The Global VSAT Forum

Education & Training Working Group

VSAT Installation & Maintenance Training

Level 2

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The Global VSAT Forum (GVF) is a not for profit organization comprised of a large number of satellite communications companies from over 60 countries in every major region of the world. The GVF's mission is to act in an independent manner for the general promotion of the global VSAT Industry, whether this be technology or service based. The Global VSAT Forum represents the best interests of its membership at relevant industry symposia, regulatory and legal consultations and forms a single point of contact for any suppliers to the industry or any users of VSAT equipment or services. The Forum's actions are always consistent with the promotion and growth of the VSAT Industry and its membership.

Second Edition February 2006.

Dear Reader,

Everyone knows that modern communications satellites are at the heart of the high quality telecommunications services satellite service provides to our myriad customers around the world. However we sometimes take for granted just how remarkable these satellites and their associated ground systems have become. Weighing about the same as a full size American car, when these satellites roll of the assembly line their fuel tanks will be filled and then they will be subjected to the full force and fury of a controlled explosion known as a launch vehicle. With several additional pushes from an internal rocket, after two weeks they will finally arrive at the proper orbital slot 22,300 miles above the earth. For the next thirteen to fifteen years, in spite of the continuous push from the “solar wind” and the constant pull of gravitational forces, the satellite must be kept in exactly the same position - again using internal rockets under ground control - so that the customers antennas will not have to search to find it. After the antennas and solar panels are unfolded and a short period of testing is completed, the satellites will be expected to run twenty four hours a day, seven days a week for thirteen to fifteen years with no stops at the dealer for repairs or even routine maintenance. They will also be expected to provide continuous communications services between all points on the earth within the antenna “footprints” carrying huge volumes of video, voice and data for your or your company’s customers.

One of the goals of this training manual is to make the development, launch and operation of these “modern miracles”” and the installation of ground segment as earth stations look easy to you as a VSAT Technician and ultimately, to your worldwide customers.

Because satellite technology is a rapidly evolving area of technology it cannot be over-emphasized that training should be a continual activity. It is necessary that both the executive and technical staff keep up-to-date with technological developments in this field. As a minimum, VSAT technicians should have good knowledge of RF transmission, digital technology and some knowledge of mechanical systems. Managers need to understand the importance of continuing education for personnel to enhance knowledge, improve skills and keep up with new technology.

This Training Manual provides the reader with an overview of satellite technology and VSAT technology in particular. In addition, it addresses issues typical to all VSAT installations. It should be noted that the issue of human health and safety from electromagnetic radiation is not included in this manual, as compliance with national and regional standards and limits in this area is insured through each national licensing process.

Please take your time to read through the manuals and make notes where required. If necessary, insert comments, remarks or questions.

The Manual is far from perfect but efforts will be made to keep it updated. In addition this paper is written by a non-native English speaker what occasionally may result in funny grammar.

At any time never hesitate to contact me for remarks, suggestions or critics.

Amsterdam, The Netherlands.

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Part 1 – Level 2: Satellite Communications Basics

History Edition

Version	Date	Author	Notes
Draft 0.0	30 April 2003	Onno Beemsterboer	Initial set-up
Rev 1.0	22 July 2003	Onno Beemsterboer	Implementation of suggestions
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Rev 1.3	14 December 2003	Onno Beemsterboer	Update introduction; update charts on page 122 and 125
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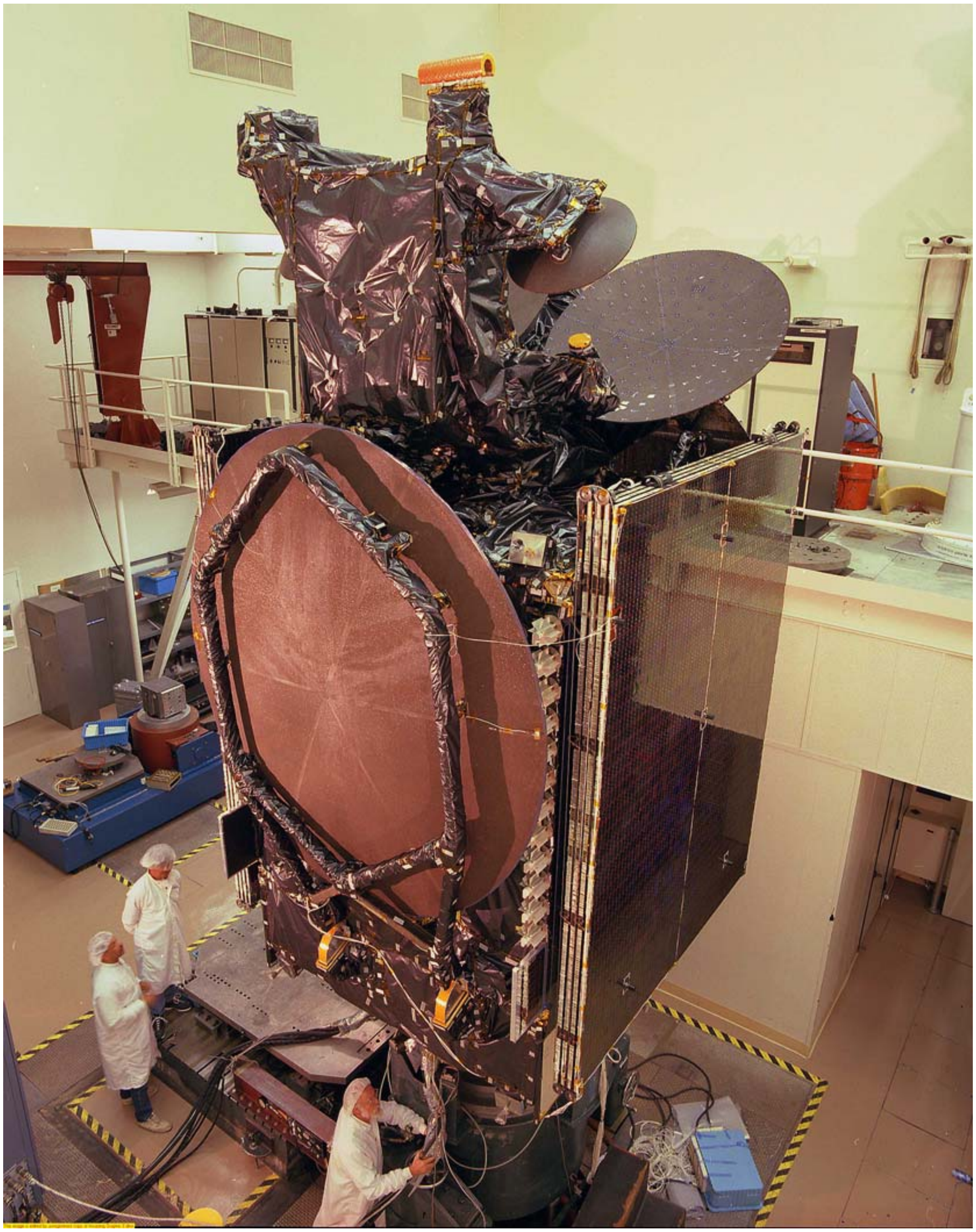


Satellite under construction at Space Systems/Loral

Part 1B – Level 2

Satellite Communications Basics

1. Indispensable basics 1 - Measurement units

To successfully understand satellite technology and further chapters of this course manual it is absolutely necessary to know in detail what the following measurement units and expressions means:

- Decibels [dB]
- Carrier-to-Noise, Signal-to-Noise and Eb/No [dB]
- Noise Temperature [K] or [dB] or [dBK]
- G/T or Figure of Merit [dBK]
- Bit Error Ratio (BER)

It's also important that you gain a feeling of what is wrong and right.

<u>Example:</u> It should be clear that 3dB is double power, attenuation of 26dB is a lot, 18dBW HPA output power is much more than 18W, a gain of 47dBi is enormous and with digital carrier C/N of 4 dB you're in big trouble, etc.

1.1. Decibels

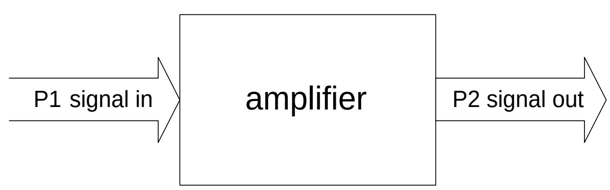
On its way from one station to another, the signal will pass through different elements such as amplifiers, attenuators, modems, antenna and even free space. Signal levels, EIRP, gain and even system losses, can be mathematically unmanageable because of unpractical values. A logarithmic expressed quantity can reduce these numbers to more practical figures. The decibel is such an expression.

The decibel [dB] is a means of expressing ratios logarithmically and is used to express the relative values of two signals. The logarithmic scale is used to compress large differences in numbers to a more manageable range. Because of pressures for standardization, the Bel (B) was defined by the following equation to relate *power* levels P1 and P2.

$$G_B = \log_{10}(P2/P1)$$

It was found that the Bel was too large, so the decibel was defined such that 10 decibels = 1 Bel

$$G_{dB} = 10\log_{10}(P2/P1)$$



A second equation for decibels shows the <u>*voltage*</u> or <u>*current*</u> gain in decibels.

$$G_{dB} = 20\log_{10}(V2/V1)$$

example: V_{in}=6 volt, V_{out} = 800 volt
The voltage amplification is 20log133.3=42.5 dB

One of the advantages of the logarithmic relationship is the manner in which it can be applied in cascade stages or in other words calculations will be reduced to addition and subtraction instead of multiplying and dividing.

<u>Example:</u> One piece of cable has an attenuation of 3.6 dB; another piece has 2.4 dB. Connected to one another, they have a total attenuation of 3.6 + 2.4 = 6.0 dB.

dBW, dBm, etc.

Decibels are also expressed relative to a reference value such as watts (dBW), milliwatt (dBm), millivolt (dBmV) and micro volts (dBμV) to show the increase in power relative to one watt, one milliwatt, one millivolt and one microvolt, respectively. Decibels correspond to finite voltage or current levels—not to ratios.

Designation	Reference	Conversion
dBm	1 milliwatt	dBm = dBW + 30
dBW	1 Watt	dBW = dBW - 30
dBV	1 Volt	dBV = dBm + 2.2

A power level of 1mW into a 600 or 50Ω load resistance (read impedance) has become standard and is defined as 0 dBm (0 dBm into a 50Ω resistance corresponds to 0.225 V)

Some practical examples of dB calculations and conversions are given below:

- Transformation of gain [dB] into absolute gain: The gain of an antenna is 47.5 dB. The *absolute* gain is equal to invlog (47.5 / 10) = 56234.1 X
- Transformation of absolute gain into gain [dB]: A piece of cable has an absolute attenuation of 117 X. Expressed in dB this negative gain is equal to -20.68 dB.
- Conversion of Watts into dBm: A radio output power of 2.3 W (=2300 mW) is equal to 10log 2300 = 33.61 dBm
- Conversion of dBm into Watts: A modem has an output power of -15 dBm. This is equal to invlog(-15/10)=0.0316 W or 31.62mW

dBmV and dBμV are more in use in the world of CATV and video using loads of 75Ω. Example: 120 dBμV corresponds to 1 V or 11.2 dBm into a 75Ω load.

20logx=120 dBμV → logx= 6 → x=invlog 6=1000000 → reference is 1μV → 1E6·1E-6= 1V. 1V into 75Ω is 0.0133 W=13.3mW → 10log13.3=x dBm → 1V=120 dBμV=11.2 dBm

dBm	mW	dBm	MW	dBm	mW
-18	0.0158	-4	0.398	10	10.0
-17	0.0200	-3	0.501	11	12.6
-16	0.0251	-2	0.631	12	15.8
-15	0.0316	-1	0.794	13	20.0
-14	0.0398	-0	1.00	14	25.1
-13	0.0501	1	1.26	15	31.6
-12	0.0631	2	1.58	21	126
-11	0.0794	3	2.00	24	250
-10	0.100	4	2.51	27	500
-9	0.126	5	3.16	30	1W
-8	0.158	6	3.98	33	2W
-7	0.200	7	5.01	36	4W
-6	0.251	8	6.31	39	8W
-5	0.316	9	7.94	42	16W
1W=0dBW=30dBm					

dBm-mW Conversion Table (50Ω load)

dBHz

Another example that occurs widely in practice is bandwidth referred to 1 Hz. Thus, a bandwidth of 36 MHz is equivalent to 10log(36000000/1) = 75.56 dBHz

1.2. Carrier over noise

As with analog transmission, the main criterion for digital communications is still the accuracy of the received information. The performance of a satellite link is considered in two parts:

1. The RF link deals with the carrier signal strength with respect to the noise signal strength (C/N). The carrier to noise ratio depends on the characteristics of the radio terminals, the characteristics of the propagation medium, and the possible interference.
2. Modulation, multiplexing & multiple access, deals with channel performance and is dependent upon the techniques and hardware used.

1.2.1. C/N [dB], S/N [dB], Eb/No [dB]

The carrier-to-noise ratio, (C/N) is the waveform term relevant *before* demodulation in the receiver. Signal-to-noise ratio (S/N) or Eb/No ratio is that relevant to the waveform *after* demodulation. The S/N ratio or Eb/No ratio is thus dependent on both the carrier-to-noise ratio and the modulation characteristics. Note that S/N is used for analog signals and Eb/No for digital signals where Eb/No represents the noise in a bit. The important feature of any signal processing must be to maximize the S/N or Eb/No ratio to obtain a high-quality analogue signal or minimize the error rate in a digital signal. Another important link parameter is the receiver's demodulator "threshold" figure. At present this is typically 7 dB but is expected to be a little lower as "threshold extension" techniques develop. Threshold is the point where the linear relationship between demodulator C/N input and S/N or Eb/No output begins to break down.

C/N is used to state the quality of the (satellite) channel and represents how much carrier power is being provided with respect to the amount of noise power present at the receiving device input of the earth station.

C/N is calculated at many points in a communication system. Its value can determine problems and trade-offs between:

- Transmit power.
- Antenna gain.
- System losses due to atmosphere and hardware.
- Receiver capability.

Typical carrier-to-noise ratios include:

- 52 dB (4 MHz) for “snow free” AM television.
- 12 dB (3 kHz) for intelligible voice communications.
- 7 dB (3 kHz) for 99.9 % data transmission.

Several carrier to noise hardware configurations can be used to measure the ratio but most of these set-ups resemble that of a *spectrum analyzer*. Important is that the noise floor of the analyzer must be (at least 10 dB) lower than the noise contributed by the device under test.

1.2.2. C+N/N

C+N/N represents the carrier plus noise-to-noise ratio and is displayed on the screen of a spectrum analyzer used to measure satellite carrier signals.

The Noise (N) is the cumulative amount of noise contributed by every active and passive device in the path between the transmit earth station, modulator output and the receive earth station demodulator input. It includes noise added by the upconverter, SSPA, sky & ground, transponder and LNB in the bandwidth of the carrier. The N in the numerator becomes insignificant at displayed C+N/N greater than 10 dB. In practice this means that C/N = C+N/N. If less than 10 dB, the N in the numerator must be calculated and the displayed value corrected accordingly.

As noise power is a function of bandwidth, the spectrum analyzer resolution bandwidth filters should also be considered. Choose the bandwidths narrow enough to resolve the noise and exclude discrete signals, but not so narrow as to slow the process.

1.2.3. Eb/No

Eb/No represents the "Energy per bit/Noise power per Hertz" and is expressed in dB. This term is commonly used to evaluate the performance of digital modems. It is defined by:

Eb/No [dB] = C/No [dBHz] - 10log(datarate/1) [dB/Hz]

1.3. Noise temperature [^{o}K] or noise figure [dB]

The noise temperature [^{o}K] or noise figure [dB] of an amplifier can be defined as the ratio of the output of the real amplifier to the output of a “perfect” (noiseless) amplifier of the same gain, with a resistor of value Rs connected across the amplifier’s input terminals in each case. The natural resistive noise of Rs is the input signal.

<u>Example:</u> A perfect, but theoretical, amplifier (or LNA/B/C) has a noise temperature of 0^{o}K, so that it would add no noise to the signal it is amplifying. Since all amplifiers add (thermal) noise, the signal or carrier-to-noise ratio at the amplifier’s output is degraded. Practical LNA/B/Cs are rated by the noise they add to the signal. The lower the noise temperature, the less noise is added by the LNA/B/C.

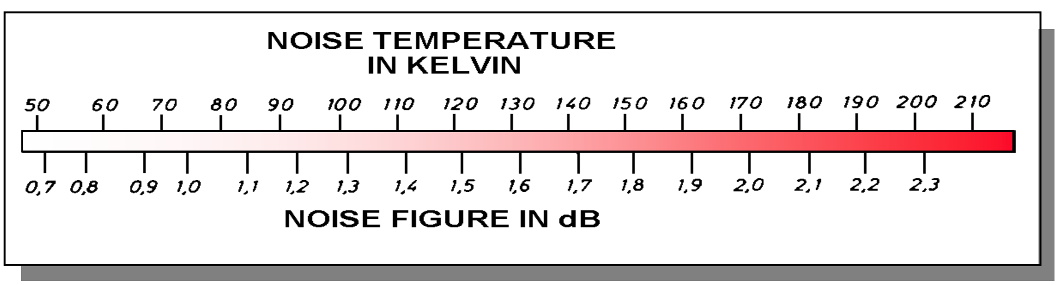
The noise temperature [^{o}K] or noise figure [dB] is a measure of the noise power produced by a communications system, subsystem, component, or “noise source.” It varies with frequency and source impedance but is always greater than zero dB.

1.3.1. The Kelvin scale versus Decibel

The Kelvin scale is used to measure temperatures above absolute zero, the theoretical point at which all molecular motion stops. This point is equal to 0^{o}K

While most C band LNBs are rated by noise temperature, Ku band LNBs are generally categorized by noise figure (or noise factor). Common noise temperatures for C band LNBs are in the 25-30 degree (0.4 dB) range while Ku band LNBs below 0.8 dB (59^{o}K) are rather sophisticated. Test data is supplied at +23^{o}C unless specified otherwise.

Converting table noise temperature ⇔ noise figure



Or in a formula:

Noise Figure = 10 $\log_{10}$ [T/290 + 1] [dB]   290 is the assumed ambient temperature.

If the temperature is referred to one degree Kelvin, the temperature Kelvin expressed in decibels would be given as dBK.

<u>Example:</u> 290K (ambient temperature) in decibels is 10log(290/1)=24.64 dBK

2. Indispensable basics 2 - Bandwidth

Bandwidth - *the width of a band of electromagnetic frequencies* - actually means the amount of information that can be carried on a given transmission path. A signal covering a wide band of frequencies can carry more information than one covering a narrow band. This can be easily compared to a large-diameter pipe that can carry more water than a small one.

Confusing can be the difference between analog and digital bandwidth:

- In **analog** systems, bandwidth is the width of the range of frequencies that an electronic signal occupies on a given transmission medium. It is expressed in terms of the difference between the highest-frequency signal component and the lowest-frequency signal component. Frequency is always expressed in Hertz [Hz]. Another word is channel bandwidth.
    - A typical voice signal has a bandwidth of approximately 3 kHz
    - An analog TV broadcast video signal has a bandwidth of 8 MHz
- In a **digital** system, bandwidth or "capacity" is the speed data flows on a given transmission path. This is expressed in bits per second [bps] or bytes per second [Bps}.
    - A modem that works at 57,6 kbps has twice the bandwidth of a modem that works at 28,8 kbps

1 Byte equals 8 bits thus 1kB equals 8kb. 1 kb equals 1024 bits.

2.1. Transmission speed, bit, baud, and symbol rate

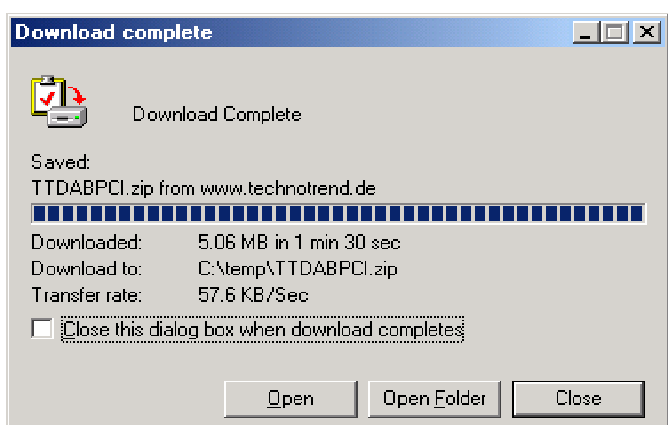
Transmission speed can be expressed in bits per second or baud rate. The speed (engineers rather use data rate) at which bits are transmitted (the bit rate) is measured in bits per second (bps) while baud rate denotes the number of symbols per second.

In QPSK and most other modulation methods, more than one bit is transmitted at a time. The bits that are transmitted simultaneously are grouped into a symbol. The rate at which symbols are transmitted is the baud rate. When there is only one bit per symbol, as in FSK transmission, the bit rate and the baud rate are the same. When there are two bits per symbol as in e.g. QPSK, the bit rate is twice the baud rate. With 64 QAM there are 8 bits per symbol, so the bit rate is 8 times the baud rate.

2.2. Throughput

Perhaps the most common mistake made in communications terminology today is to confuse data rate with throughput. Data rate is an important measure of modem performance reflecting very much the physical limits of a system in a controlled environment (which is definitely not the open Internet) while throughput is the parameter we're really interested in. Another word for throughput is user experience or transfer rate. Throughput is usually expressed in Kbytes per second (KBps).

