Targets Signals Simulation in Radar System

Mahmod A. Al-Zubaidy, Samaa K. Al-Saffar

Abstract— Radar system has many applications in the military and civilian fields; it is utilized for targets detection, obtaining the range, the direction, altitude and velocity (for moving target). These information can be extracted from target signal. Target effects on the transmitted signal, such effects are delayed and Doppler shift for moving targets. Generally, the development of radar systems and radar signal processing are always in progress and real radar systems are not always available for testing these developments. This work required computer simulators which are used to test the modification and development of these systems. In this paper, the two types of targets (moving and fixed) signals are simulated. In order to implement the target block, the transmitted signals and antenna location signals must be generated as inputs to target block. The target block is simulated using MATLAB Simulink, this block is designed by specifying the parameters of target block such as the velocity, range, azimuth of a target (direction), the direction of the target movement angle and wavelength. This block is tested for all different types of radars such as pulse radar, pulse compression radar, continuous wave radar and frequency modulation continuous wave (FM-CW) radar.

Index Terms—radar system, target signal simulation, Doppler effect, radar signals.

I. INTRODUCTION

The development of radar systems requires advanced simulation and measurement techniques in order to ensure the performance specifications. MATLAB tools were used to build radars simulators for different purposes such as, implementation of a radar system to classify moving vehicles [1]. MATLAB has many features such as interactive mode, built-in functions and the ability to add user written functions therefore MATLAB is becoming widely used among students, researchers and engineers [2].

Radar system can be classified into many types based on the specific radar characteristics, such as the frequency band, type of antenna, jobs and signals utilized [3]. Therefore, radar systems are classified into two groups according to the types of transmitted signals: continuous wave (CW) and pulse radars, each type of radar system can be classified depending on the desired application.

The transmitted signal for pulse radars are divided into pulse modulated with the fixed carrier frequency signal that is used to measure the range and radial velocity and pulse modulated with compression carrier such as linear frequency modulation (LFM) that is used to improve the range resolution of the radar.

Dr. Mahmod A. Al-Zubaidy, Lecture, Department of Electronic Engineering, University of Mosul, Iraq.
Samaa K. Al-Saffar, Department of Communication Engineering, University of Mosul, Iraq.

While continuous wave radars are divided into continuous wave and FM continuous wave (FM-CW) radars. Continuous wave radar, which is used in tracking radar, only Doppler shift (target's radial velocity) and angular position can be determined. Continuous wave radar transmits a continuous wave with unmodulated carrier frequency, while in FM continuous wave signal, the frequency is varying sweep (chirp), sine wave, saw tooth modulation with the time that is utilized to measure the range.

Many signals are used to arrange the operation of the radar system. Some of these signals are generated within the radar system itself such as transmitted signal, Clock Pulse signal (ACP) and North Pulse signal (NP). The other signals are coming as a response of the generated signals such as target signal. This signal is returned from the target as echo, that is, may be either pulse modulated with carrier signal or continuous wave (CW) signal depending on the transmitted signal. In the pulse radar, it utilized to measure the range that can be found from the delay between the transmitted and echo signal, the radial velocity of target can be found from Doppler shift. The echo signal for continuous wave radar will return with Doppler shift for not fixed target that can be used to measure the radial velocity [4].

II. TARGET EFFECTS ON THE TRANSMITTED SIGNAL

The target causes many effects on the reflected signal that carried the specification or behavior of the target. These impacts can be detected by comparing the reflected signal with the original transmitted signal.

A. Delay Effect

Delay (t_d) is the time between the transmitted signal of radar and receiving of the corresponding echo. Target range, R, can be calculated as [5]:

$$R = c \frac{t_d}{2} \qquad (1)$$

Where c is the velocity of light and it is equal to $3x10^8$ m/sec. Therefore the final equation is shown as:

$$R = 150 \, t_{d(\mu \sec)} \qquad (2)$$

B. Doppler Effect

The Doppler effect can be defined as the change in frequency of a received signal when there is a relative movement between the transmitter and the receiver. In radar, the moving target reflects the carrier frequency f_r of received signal, differs from the transmitted signal with f_0.

