ELEC 691X/498X – Broadcast Signal Transmission
Fall 2015

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Office Hours: Wednesday, Thursday, 14:00 – 15:00

Time: Tuesday, 2:45 to 5:30

Room: H 411

Lecture 9:
Link Budget (Satellite)

In this lecture we cover the following topics:

- Uplink link budget calculation.
- Downlink Link Budget Calculation.
- Combining uplink and downlink SNR’s to find the overall SNR.

Lecture 9:
Link Budget (Satellite)

In a satellite broadcasting system, the signal originates from a ground station and ends up in another ground terminal. The originating ground terminal is the one operated by the TV service provider or satellite service provider and rented to the content providers (TV stations). These Earth stations are quite powerful, i.e., they have large antennas and high power RF amplifiers. They are called gateways or Teleports or Hubs. In general, a gateway, in addition to transmission facility, needs to have reception chains in order to be able to provide bi-directional telecommunications services. However, in the case of broadcasting, the transmission is one way and the gateway needs only reception capability for monitoring purposes. In a non-regenerative satellite system, i.e., one that does not perform on-board demodulation and decoding (almost all satellites are non-regenerative), the signal received from the teleports is frequency shifted and amplified and sent to the receiving Earth terminal. This terminal is the user terminal having a small antenna and receiver chain.

The frequency translation performed on-board the satellite is due to the fact the uplink and downlink frequencies are different. For example, in Ku-band the uplink frequency is around14.0 GHz. while the downlink is around 12 GHz.

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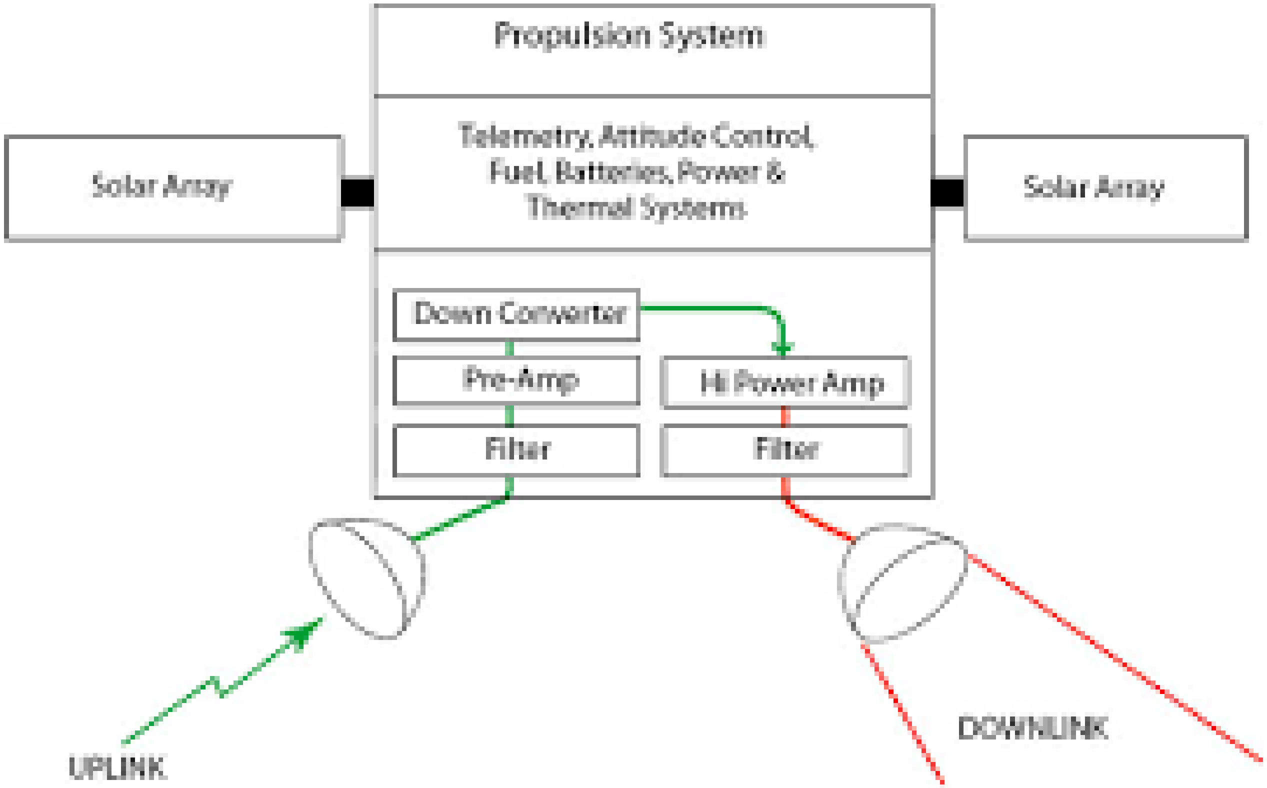

