ANALYSIS OF SYSTEM ERRORS IN REAL-TIME PROPAGATION OF SIGNALS IN L – BAND PHASED ARRAY RADAR

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ABSTRACT:
NARL has active array radar which has been designed, developed and tested at 1280 MHz. This system comprises of planar microstrip patch antenna array fed by solid-state transreceiver (TR) modules, two-dimensional (2-D) passive beam forming network (BFN) and direct IF digital receiver (DRx). Errors are the common factors that affect the data. The common errors are Random errors and Systemic errors. In random errors, it is observed that the radiation pattern does not get affected for a peak-to-peak random phase error of up to 60 degrees across the 16x16 array. In systematic errors the radiation pattern is more sensitive to the systematic phase errors across the array. In this paper we have analysed random and system error that affect the radiation pattern both at transmission and receiving system for L-Band Phased array RADAR.

Keywords: Digital Receiver, L-Band Phased Array RADAR, Random Errors, Systemic Errors, Transreceiver.

INTRODUCTION

Propagation of radar signals through the atmosphere is strongly dependent on local meteorological conditions, especially in the atmospheric boundary layer. The wind profiling radar uses naturally occurring fluctuations in the radio refractive index and precipitation as targets. Due to their small aperture, UHF profilers operating around 900-1300 MHz are most suitable for measuring the winds in the boundary layer and lower troposphere regions. Unlike the VHF wind profiling radars, UHF radars are very sensitive for hydrometeors due to the small wavelength. Therefore these profilers are very much useful in studying convection, precipitation etc. UHF radar is a potential tool to carry out research studies such as ABL Dynamics (Winds, Turbulence structure), Seasonal and Inter-annual variations, Interaction between the ABL and the free troposphere, Precipitating systems, Bright band Characterization, Rain/Cloud drop size distribution etc. It is also useful in the operational Mountain meteorology and civil aviation and identification of Atmospheric ducts.

Several UHF radars are being operated across the globe either as research tools or as a part of wind profiler networks for operational meteorology. Atmospheric radars originally developed in 1970s for the research of mesosphere and stratospheres have been extensively applied to operational use for observations of the troposphere.

NARL has developed 1280 MHz wind profiler (as shown in figure 1) for lower atmospheric research applications. The Power-aperture product of the designed system is about 1.7 x 104 W-m2. The antenna array will have 256 rectangular patch antenna elements arranged in a 16x16 square matrix, with an inter-element spacing of 0.73λ. The radar is designed in such a way that the user will have the flexibility in operating it either in Doppler Beam Swinging (DBS) mode or 3-D imaging mode, utilizing multiple beams (up to eighty one beams).

Each element is fed by a dedicated 10-Watt transmit-receive module (TRM), kept underneath. To avoid complexity, phase shifters are not used in the TRMs. Instead, a modified two-dimensional 16x 16 Butler passive beam-forming networks is used to generate multiple beams in the two-dimensional angular space. The TRMs are connected to the 256 output ports of the Butler matrix. 16 one-dimensional 16-port Butler matrices will be used in one of the principal directions (X-direction). A single 16-port Butler matrix is sufficient to steer the beam along the other principal direction (Y-direction). The Butler matrices will be developed on a low loss dielectric RT/Duroid microwave substrate. RF switches will be used to select the beam.

The Butler feed network provides phase gradients in discrete steps along the two principal directions. 81-fixed usable beams will be available in a 9x9 angular matrix with 5o angular resolution. The beam width of the main lobe is about 4.3o. Beam selection will be done by X- and Y- control words. The side lobe level (SLL) is 13.5 dB due to the uniform excitation distribution. The SLL can be improved in the transmit mode by configuring the array in a circular shape. The power amplifiers will be operated in class-A mode to keep the insertion phase uniform. Gated power supply will be employed to enhance the efficiency. The array can be configured in the transmit mode to suit different scientific experiments.

Figure1. Existing wind profile Radar at NARL

DOPPLER PRINCIPLE

The Doppler Effect, named after Christian Doppler, is the change in frequency and wavelength of a wave as perceived by an observer moving relative to the source of the waves. For waves that propagate in a wave medium, such as sound waves, the velocities of the observer and of the source are relative to the medium in which the waves are transmitted. The total Doppler Effect may therefore result from motion of the source or motion of the observer or motion of the medium. Each of these effects is analyzed separately. For waves which do not require a medium, such as light or gravity in special relativity, only the relative difference in velocity between the observer and the source needs to be considered.