In the case of moving target and the stationary radar, the relation

between f_0 and f_r can be given as;

$$f_r = f_0 \left\{ \frac{1 - v_r/c}{1 - v_r/c} \right\} \qquad (3)$$

Where v_r is the target radial velocity (along the line connecting the radar and target), $v_r = V \cos\theta$, where V is the velocity of a moving target and θ is the angle between the track of the target and the line of sight from the radar. If the difference is denoted as the Doppler frequency, $f_d = f_r - f_0$, the Doppler frequency will be obtained as:

$$f_d = f_0 \left\{ \frac{1 - v_r/c}{1 - v_r/c} - 1 \right\} \qquad (4)$$

And $f_d < 0$ for $v_r > 0$ (increasing range). Since the target velocities are always much less than the velocity of light, $v_r << c$, so the equation (4) can be expended into a series:

$$f_d \approx f_0 \left\{ 1 - 2\frac{2v_r}{c} + \ldots - 1 \approx -f_0 \frac{2v_r}{c} = -\frac{2v_r}{\lambda} \right\} \qquad (5)$$

Where λ is the wavelength of the transmitted signal.
The form of the equation (5) is mostly used in radar applications. This formula is valid for active radar, where the Doppler shift results from changes in the two-way path as the target moves. For passive radar:

$$f_d \approx \frac{v_r}{\lambda} \qquad (6)$$

because the shift applies only for the one-way path.
The Doppler effect has fundamental importance in radar applications, where it is used to determine target radial velocity and to discriminate among moving targets and clutter [5].

C. Others Effects

There are other effects that are not taken into consideration in this paper; these effects are:

1. Target Cross Section Area Effect

Cross section area (σ) is a one of the parameters that characterize the target. This parameter will effect on the amount of the power received signal where σ is the measure of a target's ability to reflect radar signals in the direction of the radar receiver, the radar equation explains this effect [4]:

$$P_r = \frac{p_t G_t G_r \sigma \lambda^2}{(4\pi)^3 R^4} \qquad (7)$$

Where:
p_r = Receiver power signal.
p_t = Transmitted power signal.
σ = Cross-section area.
$G_t G_r$ = Antenna gain.
λ = Wavelength.
R = The distance of target.

2. Noise Effect

Noise is an unwanted signal with random specifications that effects on the amount of the power received signal. The detection of the target cannot be recognized between the clutter and the target, caused by the effect of the noise, also the noise effected on the range resolution for targets. Generally, the noise is classified as target noise (caused by radar target, its shape and motion peculiarities), external (environmental) noise (caused by the environment in which radar signal propagates such as path loss) or internal noise (caused by radar hardware, primarily by the antenna and the receiver and each part of radar system such as noise figure) [5].

III. TARGET SIGNAL

The target signal is the returned signal as an echo from the target. It has the same specifications of transmitted signal but return with a delay, distortion, noise, attenuation and a Doppler shift for moving target and contains many information that gives indication about the target such as the range, direction (elevation and azimuth) and radial velocity [4].
The target signal can be represented by either radio frequency (RF) or intermediate frequency (IF) (30 or 60MHz). Also it can be represented as video signal in the phase detector circuit in radar receiver part. The video signal in the pulse radar will be appeared butterfly in the phase detector for the moved target but for the fixed target signal, the relative phase of consecutive received pulses does not change in the output of the phase detector as shown in figure (1) [4] ,[6].
In radar system, the target appeared on display radar with different forms according to the application in radar. The plan-position indicator (PPI) display of radar shows the targets as an arc in the specific azimuth and direction as shown in figure (2-A).There are also many other displays such as A-display in which targets appear as vertical deflections from a horizontal line representing a time base, but in the B-display in which each target appears as an intensity-modulated blip, with azimuth indicated by the horizontal coordinate and range by the vertical coordinate as shown in figure (2-B) and (2-C) [5].
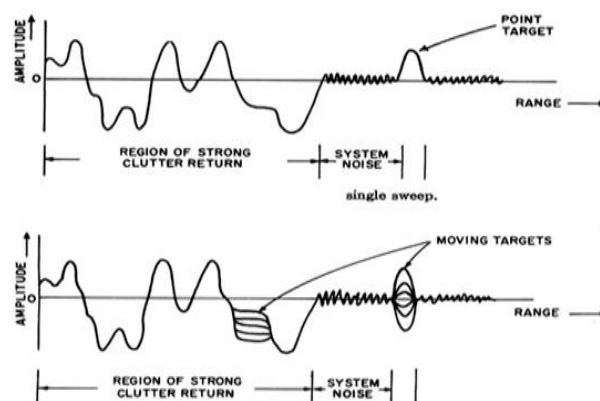
Fig.1 The video signal (the output of the phase detector in the time domain).
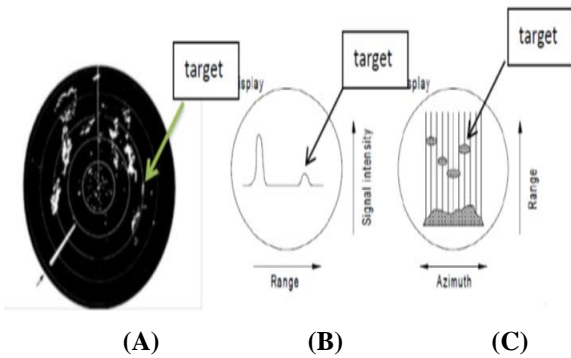
(A)   **(B)**   **(C)**
Fig. 2 PPI display, A- and B-displays.

