

## PERFORMANCE ANALYSIS OF PSK MODULATION TYPES USED IN SATELLITE COMMUNICATION SYSTEMS

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**Abstract-** In this study, effects of modulation types on data transmission performance used in satellite communication systems for earth observation satellites were examined. The effects of PSK modulation, which is commonly used especially in S band and X band communication, on BER- $E_b/N_0$  performance were also compared. The effects of "8 Phase Shift Keying-8 PSK, 16 Phase Shift Keying-16PSK, 32 Phase Shift Keying-32PSK, Quadrature Phase Keying-QPSK, and Offset Quadrature Phase Shift Keying-QOPSK" modulation techniques on system performance were studied by using Matlab SIMULINK simulation program.

**Keywords:** PSK Modulation, QPSK, OQPSK.

### I. INTRODUCTION

Nowadays, satellite communication systems are widespread used in imaging, communicating, finding position, meteorology etc. In satellite communication systems, data transmission performance shows variation depending on data transmission medium, noise in the receiver and transmitter input, used modulation and coding techniques. Power systems, communication bandwidth, modulation types, efficiency and coding techniques affect performance of communication in satellite communication.

With popularity of communication techniques, satellite communication ranked among outstanding communication techniques. Old studies on developing the performance of satellite communication systems show that modulation technique used in communication systems has a great effect in some studies, made by now, effects of some modulation techniques on data download performance comparatively were examined and tried to determine an ideal modulation technique according to obtained comparisons [1, 2].

Some researches on modelling the phase noise occurring in the system, examined their effects on modulation systems [3, 4]. In some studies, effect of noise on demodulation system was examined and made improvements to remove this effect [5].

Also, examination of modulation losses occurring in communication channels were involved in recent studies [6]. Besides, there exist some studies on modulation

techniques, which will be used in non-linear satellite communication systems [7]. Modulation techniques, which can be adapted in situations, when stable modulation techniques are inadequate are used and targeted development of communication performance [8, 9]. Due to limited power and limited band width, which inheres in satellite communication systems high performance modulation techniques we developed in space studies [10].

In this study 8-PSK, 16-PSK, 32-PSK, QPSK and OQPSK modulation techniques' performances were compared for linear and non-linear situation of the power amplifier used for phase noise effect added to the system.

### II. SATELLITE COMMUNICATION SYSTEMS

Satellite communication line has a great importance for communication of satellite with earth station. Satellite signals in Figure 1 have repeater feature. Information sign, formed by earth station, encoded, loaded on modulator and carrier, comes to upper converter. Then the signal is oriented to the power amplifier, its power is amplified and the signal is transmitted with transmitter antenna. As the satellite, showed in Figure 1 is a repeater satellite, the signal received by receiver antenna comes to transmitter antenna and transmitted to the receiver antenna of the ground station. Signal, which access to low noise block converter, is transmitted to demodulator block for demodulation. After code reconstruction, information sign is observed [11].

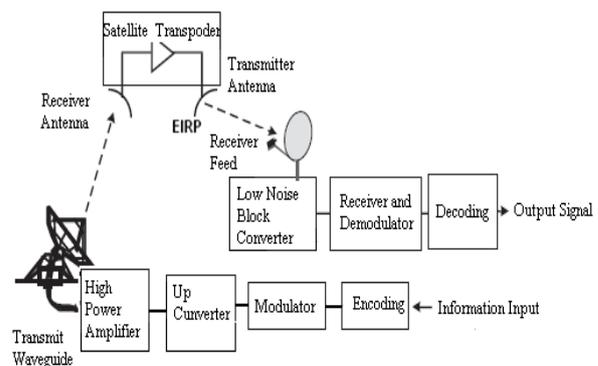


Figure 1. Block diagram of satellite and earth station

**A. Received Signal Power**

The power  $P_R$  is collected by the receiving antenna can be written as

$$P_R = P_T \left( \frac{\lambda}{4\pi R} \right)^2 G_T G_R \text{ [W]} \tag{1}$$

Equation (1) relates the power  $P_R$  to the input power of the transmitting antenna  $P_T$ , where  $1/L_{FS} = (\lambda / 4\pi R)^2$  is called the free-space loss factor, it takes into account losses due to the spherical spreading of the energy by the antenna.  $G_T$  and  $G_R$  are the gain of antennas transmitting and receiving, respectively.

$$P_R = P_T G_T \left( \frac{1}{L_{FS}} \right) G_R \text{ [W]} \tag{2}$$

Noise, radiating as a result of radiation of natural resources, coming to receiver antennas and originating from components of receiver equipment's, effects on the system. System noise is expressed as

$$N_0 = k.B.T \tag{3}$$

where,  $B$  is band width,  $T$  is system temperature and  $k$  is Boltzman constant,  $k = 1.379 \times 10^{-23} \text{ J/}^\circ\text{K} = -228.6 \text{ a (dBW/HzK)}$ .

