A Novel Implementation of GEO Satellite Step Track Subsystem

A. Pirhadi, M. Hosseini, and M. Hakkak

***Abstract*—In this paper, the step track subsystem, suitable for geosynchronous orbit (GEO) satellites, is simulated. By using Standard MATLAB® Package and its features such as Simulink toolbox, Data Acquisition toolbox, Real Time Workshop (RTW) and Real Time Windows Target (RTWT), it is possible to completely simulate a control system. Also, by using these properties it is possible to construct a practical real-time system, change its parameters and view their effects on the system during operation.**

***Index Term*—Satellite, tracking, step track.**

I. INTRODUCTION

A GEOSTATIONARY satellite drifts from its orbit due to several effects [1]-[3]. The most important of these effects are the perturbation due to gravities of the sun and moon, anisotropic geopotential due to the slightly oblate shape of the earth and solar radiation pressure. The integral effect of these factors is an oscillation around the GEO position that has a period of 24 hours. Now, since large antennas usually used in the associated earth stations have narrow beamwidths, a little drift in the satellite position greatly reduces the strength of the received signal. Therefore, it is necessary for the earth station antenna to be able to accurately track the satellite periodically [3]. The tracking subsystem can be implemented using either microcontroller units [4]-[7] or PC [8]. Because of low cost, easy programming, high speed CPU processing and capability of modification in programming, the second option is more efficient. In the following, by using the MATLAB® Package an appropriate method for using PC to implement the tracking procedure is presented. Besides being easy to implement, its algorithm is capable of being modified and improved without changing its hardware. Also by using the GUI builder capability of the MATLAB® Package, a suitable menu to easily interface the user and the tracking hardware is suggested so that the PC can do control of the antenna.

II. TRACKING TECHNIQUE

The step-track method is commonly used in earth stations with medium size antennas because of simple design, low cost, and need for only one RF channel. There are several strategies to implement step-track [8], most common of which are: hill climbing technique, curve fitting and gradient algorithm method. The most efficient strategy that has been used so far is the gradient method [1], [9]. In the following the basic theory of this method is introduced [10]. The direction of the gradient of a function is the direction of the steepest ascent. The opposite direction is thus the direction of steepest decent. This property can be proved as follows. If we want to find the maximum of $f(X)$ where f is the beacon signal that is modeled in Appendix A, suppose we move from a point X to a neighboring point $X+hd$ where d is displacement normal vector and h is step length. In each step $\delta X = hd$ and normal vector d component must satisfy

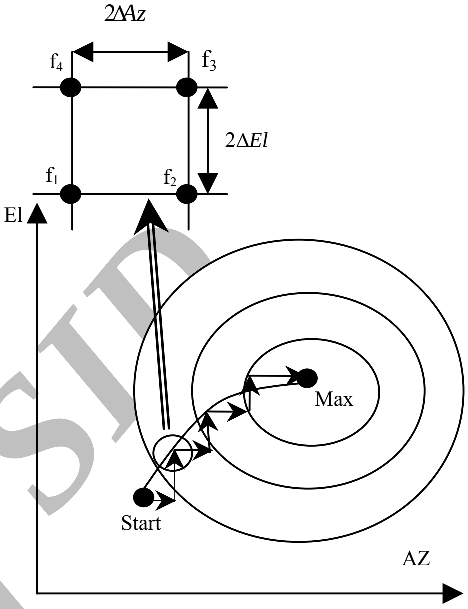

Fig. 1. Contour graph of $f(Az, El)$.

$$\sum_i d_i^2 = 1 \qquad (1)$$

the changing in function value is given by

$$df = f(X+\delta X) - f(X) = \frac{\partial f}{\partial x_1}\delta x_1 + \dots + \frac{\partial f}{\partial x_n}\delta x_n \qquad (2)$$

how should we choose the d_i subject to (1) so that we obtain the largest possible value for df. To this purpose the Lagrange method must be used. Therefore the following equation must be defined

$$\phi(d_1, d_2, d_3, \dots, d_n) = df + \lambda\Big(\sum_i d_i^2 - 1\Big). \qquad (3)$$

To maximize (2) subject to (1) we must to maximize (3) so that the following set of n equation and (1) must be solved

