ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 12, December 2015

Signal Generation and Timing Control of HF Radar

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ABSTRACT: The radars are crucial component in assessing the behavior of electro jets and wind current. The working principal of HF radar is based on Doppler shift induced on the incident signal by the electro jets at higher altitudes of atmosphere. The Doppler shift induced on the echoes received from different altitudes indicates the characteristics of the electro jet. The exciter generates low level RF signals of frequency 18MHz. These signals pulse modulated, using timing pulses of selectable width and Pulse Repetition Frequency (PRF) is generated by the radar timing controller and amplified to a peak power of 50Kw by transmitter unit. Phase array antenna consists of 72 wire dipoles arranged in 12X6 rectangular configurations and is designed to operate harmonically at 18MHz. The same antenna array functions as transmitter and receiver and a T/R switch enables use of same phased array antenna for transmission and reception. The timing control unit controls the whole synchronization of the high frequency radar receiver. In order to get synchronization, timing unit has to adjust the timing of transmission and reception. Transmission and reception takes place based on some scientifically proved specification values. User writes these specification values to the system in real time. So there need some system to enter these values. For this RS232, a serial communication protocol is used. Timers take these specification values and thus solve the timing issues related to the High Frequency Radar receiver.

KEYWORDS: Doppler shift, Radar, HF Radar Receiver, Timing control.

I. INTRODUCTION

RADAR (Radio Detection and Ranging) is an active system that transmits a beam of electromagnetic (EM) radiation in the microwave region of the EM spectrum. They are very complex electronic and electromagnetic systems. Radar systems are composed of many different subsystems, which themselves are composed of many different components. The function of the radar receiver is to detect wanted echo signals in the presence of noise, clutter, and interference. It must separate desired signals from undesired signals, and amplify the desired signals for later processing. Radar transmits radio signals at distant objects and analyzes the reflections. Data gathered can include the position and movement of the object. There are many forms of radar- such as continuous, CW, Doppler, ground penetrating or synthetic aperture; and they are used in many applications, from air traffic control to weather prediction.

The HF Radar system used here works mainly on 18 MHz; a pulsed RF signal of the above frequency is generated by the exciter. This signal is amplified to 50kW peak power in the transmitter and is fed to the antenna. This electromagnetic energy is radiated into space by antenna array. The back scattered signal from the irregularities are passed through a coherent receiver where the signal is phase detected using two reference signals having quadrature phase relationship. The in phase and quadrature phase outputs of the two phase detectors (sine and cosine channels) have all the information contained in the backscattered received signal.

Equatorial Electro Jet (EEJ) -The Equatorial Electro Jet or E.E.J is a narrow ribbon of current flowing eastward in the day time equatorial region of the earth's ionosphere. In the day side ionosphere, the neutral winds set up a polarization electric field which usually points in the eastward direction. At the magnetic dip equator, where the magnetic field is exactly horizontal, this electric field has an interesting effect. The resulting upward $E \times B$ drift of the electrons generates a negative charge at the top and a positive charge at the bottom of the ionosphere E-region (about 90-130 km altitude). The resulting electric field prevents the further upward drift of electrons. Instead, they are now propelled westward by the eastward electric field. This westward movement of the electrons constitutes an eastward electric current which is called the Equatorial Electro Jet Equatorial Spread F Irregularity (ESF) - The Equatorial Spread F irregularity phenomenon results from vertical coupling process involving upward propagation of atmospheric waves (in

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 12, December 2015

the form of tides, gravity and planetary waves) from the lower atmospheric regions to the region in the ionosphere where the electric fields are generated. This irregularity will affect almost all radio communication and navigational systems utilizing the earth-space propagation path. Equator ionosphere F region irregularities, known as Equatorial Spread F (E.S.F) irregularities occur over a wide range of sizes extending from a few kilometers to a few tens of centimeters. Coherent backscatter radars in the VHF range and above the have been used to get valuable information on the nature of the irregularities. However, radars operating at frequencies above 50 MHz experience ambiguity in the measurement of Doppler spectra when irregularities having drift velocity greater than about 400 m/s are encountered at altitudes greater than 400Km. Multiple and staggered P.R.F techniques can solve the problem but unlike in the case of multiple point target environment, the resulting data is very complex to analyze and interpret in the case of a continuous volume target as encountered in E.S.F. A simple way to overcome the problem is to make the observation with HF Radar so that the Doppler shift will be smaller for the same drift velocity of irregularities. The radar can then be operated at a lower P.R.F, thus extending the altitude capability. The signal returns obtained in coherent radar are mainly from irregularities of scale sizes corresponding to half the wavelength of the radar. Thus, multi frequency operation is required to make observations on the characteristics of irregularities of different scales.

