VALIDATION OF THE RANGE TRACKING RESPONSE OF THE TACTICAL ENGAGEMENT SIMULATION SUITE

Introduction

Of primary concern to users of software simulations is the degree to which the simulated system's response matches that of the real system being simulated. This concern is particularly acute when the simulation results may be used in mission critical applications, like the programming of electronic countermeasure (ECM) equipment for maximizing platform survivability in combat. To validate that a software simulation's response matches that of the real system the usual procedure is to measure the response of both the real system and the simulated system using matched input test conditions and then to ensure that the output responses also match.

This paper discusses the validation of the range tracking performance of a Tactical Engagement Simulation Suite (TESS) product to that of an actual airborne interceptor fire control radar. Of particular concern in this validation test activity was determining the degree of match between the simulated fire control radar and the real radar in their responses to the Range Gate Steal (RGS) deception countermeasure.

Hardware In The Loop (HWIL) tests were carried out on an actual fire control radar system using the Electronic Warfare Environment Simulation Facility (EWESF) at Defence Research Establishment Ottawa (DREO). This is a facility in which free-space radiation of target and ECM signals can be generated under computer control in a microwave anechoic chamber and the responses of the radar-under-test can be measured. The radar used in these tests was the MG-13 radar system that was flown operationally on the CF-101 interceptor aircraft. This radar was declassified prior to the aircraft's decommissioning in the late 1970s. The radar is a 1950's vintage fire control system.

The primary purpose of the tests described here was to investigate the behaviour of the radar under ECM conditions, specifically under conditions of range gate steal deception. The first tests were designed to characterize the radar's range tracker by measuring its response to an abrupt small step in the target's range. Subsequently, a number of different range gate steal waveforms were applied to the radar to observe its response to these signals. The ultimate goal of these tests was to support the validation of TTI's TESS simulation software, by comparing the radar equipment's responses to those produced by a matching configuration of TESS model. This paper summarizes the analysis of select data obtained from these tests.

For all of the test results, the first step in the analysis involved filtering (5 Hz cut-off frequency) and then decimating (factor of 40) the data, in order to remove 60 Hz and

400 Hz interference coming from the EWESF power supply. Filtering and decimation were accomplished using Matlab/Simulink[1]. Subsequent steps in the analysis then involved the following activities:

- Analysis of the MG-13 range discriminator;
- Assessment of the MG-13 range servo loop bandwidth;
- Comparison of the MG-13 radar and the TESS simulation software to range gate steal ECM.

The Radar's Range Discriminator

The MG-13 radar is a pulsed radar system capable of tracking targets in range and angle. A key component of its range tracking circuitry is the range discriminator. The MG-13's range tracker tracks targets using a pseudo-split gate discriminator with either nose (leading edge) or tail (trailing edge) tracking modes being user selectable.

Under normal tracking conditions, the radar transmits 450 ns wide pulses. When the radar is nose tracking, the tracking processor allows only the first 275 ns of the pulse through to the discriminator (using delay lines, pulse cancelers and rectifier circuits). When the radar is tail tracking, only the last 275 ns of the pulse are sent to the discriminator.

In the radar's discriminator, the 275 ns incoming pulse is used to produce two pulses. One pulse is an inverted version of the incoming pulse. The other is a time-delayed version of the incoming pulse, delayed by 275 ns. These two pulses are added together to produce a 550 ns pulse whose first half is negative-going and whose second half is positive-going. The time position of this pulse is then compared to that of the MG-13's range gate by integrating the pulse voltage over the range gate's 275 ns time window. A positive result means the gate is lagging the target position. A negative result means the gate is leading the target position.

The performance of the radar's range discriminator is characterized by its discriminator curve, an idealized form of which is shown in Figure 1. This curve depicts the discriminator output signal as a function of the radar's range gate position, referenced to the slant range position of the target.

---

[1] Matlab and Simulink are trademarks of The MathWorks Inc., Natick, N.H.

