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Test Validation of Phase Switched Interferometer Module for Calibration of MST Radar Array

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Abstract: Studies of the earth atmosphere in the regions of Mesosphere, Stratosphere and Troposphere (MST) are being performed by radar operating at a frequency of 53 MHz. This paper outlines the MST Radar signal and data processing along with the test validation activity of phase switching interferometer for phased array antenna calibration. An advanced digital receiver based radio interferometer has been developed which has advantage over prior analog module. The system consists of RF module, phase switch controller module and Digital receiver module. The MATLAB program separates the interlaced data of SUM and DIFF, which were collected on the single channel digital receiver. The successful testing of the system is demonstrated by the signal injection with signal generator and software for separation of data sets of two channels of Phase Switching system that is used to increase discrimination and sensitivity of an interferometer in detecting weak radio sources.

Keywords: MST radar, Coherent Integration End (CIE) pulse, phase switch control, RF interferometer.

I. INTRODUCTION

MST radar operating at 53 MHz transmits high power pulsed RF signals into the atmosphere and receives the backscattered echoes. It is a high power, highly sensitive, pulse-coded, coherent Doppler radar to estimate the atmospheric wind vector using the Doppler shift in atmospheric echoes. Figure 1 presents block diagram of radar, where the four important sections of the radar are represented with different colors. The major subsections are Antenna array and feeder network, Exciter and Radar controller, Transmitter system, Receiver and Signal processing.

A. Antenna array and feeder network

Phased array antenna of radar consists two orthogonal sets of 1024 three-element linear horizontal polarized Yagi-Uda antennas. They are in 32X32 matrixes occupying an area of 17000 sq. m. The inter-element spacing in the matrix grid is 0.71λ, where λ is radar wavelength. Antenna is characterised with beam width of 2.8deg, gain of 36 db, and a side lobe level of -20 dB. The antenna pattern has been characterized in the receive mode by recording the signal from a weak radio source Virgo-A (3C274) in the phase switching interferometer technique developed by Ryle, 1952.

B. Exciter and Radar Controller

The exciter unit generates all the RF and timing and control signals of radar. The 5 MHz RF synthesizer is a highly stable reference signal generator. The 48 MHz synthesizer serves as local oscillator (LO) for up conversion while transmitting, down-conversion during reception. The bi-phase coder generates a 5 MHz complementary coded RF pulse.

The timing and control signal generator (TCSG), design is based on ADSP 21062 SHARC DSP processor.

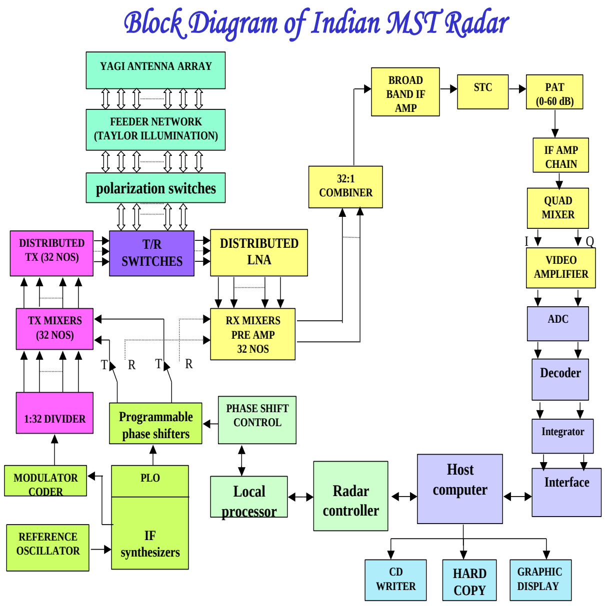

Figure 1 : Functional Block Diagram of Indian MST Radar

The outputs from TCSG include transmitter and receiver gate signals, duplexer signal, coder and analog-to-digital converter (ADC) sample clocks.

