X-BAND CW DOPPLER RADAR, AN ANALYSIS AND PRACTICAL EVALUATION

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ABSTRACT

The present paper investigates the possibility of using low power X-Band transmitter system as a low-cost X-Band Continuous Wave doppler radar. Here, the overall system scheme is analysed focusing on the radiofrequency components and related effects of return electromagnetic wave from moving objects. The proposed solution is tested with different targets with different equivalent radar cross section, and the effects of the antenna polarization on target speed detection evaluated.

Keywords: X-Band, CW radar, doppler effect, radiofrequency transmitter

1. INTRODUCTION

Microwave transmitters and receivers are common elements on telecommunications networks known as microwave link. Their primary task is to transfer data (digital or analogic) from one point to another physically distant in space. Radar devices on the other hand, have multiple elements in common with microwave transmitter, starting from the name (RADAR: radio detection and ranging) and up to the elements used for transmitting radiofrequency energy. Radars are used to detect objects, velocities, and from signal elaboration, to enhance target information (Dąbrowski *et al*., 2020). The application range of radar systems are more widely spread respect to microwave links. Those applications arrange from object detections in radar proximity as in autonomous car guidance and collision avoidance systems (Ouaknine *et al*., 2021; Pongthavornkamol *et al*., 2021), up to medical radar used for imagining diagnostic (Aardal *et al*., 2013). For many applications, especially in short range radars, accurate measurement of speed and range are required (Guo *et al*., 2019; Heddallikar *et al*., 2021).

Radar configurations can be suitable for different applications — each requiring enhanced radar capabilities to better fit the particular application, by changing frequency band (Hyun *et al.*, 2017; Tongboonsong *et al.*, 2021), signal modulation type (Hyun *et al.*, 2017; Guo *et al.*, 2019), and receiver bandwidth, etc. Although, the radar configurations are variable, the basic schema is very similar.

The present paper reports about a basic schema starting from an X-band transmitter and converting it into an X-Band Continuous Wave Doppler radar. Consequently, the overall schema and theoretical configuration will be firstly drowned in section 2 and 3. Here, the required mathematical calculations and additional elements over the heterodine transmitters are also described. Section 4 presents measurements obtained with the realized radar for different target conditions. The realized radar will be tested for targets moving forward or approaching the transmitter. Part of the test case is also the interactivity of target based on the transmitted electromagnetic wave polarization as shown on equivalent Radar Cross Section (RCS). On all cases, the doppler frequency is measured and converted into the real target moving velocity. At the end, some conclusions could be drawn.

Microwave transmitter and receiver architecture

Here, a microwave link consisting of one transmitter and the relative receiver as in the Figure 1 depicted is modified to be used as X-band continuous wave doppler radar alike in the Figure. This schematic shows the overall superheterodyne transmitter with baseband, IF and RF components. The overall superheterodyne transmitter (Figure 1), consist of two up-converters, where the second one with a local oscillator set at 8.3GHz is responsible for the X-band signal generation. The operating frequency is 10.7GHz with 27 MHz bandwidth. The horn antenna is connected at the end of a rectangular waveguide model WR-90 with operating in single mode in the frequency band 8.2 – 12.4 GHz. Similar architecture is also for the receiver microwave link. The receiver will not be used in this configuration, but can be set in a future radar implementation as a bistatic radar.

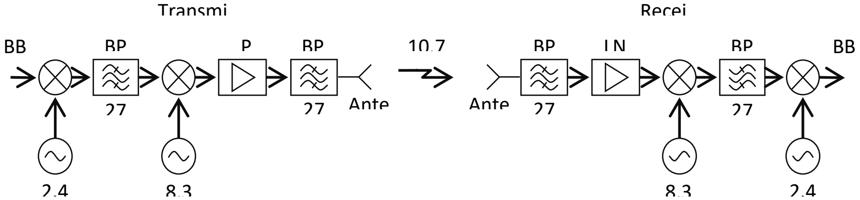


Fig. 1: Schematic of microwave transmitter and receiver architecture.

