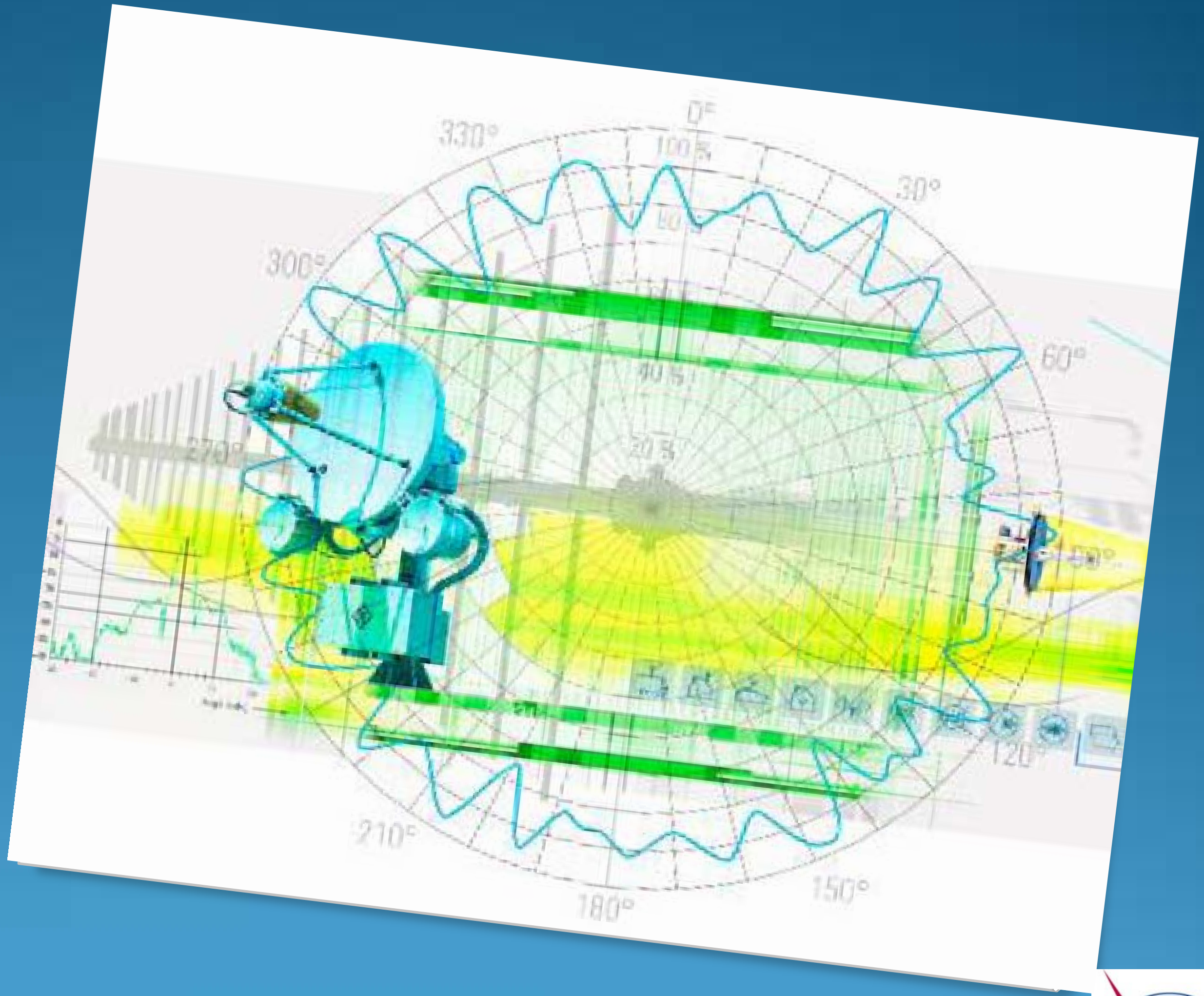
# Agenda

- Day 1 - Basics  of Satellite Communications
- Day 2 - Policy and Regulatory Guidelines for Satellite Services (first half / second half)
- Day 3 - Network Planning and Link Budget Analisys
- Day 4 - Vsat Installation and Maintenance
- Day 5 - Vsat Equipment and Bandwith Procurement

# Day 3

## NETWORK



# Network planning

- Vsat network topologies
  - Point  2 Point links
  - Star Networks
  - Mesh Networks
  - Broadcast
  - Hybrid Networks
- Access Schemes
  - SCPC
  - TDMA
  - FDMA

…

# Network planning

…

- Frequency Bands
  - C band
  - $K_u$ band
  - $K_a$ band
- Baseband Signals
- Digital Communications Techniques
- Link Budget Analysis

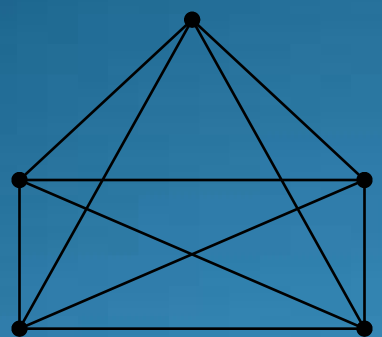
# Network planning
## (vsat network topologies)

- Basic concept for communications between 2 points is a direct connection. If the number of terminals increases more the complexity for the design and some specification shall be applied to define if A connects only with B or if also with B and C or this last is connected only via B.
- Assume for instance the connection of all the terminals among them e.g:
  - n x (n-1) / 2 ( being n the nodes number)
  - to 5 nodes for instance will mean 10 connections, and so on

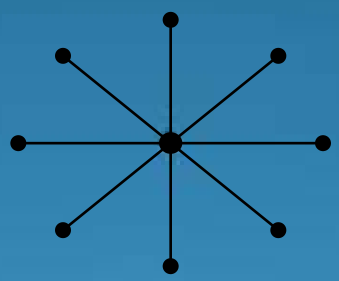
# Network planning (vsat network topologies)

- We are discussing the type of network and its associated cost of implementation
- The covered area can be LAN, WAN, MAN if we refer to a dispersion of users of up to 5Km, about 50Km or above.
- Generically the topologies to be used are in the following slide

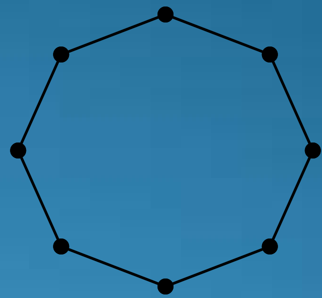
# Network planning
# (vsat network topologies)



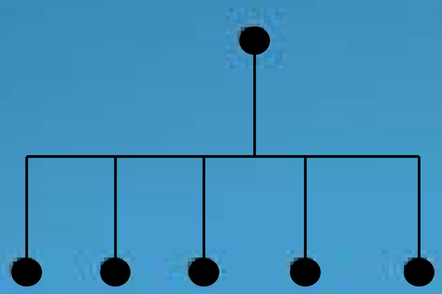
Mesh - Common WAN & MAN
complete redundancy



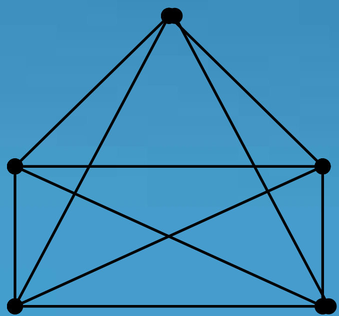
Star - Critical central node



Ring - common LAN
critical node fails

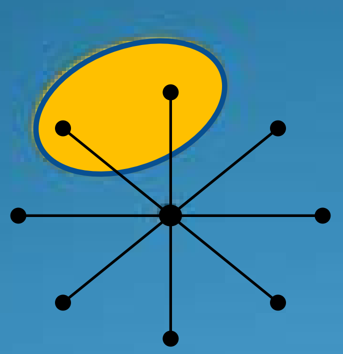


Bus - Common LAN, easy nodes
increase, any node might control

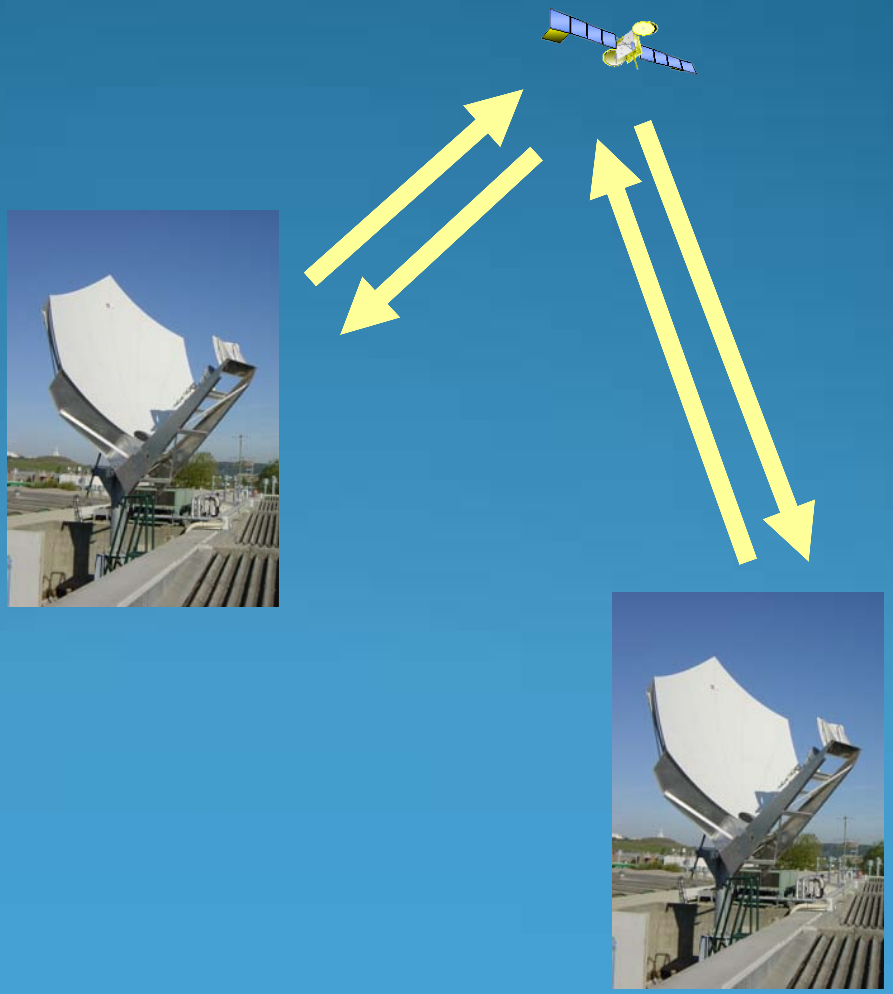


Hybrid - mesh through wired
ehternet and wireless
(sat, WiFi,WiMax)

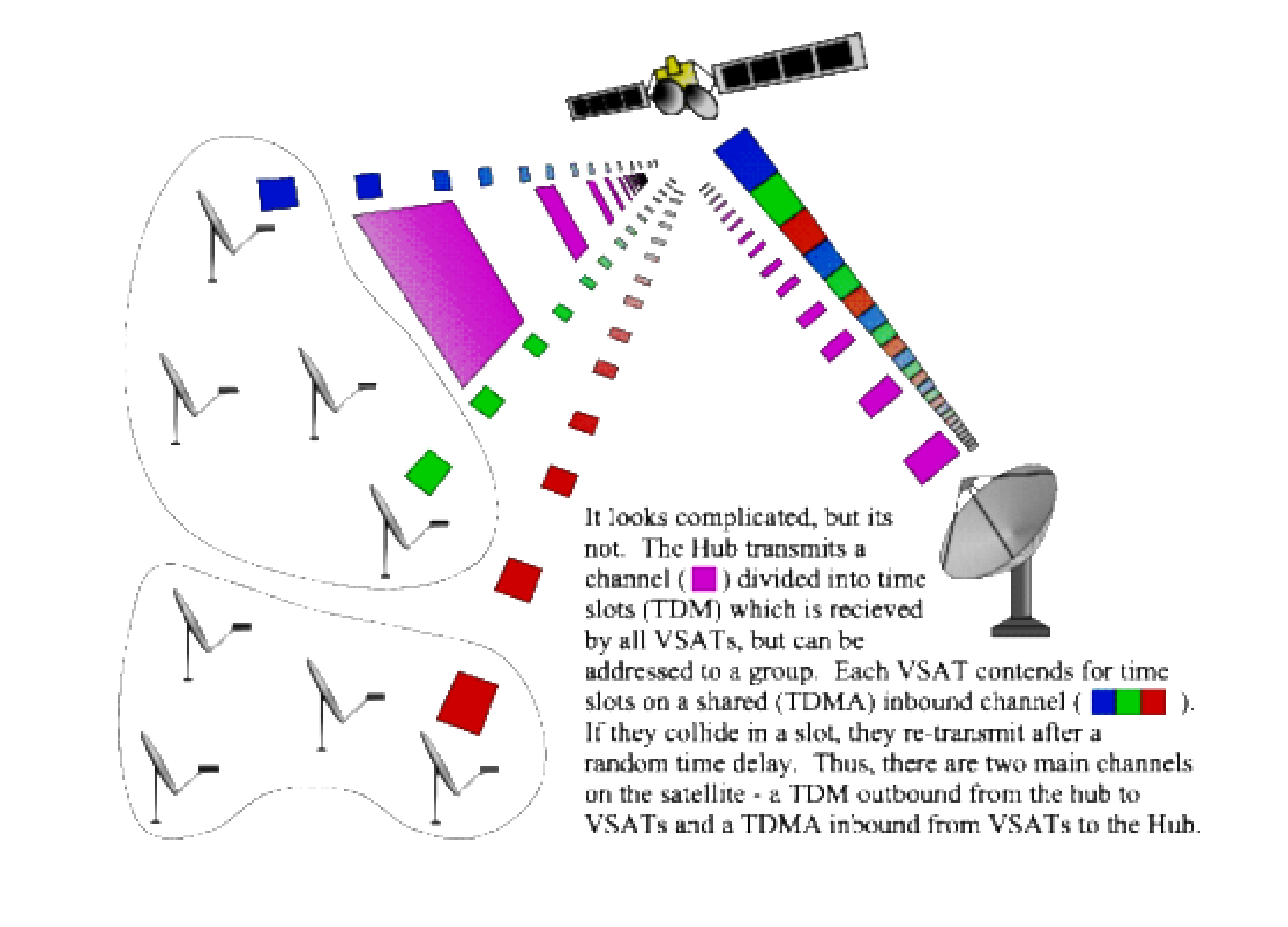
# Network planning
## (point 2 point links)



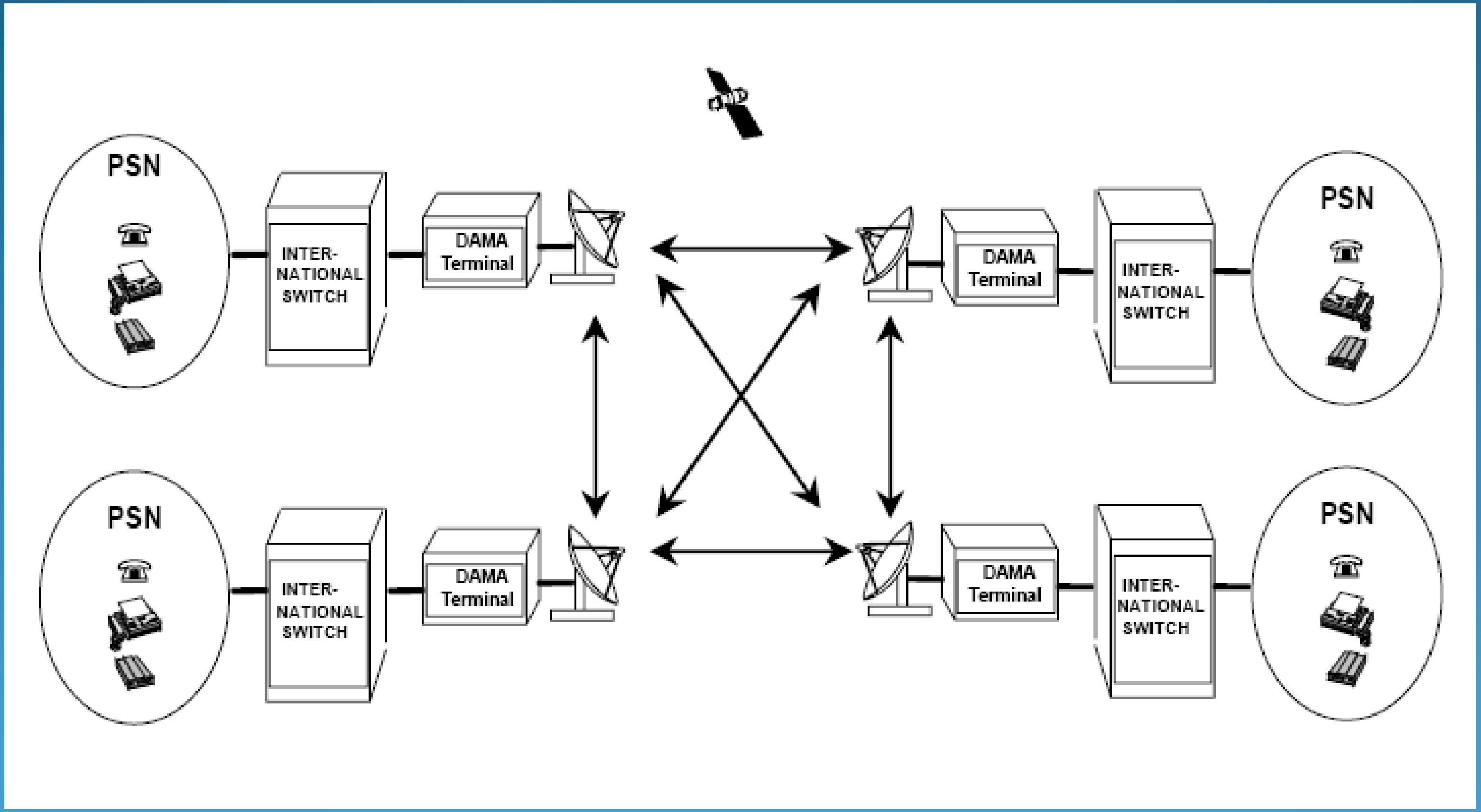
Star - Critical central node



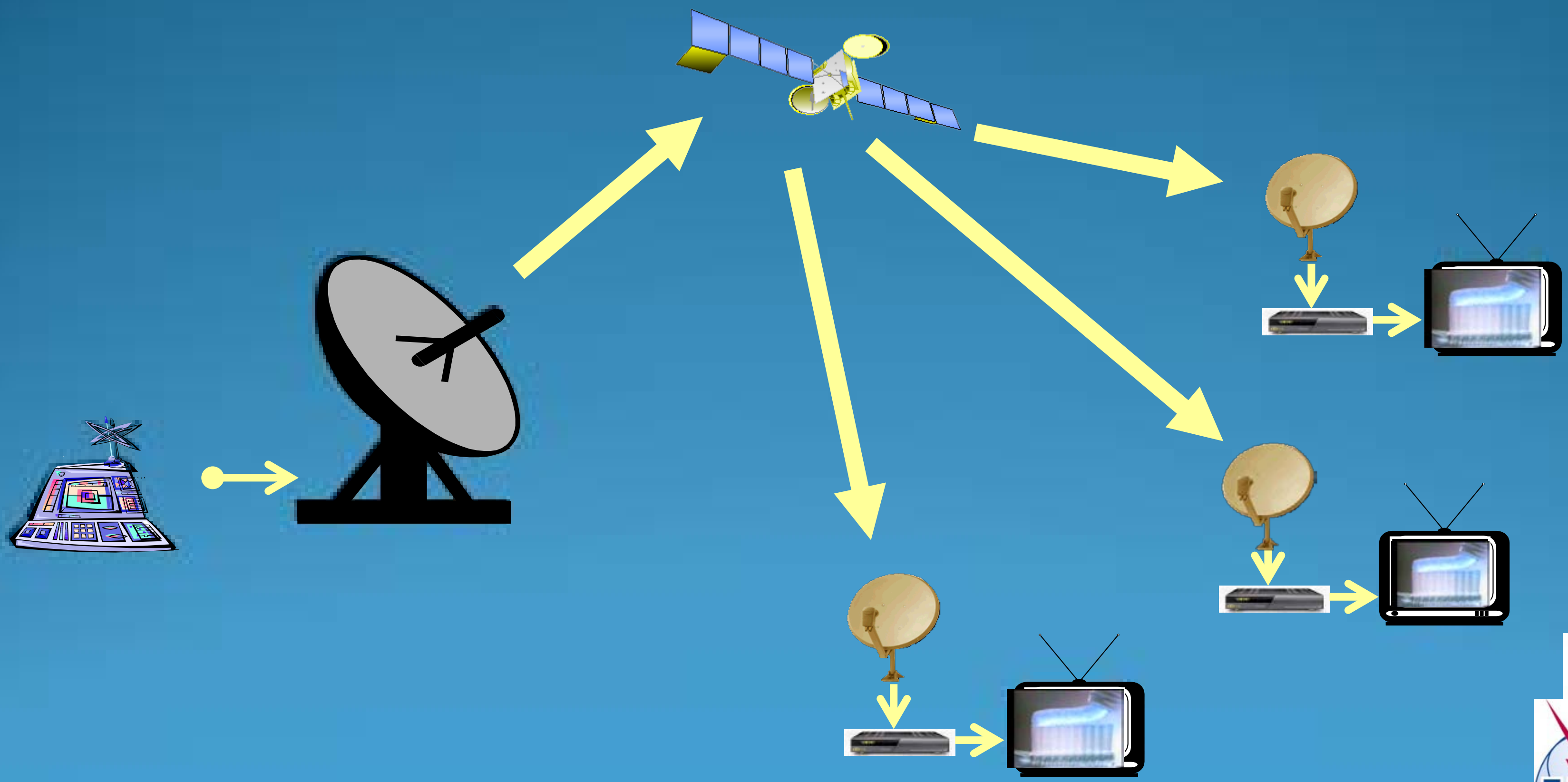
# Network planning (star networks)



