RADAR TARGET SIMULATOR: A LABORATORY MODEL

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Abstract

This paper proposes a laboratory analog model for Radar Target Simulation. In the realization of the model, mathematical equations are formulated and are used for obtaining target information in terms of Range, Azimuth and Elevation. The mathematics of the model was simulated on the IBM 360/44 computer and the results are presented in the form of graphs.

Key words: Simulator; Target; Range; Azimuth; Elevation.

1. Introduction

A radar target simulator simulates realistic target information (Range, Azimuth, Elevation) which can be used advantageously in conjunction with design of display system, filters and the like, and also for training of personnel.

At present, many sophisticated radar target simulators [3–6] are available. In Leskinen's [3] model, delayed pulses are gated to simulate range, azimuth and elevation. In this model the electromechanical target course generator simulates target speeds upto 2,400 knots. Packer, Raphael and Sakes [4] developed a simulator which generates the track of thirty-two aircrafts in x, y and h coordinates. Their equipment consists of one program control console which houses the tape recorder storing 20 targets tracks and all the controls for the tracks. Norton [5] developed a dynamic target and counter measure simulator. This system mainly uses the sine-cosine resolving potentiometers for simulating initial conditions and speed of the target. In Silverberg's [6] simulator, a general purpose photoelectric function generator is used to generate any single valued function.

The above description of the existing models reveals that expensive equipment and/or complicated digital circuitary are required for the construction. It is desirable that a laboratory model is simple and inexpensive. This paper provides such a model.

Mathematical equations which enable one to get the target information are derived in Sec. 2. Section 3 describes how the model can be realized. In Sec. 4, a specific example is given along with the detailed description of how one can use the commercially available modules [1, 7] to fabricate the model. Finally, the results of simulating the model on the IBM 360/44 computer are presented.

2. SIMULATOR MATHEMATICS

Notations.—(x_0, y_0, h_0) the initial position of the target in three-dimensional space (Fig. 1).

v = Velocity of the target;

ϕ = Heading angle of the target in XY plane;

ξ = Angle of climb/down;

β = Angle of elevation;

θ = Azimuth angle;

t = Time in seconds;

R_{xy} = Range of the target in XY plane;

R = Range of the target in three-dimensional plane.

It is easy to see from figure 1 [4] that

$$v_{xy} = v \cos \alpha \simeq v.$$

The velocity components in X, Y and H directions are

$$v_x = v \sin \phi \tag{1}$$

$$v_y = v \cos \phi \tag{2}$$

$$v_n = v \sin \xi. \tag{3}$$

The instant position of the target in three-dimensional space at time t is defined by

$$x = x_0 + v_x \cdot t \tag{4}$$

$$y = y_0 + v_y \cdot t \tag{5}$$

$$h = h_c + v_h \cdot t. \tag{6}$$

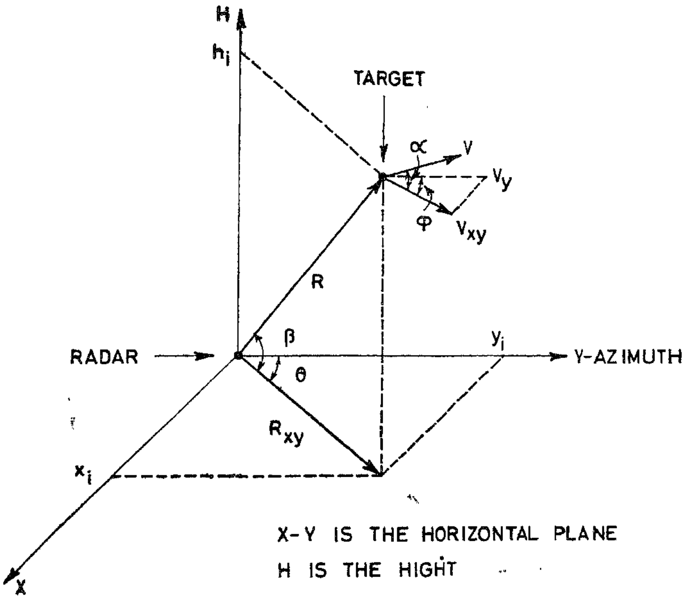


FIG. 1. Co-ordinate system of the target.