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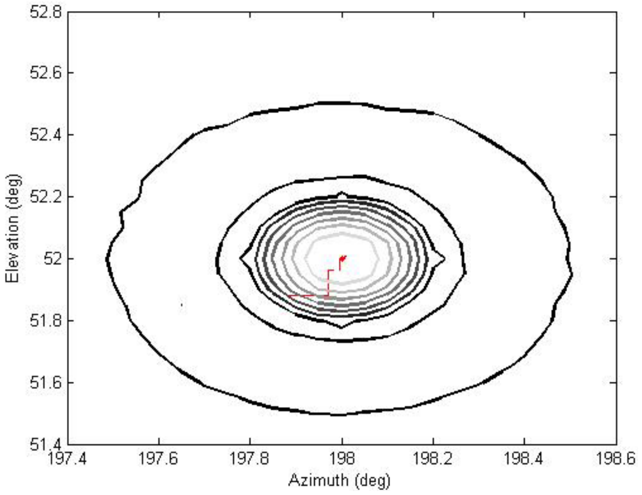


Fig. 2. Gradient step track method.

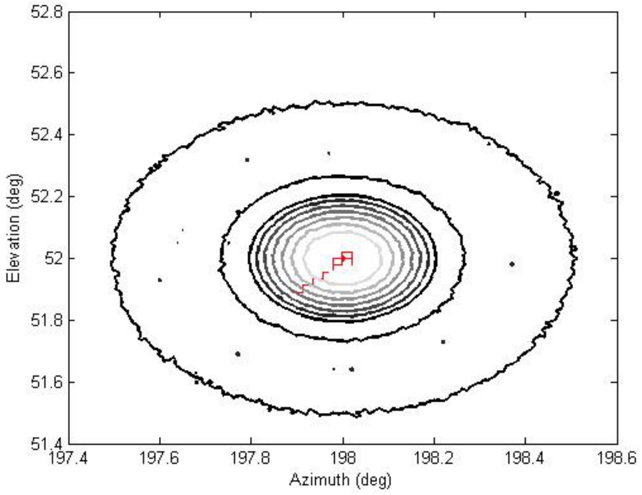
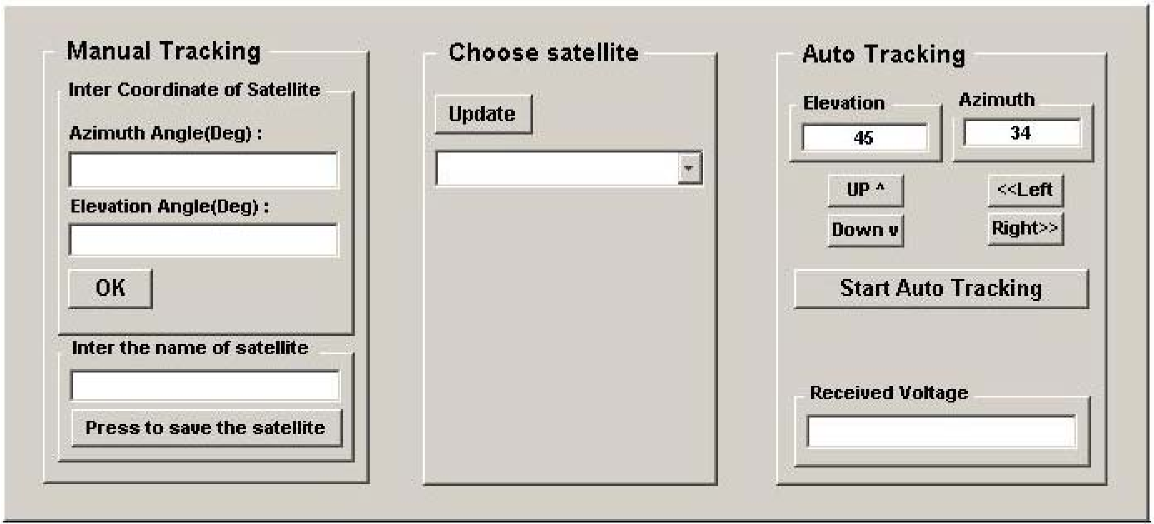


Fig .3. Hill climbing step track method.