II. SYSTEM MODEL

The HF(80-1000 Km) and PR(65-95 Km; target level is 120m) radars are crucial components in assessing the behavior of electro jets and wind currents at an altitude range of 60 Km – 110 Km above the earth surface and thereby forming a model of the earth's near space atmosphere. Working principle of the HF radar is based on the Doppler shift induced on an incident signal by the electro jets present at higher altitudes of the atmosphere. Electro jets are the collective motion induces on the electron clouds of the E and F region of the atmosphere due to numerous factors including solar flares, high wind velocities, earth's magnetic field etc. The radar transmits a high frequency pulse (18 MHz TPn in the current case) for a fixed period of time (PW) and listens to the reflections received from different altitudes. The Doppler shifts induced on the echoes received from different altitudes are indicative of the speed of the electro-jets at that altitude range. However, the electron clouds that constitute the electro-jets are in ad-hoc random motion within themselves. This results in a mixture of frequency shifts observable in the received signal. An analysis of the amplitude of each frequency component gives a how random the constituents of the electro jet under observation are. The granularity of altitude ranges that can be observed is determined by the net energy of the transmitted pulse. The received signal corresponding to each altitude range is only a small fraction of the transmitted signal. The delectability of these feeble signals is determined solely by the noise tolerance and sensitivity of the receiver subsystem of the radar. Each sampling bin in the receiving system is of the same width as that of the transmitted pulse. This is because we are listening to the different echoes of the transmitted pulse from different heights. A pulse of 20µs corresponds to an altitude bin of 3 km; this is derived from the speed of light. The receiving subsystem relies on the principle of under sampling and down conversion. Thus, only one sample per range gate is taken to observe only the low frequency Doppler shifts in the frequencies. The basic operational principle of the weather radars under consideration is based on the Doppler shift induced on a signal that reflects back from the region under study. The system being developed should therefore be capable of isolating subtle signal parameters (of frequencies ranging from 25-50 Hz) from the reflected signals, process and store them in real time and derive meaningful information using various computational schemes.

The generated transmit wave (18 MHz) is transmitted for a time period PW, after which there is a wait time tw during which the backscattering from the different layers of the atmosphere occurs. After the wait time has expired, the receive phase begins where the backscattered Doppler Shifted waves are received at the antenna at stipulated time intervals for a continuous window period of tr. The Current system has an analog transceiver that processes the received signals in analog domain and generates data in an intermediate form that is to be collected by a digital Data Acquisition system (DAQ). Further processing is done off-line on a dedicated PC connected to the DAQ. However, there is very little control over the possible configurations that can be done on the transceiver system. Also, the data collected over the existing system is sufficient only to assess the conditions accurately over longer spans of time (hourly basis) while the current requirements have grown such that monitoring is to be done at least every 10 minutes. Also, a higher degree of control over the transmitting system is required for advanced scientific studies. Within the sampling window, corresponding to Doppler shifts at each altitude (multiples of 3 km), suitable number of range bins can be divided to find the shifts at each altitude. The division of timing interval of the receive phase into bins.

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ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

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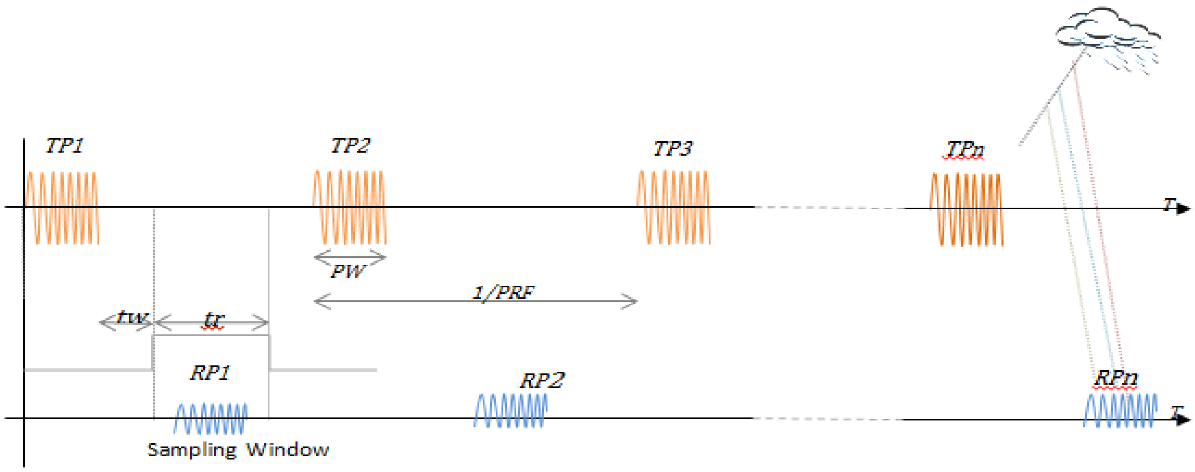

Figure 1. Theory of operation

Altogether, these requirements resulted in the current project to develop a more sophisticated software controlled, digital transceiver that can do online processing on the data thereby accelerating the pace of scientific study based on the data received from the existing radar. At the same time, the implementation also enhances the usability of the existing system by providing a finer granularity in the control options and a better user interface.

