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# Experimental Verification of Object Detection using X-Band Radar

Amit Arora
Assoc. Professor, CVR College of Engineering/ECE Department, Hyderabad, India
Email: amit06arora@gmail.com

***Abstract:*** **In this paper, experimental setup for object detection using continuous wave X-band radar (Radio Detection and Ranging) is presented. Detection of object in free space through the radar system at X-band is verified. It is observed that as the size of the object (target) is increased, the received echo will be more such that the received signal strength is high. Furthermore, as the distance between the radar and the target is increased, the received signal strength is low.**

***Index Terms:*** **Detection, EM wave, horn antenna, microwave, radar, X-band**

## I. INTRODUCTION

Radar is an electromagnetic (EM) system equipped with microwave sensor (antenna) for the detection and location of objects present on the ground, in the space, underground and undersea in situations like darkness, haze, fog, rain and snow. The range to the target is calculated from the relation,

$$R = cT_R / 2 \tag{1}$$

where c is the speed of light (3x10$^8$ m/s) and $T_R$ is the time the radar signal takes to travel to the target and back. It is possible to obtain the range of information using continuous wave (CW) radar by modulating the carrier with frequency or phase. Depending on the application several types of radars are available. Long range ground-to-air and air-to-ground missiles employ the bistatic radar, where radar transmitter and receiver are in two separate locations. For better immunity from the interference by large, stationary / slow moving objects continuous wave radar is preferred [1]. To determine the velocity of moving object Doppler radar is utilized.

Monopulse radar is designed such that it compares the incident signal with differently polarized reflected signals and is used for tracking the targets. To find out the probability of rain and atmospheric condition weather, radar is used. It works on Doppler shift to measure the speed of wind and precipitation in clouds. For geographical planning of smart city, dams and roads, mapping-radar is preferred. For avoiding the collision of ships and marine application, navigational-radar is used. Search radar searches if any object is present in its surrounding space. It has the knowledge of all the objects around it [2]. A tracking radar tracks a continuously a particular target and predicts its future position.

After receiving signals from objects, processing is needed to reduce the noise and increase the signal strength so that the signal is properly displayed on the screen. The display is another important part of radar like A-scope, B-scope, C-scope and widely used Plan Position Indicator (PPI) in which distance from the centre indicates a range, angle around the display represents the azimuth angle to the object.

## II. THEORY

A radar system has a transmitter and an antenna that radiated EM in desired directions. When these waves are intercepted by an object (metallic) they are usually reflected or scattered in various directions. The radar waves that are scattered back toward the transmitter (echo) are the desirable ones that make the radar work. Radar receivers are usually, but not always (bistatic), in the same location as that of the transmitter (monostatic) [3]. The weak absorption of radio waves (in the microwave frequency range) by the medium (air/atmosphere) through which it passes is what enables radar to detect objects at relatively long distances.

The maximum distance at which an object can be detected by the radar is,

$$R_{\max} = P_t A_e^2 \sigma / 4\pi\lambda 2S_{\min} \tag{2}$$

where $P_t$ is the transmitter power, $A_e$ is receiver antenna aperture area, σ is radar cross section (size) of the target, λ is the wavelength of the signal and $S_{\min}$ is minimum detectable signal strength (sensitivity) [1].

The determination of the position and motion target size and shape of the target can be done by using different parameters of receiving a signal like echo time, antenna position, Doppler frequency shift, polarization, strength of the received signal etc. [4].

In practical radar applications the echoes are monitored continuously on an electronic display, such as an A-scope or B-scope or PPI [1]. As shown in figure 1, the A-scope, shows the amplitude of the echo versus range to the reflecting object. The B-scope provides a representation of space, with the vertical axis representing range of the reflecting object and the horizontal axis azimuth angle of the object. C-scope displays azimuth vs. elevation of the target. The spot is displayed indicating the direction of the target off the centerline axis of the radar, or more specifically the aircraft or weapon it is attached to. The PPI display provides display of the airspace around a radar site. The distance out from the center of the display indicates range, and the angle around the display is the azimuth to the target [1].

