07 [i.20]	F.636-4 [i.42]
18	17,7 to 19,700	13,75 to 110	12-03 [i.21]	F.595-10 [i.43]
23	22,0 to 23,6	3,5 to 112	T/R 13-02 [i.22]	F.637-4 [i.44]
26	24,5 to 26,5	3,5 to 112	T/R 13-02 [i.22]	F.748-4 [i.45]
28	27,5 to 29,5	3,5 to 112	T/R 13-02 [i.22]	F.748-4 [i.45]
31	31,0 to 31,3	3,5 to 28/56	(11)01 [i.23]	F.746-10 [i.46]
32	31,8 to 33,4	3,5 to 112	(01)02 [i.24]	F.1520-3 [i.47]
38	37,0 to 39,5	3,5 to 112	T/R 12-01 [i.25]	F.749-3 [i.48]
42	40,5 to 43,5	7 to 112	(01)04 [i.26]	F.2005 [i.49]
50	48,5 to 50,2	3,5 to 28	12-11 [i.27]	-
52	51,4 to 52,6	3,5 to 56	12-11 [i.27]	F.1496-1 [i.50]
55	55,78 to 57,0	3,5 to 56	12-12 [i.28]	F.1497-1 [i.51]
60	57 to 64	n*50	(09)01 [i.29]	-
64	64 to 66	n*30, n*50	(05)02 [i.30]	-
70	71,0 to 76,0	250 to 2 250	(05)07 [i.31]	F.2006 [i.52]
80	81,0 to 86,0	250 to 2 250	(05)07 [i.31]	F.2006 [i.52]
70 /80 paired	71,0 to 76,0 paired with 81,0 to 86,0	250 to 4 500	(05)07 [i.31]	F.2006 [i.52]
92	92 to 95 (see note)	50 to 400	(14)01 [i.14]	F.2004 [i.53]
95	95 to 100	-	-	-
102	102 to 105	-	-	-
105	105 to 109.5	-	-	-
110	111,8 to 114,25	-	-	-
	122,25 to 123	-		
130	130 to 134	-	-	-
	141 to 148,5	-	-	-
	151,5 to 164	-	-	-
	167 to 174,8	-	-	-
	191,8 to 200	-	-	-
	209 to 226	-	-	-
	231,5 to 235	-	-	-
	238 to 241	-	-	-
	252 to 275	-	-	-

NOTE: 94 GHz to 94,1 GHz band is not available for FS.