III. SYSTEM ARCHITECTURE CURRENTLY INSTALLED

The exciter generates low level RF signal of frequency 18MHz. These signals pulse modulated, using the timing pulses of selectable width and Pulse Repetition Frequency (P.R.F), is generated by the radar controller and amplified to a peak power of 50 kW by the transmitter unit. The T/R (Transmit/Receive) switch enables the use of same phased array antenna for transmission and reception. Switched line phase shifters controlled by signals from the radar controller produces signals of required phase for feeding the antenna for generating beams with the desired orientations. It should be possible to switch the beam orientations in three different directions i.e. zenith, ±30° from zenith in E-W plane.

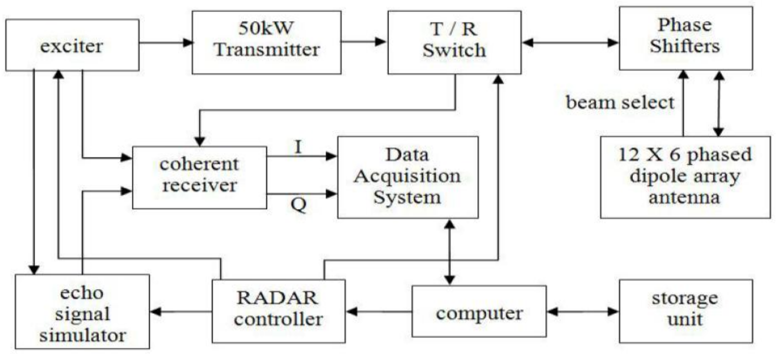

Figure 2. Block Level Architecture of HF Radar

The phased array antenna consists of 72 wire dipoles arranged in a 12×6 rectangular configuration and is designed to operate harmonically at 18MHz. Aperture requirement of the antenna is 10000m². The zenith beam will have an E-W HPBW of 6.3° at 18 MHz and 12.6° at 9MHz. The backscattered signals collected by the antenna are processed in a phase coherent receiver whose output I and Q contains all information needed from the radar. The data acquisition system samples and digitizes the I and Q (in-phase and quadrature phase) outputs of the receiver and the resulting digital data are fed to a computer. These data are subjected to spectral analysis using the Fast Fourier Transform (FFT) and meaningful spectral results obtained. Normalized power spectra from all the range gates are displayed on a monitor along with peak power information and other radar parameters. Vertical motions of the irregularities can be studied

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ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

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using the zenith pointing beam and the E-W motions can be studied by using the oblique and zenith beam measurements. Since the radar is located at the magnetic equator, the beam can be positioned ±30º zenith angle in the E-W plane, transverse to the magnetic field, satisfying the aspect sensitivity for backscatter echoes from field aligned irregularities, at all height regions of interest.

HF Radar Receiver Architecture

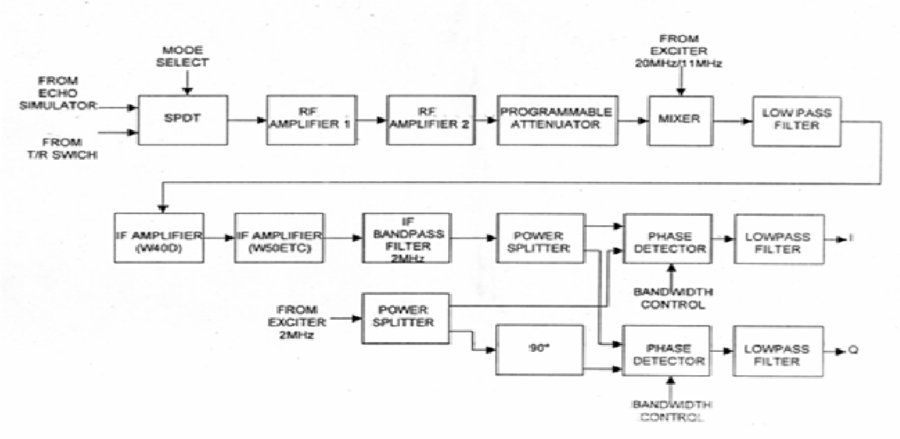

Figure 3. HF receiver Diagram

IF amplifiers: An IF of 2MHz has been chosen for the receiver. The band width required is 80 KHz. The two stages of tuned amplifiers are needed to get the required gain. Model W50C and W50ETC of trontech amplifiers with the gain of 60db and 24db respectively will be used in cascade. The power output of W50ETC at 1db compression point is +23dbm (min).

Power Splitter: Power dividing will be done by ZSC-2 2-WAY, 0^{O} power splitter/combiner of mini- circuits with an insertion loss of 0.5db (max), phased unbalance of 2^{o} (max) and an amplitude unbalance of 0.15db(max).

Phase detection: Two identical phase detectors will be used. The reference signal (2MHz signal from transmitter signal generator) to one of the phase detectors will be shifted by 90^{0} using a phase shifter. The maximum DC output of this phase detector is 1000mv with +7dbm applied to LO and RF ports, and DC offset is 1mv (max). The isolation between L and R Port is 40db (min).

