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Satellite Orbit & Link Budget Design

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ABSTRACT

Satellite communications require more efficient way to design a radio transmitter/receiver to accommodate the demand for voice, video and data transmission.

The objective of this project is to study and analysis and performance of satellite orbit's and link budget design.

The objective was achieved using descriptive analysis of the signal from the satellite to receiver.

The performance analysis was implemented using Matlab simulink soft ware program to simulate bite error rate for satellite orbit's, after the execution of simulink the result were obtained in term of graphs'

KEYWORDS: ***QAM:*** *Quadrature Amplitude Modulation,*

1. INTRODUCTION

The world's first artificial satellite, the Sputnik 1, was launched by the Soviet Union in 1957. Since then, thousands of satellites have been launched into orbit around the Earth; also some satellites, notably space stations, have been launched in parts and assembled in orbit. Artificial satellites originate from more than 50 countries and have used the satellite launching capabilities of ten nations. A few hundred satellites are currently operational, whereas thousands of unused satellites and satellite fragments orbit the Earth as space debris. A few space probes have been placed into orbit around other bodies and become artificial satellites to the Moon, Mercury, Venus, Mars, Jupiter, Saturn, and the Sun.

Satellites are used for a large number of purposes. Common types include military and civilian Earth observation satellites, communications satellites, navigation satellites, weather satellites, and research satellites. Space stations and human spacecraft in orbit are also satellites. Satellite orbits vary greatly, depending on the purpose of the satellite, and are classified in a number of ways. Well-known (overlapping) classes include low Earth orbit, polar orbit, and geostationary orbit.

Subscripts and superscripts in a slightly smaller font size, this is acceptable.

2. SATELLITE ORBIT AND LINK BUDGET DESIGN

2.1 Descriptive Analysis:

The performance analysis of link budget for satellite orbits that consists of Satellite Downlink Transmitter, Downlink Path and Ground Station Downlink Receiver system, was analyzed in term of bit error rate (BER). The system was modeled using Matlab Simulink software program.

At the downlink transmitter a random data stream (baseband signal) was generated by Random Integer Generator, then the signal will modulate by Rectangular QAM Modulator Baseband (16-QAM constellation), Pass through Cosine Transmit Filter, pass through High Power Amplifier (model) and transmit by Dish Antenna Gain. At the downlink path the signal Attenuates due to Free Space Path Loss, and then the signal Rotates to model phase and Doppler error on the link (Phase/Frequency Offset). At the downlink receiver Added white Gaussian noise to the signal due to Receiver Thermal Noise, then received by Dish Antenna Gain, Introduces random phase perturbations (Phase Noise), Introduces DC offset, amplitude imbalance, or phase imbalance to the signal (I/Q Imbalance), Estimate and remove to the DC offset from the signal (DC Offset Comp), Select AGC, Pass through Cosine receiver Filter and then the signal will demodulate by Rectangular QAM Demodulator Baseband (16-QAM constellation).

2.2 Mathematical model:

The descriptive analysis of the link budget for satellite orbits was modeled using mat lab model to calculate bit error rate is given by:

Random Integer Generator (baseband signal):

S_m(t)

Rectangular QAM Modulator Baseband (16-QAM):

$$S_{QAM}(t) = A_e\sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c(t)) + A_0\sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c)) S_{QAM}(t) = A_e\sqrt{\frac{2E_b}{T_b}} \quad \text{.....(2.1)}$$

keywords: E_b: Enargy of ,

T_b Time of bit.

Transmit Filter:

The impulse response of a normal raised cosine filter:

$$h(t) = \frac{\sin(\pi t/T)}{(\pi t/T)} \cdot \frac{\cos(\pi R t/T)}{(1 - 4R^2 t^2/T^2)} \quad \text{..(2.2)}$$

The impulse response of a square root raised cosine filter:

$$h(t) = 4R\,\frac{\frac{\cos(1+R)\pi t}{T} + \frac{\sin((1-R)\pi t/T}{(4Rt/T)}}{\pi\sqrt{T}(1-(4Rt/T)^2)} \qquad (2.3)$$

Where:

R : The Rolloff factor parameter is the filter's rolloff factor.
T : symbol period.

