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Cost Effective FMCW Radar for Doppler and Ranging

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ABSTRACT

The complexity and high cost factor has restricted the use of Radar technology in daily life common applications, due to which the interest and this field itself is waning out among student community. In this paper we present a simple, cost effective Radar system of FMCW architecture working in 2.4GHz ISM Band. The system is designed as a training module for microwave laboratory. Modes of operation includes Ranging and Doppler measurement. Despite low cost and less circuitry involved than existing systems desirable results are obtained.

Keywords: *FMCW, CW Ranging, Doppler, ISM.*

1. INTRODUCTION

Whether it was World War or natural catastrophes, the Radar technology saved millions of lives. It would not be wrong to say that the surveillance of entire world depends on Radar systems. The value of Radar lies not in being a substitute for eye but in doing what the human eye cannot do. It gives us vision beyond vision. The most fundamental attributes of any Radar system is to either measure the distance of target or velocity i.e. Doppler. Hence importance of Radar systems is indelible. Besides defense related applications Radars are of utmost importance in weather forecasting, mapping and SAR imaging.

Unfortunately due to rather complex nature and costly modules involved in designing a Radar systems this field is primarily confined to military application. While most of the research is done in post graduate level. There is a certain lack of interest developing in students towards pursuing this field and hence this field is slowly waning out in most parts of the world.

In this paper we present a cost- effective 2.4 GHz ISM Band FMCW Radar with minimal circuitry and less cumbersome design, capable of measuring Range and Doppler. Moreover minimal knowledge is required to build this system. Aim is to provide a simple system with basic components to break the cost and complexity dilemma and to introduce students to the field of applied electromagnetics, RF design, signal processing, analog design, and Radar system design.

In contrast to currently available modules, we further lowered the cost of our system while not compromising on the quality of results and to make it accessible used components that are easily available in every market.

The remainder of the paper is organized as follows: In section 2 we explain the overall architecture of our system. Section 3 presents the core of the paper where we design and implement our Radar system part by part. Section 4 presents the results and finally in section 5 we present our conclusions.

2. FMCW ARCHITECTURE OVERVIEW

To allow the detection of targets chosen on the studied image, we processed a supervised classification of the scene based on 32 samples representing four predefined targets (Table 1).

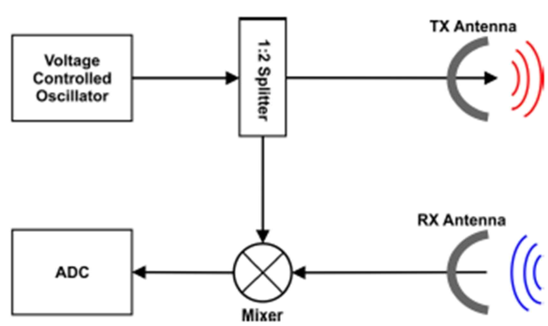

Fig. 1. Basic Block Diagram of FMCW Radar

Out of all Radar architectures CW (Continuous Wave) Radars are the simplest yet the most efficient one. Operating at 100% duty cycle the maximize the use of transmitter power [1]. The most fundamental modes of operation of any Radar systems are: Doppler and Ranging. The CW Radar can measure Doppler but lacks the capability of measuring range.

The inability of CW Radar to measure range is related to the relatively narrow spectrum of its transmitted waveform. Some sort of timing mark must be applied to CW carrier if range is to be measured [2]. This timing mark is the main key and allows recognition of time of transmission and time of return. The distinct the timing mark the accurate will be the ranging measurement. For broadening the CW transmission modulation technique is used in our case it's Frequency Modulation. The timing mark in this case is frequency. The greater the transmitter frequency deviation, the more accurate the measurement of transit time and greater will be the transmitted spectrum. [2]