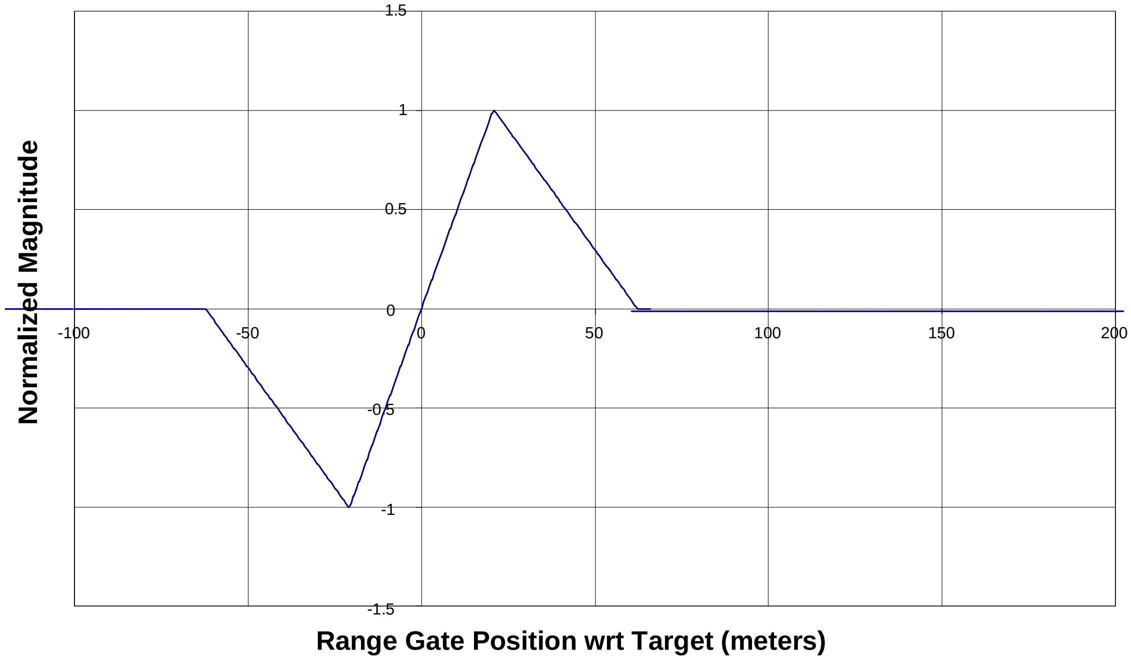

Figure 1 Idealized Single Target Range Discriminator Curve

With the simulated discriminator being based on a conventional split-gate range tracker, its characteristics were adapted to emulate the unconventional range tracker in the MG-13 radar. This was achieved by setting the transmitter pulse width in the TESS simulation to 275 ns and the track's range gate width to 550 ns.

The Radar's Range Servo Loop Bandwidth

Another important radar parameter affecting the response of a range tracker to a range gate steal waveform is the tracker's servo loop bandwidth. The radar's 3 dB range servo bandwidth in TESS products is a user enterable parameter.

To estimate the 3 dB range servo bandwidth of the MG-13 radar, a number of range step response tests were conducted at the EWESF. The results of one such test are shown in Figure 2. At the start of this test, the target being tracked was positioned at a simulated range of 20,000 meters. After approximately 2.4 seconds the target's range position was abruptly increased by 40 meters. At this time the radar's range tracking servo responded by repositioning the target track point. The tracking servo bandwidth was then deduced by measuring the response lag and overshoot of the radar's range tracking point.

