An Approach to Data Level Target Simulation

Anindita De, Senthil Rengarajan, Rakesh Dand, M. Sheik Althaf
Electronics & Radar Development Establishment
C.V Raman Nagar, Bangalore – 560093 (India)
Tel No.080-25025788 Fax No.080-25242677 aninditade@gmail.com

Abstract:

The Radar Data Processor comprises of a large number of complex algorithms that need to be validated. This paper explains the design of a data-level target simulator which is used to test the Data Processor in presence or absence of a Signal Processor in the radar. It can generate detection reports by using accurate radar detection model for any given target scenario. The target scenario can be defined for single or multiple targets.

The Target Simulator takes target database loaded by the operator and the waveform parameters from the Data Processor as inputs. It performs a correlation between the beam position and the target position. The correlated target’s parameters are processed through a series of algorithms to determine whether a real target with similar parameters will be detected by the radar or not. In case the simulated target gets detected, detection reports are simulated in a realistic manner.

Key Words: Radar cross-section (RCS), Pulse Repetition Interval (PRI), Burst, Dwell

I. INTRODUCTION

The data level target simulator generates detection reports for simulated target scenarios containing single or multiple targets. This acts like a simulated signal processor of the radar for the simulated target. Therefore, even in the absence of signal processor in the radar, the target simulator can generate detection reports for simulated targets in a realistic manner which can be used to test the radar data processor.

II. DATAFLOW OF TARGET SIMULATOR

The target simulator is interfaced with a number of radar sub-systems like Data Processor, Signal Processor as indicated in Fig 1.

Figure 1. Interfaces of Data Level Target Simulator

The target trajectory is sampled at regular intervals and stored in the database. The target scenario is started as per the operator’s instructions. The target parameters included in the database are its position, velocity, acceleration, and RCS. The target simulator indexes into the database according to the elapsed time from the scenario start. The target simulator takes waveform parameters like PRI, pulse width, transmit frequency, and beam position in azimuth and elevation, from the Data Processor as inputs. It performs a correlation between the beam position and the target position. The correlated target’s parameters are processed through a series of algorithms as indicated in the Fig 2.

Figure 2. Dataflow of Data Level Target Simulator

The entire processing is divided into the following steps:

1. Target Selection
   The difference between the target position and beam position is computed and compared against the beam width of the dwell. All those targets that fall within the beam are selected for burst plot generation.

2. SNR Computation
   The target simulator computes Signal to Noise ratio taking into account the target parameters, antenna parameters and simulated system losses as inputs to the range equation. The computation of SNR is done using equation (1) and (2):

\[
P_{\text{rec}} = \frac{P_t G_t P_t \rho(\theta) G_P \rho_P(\theta) \sigma^2}{L_a L_b L_p L_b(4\pi)^2 R^4} \tag{1}
\]

where

- \(P_{\text{rec}}\) : received target power
- \(P_t\) : transmit power
- \(G_t\) : transmit gain of the antenna
$\rho_t(\theta_0)$ : attenuation in the transmit gain as a function of beam steering deflection

$G_r$ : receive gain of the antenna

$\rho_r(\theta_0)$ : attenuation in the receive gain as a function of beam steering deflection

$G_p$ : processing gain

$\theta_0$ : deflection of the beam

$\lambda$ : wavelength of the transmit beam

$\sigma$ : RCS of the target

$L_a$ : atmospheric losses

$L_b$ : beam shape loss

$L_p$ : processing loss

$L_t$ : transmit loss

$R$ : range of the target

$\text{SNR} = \frac{P_{\text{rec}}}{N_t}$ (2)

where

$\text{SNR} : \text{Signal to noise ratio}$

$P_{\text{rec}} : \text{received target power}$

$N_t : \text{thermal noise}$

Amongst the various inputs to the radar equation, fluctuations in the target RCS, processing gain, beam steering attenuation and system losses are simulated online. The antenna patterns are stored in the database. The thermal noise power is computed online according to the waveform bandwidth.

