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Analysis Of Square Loop And Costas Loop Demodulator Using Simulink

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Abstract: *Student satellites are launched with an objective to have hands on experience for students to design, implement and realize the space mission. BPSK modem is designed for telecommand receiver of the satellite. The transmitted signal from transmitter is received back efficiently using BPSK modem. Costas loop is designed to self correct the phase and frequency error of the recovered carrier signal observed in squaring loop demodulator. This paper represents the simulation of BPSK modem using squaring loop and costas loop in MATLAB simulink. It is observed that there is a delay of 2 sample units in the received signal using BPSK demodulator.*

Keywords*: Binary Phase Shift Keying (BPSK), Bit Error Rate (BER), Phase Locked Loop (PLL).*

I. Introduction

ISRO is motivating educational institutions in making satellites for communication, remote sensing, etc.

This motivated student's community in developing their own satellite called student satellite. Student satellites are launched with the mission objective to have hands on experience for students on space mission. Every satellite carry unique payload to perform intended function.

In spacecraft, the telecommand function involves transmission of command from ground station to satellite to control satellite functions. Digital modulation is more reliable than analog modulation. The main objective of digital communication is to receive data similarly as sent with minimum probability of error. There are different digital modulation techniques each modulation technique has different performance in dealing with signals. Consulative committee for space data systems (CCSDS) recommended BPSK modulation techniques for earth space communication, since it has better bit error rate performance and it has low complexity in design.

II. Telecomm and System

A telecommand is send to control a remote system from fixed point on earth station. The sensors placed around the space craft measures the azimuth and elevation errors and sends it to the earth station. The earth station generates the telecommand signal to command space station and make it rotate in designed orbit. The telecommand data is modulated onto a carrier wave and is transmitted with adequate power to remote system. In the space station the signal is received by TTC antenna and then applied to the receiver via diplexer. The received signal that consists of phase modulated carrier is demodulated by means of BPSK demodulator.

The 180^o phase ambiguity in the phase carrier is recovered using differential decoder. The digital modulation of BPSK has proven to be the best modulation technique with good BER performance.

III. BPSK Modem

Digital modulation is a process by means of which analog carrier signal is modulated by means of binary data. In BPSK technique the phase of the carrier is changed between 0^0 and 180^0 according to input data signal. The phase of the modulated signal conveys some information. To generate binary PSK signal the input binary sequence has to be represented in the non return to zero form. The resulting waveform is multiplied with the sinusoidal carrier whose carrier frequency is f_c. The modulated signal is passed through AWGN channel. Fig 1 shows the block diagram of BPSK modem.

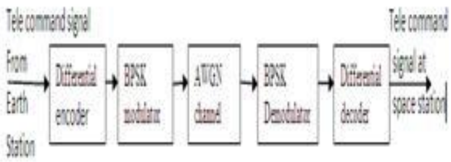

Figure1. Block diagram of BPSK modem.

BPSK demodulation can be implemented using two methods.

a) Squaring loop
b) Costas loop

In squaring loop modulated signal is squared, Band Pass Filtered and then multiplied with the carrier that is recovered using PLL to get back base band signal. Although the circuit is simple to implement, it explicits the presence of phase error. Figure 2 shows the block diagram of square loop BPSK demodulator.

m(t) be the message signal transmitted. The BPSK modulated signal is given by

$A\ m(t)\cos(\omega_c t + \theta_c)$. - 1

The squared output is given by $A^2 m^2(t)\cos^2(\omega_c t + \theta_c)$.

The BPF output is given by

$A_0\cos 2(\omega_c t + \theta_c)$.

PLL output is given by $A_0\cos 2(\omega_c t + \theta_e)$.