- **Model Parameters:**

- The AM/AM:

$$F_{AM/AM}(u) = \frac{\text{alpha} \times u}{1 + \text{beta} \times u^2} \qquad ..2.4$$

Where:
alpha and beta : are used to compute the amplitude gain for an input signal.
u : is the magnitude of the scaled signal.

The AM/PM:

$$F_{AM/PM}(u) = \frac{\text{alpha} \times u^2}{1 + \text{beta} \times u^2} \qquad ..2.5$$

Where: **alpha and beta:** are used to compute the phase change for an input signal.
U: is the magnitude of the scaled signal.

Gain:

$$G = \eta\,(10.472\, fD)^2 \,\text{……..}\mathbf{2.6}$$

Where:
η : the aperture efficiency.
f : is the carrier frequency in gigahertz.
D : is the reflector diameter in meters.

$$G = \eta_A[SD] \qquad .(2.7)$$

Where:
η_A : antenna efficiency.
[SD] : denoting the directivity.

Free Space Path Loss:

FSL = 20 log r + 20 log *f* – 147.5 …(2.8)

Where:
***f*:** frequency in megahertz .
r: distance in kilometers.

Thermal noise:

N = KTB (watts) where:

N : thermal noise power (watts).

K : Boltzmann's proportionality constant (1.38 X 10-23 joules per kelvin).

T : temperature (kelvin: 0 K=-273° C, room temperature = 290 K).

B : bandwidth (hertz).

Phase Noise:

$\frac{1}{f}$ **Where: *f*: frequency**

I/Q Imbalance:

For an I/Q amplitude imbalance, I_a:

$y_{AmplitudeImbalance} = \left[10^{(0.5\times\frac{Ia}{20}} \times x_r\right]$

$y_{AmplitudeImbalance} = y_{rAmplitudeImba}$

+ j$\times$ $y_{iAmplitudeImbalance}$

Tx

….(2.9)

For an I/Q phase imbalanceI_p:

$y_{phaseImbalance} = \left[\exp\left(-0.5 \times j \times \pi \times \frac{Ip}{180}\right) \times y_{rAmplitudeImbalance}\right] + j\{\exp\left[j\ \left(\frac{\pi}{2} + 0.5 \times \pi \times \frac{Ip}{180}\right)\right] \times y_{iAmplitudeImbalance}$

$y_{phaseImbalance} = yr_{phaseImbalance}$

+ j *$yi_{phaseImbalance}$

Ch

For DC offsets I_{DC} and Q_{DC}

$y_{phaseImbalance} = yr_{phaseImbalanc}$ + j*$yi_{phaseImbalance}$

Y=$yr_{phaseImbalance}$

+ I_{DC} + j *$yi_{phaseImbalance}$ + Q_{DC} …(2.10)

Where: Ia: I/Q amplitude imbalance.

Ip; I/Q phase imbalance.

IDC; inphase DC offset.
QDC: quadrature DC offset.
Also: x $= x_r + x_i$ ..(2.11)

x_r, x_i :complex input to the block, real and imaginary parts,
Y : the complex output of the block.

3. **Computer model:**

The flow chart to plan mathematical model to calculate bit error for link budget for satellite orbits. As show in **Figure**

