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Determination Of The Clear Sky Composite Carrier To Noise Ratio For Ku-Band Digital Video Satellite Link

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***Abstract*— In this paper, the determination of the clear sky composite carrier to noise ratio for Ku-band digital video satellite link is presented. Specifically, the uplink and downlink analysis are presented along with the determination of the composite carrier to noise ration of the Ku-band satellite link. The analysis is for clear sky condition. The mathematical expressions for the computation of requisite satellite link parameters are presented along with sample numerical example that has 14 GHz uplink frequency and 12 GHz downlink frequency. The results showed that the composite carrier to noise ratio (C/N) is 15.6 dB at a data rate of 76 Mbps. The downlink C/N is 17.4 dB whereas the uplink C/N is 20.2 dB. Also, the downlink the uplink energy per bit (Eb) to the spectral noise density (No) ratio denoted as Eb/No is 12.4 dB and the bit error rate (BER) is 2.12263 x 10^{-9} . On the other hand, Eb/No is 15.4 dB and the bit error rate (BER) is 5.55112 x 10^{-17}. With BER of the order of 1 x 10^{-9}, the link can be assumed to be adequate for the specified date rate. However, considering that the analysis is for clear sky condition, it may not be good enough, especially in regions with heavy rain fall rate. In such case, additional measures must be taken to improve on the Eb/No and hence the BER.**

Keywords*— *Ku-Banrd, Satellite Communication, Digital Video, Link Budget, Video, Carrier To Noise Ratio, Bit Error Probability

I. INTRODUCTION

Over the year, satellite technologies have developed rapidly and the applications of satellite technologies have also increased exponentially [1,2,3,4,5,6,7]. Beyond radio communications, satellites are being used for broadcasting, astronomy, mapping, weather forecasting, and so many other applications [8,9,10,11,12]. Due to the growing demand and applications of satellite communication, the lower frequency C-band earlier used for satellite communication is highly congested [13,14,15,16,17,18]. As such, higher frequency bands, such as the Ku-band and the Ka-band are considered. However, when compared with the lower frequency bands, the higher frequency bands are more affected by climatic factors like rain, fog etc [19,20,21,22]. Notably, the Ku-band has been widely deployed in different satellite communication applications such as direct-transmission satellites for satellite TV and Vsats (Very Small Aperture Terminal). The advantages of the Ku-band include; high efficiency, availability levels of over 99.5% and the use of small size equipment [23,24,25,26]. In any case, any deployment of Ku-band satellite communication system require link budget analysis which accounts for all the losses expected in the link, as well as the required system component and link parameters that will ensure the desired quality of service (QoS) is met [27,28,29,30,31]. Specifically, in this paper, link budget analysis is conducted to determinate the clear sky composite carrier to noise ratio (C/N) for Ku-band digital video satellite link. The composite C/N is determined from the uplink C/N and the downlink C/N. First, detailed uplink budget analysis is presented from which the uplink C/N is determined. Next, detailed downlink budget analysis is presented from which the downlink C/N is determined. Then, the composite link C/N is determined from the uplink C/N and the downlink C/N. In addition, bit error performance analysis of the uplink and the downlink are determined. Particularly, the probability of bit error is based on the Quadrature Phase Shift Keying (QPSK) modulation scheme. All requisite mathematical expressions are presented and numerical example is used to demonstrate applicability of the ideas presented in this paper.

II. METHODOLOGY

The satellite uplink (connection from the transmitting earth station to the satellite) budget analysis is first conducted. Then, the satellite downlink (connection from the satellite to the receiving earth station) budget analysis is conducted. Afterwards, the composite link analysis is performed where the composite C/N is determined.