Elevation 45

Azimuth 34

Fig. 4. MATLAB® GUI suitable to control the antenna and implement autotrack system.

$$\frac{\partial\phi}{\partial d_i} = h\frac{\partial f}{\partial x_i} + 2\lambda d_i = 0, \quad i = 1,2,\ldots,n . \qquad (4)$$

From (4) it is obvious that $d_i \propto f/\partial x_i$ so that the vector d is parallel to ∇f and the exact value of it, is

$$d = \frac{\nabla f}{|\nabla f|} = \frac{\nabla f_x}{|\nabla f|} + \frac{\nabla f_y}{|\nabla f|} \qquad (5)$$

where ∇f represents the gradient of the received beacon signal. Considering x-axis as Az and y-axis as El, Fig. 1

$$\begin{aligned} Az_{new} &= Az_{old} + \frac{(f_1+f_2)-(f_3+f_4)}{2\Delta Az|\nabla f|}\times h \\ El_{new} &= El_{old} + \frac{(f_1+f_2)-(f_3+f_4)}{2\Delta El|\nabla f|}\times h \end{aligned} , \qquad (6)$$

$$\begin{aligned} (\nabla f)_y &= \frac{(f_2+f_3)-(f_1+f_4)}{2\Delta El} \\ (\nabla f)_x &= \frac{(f_1+f_2)-(f_3+f_4)}{2\Delta Az} \end{aligned} . \qquad (7)$$

To reduce the computations, (6) and (7) can be changed to

$$Az_{new} = Az_{old} + k_1[(f_2+f_3)-(f_1+f_4)] \qquad (8)$$

$$El_{new} = El_{old} + k_2[(f_3+f_4)-(f_1+f_2)] \qquad (9)$$

where k_1 and k_2 must be determined for each function [6]. The results of simulation for antenna pattern model (Appendix A), for $S/N = 40$ dB are presented in Fig. 2.

Comparing this result with the result in Fig. 3 of [11] (Hill climbing technique) shows the efficiency of the gradient method. As seen in [11], the Hill Climbing technique needs extra and smaller steps to converge to the maximum point. Small steps in Hill Climbing are necessary because of spreading the noise of received signal in the implemented system [1].

III. ANTENNA CONTROL UNIT GUI

In this section the MATLAB® graphical user interface (GUI) suitable for the control of the antenna and implementation of the autotrack system is introduced. Because these procedures must be done in different modes, the GUI described in Fig. 4 must have all features required to implement these procedures. The typical modes that are considered in the suggested GUI are: manual tracking, choosing satellite from the table and auto track. In the manual-tracking mode, the coordinates of the earth station (Azimuth and Elevation angles) together with the name of satellite are filed in their respective windows.

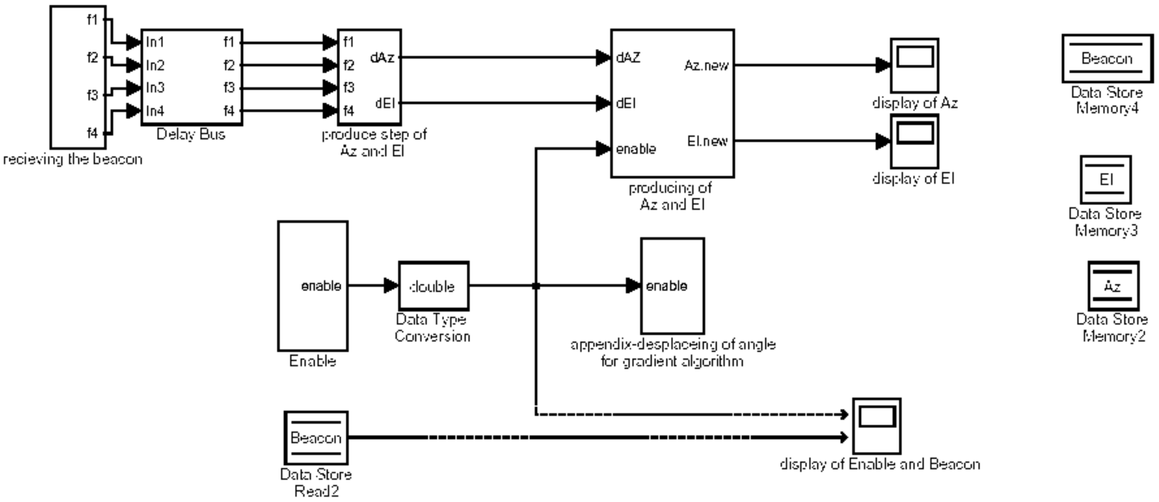


Fig. 5. Simulink model based on gradient algorithm to implement autotrack procedure.