The range of the target in the XY plane and azimuth angle respectively are:

$$R_{xy} = \sqrt{x^2 + y^2} \tag{7}$$

and

$$\theta = \sin^{-1}\left(\frac{x}{R_{xy}}\right). \tag{8}$$

The range of the target in three-dimensional space and the angle of elevation are

$$R = \sqrt{R_{xy}^2 + h^2} \tag{9}$$

and

$$\beta = \sin^{-1}\left(\frac{h}{R}\right). \tag{10}$$

3. MODEL REALISATION

Unscaled analog set up realisation of the preceding equations (1–10) is shown in Fig. 2. Outputs of the first three multipliers v_x, v_y, v_v represent the equations 1, 2 and 3 respectively. Angles ϕ and ξ are controlled by function generators (See. 4). Information x, y and h from equations 4, 5 and 6 is given by the outputs of the integrators. Equations 7, 8, 9 and 10 are implemented by using multipliers, summers, dividers, and arcsine function generators. To perform the various operations that are shown in Fig. 2, commercially available modules [1, 7] with their features are taken into account. All the above components or modules have operating range between -10 volts and $+10$ volts.

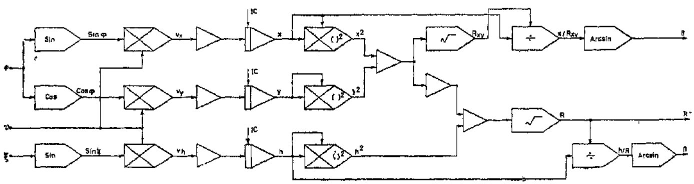


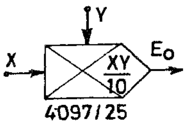
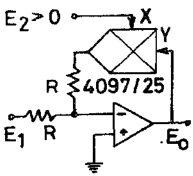
FIG. 2. Unscaled diagram.

A specific example will be discussed in Sec. 4 by considering the electrical features of the modules. The 4118/25 [1] module is for sin/cos functions, 4097/25 [7] is for multipliers and dividers and 4118/25 is also for arc sine function. Module 4118/25 is a two-quadrant sin/cos function generator. But, by adding one or more external operational amplifiers, module 4118/25 can be used in four-quadrant sine and cosine functions. Input-output relations of the above modules are shown in Table I.

4. A SPECIFIC EXAMPLE

Problem.—A target is moving along the azimuth (Y) line towards the radar with a constant velocity 1,000 ft/sec. at a high of 1,000 ft. Initial

TABLE-1
FUNCTION GENERATORS SPECIFICATIONS

Sl. No.	Type of Function	Block Diagram	Output-Input Relation
1	Sine (Two-quad.)		$E_o = -10 \text{ Sin } \theta$, where $\theta = 9E_1$ degrees and $-10\text{v} \leq E_1 \leq +10\text{v}$
2	Sine (Four-quad.)		$E_o = 10 \text{ Sin } \theta$, where $\theta = 18E_1$ degrees and $-180°\text{C} \leq \theta \leq +180°$
3	Cosine (Four-quad.)		$E_o = 10 \text{ Cos } \theta$, where $\theta = 18 E_1$ degrees $-180° \leq \theta \leq +180°$
4	Arc-sine		$E_o = -1/9 \text{ Sin}^{-1}(E_1/10)$ $\theta = 9 E_0$ degrees
5	Multiplication		$E_o = XY/10$
6	Division		$E_o = -10 (E_1/E_2)$ (if $E_2 < 0$ choose $-XY/10$ for multiplier)

position of the target on azimuth line is 1,00,000 ft. After 40 seconds, target has taken 1 g turn in the horizontal (XY) plane and moved away from the radar, parallel to the azimuth line.

From the above problem, it is clear that

$$\xi = 0\cdot 0$$
$$x_0 = 0\cdot 0$$
$$y_0 = 1{,}00{,}000 \text{ ft.}$$
$$h_0 = 1{,}000 \text{ ft.}$$

and

$$v = 1{,}000 \text{ ft/sec.}$$

It is assumed that the problem time equals set up run time, 100 seconds.

Amplitude scaling of the set up is

1,000 ft. = 0·1 V

and

1,000 ft/sec = 1·0 V.

Outputs of the integrators are obtained by the equation

$$e_0 = -\frac{1}{RC}\int e_i\,dt + IC \tag{1}$$

where

e_0 = Output voltage of the integrator.

e_i = Input voltage of the integrator.

IC = Initial condition of the integrator.

RC = Time constant (gain) of the integrator.