Table 1 MST Radar specifications

Parameter	Value
Location	13.47°N, 79.18°E
Frequency	53 MHz
Average power aperture product	$7X10^8$ W m^2
Maximum Duty	2.5 %

Mode of operation	Doppler Beam Swinging
Number of beams	82
Pulse width	1 to 32 µ sec. un-coded and16 & 32 µ sec. coded
Inter pulse period	125 µ sec. to 8000 µ sec.
Number of range-bins	1 to 256
Number of coherent Integrations	1 to 1024
Number of FFT points	1-128

C. Transmitter system

The transmitter system consists of 32 transmitters ranging in power from 15 kW to 120 kW to provide a total transmitter power of 2.5 Mega watt. The high power transmitters feed the central area and low power ones feed peripheral antennas for achieving Taylor windowing of antenna power aperture required for better antenna side lobe level. Each transmitter has four amplifying stages and associated power monitoring and controlling and safety interlock circuits. The input to the transmitters is a low level (1 m watt) pulse modulated (coded, un-coded) signal. The output power of the transmitter is maintained within ± 1 dB of the specified level by adjusting the input to SSA by means of a PIN attenuator, by sensing transmitter output power level in –60dB dual directional coupler (RF power-monitor coupler).

D. Receiver and Signal processing system

The super heterodyne receiver has an overall gain of about 120 dB and a dynamic range of 70 dB. The receiver front-end unit consists of a blanking switch, a Low Noise Amplifier (LNA) and a mixer-preamplifier for each of the 32 channels. The blanking switch provides isolation to receiver during transmit period, in addition to the isolation provided by Duplexer. It consists of a limiter stage to limit maximum power to receiver within 13 dBm. The LNA is a 53 MHz-tuned amplifier with noise figure of 3 dB and a gain of 24 dB and a bandwidth of 4 MHz. Radar consists of a conventional analog IF receiver and a digital I&Q signal processor to process the signals. In the analog receiver, IF signal is split and applied to pair of quadrature mixers which mix them with 5 MHz LO signals having quadrature phase of 0^0 and 90 ^{0} to get video I and Q signals for further processing in Host computer. In this project a digital receiver, where 5MHz IF signal is digitized and down converted by DDC (digital down converter) is used, where the data is transferred to PC on USB2.0 for archival & display purpose.

II. PHASE SWITCHED INTERFEROMETER

The far field point of the MST radar is above 4 km in space, a conventional antenna pattern testing is not possible. Hence, natural radio source, Virgo-A is used as point source for antenna pattern testing. The Radio source 3C274 (Messier 87) was identified with the strong radio source Virgo-A. The declination of Radio source is +12° 23′ 28.0439″is within the zenith beam of MST Radar located at +13° 27' 21.60"N latitude. Hence this radio source is suited for calibration of MST Radar antenna. The source transits over the radar everyday due to earth's rotation. The transit time at particular location is accurately calculated with Right ascension of source. To detect the weak radio source Virgo-A, a digital domain phase switched interferometer is being developed in the present exercise. The antenna of radar is split into two in east west line and the two halves signals are processed. Figure 2 presents the Receiver connectivity for the interferometer setup.