By pushing the *OK* button, the antenna turns to these angles. Also, we can add a satellite to the list by pushing *Press to save the satellite* button. Alternatively, it is possible to choose the satellite from a saved list of satellites. This situation is presented in the menu in the middle frame of Fig. 4. After the antenna moves to an approximate position near the satellite direction it must be possible to start the autotrack procedure to hold the antenna toward satellite permanently. These procedures are done by *Up, Down* and *Left, Right* and *Start auto tracking* buttons in the frame in right hand of the menu in Fig. 4. GUI fine tuning is done by pressing the *Up, Down* and *Left, Right* buttons. When these buttons are pressed, their callbacks are functions that produce suitable signals to rotate the motors to the desired angles. When the *Start auto-tracking* button is pressed, its callback is MATLAB® Simulink model that implements the autotrack procedure using the gradient method, Fig. 5.

IV. TIMING THE AUTOTRACK PROCEDURES

Steps of the autotrack procedures must be done sequentially. Therefore, before starting simulation we must determine timing and operation that must be done in each step of procedure. This timing is shown in Fig. 6.

V. MATLAB SIMULINK FOR AUTOTRACK PROCEDURE

Simulink is one of the most useful features of the MATLAB® package. By using Simulink, we can simulate control and mechanical systems before designing them and view the effect of various parameters on them. Further, by using other properties of the MATLAB® package such as RTW and RTWT it is possible to apply the Simulink model to a practical situation. Fig. 6 shows the Simulink model based on gradient algorithm to implement autotrack procedure.

The operation of each block is described in the following subsections.

A. Receive the Beacon Block

In Simulink model this block computes the beacon signal from MATLAB® M-file that produces beacon signal (the value of function $f(X)$ in Appendix A). In a real time situation, it reads the antenna beacon signal from the input port.

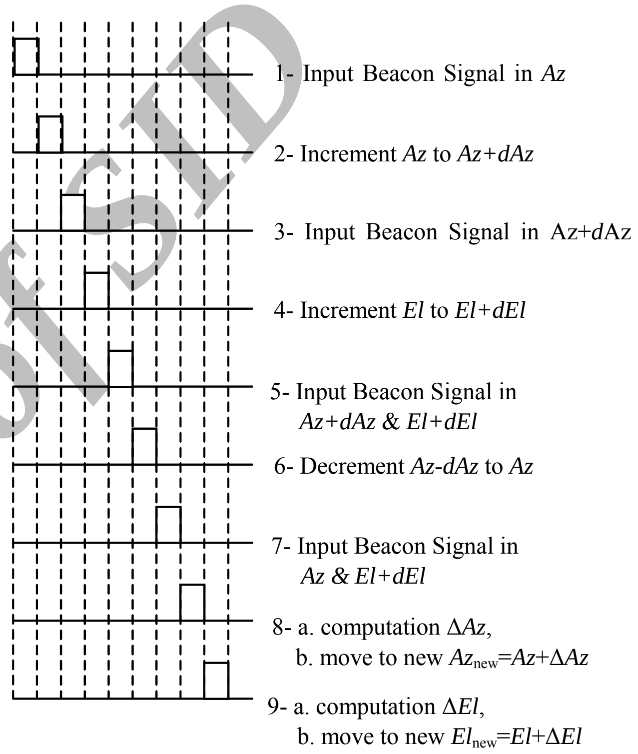


Fig. 6. Timetable of tracking procedure.

B. Displace Angles

In Simulink model this block produces the desired changes in Azimuth and Elevation angles (Az and El in (8) and (9)) .In real time situation it reads Azimuth and Elevation angles from their input ports and sets the amount of changing them to their output ports.

Produce steps of Azimuth and Elevation block: this block produces the amount of ΔAz and ΔEl after computing the gradient of the function of pattern of antenna in each step.

