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Communication via satellite

Space technology I

Vendela Paxal

Overview

- Basics of satellite communication
- Beam coverage
- Frequency plan – transponders
- Link budget
    - antennas
    - frequency bands
    - coding and modulation
    - noise and filtering
    - non linearities
    - fading
    - elevation and athmospheric loss
    - cross polarisation
    - interference
- Satellite components
    - bent pipe
    - on board processing
- Types of traffic
- IP transmission over satellite
- Summary
- Examples of satellite communication systems

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Motivation for satellite communication

Pros:

- Coverage
- Simple earth infrastructure
- Visibility
- Availability
- Bandwidth
- Unvulnerability to human or natural terrestrial damage
- Better ”economy”

Cons:

- Distance – satellite environment
- Vulnerability to space damage – difficult repair
- Poor link budget
- Interference
- Cost
- Development time
- End of life – space debris

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Two-way satellite connection on the Brazilian countryside in 2004

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Installation by Nera SatCom (STM/EMC).

Satellite monitoring and control

- Position control
- Telemetric measurements
- Power control
- Frequency control
- Beam steering control
- Software upload
- Failure control
- Switching systems
- Fuel control
- Into graveyard control

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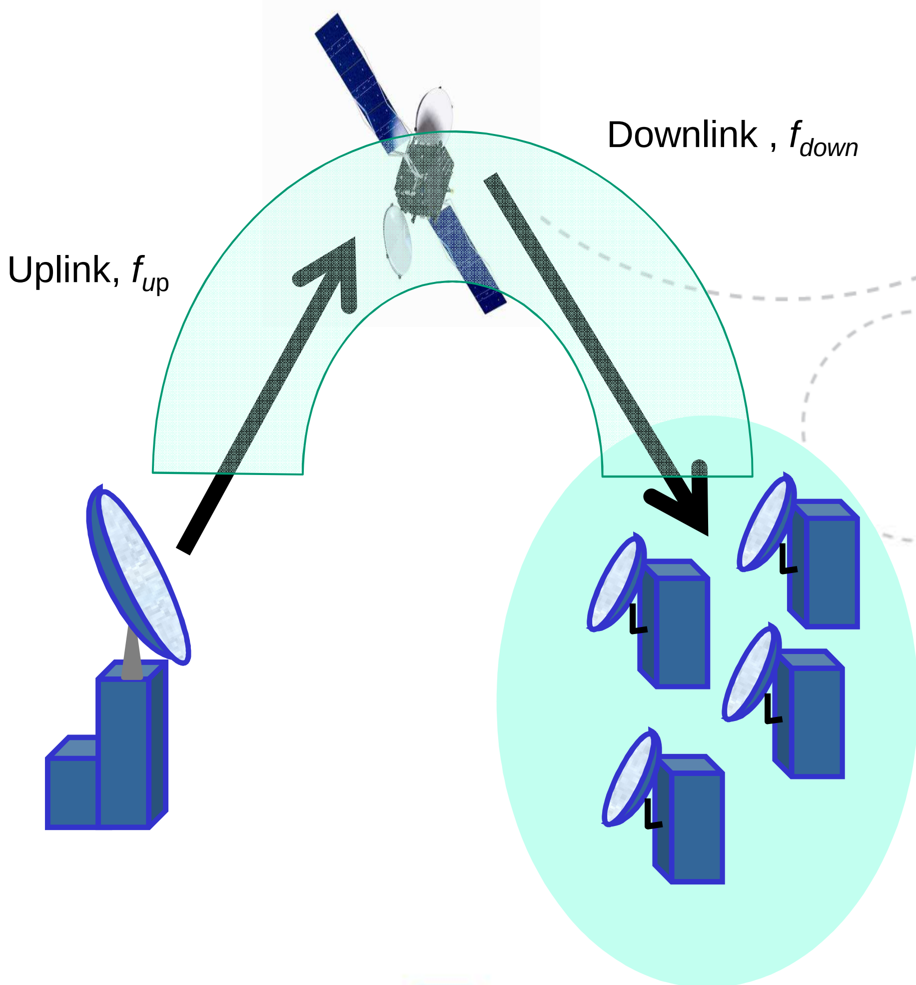
Satellite communication network types

- Broadcasting
- Point to multipoint
- Point to point
- Interactive
  - Star
  - Mesh

Broadcasting

- Large coverage
- Typically TV signals
- Large transmitter antennas
- Small receiver antennas
- Bent pipe – repeters in the satellite – just frequency transformation, filtering and amplifiaction
- $f_{up} > f_{down}$



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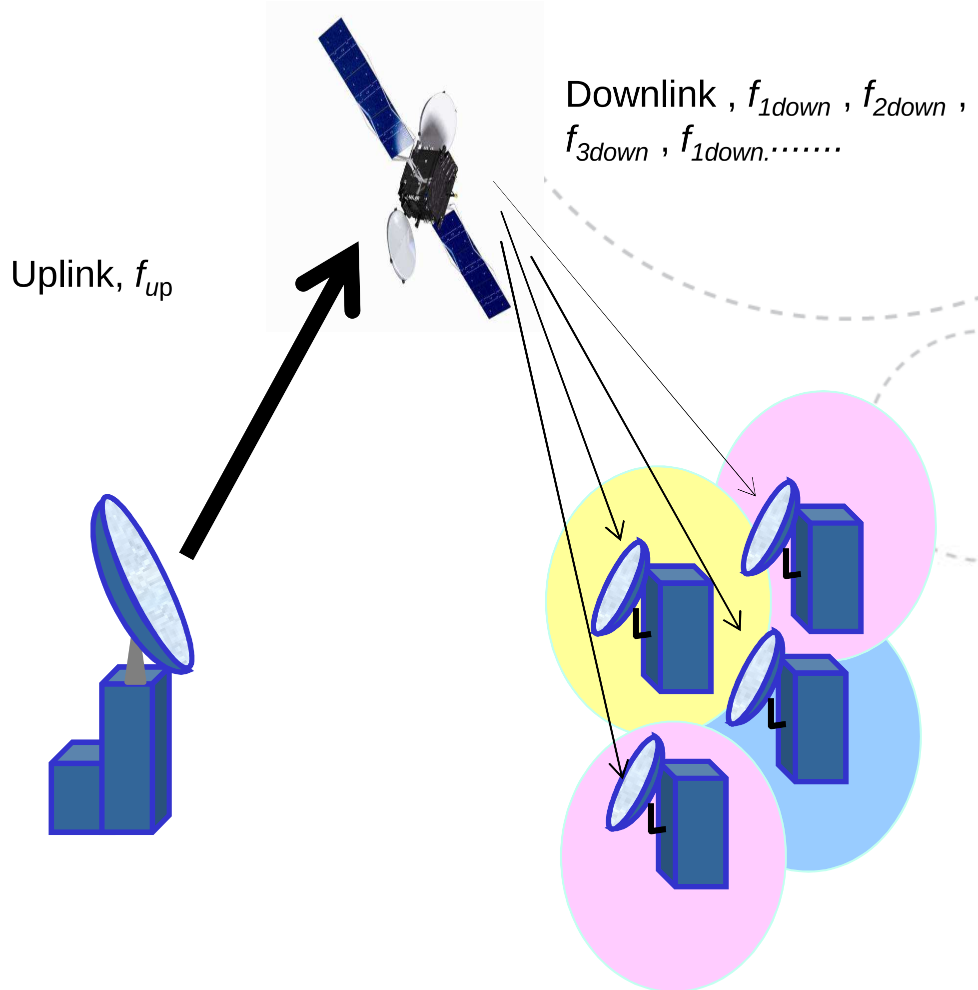
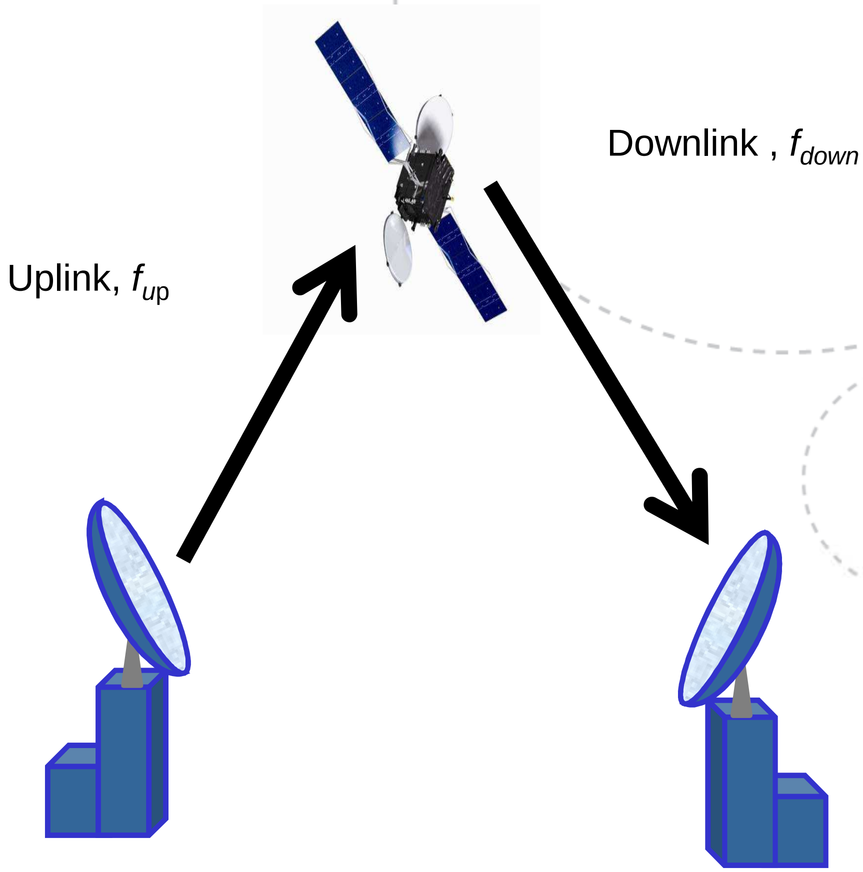
Point to multipoint

- May require use of spot beams
- May require on-board processing (OBP)
- Adresses the individual receiver (group)



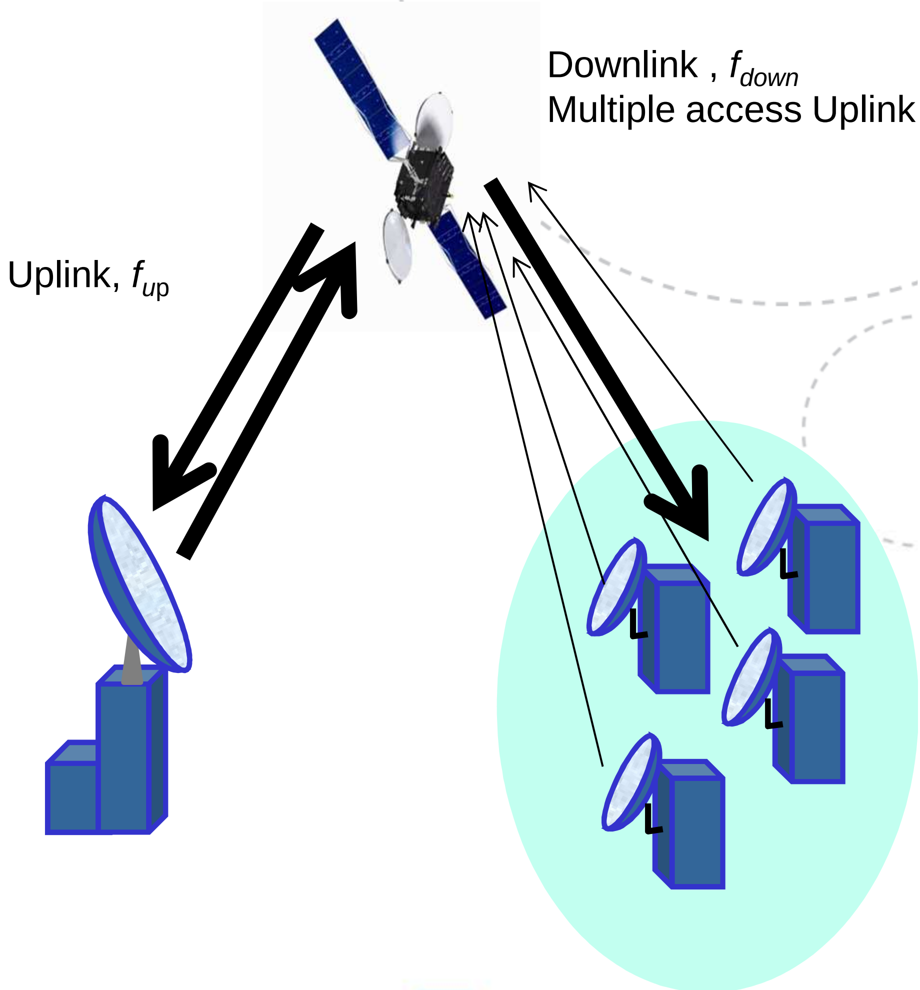
Point to point

- The satellite as part of a large communication network, e.g. telephony between Europe and America
- Bent pipe system



Interactive systems - star

- The terminals are not only receivers, but also transmitters
- VSAT systems
- Bent pipe, adresse in the signal
- Return link governed by the transmitter, gateway
- Internet browsing, video on demand, file transfer.....



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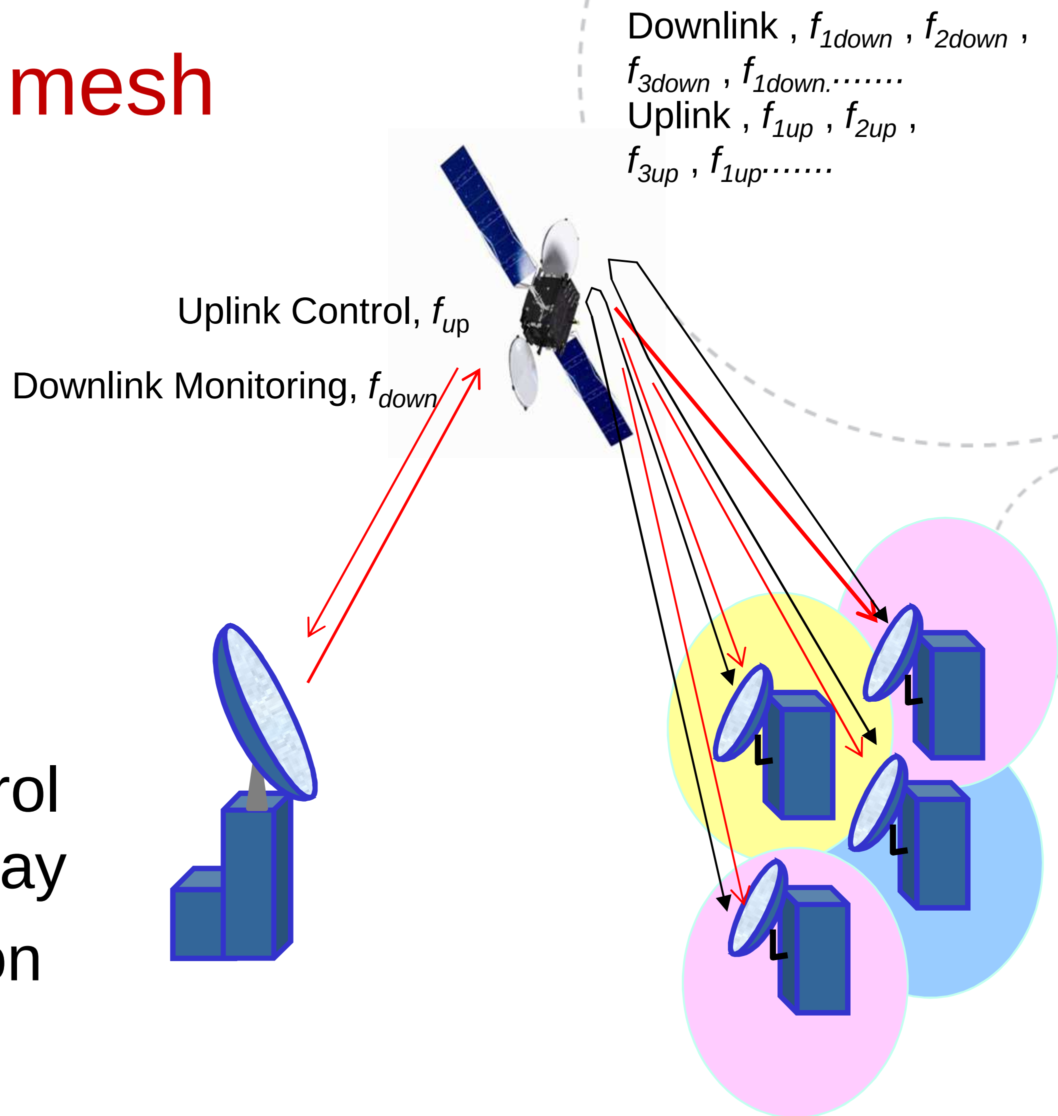
Interactive systems - mesh

- On-board processing
- Spot beams
- Two separate satellite networks, control network and communication network
- Network and access control monitored from the gateway
- Internet browsing, video on demand, file transfer.....
- Point to point communication



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Norway at 1°W – Thor satellites

- Thor I
  - Launched in August 1990 from Cape Canaveral.
  - Analog and digital tv and radio broadcasting.
  - 5 Ku transponders – TWTA output 55W – 27MHz transponder bandwidth.
- Thor II
  - Launched in May 1997 from Cape Canaveral.
  - Analog and digital tv and radio broadcasting.
  - 15 Ku transponders – TWTA output 40W – 26MHz transponder bandwidth.
- Thor III
  - Launched in June 1998 from Cape Canaveral.
  - Analog and digital tv and radio broadcasting.
  - 14 Ku transponders – TWTA output 47W – 33MHz transponder bandwidth.
- Thor 5 (II-R)
  - Launched in Februar 2008 from Baikonur.
  - Replacement of Thor II.
  - 24 Ku transponders – TWTA output 150/55W (BSS/FSS) – 33/27MHz (BSS/FSS) transponder bandwidth.
- Thor 6
  - Launched in October 2009 from Kourou.
  - Replacement of Thor III.
  - 24 transponders – TWTA output 91/53W (BSS/FSS) - 33/27MHz (BSS/FSS) transponder bandwidth.
- Thor 7
  - Launched in April 2015
  - Ku-band TV broadcast services to Europe
  - Ka-band interactive services for maritime market
  - Ka-band steerable beam
  - Ka-band spot-beam for Antarctica (Troll)

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http://www.telenorsbc.com/

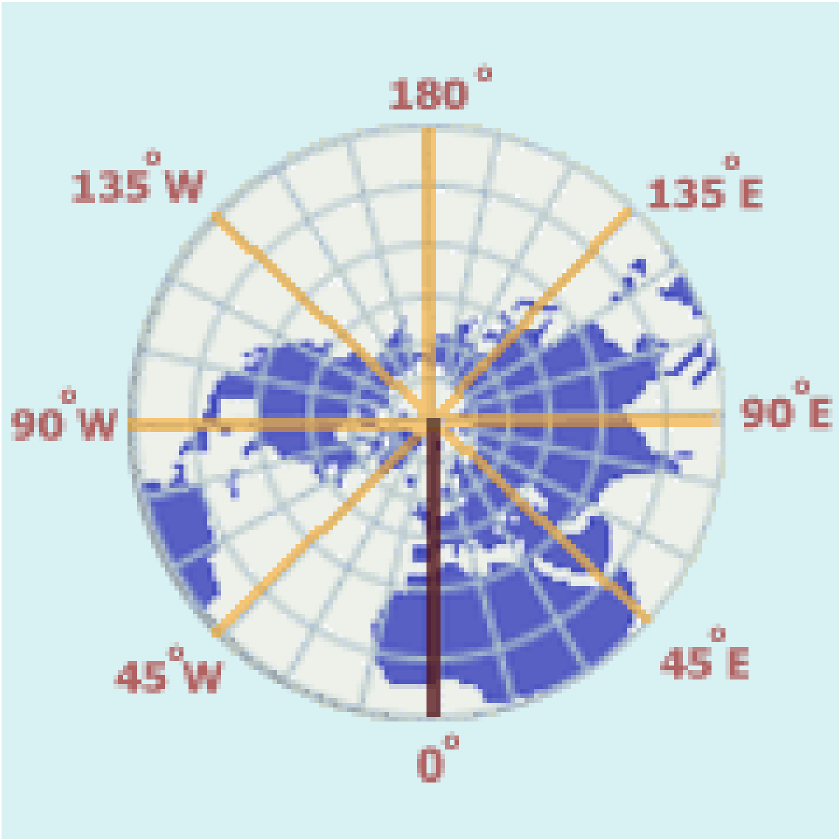
Frequency bands allocated for satellite communication

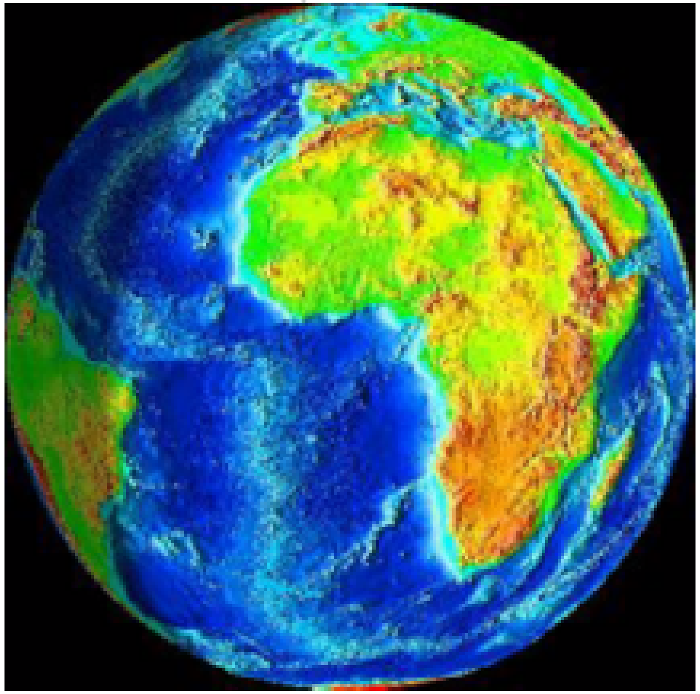
Band	Frequency range	down/up-link
V band	40 to 75 GHz	40/50 GHz
K_a band	27 to 40 GHz	20/30 GHz
K_u band	12 to 18 GHz	11/14 & 12/18 GHz
X band	8 to 12 GHz	7/8 GHz
C band	4 to 8 GHz	4/6 GHz
S band	2 to 4 GHz	~2 GHz
L band	1 to 2 GHz	1.5/1.6 GHz

Note that the uplink frequency is always higher than the downlink frequency.

Key words: Transmit power, antenna size, directivity.

Longitudes





The satellite's view of Norway from our allocated position in space: 1°W

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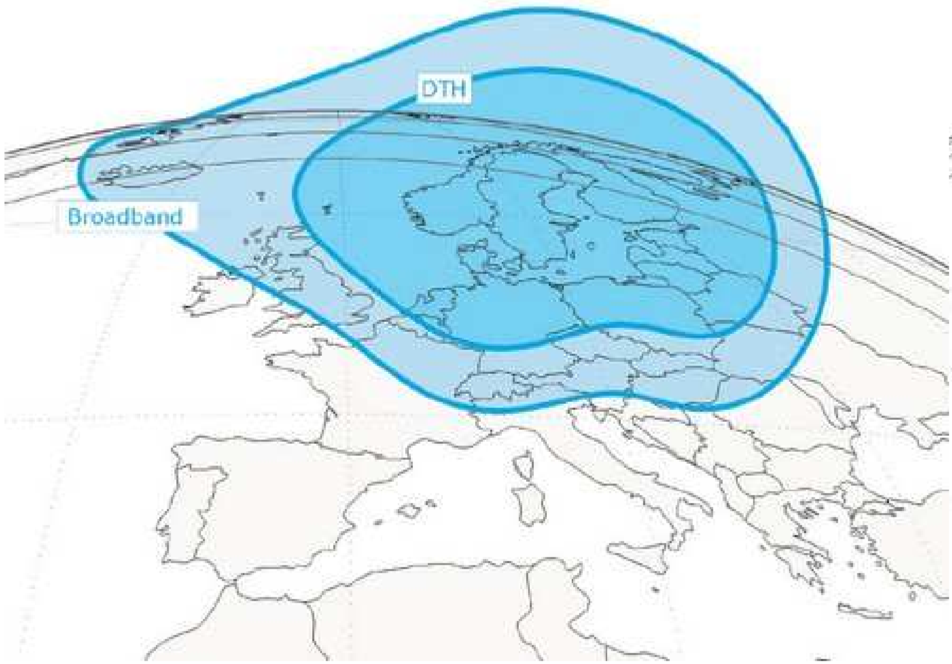
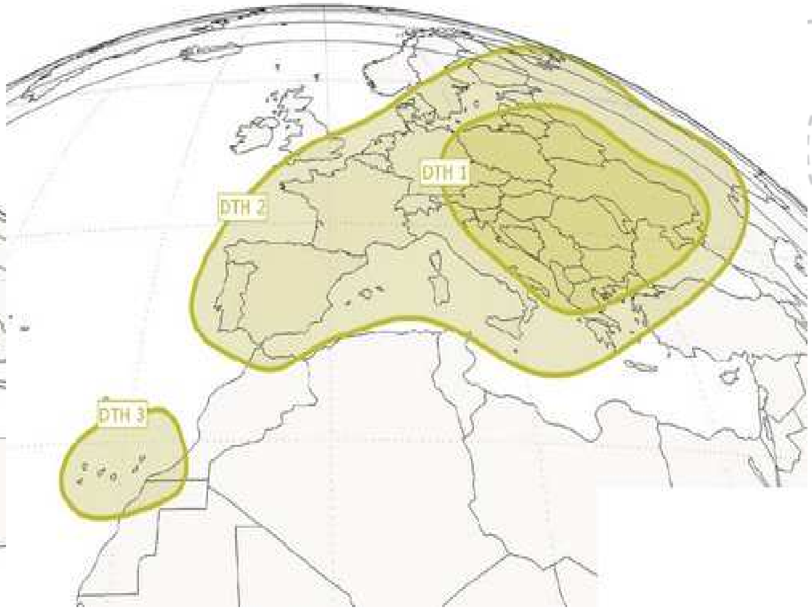
http://nationalatlas.gov/articles/mapping/a_latlong.html#one