Frequency band and equipment choice

Radio Channel Arrangement Plans

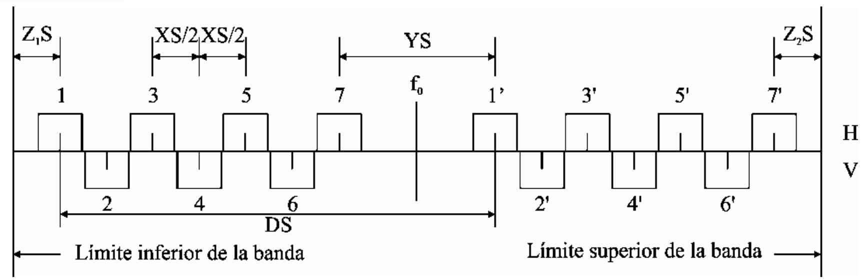
Most channel plans are typically FDD

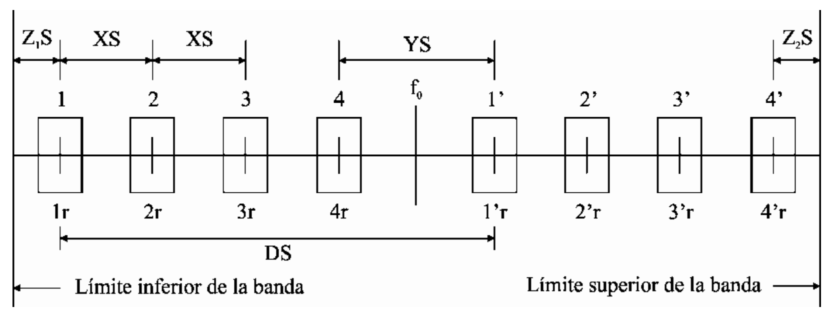


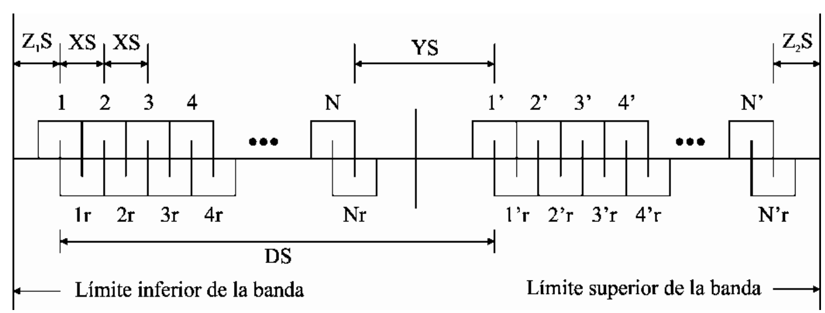
Frequency band and equipment choice

Radio Channel Arrangement Plans

- Alternated
- Co-channel
- Interleaved

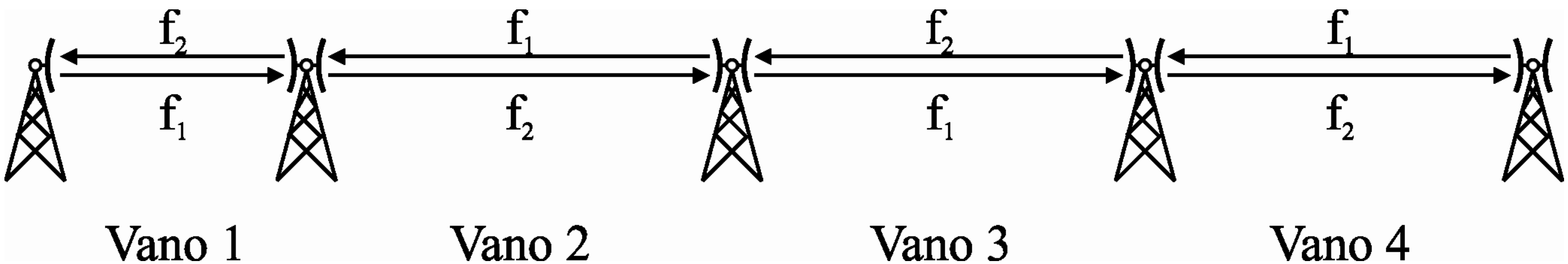


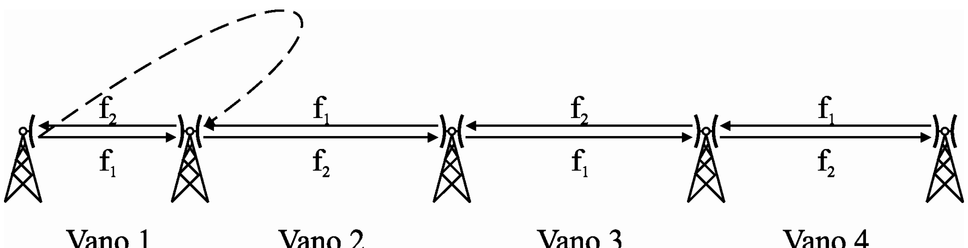




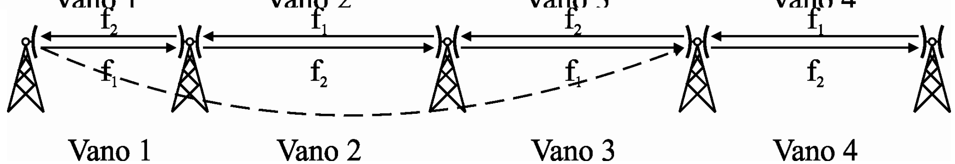
Frequency band and equipment choice

Frequency Plans: 2 Frequencies

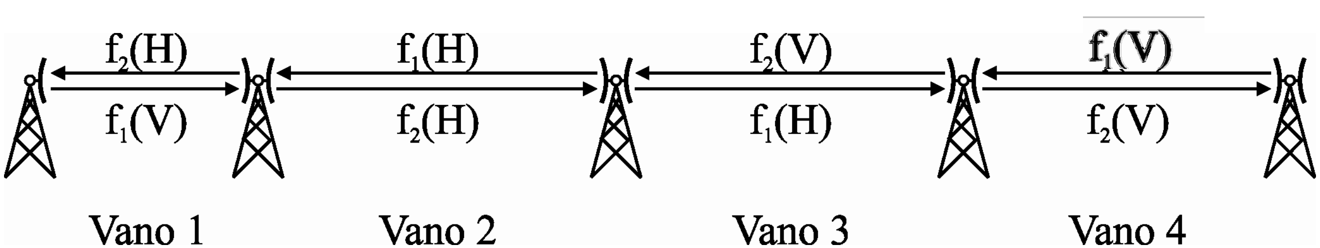




Co-channel interference caused by neighbouring stations



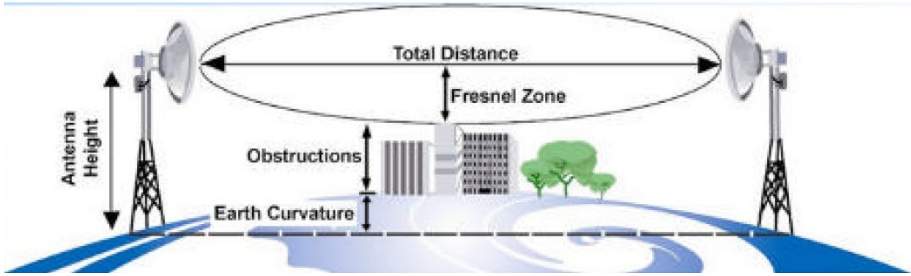
Over-shoot interference in two frequency plans.