IV. TARGET SIGNAL GENERATION BLOCK IN MATLAB

Target signal generation block can be divided in to five parts as shown in Figure (3).
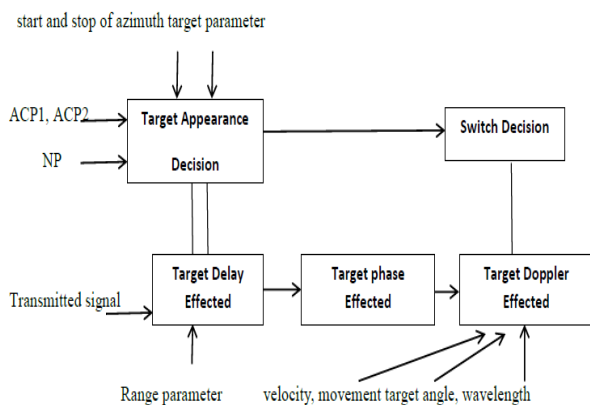

Fig.3 Target signal generation block.

The first part is the target appearance decision that will decide the target appearance at a specific azimuth (direction of the target). This block has three input signals that come from the antenna system. The antenna location signals includes Clock Pulse signal (ACP) and North Pulse signal (NP). The ACP signal includes ACP1 and ACP2 each one has 4096 square pulses per radar antenna turn which represents the angle of the antenna and gives indication about the angle of the target, ACP1 is either lagging or leading from the ACP2 by quarter wave which give an indication if the rotation of the antenna is clockwise or counter clockwise, while NP has one pulse per antenna turn with one ACP clock width to indicate that the radar antenna is in the real north [1]. These signals will be generated using MATLAB Simulink which are generated from a location antenna signals block that is passed to up/down counter that will be used to give a specific angle, then the value of counter is compared with the start and stop azimuth target input parameters to make the target appear at a specific azimuth.

The second part represents the target delay effected which has one input that represent the transmitted signal. This part will delay the transmitted signal depending on the range parameter of the target. In MATLAB Simulink, this part is simulated by using transport delay.

The third part is a target phase effected part that will effect on the phase angle of the transmitted signal. The phase angle for target signal is calculated from the range and the wavelength of the transmitted signal according to the equation[6]:

$$\beta = 2\pi \frac{2*r}{\lambda} \tag{8}$$

Where β = the phase angle.

The fourth part of the target signal generation block is the target Doppler effected block that will be affected by the increasing or decreasing from the carrier frequency of the transmitted signal. The Doppler effect will be influenced by the velocity, the direction of the target movement angle and wavelength of transmitting signal. Therefore, The Doppler effect will be specified by the target block parameters which are the velocity, azimuth of a target, and wavelength of the transmitted signal.

In MATLAB Simulink, the equation (9) explains the principle that will be accredited in the simulation to change the frequency and phase of the transmitted signal according to the Doppler shift:

$$\sin((y+x)t+\beta) = \sin(xt)\cos(y+\beta) + \sin(yt+\beta)\cos(xt) \tag{9}$$

Where:

x = transmitted signal frequency.

y = the Doppler shift.

The final part represents the switch decision that will decide where the target will appear or disappear at the time according to the range and azimuth for this target. This part will be simulated as IF statement.