**Computation of fluctuating RCS:** The RCS of the target fluctuates based on the Swerling models. The following Swerling laws are used by the target simulator.

Swerling Case 1 (SW1):

$$p(\sigma) = \frac{1}{\sigma_{av}} e^{-\sigma/\sigma_{av}}$$ (3)

Swerling case 3 (SW3):

$$p(\sigma) = \frac{4\sigma}{\sigma_{av}} e^{-2\sigma/\sigma_{av}}$$ (4)

for $\sigma \geq 0$

Aircraft and missile fluctuating targets with no frequency diversity follow SW1 and SW3 respectively. When there is frequency diversity from pulse to pulse, fluctuations are also observed pulse to pulse. For such fast fluctuations SW2 and SW4 are followed. SW2 and SW4 have the same pdf as (3) and (4) respectively.

To simulate RCS fluctuation, uniform random number that follows the appropriate Swerling law probability density function. A fluctuating RCS is realized by taking the product of the random number from the Swerling pdf and the fed RCS value in the database. The seeds used to draw a new random number are target identification number, the transmit frequency of the radar antenna and the scan duration i.e whenever there is a new scan, a different RCS is computed.

**Computation of thermal Noise Power:** Thermal noise power is computed as:

$$N_t = kTB\nu$$ (5)

where

$N_t = \text{thermal noise power}$

$k = \text{Boltzmann's constant}$

$T = \text{thermal temperature}$

$\nu = \text{bandwidth of the waveform played}$

$F = \text{Noise Figure of the radar receiver}$

**Computation of Beam steering attenuation:** As the beam is steered from the bore sight, there is an increase in the beam width and reduction in the maximum gain. The beam width varies inversely as $\cos\theta_0$ and the antenna gain decreases as $\cos\theta_0$ where $\theta_0$ is the deflection of the beam from the bore sight.

**Beam shape loss:** The antenna gain used in the radar equation is assumed to be a constant equal to the maximum value gain. But the train of pulses returned from the target by a scanning antenna is modulated in amplitude by the shape of the antenna beam. Only one from the complete set of pulses has the maximum gain. Therefore Beam shape loss is calculated to consider the reduction in total signal energy received from a modulated train of pulses compared to what would have been received from a constant amplitude pulse train. Beam shape loss is calculated in the following manner:

$$L_b = \frac{n}{1 + 2\sum_{k=1}^{n-1} e^{-\omega^2 k^2 PRI^2}}$$ (6)

Where

$L_b = \text{beam shape loss}$

$n = \text{number of pulses}$

$\omega = \text{angular speed of the antenna}$

$PRI = \text{Pulse Repetition Interval}$

Beam shape loss is calculated only in case of a rotating antenna. The antenna pattern is approximated by a Gaussian shape.

**Processing loss:** Due to the radar processing chain, the received SNR of the target suffers from some loss which is being considered here. These are sampling loss, encoder loss, CFAR loss etc. CFAR loss is computed as shown in (9).

$$\chi = \frac{(P_d/n)^{1/N}}{1-P_d/n^{1/N}}$$ (7)
\[ \chi_{\infty} = \frac{\ln \left( \frac{P_{fa}}{P_d} \right)}{\ln (P_d)} \quad (8) \]

\[
\text{CFAR loss} = \frac{X_N}{\chi_{\infty}} \quad (9)
\]

where \( P_{fa} \) : probability of false alarm
\( P_d \) : probability of detection

**Processing gain**: The gain obtained in the received waveform due to processing algorithms is coherent and non-coherent integration gain. In coherent integration the samples are added in both amplitude and phase. It is obtained as a result of Doppler processing in the radar signal processor. It is as in (10).

\[
G_C = N_f \quad (10)
\]

where \( N_f \): number of Doppler filters meant for the waveform played by the Data Processor

In case of multiple bursts a non-coherent integration is done across the output of multiple bursts in the radar signal processor. Here only the power amplitudes get added. Non coherent integration gain \( G_{nc} \) is as in (11).

\[
G_{nc} = \sqrt(N_b) \quad (11)
\]

where \( N_b \): the number of bursts in the waveform

These two gains are considered for SNR computation as in (12).

\[
G_p = G_c G_{nc} \quad (12)
\]

where \( G_p \) is the processing gain considered for SNR computation.