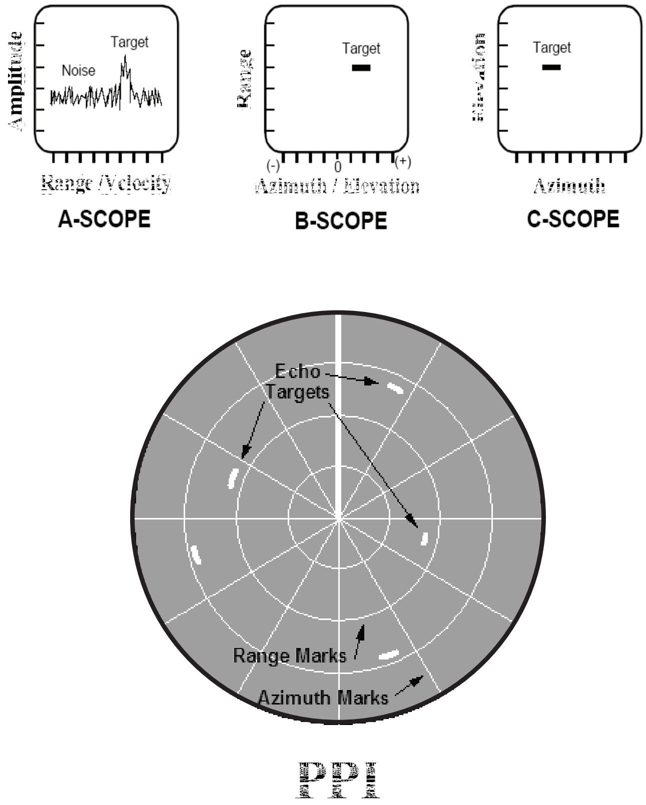

Figure 1. Standard radar displays.

## III. EXPERIMENTAL SET UP

Components used in this experimental setup have high mechanical, electrical standards and tolerances. Waveguides are fabricated by drawing tubes of different cross sections of brass or copper plate with high extrusion quality. The specifications of X-band waveguide, frequency range 8.2-12.4 GHz, width 2.286 cm, height 1.2 cm and tolerance 7.6 µm.

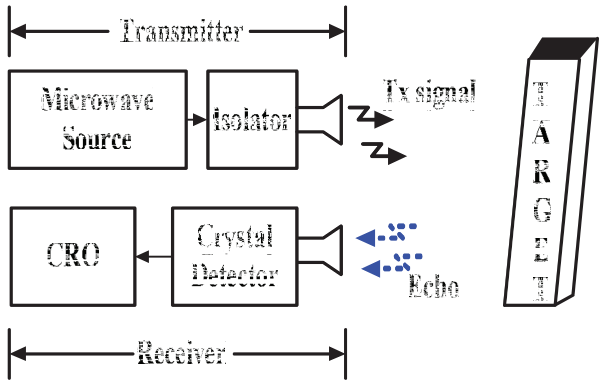

Figure 2. Experimental setup for object detection using cw X-band radar.

Figure 2 shows the block diagram of the experimental setup of X-band cw-radar including target. In the transmitter section main parts are microwave source, isolator and pyramidal horn antenna and in the receiver section pyramidal horn antenna, crystal detector and CRO.

## IV. DESCRIPTION OF EQUIPMENT

### *A. Microwave Source*

Figure 3 shows the image of the reflex klystron tube. The reflex klystron tube oscillator has been used as microwave source. For proper working of microwave tubes, a reliable power source with very high regulation and low ripple contents is used. The klystron power supply also provides all the other d.c. voltages required for operation of the reflex klystron tube such as beam, heater anode and repeller voltages. The klystron power supply has built in modulation facilities of amplitude and frequency modulation.

Figure 3. Reflex Klystron tube.

The klystron tube is a single cavity variable frequency microwave generator of low power and low efficiency. Figure 4 shows the schematic diagram of reflex klystron tube [5]. It consists of an electron gun, a filament surrounded by cathode and a focusing electrode at a cathode potential.

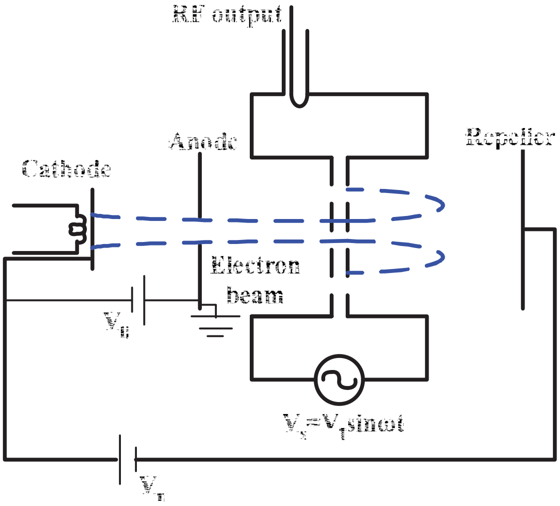

Figure 4. Schematic diagram of Reflex klystron.