Thor 6 coverage





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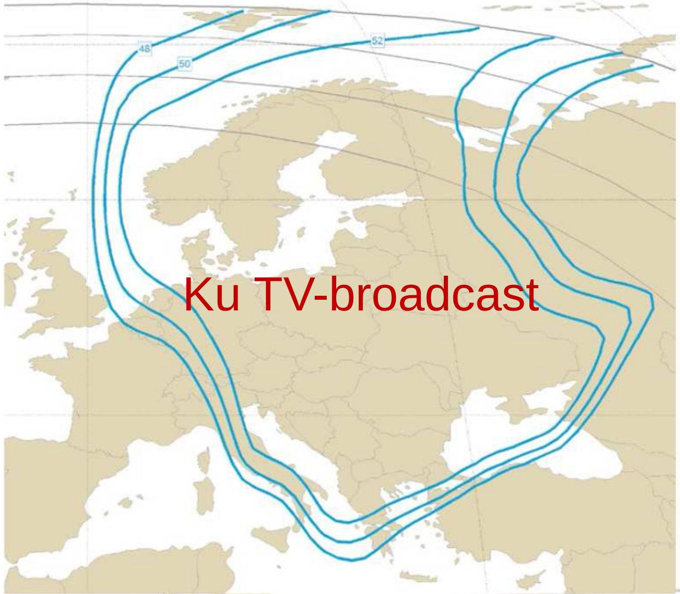
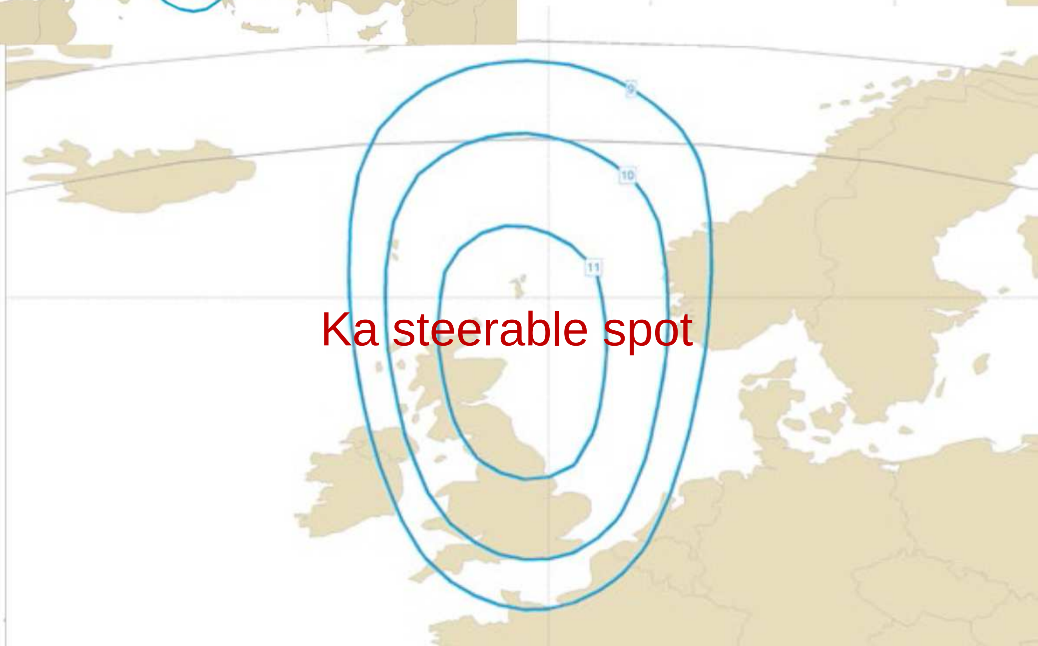
http://www.sat-universe.com/showthread.php?p=415915

Thor 7 coverage





http://www.sat-universe.com/showthread.php?p=415915

Nittedal earth station

Standardisation and regulation

- **ITU** – International Telecommunication Union - ITU is the leading United Nations agency for information and communication technology issues, and the global focal point for governments and the private sector in developing networks and services. For nearly 145 years, ITU has coordinated the shared global use of the radio spectrum, promoted international cooperation in assigning satellite orbits, worked to improve telecommunication infrastructure in the developing world, established the worldwide standards that foster seamless interconnection of a vast range of communications systems and addressed the global challenges of our times, such as mitigating climate change and strengthening cybersecurity.
  ITU is based in Geneva, Switzerland, and its membership includes 191 Member States and more than 700 Sector Members and Associates. **www.itu.int**
- **ETSI** - European Telecommunications Standards Institute –produces globally applicable standards for Information & Communications Technologies including fixed, mobile, radio, broadcast, internet, aeronautical and other areas. ETSI is recognised as an official European Standards Organisation by the European Union, enabling valuable access to European markets. **www.etsi.org**
- **EBU** – European Broadcasting Union - The European Broadcasting Union is the largest association of national broadcasters in the world. We promote cooperation between broadcasters and facilitate the exchange of audiovisual content. The EBU works to ensure that the crucial role of public service broadcasters is recognised and taken into consideration by decision-makers. The EBU has 75 Active Members, from 56 countries in and around Europe, and 43 Associate Members around the world. **www.ebu.ch**
- **NKOM** – Norwegian Communications Authority, formerly Post og Teletilsynet. Nkom is an autonomous agency of the Ministry of Transport and Communications. Nkom supervises providers of post and telecommunications services, manages frequencies and numbering resources, investigates ex ante competition problems in the electronic communications markets and makes decisions pursuant to the Electronic Communications Act and the Norwegian Postal Services Act. Nkom also manages the duty of confidentiality in electronic communications and works on security and readiness. Nkom is self-financed, primarily through fees and charges.**www.nkom.no**

Basic mission for a satellite communication system

-To convey information from A to B
  - Different applications -> different requirements
- May complement, replace or compete with terrestrial systems
- Usual requirements
  - cheap – possibility to earn money
  - to as many people as possible – TV or public coverage
  - best effort vs. secure transmission
  - availability
  - coverage
  - real time vs. non real time
- Budgets
  - cost
  - fuel
  - mass
  - link

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Link Budget

Signal to noise ratio: $S/N = EIRP/L_0 \times G/T \times 1/kB \times 1/L_a$

Equivalent isotropically radiated power: EIRP
Figure of merit: G/T
Free space loss: $L_0=(4\pi d/\lambda)^2$
Additional losses: L_a
Bandwidth: B
Boltzmann's constant: k

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Antenna Gain

- Directional antennas
- Isotropic antennas
- The antenna gain is the ratio between the amount of energy propagated in a certain direction and the energy that would be propagated if the antenna was isotropic

$G = \eta \times 4\pi A / \lambda^2$

η = antenna efficiency $0<\eta<1$, typically $0.5<\eta<0.8$

A = aperture area of the antenna

λ = radio wavelength of the carrier

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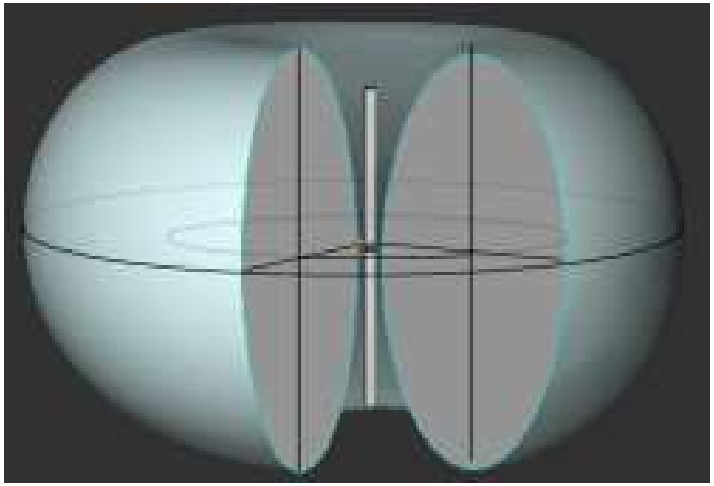
Isotropic antenna

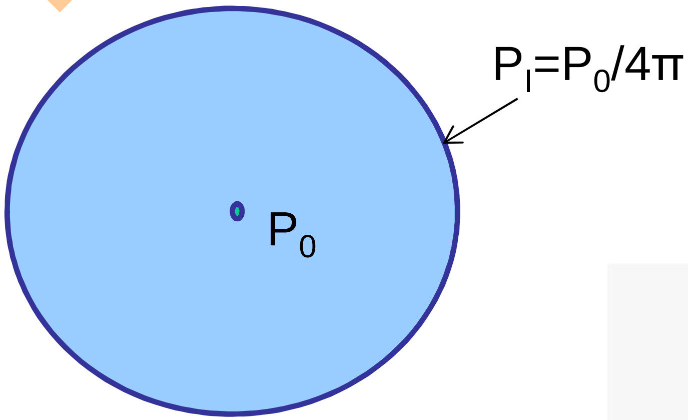
- An isotropic antenna radiates energy equally in all directions
- It is a theoretical antenna only used for reference
- The sun is an example of an isotropic radiator
- A point, or a ballshaped antenna will radiate isotropically
- A dipole antenna has a flattened torus radiation diagram



From: http://www.radartutorial.eu/06.antennas/

Antenna gain

Isotropic radiation: G=1

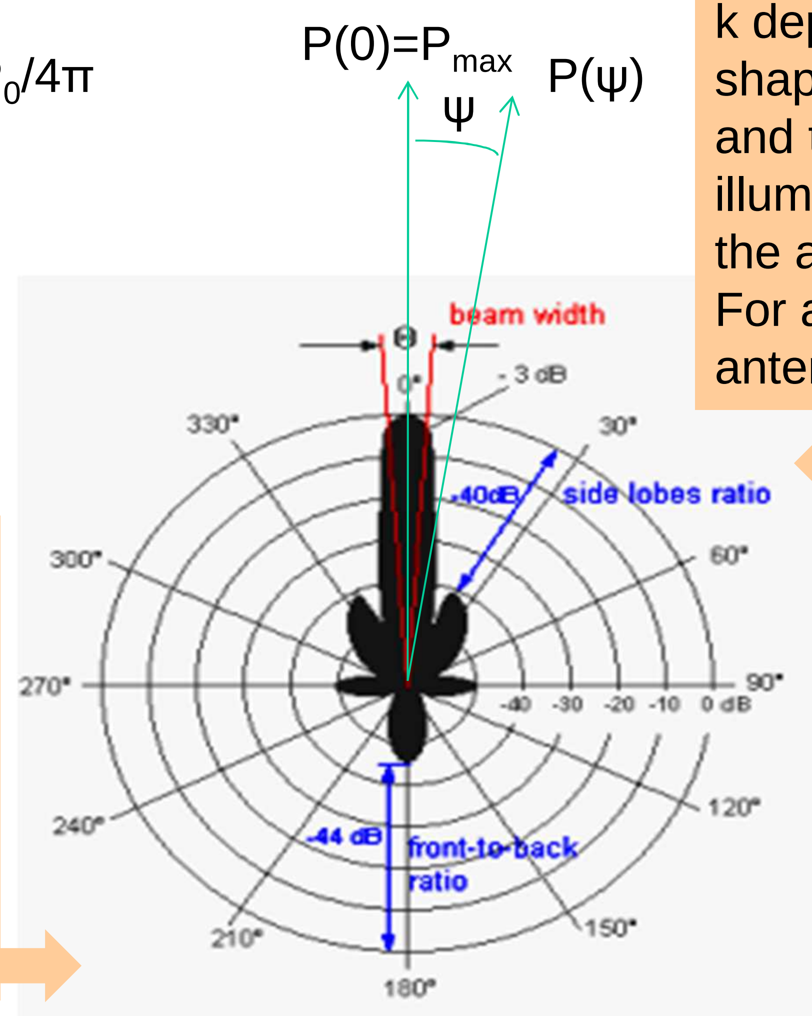


Gain (dimentionless):

$G(\psi) = P(\psi)/P_I$

$G_{max} = G(0) = 4\pi \times P(0)/P_0$

$G_{max} = \eta \times 4\pi A / \lambda^2$

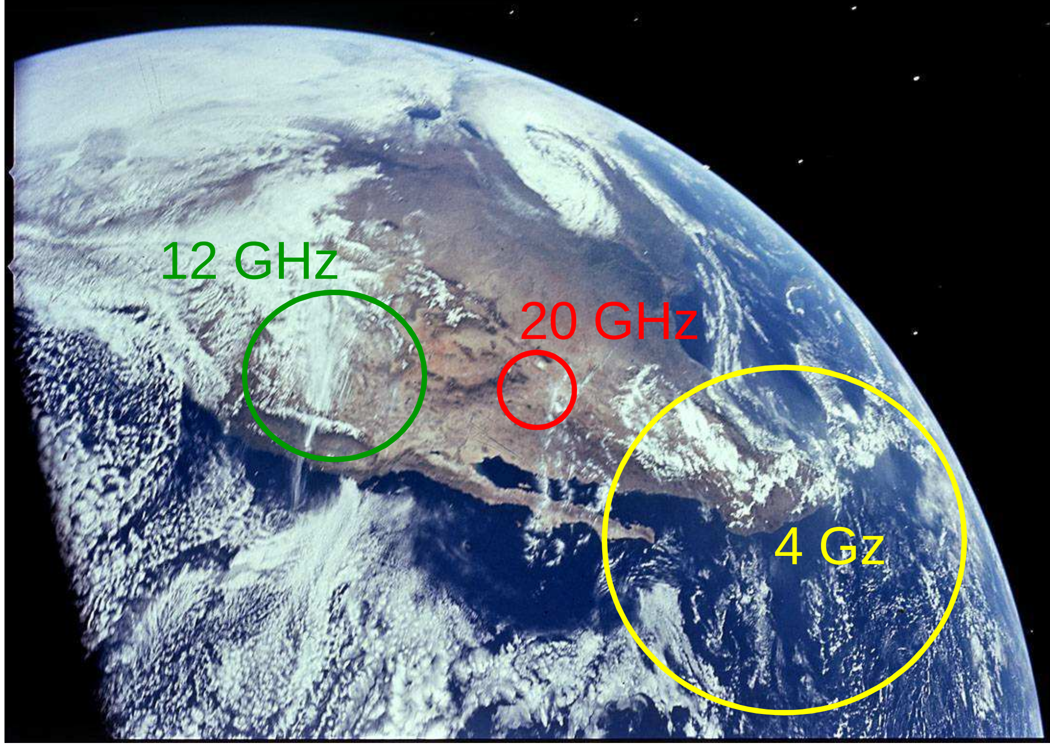


Beamwidth (deg):

$\theta_{3dB} = k \times \lambda/D$

k depends on the shape of the reflector and the method of illumination, and D is the antenna diameter. For a parabolic antenna k=70.

Satellite coverage depending on frequency



EIRP

Equivalent isotropically radiated power (EIRP) is the amount of power that an isotropic antenna would emit to produce the power flux density observed in the direction of maximum antenna gain.

$$EIRP = G_{max}P_0 = G_tP_t$$

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http://www.aticourses.com/antennas_tutorial.htm

Received Power & Free space loss

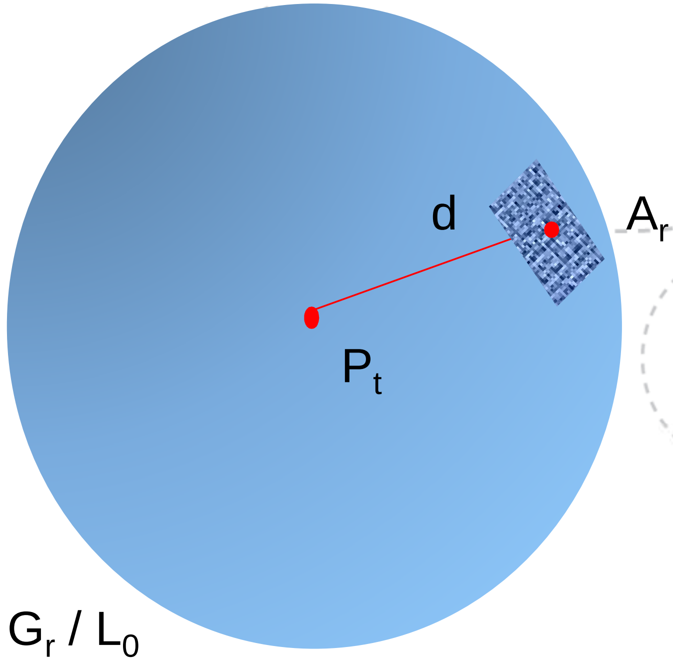
Radiated power flux isotropic antenna: $\varphi_i = P_t / 4\pi d^2$

Radiated power flux antenna: $\varphi = P_t G_t / 4\pi d^2$

Received power on
efficient receiver antenna surface, A_e: $P_r = \varphi \cdot A_e$

Efficient antenna surface: $A_e = \eta \cdot A_r = G_r \cdot \lambda^2 / 4\pi$

=> Received power: $P_r = EIRP \cdot G_r \cdot (\lambda / 4\pi d)^2 = EIRP \cdot G_r / L_0$



Defining Free space loss: $L_0 = (4\pi d / \lambda)^2$

Link Budget

P_r

Signal to noise ratio: $S/N = EIRP/L_0 \times G_r/T \times 1/kB \times 1/L_a$

Equivalent isotropically radiated power: EIRP
Figure of merit: G_r/T
Free space loss: $L_0=(4\pi d/\lambda)^2$
Additional losses: L_a
Bandwidth: B
Boltzmann's constant: k

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Various additional losses L_a

- Pointing error
- Implementation loss
- Quantification noise
- Interference
- Non linearities
- Rain fade
- ....

Link Budget

P_r

Signal to noise ratio: $S/N = EIRP/L_0 \times G_r/T \times 1/kB \times 1/L_a$

- Pointing error
- Implementation loss
- Quantification noise
- Interference
- Non linearities
- Rain fade
- ....

What is T?

T is the System Temperature in K, describing the amount of noise

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Earth station solar interference problems

External thermal noise

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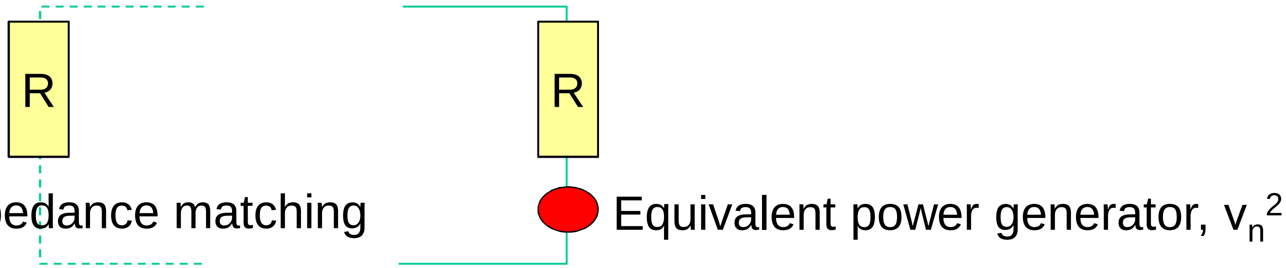
Internal thermal noise

Is the electronic noise generated inside an electrical conductor at equilibrium, regardless of any applied voltage. It is the noise generated by thermal agitation of the electrons.



Power of the AWGN for a given bandwidth B: $v_n^2 = 4kTRB$

k= Boltzmann's constant = 1.38×10^{-23} J/K

T= absolute temperature in K

R= resistor value in Ω

$N = kTB$

$N_0 = kT$

Noise power density with impedance matching is: $N = v_n^2/4R = kTB$ in JHz (W)

Noise spectral power density is: $N_0 = N/B$ (W/Hz), and N_0 is proportional to σ^2

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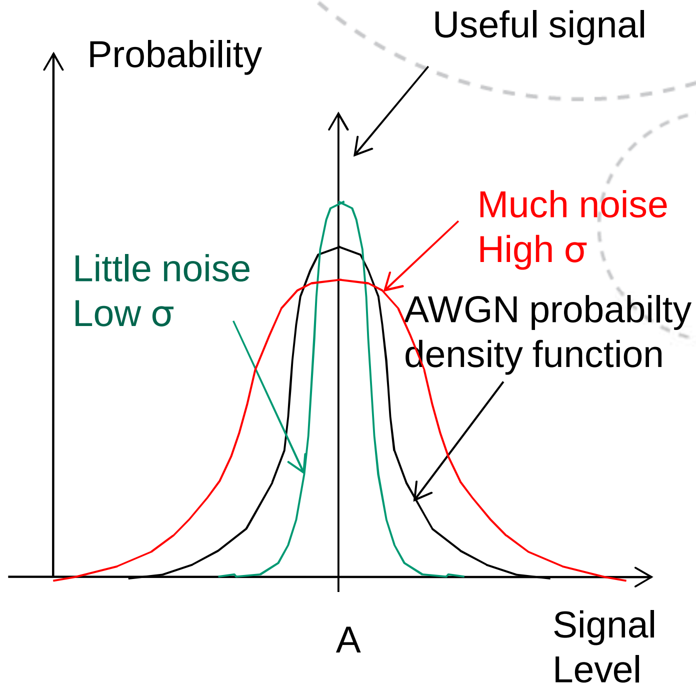
Additive White Gaussian Noise (AWGN)

- White noise, usually called Additive White Gaussian Noise is generated by internal and external thermal noise
- Additive: adds to the signal $r(t)=x(t)+n(t)$, where e.g. $x(t)=\pm A\cos(2\pi ft)$ is the modulated BPSK signal
- White: spectral density is constant for all frequencies
- Gaussian distribution, zero mean and variance σ; gaussian probablity density function



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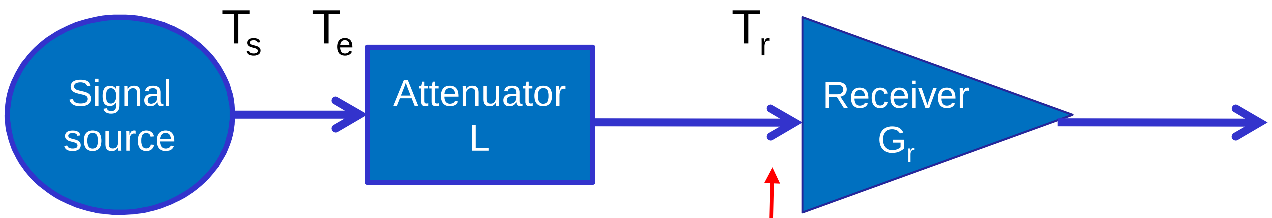
System Noise Temperature T



$$T = T_s/L + T_e/L + T_r = T_s/L + T_0(1-1/L) + T_r$$

Figure of merit

Signal to noise ratio: $S/N = (EIRP \times G_r) / (L_0 \times L_a \times kTB)$

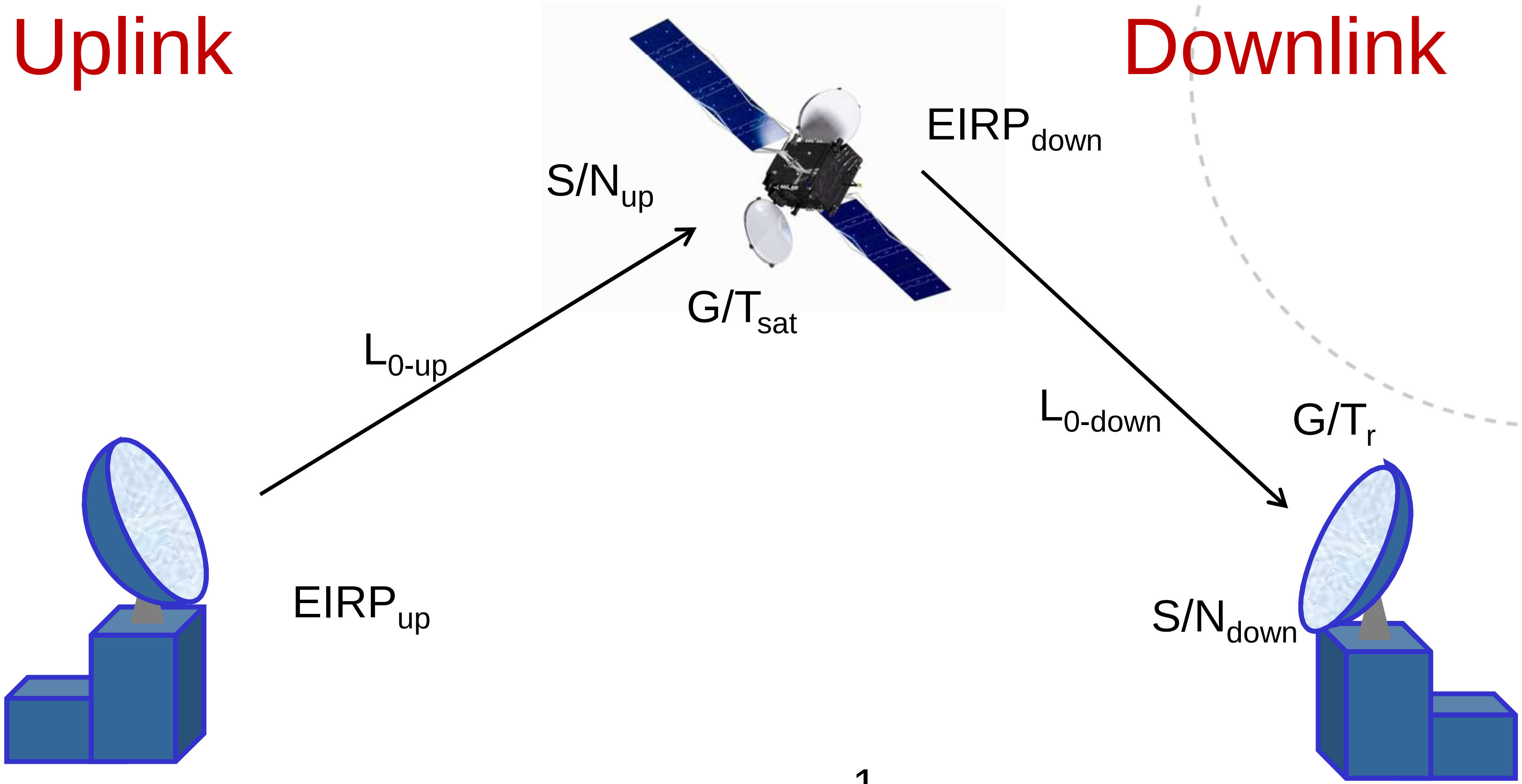
Signal to noise ratio: $S/N = EIRP/L_0 \times G_r/T \times 1/kB \times 1/L_a$

transmitter

free space loss

receiver

additional loss



Total signal to noise ratio: $S/N = \dfrac{1}{\dfrac{1}{S/N_{up}} + \dfrac{1}{S/N_{down}}}$

NB! linear expression only

”Addition of noise”

How to use S/N

It shall be used to calculate the margin

- This is needed to dimension the system (A, G, P, λ, B...)
- To determine the best modulation and coding techniques
- To evaluate vulnerability to fading and other impairments
- To determine availability, expressed in % of up-time in one year

In the following: the importance of shaping the signal

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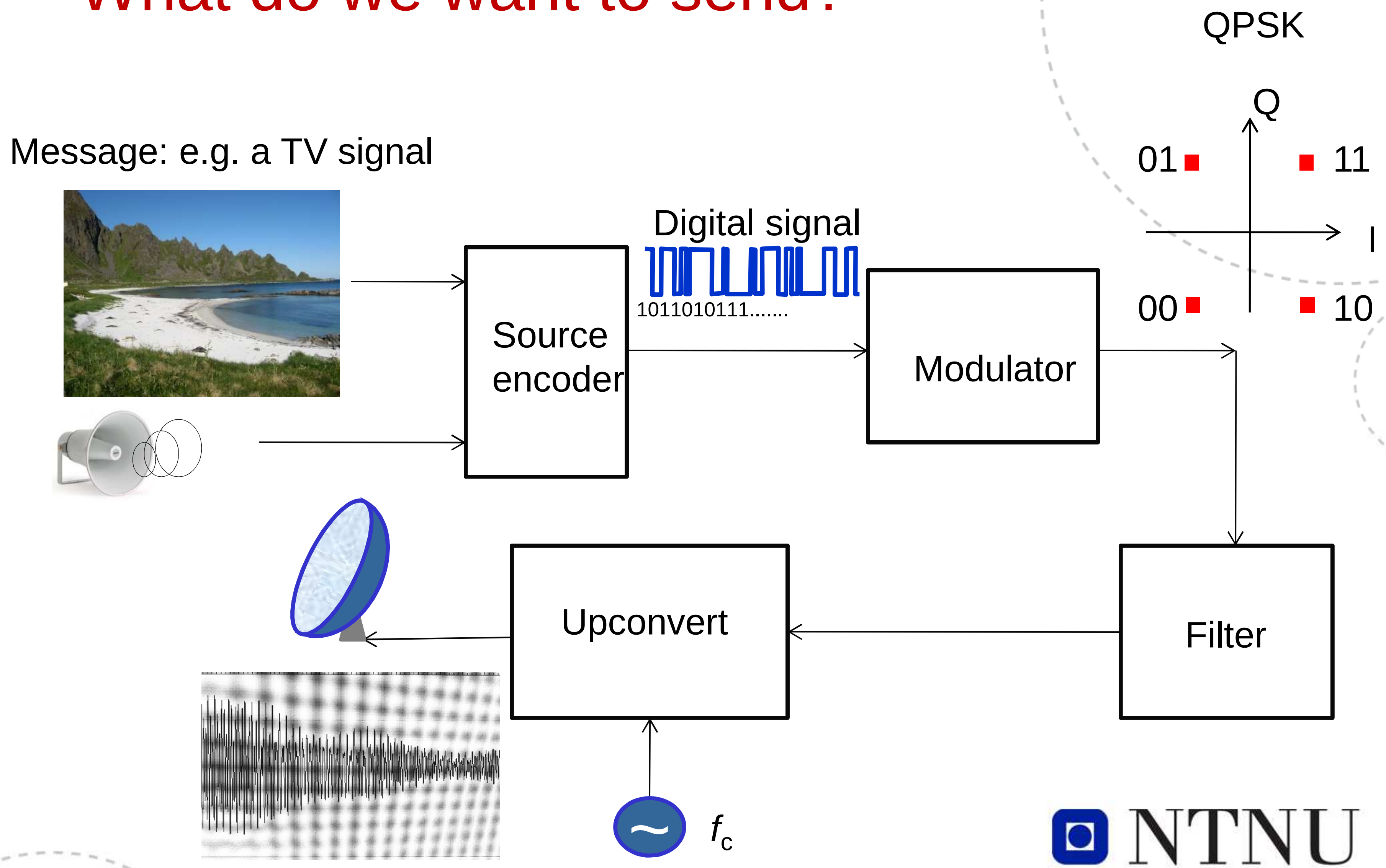
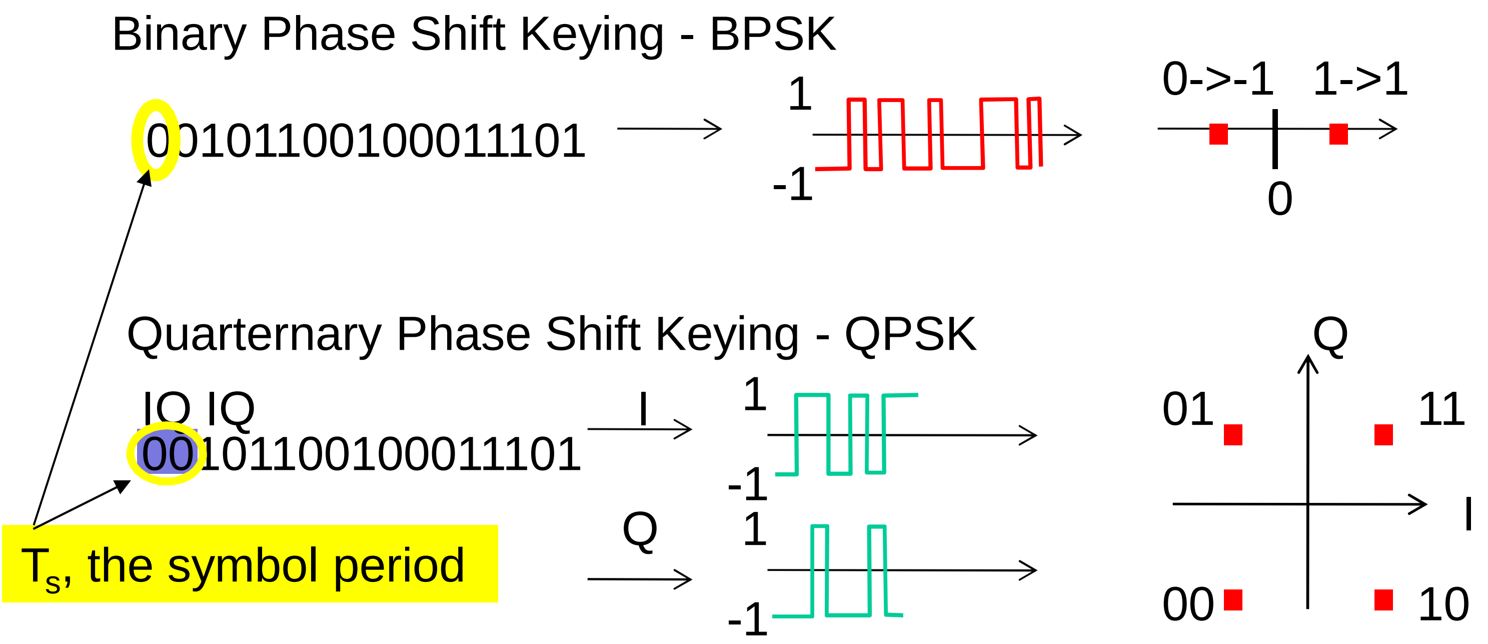
What do we want to send?



