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Link Budget Analysis

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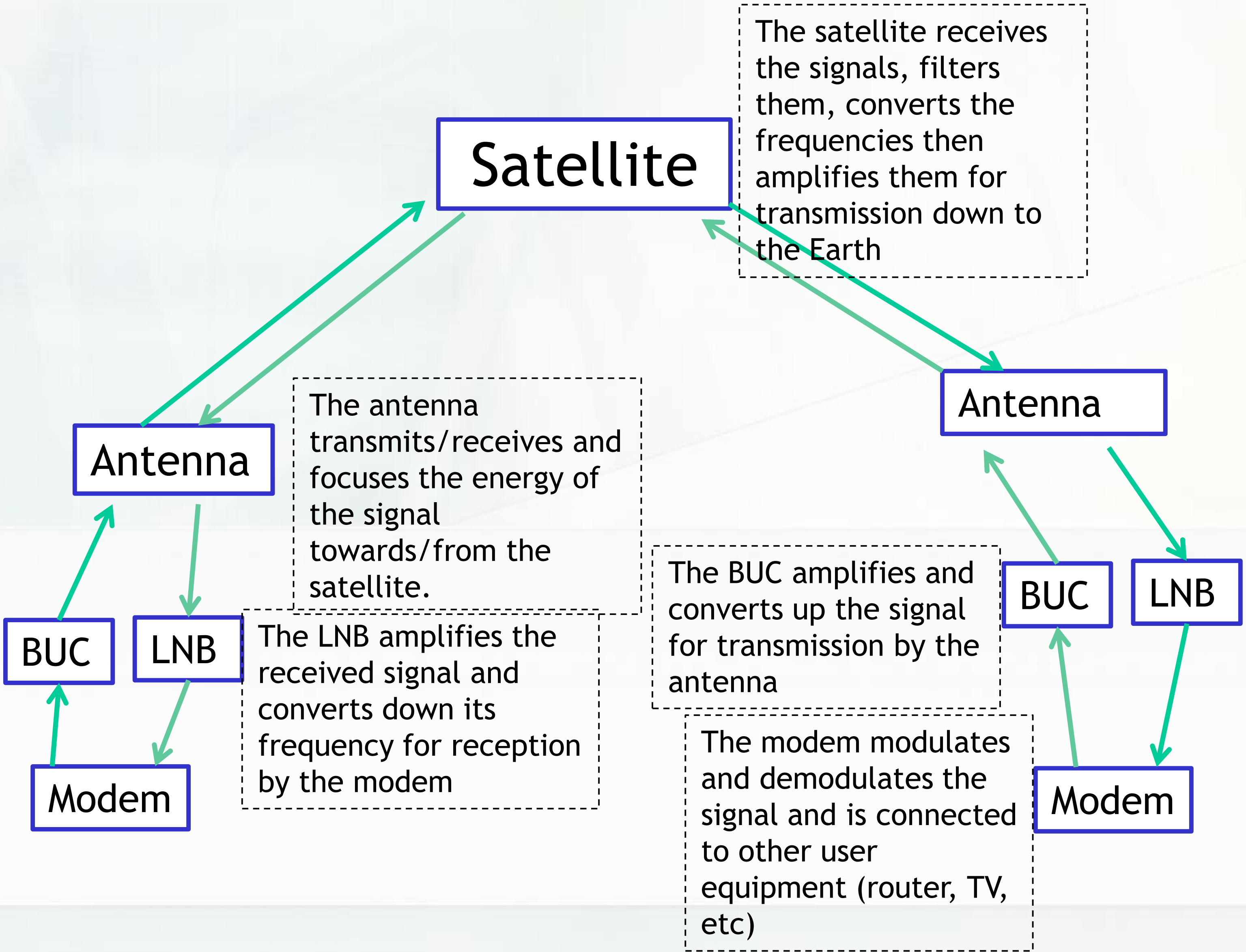
This will Module will provide an overview of the information that is required to perform a link budget and their impact on the Communication link

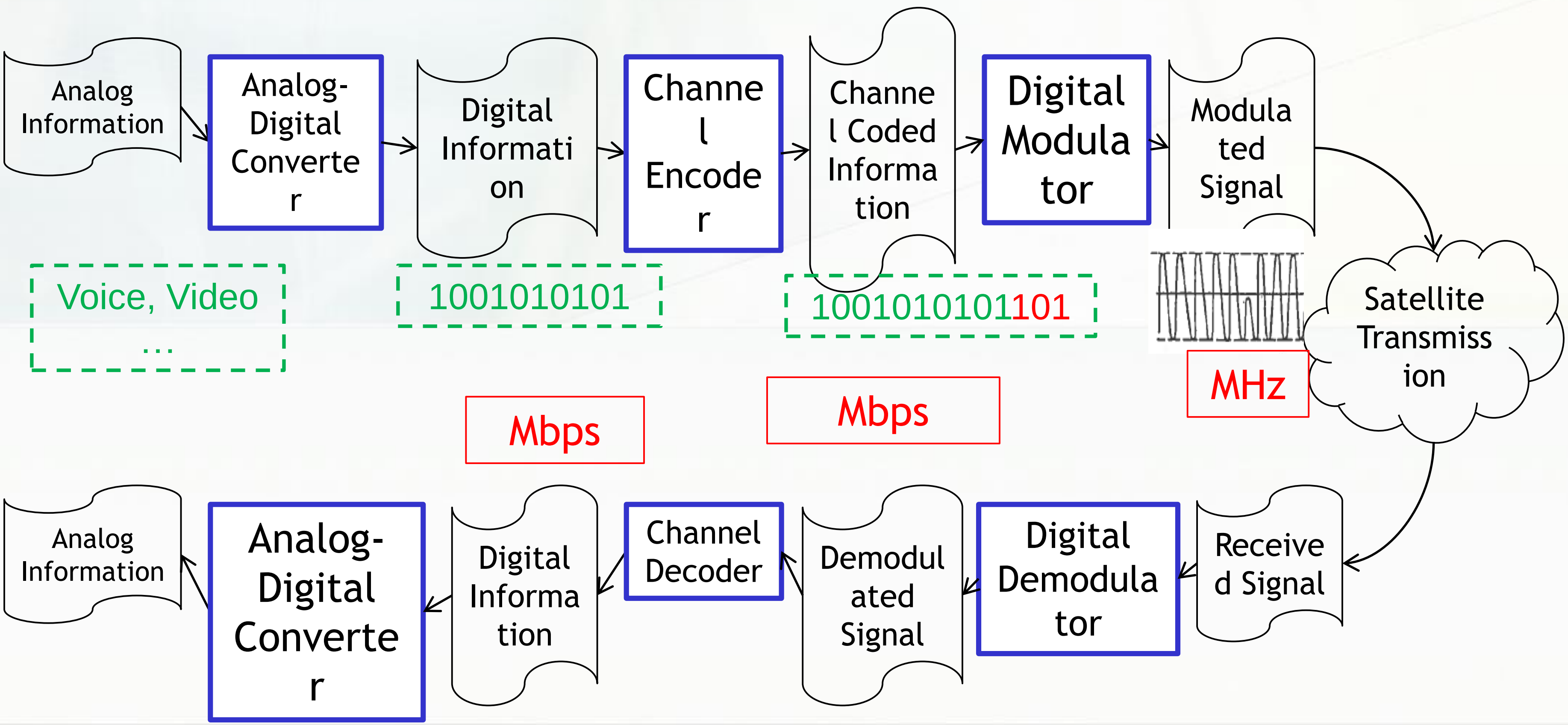
Link Budget tool:

- Has much of the information we'll cover in its database
- Make's your job much easier

Components of a satellite circuit



Simplified digital communications chain:



Modulation

Modulation is the process of varying some characteristics of a periodic waveform, called the *carrier signal*, with a *modulating signal* that contains information.

Characteristics that can vary are the amplitude, frequency and phase.

Typical modulations used in satellite communications are PSK and QAM.

The order of the modulation how many different symbols can be transmitted with it.

E.g. Order 2: BPSK

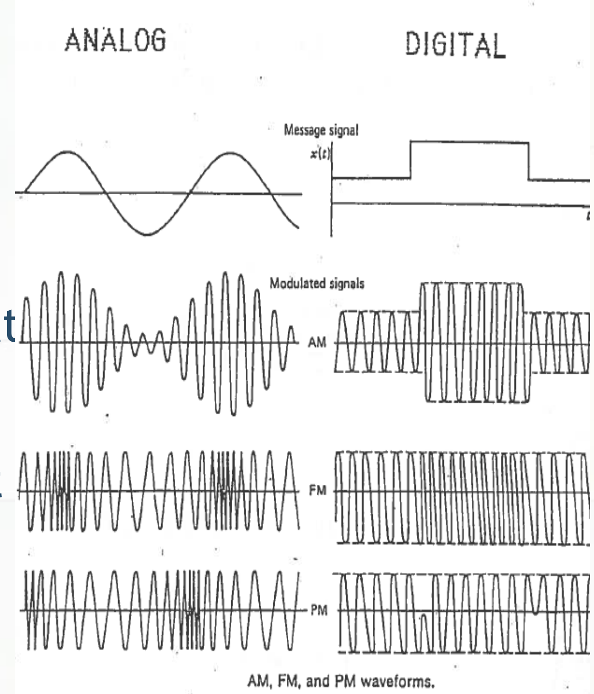
Order 4: QPSK, 4-QAM

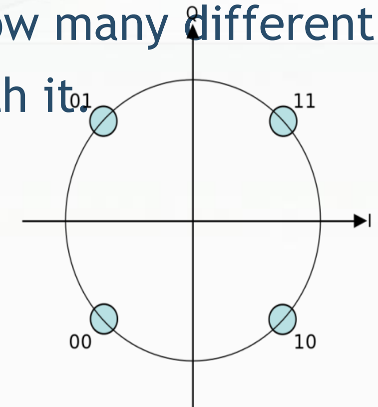
Order 8: 8-PSK, 8-QAM

Order 16: 16-PSK, 16QAM

Carrier signal (no information)

Modulating signal (with information)





Constellation diagram for QPSK

Channel Coding

- Channel coding (FEC: Forward Error Correction) consists of adding redundant bits to the useful information to allow detection and correction of errors caused by the transmission channel.
- The FEC is usually given as a fraction $\frac{Number\ of\ useful\ bits}{Total\ number\ of\ bits}$
- The FEC is usually given with the modulation scheme.
- E.g.: QPSK 3/4 means that:
  - A QPSK modulation is used (order 4)
  - And for every 3 bits of useful information, 1 redundant bit is added.
    - Said otherwise, 4 bits are required to send 3 bits of information
    - Or 25% of the bits sent are useless from the user point of view (but still necessary to detect and correct errors)

Efficiency

On the importance of efficiency

- From user point of view, the key parameter is Information Rate (IR) (in Mbps or kbps)
- The required bandwidth in MHz for a given information rate is directly related to the modulation and coding scheme (modcod).
  - The higher the modulation order (2^n), the less bandwidth is required
  - The higher the FEC ratio, the less bandwidth is required
  - Other parameters also matter: roll-off factor (α), Reed-Solomon coding (RS)

$$BW = \frac{IR \times (1 + \alpha)}{n \times FEC \times RS}$$

- The efficiency is defined as the ratio $\frac{Mbps}{MHz}$: that is the number of Mbps that can be transmitted in a given MHz. The unit is bit per second per Hz (bps/Hz)
- The higher the efficiency, the more cost-effective a service is.