In normal operation mode, the transmitter antenna has an impedance match with the relative feeding wave guide, band pass filter and relative power amplifier (PA). In real systems, mismatched impedances cause some of the power to be reflected toward the source (like an echo). Reflections cause destructive interference, leading to peaks and valleys in the voltage at various times and distances along the line known as VSWR (Voltage Standing Wave Ratio). To be able to measure the antenna mismatched and eventually any amount of power reflected toward the source, a slotted line is inserted between antenna and final filter (Figure 2). At the slotted line, an RF probe using a gun diode detector, is possible to measure the reflected energy as VSWR. Using the microwave link (transmitter and receiver) as in the Figure 1 reported, no reflected wave could be observed at the antenna input, and 100% of PA energy is fitted to the transmitting antenna.

When a moving or stationary object, that reflects to the transmitter part of the transmitted energy, a variation on the VSWR is observed. The present paper aims to measure these variations, and correlate them to the target moving velocity.

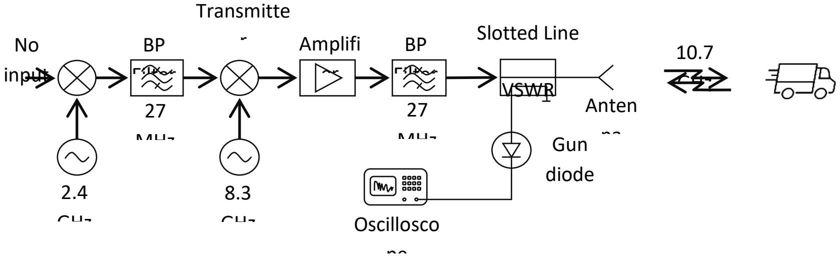


Fig. 2: Modified transmitter to be used as CW X-Band Doppler radar.

The gun diode, used as detector, is a nonlinear component that acts as mixer. Its output is the differences of the two signals reaching the diode, the transmitted one and the reflected one.

If the antenna is perfectly matched, and no obstacles are set on front of the transmitting antenna, there is no standing wave inside the transmitter waveguide as no reflected signal is observed. In this case, no signal is produced at diode output. In case of stationary target, the transmitted and reflected frequency are equal because no frequency variation is introduced by the target. Only a DC (direct current) component could be observed at the diode output. The amplitude of output voltage is proportional to the amount of energy reflected by the target. If the target is moving, toward or forward the transmitter, the reflected signal will have different frequency if referred to the transmitted one, higher frequency if the target is approaching the transmitter or lower frequency in the opposite case.

Doppler effect on VSWR and measurement via mixing diode

Using the modified transmitter (Figure 2), without any input signal, the output X-band signal is only a continuous single tone frequency at 10.7 GHz as by equation (1) with amplitude A_T.

$$S_T = A_T \cos\left(2\pi f \cdot t\right) \tag{1}$$

The time required by the signal to reach the target and reflected back to the source is related by its distance and light velocity in the medium. This way, a portion of the transmitted signal is reflected by the target to the transmitter as by equation (2) (Heddallikar *et al.*, 2021). Where the received amplitude A_R is related by target radar cross section, its relative distance to the transmitter.

$$S_R\left(t\right) = A_R \cos\left(2\pi f \cdot t - \frac{2\pi D}{c}\right) \tag{2}$$

Where D is the distance from the transmitter to the target and related as $D = D_0 \pm v\ (t\text{-}t_0)$ and D_0 is the distance at instant t_0; v is the target moving velocity (supposed constant). The '+' sign in the above expression is related to target moving away from the transmitter and vice versa the '-' sign is for approaching target.