Modulation

Digital information to be transmitted will be matched to modulated signal waveforms representing one or several bits depending on the chosen modulation format.



I=In-phase, cosinewave modulation,

Q= Quadrature, sinewave modulation

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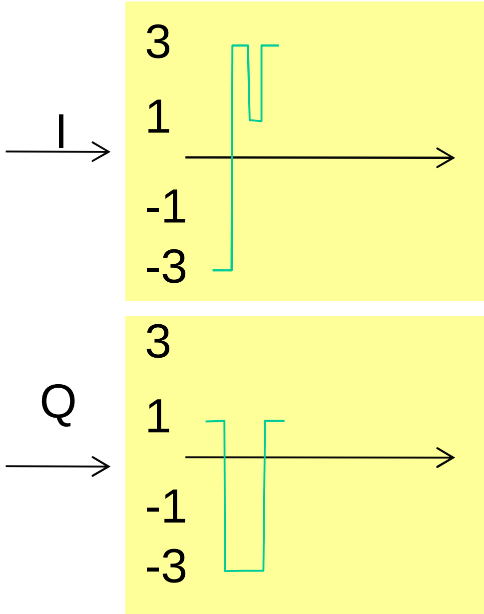
Higher order modulations

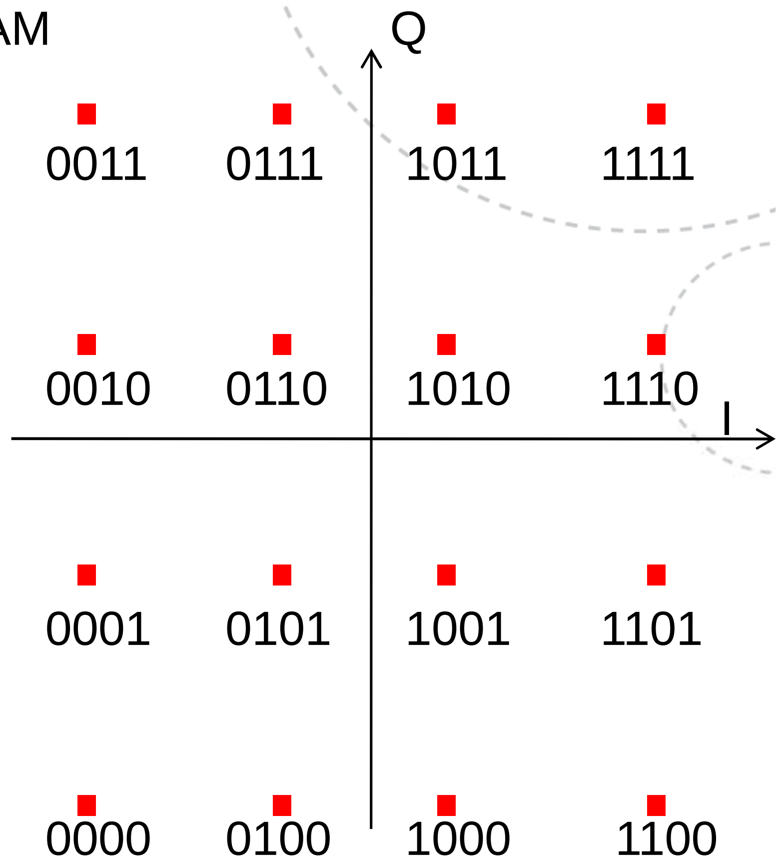
16 state Quadrature Amplitude Modulation – 16-QAM

IIQQ IIQQ
0010 1100100011101



Ex. coding rule:
00->-3
01->-1
10->1
11->3

T_S, the symbol period



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Other modluation schemes

Quadrature modulation – square:

4-QAM, 16-QAM, 64-QAM, 256-QAM......

Quadrature modulation – cross:

32-QAM, 128-QAM, 512-QAM......

Phase shift keying:

QPSK, 8-PSK, 16-PSK, 32-PSK.....

Amplitude and phase shift keying:

16-APSK, 32-APSK,.....

And:

CPM, OQPSK, DPSK, π/4-QPSK, FSK, CPFSK, MSK, GMSK.....

Most used in satellite communication

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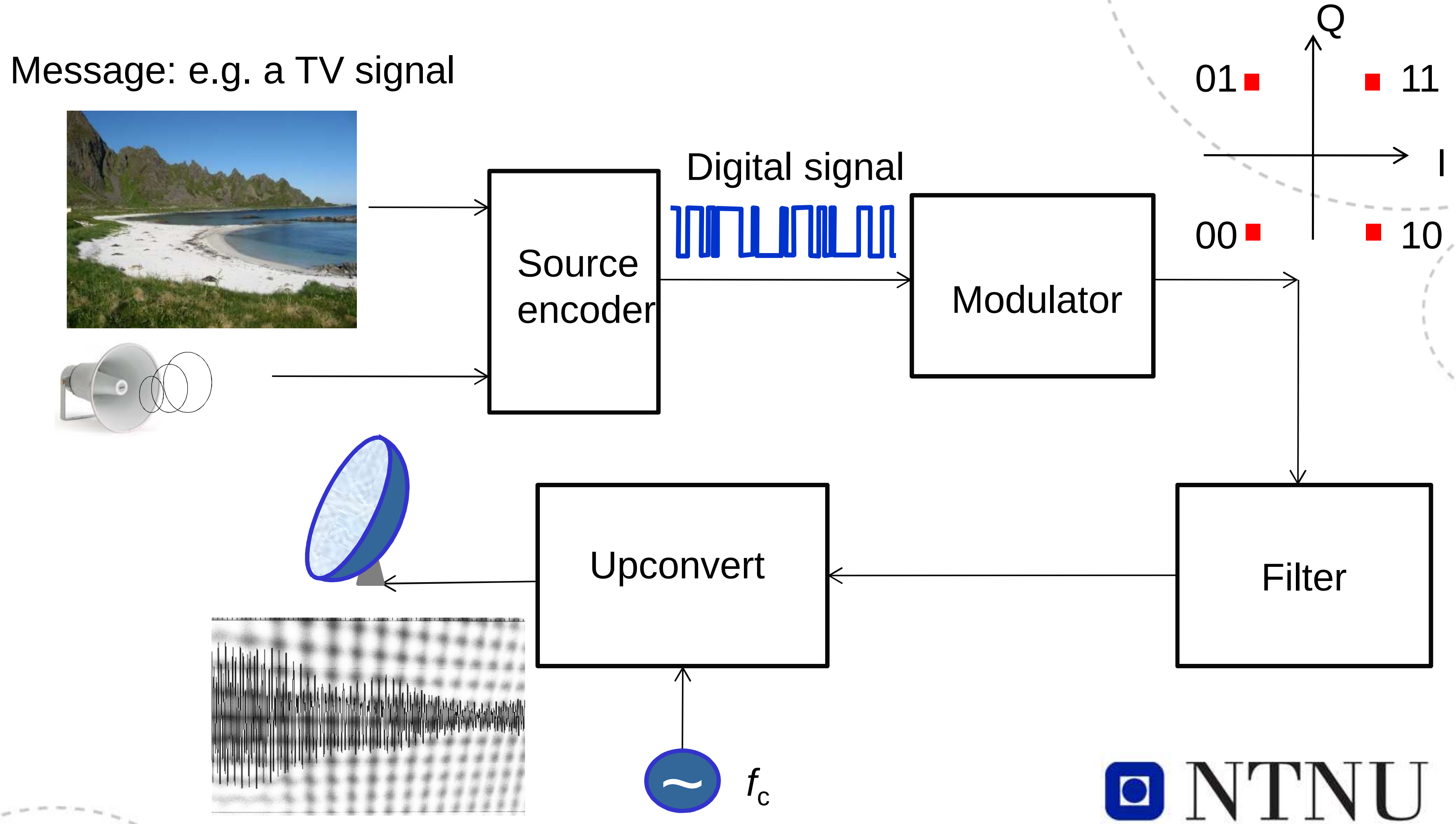
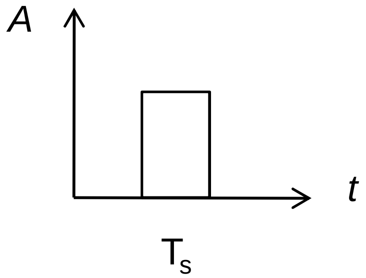
Back to basic scheme; why do we filter?



The signal symbol must have a pulse shape

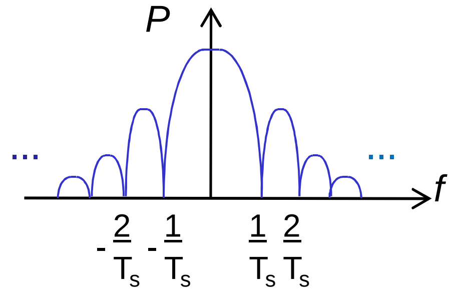
A modulated symbol has limited time duration, limited to the symbol period T_s. This gives an infinite spectrum.

Time domain

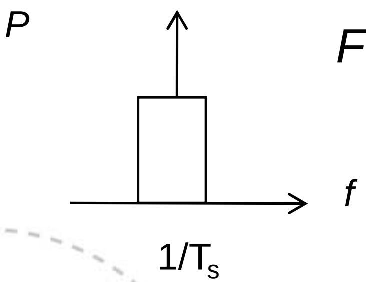


Fourier transform

Frequency domain

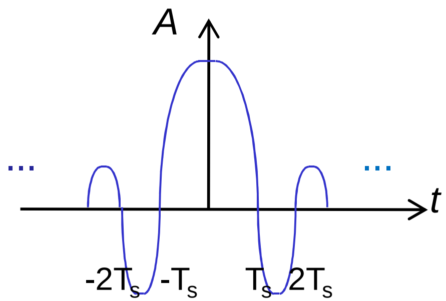


Frequency domain



Fourier transform

Time domain



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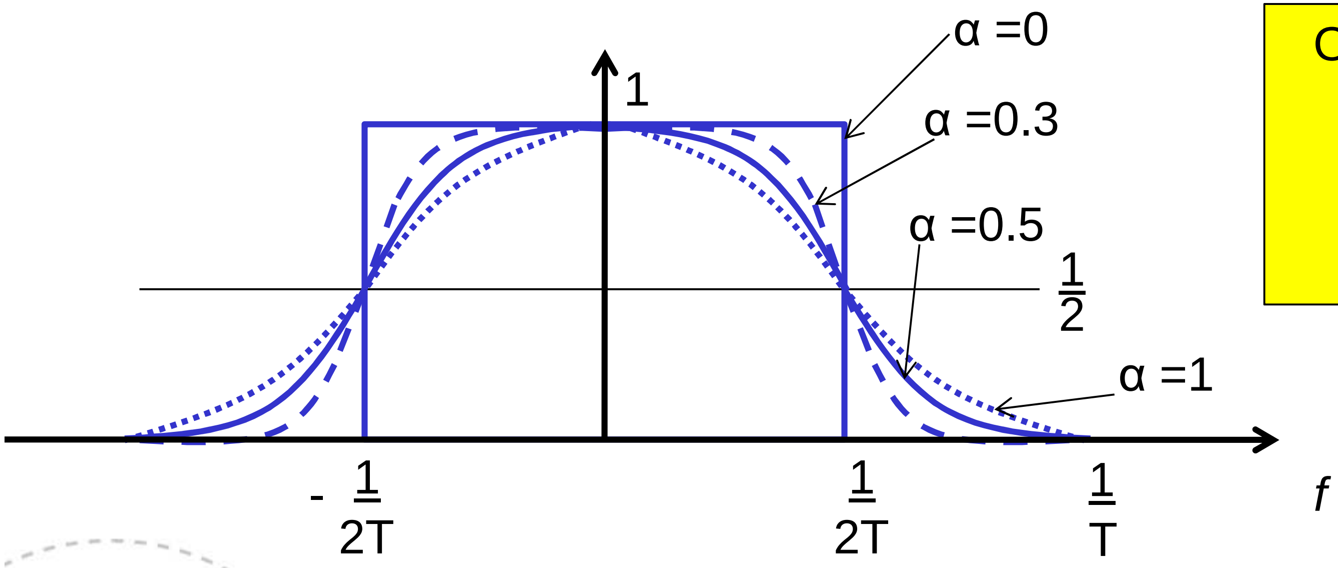
From this point T_s is simplified to T.

Nyquist filtering – filter without ISI

The Nyquist filter must have a bandwidth larger than 1/2T in baseband in order for the signal to be without intersymbol interference (ISI).

One commonly used Nyquist filter is the Raised Cosine (RC) filter with roll-off α; 0<α<1.

$$Ny(f) = \begin{cases} 1\,, & |f| \le (1-\alpha)/2T \\ (1/2)\cdot(1-\sin(\pi T(|f|-1/2T)/\alpha)), & (1-\alpha)/2T \le |f| \le (1+\alpha)/2T \\ 0\,, & |f| \ge (1+\alpha)/2T \end{cases}$$



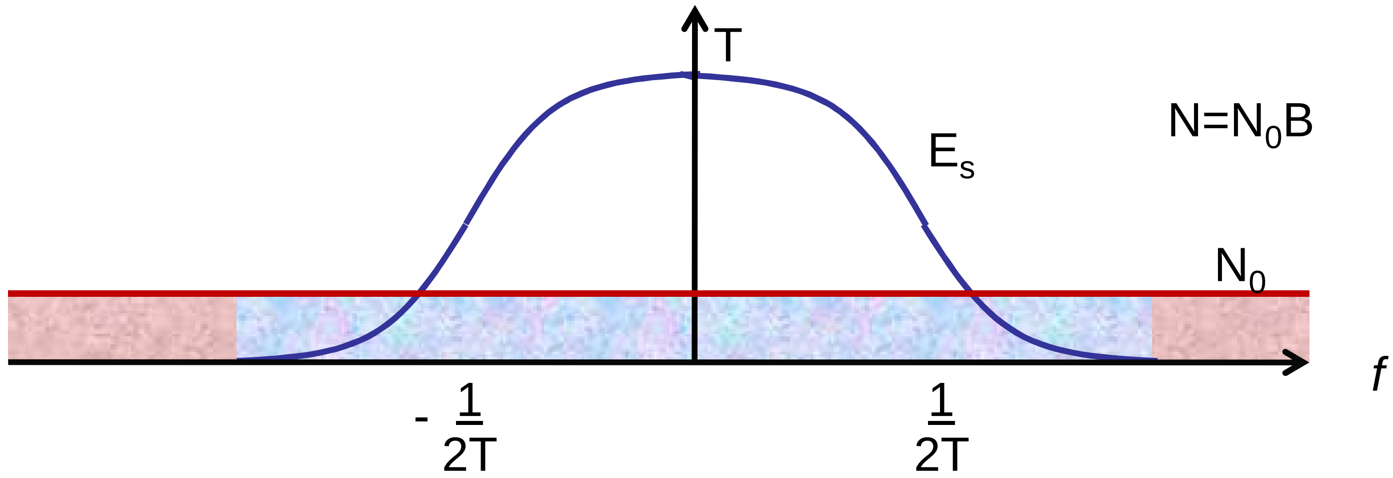
One main characteristic:

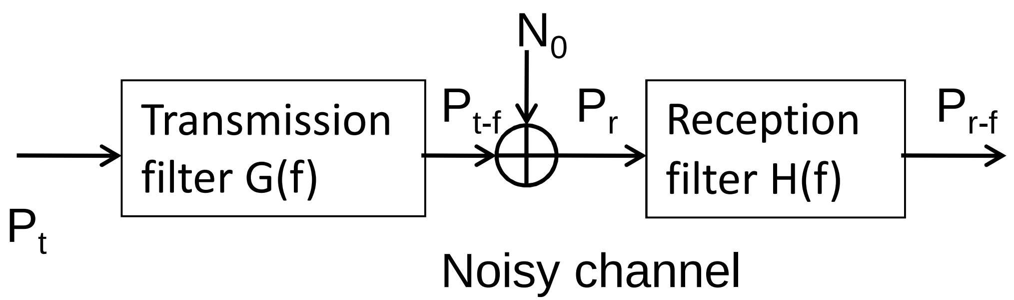
$$\int_{-\infty}^{\infty} Ny(f)\,df = 1/T = B$$

NB! In this context T= T_s, the symbol period, not the temperature

Why do we filter at the receiver?

In order to eliminate noise. And to match the transmitter.





$$P_{t-f} = E_s \int_{-\infty}^{\infty} |G(f)|^2 df$$

$$P_{r-f} = E_s' \int_{-\infty}^{\infty} |H(f)|^2 df$$

$$P_{N-f} = N_0 \int_{-\infty}^{\infty} |H(f)|^2 df$$

Optimising the filtering

In order to obtain a received signal with InterSymbol Interference (ISI) zero, and restricting the noise to a minimum the filters must satisfy the following condition:

$$G(f) \cdot H(f) = Ny(f)$$

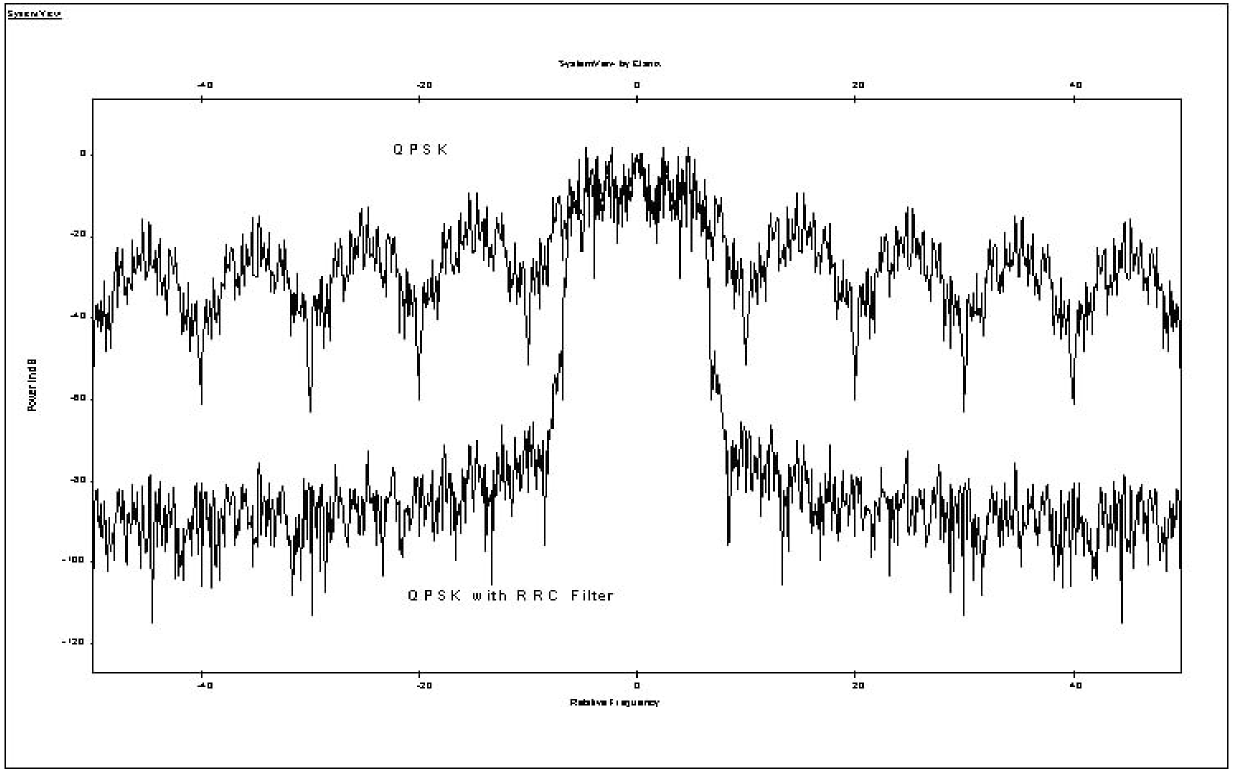
Optimising this condition leads to:

$$G(f) = H(f) = \sqrt{Ny(f)}$$

This is called matched Nyquist filtering.

What does all this look like on an oscilloscope or on a frequency analyzer?

Filtering – frequency domain



RRC filter = Root Rised Cosine filter = $\sqrt{Ny(f)}$

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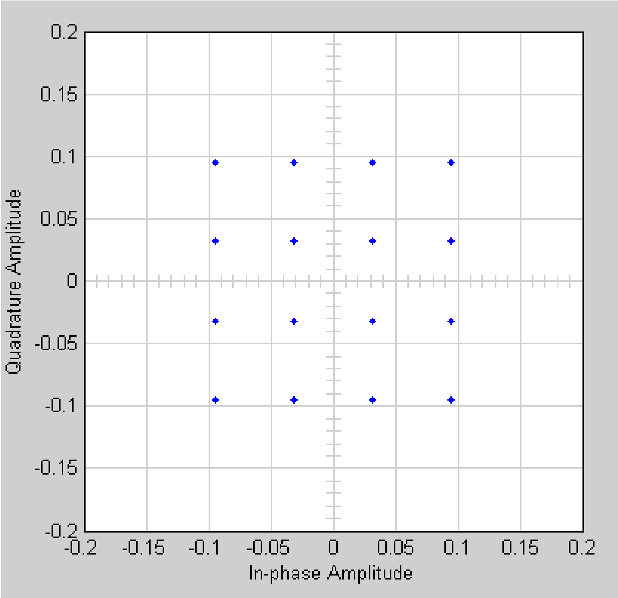
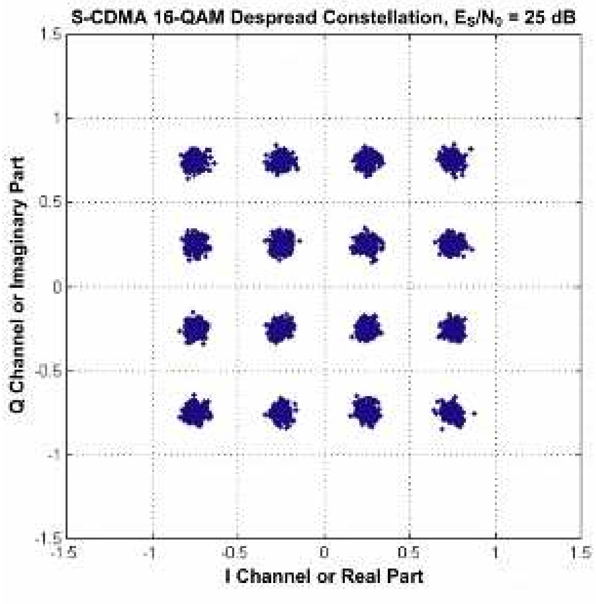
Modulation – time domain





Noisy signals, and signals with ISI look much the same.

Increasing the signal power will help on the

signal to noise ratio, but not on the signal to ISI ratio.