Bessel LPF amplifier: The outputs of the two phase detectors will be passed through two identical second order LPF of Bessel type. The bandwidth of filters can be controlled. The I and Q signals are amplified to a level suitable for operating analog to digital converter.

Radar Controller and Data Acquisition And Processing System

Radar controller: The radar controller generates control pulses required for the transmitter, receiver and antenna. This unit sets the PRF, PW and frequency of operation for the transmitter, bandwidth for the programmable receiver and beam selection for the antenna. This unit comprises of a large memory built using UV erasable programmable read only memory circuits which are programmed for all the required PRF and PW settings. The memory is scanned every time a transmitter pulse is generated. The radar controller sets the required bandwidth for the tunable receiver and the orientation for the beam also. The unit works with a basic clock of 1MHZ. Hence the pulses generated will be precise to 1µs.
Data acquisition control: This unit sets the parameters for the data acquisition such as number of pulses, number of gates, sampling interval and position of window within the inter pulse period.

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ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

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In model, the front panel thumb wheel switches are used to set these parameters. The hardware operates with a clock of 1MHz and the sampling pulses are generated at the proper time by the unit. The data acquisition parameter such as PNPG (preset number pulse generator) setting, window position, number of gates and sampling interval are recorded along with the raw data. In mode2, the data acquisition scheme will be generated by the computer in interactive mode and will be recorded in the acquisition set up file. This will be used to program a set of programmable timers to generate sampling pulses at the required time. Operating mode of the data acquisition control unit is selected by a control from computer. When the computer is not running the radar program, the data acquisition control unit defaults to mode1. The buffered output signals of the data acquisition control unit are available for driving the analog input unit. Separate outputs are provided for the multiplexed data bus for raw data recording.

Analog input unit: The analog input unit acquires I and Q information from the receiver system and digitizes them. The unit comprises of two sets of analog to digital converters and sample and hold circuits to acquire I and Q channels. The fastest sampling rate is 20µs. Hence the sampling time of 1µs and conversion time of 2µs are chosen. The digitized I and Q channel data are available in 5µs. Two data paths are provided to meet the requirements of two operating modes. In mode1 the data is multiplexed into 8bit data bus to record raw data on tape. In mode2 data is taken through the 16bit wide DMA channel to the computer.

Data processing unit: Data processing is centered on the computer and the hardware and software resources of the computer are extensively used for this purpose. Thus data processing is possible only in the computer assisted mode.

These operations for the radar are organized in the following software modules
i) Program for radar controller
ii) Program for data acquisition
iii) Program for data processing
iv) Program for data logging

Echo simulation control: A simulated echo is required to test the receiver, data acquisition and processing units of the radar. This unit receives the transmitter pulse and measure the width of the pulse. A pulse of equal width is generated during the sampling window. This pulse is used by the echo simulator to generate an echo. The operation of the echo simulator control unit is independent of the mode and is switched on by a front panel switch.

Echo signal simulator: The purpose of the echo signal simulator unit is to generate a test signal of known Doppler shift and known signal strength which when fed at the input of the receiver can check out the entire receiver and data processing systems. The principle used is the phase shift method of single side band signal generation. By this method two signals of frequencies2000010Hz and 1999990Hz (2MHz±10Hz) are generated separately. Either one of them can be selected using a SP2T switch and passed through three separate double balanced mixers having LO signals of frequencies 20MHz 11MHz and 4.5MHz. The outputs of the mixers are passed through tuned amplifiers to separate the two signals of frequencies (18MHZ±10Hz), (9MHz±10Hz) and (2.5MHz±10Hz). The simulated signal of required frequency is selected using a SP3T switch and then pulse modulated using the echo pulse generated by the radar control unit. The echo pulse has the same width and repetition frequency as the TX pulse but is delayed with respect to the Tx pulse. The delay can be varied so that the simulated echo signal can be positioned suitably. The simulated pulsed RF signal having a Doppler shift of +10Hz or -10Hz is passed through a calibrated attenuator so that the signal strength can be varied as desired. Using the above test signal, the receiver and the data processing system can be checked out without putting off the transmitter.

IV. PROPOSED SYSTEM

The task of implementing the HF Radar Receiver as a whole (shown in Figure below) is divided into four modules:
- Timing and Control Signals Generation (TCSG)
- Signal Generation and Down Conversion block (DDS &DDC)
- Signal Processing Unit (FFT)
- GUI - Data Storage Interfacing & ADC - DAC Interfacing

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

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ADC module is for digitizing Doppler shifted data (18MHz ± f_d). For Analog to digital conversions and vice versa use 4DSP FMC 150 ADC/DAC FMC daughter card with ADS62P49, dual 14bit 250 MSPS ADC and DAC 3283, dual 16bit 800MSPS DAC. HF Radar settings are to be entered into TCSG module in FPGA in run time. Direct Digital Synthesis (DDS) module is for generating 18MHz sine wave for transmission, as well as in phase (I) and quadrature phase (Q) Cosine and Sine signals for digital down conversion. Digital Down Converter(DDC) performs digital down conversion and filtering. Incoming Doppler shifted signal (18MHz ± f_d) is given to the digital multipliers for mixing with cosine and sine for generating the I and Q channels respectively. Following stages are incorporated with decimation filter chains to reduce the sampling rate in order to reduce the processing rate in signal processing modules. Signal processing module consists of a run time reconfigurable FFT processor. Finally Data from radar has to be stored in a Compact Flash card for data acquisition study.

