Radio Frequency Satellite Links

Prof. Dr. Sören F. Peik

22nd October 2023

MICROWAVE LAB

Contents I

References I

- Gerard Maral and Michel Bousquet.
  Satellite Communications Systems.
  Wiley-Blackwell, 6 edition, 4 2020.
- Bruce R. Elbert.
  Introduction to satellite communications.
  Artech House space application series. Artech House, Boston, Mass. [u.a.], 3. ed edition, 2008.
  Includes bibliographical references and index.
- Louis J. Ippolito.
  Satellite Communications Systems Engineering: Atmospheric Effects, Satellite Link Design and System Performance (Wireless Communications and Mobile Computing).
  Wiley Publishing, 2008.

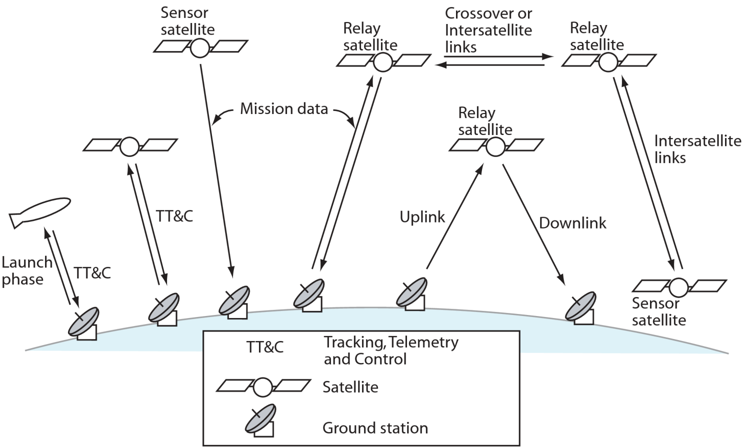
References II

Teresa M. Braun.
Satellite communications payload and system, 2012.
Restricted to subscribers or individual electronic text purchasers.

D.M. Pozar.
Microwave and Rf Wireless Systems.
John Wiley, 2001.

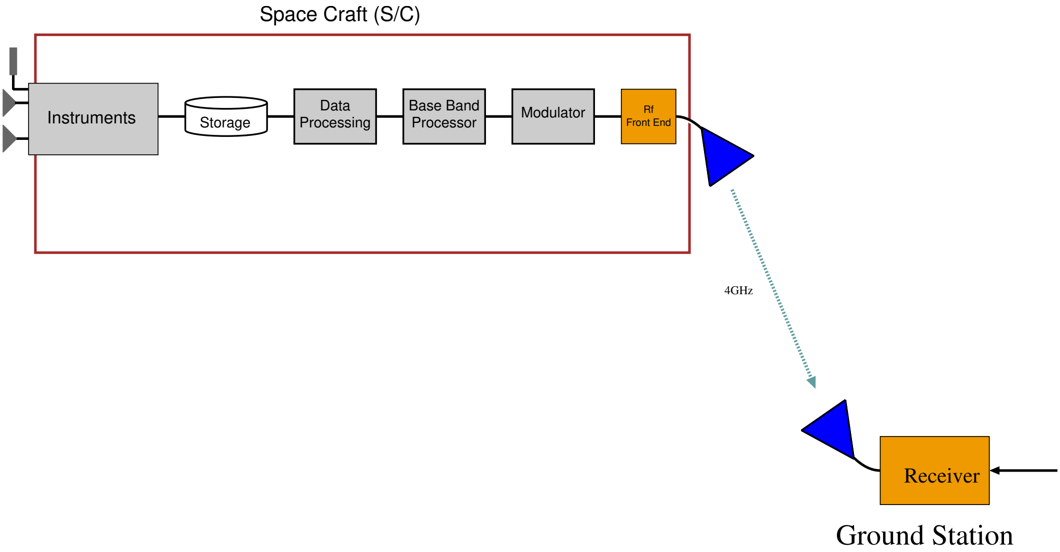
Outline

Satellite Communication

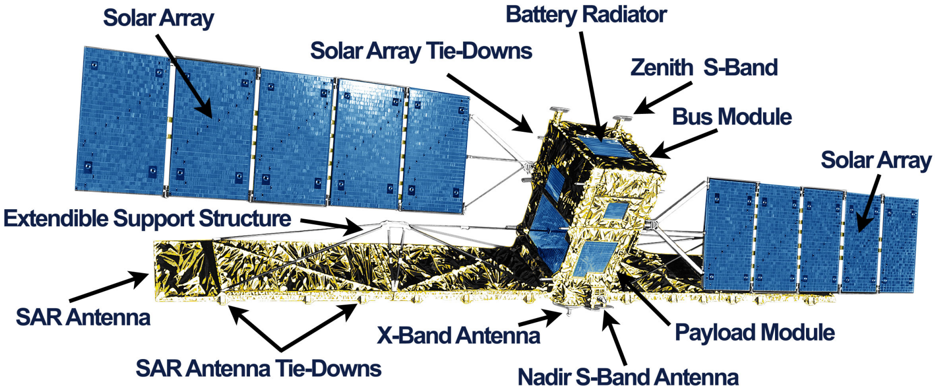


The communications architecture consists of satellites and ground stations interconnected with communications links. (Adapted from SMAD.)

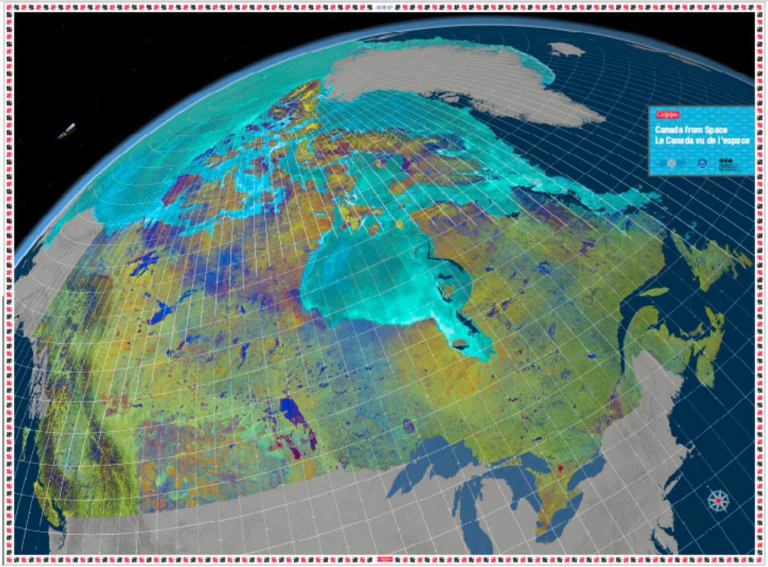
MICROWAVE LAB



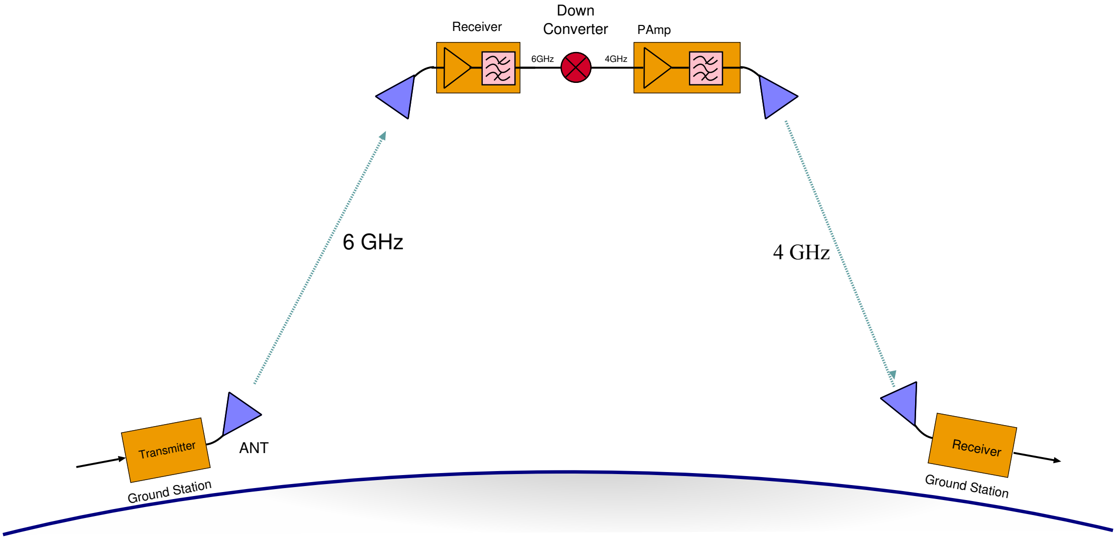
Radarsat 1


Solar Array
Battery Radiator
Solar Array Tie-Downs
Zenith S-Band
Bus Module
Solar Array
Extendible Support Structure
SAR Antenna
X-Band Antenna
Payload Module
SAR Antenna Tie-Downs
Nadir S-Band Antenna

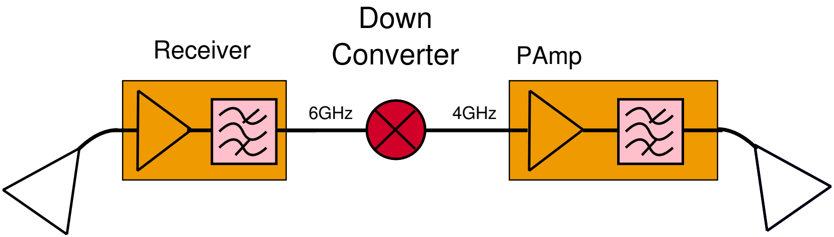
RadarSat Image



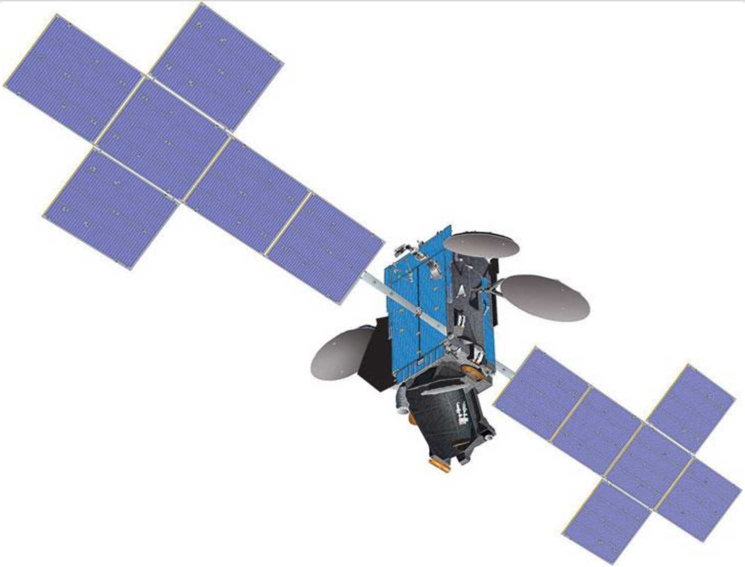
Bend-Pipe


Receiver
Down Converter
PAmp
6GHz
4GHz
6 GHz
4 GHz
Transmitter
ANT
Ground Station
Receiver
Ground Station