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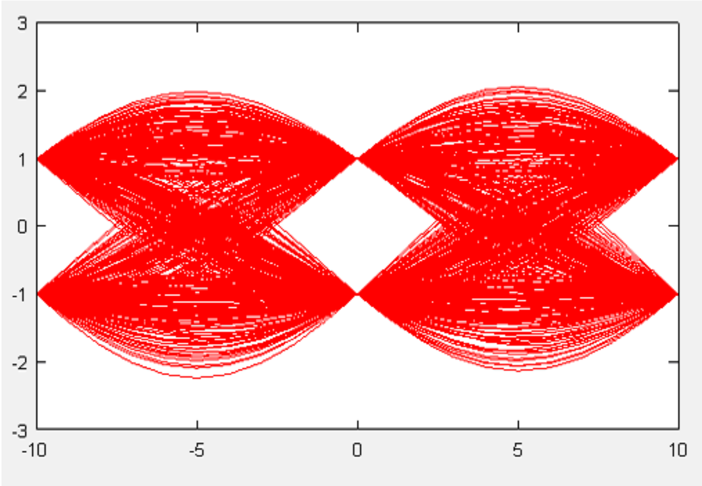
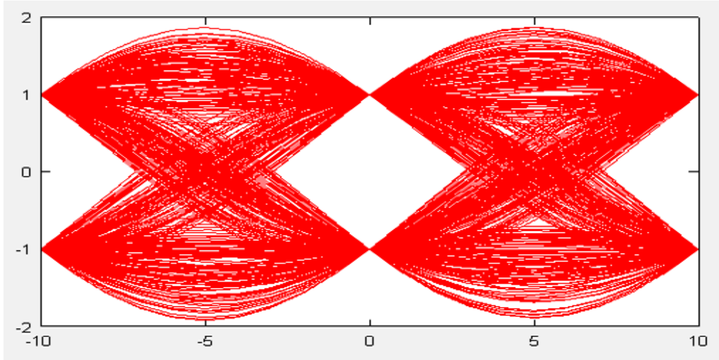
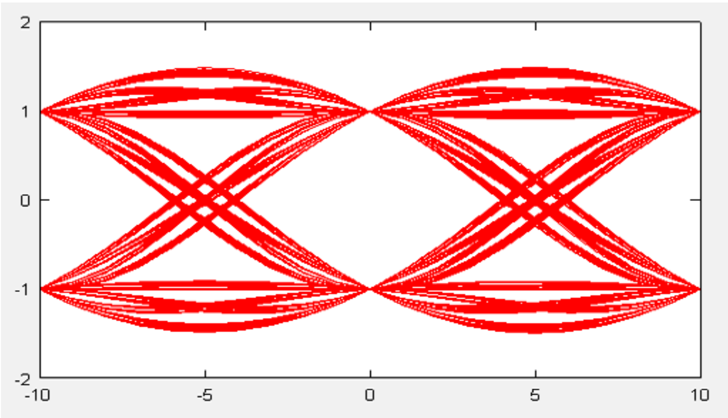
Eye diagrams of a BPSK signal – time domain



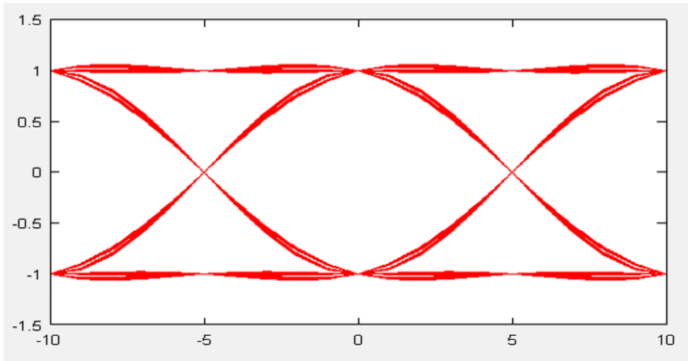
α=0.125



α=0.25



α=0.5



α=1

http://www.dsprelated.com/showarticle/60.php

Back to the signal to noise ratio

You can write $S/N = E_s/N_0$ if the filtering is matched Nyquist filtering.

$$S = P_{t\text{-}f} = E_s \int_{-\infty}^{\infty} |G(f)|^2 df = E_s B_t$$

$$N = P_{N\text{-}f} = N_0 \int_{-\infty}^{\infty} |H(f)|^2 df = N_0 B_r$$

$$G(f) = H(f) = \sqrt{Ny(f)}$$

$$\int_{-\infty}^{\infty} Ny(f) df = 1/T = B$$

$S/N = E_s/N_0$

and

$B=1/T$

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What are we trying to do?

Find the link budget margin in order to determine if the signal will come through to the receiver.

Then we have to introduce error rates:
Bit error rates (BER)

Common bit error rate tolerances:

- Voice: BER < 10^{-2} - 10^{-3}
- Image: BER < 10^{-6} - 10^{-7}
- Data: BER < 10^{-7} - 10^{-10}
- Audio: BER < 10^{-3} - 10^{-4}

QEF = Quasi Error Free: BER < 10^{-10} - 10^{-12}

Notes:
- The more we are clever at source encoding (signal compression), the more the signal will be vulnerable to errors
- There is a big difference between the effects of isolated errors and error packets.

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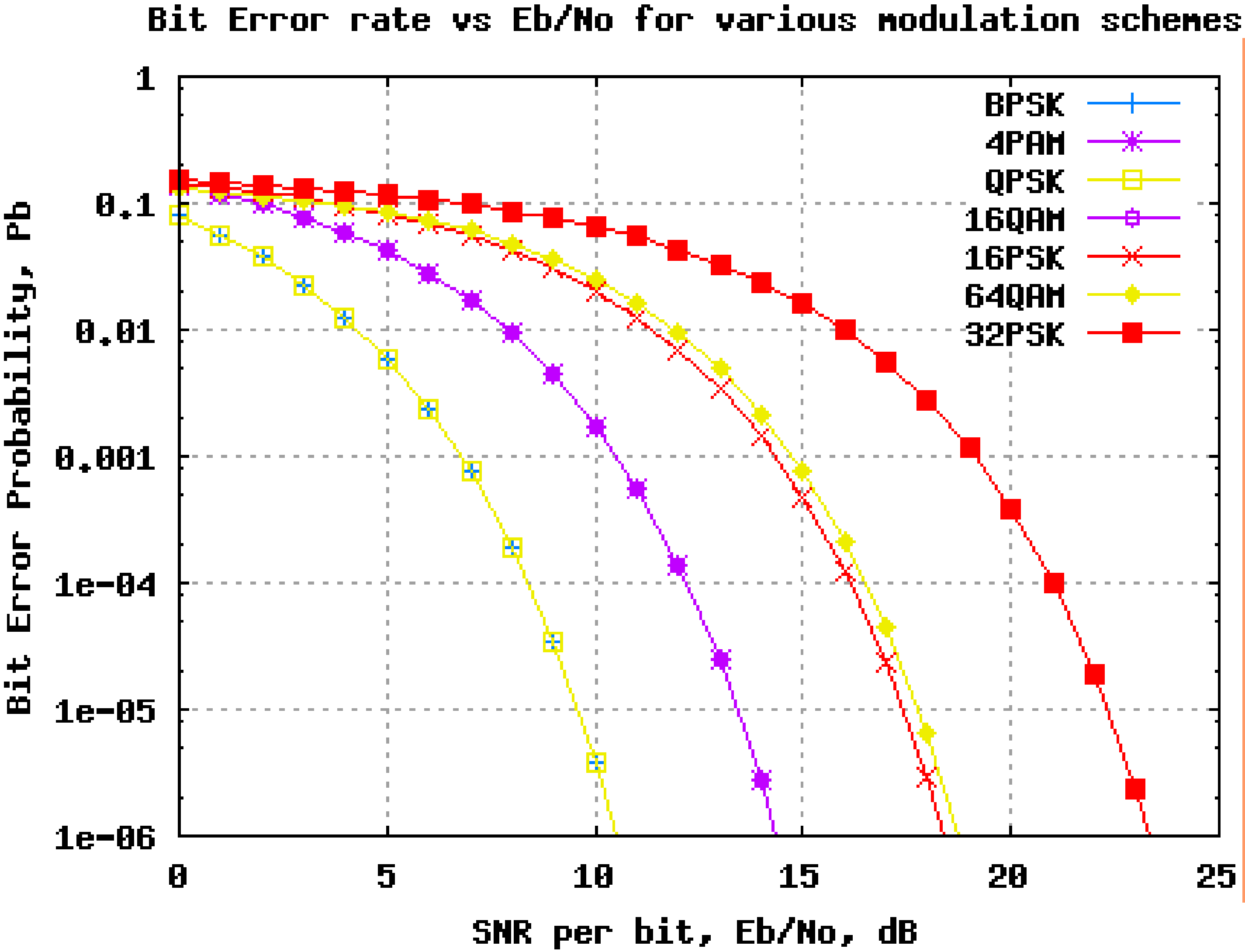

The job is to dimension the satellite system with power, antennas, bandwidts, modulation schemes etc., so that your signal comes through with the correct E_b/N_0, in order to give the correct BER for your application.

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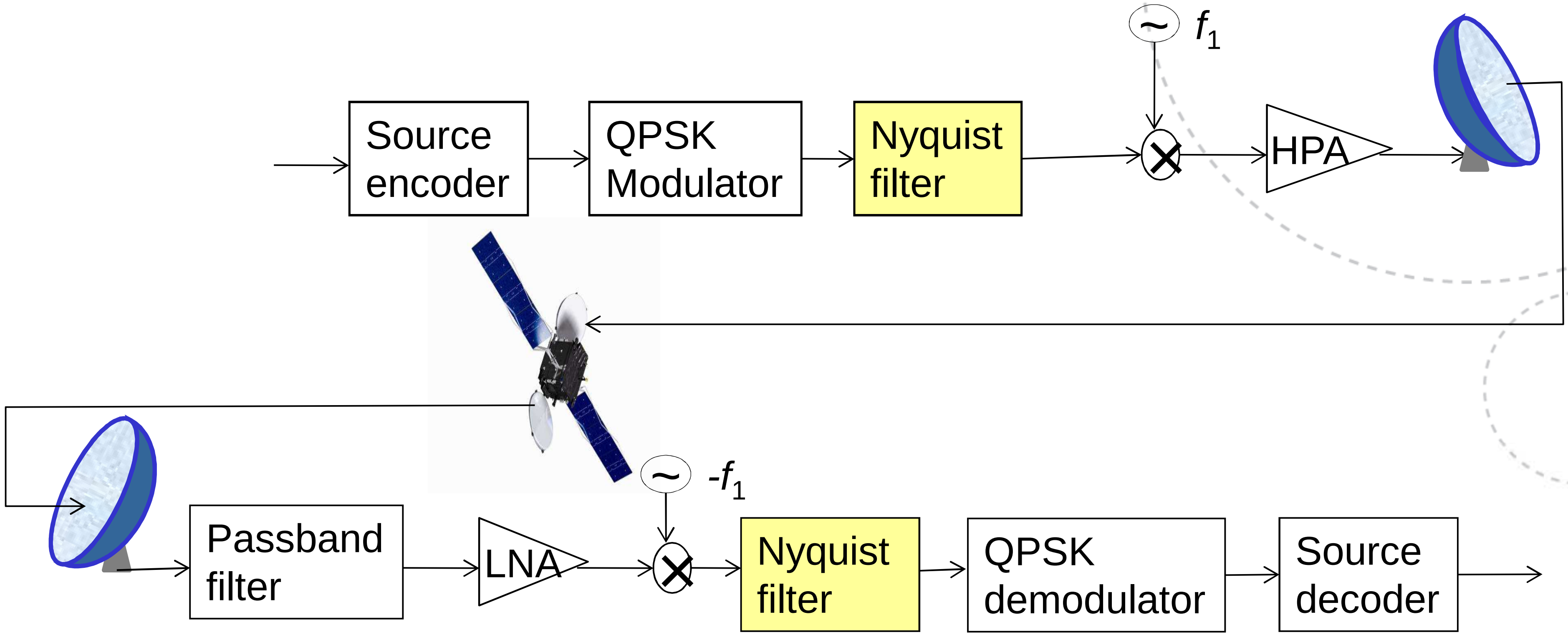
http://i.cmpnet.com/dspdesignline/2008/07/image045.gif

Transmitter - Receiver



Signal to noise ratio – use of deciBel (dB)

S/N, dimentionless, usually expressed in dB

$X_{dB} = 10 \cdot \log_{10} (P_1/P_2)$

S and N expressed in Watt (W), dBW or dBm
$X_{dBW} = 10 \cdot \log_{10} (P_1)$
$X_{dBm} = 10 \cdot \log_{10} (P_1/1mW)$

But, anything can be expressed in dB, just take the 10log: $X_{dB\text{-}dim} = 10 \cdot \log_{10} (Y)$ dB-dimention of Y

Power spectral density (noise): $N_0 = N/B$ in W/Hz

E_s/N_0 is dimentionless, and is the signal to noise ratio of power spectral densities,
E_s being the energy transmitted per modulated symbol

E_b is the transmitted energy per bit and $E_b = E_s/m$ if each modulated symbol represents m bits

You can write $S/N = E_s/N_0$ if the filtering is matched Nyquist filtering.

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Back to the link budget

BER<10^{-6}

E_b/N_0>10.5dB

Example: TV signal, Modulation: QPSK, Bandwidth B = 2.048MHz, B_{dB}= 63.1dBHz

Boltzmann constant k = 1.38×10^{-23} W/Hz/K, k_{dB} = -228.6 dBW/Hz/K

$L_0=(4\pi d/\lambda)^2$

$S/N= EIRP/L_0 \times G/T \times 1/kB \times 1/L_a \rightarrow S/N_{dB} = EIRP - L_0 + G/T - k - B - L_a$

Transmit (Tx) figures or Up-link:

EIRP = 50 dBW

Tx frequency = 29.7 GHz

Pointing loss = 1 dB

Atmospheric loss = 0.9 dB

Terminal to satellite distance = 38 039.81 km

G/T satellite = 13 dB/K

$L_0=10\log_{10}(4\pi d/\lambda)^2$ = 213.5 dB

L_a= 1 dB + 0.9 dB

$S/N_{dB}= EIRP - L_0 + G/T - k - B - L_a$

$= 50 - 213.5 + 13 + 228.6 - 63.1 - 1.9$

$= 13.1$ dB

Receiver (Rx) figures or Down-link:

EIRP = 29.8 dBW

Rx frequency: 18.5 GHz

Pointing loss: 0.3 dB

Atmospheric loss: 0.6 dB

Coupling loss: 0.5 dB

Satellite to receiver distance: 38 460.53 km

G/T receiver = 35.12 dB/K

$L_0=10\log_{10}(4\pi d/\lambda)^2$ = 209.5 dB

L_a= 0.3 dB + 0.6 dB + 0.5 dB

$S/N_{dB}=29.8 - 209.5 +35.12 +228.6 - 63.1 - 1.4$

$= 19.5$ dB

$S/N = ((S/N\ up)^{-1} + (S/N\ down)^{-1})^{-1}$ NB! Linear calculation, convert to dB: S/N = 12.2 dB

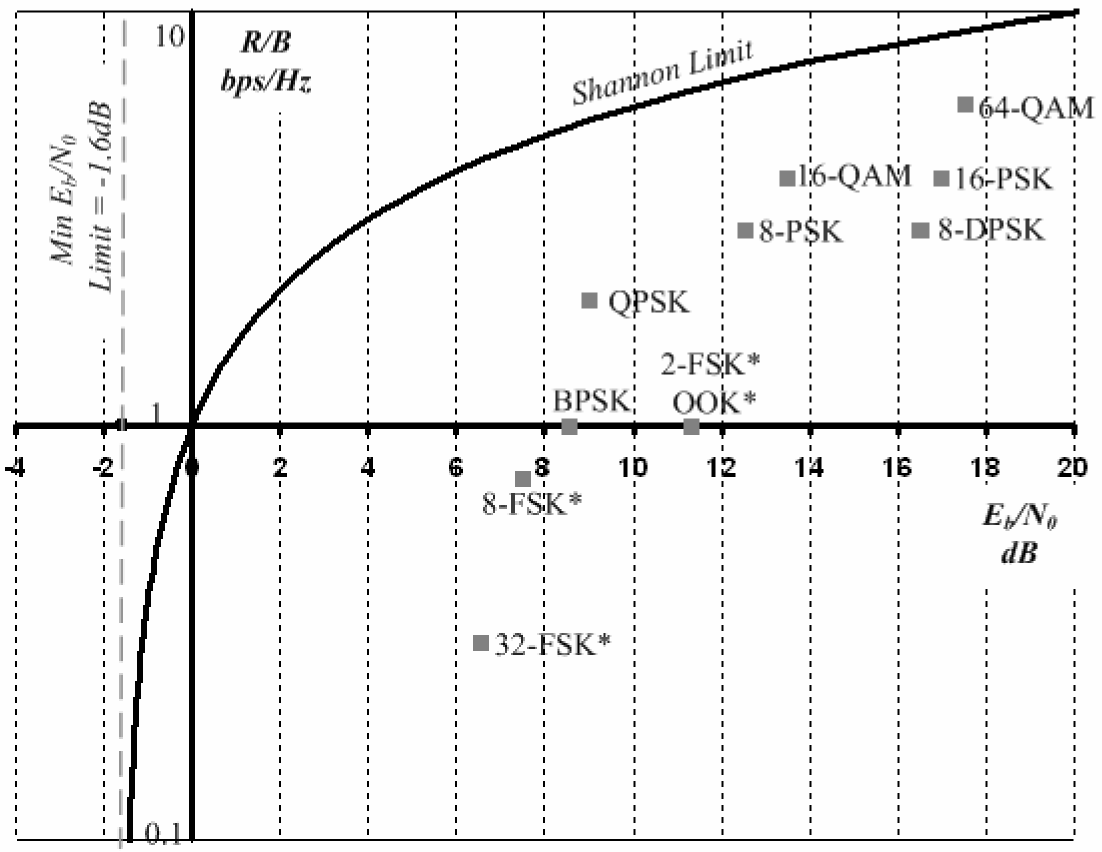
$S/N = E_s/N_0 = E_b \times m /N_0 = E_b \times 2/N_0 \rightarrow E_b/N_{0dB} = S/N_{dB} - 3dB = 12.2 - 3 = 9.2$ dB

We want a BER < 10^{-6} $\rightarrow E_b/N_{0dB} = 10.5$ dB $\rightarrow$ Margin = 9.2 – 10.5 = -1.3 dB $\rightarrow$ ☹

The answer may be Coding

- Channel coding (as opposed to e.g. Source coding and encryption)

Modulation schemes vs. Shannon limit for BER=10^{-4}



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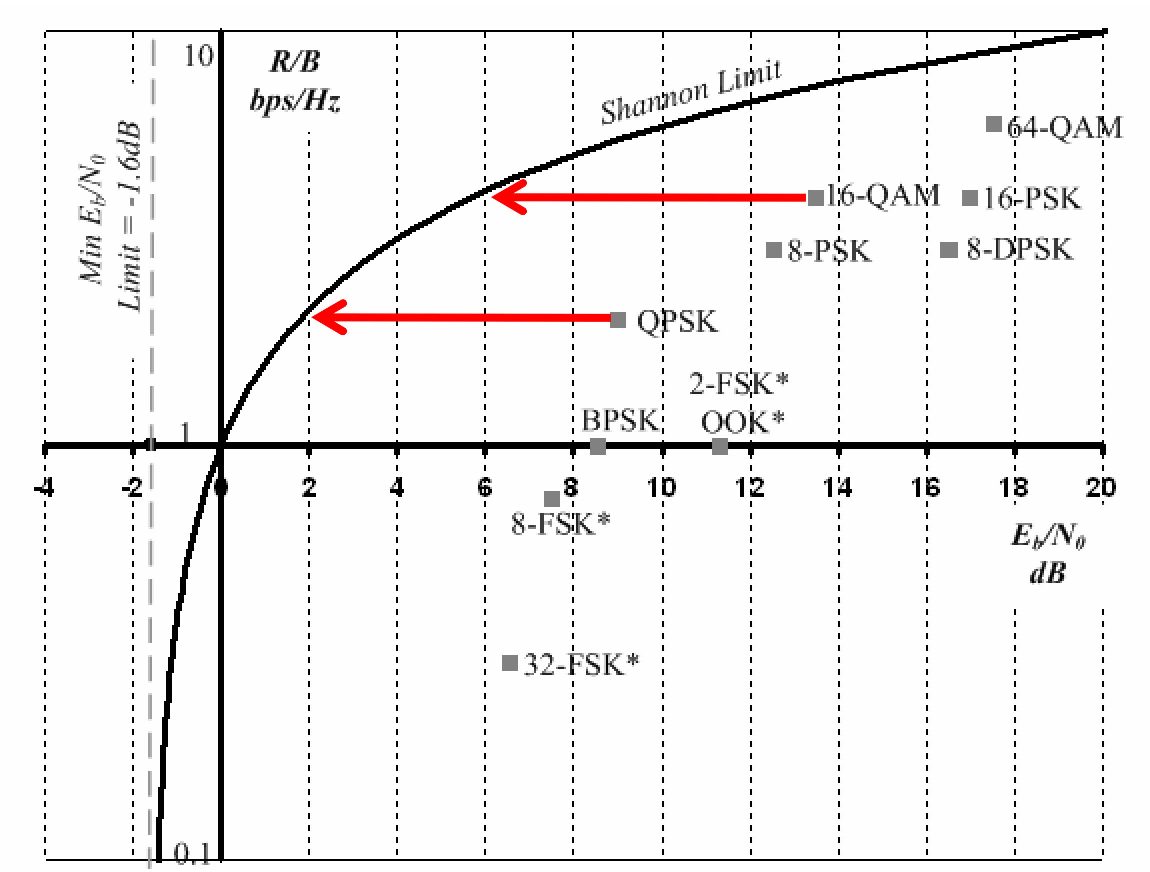
http://www.eecs.berkeley.edu/Pubs/TechRpts/2007/EECS-2007-57.pdf

Since 1948 and Shannons theorem, the aim for all channel coding experts has been to reach the Shannon limit.



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http://www.eecs.berkeley.edu/Pubs/TechRpts/2007/EECS-2007-57.pdf

The coding principle

The principle of channel coding (not to be confused with source coding, encryption or spread spectrum techniques) is to introduce redundancy in a controlled manner, in order to increase the distance (Hamming or Euclidean) between code words.

The ”best code” is the infinitely long random code, with maximum likelihood decoding. However this code is impossible to use in practice.

The optimisation of a code between the ”best code” and ”no code” will be conditioned by the decoding complexity, impacting circuit design (cost) and decoding latency.

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Binary codes – Hamming distance

The simplest code is the repetition code:

0 -> 000 and 1 -> 111

The Hamming distance has been increased from 1 to 3 between the two code words.

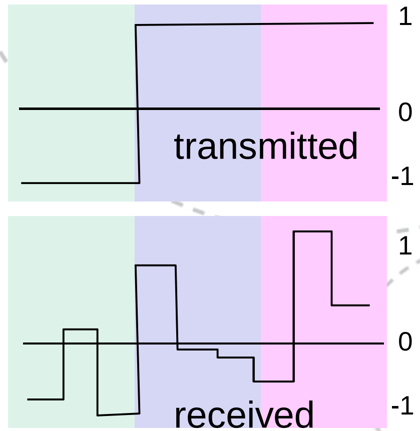
If the received word at the output of the noisy channel is 010, the decoded word will be the closest to the two possible code words in Hamming distance: 000 at a distance 1. The Hamming distance to 111 is 2.

Hard and soft decoding, Hamming and Eucledean distances

Information bits are: 011

Repetition coded bits to transmit: 000111111 BPSK mapping:

At the output of the noisy channel the received signal is:



Hard decision will give: -11-11-1-1-111, and Hamming distance decoding: 000000111

Soft decision will give: -0.6 0.2 -0.8 $\boxed{0.9\ -0.1\ -0.2}$ -0.4 1.2 0.5

Soft, Eucliedean distance, decoding for the middle word:

The distance to 000 is $\sqrt{1.9^2 + 0.9^2 + 0.8^2} = 2.25$

The distance to 111 is $\sqrt{0.1^2 + 1.1^2 + 1.2^2} = 1.63$

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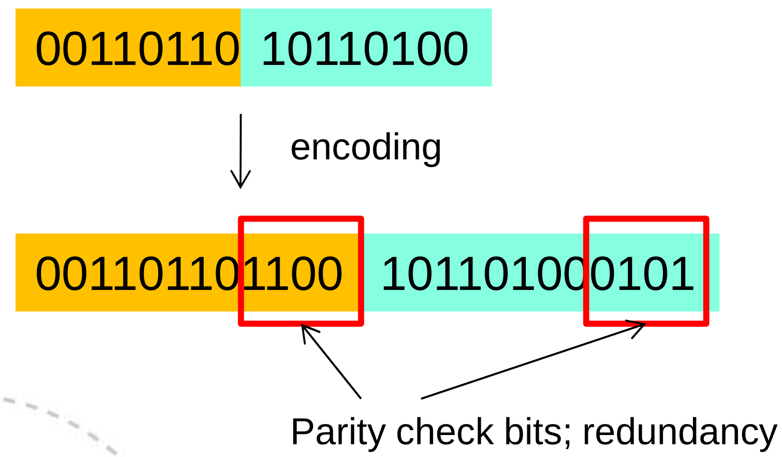
Common codes

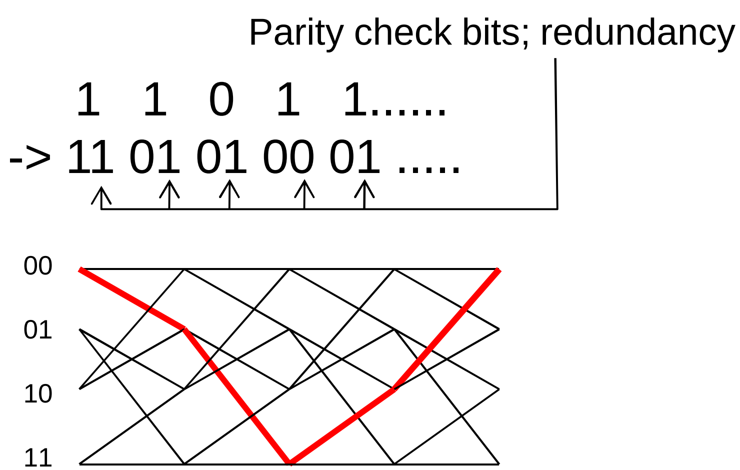
Block codes:

- Hamming codes
- RS and BCH
- BCM
- Turbo Block codes

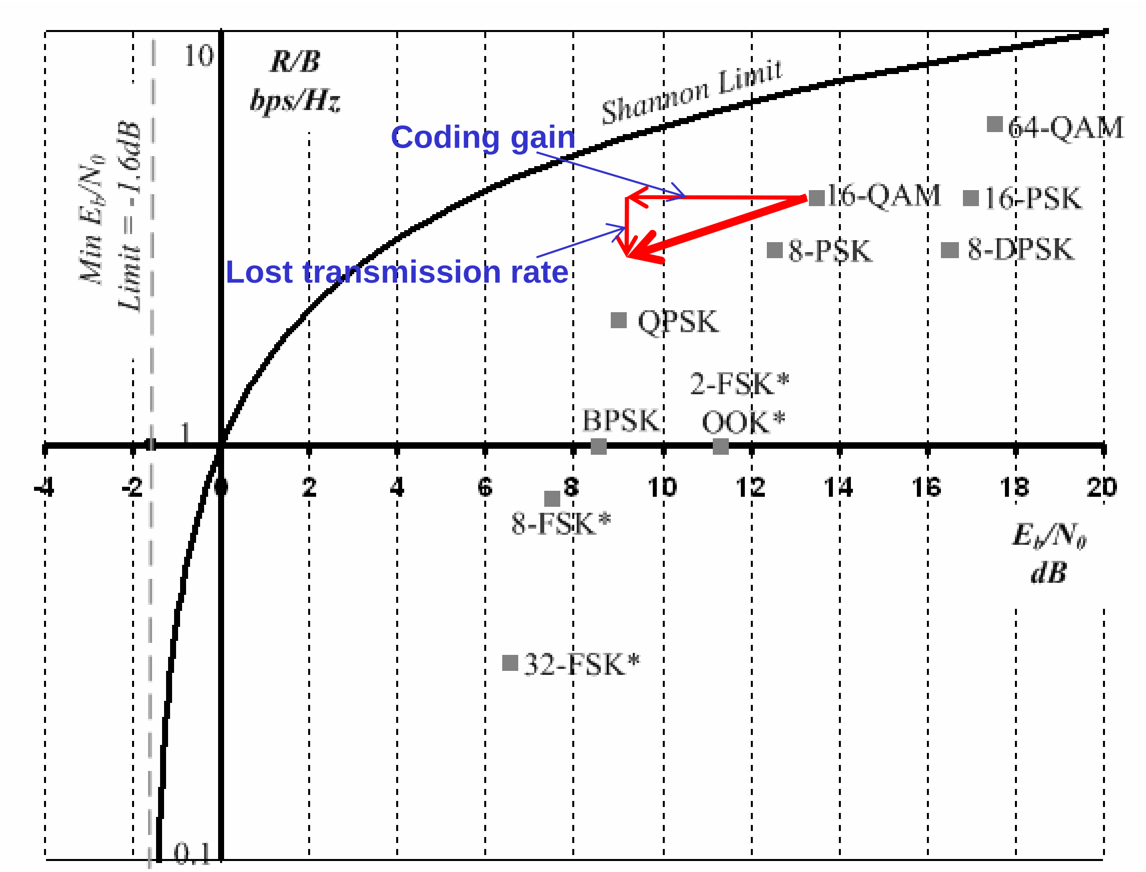
Trellis codes:

- Convolutional codes
- TCM
- Turbo codes





Since 1948 and Shannons theorem, the aim for all channel coding experts has been to reach the Shannon limit.