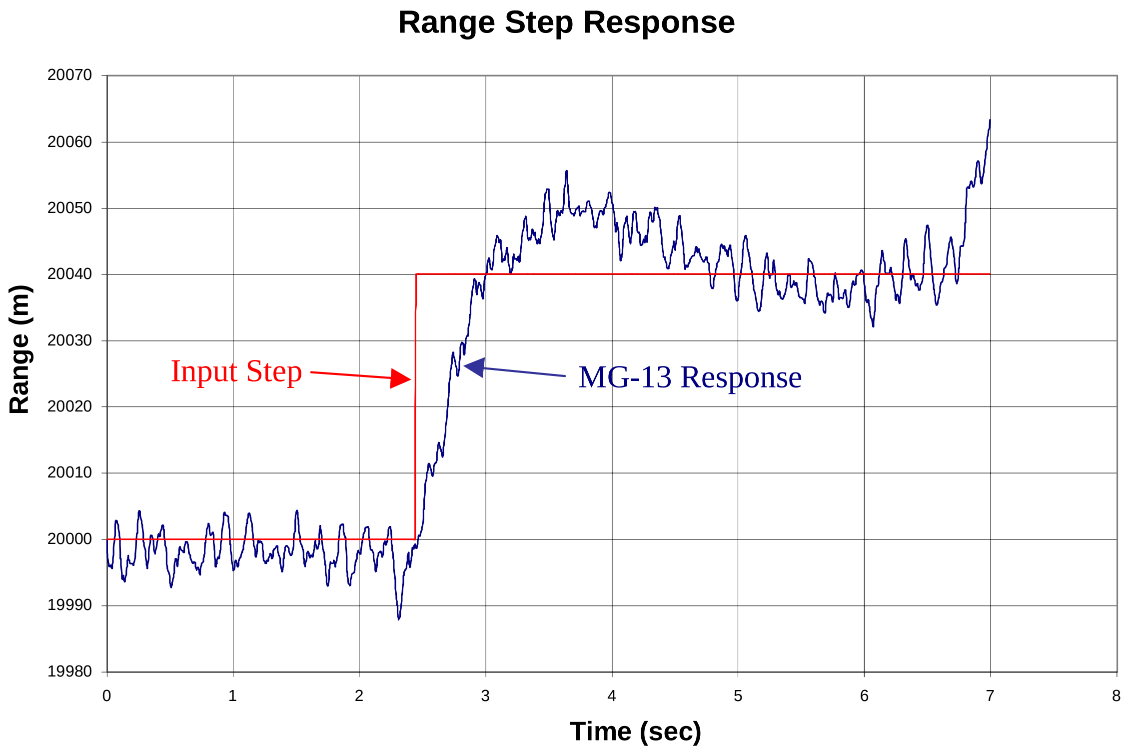

Figure 2 Range Step Response Of MG-13 Radar

Assuming that the MG-13 radar uses a Type I range servo (single integrator in the open-loop control servo), then the servo bandwidth may be assessed by matching the rise time and overshoot of the observed step response to that of an ideal, linear Type I servo system. The ideal Type I servo response has a Laplace transfer function of the form:

$$V_{out} = \frac{\omega_n^{2}}{s^{2} + 2\cdot\zeta\cdot\omega_n\cdot s + \omega_n^{2}}\cdot V_{in}$$

where ζ is the damping factor, ω_n is the natural resonant frequency of the ideal servo, and s is the Laplacian operator. The servo's 3-dB bandwidth may then be calculated from:

$$f_{3dB} = \frac{\omega_n\cdot\sqrt{\left(1-2\zeta^{2}\right)+\sqrt{4\zeta^{4}-4\zeta^{2}+2}}}{2\pi}$$

The resulting Type I linear servo response is depicted in Figure 3. The figure shows four plotted lines. The noisy dark-blue line is the MG-13 radar measured data for a 40-meter range step. The smooth violet line that provides a reasonably close match to the measured radar data represents the response of an ideal Type I servo. The selection of ζ (damping factor) and ω_n (natural resonant frequency) that provides the Type I servo response shown is $\zeta = 0.37$ and $\omega_n = 2.2$ rad/sec. The 3-dB bandwidth for this Type I servo is given by:

$$f_{3dB} = \frac{2.2 \cdot \sqrt{\left(1 - 2 \cdot 0.37^2\right) + \sqrt{4 \cdot 0.37^4 - 4 \cdot 0.37^2 + 2}}}{2\pi}$$

$$= 0.49 \quad Hz$$

The red line with an abrupt step at about 2.4 seconds is the target range step in CJASCM, the TESS model used for the validation comparison. It is perhaps noteworthy that this TESS model uses a feed forward compensated Type II servo with a preset overshoot of 7%. Only one user enterable parameter, the range servo's 3 dB bandwidth, is available in this TESS model to provide a match between the simulated step response and the actual system's step response. The value of 0.49 Hz for the TESS 3 dB servo bandwidth provided the match shown in Figure 3 between the TESS model's (0% to 100%) rise time and that of the MG-13 radar. It is of some interest to note that a 3 dB servo bandwidth of 0.49 Hz for TESS's compensated Type II servo is the same as that also calculated above based on a match to an ideal Type I servo.