Carrier noise proportion in receiver input when below noises and losses are considered is expressed as  $C/N_0$ .

- Atmospheric attenuation  $L_A$ ,
- Polarization loss  $L_{POL}$ ,
- The transmitter antenna feed loss  $L_{FTX}$ ,
- The receiver antenna feed loss  $L_{FRX}$ ,
- The receiver system noise temperature  $T_{eRX}$ ,
- The receiver antenna noise temperature  $T_A$ ,
- The transmitter antenna orientation disorder loss  $L_T$ ,
- The receiver antenna orientation disorder loss  $L_R$ ,
- Feed noise temperature  $T_F$ .

$$\frac{C}{N_0} = \frac{\left( \frac{P_T G_{T \max}}{L_T L_{FTX}} \right) \left( \frac{1}{L_{FS} L_A} \right) \left( \frac{G_{R \max}}{L_R L_{FRX} L_{POL}} \right)}{\left( \frac{T_A}{L_{FRX}} + T_F (1 - L_{FRX}) + T_{eRX} \right)} \cdot \left( \frac{1}{k} \right) \tag{4}$$

The transmitter antenna orientation disorder loss in the direction angle  $\theta_T$  is given by

$$L_T = 12(\theta_T / \theta_{3dB})^2 \text{ [dB]} \tag{5}$$

and the receiver antenna orientation disorder loss in the direction angle  $\theta_R$  is given as

$$L_R = 12(\theta_R / \theta_{3dB})^2 \text{ [dB]} \tag{6}$$

Geometrical orientation losses in Figure 2 and Feed losses in Figure 3 are given respectively for both transmitting and receiving antennas [12].

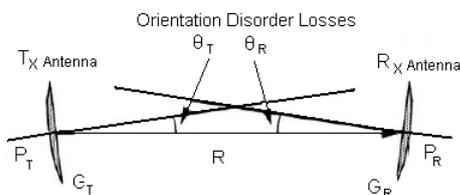


Figure 2. Geometrical orientation of transmitting and receiving antennas

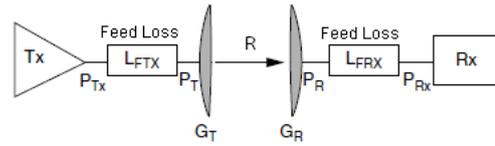


Figure 3. Feed losses of transmitting and receiving antennas

Carrier noise proportion is expressed in terms of  $E_b/N_0$  which is noise proportion of bit per energy in digital systems.

$$\left( \frac{E_b}{N_0} \right) = \left( \frac{C}{N_0} \right) \left( \frac{B}{r_b} \right) \tag{7}$$

where,  $r_b$  is bit velocity and  $E_b$  is bit energy.

**B. Bit Error Ratio (BER)**

The Bit Error Ratio ( $BER$ ) is the number of bit errors divided by the total number of transferred bits during a studied time interval.  $BER$  is considered as a performance criteria in the transmission system. Noise, distortion, bit synchronization problems and attenuation affects the  $BER$  in the transmission channel. Besides modulation types affect the  $BER$  performance on a communication systems. Compared effects of PSK modulations on  $BER-E_b/N_0$  performance were given in Figure 4.

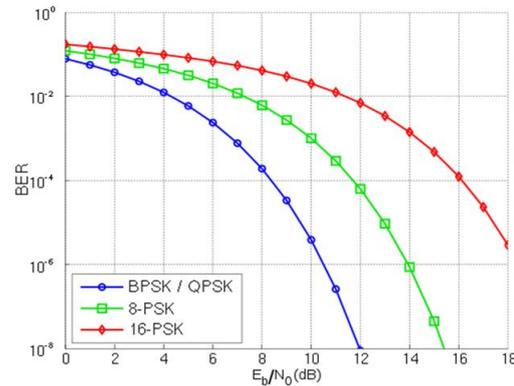


Figure 4. BPSK/QPSK, 8-PSK, 16-PSK modulations on  $BER-E_b/N_0$  performance

**C. Comparison of PSK Modulation Techniques**

Phase Shift Keying technique is a commonly used modulation technique, especially used in Low Earth Orbit satellites (LEO). PSK modulation is preferred especially in  $S$  band and  $X$  band communication systems. In PSK technique, information corresponding to the phase of the sinusoidal carrier is modified. In Equation (8),  $\omega_c$  expresses carrier's angle. The angle  $\theta$  changes according to the kind of PSK modulation.