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http://www.eecs.berkeley.edu/Pubs/TechRpts/2007/EECS-2007-57.pdf

The ”cost” of a code is the redundancy

Introducing redundancy will increase the use of power or alternatively reduce the efficient rate

$$S/N = E_s/N_0 = E_b m_i/N_0 = E_b mR/N_0$$

E_s is the energy per transmitted symbol
E_b is the transmitted energy per information bit
m_i is the number of information bits per symbol
m is the number of bits per transmitted symbol
R is the code rate

Example: 16-QAM: m=4
If R=3/4, then m_i=3, e.i. only 3 information bits are transmitted per symbol instead of the maximum possible for a 16-QAM which is 4.
If S/N is constant, then the energy needed per information bit has increased by 4/3.

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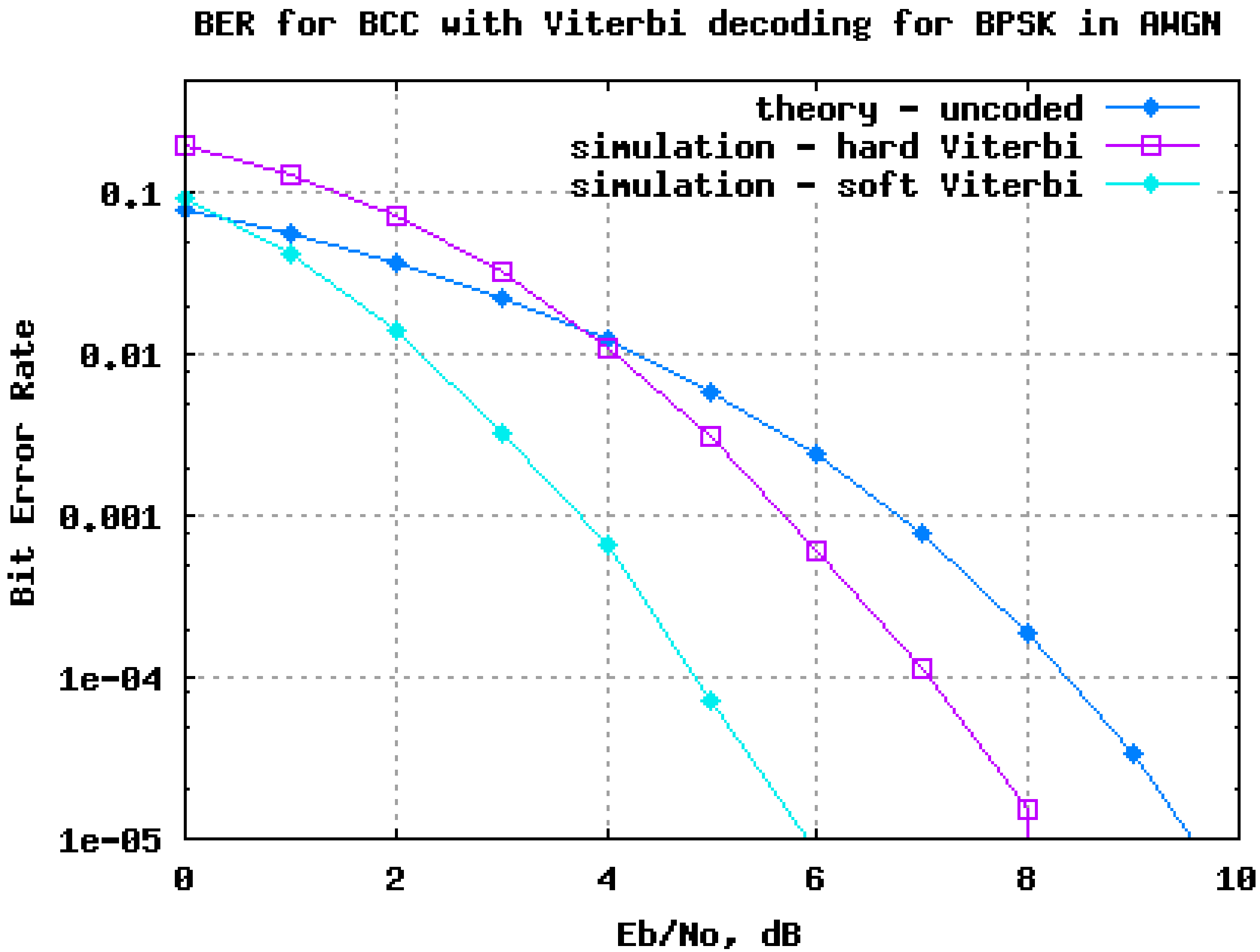
Coding gain – BER as function of E_b/N_0



http://www.dsplog.com/db-install/wp-content/uploads/2009/01/ber_plot_bcc_soft_viterbi_decoder.png

Back to the link budget

TV signal, Modulation: QPSK, Bandwidth 2.048MHz

Boltzmann constant k_{dB} = -228.6 dBW/Hz/K

$L_0=(\lambda/4\pi d)^2$

$S/N = EIRP/L_0 \times G/T \times 1/kB \times 1/L_a \rightarrow S/N_{dB} = EIRP - L_0 + G/T - k - B - L_a$

$S/N = ((S/N\ up)^{-1} + (S/N\ down)^{-1})^{-1} \rightarrow S/N = 12.2$ dB

$S/N = E_s/N_0 = E_b \times m / N_0 = E_b \times 2/N_0 \rightarrow E_b/N_{0dB} = S/N_{dB} - 3dB = 12.2 - 3 = 9.2$ dB

We want a BER < 10^{-6} → E_b/N_{0dB} = 10.5 dB → Margin = 9.2 – 10.5 = -1.3 dB

So if we select a code with 3 dB coding gain in E_b/N_0 at BER < 10^{-6}

→ Margin = -1.3 dB + 3dB = 1.7 dB

And we have a positive margin.

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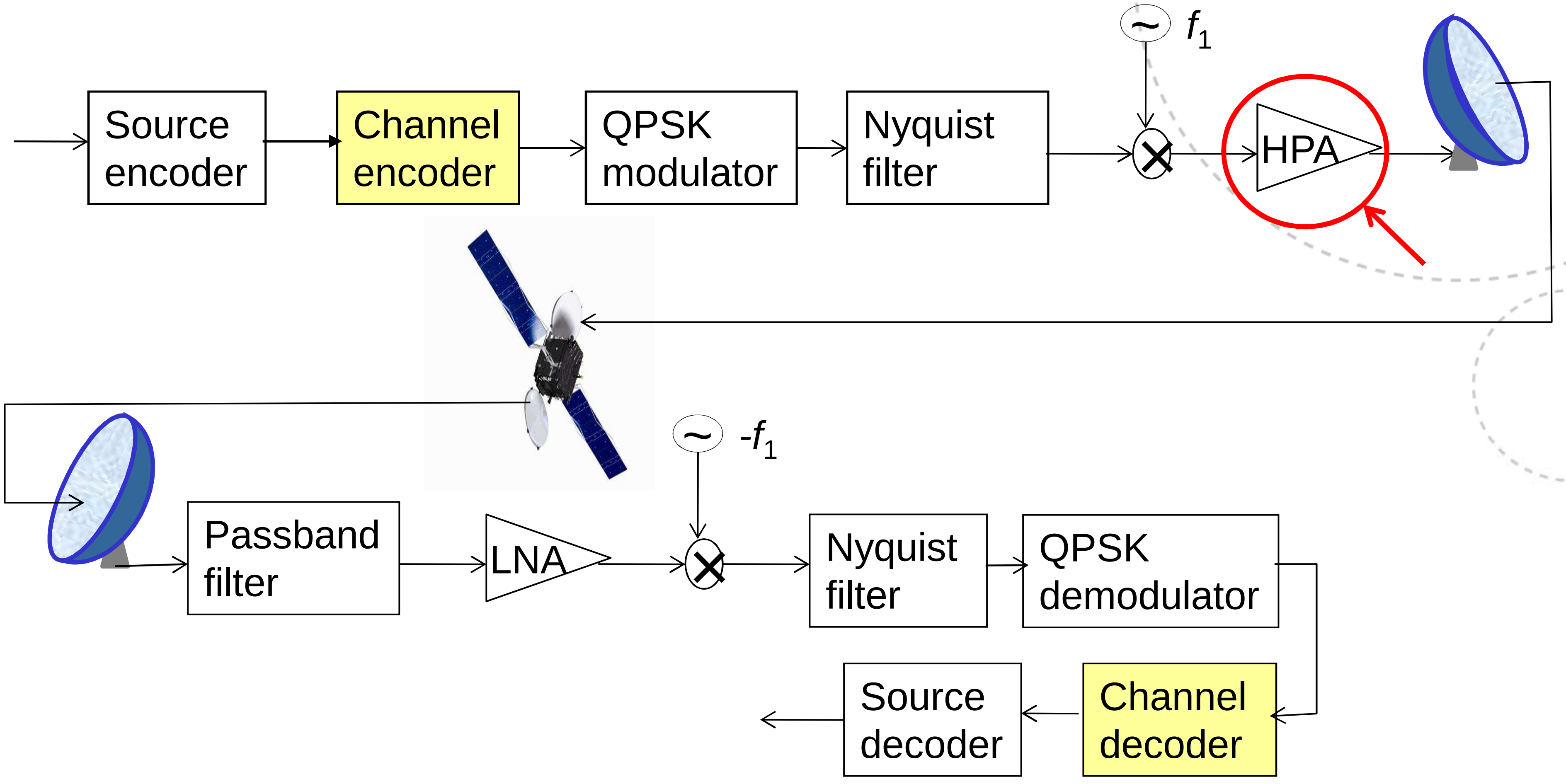
Transmitter - Receiver

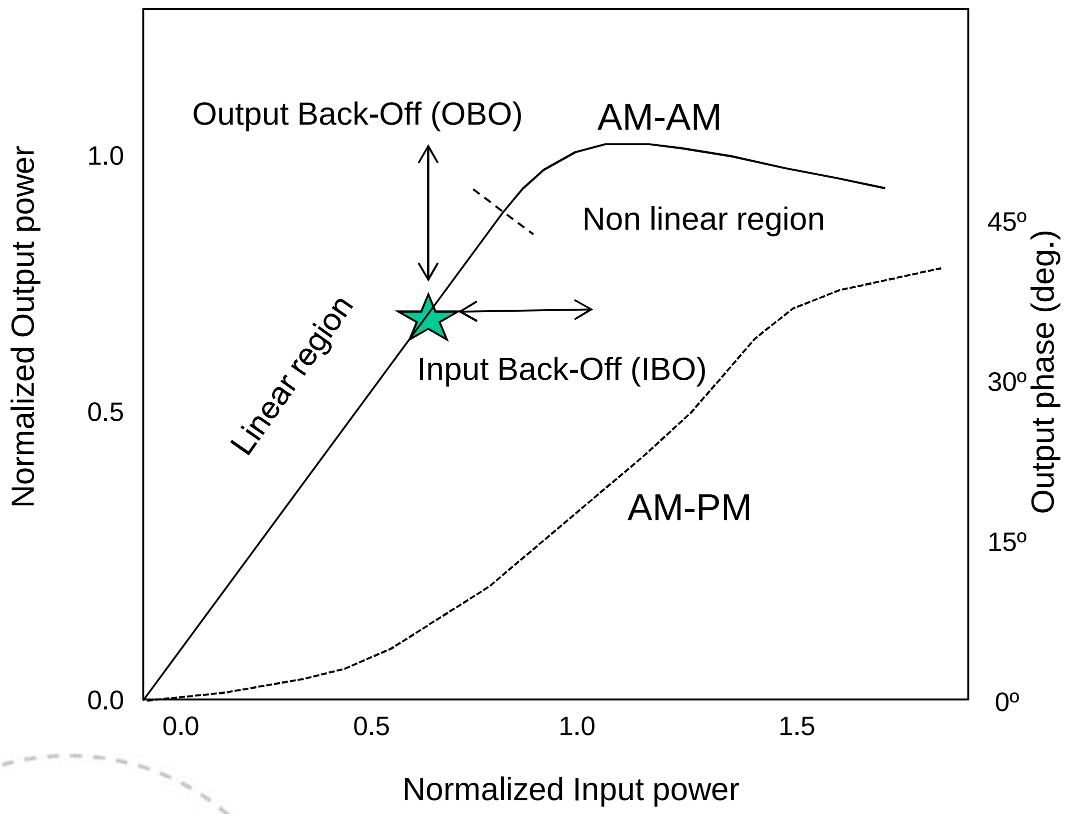


Additional losses L_a

- Pointing error
- Implementation loss
- Quantification noise
- Interference
- Non linearities
- Rain fade
- ....

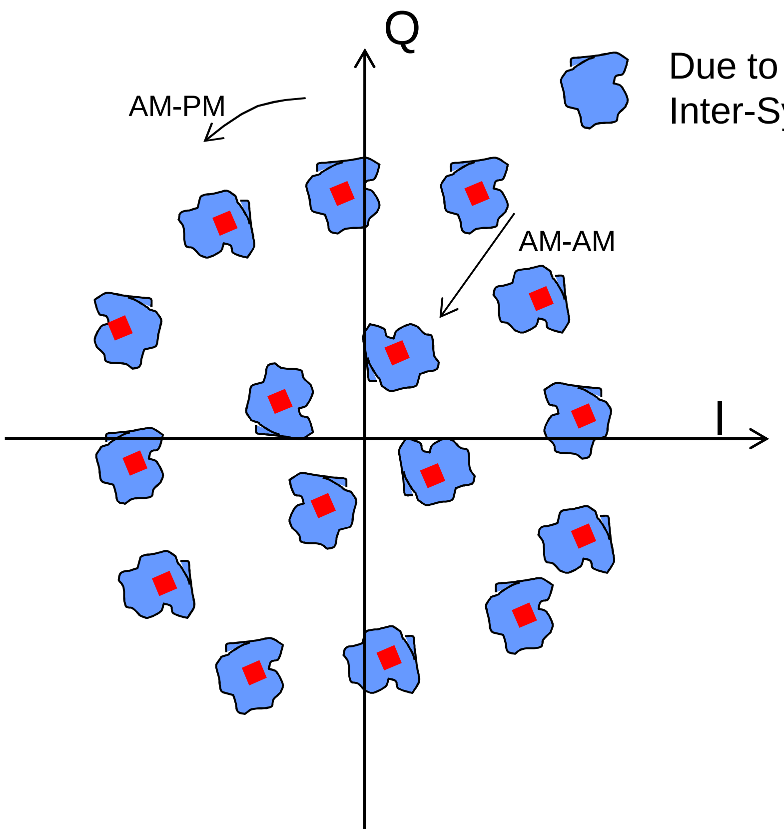
Non linearities in a high power amplifier (HPA)

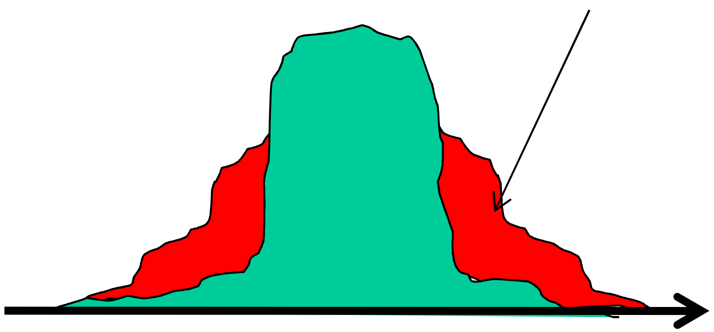
Typical caracteristics of a TWTA (Travelling Wave Tube Amp.)



The OBO is lost/vasted energi, but the non linearities result in signal degradation and increased BER.
A compromise must be found.

Effects of non linearities





Spectrum:
Spectral regrowth

Constellation:
transformation AM-AM and AM-PM, plus ISI

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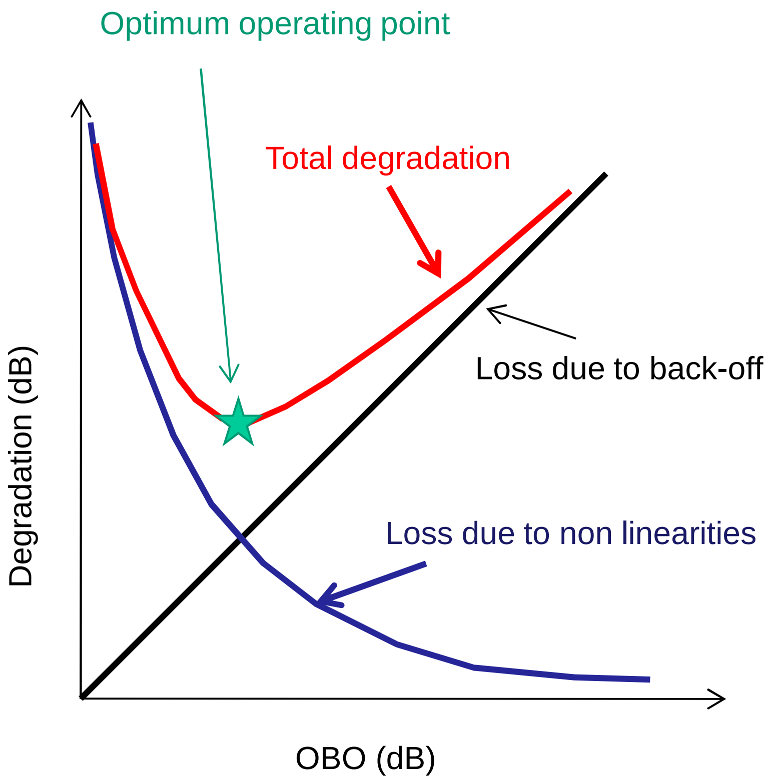
Find the operating point



How to combate effects of non linearities:
- Reduce amplitude fluctuations
- Increase the roll-off factor α
- Correction techniques at the receiver
- Predistortion techniques at the transmitter

Even though this is a static distortion, the problem is complex.

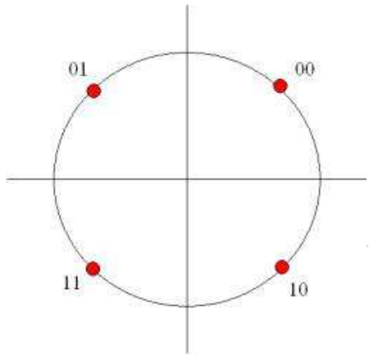
In addition: Intermodulation products are due to the HPA. When several carriers are amplified in the same HPA, the non linearity will cause intermodulation products.

The choice of modulation and coding for satellite communication

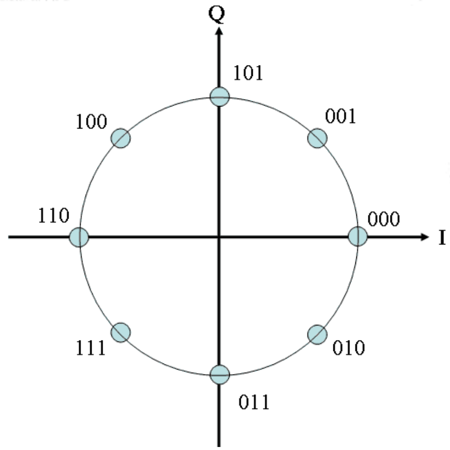
Modulation:

- Avoid amplitude modulation
- Simple
- Power efficient
- Robust

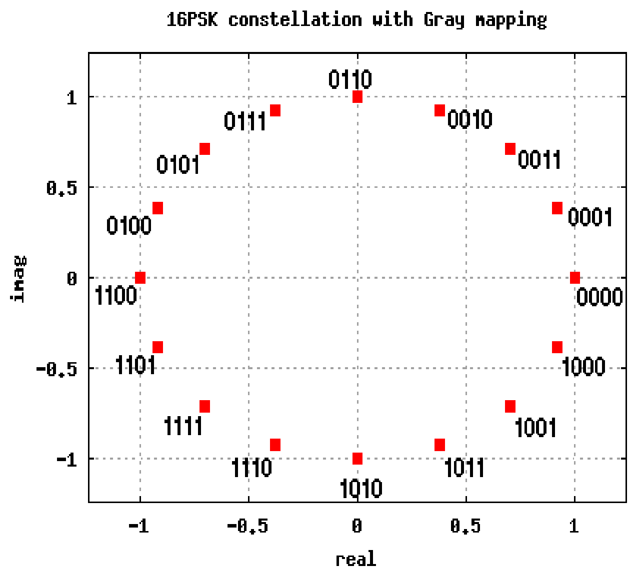
PSK
CPM
APSK
……

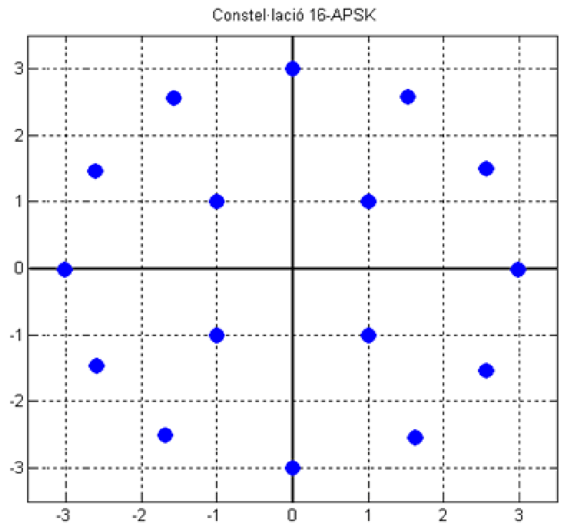


QPSK Signal Constellation



8PSK signal constellation





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Fading – meteorological maps

Fading due to hydrometeors: given in nb. of dB loss per km, function of the frequency and precipitation given in mm/hr.

It will usually be introduced as a reduction in availability (up-time for the link) in % of time.

The loss increases with the transmit frequency and with the precipitation, but the type of rain is also influencing.

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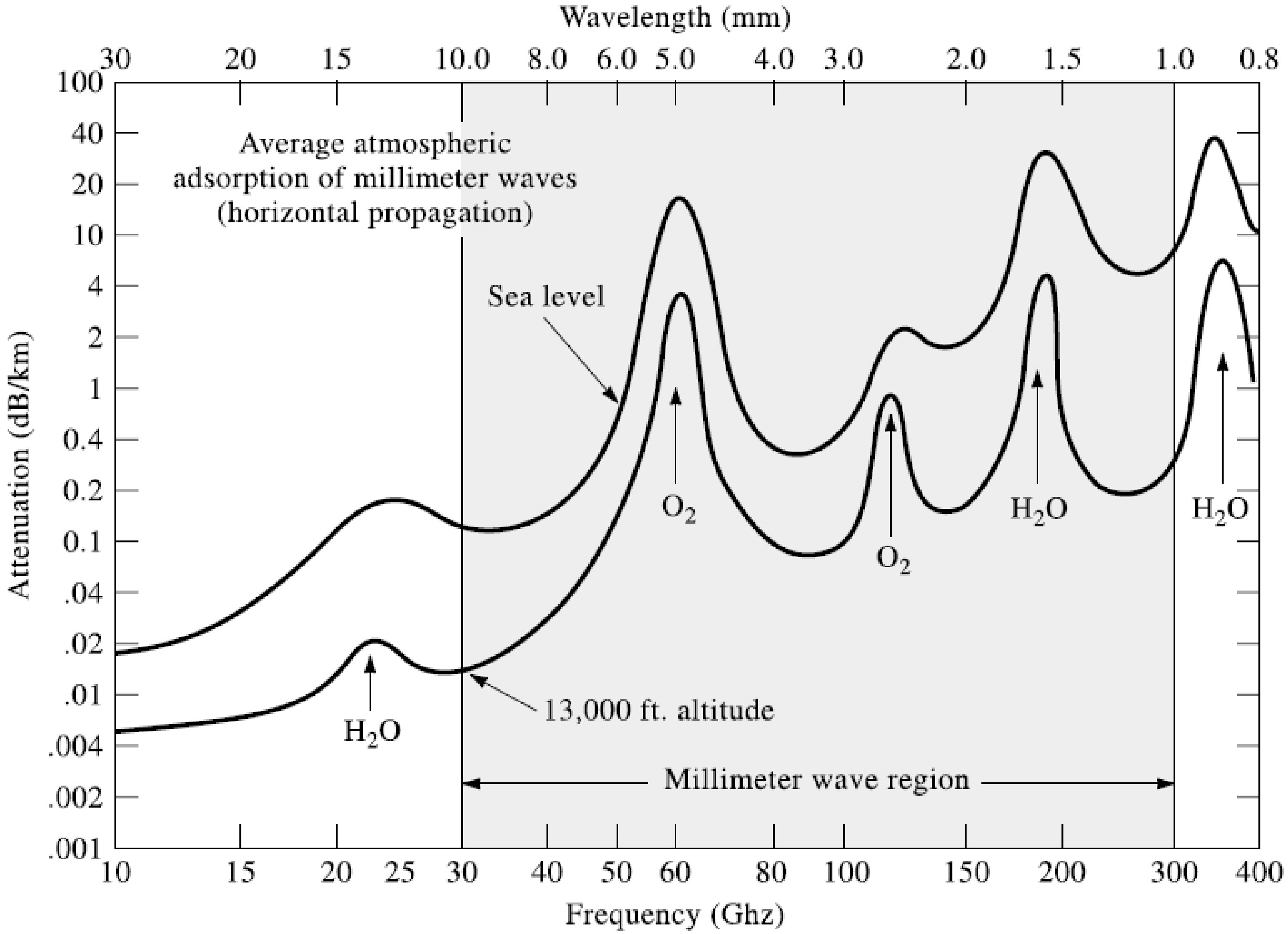
Attenuation in the atmosphere



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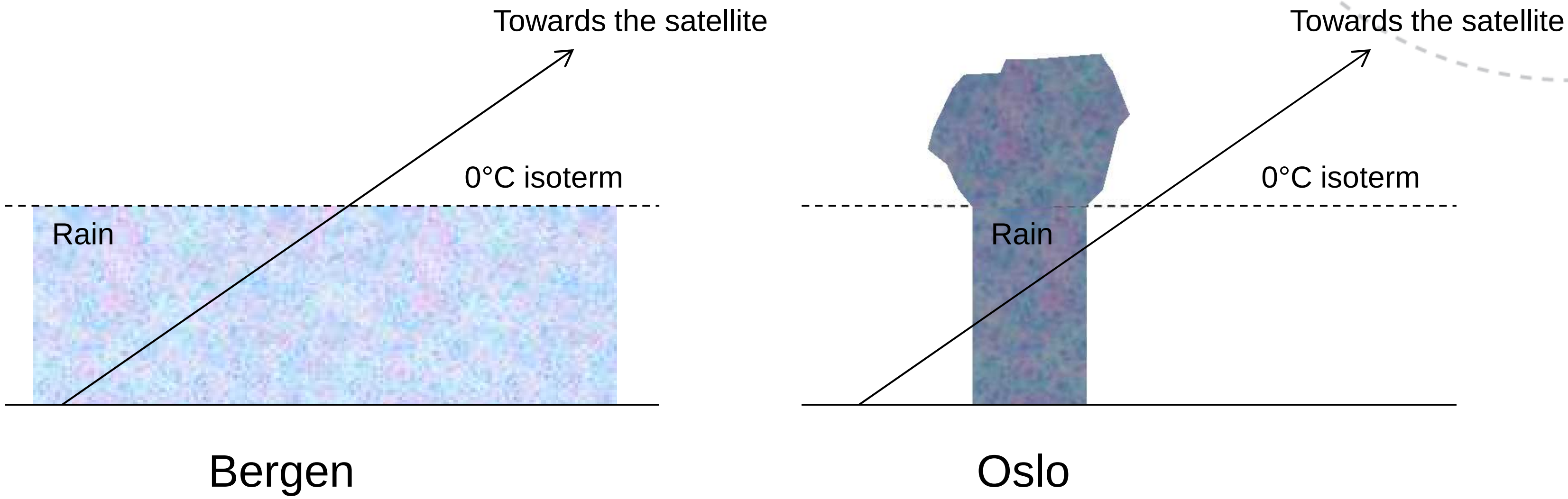
From http://www.qsl.net/va3iul/Antenna/Basics_of_Radio_Wave_Propagation.pdf