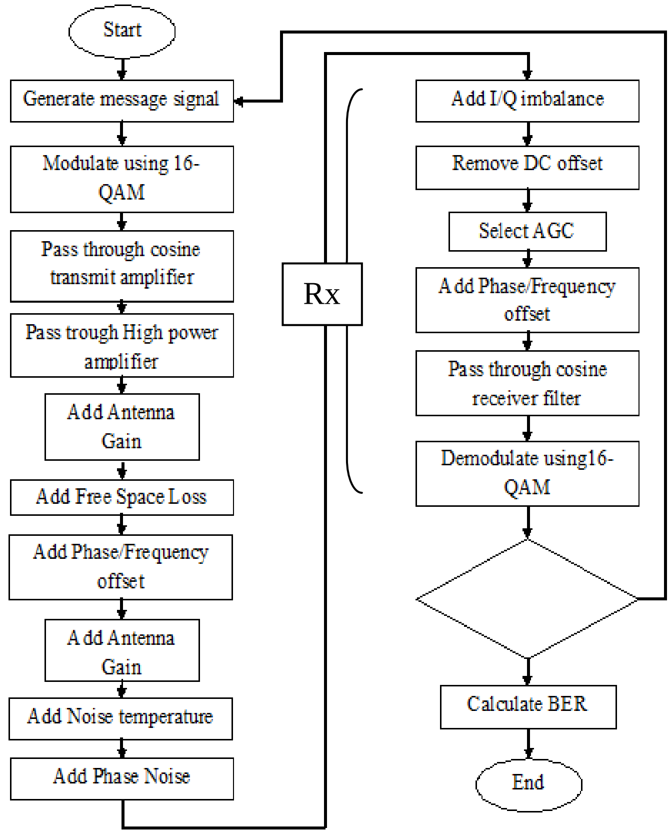

Figure 3.1 satellite orbits and link budget design computer model

4. Simulation environment:

The link budget design of a satellite orbit has been taken for a deferent altitude s (orbits) and deferent parameters with variable values.

Parameters	Values
Satellite Orbit (km)	LEO, MEO, GEO
Frequency (MHZ)	3000, 4000, 5000
Transmit antenna diameters (m)	0.3, 0.4, 0.5
receive antenna diameters (m)	0.3, 0.4, 0.5
Noise temperature (k)	0 (no noise), 20 (very low noise level), 290(typical noise level)
HPA bakoff level	30 dB, 7dB, 1 dB
Phase correction	None, correct for moderate HPA AM to PM, correct for severe HPA AM to PM
Doppler error	None, Doppler (0.7 Hz-uncorrected), Doppler (3 Hz-corrected)
Phase noise	Negligible(-100), Low(-55 dB), High (-48 dB)
I/Q Imbalance	None, Amplitude imbalance (3 dB), Phase imbalance (20 deg), in-phase DC offset (2e-6), Quadrature DC offset (1e-5)
Dc offset compensation	Enable, Disable
AGC Type	Magnitude only, Independent I and Q

Table 4.1 Values of parameters

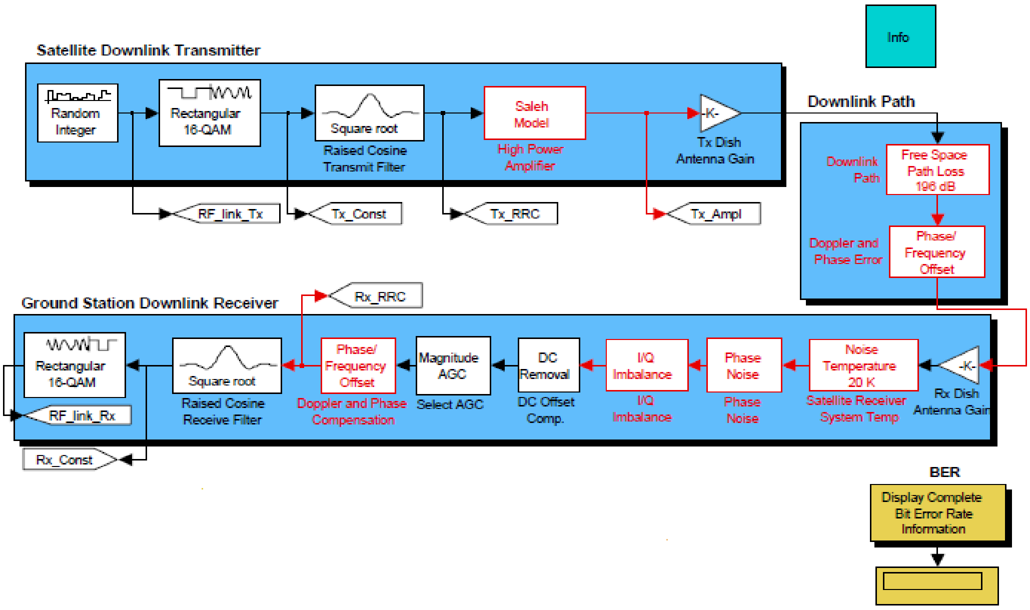

Figure 4.1 Simulation block diagram of a satellite orbit and link budget design

5. Results:

Frequency	BER		
	LEO	MEO	GEO
L-band	0.2962	0.3319	0.3996
S-band	0.2965	0.3	0.3146
C-band	0.2965	0.2977	0.3023
X-band	0.2965	0.2973	0.2988
KU-band	0.2962	0.2962	0.2977
K-band	0.2962	0.2962	0.2977
KA-band	0.2962	0.2973	0.2973

