Frequency Modulated Continuous Wave (FMCW) Radar

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Abstract
A bistatic radar for monitoring the winds and atmospheric refractive index structure constant up to boundary layer (up to 2 - 3Km height) has been proposed. This radar utilizes FM-CW techniques to provide high resolution data at a fraction of the cost as compared to pulsed radars. Details of this radar are presented along with the waveform synthesis.

Keywords—FMCW, gust, boundary layer

I. Introduction

The Atmospheric Boundary Layer (ABL) is the lowest part of the atmosphere, where the Earth's surface directly influences atmospheric processes. The structure and dynamics of the ABL are of vital importance for the understanding of weather and climate, the dispersion of pollutants, the exchange of heat, water vapour and momentum with the underlying surface.

Ordinary pulsed radar detects the range to a target by emitting a short pulse and observing the time of flight of the target echo. This requires the radar to have high instantaneous transmit power and often results in a radar with a large, expensive physical apparatus. Frequency modulated continuous wave (FMCW) radars achieve similar results using much smaller instantaneous transmit powers and physical size by continuously emitting signals whose frequency content varies with time.

It is proposed to have FMCW atmospheric radar with simple and low cost system for the following research areas

- ❖ To study Boundary Layer structure and dynamics
- ❖ Study of Gust winds
- ❖ Long term observations of refractive index structure constant (C_n^2)

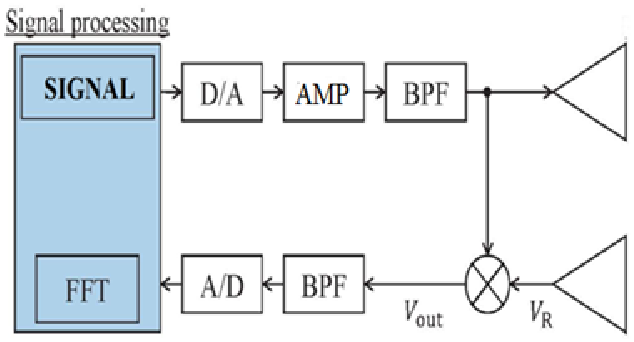

Fig. 1 Block Diagram of FMCW radar

Figure 1 shows the simple block diagram of FMCW radar which is bistatic radar consisting of two antennas one for transmission and the other for reception and the subsystems description is done in the following sections.

II. UNIQUE ADVANTAGES OF FMCW RADAR

- ➢ Very high range resolution making excellent capability to distinguish close together targets and detection of small objects in heavy sea clutter
- ➢ Pulsed mode radars have a limitation on minimum height coverage based on pulse width and FMCW radar (theoretically) does not have any limitation on minimum height coverage.
- ➢ Time resolution wise also it gives the best time resolution of the order of seconds as compared to pulsed radars
- ➢ Fully solid-state transmitter design (due to the low radiated power) ensures excellent Mean Time Between Failures (MTBF) and practical without service continuous operation (lack of magnetrons, microwave tubes, high voltages, etc.)

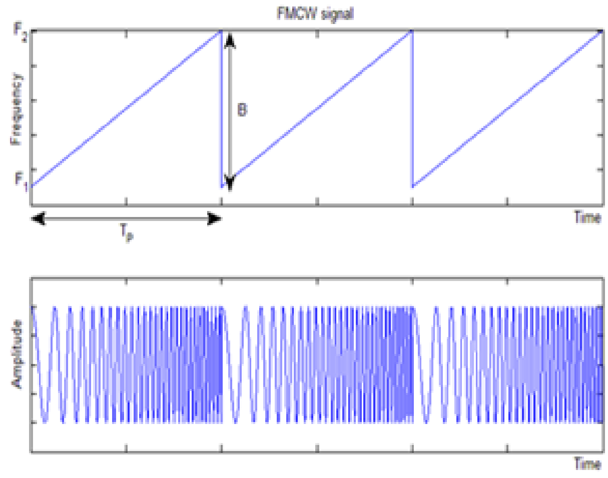

Fig. 2 FMCW waveform

1 Challenges

- Related to transmitting and receiving simultaneously as the transmitted power can be more than 100dB higher than the received echo, so if even a small fraction of the transmitted power leaks into the receiver it can saturate or even damage the sensitive circuitry.
- The accuracy of the range measurement depends on the FM sweep linearity. Any nonlinearity of the FM signal will cause the calculated range of the target to be ambiguous.