Rain type



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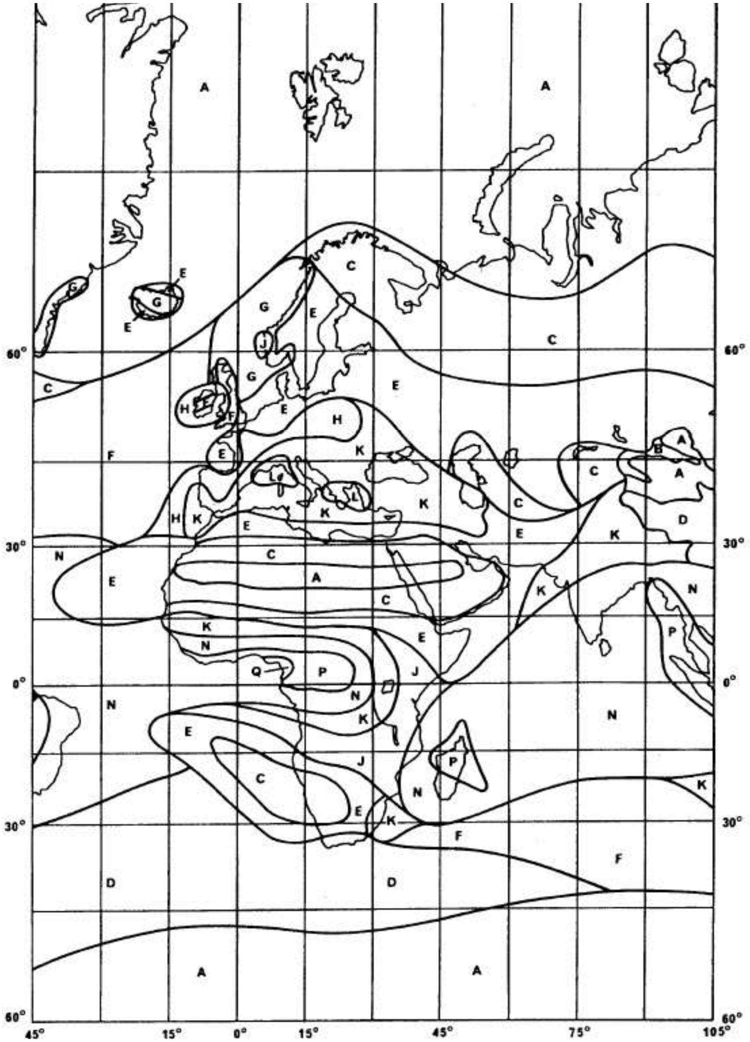
Hydrometeorological map for Europe and Africa

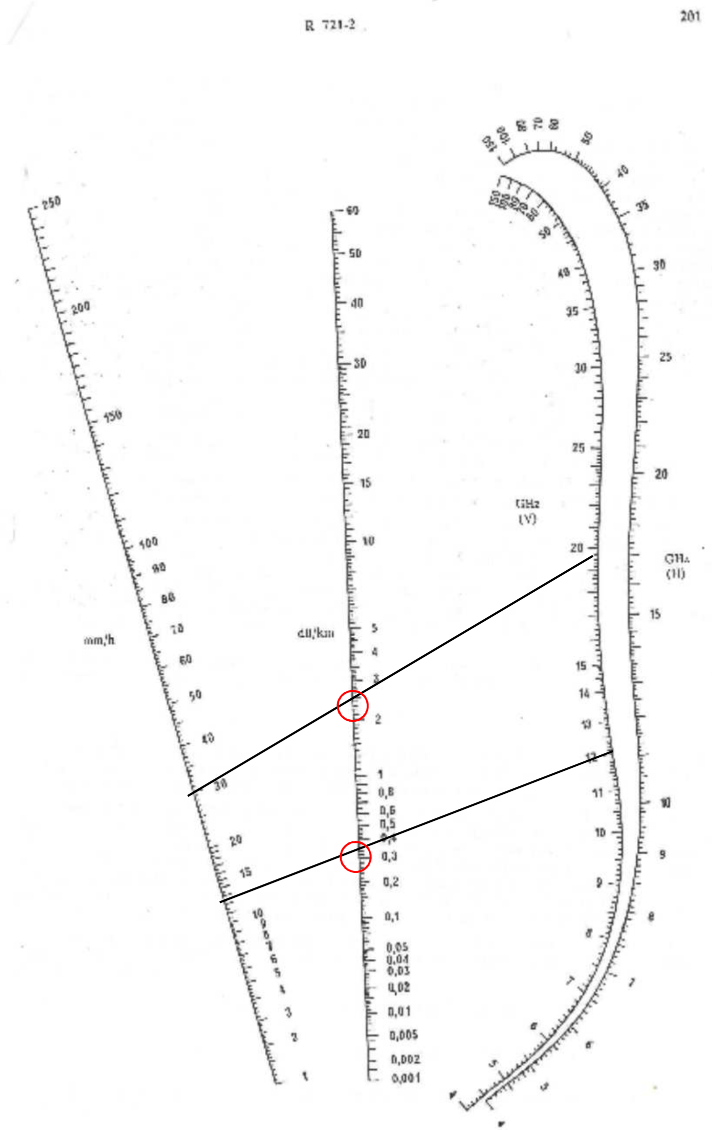


Resulting loss in dB/km

Rain attenuation in (dB/km): $\gamma_R = kR^{\alpha}$
R is the rain intensity in mm/h
k and α depend on frequency, polarisation, temperature, shape of rain drops.......

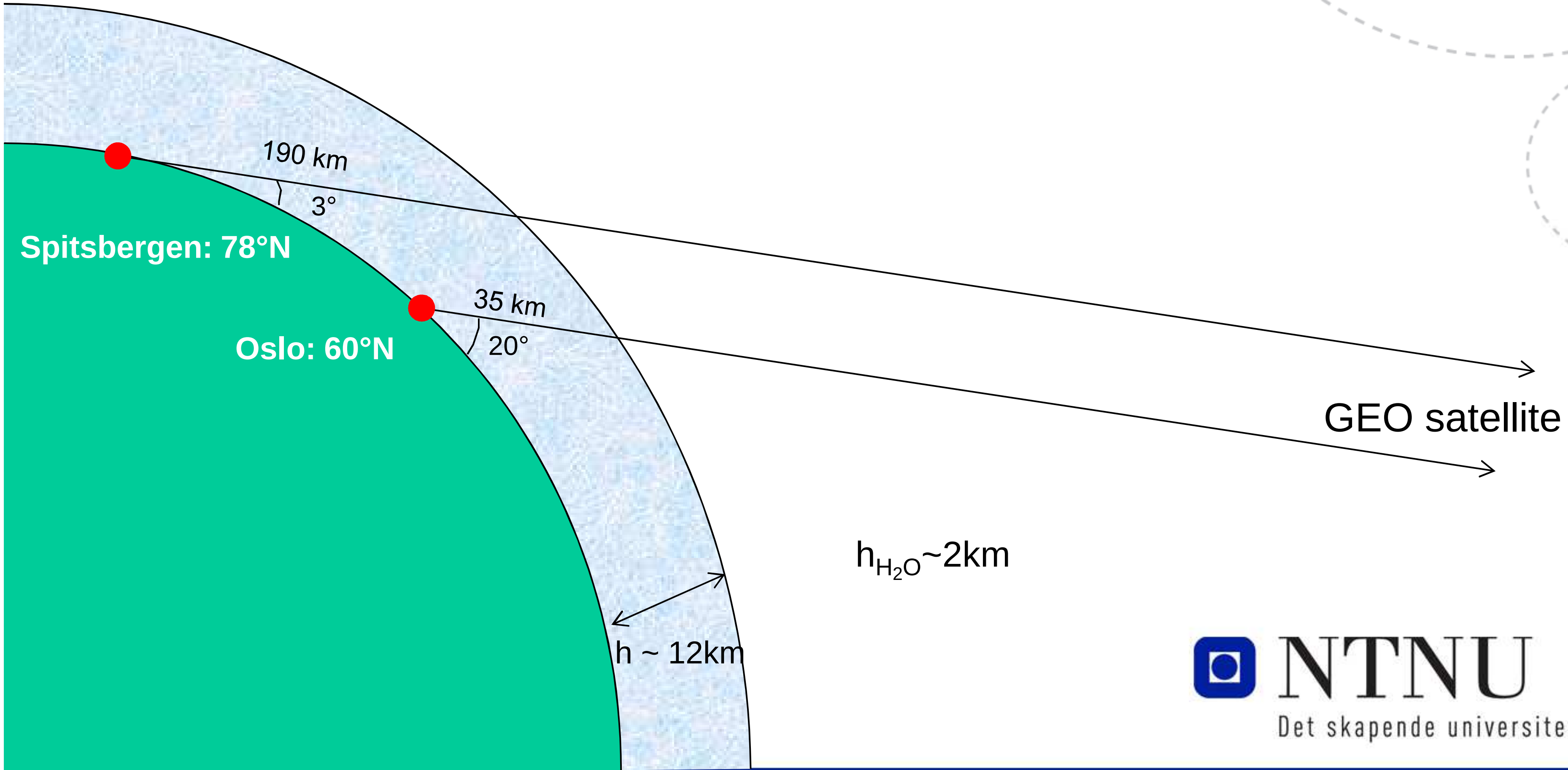
% Outage	ITU Rain Regions														
	A	B	C	D	E	F	G	H	J	K	L	M	N	P	Q
0.001	22	32	42	42	70	78	65	83	55	100	150	120	180	250	170
0.003	14	21	26	29	41	54	45	55	45	70	105	95	140	200	142
0.01	**8**	**12**	**15**	**19**	**22**	**28**	**30**	**32**	**35**	**42**	**60**	**63**	**95**	**145**	**115**
0.03	5	6	9	13	12	15	20	18	28	23	33	40	65	105	96
0.1	2	3	5	8	6	8	12	10	20	12	15	22	35	65	72
0.3	0.8	2	2.8	4.5	2.4	4.5	7	4	13	4.2	7	11	15	34	49
1	<0.1	0.5	0.7	2.1	0.6	1.7	3	2	8	1.5	2	4	5	12	24

Exhibit 2.2.4.1-2: ITU-R Rain Regions. Rain Rate in mm/h.



In Oslo: availability 99.99%, transmit frequency ~20GHz, loss 2.5dB/km

Atmosphere, latitude and elevation



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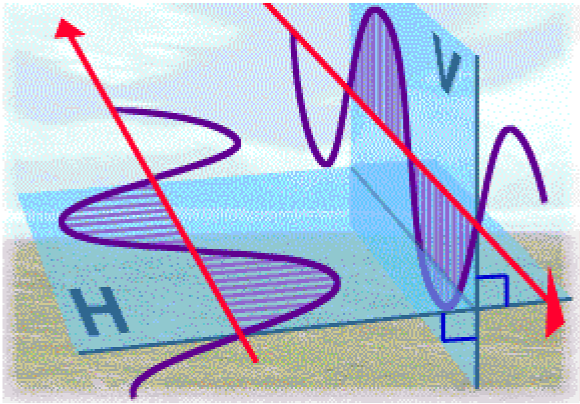
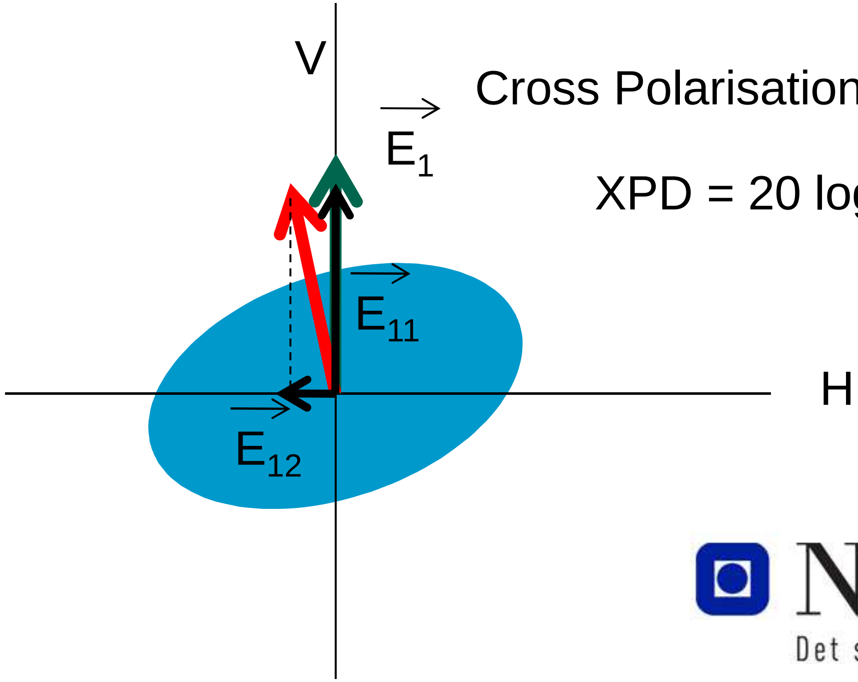
Cross polarisation, XPOL



The aim is to double the transmission capacity by using two polarisations; horisontal vs. vertical



Cross Polarisation Discrimination

$$XPD = 20 \log \frac{E_{11}}{E_{12}}$$

Interference

- Interference from other satellites into the earth station
- Interference from other earth stations into the satellite
- Interference from other earth stations into earth stations
- Interference from natural radiation
- Pointing errors may give interference, but will also reduce the gain of the antenna

➢ Strict regulations by international and national radio communication authorities (ITU, ETSI, NKOM)

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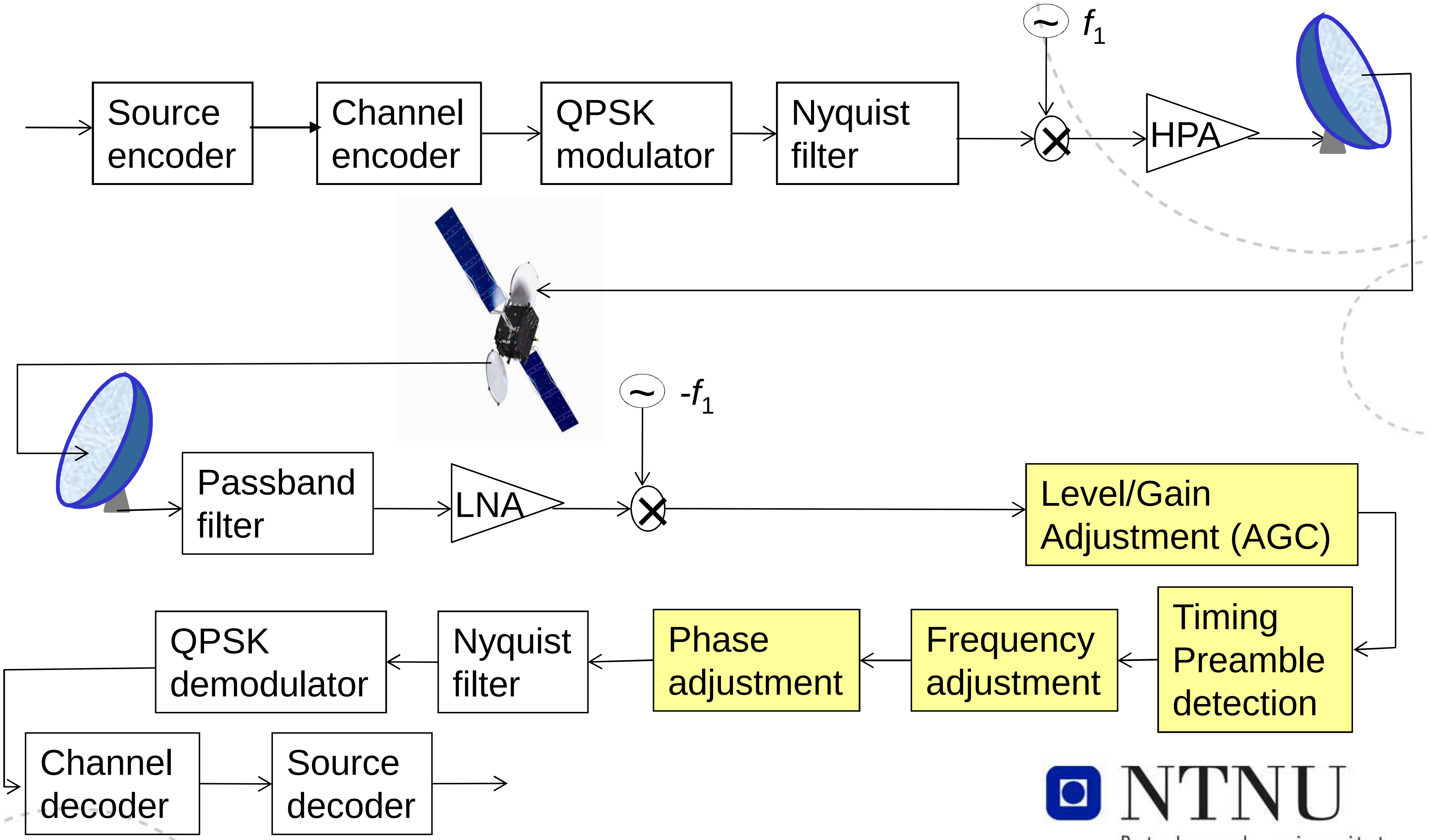
Power - restrictions

- On ground due to regulations
- In space due to limitations in power supply

Other receiver problems

- Carrier frequency synchronisation (RF, IF, BB, Doppler shift)
- Phase synchronisation
- Symbol timing
- DC (Direct Current) offset
- AGC (Automatic Gain Control)
- ....

Transmitter - Receiver



Type of data

Applications:

- TV signals
- Audio signals (radio, telephony)
- Video signals (films, video conference)
- Internet traffic
- File transfer
- Satellite News Gathering (SNG)

Challenges:

- Source encoding and vulnerability
- Latency
  - Interactive real-time signals
  - Protocols like TCP/IP
- Acceptable bit error rates (BER)
- Acceptable outage/availability
- Mobility (satellite or terminal) – handover Line of sight (LOS)
- Network control - interactivity

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TV broadcasting

- Power is available if link budget is OK
- Latency no problem
- BER is a challenge, TV signals, Quasi Error Free (QEF) requirement: BER < 10^{-10} – 10^{-12}
- The better your source encoder is (power and/or bandwidth efficiency) the higher requirements to BER (channel coding – receiver complexity - price)

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Audio signals - telephony

- Power is available
- Less stringent BER requirements, BER < 10^{-4}
- Latency problem, real-time application, Round Trip Delay (RTD) = 500 ms (one hop is 250 ms)

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Internet traffic

- Variable BER requirements depending on type of data (File transfer, low BER requirements)
- Latency due to protocols – e.g. ACK signals for TCP/IP traffic
- Power and/or frequency waste in bent pipe systems – local caching may solve – OBP may solve
- OBP problem
  - unwrap signal all the way to the TCP/IP protocol in the satellite
  - complete demodulation and remodulation in the satellite
  - increases the latency
  - multiplying possible points of failures in the satellite
  - increases the cost of the satellite

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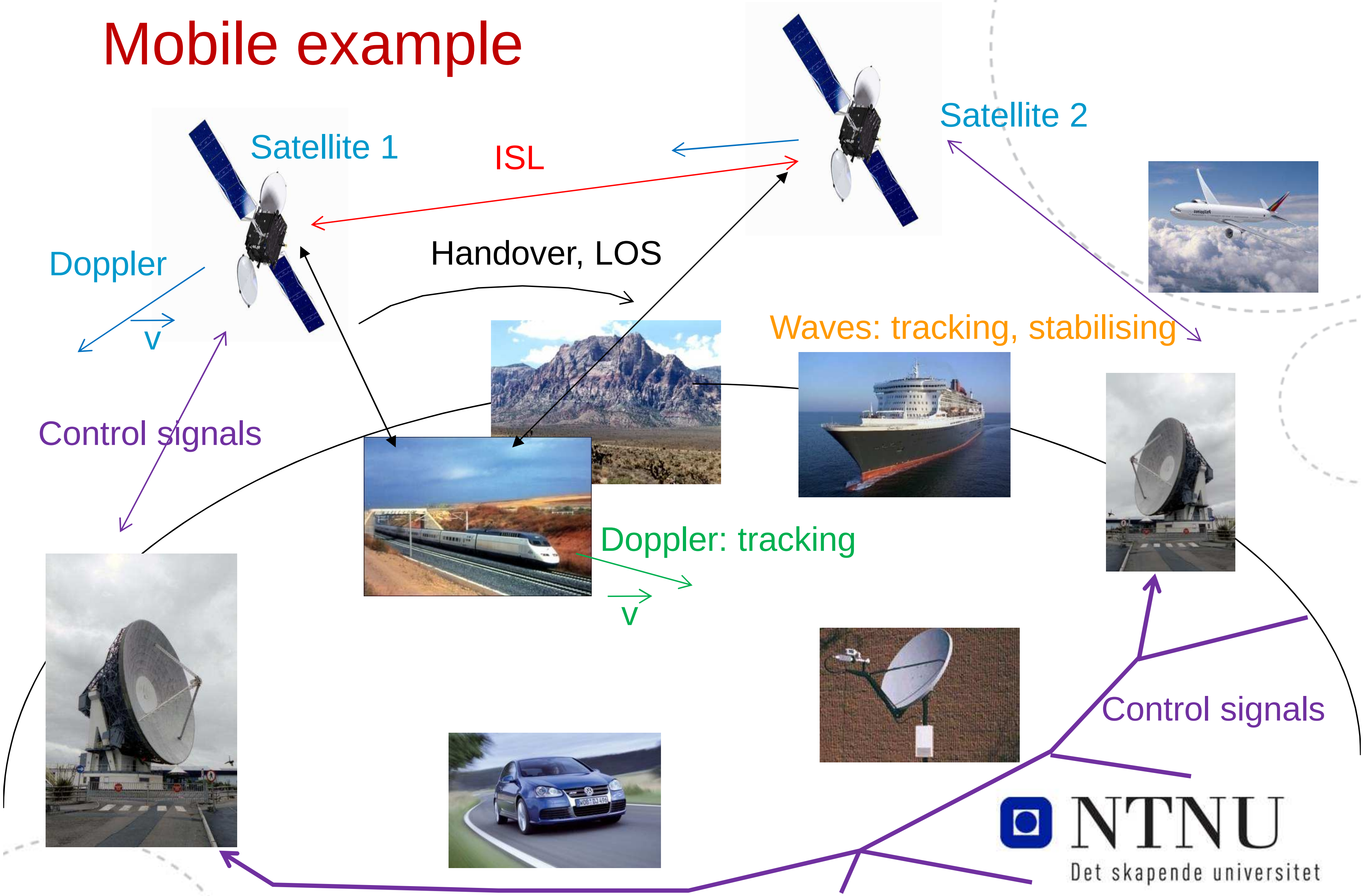
Interactive systems

- Control of access – efficient access schemes
- Radio Resource Manegement (RRM)
- Control of interference (on purpose and by accident)
- Increase of overhead – loss of power and/or frequency efficiency
- OBP
- Complexity – cost in terminal equipment
- Power availability in the terminal transmitter – size of the antenna
- Amount of data from the terminal (SNG very different to Internet browsing or VoD)

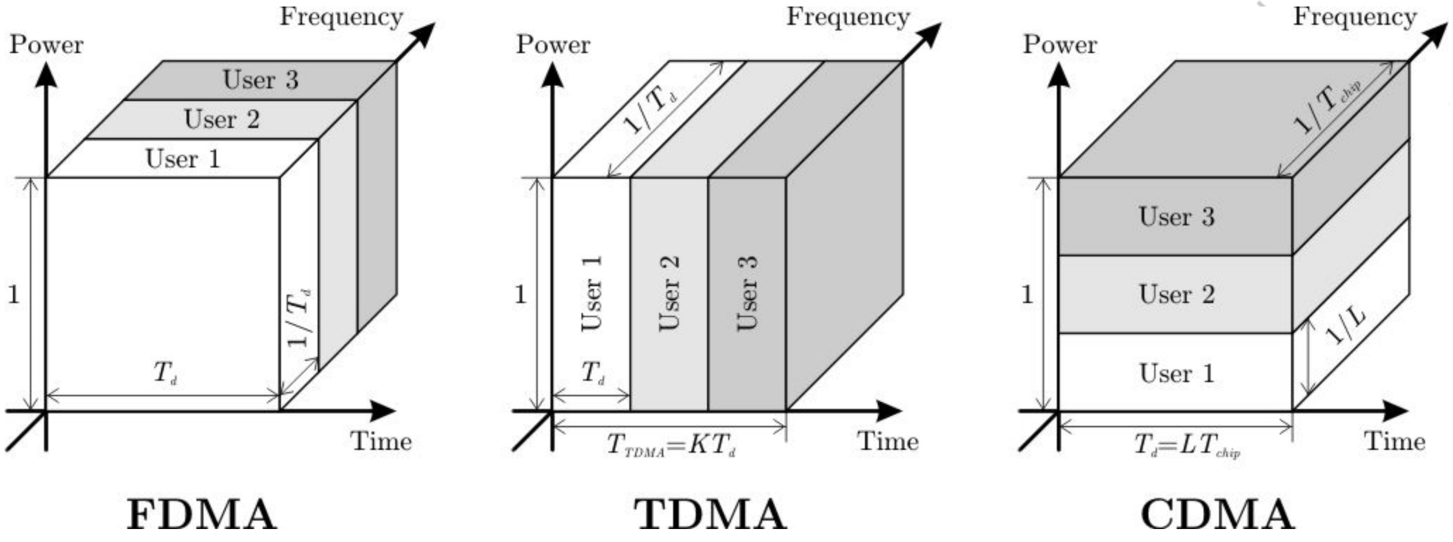
Mobile systems

- Pointing error
- Tracking
- Stabilisation
- Hand over - intersatellite links (ISL)
- LOS
- Doppler effect, increased guard time