Efficiency

On the importance of efficiency - Examples

- 2 Mbps link using QPSK-3/4 (order $4 = 2^2$), with 25% roll-off factor and no Reed-Solomon:
  - Required bandwidth is: $2 \times (1 + 0.25) \times \frac{4}{3} \div 2 = 1.67\ MHz$
  - Efficiency is 1.20 bps/Hz
- Same 2 Mbps link using 8PSK-3/4 (order $8 = 2^3$), with 25% roll-off factor and no Reed-Solomon:
  - Required bandwidth is: $2 \times (1 + 0.25) \times \frac{4}{3} \div 3 = 1.11\ MHz$
  - Efficiency is 1.80 bps/Hz
- Same 2 Mbps link using 8PSK-7/8 (order $8 = 2^3$), with 25% roll-off factor and no Reed-Solomon:
  - Required bandwidth is: $2 \times (1 + 0.25) \times \frac{8}{7} \div 3 = 0.95\ MHz$
  - Efficiency is 2.10 bps/Hz

Efficiency

- The selection of a modcod is constrained by the signal over noise ratio at reception:
  - The higher the modulation order, the higher the signal to noise ratio must be for the modem to be able to demodulate it.
- Signal over noise ratio is affected by:
  - Link conditions - propagation attenuation and impairments
  - Available power - on ground and on the satellite (PEB)
  - Performance of the satellite
  - Antenna size at reception
  - Capabilities of the modem
- A satellite link budget analysis will determine what modcod can be used and what are the required bandwidth and power.

Efficiency

What is a good efficiency?

- In general, the higher the efficiency, the better, but …
  - Efficiency is not the only parameter to consider
  - Service availability, cost of equipment, network topology, … are also key factors
- Sometimes a lower efficiency is acceptable to reduce required investment or size of equipment.
  - Example: a Direct-To-Home service with small receiving antennas and cheap demodulators will typically have a lower efficiency than a CBH service using large antennas and efficient modems.

Summary

- The modcod scheme determines the ***efficiency*** which tells how many MHz are required to transmit one Mbps.
- The achievable efficiency is constrained by link conditions, satellite characteristics and available ground equipment.
- A **link budget analysis** is required to determine the maximum efficiency.
- Efficiency can be increased with better ground equipment (antenna, modem, amplifier) → tradeoff to be made between investment (CAPEX) and cost of bandwidth (OPEX) A signal transmitted by satellite has to be modulated and coded (*modcod*).

Questions so far?

Link Budget Information

- Site latitude
- Site longitude
- Altitude
- Frequency
- Polarization
- Availability
- Rain-climatic zone
- Antenna aperture
- Antenna efficiency (or gain)
- Coupling Loss
- Antenna mispointing loss
- LNB noise temperature
- Antenna ground noise temperature
- Adjacent channel interference C/ACI
- Adjacent satellite Interference C/ASI
- Cross polarization interference C/XPI
- HPA intermodulation interference C/I
- Satellite longitude

- Satellite receive G/T
- Satellite saturation flux density SFD
- Satellite gain setting
- Satellite EIRP (saturation)
- Transponder bandwidth
- Transponder input back-off (IBO)
- Transponder output back-off (OBO)
- Transponder intermodulation interference C/IM
- Required Overall Eb/No
- Information rate
- Overhead (% information rate)
- Modulation
- Forward error correction (FEC) code rate
- Roll off factor
- System margin
- Modulation
- Bit Error Rate (BER)

Link Availability

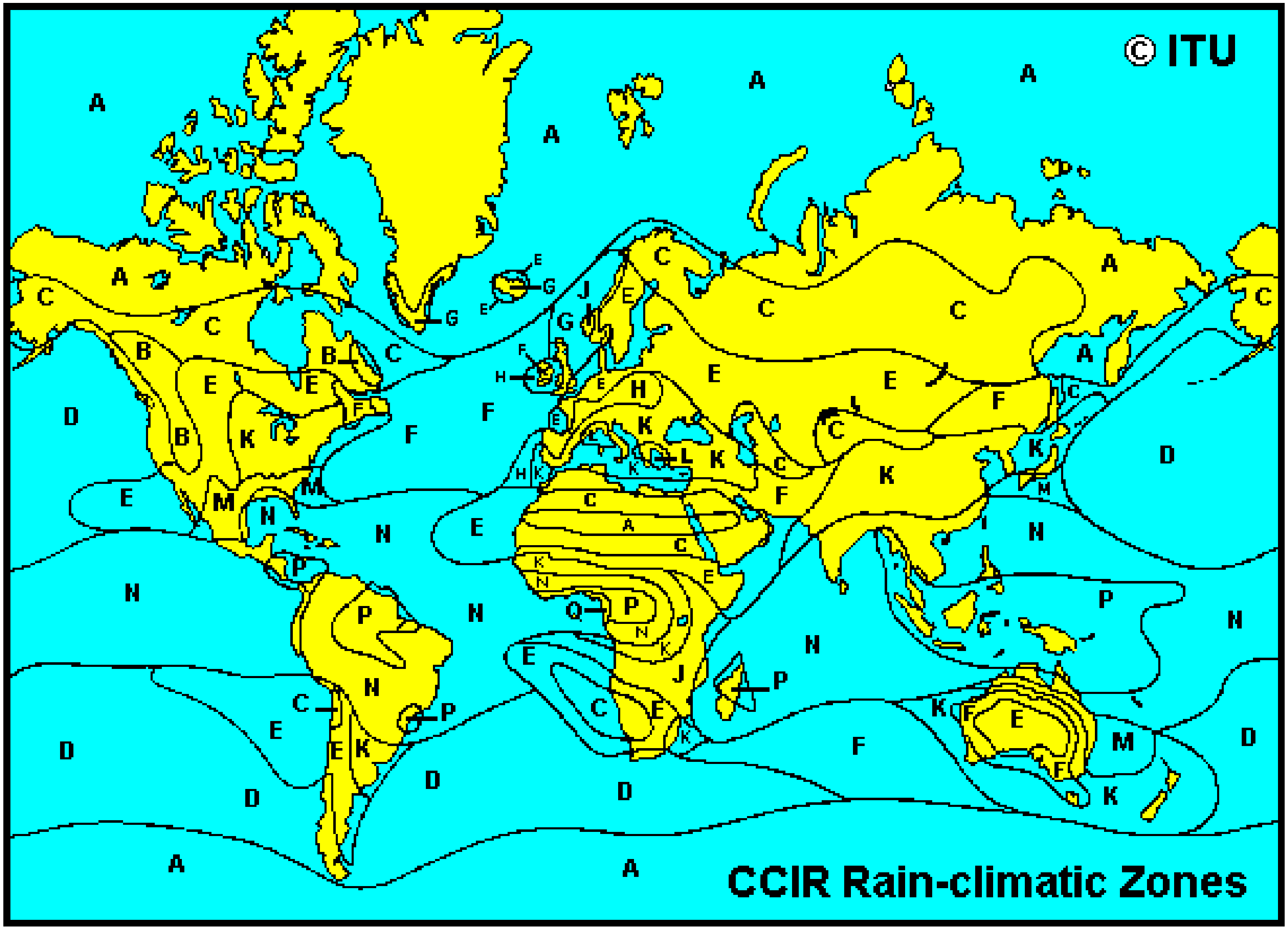
- Uplink in %
- Downlink in %
- End to End Link = 100-[(100-Au)+(100-Ad)]
  - Example: 99.75 % uplink, 99.75 % downlink

    = 100 - [(100-99.75)+(100-99.75)]

    = 100- (.25)+(.25)

  End to End Link = 99.50 %
- Uplink and Downlink rain attenuation must also be added
  - Minor impact on C-Band
  - Major impact on Ku-Band
- Caution:
  - Do not use a large difference in uplink and downlink availability to meet End to End availability requirements

Rain-Climatic Zones



Rain-Climatic Zones

14 GHz Rain Attenuation vs. Availability for ITU rain Zones

	14 GHz Rain Attenuation by Zone													
AV(av.yr.)	A	B	C	D	E	F	G	H	J	K	L	M	N	P
99.999	4.15	6.56	8.42	10.93	12.83	16.62	17.88	19.13	20.98	25.23	35.24	36.75	49.19	50.47
99.995	2.49	3.93	5.04	6.55	7.69	9.96	10.71	11.46	12.58	15.12	21.12	22.02	29.48	30.25
99.990	1.94	3.06	3.93	5.10	5.99	7.76	8.34	8.92	9.79	11.77	16.44	17.15	22.96	23.55
99.950	1.01	1.60	2.05	2.66	3.12	4.05	4.35	4.66	5.11	6.14	8.58	8.95	11.98	12.29
99.900	0.74	1.17	1.50	1.95	2.29	2.97	3.19	3.42	3.75	4.51	6.30	6.56	8.79	9.02
99.700	0.44	0.69	0.89	1.15	1.35	1.75	1.88	2.02	2.21	2.66	3.71	3.87	5.18	5.32
99.500	0.34	0.53	0.68	0.89	1.04	1.35	1.45	1.55	1.70	2.05	2.86	2.98	3.99	4.10
99.000	0.23	0.37	0.47	0.61	0.72	0.93	1.00	1.07	1.18	1.42	1.98	2.06	2.76	2.83
98.000	0.16	0.25	0.32	0.42	0.49	0.63	0.68	0.73	0.80	0.96	1.34	1.40	1.87	1.92
97.000	0.13	0.20	0.25	0.33	0.39	0.50	0.54	0.58	0.63	0.76	1.06	1.11	1.48	1.52
96.000	0.11	0.17	0.21	0.28	0.33	0.42	0.45	0.49	0.53	0.64	0.89	0.93	1.25	1.28
95.000	0.09	0.15	0.19	0.24	0.28	0.37	0.40	0.42	0.47	0.56	0.78	0.82	1.09	1.12

Rain-Climatic Zones

12 GHz Rain Attenuation vs. Availability for ITU rain Zones

	12 GHz Rain Attenuation by Zone													
AV(av.yr.)	A	B	C	D	E	F	G	H	J	K	L	M	N	P
99.999	2.86	4.61	5.98	7.85	9.28	12.17	13.13	14.09	15.53	18.84	26.77	27.99	38.22	39.32
99.995	1.71	2.76	3.58	4.71	5.56	7.29	7.87	8.45	9.31	11.29	16.05	16.77	22.91	23.57
99.990	1.33	2.15	2.79	3.66	4.33	5.68	6.13	6.58	7.25	8.79	12.49	13.06	17.84	18.35
99.950	0.70	1.12	1.46	1.91	2.26	2.96	3.20	3.43	3.78	4.59	6.52	6.82	9.31	9.58
99.900	0.51	0.82	1.07	1.40	1.66	2.17	2.35	2.52	2.77	3.37	4.78	5.00	6.83	7.02
99.700	0.30	0.49	0.63	0.83	0.98	1.28	1.38	1.48	1.64	1.99	2.82	2.95	4.03	4.14
99.500	0.23	0.37	0.49	0.64	0.75	0.99	1.07	1.14	1.26	1.53	2.17	2.27	3.10	3.19
99.000	0.16	0.26	0.34	0.44	0.52	0.68	0.74	0.79	0.87	1.06	1.50	1.57	2.14	2.21
98.000	0.11	0.18	0.23	0.30	0.35	0.46	0.50	0.54	0.59	0.72	1.02	1.07	1.46	1.50
97.000	0.09	0.14	0.18	0.24	0.28	0.37	0.40	0.42	0.47	0.57	0.81	0.84	1.15	1.18
96.000	0.07	0.12	0.15	0.20	0.24	0.31	0.33	0.36	0.39	0.48	0.68	0.71	0.97	1.00
95.000	0.06	0.10	0.13	0.17	0.21	0.27	0.29	0.31	0.34	0.42	0.59	0.62	0.85	0.87