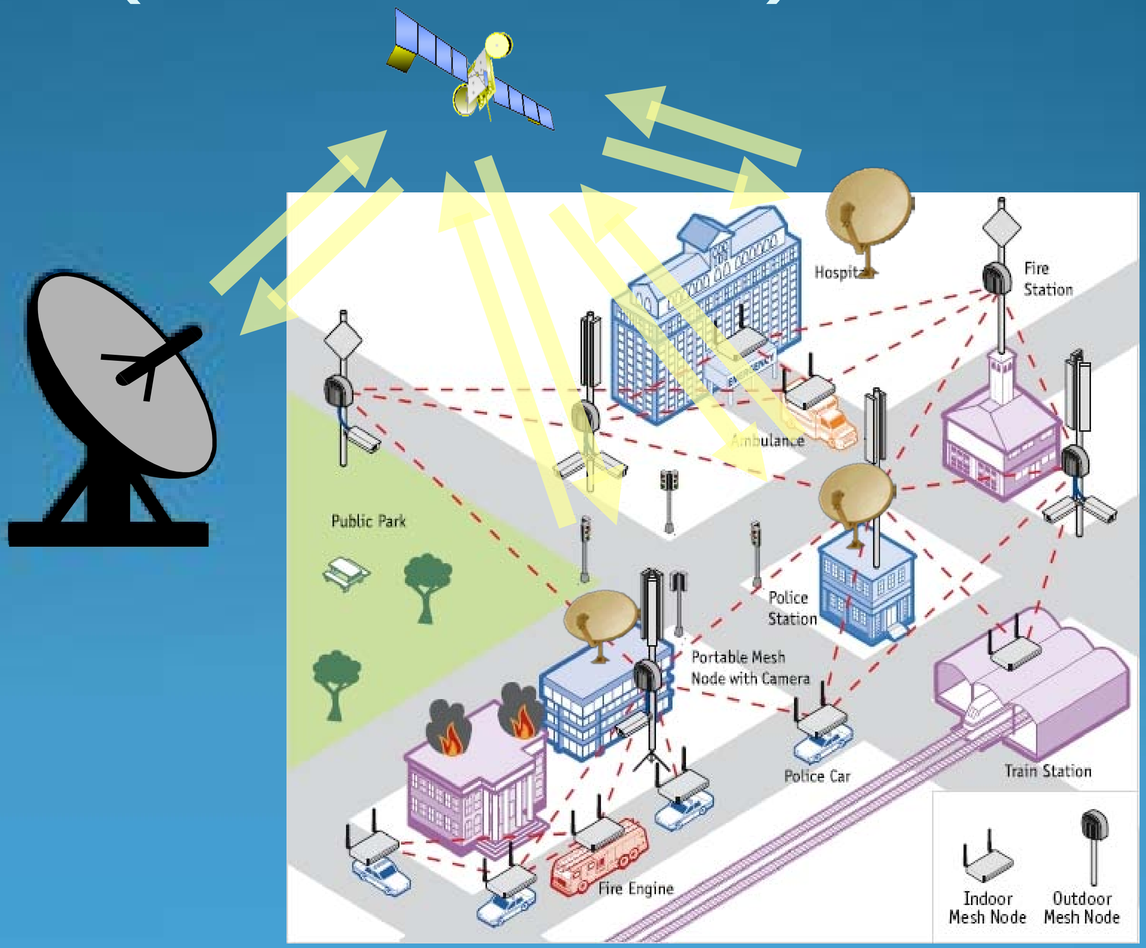
# Network planning (mesh networks)



# Network planning
## (broadcast networks)



# Network planning (hybrid network)



# Network planning (access schemes, multiple access)

- The easiest and cheapest way to of interconnect one to one or one to more terminals is through a satellite link, but with simultaneously working terminals (versus single access) multiple access shall be employed.
- Multiple access is the ability of a large number of terminals to simultaneously interconnect their respective voice, data and television through a satellite. The basic problem involved is how to permit a changing group of terminals to share a satellite in a way that optimizes, satellite capacity, spectrum utilization, satellite power, interconnectivity, flexibility, adaptability to different traffic mixes, cost and user acceptability ……

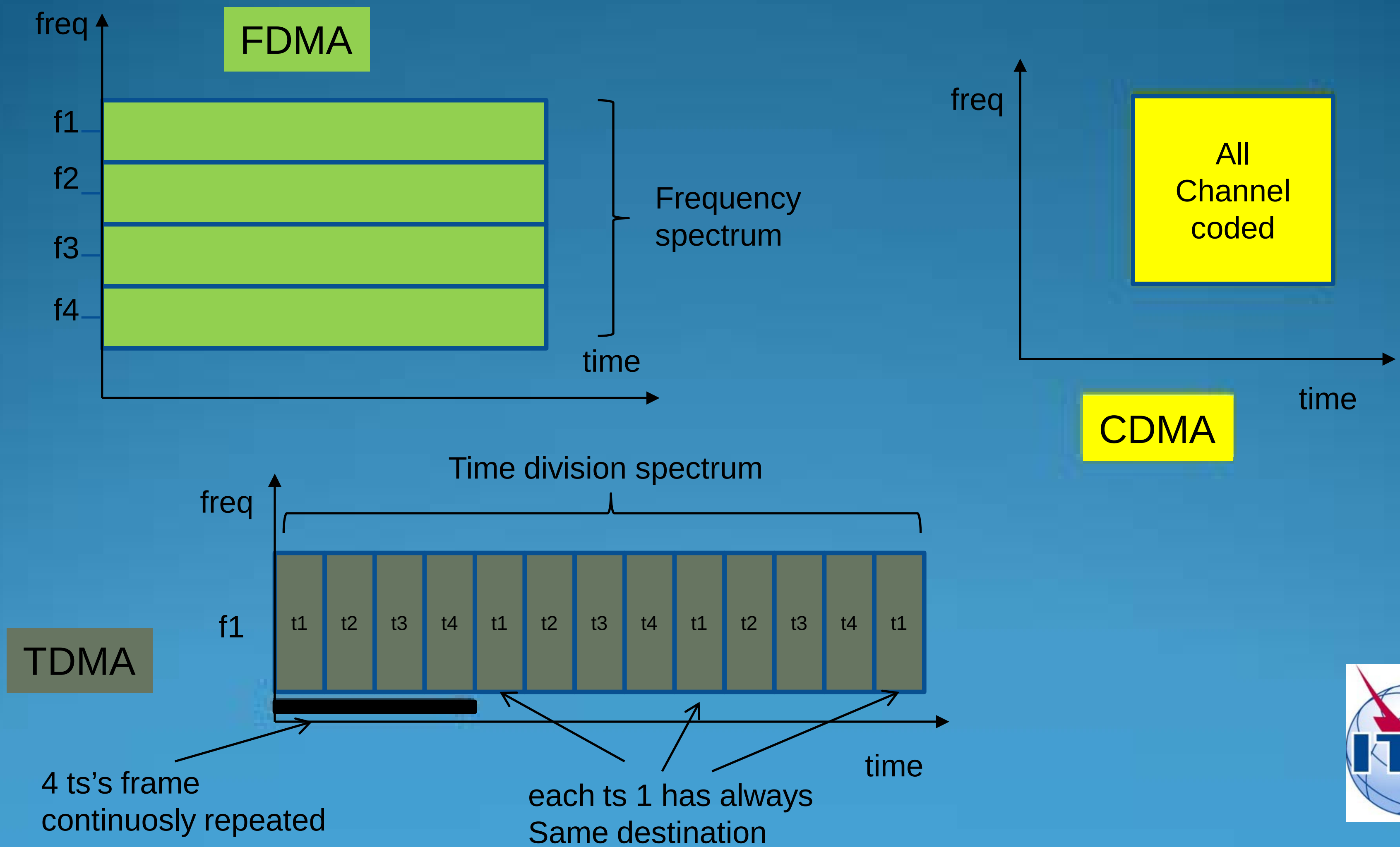
# Network planning (access schemes, multiple access)

- In the downstream path same signal is distributed to all terminals, being the responsibility of each to determine and decode its component (whatever it would be in frequency, time, or hybrid domain)
- In the upstream path things are more complicated once the bandwidth has to be shared by all terminations. The scheme “multiple access” consists a group of stations each transmitting in its own frequency, time or hybrid e.g each station group has a differentiated link in the satellite reception channel.

# Network planning (multiple access)

- FDMA - Frequency Division Multiple Access where the band allocated is divided into channels, each one occupying its frequency. If the channel is permanently assigned (also called *Fixed Assignment*) or on request (*Demand assignement*) the arrangement is referred to as: FDMA / FA or FDMA / DA
- TDMA - Time Division Multiple Access the common channel frequency in the upstream *is shared by all remote*, being each one being authorized (means synchro) to transmit in it own time (slots). This way the channel is shared in time division.
- *Possibilities are:* TDMA / FA ou TDMA / DA possibilities.
- CDMA - Code Division Multiple Access where all the stations use the same channel at same time, being made the separation through specific codes

# Network planning (multiple access)



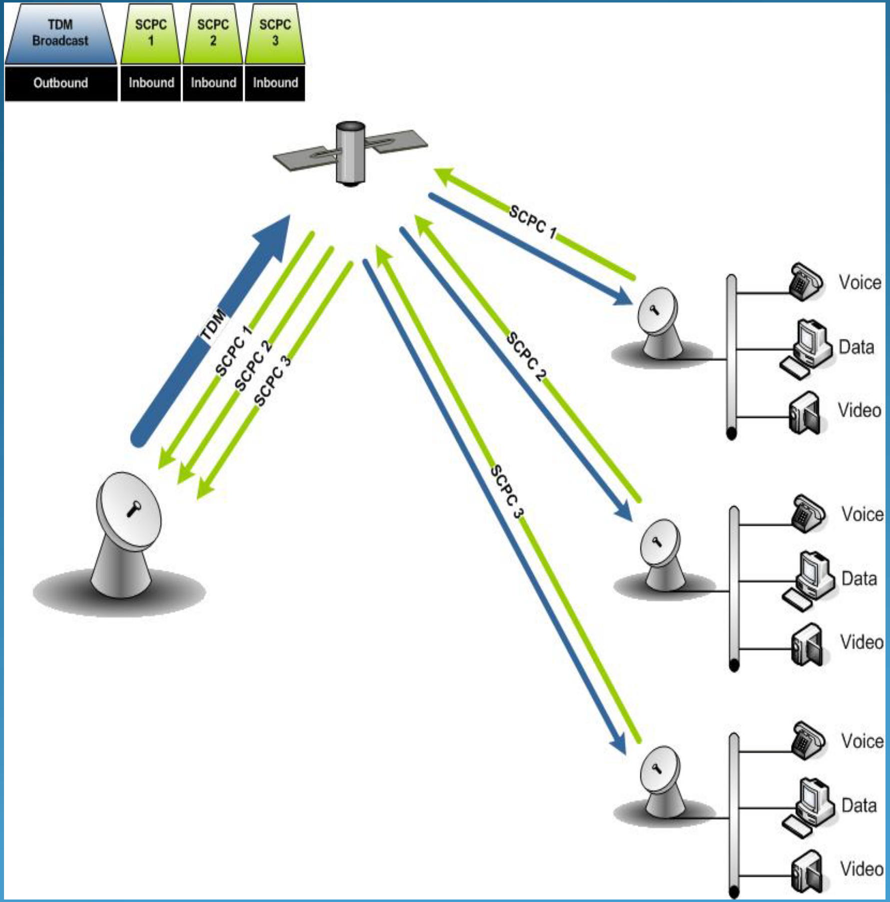
# Network planning (SCPC)

- In the frequency domain, we can see that each signal telephony signal channel is allocated a bandwidth of 4 kHz to access the local exchange, or many of the single channels are multiplexed together to form the transmission hierarchy to transmit the telephony channel over satellite. A carrier has to be generated which is suitable for satellite transmission on the allocated frequency band with the channel signal modulating the carrier being transmitted over satellite.
- At the receiving side, the demodulating process can separate the channel signal from the carrier; hence the receiver can get back the original telephony signal to be sent to a user terminal or to a network which can route the signal to the user terminal……

# Network planning (SCPC)

- If a single channel modulates the carrier, we call it single channel per carrier (SCPC) e.g, each carrier carries only a single channel. This is used normally for user terminals to be connected to the network (or other terminals as an access network). It is also possible to use this as a thin route to connect a local exchange to the network where the traffic density is low.
- If a group of channels modulate the carrier, we call it multi channel per carrier (MCPC). This is normally used for interconnect between networks as a transit network or local exchange to the access network.

# Network planning (SCPC)



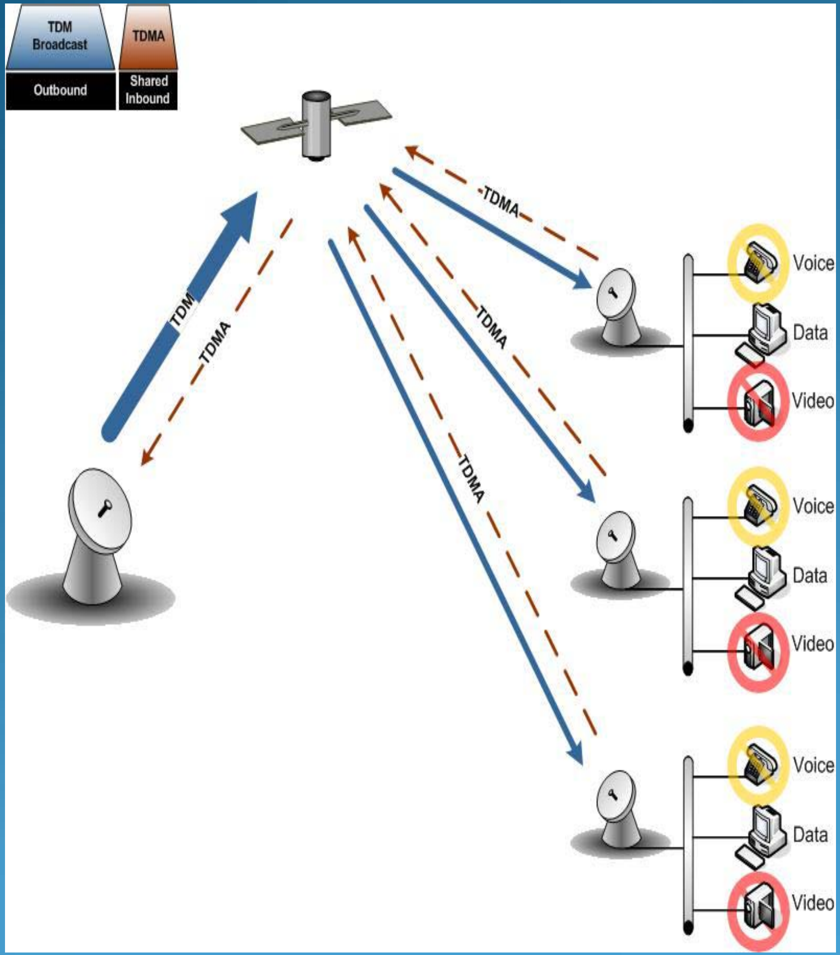

| Advantage | Disadvantage |
|---|---|
| Dedicated bandwidth for each remote inbound | Each remote requires its own space segment |
| Provides superior Quality of Service for critical applications | Expensive OPEX if each remote bandwidth is not fully utilized |
| Low Latency and Low Jitter | SCPC modems typically more expensive than TDMA modems |
| Best transmission method for real-time applications, voice, data, video, broadcast, etc. | Fixed data rates on the inbound links |

**Single Channel Per Carrier**

# Network planning (TDMA)

- Each terminal is required to transmit bursts in short non overlapping timing intervals which requires some form of *frame structure and a global timing synchronization mechanism.*
  - The frame is the time interval over which a signal format is established and repeated. A frame is subdivided into time slots and a burst consists of an exact number of slots and occupies a precise position in the frame .
  - Each burst must arrive at the satellite transponder at a prescribed time. This insures no *overlapping* with others terminals to guarantee a high transmission efficiency. A mechanism of synchronization provides timing information at all stations.

# Network planning (TDMA)




**Time Division Multiple Access**

| Advantage | Disadvantage |
|---|---|
| Sharing of satellite bandwidth | Increased Latency and Jitter |
| Lower overall OPEX compared to dedicated pipes | Demanding remotes can burden the system |
| Good for low data rate applications | Fragmentation of packets. Less effective for voice and video |
| Low cost remotes | Expensive hub equipment |
| Large population of users | All remotes must be designed around worst case link |

# Network planning (FDMA)

- FDMA is a traditional technique where several terminals transmit simultaneously but on different frequencies into a transponder. FDMA is attractive because of its simplicity for access by ground terminals. Single channel per carrier is commonly used for thin route telephony, VSAT systems and mobile terminal servicesfor access networks. Multiplexing a number of channels to share a carrier for transit networks also uses FDA. It is inflexible for applications with varying bandwidth requirements…..

# Network planning (FDMA)

- When using multiple channels per carrier to transit networks FDMA has significant problems with inter-modulation (IMPs) and hence a few dB of back-off form saturation trasmission power is required to overcome the problem of non linearity at high power. The resultant EIRP may represent a penalty , especially to small terminals
- Involves well mastered techniques and no synchronization is needed, between different stations.
- Need for linear transponder or back off operation, and loss in transponder capacity relative to a single access
- Lack of flexibility when there is need to change frequencies allocated to different stations

# Network planning (frequency bands)

- C band was the first to be used in satellite systems and only when this space has been scarce (where its re-use by terrestrial links worldwide increased the problem) Ku band has been adopted.
- Ku band is typically used for broadcasting and for Internet bidirectional communications , with the advantage of the satellite having high power transmitter (smaller antenna diameter and RF units easier to get)
- Ka Band is more popular for high speed Internet access rather than for classical satellite TV.

# Network planning (C band)

- C band
  - Down Link : 3,7 - 4,2 GHz
  - Up Link : 5,9 - 6,4 GHZ
  - Advantages : More immune to heavy rain
    cheaper bandwitdh and global
    satellite footprint
  - Disadvantages : larger antenna diameter
    expensive RF units
    expensive hardware
    more prone to terrestrial link
    interferences

# Network planning (Ku band)

- Ku band
  - Down Link : 11,7 - 12,2 GHz
  - Up Link : 14,0 - 14,5 GHz
  - Advantages : more prone to terrestrial link interferences small diameter antenna ( +/- 90 cm ) simpler and cheap RF units
  - Disadvantages : expensive bandwith less immune to heavy rain, although may be balanced through bigger diameter antennas

# Network planning (Ka band)

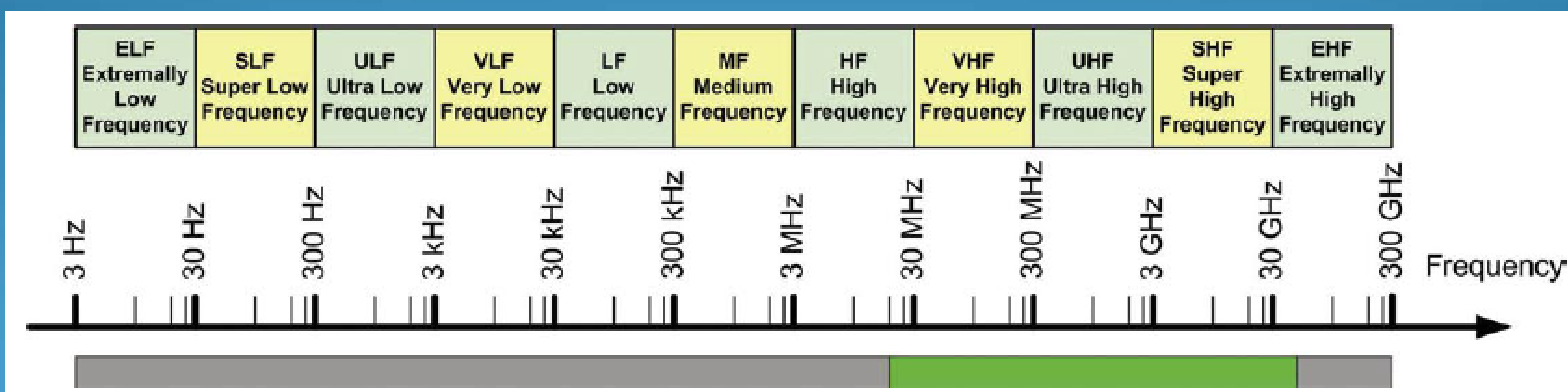
- Ka band
  - Down Link : 19,7 – 20,2 GHz
  - Up Link : 29,5 - 30 GHz
  - Advantages : very interesting for faster
  - Internet

    Low cost terminal vsat

    Resilient high speed corporate data networks
  - Disadvantages : due to highly attenuation by rain, direct TV is very risky in not very dry regions

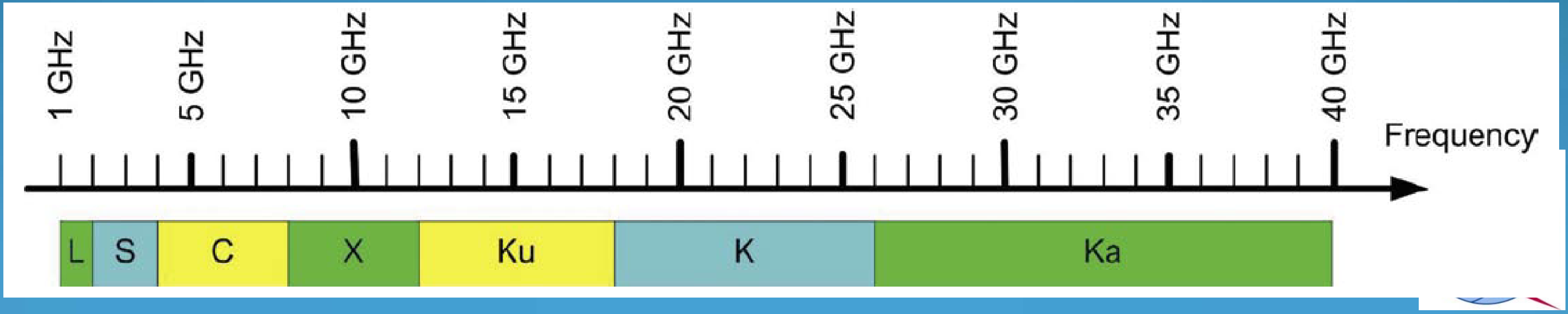
# Network planning (frequency band)

- We can see below the range of frequency that we can use for satellite communication, a green bar starting at around 20 MHz and ending at about 40 GHz. Occasionally also lower and Ku Band terms. By expanding the green bar we see the actual satellite bands



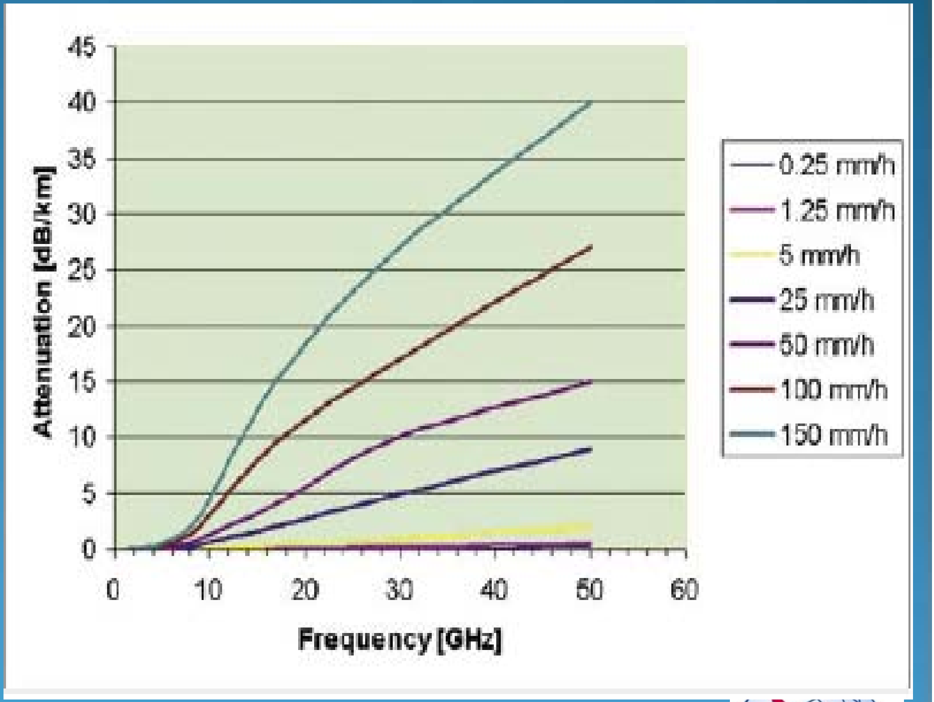
# Network planning (satellite bands)

- Ku Band starts at 12 GHz while some of the Ku Band transponders transmit even below 11 GHz, so formally in X Band. Indeed, the downlink uses both Ku Band and X Band but the uplink uses only Ku Band. For this reason, we call them Ku Band satellites or transponders. Moreover, we should also keep in mind that we can not use the whole band (Ku, C or whatever) for the satellite downlink. A part of the band has to be reserved for the uplink, and some parts of the bands are dedicated for military or professional services (e.g. radars).