Contents

Link path engineering

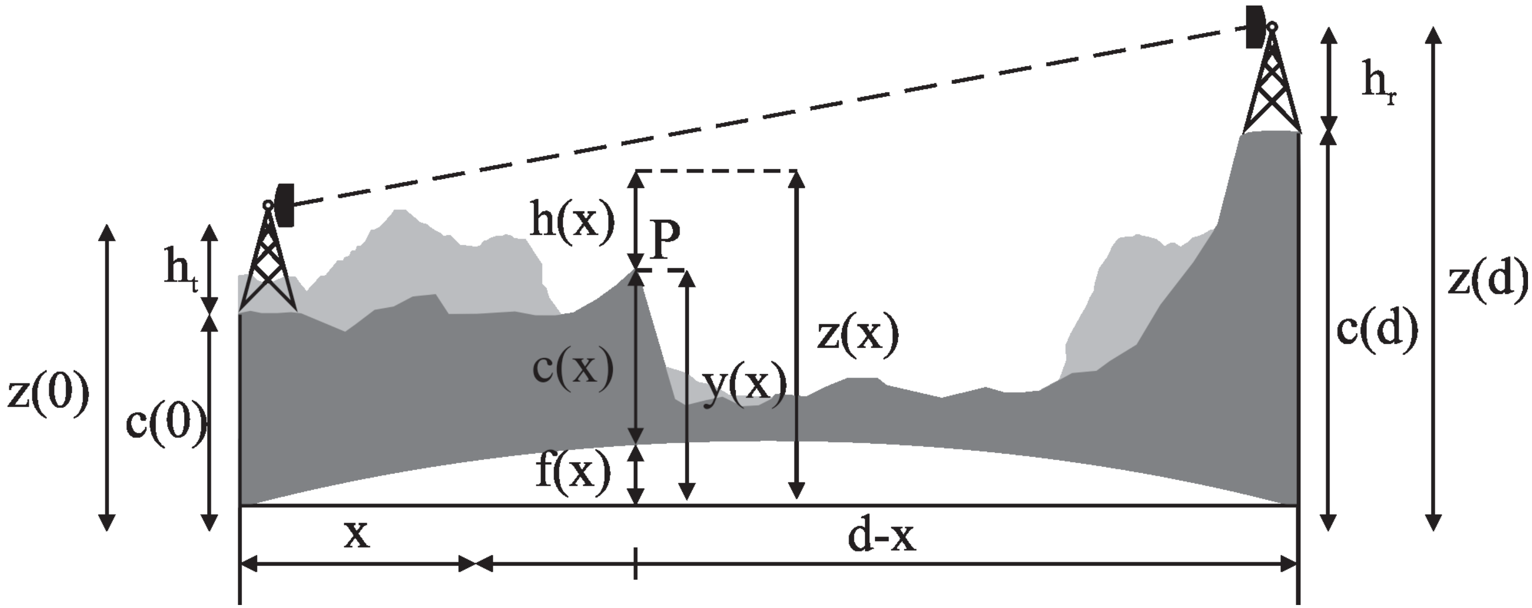
- Also referred as Path engineering analysis
- Studies the alternatives for providing a line of sight (LOS) path between transmitting and receiving antennas
- Clearance high enough to avoid diffraction even in the case of rough troposphere conditions (severe subrefraction)
- Calculations
  - location of each of the nodes of the link (repeater stations),
  - Dimensioning
    - transmission site
    - building and equipment room
    - power supply
    - Access
    - Towers
    - antenna installation special requirements.
  - Interference problems



- Line of sight (LOS) clearance is based on geometrical calculations:
  - topographical databases: path profile extraction
  - Signal path
  - Analysis of diffraction or reflection
- Software tools support the task of decision making

Link path engineering

Profile extraction, clearance and obstructions



$$f(x) = \frac{x(d-x)}{2kR_0}$$

Link path engineering

Optimum choice of antenna heights

Compromise between a series of factors, that include propagation aspects as well as practical criteria:

- Guarantee the **absence of obstacles** that block the Line of Sight
- Minimize the presence of **multipath propagation** fading phenomena: paths with low inclination are more likely to suffer multipath fading
- Minimize the **impact of reflections** on the Earth's surface: links over bodies of water, and in general, flat profiles with good conductivity.
- **Minimize interferences**

Link path engineering

Optimum choice of antenna heights

Reference: ITU-R P.530

1. Clearance over the highest obstacle equal to the first Fresnel ellipsoid R1 assuming the median value of the k factor (if the median is not available the default k=4/3 will be supposed). This condition applies both in temperate and tropical climates.

2. For the effective k factor value, *ke*, exceeded the 99,9%

Temperate climate	Tropical climate
Clearance: 0.0 R_1 (i.e. grazing) if there is a single isolated path obstruction	Clearance: 0.6 R1 for path lengths greater than about 30 km
Clearance: 0.3 R_1 if the path obstruction is extended along a portion of the path	

Contents

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Threshold Analysis

- The legacy links (SDH or PDH) have been designed according to two criteria:
  - Availability:
    - Statistics associated to the periods where the link is degraded severely, when we could state that the link is in a state equivalent to inactivity.
    - Availability has been considered since long time as a kind of indicator of a serious event. For this reason, a minimum criterion of 10 consecutive seconds base time of service interruption has been adopted to declare this condition.
  - Error Performance:
    - Statistics associated to periods where the link is active. Degradation might occur but not below availability threshold
    - Causes of error performance degradation: Flat Fading // Selective Fading // Rain Absorption
    - Design objective parameters: Link budget (fixed losses) + Flat Fading Statistics (only if Flat Fading is the key factor) + Rain Fading Statistics

Determination of system operation thresholds and system margins

Thresholds:

- Error parameters are associated with B.E.R. and power threshold values:
  - B.E.R. shows the % of bits of data with errors vs the total number of bits that have been transmitted during a period of time. The value is usually expressed as 10 to a negative power. The lower this figure, the better is the link quality. Good BER rates are usually in range of 10^{-8} or better.
    - SESR: Severely Errored Second Ratio
    - BBER: Background block error ratio

Criterion		*ITU Recs.*	*B.E.R*	*Associated Power Threshold*
SESR	Availability		10^{-3}	T_{h3}
SESR	Error Performance	ITU-T: G.826, G.828,G.829 ITU-R F.1668	10^{-6}; 1,7 10^{-5}	T_{h6}, T_{h5}
BBER	Error Performance	ITU-T: G.826, G.828,G.829 ITU-R F.1668	10^{-12}	T_{h12}

  - Thresholds are usually provided by the manufacturer. If this was not the case, as they depend on the modulation scheme and the internal noise of the receiver units, it will be necessary to obtain them from theoretical calculations for each modulation and coding scheme plus a penalization associated to practical implementation.

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Threshold Analysis

- Since the advent of packet based networks, shorter time bases, were proposed in contests other than ITU.
- Availability and quality or performance error are referred to percentages of time in which a given B.E.R is exceeded (Thresholds)
- The receiver's sensitivity defines the minimum level of the received signal at which the receiver is able to process the signal without losses or affecting the transmitted data (for BER better then 10^{-6}).
- A reliable microwave link should have link availability in range of 99,9 ÷ 99,999 %

Determination of system operation thresholds and system margins

Thresholds:

- In order to obtain the margins, the first step is to calculate power thresholds associated to error events (actually associated to BER).
- Thresholds are related to the parameter w necessary to obtain this power threshold in the receiver.

$$w = \frac{e_b}{n_o} = \frac{T_h}{kT_o fR}$$

or in dB units:

$$\mathrm{T_h}(dBm) = W(dB) + F(dB) + 10\log R(bits/s) - 174$$

where:

$\mathrm{T_h}$	Power level threshold associated to a specific BER
K	Boltzman Constant
T_0	Standard Temperature (usually 270º)
f	Receiver noise figure
R	Bitrate

Determination of system operation thresholds and system margins

- BER values (10^{-3} and 10^{-6}) can be associated with w =E_b/N_o for different modulation schemes:

	E_b/N_0 (dB)@(BER=10^{-3})	E_b/N_0(dB)@(BER=10^{-6})
BPSK	6.8	10.5
QPSK	6.8	10.5
4DPSK	9.1	12.8
8 PSK	10.0	13.8
16 QAM	10.4	14.4
64 QAM	14.7	18.8
256 QAM	19.3	23.5

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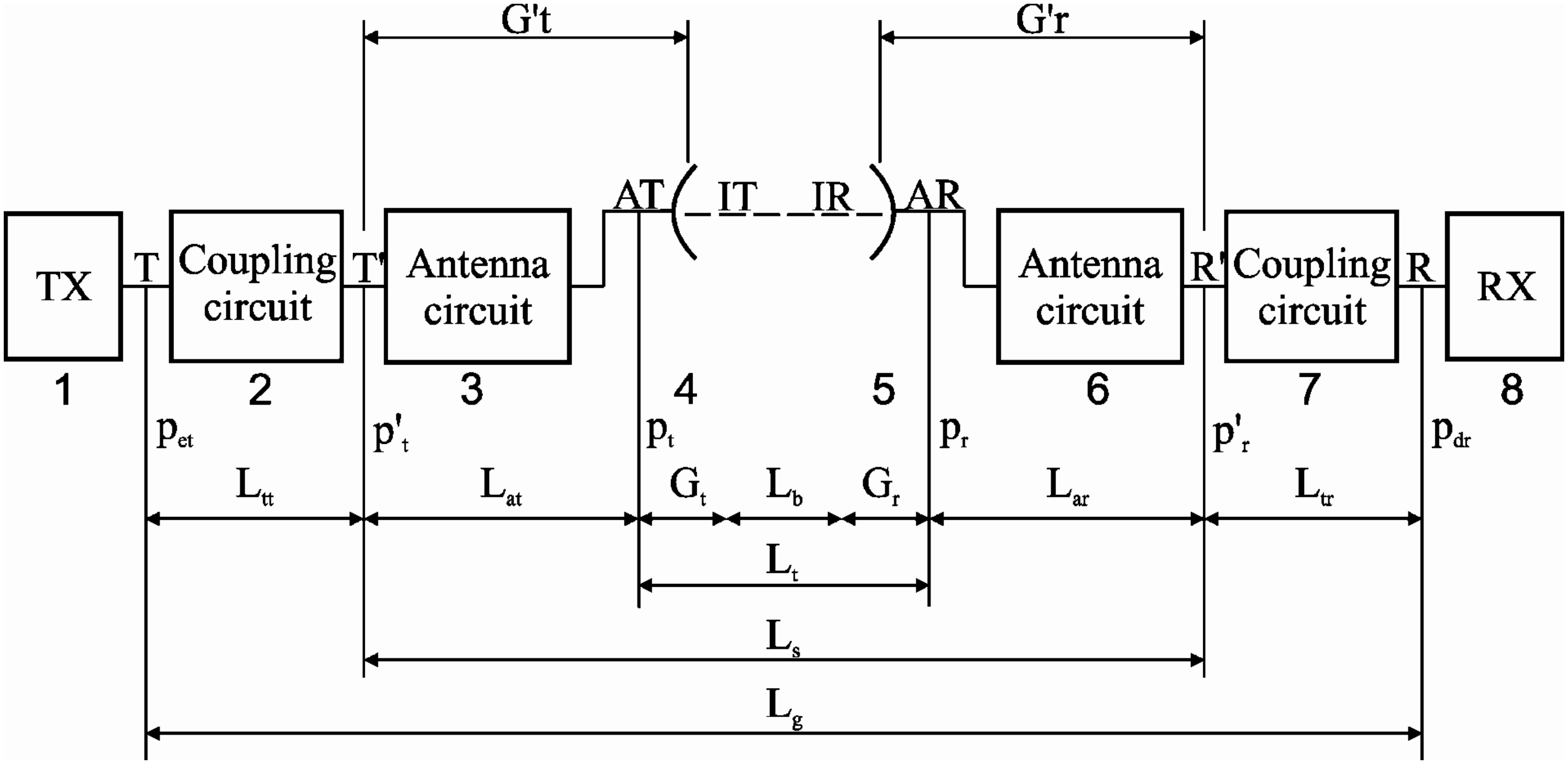
Link Budget