Rain-Climatic Zones

6 GHz Rain Attenuation vs. Availability for ITU rain Zones

	6 GHz Rain Attenuation by Zone													
AV(av.yr.)	A	B	C	D	E	F	G	H	J	K	L	M	N	P
99.999	0.31	0.51	0.67	0.89	1.06	1.42	1.54	1.66	1.84	2.25	3.28	3.44	4.84	5.00
99.995	0.18	0.30	0.40	0.53	0.64	0.85	0.92	0.99	1.10	1.35	1.97	2.06	2.90	2.99
99.990	0.14	0.24	0.31	0.42	0.50	0.66	0.72	0.77	0.86	1.05	1.53	1.61	2.26	2.33
99.950	0.07	0.12	0.16	0.22	0.26	0.34	0.37	0.40	0.45	0.55	0.80	0.84	1.18	1.22
99.900	0.05	0.09	0.12	0.16	0.19	0.25	0.27	0.30	0.33	0.40	0.59	0.62	0.86	0.89
99.700	0.03	0.05	0.07	0.09	0.11	0.15	0.16	0.17	0.19	0.24	0.35	0.36	0.51	0.53
99.500	0.02	0.04	0.05	0.07	0.09	0.11	0.12	0.13	0.15	0.18	0.27	0.28	0.39	0.41
99.000	0.02	0.03	0.04	0.05	0.06	0.08	0.09	0.09	0.10	0.13	0.18	0.19	0.27	0.28
98.000	0.01	0.02	0.03	0.03	0.04	0.05	0.06	0.06	0.07	0.09	0.13	0.13	0.18	0.19
97.000	0.01	0.02	0.02	0.03	0.03	0.04	0.05	0.05	0.06	0.07	0.10	0.10	0.15	0.15
96.000	0.01	0.01	0.02	0.02	0.03	0.04	0.04	0.04	0.05	0.06	0.08	0.09	0.12	0.13
95.000	0.01	0.01	0.01	0.02	0.02	0.03	0.03	0.04	0.04	0.05	0.07	0.08	0.11	0.11

Rain-Climatic Zones

4 GHz Rain Attenuation vs. Availability for ITU rain Zones

	4 GHz Rain Attenuation by Zone													
AV(av.yr.)	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**J**	**K**	**L**	**M**	**N**	**P**
99.999	0.08	0.12	0.15	0.19	0.22	0.29	0.31	0.33	0.36	0.42	0.57	0.60	0.77	0.79
99.995	0.05	0.07	0.09	0.12	0.13	0.17	0.18	0.20	0.21	0.25	0.34	0.36	0.46	0.47
99.990	0.04	0.06	0.07	0.09	0.10	0.13	0.14	0.15	0.17	0.20	0.27	0.28	0.36	0.37
99.950	0.02	0.03	0.04	0.05	0.05	0.07	0.07	0.08	0.09	0.10	0.14	0.15	0.19	0.19
99.900	0.01	0.02	0.03	0.03	0.04	0.05	0.05	0.06	0.06	0.08	0.10	0.11	0.14	0.14
99.700	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.03	0.04	0.04	0.06	0.06	0.08	0.08
99.500	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.05	0.05	0.06	0.06
99.000	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.04	0.04
98.000	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.03
97.000	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02
96.000	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02
95.000	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02

Coupling Loss

- Uplink
  - The total loss between HPA output and the antenna
    - Waveguide components
    - OMT
    - Feed
    - Filter truncation

Downlink
  - The total loss between antenna and LNA/LNB input
    - Feed
    - OMT
    - Waveguide components

Antenna Mis-pointing Loss

- Allows for the pointing loss between the ground station antenna and the satellite antenna
  - It is unlikely that the antenna will be targeted exactly due to initial installation errors
  - Antenna stability due to wind
  - Station keeping accuracy of the satellite

- A typical allowance for mis-pointing is 0.5 dB
  - A large antenna without tracking may require more due to the narrow beamwidth

LNA / LNB Noise Temperature

- C-Band are normally quoted as Noise Temperature in °Kelvin
- Ku-Band are normally quoted as Noise Figure in dB
  - Noise Figure to Noise Temperature
    - Noise temperature (T) = 290 * (10^(Noise Figure/10)-1)

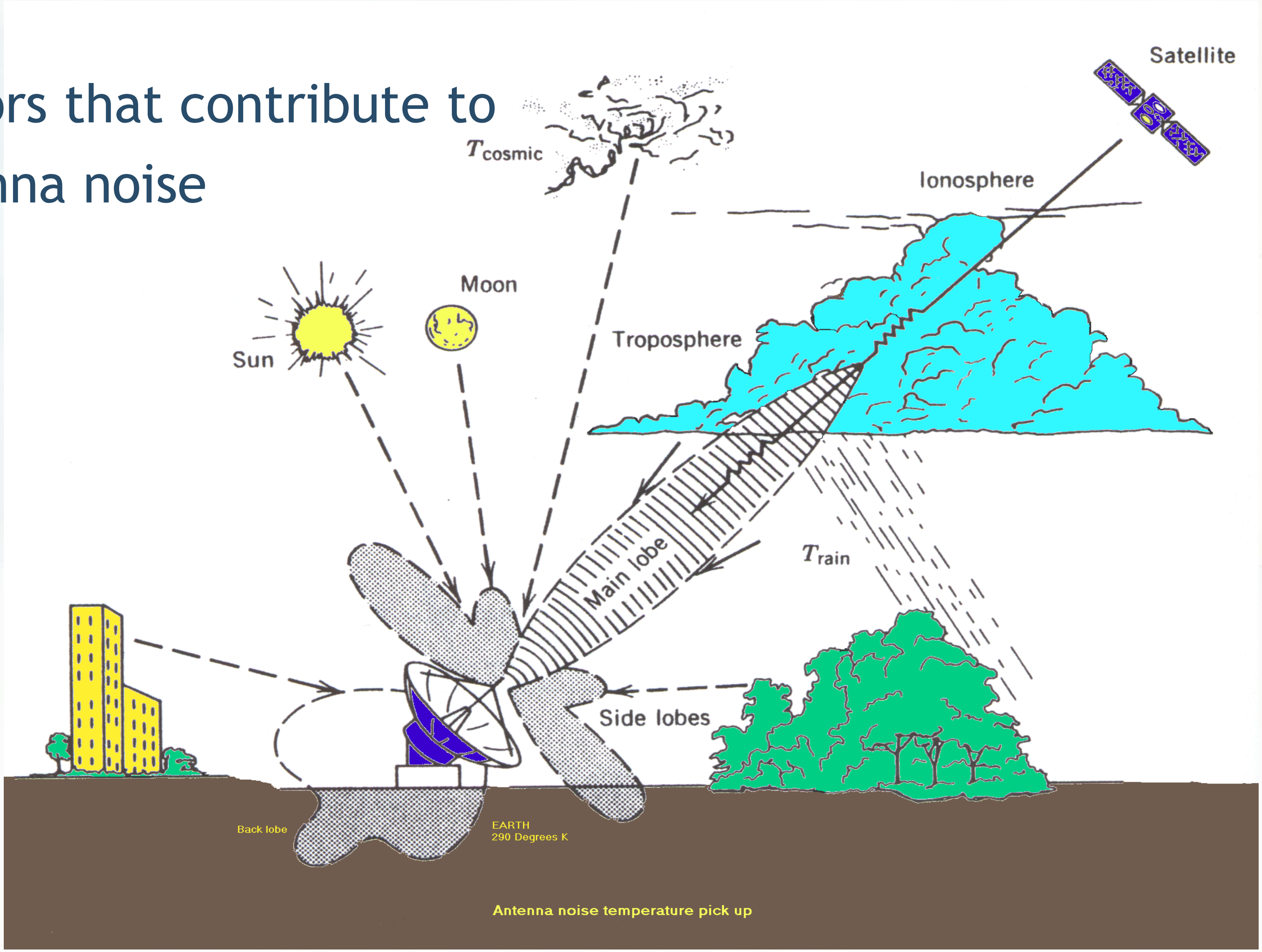
Example: Noise Figure = 1.0 dB
Noise Temp = 290 * (10^(1.0/10)-1 = 75°K

  - The higher the frequency the more difficult and expensive it is to achieve low noise figures

- The LNA/LNB is one of the most critical components of an antenna system receive system
  - *Major factor in determining the systems figure of merit (G/T)*
  - Frequency stability of LNB critical depending on type of service

Antenna Noise Temperature

Factors that contribute to antenna noise



Antenna Noise Temperature

- The total noise temperature of the antenna , ($T_{ant} = T_{sky} + T_{gnd}$) depends mainly on the following factors:
  - Sky Noise (T_{sky})
    - The sky noise consists of two main components, atmospheric and the background radiation (2.7K)
    - The upper atmosphere is an absorbing medium
    - Sky noise increases with elevation
  - Ground Noise (T_{gnd})
    - The dominant contribution to antenna noise is ground noise pick up through side lobes
    - Noise temperature increases as the elevation angle decreases since lower elevation settings, will pick up more ground noise due to side lobes intercepting the ground
    - A deep dish picks up less ground noise at lower elevations than do shallow ones
- Since antenna noise temperature has so many variable factors, an estimate is perhaps the best we can hope for

Antenna Noise Temperature

- Typical 3.6m antenna - Offset

Elevation angle (deg)	Noise temp (C band)	Noise temp (Ku band) (K)
10	24	31
20	16	23
30	15	21
40	14	20

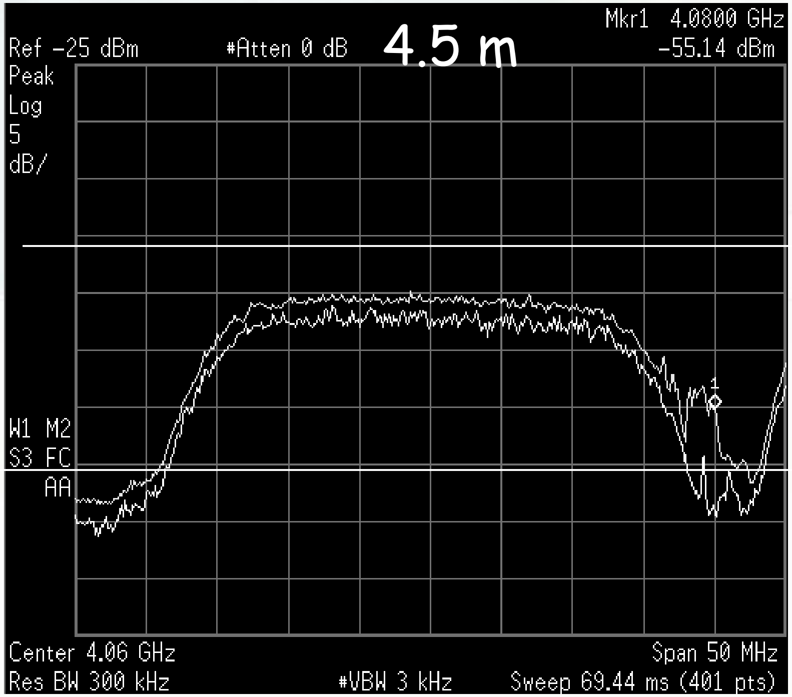
- Typical 6m antenna

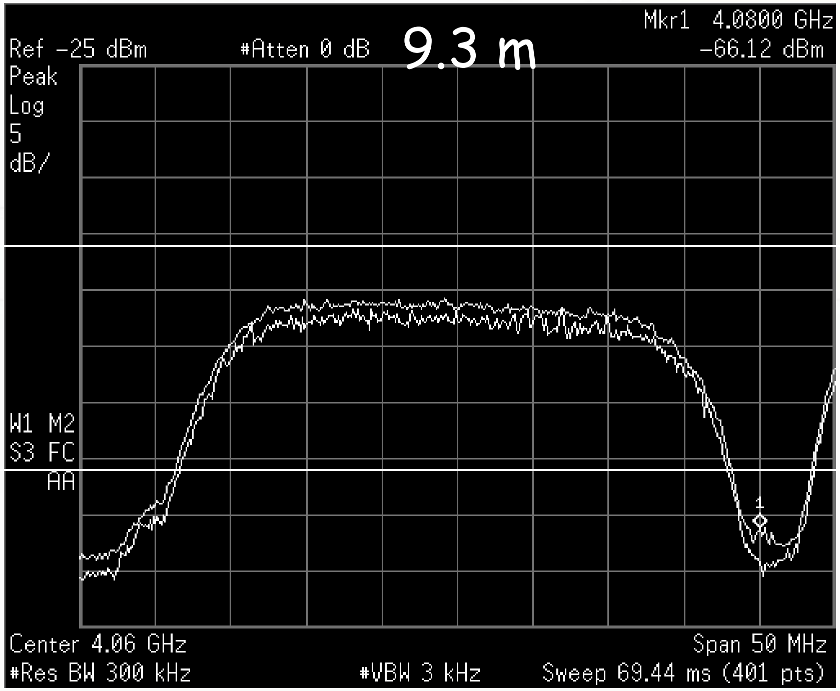
Elevation angle (deg)	Noise temp (C band)	Noise temp (Ku band)
10	39	55
20	30	40
40	23	37