At $\phi = 0\cdot 0$ and $\xi = 0\cdot 0$, input to the integrators are:

$$v_x = 0\cdot 0$$
$$v_y = v$$

and

$$v_h = 0\cdot 0$$

Outputs of the integrators are

$$x = x_0 = 0 \cdot 0$$

$$y = y_0 - v_y \cdot t.$$

(—ve sign indicates that target is moving towards radar).

and

$$h = h_0 = 0 \cdot 1 \text{ V}.$$

After one second, the outputs of the integrators are:

$$x = 0 \cdot 0 \text{ V}$$

$$y = 9 \cdot 9 \text{ V}$$

and

$$h = 0 \cdot 1 \text{ V}.$$

Then, from equation (11), RC is calculated as

$$9 \cdot 9 = -\frac{1}{RC}(1 \times 1) + 10 \qquad (\text{since } IC = y_0)$$

so that $RC = 10$ seconds.

Therefore, the required gain of each integrator is 10.

Since the target is taking 1g turn [2], angle ϕ turns out to be $3 \cdot 6^\circ$ per interval (*i.e.*, per second). To complete 180° turn, total time required is 50 seconds. Therefore, ϕ (*cf.* Fig. 3) should vary from 0–10 volts in 50 seconds at the rate of $0 \cdot 2$ voltas per second. From equation (11), the time constant of the above ramp for ϕ is obtained as 50 seconds. But, in the problem, it is said that the target has taken 1 g turn at 41st second. Hence, the above ramp should be triggered after 40 seconds of switching on of the main set up.

The square-root and division functions are obtained by using the multiplier 4097/25 as the feedback element (Table I).

The scaled diagram (Fig. 3) is again simulated on the IBM 360/44 and results are shown in Fig. 4.

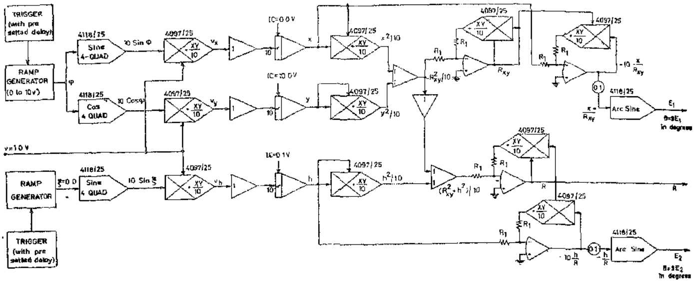


FIG 3. Scaled diagram.

5. CONCLUSIONS

The proposed radar target simulator has considerable flexibility in simulating any type of trajectory of the target. The necessary adjustments are to be made only in generating the heading angle ϕ and climb/down angle ξ. But, necessary care must be taken while scaling the angles ϕ and ξ. The estimated accuracy of the system is better than 3%. If the target information is required in digital form, A/D converters may be connected at the outputs of the simulator. For storing and repeated use of the digital information of the target, RAMs (Random Accesses Memories) can be used. The stored information in RAMs can be used for testing digital filters such as a Kalman filter. At present, hardware implementation of the storage part using RAMs is in progress.

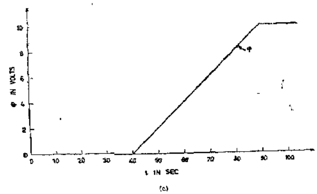


FIG 4 *a*

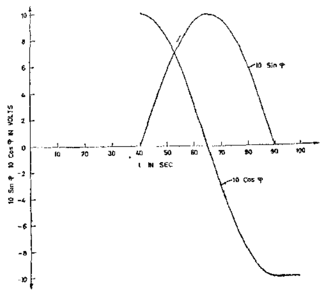


FIG. 4 *b*

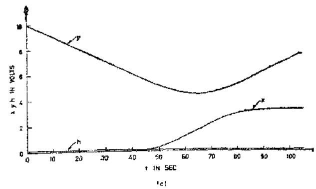


FIG. 4 *c*

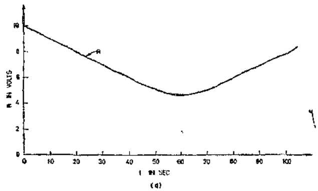


FIG. 4 *d*

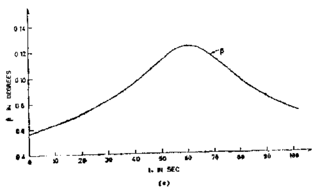


FIG. 4 *e*

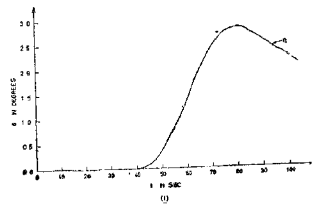


FIG. 4 *f*

Computer simulated results.

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