In data transmission, throughput is defined as the amount of data moved *successfully* from one place to another in a given time period. This means that the bandwidth of a data channel is not necessary equal to the throughput. In general throughput is significantly lower.



The famous Windows dialog box informs you about the transfer rate or throughput. Be advised that text transfer should be faster than true throughput, due to data compression performed by the modem.

Keep in mind that throughput or the user experience can be seriously affected by the following factors:

- Network under-capacity problems (often the result of overselling the available capacity to too many subscribers). The usual symptoms of network under-capacity are high latency (the time it takes a packet to cross the network path from one end to the other) and packet loss (where transmitted data is literally lost because of insufficient network capacity). High latency has an adverse effect on interactive use; Packet loss has an adverse effect on just about everything.
- Different behavior of the different transmission media (e.g. satellite shows a better user experience for larger files than for browsing)
- New and fast computers process downloads more quickly than older machines.
- A local area network (LAN) can impede the flow of data to the computer, thus resulting in a slower throughput.
- Throughput may be slower if there is heavy traffic on the Internet. It's more likely to run into slow Internet traffic during peak use hours than those times when fewer people are online. Internet traffic in the different parts of the world can be made visible by clicking on http://www.internettrafficreport.com

2.3. What makes the channel bandwidth

Generally speaking, bandwidth is directly proportional to the amount of data transmitted or received per unit time. The absolute channel bandwidth [Hz] not only depends on the data rate but also very much on the used type of (digital) modulation, compression and forward error correction (FEC).

- Modulation: Examples of digital modulation are X-PSK or X-QAM where the highest schemes are the most bandwidth efficient. By comparison QPSK (= 4-PSK) to 8-PSK, 8-PSK has the advantage to carry more data without an increase in bandwidth. Since more states produce a higher channel throughput, it would seem that increasing the states would provide a simple way of increasing channel capacity. Unfortunately, more bandwidth-efficient modulation schemes suffer from higher bit errors and packet losses. A higher signal-to-noise ratio is necessary to achieve acceptable error rates.

- Compression: Compression is storing data in a format that requires less space than usual. Data compression is particularly useful in communications because it enables devices to transmit the same amount of data in fewer bits resulting is serious bandwidth (cost) reduction There are a variety of data compression techniques, but only a few including MPEG (and DVB) have been standardized.

- Forward error correction or FEC: FEC combats errors by inserting error-correcting bits in the transmit information stream. There are various FEC techniques available but all involve sending extra (redundant) bits in the signal, which can be used to detect and correct errors in the received data. As an example using R1/2, an encoding bit is inserted for every information bit. Using R3/4 an encoding bit is inserted for every three information bits. Error correction will allow the user to receive a good signal on a marginal circuit. Common schemes of encoding are 7/8, 3/4 and 1/2 FEC.

In digital cable and fiber optic systems, the demand for ever-increasing data speeds outweighs the need for bandwidth conservation. Current generation satellite transponder capacity is limited and is not sufficiently available to satisfy demand for broadband communication. In the electromagnetic radiation spectrum, there is only so much available bandwidth to go around, but in hard-wired systems, available bandwidth can literally be constructed without limit by installing more and more cable.

2.4. How to measure bandwidth and throughput

This is not easy and you really have to know what you want to measure and what you are doing. Again it can be split-up into three categories:

- Channel bandwidth: There are different ways to measure the occupied channel bandwidth but the most common is with a rather expensive piece of equipment called a spectrum analyzer. Reliable measurements require good knowledge of spectrum analyzers (and RF technology)
- Data rate*:* The best way to measure the data rate in a point-to-point network is by using a network analyzer or BER (bit error rate) tester. Also computers can be used.
- Internet throughput: Unfortunately, while there is compatibility testing, there are no consistent performance criteria across the industry. It, therefore, becomes rather difficult to compare the performance of different vendor offerings.

  To measure the Internet throughput, the Internet itself offers different websites you can use as a *reference.* However, be aware that they do not always provide a reliable measurement of your local link speed. The reason is that no speed test from an arbitrary remote server will tell you much about anything other than that particular route at that particular time under that particular server load, all things that can and do vary widely.

  The table below shows a few useful URLs active in January 2001:

  http://webservices.cnet.com/bandwidth
  http://speedtest.mybc.com
  http://www.2wire.com/services/bandwidth.asp
  http://msn.zdnet.com/partners/msn/bandwidth/speedtest500.htm
  http://206.170.44.66/
  http://www.people.cornell.edu/pages/dhl12/band.html

  To accurately measure the speed of your local link, download a large file (at least 1 Mbyte) from a local server under light load (e.g., Internet software from your ISP in the wee hours) and time how long it takes. When all the various overheads are taken into account, your binary FTP download speed in bytes per second will be about 1/10 of the raw link speed in bits per second (e.g., about 150 Kbytes/sec over 1500 Kbps link), assuming optimum configuration of your computer.

During a throughput measurement the proxy server (if any) must be disabled. If not, the proxy server receives the request for an Internet service (e.g. your speed test). If the request passes the filtering requirements, the proxy server, assuming it is also a cache server, looks in its local cache of previously downloaded Web pages. If it finds the page, it returns it to the user without needing to forward the request to the Internet. This means that not the throughput is measured but the efficiency of the cache.

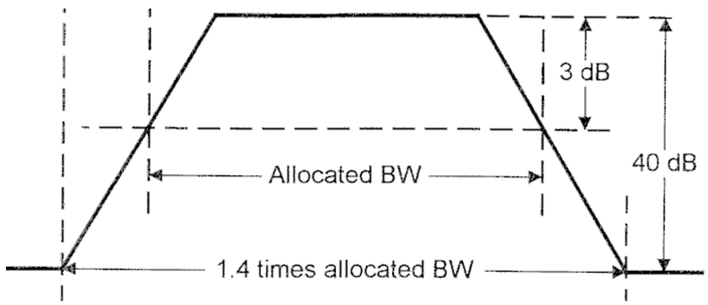
A proxy server is a server that acts as an intermediary between a workstation and the Internet. The proxy ensures security, administrative control, and caching service. A proxy server is associated with or part of a gateway server that separates the local network from the outside network (Internet) and a firewall server that protects the local network from outside intrusion.

2.5. Occupied bandwidth

Occupied Bandwidth (BW) is a measure of how much frequency spectrum is covered by the signal in question. The units are in Hz, and measurement of occupied BW generally implies a power percentage or ratio. Simple frequency-counter-measurement techniques are often not accurate or sufficient to measure center frequency. A spectrum analyzer as measurement tool is here indispensable.

2.6. Useable transponder bandwidth

The bandwidth and power for digital (bell shaped) carriers on the satellite is a matter of optimal use of the transponder resource; it's determined such that receivers hooked onto the dishes at home etc. get enough carrier to noise (C/N) ratio [dB], and not too much intermediation. A roll-off factor of roughly 1.25 - 1.5 times the Symbol Rate is assigned to them. Additional, to protect other satellite users from interference, the level of earth station emissions must be limited in the frequency range outside of the allocated bandwidth of the customer.



Standard, multiple carriers are spaced at 1.3 x Symbol Rate. Because of this, if not in saturation with one single carrier, the useable transponder bandwidth is roughly the given transponder bandwidth (common is 36 MHz or 54 MHz) divided by 1.2

Transponders are available with bandwidths of between 18 and 150 MHz. In general transmitting a broadband carrier to the satellite requires more uplink power than a small band carrier.

2.7. Used bandwidth in relation to modulation and coding

Standard order of modulation [m] is QPSK however 8PSK or 16QAM can be chosen to realize dramatic increase in the total bit rate passing through the satellite channel. The disadvantage is that more transmit power and transponder capacity is required.

Modulation	M	Relative Radiated Bandwidth
BPSK	1	1
QPSK	2	0.5
8PSK	3	0.33
16QAM	4	0.25

FEC or forwards error correction improves the quality of the signal and reduces the transmitted carrier level but increases the bandwidth of the transmitted signal. If Viterbi and Reed-Solomon coding is used the combined code rate CR is the product of the two and the bandwidth is increased by $1/(CR_{viterbi} \times CR_{reed\text{-}solomon})$.

$CR_{Viterbi}$	$CR_{reedsolomon}$	Relative Radiated Bandwidth
7/8	188/204	1
5/6	188/204	1.05
3/4	188/204	1.17
1/2	188/204	1.75

2.8. Carrier $_{(-3dB)}$ bandwidth

This is the effective transponder capacity on the satellite you need for the service. There is a direct relationship between the bandwidth [MHz], the symbol rate SR, the data rate DR, the order of modulation m and the code rates CR.

$$BW_{(3dB)} = DR / (m \times CR_{viterbi} \times CR_{reed\text{-}solomon}) \qquad (1)$$

$$SR = BW / 1.28 \qquad (2)$$

The useful bit rate [Ru] is the bit rate achievable on a transponder after MPEG2 multiplexing

$$Ru = SR \times (m \times CR_{viterbi} \times CR_{reed\text{-}solomon}) \qquad (3)$$

Examples of bit rates versus transponder bandwidth						
BW $_{(-3dB)}$ [MHz]	SR [Mbaud]	Ru 1/2 [Mbps]	Ru 2/3 [Mbps]	Ru 3/4 [Mbps]	Ru 5/6 [Mbps]	Ru 7/8 [Mbps]
54	42.2	38.9	51.8	58.3	64.8	68.0
46	35.9	33.1	44.2	49.7	55.2	58.0
40	31.2	28.8	38.4	43.2	48.0	50.4
36	28.1	25.9	34.6	38.9	43.2	45.4
33	25.8	23.8	31.7	35.6	39.6	41.6
30	23.4	21.6	28.8	32.4	36.0	37.8
27	21.1	19.4	25.9	29.2	32.4	34.0
26	20.3	18.7	25.0	28.1	31.2	32.8

Satellite transmission capacity

The symbol rates used on satellite systems are 22 Mega Symbols/s (abbreviated MS/s) in a 26 MHz transponder and 27.5 MS/s in a 33 MHz transponder respectively. As with QPSK modulation one symbol represents 2 bits, 22 MS/s correspond to a gross transponder capacity of 44 Mbps whereas 27.5 MS/s correspond to 55 Mbps. Because of the parity bits used for the error correction the actual useful data capacity is less than 44 or 55 Mps.

Audio and video is compressed into 8.448 Mbps. Added is an overhead of 16 bytes upon each packet of 188 bytes. Forward Error Correction adds a bit onto each 3, and then convolves (= mingles) those bits, so that's noted as FEC = 3/4. The modulation key (M-ary Phase Shift Keying) is nowadays mostly QPSK (M=4), which puts a di-bit on each transmitted symbol. Multiplying this all, you get a symbolrate:

Symbolrate = (bitrate + overhead) x (1 / FEC): (M/2)

So, Symbolrate = (8.448 x 204/188) x 4/3 : 2 = 6.111 MBd.

Now, the bandwidth and power for digital (bell shaped) carriers on satellite is a matter of optimal use of the transponder resource; it's determined such that receivers hooked onto the dishes at home etc. get enough C/N, and not too much intermediation (caused by the non linear transponder tube). A roll-off factor of roughly 1.5 times the symbolrate is assigned to them. In the example, this leads to a commercial lease bandwidth of 9.5 (MHz). For thin route traffic (= well below 1 Mbps) the factor could be diminished to 1.25, because they also get less power and thus less burden the transponder.

3. Earth station antennas

The initial gain in a satellite system, by far the most important gain for receiving and transmitting, is provided by the antenna. Depending on the purpose and the wavelength, antennas are made in various forms and sizes. To help to understand the relationship between antenna diameter and transmit or receive frequency, it is important to note that there is an inverse relationship between frequency and antenna diameter. As the frequency increases, antenna diameter decreases. This means that C band communications require larger dishes than Ka band. Satellite earth stations use dish diameters of 0.3 – 30 meters depending on the frequency and application

The primary specifications of an earth station antenna are given by shape, diameter, azimuth, elevation, fixed or tracking, de-ice system. It’s important that technicians appreciate the theoretical aspects of antennas, in order to react effectively when the antenna has to be repositioned or when setting up radio/HPA output power which relies on knowing the antenna gain and feed system losses.

3.1. Dish or parabolic antennas

Microwaves are nearly completely reflected by a solid metallic surface. When this surface is shaped into a parabola, almost all of the energy striking the parabola along its main axis is focused to a well-defined focal point. The main advantages of a parabolic antenna are as follows:

- In principle, they can be made to have as large a gain as is required.
- They can operate at any frequency.
- Small dishes require little set-up.

Disadvantages, however, are:

- Parabolic antennas are difficult to point accurately, limiting the frequency at which a dish can be used.
- Large dishes are difficult to mount and may have a large wind load figure.

Geometry

The basic principle of a parabolic antenna is that all the energy received by the dish is reflected to a single point at the focus of the dish or, in the case of transmitting, all the reflected output of the antenna feed is focused toward the satellite.

There is more illumination in the center area of the parabola and less near the edge.

Note that a dish or satellite reflector is generally incorrectly termed a satellite antenna. The true (receiving) antenna is actually the small probe inside the feedhorn that detects the reflected signal for relay to an LNA/B/C.

Satellite earth station antennas are usually of a segmented construction, the segments being high-pressure compression molded. Because earth station antennas can be shipped in segments, they offer significant savings for the customer in freight costs and are particularly easy to handle on site, reducing overall installation costs. Typically, the antenna is manufactured of RF reflecting material in the geometric form of a parabola. Spun or hydroformed aluminum/steel antennas are normally used for "cheap" TVRO applications. Fiberglass coated with RF reflecting material is more popular in the professional field. This type of antenna (e.g. Prodelin 1.8m and 2.4m) is relatively easy to assemble but heavy.

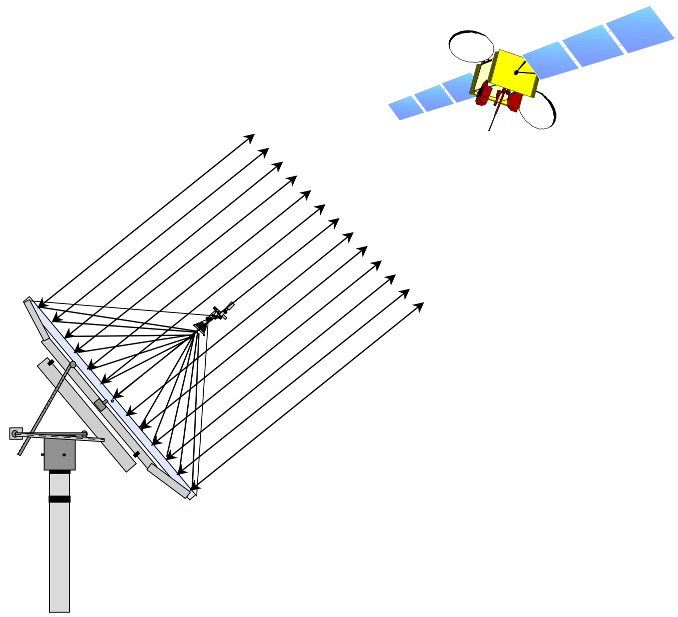
3.2. Parabolic antennas

There are two main types of parabolic antennas:

- Center feed antenna: Center feed antennas have the feed in the paraboloid. The major advantage of such configurations is that they are mechanically relatively simple, reasonable compact and, in general, fairly inexpensive.
- Offset antennas: An offset antenna is oval and the feed/ LNA/B/C has an offset from the center of the reflector. Because of its oval form, this type is more difficult to manufacture.

3.2.1. Prime focus antenna

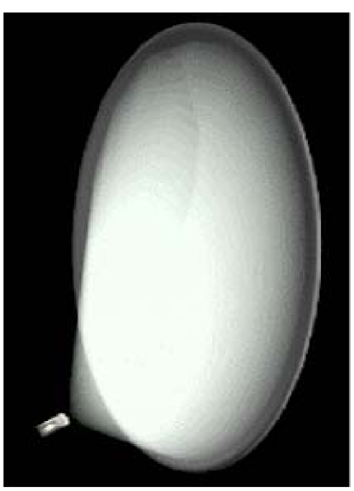
The prime focus antenna is round and has its feed/ LNA/B/C assembly at the focal point directly in front of the antenna. A prime focus antenna is easy to manufacture

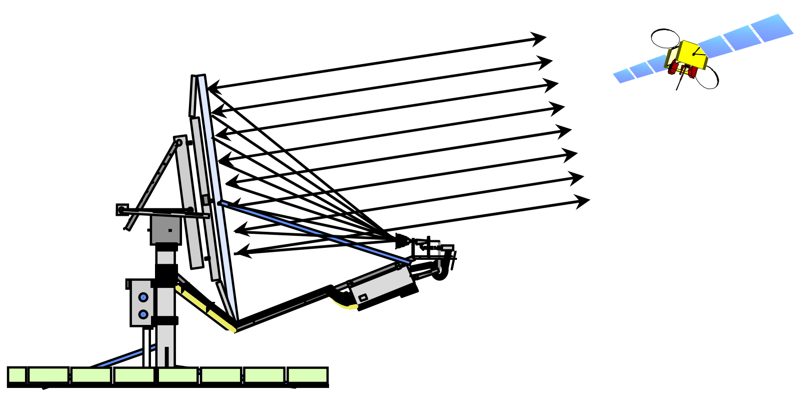


Prime focus antenna

3.2.2. Offset antenna

Offset fed antennas have smaller diameters (30 cm-4 m) and the feed is located below the lower edge of the offset block the antenna aperture. Offset antennas achieve a better radiation pattern because of less aperture blockage.





Offset antenna

3.2.3. Cassegrain antenna

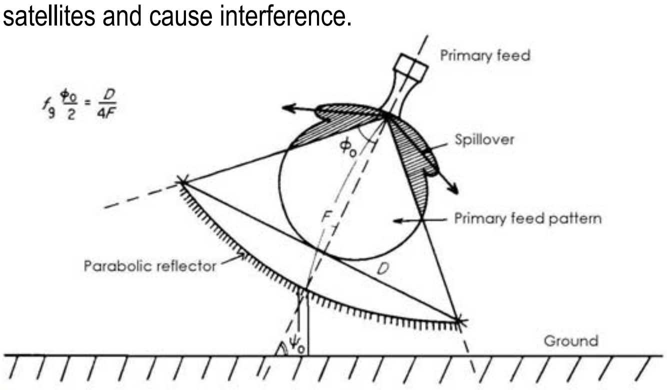
A Cassegrain antenna can be either center feed or offset feed and is a parabolic dish using a secondary hyperbolic sub-reflector. It achieves higher efficiency (because of better side lobe performance) than the primary types because the angle of the wave front entry to the feed horn is less. (The antenna principle is a sub reflector at the focal point that reflects energy to or from a feed located at the apex of the main reflector). The bigger earth station dishes are usually of this type of antenna.

Sub reflectors are usually only used at large dishes, when signal quality is an issue. They reduce noise caused by ground heat because the feed horn is not pointed at the Earth

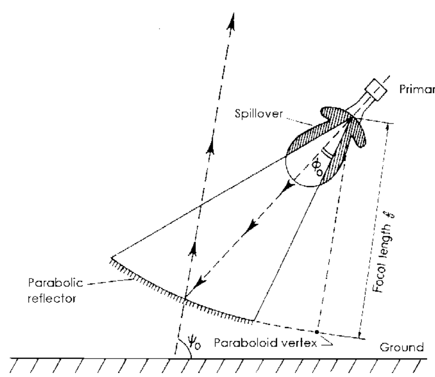
3.2.4. The differences between offset and prime focus antennas

The physical elevation for an offset antenna is normally about 20^{o} less than that of a prime focus antenna. The foreshortened elevation can be an advantage in more northerly latitudes where the antenna can be installed in an almost vertical position so that snow accumulation is minimised. Also, the antenna noise temperature is impacted favourably Prime focus dishes will tend to have higher antenna noise temperatures than offset fed dishes and especially more so than dual reflector dishes because, in as much as there is any spill over of the feed's reception pattern over the edges of the dish, the feed will be looking at the relatively high temperature ground (typically 290K), not at a low temperature object (the sky, 4K)..

Since an offset antenna feed is easier to tweak during cross-pol setting, offset antennas are preferred. Small offset antennas however have larger side lobes and a wider beamwidth than a prime focus antenna. Therefore, the antenna must be properly aligned on the main beam, rather than on a side lobe. Otherwise, signals radiate towards adjacent satellites and cause interference.



Prime focus antenna



Offset antenna

For antenna sizes up to about 2.4 meter offset feed offers higher efficiency. Above this it is difficult to make a low cost, stable construction and prime focus dishes tend to dominate. Dual reflector dishes are little used for small aperture TVROs (one of the main reasons is that the sub reflector obscures too much of the dish's effective aperture).

3.3. Azimuth and elevation

Any location on Earth is described by two numbers: its latitude and its longitude. On a globe of the Earth, lines of latitude are circles of different size. The longest is the equator, whose latitude is zero, while at the poles--at latitudes 90° north and 90° south (or -90°) the circles shrink to a point. On the globe, lines of constant longitude ("meridians") extend from pole to pole, like the segment boundaries on a peeled orange. For historical reasons, the meridian passing the old Royal Astronomical Observatory in Greenwich, England, is the one chosen as zero longitude.