G/T

- Spec An plots showing G/T difference
- 4.5m
  C+N/N ≈ 17.5 dB
  NF ≈ -65 dBm

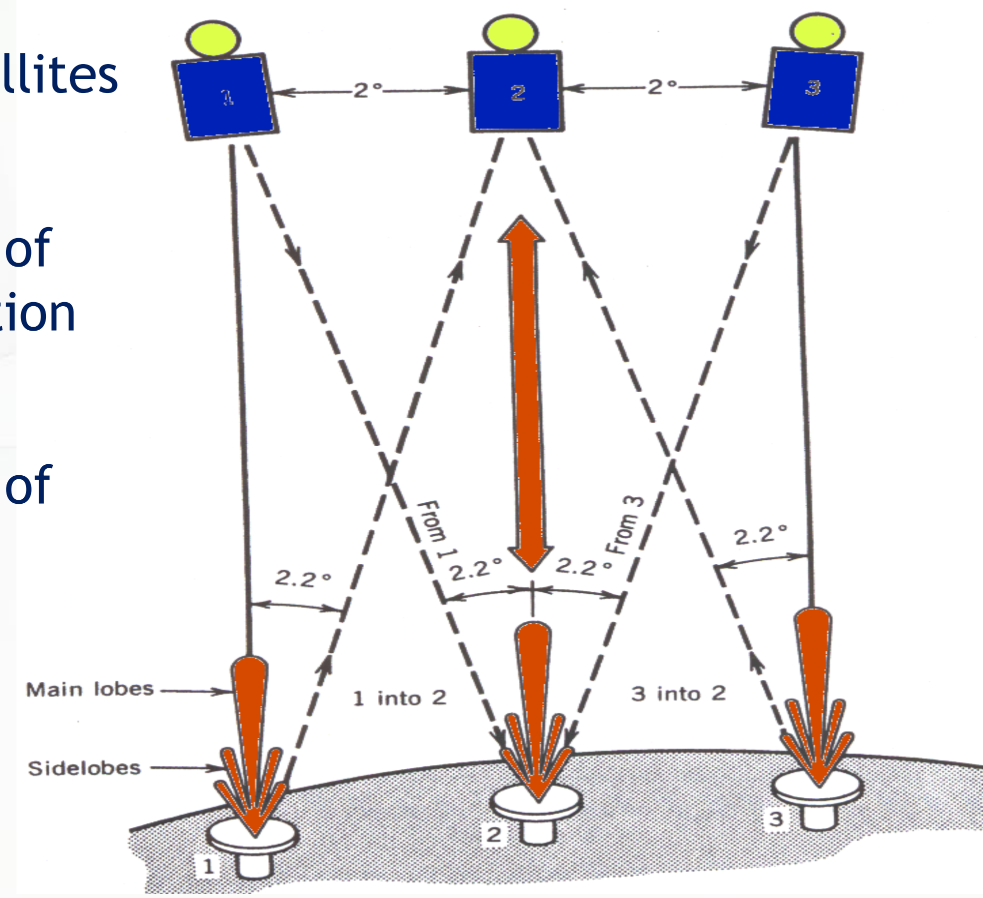
9.3M
C+N/N ≈ 22.5 dB
NF ≈ -70 dBm





Adjacent Satellite Interference (C/ASI)

- The level of ASI is a function of several parameters:
  - Orbital separation between the desired and the interfering satellites
  - Antenna side lobe performance of the interfering uplink earth station
  - Antenna side lobe performance of the receiving earth station
  - Spectral Power density of the carriers
  - Typically in the range of 18 to 30 dB



Cross Polarization Interference C/XPI

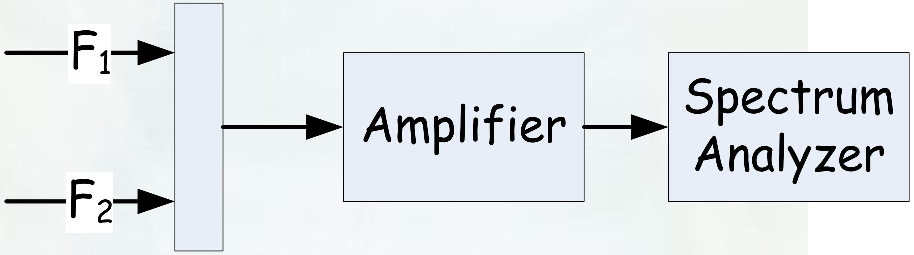
- A value for the carrier to cross polarization interference noise ratio C/XPI in dB
- Specifies the expected interference level with respect to the wanted carrier
- Typical values, irrespective of whether the uplink or downlink C/XPI is of interest, are in the range 24 to 34 dB

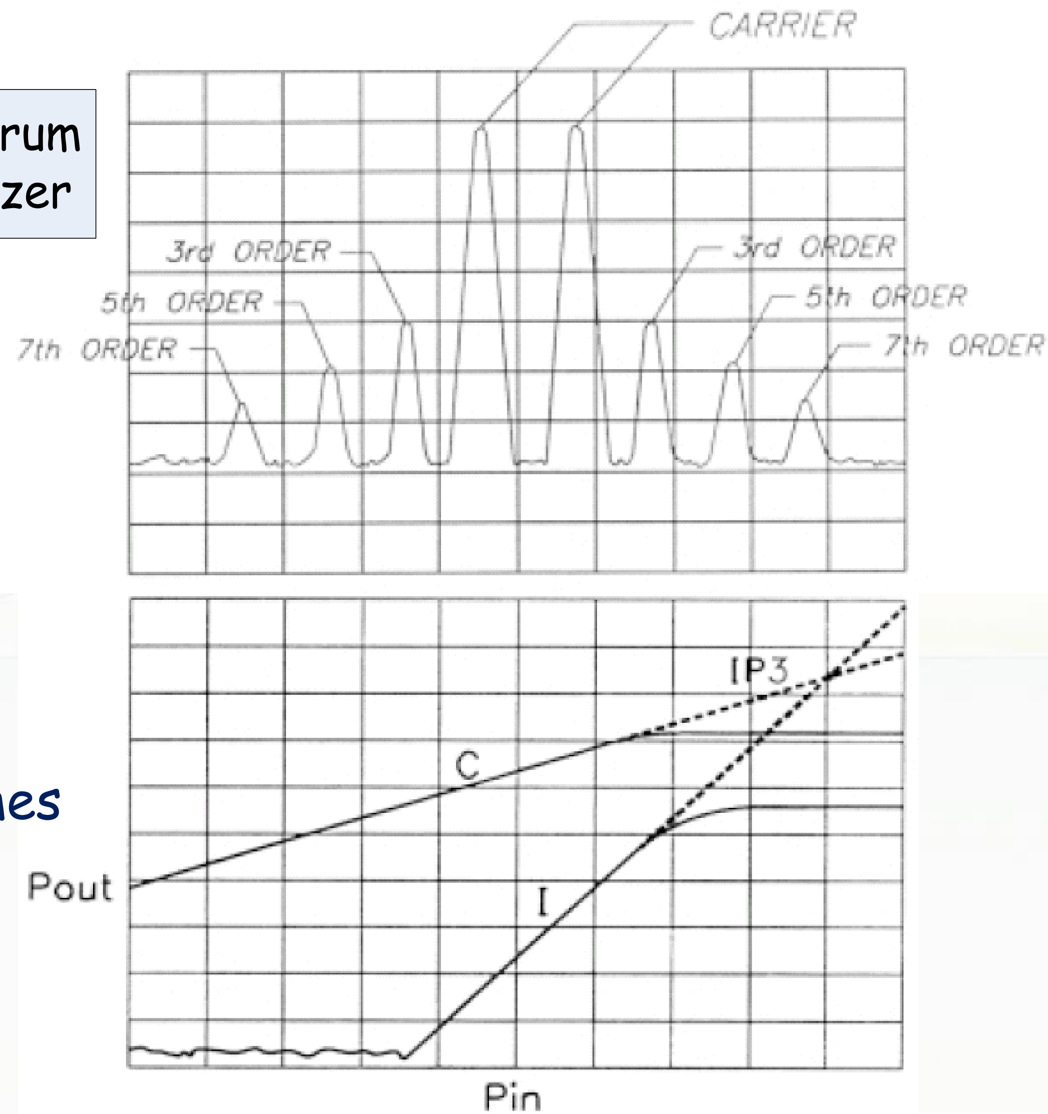
Total Cross-Pol Isolation Total XPI $=-20\log[10^{(Sxp/20)}+10^{(Exp/20)}]$		
Satellite X-Pol =	40	db
Antenna X-Pol =	35	dB
Total X-Pol Isolation =	31.1	dB

Cross Polarization Interference C/XPI

- Frequency re-use by dual polarization doubles the available frequency spectrum at each orbital location using orthogonal signals (V-H)
- Since orthogonal polarization is not perfect in actual implementation
  - There is some coupling between the orthogonal signals generated by the transmitting antenna and at the receiving antenna
    - These couplings can create signal degradation
  - In addition, the transmitted wave and the orientation of the receiving antenna polarizer also affect the polarization angle and, hence, introduce degradation to the receiving antenna polarization performance
  - The rotation of the antenna polarizer angle with respect to the satellite downlink wave’s tilt angle effects the receiving antenna polarization isolation performance.