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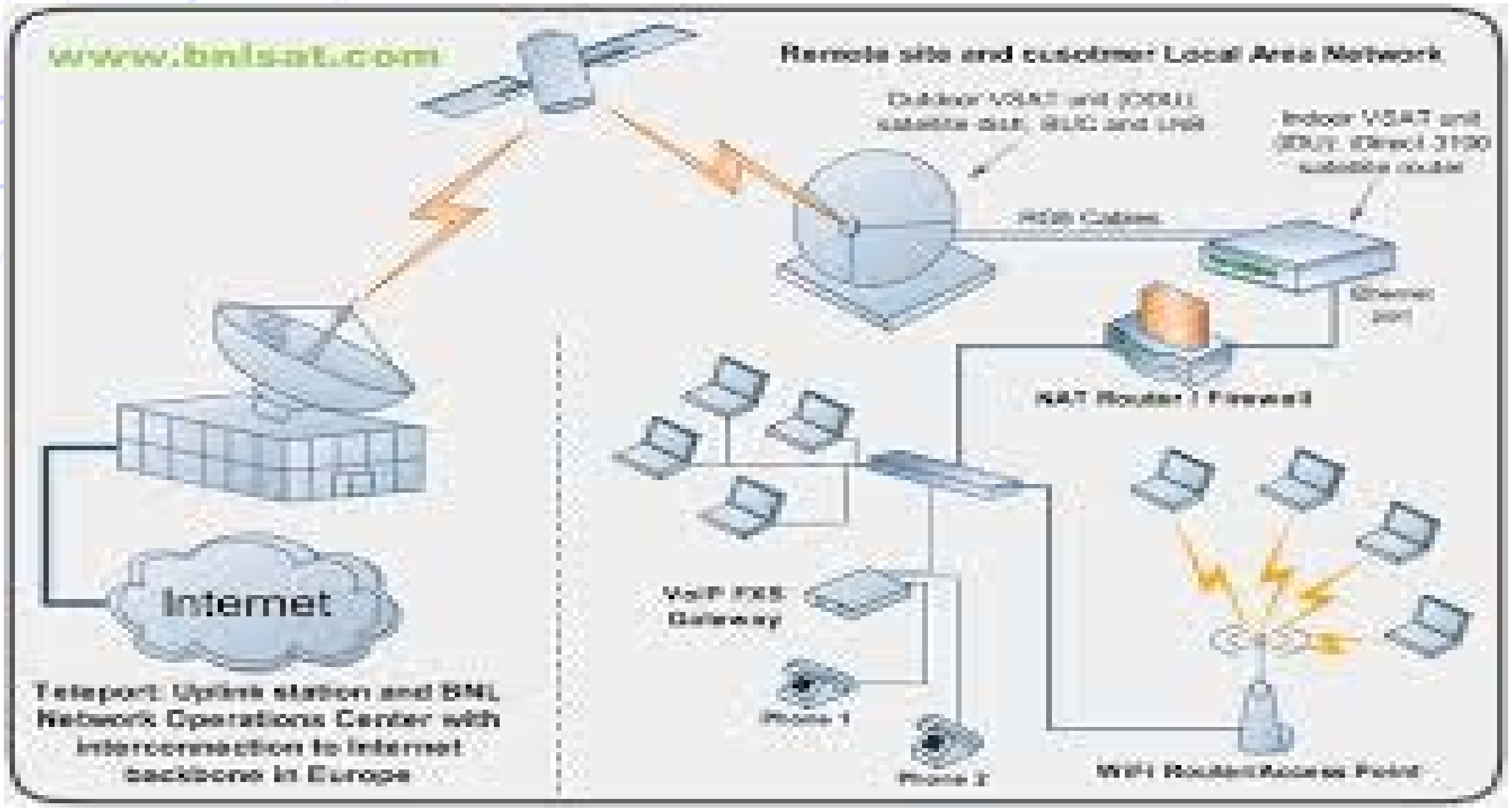
This figure shows a bi-directional satellite communication system providing Internet services.