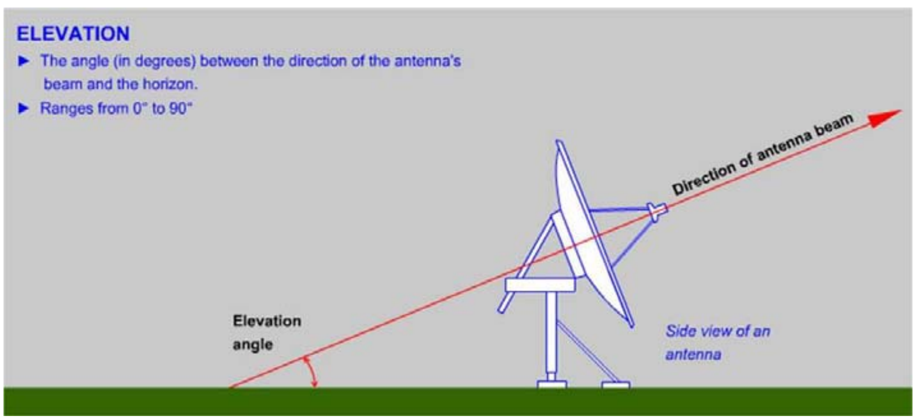
References to any satellite's orbital location, as well as to the intervals between adjacent satellites, are made in degrees of longitude. Keep in mind, however, that the geostationary orbit is a circle and the reference point for the calculation of degrees longitude is the Earth's center.

The conclusion is that if you want to point a parabolic antenna to a satellite only two parameters are required:

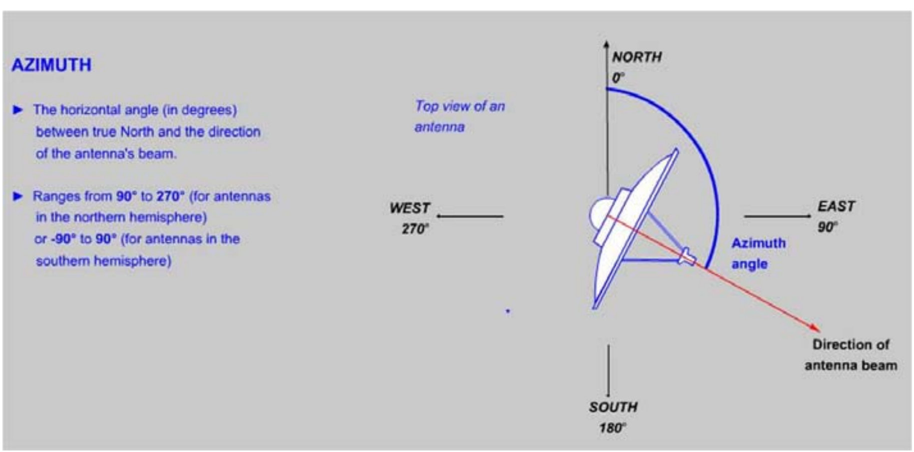
1. The longitudinal position of the satellite.
2. The longitudinal and latitudinal position of the antenna.

From those parameters the antenna's azimuth and elevation can be determined:

- Elevation: The vertical angle measured from the horizon up to a targeted satellite. When the beam axis is parallel to the ground, the elevation is zero. A 90º-elevation rotation points the beam to the zenith.



- Azimuth: Angle between antenna beam and meridian plane (measured in horizontal plane). The zero reference for measuring true azimuth is north, east is 90º, south is 180º and west 270º.



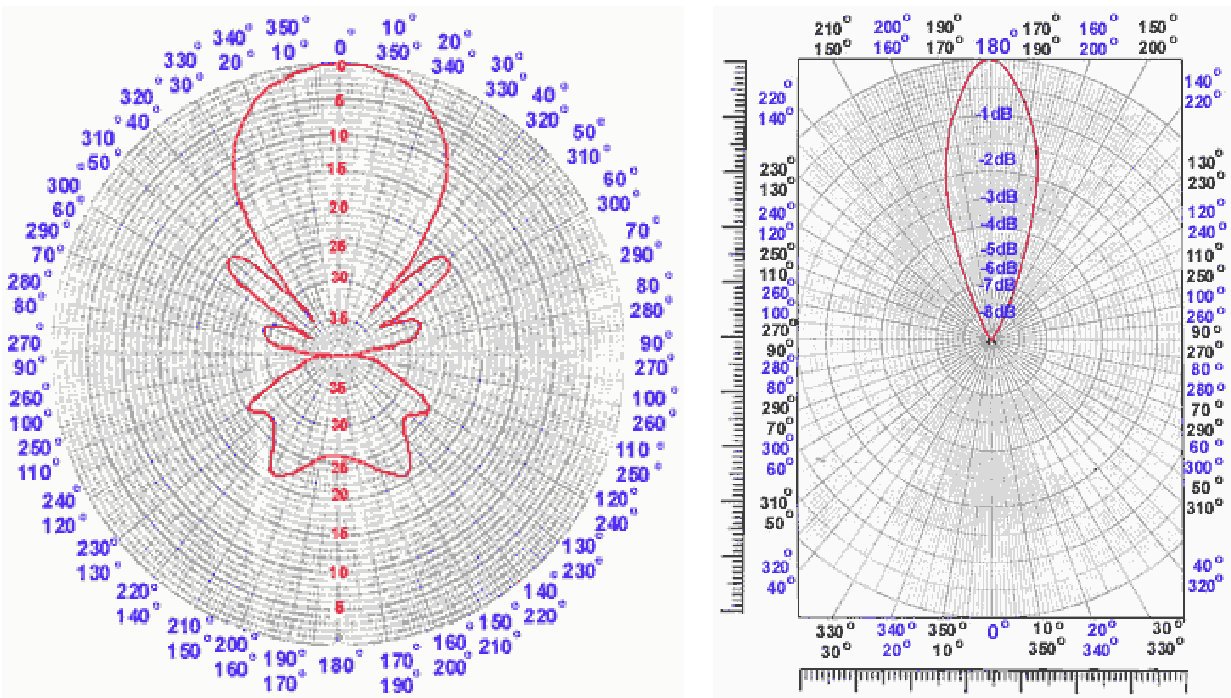
The elevation-over-azimuth pointing system is a universal method of describing the direction of a point on earth as well as points in space.

3.3.1. Antenna radiation pattern

Radiation patterns of an antenna depend on the type of antenna, the frequency, the polarization, and the efficiency of the antenna. On top of this, antenna performance is modified by the effect of ground-reflected energy. The performance also depends very much on the antenna construction and its surroundings. As a result, each individual (site) antenna has its own radiation pattern.

In general radiation patterns can be plotted in two ways:

1. *Field pattern* for the electric or magnetic field produced by the antenna
2. *Power pattern* in which the pattern amplitudes are proportional to the power density radiated by the antenna.



Example of a field radiation pattern plot

The radiation pattern for each parabolic dish is defined by its specified main lobe, or main beam. Depending on the antenna diameter, this beam is between 0.5 and 4 degrees wide. The pattern also has (undesired) side lobes, which in case of transmitting, radiate energy in an undesired direction or, in case of receiving, worsen the antenna noise temperature and thus the G/T. The radiation pattern is individual for every antenna but should meet the minimum requirements set by the International Radio Consultative Committee (CCIR) and/or the national regularity agencies.

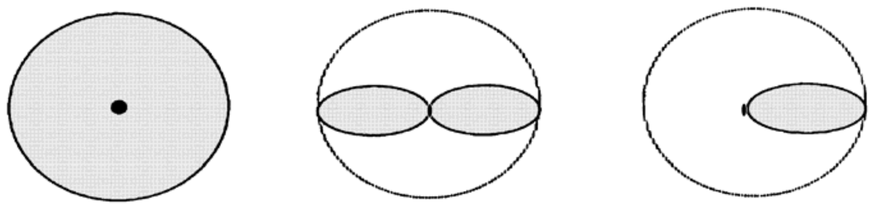
Effective Isotropic Radiated Power (EIRP)

Effective Isotropic Radiated Power (EIRP) is the product of power supplied to the antenna and the antenna gain, in a given direction. EIRP is the greatest at the bore sight (center of the beam) and decreases at angles away from the bore sight.

$EIRP_{transp}$ = Transmit $power_{transp}$[dB] + $Gain_{ant}$[dB] Higher satellite EIRPs permit the use of smaller receive antennas on the ground.

<u>Example:</u> An isotropic antenna is omni directional and has no gain. If the transmit power P_{tx}= 60 dBW (=1MW) the EIRP will be 60dBW + 0 dBi = 60 dBW.

Example: If an unidirectional antenna has 30 dB gain and Ptx = 30 dBW (=1 kW) the EIRP will be then 30 dBW + 30dBi = 60 dBW.



Radiation patterns of an isotropic antenna (left), bi-directional (middle) and unidirectional antenna (right)

The isotropic antenna is a hypothetical loss free antenna having equal radiation intensity in all directions. The make believe antenna is a convenient reference for expressing the directional properties of actual antennas. EIRP can also refer to the signal strength transmitted from a VSAT towards the satellite, but is usually referred to as an earth station EIRP (E/S EIRP) or a VSAT EIRP.

3.3.2. Antenna gain

The isotropic antenna is a hypothetical loss free antenna having equal radiation intensity in all directions. The make believe antenna is a convenient reference for expressing the directional properties of actual antennas. The gain of every antenna is always relative to an isotropic antenna and therefore, expressed in dB(i). The gain (G) of a dish antenna depends on a few parameters:

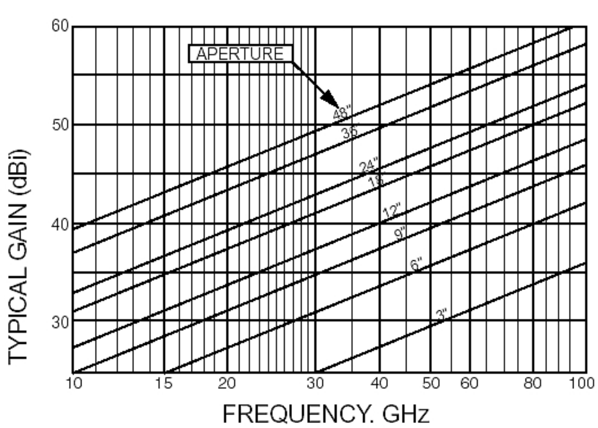
- Match between the feedhorn and the parabolic surface.
- Size or diameter D [cm] of the aperture.
- Type of surface (accuracy) or efficiency E (%) (Common E=55-65%)
- Wavelength λ (cm)

Or in a formula:

$G=10\log\{E(\pi D/\lambda)^2\}$ [dBi]

G	= antenna gain (dBi)
D	= antenna diameter (cm)
λ	= wavelength (cm)
E	= antenna efficiency (%)

Example: a Prodelin 2.4 meter 12 GHz antenna with efficiency of 55% has a gain of 47 dBi.



Relationship between aperture diameter [inches] and gain [dBi] and frequency [GHz]. Each time the diameter of a dish or the used frequency is doubled, its gain is quadrupled (= 3 dB), other things being equal.

3.3.3. Antenna efficiency

Efficiency is an important factor in antenna design. Special techniques are used to optimise the efficiency of earth station antennas. Antenna efficiency is affected by:

- The power which is radiated in the side lobes (see 9.2.9)
- Illumination efficiency, which accounts for the non-uniformity of the illumination and phase distribution across the antenna surface
- The quality of the main reflector and sub-reflector if any
- Feed supporting structure blockage

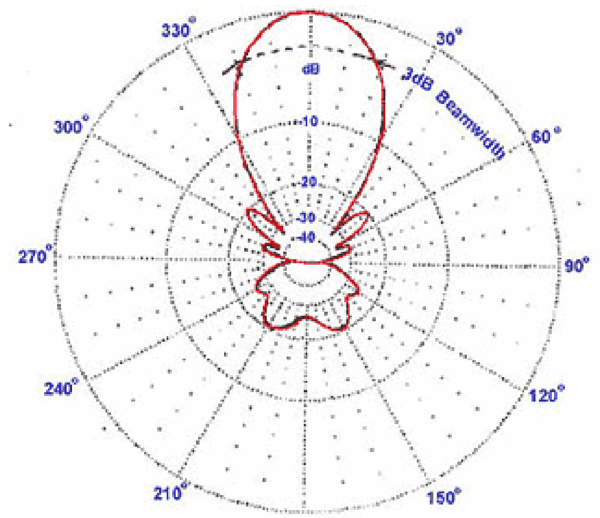
Aperture efficiencies between 55% and 65% are typically attainable.

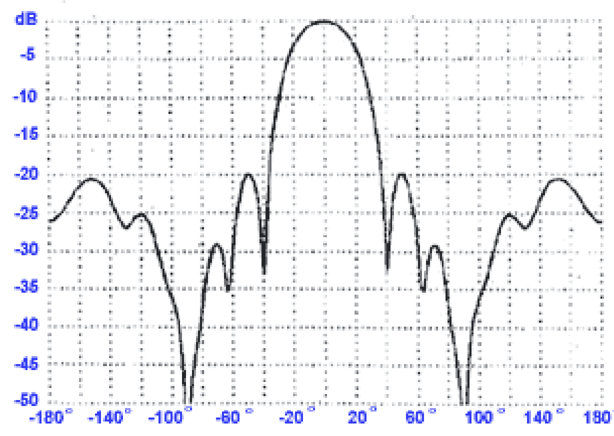
3.3.4. Beamwidth

The beamwidth is a measure of the angle over which most of the antenna gain occurs, it's typically defined with respect to the *half power beamwidth* or –3dB point of the main lobe in the antenna radiation pattern. An approximate but very useful formula for the 3 dB antenna beamwidth is:

Beamwidth = 70λ / D. Narrowness of the beamwidth tends to be a limiting factor for the size of an antenna.

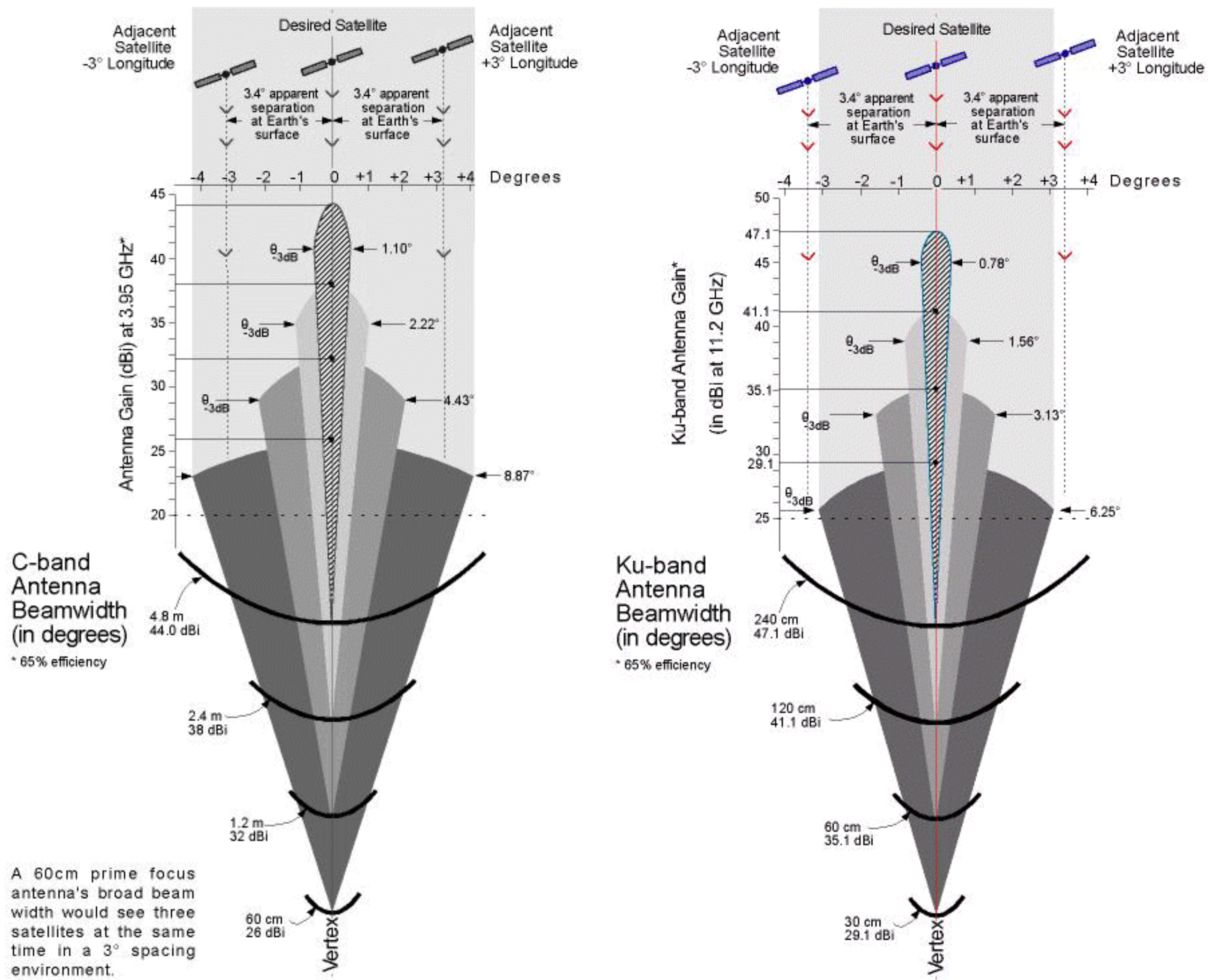
λ = the wavelength of the incoming signal (cm)
D = the antenna diameter (cm)





Example: a 2.4-meter antenna has, for a frequency of 12 GHz, a 3 dB beam width of 0.73° and a 1.8-meter antenna has a 3 dB beam width of 0.97°.

Dish antennas are wideband devices. As seen from the gain equation for a given diameter, the gain of the dish will increase as the frequency of operation increases. However operation away from the design frequency will normally result in impaired performance due to the limitations of the feed system.



3.3.5. Side lobes

Most of the power radiated by an antenna is contained in the so-called "main lobe" but a certain amount of power can be transmitted or received in off-axis directions. Side lobes are an intrinsic property of antenna radiation and cannot be completely suppressed. However Side lobes are also do to antenna defects which can be minimized with proper design

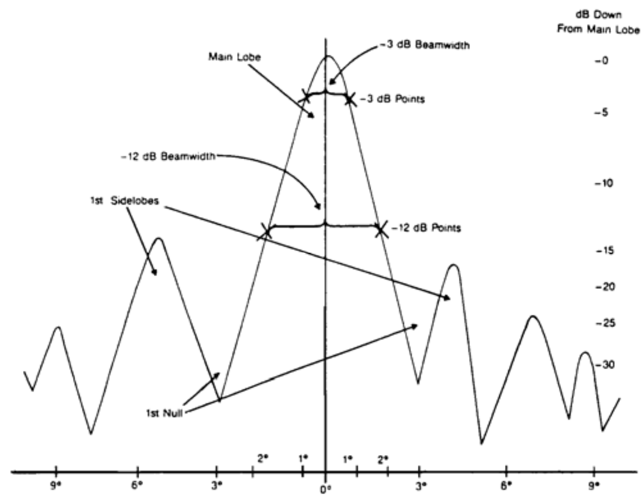
The most important parameters used in determining parabolic antenna performance are:

- The main lobe gain.
- -3 dB points.
- The first null.
- Cross-pol performance.
- Side lobes.

A Side lobe is (an undesired) parameter used to describe an antenna's ability to detect off axis signals. The larger the side lobes, the more noise and interference an antenna can detect.

The side lobe performance of an antenna is mainly defined by:

- Blockage effects.
- Feed spill over.
- Edge diffraction of the reflector.
- Edge illumination of the reflector.



Typical parabolic antenna radiation pattern

After the installation of a VSAT it is absolutely required to do a side lobe performance test. You not only check the overall installation quality, but it also avoids you from transmitting power towards the wrong satellite. In footprint areas with high EIRP levels good reception might be possible even when a side lobe is aligned on a satellite, at least until rain falls and signal attenuation increases.

3.3.6. Antenna noise

Antenna noise temperature is essentially a measure of how much noise the antenna system detects from the surrounding environment. A typical antenna noise temperature lies in the range, 50K to 100K. However, the overall noise temperature depends upon the direction in which the antenna is looking. At *lower look angels (<7°),* antennas begin to pick up noise caused by the ambient temperature of the earth. Since the warm ground emits radiation, noise temperature increases as an antenna is pointed at regions progressively further from the equator. Near the equator, the sun is the main noise source. In addition, less efficient antennas pick up more noise through relatively larger side and back lobes.

Sky noise temperature 'seen' by an antenna	
Sun	6000 K
Moon	20 K
Average star	1/2 k

Since the earth radiates noise, there is a look angle at which satellite signals can no longer be demodulated. As a result, the practical limit for viewing satellites is at an elevation of about 5 degrees above the horizon. Larger antennas detect less noise because they have smaller side lobes and a narrower main lobe.

Antenna noise generally will not be a major component of total system noise unless very low noise LNCs are being used.