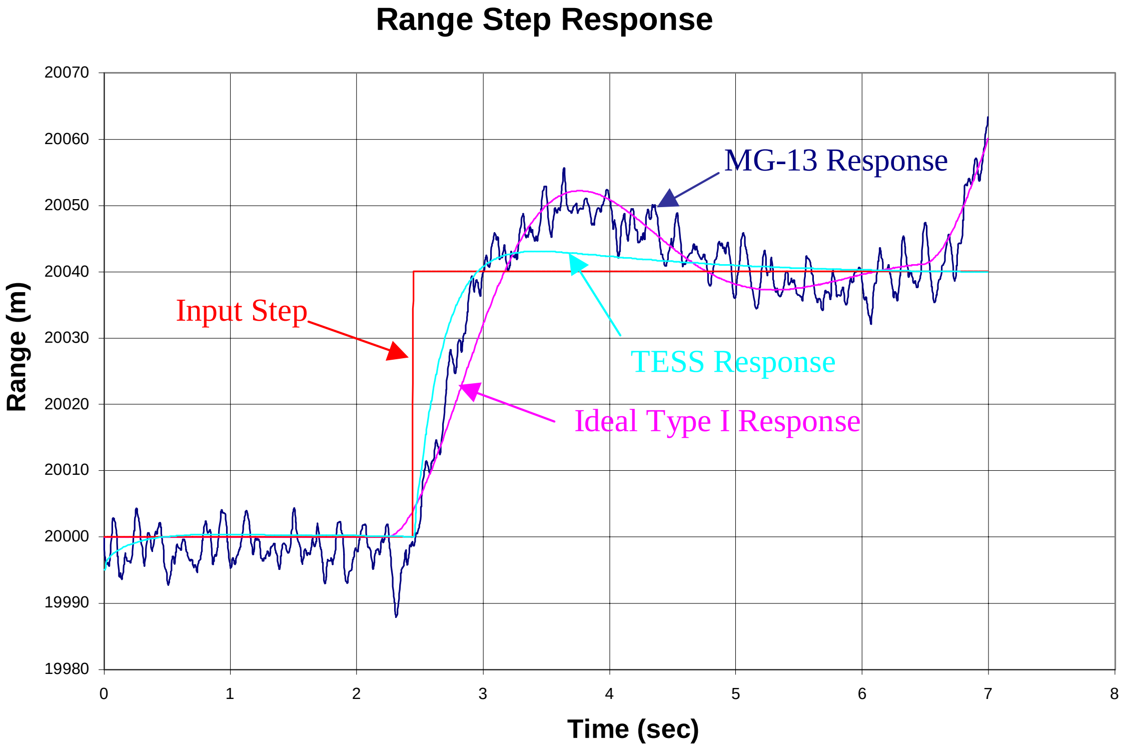

Figure 3 Comparison of Step Responses of MG-13 Radar, Type I Servo and TESS

Comparison of MG-13 Radar and TESS Range Gate Steal Results

The objective of this phase of the analysis was to determine how well the RGS response of TESS's simulated radar matched that of the MG-13 radar. The values of range tracker parameters entered in the TESS model that provide a match to the characteristics of the MG-13 range tracker were as follows:

Pulse Width = 275 ns
Range Gate Width = 550 ns
Tracking Loop Bandwidth = 0.49 Hz
Trailing Edge Bias = 3 dB

The 275-ns pulse width and 550-ns range gate width produced a discriminator curve within TESS equivalent to that of the MG-13 radar as discussed above. The tracking loop bandwidth used was based on the results of the step response analysis also discussed above. The trailing edge bias was entered in the TESS model to represent the tail tracking mode that had been selected during the MG-13 radar test runs. For both hardware and software RGS tests the RGS pulse power equaled the target power (ie. J/S = 0 dB). Comparisons of MG-13 HWIL test results to TESS simulated results for two different RGS velocities are shown in Figures 4 and 5. The RGS velocity used to generate the Figure 4 results was 100 m/sec. The RGS velocity used to generate the Figure 5 results was 120 m/sec.