Mobile example

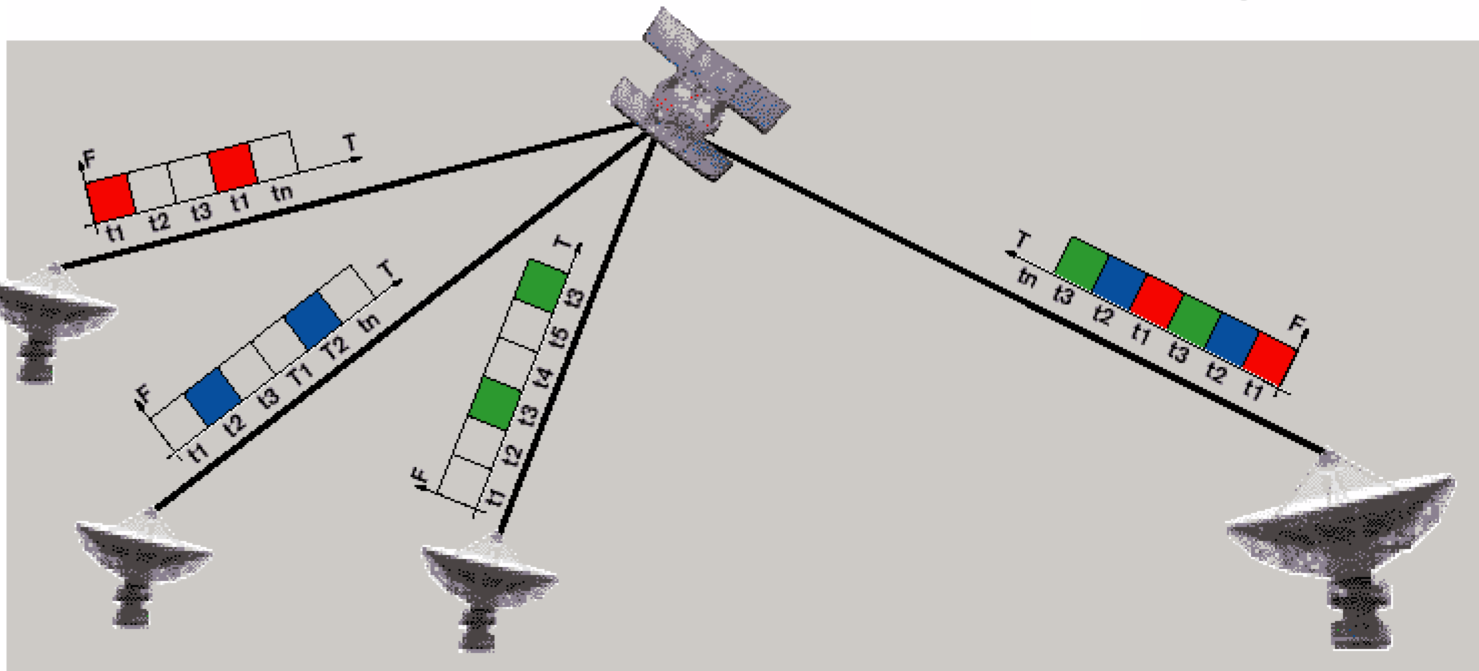


Access schemes



http://www.kn-s.dlr.de/People/Haas/fdma_tdma_cdma.jpg

TDMA – Time Division Multiple Access



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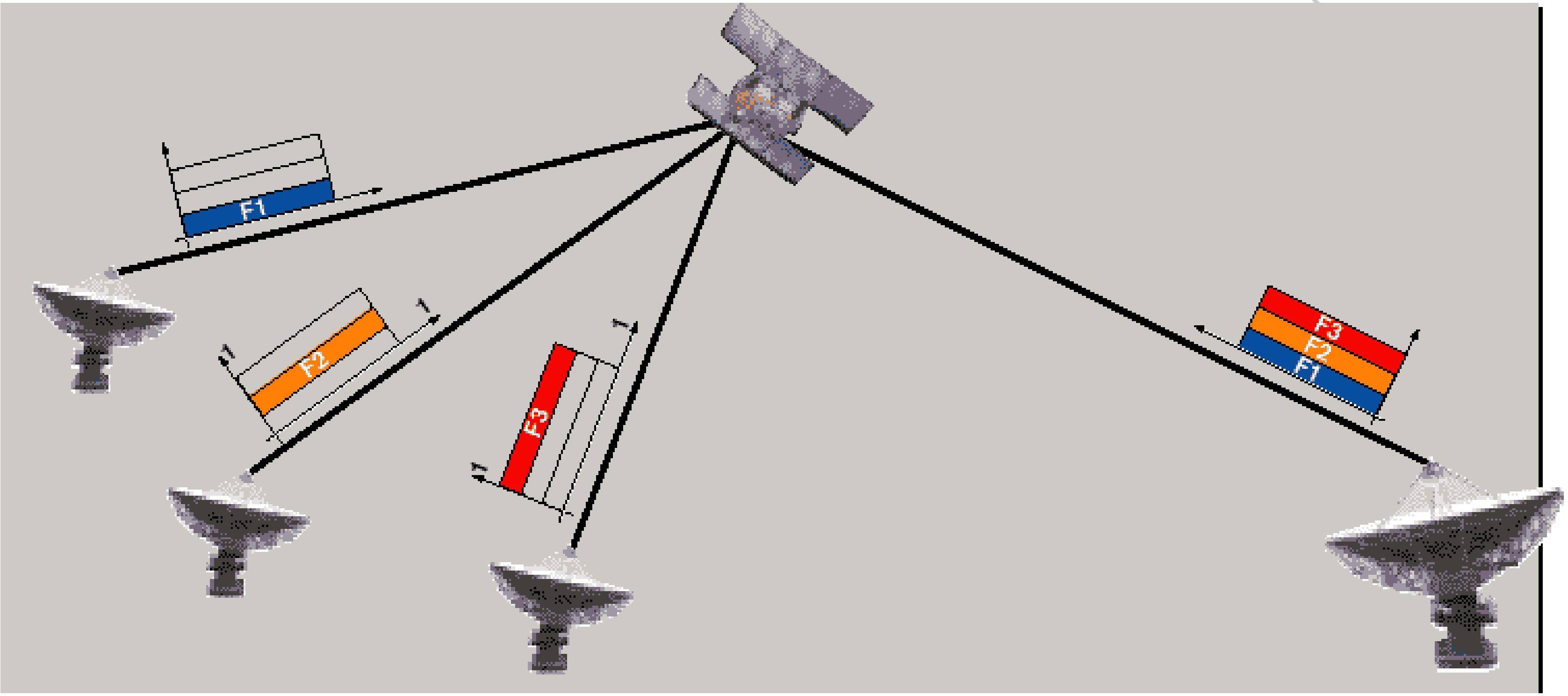
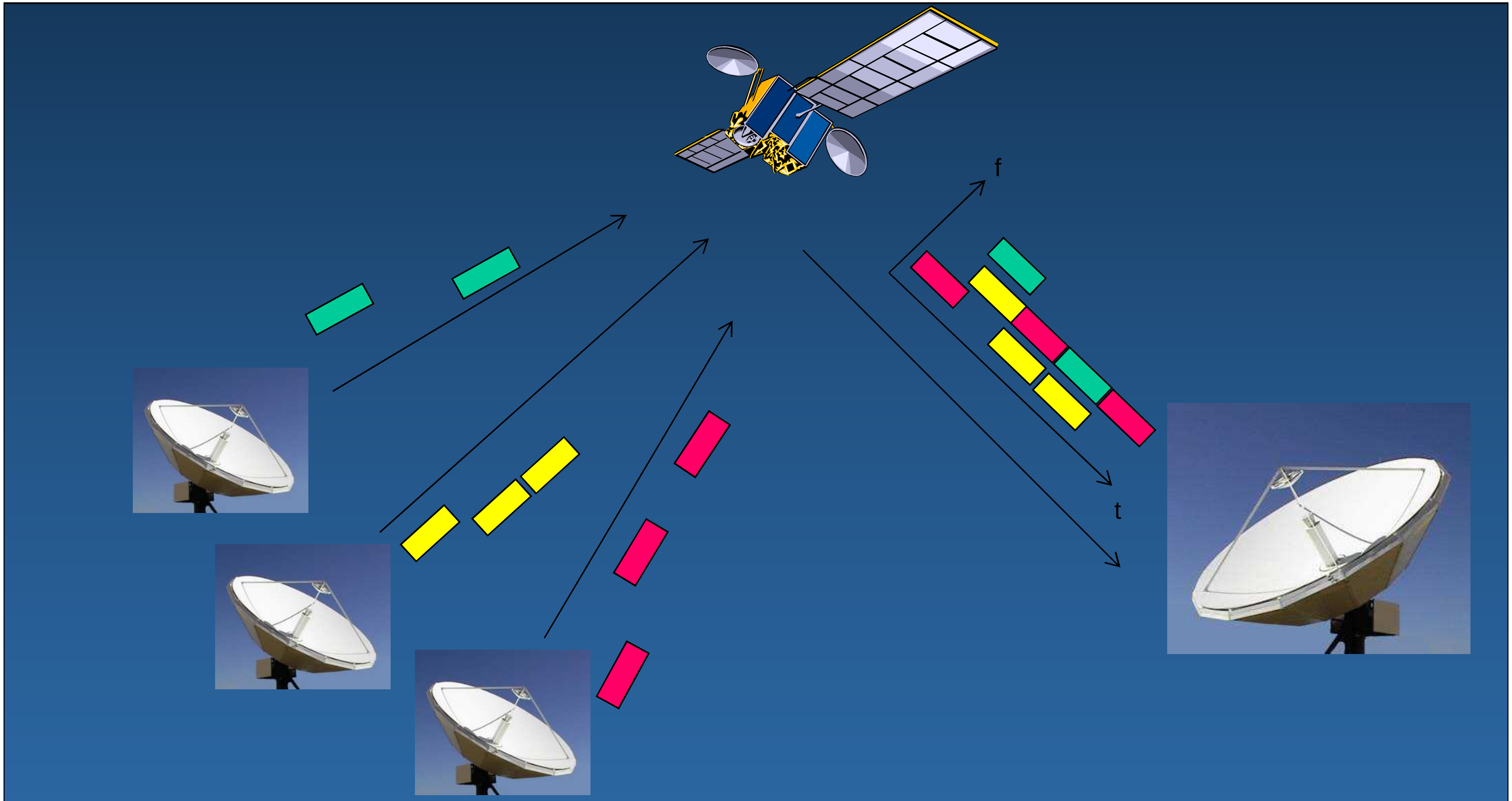
www.dsna-dti.aviation-civile.gouv.fr/

FDMA – Frequency Division Multiple Access

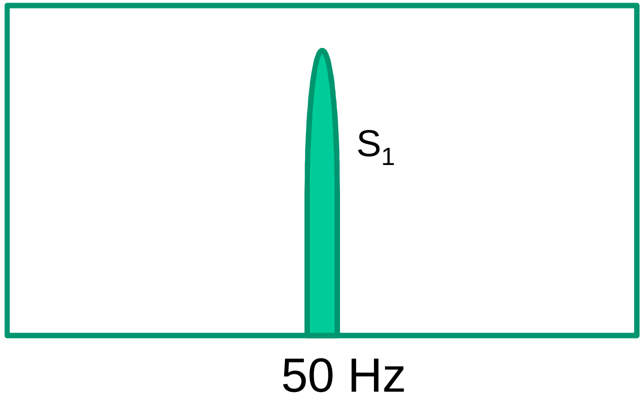


MF-TDMA Multiple Frequency - Time Division Multiple Access

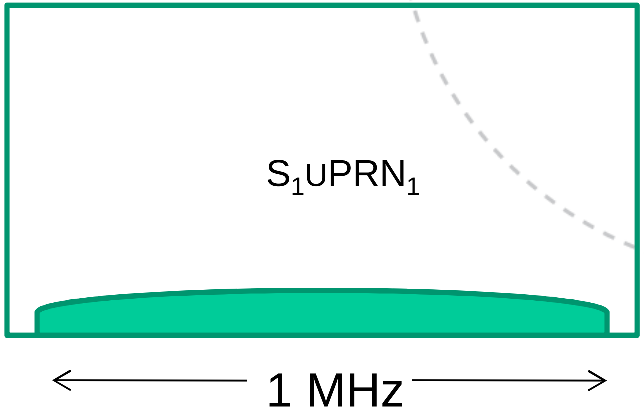


CDMA – Code Division Multiple Access

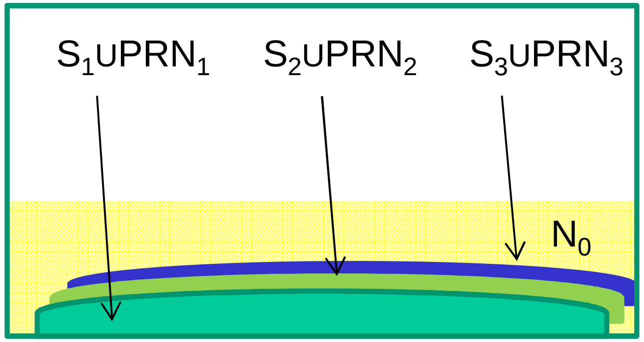
Signal spectrum before PRN coding



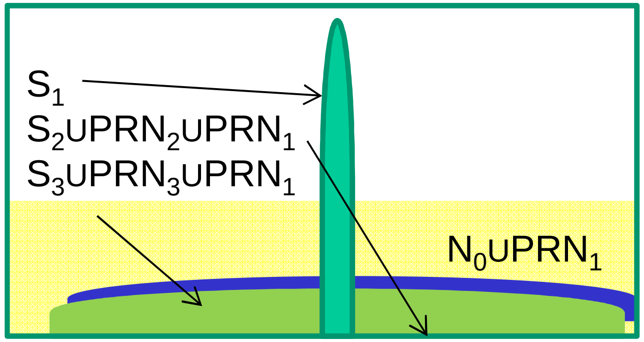
Signal spectrum after PRN coding



Signal spectrum at reception



Signal spectrum after correlation



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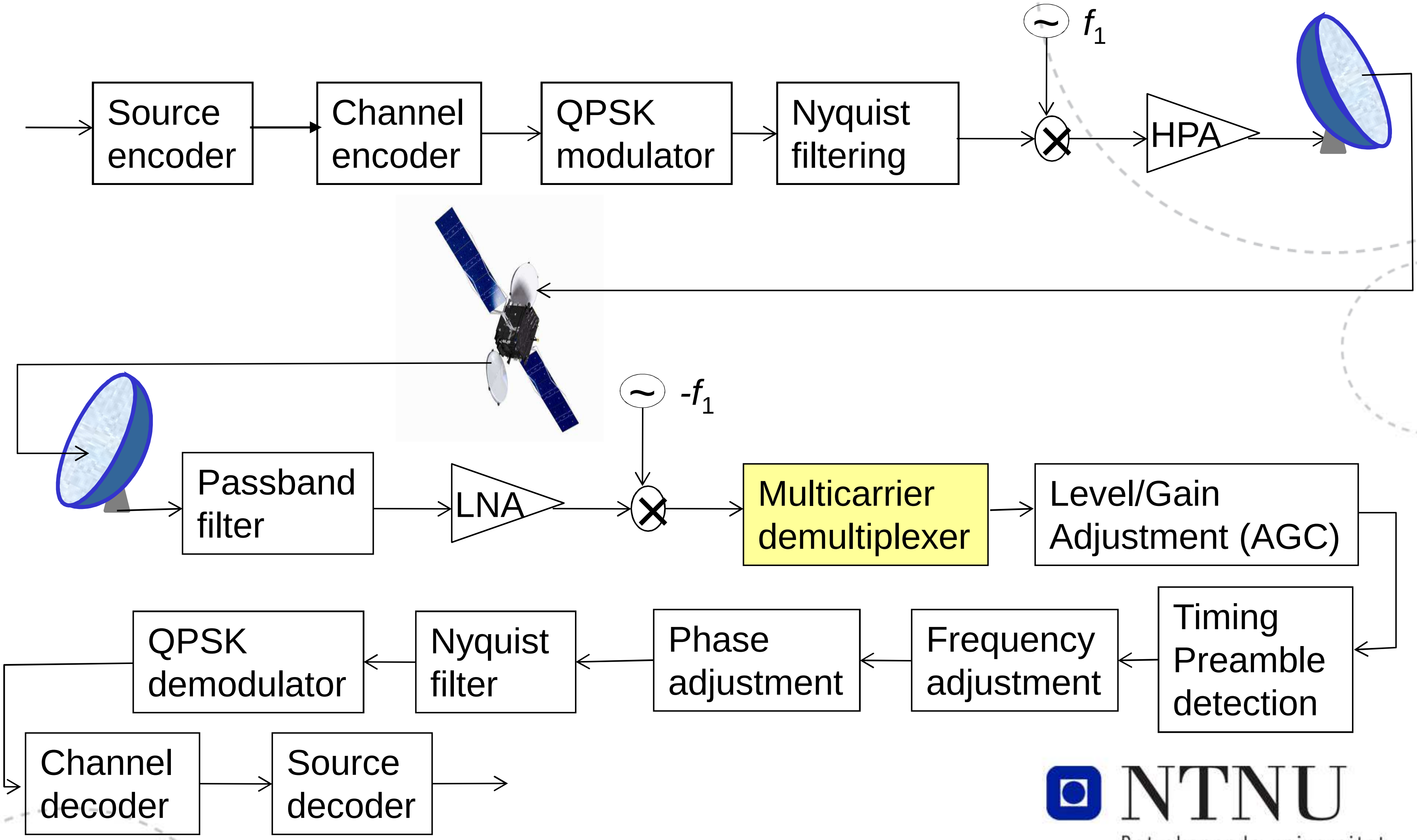
Transmitter - Receiver



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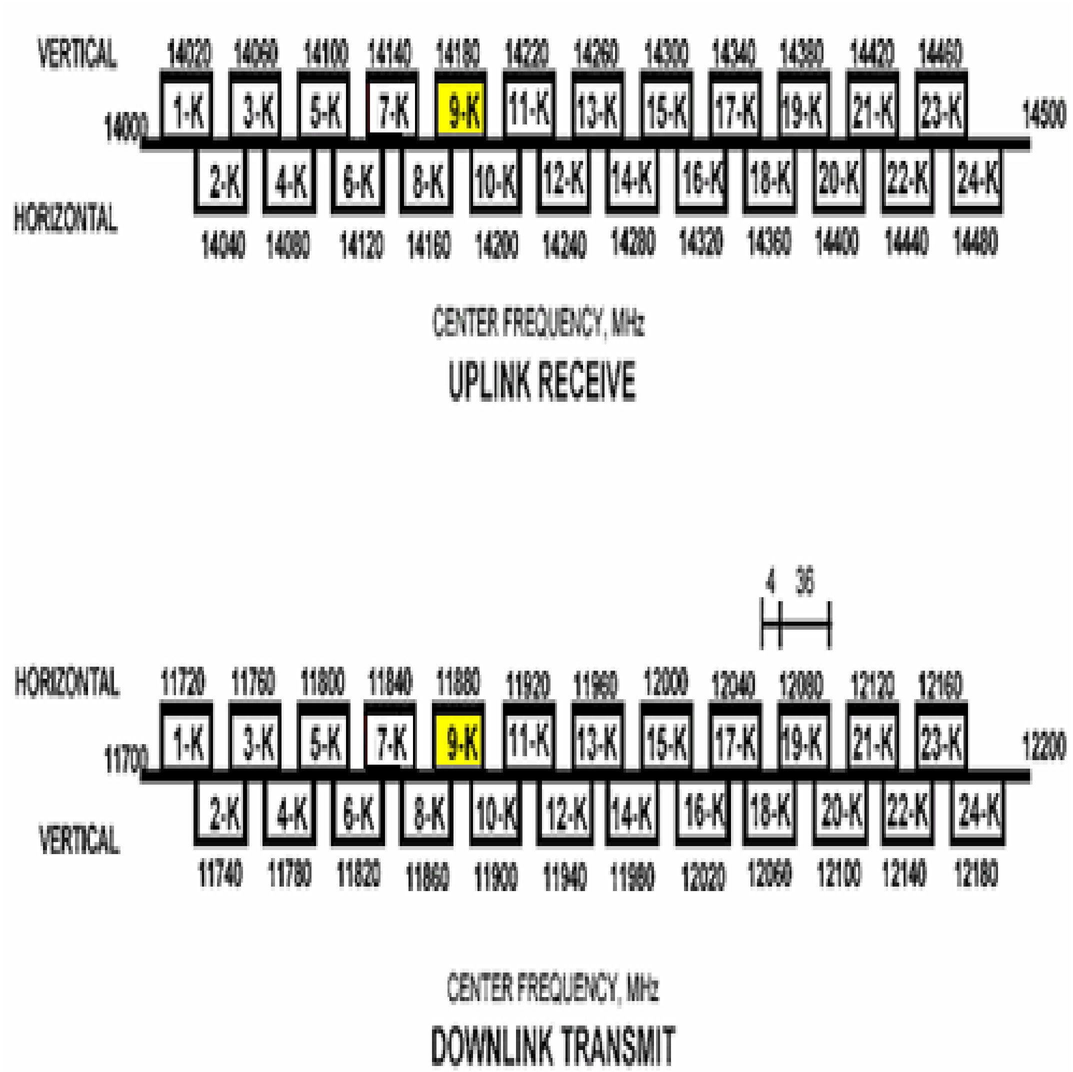
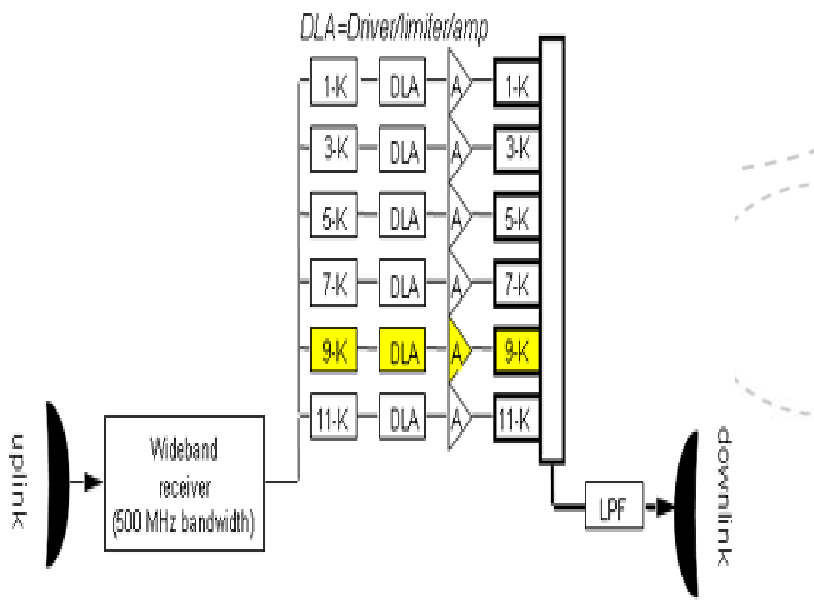
Transponders – frequency plan and polarisation





Bandwidth 36MHz

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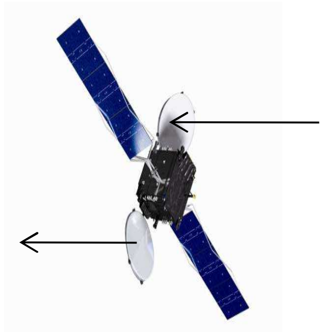
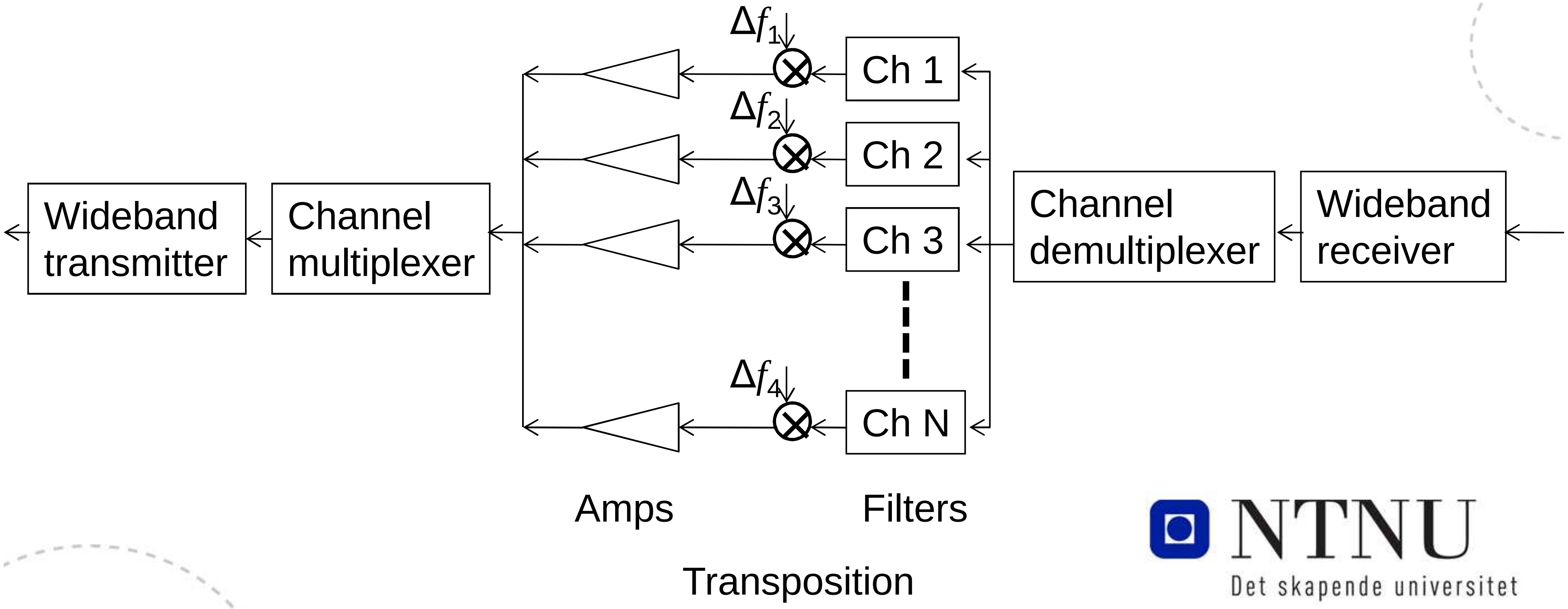
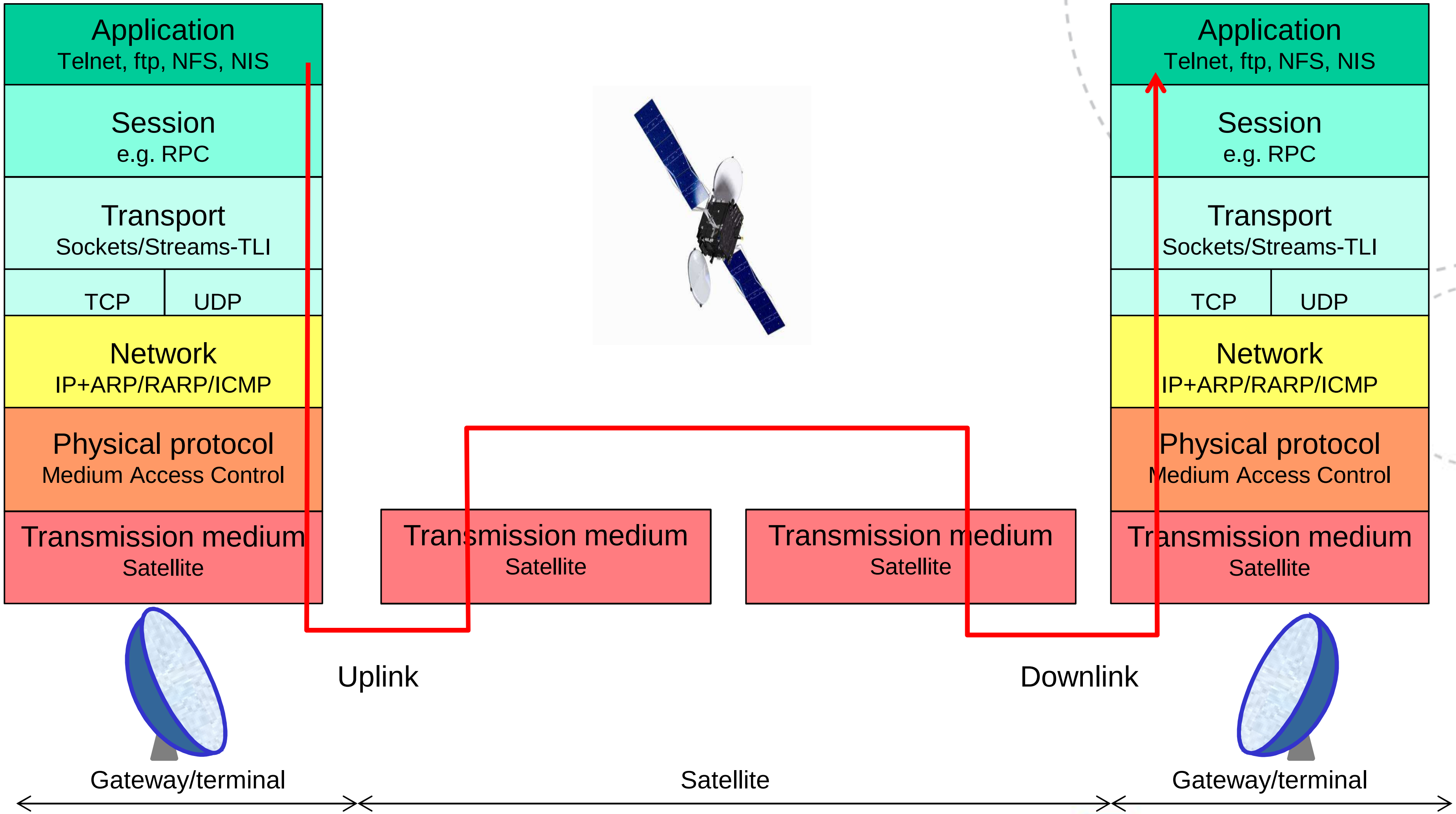
http://www.jsati.com/why-satellite-how-Spacesegment4.asp

Bent pipe satellite





Bent pipe affected OSI* layers

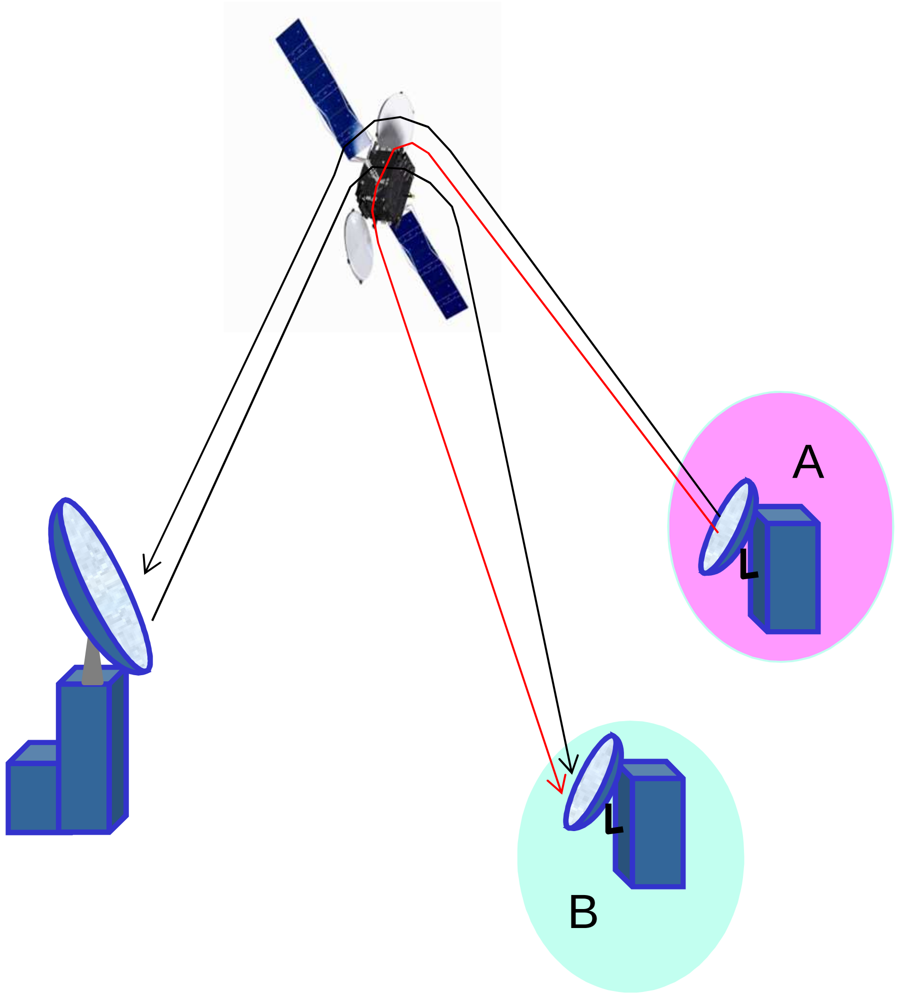


* Open Systems Interconnection

Onboard processing

- A switch/router in the sky
- Advantages:
  - Directivity
  - Latency reduction
  - Efficiency – bandwidth and power savings
- Disadvantages:
  - Complexity
  - Increased number of points of failures

Interactive systems - mesh



Objective: to send IP traffic from terminal A to terminal B

Bent pipe system, latency: 500 ms

OBP system, latency: 250 ms

Power and bandwidth savings.