All target signal generation simulation parts will be integrated in to one block under the name target block in MATLAB Simulink as shown in figure (4). This block has four input signals: T_x represents transmitted signal, (ACP1), (ACP2) and (NP) which represents the antenna location signals. This block has five input parameters that specify the target specifications: velocity (m/sec), the direction of the target movement angle (degree), range (m) and azimuth of a target (degree) as shown in figure (5).
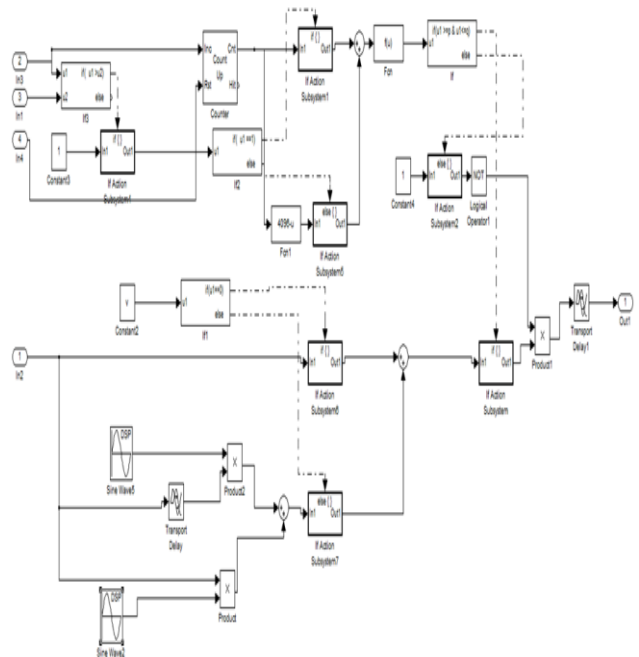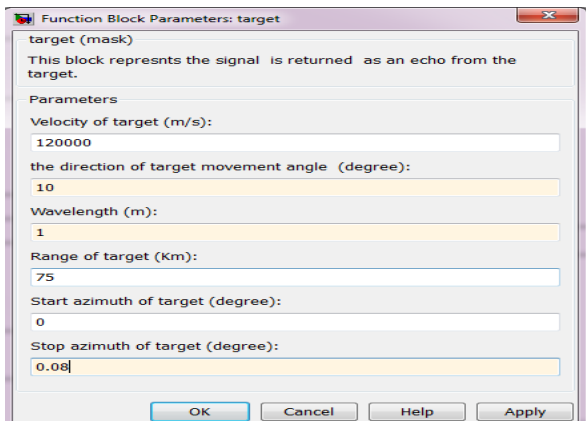

Fig.4 Target blocks in Simulink.

(A) Target block

(B) The target block parameters.
Fig.5 Interface target block.

V. SIMULATION RESULTS

The target generation block and all other required blocks were implemented using MATLAB Simulink in order to test target block within different conditions and different types of radars as illustrated below:

A. Case (1) Pulse Radar

This case includes two subcases: one for fixed target and the other for a moving target. The generation target block is tested under the following input parameters as shown in table I.

Table I. Pulse radar input parameters.

Transmitted pulse signal
Period of pulse =1msec
Pulse width = 6µsec
Carrier frequency =300MHz
Antenna location signal
Number of turn per minute: 3 turns
Movement direction of antenna :Clock wise
Target block parameters
The velocity=120000 m/sec for moving target
The velocity=0 for fixed target
Movement target angle = 10 degree
Wavelength =1m
Range =75 Km
Azimuth = (0-.008)

For fixed target, the received signal will only be affected by the delay which is computed from the equation (1) and

equaled 0.5msec while there is no Doppler shift effect in to transmitted signal because the velocity=0 therefore the transmitted and received signals have the same frequency but different phase. The phase change can be calculated by using the equation (8), RF and IF stages are shown in figure (6-A), (6-B), (6-C) and (6-D) for this case. For moving target, the value of velocity is not real value in order to observe clearly the Doppler shift which is calculated from equation (6) and equal to 236.4 KHz. The frequency change in the received RF signal from the frequency of transmitted signal due to the Doppler effect is not observed, but in the IF stage, this effect will be observed clearly as shown in figure (7-A), (7-B), (7-C) and (7-D).

