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Satellite Link Budget Design and System Performance Evaluation for a Specified Carrier to Noise Ratio

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***Abstract*— This paper presents the rudiments of satellite link design, and the evaluation of link performance based on the specified minimum carrier to noise ratio (C/N). The design of satellite links and evaluation of the system performance is based on the use of link budget. The results of the link budget analysis showed that the carrier to noise ratio of 16.0 dB in the design specification. Satellite engineers and designers of satellite communication systems should apply the design methodology presented in this paper in the analysis and design of satellite links, in order to produce satellite networks with minimum outage.**

Keywords: Uplink, Downlink, Link Budget, Carrier To Noise Ratio.

1. INTRODUCTION

The design of a satellite communication system is a complex process requiring compromises between many factors to achieve the best performance at an acceptable cost [1]. The performance of a satellite link is dependent on a number of factors and on the configuration of the transmit and receive components [2]. The other factors which influence system design are: the performance of the satellite itself; the configuration and performance of the uplink and downlink earth stations; atmospheric propagation effects; and the choice of the frequency band [2, 3]. It is difficult to generalize on the expected performance of a given link without a thorough analysis of the specific parameters and conditions on the link.

Satellite link design involves at mathematical approach to the selection of link subsystem parameters is such a way that the overall system performance criteria are met [4]. The most important performance criterion is the carrier to noise ratio (C/N or CNR) of the receiver.

In a satellite link there are two signal paths, an uplink from the earth station to the satellite, and a downlink from the satellite to the earth station [5]. The overall C/N at the earth station receiver depends on both links, and both therefore must achieve the required performance for a specified percentage of time. Path attention in the earth's atmosphere may become excessive in heavy rain, causing the C/N ratio to fall below the minimum permitted value, leading to link outage.

It is possible that sometimes, some system parameters may not be given, and thus a link designer should estimate such values based on assumed scenarios. Moreover, it is usually impossible to design a complete satellite communication system at the first attempt [5]. Hence, a trial design must first be tried, and then refined, until a workable compromise is achieved.

II. REVIEW OF RELATED WORKS

The optimization of satellite link design is presented by [5]. The authors did not stipulate the mathematical link equations for the optimization of satellite link design. The authors in [6] published a tutorial on satellite link design. The authors solve numerical problems necessary for calculations of link power budgets with desired characteristics. The published works of [1, 2, 7, 8] present the concepts of design and analysis of satellite communication system.

III. BASIC RADIO LINK EQUATIONS

The simplified satellite communication links is shown in Figure 1 [3, 4, 9]. The radio link equations derived in this section is required for the calculation of the available C/N over a satellite link [4].

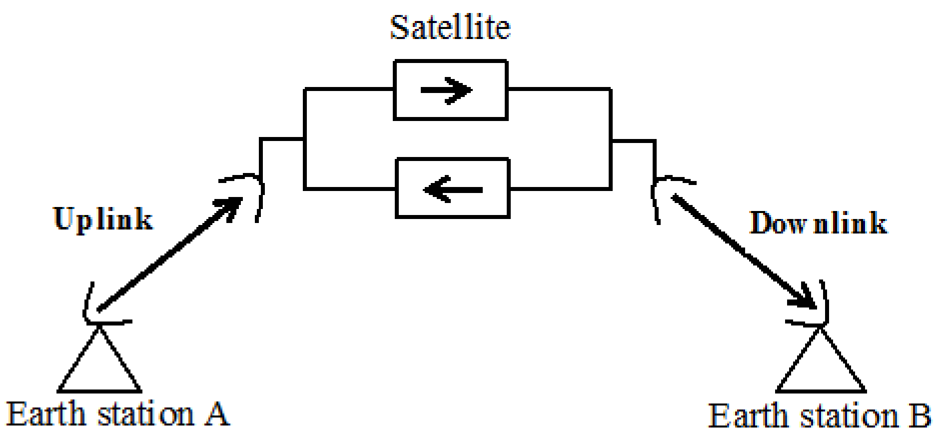

Figure 1: Basic satellite communication links

Considering the uplink, the received power flux density (F) at the receive satellite antenna from an earth station is given in [1] as:

$$F = \frac{P_t G_t}{4\pi d^2} \quad (1)$$

where: P_t is the transmitted power, G_t is the gain of the transmit antenna, and d is the distance between the transmit and receive antennas.
The product $P_t G_t$ is called the effective isotropic radiated power (EIRP). Mathematically, EIRP is given by:

$$EIRP = P_t G_t \quad (2)$$

The expression for EIRP in decibels (dB) is:

$$[EIRP] = 10\log(P_t) + 10\log(G_t) \quad (3)$$

According to [9], the power flux density in dB is given by:

$$[F] = [EIRP] - 10\log(4\pi d^2) \quad (4)$$

The received carrier power C at the satellite is given in [9] as:

$$C = FA_e = \frac{P_t G_t A_e}{4\pi d^2} \quad (5)$$

where A_e is the effective aperture area of the receive antenna.