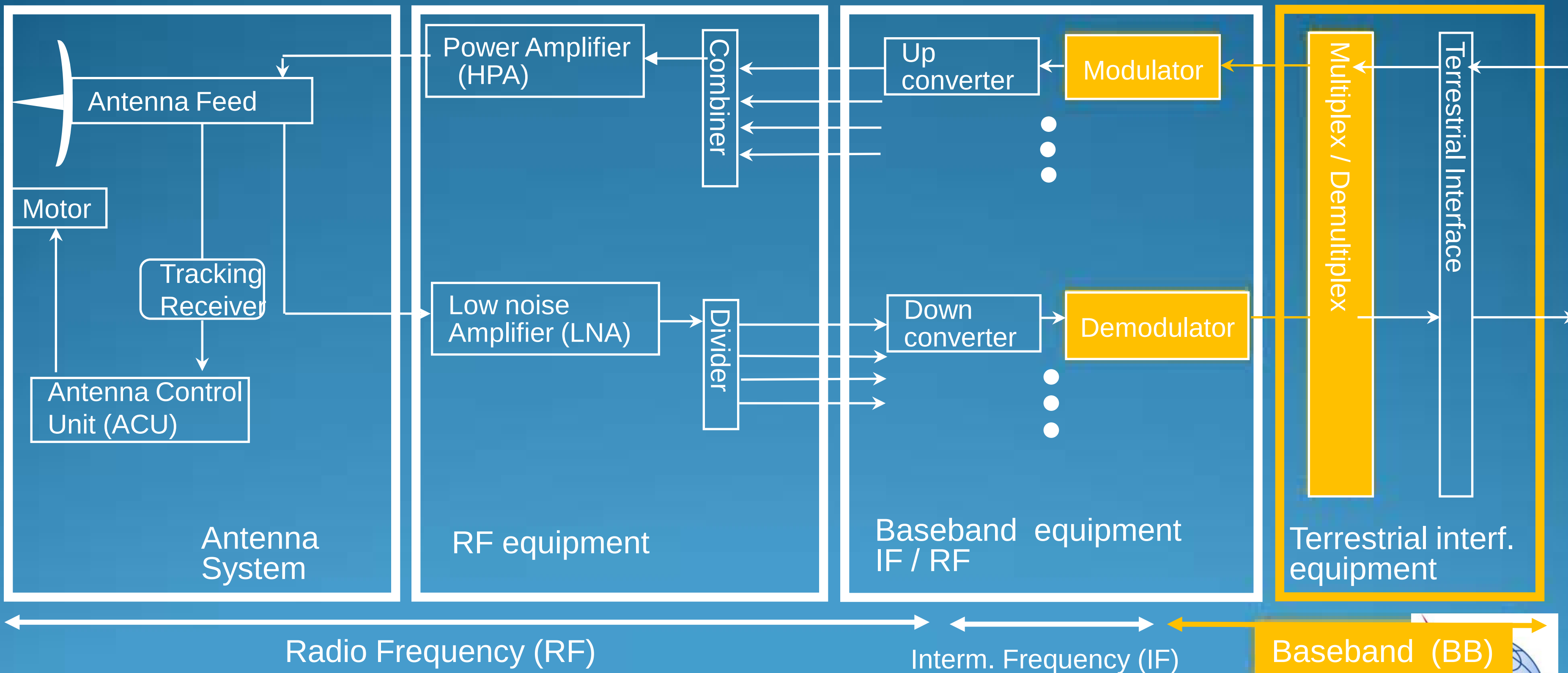


# Network planning (Ka band restrictions)

However, what can be easily seen is that the space for TV or data channels is much greater in Ka band than in C, and Ku has no problem in using frequencies up to 50 GHz or so. Attenuation of less than 1 dB is not a big deal. Unfortunately this is not the whole picture. Atmosphere containing water vapor is one thing, and raining is another thing. Attenuation caused by rain dramatically increases with frequency, as you can see



# Network planning (baseband signals)



# Network planning (baseband signals)

- The signal to be transmitted can be digital, such as data flowing between computers, printed text, communications between remote terminal and computers, or analog such as telephone or TV, channels.
- Whatever will be digital or analog information signals, they must be gathered to carry on several telephone channels or several data circuits, in other words information occupy a defined bandwidth, that:
  - When using the shift in frequency and the Channel Translating Equipment, the bandwidth occupied by all the information shifted in frequency constitutes the FDM baseband

…

# Network planning (baseband signals)

…

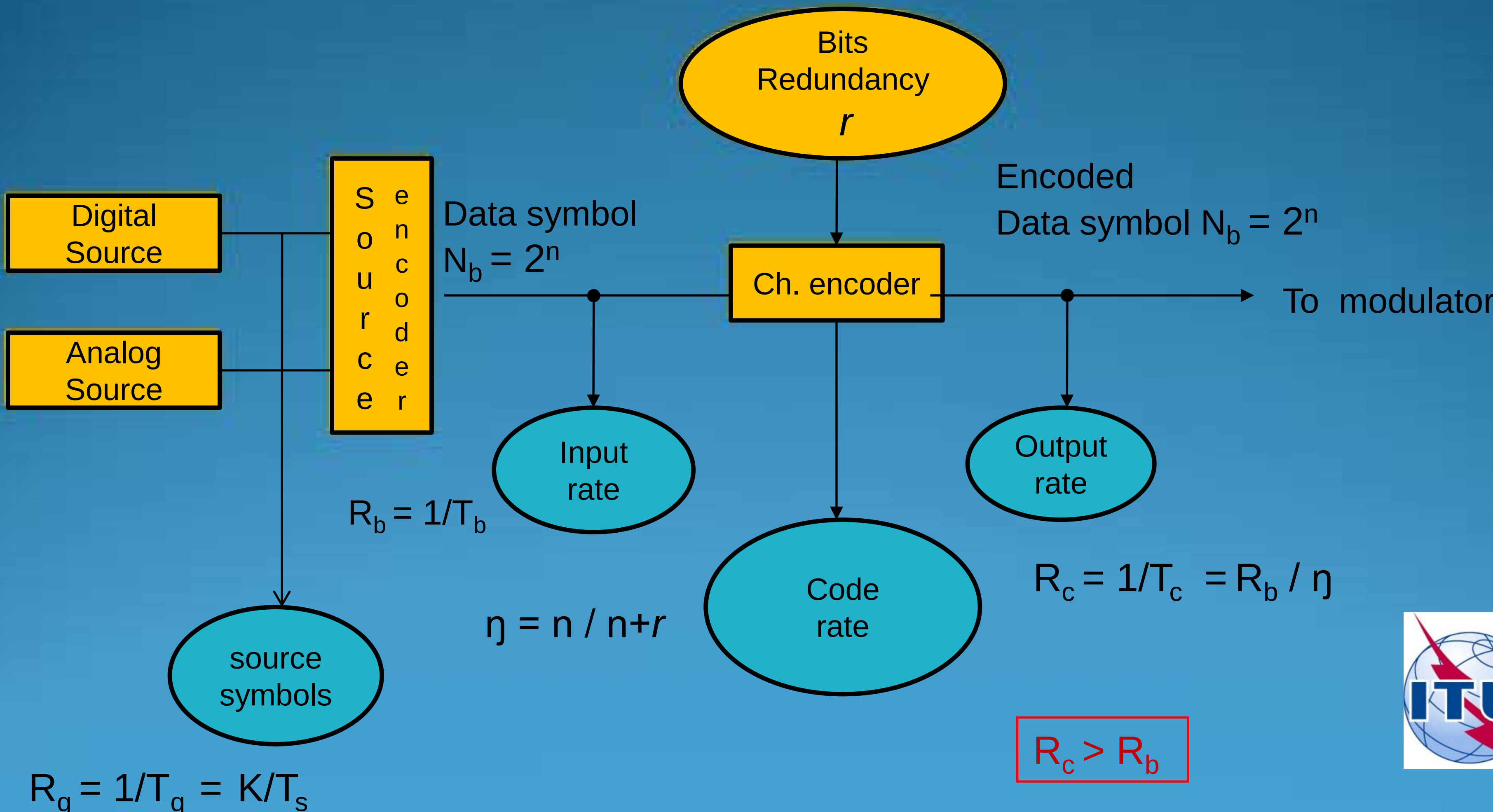
- When using bits of information e.g. 0's and 1's, to translate information we got from discrete signals previously sampled and quantized, information signals are referred to as TDM baseband signals once we are not limited in frequency.
- A baseband signal can be all-information or it can contain redundant bits making it a coded signal but it is still at baseband and still has fairly low frequency contents.

# Network planning (baseband signals)

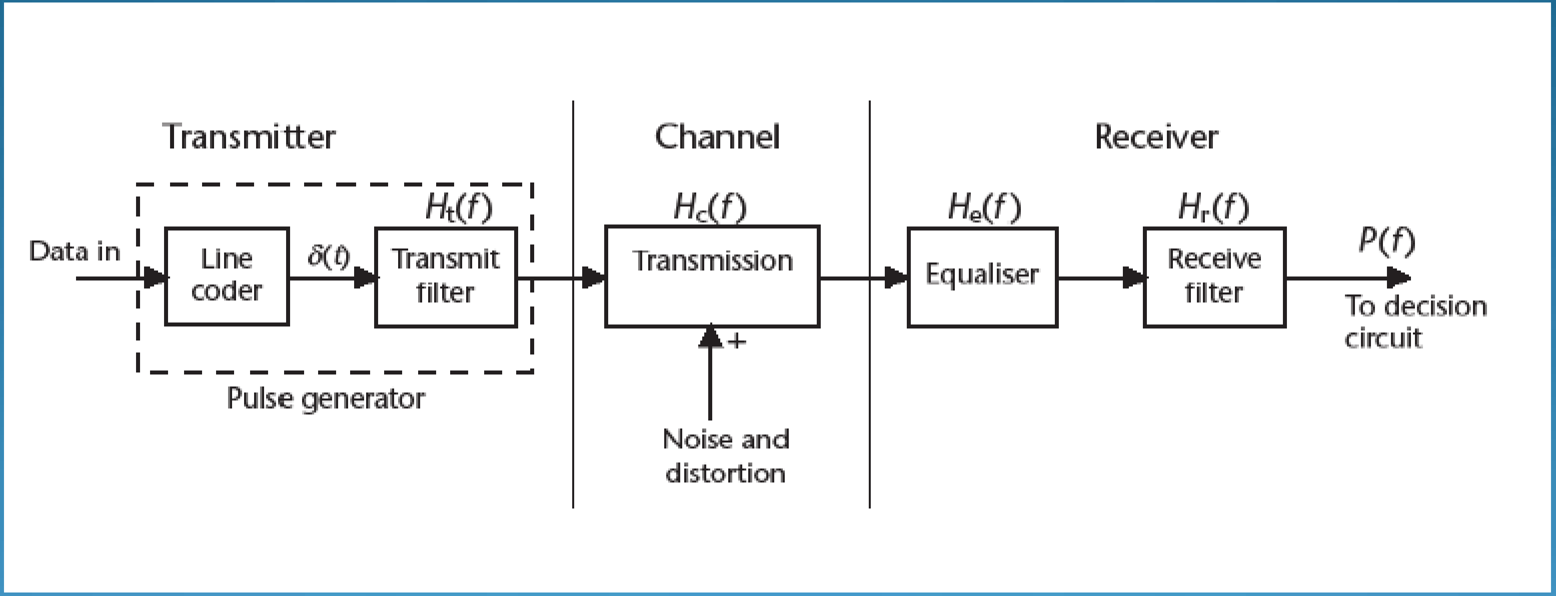
The main steps involved in the baseband signals structuring , are:

- Sampling, quantizing and encoding (analog to digital)
- Multiplexing from basic hierarchy to higher order
- Source encoding ( to alter the information source for efficient transmission over the medium, that is minimize the source bit rate)
- Channel encoding (to make efficient use of the communication channel resources, e.g. bandwidth and power, redundancy bits are inserted for purposes of error control and error corrrection)
- Modulation (the process of converting the information so can be successfully sent through radio)

# Network planning
## (digital transmission system)



# Network planning
## (digital transmission system)



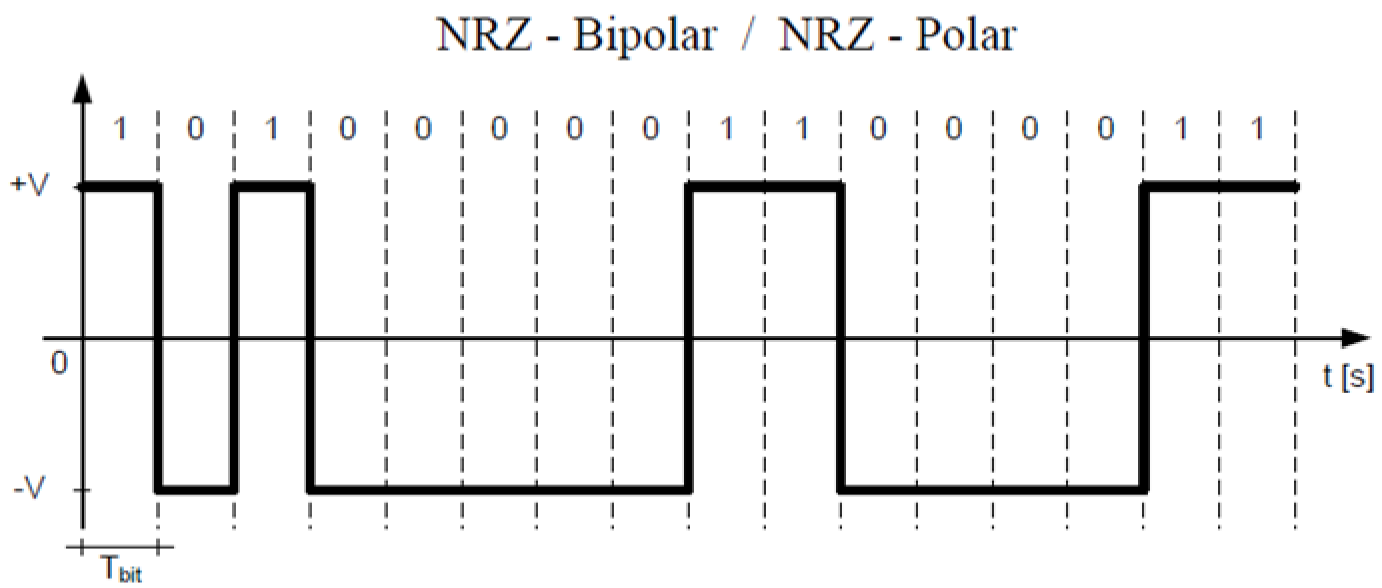

**Transmitter** - Line coder ( NRZ, Manchester..), raised cosine filter
**Transmission medium** - attenuation, phase distortion, limited bw, noise and ISI
**Receiver** - equalizer (distortion compensation), raised cosine filter,

# Network planning
## (bb signals - line code characteristic)

- Use of electrical pulse to codify bits “0” and “1”
- Pulses are directly in the medium
- Usually square wave
- Data stream spectrum adapted to frequency response of medium
- Data stream shall follow some timing rules for transitions to avoid synch loss and clock timimg is embeded in data stream for recovery
- Vulnerable to environmental noise, interferences and ISI - Intersymbol interference

# Network planning
## (bb signals - NRZ code)

NRZ-Bipolar or NRZ-Polar




1° **spectral zero**

$$B_T = R_b$$

**bandwidth**

$$B_T = \frac{R_b}{2}(1+\alpha)$$

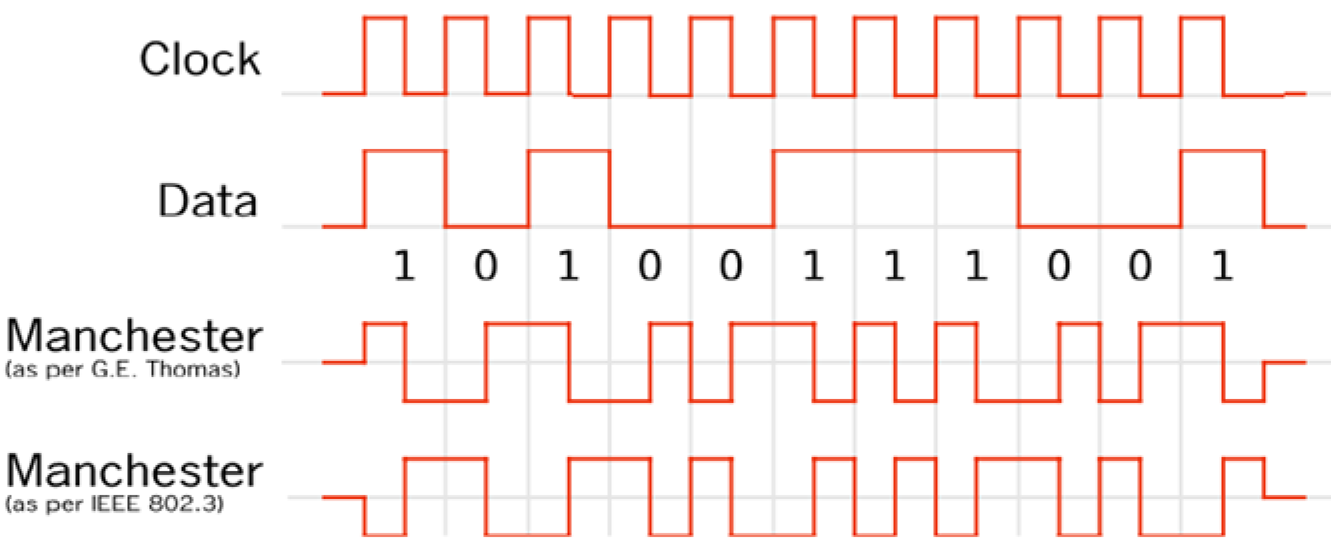
**Energy per bit**

$$E_b = V^2 \cdot T_{bit}$$

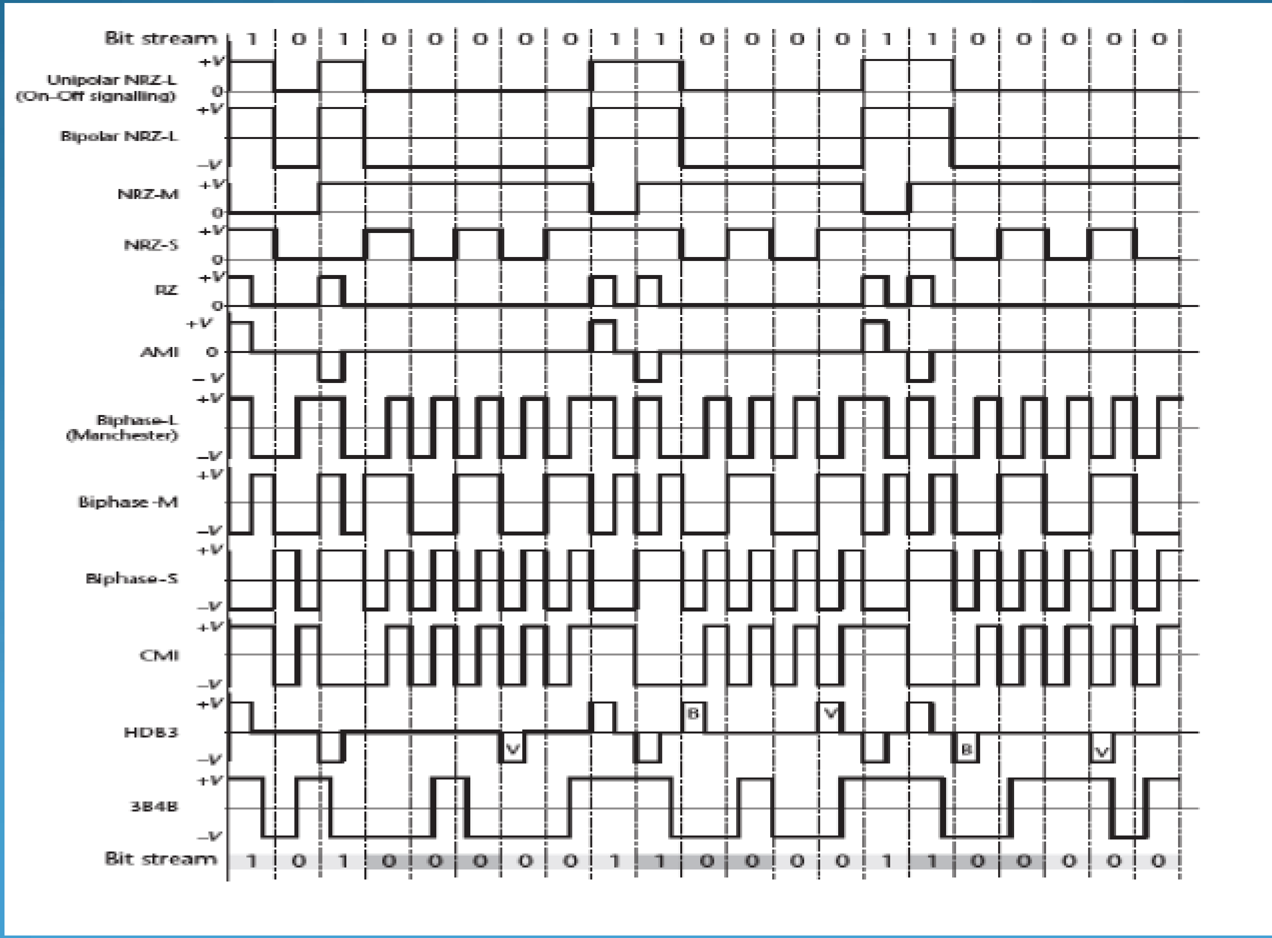
# Network planning
## (bb signals - Manchester code)

## Código Manchester

- Manchester – **Always mean value null**
- **Transition in the half bit period**
  - **The bandwidth is bigger than other codes**

