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Analysis of Pointing Error on Satellite Link using GNU Radio

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Abstract:-Satellite technology plays an important role in the global communication system. A significantamount of cost and resources are dedicated for tracking and telemetry of satellite, so that no compromise is made on pointing accuracy. This paper analyses, how the antenna misalignment error affects the received power and in turn Bit Error Rate (BER). For simulation we used a Linux based open software development toolkit called GNU Radio.

Keywords *– QPSK modulation, QPSK demodulation, satellite link, pointing error, Bit Error Rate (BER)*

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I INTRODUCTION

Satellite communication systems have ventured into different fields such as physics, astrophysics, geography, electronics and communications. It acts as a significant tool to ease human scientific research. It is also used widely for commercial purposes. Thereby it is important to design a satellite link with high fidelity [1].

The popularity of LEO (Low earth orbits) satellites is increasing rapidly. The advent of LEO constellations like Iridium, Globastar suggests that LEO constellations could become the basis of future two-way wireless communications systems. This makes the tracking of LEO satellites an important issue for today's earth station designer [2].

High frequencies likeKa band is gaining popularity but designing and manufacturing earth stations at high frequencies is a hurdle to designers. Even a medium sized antenna produces a narrow beam width at high frequencies, resulting in stringent antenna pointing requirements. The combination of the uplink and downlink beam widths requires a pointing accuracy on the order of 0. 3° to minimize attenuation caused by pointing errors. Therefore it is necessary to analyze the pointing error on received power[2].

In this paper a satellite link is modeled from the hub to a VSAT terminal and it is termed as outbound link. The link consists of two parts uplink and downlink. QPSK modulation technique is used as it can deliver better data rates with minimum error[3].
For our simulation we used a Linux based open software development toolkit called GNU Radio. This software provides a library of signal processing blocks and these blocks are tied together for building and deploying software defined radios.

Using GNU Radio, a radio system can be built by creating a graph where the vertices are signal processing blocks and the edges represent the data flow between them. The signal processing blocks are implemented in C++ and the graphs are constructed and run in Python. Conceptually, a signal processing block processes an infinite stream of data flowing from its input ports to its output ports. A block's attributes include the number of input and output ports it also determines the type of data that flows through each. Some blocks have only output ports or input ports. Input and output ports serve as data sources and sinks in the graph [4].

II DESIGN CONCEPT

The pointing error is obtained by modeling the transmitted beam as a parabola. The vertex form of a parabola's equation is generally expressed as:

$$Y = a(x - h)^2 + k \qquad (2.\ 1)$$

where, (h, k) is the vertex.
To get the equation of the parabola, two points are required that is vertex and another point on the parabola.
We know that maximum power is transmitted when there is no pointing error. Therefore, the vertex of the parabola is(0, Pmax). To get another point on parabola, we use the concept of θ_{3dB}(half-power beamwidth). At $\theta_{3dB}/2$, the power becomes half of the maximum power. Thereby we use this point and the vertex in equation (2. 1) to model the beam as a parabola. Angle θ can be varied in degrees and the corresponding power is obtained.

$$\text{Pointing loss} = P_{max} - P_{\theta}$$

where, P_{θ} : Power corresponding to θ
The link between the satellite and earth station is governed by the basic microwave link equation.

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$$Pr = \frac{PtGtGr}{(4\pi R\lambda)^2} \quad (2.2)$$

where, Pr:Power received by the receiving antenna
Pt:Power applied to the transmitting antenna
Gt:Gain of the transmitting antenna
Gr:Gain of the receiving antenna
R: Path length in meters
λ:Wavelength in meters

All link calculations are performed after converting it to decibels. Equation (2. 2) becomes

$$Pr = Pt + Gt + Gr - L_P \quad (2.3)$$

where, L_P: Path loss
On adding the pointing loss to equation (2. 3) we get

$$Pr = Pt + Gt + Gr - L_P - L_{PL} \quad (2.4)$$

where, L_{PL}: Pointing loss

Link design requires the knowledge of the free space path loss between the earth station and the satellite.
Free space path loss:

$$Lp = 20\log\left(\frac{4\pi R}{\lambda}\right) \quad (2.5)$$

Gain of the antenna is given by,

$$G = \frac{4\pi\eta A}{\lambda^2} \quad (2.6)$$

Where, η: Antenna efficiency
A: Effective area, $A = \pi r^2$
λ: Wavelength in meters

Table-2 and Table-3 helps in the calculation of the transmitter and receiver gain [3]. The maximum antenna gain for uplink and downlink was found by taking the carrier frequency into account as per Table-1[3].