Table 5.1 Frequency vs. BER

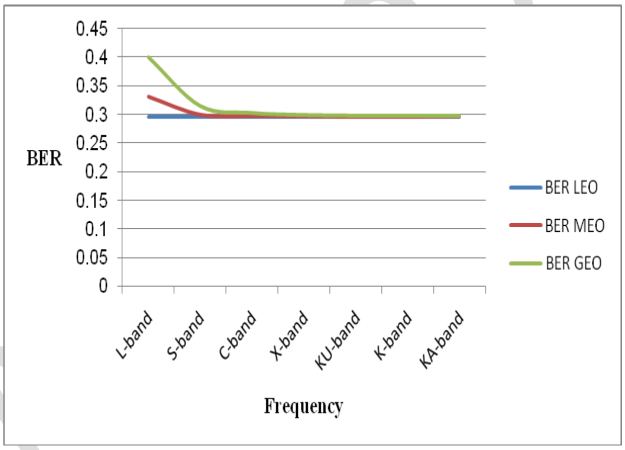

Figure 5.1 Frequencies vs. BER

Table 5.2 Antenna Diameter vs. BER

Transmit Antenna diameter(m)	Receive Antenna diameter(m)	BER		
		LEO	MEO	GEO
0.1	0.1	0.3004	0.5404	0.8138
0.2	0.2	0.2962	0.3319	0.3996
0.3	0.3	0.2973	0.3069	0.3354
0.4	0.4	0.2965	0.3	0.3146
0.5	0.5	0.2965	0.2977	0.3019
0.6	0.6	0.2965	0.2973	0.3
0.7	0.7	0.2965	0.2973	0.2981
0.8	0.8	0.2962	0.2962	0.2977
0.9	0.9	0.2962	0.2962	0.2973
1	1	0.2962	0.2969	0.2973

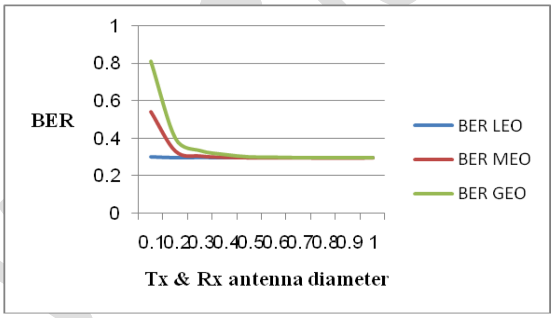

Figure 5.2 Antenna Diameters vs. BER

Noise temperature(k)	**BER**		
	LEO	**MEO**	**GEO**
0 (no noise)	**0.2954**	**0.2954**	**0.2954**
20 (very low noise)	**0.2965**	**0.3**	**0.3146**
290 (typical noise)	**0.2962**	**0.3288**	**0.3946**

Table 5.3 Noise temperature vs. BER

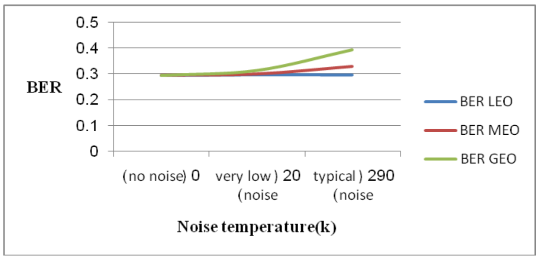

Figure 5.3 Noise temperatures vs. BER

HPA backoff level (dB)	BER		
	LEO	**MEO**	**GEO**
30	**0**	**0**	**0**
7	**0.2965**	**0.3**	**0.3146**
1	**0.6823**	**0.6812**	**0.6608**