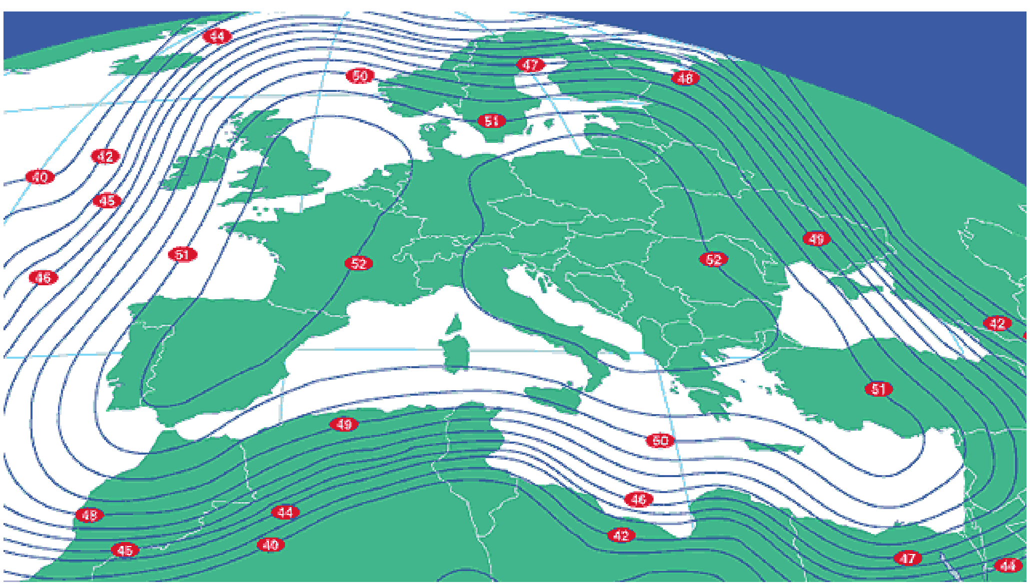
3.4. Recommended dish sizes

Antenna sizes are valid for high quality solid aluminum dishes (not mesh wire)

EIRP	LNB Noise in dB			EIRP	LNB Noise in dB		
	0.6 - 0.7	0.8 - 1.0	1.1 - 1.3		0.6 - 0.7	0.8 - 1.0	1.1 - 1.3
35 dBW	300 cm	360 cm	480 cm	50 dBW	60 cm	60 cm	65 cm
36 dBW	240 cm	300 cm	360 cm	51 dBW	55 cm	60 cm	60 cm
37 dBW	180 cm	240 cm	300 cm	52 dBW	50 cm	55 cm	55 cm
38 dBW	150 cm	180 cm	240 cm	53 dBW	50 cm	50 cm	55 cm
39 dBW	135 cm	150 cm	180 cm	54 dBW	45 cm	50 cm	55 cm
40 dBW	120 cm	135 cm	150 cm	55 dBW	40 cm	45 cm	50 cm
41 dBW	120 cm	120 cm	150 cm	56 dBW	38 cm	40 cm	44 cm
42 dBW	110 cm	120 cm	135 cm	57 dBW	36 cm	38 cm	41 cm
43 dBW	99 cm	110 cm	120 cm	58 dBW	34 cm	36 cm	38 cm
44 dBW	90 cm	99 cm	120 cm	59 dBW	32 cm	34 cm	36 cm
45 dBW	90 cm	99 cm	99 cm	60 dBW	30 cm	32 cm	34 cm
46 dBW	80 cm	90 cm	99 cm	61 dBW	28 cm	30 cm	32 cm
47 dBW	75 cm	90 cm	90 cm	62 dBW	26 cm	28 cm	30 cm
48 dBW	60 cm	75 cm	75 cm	63 dBW	24 cm	26 cm	28 cm
49 dBW	60 cm	60 cm	65 cm	64 dBW	22 cm	23 cm	25 cm

To help to understand the relationship between antenna diameter and transmit or receive frequency, it is important to note that there is an inverse relationship between frequency and antenna diameter. Higher frequencies have shorter wavelength than lower frequencies: This implies smaller microwave components and subsystems (antennas). This means that C band communications require much larger dishes than Ka band systems. In general satellite earth stations use dish diameters of 0.3 – 30 meters depending on the frequency and application.

The wavelength at Ku band is about 2.5-cm (1 inch) compared to 7.5 cm (3 inches) at C band. As a result, a 1m dish at Ku band has approximately the same gain as a 3m antenna at C band.



Footprint map (Sirius 2) clearly indicating EIRP levels

3.5. Antenna de-ice system

Ice buildup on the antenna reflector and feed horn affects transmission and reception between the satellite and the earth station by decreasing signal strength. Antennas in localities where there is likely to be ice buildup require anti-icing equipment.

Ice buildup on the antenna back panel

Ice buildup on the antenna reflector

3.6. Antenna mounts

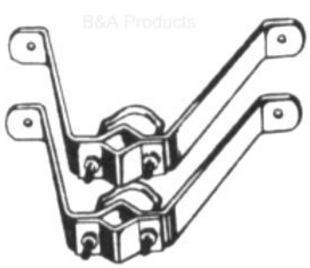
An earth station typically requires a rigid steel backing structure combined with an accurate dish surface and fitted with the necessary bearings, gears and drives to enable pointing accuracy to the satellite within a few fractions of a degree. Every site requirement is different and therefore various types of standard antenna mounts are available. In general, either a roof, wall or ground mounting can be used. It depends upon such factors as the look angle to the satellite, security requirements, physical characteristics of the site (roof), etc. The configuration selected must provide adequate structural support and rigidity as specified in the vendor's manual.

The roof top installation enhances security by limiting access to the outdoor equipment to authorised personnel and provides the height to clear local obstructions for the signal path. The roof mount option can be either penetrating or non-penetrating in design. Another-less preferable- option is wall mounting.

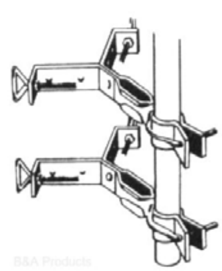
3.6.1. Wall mounting

Wall mounting the antenna offers limited access to the equipment while avoiding placement on the roof and is useful in a variety of situations. A wall mount is often a custom designed installation. Generally, wall mountings are only approved for use on solid concrete walls or concrete block walls that are filled with concrete. When mounting bolts pass through the walls, backup plates are required. Alternately, the mount may be attached to a vertical steel beam. For the antenna quick re-point feature to be usable, the mount must permit the antenna to move through the required range of azimuth without being limited by the antenna reflector striking the wall.

One option is to attach the wall mount so that the reflector is above the roofline. The antenna must also be mounted in a way that allows easy service access.



Wall mount



Chimney mount

3.6.2. Penetrating (roof) mount

This type of mounting can be either welded or bolted to suitable structural members of the building. Another option is to attach the antenna to a suitable roof mounted pole which has been provided by the customer. This option is typically used when installations are associated with a newly constructed building.

Example of a penetrating roof mount

3.6.3. Non-penetrating mount

The use of a non-penetrating mount (NPM) is preferred and provides a method for an antenna to be mounted on the roof (or other flat surface) when penetration of the roof barrier is not feasible. This non-penetrating mount is easy to assemble, offers low uniform load distribution, minimum settlement into the roof barrier, and is compatible with many types of flat roof constructions. Generally, the NPM's are not physically attached to the building and use the weight of ballast (such as concrete blocks or block caps) and specially designed braces to hold the mast vertical and to avoid moving.

Non-penetrating roof mount and sufficient ballast.

3.6.4. Antenna mount stability

The most common causes for antenna deflection and resulting beam pointing errors are:

- Flexing of the supporting structure
- Settling of the antenna mounting
- Loosening of the assembly due to weather and wind conditions
- High winds or gusting wind conditions
- Satellite movement (rarely)

In general, the amount of allowable deflection varies inversely with the size of the antenna reflector. For example, the 2.4m antenna has less allowable deflection compared to the 1.8m antenna as shown in the table.

Size (m)	Deflections in Degrees
0.75	0.60
1.0	0.40
1.2	0.30
1.8	0.20
2.4	0.15

When a non-penetrating mount is used it is extremely important that there is enough ballast to secure the installation.

4. Signal polarization

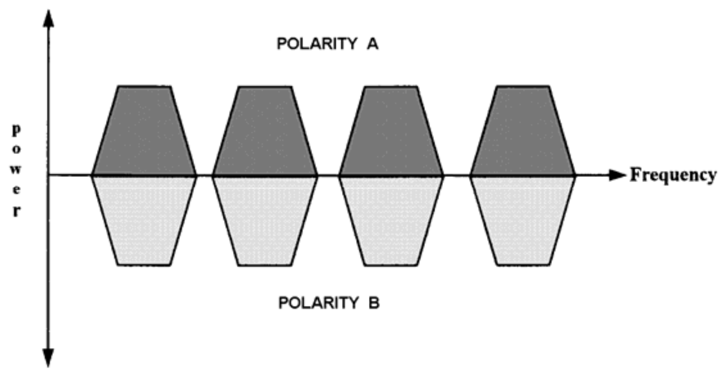
For a good understanding how antenna feed systems work it is important to know that all electromagnetic waves are polarized. Polarization is determined by the orientation of the electric and magnetic fields radiating from the transmitting antenna. If polarization is used two different signals can be transmitted in the same frequency range without interference, even if they overlap in frequency. In this way, twice the number of channels can be transmitted in a given bandwidth (frequency reuse).

Example: Conventional over-the-air television broadcasts are horizontally polarized; therefore, TV antennas must be oriented horizontally in order to receive the TV broadcast signals. If the TV antenna is rotated by 90 degrees to a vertical position, the signals cannot be received and the TV reception becomes poor.

Satellite (and radio and television) signals can be transmitted using one of four different polarization formats:

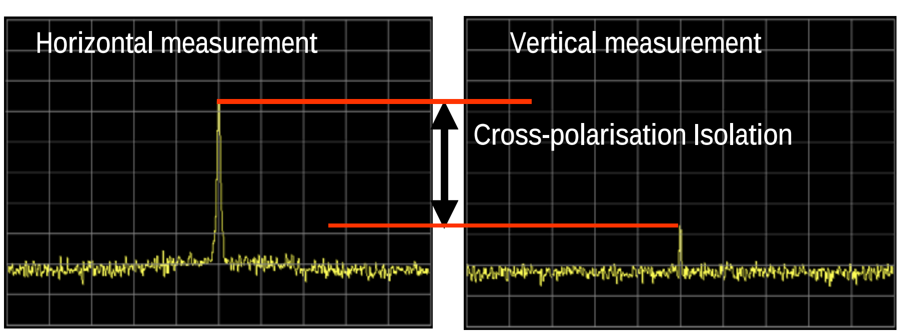
- Linear horizontal
- Linear vertical
- Circular clockwise or left hand circular (LHCP)
- Circular counterclockwise or right hand circular (RHCP)

In the case of satellite and microwave communications, regardless of the polarization, all dishes reflect the incoming signal to one focal point where the feedhorn is located. The feedhorn collects the energy and directs the microwaves via a waveguide to the "actual" antenna, usually a small probe precisely positioned within the waveguide. The position of this probe determines which sense of (linear) polarization is transmitted to the LNB. In some installations, the feedhorn has the capability of receiving the vertical and horizontal transponder signals simultaneously, and routing them into separate LNAs for delivery to two or more receivers.



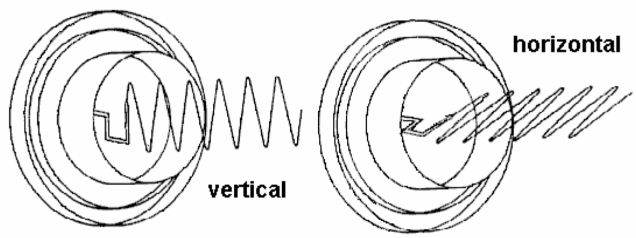
Satellite transponder spectrum showing frequency reuse

The isolation between the two planes is expressed in dB. A minimum power isolation of 30 dB between, *e.g.*, horizontal and vertical is mandatory. If isolation is not sufficient this may introduce cross-pol interference resulting in bad link performance.



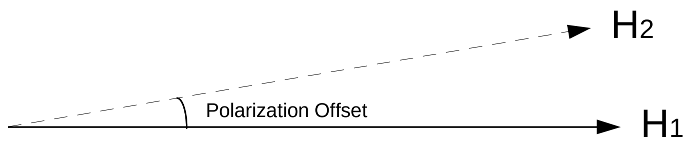
4.1. Linear; horizontal or vertical polarization

Horizontally (parallel to the ground) and vertically (perpendicular to the ground) polarized signals vibrate at 90° relative to each other.



The polarization *angle* depends on the location of the earth station. Because of depolarization, an offset of more than 20° (referring to the horizontal or vertical axis) is common. Circular polarized signals do not have this “problem”.

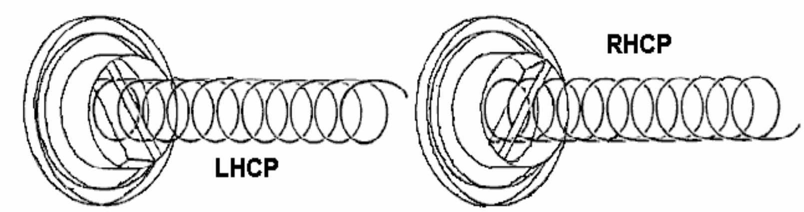
Depolarization is the twisting of the polarization of a satellite signal as it passes through the atmosphere (Due to ionic layer propagation)



<u>Example:</u> the signal leaves the satellite in the horizontal plane (H1) and arrives at the earth station with a certain offset (H2). This offset depends on the location of the earth station. The offset or polarization angle can easily be found in the Field Installation Manual. The offset indicates the exact position of the feedhorn.

4.2. Circular; left hand (LHCP) or right hand (RHCP) polarization

Circular polarized waveforms vibrate in one plane and travel like a corkscrew through space with the electric field rotating clockwise.



A linearly polarized antenna receives 3 dB fewer decibels of power for a given circular polarized signal than would be received by a circular polarized antenna of the same size and the correct rotation sense.

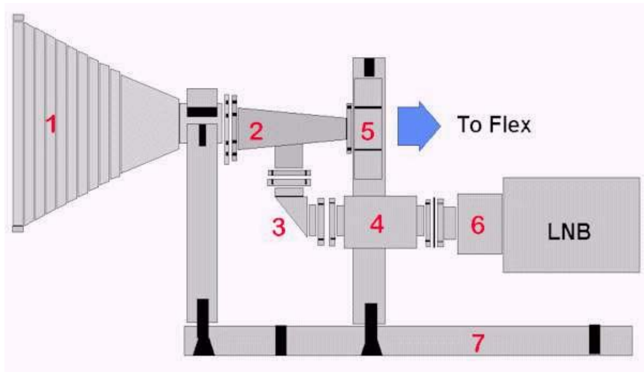
An antenna may radiate unwanted energy in a polarization, which is different from the polarization in which the antenna is intended to be used. This unwanted radiation is known as cross-polarization. The feedhorn must be set precisely to minimize cross-pol interference and receive signal loss. Care must be taken in the design and installation of earth station equipment to avoid transmitting or receiving on the wrong polarization.

5. Typical antenna feed construction

The antenna feeds of all earth stations perform the same basic functions, which are:

- To shape the beam in order to provide the required uniform illumination of the main reflector (main function of feedhorn)
- To separate the transmit and receive signals with minimum loss and interference (main function of OMT)

Basically with VSAT installations two types of antenna feed constructions are in use. Most common is the standard feed construction with either a LNC (for IF applications) or a LNB (for L band applications). With standard feeds the TX polarization is always opposite from the RX polarization. Occasionally the assigned TX and RX frequencies do have the same polarization and a co-pol feed is used.

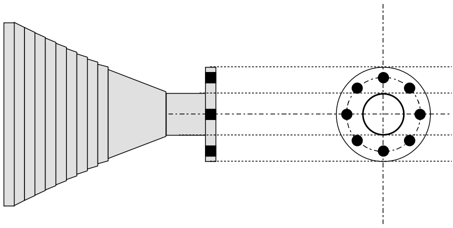
Feed system with feedhorn and redundant LNC

A typical offset antenna feed construction normally consists of:

1	Feedhorn
2	OMT
3	90º Waveguide
4	Transmit Reject Filter
5	Donut
6	LNB or LNC
7	Cradle
8	(Flexible) Waveguide / transmission line to the radio

5.1. The feedhorn

Proper installation and adjustment of the correct feedhorn is critical to the system performance. It is particularly important if you are installing a feedhorn that receives Ku band signals. An antenna Ku band feedhorn must be placed within 0.25 inch = 0.64 cm of the specified location to meet the expected system performance (G/T).



Example C band feedhorn

Example Ku band feedhorn

The size of the feedhorn depends not only on the frequency (C band feedhorns are three times bigger than Ku band feedhorns) but also on the f/D of the antenna. The f/D ratio is the focal distance of the dish (f), divided by the diameter (D). Besides, offset antenna feedhorns are not interchangeable with prime focus antenna feedhorns.

In order to obtain maximum efficiency the feedhorn must be at the correct distance from the center of the dish, properly oriented, centered and perpendicular to the plane of the antenna. Only if the feedhorn is exactly in the focal point of the antenna it can collect a maximum of signal and picks up a minimum of environmental noise. Offset antenna feedhorns are not interchangeable with prime focus antenna feedhorns.

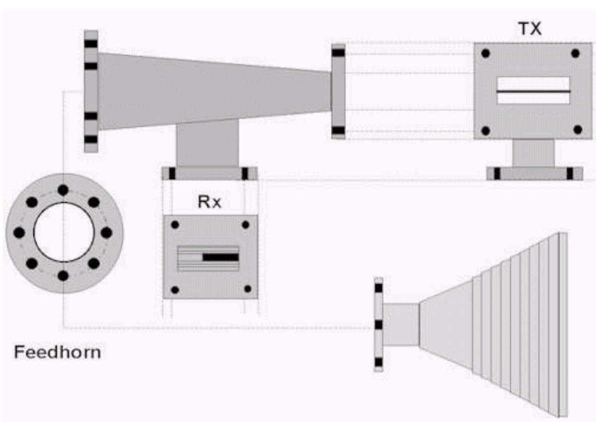
5.2. The OMT or diplexer

OMT stands for Ortho Mode Transducer also known as diplexer. This device can transmit and receive signals to co-exist in a common waveguide unit with minimum interaction between the two. This enables the removal of energy at the receive frequency with no resultant effect on the transmit frequency.

The OMT consists of a circular section of waveguide with a rectangular branch section. The rectangular opening behaves as a low impedance to one component and a very high impedance to the other one.

Be advised that a bad OMT can be one of the reasons for not meeting the cross-pol specifications (isolation better than 30 dB). Very important for the performance is that the inside surface is undamaged and feels smoothly. Since the OMT is a mechanical device this is very easy to check.

To divide signals of both horizontal and vertical polarization the LNB/C (RX section) and the High Power Amplifier (TX section) can be fed in parallel via an OMT in the manner indicated in the figure below.



Typical example of an OMT

5.3. The transmit reject filter

The incoming RF downlink signal passes through a 14 GHz (Ku band) transmit reject filter (for C band this is 6 GHz) before it enters the LNB or LNC. The (low pass) transmit reject filter is necessary to avoid uplink signal at the input of the LNA and is typically connected to the receive port of the OMT. This filter provides isolation of better than 50 dB over the transmit bandwidth.

No filter at the input can give intermodulation products in the received signal or more badly permanent damage to the first input stage of the amplifier. The implementation of a transmit reject filter is only necessary if the LNB/C is used in combination with a transmit device.

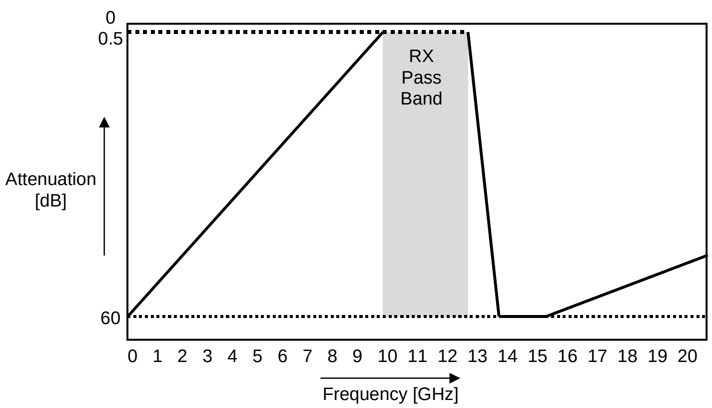


Diagram of a Ku band transmit reject filter

Example of a C band TRF

Typical TRF Specs:	Ku band	C band
Passband:	10.5 to 12.75 GHz	3.7 to 4.2 GHz
Passband insertion loss:	0.15 dB typical	0.1 dB typical
Rejection of:	14.0 to 14.5 GHz: 70 dB min	5.9 to 6.4 GHz: 60 dB typical

5.4. Transmission lines or waveguides

In a closed system electrical energy is normally made to flow down a wire or cable. However at microwave frequencies the attenuation of such a transmission line cannot be tolerated, hence an alternative means of transmission has to be used. Waveguide, as the name implies, is a device that guides a radio wave along its length thereby providing a low loss transmission path for microwave energy.

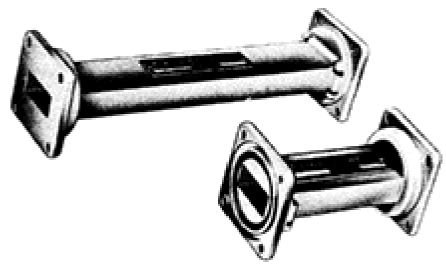
Attenuation due to conductor losses and dielectric losses increase with frequency. These losses can be reduced with the use of larger diameter inner conductor and an air-spaced dielectric respectively. Above 3 GHz the attenuation of coaxial cable is approximately 5 times that of a waveguide. While a coaxial cable is a wide band transmission line, the waveguide can be used only from a determined low frequency called "cutoff" frequency

A waveguide has the same function as a coaxial cable however at frequencies above about 1500 MHz, the losses in coaxial transmission lines become unacceptably high and therefore waveguides are commonly used. Although waveguides are physically larger, mechanically stiffer and more expensive than coax, these disadvantages are easily out-weighed by the low losses at microwave frequencies. Waveguides can be either flexible or rigid depending on the application. Flexible does not mean indestructible. Be aware of this while mounting a flexible waveguide to the radio and the OMT!

