Design of Ku-band High Power Solid State CryoSat Transponder

Muhammad Kashif Ishaque [1], Fargham.S [2], Asim.Shahzad [3], Muhammad Riaz Moghal[4]

[1] **Electrical Engineering Department, Federal Urdu University of Arts Science & Technology, Islamabad, Pakistan**

[2] **Electrical Engineering Department, Federal Urdu University of Arts Science & Technology, Islamabad, Pakistan**

[3] **Electrical Engineering Department, Federal Urdu University of Arts Science & Technology, Islamabad, Pakistan**

[4] **Computer Systems Engineering Department, Mirpur University of Science & Technology, Mirpur (AJK) Pakistan**

Abstract

High power solid state transponder for CryoSat operating in Ku-band, centre frequency is 13.575 GHz and bandwidth is 350 MHz and delay between consecutive pulses is 370 ns is proposed. For calibration purpose ground based satellite are deployed in different areas under the range window of the radar altimeter. Transponders are deployed under the passage of satellite. Transponder provides a target of stable radar cross-section, which can be directly measured, and can be used for calibration of the radar cross-section measurement.

Keywords: *CyroSat, Ku-band, radar altimeter, MMIC, Radar.*

1. Introduction

Global warming is the term which comes from climate change, this is a long and slow process that brings significant changes in the "average weather", that occurs in specific areas of the world. The average weather changes are rise of temperature, natural storms, variation of sunlight and distortion of ozone layer due to greenhouse gasses. Carbon dioxide is the most harmful and dangerous anthropogenic greenhouse gas. The concentration of carbon dioxide in the atmosphere is increasing day by day due to the rapid growth of industries in developed countries like China and USA. Its pre-industrial value in 2005 was about 280 ppm^3 (particles per million, a measuring unit of gases in atmosphere) to 379 ppm^3. Due to rise in average temperature of the world, the depth of the oceans has increased to at least 3000 m. The oceans particularly absorb heat; they absorb more than 80% of the heat that is produced by different ways. Most are due to manmade activities, which are added to the climate system. This huge amount of absorbed heat raises water temperature of the oceans and causes arise in sea level. Nearly 77% of the Earth's fresh water is frozen in Greenland and Antarctica. Due to Global Warming this ice has started to melt. This effect is significantly contributing to the increase in sea level [1].

In recent years European Space Agency (ESA) has started a program for the complete survey of earth. For this purpose ESA has lunched different satellites like ERS-1, ERS-2 and Envisat. Their task is to give more focused information to environment changes by deploying satellites with some observational instruments [1].

2. CryoSat

The CryoSat mission is used to determine slow and continuous fluctuations in the mass of the Earth which cause changes in earths land and sea ice fields and frozen oceans. These fluctuations cause climate changes and rise in sea level. Satellites (or Spacecraft) are used to monitor these fluctuations. It is particularly aimed to measure variations in the thickness of sea and land ice with time. CryoSat measures and estimates ice variations with time [5].

3. Transponder

In general a transponder is the combination of receiver and transmitter that receives RF signals, amplifies them, processes them, and retransmits it on different or same frequency. The main function of the transponder in CryoSat is to retransmit an echo of the input signal i.e. received from the radar [2].

In CryoSat, a ground based transponder acts as a point target for the radar that retransmits the scattered signal with minimum (fixed) delay (distortion). Several transponders are deployed on the ground under the range window of the satellite in a few kilometers area. When satellite passes over the transponders, it receives pulses from Radar Altimeter (RA) and retransmits them after some delay (distortion). During this process, the range (distance) between the transponder and RA will change according to the following relation [3].

$$r^2 = (r_0^2 + [v(t - t_0)]^2 \quad (1)$$

Where

- r is range of transponder at time t
- r_0 is range of transponder at time t_0 in line of sight between transponder and RA this is the closest distance between RA and transponder.
- v is velocity of satellite (RA).

3.1 Transponder Requirements

According to ESA requirements, transponders can be designed for CryoSat satellites. It is however, necessary for Radar Altimeter that it receives scattered pulse from transponder only and not from any other source as it is acting as a point target for the radar. For the design of the transponder, coupling is an important factor because radar is transmitting pulses in burst modes for which coupling and timing is critical. Three important factors which are necessary for transponder design are [2].

- Clutter
- Gain
- Coupling

According to ESA requirements, to discriminate clutter, following are some important factors:

- Transponder must use time-delay
- Transponder must use combined time-delay
- Transponder must use frequency offset.

3.2 Transponder Design

A simple ESA certified transponder design is shown in the following Figure. This design is approved for Ku and S band. The main elements of this design are shown in the block diagram [1].