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Link Budget

- *P_{tx} (dBm)* Power delivered by the transmitter to the antenna circuit
- *P'_t (dBm)* Power delivered to the real antenna at the input of the Antenna Circuit (lossy)
- *P_t (dBm)* Virtual power delivered to the ideal loseless antenna and equivalent to the total radiated power
- *EIRP (dBm)* Equivalent Isotropic Radiated Power in the direction to the receiver
- *P_r (dBm)* Available power (virtual) in the loseless ideal receiving antenna
- *P'_r (dBm)* Available power (real) at the Antenna Circuit output (coupling network input)
- *P_{rx} (dBm)* Available power at the receiver input

Link Budget

- Ltt Losses on the antenna Distribution and Coupling Circuits, between T and T' interfaces
- Lat Losses on the Antenna Circuits on the transmission side, between T' and AT interfaces
- Ltr Losses on the Distribution and Coupling Circuits connecting the antenna and the receiver, between R' and R interfaces
- Lar Losses on the Antenna Circuits on the receiver side, between AR and R' interfaces

- Lb Basic propagation loss , function of the distance, frequency and propagation mechanism
- Lt Transmission loss. It is calculated as the basic propagation loss minus the ideal antenna gains (transmitter plus receiver)
- Ls System loss. It represents the difference in levels between the input ot the real antenna in transmission and the output of the real antenna at the receiver side
- Lq Total loss, defined between the transmitter output and the receiver input

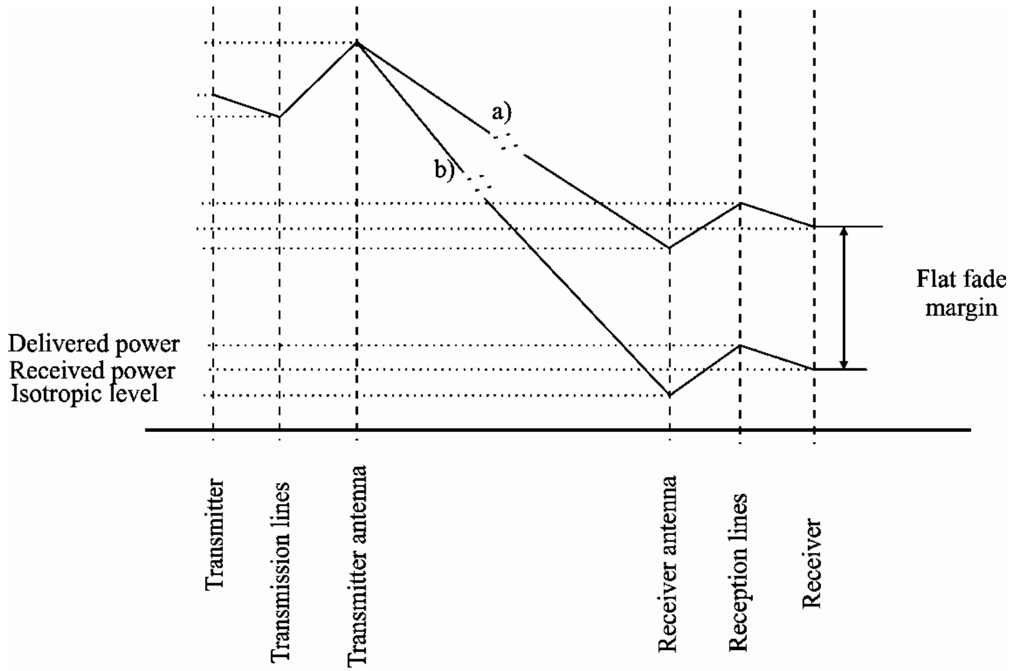
Link Budget

$$P_{rx} = P_{et} - L_{tt} + G_t - L_b + G_r - L_{tr}$$

where

P_{rx} *(dBm)*	Available power level on the receiver input
P_{tx} *(dBm)*	Power delivered by the transmitter to the antenna distribution network
L_{tt} *(dB)*	Losses associated to the antenna distribution network (transmitter to antenna)
L_{tr} *(dB)*	Losses associated to the antenna distribution network (antenna to receiver)
L_b *(dB)*	Basic propagation loss
G_t *(dB$_i$)*	Transmitter antenna gain (directive gain, assuming negligible antenna losses)
G_r*(dB$_i$)*	Transmitter antenna gain (directive gain, assuming negligible antenna losses)

