X Band Doppler Radar

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Abstract- Like most radars, Doppler radar detects an object by sending out a series of pulses of electromagnetic radiation in the radio or microwave region of the spectrum. In this research, Doppler radar is used to find out the time period of a moving pendulum for different lengths, to measure the rotation rate in rpm, to determine the Doppler frequency of moving object and to know the less vibration measurement. This radar contains parabolic reflector and Monolithic Microwave ICs (MMICs) transceiver. Observation and measurements are taken from zelscope software. This software extracts the information of amplitude, time, frequency, FFT etc and this information can be used to device various configurations of the radar.

Index Terms- Doppler frequency, pendulum, radar, zelscope

I. INTRODUCTION

Doppler effect is a shift in the frequency of a wave caused by the relative motion of the transmitting source, the reflecting object or the receiving system. If the energy source and the reflecting object are moving toward each other, the reflected frequency will be higher. If the energy source and the reflecting object are moving away from each other, the reflected frequency will be lower. If an object is moving, its velocity, relative to the radar, can be detected by comparing the transmitter frequency with the echo frequency. The difference frequency called the Doppler frequency (f_d) is related to object velocity. Doppler effect can be described mathematically in the case of Doppler radar by the following equation [1].

f_d = (2u/ lambda) cos (q) (1)

where f_d is the change in frequency, u is the velocity of the relative motion, lambda is the wavelength of the transmitted waves, and q is the angle between the source and the direction of motion.

In this design, the wavelength corresponds to free space wavelength of the 10.525 GHz CW signal generated by the radar.

Since

Speed of light= frequency × wavelength (2)

Hence

3×10^8m/s = 10.525×10^9 × wavelength (3)

Wavelength = 2.85×10^{-2}m (4)

So

$f_d = 2\times u/2.85\times10^{-2}$Hz where u is in m/s (5)

$f_d = 70.17 \times u$ Hz (6)

which means that a relative velocity of 1m/s produces a Doppler shift of 70.17 Hz for a carrier frequency of 10.525 GHz.

II. SYSTEM BLOCK DIAGRAM

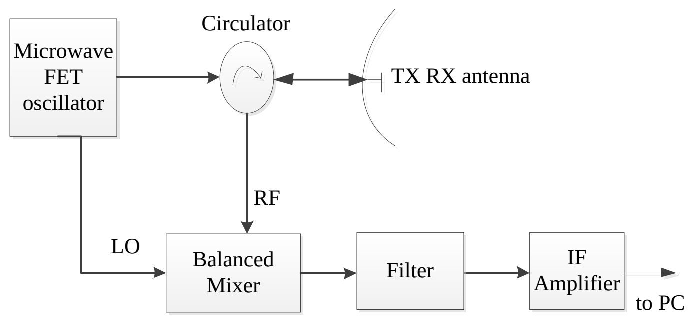

Figure 1: Overall Block Diagram

CW Doppler radar contains a dielectric resonator stabilized microwave FET oscillator, providing a frequency and amplitude stable signal at the operating frequency. The power from this oscillator is filtered to remove harmonic and spurious signals and is then split into two approximately equal amplitude signals. One of these signals is further filtered and feeds the transmit antennas, illuminating the target. The other signal is routed to the local oscillator input of a balanced mixer providing the reference signal against which the Doppler return signal is compared. The Doppler return signal, reflected from the target is collected by the received antennas and coupled to the RF input of the balanced mixer where it is compared with the transmitted signal. The Doppler received signal is extracted and is available at the IF output for signal processing [3].

III. HARDWARE COMPONENTS

Since some of the more complex functions in the generic transceiver block diagram can be fabricated by using MMIC technology, the components that can be realized through the use of this technology can be employed to create system architectures that are difficult if not impossible to design with other, less integrated technologies. The MMIC design approach utilizes active and passive devices that have been manufactured by using a single process. Active and passive circuit elements are formed on a semi-insulating semiconductor substrate, GaAs, through various deposition schemes. The monolithic approach to circuit design inherently offers several advantages [2].