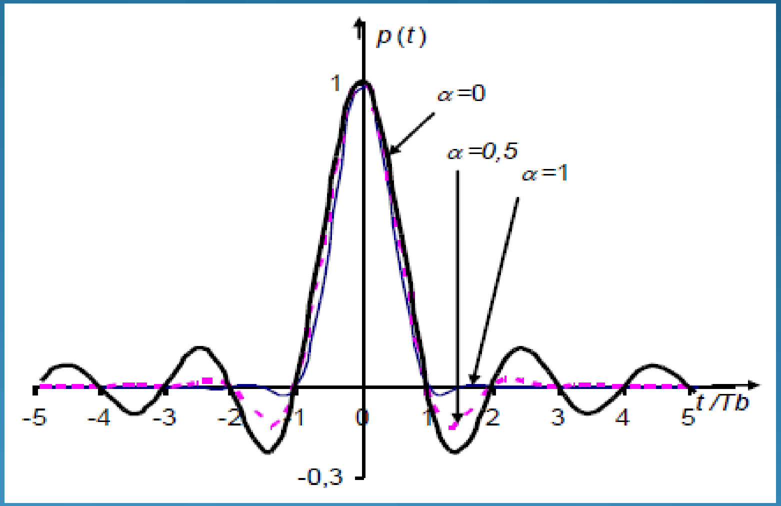


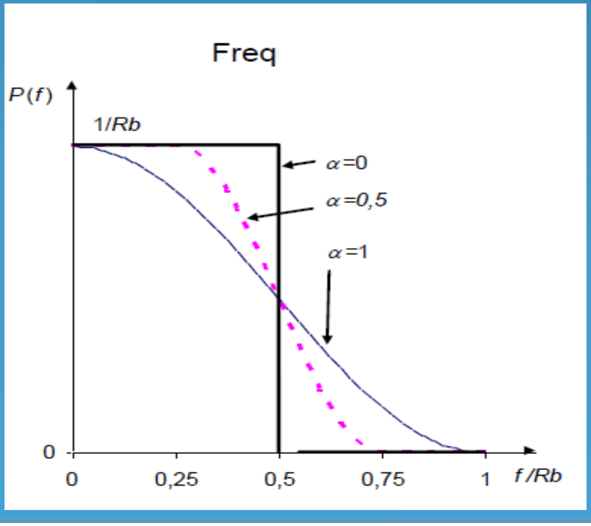
# Network planning
## (bb signals - more common codes)



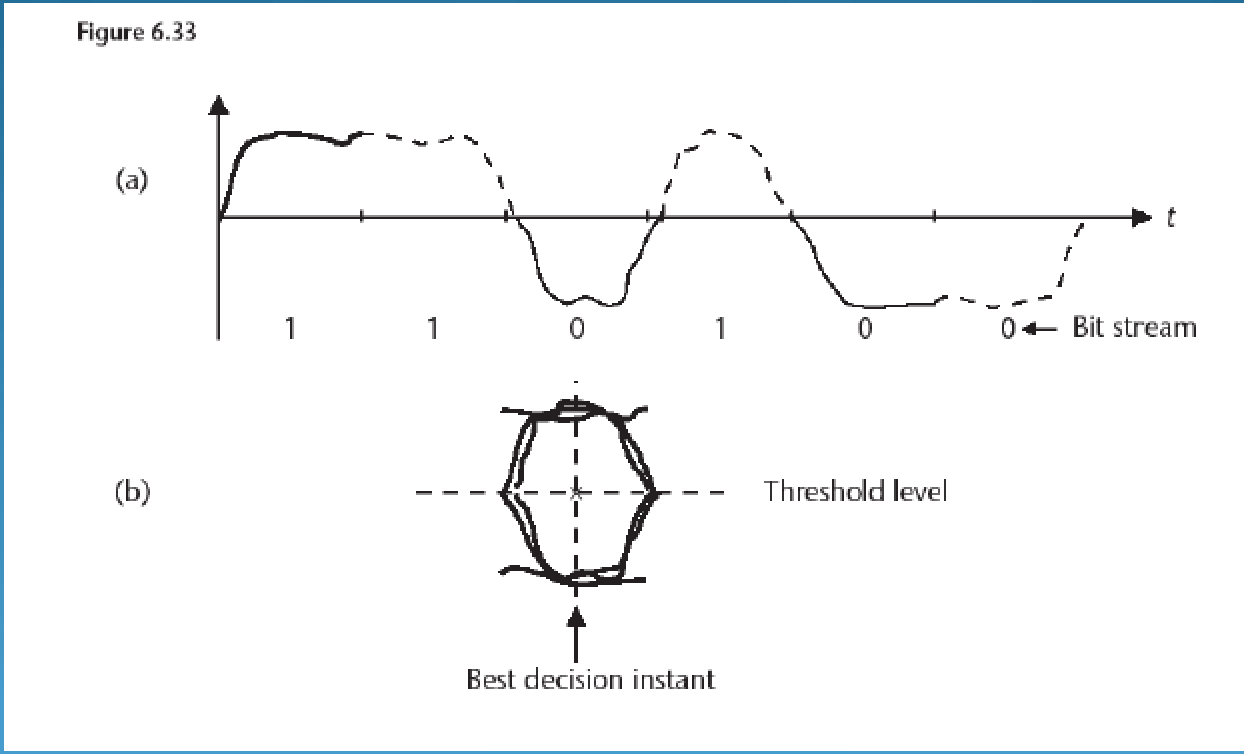
# Network planning
## (bb signals - ISI interference 1)

- In a baseband system ISI can be avoided by an appropriate choice of lowpass filter, according to Nyquist criteria, called "raised cosine filter" whose objective is to create in the receiver a pulse whose shape is "sin x / x", where Tb is the bit period, so that at the instant one pulse is sampled the "tails" from all preceeding pulses which have zero value



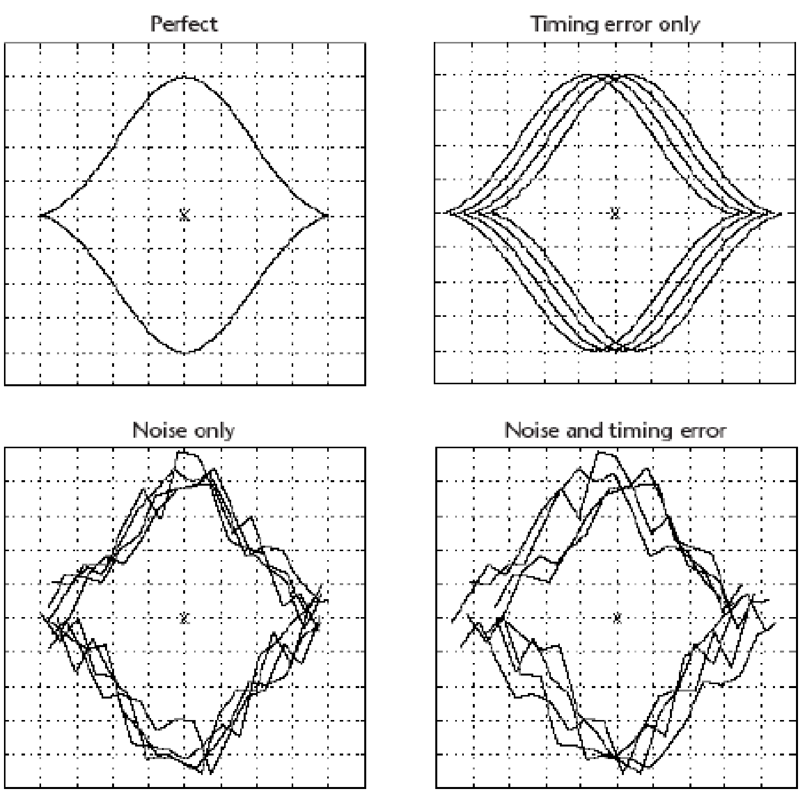
# Network planning
## (bb signals - ISI interference 2)




**Eyediagram**, does evaluate the ISI in a digital transmission

# Network planning
## (bb signals - ISI interference 3)

**Figure 6.34**



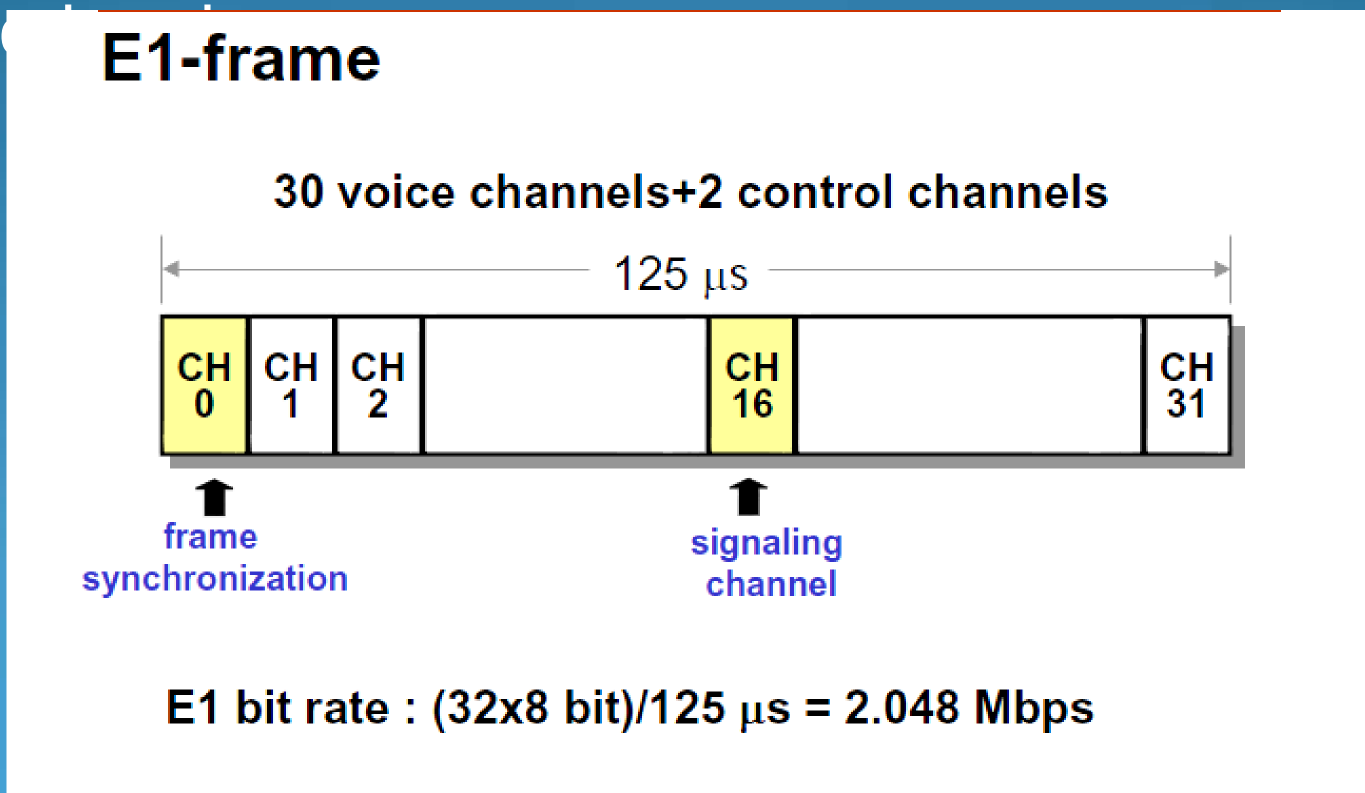

Taken from *Communication Engineering Principles*, © Ifiok Otung, published 2001 by Palgrave

# Network planning
## (digital com. techniques - multiplexing)

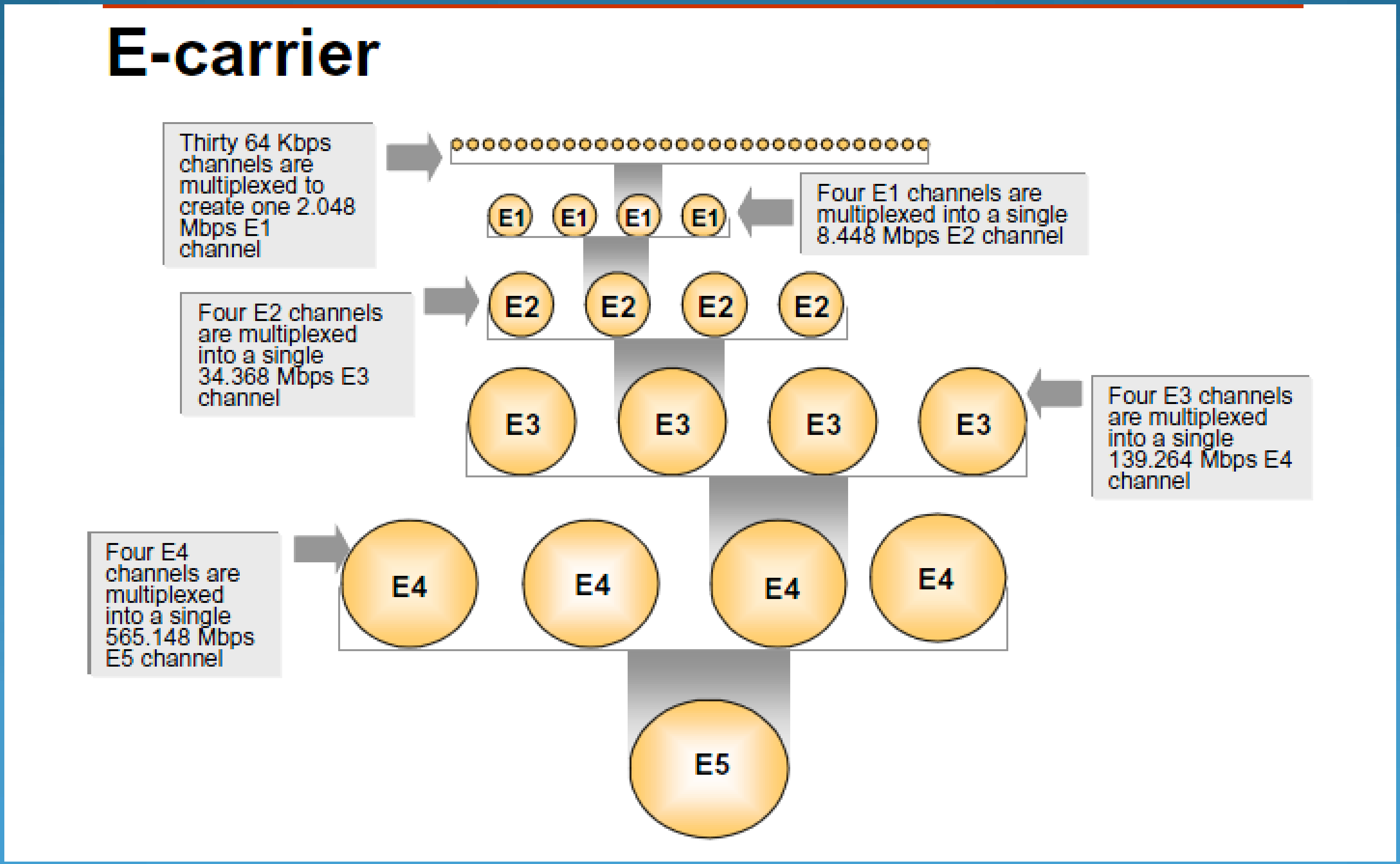
- A group of signals previously digitized are combined so as to be transmitted in a process named “multiplexing” where many channels share the medium by “taking turns”, each one being connected very briefly then replaced by the next.
- At the receiving end of the link a matching demultiplexer carries out the reverse operation. Here the receiver must know the sequence of the “8 bits words” it receives , which is done by inserting a sychronizing word in the traffic at the multiplexer that can be recognized at the remote end and is used as reference
- There are also extra words whose information is often referred to as “overhead” because it is carried along with the traffic, and has nothing to do with the traffic information

# Network planning
## (digital E1 structure)

We reached the 1st hierarchy in digital transmission, e.g 2,048 Mb/s (not 64*30) because ov



# Network planning
## (higher digital hierarchy)



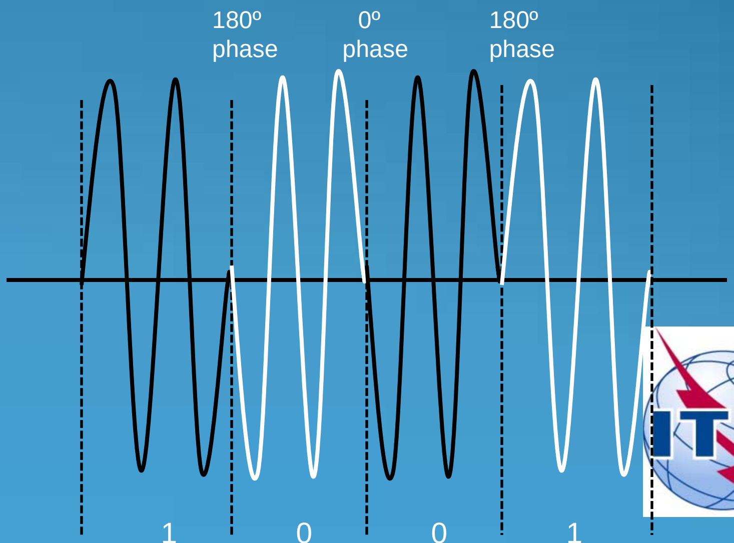
# Network planning
## (Digital Communications techniques)

- With advent of transmission between computers, between terminals and computers, digital voice (VoIP) etc, the digital modulation is the most obvious choice to assure transmissions that were originally digital or used by digital equipments. Even in case of analog signals - as telephone channel or television - with large bandwidth requirements, there is benefit from analog to digital code processing (and digital to analog conversion). Although this process can be costly in terms of bandwidth, offers improved noise performance, and immunity to interference.
- Digital transmission leads naturally to TDM and TDMA, respectively, being Time division Multiplex and Time Division Multiple Access, techniques used to transmit a signal through a transponder allowing just one signal at a time, thus avoiding intermodulation problems..

# Network planning (modulation techniques)

While any feature of a signal - amplitude, frequency and phase - may be digitally modulated, phase modulation is almost universally used for satellites. For historical reasons, digital phase modulation is frequently called *phase shift keying abbreviated PSK.* An M-phase PSK modulator puts the phase of a carrier into one of the M states according to value of a modulating voltage. Two phase or biphase PSK is called BSK .

In this case of modulation (direct codification) the phase of the signal carrier is advanced or delayed depending on the type of modulation equipment (terminal equipment) , hence in the present case what matters are change state (phase)

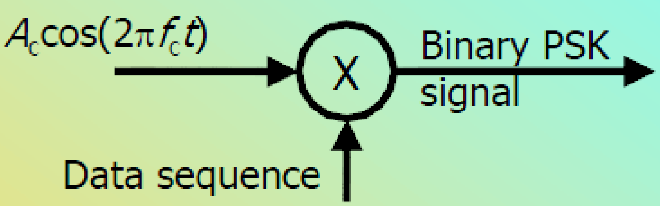


# Network planning (modulation techniques)

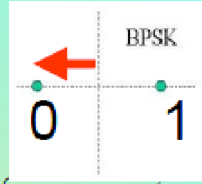
- Biphase or Binary Phase-Shift Keying (BPSK) modulation is the simplest form of PSK, where the phase shift changes with each new data bit. In this case, a binary source code is mapped one bit at a time into a pair of phase states with 180-degree phase difference.
- Quadrature Phase Shift Keying (QPSK) encodes each pair of bits into one of four phases, and one of the principal advantages of QPSK over BPSK is that QPSK achieves the same power efficiency as BPSK with only half of the bandwidth. QPSK is of particular importance for satellite data transmissions and, therefore. The name four-phase or quadriphase refers to the fact that one carrier is modulated along a 0 - degree, 180 - degree phase vector (the in-phase or cosine channel), and the other along a 90 - degree, 270 -degree phase vector (the quadrature or sine channel). Ideally, the two channels are independent.

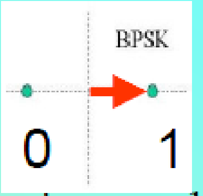
# Network planning (modulation techniques - BPSK)

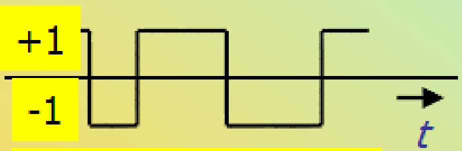
## Binary Phase-Shift Keying BPSK (2-QAM)




- Signal is represented as a vector
- A change in phase (180º) is a change in Binary code ~



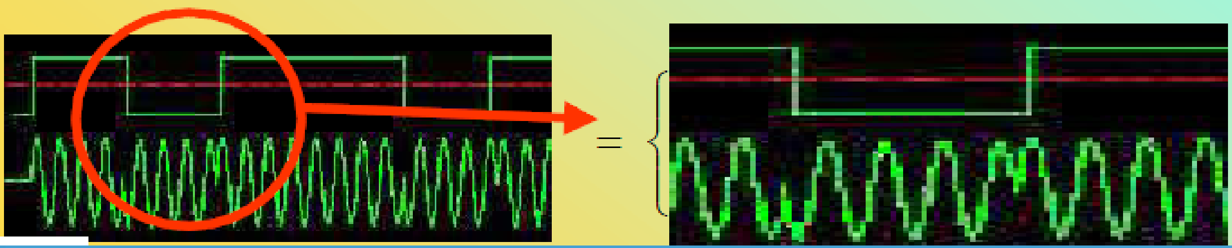




Carrier is multiplied +1(Binary 1) or –1(Binary 0)

$$s(t) = \begin{cases} A\cos(2\pi f_c t) & \text{binary } 1 \\ A\cos(2\pi f_c t + \pi) & \text{binary } 0 \end{cases}$$

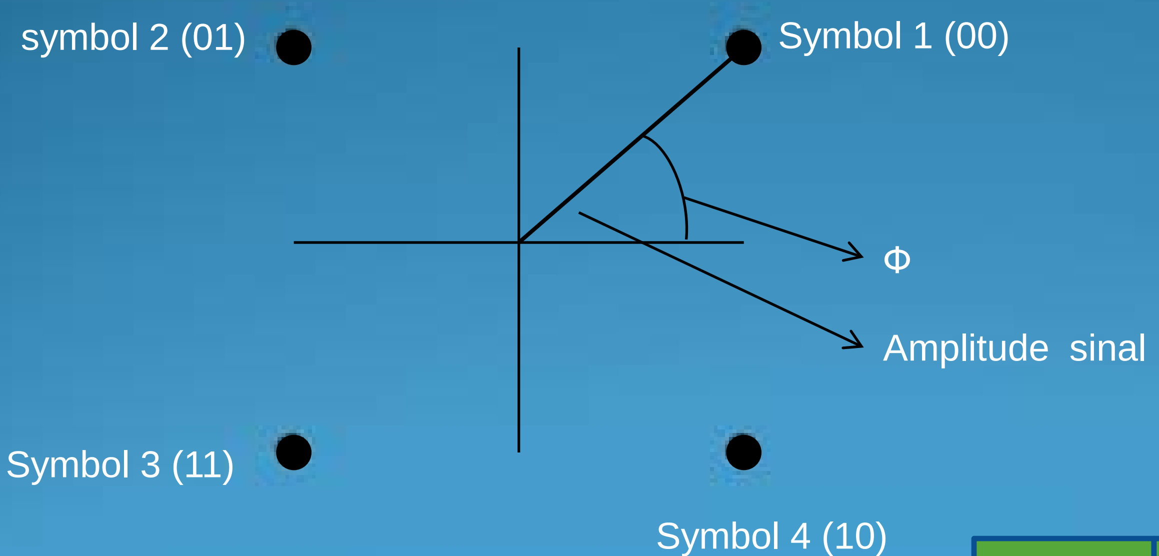
$$\begin{matrix} A\cos(2\pi f_c t) & \text{binary } 1 \\ -A\cos(2\pi f_c t) & \text{binary } 0 \end{matrix}$$



# Network planning

## (modulation techniques - QPSK)

- Representation of modulation diagram, known per "constellation" (screenshot of polar representation –magnitude and phase - of the measurement equipments display)




| Symb. ch | 00 | 01 | 11 | 10 |
|---|---|---|---|---|
| Φº | 45 | 135 | 225 | 315 |