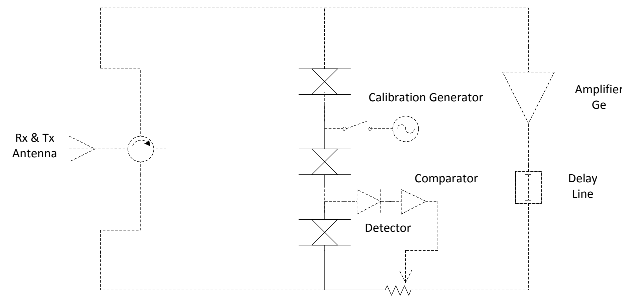

Fig. 1: Simple block diagram of Ku-band HPSSCT

In this model after receiving signal from the receive antenna it is amplified (G_e) and delayed with the help of a delay line. The signal is internally calibrated and amplified and then it is retransmitted through the Tx antenna [2]. A separate set of Tx and Rx antenna may also be used to eliminate the duplexer losses.

According to ESA Radar Altimeter, relevant parameters for transponder design are:

- Altimeter antenna diameter = 1.2 m
- Ku-band carrier frequency = 13.575 GHz
- Ku-band radar footprint diameter = 18.8 km [3]

3.3 Implementation

The detailed block diagram of the transponder with all components is shown in the figure 2. We will be more focused on the transponder amplifier design.

A signal with central frequency of 13.575 GHz is received by the Rx antenna of the transponder as described in the system block diagram. Some main components used in the amplifier design are listed:

- Buffer Amplifier (XB1008-QT)
- Band pass Filter(K&L MICROWAVE's Mini Pack Cavity Filter)
- Receiver (XR1007-QD)
- Branch Line Coupler
- Schmitt Trigger
- Programmable 8-bit binary downcounter (74HC40103)
- Retriggerable Monostable Multivibrator (SN74LV123A-Q1)
- Oscillators
- Frquency Doubler (HMC573LC3B)
- Low-pass Filter (K&L MICROWAVE's Mini Pack Cavity Filter).
- Power Amplifier (CMM1434-SM)
- Transmitter (XU 1005-QD)

Most of the components like buffer amplifier, receiver, oscillator, frequency doubler, power amplifier and transmitter used in this design are based on MMIC (Microwave monolithic integrated circuit) technology. A MMIC is a microwave circuit where one or more discrete microwave devices are mounted on a substrate. It contains all active and passive circuit elements in a single chip [4].

3.4 Operation

The central frequency of the Receiver at the Rx antenna is 13.575 GHz, which is also the center frequency of the transponder.

Buffer amplifiers are used for matching the characteristic impedance Z_0 of the device components and the antenna system and to amplify the signal with low noise injection. According to ESA, the characteristic impedance Z_0 of antenna and other components must be 50 Ω.

Band pass filters (BPF) are used to get the required frequency band. The BPF used in the transponder has a typical frequency range from 6 GHz to 18 GHz and it is tuned to a frequency spectrum of 13.575GHz-350/2 MHz to 13.575GHz+350/2 MHz with a center frequency of 13.575 GHz. A chirp signal always lives between these values.

For reception, 10 to 18 GHz MMIC receiver is used which is tuned to a central frequency (f_c) of 13.575 GHz. The central frequency (f_c) is down-converted using a Local Oscillator (LO) frequency.

The received signal is passed through an image reject mixer to reject the image frequency. Two outputs as intermediate frequencies IF1 and IF2 are taken from the mixer.

Since f_{RF} and f_{LO} frequency is 13.575 GHz.

$$f_{RF} = (f_{LO} \pm f_{IF}) \qquad (1)$$

The intermediate frequencies from down- conversion are

$$f_{IF} = (f_{RF} - f_{LO}) \qquad (2)$$

Consider IF1 will be

$$f_{IF1} = (f_{RF} - f_{LO}) \qquad (3)$$

Then IF2 will be

$$f_{IF2} = (f_{RF} + f_{LO}) \qquad (4)$$

Now equation (3) becomes

As band-pass filter's spectrum is between 13.40 GHz to 13.75 GHz and bandwidth is 350 MHz then

$$f_{IF1} = \left(13.575 \times 10^9 - \frac{350 \times 10^6}{2}\right) - \left(13.575 \times 10^9\right)$$

$$f_{IF1} = 0.175 GHz$$

Similarly equation (4) becomes gives

$$f_{IF2} = \left(13.575 \times 10^9 + \frac{350 \times 10^6}{2}\right) - \left(13.575 \times 10^9\right)$$

$$f_{IF2} = -0.175 GHz$$

The total IF is the difference between IF1 and IF2 as we are down converting will be $f_{IF} = f_{IF1} - f_{IF2}$