3. RADAR SYSTEM DESIGN

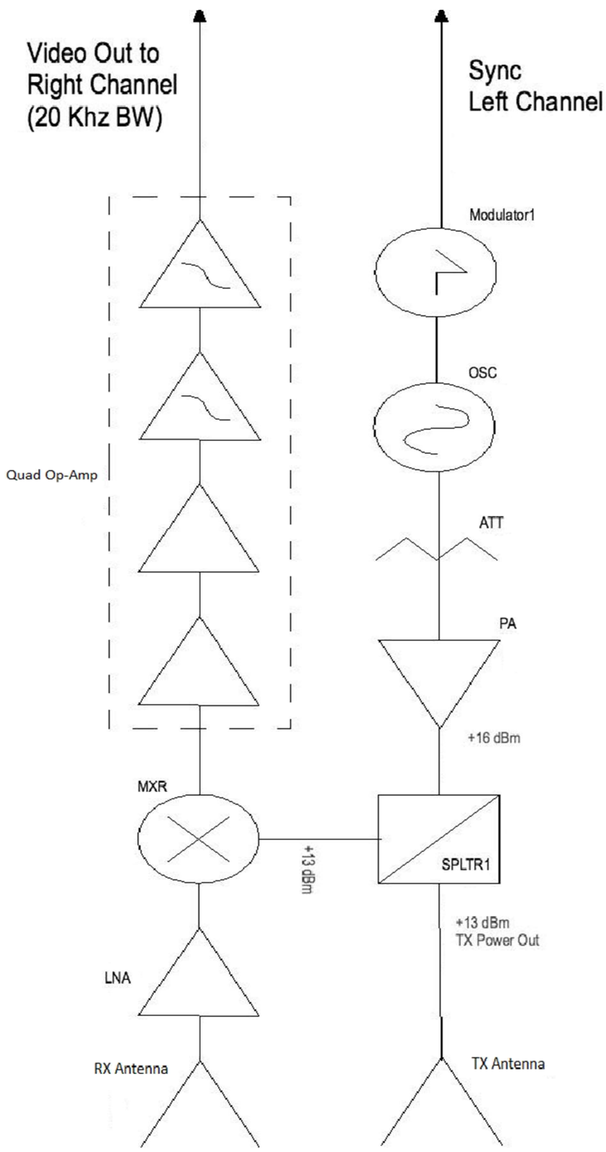

Fig. 2. Block Diagram

A. Antenna Design:

For reducing the cost of our Radar system, we salvaged cans from household and transformed them in to circular waveguide antennas. The gain G(relative to an isotropic radiator) of an antenna aperture of arbitrary shape is given by the following expression:

$$G= 4\pi Ae/\lambda^2$$

where Ae is the antenna effective aperture area and λ is the wavelength. An antenna with circular aperture (diameter D) has a maximum gain value in dBi(relative to isotropic) equal to:

$$G_{m,dBi}= 10 \log10(\pi D/ \lambda)^2$$

Antenna half-power beamwidthis approximately:

$$HPBW = 58°\lambda/ D$$

Wavelength λ of an electromagnetic wave in free space λ= c/ f, where c is the speed of light, f is the frequency TE11 mode cutoff wavelength λc in circular waveguide [λc= c/ fc] λc= 1.705 D, where Dis the diameter of the circular waveguide

Dominant TE11 mode will not propagate below corresponding cutoff frequency [3] .Guide wavelength λg Wavelength is longer in waveguide compared to wavelength in free space:

$$\lambda g= \lambda/ \text{sqrt}(1 –(\lambda/(1.705\ D))\text{^}2)$$

For Diameter = 3.9" (9.9 cm), Frequency = 2.4 GHz. Using the equations explained above following values were obtained [4]

Parameter	Value
Wavelength (free space), λ	4.9" (12.5 cm)
Cutoff Frequency, f_c	1.8 GHz
Guide Wavelength, λ_g	7.3" (18.5 cm)

Using the equations for the free space wavelength, cutoff wavelength, and guide wavelength. it was determined that a 3.9" (9.9 cm) diameter circular waveguide will have a cutoff frequency of 1.8 GHz. Therefore, since 2.4 GHz is greater than 1.8 GHz the can will behave as a good waveguide for electromagnetic waves. For good radiation, the monopole wire antenna inside the coffee can should be approximately one-quarter free-space wavelength long (or 1.2" (3 cm)) and the monopole should be about one-quarter guide-wavelength (or 1.8" (4.6 cm)) spaced from the back wall. The monopole antenna is constructed by extending the center pin (wire) of a standard SMA microwave connector to a length of 1.2" (3 cm)

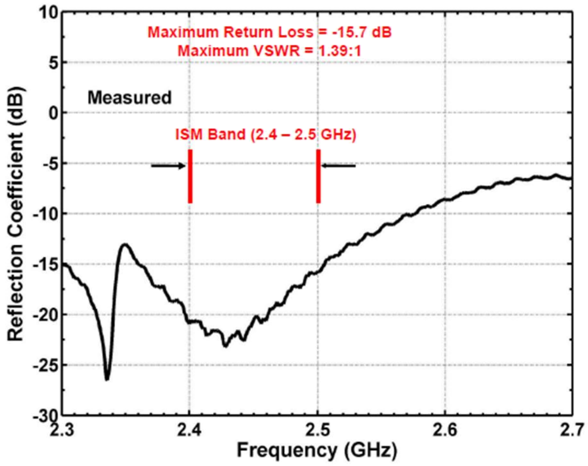

Fig. 3. The reflection coefficient measurement of the designed antenna shows optimal performance over the full ISM band [4]

B. RF System Design:

While designing the RF system, aim was to use connectorized parts which are easy to assemble and require minimal soldering. All components have 50 ohm impedance.