# Network planning

## (digital modulation - design trade off)

Required IF bandwidth ( ~ 1.3 symbol rate )

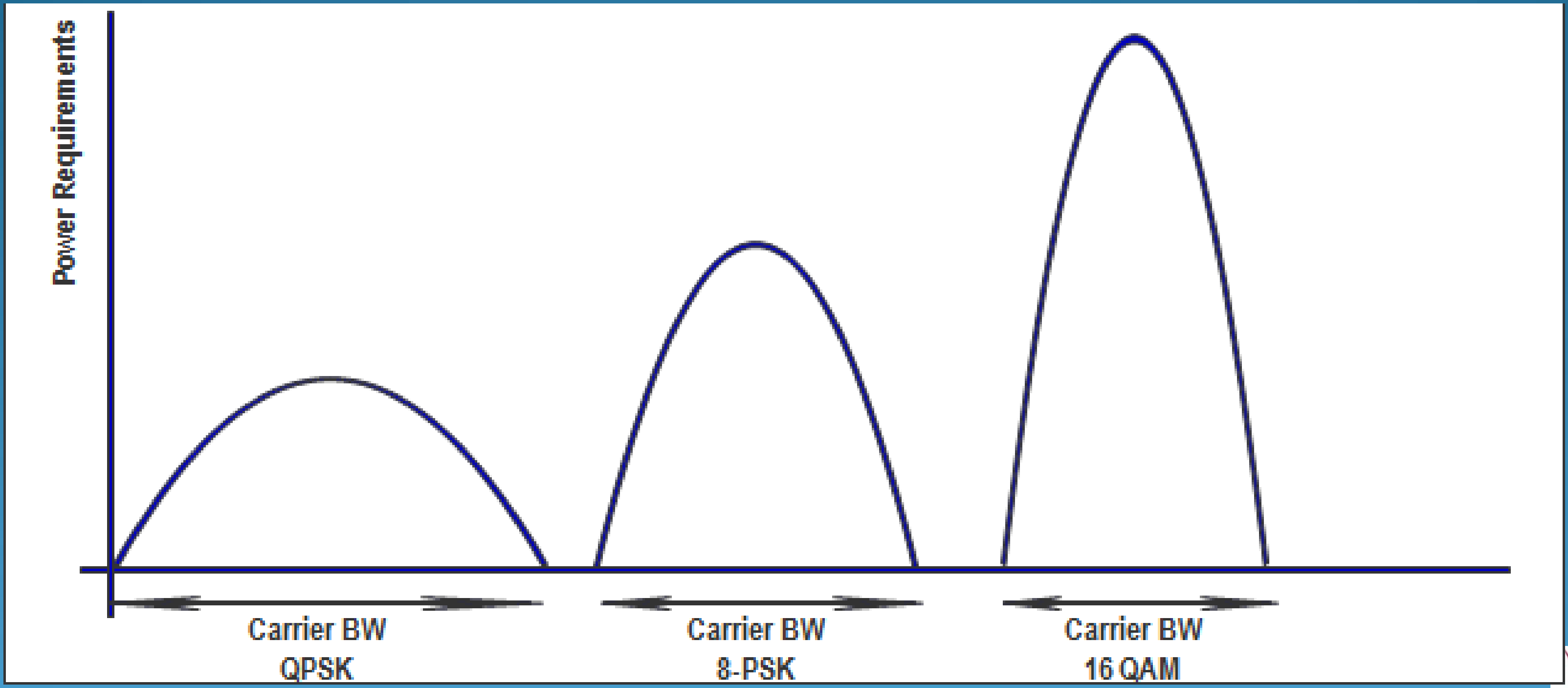
- Assume Bit rate 26 Mbits/s
- BPSK → ( 1 bit / symbol ) → 26 * 1.3 = 33.8 MHz
- QPSK→ ( 2 bit / symbol ) → 26 * 1.3 / 2 = 16.9 MHz
- 8PSK→ ( 3 bit / symbol ) → 26 * 1.3 / 3 = 11.3 MHz
- 16QAM→( 4 bit / symbol )→ 26 *1.3 / 4 = 8.65 MHz

So

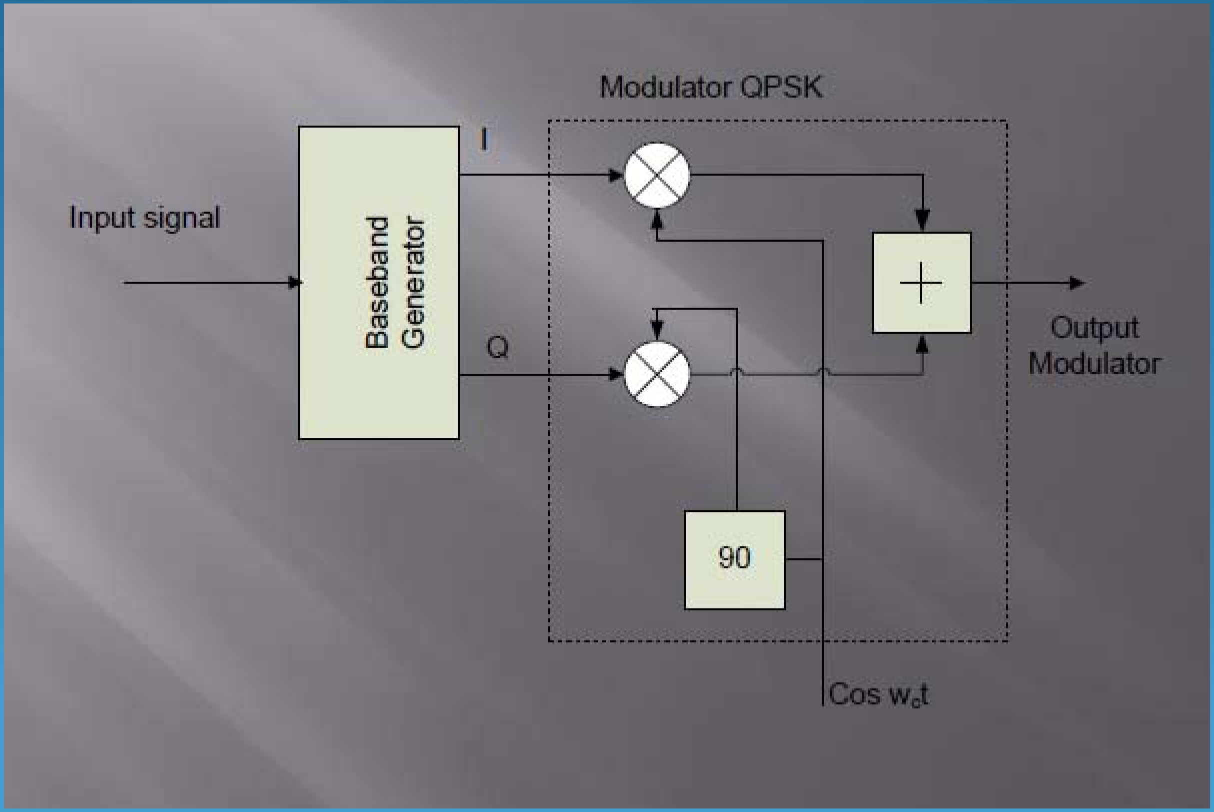
- More complex modulation requires less bandwidth & less power, see example nest slide

# Network planning

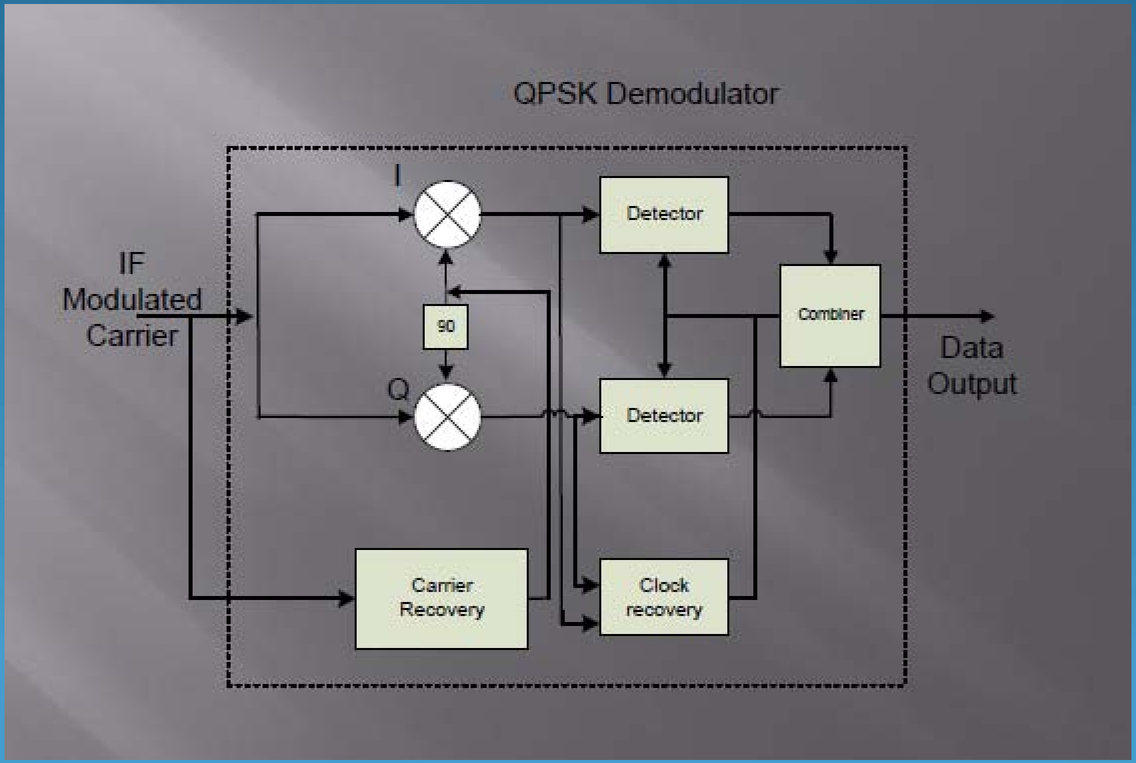
## (modulation techniques - differente sat carrier)



# Network planning (modulation techniques - QPSK modulator)



# Network planning
## (modulation techniques – QPSK demodulator)



# Network planning
# (link budget analysis 1)

- The design of a satellite communications link involves compromises among several factors with purpose of achieving maximum performance, e.g
  - Specified BER In normal conditions of working (digital link) or C/N
  - Link availability or % time the BER is better than previously specified as threshold ( ex.10-3 ou 10-4 ) or a minimum S / N (analog link )

**But at what costs?**

# Network planning (link budget analysis 2)

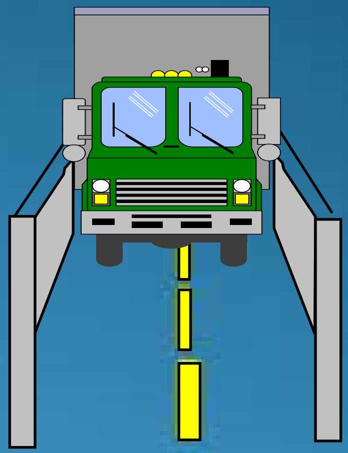
- Customer requests:
- Minimum Lease Bandwidth
- Maximum Power
- Maximum Carrier Size
- Minimum Earth Station Size

**You can’t have it all!**

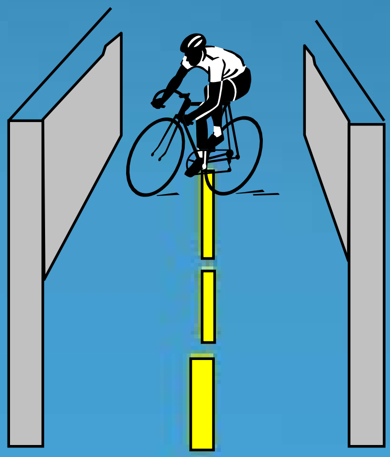
# Network planning
# (link budget analysis 3)

Requirement “minimum bandwidth”

Any satellite has bandwidth and power limitations



| Satelite | Banda | BW | EIRP |
|---|---|---|---|
| IS- IX | C | <72 | < 42,8 |
| IS-IX | Ku | <77 | <47 |
| IS-10 | C | <36 | <46,4 |
| IS-10 | Ku | <36 | <55,4 |

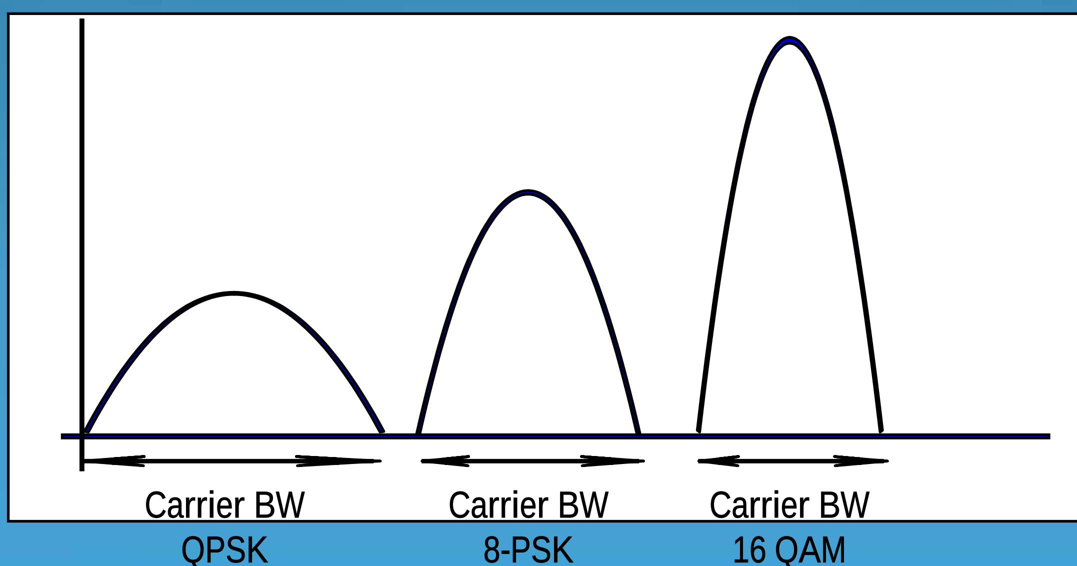


# Network planning
# (link budget analysis 4 )

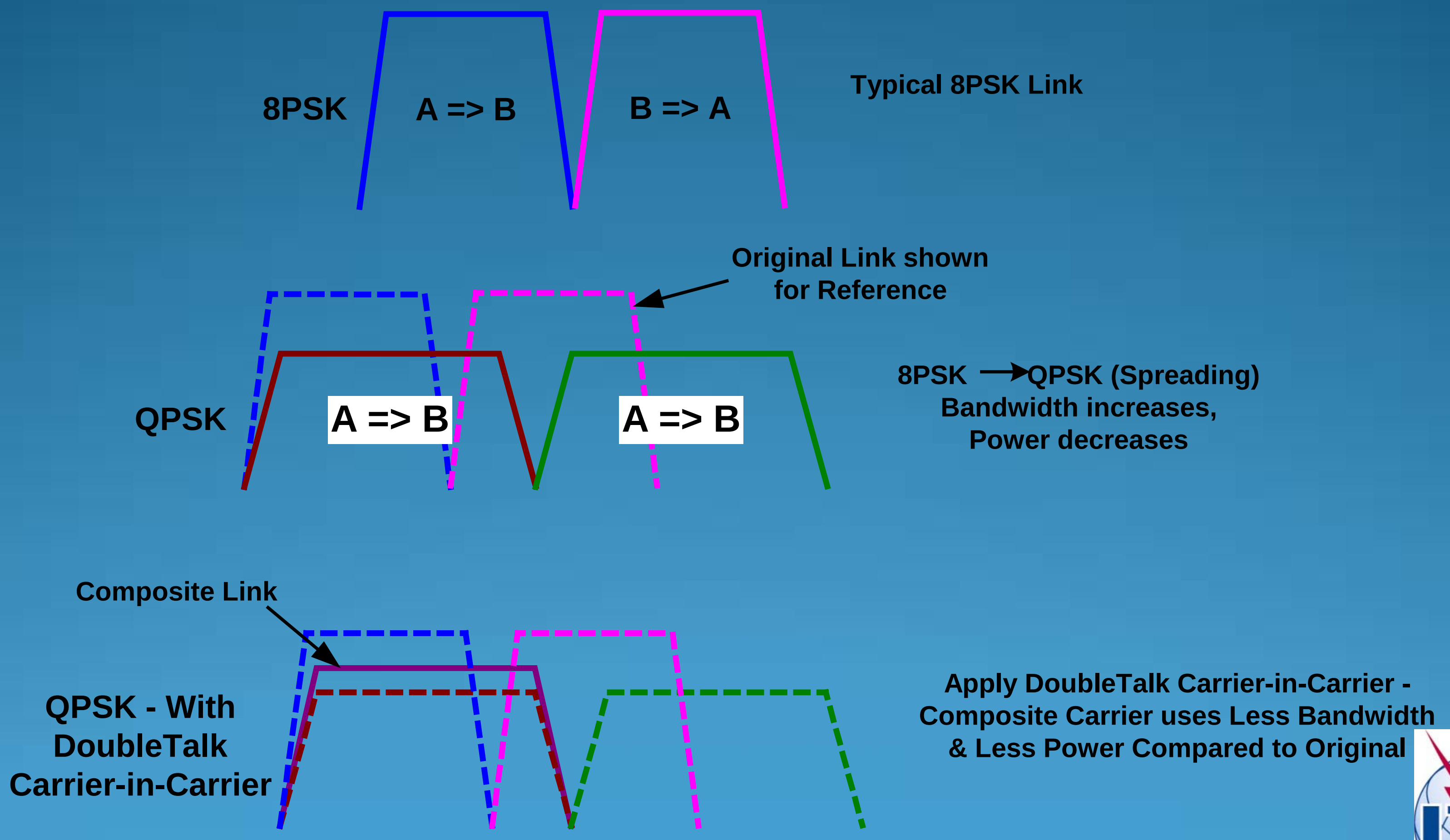
The solution is to limit the bandwidth occupied using the satellite techniques discussed earlier, and the level of the carrier signal, through the use of

- Modulation - QPSK, 8-PSK…..
- Data rate, FEC, código RS etc

Impact of Modulation

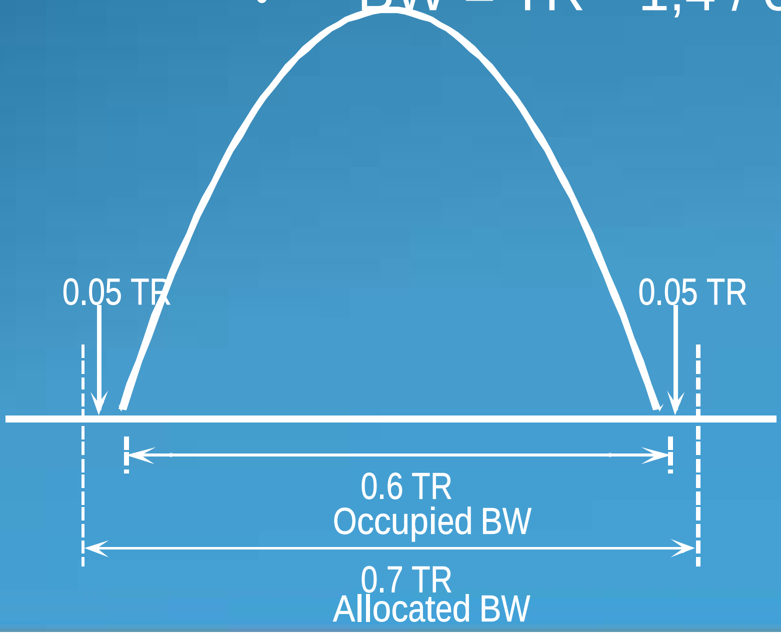


# Network planning (link budget analysis 5)



# Network planning (link budget analysis 6)

- Binary Output taking into account the transmission rate which in turn is dependent on the used FEC, not forgetting the guard bands for the bandwidth that is allocated:
  - TR = DR * 1 / FEC * 1/ RS
  - BW = TR * 1,4 / δ (δ=1-BPSK,2-QPSK,38PSK,4-16QAM)




| BW | 512K-1/2 | 512K-3/4 |
|---|---|---|
| BPSK | 1,4366 | 0,9557 |
| QPSK | 0,7168 | 0,4778 |
| 8PSK | 0,4778 | 0,3186 |
| 16QAM | 0,3584 | 0,2389 |

# Network planning
# (link budget analysis 7)

- Requirement to "maximize the output power of the satellite“ or what will give the same "power conversion efficiency by bandwidth” (PEB-power equivalent bw) translates into the inverse of saving bandwidth. In fact the result of excessive use of resources, reflected in higher MOD.