**STC correction**: Sensitivity Time Control (STC) helps in preventing the saturation of the receiver with the high power echo received from nearby targets. Based on the range of the target and the selected law STC attenuation is applied on the received echo. To simulate this attenuation in received echo power, STC correction is applied to the SNR computed from the range equation.

3. **Threshold comparison**

The detection threshold is modeled using Numerical technique. SNR computed with STC attenuation applied is compared against this threshold for detection.

4. **Burst plot generation**

Burst Plots or Detection reports are simulated for the detected targets according to Figure 3. The Plot contains a list of target attributes required by the Data Processor to establish the track. The attributes are Range, Azimuth and Elevation of the target, Doppler processing output, the spread of the target in range cells, how good the target’s SNR is for detection etc.

To make the detection simulation more realistic, noise is generated and added to Range, Azimuth and Elevation of the target. To simulate range straddling, true range is added with noise drawn from Uniform Distribution over the range cell and considered for the Plot. Due to Range-Doppler coupling, the radar’s Signal Processor fails to report the true range of the target. To simulate this aspect a range error is computed as a function of radial velocity of the target, transmission frequency and bandwidth of the waveform played as shown in equation (13).

\[
\text{Range bias} = \frac{\tau v_f}{\Delta f} \quad (13)
\]

where \( \tau \): pulse width
\( v_f \): Radial velocity of the target
\( f \): current transmit frequency
\( \Delta f \): Bandwidth of the transmit pulse

Considering the calibration defects in the Sum and the Delta channels, the azimuth and elevation results reported by Signal Processor would deviate from the true angular locations. To consider these deviations, random numbers drawn from Gaussian distribution is added to the true azimuth and elevation of the target.

The spread of the target in range is computed based on the difference between the SNR of the detected target compared to the threshold.

5. **Appending of simulated Burst plots**

The simulated plots are appended to the real target detection reports if any obtained from the Signal Processor. The modified detection reports are sent to the Data Processor.

In the absence of Signal Processor the simulated burst plots are sent to the Data Processor directly.

**III. Results**

The SNR of the detected target computed by the target simulator has been plotted against the target Range and is as indicated in the Fig 5.

**CONCLUSION**

The system is designed, developed, and integrated and is at present operational in the radar. The Data Level Target Simulator is an extremely useful tool to test and validate the Radar Data Processor algorithms with different target trajectories.
ACKNOWLEDGEMENT

We would like to express our thanks to Shri K.T Udayanarayana, Sc ‘G’ for his support and suggestions.

REFERENCES


WEBSITES


BIO DATA OF AUTHOR(S)

**Anindita De:** Born in 1987 at Calcutta, West Bengal, India. Graduated in Electrical and Electronics Engineering from National Institute of Calicut, Kerala. She joined LRDE in 2010. She is currently working on Radar Signal and Data Processing and interests include real-time embedded systems and Modeling and Simulation.

**Senthil Rengarajan:** Born in 1975, Dindigul, Tamil Nadu. Graduated in ECE from National Engineering College, Kovilpatti, Tamil Nadu and M Tech in ECE from IIT Delhi. He joined DRDO in 1996. His interests include Radar Signal and Data Processing, real time embedded system and Radar System Engineering.

**Rakesh Dand:** Born in 1977 at Hubli, Karnataka India. Graduated in Computer Science from MNREC, Allahabad. He joined LRDE in 1999. He is currently working on real-time embedded systems and interests include Artificial Intelligence and Radar Data Processing.