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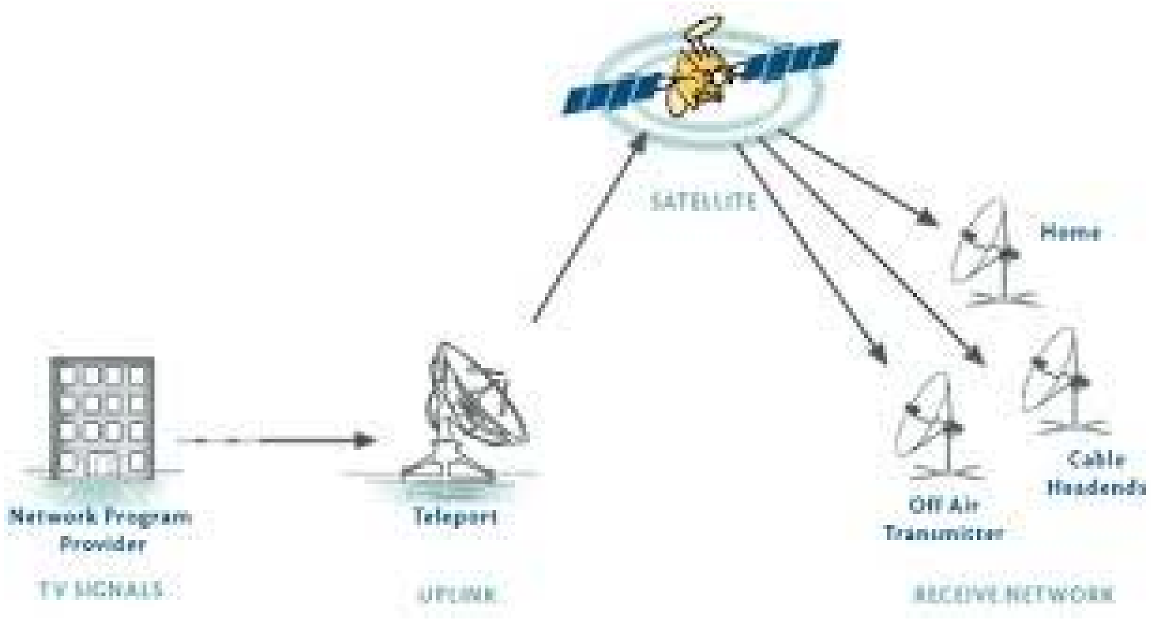
The system shown in this figure, on the other hand, is a TV signal broadcasting system. Here, the content provider (a network such as CBC, CTV or Global) sends its content (programs) via, say, Internet over Fiber, to a Teleport (operated say by a company such as Telesat) and the signal is distributed via the satellite to **homes, Cable Headends** or the **Networks affiliates** who may distribute it over the air.