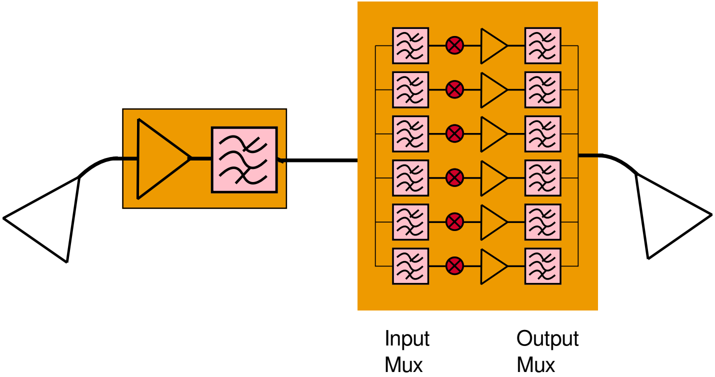
Bendpipe

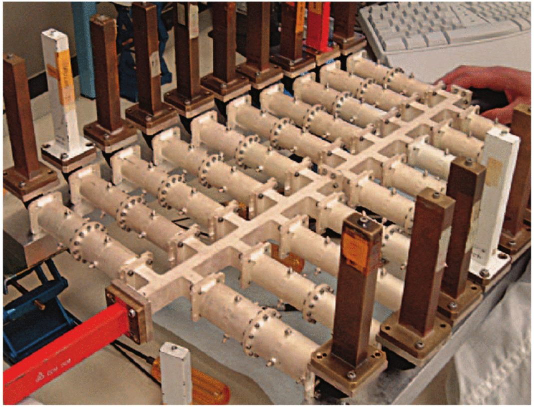


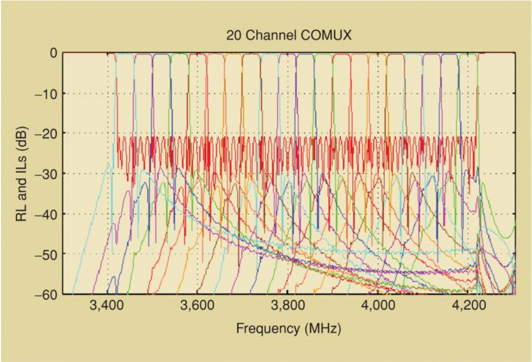
Asiasat 9



Bendpipe

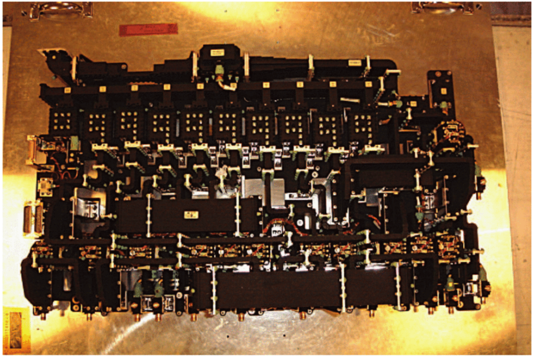


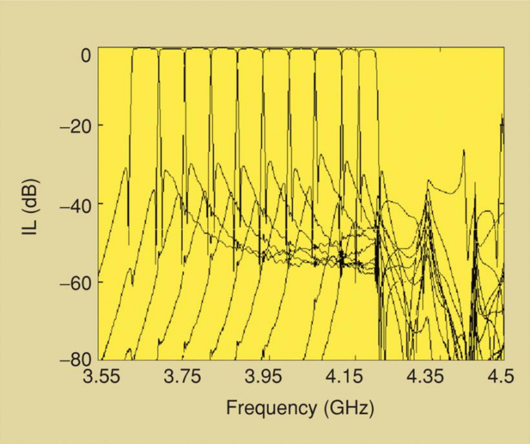




from R. Cameron, IEEE Microwave Magazine, Volume: 8 , Issue: 5 , Oct. 2007

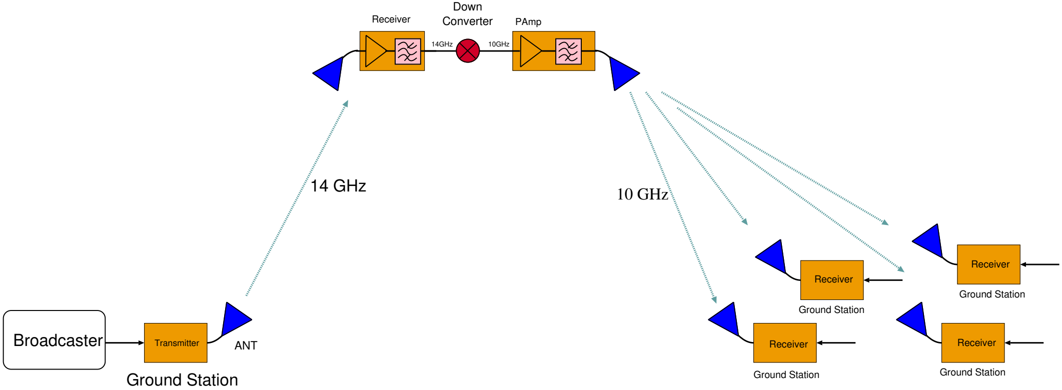
C-Band Multiplexer



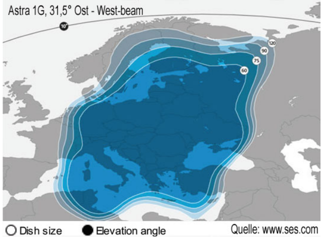


from R. Cameron, IEEE Microwave Magazine, Volume: 8 , Issue: 5 , Oct. 2007

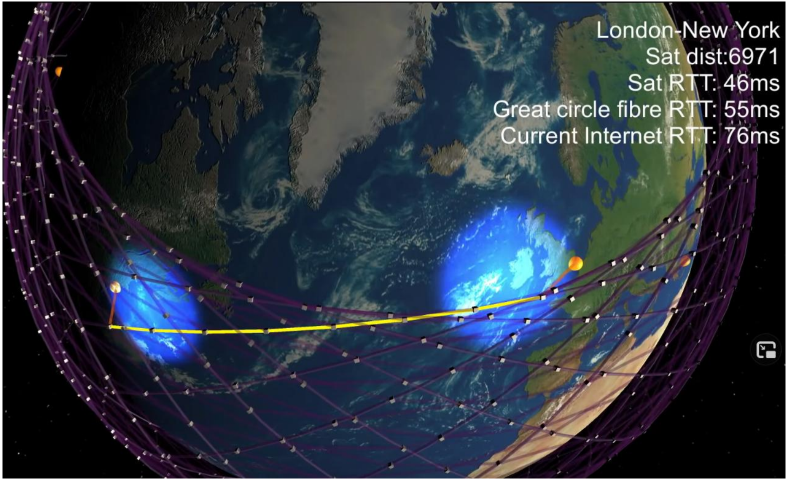
Broadcast Satellite



Astra 1G


Astra 1G, 31,5° Ost - West-beam
Dish size
Elevation angle
Quelle: www.ses.com

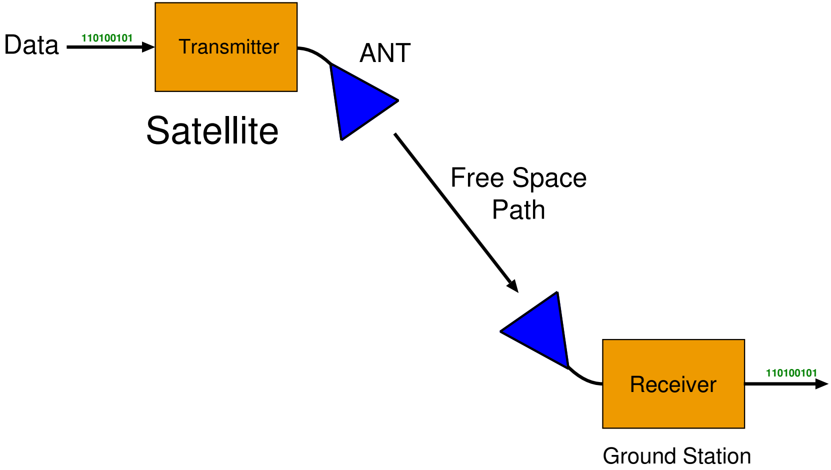
Satellite Constellations for “Internet in the Sky”