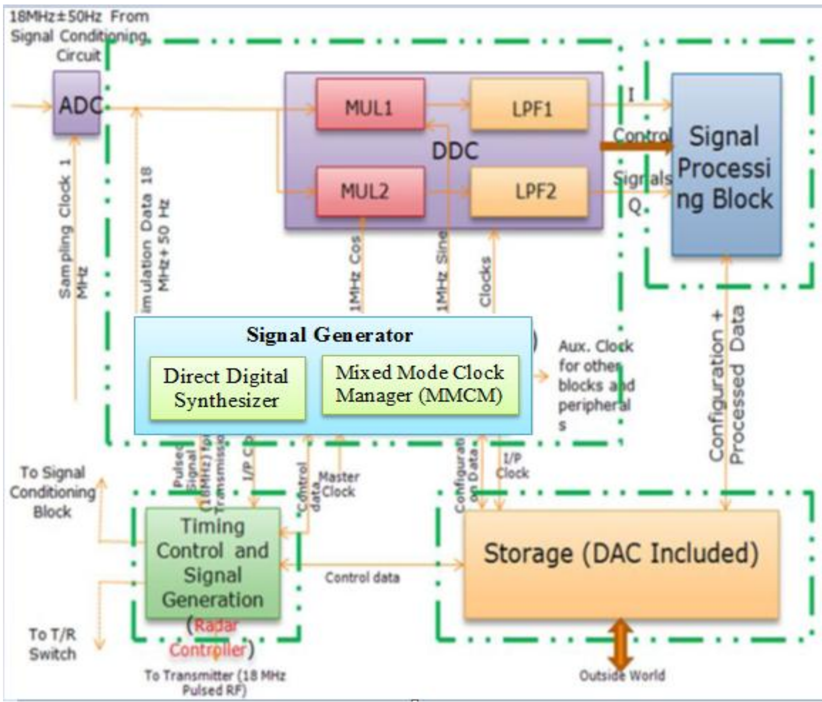

Figure 4. Architecture of the new proposed system

The proposed new architecture of HF Radar Receiver consists of four modules and my thesis objective is to design and implement the Timing and Control Signals Generation (TCSG) module for HF Radar Receiver in FPGA using LabVIEW. The Timing and control unit controls the whole synchronization of HF radar receiver. So timing control circuit form an important class of circuits in HF radar receiver. In order to get synchronization, timing unit has to adjust timing of transmission and reception at a time. Transmission and reception takes place based on some scientifically proved specification values (discussed in earlier chapter). User writes these specification values in a system in real time. So there need some system to enter these values. Using RS232,a serial interface communication protocol, timer takes these specification values and thus solves the timing issues related to high frequency radar receiver. VHDL is used to model this circuit and is simulated in Xilinx ISE13.1.To implement this, hardware Virtex 6 ML605 Evaluation Board is used.

TIMING AND CONTROL SIGNAL GENERATION

Timing and control signal generation (TCSG) unit controls the whole synchronization of HF radar receiver. In order to get synchronization, timing unit has to adjust timing of transmission and reception at a time. Transmission and

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reception takes place based on some scientifically proved specification values. User writes these specification values in a system in real time. The block diagram of TCSG is given below.