A. *The Uplink Analysis*

The uplink input data are given in Table 1 The transmitted power in dB ($P_{tu(dB)}$) can be calculated as follows;

$$P_{tu(dB)} = 10Log(P_{tu}) \quad (1)$$

$$P_{tu(dB)} = 10Log(195) = 22.9\ dB$$

$$\lambda_{tu} = \frac{3x10^8}{f_u} \quad (2)$$

$$\lambda_{tu} = \frac{3x10^8}{12x10^9} = 0.02143\ \text{m}$$

$$G_{tu} = \left(\frac{\eta_{Gtu}}{100}\right)\left(\frac{\pi(D_{Gtu})}{\lambda_{tu}}\right)^2 \quad (3)$$

Table 1 The data used for the uplink design

S/N	Parameter Description	Parameter Symbol Representation	Parameter Value	Parameter Unit
1	Transmitter Power,	P_{tu}	195	W
2	Transmitter antenna diameter	D_{Gtu}	1.2	m
3	Transmitter antenna efficiency	η_{Gtu}	55	%
4	Transmitter waveguide loss	$L_{tu(dB))}$	1.2	dB
5	Path length	d_u	37,831	km
6	Atmospheric absorption loss	$L_{atmu(dB)}$	0.1	dB
7	Receiver antenna diameter	D_{Gru}	0.5	m
8	Receiver antenna efficiency	η_{Gru}	60	%
9	Receiver waveguide loss	$L_{ru(dB))}$	1.0	dB
10	System Noise Temperature	T_{sysu}	350	K
11	(Noise) Bandwidth	B_{Nu}	25	MHz
12	Boltzmann's constant	K	1.381 x 10^{-23}	
13	Frequency	f_u	14	GHz
	Data rate	R_u	76	Mbps
	Modulation Scheme	QPSK		

The gain of the transmitter in dB ($G_{tu(dB)}$) can be calculated as follows;

$$G_{tu} = 10Log\left(\frac{55}{100}\right)\left(\frac{\pi(1.2)}{0.02143}\right)^2 = 17023.09367$$

$$G_{tu(dB)} = 10Log(\,G_{tu}\,) \quad (4)$$

$$G_{tu(dB)} = 10Log(17023.09367) = 42.31 \text{ dBi}$$

At the transmitter, the effective isotropic radiated power ($EIRP_{tup(dB)}$) in dB can be calculated as follows;

$$EIRP_{tup(dB)} = P_{tup(dB)} + G_{tup(dB)} - L_{tup(dB)} \quad (5)$$

$$EIRP_{eup(dB)} = 22.9 + 42.31 - 1.2 = 64.01 \text{ dB}$$

The pathloss based on free space path loss model is denoted as $L_{FSPup(dB)}$ where the path length, d_{up} is in km and the frequency, f is in MHz)

$$L_{FSPup(dB)} = 32.45+20\,\text{Log}(f_{up})+20\text{Log}(d_{up}) \quad (6)$$

$$L_{FSPup(dB)} = 32.45+20\,\text{Log}(14000)+20\text{Log}(37{,}831) = 206.9 \text{ dB}$$

The total path loss $L_{Pup(dB)}$ is computed as;

$$L_{Pup(dB)} = L_{FSPup(dB)} + L_{atmup(dB)} \quad (7)$$

$$L_{Pup(dB)} = 206.9 + 0.1 = 207.0\ dB$$

The gain of the receiver in dB ($G_{ru(dB)}$) is determined as follows;

$$G_{ru} = \left(\frac{\eta_{Gru}}{100}\right)\left(\frac{\pi(\,D_{Gru}\,)}{\lambda_{tu}}\right)^2 \quad (8)$$

$$G_{tu} = 10Log\left(\frac{60}{100}\right)\left(\frac{\pi(0.5)}{0.02143}\right)^2 = 3224.070771$$

$$G_{ru(dB)} = 10Log(\,G_{ru}\,) \quad (9)$$

$$G_{ru(dB)} = 10Log(3224.070771) = 35.08 \text{ dB}$$

The power at the receiver, $P_{rup(dB)}$ is computed as;

$$P_{rup(dB)} = EIRP_{eup(dB)} + G_{rup(dB)} - L_{rup(dB)} - L_{Pup(dB)} \quad (10)$$

$$P_{rup(dB)} = 64.01 + 35.08 - 1.0 - 207.0 = -108.9\ dB$$

The figure of merit of the receiver, $G_r/T_{sys}|_{rup(dB)}$ is computed as

$$G_r/T_{sys}|_{rup(dB)} = G_{rup(dB)} - L_{rup(dB)} - 10Log(T_{sysup}) \quad (11)$$

$$G_r/T_{sys}|_{rup(dB)} = 35.08 - 1.0 - 10\text{Log}(350) = 35.08 - 1.0 - 25.4 = 8.6 \text{ dB}$$