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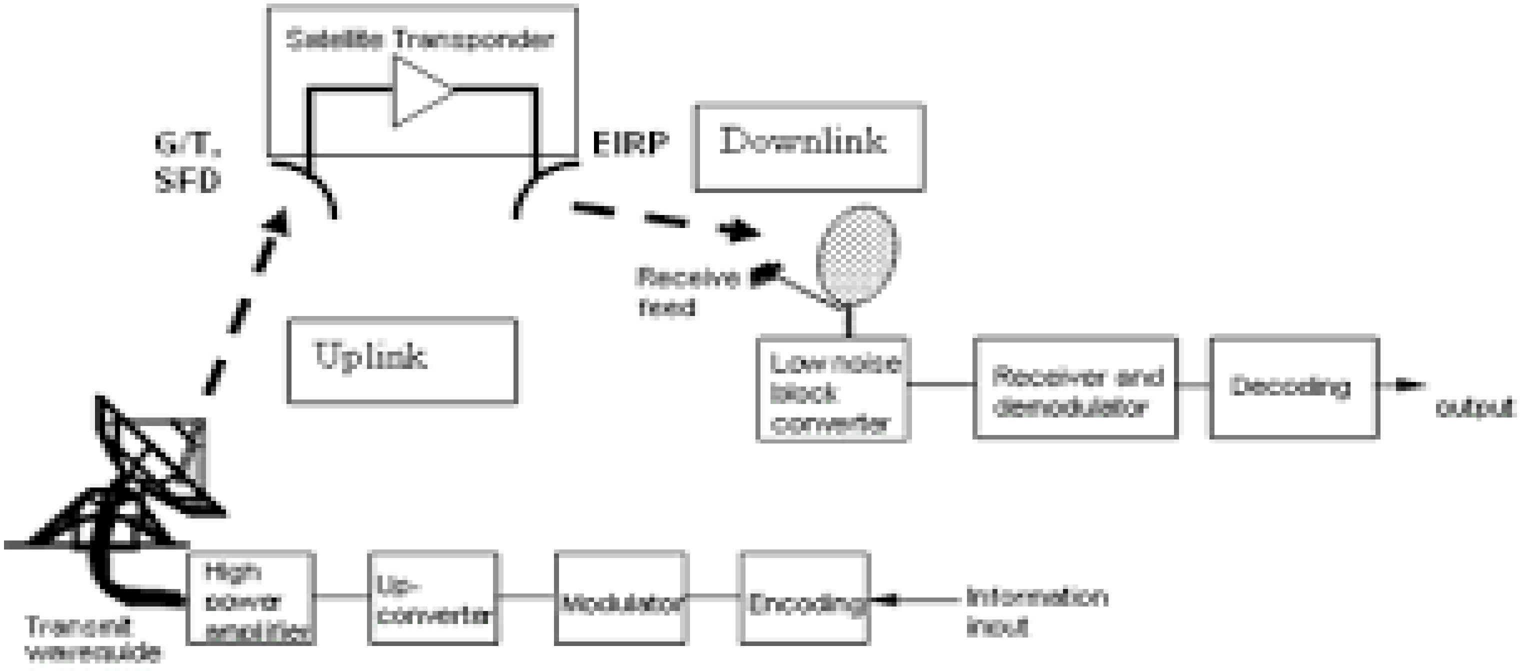
The fact that a satellite link is divided into an uplink and a downlink part means that we need to perform two link budget calculations: one for the uplink and another for the downlink.



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Denoting the uplink SNR by $\left(\frac{E_b}{N_0}\right)_U$ and the one for the downlink by $\left(\frac{E_b}{N_0}\right)_D$, the overall $\frac{E_b}{N_0}$ can be found as,

$$\left(\frac{E_b}{N_0}\right)_{ov}^{-1} = \left(\frac{E_b}{N_0}\right)_U^{-1} + \left(\frac{E_b}{N_0}\right)_D^{-1}.$$

The calculation of the link budget on the uplink and downlink are basically the same as what we did in the last lecture for the terrestrial link. The only difference is that some of the losses are different since in a satellite link, the electromagnetic wave travels through the different layers of atmosphere with different propagation properties.

Also, some of the terms used are either used only or are commonly used in the satellite communications community.