II. SPECIFICATIONS OF SYSTEM

The proposed system specifications are as below

Centre frequency : 1.48 GHz

Bandwidth : 25MHz

Transmit power : 250W

Transmitter type : SSPA

Sweep time : 2.5ms (400Hz)

Noise figure : 3dB

Maximum unambiguous

Velocity : 23 ms^{-1}

Range resolution : 6m

Height coverage : 3km

Antenna size : 2m X 2m (patch array)

Antenna beam width: 5deg

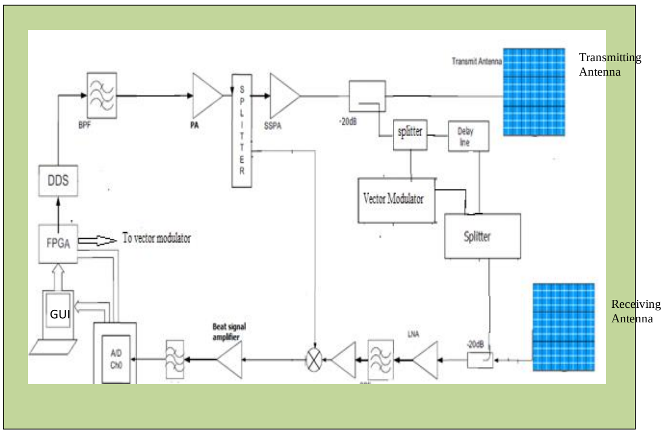

Fig. 3 Block Diagram of FMCW radar – DBS mode

Figure 3 shows the block diagram of the proposed radar in which the *Radar Controller* consists of GUI and FPGA, *Exciter and transmitter* consists of DDS, BPF and power amplifiers, *Receiver* part consists of LNA, mixer, Beat signal amplifier and band pass filter, *Calibration loop* consist of delay line and splitters and *signal processing* consists of A/D and host pc for processing.

IV. SUBSYSTEMS DESCRIPTION

1 Radar controller

The radar controller (RC) allows the user to set the experimental parameters and control the subsystems of the radar. It will have GUI software to allow the user to set the experimental parameters. The FPGA, which is a part of RC generates all the radar signals required for the proper operation of the radar. It uses a reference clock at 10MHz. The design is characterized by the generation of all signals in total synchronization. The operator stores the necessary parameters to configure the radar in a file which will be sent via serial interface to the FPGA. That file and its parameters can be modified at any time, making the radar flexible to operate in different contexts.

2 Exciter and transmitter

The transmitted chirp is generated by a 12-bit Digital Signal Synthesizer from Analog Devices (AD9914 DDS). The DDS receives the needed parameters for frequency sweep generation from the FPGA. The undesired mixing products are filtered and the signal is amplified. A 2-way splitter splits the transmitted signal to the LO input of the receiver mixer and to the RF high power Solid State Power Amplifier (SSPA). The high power amplifier is a linear power solid state RF amplifier providing a 250W (54 dBm) output. A 20dB directional coupler delivers the output of the amplifier to the antenna and couples part of it to the calibration loop.

3 Receiver

The receiver chain consists of a single channel for DBS (Doppler Bean Swinging) technique to retrieve horizontal winds. To ensure a good noise figure, the first component in the receiver is a low noise amplifier. The next components in the chain are a band pass filter and an amplifier.

The output of the amplifier is passed on to the RF port of the mixer in which the return signal is mixed with an attenuated copy of the transmitted signal. The beat signal at the mixer output is fed into module designed with low noise components. This consists of amplifier and band pass filter and this base band signal is digitalized by a Analog-Digital Converter (ADC) and stored on a local computer for further processing.

4 Calibration loop and Vector modulator

The calibration signal is coupled to the received signal in the front end through a 20dB coupler. The radar implements an internal calibration loop by injecting into the receiver an attenuated and delayed sample of the high power amplifier output via a surface acoustic wave (SAW) delay line. This produces a continuous echo at an apparent range (for example 1500 m corresponding to 10 ms delay), permitting radar system monitoring.

In continuous-wave radar as the transmitter and receiver operate simultaneously, the leaking power from transmitting antenna to receiving antenna may affect the operation of the radar. This leakage signal will be cancelled by using a vector modulator.

5 Signal Processing

The signal processing involves converting the signal in to digital format and further processing for retrieval of the winds based on DBS technique. In this method the beam of the antenna is switched in three or five non-coplanar directions. The typical beam configuration is shown in below figure 4. The Doppler obtained in all beam directions are averaged to compute the three components of the winds viz. Zonal (u), meridional (v) and vertical (w).