We know two types of waveguides:

1. <u>Circular waveguide,</u> which is transparent to linear polarization and discriminate between left and right hand rotation. This one is used to relay signals from the antenna into the feed or vise versa.
2. <u>Rectangular waveguide</u>, which is a polarized transmission line and discriminates between vertical and horizontal waves. This one is used to route signals to the LNB or HPA.

Waveguide acts like a high pass filter, because at some low frequency a critical wavelength occurs where the energy is simply reflected back and forth across the guide so that propagation ceases. A waveguide must be of a specific size and shape to match the frequency band of interest.



Typical example of rigid wave guides

5.5. Co-pol feed construction

It may happen that receiving and transmitting in the same polarization format is required. Except of the OMT, the feed construction as described above before will be used. The only difference is that the OMT is replaced by a co-pol. Because of its mechanical construction a co-pol feed makes it possible to transmit and receive simultaneously in the same polarization plane.

Co-pol feed Construction

5.6. Inverted feed construction

TBW

Standard Installation with inverted feed

6. Down Converters - LNA / LNB / LNC

6.1. LNA or Low Noise Amplifier

The LNA or Low Noise Amplifier is the heart of every satellite system and is the preamplifier between the antenna and the earth station receiver. The LNA is especially designed to contribute the least amount of thermal noise to the received signal. The gain is typical 50 - 100 dB. The LNA is normally a part of the LNB (Low Noise Block converter) or the LNC (Low Noise Converter). For maximum effectiveness, it must be located as near the antenna as possible, and is usually attached directly to the antenna receive port.

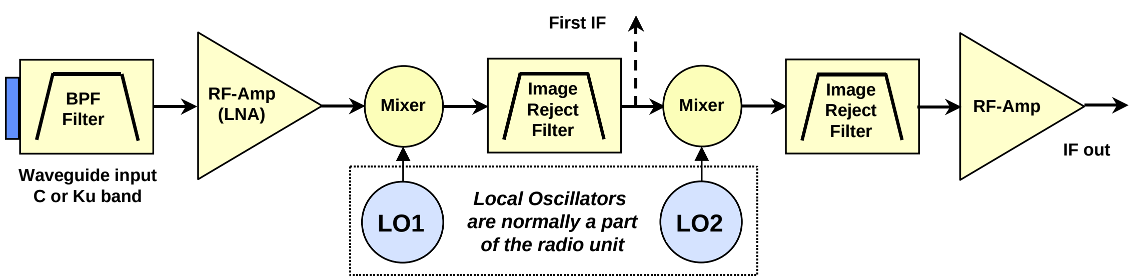
LNA provides no down conversion and is normally a part of the LNB or LNC. If the LNA is of poor quality even an antenna as large as six meters will not produce any good signals. In order to function properly, the LNB or LNC must be correctly attached to feedhorn and to the OMT/waveguide combination.

6.2. LNC or Low Noise Converter

A LNC is a combination of a LNA and down converter, which receives RF signals from satellites and converts them into IF used by demodulators. Typically a LNC requires external mixing signals for down conversion.

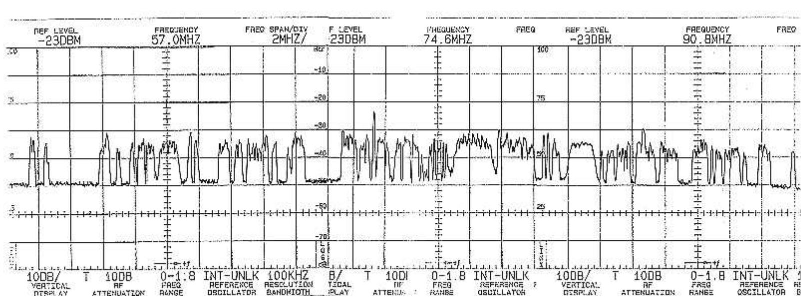
The primary function of a LNC is to down convert the received RF signal to an IF signal for use by the demodulator. IF stands for Intermediate Frequency, usually a frequency between 50 MHz and 90 MHz.

The quality of the LNC depends very much on the combination of noise factor and overall gain. The noise factor for a Ku band LNC is in general between 110°K (good) and 160°K (usable). For C band this figure is slightly better. Normally the overall gain is fixed and about 80 dB +/- 5 dB (SSE). Sometimes the gain can be set between 80 - 100 dB (Anacom). The figure below represents a basic configuration of a C- or Ku band LNC.



Basic configuration of a LNC

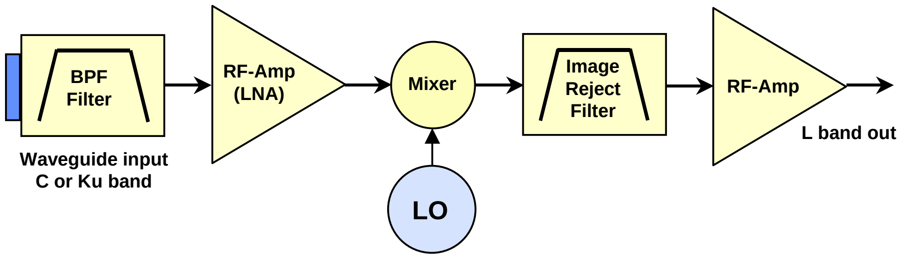
The LNC receives its power and two (sometimes 3) local oscillators via separated cables from the radio device. One of the local oscillators needs to be programmed to obtain the desired frequency conversion. Be advised that some of the LNCs support different operating frequency ranges. The operating frequency range is the range of frequencies over which the LNC will meet or exceed the specification parameters.



Spectrum analyzer display of a LNC output; Telstar 11 Transponder 1

6.3. LNB or Low Noise Block Converter

The LNB is relatively inexpensive receiver component, which converts broadband data and video signals on satellite downlinks to L band frequencies. It receives its power via the coaxial cable and no external local oscillators signals are required for down-conversion. You can use two types of LNB's. The main difference can be found in the type of local oscillator; PLL (stable and expensive for small band applications) or DRO (free running and cheap for broadband applications).



Basic configuration of a LNB

A perfect, but theoretical, amplifier (or LNA/B/C) has a noise temperature of 0ºK, so that it would add no noise to the signal it is amplifying. Since all amplifiers add (thermal) noise, the signal or carrier-to-noise ratio at the amplifier's output is degraded. Practical LNA/B/Cs are rated by the noise they add to the signal. The lower the noise temperature, the less noise is added by the LNA/B/C.

While most C band LNBs are rated by noise temperature, Ku band LNBs are generally categorized by noise figure (or noise factor). Common noise temperatures for C band LNBs are in the 25-30 degree (0.4 dB) range while Ku band LNBs below 0.8 dB (59ºK) are rather sophisticated. Test data is supplied at +23ºC unless specified otherwise.

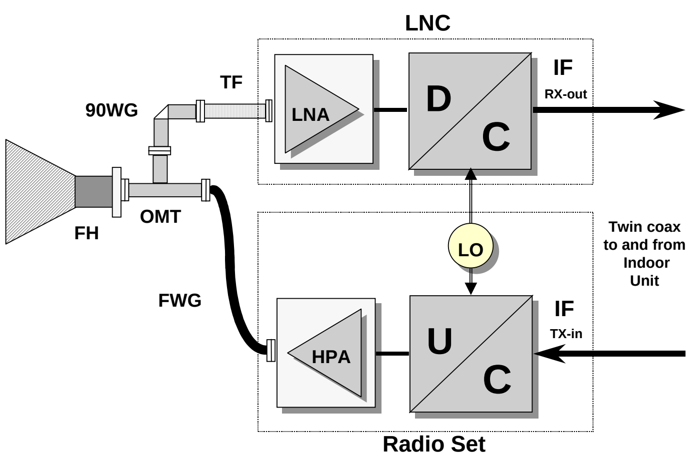
Examples of typical LNBs

7. The radio unit or transceiver

The transceiver is comprised of a low noise converter (LNC) or a low noise block converter (LNB) and a driver unit. The driver unit contains the power supply, up converter, synthesized frequency sources for the LNC, monitor and control (M&C) circuitry, and solid state (= semiconductor) power amplifier (SSPA). The up converter converts 70 MHz IF to a Ku band or C band frequency. The overall transmit gain depends very much on the maximum specified output power. Typical standard SSPA's support an output power of 2W, 4W, 8W, 16W or 25W. The Ortho Mode Transducer (OMT) or diplexer and waveguide (WG) separate and conduct the transmit and receive signals which normally have an opposite polarization format to each other.

Ku band radio and feed construction

C band HPA and feed construction



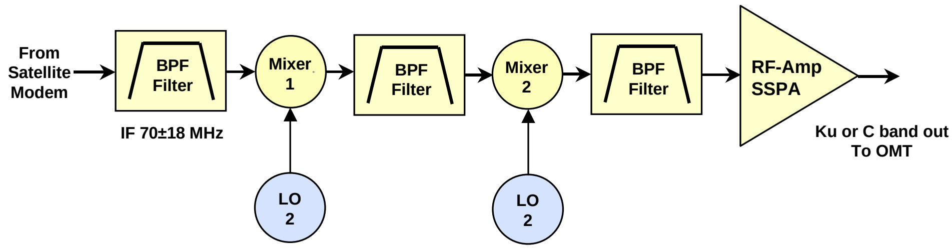
FWG:	(Flexible) Waveguide	DC:	RX down converter
FH:	Feedhorn	UC:	TX up converter
OMT:	Ortho Mode Transducer	LNA:	Low Noise Amplifier
LO:	Local Oscillators (1,2, or 3)	HPA:	High Power Amplifier (Solid State)
TF:	Transmit Reject Filter	90WG	90 Degrees Waveguide

Most of the radios used for VSAT are based on the same principal and designed for a two-way satellite communications system that operates in the C or Ku or Ka band. Due to the importance of Ku only this frequency range will be highlighted.

7.1. The radio system

The three primary functions of the Radio *or* Radio Frequency Unit (RFU) *or* Transceiver (TRX) are:

1. To up convert and amplify the satellite modulator's IF output to a RF signal for transmission via an antenna.
2. To provide the local oscillators for up conversion and down conversion (by the LNC)
3. To process and display alarm signals.



LO: Local Oscillator
BPF: Band Pass Filter
SSPA: High Power Amp.

Functional block diagram of the RFU

The RFU up converts, in two or more steps, an IF signal from a modulator to a RF frequency in the C- or Ku band. After filtering the high power amplifier (HPA) provides signal amplification as a final step before transmission. Solid state amplifiers (SSPA) generally support an output power up to 40 W. Higher output powers (>40 W) require traveling wave tubes (TWT). Solid state means that semiconductors have been used. A TWT is a some kind of "radio tube"

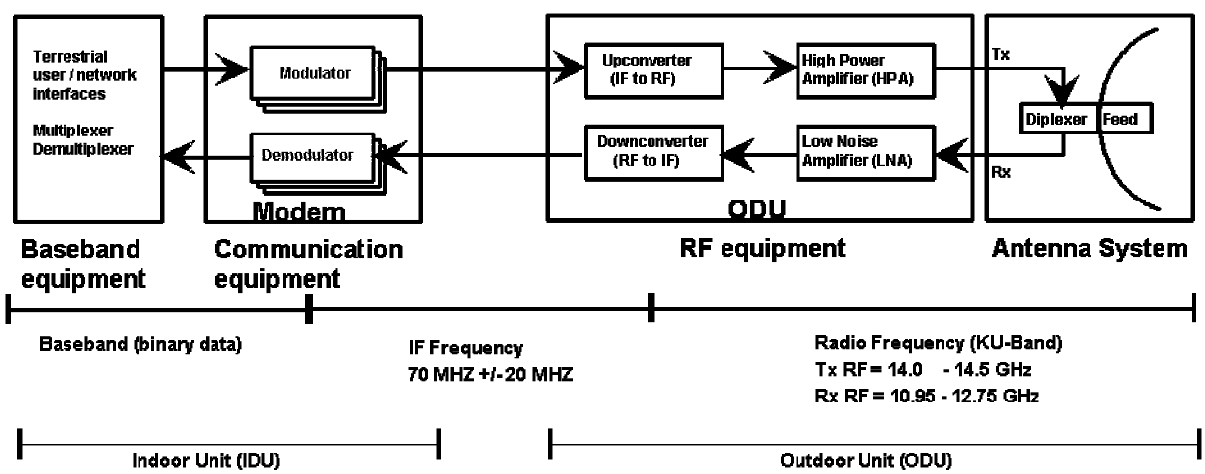
In fact the IF signal could be of any frequency, however for VSAT use an IF of 70 MHz is most common. 140 MHz is an other standard but is used less often. L band input is gaining in popularity. Concerning the receiving path. The entire down conversion amplification process occurs in the LNB or LNC. The RFU provides the LNC with the necessary LO frequencies only. Usually there is no further received signal manipulation inside the radio box. The LNB does not require an external local oscillator since it is incorporated in the LNB hardware.

Both transmitter and receiver function on the dual conversion, double super heterodyne principle. The Local Oscillator (LO) is normally a crystal controlled phase lock loop (PLL), with frequency synthesis to select the correct frequencies for up and downlink operation. The typical 1st IF is in the L-band (around 1 GHz), while the 2nd IF is commonly either 70 MHz or 140 MHz. To facilitate independent tuning of receive and transmit radio frequencies, the transceiver has to be dual synthesized

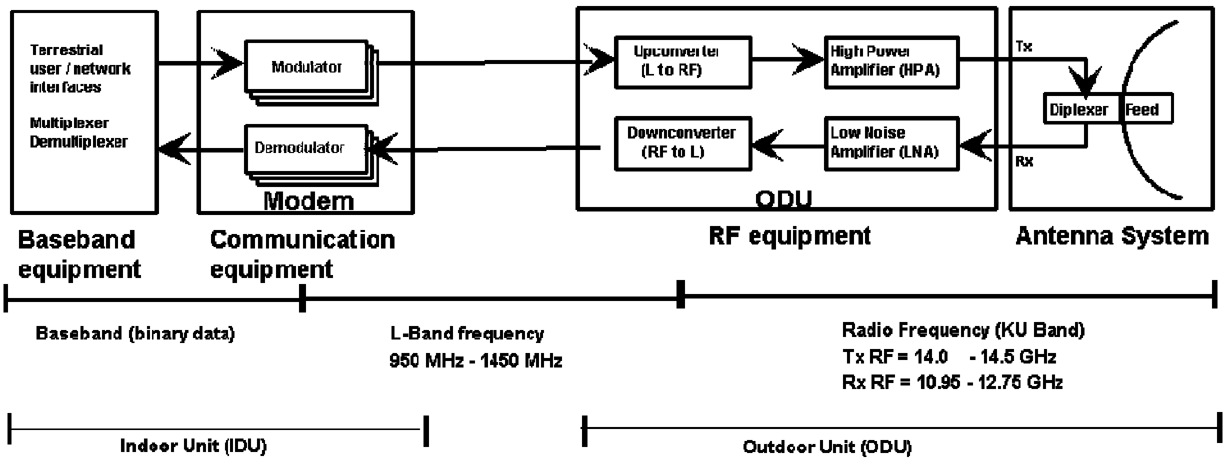
7.1.1. Two systems

In commercial VSAT applications 2 different radio systems are common use:

1. IF [70 MHz] input – C or KU band output
2. L band [950 MHz –1450 MHz] – C or Ku band output



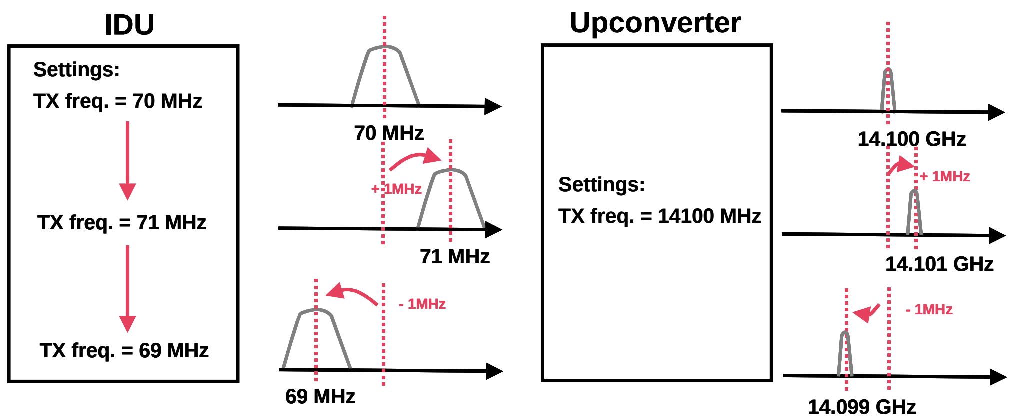
Schematic diagram typical VSAT system with IF radio input



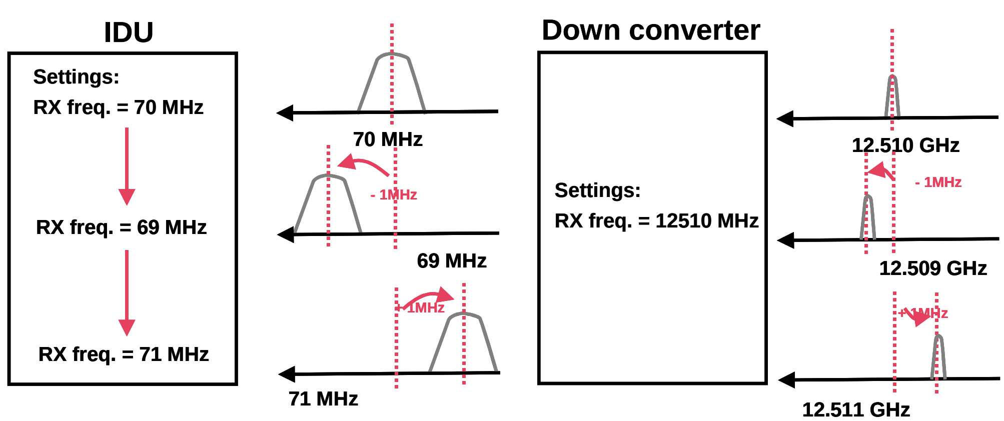
Schematic diagram typical VSAT system with L band radio input

7.2. Frequency setting on a 70 MHz [IF] radio system

Example: KU Band out – 70 MHz IF in

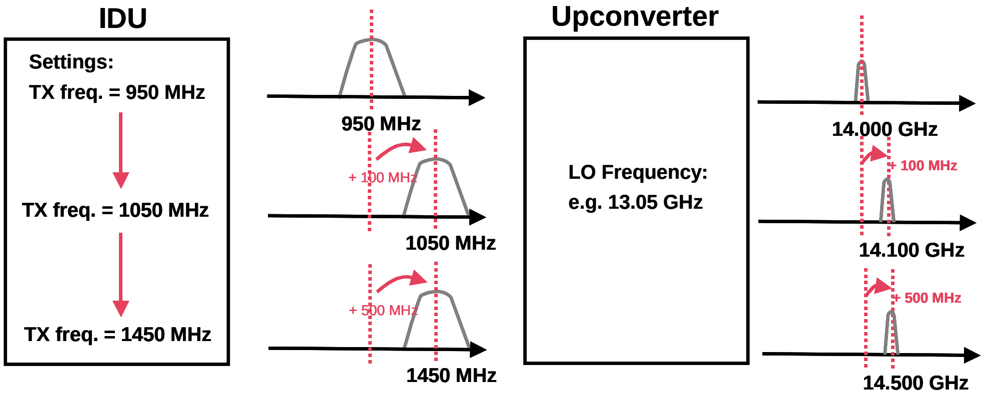


Example: KU Band in – 70 MHz IF out



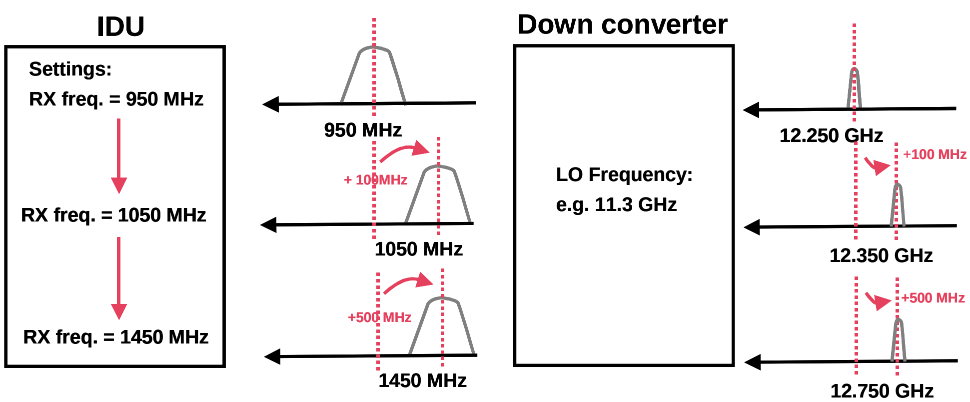
7.3. Frequency setting on a L band radio system

Example: KU Band out – L band in



TX freq L band = RF freq – LO freq

Example: KU Band in - L band out



RX freq, L band = RF freq – LO freq

7.4. Radio output power

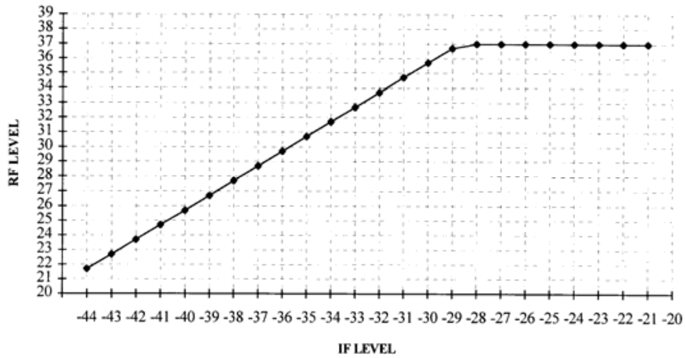
The output power of the radio depends on two parameters:

1. The type of radio expressed in Watts or dBm. Standard outputs for Ku band is: 2W (33dBm), 4W (36dBM), 8W (39dBm), and 16W (42dBm).
2. IF driving level (always expressed in dBm) which is given for every individual type by the radio curve.