Before presenting an end to end satellite link budget calculation, the definition of some of the terminology will be given:

EIRP: Equivalent Isotropically Radiated Power. This is the product of the transmit power P_t and transmit antenna gain G_t.

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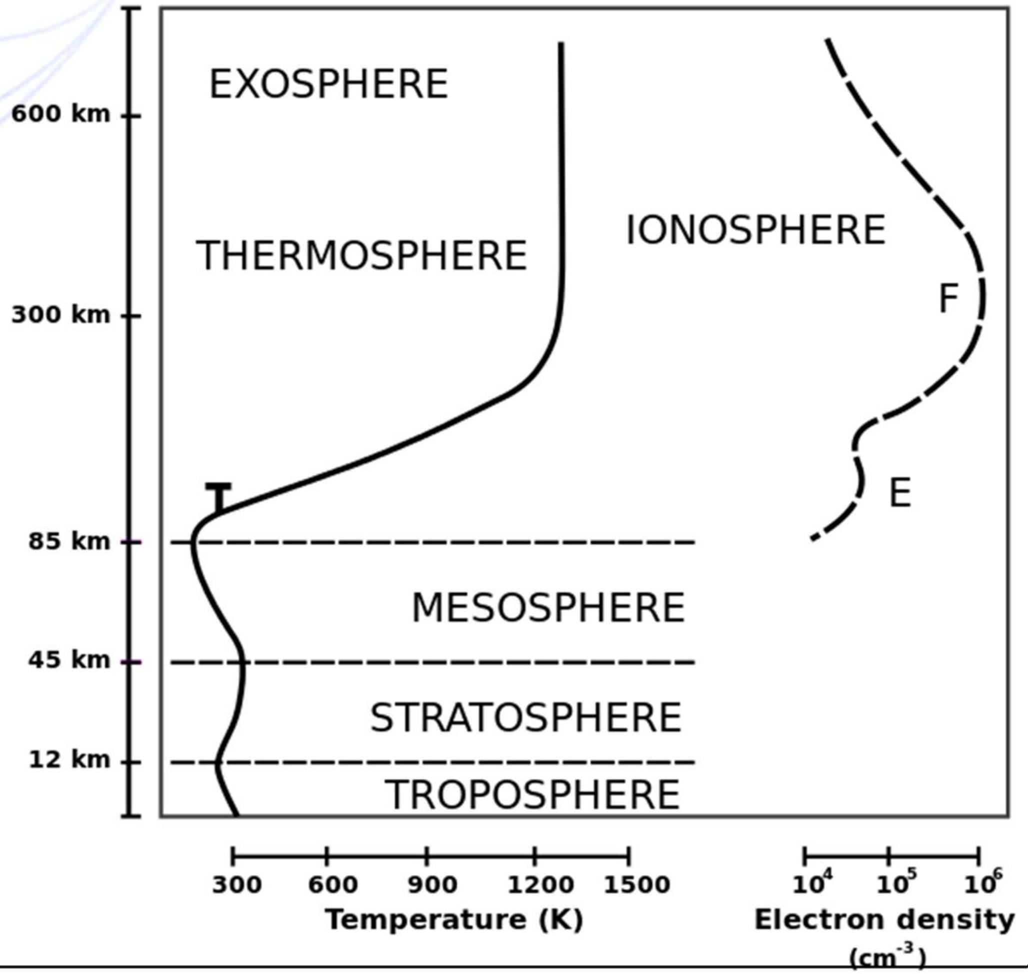

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Recall that, the range equation, i.e., the equation relating the transmitted power and the received power is:

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2},$$

Substituting $EIRP = P_t G_t$, we get,

$$P_r = \frac{EIRP G_r \lambda^2}{(4\pi d)^2},$$

It is as though we have an amplifier with power EIRP connected to an antenna with the gain of unity, i.e., and **isotropic** antenna.

Another combination of parameters we encounter is the quantity G/T.