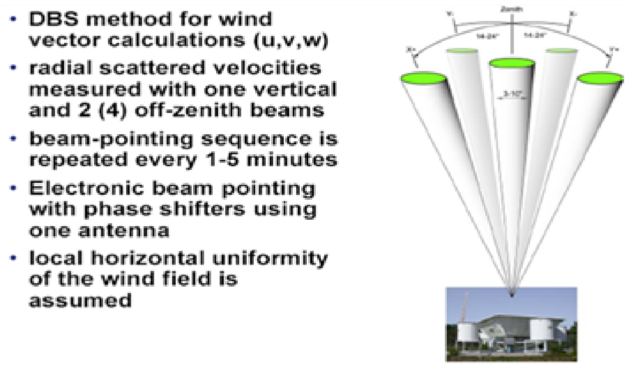

Fig. 4 Typical beam directions used in DBS

V. WAVEFORM SYNTHESIS

The FMCW waveform is synthesized using Signal generator (Agilent N5182 A), Waveform generator (Keysight 33600A) and the oscilloscope (Keysight DSOX2024A) with the test setup as per below diagram and snapshot (Fig. 5)

The synthesized FMCW waveform with out and with frequency modulation is as shown in Fig. 6

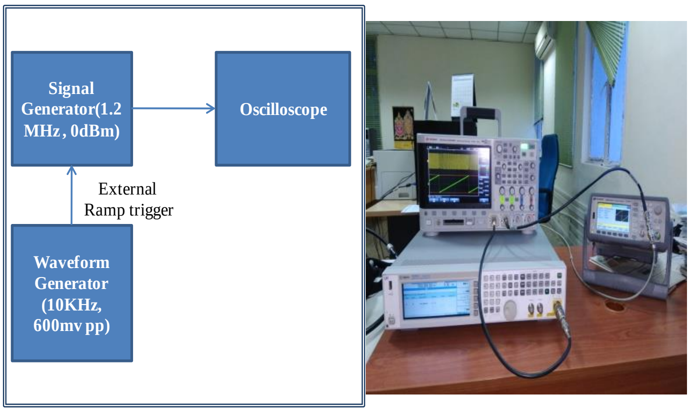

Fig. 5 Waveform synthesis test setup

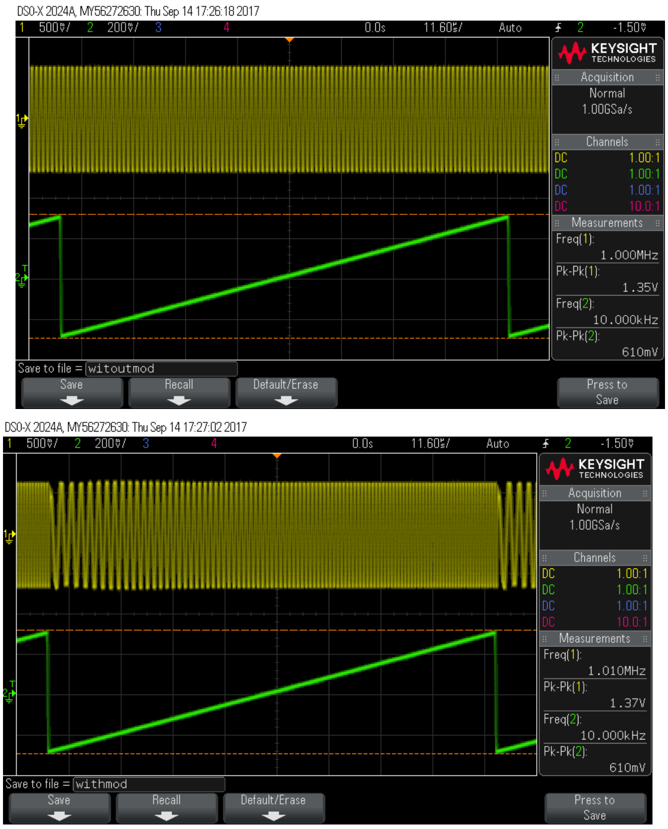

Fig.6 Synthesized Waveforms of CW signal without (top) and with (bottom) FM modulation

In this, the carrier signal is at 1.2MHz and the saw tooth modulating signal is at 10 KHz which is a scaled version of the specifications considered.

VI. CONCLUSION

As the boundary layer is examined at higher spacial and temporal resolution by advanced state of the art radars, more unsuspected fine structure is revealed and these radars with their fine resolution can also be used as surveillance radars for air traffic. The characteristics of this new FMCW radar (low peak power, low probability of interception, low interference to other systems ,high resolution, ultra sensitivity, accurate calibration, and sensing near the ground) are crucial for modern experimental programs in the ABL (Atmospheric boundary layer).

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