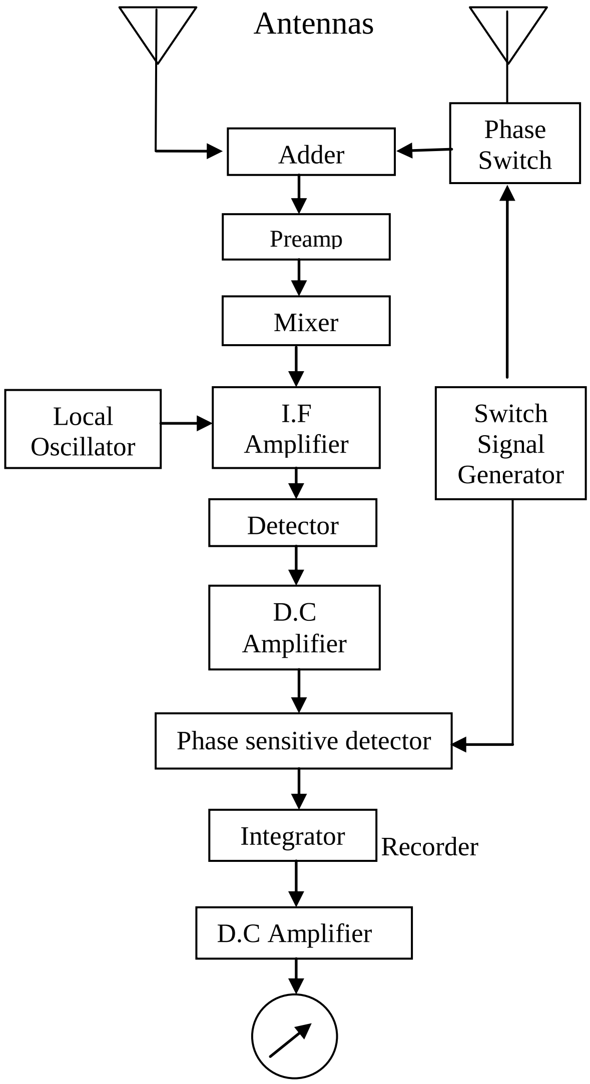

Fig 2: Phase Switched Interferometer

The two antenna signals are added synchronously in In-phase and Anti- phase, using a square wave derived from the radar data processor clock.

The general description of the phase switched interferometer technique developed to detect weak radio sources by 'Ryle' is described as follows - "The phase-switched interferometer system makes use of two identical antennas placed in the east-west line, with a switch arranged so that an additional half-wave-length of cable may be introduced in one of the antenna cables. By this means it is possible to displace the interference pattern so that the new maxima correspond to the minima of the original pattern. The envelope of the interference patterns

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is determined by the reception pattern A(θ) of the individual antennas. The power receptivity of the system when antennas are in phase and anti phase is given by A(θ)[1±cos(k d sin θ)], where θ is the angle between the source and the axial plane, d is the spacing between the antennas and k is the propagation constant (k= 2π/λ) and λ is the wave-length. If the analysis is restricted to the angles near the axial plane of the interferometer, the expressions may be simplified to A(θ)[1±cos(k d θ)]. Due to earth rotation a point-source of radiation direction θ changes slowly. If the system is switched rapidly between the two conditions, the antenna system power will contain an alternating component whose magnitude is the difference between the powers intercepted in the two switch conditions If receiver is having square-law detector, the output voltage will contain a alternating component."

III. HARDWARE DEVELOPMENT AND TESTING - PHASE SWITCH AT 5MZ, TOGGLE FLIP FLOP BASED PULSE TO SQUARE WAVE GENERATOR

A RF phase switch module has been developed to introduce either 180° or 0° zero degrees of phase shift into one of the two channels of IF at signal 5MHz. A TTL IC Toggle flip flop based circuit, which generates square wave from the timing pulses of reviver signal processor, is developed to synchronise the phase switching with the receiver signal processor. The coherent integration end(CIE) pulse is used to toggle the state of the circuit output .With this setup , 0/180° phase is introduced in the RF switch respectively to record data corresponds to each phase state alternatively, i.e. all odd data points of time domain data record corresponds to 0° zero degrees phase insertion and all even data points corresponds to 180° phase insertion time periods. The data record is synchronised to radar timing pulses that can be easily separated in the receiver data in software. The block diagram of the phase switch test setup is shown in the figure 3.