Electrons are emitted from the cathode material (by heating the cathode), focused by a focusing electrode, accelerated by applying a positive potential to the accelerated electrode. The electron beam enters the rf cavity, interacts with the rf signal (filtered noise) in the cavity proceeds further into the repeller space, and gets reflected by the repeller electrode, gives away its energy to the anode, and finally gets collected by the anode. A magnetic field of sufficient strength is applied along the length of the tube to avoid the de-bunching of the electrons in the beam. The mechanism of velocity modulation takes place in the reflex klystron tube, and converts the unmodulated dc electron beam into the modulated rf beam.

### *B. Isolator*

As shown in Figure 5, it is a two port device which provides negligible (ideally zero) attenuation for transmission in one direction and maximum (ideally infinity) attenuation for transmission in the other direction. This device is essential to avoid the reflected power from the load to reach the microwave source, thereby avoiding damage to the source.

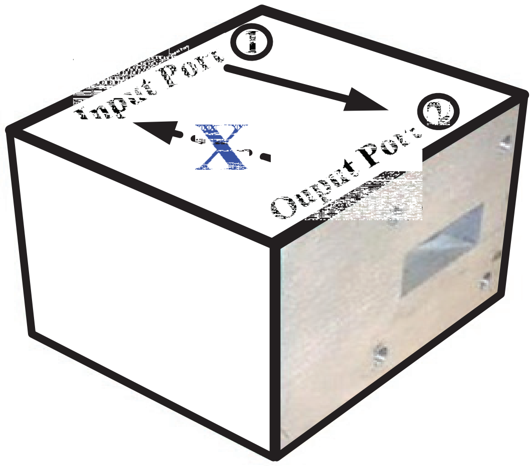

Figure 5. Isolator.

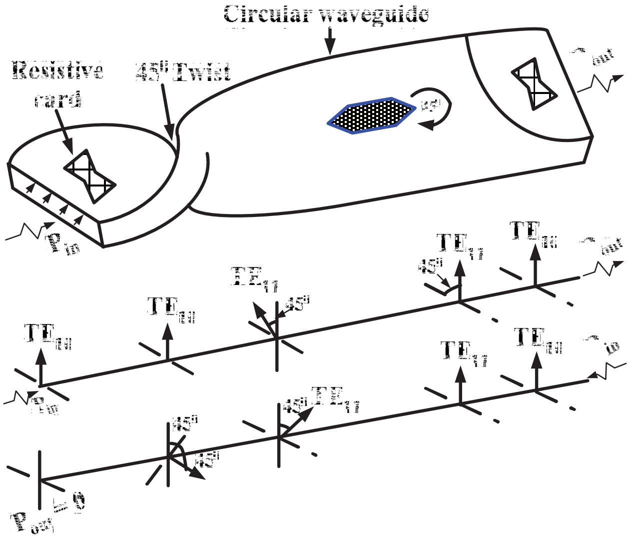

Figure 6. Working principle of Isolator.

Figure 6 depicts the working principle of isolator. An EM wave entering in the input port is perpendicular to the resistive card, hence passes through it unattenuated, but rotated 45° (CCW) due to the twist in the waveguide. As the signal progresses further the ferrite material ($MeO.Fe_2O_3$) along the path rotates the signal 45° CW. This result in cancelling each other's rotating effect, resulting in no change in orientation of the wave. Hence the signal is perpendicular to the resistive card at the output end, therefore unattenuated by it. The EM emerges from the output port without attenuation.

When an EM wave enters from the output port perpendicular to the resistive card, it is unattenuated by the resistive card, but rotated $45^0$ CCW due to the ferrite material present along the path. It is further rotated $45^0$ CCW due to the twist section of the waveguide resulting in a total twist of $90^0$. The signal now becomes oriented parallel to the resistive card and hence completely attenuated by it.