Link Budget



Transmission medium

a)Fixed basical losses

- L_{fs} : Propagation basical loses (free space)
- L_{gases} : Gases and water vapor absortion
- $L_{vegetation}$: Vegetation attenuation

b) Time-varying losses in excess

- $L_{difraction}$: Diffraction losses (anomalous difraction)
- $L_{scintillation}$: Atmospheric scintillation losses
- L_{rain}: Losses due to rain and other hydrometeors
- $L_{mutipath}$: Losses due to multipath
- $L_{beam\ spreading}$: Fading due to beam spreading

Determination of system operation thresholds and system margins

Gross Margin & System Gain

- Gross Margin, also called thermal noise margin or System operating margin, is the difference (in dB) between the nominal signal level received (level received in nominal conditions) and the threshold power level (signal level required by that radio to assure that a packet of data is decoded with an associated BER).
- System Gain is the difference (in dB) between the nominal transmitter Power and the threshold power level

Determination of system operation thresholds and system margins

Gross Margin & System Gain

- If we designate:
  - Gross Margin as M_3 ,M_5 ,M_6 and M_{12} associated to a BER of 10^{-3} 1,7 x 10^{-5}, 10^{-6} and 10^{-12}. (dB)
  - System Gain as GS_3, GS_5, GS_6, and GS_{12} (dB)
  - Threshold power as T_{h3}, T_{h5}, T_{h6}, and T_{h12} (dBm)
  - C the nominal received power (dBm)
  - P_t the nominal received power (dBm)

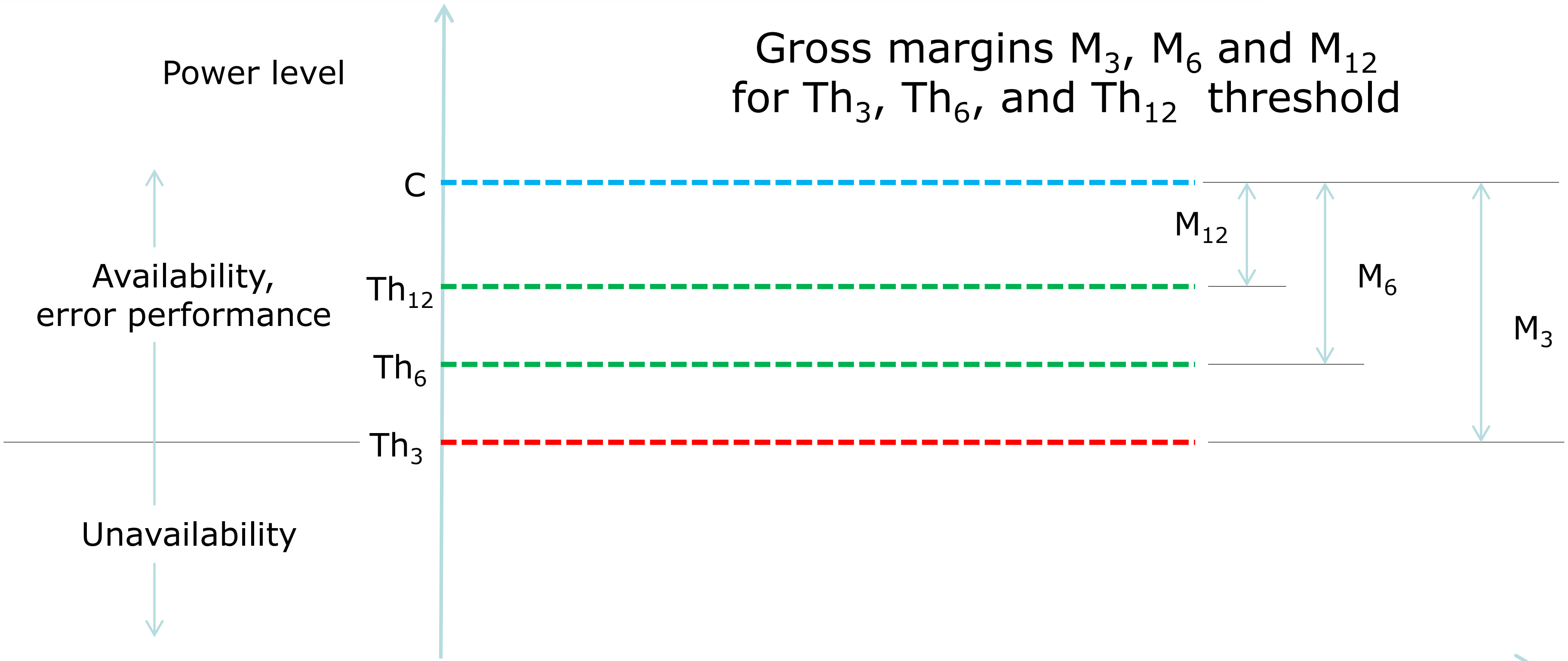
$$M_3 = C - T_{h3} \qquad GS_3 = P_t - T_{h3}$$

$$M_5 = C - T_{h5} \qquad GS_5 = P_t - T_{h5}$$

$$M_6 = C - T_{h6} \qquad GS_6 = P_t - T_{h6}$$

$$M_{12} = C - T_{h12} \qquad GS_{12} = P_t - T_{h12}$$

Determination of system operation thresholds and system margins



Th_3 : Threshold power for B.E.R. = 10^{-3}. Associated to availability.
Th_6 : Threshold power for B.E.R. = 10^{-6} . Associated to error performance.
Th_{12} Threshold power for B.E.R. = 10^{-12} . Associated to error performance.