$$PSK = \begin{cases} A \cos \omega_c t & \text{for bit } 1 \\ A \cos(\omega_c + \theta) t & \text{for bit } 0 \end{cases} \tag{8}$$

PSK technique is specialized as BPSK (Binary Phase Shift Keying), QPSK, OQPSK and FQPSK (Feher Quadrature Phase Shift Keying), which was developed for deep space communication systems [12].

### III. MODELLING

In this study LEO satellite's communication system was simulated. Satellite part was modelled by using of X band block, which supplies telemeter communication. In transmitter block a signal generator, a power amplifier and an antenna gain were modelled (Figure 5).

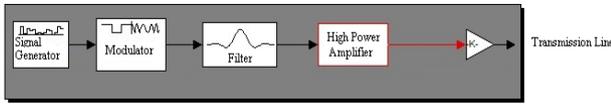


Figure 5. Transmitter block diagram of satellite

While modelling the transmission line, space loss, Doppler and mistakes occurring from phase shifts were considered (Figure 6). Earth station was modelled as receiver, phase noise, phase and frequency offset and demodulator were also modelled (Figure 7).

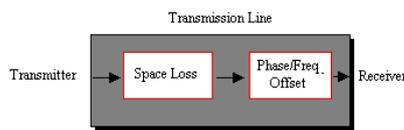


Figure 6. Transmission line

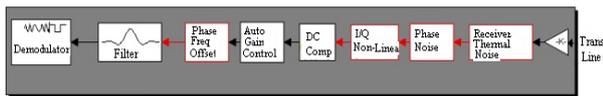


Figure 7. Receiver block diagram of earth station

The parameters in system modelling are Orbit height: 686 km, Orbital Inclination: 98 degrees, X-Band Frequency: 8320 MHz, X-Band Power: 7 watts, and X-Band Bandwidth: 40 MHz.

### IV. PERFORMANCE EVALUATION

First of all modelling parameters given in the below table were used. Secondly, effects of PSK modulation techniques of modulation types on system performance were examined. Finally, the modulator and demodulator outputs have been determined by using the receiver-transmitter signal spectrum chart. In addition, each modulation technique at the transmitter side and the receiver side was given in the clustering match. Performance evaluation was performed by examining the BER value.

Table 1. Parameters Used in Modelling

| Parameter                           | Value                              |
|-------------------------------------|------------------------------------|
| Satellite height                    | 686 km                             |
| Frequency                           | 8320 MHz                           |
| Transmitter Antenna Diameter        | 0.05 m                             |
| Receiver Antenna Diameter           | 6 m                                |
| Noise Temperature                   | 290 K                              |
| High Power Amplifier Back-off Level | 30 dB (nonlinearity is negligible) |
| Phase Correction                    | No                                 |
| Doppler Error                       | No                                 |
| Phase Noise                         | -100 dBc/Hz @ 100 Hz (neglig.)     |
| I / Q imbalance                     | No                                 |
| Automatic Gain Control Type         | Only Magnitude                     |
| Space Loss                          | 167                                |

Parameters which expresses the linear feature of high power amplifier were given in Table 1. Performance of PSK modulations was compared by changing the phase noise parameter and back-off level.

The results obtained for 8-PSK, 16-PSK, 32-PSK, QPSK, and QQPSK modulation technique were given below. On the receiver side, cluster diagram signals are matched with received signals in the same way. Phase noise level is considered to be negligible around the dispersion point in the system model for all PSK modulations.

#### A. 8-PSK Modulation

In 8-PSK modulation, each symbol was mapped in the data string clustering diagrams to be expressed with 3 bits. Constellation diagrams of 8-PSK modulations were given in Figure 8 and power spectrum was also given in Figure 9.