Starting from the voltage controlled oscillator, by applying tuning voltage from 2- 3.2Volts frequencies are generated within ISM band having bandwidth of 80MHz and RF power of 6dBm [5]

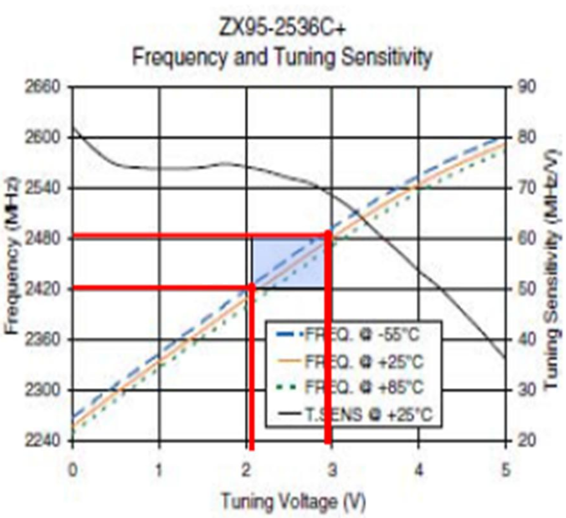

Fig. 4. This data is taken from specification sheet of used VCO.

The 3dB attenuator, attenuates the RF power by 3.3dB. Resultant signal is fed to Low Noise Amplifier having 14 dBm. The splitter splits the signal to half, hence approx. 13dBm is transmitted via transmitter antenna while other half is fed to frequency mixer. Echoed signal when received by the receiver antenna is passed through the low noise amplifier and fed to frequency mixer. Mixer then multiplies the signals and gives the actual phase difference between transmitted signals and received one.

C. 15 KHz Low Pass Filter:

As explained in the previous section, this Radar system operates by recording the received signal via audio input of computer. The recorded file is then processed using MATLAB to acquire Ranging and Doppler results [7]. Hence the output generated by the mixer must be passed through a low pass filter. For this purpose, Quad op-amp is used in single-supply configuration. Gain stage to amplify output of mixer, followed by 15 KHz 4th order LPF which prevents aliasing of PC's input audio port.

D. Signal Processing:

For Doppler vs. Time plot, .wav file is recorded while deploying the Radar towards moving objects. The technique we resolved the recorded .wav file in to 4410 sample blocks and then taking IDFT of each block to get Doppler vs. Time plot.

For Ranging, as explained briefly in section II of paper, modulated CW waveform is used. By Setting up-ramp duration to 20 ms, adjust magnitude to span desired transmit bandwidth .wav file of target is recorded. By Looking for rising edges of sync pulse on Left channel and Saving 20 ms of Right channel data from rising edge, puts into array of de-chirped range profiles. Then by coherently subtracting the last range profile from the current one, displays the log magnitude of the IDFT of the result as a range-time-indicator (RTI) plot [6].

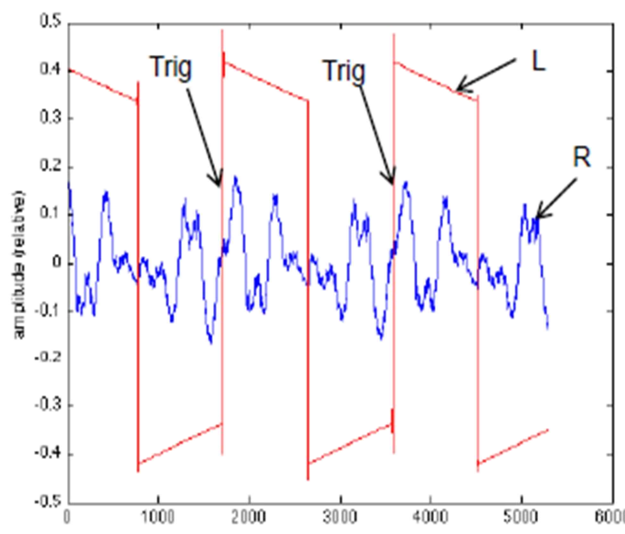

Fig. 4.1. This data shows the result of range-time-indicator (RTI) plot

4. RESULTS

For determining the performance of our designed system we tested our designed module in different environments. For measuring doppler we deployed our system on a side of a road and recorded multiple .wav files. The initial results are encouraging. Our system was able to distinguish between multiple targets speeds effectively. Below is the Doppler vs. Time plot.