C : Power received at nominal conditions: Maximum transmitted power, perfect alignment of antennas and $L_{OTHER\ PROPAGATION}$ including all present losses, except rain losses.

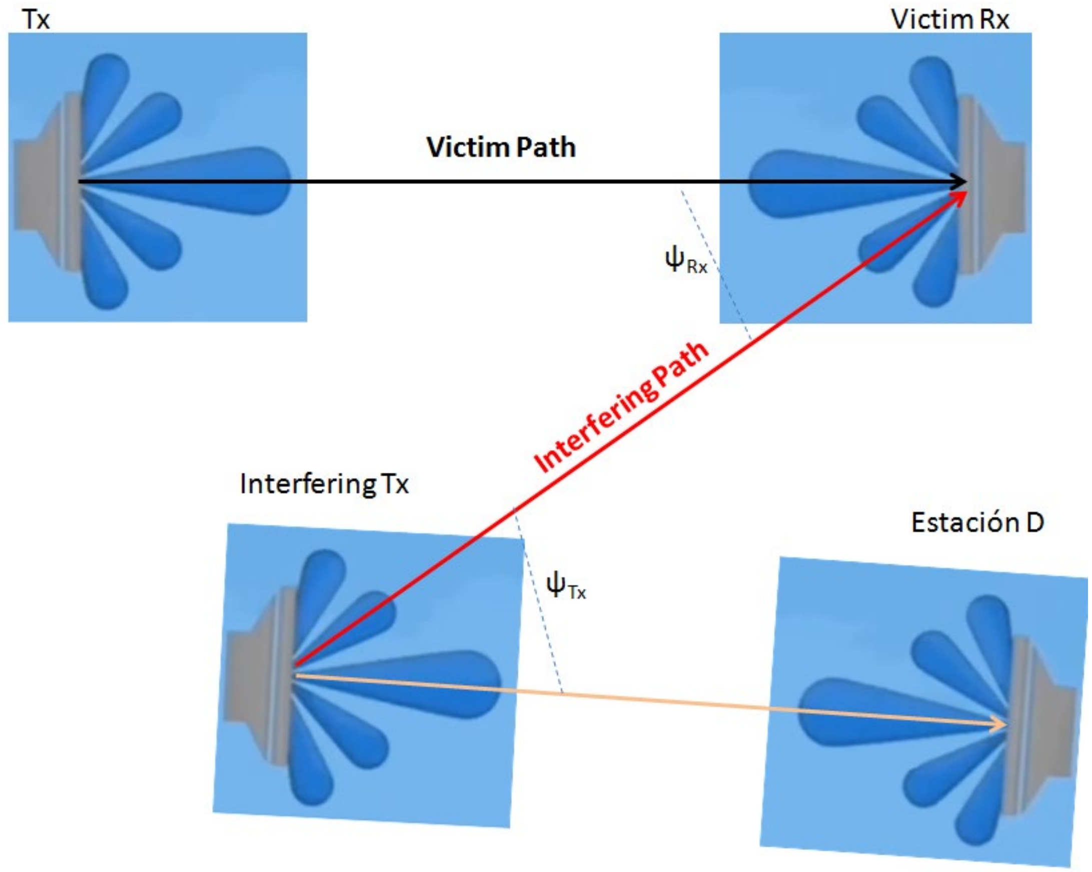
Contents

Interference Analysis

- In practice, the Gross Margin is not the only determining factor.
- It's the actual C/(N+I) at the receiver that makes a link reliable if co-channel interference is present when the radio station is co-locating at a site with other radios operating in the same band:
  - If noise is the dominant effect the *C*/*N* ratio can be used: This ratio is measured by dB and shows the strength of signal vs the noise level for that bandwith channel. The higher the value, the better but it should be at least 20 dB.
  - If interference is the main effect the *C*/*I* ratio is used.
  - In many cases the interference is considered as noise and the *C*/(*N*+*I*) is used. (In this case degradation power = n + i)