The type of radio is a given fact, the IF driving level is a modem adjustment which depends on the required bandwidth and IFL cable losses. For a minimum of distortion (cross- / intermodulation due to overloading the amplifiers) it is absolute necessary that the IF input level (at the radio input connector) does not exceed a specified limit.

Overdriving the radio doesn't only give a highly undesired spectrum at the radio output but can cause permanent damage as well. Too little signal at the input can limit the fade margin. The correct required radio driving level is the result from the link budget calculation.

The radio only works properly within its dynamic range. This is the range over which the output power varies linearly with respect to the input power; the increasing slope in the radio curve. For example in the radio specification is indicated the “output power at 1 dB compression” This is a rather common specification. The 1dB output compression point of an amplifier is simply defined as the output power level at which the gain drops 1 dB bellow the small signal. As the output power increases to near its maximum, the transmitter will begin to saturate. The definition for the 1dB compression point is the point at which the saturation effects are 1 dB from linear.



Typical 4 Watt RF/IF radio curve for the SSE 1214 Radio.

7.5. Back-off

Due to the radio’s non-linearity, if several independent carriers occupy the amplifier simultaneously, that is, single channel per carrier frequency division multiple access (SCPC FDMA), the input power has to be "backed off" by about 6 dB, corresponding to one-fourth of the maximum input power, to avoid the phenomenon of intermodulation. The non-linearity of the transfer characteristic creates an admixture of frequencies outside of the carrier channel that interfere with neighboring channels unless the operating point is in a region of sufficient linearity.

Amplitude Modulation (AM) to Phase Modulation (PM) conversion is the change in phase angle between the input and output signal as the input signal level varies. This factor is measured statistically and is expressed in degrees per dB at a specified value of power output.

The back-off (BO) can refer to the input power (input Back-off), as the ratio in dB between the level required for a single carrier to reach the saturation level at the output, to any other input level. The Output Back-off is the ratio in dB between the saturation output power and any output power lower than saturation.

A rule of thumb frequently used is 6dB output back-off for multi carrier operation. This will keep the radio working in the linear portion of its transfer curve. Back-off is not necessary when only one carrier is present at a time, such as in time division multiple access (TDMA) or when the input signals are multiplexed into a single carrier that occupies the full transponder bandwidth.

7.6. Redundant transceiver systems

Several VSAT installations have been fitted with redundant transceiver systems. Redundant systems are used to increase system reliability for critical transmission circuits. The function of the system is to accomplish automatic or manual switching, from an active transmit or receive chain to a standby transmit or receive chain, in the event of a failure. In a redundant system, two off the driver units are fitted at the rear of the antenna, the left hand unit when viewed from the rear is driver unit A. Two off LNC assemblies are mounted on the feed.

8. Modulation

Modulation is the process by which intelligence, to include voice, data, and/or video, is added or encoded onto a carrier wave. Among other methods, this can be accomplished by frequency (FM), amplitude (AM) or phase (PM) modulation.

- Amplitude modulation (AM) encodes the information by changing the voltage, current, or power of the carrier signal.
- Frequency modulation (FM) encodes the information by changing the frequency of the carrier signal.
- Phase modulation (PM) encodes the information by changing the phase of the carrier signal.

Basically telecommunications can be done in three ways:

1. Analog modulated communications channel
2. Digital modulated communications channel
3. A mix between analog and digital modulation

All systems have their own pros and cons. The today's moving away from analog modulation in favor of digital modulation provides more information capacity, compatibility with digital data services, higher data security, better quality communications, and quicker system availability.

Developers of communications systems face three main constrains:

1. Available bandwidth
2. Permissible power
3. Inherent noise level of the system

The RF spectrum must be shared, yet every day there are more and more users for that spectrum as demand for communications services increase. Digital modulation schemes have greater capacity to convey large amounts of information than analog modulation schemes.

8.1. Trading off simplicity and bandwidth

There's a fundamental tradeoff in communications systems. Simple hardware can be used in transmitters and receivers to communicate information. However, this uses a lot of spectrum, which limits the number of users. Alternatively, more complex transmitters and receivers can be used to transmit the same information over less bandwidth. The transition to more and more spectrally efficient transmission techniques requires more and more complex hardware. Complex hardware is difficult to design, test, and build. This tradeoff exists whether communications is over air or wire, analog or digital.

8.2. Industry trends

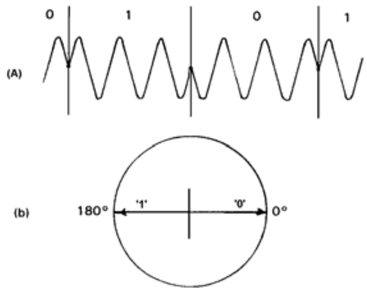
Over the past few years a major transition has occurred from simple analog amplitude type of modulations and frequency/phase type of modulation to new digital modulation techniques. Examples include:

- QPSK (Quadrature Phase Shift Keying)
- FSK (Frequency Shift Keying)
- MSK (Minimum Shift Keying)
- QAM (Quadrature Amplitude Modulation)

Another layer of complexity in many new systems is multiplexing. Two principal types of multiplexing (or "multiple access" are TDMA (Time Division Multiple Access) and CDMA (Code Division Multiple Access). These are two different ways to add diversity to signals allowing different signals to be separated from one other.

8.3. PSK, Phase Shift Keying

There are hundreds of types of modulation and many of them, to understand them well, require highly developed skills in electronics and mathematics. Pure AM is being used less frequently, while FM types of modulation are still widely spread and PM types are becoming rather popular. For most of the VSAT systems, important are: FSK (because it is the base), BPSK and QPSK (the latter two are both derived from PSK)



PSK is essentially a single frequency method where the data stream causes the carrier phase to change.

(a) Phase shift keyed signal waveform
(b) The phase diagram

8.3.1. BPSK

In binary phase-shift keying (BPSK or 2-PSK), for example, a carrier phase of 0° represents a bit value of zero, while a bit value of one produces a carrier phase of 180°. At one bit per symbol, this simple approach transmits data very accurately, but requires a lot of bandwidth. A data stream of 25 kbs, for example, would require a bandwidth of 225 kHz, clearly excessive for cellular phone and other practical applications.

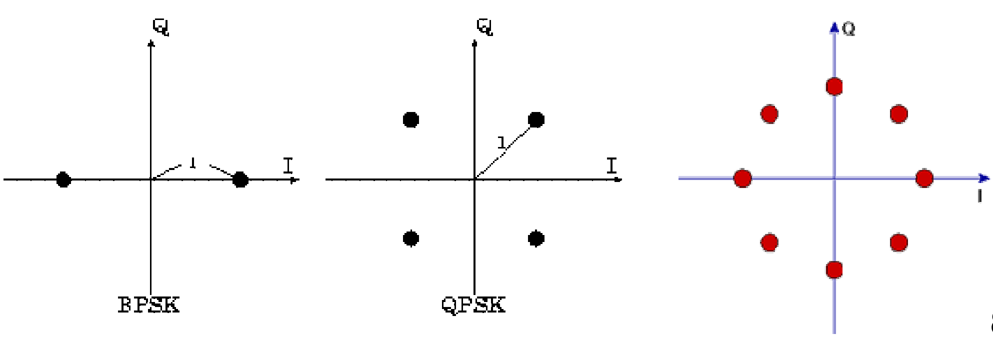
More advanced modulation techniques convey multiple bits of information simultaneously by providing multiple states in each symbol of transmitted information.

8.3.2. QPSK

QPSK is the most common modulation technique in satellite systems. Quadrature phase shift keying (QPSK or 4-PSK) conveys 2 bits per symbol. Some systems use 8-state PSK (8-PSK)

More advanced variations permit a symbol to have more than two states, so it contains more than one bit. In quadrature (4-state) phase shift keying (QPSK), the carrier has four possible phase states 90° apart, representing binary combinations 00, 01, 10, and 11. Because the bit rate for this transmission is twice the symbol rate, the bandwidth necessary to convey a specific quantity of information is comparably smaller. The same 25 kbps data stream requires only 100 kHz - still too high, but better than for BPSK. Extending this principle, eight-state PSK (8PSK) offers 3 bits per symbol, 16-state PSK provides 4 bits, and so on.

The set of available transmission symbols in a particular modulation scheme is known as its alphabet. A graph of the alphabet on a complex plane is called a constellation. The alphabet for a quadrature phase shift keying (QPSK) approach, for example, might consist of the set of complex numbers A = {+1+j, +1-j, -1+j, -1-j}.

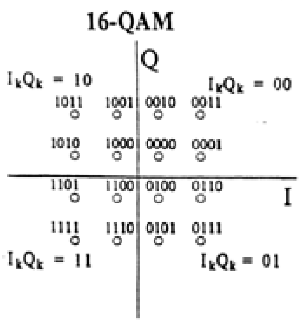


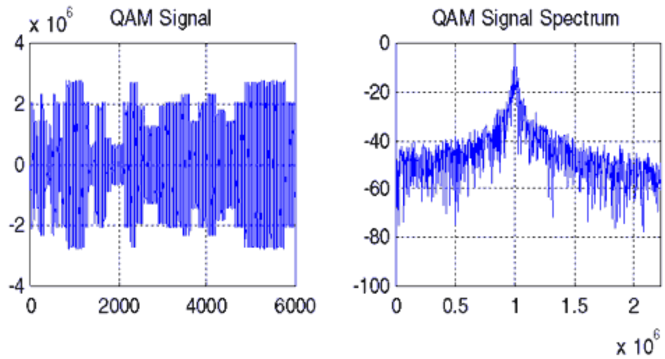
8PSK

8.3.3. QAM

Very popular in the world of “digital video” are Quadrature Amplitude Modulation (QAM) systems. QAM combines PSK and ASK to increase the number of states per symbol. Each state is defined as a specific amplitude and phase. This means that the generation and detection is more complex than a simple phase detection or amplitude detection device.

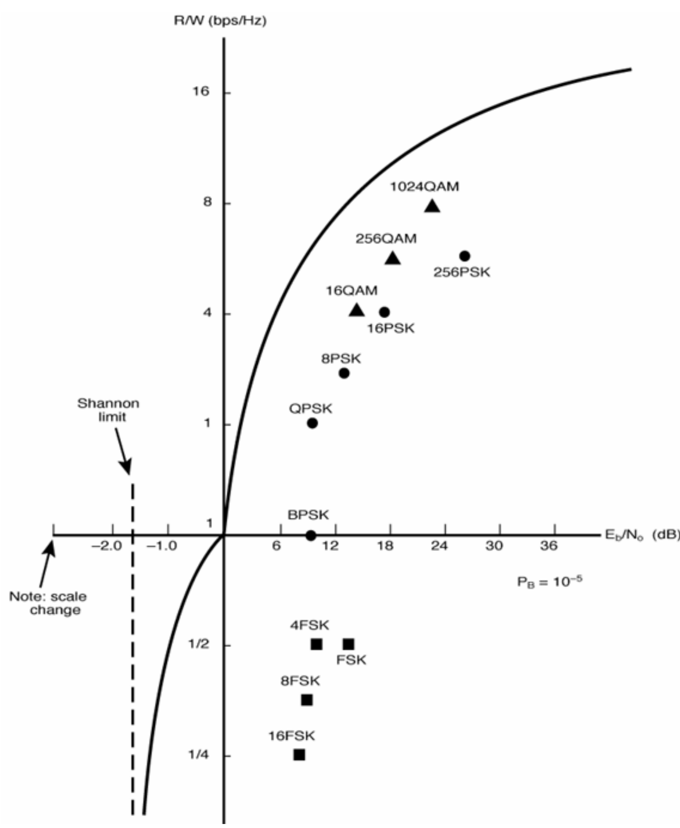
Since QPSK signal causes undesirable side lobes in the spectrum of the modulated signal QAM is more bandwidth efficient than QSPK. QAM and its derivatives are used in both mobile radio and satellite communication systems.





8.4. Other common types of (digital) modulation

The highest schemes on the graph (right) are the most bandwidth efficient. As an example, note that bandwidth efficiencies for 16-QAM and 16-PSK are identical, but QAM is more power-efficient and is therefore preferred. The curve itself represents the Shannon Limit - the absolute maximum amount of information that can be transmitted for a given bandwidth and S/N ratio. Each time the number of states per symbol is increased, the bandwidth efficiency also increases. This bandwidth efficiency is measured in bits per second/Hz (bps/Hz). The modulation schemes shown in the figure all occupy the same bandwidth (after comparable filtering), but have varying efficiencies of 1 through 4 bps/Hz. Since more states produce a higher channel throughput, it would seem that increasing the states would provide a simple way of increasing channel capacity. Unfortunately, entropy prevents us from taking full advantage of the increased states.



By comparison of FSK to PSK, PSK has the advantage of the narrowest bandwidth and the capability of expansion to carry even more data without an increase in bandwidth.

8.5. Bit rate, Baud rate, and Symbol rate

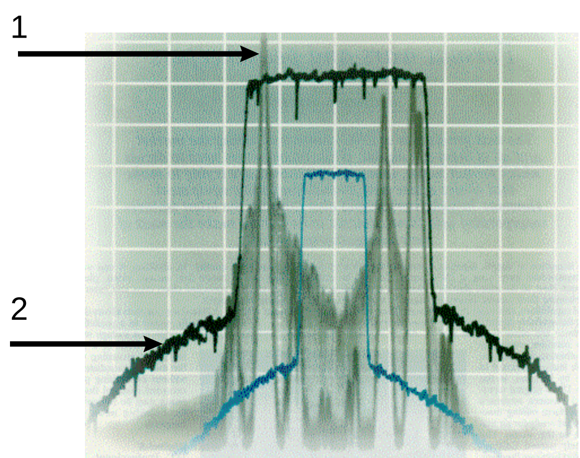
Perhaps the most common mistake made in communications terminology today is to confuse that rate at which data is transmitted, with the rate that symbols are transmitted. The rate at which bits are transmitted (the bit rate) is measured in bits per second (bs). However, in QPSK and most other modulation methods, more than one bit is transmitted at a time. The bits that are transmitted simultaneously are grouped into a symbol. The rate at which symbols are transmitted is the baud rate. When there is only one bit per symbol, as in most FSK transmission and in BPSK transmission, the bit rate and the baud rate are the same. When there are two bits per symbol as in e.g. QPSK, the bit rate is twice the baud rate. With 64 QAM there are 8 bits per symbol, so the bit rate is 8 times the baud rate.

9. Scrambling

Scrambling (or linearization) used in the data transmission sense is not the same as the word used in the traditional cable TV sense. In traditional cable and satellite TV, the word refers to the process of rendering a video/audio signal unintelligible to a normal receiver. In data transmission, scrambling is the process of combining a data stream with a pseudo-random bit sequence. If digital signals at the input of a phase modulator are not scrambled, long sequences of ones or zeros may be present at the input of the modulator resulting in a non-modulated tone at the output. Also if a long transmission of 0s or 1s occurs, it is possible to lose clock synchronization, so "scrambling" is often used to force a state change very so often.

In addition when a non-scrambled signal is fed to the RF power amplifier, intermodulation distortion (IMD) is generated which give rise to interfering signals in adjacent channels.

To ensure that a uniform spectral spreading is applied to the transmitted digital carrier at all times, a data scrambler should be provided. V.35, or a functional equivalent with similar spectrum spreading characteristics, shall be used.



Scrambled signal (2) versus unscrambled signal (1)

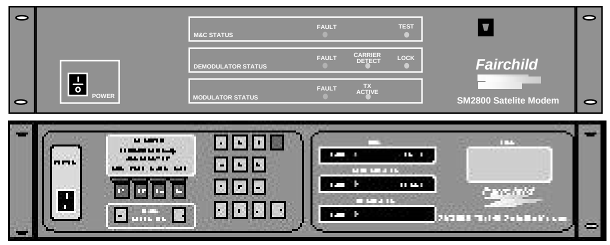
10. Encryption and conditional access

TBW

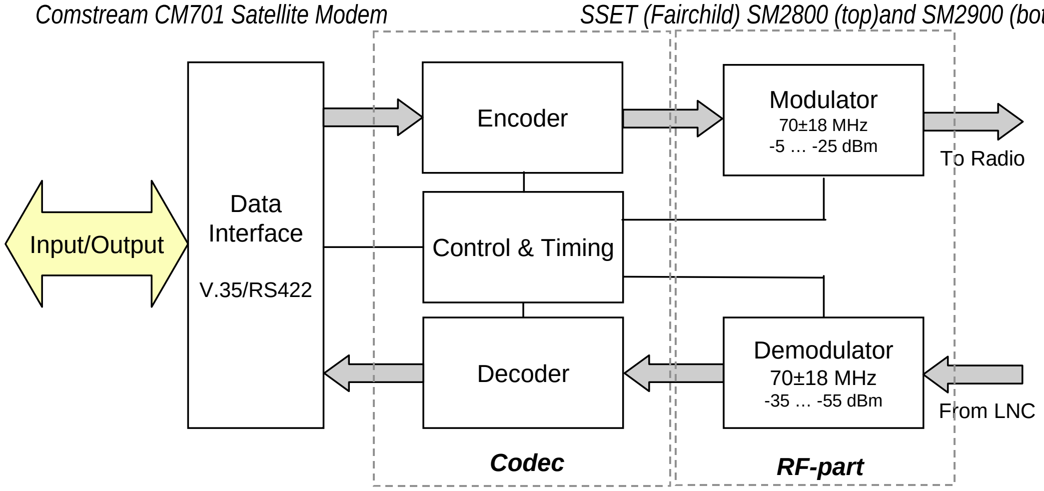
11. Simplified description of the satellite modem.

Most of the satellite modems are based on the same principle and act similar. The differences mainly can be found in the bells and whistles. Skynet prefers the use of SSET (Fairchild) SM2800, SM2900, SM3000, Paradise P300 and Comstream CM701 modems.

Comstream CM701 Satellite Modem



SSET (Fairchild) SM2800 (top)and SM2900 (bottom)

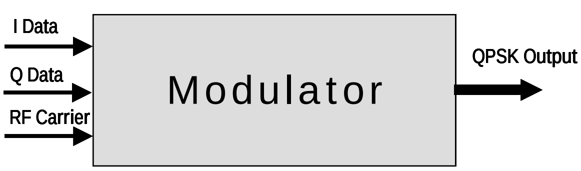


Satellite modems usually support the following features and functions:

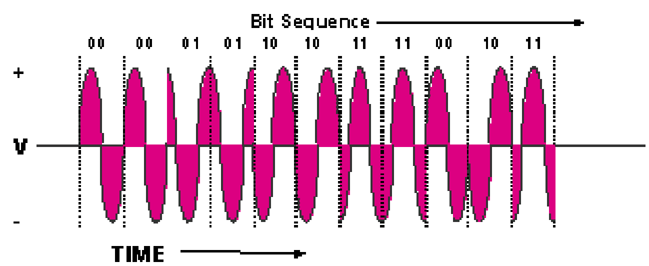
- **Satellite Modem Transmit:** The send data from the DTE (Data Terminal Equipment) is presented to the data interface. This data has an “over head” of data bits added in the encoder for error correction and is then modulated onto a 70 MHz IF carrier. Modulation is either BPSK or QPSK, the latter being preferred because it doubles the channel capacity without increasing the bandwidth. The modulated IF carrier is amplified to the correct level to drive the RF transceiver. An IF filter removes all unwanted out of band components.
- **Satellite Modem Receive:** The received 70 MHz IF signal is first filtered to remove unwanted components and adjacent carriers before being presented to the demodulator. The demodulator recovers the data stream, which is passed onto the decoder for error correction. The recovered data is then presented to the data interface for onward transmission to the DTE.
- **Data Interface:** Accepts the user information in a form specified by international standards (V.35, RS422, RS232, etc.) and conforms to all mechanical and electrical standards. The interface serves primarily as a data and clock routing switch converting the unique signal levels from external equipment to digital levels for processing in the modem.
- **FEC Encoder/Decoder**: Is applied to the data stream before modulation and decoding is done after demodulation. Encoding adds a “overhead” to the data stream to enable error correction. The modems used by Skynet normally use either Viterbi or Sequential coding. This encoding/decoding is selected with a defined overhead or FEC (Forward Error Correction) of either 1/2, 3/4 or 7/8. The higher quality modems can also be fitted with a Reed Solomon Encoder which adds further correction to the already encoded data stream.