HPA Intermodulation (C/IM)





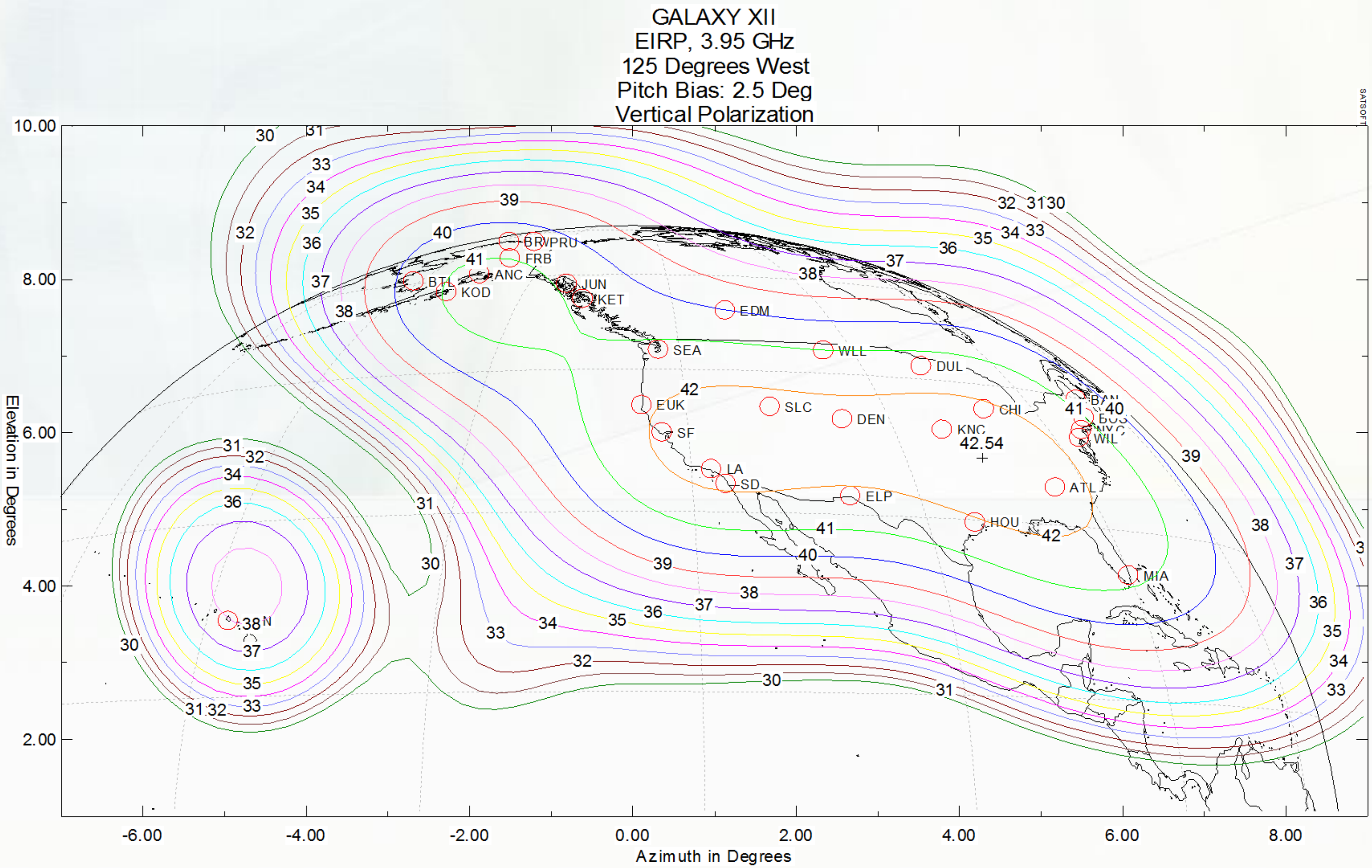
As P_{in} is increased, the intermodulation signal will increase with power three times as fast as the carrier signal.

Questions so far?

Satellite Information

- Satellite Longitude
  - Orbital position
- Satellite receive G/T
  - Value to the specific location of the uplink earth station
  - Obtained from satellite operators or G/T contour maps
- Satellite saturation flux density SFD
  - The power needed to saturate the satellite's transponder
- Satellite gain setting
  - Most satellites have a gain step attenuator, which affects all carriers in the transponder
  - May, or may not, be include in the SFD specification
- Satellite EIRP (saturation)
  - Transponder's effective isotropic radiated power (EIRP) at saturation in the specific direction of the receive earth receive station Value to the specific location of the uplink earth station
  - Obtained from satellite operators or G/T contour maps

Example of EIRP Contour



Satellite Information (Cont'd)

- **Transponder bandwidth**
  - Satellites full transponder bandwidth
- **Transponder input back-off (IBO)**
  - Input back off, or operating point, relative to saturation to reduce intermodulation interference
- **Transponder output back-off (OBO)**
    - Related, in a non linear fashion, to the input back-off
- **Transponder intermodulation interference C/IM**
  - Specifies the carrier-to-intermodulation noise ratio in dB
  - Depends on such factors as center frequency and the exact number, type and positions of other carriers sharing the transponder
  - Increasing the input back-off also reduces the effect of this interference.
  - There is little C/IM effect if only one carrier is present in the transponder

Carrier Information

Required Overall Eb/No for desired BER

- Depends on
  - Modulation Type
  - FEC Rate
  - Coding

BER PERFORMANCE (E_b/N_0, dB)

Viterbi

BER	1/2	3/4	7/8
10^{-3}	3.8	4.9	6.1
10^{-4}	4.6	5.7	6.9
10^{-5}	5.3	6.4	7.6
10^{-6}	6.0	7.2	8.3
10^{-7}	6.6	7.9	8.9
10^{-8}	7.2	8.5	9.6

Viterbi & Reed-Solomon

BER	1/2	3/4	7/8
10^{-6}	4.1	5.6	6.7
10^{-7}	4.2	5.8	6.9
10^{-8}	4.4	6.0	7.1
10^{-10}	5.0	6.3	7.5

56 kbps, Sequential

BER	1/2	3/4	7/8
10^{-3}		4.6	5.5
10^{-4}	4.1	5.1	6.1
10^{-5}	4.5	5.5	6.6
10^{-6}	5.0	5.9	7.3
10^{-7}	5.4	6.4	7.8
10^{-8}	5.8	6.8	8.4

1544 kbps Sequential

BER	1/2	3/4	7/8
10^{-3}	4.8	5.2	6.0
10^{-4}	5.2	5.7	6.4
10^{-5}	5.6	6.1	6.9
10^{-6}	5.9	6.5	7.4
10^{-7}	6.3	7.0	7.9
10^{-8}	6.7	7.4	8.4

1544 kbps, Sequential & RS

BER	1/2	3/4	7/8
10^{-6}	4.1	5.6	6.7
10^{-7}	4.2	5.8	6.9
10^{-8}	4.4	6.0	7.1
10^{-10}	5.0	6.3	7.5

8PSK with/without RS

BER	2/3 w/o RS	2/3 with RS
10^{-6}	8.7	6.1
10^{-7}	9.5	6.4
10^{-8}	10.2	6.6
10^{-9}	11	6.9
10^{-10}	11.8	7.2

Viterbi, OQPSK

BER	1/2	3/4	7/8
10^{-3}	4.1	5.2	6.4
10^{-4}	4.9	6.0	7.2
10^{-5}	5.6	6.7	7.9
10^{-6}	6.3	7.5	8.6
10^{-7}	6.9	8.2	9.2
10^{-8}	7.5	8.8	9.9

Turbo Product Codec

	QPSK	BPSK		8PSK
BER	3/4	21/44	5/16	3/4
10^{-6}	3.9	2.8	-	7.0
10^{-7}	4.1	3.1	-	7.3
10^{-8}	4.3	3.3	-	7.6
10^{-9}	4.8	3.7	4.0	8.0

Carrier Information

- **Information rate**
  - User information rate of the data in Mbps
- **Overhead (% information rate)**
  - Amount of "overhead" added to the information data rate to account for miscellaneous signaling requirements
    - i.e. Reed Solomon
- **Modulation**
  - Type of modulation
    - BPSK, QPSK, 8PSK, 16QAM, etc.
- **Forward error correction (FEC) code rate**
  - Code rate used with forward error correction
    - 0.5, 0.667, 0.75, .875, etc.

Carrier Information

- **Roll off factor**
  - The occupied bandwidth of a carrier is normally taken to be 1.1 times the symbol rate, thus the roll off factor is 1.1
- **System margin**
  - Accounts for uncertainty in the various input parameters and to allow for difficult to quantify non-linear effects such as AM-PM conversion and perhaps terrestrial interference
- **Bit error rate (BER)**
  - The BER of the link
  - 10-7 was typical of legacy systems
  - 10-9 is desirable for IP links

Questions so far?

Controllable Parameters

Link Budget Parameters

- The majority of link budget parameters are out of your control

- Those that you may control
  - Antenna size
    - Transmit
    - Receive
      - Existing or new
  - LNA / LNB
    - Noise Temperature
  - Carrier
    - Modulation type
    - FEC rate
    - Coding

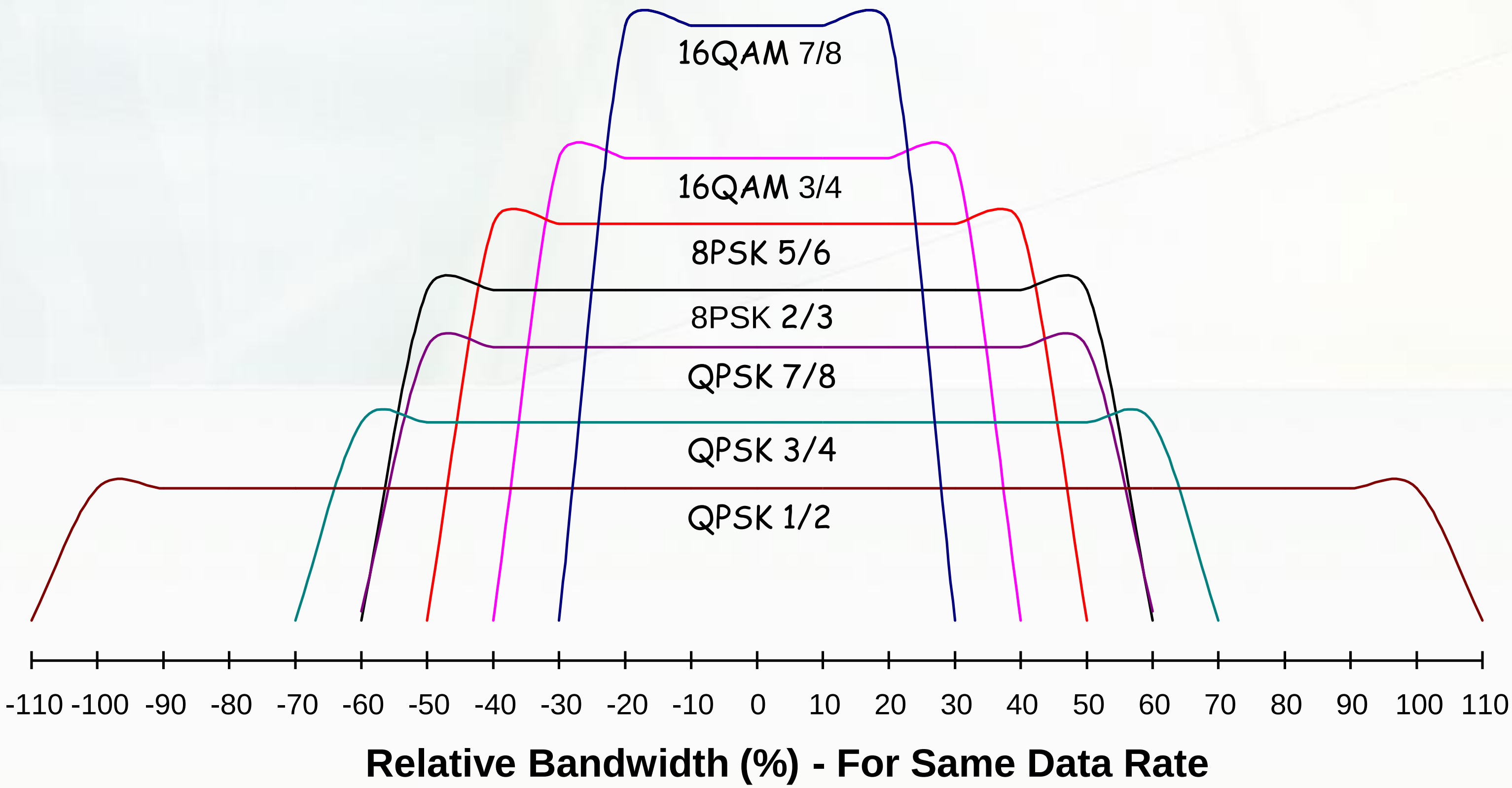
Link Budget Parameters

- Carrier – (modulation, FEC, coding)
  - Satellite bandwidth required
    - Balanced power and bandwidth operation
      - i.e. 10% transponder power, 10% transponder bandwidth

- HPA power requirement
  - Ensure proper backoff to prevent intermodulation and spectral regrowth

  - Antenna requirements
    - Larger transmit, less HPA power required
    - Larger receive, less satellite power required