Frequency divider output is given by $A_0\cos(\omega_c t + \theta_e)$

The recovered carrier output is given by

$\cos(\omega_c t + \theta_e)$ - 2

The recovered carrier has phase error of θ_e

The output of LPF is the demodulated output and is given by

$A_0 A\ m(t)$ - 3

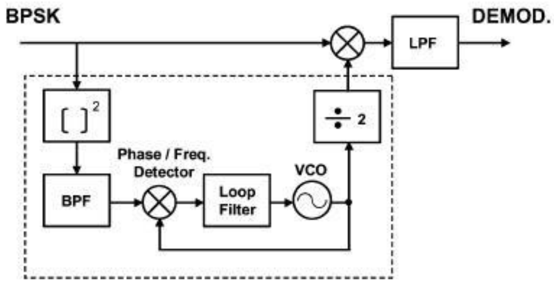

Figure 2. Squaring loop carrier recovery

Costas loop demodulator is an optimal method to attain data and carrier recovery for BPSK signal. It comprises of mixer, low pass filter, phase detector, loop filter and numerically controlled oscillator (NCO). The arm connected to in phase signal is called I channel and one that is connected to quadrature phase signal is called Q channel.

The BPSK modulated signal is multiplied with in phase and quadrature phase carrier signal.They are then passed through LPF where high frequency component are filtered out.The phase detector estimates the phase difference between the two arms of the signals. The error signal is given to loop filter where it removes the unnecessary spikes. The loop filter controls the phase and frequency of NCO output signal which gives the carrier signal. The demodulated signal is obtained at the output of I-channel. Phase reversal problem obtained at the output of demodulator can be avoided using differential decoder. Figure 3 shows block diagram of costas loop.

BPSK modulated output is given by

$m(t)\cos(\omega_c t + \theta_c)$ - 4

In phase LPF output is given by $m(t)\cos(\theta_c - \theta_v)$

Q- phase LPF output is given by $m(t)\sin(\theta_c - \theta_v)$

PLL is used to lock the carrier phase of modulated signal with the recovered carrier.

The recovered carrier will be

$\cos(\omega_c t)$ - 5

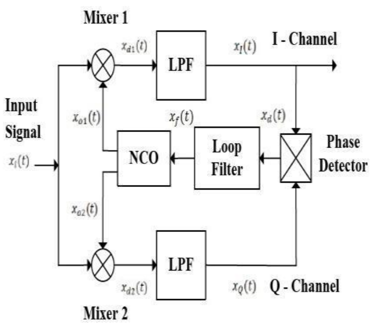

Figure 3. Costas loop carrier recovery

IV. Simulink Simulation

The telecommand signal generated by the earth station must be send to space station to adjust orbital and attitude changes. The low data rate base band signal is modulated with high frequency carrier so as to travel a long distance. BPSK is the preferred modulation for low data rate signal. The phase reversal problem which occurs when travelling over the channel can be avoided using differential encoder and decoder. Simulink is the modeling tool used to model the design and to validate the design.

A. Differential Encoder

The tele command signal generated by the earth station is encoded using differential encoder. Differential encoder can be obtained by XOR operation of current input with the previous output. The simulink model for differential encoder is shown in Fig 4.

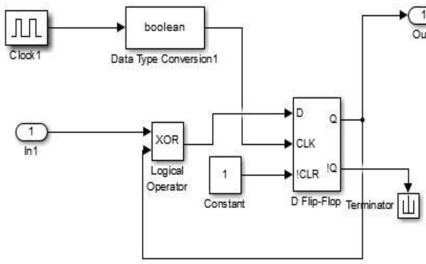

Figure 4. Differential encoder schematic

B. Bpsk Modulator

Modulation of base band signal is done to carry the signal through a long distance with minimum error. Modulation of differential encoded signal can be obtained by multiplying the signal of 1 Kbps with high frequency carrier of 10 KHz. Fig 5 represents the model of BPSK modulator in simulink.

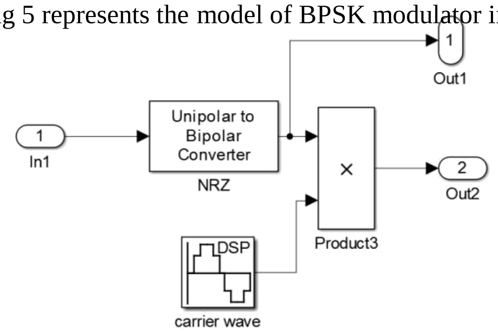

Figure 5. BPSK modulator schematic

C. Bpsk Demodulator Using Squaring Loop

Squaring loop demodulator is used to recover carrier and data from modulated signal. Phase offset is observed from recovered carrier which can be rectified using costas loop. Fig 6 shows the model of BPSK demodulator using squaring loop.