A. Doppler Antenna

An antenna is used to transmit and receive the radio frequency signal, which is 10.525 GHz (X Band) in this system. It is a parabolic reflector located at the front of the feed module, and has a fairly narrow beam width for pointing accuracy. The antenna mount uses adjustable feed point for the best gain of antenna. The focal point of the reflector antenna coincides with the phase center of the feed horn for maximum gain. Antenna gives a gain of around 10dB under optimum conditions.

Circulator is used as a type of duplexer to route signals from the transmitter to the antenna and from the antenna to the receiver, without allowing signals to pass directly from transmitter to receiver [6].

B. Oscillator

The microwave FET based oscillator requires 5V ± 0.25V applied to the +5V terminal of the device. If the oscillator is powered continuously in CW mode, the current consumption is typically 50mA. The peak value of the pulse voltage lays between 4.75 and 5.25 V and the flatter the pulse top the better the detection capability of the Doppler will be. Under these conditions pulse chirp will be less than 1MHz.

C. Balanced Mixer

The mixer in this system compares the frequency of the transmitted signal with the signals reflected back from targets in the coverage area. A portion of the oscillator signal is fed to the LO port of the mixer, and the return signal intercepted by the receive antenna is fed to the RF input. The magnitude of the IF output signal is proportional to the magnitude of the signal received at the RF input, and the frequency is proportional to the relative velocity of the target reflecting the received signal [3].

D. Radio Frequency Module

The Doppler module supplies the transmitted RF signal to the antenna and it also performs a mixing operation on the received signal. Typically three frequencies are in a mixer: the RF, the local oscillator frequency, and the difference frequency. The difference between the LO and RF is the Doppler shift causes and this is the output from the mixer

In CW mode, the total transmitted power is less than 15mW. This power is distributed within the coverage pattern of the unit, and the maximum power density is 1mW/cm^2 at a distance of 5mm from the front face of the radar.

E. Amplifier

Amplifier is used to amplify the signal so that a good magnitude of signal could be achieved on display (either PC or any CRO) for *f*urther analysis of this signal. In this system, Amplifier provides a gain of around 40dB as the signal received from the radar is a few micro volts only.

F. Filter

Filter circuit is used to filter the noise in the Doppler echo signal [2]. It is a low pass filter.

IV. SIGNAL PROCESSING

The processing unit amplifies the baseband signal f_d and filters any DC components. The processor makes use the sound card of the PC for baseband processing. A fast A/D converter converts the incoming analog IF signal to digital signal with an accuracy of 16 bits and a sampling rate of 44100 samples per second.

Zelscope is Windows software that converts your PC into a dual-trace storage oscilloscope and spectrum analyzer. It uses your computer's sound card as analog-to-digital converter, presenting a real-time waveform or spectrum of the signal which can be music, speech, or output from an electronic circuit. Zelscope features the interface of a traditional oscilloscope, with conventional gain, offset, time base, and trigger controls. As a real-time spectrum analyzer, Zelscope can display the amplitude and phase components of the spectrum. Sampling rate is 11 kHz to 44 kHz. Available bandwidth is between 10Hz and 20 kHz. On screen measurement, by setting two cursors left and right, voltage and time difference and direct frequency can be readout. Raw data can export as WAV file [4].

V. TEST AND RESULTS

X band Doppler radar is shown in Fig.2. The feed phase center in this radar is placed at the focus of the parabolic dish for best gain from antenna. The very small wavelength of signal is used for transmission and reception, adjustment becomes very important aspect in order to achieve better sensitivity. To get accurate measurement, target will be in the range of 1m in front of radar in its line of sight.

Figure 2: X band Doppler Radar

A. Determination the velocity of the object

When target is moved slowly from right to left or left to right, corresponding Doppler frequency can be observed and measured on test point f_d. From this frequency we can calculate the velocity of target by using equation (1). In Fig.3, Doppler frequency is 6 kHz and it means that target is moving with the velocity of $9ms^{-1}$ in radial motion. Aspect angle is zero degree and distance is at 1m from the Doppler radar. In Fig.4, the distance of target is decreased and we can see that the signal level increase.