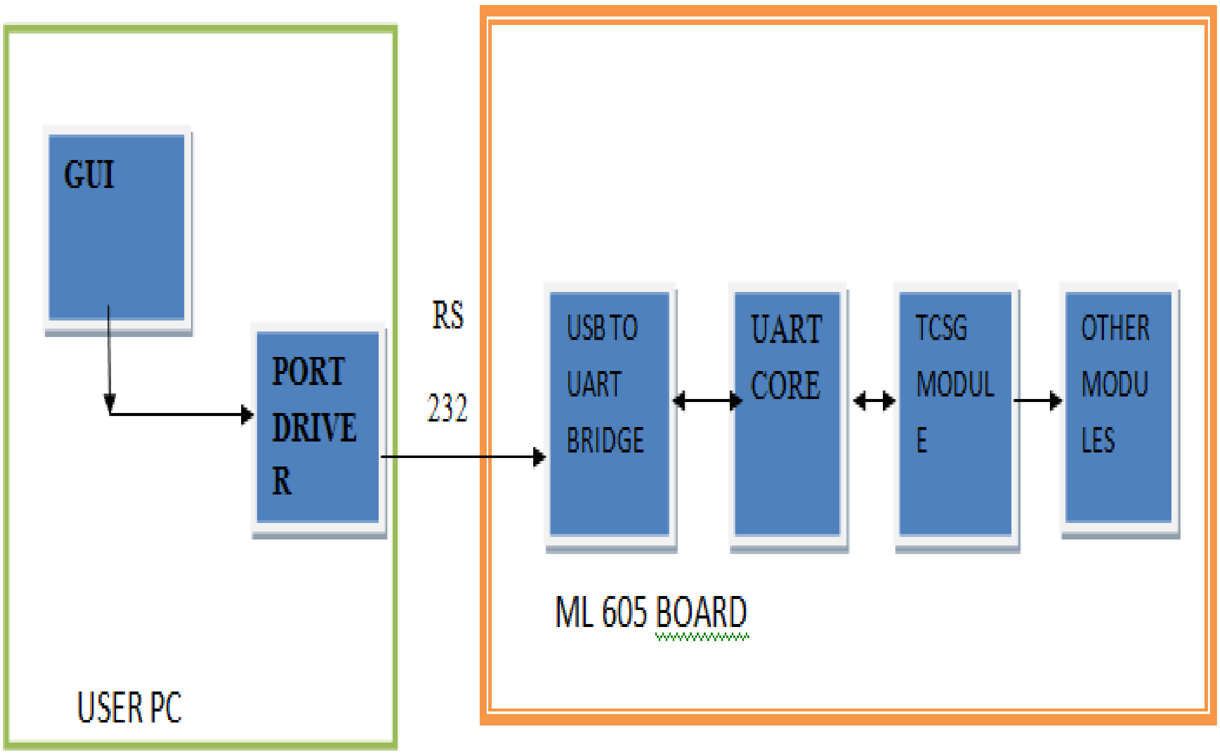

Figure 5. TCSG general block diagram

HF radar transmitter transmits signals when T/R (transmit/receive) pulse is high. Transmission period lasts for 200µs. After 50µs, transmitter sends 18 MHz RF pulse of required pulse width. The pulse width (PW) used is: 20µs (3km), 60µs (9km), 80µs (12km) & 100µs (15km). The beam is designed to orient in 3 directions: zenith, 30° east off zenith and 30° west off zenith. Zenith beam is used for studying ESF and the oblique beam is for EEJ studies.

Reception happens when T/R pulse is low. Reception period is not fixed. It depends on PRF. i.e. transmission + reception=1/PRF. ‘Window starts at’ (start of reception window) is different for zenith and oblique beam. For zenith, it is 540µs (ESF studies taken from 81 Km, which corresponds to 540µs) and for oblique, 640µs (EEJ studies: from 96-106 km).Commonly used windows start at is 540 µs. The width of the reception window depends on pulse width and no: of range gates. In the above fig. the no: of range gate (N_b) is chosen as 64 and therefore reception window can be extended upto1820µs(64*20+540) for 20µs PW. Similarly 4380µs for 60µs, 5660µs for 80µs, 6940µs for 100µs [zenith beam]. ADC sampling is enabled at ‘window start at’. Sampling interval gives the time interval between the two successive range gates.

V. RESULT AND DISCUSSION

1. Figure 6 represents Timing diagram of transmitted RF signal(t1),transmitting pulse (t2), received pulse(at prf =100(default) and pulse width=20 µs)

 DOI:10.15662/IJAREEIE.2015.0412009

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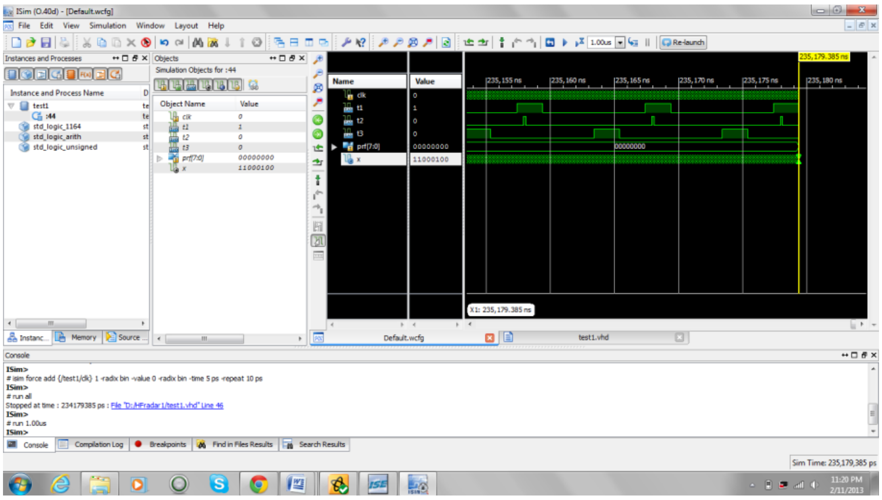

Figure 6. Timing diagram of transmitted RF signal, transmitting pulse, received pulse (at prf =100(default) and pulse width=20 µs)