The effective aperture area (A_e) is:

$$A_e = \eta A \quad (6)$$

whereη is the aperture efficiency, and A is the physical area of the antenna.

A fundamental relationship in antenna theory is that the gain (G) and effective aperture area (A_e) of an antenna are related based on [1, 10, 11] as:

$$G = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi A\eta}{\lambda^2} \quad (7)$$

The effective aperture area (A_e) is expressed in [2, 4] as:

$$A_e = \frac{G\lambda^2}{4\pi} \quad (8)$$

Replacing A_e in Equation (5) with Equation (8) gives:

$$C = P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2 \quad (9)$$

The squared component in Equation (9) is the free space (path) loss (FSL) given in [2, 4] as:

$$FSL = \left(\frac{4\pi d}{\lambda}\right)^2 \quad (10)$$

\Or, exposed in dB as:

$$[FSL] = 20\log\left(\frac{4\pi d}{\lambda}\right) \quad (11)$$

For distanced in meters, and the frequency f in GHz, Equation (11) becomes:

$$[FSL] = 20\log f + 20\log d + 32.44 \quad (12)$$

For distance d in km, and the frequency f in GHz, Equation (11) gives:

$$[FSL] = 20\log f + 20\log d + 92.44 \quad (13)$$

Substituting Equation (10) into Equation (9) yields:

$$C = P_t G_t G_r \left(\frac{1}{FSL}\right) = EIRP\ G_r \left(\frac{1}{FSL}\right) \quad (14)$$

Equations (9) and (14) expressed in dB give:

$$[C] = [EIRP] + [G_r] - [FSL] \quad (15)$$

Equation (15) gives the basic link equation referred to as the link power budget equation, for satellite communications link, and is the design equation from which satellite design and performance evaluation proceed [2].

The carrier to noise ratio (C/N) is obtained by dividing the carrier power by the system noise power at the receiver input. The system noise power is defined in [4,12] as:

$$N = K\ T_s B_n \quad (16)$$

where: K = Boltzmann's constant = 1.39 x 10^{-23} J/K = -228.6 dBw/k/Hz, T_S = system noise temperature in Kelvin (K), and B_n = noise bandwidth in hertz (Hz).

In decibel unit, noise power budget according to [12] is expressed as:

$$[N] = [K] + [T_s] + [B_n] \quad (17)$$

Since thermal noise is independent of the frequency of operation, it is often useful to express noise as noise power spectral density (N_o) or noise power density as:

$$N_o = \frac{N}{B_n} = kT \quad (18)$$

The noise power density is usually the parameter of choice in the evaluation of system noise power in satellite link communication system.

A measure of the performance of a satellite link is the ratio of carrier power to noise power (C/N) ratio at the receiver input, and link budget designs (calculations) are often concerned with determining C/N. In terms of decibels, C/N is:

$$\left[\frac{C}{N}\right] = [C] - [N] \quad (19)$$

$$= [EIRP] + [G_R] - [LOSSES] - [k] - [T_S] - [B_n] \quad (20)$$

But

$$[G_R] - [T_S] = [G_R / T_S] \quad (21)$$

$$\therefore \left[\frac{C}{N}\right] = [EIRP] + \left[\frac{G_R}{T_S}\right] - [LOSSES] - [k] - [B_n] \quad (22)$$

The losses for clear-sky conditions are:

$$[LOSSES] = [FSL] + [RFL] + [AML] + [AA] + [PL] \quad (23)$$

where: [FSL] = free space loss is dB, [RFL] = receiver feeder loss in dB, [AML] = antenna misalignment loss in dB, [AA] = atmosphere absorption loss in dB, [PL] = polarization mismatch in dB.

Finally, the link budgets on the uplink and downlink are given by Equations (24) and (25) respectively.

$$\left[\frac{C}{N}\right] = [EIRP]_G + \left[\frac{G}{T}\right]_S - [LOSSES]_u - [k]_u - [B_n]_u \quad (24)$$

$$\left[\frac{C}{N}\right] = [EIRP]_B + \left[\frac{G}{T}\right]_G - [LOSSES]_D - [k]_D - [B_n]_D \quad (25)$$

where the subscripts U and D refer to the uplink and downlink respectively, and S and G refer to the satellite transponder and ground station respectively.

IV METHODOLOGY

The design methodology for a one-way satellite communication link is summarized into the following step [1]. The return link design follows the same procedure.