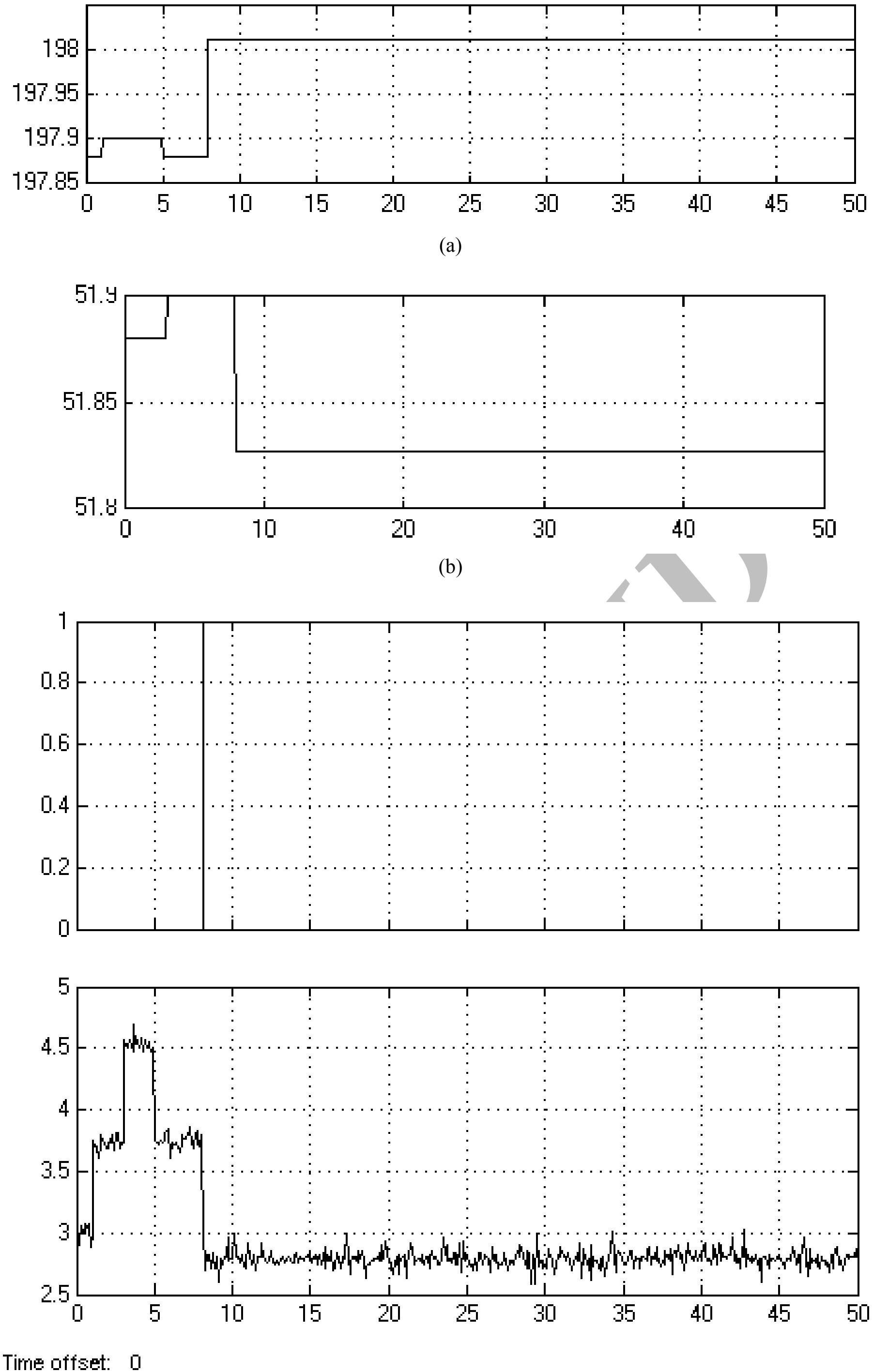
Produce new Azimuth and Elevation block: this block produces the new Azimuth and Elevation angles (8), (9).

Enable block: Produces the enable signal to:

1- Stops the tracking when the strength of Beacon signal in nth step is less than its strength in $(n+1)$ -th.

2- Starts tracking procedure at special periods of time.

The details of some important features of these blocks are given in Appendix B.