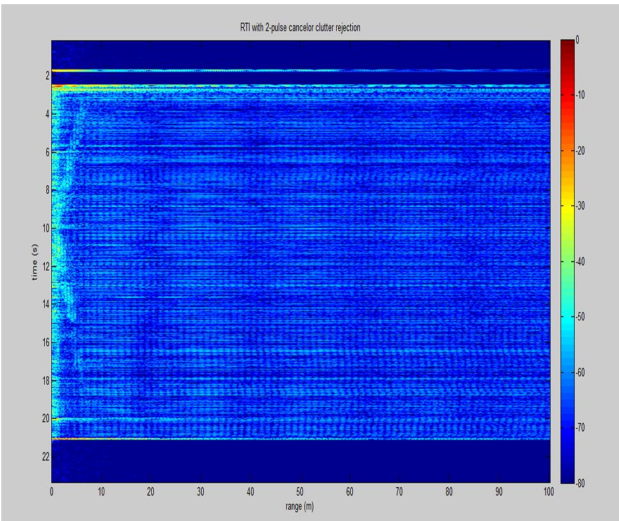

Fig. 5. Doppler vs. Time at Adiala Road

Ranging results were also found to be accurate and system was able to detect the range of targets within 50 meters. Clutter rejection techniques were applied to further improve ranging results.

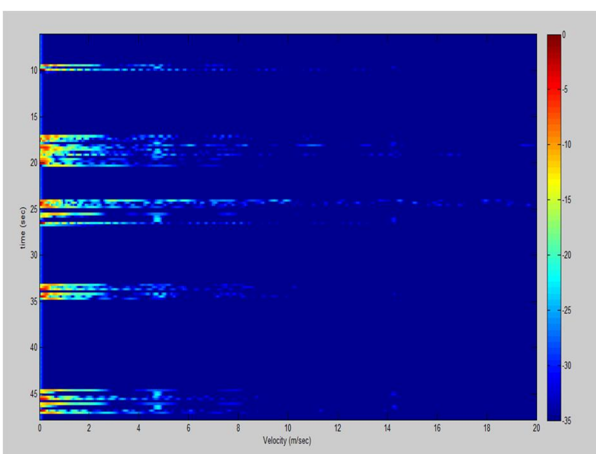

Fig. 6. Ranging vs. Time Walking towards and away from Radar (without clutter rejection)

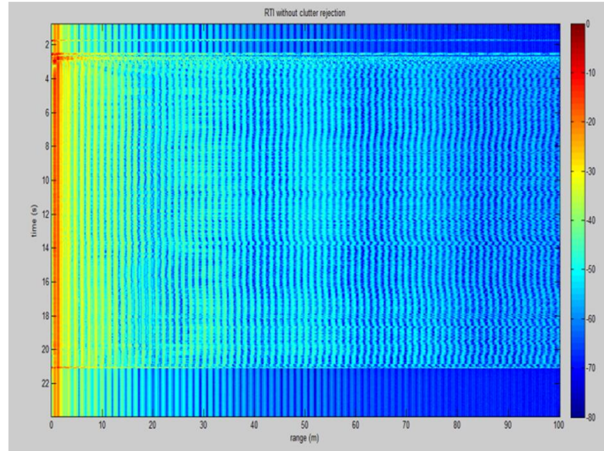

Fig. 7. Ranging vs. Time Walking towards and away from Radar (without clutter rejection)

5. CONCLUSION

In this paper we presented a cost-effective Radar module capable of measuring Range and Doppler for microwave laboratory. Radar operates by recording the received signal via audio input of computer. The recorded file is then processed to acquire Ranging and Doppler results. Aim was to give an efficient yet simple design to increase student community interest in the field of electromagnetics and Radar systems design. Moreover by using our proposed system, performance of various antennas can be tested
Despite low cost and simple design, results obtained are above acceptable level. By making improvements, operating range and results can be further improved and same system can be upgraded to include SAR measurement.

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