To represent the video signals for moved target in the output of the phase detector in the received part of the radar, the velocity input parameter will be taken 1200 m/sec, and the target signal will appear in all angles. From figures (6-E) and (7-E), one can observe that the video signal for the fixed target has the same amplitude and polarity within the time of duration pulse only while the video for the moving target, has a different amplitude and polarity within the time of duration pulse.
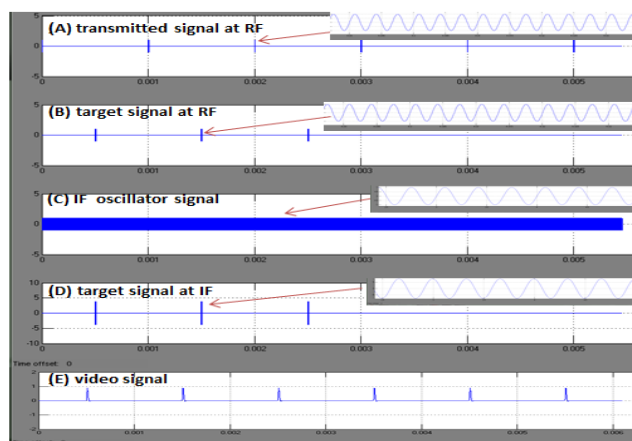

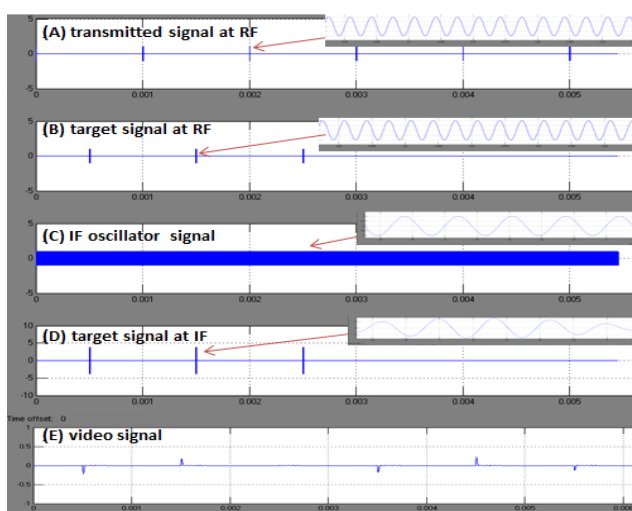
Fig.6 Transmitted and fixed target signals.

Fig.7 Transmitted and moving target signals.

B. Case (2) Continuous Wave Radar :

In this case, the generation target block is tested for fixed target and moving target under the following input parameters as shown in table II.

Table II. Continuous wave radar input parameters.

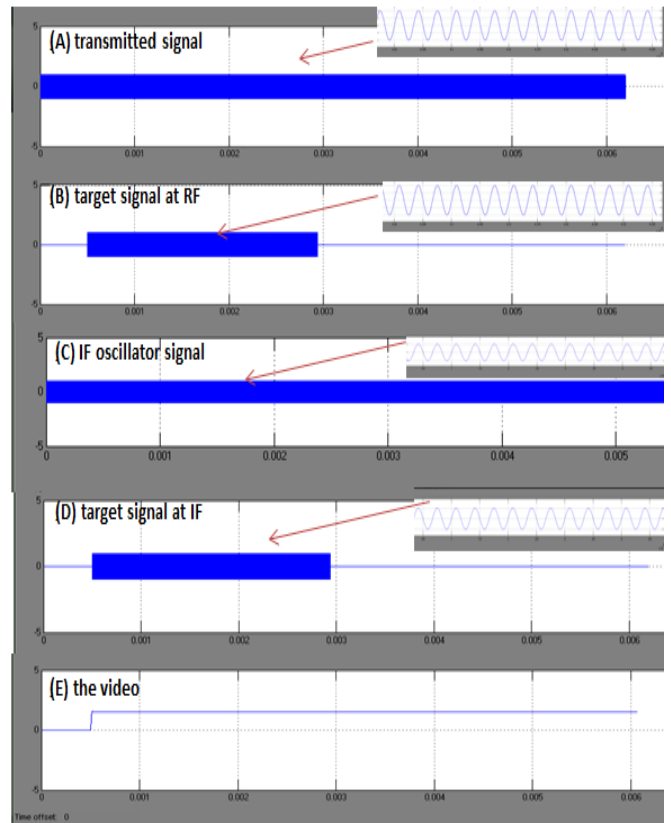| Transmitted continuous wave signal |
|---|
| Carrier frequency = 300MHz |
| **Antenna location signal** |
| Number of turn per minute: 3 turns |
| Movement direction of antenna : Clock wise |
| **Target block parameters** |
| The velocity =120000 m/sec for moving target |
| The velocity = 0 for fixed target |
| Movement target angle = 10 degree |
| Wavelength =1m |
| Range =75 Km |
| Azimuth = (0-0.008) |