The received signal or echo signal can be written as in equation 3 below:

$$S_R\left(t\right) = A_R \cos\left[2\pi\left(f - f_D\right)\cdot t - \frac{2\cdot 2\pi fD_0}{c} \pm 2\pi f_D \cdot t_0\right] \tag{3}$$

where f_D is the frequency variation caused by the reflected energy by the target motion and expressed in equation (4) (Heddallikar *et al.*, 2021).

$$f_D = \frac{2\cdot f}{c} v \tag{4}$$

From this expression, we can affirm that the frequency variation is proportional to the radial speed of the target, and this is called doppler frequency.

To detect and measure the doppler frequency (f_D), the reflected signal, which have frequency $f_R = f_T \pm f_D$ need to be combined with the transmitted frequency f_T. To be able to obtain only the doppler frequency, a mixer or more general, a nonlinear device needs to be used. In this implementation, a gun diode detector is used which behaves as a mixer of the transmitted signal (f_T) and reflected one (f_R) resulting in an output signal frequency equal to the doppler frequency ($f_D = | f_R - f_T |$).

The Figure 3 depicts a real image of the implemented radar solution.

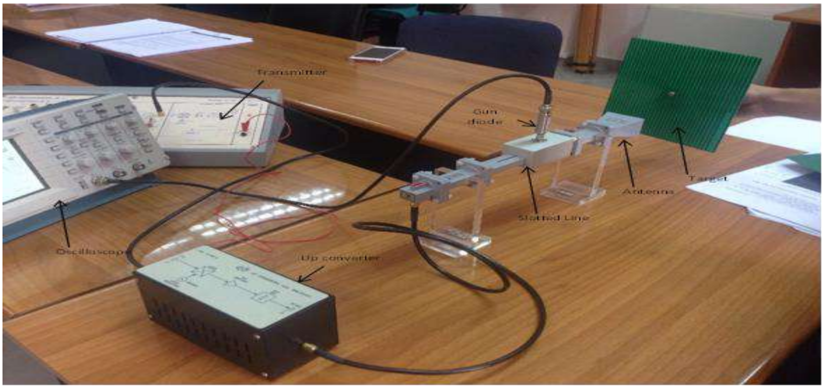
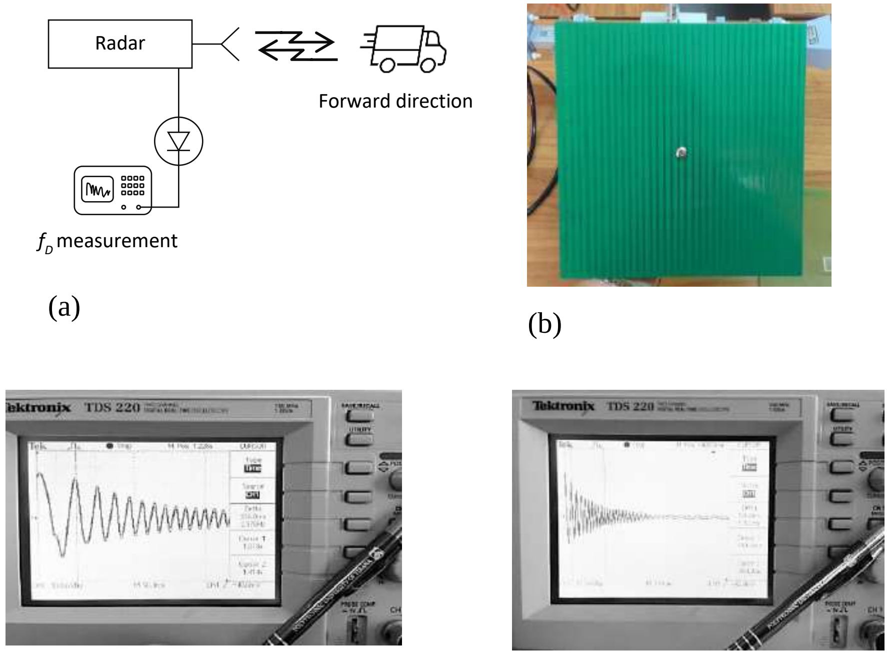


Fig. 3: X-band transmitter used as continuous wave Doppler radar system.