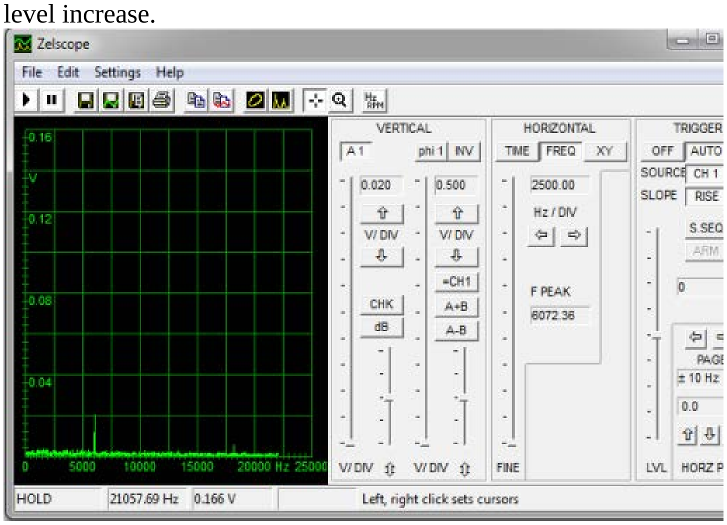

Figure 3: Target Signal Captured by Radar at 1m

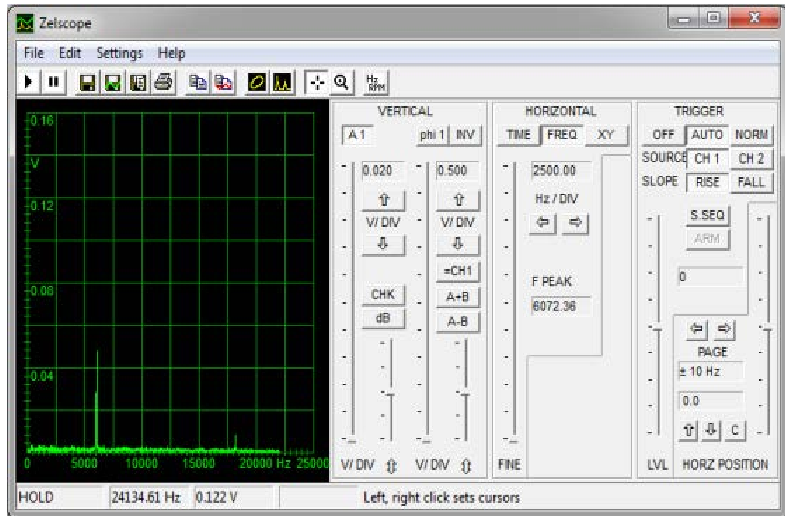

Figure 4: Target Signal Captured by Radar at 0.5m

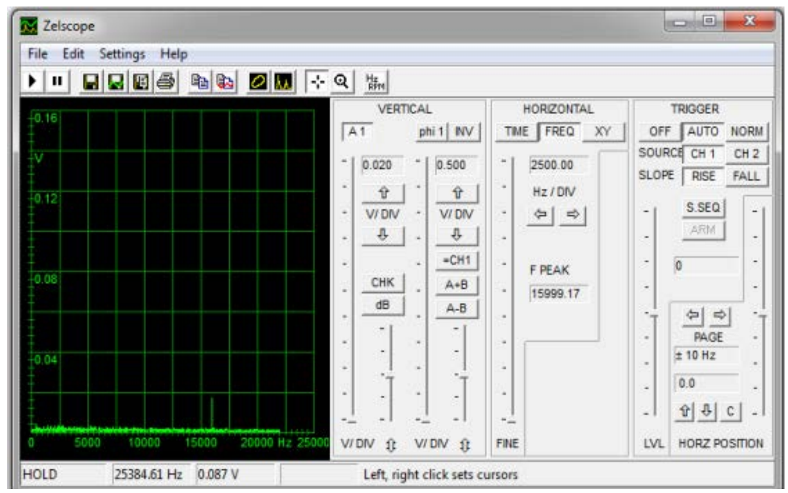

Figure 5: 16 kHz Target Signal Captured by Radar at 1m

B. Time and frequency measurement of moving pendulum

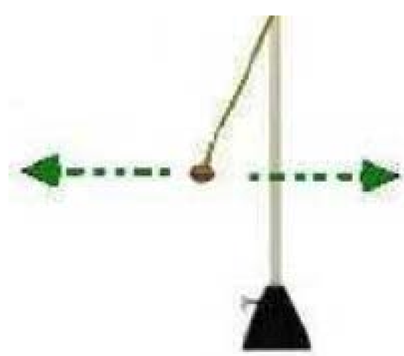

Figure 6: Hanging Pendulum on Stand

Theoretically the time period T of pendulum in Fig.6 is given by

$$T=2\pi\sqrt{l/g} \tag{7}$$

where l is length of pendulum and g is constant $9.8ms^{-2}$.
Time period of pendulum is independent of amplitude of oscillations. When bob of pendulum moves to and fro, it will reflect the incoming microwave signal.

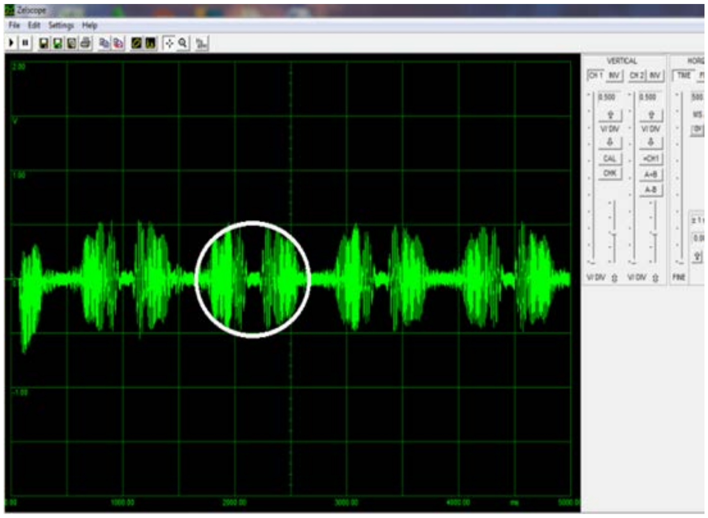

Figure 7: Pendulum Signature Captured by Doppler Radar