(a)

(b)

(c)

Fig. 7. Simulation results of beacon signal (a) versus variations of azimuth, (b) elevation, and (c) during tracking procedure.

VI. REAL TIME IMPLEMENTATION OF THE SIMULINK MODEL

To work in the Real Time mode in the first step, the system must be implemented using MATLAB® Simulink. This step has been done in previous section. In the second step the simulink model is prepared to work for practical situation. Since in real situation the beacon signal is received from the antenna, and also the values of Azimuth and Elevation angles are sent or received from motors, it is necessary to use suitable input and output ports for each parameter and use them as such in the simulink model. These features can be found in the RTWT sub index of Simulink library. In the third step, by using the procedures completely mentioned in [12] it is possible to use the simulink model in external mode and start the real time mode operation. After doing these steps our system starts working in real time and we can view each of the desired parameters or change any of them during operation. Results of simulation of the gradient algorithm, applied to the antenna pattern model presented in Appendix A as a received beacon signal, are shown in Fig. 7. In this example, we assume that the antenna axis is in the direction $Az = 198°$ and $El = 52°$ (Maximum Point) and the satellite is drifted to $Az = 198.8°$ and $El = 51.8°$. Also, we assume that $S/N = 40$ dB for the beacon signal.

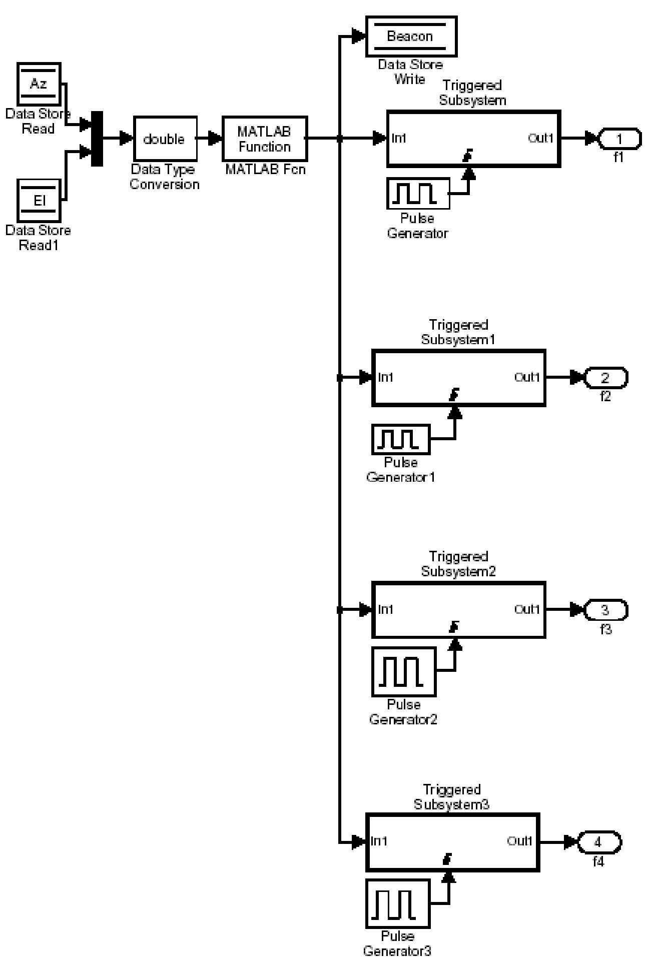


Fig. B-1. Receiving the beacon block.

VII. CONCLUSIONS

A new method for implementing geostationary satellite tracking by using a standard PC and the MATLAB® package has been described. The results indicate that by using the MATLAB® package and its properties it is easy to implement a desired algorithm such as the gradient method to autotracking geostationary satellites. Also, it is possible to change and improve the algorithm without any change in the hardware.