Table 5.4 HPA backoff level vs. BER

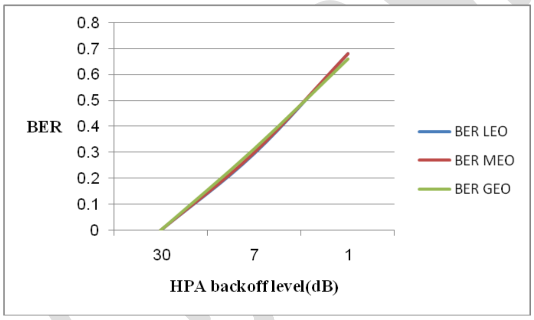

Figure 5.4 HPA backoff level vs. BER

Phase correction	BER		
	LEO	**MEO**	**GEO**
None	**0.2965**	**0.3**	**0.3146**
Correct for moderate HPA AM to PM	**0.0003846**	**0.0003846**	**0.001154**
Correct for severe HPA AM to PM	**0**	**0**	**0**

Table 4.6 Phase correction vs. BER

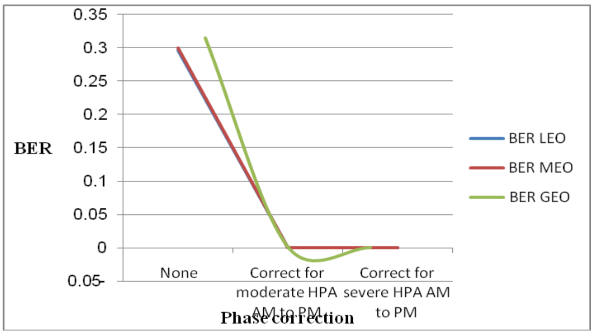

Figure 5.5 Phase correction vs. BER

Doppler Error	BER		
	LEO	MEO	GEO
None	0.2927	0.2958	0.3104
0.7 Hz-uncorrected	1	1	1
3 Hz-corrected	0.2965	0.3	0.3146

Table 5.5 Doppler Error vs. BER

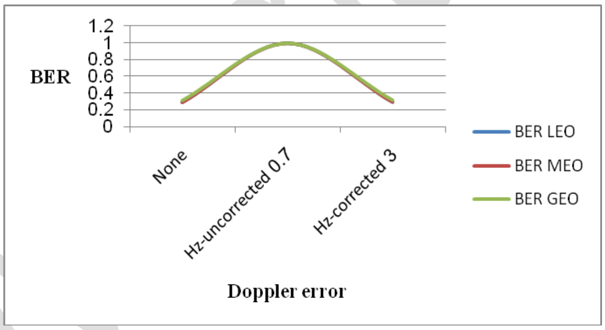

Figure 5.5 Doppler Errors vs. BER

Phase Noise	BER		
	LEO	MEO	GEO
Negligible (-100 dB)	0.2965	0.3	0.3146
Low(-55 dB)	0.3135	0.315	0.3192
High (-48 dB)	0.3354	0.3331	0.3342

Table 5.6 Phase noise vs. BER

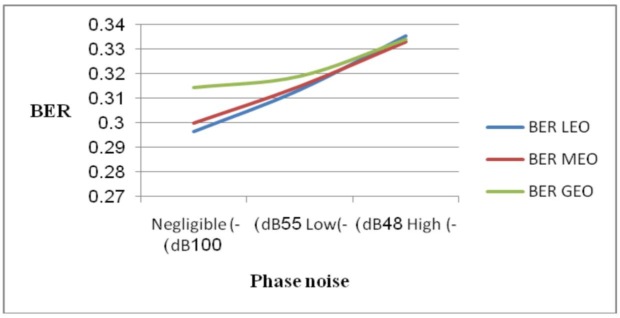

Figure 5.6 Phase noise vs. BER

I/Q imbalance	BER		
	LEO	MEO	GEO
None	0.2965	0.3	0.3146
Amplitude imbalance (3 dB)	0.3569	0.3588	0.3585
Phase imbalance (20 deg)	0.3873	0.3865	0.3888
In-phase DC offset (2e-6)	0.2965	0.3188	0.4862
Quadrature DC offset (1e-5)	0.3023	0.6935	0.7488