The receiver noise power, N_{up} is computed as;

$$N_{up} = 10(\text{Log(K)}) + 10Log(T_{sysup}) + 10(\text{LOG}(\,B_{Nup})) \quad (12)$$

$$N_{up} = 10(\text{Log}(1.381 \times 10^{-23}) + 10Log(350) + 10(\text{LOG}(25000000))$$

$$N_{up} = -228.6 + 25.4 + 74 = -129.2 \text{ dB}$$

The uplink $C/N|_{dBup}$ is computed as

$$C/N|_{up} = P_{rup(dB)} - N_{up} \quad (13)$$

$$C/N|_{dBup} = -108.9 - (-129.2) = 20.2 \text{ dB}$$

The uplink energy per bit (Eb) to the spectral noise density (No) ratio denoted as $E_b/N_o|_{dBup}$ is given as;

$$E_b/N_o|_{dBup} = EIRP_{eup(dB)} - L_{rup(dB)} - G_r/T_{sys}|_{rup(dB)} - 10(\text{Log(K)}) - 10Log(\,R_{up}) \quad (14)$$

$$E_b/N_o|_{dBup} = 64.01 - 207.0 - 8.6 - 10(\text{Log}(1.381 \times 10^{-23}) - 10Log(\,76 \times 10^6)$$

$$E_b/N_o|_{dBup} = 64.01 - 207.0 - 8.6 - (-228.6) - 78.8 = 15.4\ dB$$

$$E_b/N_o|_{up} = 10^{\frac{(E_b/N_o|_{dBup})}{10}} \quad (15)$$

$$E_b/N_o|_{up} = 10^{\frac{(15.4)}{10}} = 34.8 \quad (16)$$

QPSK modulation scheme is adopted, hence, the probability of bit error is given as ;

$$P_{bup(QPSK)} = 0.5\left(erfc(\sqrt{E_b/N_o|_{up}})\right) \quad (17)$$

$$P_{bup(QPSK)} = 0.5\left(erfc(\sqrt{34.8})\right) = 0.5(1.11022\text{E-}16) = 5.55112 \times 10^{-17}$$

B. Downlink Analysis

The downlink input data are given in Table 2. The transmitted power in dB ($P_{td(dB)}$) is determined as follows;

$$P_{td(dB)} = 10Log(\,P_{td}) \quad (18)$$

$$P_{td(dB)} = 10Log(10) = 10\ dB$$

$$\lambda_{td} = \frac{3x10^8}{f_u} \quad (19)$$

$$\lambda_{td} = \frac{3x10^8}{12x10^9} = 0.02500 \text{ m}$$

$$G_{td} = \left(\frac{\eta_{Gtd}}{100}\right)\left(\frac{\pi(\,D_{Gtd}\,)}{\lambda_{td}}\right)^2 \quad (20)$$

Table 1 The data used for the downlink design

S/N	Parameter Description	Parameter Symbol Representation	Parameter Value	Parameter Unit
1	Transmitter Power,	P_{td}	10	W
2	Transmitter antenna diameter	D_{Gtd}	1.2	m
3	Transmitter antenna efficiency	η_{Gtd}	70	%
4	Transmitter waveguide loss	$L_{td(dB))}$	0.5	dB
5	Path length	d_d	37,831	km
6	Atmospheric absorption loss	$L_{atmd(dB)}$	0.1	dB
7	Receiver antenna diameter	D_{Grd}	0.6	m
8	Receiver antenna efficiency	η_{Grd}	70	%
9	Receiver waveguide loss	$L_{rd(dB))}$	0.5	dB
10	System Noise Temperature	T_{sysd}	75	K
11	(Noise) Bandwidth	B_{Nd}	24	MHz
12	Boltzmann's constant	K	1.381 x 10^{-23}	
13	Frequency	f_d	12	GHz
	Data rate	R_{bd}	76	Mbps
	Modulation Scheme	QPSK		