BASIC PRINCIPLE OF WIND PROFILING RADARS

Wind profiling radars depend upon the scattering of electromagnetic energy by minor irregularities in the index of refraction of the air. The index of refraction is a measure of the speed at which electromagnetic waves propagate through a medium. For wind profiling, this medium is the atmosphere. A spatial variation in this index encountered by a propagating electromagnetic (radio wave) causes a minute amount of the energy to be scattered (or dispersed) in all directions. Most of the energy incident on the refractive irregularity propagates through it without being scattered.

In the atmosphere, minor irregularities in the index of refraction exist over a wide range of sizes. In the lower portion of the atmosphere (troposphere and stratosphere), the index of refraction depends on primarily upon the temperature, pressure and humidity of the air. The atmosphere is in a constant state of agitation, which produces irregular, small-scale variations in temperature and moisture over relatively short distances. The wind, as it varies in direction or speed, produces turbulent eddies (small, whirling currents of air). Likewise, irregular heating of the ground by the sun, associated with different surface conditions, provides another mechanism for the formation of eddies. Turbulent eddies are created over a spectrum of sizes ranging from many tens of meters down to centimetres, or even millimetres. Current theory holds that an eddy, once created, is unstable and tends to break up into smaller eddies, and so on. At the smallest sizes, the cascading of energy into smaller eddies ceases and is replaced by dissipation of the energy by viscous heating.

These eddies produce the small and irregular variations in the index of refraction of the air that initiate scattering. As mentioned above, radio frequency electromagnetic pulses propagating through air lose part of their energy to scattering from these refractive irregularities. A small portion of this scattered energy is returned to the radar site, where it can be received and analyzed. Backscattering (scattering of energy toward its point of origination) occurs preferentially from irregularities of a size about one-half the wavelength of the probing radio wave. Since these irregularities are carried by the wind, they prove to be good “tracers” of the mean wind.

The highest altitude from which scattering can be detected depends upon the average power transmitted, the size of the antenna, meteorological conditions, and the frequency (or wavelength). The greater the transmitted power or the larger the antenna, the stronger the returned signal and greater the return signal and greater the height range of detection. Likewise, the more turbulent the atmosphere, the stronger the returned signal and greater the height range of detection. The dependence of scattering upon the wavelength is related to the abundance of scatters of the appropriate size. The smaller “irregularities” (cm size) are abundant only at the lower heights. The higher frequency waves, therefore, aren’t backscattered as effectively at the greater heights, as are those at the lower frequencies.

The lowest heights from which useful echoes are obtained depend upon the electronics of the profiler. The receiver is disconnected from the antenna before the transmission of a pulse, to prevent its circuits being overloaded, and reconnected a short time after the pulse has been transmitted. Because the backscattered energy from the lowest altitude arrives when the receiver is disconnected, the echoes that originate from the portion of the atmosphere adjacent to the ground are not measured. Pulse length and system recovery time determine the lowest measurable height.

Echoes are received from all heights within the range of operation of the profiler. The received signal is spread out in time, with echoes from the lower heights arriving before those from the greater heights. Echoes from equally-spaced heights are obtained by measuring (sampling) the returned signal at equally-spaced times; this is referred to as range gating. Because the transmitted pulse has a finite length, at any instant the received signal is coming from a volume of the atmosphere (spread of ranges), rather than a single height (single range). This spread is called the resolution and is equal to one-half the pulse length. Normally, the sampling interval used in range gating is set equal to the resolution to assure that the sample points are independent of each other.

The transmitted radio energy is not only confined to a certain pulse length, it is also concentrated into a beam. The angular width of the beam depends upon both the effective area of the antenna and the operating frequency of the profiler. Since the beam needs to be narrow, either a large antenna or a relatively high operating frequency is required. For the best results, the angular beam width should be 5^0 or less.

SYSTEM DESCRIPTION

The system will be state-of-the-art in its class of wind profiling radars. The system, basically aimed to serve the research applications, will have flexibility in configuration and facilitate multi-mode operations as shown in figure 2. It consists of the following major subsystems

1. Control and Signal Generation System
2. Butler Beam Feed Network
3. Transmit-Receive (TR) Modules
4. Antenna array
5. Receiver System
6. Data Analysis