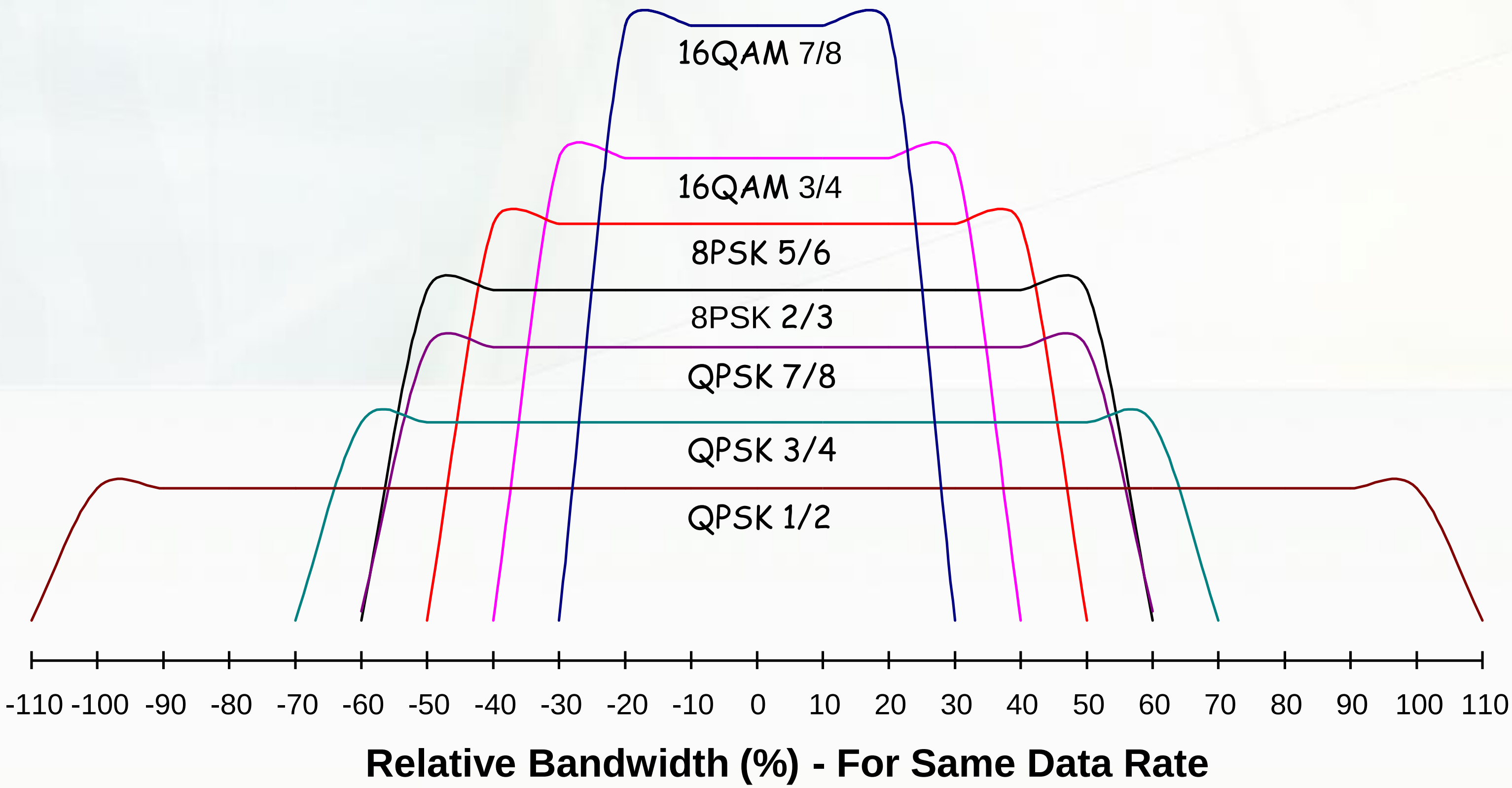
Link Budget Parameters



Link Budget Parameters

Effect of Modulation & FEC

Bandwidth For Various Modulation & Coding Types



Symbol Rate and OBW Calculations

Bandwidth Calculation		
Symbol Rate = Information Rate/(Modulation * FEC Rate)		
Information Rate =	1544	kbps
Modulation Type =	2	1 = BPSK, 2 = QPSK, 3 = 8PSK, 4 = 16QAM
FEC Rate =	0.75	.5, .75, .875, etc
Symbol Rate =	1029.3	kHz
Occupied Bandwidth =	1132.3	kHz

Bandwidth Calculation with Reed Solomon		
Symbol Rate = Information Rate/(Modulation * FEC Rate * Coding)		
Information Rate =	1544	kbps
Modulation Type =	2	1 = BPSK, 2 = QPSK, 3 = 8PSK, 4 = 16QAM
FEC Rate =	0.75	.5, .75, .875, etc
Inner =	188	
Outer =	204	
Reed Solomon	0.92	Overhead
Symbol Rate =	1116.9	kHz
Occupied Bandwidth =	1229	kHz

Satellite Carrier Spacing

- Occupied Bandwidth *(OBW)*
  - Bandwidth the carrier actually occupies
    - Typically 1.1 - 1.2 x Symbol Rate

- Allocated bandwidth *(ABW)*
  - Satellite bandwidth allocated for the carrier
    - Equal Symbol Rate *(SR)* carriers
      - (SR) x 1.4 = Carrier Space Traditional
      - (SR) x 1.2 = Carrier Space Practical

    - Different Symbol Rate carriers
      - (SR1 + SR2) x 0.7 = Carrier Space Traditional
      - (SR1 + SR2) x 0.6 = Carrier Space Practical

Eb/No and C/N

- Convert C/N to Eb/No

Eb/No = C/N + (10*log(OBW/DR)		
Bandwidth =	750.9	kHz
bps =	1024	kbps
C/N =	10.65	dB
Eb/No =	9.30	dB

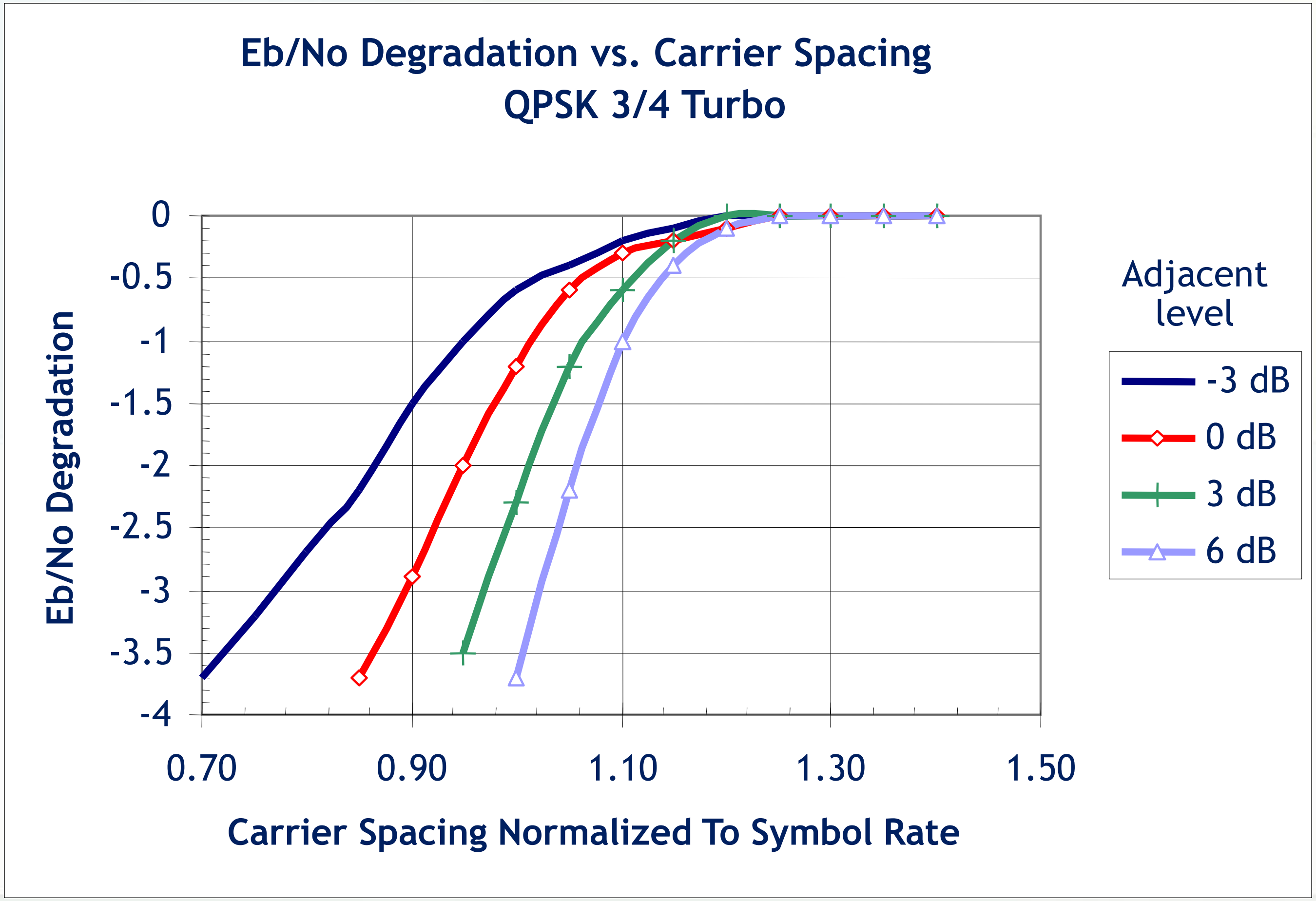
- Convert Eb/No to C/N

C/N = Eb/No - 10*log(OBW/DR)		
OBW =	750.9	kHz
DR =	1024	kbps
Eb/No =	9.3	dB
C/N =	10.6	dB

Performance as effected by Channel Spacing

Degradation created by 2 adjacent carriers QPSK

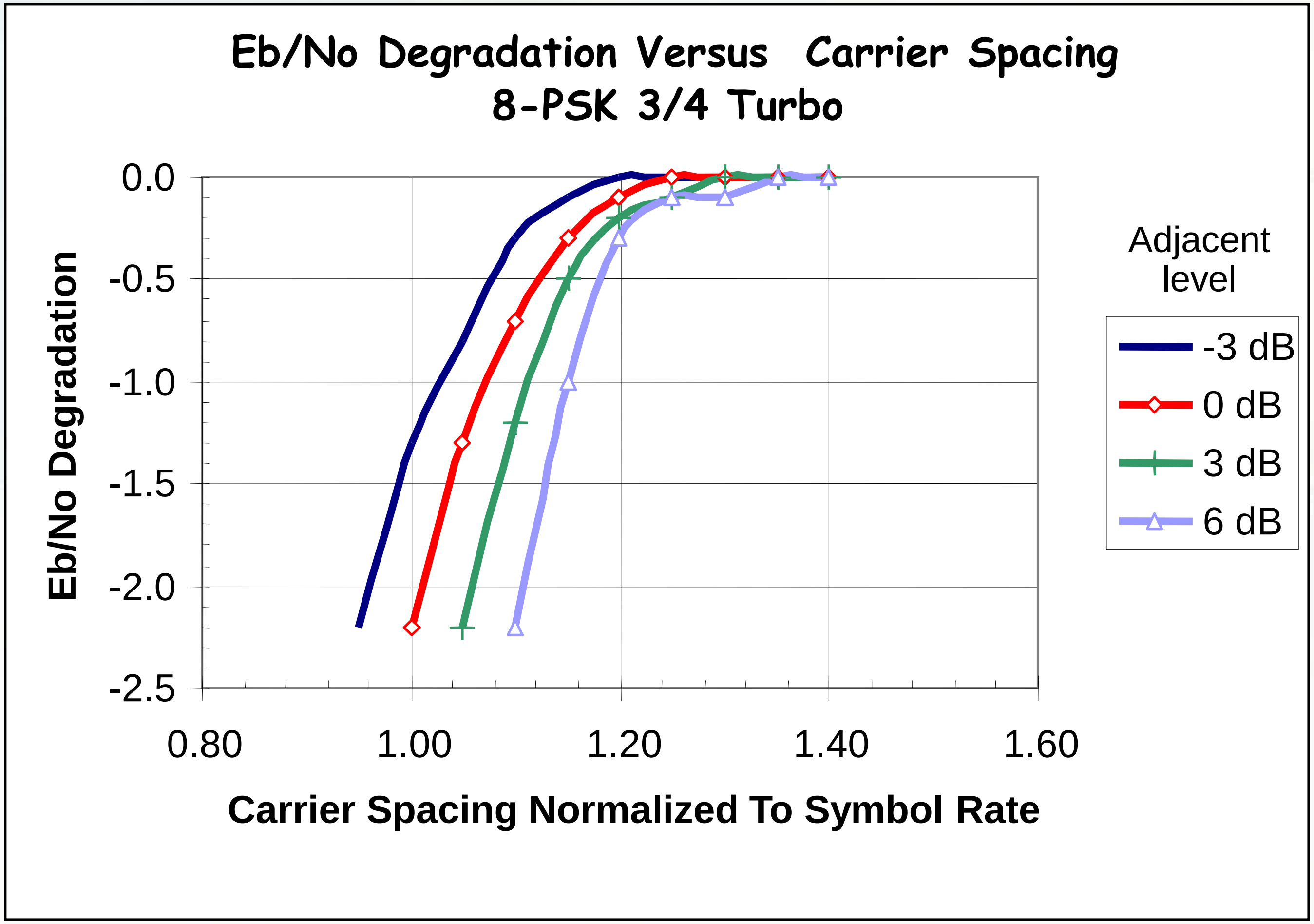
Zero degradation line = BER performance 10^{-8}