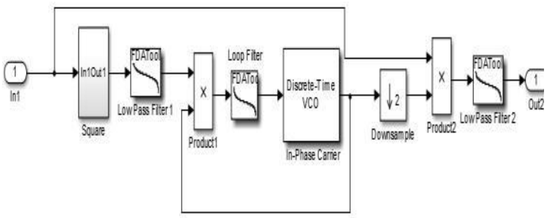

Figure 6: Carrier Recovery circuit – Squaring loop

D. Bpsk Demodulator Using Costas Loop

BPSK demodulator using Costas loop is used for data and carrier extraction from modulated signal. The modulated signal is again multiplied with carrier to get back the base band signal. Phase locked loop with low pass filter and NCO is used for carrier extraction. Fig 7 represents the model of BPSK demodulator.

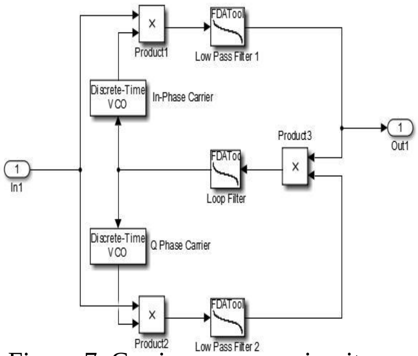

Figure 7. Carrier recovery circuit

E. Differential Decoder

Phase reversal obtained at the ouput of demodulator can be rectified using differential decoder. Differential decoder performs the XOR operation between the current input and previous input. Fig 8 shows the simulink model of differential decoder.

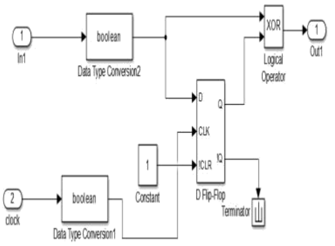

Figure 8. Differential decoder schematic

F. Clock Recovery

PLL with low pass filter and NCO are used to recover the clock from the demodulated output of BPSK demodulator. Fig 9 shows the simulink model of clock recovery circuit.

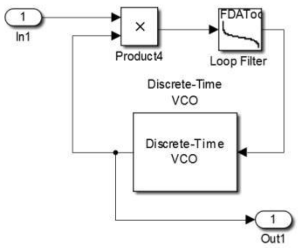

Figure 9. Clock recovery circuit

V. linx System Generator Model And Results

Xilinx system generator synthesis the design and generate bit stream to implement in FPGA. Fig 10 shows the block diagram of BPSK modulated transmitter.

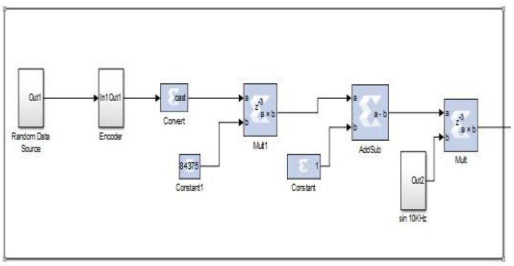

Figure 10. Transmitter module

In the space station the signal received by the RF antenna is BPSK demodulated using Costas loop and down sampled to base band frequency and differential decoded to avoid phase reversal errors. Fig 11 shows the Xilinx module of receiving station.

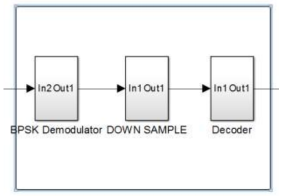

Figure 11. Receiver module

The BPSK demodulator is designed with PLL for carrier recovery. Carrier recovery done using squaring loop and Costas loop has low pass filter to filter out the high frequency component and PLL. The Xilinx model of low pass filter is shown in Fig 12.