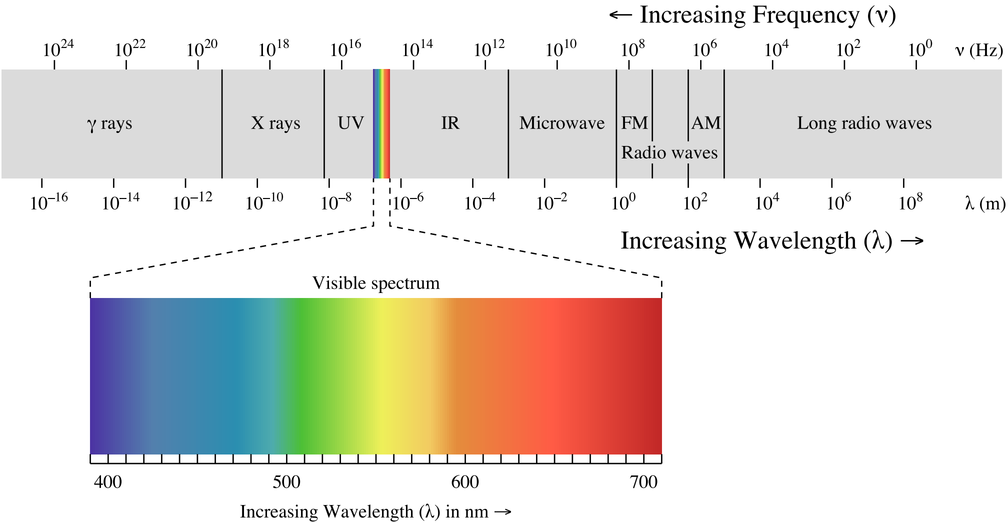


12,000 high-speed internet satellites

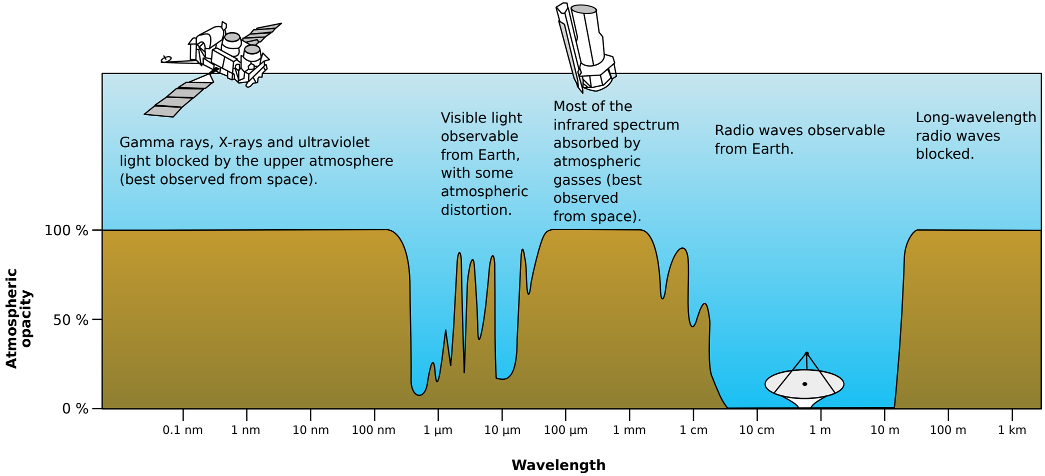
`https://youtu.be/m05abdGSOxY?t=78`

Outline


Data
110100101
Transmitter
ANT
Satellite
Free Space
Path
Receiver
110100101
Ground Station


← Increasing Frequency (ν)
10^24 10^22 10^20 10^18 10^16 10^14 10^12 10^10 10^8 10^6 10^4 10^2 10^0 ν (Hz)
γ rays
X rays
UV
IR
Microwave
FM
AM
Radio waves
Long radio waves
10^−16 10^−14 10^−12 10^−10 10^−8 10^−6 10^−4 10^−2 10^0 10^2 10^4 10^6 10^8 λ (m)
Increasing Wavelength (λ) →
Visible spectrum
400 500 600 700
Increasing Wavelength (λ) in nm →

Attenuation of Atmosphere



from openclipart.org

Waves can be characterised by its wave length or frequency. They are related by

$$\lambda \cdot f = c$$

Art	Frequency	typ. Wavelength
P-Band	220-300MHz	115cm
L-Band	1-2 GHz	20cm
S-Band	2-4GHz	10cm
C-Band	4-8 GHz	5cm
X-Band	8-12,5 GHz	3cm
Ku-Band	12,5-18GHz	2cm
K-Band	18-26,5GHz	1,35cm
Ka-Band	26,5-40GHz	1cm

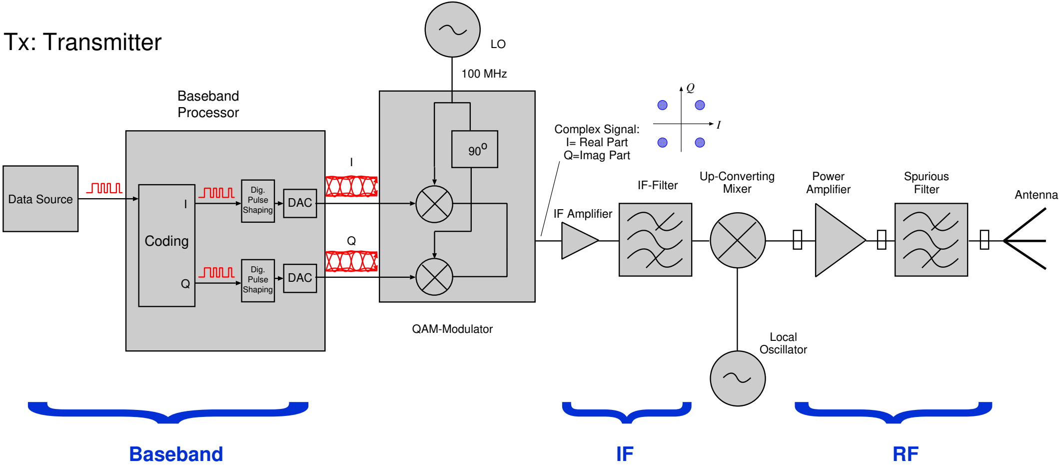
Satellite Bands

Band	Uplink [MHz]	Downlink [MHz]	Short [GHz]
C	5,925-6,425	3,700-4,200	6/4
X	7,900-8,400	7,250-7,750	8/7
K_u	14,000-14,500	10,950-11,200 11,450-11,700	14/11
K_u	14,000-14,500 17,300-18,100	11,700-12,200 12,200-12,700	14/11
K_a	27,500-30,000	17,700-20,200	30/20

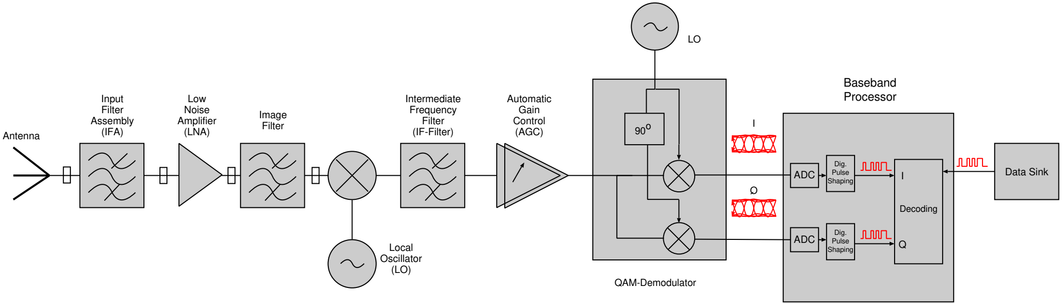
The typical bandwidth of one satellite channel is 36 to 112 MHz.

MICROWAVE LAB

Tx: Transmitter

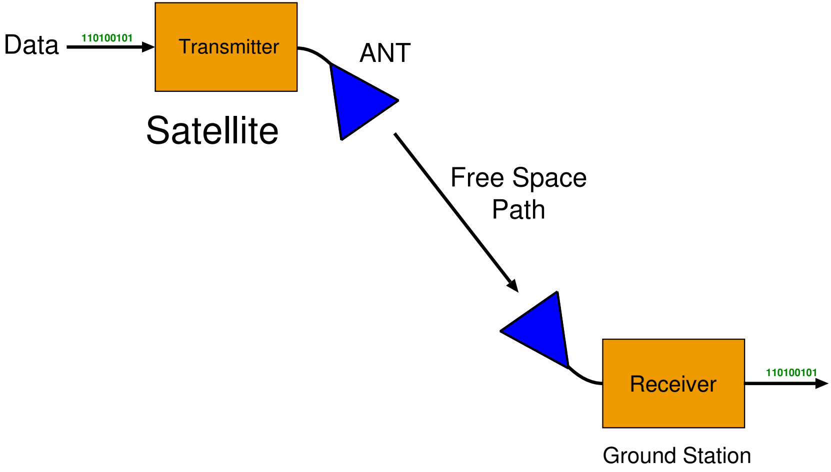


Block Diagram Receiver

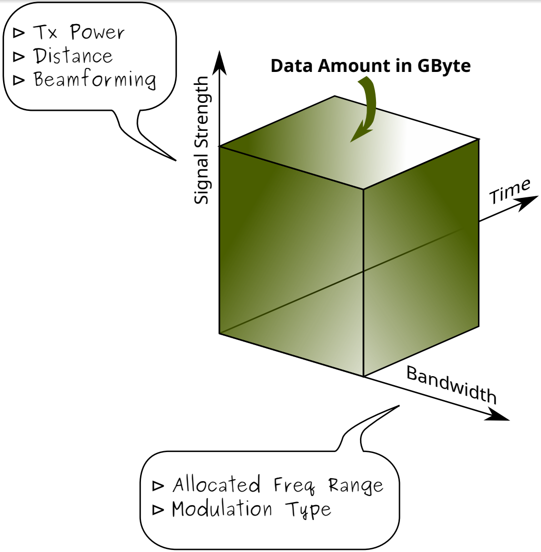


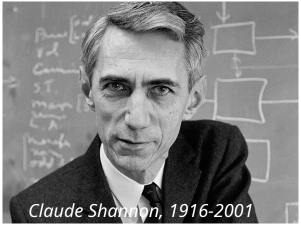
Outline

The Link


Data
110100101
Transmitter
ANT
Satellite
Free Space
Path
Receiver
110100101
Ground Station