For fixed target, the target signal will be affected by the delay that also calculated from equation (1), the target signals in the RF and IF stages explain the delay and there are no Doppler effect as shown in figures (8-A), (8-B), (8-C) and (8-D). For moving target, the Doppler effect will be equal to 238.4 KHz. The Doppler shift in the target signal is not observed in RF stage in the receiver part, but in the IF stage, the effect can be observed clearly as shown in figure (9-A), (9-B), (9-C) and (9-D).

Because there is no Doppler effect for fixed target, the video signal appears as the DC value which represents the phase change due to the propagation of the transmitted signal through round-trip as shown in figure (8-E).

For moving target, the video signal will appear as sine wave that represents the value of Doppler shift, as shown in figure (9-E). In this case the targets appear in all angles and the velocity of moving target equal 1200 m/sec therefore the Doppler effect will be equal 2363.53Hz.

C. Case (3) FM-CW Radar

The generation target block is tested for fixed target and moving target in FM-CW radar under the following input parameters as shown in table III.

Fig.8 Transmitted and fixed target signals.
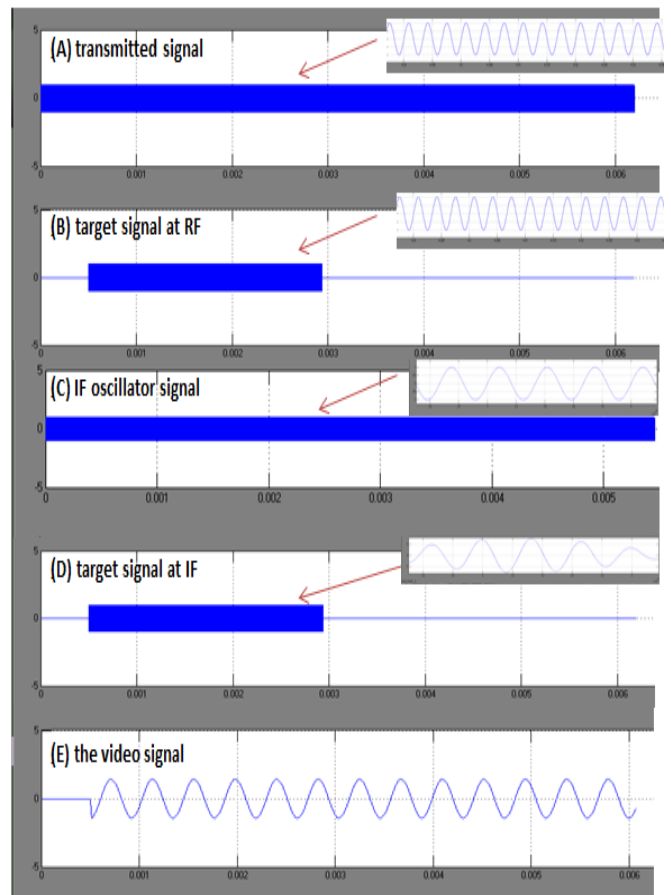
Fig.9 Transmitted and moving target signals.

Table III. FM-CW radar input parameter.