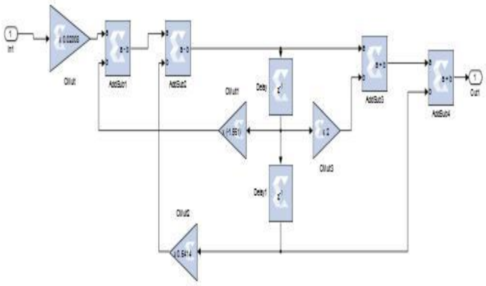

Figure 12. Low pass filter design

Differential decoder is used to remove phase ambiguity problem that arises in received signal. Differential decoder performs XOR operation between the current input and previous input. The recovered clock signal from clock recovery circuit is used in differential decoder.

The simulation is done using Xilinx system generator and the transmitted signal is retrieved back with minimum delay. Fig 13 shows the simulation results of telecommand module. It is observed from the figure 11 that there is a delay of two sample units between transmitted and received signal.

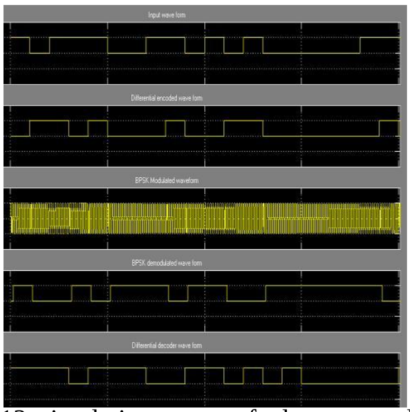

Figure 13. simulation output of tele command module

Carrier recovery done using squaring loop has phase error compared with modulator carrier. Equation 3 shows the recovered carrier with phase error. Fig 14 shows the recovered carrier using squaring loop demodulator.

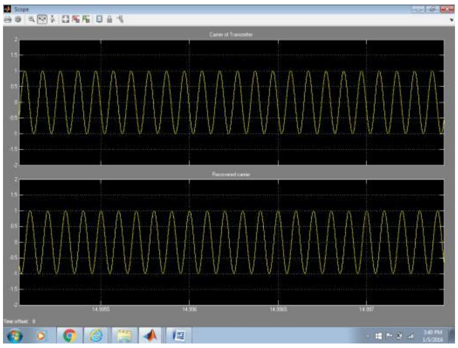

Figure 14. Carrier recovery using squaring loop

Costas loop carrier recovery is used to recover the carrier signal without phase error. Equation 5 shows the recovered carrier which is same as carrier of modulator. Fig 15 shows the self corrected recovered carrier signal using Costas loop.

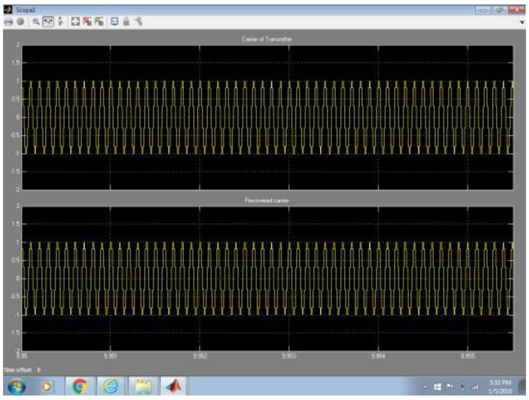

Figure 15. Carrier recovery using Costas loop

VI. Conclusion

BPSK demodulation using Costas loop is the accurate demodulation technique compared to squaring loop technique. In squaring loop demodulator, phase error is present due to the frequency divider. The digital Costas loop technique, overcome the phase offset problem. Both costas loop and square loop has disadvantage of 180^o phase ambiguity which is recovered using differential encoder and decoder.

The base band signal of 1000 bps is modulated with carrier signal of 10 KHz frequency and is transmitted from earth station and is retrieved back in space station by means of Costas loop BPSK demodulator. The transmitted signal is retrieved back efficiently with the delay of 2 sample units. BPSK modulator and demodulator is designed using Xilinx system generator. Future work includes BER calculation using BER tool and power analysis using Xilinx power analyzer.

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