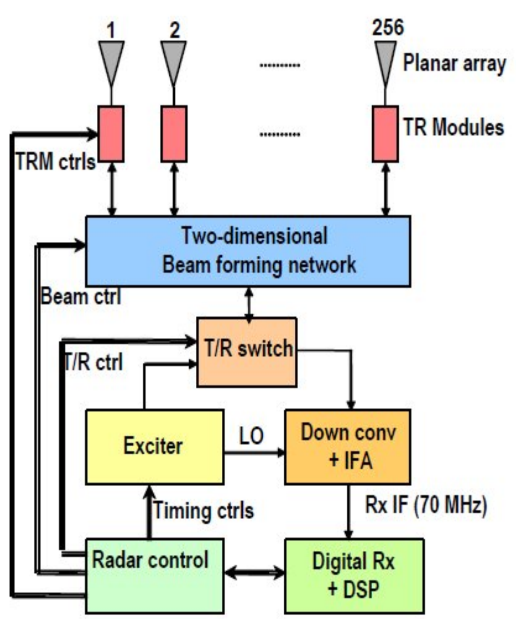

Figure 2. Block diagram of the UHF Wind Profiling Radar

Specifications

Frequency	1280 MHz
WP Technique	Doppler Beam Swinging
Antenna	Active Patch Array (2.8m x 2.8m) 4.5 deg beam width
Tx/Rx type Peak power Pulse width	Solid-state TR Modules (256) 2.0 kW 0.25 - 8 micro sec
Feed Type	Passive 2D Beam Forming Network
Receiver	Super heterodyne Direct IF Digital Receiver
R min R max	100 m 3 - 6 km (in clear air) 12 km (during precipitation)

The brief description of each block of the above subsystems is given below

1. CONTROL AND SIGNAL GENERATION SYSTEM

The master controller, which is PC-based one, facilitates the user to set the experimental parameters such as pulse width, IPP, number of coherent integrations, range window etc. It controls the signal generation system and Digital receiver directly as they are located at the same place.

A rubidium oscillator provides the free running high stable 10 MHz reference signal. The FPGA-based sync generator, controlled by the master radar controller, provides the required IPP (inter-pulse-period) marker pulse. The 10 MHz reference signal is distributed to all other subsystems as clock/reference input.

The IPP marker is also fed to the FPGA-based timing control signal generator, which generates the Tx pulse, Blanking pulse, transmit/receive pulse, Tx on/off pulse, beam selector switch control signals. All these signals are sent to the remote driver unit located beneath the antenna array, where they are conditioned and distributed before reaching the target subsystems. The 10MHz REF signal is also sent to the out-door unit located near the array, where it is used as reference to generate the LO (1210 MHz) and RF (1280 MHz) signals. The LO signal is fed to the down converter whereas the RF signal is pulse modulated and sent to the antenna feeder. The receive RF and TX RF signals are separated by a T/R switch.

2. TWO DIMENSIONAL BUTLER FEED NETWORK

The Butler feed matrix serves two purposes. It distributes the input Tx RF Pulse to all TRM and also provides the progressive phase shift at the output ports, needed for beam tilting. The feed matrix is two-dimensional having 256 output ports. The Tx RF and Rx RF are switched between the input ports by the beam selector switches. Each input port of the Butler network corresponds to a particular beam direction.

3. TRANSMIT-RECEIVE MODULES (TRMs)

The system employs 256 TRMs. Each TRM consists of i) T/R switch at the input, ii) Transmit section, iii) Front end Rx section, and iv) Circulator and dual directional coupler at the output. The TRMs are connected to the antenna element on one side and Butler beam-forming network on the other side. The transmit chain consists of an RF on/off switch, a driver amplifier and power amplifier. The front-end section consists of a limiter, blanking switch, and LNA.

4. ANTENNA ARRAY

The antenna array under consideration consists of 256 micro strip patch antennas arranged in a 16x16 square matrix. The beam width is 4.5 deg and the SLL is about 13.5 dB. The inter-element spacing is 0.7 λ, which allows a grating lobe-free scanning up to 20 deg.

5. RECEIVER SYSTEM

The received signal from the feeder network is given to the receiver system which consists of an RF down converter, IF amplifier chain and digital receiver. The IF chain consists of amplifiers, various switches, programmable attenuator and BPF. The digital receiver consists of an ADC card, and FPGA-based digital down converter, FIR filter, decoder and integrator. Digital receiver is connected to the PC by means of an Ethernet switch.

6. DATA ANALYSIS

The raw data received from the receiver is first subjected to DC removal. Processing involves FFT computation, estimation of mean Doppler, Doppler width, echo power and noise level for each beam direction. The three components of the wind vector are derived from the mean Doppler obtained from all the beam directions through a least mean square technique. The physical parameters are stored in an archival PC networked with the on-line analysis PC.

ANALYSIS OF SIGNALS – SYSTEM ERRORS:

Signal when passing through the electronics components of the RADAR system some position of the main beam and side beam are disturbed. Due to this noise is going to be added to the original signal as shown in figure 3 to 7.