Radar doppler frequency measurement

For laboratory purposes, the overall transmitted power is less than 1W (≤ 30dBm). A polarized reflection plane is used as a target. The plane consists of parallel metallic strips separated by non-metallic ones. Metallic strips periodicity is set as to be less than /10 at 10GHz. This allows the plate to be reflective for one polarization and transparent (partially transparent) for the cross polarization. This configuration will be used also test the configuration for two orthogonal polarizations. In this section, the setup configuration will be used to test the functionality of the radar for target moving away and toward the transmitter, and both cases will be tested on both polarizations. To have a more general approach, different target moving velocities will be applied.

The first test case (Figure 4a) shows the radar configuration setup with target moving forward the transmitter. In this case, the target plate (Figure 4b) is used to be in the opposite polarization respect the antenna used, as to have the maximum reflectivity and enhance the amplitude of the reflected wave. In the next two images (Figure 4c and 4d), the equivalent voltage signal relative to the Doppler effect is shown on the oscilloscope display. From measuring the frequency of the displayed signal, for the first case, a doppler frequency is 2.976 Hz. Using equation (4), target velocity is 4.17 cm/s. For the result shown in figure 4d, the target is moving faster than in figure 4c. In this case, the doppler frequency is 5.102 Hz, and the calculated velocity is 7.14cm/s.



(a) (b)

(c) (d)

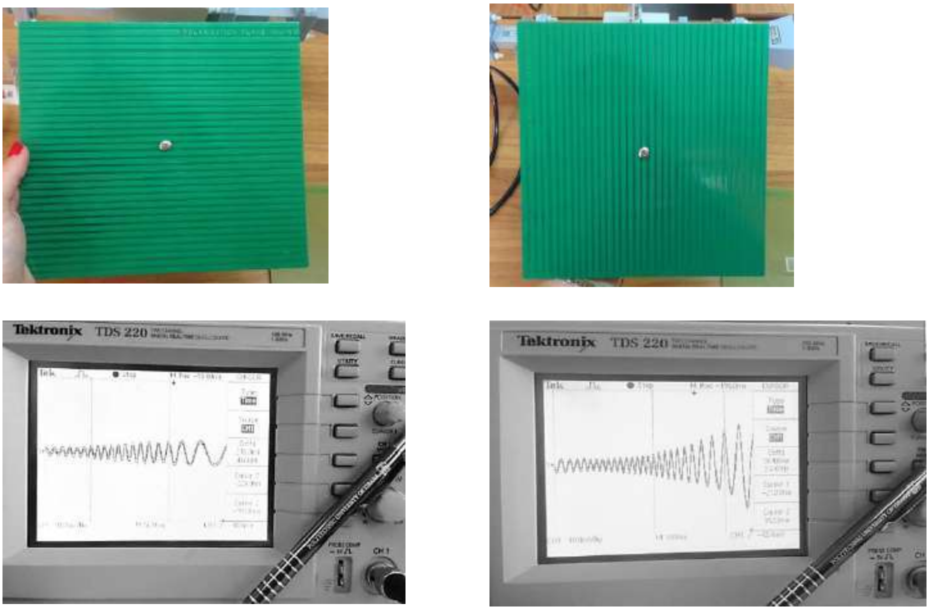
Fig. 4: Measured voltage proportional to reflected wave for different target velocities: (a) schematic of the test analysed; (b) polarized target plate; (c) slow moving target; (d) fast moving target.

Signal amplitude in the moth Figures 4c and 4d are both decreasing, as the target is moving away from the transmitter. Due to the propagation effect, the amplitude of the received signal decreases with increasing the distance of the target. Greater the distance and smaller the received signal.