APPENDIX-A

A. Bacon Signal Model

Antenna pattern model is supposed as follows

$$G(Az,El)=20\log(\cos(2\pi(\frac{|\theta|}{\theta_0})) \qquad 0\le|\theta|<\theta_0$$

$$G(Az,El)=20\log(\left|\sin(\frac{|\theta|}{\theta_0})\right|) \qquad \theta_0\le|\theta|<2.718\theta_0$$

$$G(Az,El)=20\log(s)+32-25\log(\theta)-G_0 \quad |\theta|>2.718\theta_0$$

where

$$\theta=\sqrt{(Az-Az_0)^2+(El-El_0)^2}$$

$$s=1-\exp(-((\theta/\theta_0)-2.718))$$

$$\theta_0=3\,\text{dB Beamwidth}$$

$$G_0=on-axis\ \text{Gain}$$

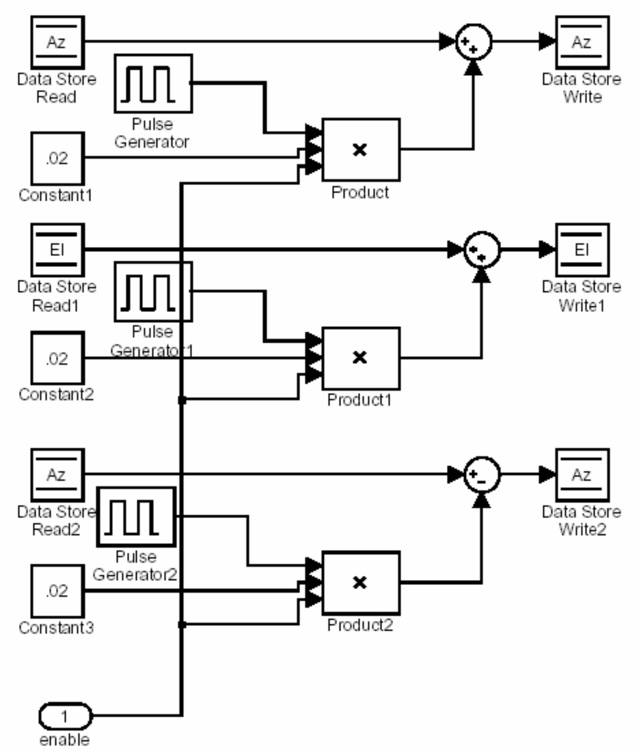


Fig. B-2. Producing steps of azimuth and elevation block.

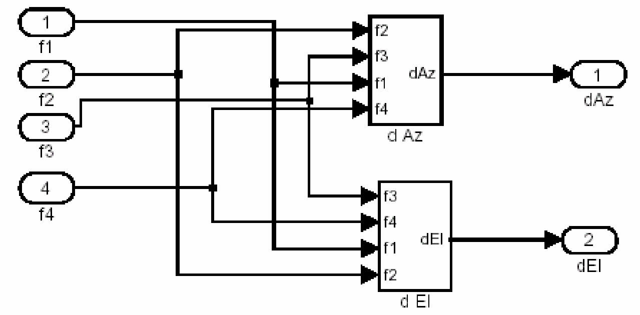


Fig. B-3. Enable signal production block.

Noise model is considered as

$$SNR=20\log(\frac{V_s}{V_n})$$

Bacon Signal=$V_s\times10^{(G/20)}$+Noise

where

V_s : Amplitude of received signal

V_n : Amplitude of noise (Gaussian noise with a mean of zero).

APPENDIX B

Blocks of the Simulink model used in our simulation are presented in Figs. B-1 to B-4.

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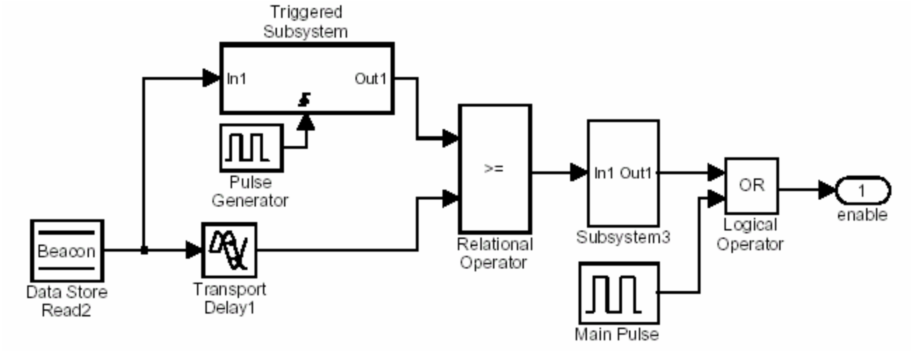

Fig. B-4. Angles displacement block.

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