In Fig.7, captured signal on display can be observed that when pendulum is moving to and fro then Doppler radar draws the signal twice, so the time period can be measured between any peaks of the signal. Since the radar responds to both to and fro movements the time taken for oscillation is two graticule (1000 ms). The length of pendulum is 25cm. The theoretical time period is 1.0 second. Results can be changed by changing the length. It means radar can detect for very small objects, with the accurate results. Fig.8 shows the time period of 10cm length pendulum.

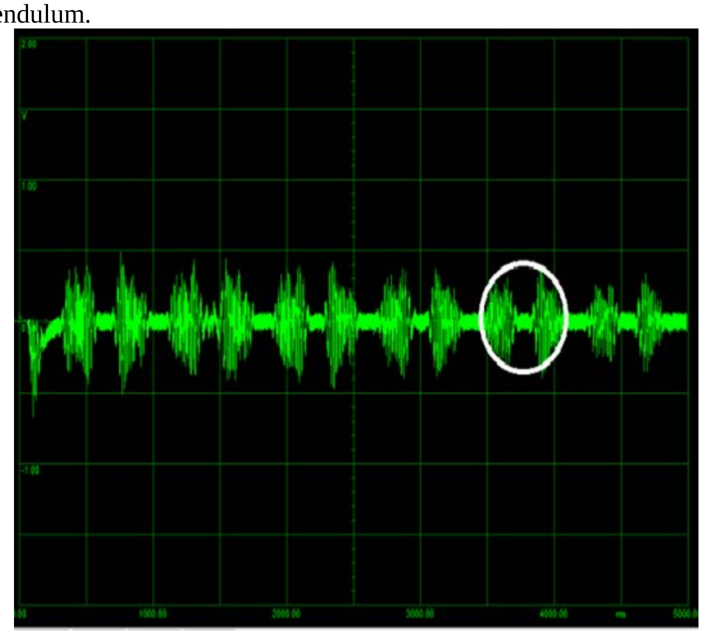

Figure 8: Pendulum Signature for 10 cm in length

C. Detection of vibration of tuning fork

For generating the vibrations, stroke any tuning fork and bring it in front of the radar antenna. The Doppler frequency is generated because of vibrations of tuning fork as approximately frequency written on it.