Performance as effected by Channel Spacing

Degradation created by 2 adjacent carriers 8PSK

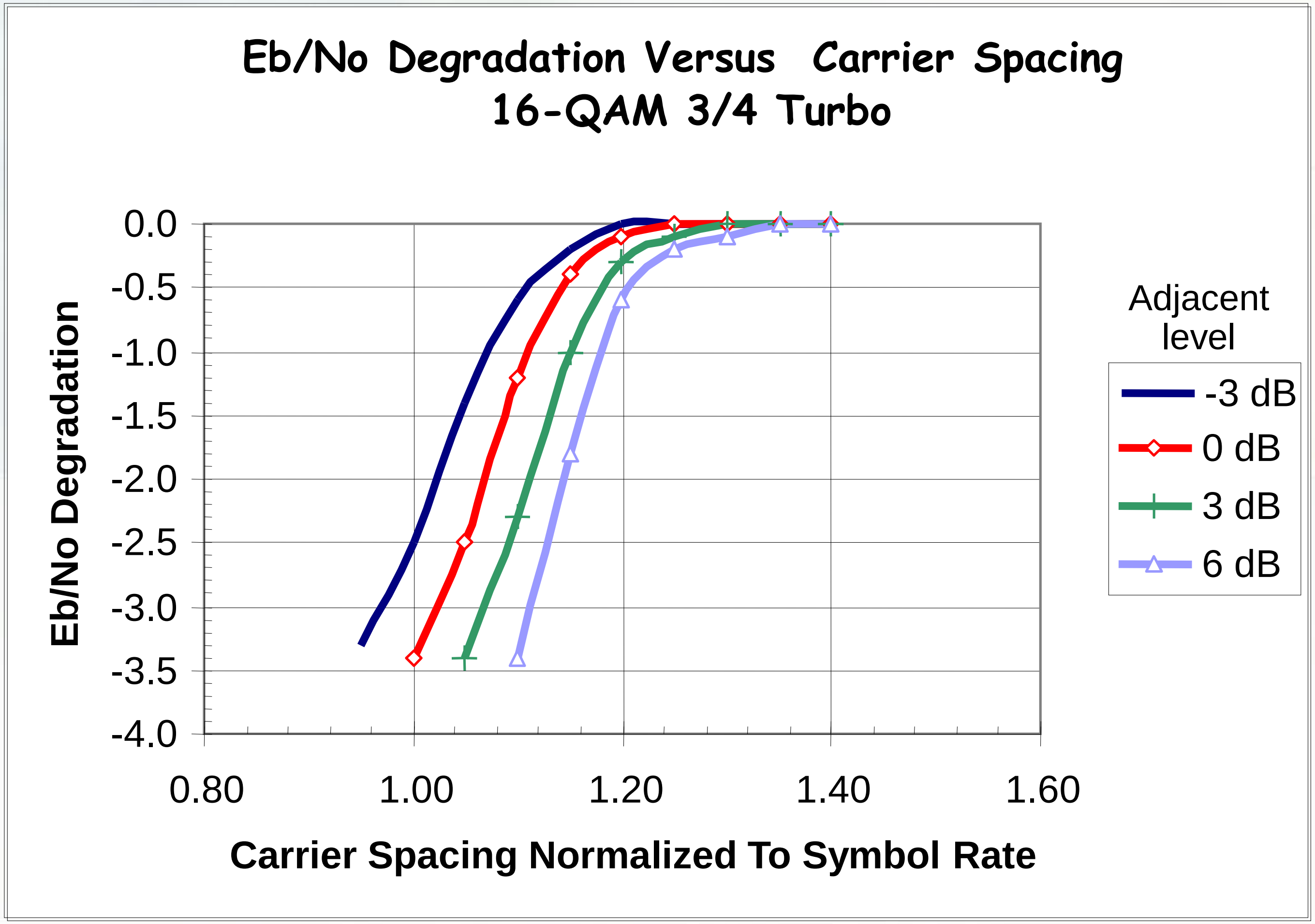
Zero degradation line = BER performance 10^{-8}



Performance as effected by Channel Spacing

Degradation created by 2 adjacent carriers 16QAM

Zero degradation line = BER performance 10^{-8}

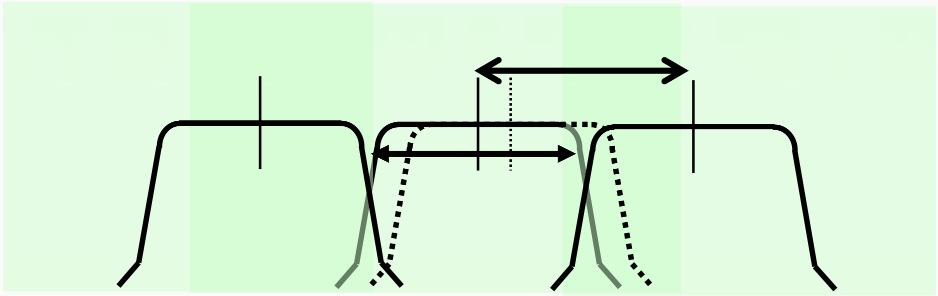


Carrier Spacing at Low Data Rates

- Low Data Rate carriers
  - Must take into consideration frequency drift possibilities for all uplink carrier equipment
  - Use worse case frequency drift based on the equipment specs

Example:		
	Symbol Rate	= 19.200 kbps
	1.2 channel spacing	= 23.040 kHz
	Mod Freq Stability	= 0.255 kHz
	U/C Freq Stability	= 3.055 kHz
	Spacing with drift	= 22.510 kHz

  - Carriers could be impacted by ACI
    - Use 1.3 or 1.4 spacing for low data rate carriers



Coding

- **Reed Solomon**
  - **Advantages**
    - 2 dB better Eb/No performance over Viterbi
    - Excellent when combined with 8PSK TCM
  - **Disadvantages**
    - Increased Latency
    - ≈ 10% bandwidth for overhead
    - Hard decision decoder

Coding

- Turbo Product Codec
  - Advantages
    - Best BER performance at given power level
    - Typical 1.8 dB improvement over Reed Solomon
    - Less latency then Reed Solomon
    - Soft Decision Decoder
    - Fade Tolerant
  - Disadvantages
    - Compatibility between vendors

Questions so far?

Link Budget Results

- Verify bandwidth % vs. power % of transponder
  - Bandwidth greater than power
    - Smaller receive antenna
    - Higher order modulation
    - Higher FEC rate
  - Power greater than bandwidth
    - Larger receive antenna
    - Lower order modulation
    - Lower FEC rate
  - Change Eb/No requirements

Repeat calculations

BER Performance

BER PERFORMANCE (E_b/N_0, dB)

Viterbi

BER	1/2	3/4	7/8
10^{-3}	3.8	4.9	6.1
10^{-4}	4.6	5.7	6.9
10^{-5}	5.3	6.4	7.6
10^{-6}	6.0	7.2	8.3
10^{-7}	6.6	7.9	8.9
10^{-8}	7.2	8.5	9.6

Viterbi & Reed-Solomon

BER	1/2	3/4	7/8
10^{-6}	4.1	5.6	6.7
10^{-7}	4.2	5.8	6.9
10^{-8}	4.4	6.0	7.1
10^{-10}	5.0	6.3	7.5

56 kbps, Sequential

BER	1/2	3/4	7/8
10^{-3}		4.6	5.5
10^{-4}	4.1	5.1	6.1
10^{-5}	4.5	5.5	6.6
10^{-6}	5.0	5.9	7.3
10^{-7}	5.4	6.4	7.8
10^{-8}	5.8	6.8	8.4

1544 kbps Sequential

BER	1/2	3/4	7/8
10^{-3}	4.8	5.2	6.0
10^{-4}	5.2	5.7	6.4
10^{-5}	5.6	6.1	6.9
10^{-6}	5.9	6.5	7.4
10^{-7}	6.3	7.0	7.9
10^{-8}	6.7	7.4	8.4

1544 kbps, Sequential & RS

BER	1/2	3/4	7/8
10^{-6}	4.1	5.6	6.7
10^{-7}	4.2	5.8	6.9
10^{-8}	4.4	6.0	7.1
10^{-10}	5.0	6.3	7.5

8PSK with/without RS

BER	2/3 w/o RS	2/3 with RS
10^{-6}	8.7	6.1
10^{-7}	9.5	6.4
10^{-8}	10.2	6.6
10^{-9}	11	6.9
10^{-10}	11.8	7.2