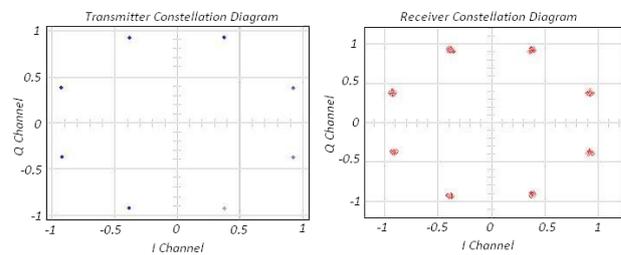


Figure 8. Constellation diagrams of 8-PSK

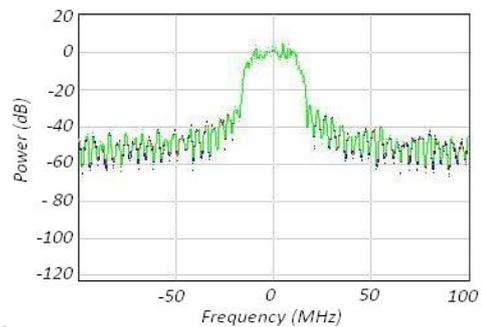


Figure 9. Comparison of receiver (blue line) and transmitter (green line) power spectrum for 8-PSK

#### B. 16-PSK Modulation

In 16-PSK modulation, each symbol was mapped in the data string clustering diagrams to be expressed with 4 bits. I and Q channels in the cluster diagram as shown in Figure 10 shows 16 points at 22.5 degree angle between each other. Figure 11 shows power spectrum for 16-PSK.

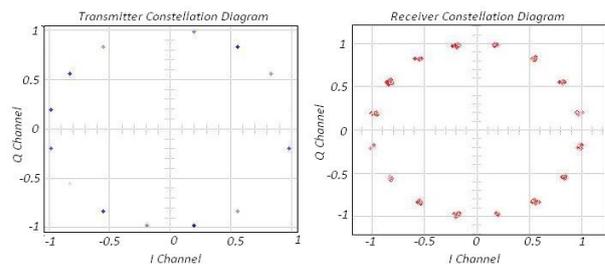


Figure 10. Constellation diagrams of 16-PSK

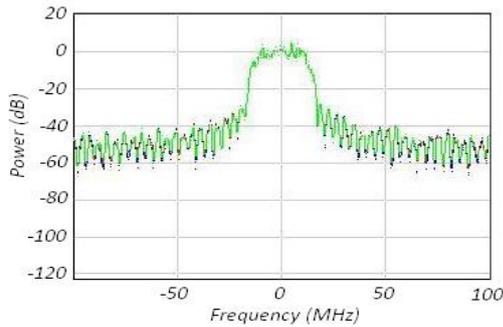


Figure 11. Comparison of receiver (blue line) and transmitter (green line) power spectrum for 16-PSK

**C. 32-PSK Modulation**

In 32-PSK modulation, each symbol was mapped in the data string clustering diagrams to be expressed with 5 bits. I and Q channels in the cluster diagram as shown in Figure 12, shows 32 points at 11.5 degree angle between each other. Phase noise is more acceptable for model of the system and is negligible around the dispersion point. Power spectrum for 32-PSK modulation was shown in Figure 13.

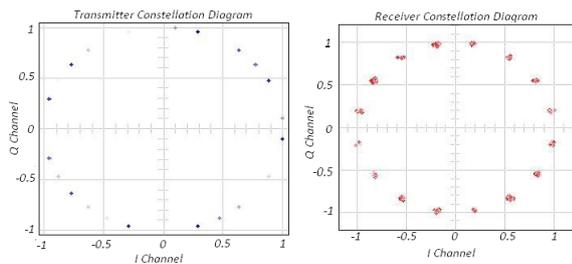


Figure 12. Constellation diagrams of 32-PSK

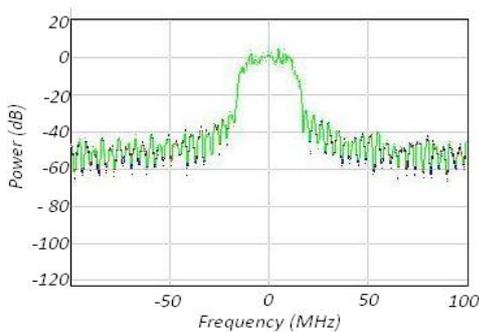


Figure 13. Comparison of receiver (blue line) and transmitter (green line) power spectrum for 32-PSK

**D. QPSK Modulation**

In QPSK modulation, each symbol was mapped in the data string clustering diagrams to be expressed with 2 bits. I and Q channels in the cluster diagram as shown in Figure 14, shows 4 points at 180 degree angle between each other. The receiver and the transmitter power spectrum for QPSK was shown in Figure 15.