To determine the performance of the link we need BER and to calculate BER we need Eb/No. Bit energy is given by,

$$Eb = Pr * [\text{bit duration}]$$

$$Eb = Pr/R \quad (2.7)$$

where, R: Data rate[bps]
Noise is considered to be "White Gaussian". The noise spectral density is given by,

$$No = kTs \quad (2.8)$$

where, k:Boltzmann constant ($1.38 \times 10^{-23}\ m^2 kg/s^2 k$)
Ts:System temperature

The ratio $\frac{Eb}{No} = \frac{Pr}{KTsR}$ (2. 9)

where, Eb: Bit energy
No: Noise spectral density
Pr: Received power
R: Data rate

In dB scale

$$\frac{Eb}{No} = Pt + Gt + Gr - Ls - L_{PL} + 228.6 - 10\log Ts - 10\log R \quad (2.10)$$

Relation between Eb/No and probability of error is

$$Pe = \frac{1}{2}\operatorname{erfc}\sqrt{\frac{Eb}{No}} \quad (2.11)$$

TABLE-1 LINK DATA

Earth station Transmitter antenna gain	52. 44dB
Satellite Transmitter antenna gain	31dB
Earth station Receiver antenna gain	36. 35dB
Satellite Receiver antenna gain	38. 2dB
Transponder Bandwidth	36MHz
Uplink frequency band	6. 875-6. 9465GHz
Downlink frequency band	4. 650-4. 7215GHz
System Noise Temperature	75K
Data rate	128Kbits
Up-link loss	200. 64dB
Down-link loss	197. 28dB

TABLE-2 TRANSMITTING ANTENNA PARAMETERS

Antenna size	7. 2m
Uplink frequency	6946MHz
Antenna efficiency	64%

TABLE-3 RECEIVING ANTENNA PARAMETERS

Antenna size	1. 8m
Downlink frequency	4721MHz
Antenna efficiency	63%

III GNU RADIO BASED MODELLING

Fig. 1 shows the complete model of the system consisting of four major blocks. Each block is explained below.

Source – A random source which generates random binary numbers at a rate of 128kbits/sec.

Modulator – QPSK modulator is used. QPSK modulation helps to visualize the constellation diagram. The scatter diagram allows us to visualize the real and imaginary components of the complex signal.

Link – A link block consists of both uplink and downlink. It is shown in fig. 2.

Demodulator – This block demodulates a signal that was modulated using QPSK modulation with a constellation on a rectangular lattice.

Receiver – this block receives the final signal after demodulation.

IV RESULTS

Complex modulations are best viewed using a scatter diagram. The scatter diagram visualizes the real and imaginary components of the complex signal. Fig. 3 shows the scatter diagram plot of QPSK Transmitter. Fig. 4 shows the scatter plot at the QPSK receiver foran Eb/No of 10dB. Fig. 5 shows the bit error rate of simulated model. Fig. 6 shows how BER varies with θ(degree) when there is a pointing error at the receiver side in downlink.

In our model we used antennas of different sizes at the transmitter and the receiver. At transmitter the diameter of antenna is 7. 2m and at the receiver the diameter of antenna is 1. 8m. The beam is broader compared to the transmitter antenna and it is shown in fig. 7 for a maximum power of 10dB.