The same radar setup has been used to measure target velocity for approaching direction. In this case, the radar system is equipped with a standard horn antenna radiating a vertical polarized radiofrequency wave. The target moving toward the radar is the polarized square plate (Figure 5 a and b). The configuration in the Figure 5a has less reflectivity for vertical polarized electromagnetic wave if compared to the configuration in Figure 5b. Consequently, the amplitude of the received doppler signal shown respectively in Figure 5c and 5d, is higher for the second case at the same distance from the radar. The increasing amplitude over the time is indicator of approaching target, if we compare figure 5 with figure 4 above.

In this case, despite the target can be classified with a relative radar cross section (RCS), the mutual interactivity of the transmitted radar wave and the target is also related to the polarization of radio frequency wave used, and consequently, the amount of reflected energy.

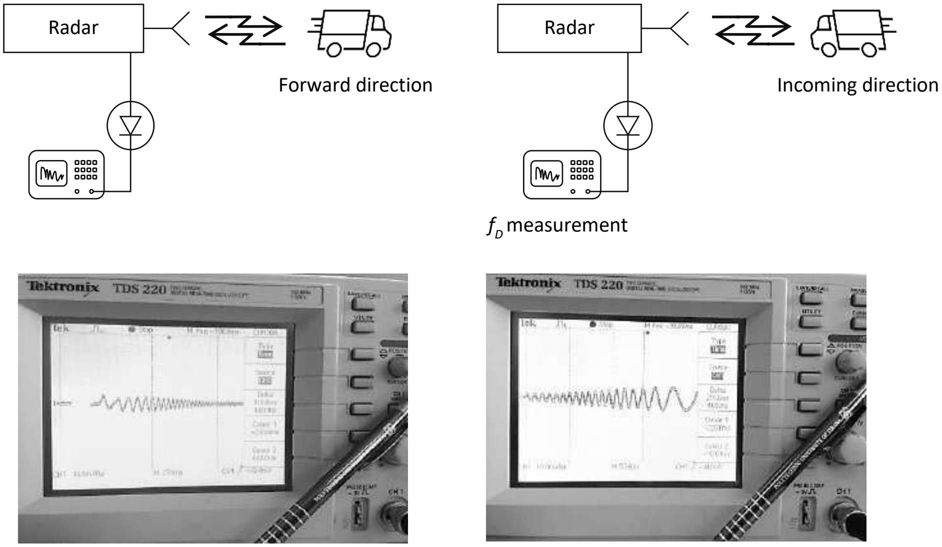
In both cases shown in figure 5, we can measure doppler frequency as 4.630 Hz for the first case and 2.747 Hz for the second. And relative target velocity is 6.48 cm/s and 3.85 cm/s.



(a) (b)

Fig. 5: Measured voltage proportional to reflected wave for outgoing target: (a) horizontal polarization; (b) vertical polarization.

The Figure 6 depicts the comparison of the reflected energy wave form for target moving forwards the radar location (figure 6a) and towards the radar location (figure 6b). Amplitude variation of the waveform over the time is indicator of the direction of the target. If the amplitude grows over the time, the target is approaching the radar and vice versa, the target is moving forwards.



(a)

(b)

Fig. 6: Measured voltage proportional to reflected wave: (a) outgoing target; (b) incoming target.

2. CONCLUSIONS

The possibility of transforming a common microwave transmitter into a X-Band continuous wave is in the present paper reported. A schematic configuration is here used for the mathematical formulation on evaluating doppler frequency and all required modifications on the transmitter side. The presented concept of converting a transmitter into a doppler radar is shown in a laboratory setup where the theoretical formulation has been validated by laboratory measurements.

For the validation, the presented setup, different target moving velocities are used and with different material reflectivity to prove the general electromagnetic theory for equivalent radar cross section of the target related to the electromagnetic wave polarization. For a small RCS the signal power at the receiver would be smaller and signal amplitude would be smaller. RCS depends on objects polarization and radar polarization. When radars and objects polarizations are the same for example both have vertical polarization, a higher RCS is measured and a higher reflected energy.

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