The gain of the transmitter in dB ($G_{td(dB)}$) is determined as follows;

$$G_{td} = 10Log\left(\frac{70}{100}\right)\left(\frac{\pi(1.2)}{0.02500}\right)^2 = 15917.69798$$

$$G_{td(dB)} = 10Log(G_{td}) \quad (21)$$

$$G_{td(dB)} = 10Log(15917.69798) = 42.01 \text{ dBi}$$

The transmitter effective isotropic radiated power ($EIRP_{td\,(dB)}$) in dB is computed as follows;

$$EIRP_{td\,(dB)} = P_{td\,(dB)} + G_{td\,(dB)} - L_{td\,(dB)} \quad (22)$$

$$EIRP_{td\,(dB)} = 10 + 42.01 - 1.2 = 51.5 \text{ dB}$$

The pathloss based on free space path loss model is denoted as $L_{FSPd(dB)}$ where the path length, d_d is in km and the frequency, f_d is in MHz);

$$L_{FSPd(dB)} = 32.45+20\,Log(f_d)+20Log(d_d) \quad (23)$$

$$L_{FSPd(dB)} = 32.45+20\,Log(12000)+20Log(37,831) = 206.9 \text{ dB}$$

The total path loss, $L_{Pd(dB)}$ is computed as;

$$L_{Pd(dB)} = L_{FSPd(dB)} + L_{atmd(dB)} \quad (24)$$

$$L_{Pd(dB)} = 205.6 + 0.1 = 205.7 \ dB$$

The gain of the receiver in dB ($G_{rd(dB)}$) is determined as follows;

$$G_{rd} = \left(\frac{\eta_{Grd}}{100}\right)\left(\frac{\pi(D_{Grd})}{\lambda_{rd}}\right)^2 \quad (25)$$

$$G_{td} = 10Log\left(\frac{70}{100}\right)\left(\frac{\pi(0.6)}{0.02500}\right)^2 = 3979.424495$$

$$G_{ru(dB)} = 10Log(G_{ru}) \quad (26)$$

$$G_{rd(dB)} = 10Log(3979.424495) = 35.99 \text{ dB}$$

The power at the receiver, $P_{rd(dB)}$ is computed as;

$$P_{rd(dB)} = EIRP_{td(dB)} + G_{rd(dB)} - L_{rd(dB)} - L_{Pd(dB)} \quad (27)$$

$$P_{rd(dB)} = 51.5 + 35.99 - 0.5 - 205.7 = -118.7 \ dB$$

The figure of merit of the receiver, $G_{rd}/T_{sysd}\big|_{ru(dB)}$ is computed as;

$$G_{rd}/T_{sysu}\big|_{rd(dB)} = G_{rd(dB)} - L_{rd(dB)} - 10Log(T_{sysd}) \quad (28)$$

$$G_{rd}/T_{sysd}\big|_{rd(dB)} = 35.99 - 0.5 - 10Log(75) = 35.99 - 0.5 - 18.75 = 16.7 \text{ dB}$$

The receiver noise power, N_d is computed as;

$$N_d = 10(Log(K) + 10Log(T_{sysd}) + 10(LOG(B_{Nd})) \quad (29)$$

$$N_d = 10(Log(1.381 \text{ x } 10^{-23}) + 10Log(75) + 10(LOG(24000000))$$

$$N_d = -228.6 + 18.65 + 74 = -136.05 \text{ dB}$$

The downlink $C/N|_{dBd}$ is computed as;

$$C/N|_d = P_{rd(dB)} - N_d \quad (30)$$

$$C/N|_{dBd} = -118.7 - (-136.05 \ ) = 17.4 \text{ dB}$$

$$E_b/N_o|_{dBd} = EIRP_{td(dB)} - L_{rd(dB)} - G_{rd}/T_{sysd}\big|_{ru(dB)} - 10(Log(K) - 10Log(R_{bd}) \quad (31)$$

$$E_b/N_o|_{dBd} = 51.5 - 205.7 - 8.6 - 10(Log(1.381 \text{ x } 10^{-23}) - 10Log(76 \text{ x } 10^6)$$

$$E_b/N_o|_{dBd} = 64.01 - 207.0 - 16.7 - (-228.6) - 78.8 = 12.4 \ dB$$

$$E_b/N_o|_d = 10^{\frac{(E_b/N_o|_{dBd})}{10}} \quad (32)$$

$$E_b/N_o|_d = 10^{\frac{(12.4\,)}{10}} = 17.3 \quad (33)$$

QPSK modulation scheme is adopted, hence, the probability of bit error is given as;

$$P_{bd(QPSK)} = 0.5\left(erfc(\sqrt{E_b/N_o|_d})\right) \quad (34)$$

$$P_{bd(QPSK)} = 0.5\left(erfc(\sqrt{17.3})\right) = 0.5(4.24526 \, x \, 10^{-9}) = 2.12263 \, x \, 10^{-9}$$