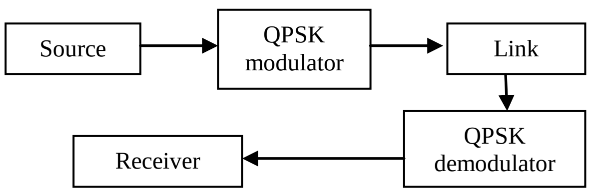

Figure-1 System model

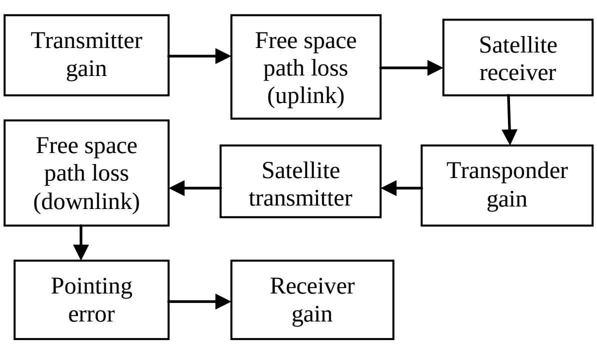

Figure-2 Link

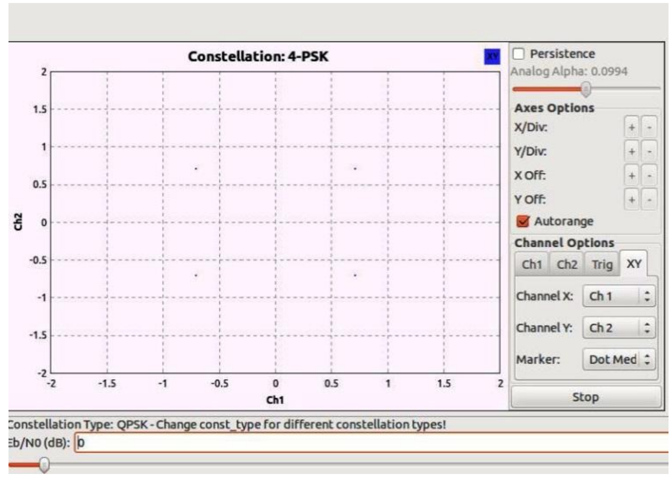

Figure-3 Scatter diagram plot of QPSK transmitter

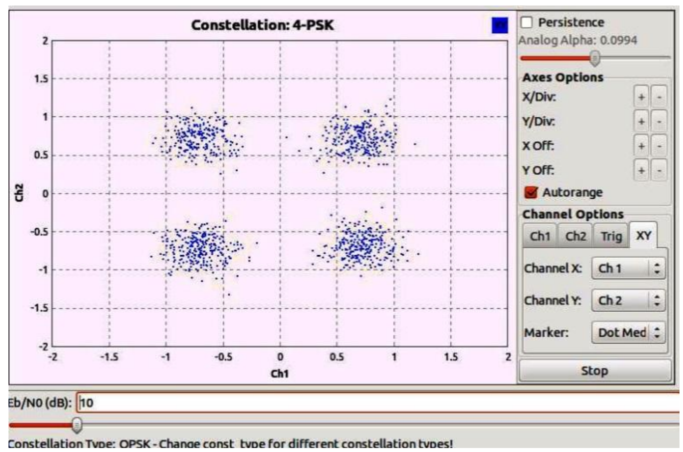

Figure-4 Scatter diagram plot of QPSK receiver

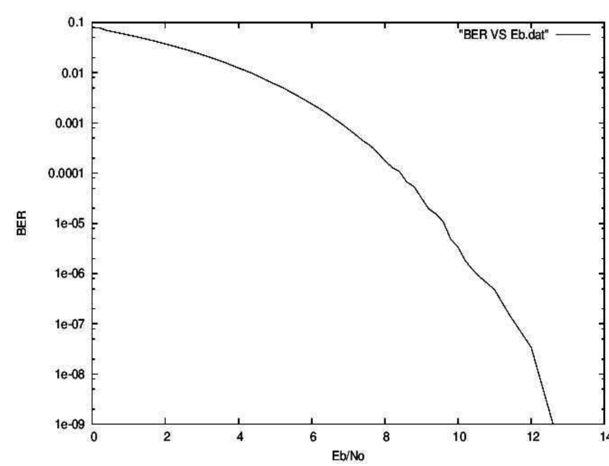

Figure-5 Bit Error Rate(BER) of simulated model

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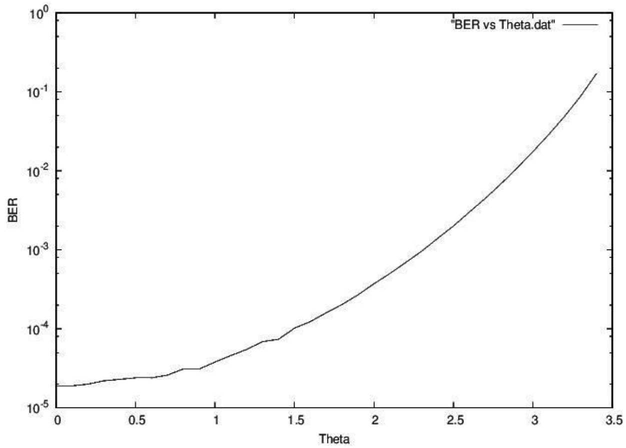

Figure-6 BER varies with θ(degree)

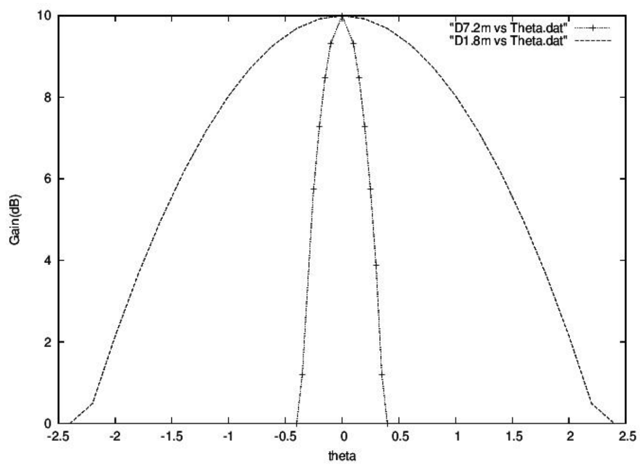

Figure-7 Gain (dB) for 7. 2m diameter antenna and 1. 8 diameterantenna verses θ

V CONCLUSION

The simulated results show how pointing error effect Bit Error Rate. If a different modulation technique like BPSK is used in place of QPSK then the effect of pointing error on Bit Error Rate would have been more. From Fig. 7 we can infer that antenna diameter limits the off boresight movement. A larger antenna will have lesser off boresight movement in degrees compared to smaller antenna. In satellite link, the antennas used are high gain so the beams are narrow so pointing error is a matter of concern. Therefore, it is necessary that an antenna optimization technique is adopted to determine an optimal antenna size for a particular satellite link. GNU Radio is an effective tool for simulation and has helped us in our project to determine the effect of θ on Bit Error Rate.

VI ACKNOWLEDGEMENT

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