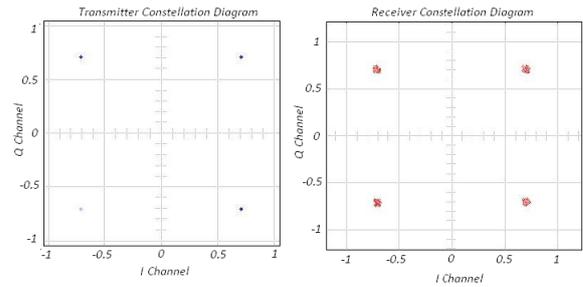


Figure 14. Constellation diagrams of QPSK

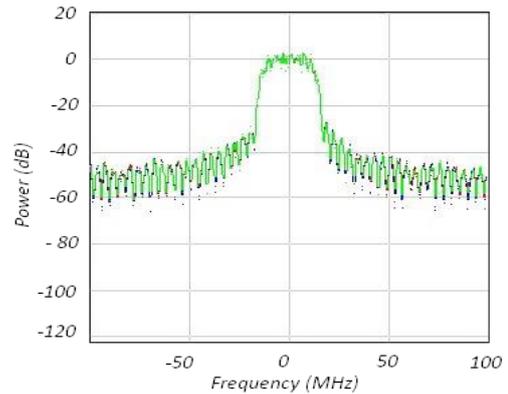


Figure 15. Comparison of receiver (blue line) and transmitter (green line) power spectrum for QPSK

**E. OQPSK Modulation**

Simulation results of OQPSK modulation are similar to QPSK modulation as shown in Figures 16 and 17.

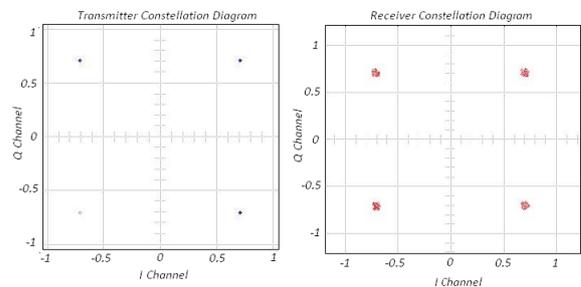


Figure 16. Constellation diagrams of QPSK

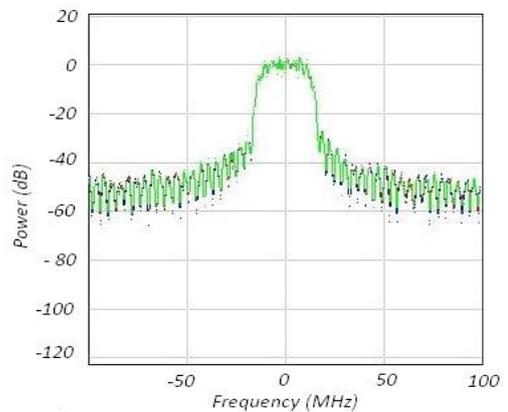


Figure 17. Comparison of receiver (blue line) and transmitter (green line) power spectrum for QPSK

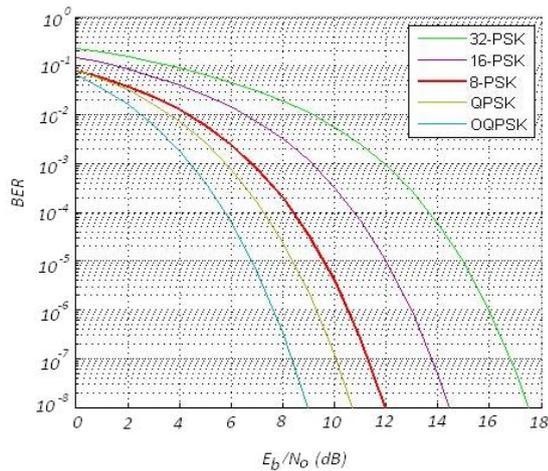


Figure 18. Comparison of  $E_b/N_0 - BER$  performance in system, in which linear power amplifier is used and phase noise doesn't exist.

According to Table 1, the fact that linear power amplifier was used in the system (Back-off level was supposed as 30 dB) and phase noise of system was assumed to be negligible. For this situation, PSK modulation performances were compared in Figure 18.

In the second model the phase noise was added to system, and the power amplifier was assumed to be linear. The modulation types and parameter expressed in Table 1 used were changed the satellite communication simulation model and phase noise was assumed as -48 dBc/Hz (Figure 19).