What if the terminals are not in the covarage area of the same satellite?

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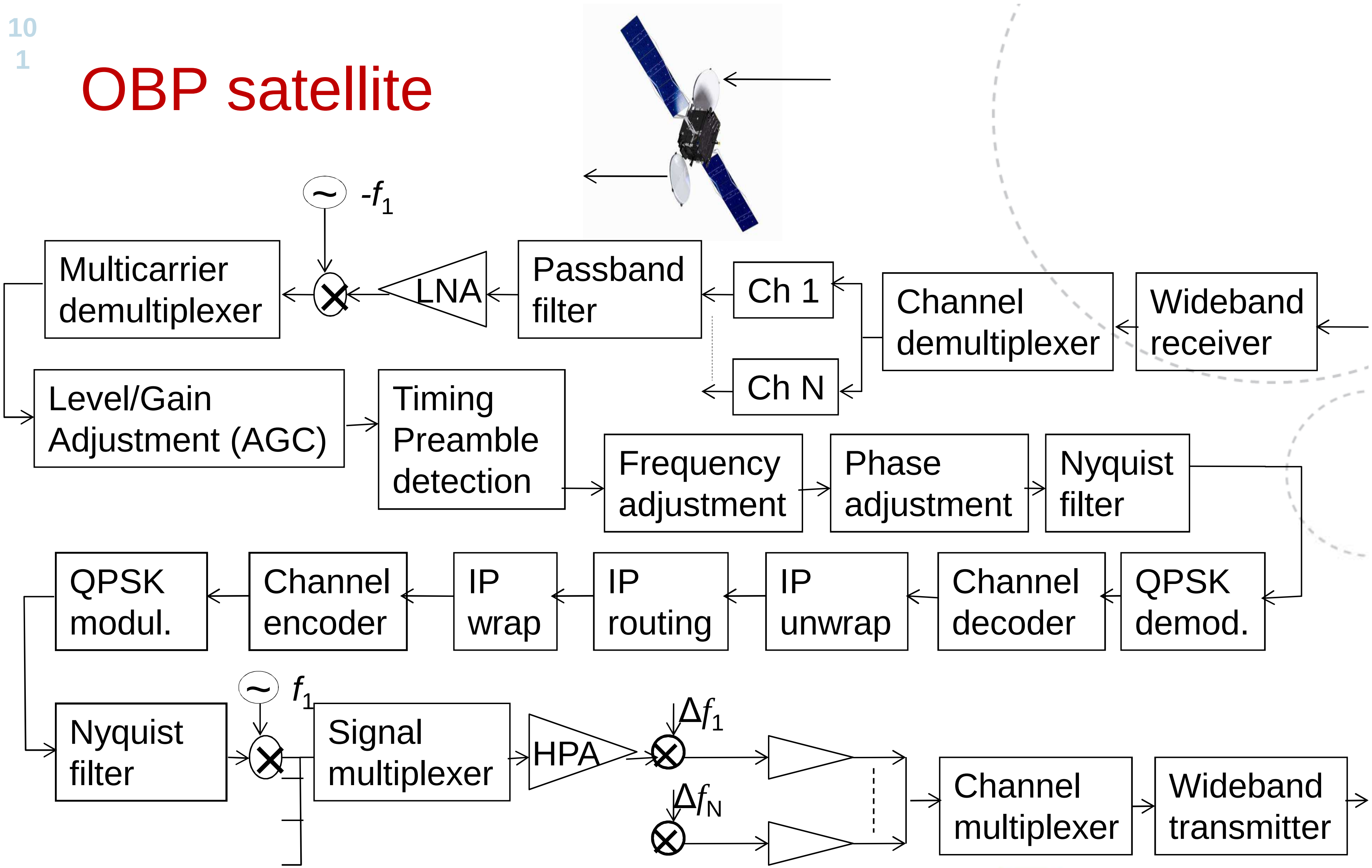
OBP satellite



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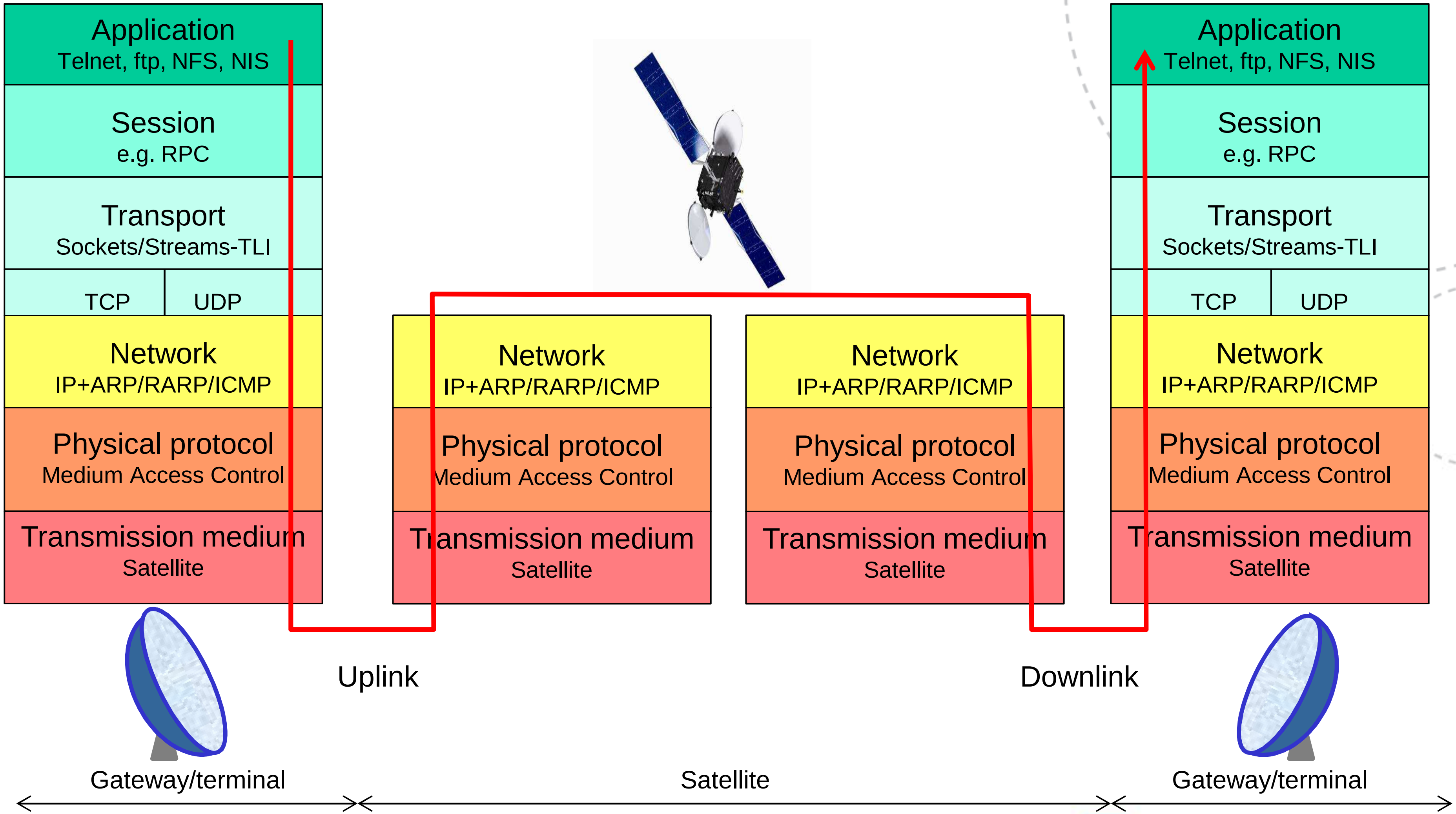
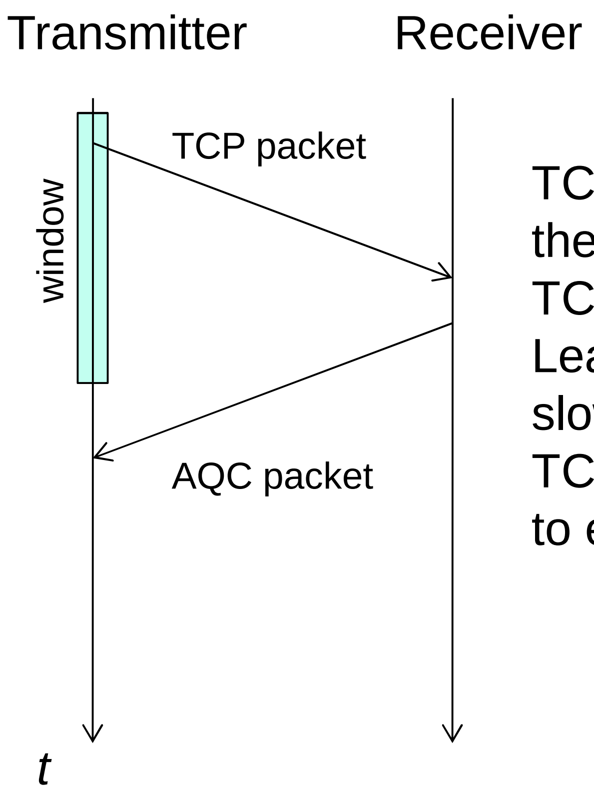
Bent pipe affected OSI layers



TCP/IP window problem

Solved by TCP/IP accelleration or PEP (Performance Enhancing Proxy).



TCP was not made for satellite communication, the satellite round trip delay (500 ms) exceeds the TCP window size.
Leads to connection problems, congestion and slow start mode problems.
TCP acceleration is used to fool the protocol and to establish and maintain connections over satellite.

Summary – how to design a satellite communication system

- Start with the application
- Find the requirements (availability, BER, data rate....)
- Set up a link budget
- Improve the conditions (increased power, better antennas, different frequency, channel coding....)
- Take location into account (rain fade, elevation angle,....)
- Ensure a margin in order to cope with phenomena difficult to quantify (interference, cross polarisation, pointing error, intermodulation.....)

Examples of satellite systems

Different systems:

- Frequency
- Orbital position
- Application

Some operating satellite communication systems today - examples

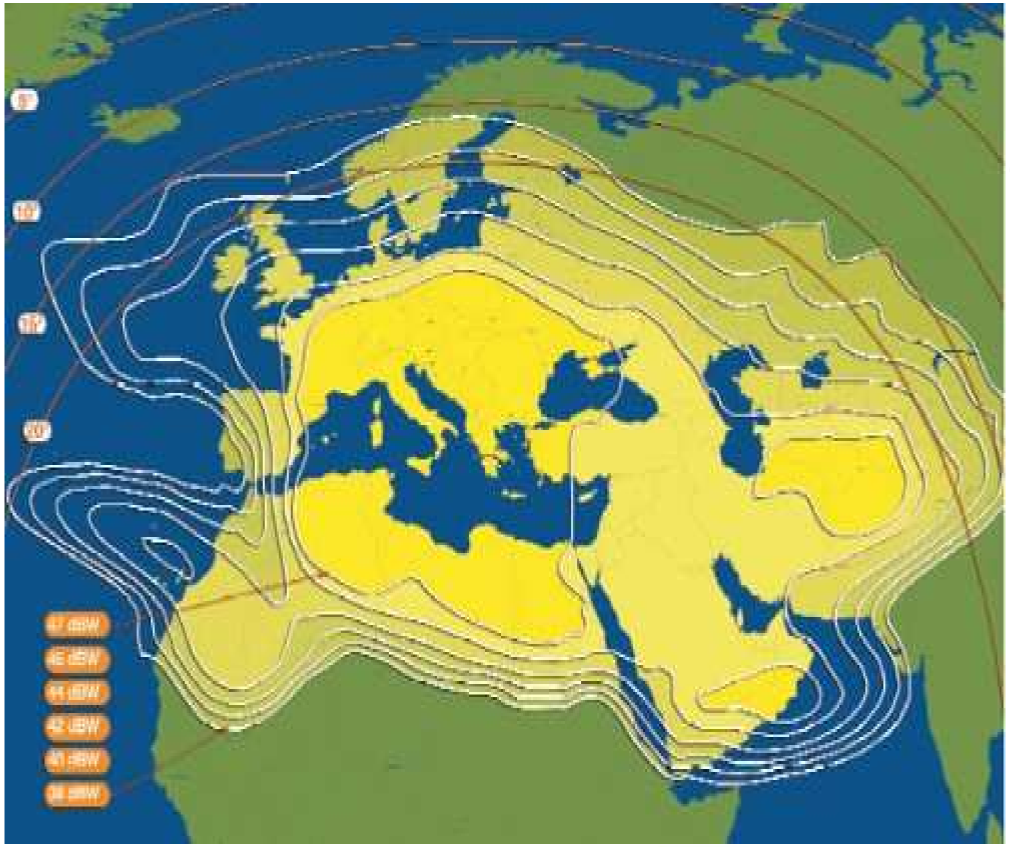
- Intelsat
- Eutelsat
- Hispasat
  - Conventional satcom
  - Amerhis
- Thor satellites
- Inmarsat
- Iridium
- Ipstar

Eutelsat W6 21.5ºW

- **Internet services iDirect equipment**
- **Eutelsat W6 Satellite Beam**
  Europe, Middle East, North Africa
- - 24 Transponders
- - Downlink EIRP 47 dBW at center
- - Uplink G/T +3 dB/K at center
- **Frequencies**
- Uplink

  13.00 - 13.25 GHz
  13.75 - 14.50 GHz
- Downlink

  10.95 - 11.70 GHz
  12.50 - 12.75 GHz



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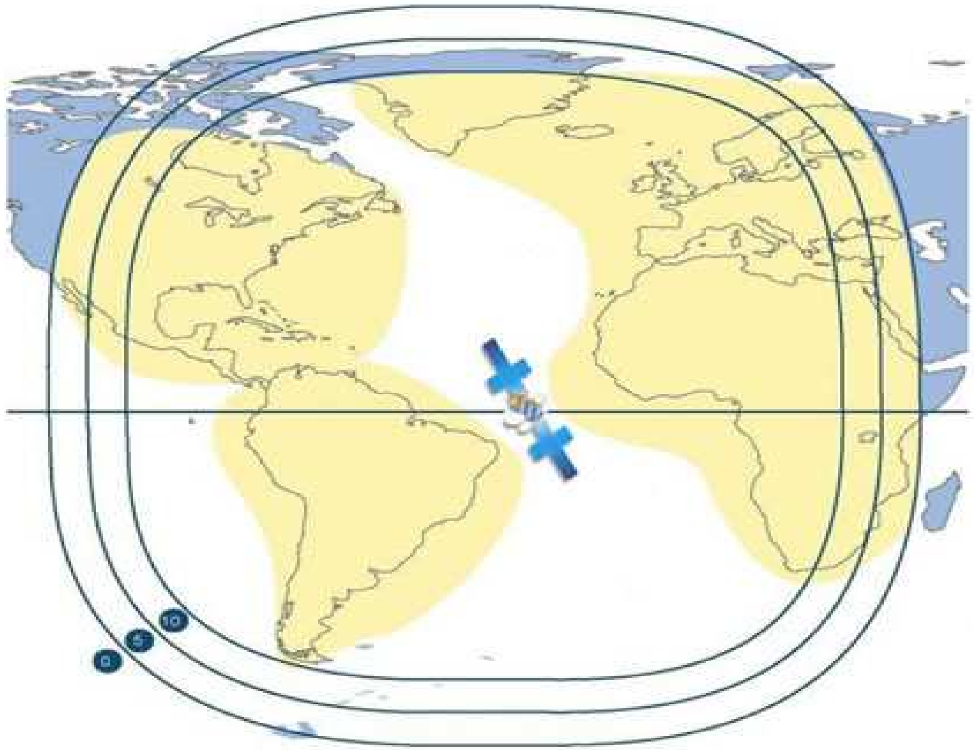
http://www.lamit.ro/satellite-coverage-maps.htm

AMC-12 iDirect C-band VSAT

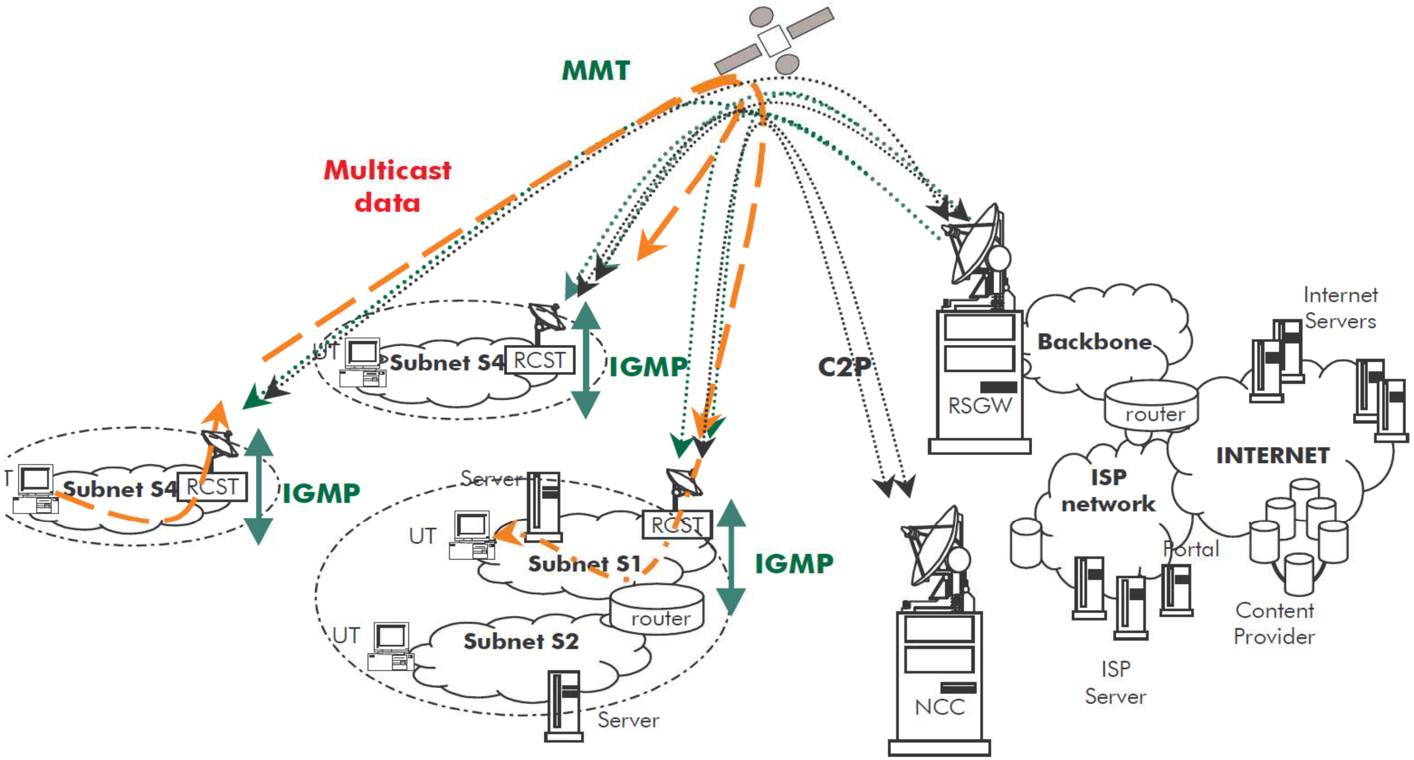
- **AMC-12, IS 904, YAMAL 202, NSS 6 satellites**
  Lamit Service Two way Satellite Internet Coverage
  for **Americas, Europe, Africa, Asia**
  Available with **iDirect** Equipment
- **Geostationary Satellites**
- - **AMC 12** - 37.4° W
  - **IS 904** - 60° E
  - **YAMAL 202** - 48.9° E
  - **NSS 6** - 95° E

C-band Frequencies :
- Uplink : 5925 - 6425 MHz

- Downlink : 3700 - 4200 MHz
Amp Redundancy : 30 for 24/beam



Example – Amerhis satellite



Mesh IP Multicast over AmerHis Network

AmerHis 1&2, Ku-band OBP

Madrid, September 22, 2009 – Hispasat's Amazonas-2 telecommunication satellite will embark AmerHis-2, the advanced Multimedia Regenerative system provided by Thales Alenia Space, and dedicated to extend the current Hispasat satellite communications capacity in North and South America. The satellite will be launched on September 30, 2009 from Kourou, French Guiana by an Ariane 5 ECA. Amazonas-2 satellite is developed under EADS Astrium prime contractorship.

Thales Alenia Space - through its subsidiary Thales Alenia Space España – was in charge of the design, production, integration and final tests of the AmerHis-2 advanced Multimedia Communication Repeater and for the supply of the Ku-band TTC Communication, receivers and passive RF equipments.

Based on the previous experience gained in the design and development of the AmerHis-1(*) Multimedia Regenerative Communication system, Hispasat and Thales Alenia Space incorporated additional improvements not only in the On-Board Processor (OBP), but also in the associated ground segment, comprising the Network Control Centre (NCC). The system represents a highly novel but proven solution for meshed broadband communications via satellite, based on the DVB-S/DVB-RCS regenerative processor.

AmerHis-2 will provide a wide range of communications services enabling direct communication between users located at any geographical point within the satellite coverage areas. It will then provide real-time voice and video services such as Voice over IP (VoIP) or videoconferencing as well as Direct To Home television (DTH).

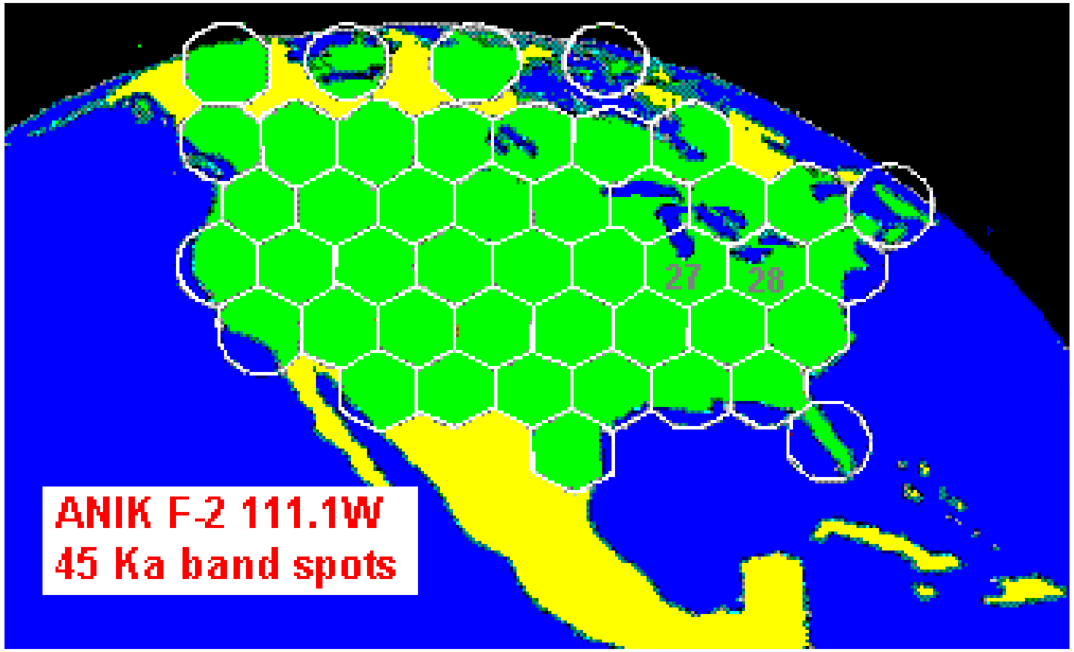
Amazonas I coverage
Hispasat 61ºW

Wildblue and Telesat, Ka-band spot beam satellite

North America, USA: United States, 48 US states only + Canada.
Direct 2-way satellite speed internet service for home or office.
Advanced technology Ka band (20 and 30 GHz) using Anik F-2 at 111.1W

The 5950 kg satellite was successfully launched 17th July 2004 by Ariane rocket from Kourou, French Guiana, South America and commercial service for the US and Canada started end June 2005.

Wildblue was bought by ViaSat on the 1st of Oct. 2009



http://www.satsig.net/ka-band-anik-f2-wildblue-telesat.htm http://www.viasat.com/

BGAN - Inmarsat

BGAN helps to give you competitive advantage by increasing your personal and business productivity.

Global coverage

Seamless network coverage across most of the world's landmass.
Mobile broadband connectivity wherever you go.

Compact

Discreet, lightweight terminals.
Smallest BGAN terminal weighs less than a kilo.
Set up a broadband mobile office in minutes.

Easy to use

No specialist technical expertise required.
Same device can be used worldwide.
Standard user interface across all terminals.
No compatibility issues with local telecoms networks.

The BGAN terminals use the "L" Band, with the terminals receiving frequencies at 1.525-1.559GHz, and transmitting at 1.6265-1.6605GHz.
Max 500kbps transmission rate.

BGAN - Broadband Global Area Network - coverage

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http://www.inmarsat.com/Services/Land/BGAN

Use of different frequency bands

- L-band/C-band – large beam coverage – large antennas for the Gateways – little directivity – interference problems and power inefficiency: global systems, robust systems
- Ku-band – directivity – continent size beam width – medium antennas – communication and tv services
- Ka-band – very directive – small spot beams – future use for meshed OBP systems – vulnerable to rain fading

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