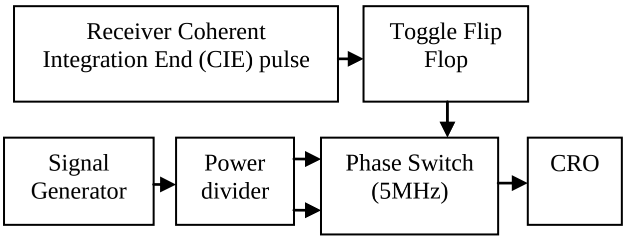

Fig 3: Block Diagram of phase switch test Setup

By using MST radar Coherent Integration End (CIE) signal, a pulse to square wave signal is generated using Toggle flip flop circuit to control the phase switch. The functioning of the phase switching is verified and shown in figure 4. Digital storage osciloscope display of phase shift change of IF signal taking place at pule low to high transisiton is shown in figure 4. The blue pulse at bottom of the figure is CIE pulse (< 1 µs time period), The square wave low to high transisiton is shown in top yellow signal, The 180^0 phase flip of IF signal at 5Mz is represented in magenta color. The RF signal of 5 MHz phase fliping can be seen clearly in the figure.

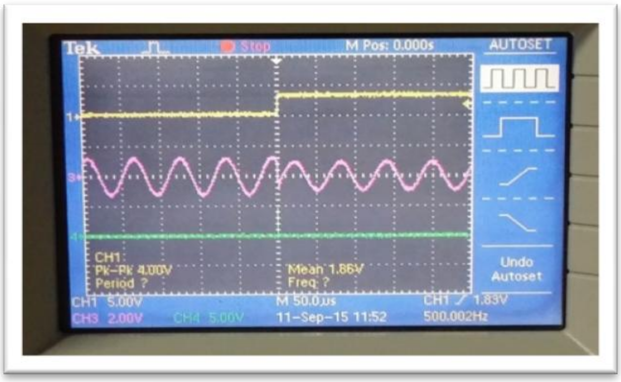

Fig 4: Phase Shift test signals In Ociloscope

The phase switching signal is a square wave signal derived from radar timing signal CIE. It is applied to a IF phase switch combiner, which acts in synchronism with CIE pulse and radar data acquisition. The phase switch is tested with a simulate signal generated by Signal generator. The power is divided in phase to two inputs of the phase switch interferometer. In the phase switch interferometer module, the two signal inputs are added while control pulse is high and subtracted when the control pulse is low.

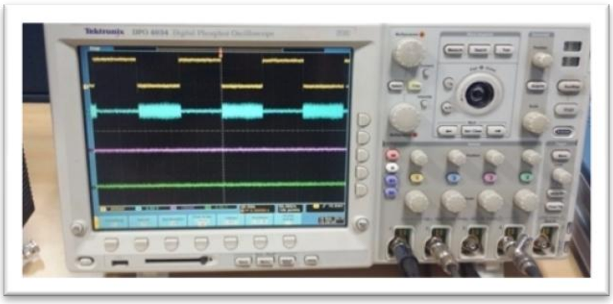

Fig 5: Output of phase switch shows Sum and Difference of the simulate signals in digital oscilloscope

Figure 5 shows the RF output at the phase switch interferometer module.The signal in the Oscilloscope is locked to square wave, shows, SUM signal during the square pulse low time period, where signal amplitude is about 2V, when both inputs are added. The signal amplitude is near zero, during the time period of DC square wave high time. This figure clearly validates the Sum and Difference operation, synchronous to the data record in digital receiver.

IV. SOFTWARE DEVELOPMENT AND TESTING

A MATLAB code has been developed to separate the data corresponding to Sum period and Difference period as two separate data streams. The flow chart in the figure 6 presents the sequence of steps followed the separation of the Sum and Difference data from the single channel Digital receiver is performed by the following algorithm.

The digital data is recorded in digital receiver such that, alternate data points is for SUM and Difference data. The sum data is stored in even data points and Difference data points are stored as odd data points of the time domain data series.