B. *The Composite Carrier To Noise Ratio*

The composite carrier to noise ratio, $C/N|_{TdB}$ is determined as follows;

$$C/N|_d = 10^{\left(\frac{C/N|_{dBd}}{10}\right)} \quad (35)$$

$$C/N|_d = 10^{\left(\frac{17.4}{10}\right)} = 54.6$$

$$C/N|_u = 10^{\left(\frac{C/N|_{dBu}}{10}\right)} \quad (36)$$

$$C/N|_u = 10^{\left(\frac{20.2}{10}\right)} = 105.8$$

$$\frac{1}{C/N|_T} = \frac{1}{C/N|_d} + \frac{1}{C/N|_u} \quad (37)$$

$$\frac{1}{C/N|_T} = \frac{1}{54.6} + \frac{1}{105.8} = 0.0183024 + 0.0094485 = 0.0277509$$

$$C/N|_T = \frac{1}{\frac{1}{C/N|_d} + \frac{1}{C/N|_u}} \quad (38)$$

$$C/N|_T = \frac{1}{0.0277509} = 36.0$$

$$C/N|_{TdB} = 10Log(C/N|_T) \quad (39)$$

$$C/N|_{TdB} = 10Log(36.0) = 15.6 \text{ dB}$$

IV. DISCUSSION OF RESULTS

The Ku-band link used in the analysis is for clear sky condition where rain attenuation is assumed to be negligible. The uplink and downlink analysis results for the case study satellite link are given in Table 2. The results in Table 2 show that in the clear sky, the composite carrier to noise ratio (C/N) is found to be 15.6 dB at a data rate of 76 Mbps.

Table 2 The uplink and downlink analysis results

S/N	Parameter Description	Parameter Value for the Uplink	Parameter Value for the Downlink	Parameter Unit
1	Transmitter Power,	22.9	10	dB
2	Gain of the transmitter	42.31	42.01	dBi
3	Transmitter effective isotropic radiated power	64.01	51.5	dB
4	Free space path loss	206.9	206.9	dB
5	Total path loss	207.0	205.7	dB
6	Gain of the receiver in dB	35.08	35.99	dBi
7	Power at the receiver	− 108.9	−118.7	dB
8	Figure of merit of the receiver,	8.6	16.7	dB
9	Receiver noise power	-129.2	-136.05	dB
10	Carrier to noise ratio	20.2	17.4	dB
11	Uplink energy per bit (Eb) to the spectral noise density (No) ratio	15.4 dB Or 34.8	12.4 *dB* Or 17.3	
12	Probability of bit error	$5.55112 \, x \, 10^{-17}$	$2.12263 \, x \, 10^{-9}$	
13	The composite carrier to noise ratio, $C/N|_{TdB}$	15.6		dB

The downlink C/N is 17.4 dB whereas the uplink C/N is 20.2 dB. Also, the downlink Eb/No is 12.4 dB and the bit error rate (BER) is $2.12263 \text{ x } 10^{-9}$. On the other hand, the uplink Eb/No is 15.4dB and the bit error rate (BER) is $5.55112 \text{ x } 10^{-17}$. With BER of the order of $1 \text{ x } 10^{-9}$, the link can be assumed to be adequate for the specified date rate. However, considering that the analysis is for clear sky condition, it may not be good enough especially in regions with heavy rain fall rate. In such case, additional measures must be taken to improve on the Eb/No and hence the BER.

III CONCLUSION

The uplink and downlink analysis and also the determination of the composite carrier to noise ration of a Ku-band satellite link are presented. The analysis is for clear sky condition. The mathematical expressions for the computation of requisite link parameters are presented along with sample numerical example. The results showed that the downlink has lower bit error rate which may not be adequate in situation with incidence of heavy rain attenuation.

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