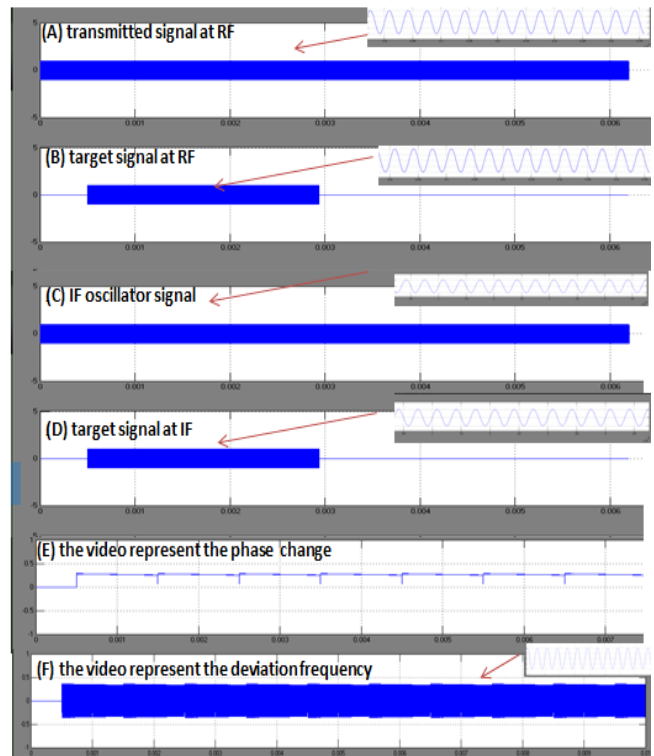| Transmitted FM-CW signal |
| --- |
| Initial carrier frequency=300MHz |
| Bandwidth=30 MHz |
| Deviation frequency= 6MHz |
| **Antenna location signal** |
| Number of turn per minute: 3 turns |
| Movement direction of antenna :Clock wise |
| **Target block parameters** |
| The velocity=120000 m/sec for moving target |
| The velocity=0 for fixed target |
| Movement target angle = 10 degree |
| Wavelength =1m |
| Range =75 Km |
| Azimuth = (0-0.008) |

Fig.10 Transmitted signal and fixed target signals.

Both fixed and moving targets signals suffer from delay time as shown in figures (10) and (11) at the RF and IF stages for these targets. But in the moving target the transmitted signal suffered from Doppler effect and equal to 236.4 KHz. As a result, the Doppler shift can be observed clearly in the IF stage when compared with RF signal in the receiver part but in the fixed target there is no Doppler effect as shown in figures (10) and (11).

The video signal is not important for calculation of range in the FM-CW. The range calculation can get from the difference frequency between the instantaneous transmitted signal and received target signal in RF stage as shown in figures (10-F) and (11-F) therefore the Doppler effect in the moving target will cause ambiguity in range calculation. One can observe the Doppler effect from the video signal, for fixed target will appear as the DC value but for the moving target, the video signal appeared as sine wave which represents the Doppler frequency as shown in figures (10-E) and (11-E). In this case the velocity of moving target is equal to 1200 m/sec.

D. Case (4) Pulse Compression Radar

The generation target block is also tested for fixed target and moving target under the following input parameters as shown in table IV.
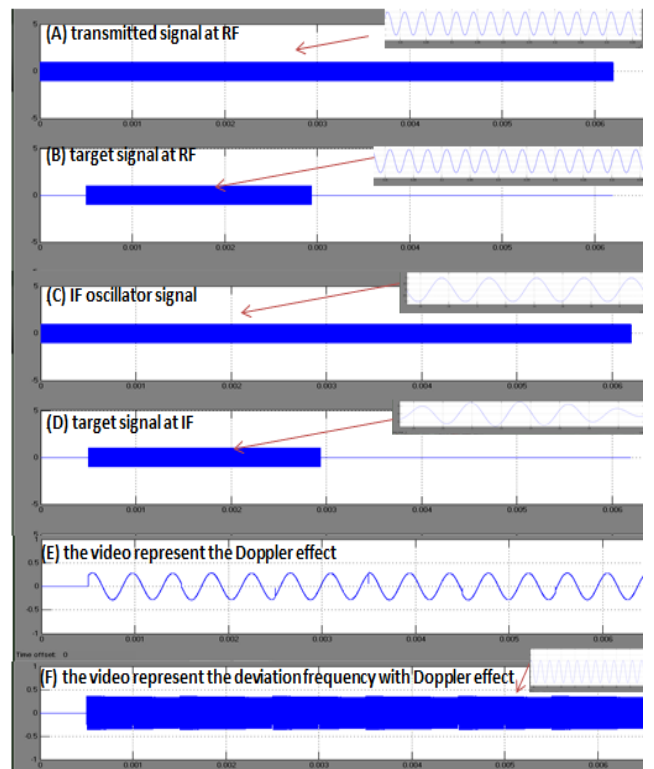

Fig.11 Transmitted signal and moved target signals.

Table IV. Pulse compression radar input parameters.