Figure 9: 256 Hz tuning fork

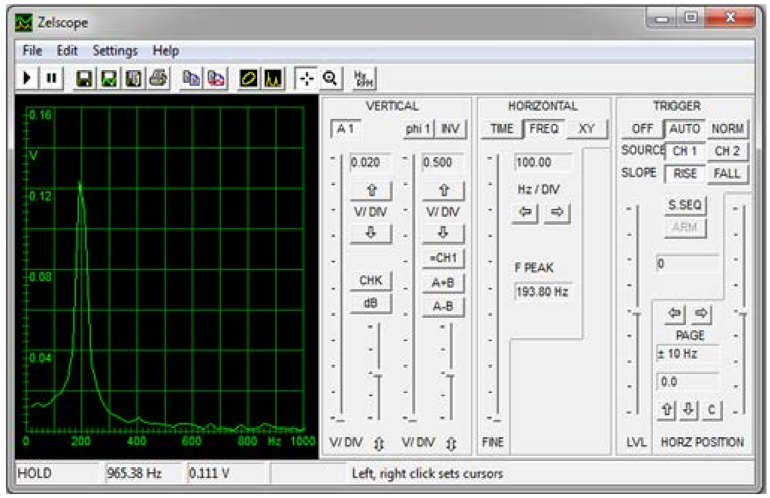

Figure 10: Signal from the Vibrating Tuning Fork

There is a small difference between the frequency of tuning fork and the Doppler frequency on PC due to the manufacturing tolerances. Radar measures the frequency, RPM, velocities accurately. Tuning fork provides the standard frequency source, which can be read off from the PC for calibration.

D. Rotation per minute (RPM) measurement of Fan

A fan at full speed is placed in front of radar at a suitable distance from antenna to get the proper deflection in the form of Doppler frequency.

Figure 11: A Fan for RPM Measurement

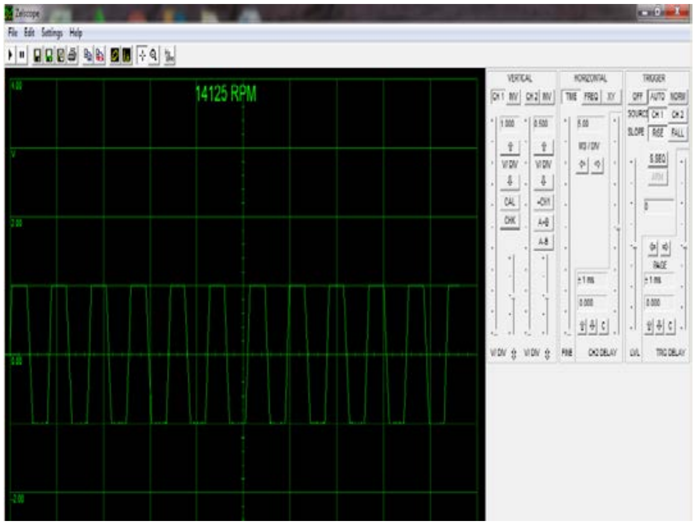

Figure 12: Signal from the Rotating Fan

The rpm of fan is measured as indicated on the radar software. To get the actual speed of fan, count the number of blades and divide the rpm of the fan indicated by software. The CPU fan has very curved blades, which provide adequate radar signature when looked at axially as compared to a ceiling fan.

VI. CONCLUSION

This system is a complete Doppler radar training system for teaching and learning in the laboratory. The CW Doppler Radar can be used to measure the speed of automobiles, shells, guided missiles etc. It can be used to detect movement of troops, vehicles even in dark and in the bad weather. Unlike pulsed radar, CW Radar is able to detect an aircraft in spite of fixed objects. However practical application of CW Radar is limited by the fact that several targets at a given bearing tend to cause confusion. Also range discrimination may be achieved only by very costly circuit complexity. Further it is the maximum power it transmits and this places a limit on its maximum range. Also it is not capable of indicating the range of the target and can show only its velocity. CW Doppler Radar has other advantages like it uses low transmitting power, low power consumption, and small size.

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