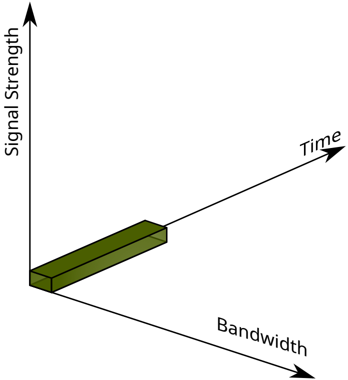
Information Theory




Claude Shannon, 1916-2001

$$C = B\log(1 + \frac{S}{N})$$

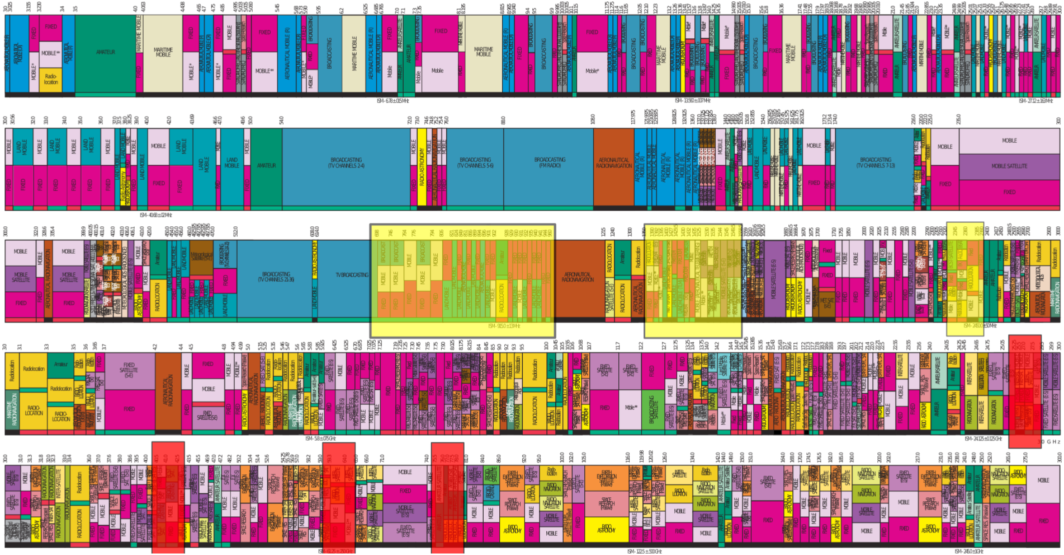
Information Theory 2

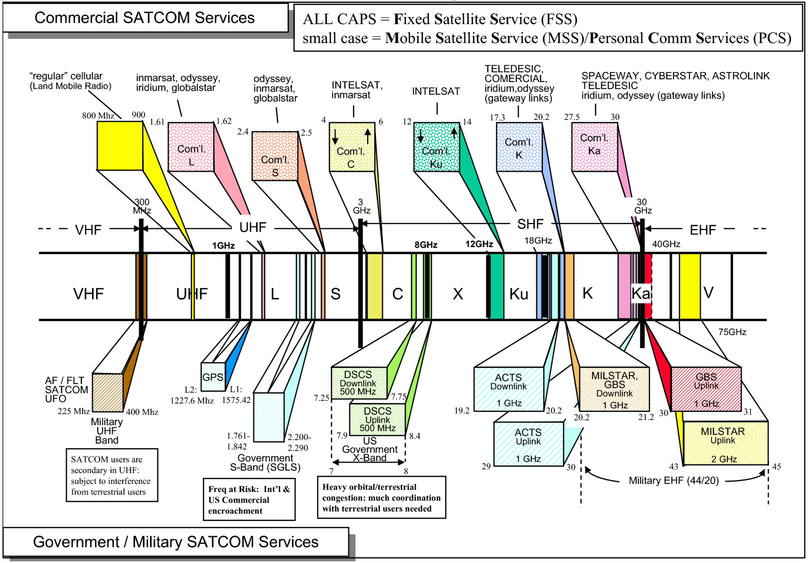


How to Transmit the Amount of X Bytes?

- Bandwidth?
- Signal Strength?
- Noise Considerations?

Bandwidth is Limited





Commercial SATCOM Services
ALL CAPS = Fixed Satellite Service (FSS)
small case = Mobile Satellite Service (MSS)/Personal Comm Services (PCS)
"regular" cellular (Land Mobile Radio)
inmarsat, odyssey, iridium, globalstar
odyssey, inmarsat, globalstar
INTELSAT, inmarsat
INTELSAT
TELEDESIC, COMERCIAL, iridium,odyssey (gateway links)
SPACEWAY, CYBERSTAR, ASTROLINK TELEDESIC iridium, odyssey (gateway links)
800 Mhz
900
1.61
1.62
Com'l. L
2.4
2.5
Com'l. S
4
6
Com'l. C
12
14
Com'l. Ku
17.3
20.2
Com'l. K
27.5
30
Com'l. Ka
300 MHz
3 GHz
30 GHz
VHF
UHF
SHF
EHF
1GHz
8GHz
12GHz
18GHz
40GHz
VHF
UHF
L
S
C
X
Ku
K
Ka
V
75GHz
AF / FLT SATCOM UFO
225 Mhz
400 Mhz
Military UHF Band
SATCOM users are secondary in UHF: subject to interference from terrestrial users
GPS
L2: 1227.6 Mhz
L1: 1575.42
1.761-1.842
2.200-2.290
Government S-Band (SGLS)
Freq at Risk: Int'l & US Commercial encroachment
DSCS Downlink 500 MHz
7.25
7.75
DSCS Uplink 500 MHz
7.9
8.4
US Government X-Band
7
8
Heavy orbital/terrestrial congestion: much coordination with terrestrial users needed
ACTS Downlink 1 GHz
19.2
20.2
ACTS Uplink 1 GHz
29
30
MILSTAR, GBS Downlink 1 GHz
20.2
21.2
GBS Uplink 1 GHz
30
31
MILSTAR Uplink 2 GHz
43
45
Military EHF (44/20)
Government / Military SATCOM Services

Outline

MTG combined Antenna

see external Slides

Outline

Outline

Sample Problem

Orbit	Distance	f	G_t	P_t	G_r
LEO	600 km	4 GHz	20 dBi	10 dBW	20 dBi
MEO	8 000 km	1.5 GHz	20	17 dBW	30 dBi
GEO	35 000 km	10 GHz	25	20 dBW	35 dBi
Moon	250 000 km	8 GHz	30	10 dBW	40 dBi

Find:

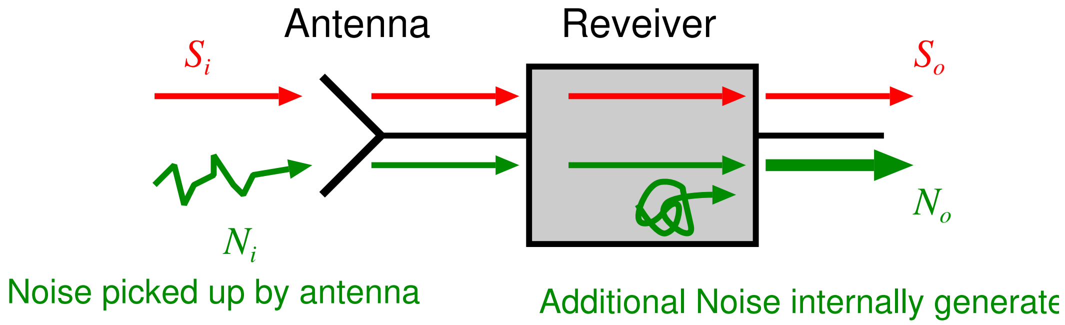
1. EIRP (in W and in dBW),
2. Path Loss in dB,
3. Received Power P_r absolute and in dBW,
4. Dish Diameter of Tx Antenna
   (assume 50% Aperture Efficiency)

Solution

Orbit	EIRP	Path Loss	P_r
LEO	1000 W / 30.0 dBW	1.01e+16 / 160.0 dB	9.89e-12 W / -110 dBW
MEO	5011 W / 37.0 dBW	2.53e+17 / 174.0 dB	1.98e-11 W / -107 dBW
GEO	31622 W / 45.0 dBW	2.15e+20 / 203.3 dB	4.65e-13 W / -123 dBW
Moon	10000 W / 40.0 dBW	7.02e+21 / 218.5 dB	1.42e-14 W / -138 dBW

Orbit	Diameter
LEO	0.338 m
MEO	0.900 m
GEO	0.240 m
Moon	0.534 m

Outline



Antenna
Reveiver
S_i
S_o
N_i
N_o
Noise picked up by antenna
Additional Noise internally generate

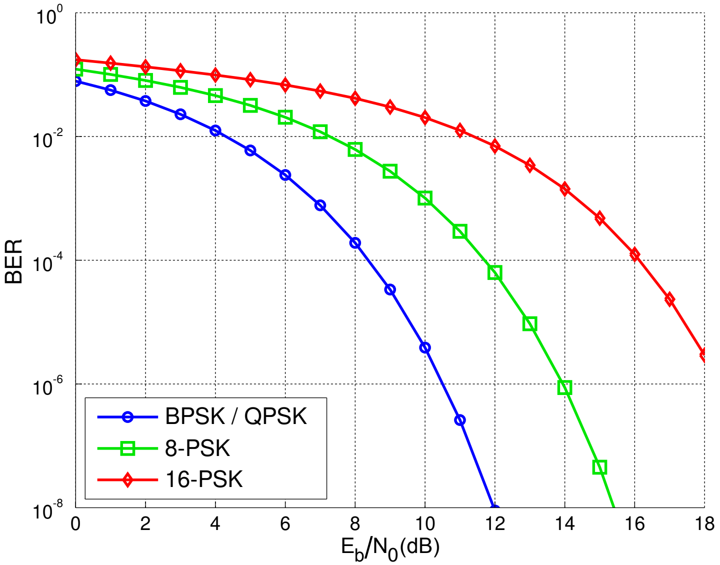
Signal to Noise Ratio SNR

The ratio of the signal power S to noise power N is a measure of the quality of a signal. the higher the ratio the better the signal can be distinguished from the noise.

$$SNR = \frac{Signal\ Power}{Noise\ Power} = \frac{S}{N}$$

The SNR is often given in dB. The higher the SNR the fewer bit errors occur in a digital system.

SNR in Digital Systems



Noise Power is determined by Bandwidth of the Receiver and the Antenna Noise Temperature T_A

Noise Temperature is dependent on

- Antenna Gain
- Antenna orientation
- Frequency
- Atmospheric Effects (Rain, Clouds etc.)