2. Figure 7 represents timing diagram of transmitted RF signal(t1),transmitting pulse (t2), received pulse (at prf =167 and pulse width=60 µs**)**

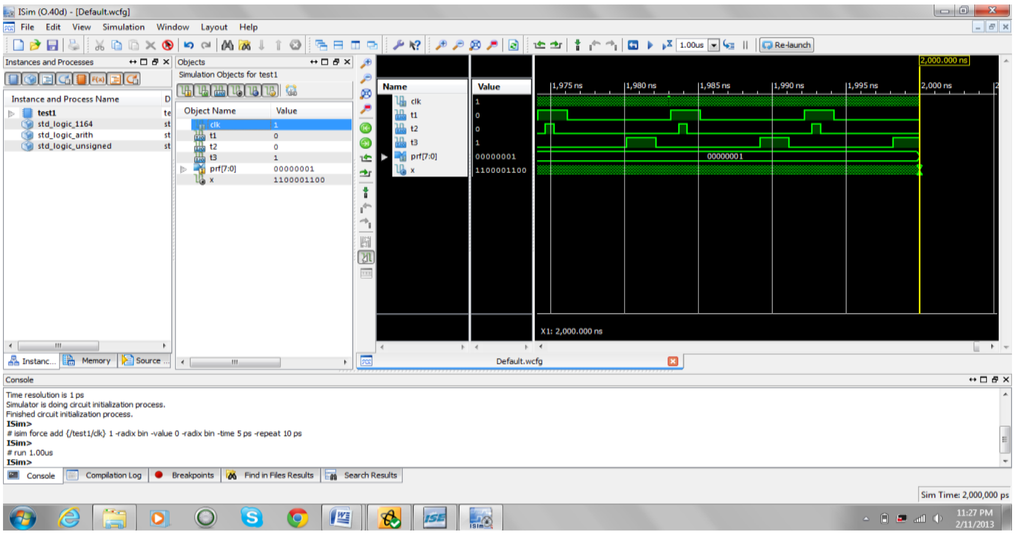

Figure 7. Timing diagram of transmitted RF signal, transmitting pulse, received pulse(at prf =167 and pulse width=60 µs)

3. Figure 8 represents timing diagram of transmitted RF signal(t1),transmitting pulse (t2), received pulse(at prf =200 and pulse width=80 µs

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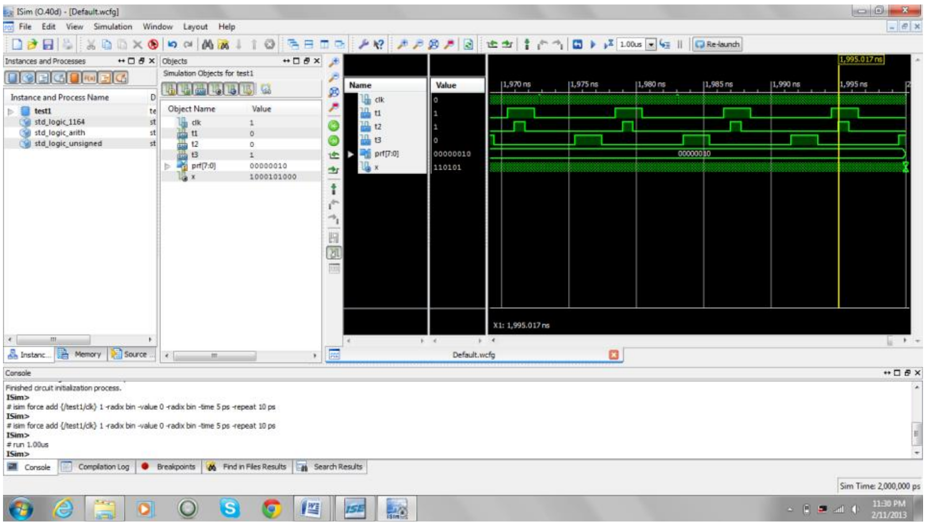

Figure 8. Timing diagram of transmitted RF signal, transmitting pulse, received pulse(at prf =200 and pulse width=80 µs)

4. Figure 9 represnts timing diagram of transmitted RF signal(t1),transmitting pulse (t2), received pulse(at prf =250 and pulse width=100 µs)