It is called Antenna Gain to Noise Temperature Ratio. To see the reason for lumping together the gain of the antenna and its noise temperature, let's write the range equation as, $P_r = \frac{EIRP G_r}{L_s L_o}$ or $E_b = \frac{EIRP G_r}{L_s L_o R_b}$

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Where,

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

is the free space loss and L_o is the product of all other losses.

Now, if we assume that the noise temperature of the receive antenna plus the LNA is T_A, we get $N_0 = k_B T_A$. Therefore,

$$\frac{E_b}{N_0} = \frac{EIRP}{L_s L_o R_b} \frac{G_r}{T_A}.$$

So, at the receiver, whether at the satellite on the uplink or on the ground on the downlink G/T is used as a figure of merit.

Another number used in describing the quality of the link is SFD or Saturated Flux Density. This is a measure of how much received power per area is needed to saturate the satellite transponder. The lower SFD is the more sensitive the transponder is. This means that the Earth terminal has to use less power to get the maximum gain from the transponder. The satellite operator controls SFD by changing the attenuation at the input of the HPA (high power amplifier).

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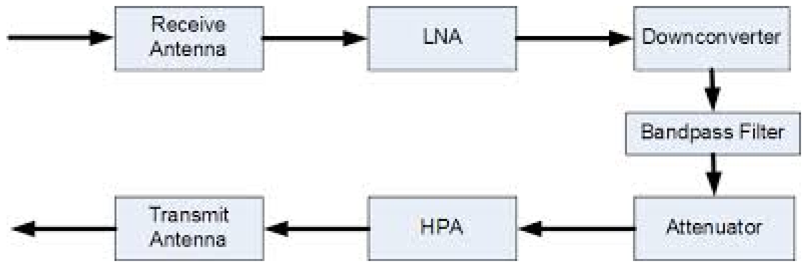
The reduction of the SFD is done through reducing the attenuation at the input of the HPA. This is done through TT&C (Telemetry, tracking, and command) commands from ground. Increasing the sensitivity of the transponder while reduces the uplink power required increases the effect of noise so signal to noise ratio is reduced. Therefore, a trade-off should be made between the size of the uplink antenna and the BUC poser and the signal to noise ratio.



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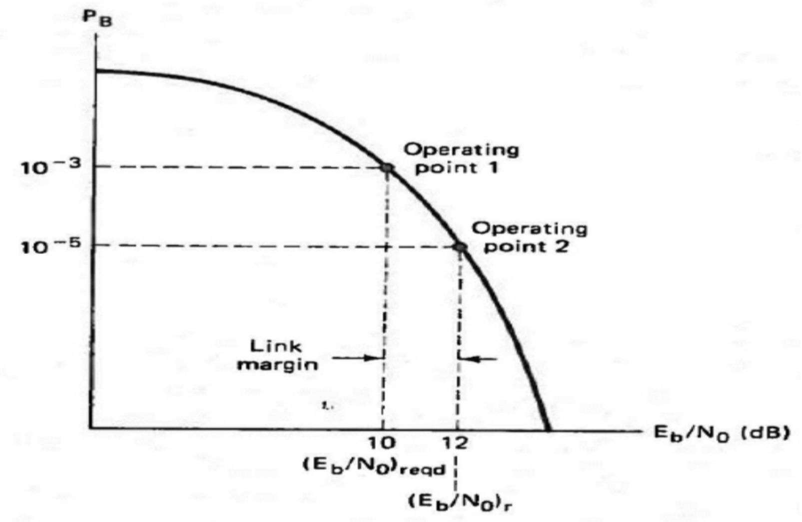
As stated in the previous lecture. Given a required BER, we can compute the required $\frac{E_b}{N_0}$. Let's denote it by $\left(\frac{E_b}{N_0}\right)_{req}$. The difference between this number and the actual $\frac{E_b}{N_0}$ at the receiver, by $\left(\frac{E_b}{N_0}\right)_r$ is the link margin.