- **Differential Encoder/Decoder:** Is an essentially part of the BPSK, QPSK system. This differential system is designed to provide a phase reference between the current and previous data symbol.
- **Scrambler/De-scrambler**: is used in satellite modems to ensure that uniform spectral spreading is applied to the carrier at all times. Scrambling does not provide a means of data security.
- **Buffering:** Is provided in both transmit and receive paths. This buffering is designed to take up any timing errors in the system. The transmit buffer is used to synchronize the transmit data stream to the selected transmit clock source. The receive buffer is usually an elastic buffer that corrects any errors due to the Doppler shift associated with the satellite, it also synchronizes the receive data to the selected receive clock source.
- **Digital Filter:** The spectrum of any PSK modulated signal contains a significant amount of out of band energy. This energy, if transmitted would result in adjacent channel interference or require a higher bandwidth allocation. To overcome this it is possible to remove all the unwanted energy in the side lobes by selective filtering whilst maintaining all the relevant information. This filtering is done using finite impulse response digital filters that emulate the Nyquist filter.
- **Clock Routing (Clocking):** Satellite modems support synchronous data services, therefore the provision of stable synchronous clocks and data are paramount. All satellite modems have an internal reference oscillator that can be utilized as a reference clock. Provision is also made for the use of an external station clock, external DTE clock, or recovered demodulator clock. The clocking options of a satellite modem are numerous depending on application. The clock router is used to selects the desired clocking options to maintain system timing.
- **IF Filters:** IF filters at the modulator output and the demodulator input are used to removes all unwanted out of band components.
- **Monitor and Control:** A Monitor and Control function is provided that allows the user to set up all operational parameters. This M&C will also monitor the performance of the modem and raise any alarms that occur.

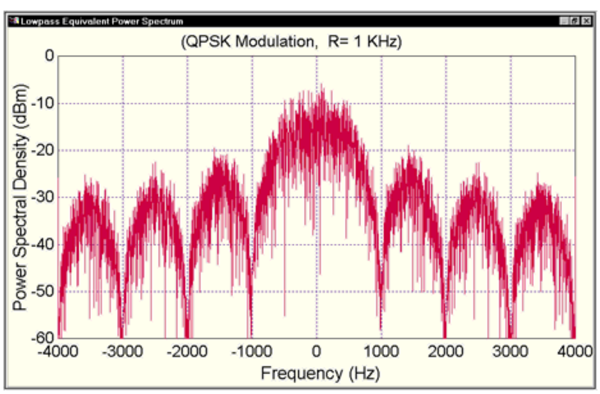
11.1. The QPSK modulator (satellite modem)



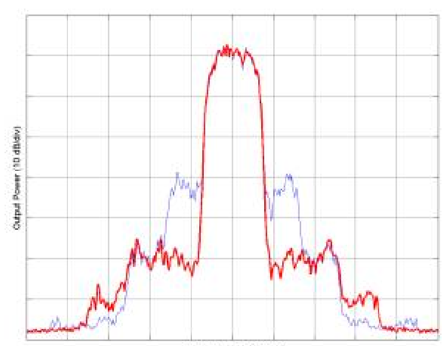
Data modulator



Modulator Output (Time Domain)



Modulator Output (Frequency Domain)



Modulator output after scrambling (see also 3.23)

12. Digital modulation encoding (channel coding)

A transmitted information bearing signal may not be correctly interpreted at the receiver due to distortion of the signal over a noisy channel so the output of the information source is fed to the channel encoder where redundancy (extra bits inserted) is introduced to reduce the bit error probability. This practice is known as Forward Error Correction (FEC) and is the only known method of providing error correction without calling for retransmission. The bit error probability and the bit error rate of the receiver's decoder (BER) are numerically equal. It seems strange at this stage that we go to all the trouble of using digital compression techniques only to add extra bits again before transmission over the channel. However there are sound reasons for this as will become apparent.

Shannon's Capacity Theorem - Forward Error Correction is achieved by incorporating redundancy into the channel coding system. Extra bits are added in a predicable and predefined way so as to aid the decoder in its task of interpreting the transmitted bits correctly. The details of the actual codes are extremely tedious to follow but fortunately we can treat it as a "black box" area.

The equivalent parameter to S/N in digital systems is Eb/No which is defined as the energy per information bit to noise density ratio. For a given digital modulation and encoding scheme there is a specific value of Eb/No corresponding to a given bit error rate (BER) expected on decoding. Experiments have shown that a BER better than 10 ^ -6 is required for ITU Grade 5 reception.

Providing the output of the source encoder is less than the capacity of the channel then it is possible to reduce the bit error rate to any desired level, using Forward Error Correction, without increasing the transmitter power above the value for which the capacity was calculated. In other words, there is an upper limit on the rate of error free communication that can be achieved over any given channel. However there is a trade off. The complexity of the channel encoding system grows alarmingly near capacity and the bandwidth is also increased.

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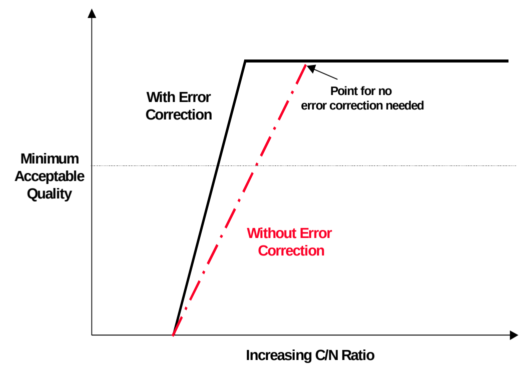
12.1. Coding gain

Coding gain is defined as the difference between the Eb/No required to achieve a particular bit error rate without coding and the Eb/No required to achieve the same bit error rate with coding. Obviously the more efficient the coding the higher will be the coding gain on demodulation but the complexity and cost will also increase. A popular code used with Satellite Digital TV is a shortened Reed Solomon code concatenated with a convolutional inner code. Its use can result in coding gains in excess of 7dB. Do not confuse channel coding with source coding (digital compression) here.

Decoder implementation losses

The receiver's demodulator will cause a certain amount of loss in the overall channel, through non linearity of filters etc. These losses are normally small in relation to the decoding gain but still significant. Values in the order of 1 to 1.5dB are commonly found in practice.

12.2. Forward Error Correction F.E.C



In satellite communications in general and in VSAT's satellite communications in particular, digital carriers in the great majority of cases employ QPSK modulation (and sometimes BPSK). The modulated carrier is always associated with the use of some kind of FEC (Forward Error Correction). There are various FEC techniques available but all involve sending extra (redundant) bits in the signal, which can be used to detect and correct errors in the received data. Error correction will allow the user to receive a good signal down to somewhat lower C/N than if it were not used.

FEC is a type of (convolutional) coding where the decoder obtains an estimate of the information sequence without the aid of a feedback channel. Convolutional coding combats errors by inserting error-correcting bits in the transmit information stream. These error-correcting bits are injected into the stream via a shift register, which gives the coding process a “memory.” The memory effect allows the decoder to correct many short duration error sequences by predicting the most likely value of the input information stream. *E.g.* K=7 and 1/2 rate refer to the mechanics of convolutional coding. K is the constraint length and also the shift register length. A 1/2-rate channel would contain one input bit for every two bits transmitted.

The use of encoding and error control is highly desirable since satellite power is expensive and higher data rates, *without the increase of bandwidth*, are required. FEC also can be used to improve bit error performance on a marginal circuit or to lower Eb/No requirements without impacting error performance on other digital circuits.

Common schemes of encoding are 7/8, 3/4 and 1/2 rate Forward Error Correction. In this course we will only focus on the more popular modulation and FEC systems used in satellite transmissions as there are:

- QPSK with Rate 1/2 or Rate 3/4 FEC.
- BPSK with Rate 1/2 FEC (rarely used)

Using R1/2 FEC, an encoding bit is inserted for every information bit. Using R3/4 FEC, an encoding bit is inserted for every three information bits.

1/2 Rate encoding has *higher* bandwidth but allows a *lower* G/T than R3/4.
3/4 Rate encoding has *lower* bandwidth but needs a *higher* G/T than R1/2.

Modulation type	Data rate	FEC	Bandwidth
QPSK	64 kbs	R1/2	90 kHz
QPSK	64 kbs	R3/4	60 kHz
BPSK	64 kbs	R1/2	180 kHz
BPSK	64 kbs	R3/4	120 kHz

12.2.1. Types of FEC

For SCPC applications the following three different types of encoding are most common:

- Sequential - Sequential encoding is a technique for (convolutional) codes, which involves searching through the code tree representation. The search or computation time is random variable depending on noise statistics.
- Viterbi - Viterbi encoding is a maximum-likelihood technique used for short-constraint-length convolutional codes. Viterbi has less delay at a lower data rate than Sequential. Viterbi decoding works best with random input noise found in a satellite link. The output-error performance of a Viterbi decoder is bursty in nature and works well as the input to a Reed-Solomon decoder

- **Reed-Solomon -** Reed Solomon encoding is a block oriented coding system that is applied on top of standard Viterbi coding. It corrects the bulk of the data errors that are not detected by the other coding systems and works best in a burst error environment.

Most of the satellite modems support Sequential and/or Viterbi coding for both BPSK and QPSK type of modulation. Your choice always comes together with a rate setting, e.g. Viterbi R7/8 or Sequential R3/4. Often Reed Solomon is optional (additional hardware) and is a little bit more complicated than Sequential and Viterbi.

Reed-Solomon Encoding decreases satellite power required for specific BERs by up to 20-50% (1 to 3 dB). It virtually eliminates all errors at nominal Eb/No levels. However for this better BER performance at a lower C/N (6 dB) is 10% more bandwidth required.

13. Indispensable basics 3 - Bit Error Ratio and Eb/No

Whereas the C/N ratio was a valuable indicator of a RF carrier quality, in digital communication systems the primary performance specifications can be characterized by its bit error ratio (BER) versus bit energy (Eb) to noise density ratio (No).

13.1. Bit Error Ratio

In digital communications, bits may disappear or unwanted bits can be generated as a result of noise, jitter or level variations. If such distortions occur, the transmitted information is received in a deformed condition. This usually affects the transmission quality. Transmission quality is in direct relationship with the link availability and is measured in terms of the degree of variation of bits (a.k.a. error rate) over a certain period of time.

Bit Error Ratio (BER) is the most fundamental measure of system performance - how well bits are transferred end to end. While this performance is affected by factors such as signal -to-noise and distortion, ultimately it is the ability to receive information error-free defines the quality of the link.

$$BER = \frac{\text{Number of bits received in error}}{\text{Number of bits received}}$$

Is equal to

$$BER = \frac{\text{Error count in measurement period}}{\text{(Bit Rate) x (Measurement Period)}}$$

A performance guarantee of BER=1E-6 for 99.5% availability means that for all year except 44 hours (of heavy rain, snow, sun outage, interference, etc.) the link will perform at BERs much better than the threshold. During the remaining 0.5% of the time there are more errors received than usual, resulting in more re-transmissions or a ‘noisy’ signal.

To measure the error rate accurately, a sequence of bits simulating the real data is transmitted at a rate equal to the transmission rate. This pattern is called the Pseudo Random Bit Sequence (PRBS). The PRBS is compared with the one generated at the receiver and the ratio of detected mismatched bits to the total number of bits is calculated as the bit error ratio.

13.2. Eb/No,

To understand the limitations of more bandwidth-efficient modulations, we need to define Eb/No and its use.

Eb/No= C/N x W/R [dB]

Eb:	Bit energy [ ]
R:	Bit rate [bs]
No:	Noise spectral density [Watt/Hz]
C:	Average modulating carrier power [Watt]
W:	Signal bandwidth [Hz]
N:	NoW

Increasing the number of states per symbol increases the bandwidth efficiency, calculated as bit rate divided by signal bandwidth (designated R/W) and measured in bps/Hz. Unfortunately, more bandwidth-efficient modulation schemes suffer from higher BERs and higher signal-to-noise ratio is necessary to achieve acceptable error rates.

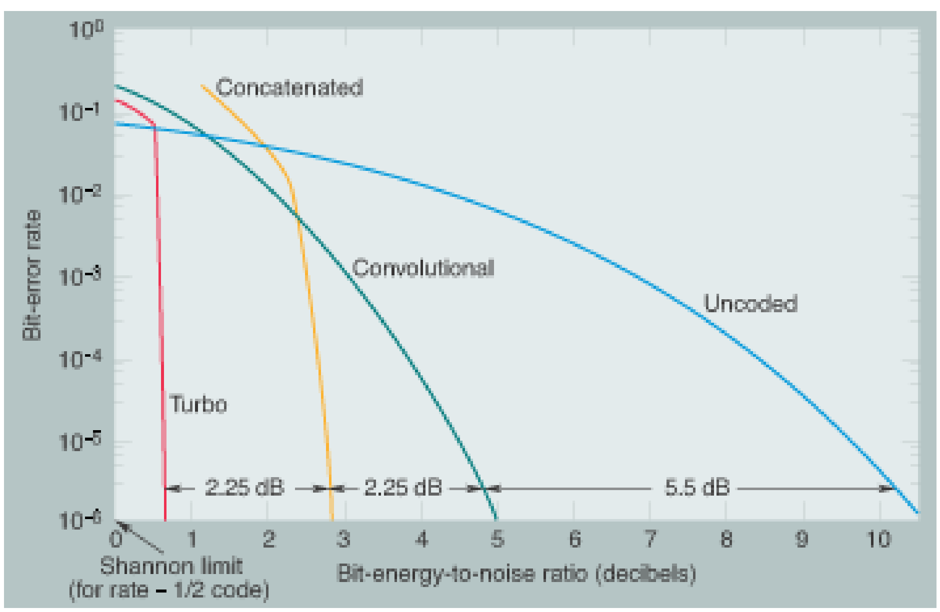
A modulation scheme with a low (Eb/No) offers high power efficiency, since the signal-to-noise ratio required to carry the necessary information is lower than for a scheme that features high (Eb/No). Lower (Eb/No), however, also increases the probability of error.

BPSK and QPSK have identical error curves, but as the number of phase states is increased beyond four, the error rate increases for a given Eb/No. A lower Eb/No means we have less information about the state, because we have more uncertainty in the form of noise. This entropy effect causes the correct state detection probability to decline as the Eb/No declines.

Each modulation type requires a different Eb/No to produce a given bit-error ratio

13.3. Eb/No versus BER

The conclusion is that the bit error probability depends on the Eb/No required for a given bit error ratio and also the type of modulation and encoding. As shown in the graphic below a small change in Eb/No ratio will cause a large change in BER.



BER versus Eb/No is a very convenient unit to use since its value is *independent* of data rate and occupied bandwidth. System engineers designing or installing earth stations are interested in evaluation modem performance in terms of Eb/No versus BER.

When the modem is connected back-to-back at IF, through an additive white (Gaussian) noise channel and in the presence of two adjacent carriers of the same transmission ratio, the BER of the data channel measured on the terrestrial side of the FEC decoder as a function of the Eb/No at the demod input shall be not more than that shown in the table below.

Theory		R3/4 FEC	
Eb/No [dB]	BER	Eb/No [dB]	BER
4.2	1 in 10^3	5.3	1 in 10^3
4.7	1 in 10^4	6.2	1 in 10^4
5.3	1 in 10^5	7.0	1 in 10^5
6.1	1 in 10^6	7.6	1 in 10^6
6.7	1 in 10^7	8.3	1 in 10^7
7.2	1 in 10^8	8.8	1 in 10^8

The exact value of Eb/No for a given BER depends on the modulation and encoding scheme adopted.

Carrier to noise vs Eb/No calculator on line

Please visit: http://home.online.no/~jensts/Satellite/Eb_No.htm (link active in Aug03). More calculators on Online Satellite Calculations (http://home.online.no/~jensts/satellite.html)

14. Clocking

In order for computers and terminals but also for digital (satellite) modems to communicate, they first need to notify each other that they are able to communicate. Second, once they are communicating, they must provide a method that keeps both devices aware of the ongoing transmissions. In essence a (digital) transmitter must transmit its signal so that the receiver knows when to search for and recognize the data as it arrives.

The receiver must know the exact time that each binary 1 and 0 is coming across the communications channel. This requirement means that a mutual time base or a common clock is necessary between the receiver and transmitter.

A transmitter must first send to the receiver an indication that it “wishes to talk” with it. If the transmitter sends the bits down the channel without prior notice, the receiver will likely not have sufficient time to adjust itself to the incoming bit stream. In such an event, the first few bits of the transmission would be lost and the receiving DTE (data terminal equipment) is temporarily interrupted. This process is part of the communication protocol and is generally referred to as synchronization.

Actually clocking signals perform two functions:

1. They synchronize the receiver into the transmission before the data actually arrives.
2. They keep the receiver synchronized with the incoming data bits.

Short connections between equipment often use a separate channel to provide synchronization. When there are long distances like with satellite links, it makes more sense economically to incorporate the timing into the signal itself instead of using a separate clocking channel. Besides, this type of clocking doesn’t present a problem in that the clock and the data can be altered as they propagate through separate channels.

14.1. Clocking options

One of the most important and occasionally time-consuming tasks on solving clocking problems is to synchronize all pieces of equipment in a network. The problems include system definition, integration of equipment from different manufactures together and possession of enough information to set up the interfaces on each piece of equipment to inter-operate with another piece of equipment. This is compounded in satellite links where Doppler shift and disparate equipment, terrestrial or national clocks conspire to complicate network synchronization.

Doppler Phase variations are caused by the movement of the satellite within the limits of its geostationary orbit. This effect leads to Doppler shifts over 24 hour periods which results in time displacements of typically 600us, and if the satellite is operating in inclined orbit time shifts may be 5 ms or more.

At the system level a variety of situations are encountered and it is necessary to decide what type of synchronization is needed. The next step is to translate this into a clocking arrangement for each piece of equipment including the clock option selected for each modem in the link. From a system perspective synchronization is considered from the question of does each piece of equipment in the network derive its timing from the:

- Terrestrial network
- Satellite link
- (Satellite) modem
- An internal (e.g. multiplexer) clock

The system configurations include often multiplexers, which are very common in many applications.

A multiplexer is a point of concentration where number of clocks converge and must be smoothly meshed if timing is to be maintained without loss of synchronization.

With a multiplexer in the network it is necessary to know whether the TX and RX clocks connecting it to the satellite link can tolerate frequency and phase variations. A frequency difference arises when both ends of a link use clock references from their respective ends and pass them over the link. Since these clocks are derived independently their frequencies may differ by 0.001 ppm. or less to 50 ppm. or more, which causes the TX and RX, clock edges to drift by each other over time. This is not necessary a problem when a modem is used which is designed to operate with independent clocks (e.g. the Fairchild SM2900)

14.2. Buffering

There are two situations, often acting in combination, that result in the TX and RX clocks sliding by one another:

1. When independent clocks are used to synchronize both ends of the link. The frequency difference between these causes an error that eventually causes the clock edges to cross one another. These clocks are called “nearly synchronous”.
2. Due to Doppler shift.

In the first situation, if the TX clock is being used to clock RX data out of the modem then eventually data errors will occur when the clock edge coincides with the data transition. This type of clock slip can be forestalled with an RX buffer but not prevented. Doppler shifts however can be completely mitigated (because it is cyclical) by using an RX buffer.

The RX buffer of a satellite modem accommodates clocking arrangements by absorbing the drift of clocking edges. Most of the satellite modems allow the RX buffer to be either OFF or programmed in BITS or MS (milliseconds).

14.3. Clock recovery

Clock Recovery consists of synchronizing a clock to the transitions in the received data. Where no transition occurs, the clock “freewheels” through the time where the transition should occur. If a long transmission of 0s or 1s occurs, it is possible to lose clock synchronization, so “scrambling” is often used to force a state change very so often.

15. Elements affecting link quality and communications system performance

The quality of a satellite link depends very much on:
- Received level and used bandwidth
- Type of Modulation and used Error Correction Technique
- Noise (from all possible sources, including interference)

Link quality criteria

All satellite links are designed to provide availability to meet a required level of performance. The performance criteria are usually the minimum (*or threshold*) Bit Error Ratio (BER) and the availability, as a percentage, of time that the minimum BER must be met or exceeded.

The BER is the total number of erroneous bits divided by the total number of bits received. A performance guarantee of BER=1E-6 for 99.5% availability means that for the entire year except for 44 hours (of heavy rain, snow, sun outage, interference, etc.) the link performs at BERs much better than the threshold. During the remaining 0.5% of the time, more errors are received than usual, resulting in more re-transmissions or a noisy signal.

Elements affecting the quality of the link can be generally divided into:

- Atmospheric absorption and rain fade
- Satellite interference
- Terrestrial interference (IF/LF Interference)
- Power failure
- Noise
- Orbital Effects (See next chapter)
  - Doppler shift
  - Transmission Delay
  - Scintillation or Tropospheric
  - Sun Outage & Eclipse

15.1. Rain fade

High frequency signals such as Ku band are susceptible to attenuation caused by absorption and the scattering effects of water in the atmosphere. The geometry of rain droplets is quite similar to a ¼ wave attenuator at the Ku band wavelength, resulting in worsened link performance. Clouds attenuate according to their liquid water content and their proportions. The total attenuation due to absorption by water depends not only upon the frequency (the higher the frequency, the higher the attenuation) but also upon the elevation angle (the smaller the angle, the higher the attenuation). This attenuation is overcome by increasing transmit power levels and/or lowering receive station noise temperatures in the initial design of the system. Models are used to predict the amount of rainfall and a percent availability is given to the system. Systems such as uplink power control are sometimes used to sense rain fade and increase transmit power levels accordingly. However, uplink power control systems are not usually used in VSAT systems due to the requirement of providing low cost systems.