$$f_{IF} = \{0.175 - (-0.175)\} \text{ GHz}$$

$$f_{IF} = 0.35 \text{ GHz}$$

$$f_{IF} = 350 \text{ MHz}$$

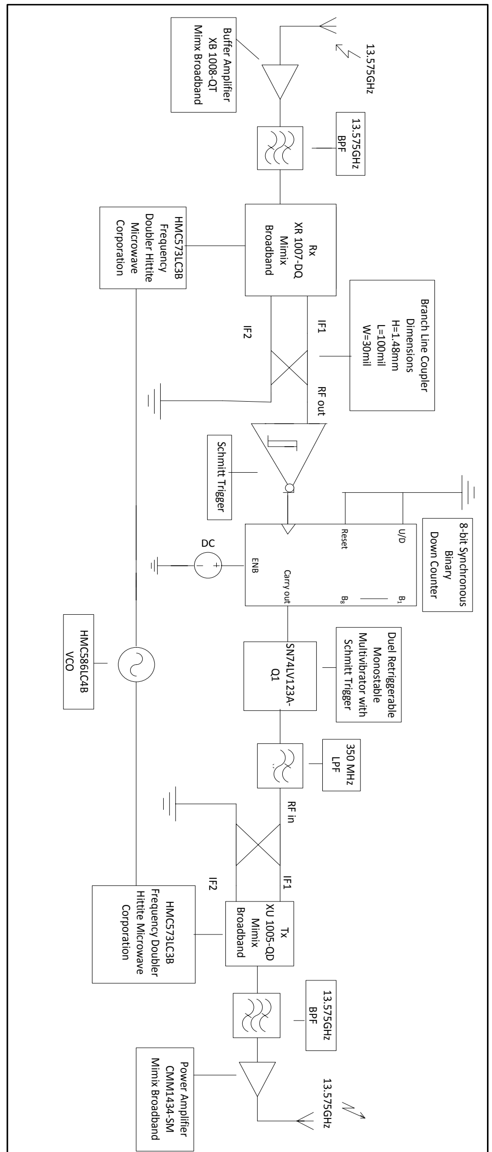

Fig.2: Ku-band HPSSCT Functional Diagram

3.5 Coupling

A branch line coupler is used to combine these two intermediate frequencies to get a single RF output.

According to ESA standard, the bandwidth must be 350 MHz with a central frequency (f_c) of 13.575 GHz with a phase difference of 90º (λ/4). The branch line coupler is designed using a computer tool ADS 2011.

Physical dimensions of coupler branches Z_A and Z_B were calculated by PUFF and verified through simulations.

Branch Line Coupler were built on PCB using micro-striplines with the dimensions H = 1.48 mm, W = 30 mil and L =100 mil. Permittivity of the board is 4.5. Pure copper based strip-lines with zeros tangent loss were assumed.

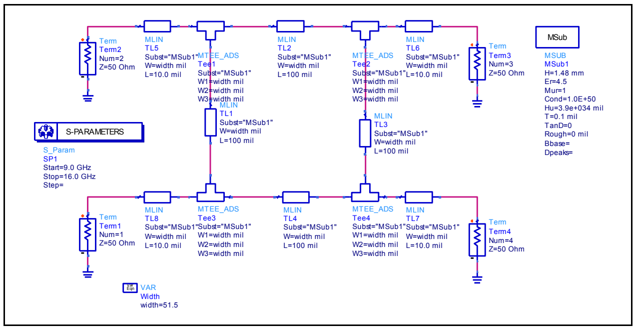

Fig.3: Schematic of the Branch Line Coupler

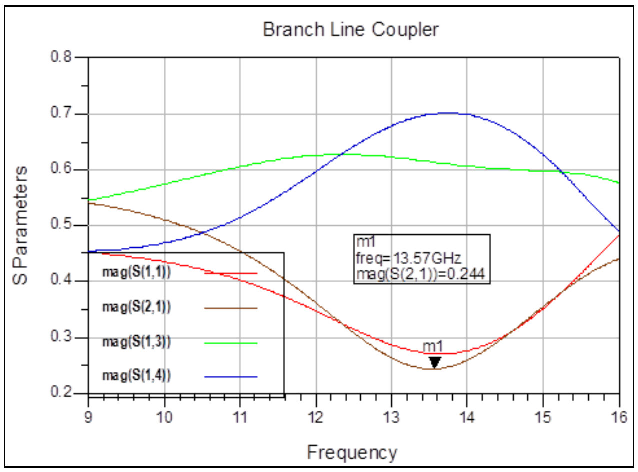

Fig.4: Simulated response of the BLC

The coupler shows 90 degree phase difference between two outputs of the coupler. One of the output ports is terminated using 50Ω termination with ground. The output signal is received from the other port IF (output). A VCO is used for down-conversion and up-conversion.