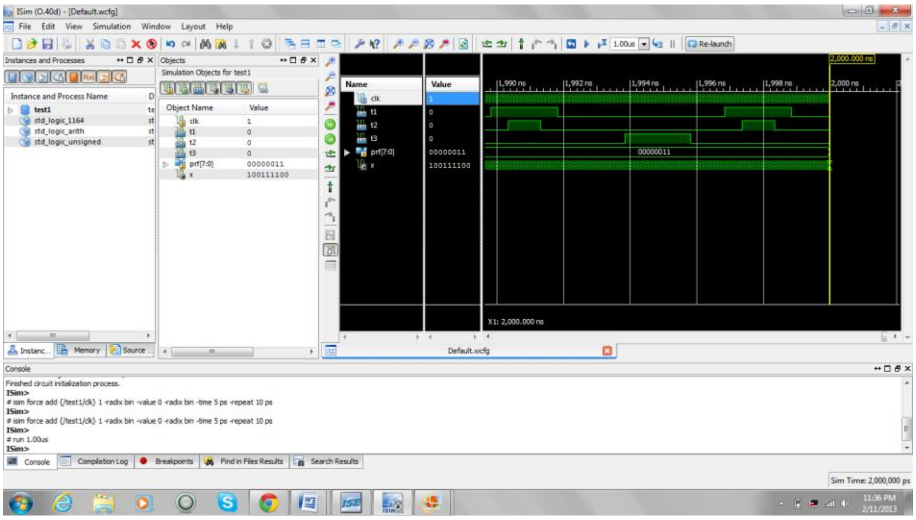

Figure 9. Timing diagram of transmitted RF signal, transmitting pulse, received pulse(at prf =250 and pulse width=100 µs)

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5. Figure 10 represents the timing diagram of serial transmission

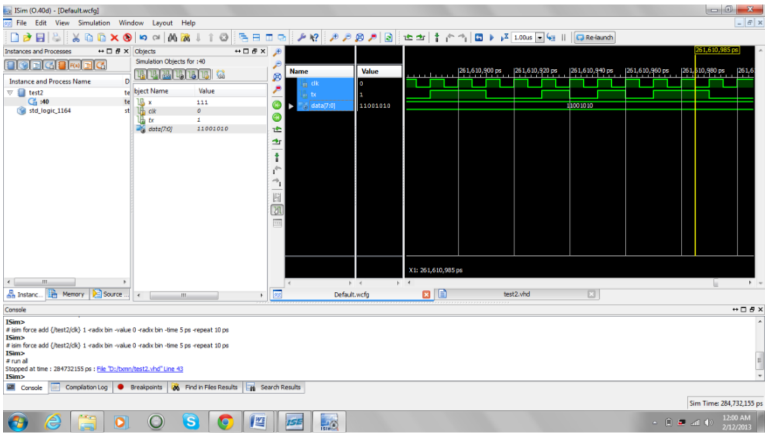

Figure 10. Timing diagram of serial transmission

VI. CONCLUSION

HF RADAR is a crucial component in accessing the behavior of electro jets (E - Region) and wind currents at an altitude range of 80-110 km and 150 to 1000 km (F- Region) above the earth's surface. The augmentation of the HF Radar Receiver to a state-of-art Digital Receiver in Field Programmable Gate Array (FPGA) has been configured. The project objective is implementing the timing and control signal generation (TCSG) module for HF radar digital receiver. In this project the TCSG module is used to control the transmitting signal timing ,pulse width according to different prf (100,167,200,250) and receiving signal timing. The TCSG controls the whole synchronization of HF Radar receiver. HF Radar settings are to be entered into TCSG module in FPGA in run time. For this, TCSG and URAT unit is coded in VHDL and synthesized in Xilinx ISE 13.1. Then a GUI is created in PC from where settings can be serially sent to the UART core module, with the help of USB to UART bridge on-board. Finally the TCSG-UART module configured in FPGA and integrated with the system.

REFERENCES

[1] G. Desodt, D. Muller, D. Puzenat, ―OSCAR, a simulation environment dedicated to the design and performance assessment of RADAR system, ―International Conference on Radar, Paris, 1994.
[2] Sulaiman H. M. Al Sadoon1, Badal H. Elias2 ―Radar theoretical study: minimum detection range and maximum signal to noise ratio (SNR) equation by using MATLAB simulation program‖ 2013; 2(4): 234-241 Published online July 20, 2013 doi: 10.11648/j.ajmp.20130204.20
[3] Ashagrie Getnet Flattie,‖ Performance Evaluation of MIMO Cooperative Radar by Considering High Altitude Aeronautical Platforms‖ International Conference on challenges in IT, Engineering and Technology (ICCIET‘2014) July 17-18, 2014 Phuket (Thailand).
[4] Ying Roger Lee and Asad Yousuf,‖ Radar performance analysis system: A software package of learning simulations for electronic laboratories‖ journal of applied science and enginee ring tec hnology 2007.
[5] Andreas Arnold-Bos, Student Member, IEEE, Ali Khenchaf, Associate Member, IEEE, and Arnaud Martin, Member, IEEE ―Bistatic Radar Imaging of the Marine Environment—Part II: Simulation and Results Analysis‖ IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 45, NO. 11, NOVEMBER 2007.
[6] Mahmod A. Al-Zubaidy, Samaa K. Al-Saffar ― Targets Signals Simulation in Radar System‖ International Journal of Emerging Science and Engineering (IJESE) ISSN: 2319–6378, Volume-2, Issue-1, November 2013‖
[7] Nathanson, F.E.: ‗RADAR DESIGN PRINCIPLES‘ (McGraw- Hill, New York, 1969), pp.452–469