  FEC means >> PEB, Power limited links have >> PEB
- OIS charge the largest
  - Allocated bandwith or PEB

Once again balance shall be achieved so the carrier must be optimized, following:

1. BER = f (Eb / N0 ) and the Eb / N0 comes from C/ N
2. Some additional margins shall be considered to compensate the rain attenuation, e.g.
   - Ku band 3 - 8 dB
   - C band 1- 2 dB

# Network planning (link budget analysis 8)

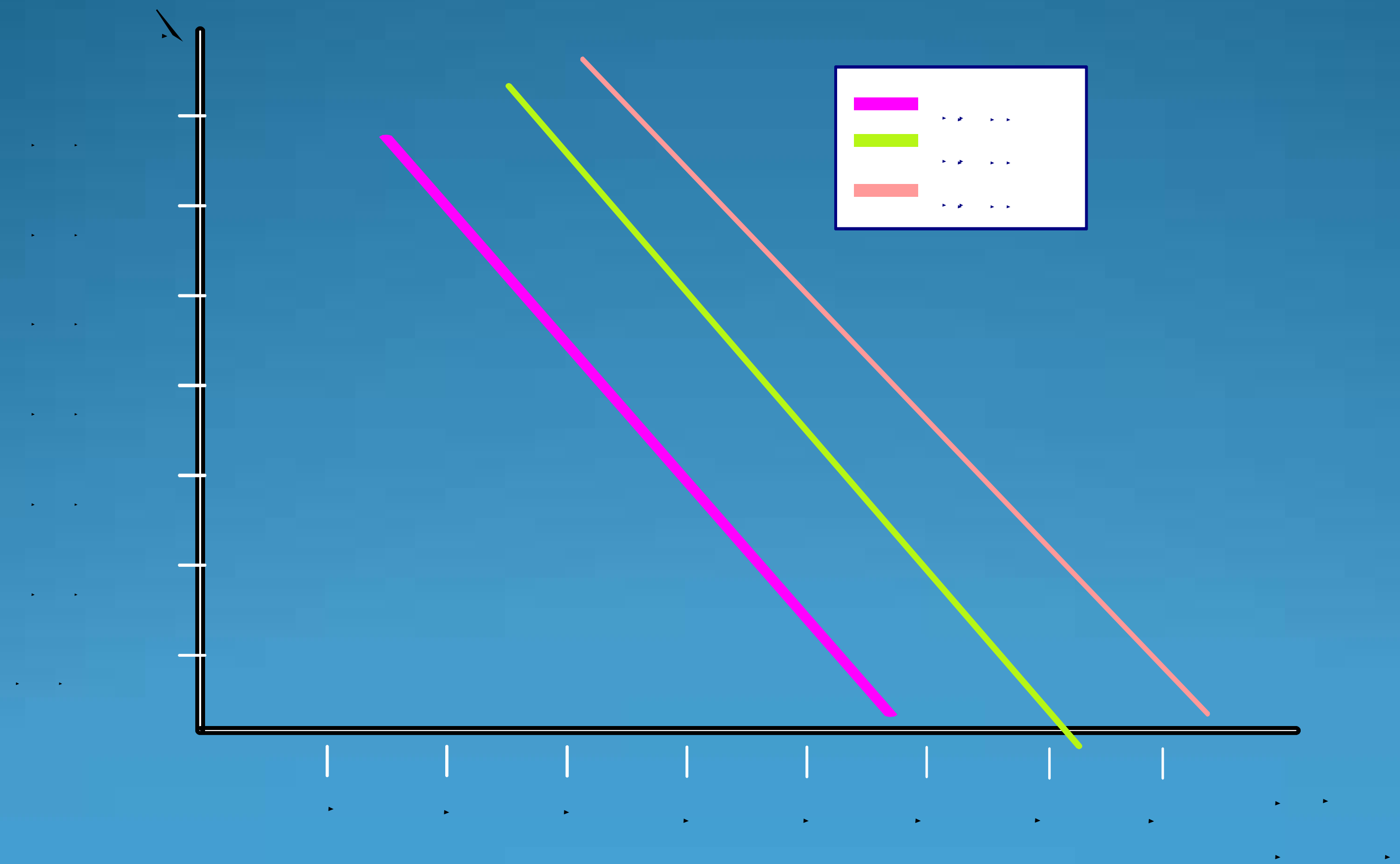
## Allocated BW

- Actually used Xp BW
- Linear function of modulation and FEC
- Decreases with higher order MODs and FECs
- “Bandwidth Limited” links have greater allocated BW compared to PEB

## Power Equivalent BW

- Required to close link Xp power
- Complicated function of hub antenna, remote antenna and satellite specifics along with required Eb/No
- Increases with higher order mods and FECs
- “Power Limited” links have greater PEB compared to allocated BW

# Network planning
## (link budget analysis 9)

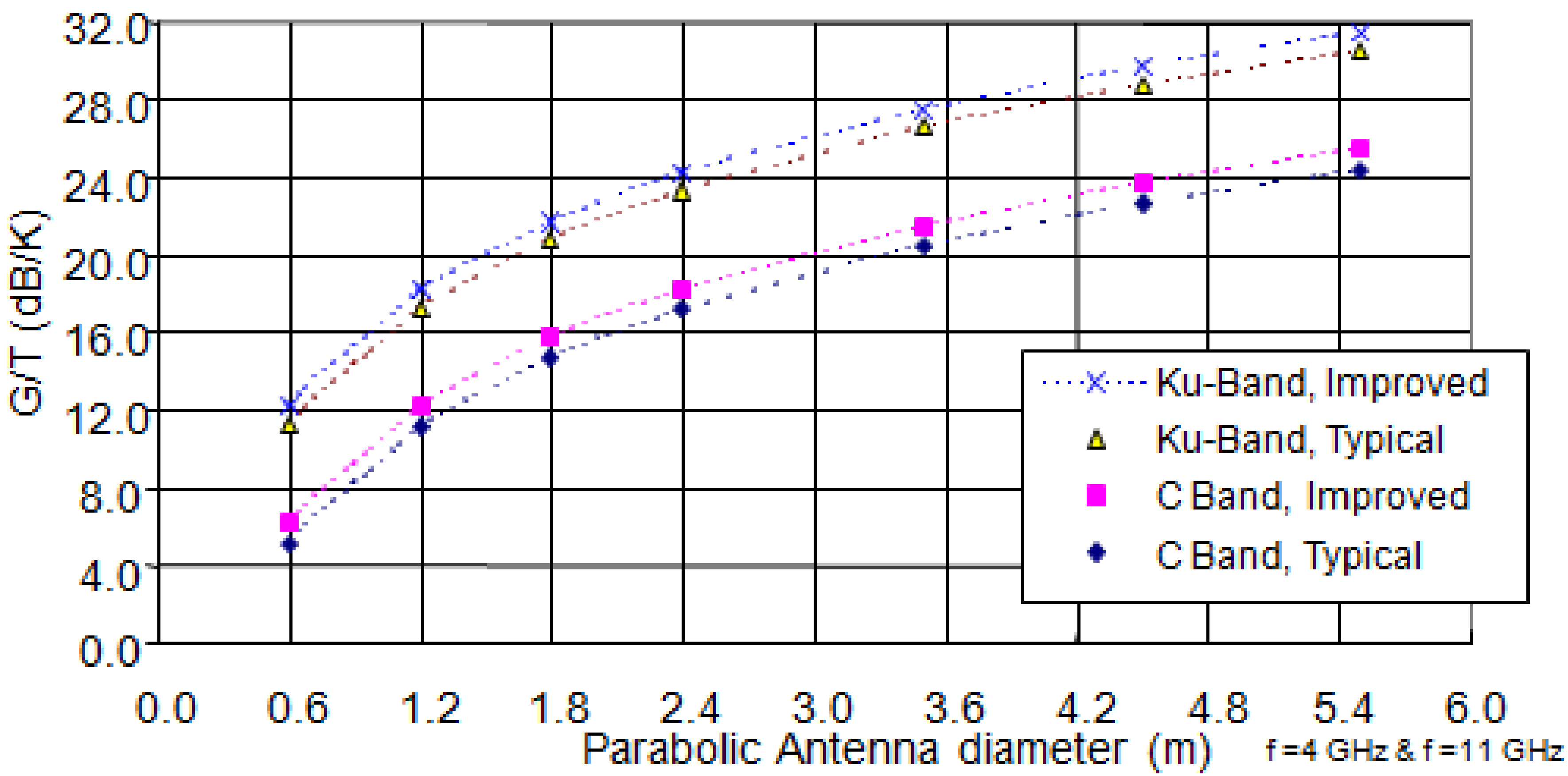


# Network planning (link budget analysis 10

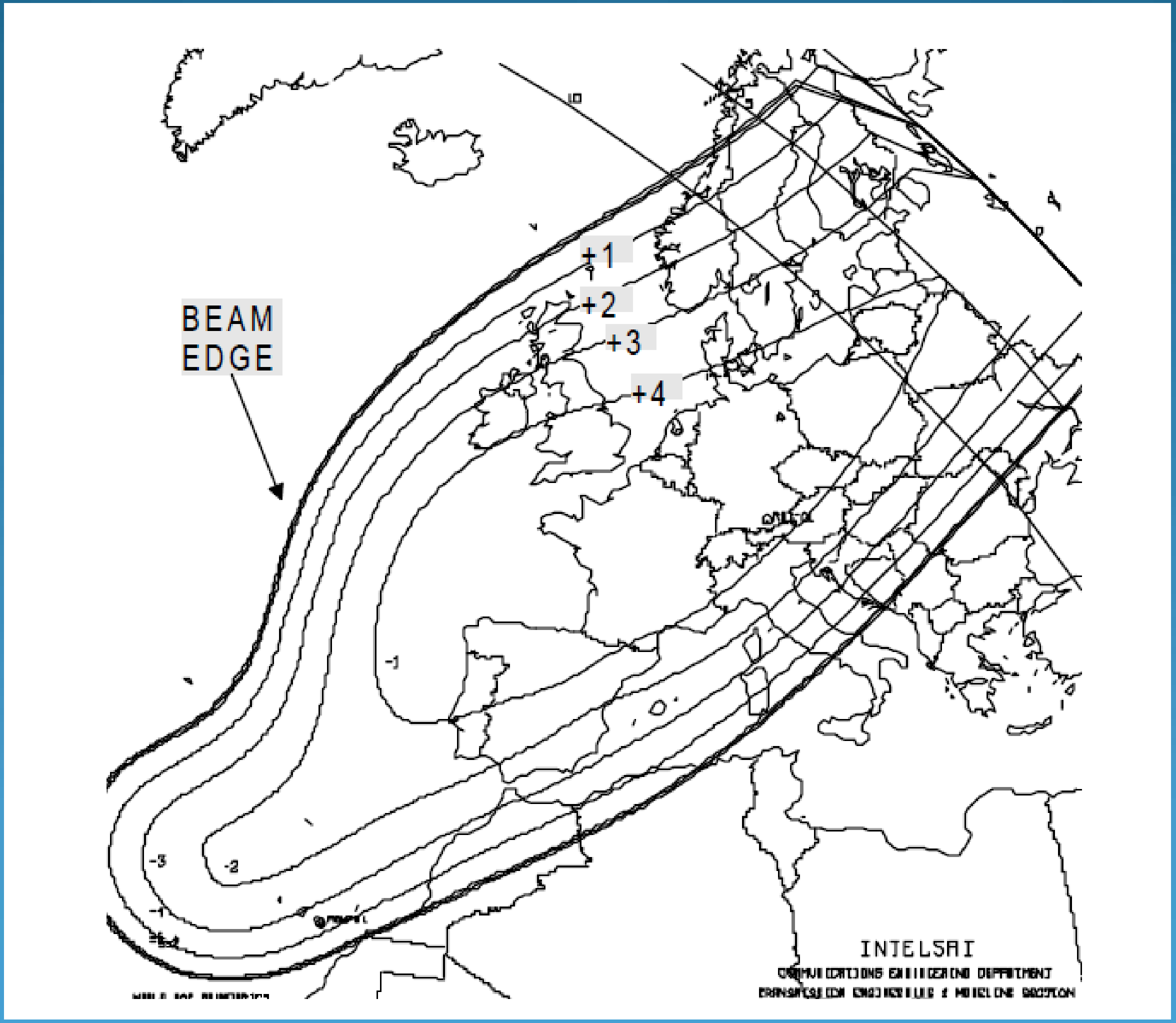
Requirement “minimize investment”

- Antena size
  - Bigger antenna bigger gain, more expensive
- HPAn sizeing, impact on
  - Carrier characteristics ( Data rate)
  - Link performance
  - Transponder sensibility
- Antenna G / T optimization
  - Bigger antenna better G / T
- Antenna location, e.g
  - Pattern advantage in the pattern radiation

# Network planning (link budget analysis 11)



# Network planning
# (link budget analysis 12)



# Network planning (input parameters – basic tx)

$$F = \frac{P_t}{4\,\pi R^2}\ \mathrm{W/m^2}$$ Or with na antenna (G) $$F = \frac{P_t G_t}{4\,\pi R^2}\ \mathrm{W/m^2}$$

To a parabolic antenna with $A_e = \eta\, A_r \rightarrow P_r = F\, A_e$

$$P_r = \frac{P_t G_t A_e}{4\,\pi R^2}\ \mathrm{W/m^2}$$ And from antenna theory $$G_r = \frac{4\pi A_e}{\lambda^2}$$

$$P_r = P_t G_t G_r \left[\frac{\lambda}{4\,\pi R}\right]^2 \mathrm{W}$$ In other way $$P_r = \frac{\mathrm{EIRP} \times G_r}{\text{Total Loss*}}$$

Into dB

$$P_r\Big|_{dB} = (\mathrm{EIRP} + G_r \underbrace{- L_p - L_a - L_{ta} - L_{ra}}\,)\ \mathrm{dBW}$$

* >> includes path loss

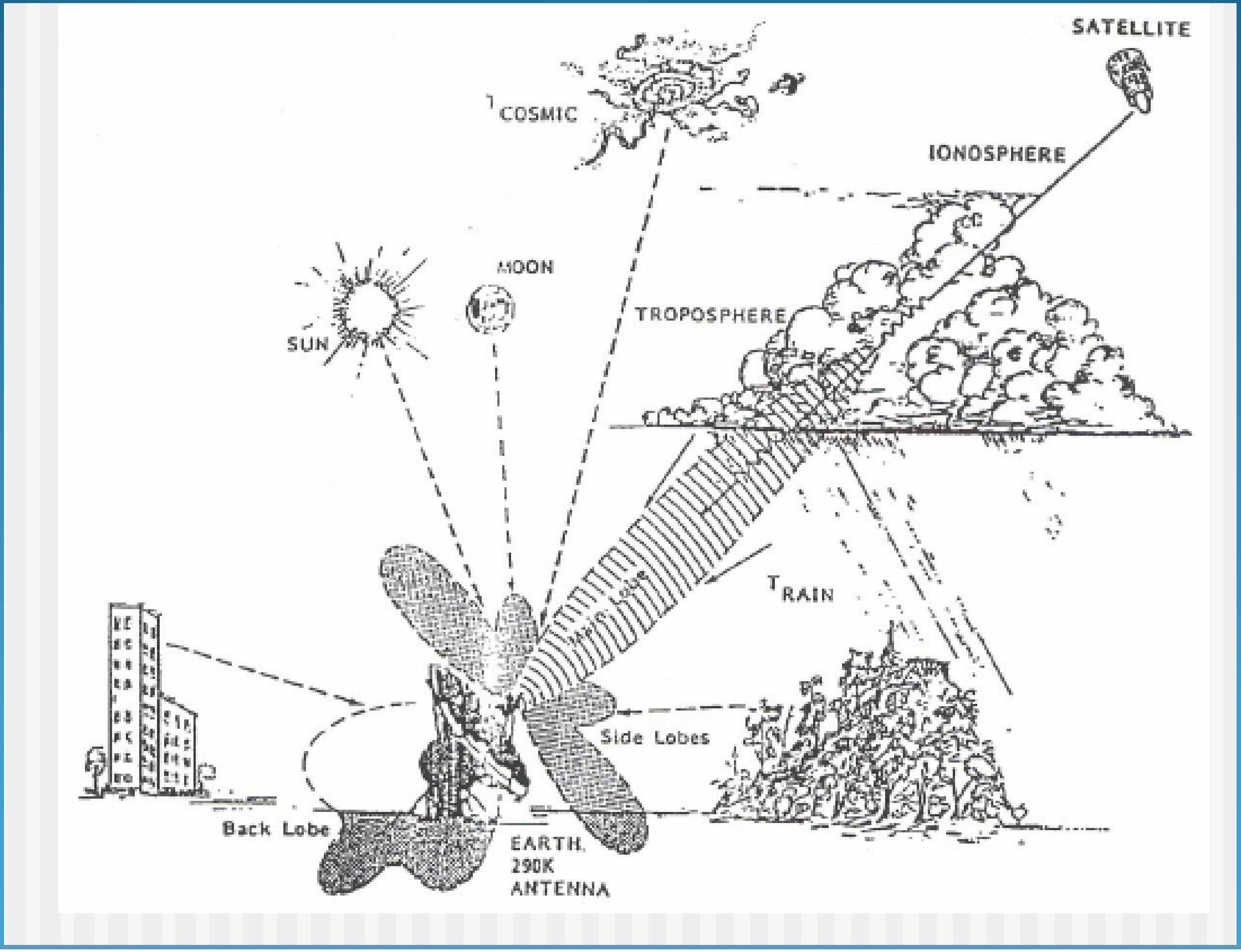
# Network planning (noise temperature 1)

- At microwave frequencies all objects with physical temperature Tp greater than 0ºK generate electrical noise. This noise can impact on the level of signal that the antenna has to receive.
- Being $N_0$ the spectral noise density and TA (to the antenna) the temperature (in ºK) the value of that is $N_0 = KT_A$ W/Hz
- The TA is function of the antenna physical temperature, of the thermal absorption of external sources as well as its gain and its orientation towards those radiant sources ..

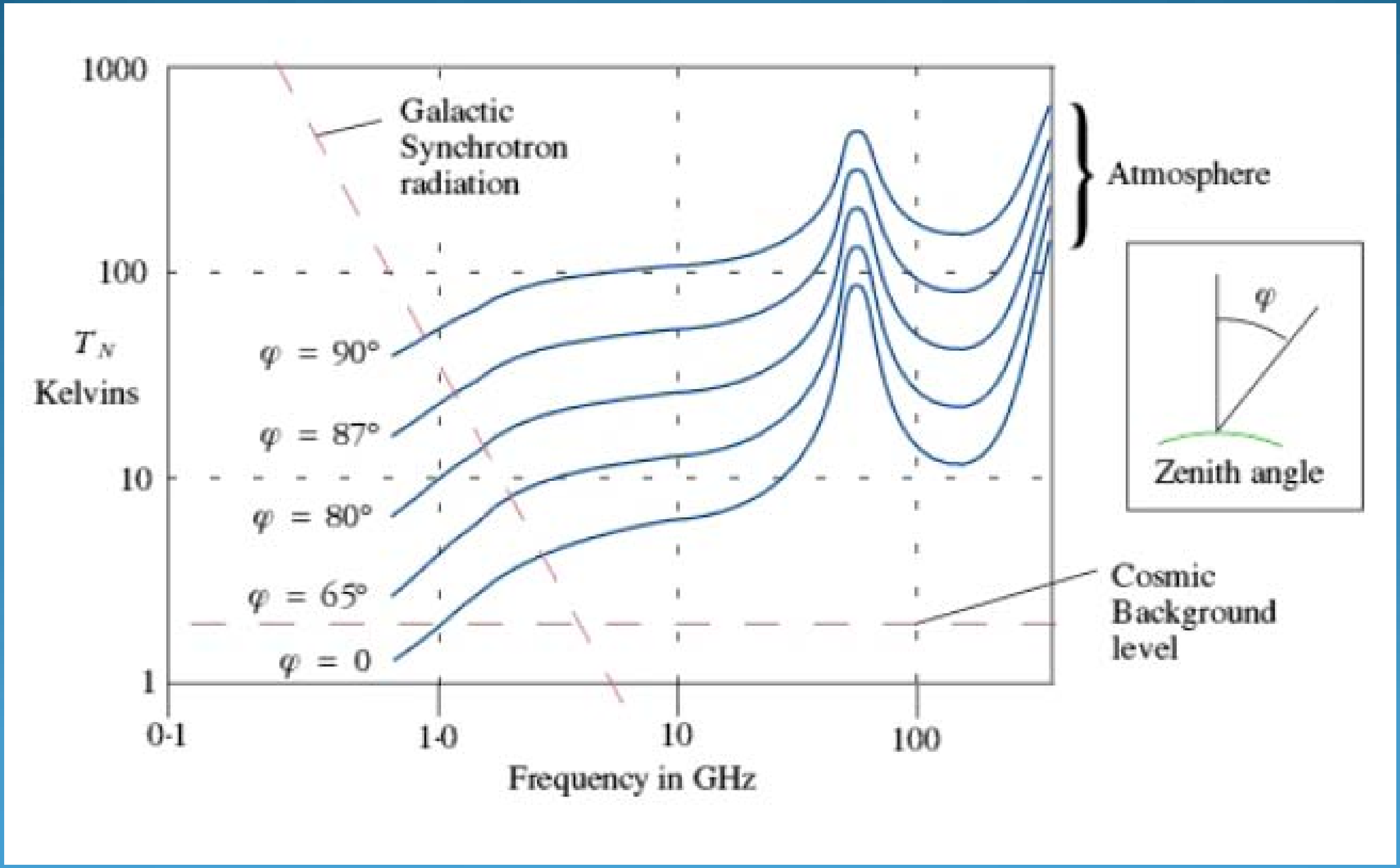
# Network planning (noise temperature 2)

- The antenna once pointed to the satellite is affected by the star noise and terrestrial radiation (see next slides), whose magnitude will be a function of the antenna elevation and the size of the main and sidelobes.
- There are also other phenomena that are a function of *path length* such as - rain absorption and diffusion, refraction or electromagnetic wave depolarization - in the atmosphere and ionosphere (see next slides) which contribute to the noise power increase at the antenna either through the signal attenuation or TA increase

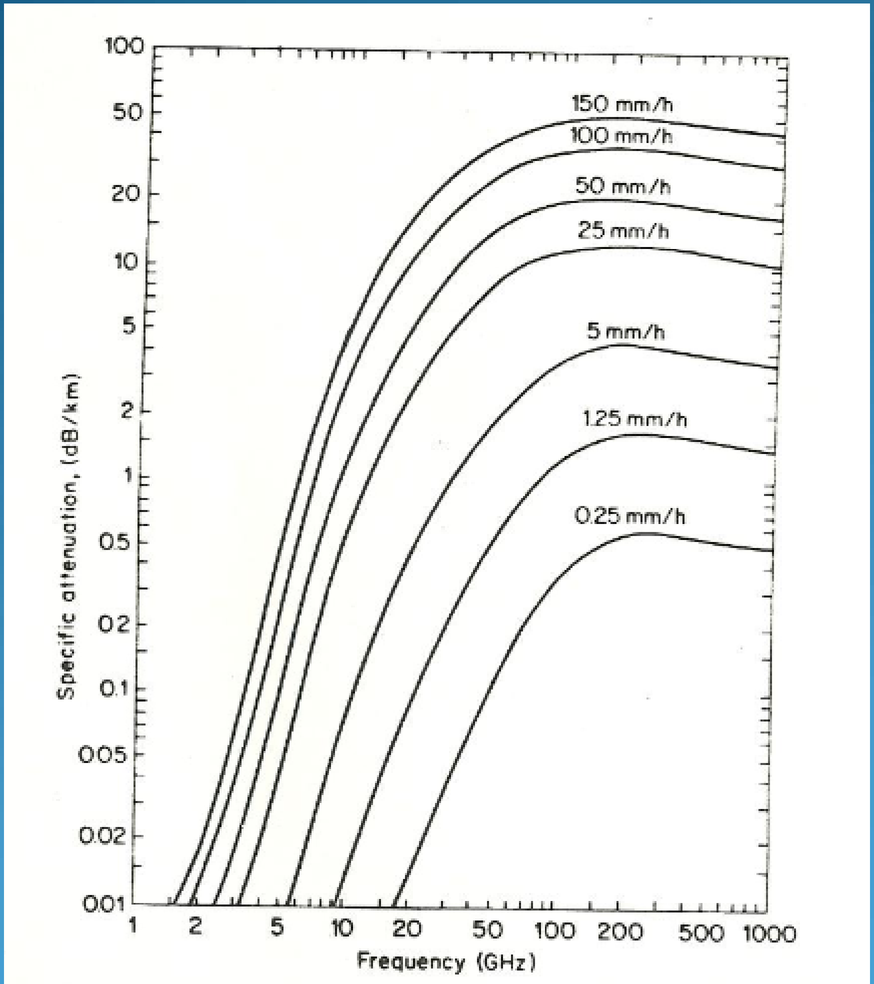
# Network planning (noise sources)