To create 13.575 GHz signal in the transponder a VCO is used as a LO. A *WIDEBAND MMIC VCO w/ BUFFERAMPLIFIER, 4 - 8 GHz* of *Hittite Microwave Corporation* is used. It is tuned on 6.7875 GHz frequency then this signal is doubled using a frequency doubler. To get a stable LO frequency it is very necessary to have some feedback system.

A phase locked loop must be implemented to lock the frequency at the desired value. To get 6.7875 GHz frequency it must tune the VCO at 9.1 V approximately.

The frequency doubler just doubles the input frequency with negligible distortion and power loss.

To produce 370 ns delay a Schmitt Trigger with an 8 bit binary down counter (74HC40103) and a mono stable multi-vibrator (SN74LV123A-Q1) are used.

To down-convert the signal to 350 MHz a Counter and MMV are the devices used. A schmitt Trigger inverter is used to convert signals into inverted output as compared to the input waveform. This is because at the input of 8-bit synchronous binary down counter, inverted output is required for Triggering.

The Output pulses coming from Schmitt Trigger Inverter circuit are given at the $\overline{PE}$ pin while f_{IN} is the clock frequency of 350 MHz used to measure 30 MHz. The counter will give a count of 11, 12 or 13. Any clock speed adjustments depend on its requirements. For instance if it is adjusted at 11 it will give 330 MHz and if it is adjusted at 12 it gives 360 MHz. In normal operation, the counter is decreased by one count on each positive-going transition of the clock (CP). Counting is held back when the input $(\overline{TE})$ is HIGH; the terminal count output $(\overline{TC})$ goes LOW when the count reaches to zero. While if $(\overline{TE})$ is LOW, output remains LOW for one full clock period.

Similarly after complete one cycle when input $(\overline{TE})$ is again high the process is started again. When the synchronous pre-set enables input (output from Schmitt Trigger Inverter circuit) $(\overline{PE})$ is LOW, data at the jam inputs that are from P0 to P7 is clocked into the counter on the next positive-going clock transition regardless of the state of $(\overline{TE})$. The jam inputs P0 to P7 represent a single 8-bit binary word. To create a delay of 370 ns for transmission in signal these jam inputs (P0 to P7) can be controlled by deploying a microcontroller or by a microprocessor by making a logic window. Now $(\overline{TC})$ output of counter is supplied as an input to Dual Retriggerable Monostable Multivibrator with Schmitt Trigger Inputs. This edge-triggered flip-flop output characteristic of the pulse width is controlled by three methods. In the first method, the input A is low and the input B will be high. In the second method, input A is high and input B is low. In the third method, the input A is low, input B is high and clear $(\overline{CLR})$ input will go high. In transponder design, when B is logic High $(\overline{A})$ is ($\overline{A}$ is input to the MMV as counter output) is low $(\overline{CLR})$ is high. When input Pulse which is coming from counter is triggered at a particular voltage level and is not directly related to the transition time of the input pulse. Then MMV will go on a quasi-state for delay defined by the circuit then it will come back in the stable state.

The output pulse duration i.e. delay between two consecutive pulses can be programmed by selecting suitable external resistance and capacitance values. The external timing capacitor C_{ext} and R_{ext}/ C_{ext} and external resistor and V_{cc} are connected to obtain variable pulse duration. Hence a delay of 370 ns according to ESA requirement is achieved. A LPF (350MHz) is used for reshaping the output pulse, to make its edges sharp.

Branch line coupler is used again with a different character as it is splitting one power source into two power sources. 350 MHz signal is spitted into two branches; one input of the branch line coupler is grounded (isolated). Branch line coupler is used as power splitter. It splits IF into two output ports IF1 and IF2 equally distributed. For transmission, frequency is up-converted by multiplying with source LO frequency as

$$f_{RF} = (f_{LO} \pm f_{IF})$$

As 350MHz signal is equally divided in two parts then

$$f_{RF} = \left(13.575 \times 10^9 - 175 \times 10^6\right)$$

$$f_{RF} = 13.40 \text{ GHz}$$

Similarly

$$f_{RF} = \left(13.575 \times 10^9 + 175 \times 10^6\right)$$

$$f_{RF} = 13.75 \text{ GHz}$$

There are two values each for lower and upper limit of the frequency spectrum. A sensitive BPF (K&L MICROWAVE's Mini Pack Cavity Filter) is applied in the circuit for transmission of f_c that is 13.575 GHz as shown in system block diagram.

Before transmission power amplifier (CMM1434-SM) is used to enhance the signal power.

4. Conclusion

Transponders are used as a reference target. The range is measured by radar altimeter. It depends on the accuracy of the propagation delay which is 370 ns. Transponder size has been reduced and it can be installed anywhere. All components are based on MMIC which is designed by Mimix Broadband. Sine MMIC integration technology is well established and has proven industrial application. The proposed system is a strong candidate for mobile application.

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