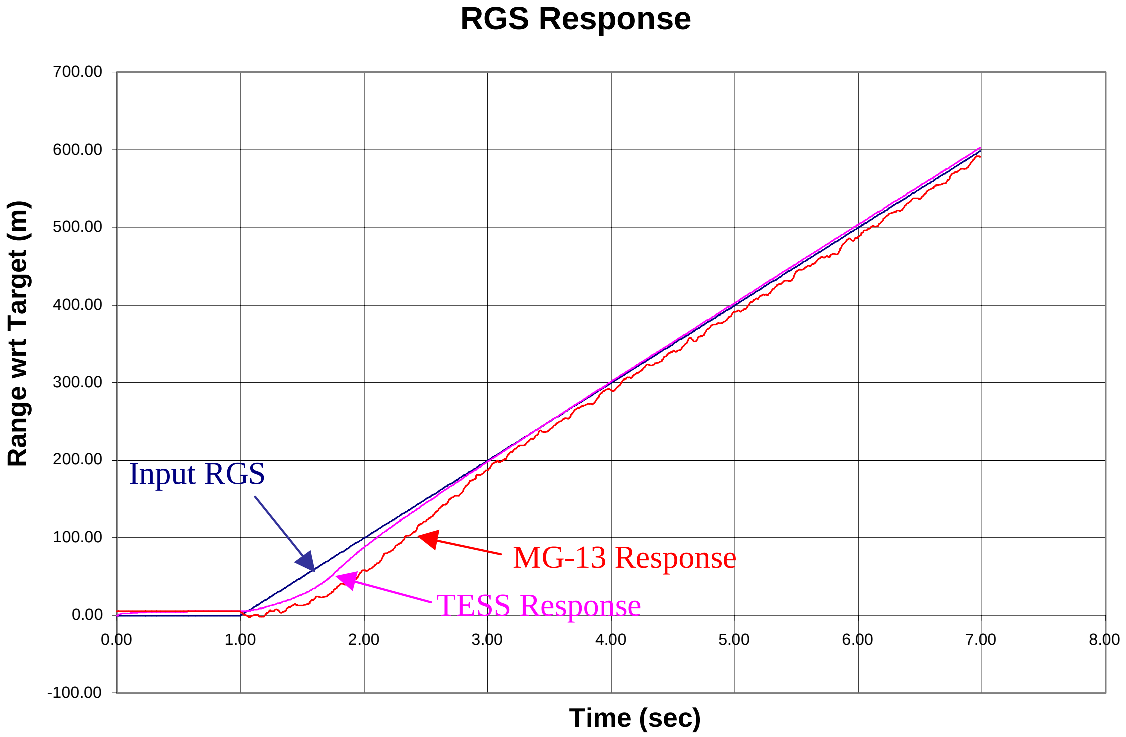

Figure 4 Comparison of MG-13 radar and TESS responses to 100 m/s RGS pulse

The noisy red line in Figure 4 is the MG-13 radar's range tracking response to a Range Gate Steal pulse with a 100-m/sec velocity. (This plot was derived from the measured range voltage data for the MG-13 radar using a conversion factor of 5.56 m/mV as measured in static range calibration tests.)

The other two lines in Figure 4 are from TESS, one being the RGS pulse's range position (blue) and the second being the simulated radar's range track point (violet). These two lines show that during the initial transient time the tracking points for both actual and simulated radars lag the RGS pulse position as expected and each ultimately establishes a small steady tracking error relative to the moving RGS pulse.

Figure 5 shows the MG-13 radar and TESS responses to a 120-m/sec RGS pulse. The noisy red line is again the MG-13 radar response and the TESS response is shown to be a reasonably good match to this.