### *C. Pyramidal Horn Antenna*

The pyramidal horn antenna as shown in figure 7 is a combination of the E-plane and H-plane sectoral horns and as such is flared in both directions. Its parameters are,

$$\varphi_e = \tan^{-1} B_1 / 2L_E \tag{3}$$

and
$$\varphi_h = \tan^{-1} A_1 / 2L_H \tag{4}$$

where $B_1$, $L_E$ is horn width and the slant height respectively in E-plane and $A_1$, $L_H$ is horn width slant height respectively in H-plane [6]. For perfect pyramidal horn antenna both angles must be same.

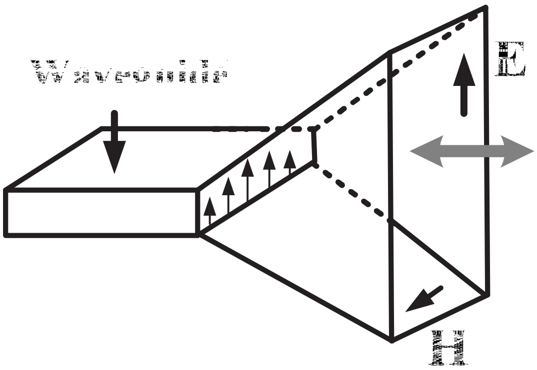

Figure 7. Pyramidal horn antenna.

An opened out waveguide also radiates, but its radiations are poor due to impedance mismatch between the waveguide and its surrounding medium (air/atmosphere). To improve impedance matching between the waveguide and the medium, the waveguide is flared out usually along its breadth and height. This becomes a pyramidal horn antenna. The flaring angle should be proportional to the axial length of the antenna so that the field at different points on the aperture of the horn is approximately in-phase. This is required to improve the directivity of the beam the horn. If the flare angle is small the resulting wave will be spherical instead of a plane wave.

The horn antenna possesses no resonant elements and therefore it is able to operate over a wide bandwidth.

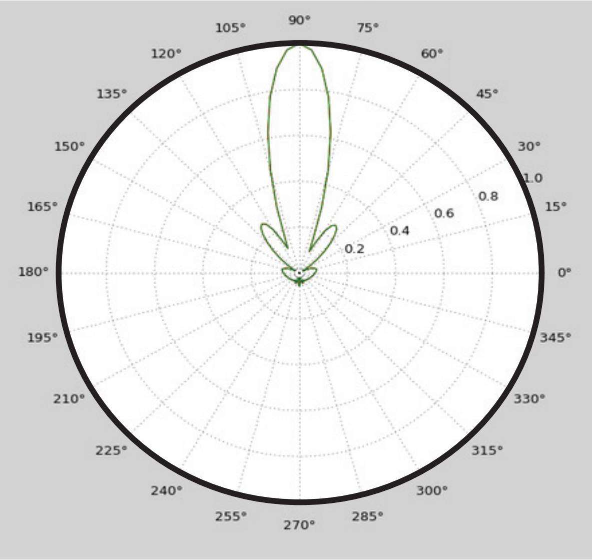

Figure 8. Radiation pattern of the horn antenna.

Figure 8 shows the typical radiation pattern of a horn antenna. It can be seen that it has a narrow beam width with negligible minor lobes. This type of antenna receives echo only from the desired object (target), and does not pick-up echoes from surrounding objects likes walls etc.

### *D. Crystal detector*

Fixed detector (crystal detector) mount is simple and easy to use component for detecting microwave power. It consists of a detector crystal mounted in a section of a waveguide and shorting plunger for matching purposes. The output from the crystal may be fed to an indicating instrument. It is shown in figure 9.

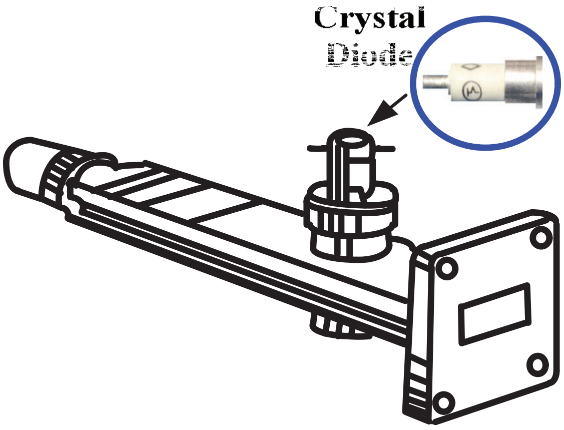

Figure 9. Fixed detector with crystal diode.