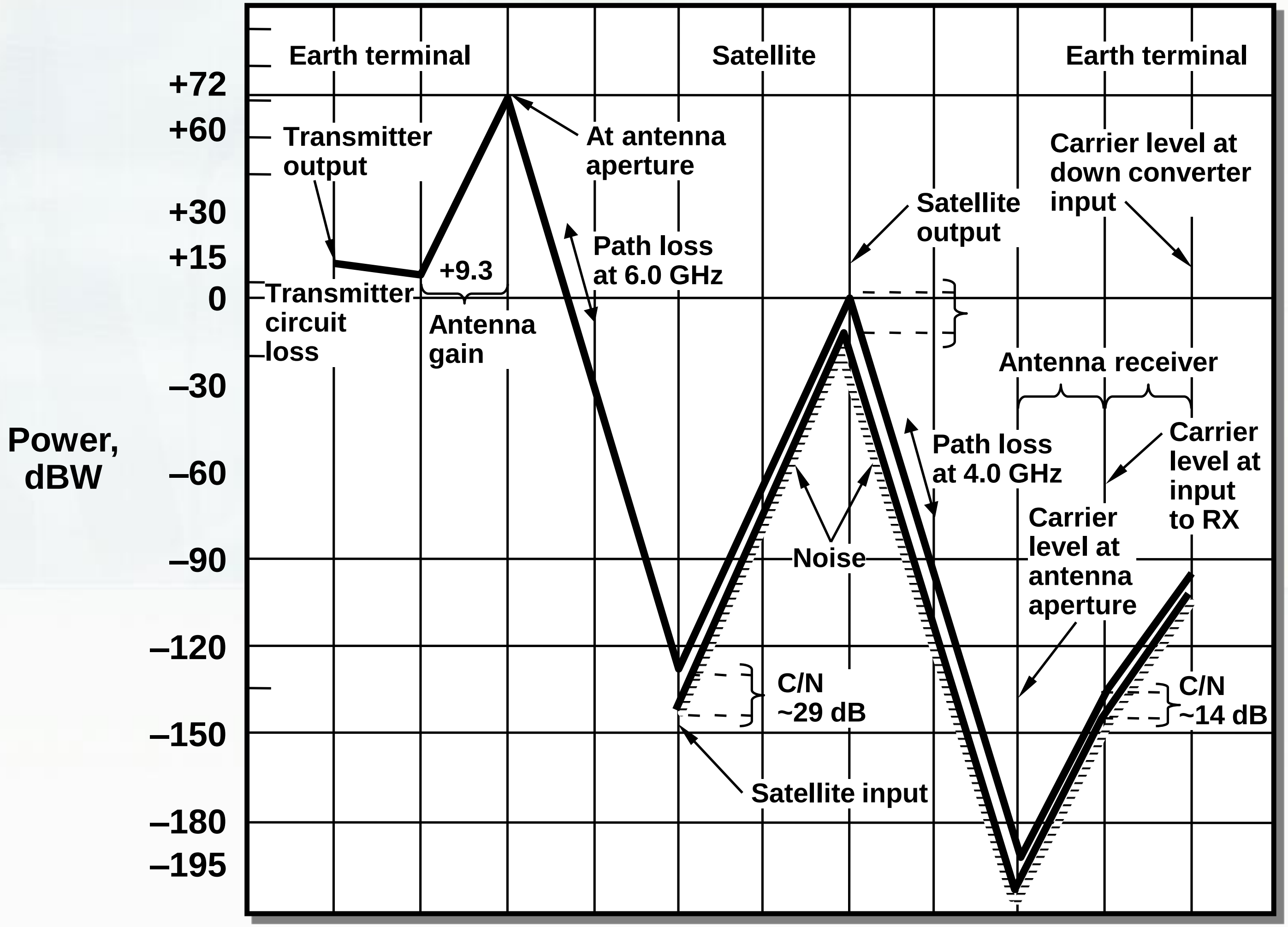
Viterbi, OQPSK

BER	1/2	3/4	7/8
10^{-3}	4.1	5.2	6.4
10^{-4}	4.9	6.0	7.2
10^{-5}	5.6	6.7	7.9
10^{-6}	6.3	7.5	8.6
10^{-7}	6.9	8.2	9.2
10^{-8}	7.5	8.8	9.9

Turbo Product Codec

	QPSK	BPSK		8PSK
BER	3/4	21/44	5/16	3/4
10^{-6}	3.9	2.8	-	7.0
10^{-7}	4.1	3.1	-	7.3
10^{-8}	4.3	3.3	-	7.6
10^{-9}	4.8	3.7	4.0	8.0

Link Budget Representation (C/N)



Gain, losses, and noise over the up and downlinks of a communication satellite system

Questions so far?

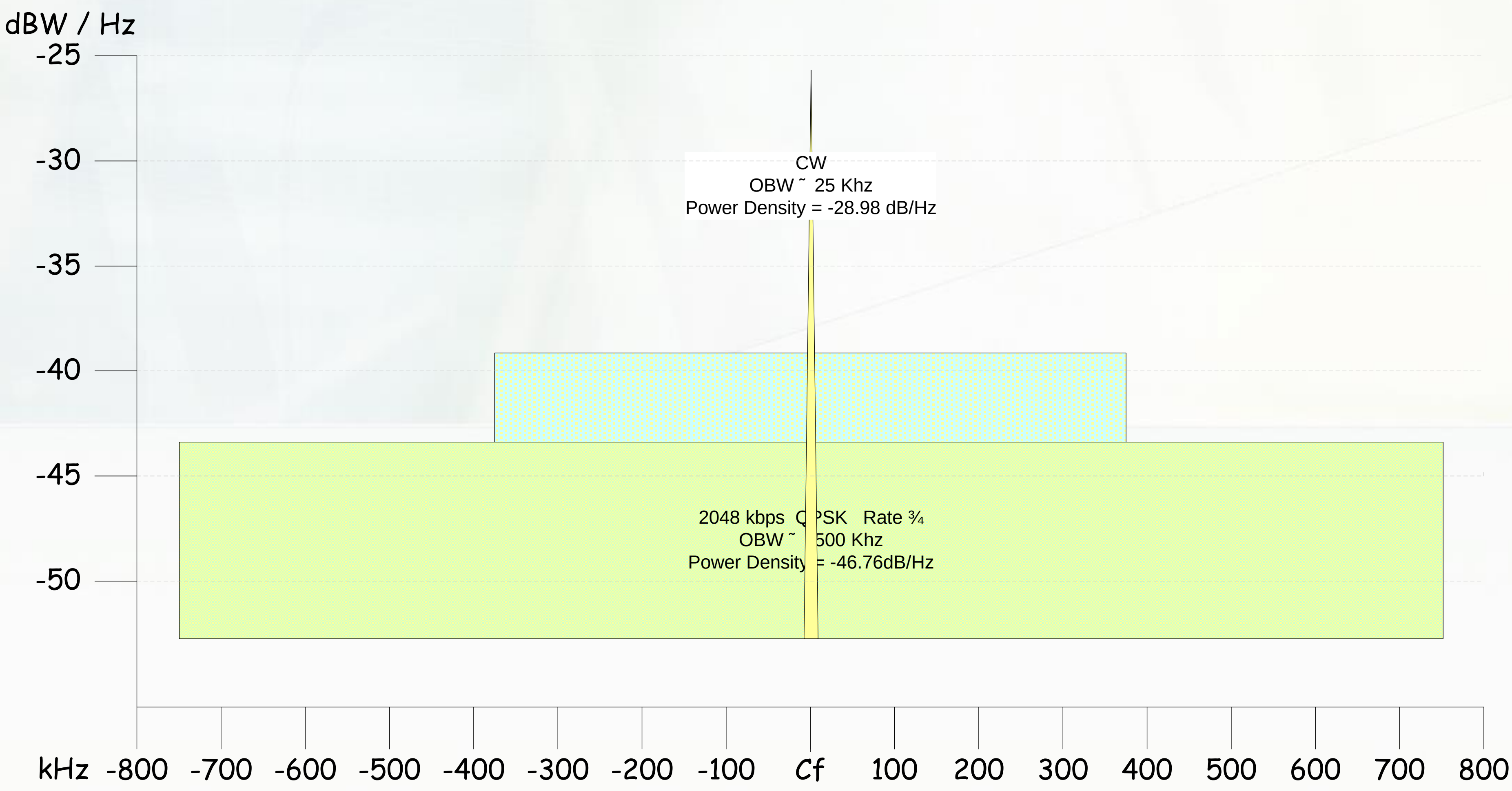
Spectral Power Density

Spectral Power Density

- What is Spectral power density?
  - The amount of power in dBW over a specified frequency span (dBW/Hz, dBW/4kHz, dBW/40kHz)
- Intelsat typical C-Band limits for antenna > 3.8 meter:
  Minus (-) 43 dBW / Hz
  - Intelsat typical Ku-Band limits for antenna > 1.9 meter:
    Minus (-) 42 dBW / Hz
- Smaller antenna may be used but there are power density restrictions
- Why do we have restrictions?
  - Prevent uplink interference to adjacent satellites
- Actual power density allowable coordinated on a satellite by satellite basis

Spectral Power Density

Increase of OBW results in a decrease in dBW/Hz



Spectral Power Density

- Power Density may be given in:
  - dB/Hz for both C and Ku-Band
  - dBW/4 kHz for C-Band
  - dBW/40 kHz for Ku-band

Power Density				
Feed Flange Power	10.52	dBW		
	11.27	Watts	11.27	Watts
Occupied Bandwidth	750.90	kHz	750.90	kHz
	0.000015	Watts / Hz	0.000015	Watts Hz
Power Density	-48.24	dBW / Hz	-48.24	dBW / Hz
	-12.22	dBW / 4 kHz	-12.22	dBW / 4 kHz
	-2.22	dBW / 40 kHz	-2.22	dBW / 40 kHz

Spectral Power Density

- Example
  - 64 kbps, QPSK, Rate ¾ with 40 Watts transmit power
  - 1024 kbps, QPSK, Rate ¾ with 40 Watts transmit power

  - 64 kbps = -31.32 dBW / Hz

40.00	Watts
54.20	kHz
0.000738	Watts / Hz
-31.32	dBW / Hz

Calculated Occupied Bandwidth

OBW_{Hz} / Watts

10*log (Watts/Hz)

  - 1024 kbps = - 43.36 dBW / Hz

40.00	Watts
867.00	kHz
0.000046	Watts / Hz
-43.36	dBW / Hz

C-Band Power Density Restrictions

	C-band				
Antenna Size (m)	Mid-band Gain (dBi) 60%	Antenna Pattern Restriction (dB)	Antenna Off-point Restriction (.5 dB)	Total Restriction	Density Limits dBW/Hz
1.20	35.58	8.35	3.63	11.98	-54.98
1.30	36.28	7.98	3.51	11.49	-54.49
1.40	36.92	7.48	3.44	10.92	-53.92
1.50	37.52	6.85	3.30	10.15	-53.15
1.60	38.08	6.10	3.20	9.30	-52.30
1.70	38.61	5.22	3.05	8.27	-51.27
1.80	39.11	4.23	2.88	7.11	-50.11
1.90	39.58	3.13	2.76	5.89	-48.89
2.00	40.02	1.92	2.64	4.56	-47.56
2.10	40.45	0.61	2.45	3.06	-46.06
2.20	40.85	0.00	2.33	2.33	-45.33
2.30	41.24	0.00	1.94	1.94	-44.94
2.40	41.61	0.00	1.46	1.46	-44.46
2.60	42.30	0.00	1.32	1.32	-44.32
2.80	42.94	0.00	0.88	0.88	-43.88
3.00	43.54	0.00	0.76	0.76	-43.76
3.50	44.88	0.00	0.78	0.78	-43.78
3.70	45.36	0.00	0.46	0.46	-43.46
3.80	45.60	0.00	0.16	0.16	-43.16

Ku-Band Power Density Restrictions

	Ku-band				
Antenna Size (m)	Mid-band Gain (dBi) 60%	Antenna Pattern Restriction (dB)	Antenna Off-point Restriction (.5 dB)	Total Restriction	Density Limits dBW / Hz
0.60	36.83	7.57	3.42	10.99	-52.99
0.65	37.52	6.85	3.30	10.15	-52.15
0.70	38.17	5.97	3.22	9.19	-51.19
0.75	38.77	4.93	3.10	8.03	-50.03
0.80	39.33	3.74	2.93	6.67	-48.67
0.85	39.85	2.33	2.82	5.15	-47.15
0.90	40.35	0.92	2.72	3.64	-45.64
0.95	40.82	0.00	2.60	2.60	-44.60
1.00	41.26	0.00	2.42	2.42	-44.42
1.10	42.09	0.00	2.25	2.25	-44.25
1.20	42.85	0.00	1.98	1.98	-43.98
1.30	43.54	0.00	1.69	1.69	-43.69
1.40	44.19	0.00	1.50	1.50	-43.50
1.50	44.79	0.00	1.20	1.20	-43.20
1.60	45.35	0.00	1.00	1.00	-43.00
1.70	45.87	0.00	0.75	0.75	-42.75
1.80	46.37	0.00	0.47	0.47	-42.47
1.90	46.84	0.00	0.28	0.28	-42.28
2.00	47.28	0.00	0.00	0.00	-42.00

End