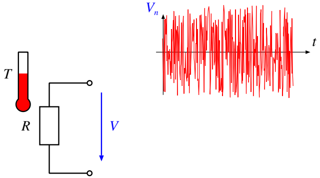
$$\boxed{N = T_A \cdot B \cdot k}$$

where $k = 1.38 \cdot 10^{-23} \frac{\mathrm{J}}{\mathrm{K}}$ (Boltzman's constant) and B is the bandwidth of the system

Noise

- Noise N is a signal with is superimposed on our signal C disturbs our signal.
- Performance of system is calculated by Signal-to-noise Ratio C/N
  - typically $C/N >$10 dB is required
- Noise comes from
  - noise picked up by the antenna
  - receiver noise, generated in the receiver

Noise Temperature

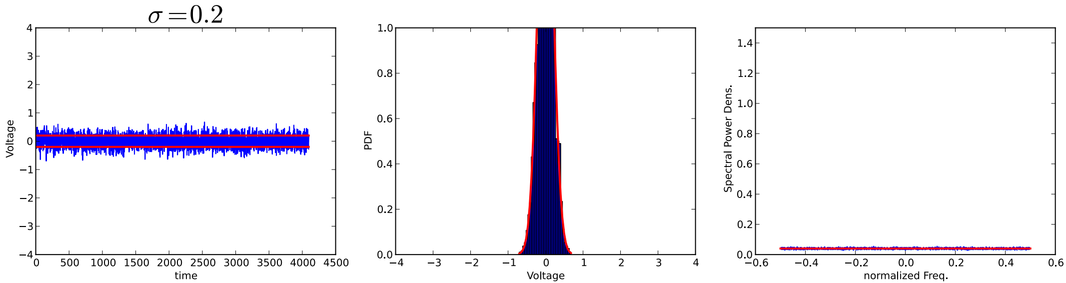


A resistor R at Temperature T generates an available noise power (matched load with R) of

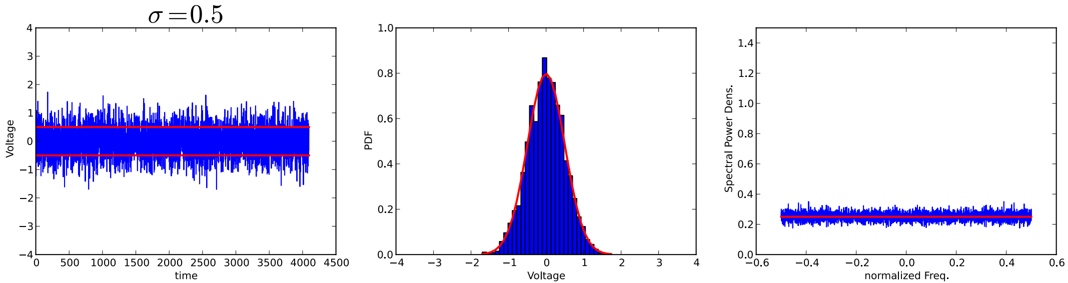
$$P_n = \frac{V_n^2}{4R} = kTB$$

where $k = 1.38 \cdot 10^{-23} \frac{\mathrm{J}}{\mathrm{K}}$ (Boltzman's constant) and B is the bandwidth of the system

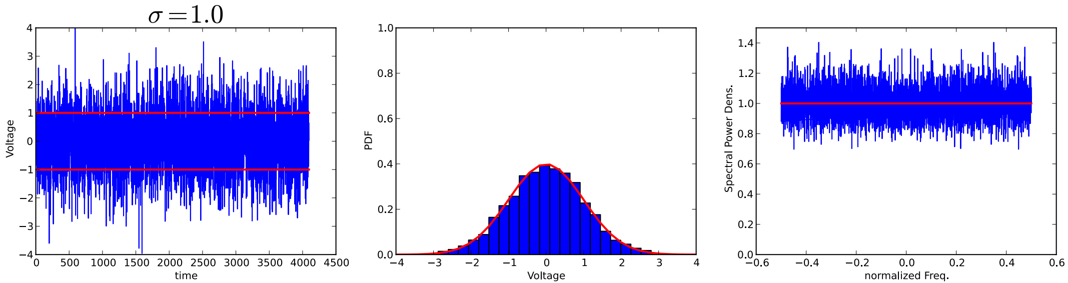
Gaussian White Noise



Gaussian White Noise



Gaussian White Noise



The noise amplitudes follow a Gaussian distribution,

$$f_n(n) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-n^2/2\sigma^2}$$

where $\sigma^2$is the variance of the Gaussian noise. This noise distribution is known as white Gaussian noise. σ describes the effektive voltage of the noise signal.

Power Spectral Density

The power can be represented in terms of the power spectral density

$$S_n(\omega) = 2B = \frac{kT}{2} = \frac{n_0}{2}$$

with $n_o = kT$

This is known as the two-sided power spectral density. having frequency terms from $-B$ to B.

The spectrum is constant, i.e. we have *white noise.*

Noise Bandwidth

The Noise Power is often given per Hz Bandwidth, such that the Noise evaluations are independent of the Bandwidth of the system.

Example:

Antenna Noise Temp. $T_A = 1000\mathrm{K}$

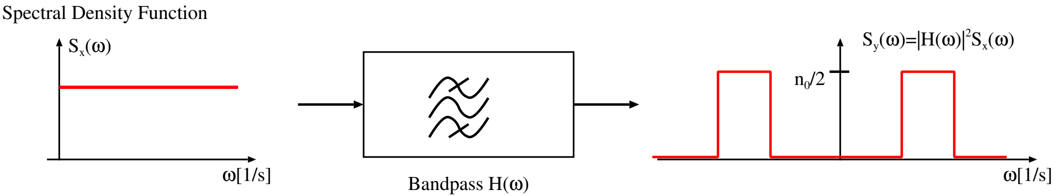
Noise per Bandwidth: $N_{Hz} = 1.38 \cdot 10^{-20} \frac{\mathrm{W}}{\mathrm{Hz}}$

Total received Noise power in a 36 MHz receiver
$N = N_{Hz} 36\mathrm{MHz} = 4.97 \cdot 10^{-13}\mathrm{W} = -123\mathrm{dBW}$

When the received signal is -92 dBW, we get

$SNR = -92\mathrm{dBW} - (-123\mathrm{dBW}) = 31\mathrm{dB}$

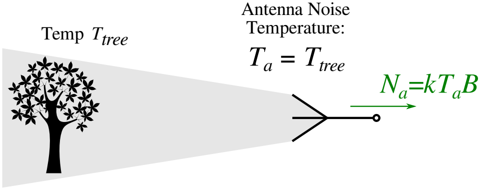
Bandlimited Noise



For band limited noise we get the total noise power of

$$P_n = \Delta f \, n_o$$

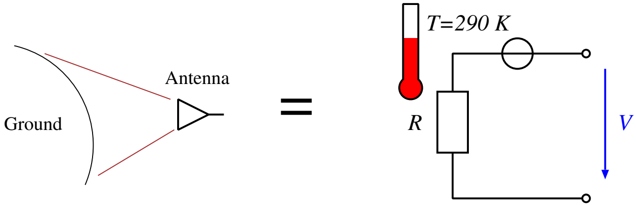
Outline



Antenna noise temperature T_a is at the temperature T of the black body

An Antenna pointed to the ground acts like a Resistor at Temperature

$$T_0 = 290\mathrm{K}$$

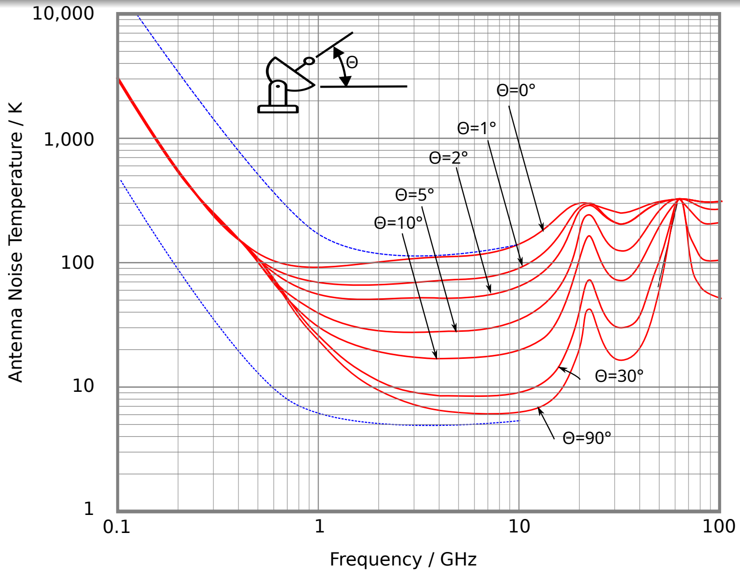


Antenna Noise

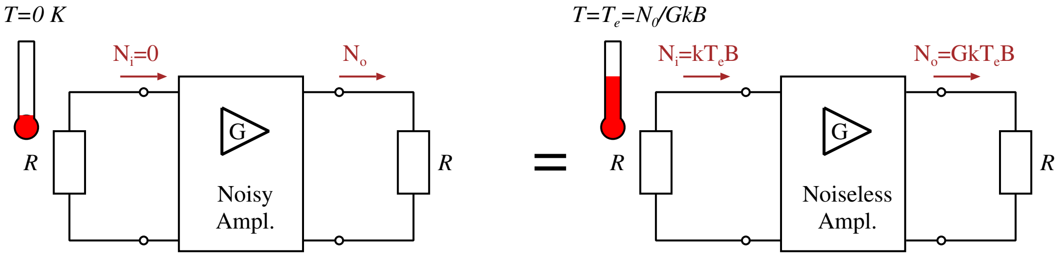
Antenna pointed partly into deep space picks up noise from

- Cosmic Noise (stars and interstellar matter)
  - decreases with frequency $\propto \frac{1}{f}$(negl. above 1 GHz)
    - Cartain parts of sky have hot sources
  - Sun $T_{Sun} \approx 12000 f^{\frac{3}{4}}\,\mathrm{K}$
    - Point Antenna away
  - Moon= Black Body with $T_{moon} \approx 200 - 300\mathrm{K}$
  - Earth Surface $T \approx 290\,\mathrm{K}$
  - Propagation Medium: rain, vapour, etc
    - Noise reduces with elevation angle
  - Man made noise

Antenna Noise



Microwave components generate noise. The noise can be characterised by an equivalent noise figure



Noise Figure

The noise figure of a two port is defined as as the ratio of the input S/N to the output S/N

$$F = \frac{S_i/N_i}{S_o/N_o} \geq 1$$

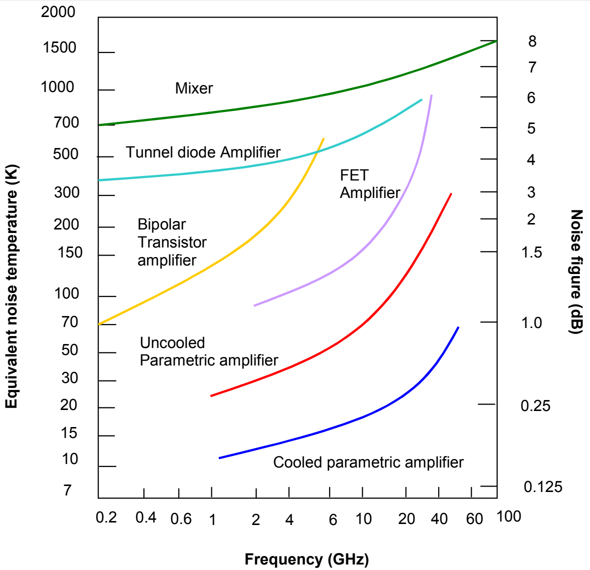
with the condition that R is at temperature $T_0 = 290\text{K}$

Noise figure and noise temperature are related by

$$T_e = (F - 1)T_0$$

where T_0 is defined as 290 K reference

Typical Noise Figures



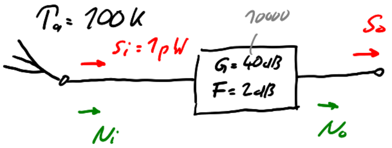
Receiver Noise

In order to achieve a good S/N it is important to know:

- first stage amplifier needs very low noise figure
- first stage amplifier needs high gain
- no lossy elements before the first amplifier
- passive components need low loss, esp. at the front
- Cooling of the front end improves S/N

- Hence, efforts (=$ spent) are made in the front end of the receiver.
- Low noise amplifier (LNA) is the determining factor of the receiver.
- Typically $G = 20\mathrm{dB}$ and $F = 0.5\mathrm{dB}$ at C-Band.