In this paper we are going to send 0dB original signal, but be get 0.312dB error signal in transmitting. In the receiving also get 0.298 dB error signal.

RESULTS:

Effect of random errors in radar signal

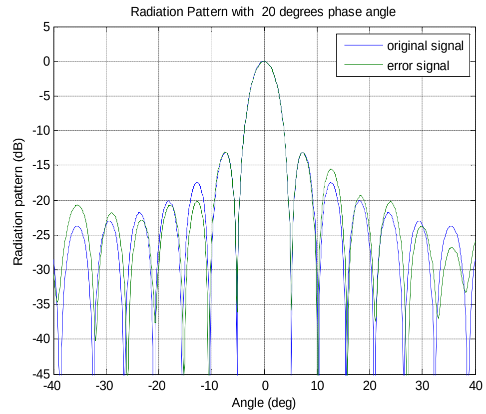

Figure 3: Effect of random error with 20^0 phase angle

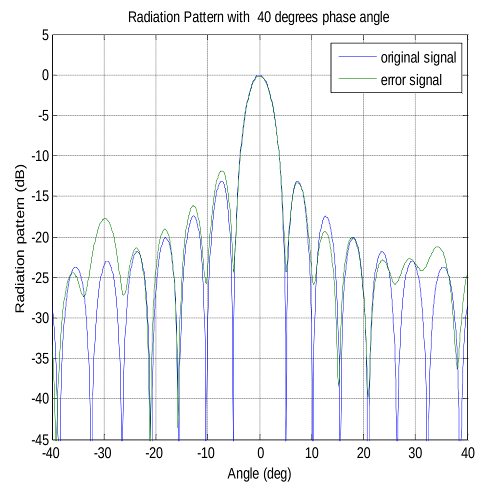

Figure 4: Effect of random error with 40^0 phase angle

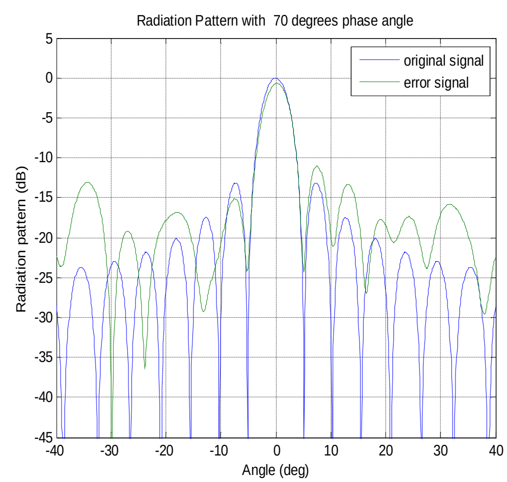

Figure 5: Effect of random error with 70^0 phase angle

Effect of system and random errors in radar signal

Expected Radiation Pattern for Transmitting and Receiving signals for z beam

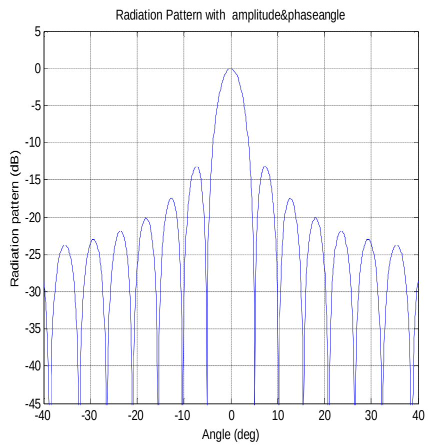

Figure 6: Original Transmitting Signal

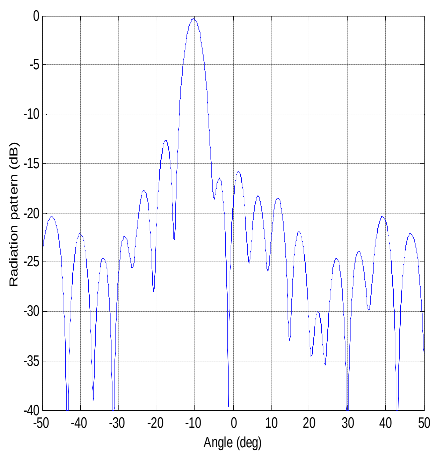

Figure 7: Original Receiving Signal

CONCLUSION

This paper is mainly intended for analysis of system errors in the radiation pattern of a 16 x 16 butler array used for UHF wind profiling radar applications.

This paper can be further extended to calculate systematic errors that effect the radiation pattern during transmission and receiving.

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