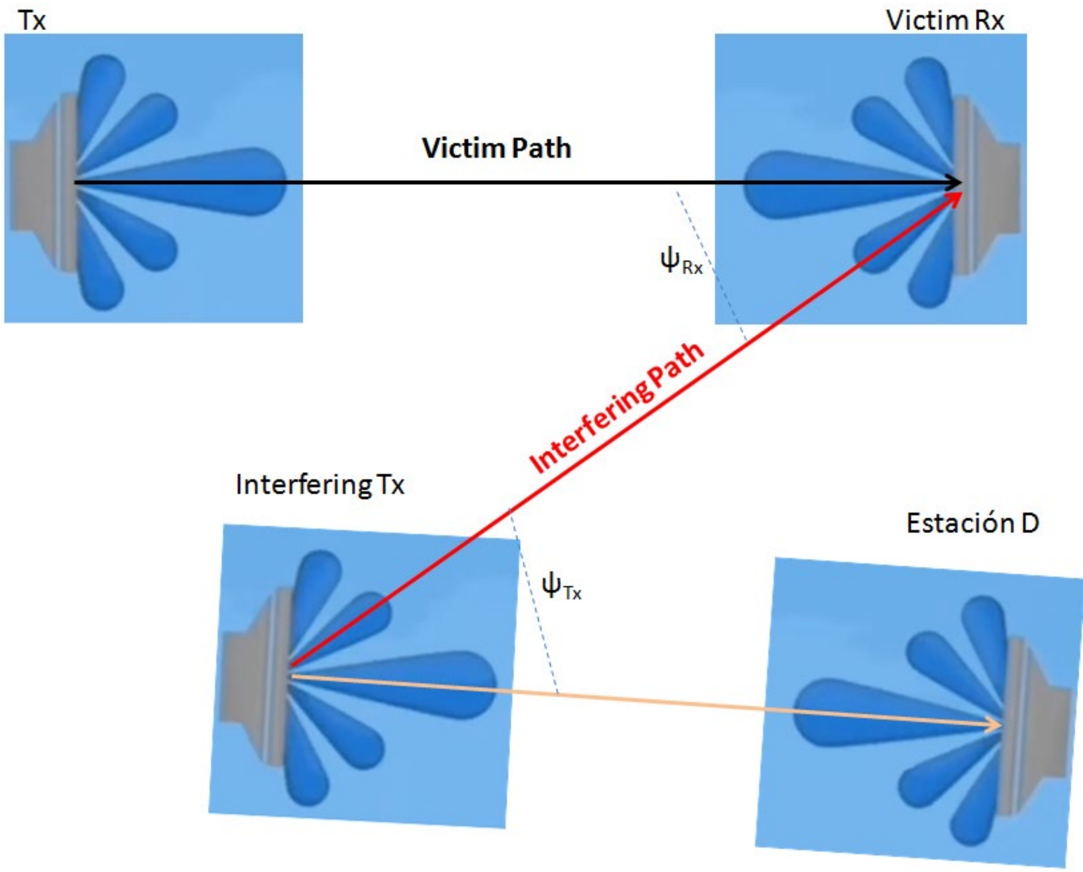
Interference Analysis

- Interference calculations (C/I)
  - C is calculated as received power in worst conditions in the link budget of victim path.



Interference Analysis

- Interference calculations (C/I):
- I is calculated as nominal received power in the link budget of interfering path:
- $G_t(\psi_{Tx})$: Transmit antenna effective gain in the direction of the victim antenna (angle ψ_{Tx} between the direction of main beam and direction towards victim antenna)
- $G_r(\psi_{Tx})$: Receive antenna effective gain in the direction of the interfering antenna (angle between the direction of main beam and direction towards interfering transmitting antenna)



Propagation Calculations

Basic propagation loss	L_{fs}	Free space loss
Basic Fixed Losses in excess to the free space loss L_{bexc}	L_{gases}	Gas (O_2) and water vapor (H_2O) absorption
	$L_{vegetation}$	Vegetation attenuation values.
Basic Variable Losses in excess to the free space loss L_{bexv}	$L_{difractionn}$	Diffraction in obstacles (caused by anomalous refraction, see Chapter 2)
	$L_{scintillation}$	Tropospheric Scintillation Fading
	$L_{hydrometeors}$	Fading caused by rain and other hydrometeors
	$L_{multipath}$	Multipath fading, including reflection effects on earth surface and multipath originated due to various refraction phenomena in higher troposphere layers.
	L_{XPD}	Depolarization losses (associated to hydrometeors and anomalous refraction)
	$L_{misaligment}$ $L_{beam\ spreading}$	These losses are caused by anomalous refraction conditions.

Losses and fading associated to different propagation phenomena.

Propagation Calculations

Frequency	*Propagation phenomenon*	*Disturbance in the radio link*	*Affected objective*
F_0 < 10 GHz	Anomalous Refraction[1]	Medium and high capacity links: Distortion/Selective Fading	Error Performance
		Low capacity links: Flat Fading	Availability and Error performance[2]
F_0 > 10 GHz	Hydrometeors	Flat Fading	Availability

(1)We assume the route is designed in such a way there are no diffraction losses related to subrefraction

(2)We do not have data for predicting duration of anomalous refraction effects. In hops of typical length below 10 GHz we assume that availability objectives are complied if error performance objectives are complied

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Propagation Calculations

Impact of propagation phenomena

- Recommendation ITU-R P.530 provides prediction methods for the propagation effects that should be taken into account in the design of digital fixed line-of-sight links:
  - Methods for calculating rain absorption statistics (availability target)
  - Methods for calculating flat fading statistics (error performance target)
  - Method for calculating selective fading statistics (error performance target)
  - Methods for calculating other perturbance sources: e.g. XPD reduction
  - Methods for calculating the impact of redundancy and diversity schemes.

Chapter 4. Fixed Service Systems

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