### *E. CRO*

The oscilloscope observes the changes in the electrical signals over time, thus the voltage and time describe a shape and it is continuously graphed beside a scale. By seeing the waveform, we can analyze the properties like amplitude, frequency etc.

## V. EXPERIMENTAL PROCEDURE AND RESULTS

Figure 10 shows the photograph of the setup used in the laboratory for carrying out this experiment. In the figure the target is on at the left side mounted on a stand. The radar system is placed on a bench on the right side in the photograph.

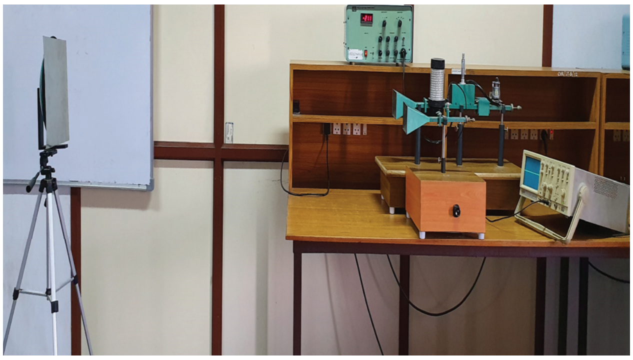

Figure 10. Photograph of experimental setup.

An Aluminum (Al) sheet of size 1ft x 1ft was placed at an initial distance of 1 foot in front of the radar system, and the received echo strength is measured. The distance of the sheet is gradually increased by 1 foot and the corresponding echo strength is measured. Later in the same procedure is repeated for the Al sheet of size 3ft x 3 ft.

TABLE I.
RECEIVED SIGNAL STRENGTH BY (1X1) FT. AND (3X3) FT OBJECT WITH DISTANCE

| S. No. | Distance of object rom radar (feet) | Received voltage from (1*1) feet Al sheet (mV) | Received voltage from (3*3) feet Al sheet (mV) |
|---|---|---|---|
| 1 | 1 | 12.2 | 26.4 |
| 2 | 2 | 8.0 | 25.2 |
| 3 | 3 | 5.6 | 13.4 |
| 4 | 4 | 3.4 | 4.4 |
| 5 | 5 | 2.2 | 3 |
| 6 | 6 | 1.11 | 2.6 |

Table 1 shows received signal strength with respect to distance for different size of Al sheet.

The variation of radar echoes strength as a function of distance is plotted in Figure 11. It can be seen that larger target results in a stronger echo as shown by the top line in the figure.

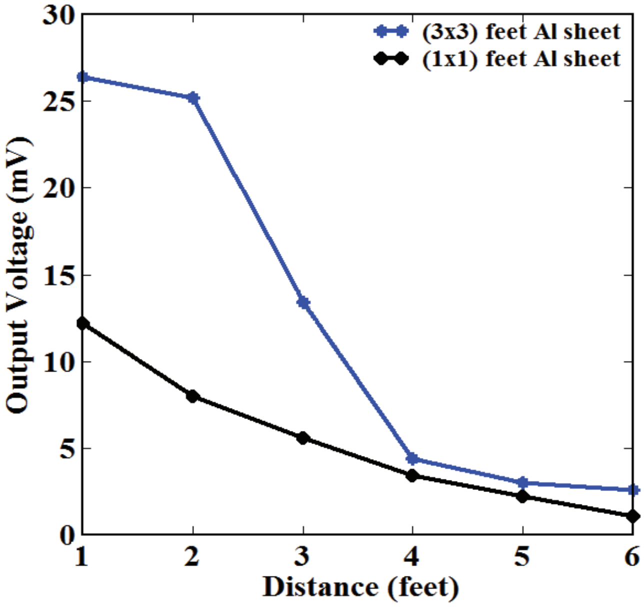

Figure 11. Variation of radar echo as a function of the object, size and distance.

## VI. CONCLUSIONS

Object detection by using X-band cw-radar has been demonstrated. Experimentally it has been observed that the received signal strength is decreasing with increase the distance of a target with radar and also found that for large target aperture received echo is more and vice versa. It is possible to observe echo from the target kept on a rotating platform. With this method we can get the approximate size and shape of the target. By placing transmitter and receiver of radar at different locations, it is possible to observe the target from different directions.

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