Table 5.7 I/Q imbalance vs. BER

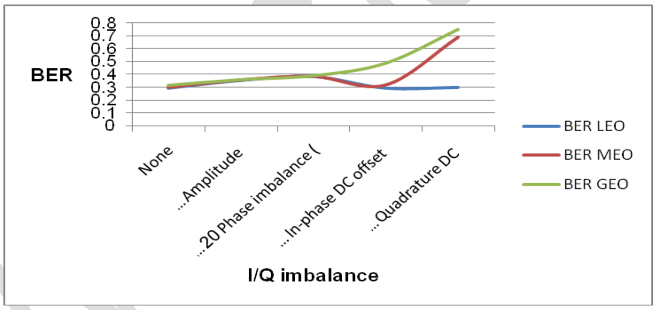

Figure 5.7 I/Q imbalance vs. BER

Dc offset compensation	BER		
	LEO	MEO	GEO
Disable	0.2812	0.2888	0.3085
Enable	0.2965	0.3	0.3146

Table 5.8 DC offset compensation vs. BER

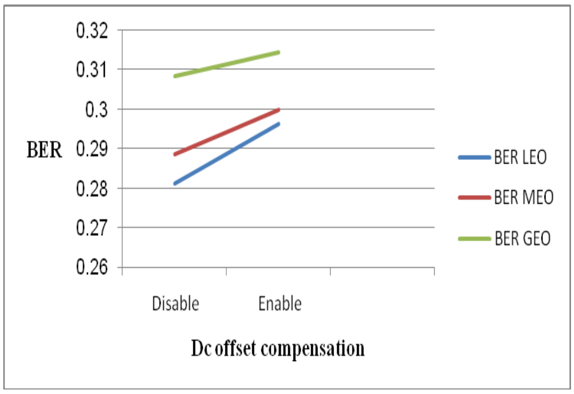

Figure 5.8 DC offset compensation vs. BER

AGC Type	BER		
	LEO	MEO	GEO
Magnitude only	**0.2965**	**0.3**	**0.3146**
Independent I and Q	**0.2981**	**0.3015**	**0.3192**

Table 5.9 AGC Type vs. BER

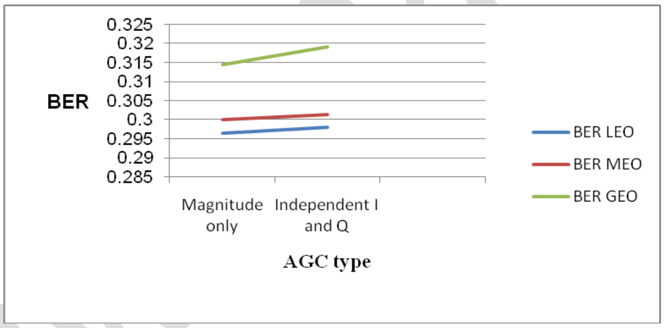

Figure 5.9 AGC Type vs. BER

6. RESULTS DISCUSSION:

From the result obtained we observe the following:

- The bit error rate is higher for GEO rather than MEO and LEO.
- As the frequency band increased the bit error rate decrease.
- As the antenna diameter increased the bit error rate decrease.
- As the noise temperature increased the bit error rate decrease.
- As HPA backoff level increased the bit error rate decrease.
- The bit error rate for the phase correction is lower at correct for severe HPA AM to PM, rather than correct for moderate and none.
- The bit error rate for Doppler error is lower at none rather than 3 Hz-corrected; and 0.7 Hz-uncorrected represent the higher bit error rate.
- As the phase noise increased the bit error rate increase.

- The bit error rate is decreased in I/Q imbalance when used none and in-phase DC offset rather than amplitude imbalance, phase imbalance and Quadrature DC offset.
- The bit error rate is increased when enable DC offset compensation rather than disable it.
- The bit error rate is increased when independent I and Q is used with AGC type rather than magnitude only.

7. CONCLUSION:

- The study analyses and designed software program for link budget design for satellite orbits has been done using Matlab simulink software program, the parameter which will take in the consideration Frequency band, Antenna diameter, Noise temperature, HPA backoff level, Phase correction, Doppler error, Phase noise, I/Q imbalance, DC offset compensation and AGC type.
- The simulation results were taken in term of bit error rate illustrated into tables and graphs. And it was found that each parameter has a different result of BER.
- The project study the link budget design of satellite orbits caused by existence of losses and gain during transmitting the signal to the downlink which cases an increased of bit error rate.

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