$BW = 10\,\text{MHz}$



$F = 2\,\text{dB} = 1{,}58$

$T_e = (F-1)\cdot 290\,\text{K} = 169\,\text{K}$

$N_i = k \cdot T_a \cdot B = 1{,}38 \cdot 10^{-14}\,\text{W}$

$N_o = G \cdot k \cdot (T_a + T_e) \cdot B = 3{,}71 \cdot 10^{-10}\,\text{W}$

$S_i = 10^{-12}\,\text{W}$

$S_o = G \cdot S_i = 10^{-8}\,\text{W}$

$SNR_i = 72{,}5 = 18{,}6\,\text{dB}$

$SNR_o = 26{,}9 = 14{,}3\,\text{dB}$

Reduction 4,3 dB

Example

We have an arrangement similar to the one above

- Bandwidth is 5 MHz
- Antenna noise temp is 50 K
- Gain of Receiver is 20 dB
- Noise figure of Receiver is F=4 dB

Find the minimum required input signal S_i in dBm for an output SNR of 20 dB

Example

We have an arrangement similar to the one above

- Bandwidth is 5 MHz
- Antenna noise temp is 50 K
- Gain of Receiver is 20 dB
- Noise figure of Receiver is F=4 dB

Find the minimum required input signal S_i in dBm for an output SNR of 20 dB

$T_e = 428\,\mathrm{K}$

$$N_o = kG(T_a + T_e)B = 3.37 \cdot 10^{-12}\mathrm{W}$$
$$S_0 = 100 \cdot N_o = 3.37 \cdot 10^{-10}\mathrm{W}$$
$$S_i = 100 \cdot S_0 = 3.37 \cdot 10^{-12}\mathrm{W} = -84\,\mathrm{dBm}$$

The G/T is defined as

$$\frac{G}{T} = \frac{\textbf{Antenna Gain } G_r}{\textbf{System Noise Temp.} T_a + T_e} \leftarrow \textbf{the bigger the better!}$$

It's a figure of merit for the receiver!

The usual unit is dB/Kelvin.

The G/T is defined as

$$\frac{G}{T} = \frac{\textbf{Antenna Gain } G_r}{\textbf{System Noise Temp.} T_a + T_e} \leftarrow \textbf{the bigger the better!}$$

It's a figure of merit for the receiver! The usual unit is dB/Kelvin.

$$SNR = \frac{S_0}{N_0} = \frac{EIRP \cdot \frac{1}{L_p} \cdot G}{kTB} = EIRP \frac{1}{L_p} \frac{1}{k} \frac{1}{B} \frac{G}{T}$$

$$SNR_{dB} = EIRP_{dBW} - L_{p,dB} \underbrace{-10\log(k)}_{+228.6\text{dB}} - 10\log(B) + \left.\frac{G}{T}\right|_{dB}$$

In the lower eqn. the power must be given in dBW!

Outline

SNR

The SNR depends linearly on:

- EIRP
- Path Loss
- Bandwidth
- G/T

SNR at Receiver Output

A satellite is at 8000 km distance and transmits with EIRP=100W at 10GHz with 100MHz Bandwidth.
The Receiver has an antenna gain of 60 dBi and an antenna noise of 40K plus receiver noise of 100K.

.

Solution

The path loss is $L_p = \left(\frac{4\pi R}{\lambda}\right)^2 = 1.1229e + 19 = 190.5\text{dB}$

The system noise temperature is $T = T_a + T_e = 140\text{K}$

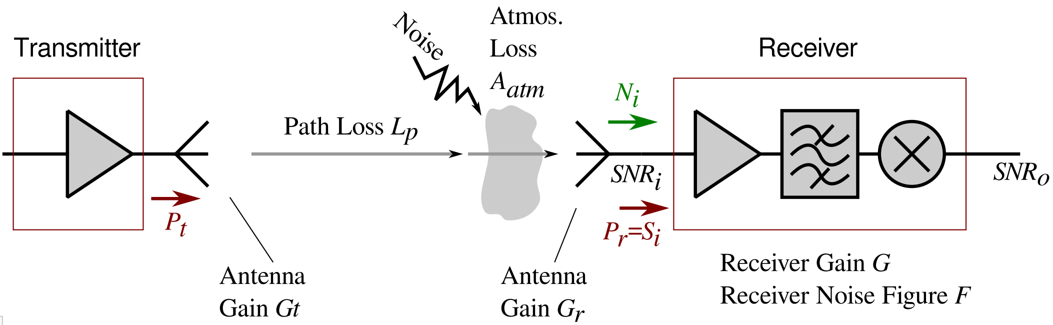
The absolute gain is 10^6.

Hence the G/T is $\frac{G}{T} = \frac{1000000}{140} = 7142 = 38.5\text{dB}$

We can now determine the complete link performance, i.e. SNR, with the three perfomance values EIRP,G/T and path loss

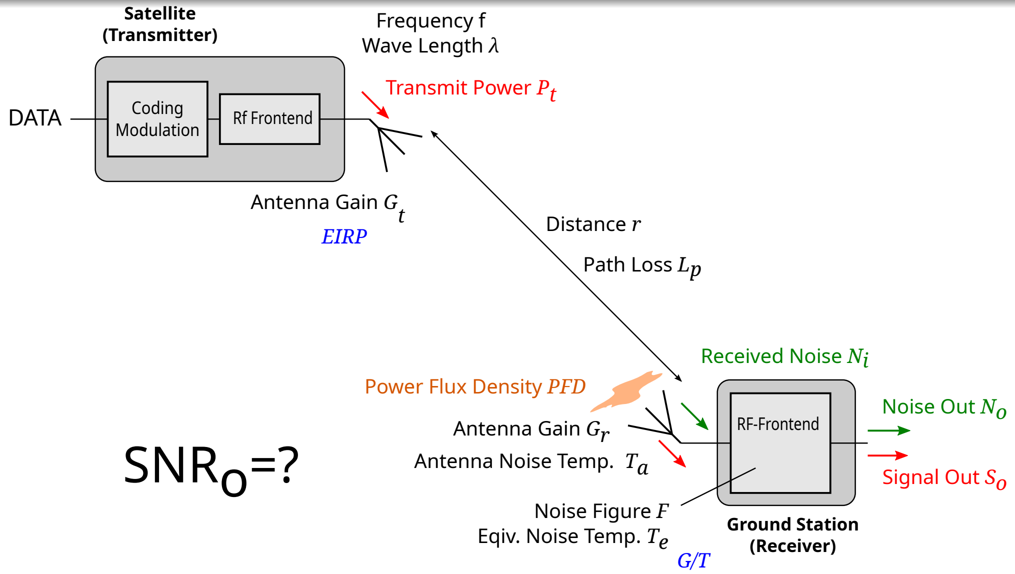
$$
\begin{aligned}
SNR_{dB} &= EIRP_{dBW} - L_{p,dB} \underbrace{-10\log(k)}_{+228.6\text{dB}} - 10\log(B) + \left.\frac{G}{T}\right|_{dB} \\
&= 20\text{dBW} - 190.5\text{dB} + 228.5 - 80\text{dB} + 38.5\text{dB} \\
&= 17\text{dB}
\end{aligned}
$$

Outline

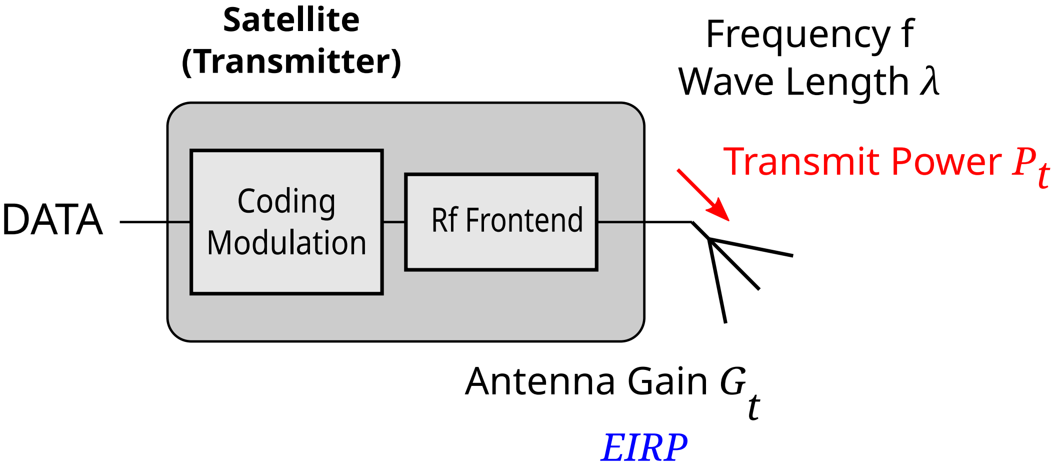


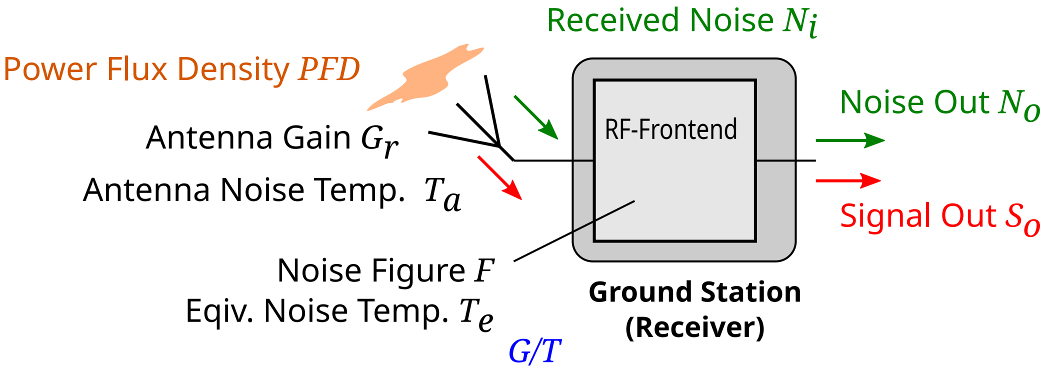
Transmitter
Noise
Atmos. Loss A_{atm}
Receiver
N_i
Path Loss L_p
SNR_i
SNR_o
P_t
P_r=S_i
Antenna Gain Gt
Antenna Gain G_r
Receiver Gain G
Receiver Noise Figure F

Link Parameters



SNR_o=?