Rain attenuation normally is 2-5 dB but can be in *extreme* situations more than 15 dB. Satellite links include rain margins, which are calculated to ensure specified link availability *e.g.*, 99.5% per year. At Ku band frequencies, occasional service interruption due to weather are expected. C band frequencies are not being affected by rain at all.

Rain, sleet, thick clouds, fog, and snow will all reduce (fade) RF signal strength. Less signal received by the satellite means less power transmitted back to earth to receiving stations. Systems not using power control must take into account the signal reductions due to inclement weather, even when operating in clear weather conditions. Without Uplink Power Control (UPC), constant extra power, or "fade margin", must be leased to ensure that a strong enough signal reaches receiving sites during fade conditions. By using UPC to adjust signal power levels, you get higher network availability while minimizing satellite costs. In inclement weather conditions, UPC automatically adjusts the power level of transmitted signals to maintain a near constant receive signal at the satellite. There is no need for constant fade margin. In addition, safeguards are built into the system to prevent operation at higher than permissible power levels. UPC is especially effective for Ku band frequencies, which are substantially more susceptible to rain fades than are C band. For Ku band systems requiring high service availability (99.95% - 99.99%), UPC can reduce the overall margin requirements from 9-20 dB without UPC to 3-12 dB with UPC. Every 3 dB decrease in margin required results in a two fold decrease in satellite costs.

Typical availability (with regards to rain fade) for Ku band satellites in tropical/equatorial regions

The tropical and equatorial regions correspond to Region H in the Crane Global model, one of the two authoritative models commonly used (the other is the ITU-R, formerly CCIR, model, which yields similar results).

In the downlink, rain degradation comes primarily from two sources: attenuation and decrease in figure of merit G/T. There is also some polarization mismatch loss. At the Ku band downlink frequency of 12 GHz, with 99.95% availability, the maximum rain rate in Region H is 97.6 mm/h, corresponding to an attenuation of 22.0 dB. There is also a reduction in G/T of about 4.5 dB because the earth station antenna sees the thermal noise of the warm rain instead of the cold sky, resulting in a total degradation of 26.5 dB. To compensate for this loss, the power would have to be increased by a factor of nearly 500, which is highly impractical. At an availability of around 99.7%, with an attenuation of 7.0 dB and decrease in G/T of 4.0 dB, the total degradation is 11.0 dB. This loss, representing a factor of 12, would be high but would be nevertheless manageable by increasing the power by this factor.

For the uplink at 14 GHz, the only loss is due to attenuation, as the satellite sees the warm Earth anyway. At 99.95% availability in Region H, the attenuation is 26.8 dB and at 99.7% it is 9.1 dB.

Therefore, a typical design goal for Ku band in tropical regions would be an availability of 99.7% or less.

One way to overcome rain fade problems is to have site diversity. Two earth stations could be separated by about 10 km and connected by a terrestrial path such as fiber. It is unlikely that the rain cell would be intense at both sites simultaneously. Another way is to assign a lower frequency, such as C band, as needed and allocate the Ku band for regions that are clear or have only light rain. A third way is to dynamically assign bandwidth to provide for more robust channel coding in regions encountering rain to lower the needed power. However, the latter technique can only mitigate -- not solve -- the rain fade problem.

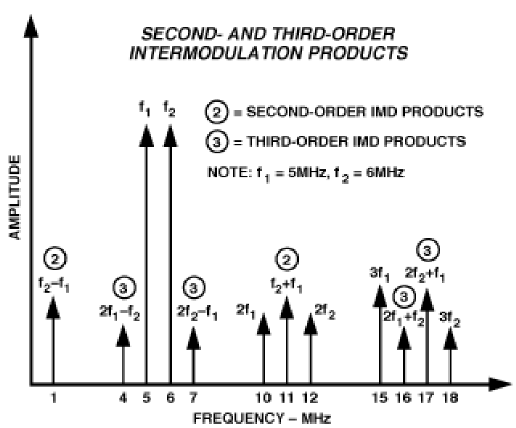
15.2. Interference on transponders

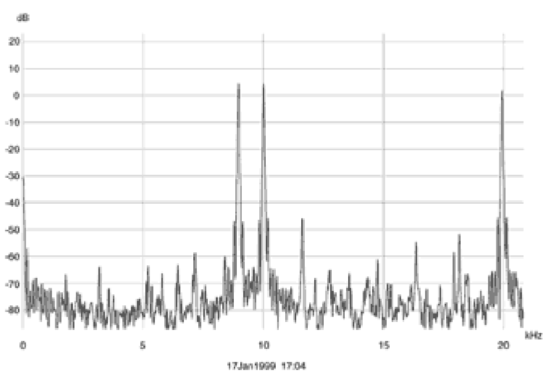
As a result of increasing satellite use, the ability of the receiver to pick out weak wanted signals in the presence of strong (interfering) signals represents a very important performance criterion. The effects listed below can cause interference:

- Cross polarization interference (see 1.10)
- Adjacent channel interference
- Adjacent satellite interference
- Overloaded transponder

Link degradation is often caused by cross modulation and inter-modulation.

- **Inter-modulation** occurs when two or more signals combine in a non-linear element (*e.g.*, amplifier) and produce a resultant interfering signal on the wanted signal.
- **Cross modulation** occurs when an interfering signal modulates the signal of interest, or, in other words, when the modulation of one signal is affecting that of another. Poor intermediate frequency (IF) link cable shielding can cause local radio and television signals to be picked up and radiated toward the satellite. Overloading an amplifier also can cause cross modulation.



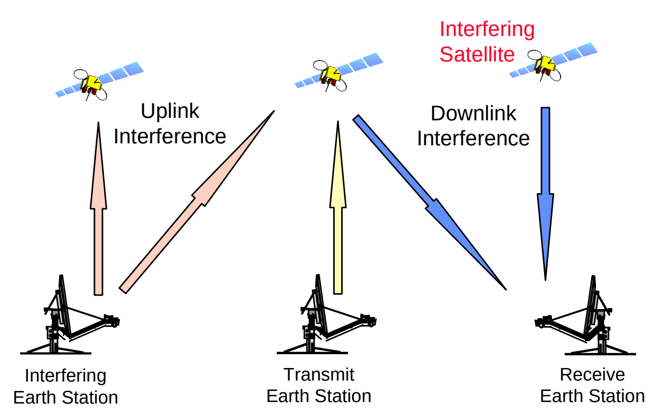


"Pollution" because of intermodulation

15.3. Adjacent satellite interference

Interference from an adjacent satellite occurs at the downlink site when the antenna is not properly assembled and/or not properly pointed. In this situation, the antenna is able to pick up signals from an adjacent satellite at the same frequency as the frequency of interest.

A similar problem can occur at the satellite site if an earth station antenna is not well enough pointed towards the satellite. In this case, the earth station antenna interferes with a satellite adjacent to the one toward which the +transmission is intended. If, for example, the antenna is pointed so that the side lobe, rather than the main lobe points toward the intended antenna, the main lobe and the lobe on the other side of the peak, could interfere with adjacent satellites.



In some cases, side lobes may be interfering even though the main lobe is on target. In this case, a more selective antenna (a larger antenna with a narrower focus might be a good solution to avoid this kind interference).

To avoid excess interference to adjacent satellites, a defined transmit co-polarised side lobe pattern is required for every earth station. At any case, a carefully pointed antenna is crucial.

All the types of previously discussed interference are RF interference or interference on “microwave level”. Other interference problems can occur on IF and LF levels.

15.4. Terrestrial interference (TI)

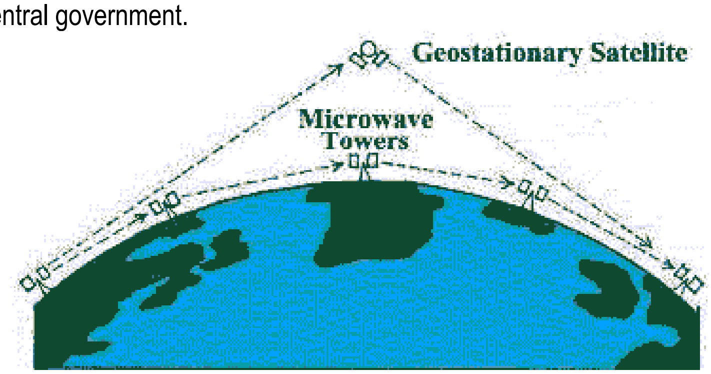
Many circuits, as well as detectors and even cables, are sensitive to terrestrial interference (TI) or IF & LF interference and could affect the BER in a negative way. Some of the most common creators of this serious problem are listed below:

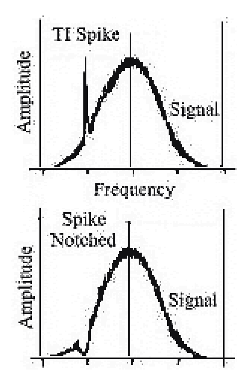
- 50/60 Hz pick-up: It has a sharp spectrum and constant amplitude and can be caused by electrical wiring in the area. Interference from electrical wiring is easy to detect.
- Impulsive interference: This type of interference can be caused by lightning and nearby electrical equipment such as motors, elevators and air conditioners. This kind of interference is broad in spectrum and spiky in amplitude. Because of its irregularity, it is hard to detect.
- Radio and television stations can cause a serious problem near large cities.
- Microwave relays

Many of these sources can be controlled by careful shielding, filtering and proper grounding.

- LF — *Low Frequency* — is any frequency of the audio spectrum.
- IF — *Intermediate Frequency* — is the frequency at which most of the signal processing takes place because the design is simplified and cheaper. For VSAT transmission or reception, IF is usually 70 MHz ± 20 MHz or 140 MHz ± 20 MHz. Mixer outputs are also called IF.
- RF — *Radio Frequency* — is any frequency between an audio sound and the infrared light portion of the spectrum but usually considered to be 1 MHz to 1000 MHz.

Terrestrial interference (TI) is a typical land-based phenomena and occurs when a satellite system receives unwanted microwave signals from a nearby microwave source operating in the same band of frequencies as the received satellite signal. The most common source of TI comes from microwave relays (towers) operated by telephone companies in the C-band range, although airport navigation systems also can disrupt satellite reception at all frequencies - especially near military installations in countries without a clear frequency coordinating authority in their central government.





In general, terrestrial interference can enter through un-terminated cable ends, poorly grounded connectors, open equipment cases, impedance mismatches and directly through the LNB and can either contribute to the noise floor or modulate their pattern onto the signal or interfere directly (replace) with the received signal. Terrestrial interference often enters from an off-axis angle, through a dish side lobe and can be most annoying and detrimental to signal quality even when the dish is not aimed directly at the TI source.

Detection of potential direct entrance TI can be as simple as performing visual inspection at a possible installation site for nearby (within site) microwave or broadcast towers or can be as detailed as connecting an LNB (the same frequency to be installed) to a spectrum analyzer and pointing the LNB at suspect TI sources while watching the analyzer for signal reception. Remember to check both polarities on the analyzer. For a single carrier microwave tower you will see a 'spike' on the analyzer screen, and for multiple carrier towers you will of course see multiple spikes. In the case of general interference, of airport or military frequency patterns, and reflected interference (scattered from nearby buildings or walls, etc.) you will typically see a series of spikes and often in jagged patterns not dissimilar from that as seen when looking at normal data carriers or compressed digital signals from a satellite transponder.

TI below about 300MHz enters a system through poorly grounded or improperly connected equipment. For frequencies above 300MHz, wavelengths are sufficiently short that they can enter a system through poorly shielded electronic cases or directly into openings, i.e. non-terminated connections. If 'loose' signals are out there wandering around, and they find an entrance into your system, they will take it and then use their power to travel with your signals in a modulated fashion or corrupt your signal by adding to the noise floor, a very simple fact.

TI is a big concern in countries where frequencies are not regulated and wattage happy users are abundant and a site survey that omits TI detection analysis, especially in urban areas, can result in a 'messy' situation after installation. Remember that microwave traffic is not usually continuous in its transmission and may be off during certain periods of the day so it does not hurt to check your potential site locations at several times during the day/night.

15.5. Power failure

The power system is most responsible for earth station outages. It is a fact that power faults, either directly or indirectly, account for 80% of all outages. To protect the system against outages due to power failures the service provider should supply an uninterruptible power supply (UPS which provide power for the essential station load (radio, LNC, modem etc.). However it's calculated that 60% of all standby power system failures are due to starter battery faults.

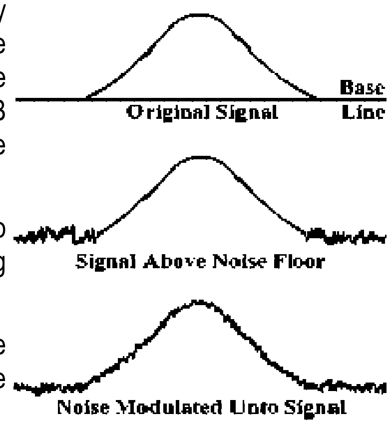
15.6. Noise

Noise is an unwanted signal, which interferes with the reception of the desired information and can affect the signal dramatically. Noise is present in all matter at temperatures above absolute zero. Noise from the environment becomes stronger as the temperature increases. Receiving antennas pick up more of this environmental noise as the signal bandwidth increases. In all cases, the lower the noise, the better the system performance.

Generally, the *sources* of noise can be divided into:

1. External Noise
   - Atmospherics, solar and cosmic noise
   - Thermal noise from the earth
   - Manmade impulse noise (*e.g.*, motorbikes, etc.)
2. Internal Noise
   - Resistive noise (caused by all the resistors used in the circuit) and thermal effects in semi conductors
   - Other similar effects within the equipment itself

When we talk about noise, we are talking about unwanted signal. We 'break out' noise into three basic categories:



1. Background noise: Background noise is the noise we always want to stay above. It is sometimes called the 'noise floor'. A signal can always be amplified above the noise floor but once it gets buried in background noise (falls into the signal floor) it cannot be retrieved; this is why the LNB amplifies the weak satellite signals as soon as they are received before passing them on into the cable and to the receiver.
2. Modulated noise: Modulated noise is an undesirable signal that enters into a system and rides on a signal, using the system power, producing undesirable side effects in for example video quality.
3. Interference noise: Interference is noise that comes in on the same frequency(ies) as the signal and masks (overwhelms) parts or all of the desired signal.

Little can be done in respect to external noise. On the other hand, considerable influence can be made to the problem of internal noise by designing carefully.

16. Orbital effects in communications system performance

The quality of the uplinked and received signal can be affected by different orbital effects as there are:

- Doppler shift
- Free space loss
- Transmission Delay
- Scintillation or Tropospheric
- Sun Outage
- Eclipse

16.1. Doppler shift

The satellite position over the equator can drift because of the gravitational attraction of the moon and the sun. Because of this drift, the satellite orbit tends to become non-circular and inclined. Without correction, the inclination plane drifts a fraction of a degree every year. Also without correction, orbit inclination causes the satellite to trace a 'figure-eight' pattern over any 24-hour period. Even with the best station keeping system available, the position of a GEO satellite with respect to the earth exhibits a 3 dimensional cyclic daily variation. This causes Doppler shift.

The satellite owner's TT&C Operators "fly" the satellite to maintain it in station within a 75 km square. This motion causes a Doppler shift in the satellite signals, resulting in data rate clocks at the receive site that are slightly different than clocks at the transmit site. Although identical in a 24-hour average, the data rate clock at a receive station will be slightly slower and slightly faster at different times of the day.

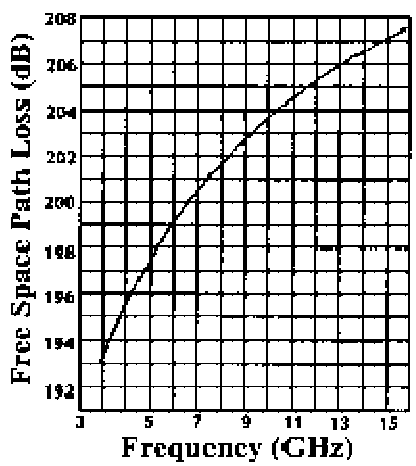
Satellite modems located at the earth stations contain Doppler buffers to counter this effect and provide a constant clock to attached equipment, which may be sensitive to these variations in frequency.

What's the problem with Doppler shift

Doppler shift results in time displacements of typically 600 us, and if the satellite is operating in inclined orbit time shifts may be 5 ms or more. Most data communication applications have no problem with this. These applications generally have independent transmit and receive clocks at each site and can tolerate the slight differences. Examples include most DTE's (Data Terminal Equipment) such as voice and data multiplexers that send an aggregate data rate over the satellite. Some applications, however, require that the receive clock and data from the satellite be exactly synchronized to another clock. These applications require the use of a Doppler buffer. An example is when the received satellite data stream is being multiplexed into a higher data rate aggregate stream at the earth station. Another example is when the received data is input to a synchronized terrestrial system. In both cases a Doppler buffer is needed because the received data from the satellite must be slaved to a specific clock.

16.2. Free space loss

Propagation of waves in free-space is different from that in cable or waveguides. With respect to signal propagation, these latter are one-dimensional systems, and a wave does not lose energy as it travels, except that due to absorption or scattering. In three-dimensions waves radiate spherically. As they travel, the surface area they occupy increases as the square of the distance traveled. However, since energy is conserved, the energy per unit surface area must decrease as the square of the distance. Thus the power of free-space waves obeys an inverse square law. For each doubling of the distance between the source and receiver, a 6dB loss is experienced. For all frequencies up to millimeter-wave frequencies, this free-space loss is the most important source of loss. Because of it, free-space systems usually require much more power than cable or fiber systems.



(Sample Site Location - Equator)
(i.e. minimal travel path through atmosphere to satellites)
(Weather Condition - Clear Sky)

16.3. Scintillation or tropospheric

At unpredictable times the levels of receive signals from the satellite rapidly fluctuate up and down. This is called scintillation. Changes of up to 12 dB have been recorded for up to 2 or 3 hours, and may be observed at an earth station when a neighboring earth station at a distance of e.g. 200km is not affected.

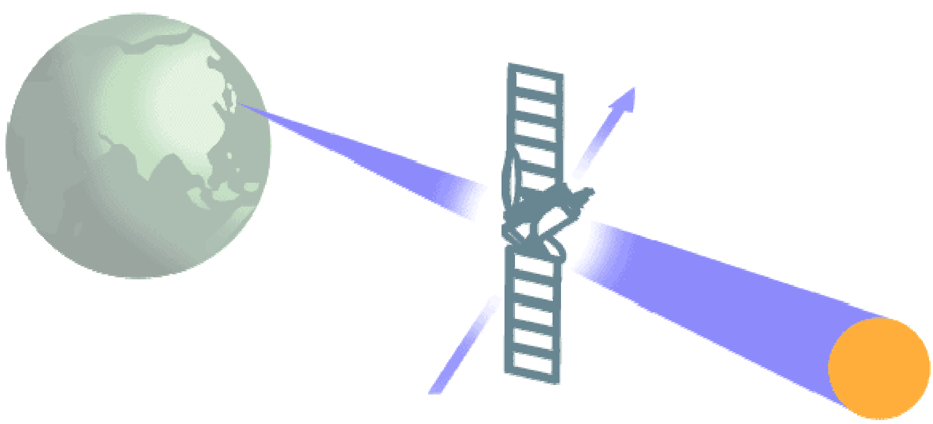
It is caused by the amplitude and phase variation that occur as the microwave signal is propagated along the slant path through the atmosphere. Because the air masses which comprise the atmosphere are not homogenous the radio refractive index of the air mass varies with time and position within the mass. This is brought about by the turbulent mixing of air mass at different temperatures and humidities, and by random addition of particles such as rain, ice, and moisture.

16.4. Sun outage and eclipse

All the satellites used by Skynet are geostationary, and therefore have an orbit, which lies in the equatorial plane. During the spring and fall equinoxes, the sun also passes through this plane. As seen from the ground, the sun seems to pass behind the satellites once per day. During the time when both the satellite and the sun are in the ground station's field of view, the RF energy from the sun can overpower the signal from the satellite. The loss or degradation of communications traffic from the satellite caused by the sun overpowering the signal from the satellite is referred to as sun fade, sun transit or sun outage. The duration of the sun outage depends on several things such as:

- Beam width of the field of view of the receiving ground antenna
- Apparent radius of the sun as seen from the Earth (about 0.25°)
- RF energy given off by the sun
- Transmitter power of the satellite
- Gain and S/N performance of the ground station receive equipment

Although the sun may degrade the signal for several minutes depending on the antenna size and available link margin, the effect of the sun fade could go unnoticed. The time of occurrence depends both on the geographic location of the earth station and the location of the satellite.



Sun outage at a fixed earth station occurs when the sun passes behind the geostationary satellite so that the earth station antenna is looking directly at the sun. The additional noise power of the sun raises the earth station system noise level causing the demodulator to operate below its threshold, rendering communication quality below acceptable limits.

The exact point at which sun outage begins and ends is difficult to determine since it is a gradual transition. Also, due to the many differences in ground station equipment, some stations may experience a complete loss of signal while others may only experience a tolerable degradation of signal. The determination of antenna outage angles is made difficult without complete information about the ground station equipment. Outage angle is defined as the separation angle (measured from the ground station antenna) between the satellite and sun at the time when sun outage or signal degradation begins or ends. (Antenna Outage Angle = half the 3dB beam width + apparent radius of the sun)

It is normal policy to advice priority customers whose traffic is susceptible to disturbances well in advance to minimize the effects of the outage

Eclipse

Eclipse is the period when the satellite passes into the Earth's or the Moon's shadow, when satellite power must be drawn from on-board storage batteries.