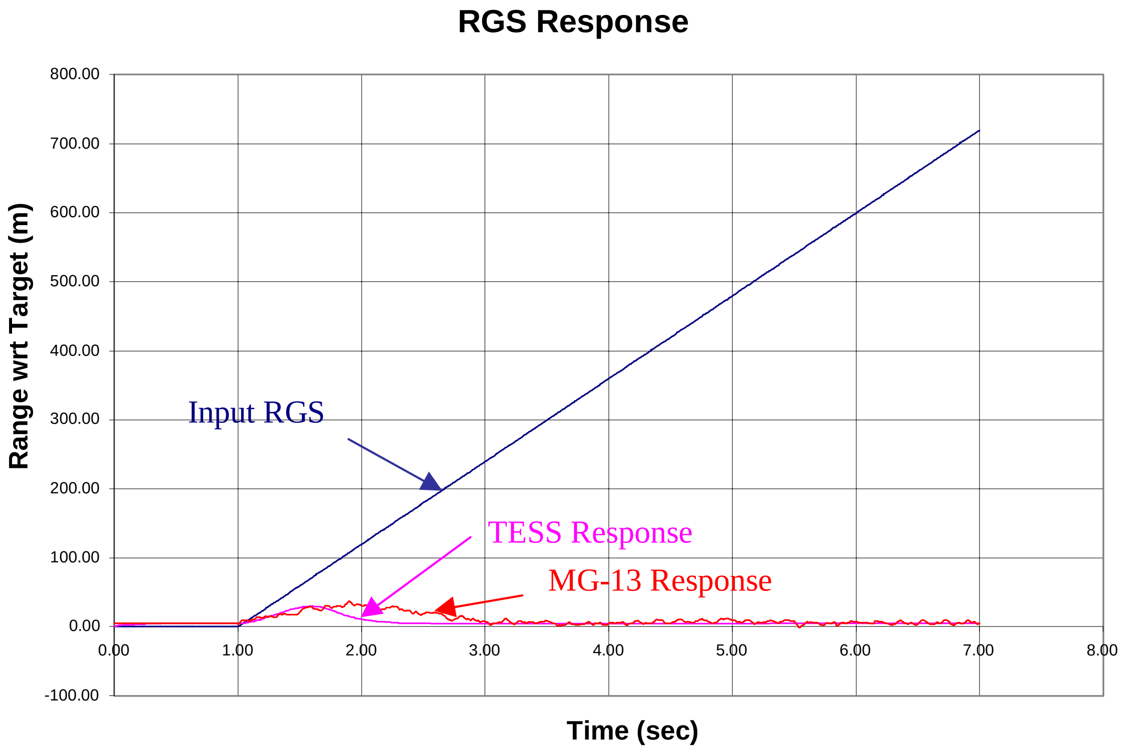

Figure 5 Comparison of MG-13 radar and TESS responses to 120 m/s RGS pulse

The RGS pulse moving at 120 m/sec was not successful in causing range deception (range track lock transfer to the RGS pulse) against either the hardware MG-13 radar or the simulated radar. The TESS simulation was a little more responsive in the sense that it settled more quickly to the target position than the MG-13 radar. However, the basic form of the responses was the same with each being biased somewhat toward the RGS pulse but ultimately each falling back to the target's position.

Conclusions

The fundamental conclusion from these tests is that TESS's simulated range tracker behaves the same way that the MG-13 radar's range tracker behaves. The match is sufficiently good that the 100 m/sec RGS deception successfully resulted in track lock transfer to the RGS pulse in both hardware and simulation tests but was unsuccessful in both with a velocity of 120 m/sec. This provides substantial evidence of valid range tracker simulation and strengthens the credibility of the TESS simulation.

Acknowledgement

We would like to thank DND's Defence Industrial Research Program which provided 50 percent funding for TTI's involvement in the work described here under DIR Contract #W2207-6-EC01. We would also like to thank DREO management and the staff of DREO's EWESF, for supporting and conducting the hardware in the loop test portion of this work.