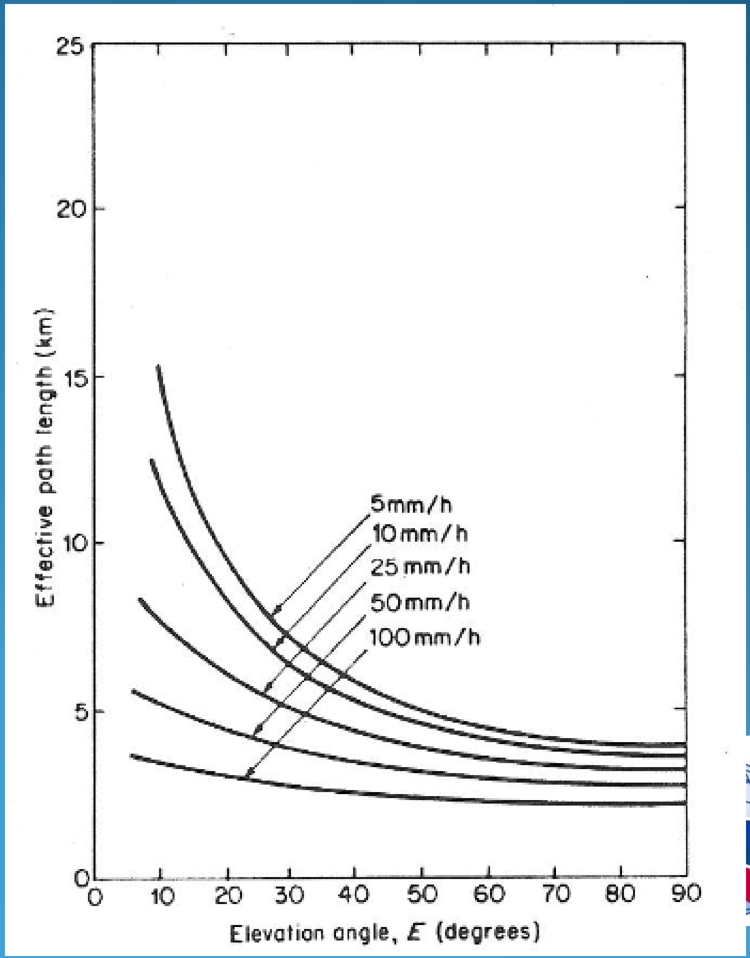


# Network planning (noise temperature - atmosphere)

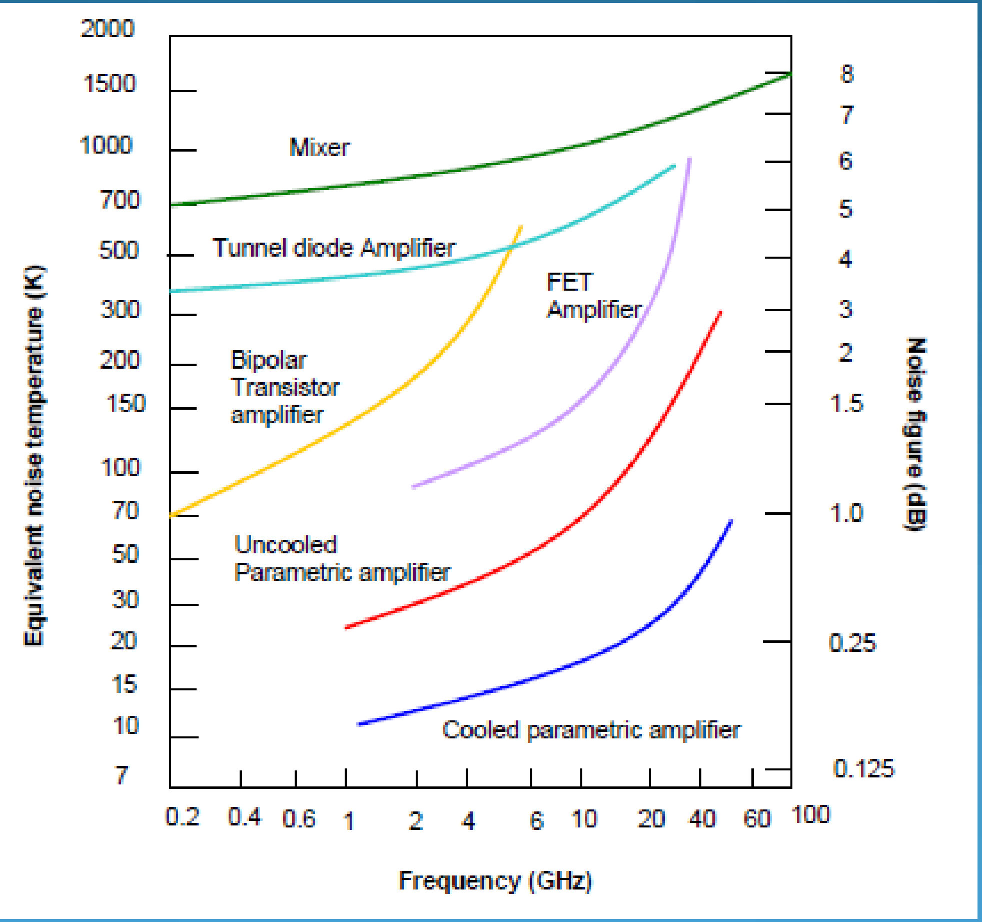


# Network planning (noise temperature - rain att)



# Network planning (noise temperature - lna technology)



# Network planning (noise temperature 3)

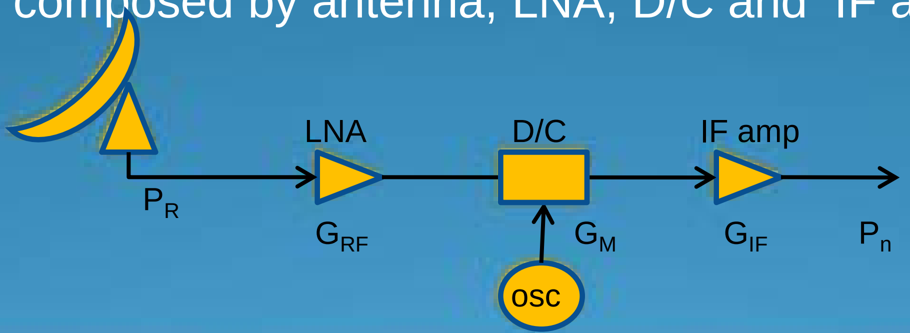
- In addition the receiver also contributes significantly to global noise, since while amplifying the original signals, it also amplifies the environmental noise and the interference from other equipments
- More common than noise temperature it the use of **noise figure**, related with noise temperature by the expression $\mathbf{N_F = 1 + T_R / T_0}$, with values from 0,2 dB up to 5 dB depending on the earth station process of cooling the low noise amplifiers.
- To evaluate the receiver noise temperature , simulate the substitution of LNA , mixer and IF amplifier by noiseless equipments (ideal) and calculate $T_s$ as follow

# Network planning (noise temperature 4)

$P_n = KT_nB$

$K$ = Constante Boltzman = 1,38 x$10^{-23}$ J/K
-228, 6 dBW/K/Hz
$T_n$ = source noise temperature ºK
$B$ = bandwidth

In a system composed by antenna, LNA, D/C and IF amplifier, e.g.




$$P_n = G_{IF}KT_{IF}B + G_{IF}G_MKT_MB + G_{IF}G_MG_{RF}KB\,(T_{RF}+T_{IN})$$

$$T_s = \left[ T_{RF}+T_{IN} + \frac{T_M}{G_{RF}} + \frac{T_{IF}}{G_MG_{RF}} \right]$$

# Network planning (input parameters G / T)

To calculate the link performance need C / N. So

$$C / N = \frac{P_t G_t G_r}{K T_s B} \left[ \frac{\lambda}{4 \pi R} \right]^2$$

In other way

$$C / N = \frac{P_t G_t}{K B} \left[ \frac{\lambda}{4 \pi R} \right]^2 \frac{G_r}{T_s}$$

Where we verify C / N as a function of $G_r$ / $T_s$ , (also known figure of merit) used to specify one receiving system. Shall be noted once increasing the G / T it is increased the global C / N

# Network planning (input parameters - G / T)

And accordingly to the Uplink , Dnlink and total

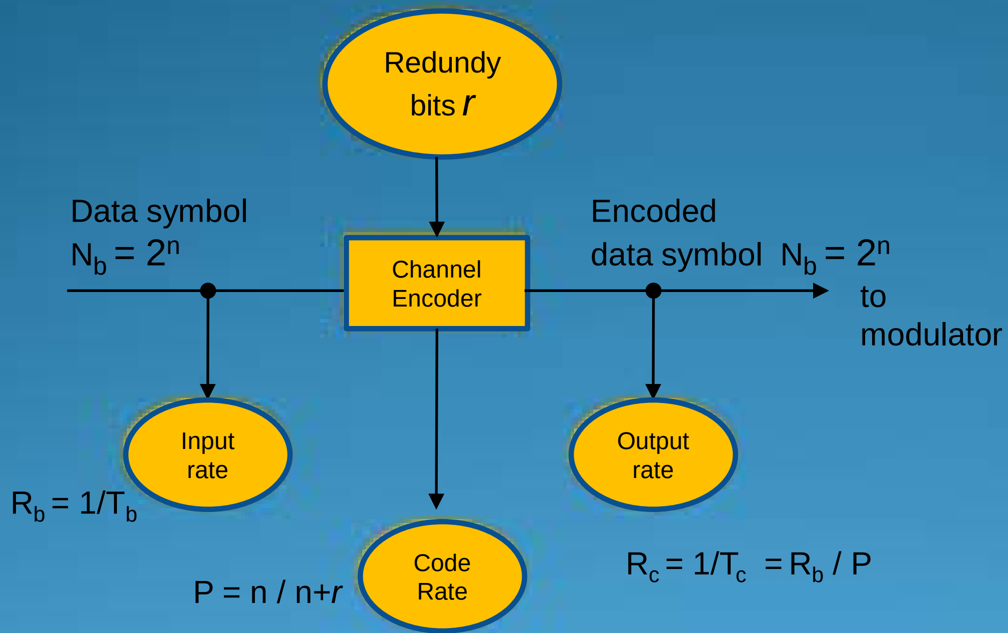
$$C/N\big|_{UPdB} = EIRP_{TX} - L_{UP} + (G/T)_{SAT} - K - BW$$

$$C/N\big|_{DNdB} = EIRP_{SAT} - L_{DN} + (G/T)_{RX} - K - BW$$

$$(C/N)^{-1}\big|_{TdB} = (C/N)^{-1}\big|_{UPdB} + (C/N)^{-1}\big|_{DNdB} + (C/I)^{-1}\big|_{IMdB} + (C/I)^{-1}\big|_{ADJdB} + (C/I)^{-1}\big|_{XPdB}$$

# Network planning

## (input parameters - $E_B / N_0$ vs $C / N$)




If we agree $E_b$, the <u>energy per bit </u>information, the energy of carrier will be:

$E_b R_b = C$

e

$E_b / N = (C/N)_T \times (1 / R_b)$

Or to noise spectral density $N_0$ and once $N = B_{IF} N_0$

$$E_b / N_0 \big|_{dB} = (C/N)_T + B_{IF} - R_b$$

# Network planning (performance margins 1)

The most important factors that influence the up and downlink are:

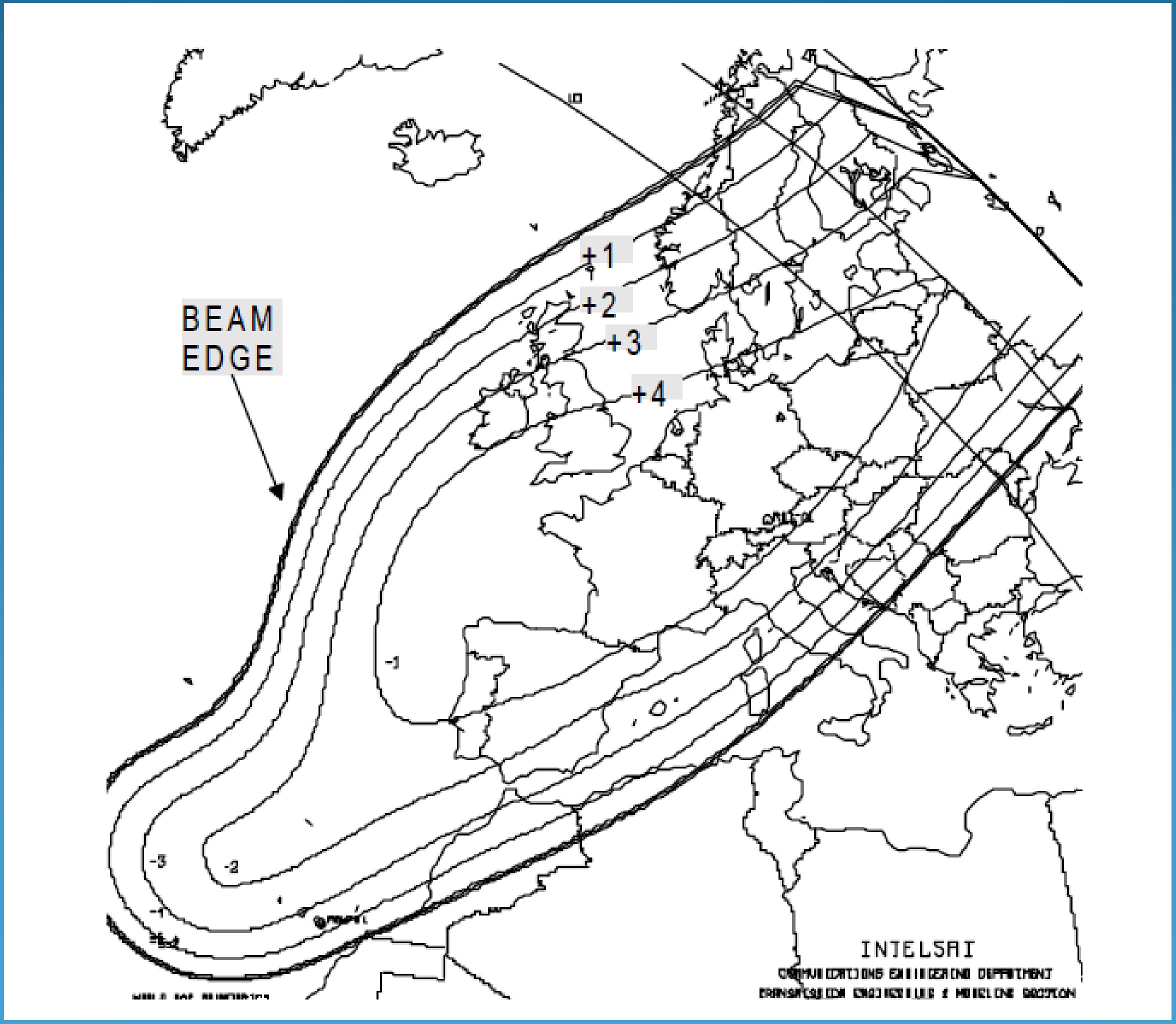
- Atmosphere propagation ( rain etc ) directly through C/N.
- Up and downlink frequencies, noting that for the frequencies above 8 GHz, the attenuation increases quickly
- The reception carrier level depending on the satellite and the receive antenna gain
- Pattern radiation and footprint of satellite antenna, namely its edge margin, the pattern advantage, the EIRP, G/T e power flux density

# Networking planning (performance margins 2)

....

- The noise generated in the receiving system, depending on the system temperature (noise receiver, waveguide loss and components) eand bandwidth used. Particular attention to the sun noise during the equinox of the year, during Spring and Autumn.
- Modulation used and receiver threshold
- Intersystem interference whatever would be the terrestrial links or other earth stations

# Network planning (pattern radiation - advantage)



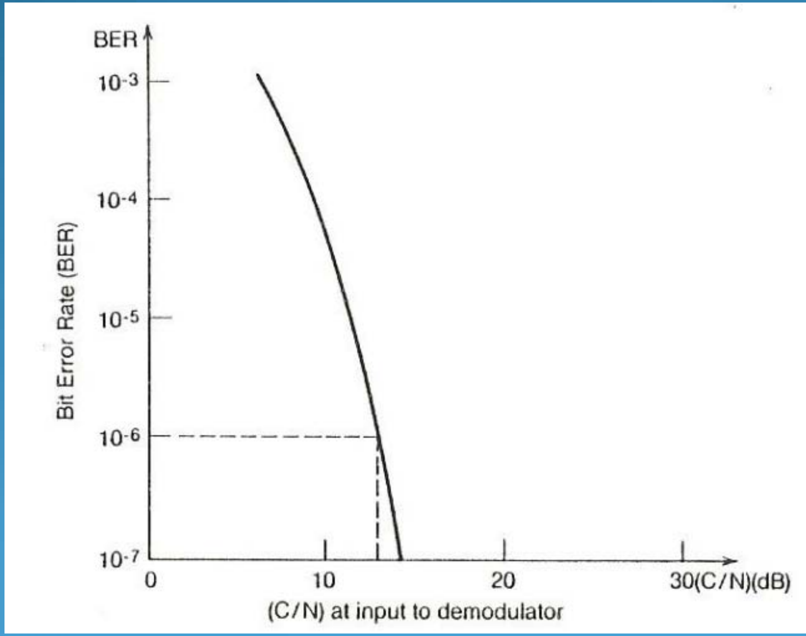
# Network planning
# (link parameters - impact on quality)

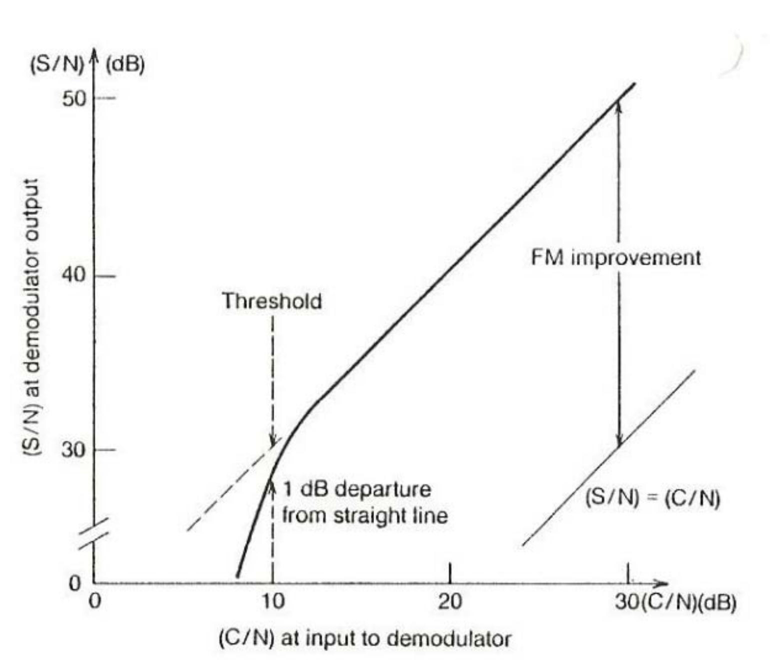
| | | |
|---|---|---|
| EIRP | $EIRP_{UP}$ | + |
| Uplink pattern advantage | $\beta_{UP}$ | |
| Transponder gain step | | |
| Downlink pattern advantage | $\beta_{DN}$ | |
| Receive antenna gain | $G_{TX}$ | |
| Free space loss | $L_{UP}, L_{DN}$ | - |
| Waveguide loss | $L_{WG}$ | |
| Atmospheric loss | | |
| Rain attenuation | | |
| Tracking errors | | |
| E/S intermodulation | $C/T_{HPAIM}$ | + |
| Uplink thermal noise | $C/T_{UP}$ | |
| Downlink thermal noise | $C/T_{DN}$ | |
| Transponder intermodulation | $C/T_{IMSAT}$ | |
| Co-channel interference | $C/T_{CCI}$ | |

C / N → BER

# Network planning (C / N specification 1)

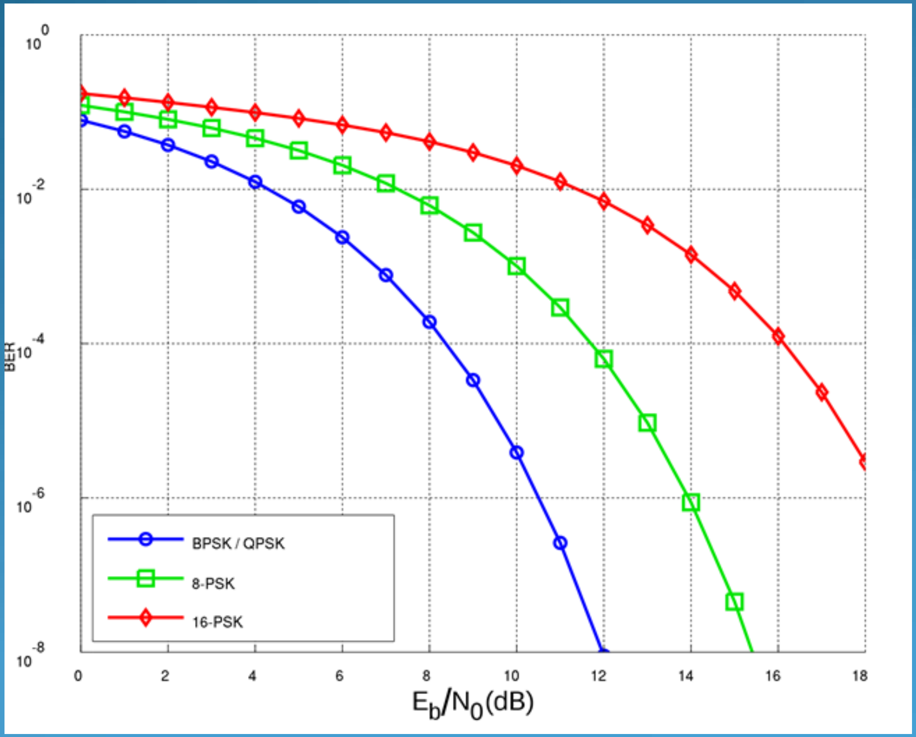
For digital carriers where the modulation is PSK, the BER calculation, being specific to the system is still valid the C/N *Threshold with values between* $10^{-3}$ e os $10^{-8}$