Satellite
(Transmitter)
Frequency f
Wave Length λ
Transmit Power P_t
DATA
Coding
Modulation
Rf Frontend
Antenna Gain G_t
$EIRP$


Received Noise N_i
Power Flux Density PFD
Antenna Gain G_r
Antenna Noise Temp. T_a
RF-Frontend
Noise Out N_o
Signal Out S_o
Noise Figure F
Eqiv. Noise Temp. T_e
G/T
Ground Station
(Receiver)

The Link Budget calculates the Power losses and gains through the complete RF link, it includes:

- Transmitter Power P_t
- Transmission losses in the Transmitter through lines etc L_{tl}
- Tx Antenna Gain G_t
- Antenna Pointing Loss $L_{point,t}$
- Free Space Loss L_p
- Atmospheric Loss (Clouds, Vapour etc.) L_{atm}
- Rx Antenna Pointing loss $L_{point,r}$
- Polarisation Loss L_{pol}
- Reception Losses in cables etc. L_{rl}
- Noise Temperature Contribution L_N
- Other Losses L_{other}

Link Budget Example

MICROWAVE LAB

GEO Satellite

Given is a satellite in GEO orbit (40000km to earth station), transmits with 2 W, Tx-Antenna-Gain is 17 dB at 11 GHz

Calculate:

a) Flux density on earth surface

b) Power received by antenna with effective aperture of $10m^2$

c) Received power when Earth station antenna has gain of 52.3 dB

Solution:

a) Flux density is

$$S = \frac{P_t}{4\pi r^2} = \frac{2\mathrm{W}\cdot 10^{-1.7}}{4\pi(4\cdot 10^7\mathrm{m})^2} = 4.97\cdot 10^{-15}\frac{\mathrm{W}}{\mathrm{m}^2} \frown -143\mathrm{dBW}$$

Or EIRP in dB by $EIRP = (P_t + G_t)\mathrm{dBW} = 20\mathrm{dBW}$

with Path Loss (with $\lambda = \frac{c}{f} = 0.027\mathrm{m}$)

$$L_P = 20\log\left(\frac{4\pi r}{\lambda}\right) = 20(\frac{4\pi 40000\cdot 10^3}{\lambda}) = 205.4\mathrm{dB}$$

Translating transmit power in dB: $P_r = 10\log_{10}(\frac{P_r}{1\mathrm{mW}}) = 33\mathrm{dBm}$

and calculating the gain of the antenna $G = \frac{4\pi A}{\lambda^2} = 169181 = 52.3$dB, we get

$$\begin{aligned} P_r &= P_t + G_t + G_r - L_p = 33\mathrm{dBm} + 17\mathrm{dB} + 52.3\mathrm{dB} - 205.4\mathrm{dB} \\ &= -103.1\mathrm{dBm} = 4.89 \cdot 10^{-14}\mathrm{W} \end{aligned}$$

Satellite Link

Consider a ground station with a receiver with a noise figure of 2 dB and 100 dB gain. The Receiver is attached to an antenna with 30 dBi Gain. The antenna is oriented in zenith direction.
The ground station is linked to a satellite with 100 W EIRP transmit power.

- Find the maximum distance in order to receive a signal at 5 GHz with 80 MHz band-width with at least an SNR of 20dB.

Solution

....

Link Budget Constraints

MICROWAVE LAB

- Satellite has limited electrical power, 1 to 500 W
- Antenna on satellite is limited, fixed <3m, folding ant <10 m
- Received must be small according to FCC requirements, <-100dBW/m^2

Choosing Frequency

- C-Band 6/4GHz : Bandwidth 500-1000 MHz
- Ku-Band 14/11GHz: Bandwidth 1000-1500 MHz
- Ka-Band 20/30GHz: Bandwidth 3000 MHz

Choosing Frequency

- FCC Regulations
- Availability
- Antenna Dimensions
- Rain Attenuation
- Noise Considerations
- Equipment Availability
- Costs

Link Design

- Sketch a link path
- Think carefully about the system of interest
- Roll up large contributors first:Transmitted Power, Antenna gains, path loss
- Comment the link budget with all units eg. dB, W, dBm
- Most important ist $(S/N)_{min}$: The minimal received Power-to-Noise Ration under worst conditions
- $(S/N)_{min}$ depends on the operation modes such as
  - Modulation schemes
  - Desired Quality of operation
  - Coding gain
  - Channel Bandwidth
  - Thermal noise of Receiver

A simple link budget includes the main power levels of the link.

- Frequency, Wavelength
- Transmit Power
- Transmit Antenna Gain, EIRP
- Distance with Path Loss
- Receiving Antenna Gain, Antenna effective Aperture
- Received Antenna Noise, Receiver Noise
- Signal-to-Noise Ratio

Example Hotbird

for a Hotbird-consumer-receiver-link in 20,000 km Distance. see also example above.

The satellite is specified with: 250W transmit power, and an Antenna gain of 26 dB. The ransmitted Signal has a centre frequency of $f_0 = 11.5$GHzand a bandwidth of 33 MHz.

The Receiver is a consumer device with a 60cm dish and an LNA with a noise figure $F = 0.8$dB and a receiver gain of 60dB. We assume an antenna noise temperature of 15K. The antenna has 60% antenna aperture efficiency.

MICROWAVE LAB

Section	Description	Qty.	Value	Unit
Transmitter	Transmit Power	Pt	**10**	W
			40	dBm
	Frequency	f	**1,15E+010**	Hz
	Wave Length	lambda	0,0261	m
	Bandwidth	B	**1,00E+007**	Hz
	Sat Antenna Gain	G	**100**	
			20	dBi
	EIRP	EIRP	1000	
			60	dBm
			30	dBW

Cont.

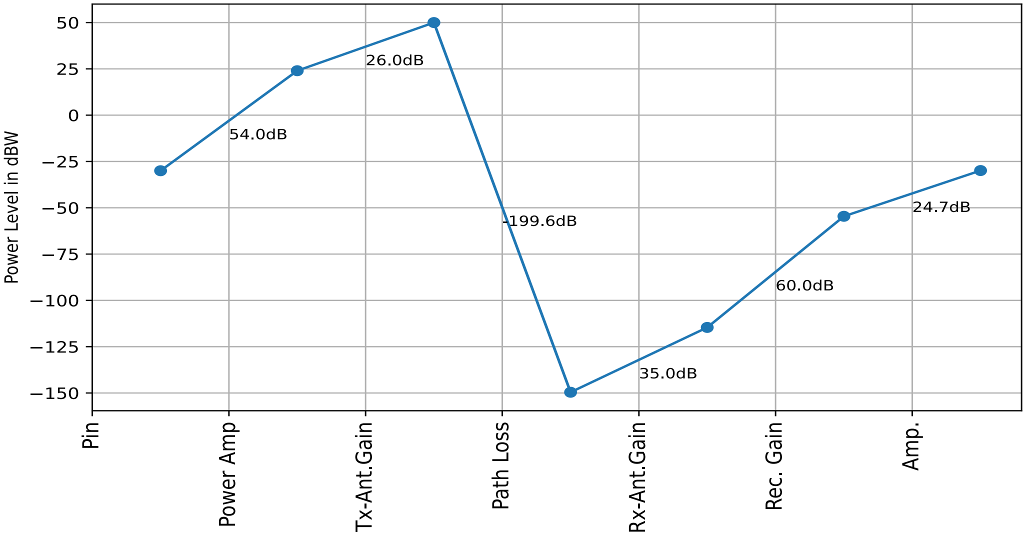
Section	Description	Qty.	Value	Unit
Path	Distance to Ground	R	**20000000**	m
	Path Loss	Lp	1,08E-020	
			199,68	dB
	Powerfluxdensity Ground	S	1,99E-013	W/m²
			-127,01	dBW/m²

Ground Station	Antenna Diameter	D	**2**	m
	Antenna physical Size		3,14	m^2
	Antenna Efficiency	eta	**60**%	
	Eff Antenna Area	Aeff	1,884	m^2
	Antenna Gain	Ga	34789,16	
			45,41	dB
	Received Power	Pr	3,75E-013	W
			-124,26	dBW
	Power at Receiver out	So	3,75E-007	W
			-64,26	dBW
	Antenna Noise	Ta	**30**	K
	Receiver Noise Figure	f	**2**	dB
			1,58	
	Receiver Gain	G	**60**	dB
			1000000	
	Equiv Noise Temp	Te	169,62	K
	Noise Output	No	2,75E-008	W

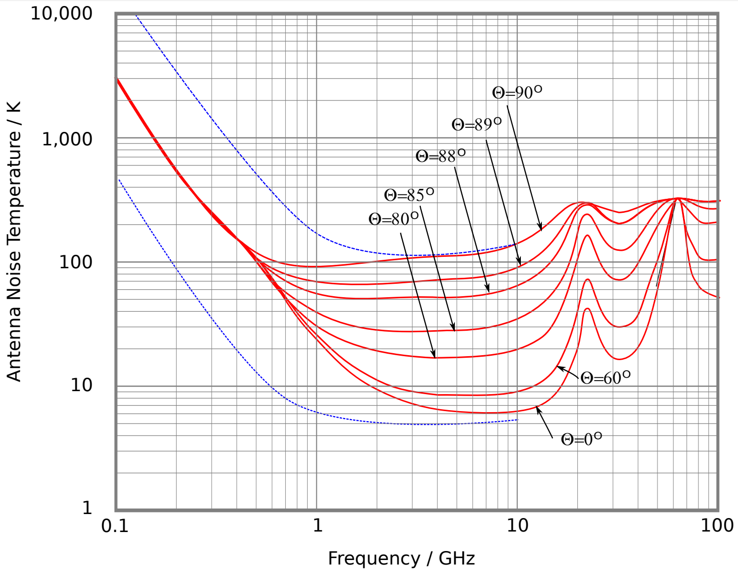
Cont.