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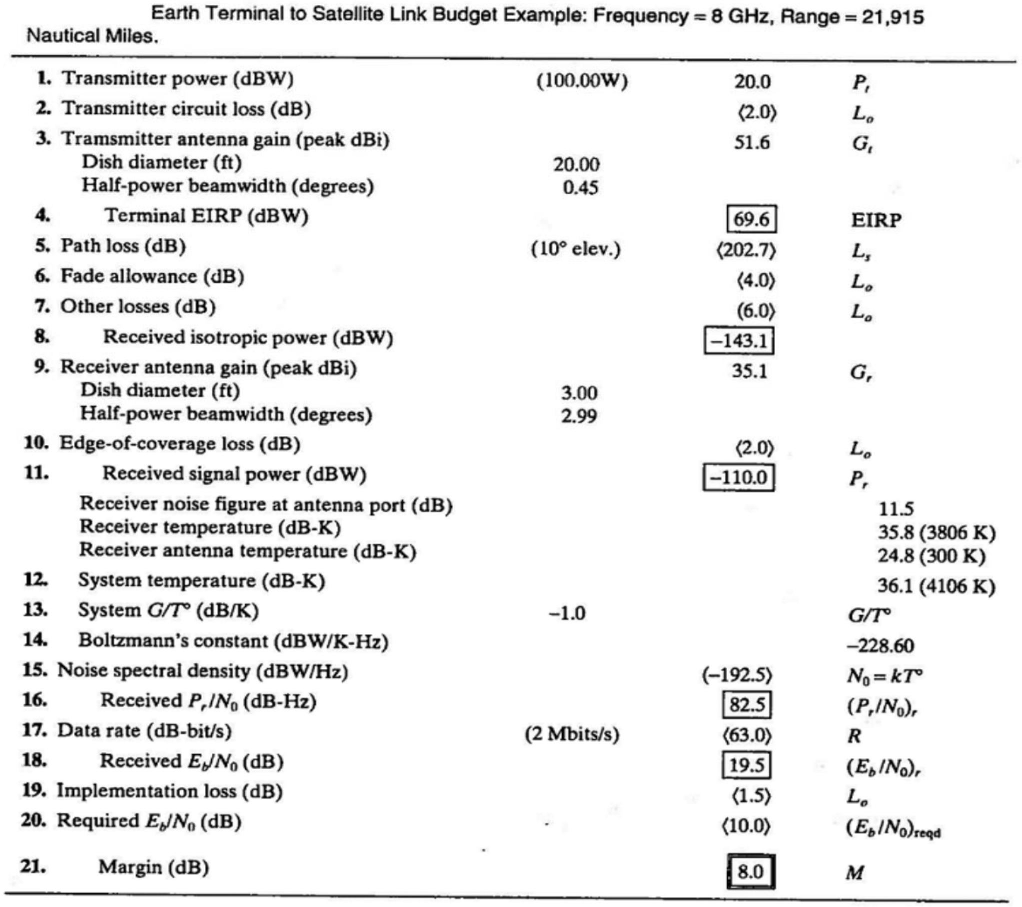
Example:



Earth Terminal to Satellite Link Budget Example: Frequency = 8 GHz, Range = 21,915 Nautical Miles.