Transmitted pulse compression signal
Pulse width = 24 μsec
Range resolution= 450m
Carrier frequency =300 MHz
FM carrier frequency (IF) =30MHz
Bandwidth=24KHz
Deviation frequency= 3KHz
Antenna location signal
Number of turn per minute: 3 turns
Movement direction of antenna :Clock wise
Target block parameters
The velocity=1 20000 m/sec for moving target
The velocity=0 for fixed target
Movement target angle = 10 degree
Wavelength =1m
Range =75 Km
Azimuth =(0-.008)

The transmitted signal suffered from the delay time effect when returned from the fixed and moving targets, that effect is shown in figures (12) and (13) at the RF and IF stages for these targets. For moving target, the Doppler shift can be observed clearly in the IF stage when it is compared with RF signal in the receiver part but in the fixed target there is no Doppler effect as shown in figures (12) and (13).

The video signals for the moving and fixed targets represent the output of the pulse compression filter that are shown in figures (12-E) and (13-E). One can observe clearly the width of the video signal smaller than the transmitted signal pulse width; that will give higher accuracy range resolution. The Doppler frequency shift due to the moving target causes some distortion of the video signal when the Doppler effect increased. In this case the distortion is very small because the Doppler effect is also small compared with the initial frequency because the velocity of the moving target is equal to 1200 m/sec.
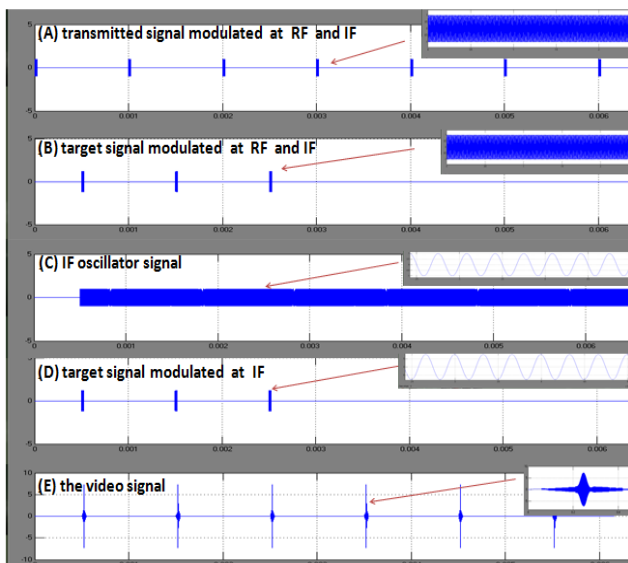

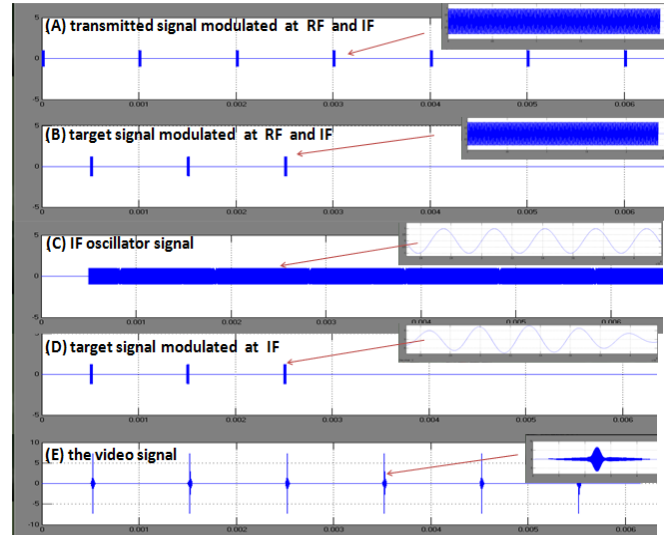**Fig.12 Transmitted signal and fixed target signals.**

Fig.13 Transmitted signal and moved target signals.

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AUTHORS PROFILE

Dr. Mahmod A. Al-Zubaidy He received the B.Sc. in Elec. Comm. Eng. From Mosul University in 1989 (Mosul/ Iraq). He received the M.Sc. and the Ph.D. both in Elec. Comm. Eng. from Mosul University (Mosul / Iraq) in 1994 and 2006, respectively. Since 2007, he had been joined University of Mosul/Collage of Electronic Engineering as a lecture. his research interests includein Radar Systems, Digital Communications, Communication Systems and Mobile Systems.

Samaa K. Al-Saffar was born in Mosul-Iraq in 1988. She received her B.Sc. in Communication Engineering from the University of Mosul/College of Electronic Engineering in 2010. She is currently a M.Sc. student in Communication Engineering. She is research interest in radar systems.