When non-linear power amplifier was used, the transmitter (red line) and receiver (blue line) power spectrums were evaluated as shown in Figure 20. It can be seen that there were some difference between transmitter and receiver powers because of the non-linear power amplifier.

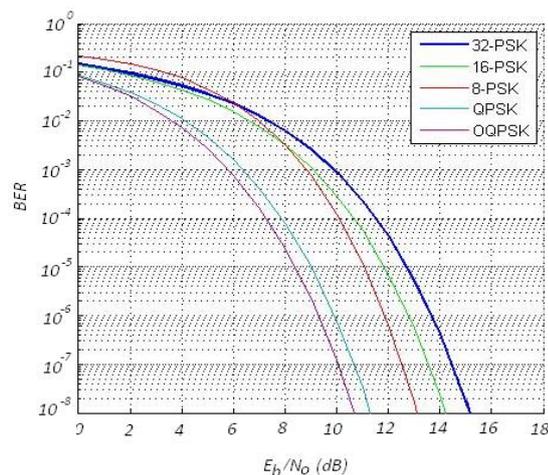


Figure 19. Comparison of  $E_b/N_0 - BER$  performance in system, in which linear power amplifier is used and high phase noise exist.

Besides the phase noise added to system in the model (Figure 21), a non-linear power amplifier was used. Phase noise parameter in Table 1 was assumed as -48 dBc/Hz and high power amplifiers' back-off level was assumed as 1 dB,  $E_b/N_0 - BER$ . The result was illustrated by using Simulink and Matlab Bertool [10].

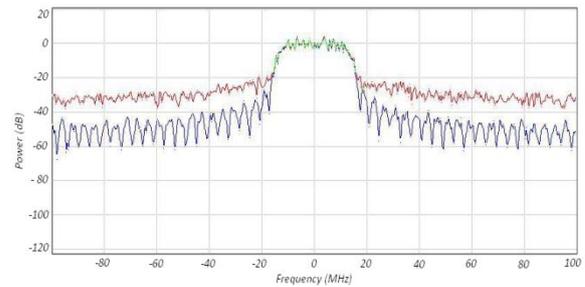


Figure 20. The transmitter (red line) and receiver (blue line) power spectrums, in which non-linear power amplifier is used and high phase noise exist

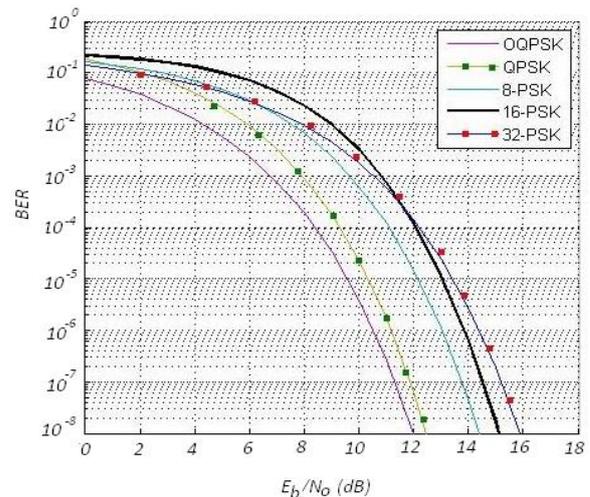


Figure 21. Comparison of  $E_b/N_0 - BER$  performance in system, in which non-linear power amplifier is used and high phase noise exist.

## VI. CONCLUSIONS

In this study, the simulation analyses to investigate the effect of different modulation techniques to the performance of data transmission in satellite communication for earth observation satellites was examined. PSK modulation techniques were compared for:

Effects of 8-PSK, 16-PSK, 32-PSK, QPSK, and OQPSK modulation techniques of modulation types on system performance were examined.

- The system in which linear power amplifier is used and phase noise doesn't exist.
- The system in which linear power amplifier is used and high phase noise exist.
- The system, in which non-linear power amplifier is used and high phase noise exist.

It was seen that high modulation techniques such as QPSK and OQPSK, has a lower BER in comparison to other modulation techniques as 8-PSK, 16-PSK and 32-PSK. It was also seen that, as the modulation degree increases to 8-PSK, 16-PSK and 32-PSK, the BER increases. When a non-linear power amplifier was used, the lowest BER rate was achieved for OQPSK modulation. Also, some results were obtained and figured by adding phase in system to show that OQPSK modulation technique has a lower BER.

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### BIOGRAPHIES



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