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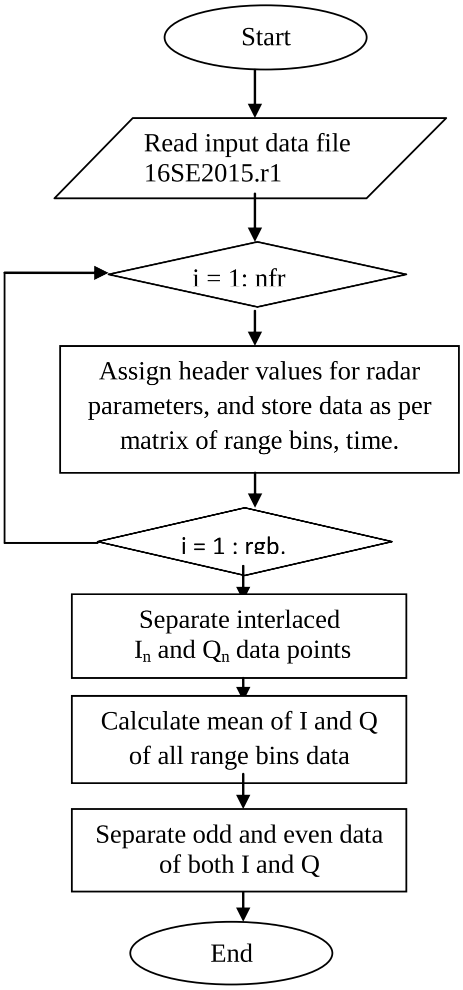

Figure6. Flow chart for separation of the Sum and Difference data from recorded data.

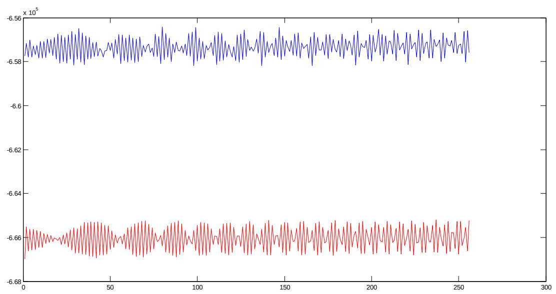

Fig 7:- Even and Odd signals

Efforts are made to store the simulated data set in single channel digital receiver as per the above methodology. Parallel efforts are also made to store the two antenna signals in the two channels of the three channel digital receiver and perform the sum and difference in software on digitized data, so that the switching can be avoided.

Data is transferred to Host computer after the experiment and then Raw data file is taken from it and then the even and odd simulation signals are obtained as shown in figure 7 are plotted using MATLAB. The expected voltage levels are obtained in the data series.

Table2. Parameter values of the experiment conducted during simulation test of phase switch with digital receiver

FIELD	VALUE
Number of range bins	30
Number of time series data points in a frame	512
Number of coherent integrations to improve SNR	128
Time period between two pulses (μ sec.)	250
Pulse width (μ sec.)	4
Year of data record	2015
Month	9
Day	16
Hour	14
Min	2
Sec	56

All the Sum data point are having similar value, with a little variation due to the presence of noise of 5 % amplitude. This can be removed. The data series in figure 7 in blue color corresponds to SUM data and in red color corresponds to DIFFFERENCE data series.

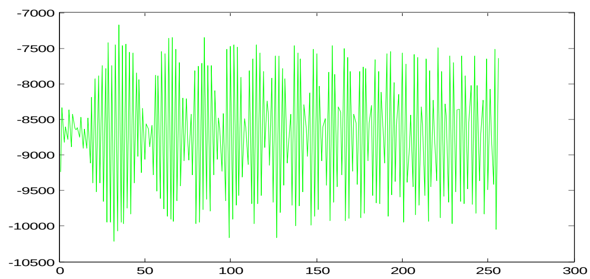

Fig 8: Difference Signal of Even and Odd Parts

Raw data file is taken from computer and, Difference of even and odd signals of Simulate signal is shown in figure 8 using MATLAB. The values in the plot are in milli volt range, which are shown expanded in y axis, the noise variation can be averaged or filtered in further processing.

IV. CONCLUSION

The Phase switched Interferometer hardware along with Digital receiver is tested successfully and satisfactory results are obtained. By using MST radar Coherent Integration End (CIE) signal, pulse to square wave signal is generated using Toggle flip flop circuit to control the phase switch. In this mode, numbers of experiments are conducted and the obtained results matched to expected results.

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BIOGRAPHIES

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