1. Transmitter power (dBW)	(100.00W)	20.0	P_t	
2. Transmitter circuit loss (dB)		⟨2.0⟩	L_o	
3. Tramsmitter antenna gain (peak dBi)		51.6	G_t	
Dish diameter (ft)	20.00			
Half-power beamwidth (degrees)	0.45			
4. Terminal EIRP (dBW)		$\boxed{69.6}$	EIRP	
5. Path loss (dB)	(10° elev.)	⟨202.7⟩	L_s	
6. Fade allowance (dB)		⟨4.0⟩	L_o	
7. Other losses (dB)		(6.0⟩	L_o	
8. Received isotropic power (dBW)		$\boxed{-143.1}$		
9. Receiver antenna gain (peak dBi)		35.1	G_r	
Dish diameter (ft)	3.00			
Half-power beamwidth (degrees)	2.99			
10. Edge-of-coverage loss (dB)		⟨2.0⟩	L_o	
11. Received signal power (dBW)		$\boxed{-110.0}$	P_r	
Receiver noise figure at antenna port (dB)				11.5
Receiver temperature (dB-K)				35.8 (3806 K)
Receiver antenna temperature (dB-K)				24.8 (300 K)
12. System temperature (dB-K)				36.1 (4106 K)
13. System $G/T°$ (dB/K)	−1.0		$G/T°$	
14. Boltzmann's constant (dBW/K-Hz)			−228.60	
15. Noise spectral density (dBW/Hz)		(−192.5⟩	$N_0 = kT°$	
16. Received P_r/N_0 (dB-Hz)		$\boxed{82.5}$	$(P_r/N_0)_r$	
17. Data rate (dB-bit/s)	(2 Mbits/s)	⟨63.0⟩	R	
18. Received E_b/N_0 (dB)		$\boxed{19.5}$	$(E_b/N_0)_r$	
19. Implementation loss (dB)		⟨1.5⟩	L_o	
20. Required E_b/N_0 (dB)		⟨10.0⟩	$(E_b/N_0)_{\text{reqd}}$	
21. Margin (dB)		$\boxed{8.0}$	M	

Link Budget Example For a Nonregenerative Satellite Repeater with 10 Users: Uplink Frequency = 375 MHz, Downlink Frequency = 275 MHz, Range = 22,000 Nautical Miles

		Uplink			Downlink	
Transmitter power (dBW)		27.0	(500.0 W)		13.0	(20.0 W)
Transmitter circuit losses (dB)		1.0			1.0	
Transmitter antenna gain (peak-dBi)		19.0			19.8	
Dish diameter (ft)	10.00			15.00		
Half-power beamwidth (degrees)	19.16			17.42		
EIRP (dBW)		45.0			31.8	(1514.7 W)
Path loss (dB)		176.1			173.4	
Transmitted signal power (dBW)					21.7	(148.5 W) B
Transmitted other signal power (dBW)					31.3	(1336.1 W)
Transmitted U/L noise power (dBW)					14.8	(30.1 W)
Other losses (dB)		2.0			2.0	
Received isotropic signal power (dBW)		–133.1			–153.7	
Received isotropic U/L noise power (dBW)					–160.6	
Receiver antenna gain (peak dBi)		22.5			16.3	
Dish diameter (ft)	15.00			10.00		
Half-power beamwidth (degrees)	12.77			26.13		
Received signal power (dBW)		–110.6			–137.4	
Received U/L noise power (dBW)					–144.3	
Receiver antenna temperature (dB-K)		24.6	(290 K)		20.0	(100 K)
Receiver noise figure at antenna port (dB)		10.8			2.0	
Receiver temperature (dB-K)		35.1	(3197 K)		22.3	(170 K)
System temperature (dB-K)		35.4	(3487 K)		24.3	(270 K)
System G/T° (dB/K)		–12.9			–8.0	
Boltzmann's constant (dBW/K-Hz)		–228.6			–228.6	
Noise spectral density (dBW/Hz)		–193.2			–204.3	
System bandwidth (dB-Hz)		75.6	(36.0 MHz)		75.6	(36.0 MHz)
Noise power (dBW)		–117.6			–128.7	
U/L noise + D/L noise power (dBW)					–128.6	
Simultaneous accesses	10					
Received other signal power (dBW)		–101.1				
Other signals + noise (dBW)		–101.0				
$P_r/(P_T + N_s W)$ (dB)		–10.1	(0.098) A			
P_r/N (dB)		7.0			–8.7	
Overall P_r/N (dB)					–8.8	
P_r/N_0 (dB-Hz)		82.6			66.9	
Overall P_r/N_0 (dB-Hz)					66.8	
Data rate (dB-bit/s)					50.0	(100,000 bits/s)
Available E_b/N_0 (dB)					16.8	
Required E_b/N_0 (dB)					10.0	
Margin (dB)					$\boxed{6.8}$	