Step 1: Determine the frequency band in which the system must operate

Step 2: Determine the parameters of the satellite. Estimate values that are not given.

Step 3: Determine the parameters of the transmitting and receiving earth station.

Step 4: Establish an uplink budget and a transponder noise power budget to find (C/N)u in the transponder.

Step 5: Find the output power of the transponder based on transponder gain or output backoff.

Step 6: Establish a downlink power and noise budget for the receiving earth station. Calculate $(C/N)_D$ at the edge of the coverage zone (worst case).

Step 7: Evaluate the result and compare with the specified C/N. Tweak parameters of the system as required to obtain acceptable C/N. This may require several trial designs.

Step 8: Determine the propagation conditions under which the link must operate. Calculate outage times for the uplinks and downlinks.

Step 9: Redesign the system by changing some parameters if the link margins are inadequate. Check that all parameters are reasonable, and that the design can be implemented within the expected budget.

Step 10: Finally, set up a table, called the link budget, to calculate the received power (C), noise power (N), and C/N using the derived link equations in Section 2 of this paper.

Step 11: Are computed parameters reasonable? If yes, the satellite link design is successful, so stop. If no, then satellite link design us unsuccessful, so go to step 1.

Design Problem in [1]. Table 1 show a typical link parameters for C-band downlink using a global beam on a geostationary earth orbit (GEO) and a 9 m earth station antenna. Determine the C/N ratio in earth station receiver in clear air condition.

Table 1: C-band GEO satellite link parameters in clear air.

C-band satellite parameters	Value/Units
Transponder saturated output power	20 W
Antenna gain, on axis	20 dB
Transponder bandwidth	36 MHz
Downlink frequency band	3.7 – 4.2 GHz
Signal FM-TV analog signal	
FM-TV signal bandwidth	30 MHz
Minimum permitted overall C/N in receiver	9.5 dB
Receiving C-band earth station	
Downlink frequency	4.00 GHz
Antenna gain, on axis, 4 GHz	49.7 dB
Receiving system noise temperature	75 k

Applying the design methodology, the estimate of the values of the link parameters not given are as follows:
Distance between the transmit and receive antenna = d = 40,000 km

The free space loss (FSL) at 4 GHz according to Equation (13) is:

$$[FSL] = 20\log f + 20\log d + 92.44$$
$$= 20\log(4) + 20\log(40{,}000) + 92.44 = -196.5 \text{ db}$$

The satellite output power (20 W) in decibel is:

$$[P_t] = 10\log_{10} P_t = 10\log_{10} 20 = 13.0 \text{ dBw}$$

Other estimate of the values of the link parameters not explicitly stipulated in the design problem in [1] are stated in the downlink budget in Table 2.

V. RESULTS AND DISCUSSION

The C-band satellite link budget calculations and results in clear air is summarized in Table 2.

Table 2: C-band satellite downlink budget.

Item	Link Parameter	Symbol	Value	Units	Computation
	Downlink power budget				
1.	Satellite transponder output power, 20 W	P_t	+13.0	dBW	
2.	Transponder output backoff	B_O	-2.0	dB	
3.	Satellite antenna gain, on axis	G_t	+20.0	dB	
4.	Earth station antenna gain	G_r	+49.7	dB	
5.	Free space loss at 4GHz	FSL	-196.5	dB	
6.	Edge of beam loss for satellite antenna	L_{ant}	-3.0	dB	
7.	Clear air atmospheric loss	L_c	-0.2	dB	
8.	Other losses	L_o	-0.5	dB	
9.	Received carrier power at earth station	C	-119.5	dBW	1+2+3+4+5+6+7+8
	Downlink noise budget				
10.	Boltzmann's constant	K	-228.6	dBW/k/Hz	
11.	System noise temperature, 75 k	T_s	+18.8	dBk	
12.	Noise bandwidth, 27MHz	B_n	+74.3	dBHz	
13.	Receiver noise power	N	-135.5	dBW	10+11+12
	C/N ratio in receiver in clear air				
14.	C/N = C – N		+16.0	dB	9 - 13

The C/N ratio of 16.0.dB in earth station receiver is above the minimum permitted C/N in receiver of 9.5 dB in Table 1. The C/N ratio is good, and so the satellite downlink will transmit signals with good acceptable quality of transmission, because signal power is greater than noise power.

VI CONCLUSION

The most important performance standard in satellite communication system is the carrier to noise ratio. This paper shows the process of designing and calculating satellite link budget for a specified minimum carrier to noise ratio. A number of factors have to be taken into consideration in the design of a robust satellite link. The system link parameters, losses in the links and communication equipment must be taken into consideration in link budget design.

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