Section	Description	Qty.	Value	Unit
System	SNR	SNR	13,61	
			11,34	dB
	G/T	G/T	174,28	1/K
			22,41	dB/K
System in dB	EIRP	EIRP	30	dBW
		G/T	22,41	dB/K
	Path Loss	-Lp	-199,68	dB
	Boltzmann Const	1/k0	228,6	dB
	S/N per Hz	S/N	81,34	dB/Hz
	S/N per Band	S/N	11,34	dB

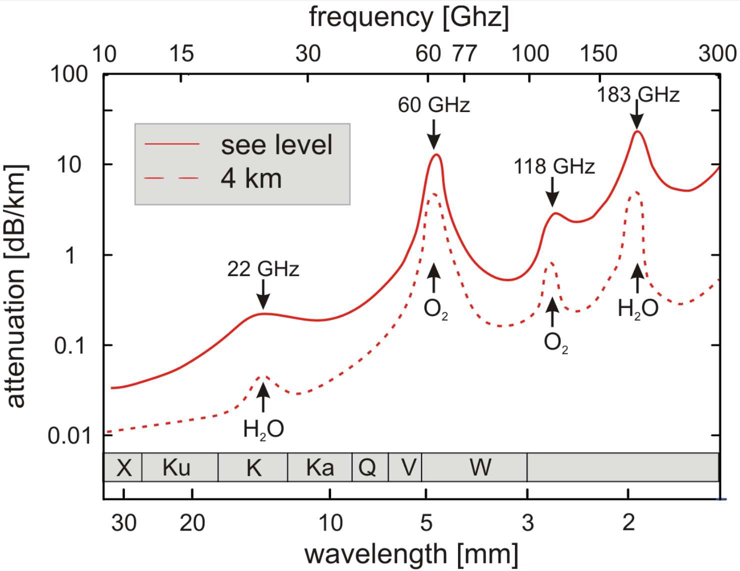
Power Diagram



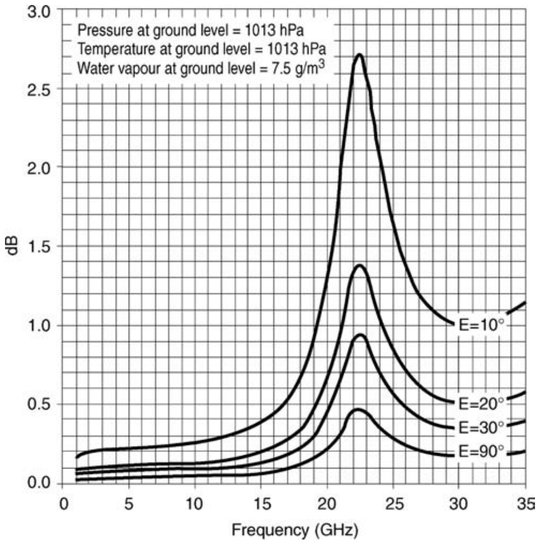
Antenna Noise Temperature



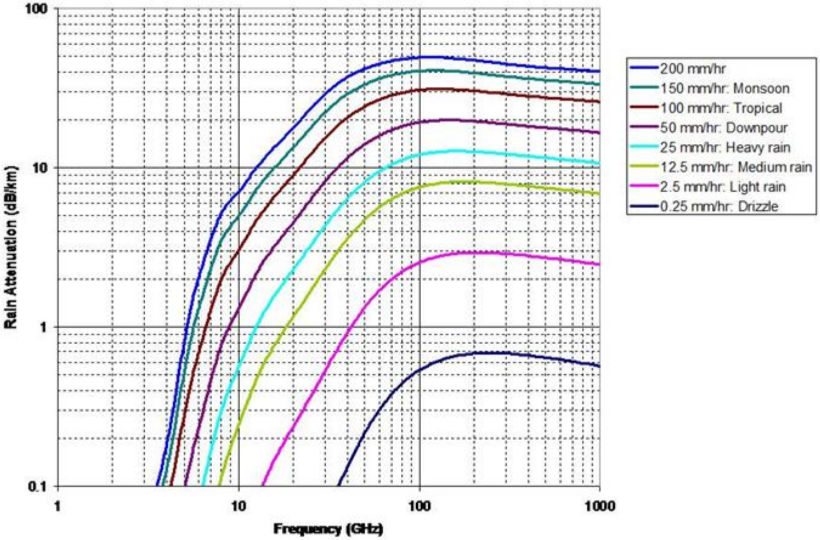
Attenuation from Atmosphere



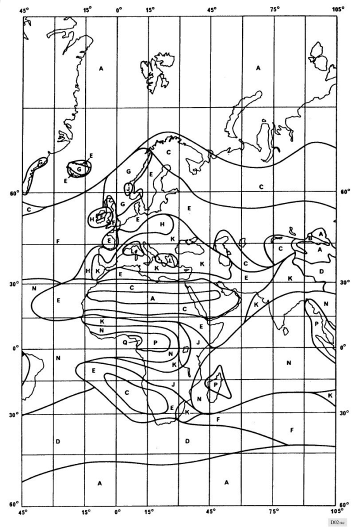
Attenuation of Atmosphere



Rain Attenuation



Rain Zones

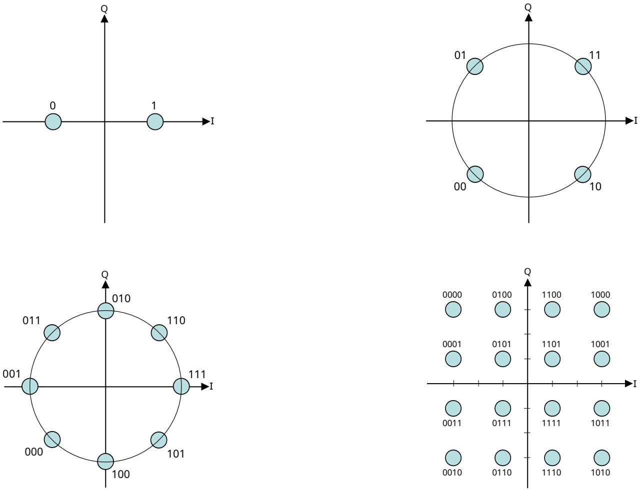


Rainfall intensity exceeded (mm/h) (Reference to Figs. 1 to 3)

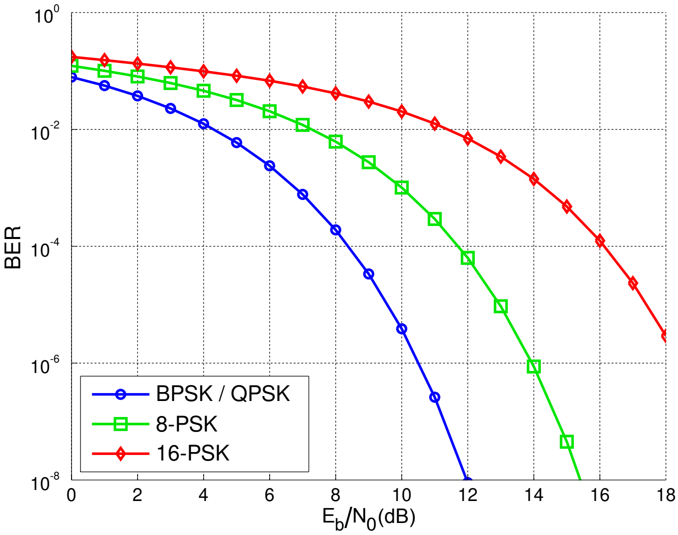
Percentage of time (%)	A	B	C	D	E	F	G	H	J	K	L	M	N	P	Q
1.0	<0.1	0.5	0.7	2.1	0.6	1.7	3	2	8	1.5	2	4	5	12	24
0.3	0.8	2	2.8	4.5	2.4	4.5	7	4	13	4.2	7	11	15	34	49
0.1	2	3	5	8	6	8	12	10	20	12	15	22	35	65	72
0.03	5	6	9	13	12	15	20	18	28	23	33	40	65	105	96
0.01	8	12	15	19	22	28	30	32	35	42	60	63	95	145	115
0.003	14	21	26	29	41	54	45	55	45	70	105	95	140	200	142
0.001	22	32	42	42	70	78	65	83	55	100	150	120	180	250	170

from: ITU R-REC-P.837-1-199408

Modulation Scheme Constellations



Bit Error Ratios for various Modulation Schemes



EIRP		13.5 dBW
Path Loss		175.5 dB
Total Link Loss		176.5 dB
Depointing Attenuation	Lp=	1.0 dB
System Noise Temperature	Trx=	164.6 K
G/T Empfänger	G/T=	30.1 dB/K
Carrier-to-Noise-Ration	C/No=	95.7 dBHz
Receiver Bandwidth	BW=	250.00 Mhz
C/N	C/N=	11.74 dB

Digital Modulation

Modulation		QPSK
Bitrate	Rc=	300 Mbit/s
Symbol Rate	Rs=	150 Msym/s
Symbol duration	Ts=	6.67E-009 S
Filterung		Raised-cos
Roll-Off Faktor	Alpha=	0.35
Bandbreitenbedarf	B=	202.5 Mhz
Spektraleffizienz	Gamma=	1.5 bit/Hz
E/No für QPSK	E/No=	9.78 dB
Bit Error Probability	**BEP=**	**6.5E-006**
C/No	C/No=	94.6 dBHz

Digital Modulation

Modulation		QPSK	
Bitrate	Rc=	300	Mbit/s
Symbol Rate	Rs=	150	Msym/s
Symbol duration	Ts=	6.67E-009	S
Filterung		Raised-cos	
Roll-Off Faktor	Alpha=	0.35	
Bandbreitenbedarf	B=	202.5	Mhz
Spektraleffizienz	Gamma=	1.5	bit/Hz
E/No für QPSK	E/No=	9.78	dB
Bit Error Probability	**BEP=**	**6.5E-006**	
C/No	C/No=	94.6	dBHz