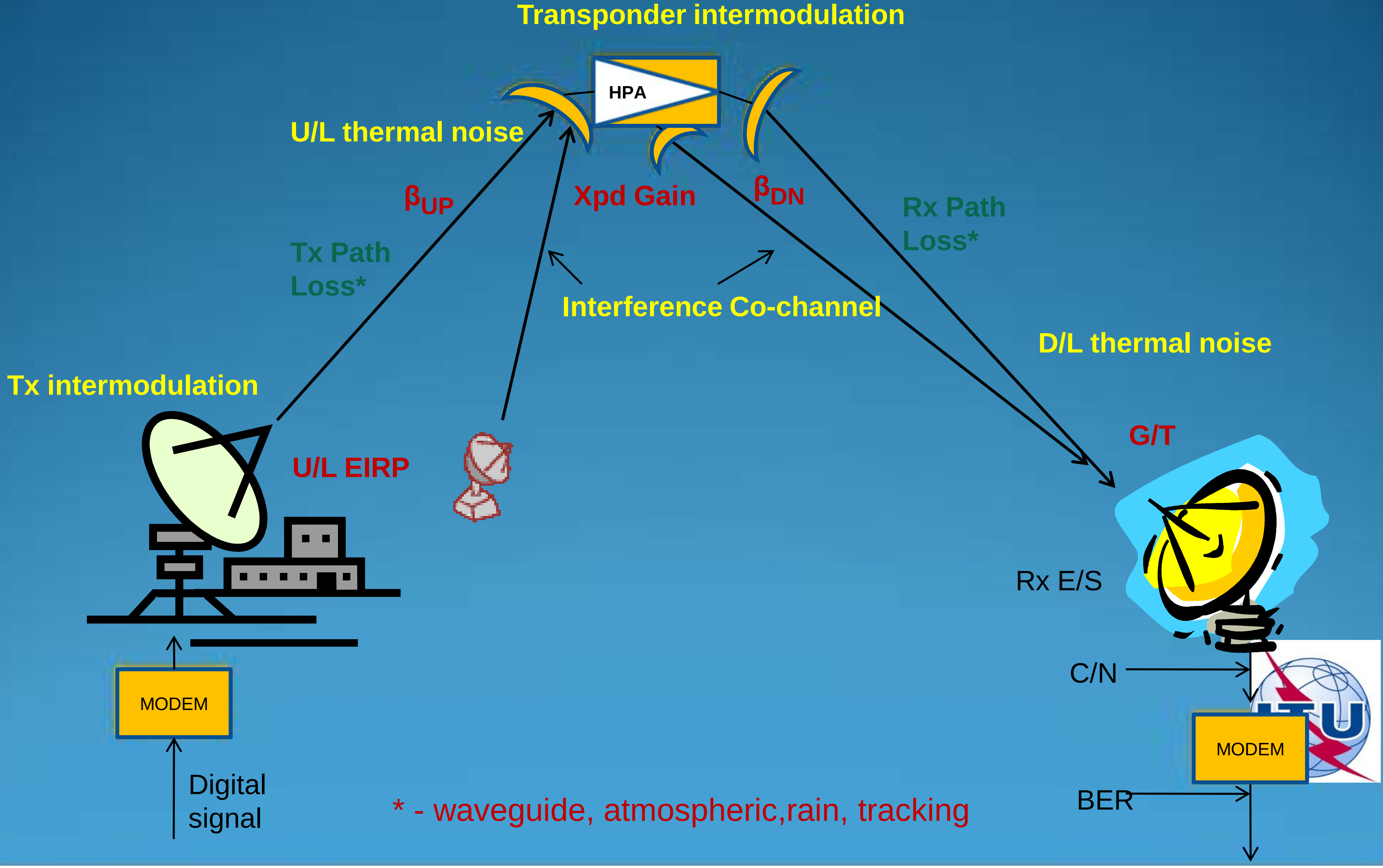

Either for analog systems
or digital there are one ratio for
the Input – output demodulator
Like S/N respectively BER and C/N

# Network planning (C / N specification 2)




Once the performance objejctives have been defined, S/N or BER or C/N, can be specified to a % of time for instance 0,01 of the year or 0,03 of the month. In $K_U$ systems which are more rain sensitive either the margin (8 dB vs 2 dB) or the availability (0,1 % vs 1%) must be considered. Also the modulation interferes in the performance, as can be seen

# Network planning (link design)




* - waveguide, atmospheric,rain, tracking

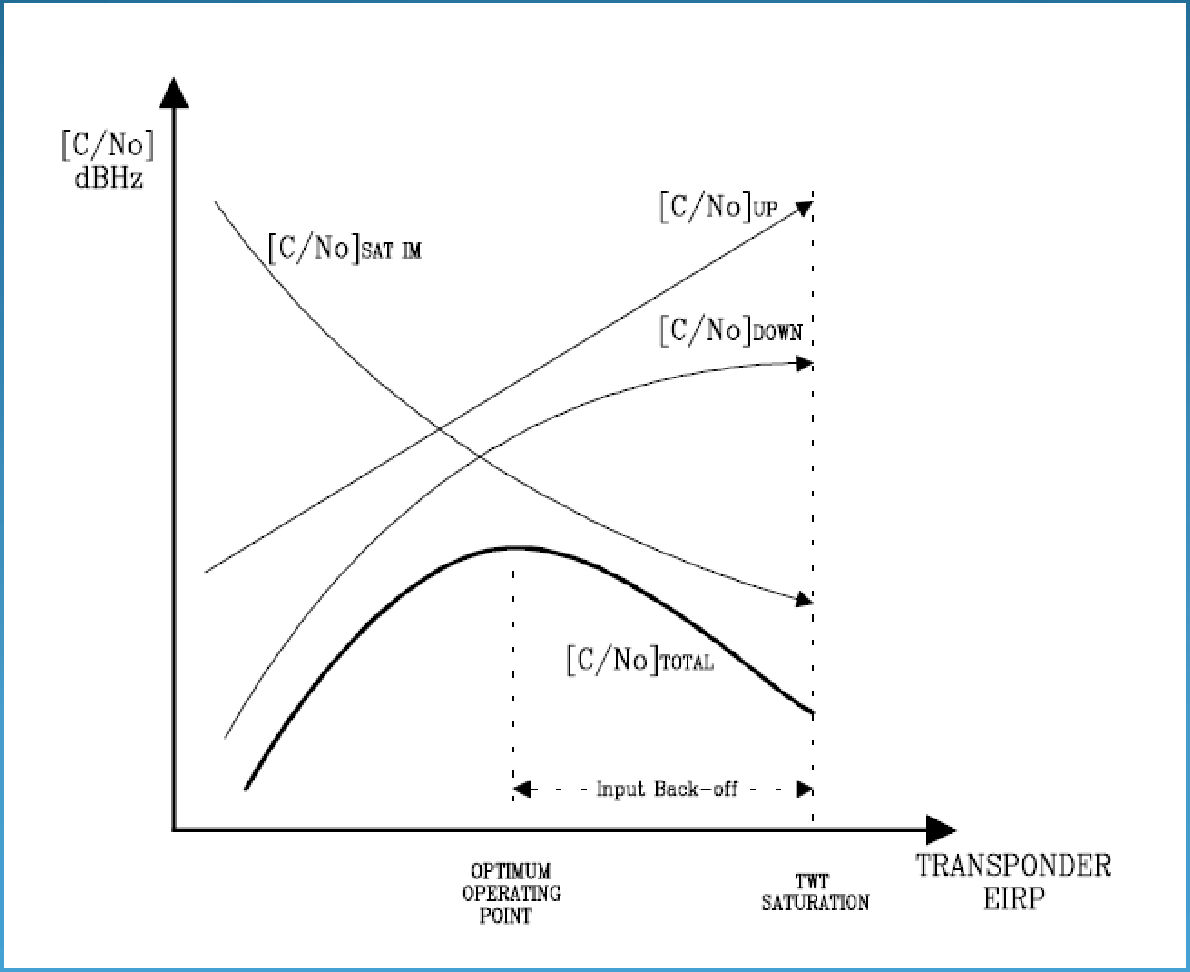
# Network planning (link design - noise components)

1. Uplink Thermal Noise - inherent to the receiving noise system prone to rain and tracking errors
2. E/S HPA Intermodulation products - inherent to HPA system with several carriers
3. Co - Channel Interference - inherent to the existance of several carriers on the same satellite, although different beams (frequency reuse) are physically or electrically (polarization) separated
4. Transponder Intermodulation - specified as a limit of EIRP density transmitted by the transponder, in a 4Khz band on the radiation pattern.

# Network planning
## (link design - noise components)

5. Downlink Thermal Noise - inherent to the receive system noise. Similarly to the uplink we must consider the rain margin and tracking errors
6. Total Link Carrier System Noise - although in a connection it is mandatory that the uplink be kept strictly at its nominal value, and a low EIRP means low C/N, it is very well known that a higher EIRP doesn’t necessarily means better $C/N_0$

# Network planning
# ($C / N_0$ vs EIRP)



# Network planning (link design assumptions)

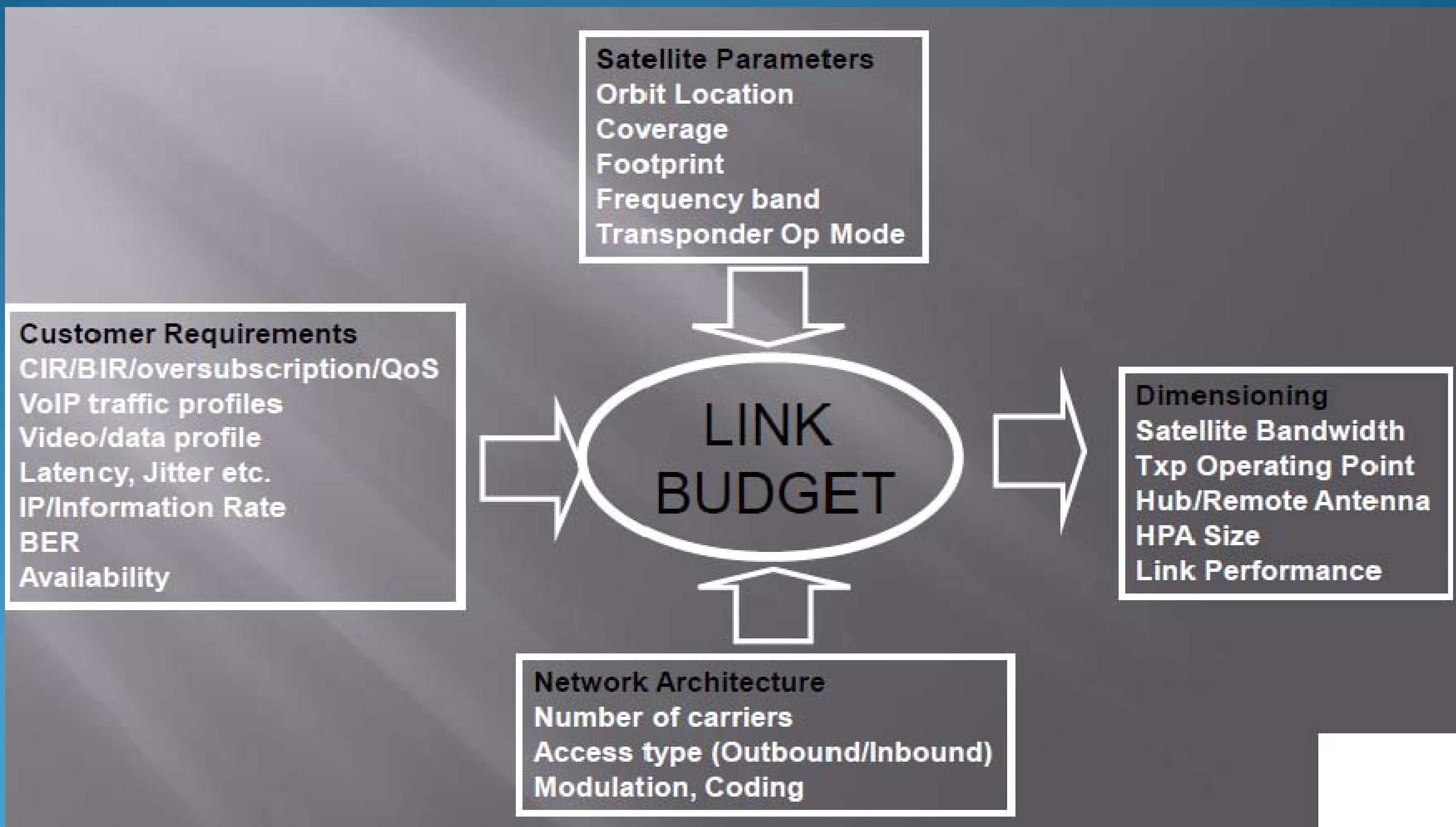
- $(C/N_0)_{UP}$ is much bigger than $(C/N_0)_{DN}$, e.g about ten's of times. Although $C_U$ is hundred's of times bigger than $C_D$, the $(C/N_0)_T$ is simply represented by $(C/N_0)D_N$, meanning that downlink determines link quality.
- The reception antenna gain is not so much limited in unlike the satellite one.

…

# Network planning (link design assumptions)

- Downlink is designed with the following objectives:
  - To guarantee continuity in % of time (typically 99,9%) with an established S/N (or BER), which imposes a minimum C/N at the receiver input. This is achieved with appropriate modulation and processing systems, to reach a minimum, S/N at the output receiver
  - To carry the large number of telephonic (or TV) channels at minimum capital expenditure and operational costs, one has to assume commitments between the antenna cost, the system tracking, the type of earth station management (on site or remote operation) and the multiple access scheme

# Network planning (link design assumptions)



# Network planning
## (link design parameters 1)

- Basic Link
- BER and FEC
- Modulation type
- G/T
- Attenuation margins
- Transponder selection
- Pattern advantage
- Interference
- Downlink power

# Network planning
# (link design parameters 2)

- Uplink pattern advantage
- Satellite uplink power
- Uplink losses
- EIRP
- Hardware losses
- HPA
- Intelsat LST calculations
- Other tools sw

# Network planning (link budget TV signal)

**C band sat. Parameters**

| | | |
|---|---|---|
| Transponder sat. Output power | 20,0 | W |
| Antenna Gain on axis | 20,0 | dB |
| Transponder bw | 36 | MHz |
| Down link frequency | 3,7-4,2 | GHz |

**Signal FM TV analog sinal**

| | | |
|---|---|---|
| FM TV signal bw | 30.0 | dB |
| Mimimum C/N overall receiver | 9,5 | dB |

**Receiving C band station**

| | | |
|---|---|---|
| Downlink freq | 4 | GHz |
| Antenna gain on axis 4GHz | 49,7 | dB |
| Receiver IF bw | 27 | MHz |
| Receiver Sistem noise temperature | 75 | ºK |

…./…

# Network planning (link budget TV signal)

**Downlink power budget**

| | |
|---|---|
| $P_T$ = Satellite transponder power output | 13,0 dBW |
| $B_0$ = Transponder output backoff | -2,0 dB |
| $G_T$ = Satellite antena gain on axis | 20,0 dB |
| $G_R$ =Earth station antenna gain | 49,7 dB |
| $L_P$ =Free space loss 4GHz | -196,5 dB |
| $L_{ANT}$ = Edge of beam loss for satellite antenna | -3,0 dB |
| $L_A$= Clear air atmosphere loss | -0,2 dB |
| $L_M$ = Other losses | -0,5 dB |
| $P_R$ = received power at earth station | -119,5 dB |

**Downlink noise power budget in clear air**

| | |
|---|---|
| K = constante boltzman | -228,6 dBw/K/Hz |
| $T_S$=System noise tem 75ºK | -18,8 dBK |
| $B_N$=Noise bw 27 MHz | -74,3 dBz |
| N = receiver noise power | -135,5 dBW |

**C /N ratio in clear air**

C / N = $P_R$ - N =-119,5 dB - ( - 135,5 dBW) = 16,0 dB

…/……

# Network planning (link budget TV signal)

**Downlink power budget in rain**

| | | |
|---|---|---|
| $P_{RCA}$ | = Received power in clear air | -119,5 dBW |
| A | = Rain att | -1,0 dB |
| $P_{RAIN}$ | = Received power in rain | -120,5 dBW |
| $N_{CA}$ | = Receiver noise in clear air | -135,5 dBW |
| $\Delta N_{RAIN}$ | = Increase in noise tem. Due to rain | 2,3 dB |
| $N_{RAIN}$ | = Receiver noise power in rain -3,0 dB | -133.2 dBW |

**C /N ratio in clear air**

$C / N = P_{RAIN} - N_{RAIN}$ = -120,5 dB - ( - 133,2 dBW) = 12,7 dB

# Networking planning (link budget DBS )

**DBS Satellite**

| | |
|---|---|
| Coverage area 3º x 2º geo orbit ( 2000Kmx1400Km) | |
| 12,2 GHz freq. | |
| Transmitter Output power per channel | 200,0 W |
| Transmit antenna Gain on axis | 37,0 dB |
| Satellite EIRP / channel | 60,0 dBW |
| Path lengh to receive afatio | 38000,0 Km |
| Flux density in coverage center | -102,5 dBW/ m2 |
| Clear air atmospheric loss | 0,5 dB |
| Actual flux density | -103,0 dBW/ m2 |

**Receiving station**

| | |
|---|---|
| Antenna diameter | 0,7 m |
| Efficiency | 60,0 % |
| Effective area of receiveing apperture (Ae) | 0,24 m2 |
| Theoretical received power ( FAe) | -109,2 dBW |

…./….

# Network planning (link budget DBS)

| | |
|---|---|
| **Theoretical received power ( FAe)** | **-109,2 dBW** |
| **Losses** | |
| Station at edge coverage zone | - 3,0 dB |
| Polarization loss in receive antenna | - 0,5 dB |
| Pointing error in receive antenna | - 1,0 dB |
| Losses in receiver before LN | - 1,0 dB |
| Actual received power ( C ) | -114,7 dBW |
| **Noise power budget** | |
| Boltzman Constante | -228,6 dBW / K / Hz |
| Receiving system noise temperature ( 700 K ) | 28,5 dBK |
| Channel bw IF ( 27 MHz) | 74,8 dB Hz |
| Noise Power (N) | -125,8 dBW |
| Worst case design (C/N) | 11,1 dB |
| Margin over 9 dB (C/N) threshold | 2,1 dB |

# Network planning
# (link design power level plan 1)

- The link analysis equations are fundamentals to determine the systems performance, and also enable the equipments auditing for instance antenna acceptance tests, equipments requirements, network design and costs evaluation
- Let us calculate the power level plan for equipaments chain alignement of a E/S such as:
  - Antenna Standard A, G/T = 35,5 dBºK
  - Reception IDR carrier( Intermediate Data Rate ) with
  - Information rate 2048 Kbps
  - FEC ¾
  - Overhead 96 Kbps
  - C/T = 155 dBW/ºK to BER 10-10 ( Intelsat VII)

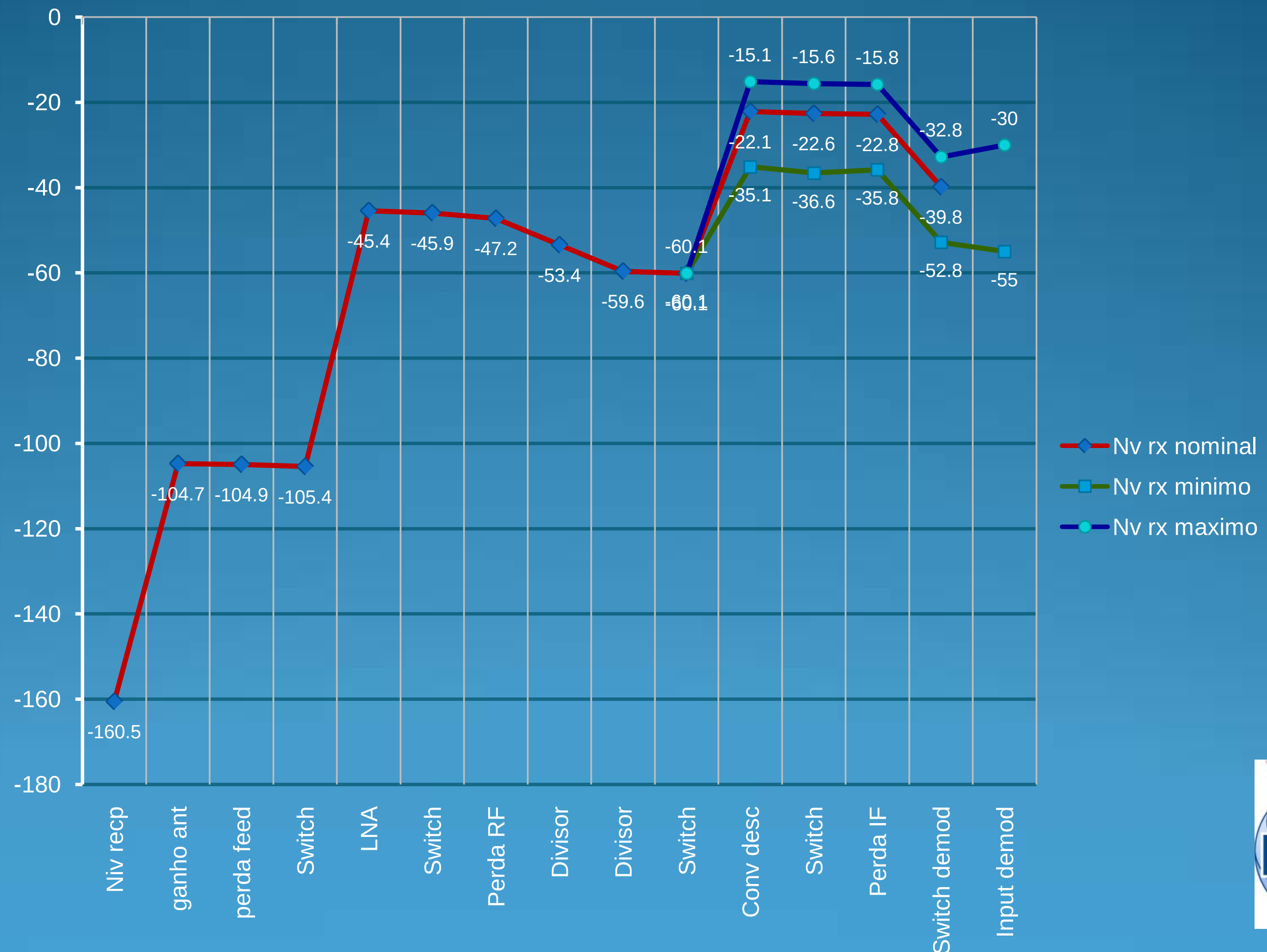
# Network planning
# (link design power level plan 2)

- Assume $G / T_{dB/ºK} = C / T – EIRP – L_0$
- $EIRP = C / T – G / T_{dB/ºK} + L_0$
- The antenna received power will be ( $EIRP – L_0$ ), so
- -155 dB/ºK - 35,5 dB/ºK = -190,5 dBW ( ou -160,5 dBm )
- Assuming the following characteristics for the equipment:
- LNA ( gain ) 60 dB
- Downconverter
  - Gain 25 a 45 dB
  - Gain adjustement 20 dB
- Demodulator
  - Input level -30 a -55 dBm
  (proper operational point) -40 dBm

# Network planning (link design power level plan 3)

| N° | Equipament | Gain (dB) | Out level (dBm) | Final G | Out level set (dBm) |
|---|---|---|---|---|---|
| 1 | Received level | | -160,5 | | |
| 2 | Antenna gain | 55,8 | -104,7 | | |
| 3 | Free loss | -0,2 | -104,9 | | |
| 4 | Switching | -0,5 | -105,4 | | |
| 5 | LNA | 60 | -45,4 | | |
| 6 | Switching | -0,5 | -45,9 | | |
| 7 | RF link | -1,3 | -47,2 | | |
| 8 | Divider | -6,2 | -53,4 | | |
| 9 | Divider | -6,2 | -59,6 | | |
| 10 | Switching | -0,5 | -60,1 | | |
| 11 | Downconverter | 25 a 45 | -35,1 a -15,1 | 38 | -22,1 |
| 12 | Switching | -0,5 | -36,6 a -15,6 | -0,5 | -22,6 |
| 13 | IF link | -0,2 | -35,8 a 15,8 | -0,2 | -22,8 |
| 14 | Demod switch | -17 | -52,8 a -32,8 | -17 | -39,8 |
| 15 | Demod input | -30 a -55 | | | -39,8 |

# Network planning (link design power level plan 4)



# Network planning (home work)

Determine the normalized receive station G/T for a F-2 station (diameter 7,5 m), using the link analysis equations, if the following information is provided:

| | |
|---|---|
| • Normalized frequency | 4 GHz |
| • Satellite EIRP | 31 dBW |
| • Downlink aspect correction | 1,85 dB |
| • C/N0 measured at receiver | 88,4 dBHz |
| • Downlink slant range | 40 586,98 Km |
| • Atmospheric | 0,15 dB |
| • Operating frequency | 4,037 GHz |

Solution G/T = 27,3 dB/ºK a 4 GHz