RF TARGET AND DECOY SIMULATOR

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ABSTRACT

RF guided missile developers require flight simulation of their target engagements to develop their RF seeker. This usually involves the seeker mounted on a Flight Motion Simulator (FMS) as well as an RF target simulator that simulates the signature and motion of the target. Missile defense developers, whose job it is to defend against guided missiles, require a similar test environment adding the ability to insert decoy RF targets that can spoof the seeker. Both seeker development and counter-measure development can benefit from an RF test facility that can provide RF targets and decoys controlled by a real-time simulation.

This paper addresses an RF Target and Decoy Simulator developed by MI Technologies that provides this test capability. The direction of the target and decoy emitters is independently controlled such that the centerlines of their radiated main antenna lobes are always directed at the RF seeker. Each emitter can be independently and simultaneously commanded along a spherical surface. High rates of acceleration and velocity are achieved all the way out to the ends of the test area to simulate the high line of sight rate that occurs at missile closure. The simulator is capable of safely stopping a decoy racing to the ends of the target area with minimal over-travel. Collision avoidance provisions prevent target and decoy from damaging each other during the simulation.

The paper presents a description of the simulator, pertinent tradeoffs considered in the design and accuracy data of the simulator's performance.

Keywords: RF Target Simulation, Precision Dynamic Positioning.

1.0 Introduction

The RF Target Simulator needed to be low cost and fit snugly into a volume defined by the dimensions of an existing anechoic chamber. Hydraulic powered scanners exist that achieve extremely high dynamic motion but they are large and expensive. RF Target Simulators exist that use an array of emitters to simulate target motion. However, the complexity and cost of a bank of emitters to provide the flexibility of desired target motion would be prohibitive. The approach selected for this simulator balanced cost and size while effectively providing the required dynamic response.

The RF Target Simulator technical challenges included maintaining the centerline of the main lobe of the horns always directed at the RF seeker while traversing across a 10ft by 10ft test area (see Figure 1), and limiting the scanner to a depth of only 18 inches.

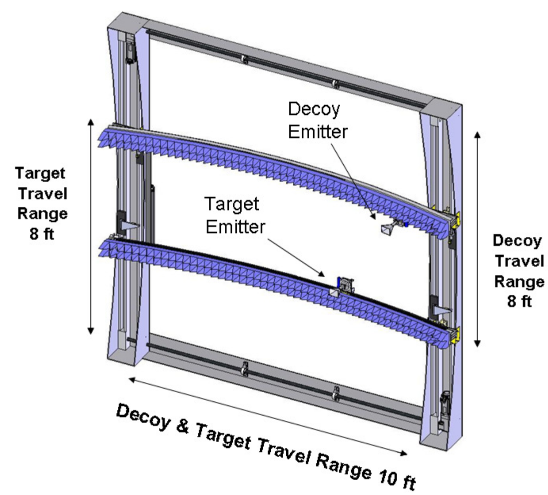

Figure 1 Target Area of RF Simulator

2.0 System Description

The RF Target and Decoy Simulator is part of a closed-loop simulation facility in which an RF receiver (Missile seeker) is mounted on a flight table and RF signals are transmitted from two RF horns at one end of an anechoic chamber toward the receiver. One of the horns simulates the RF return of the target and the other horn represents the RF signal emitted from a decoy. The two horns travel independently on the same spherical surface in order to maintain a constant radius to the RF receiver. The RF

Target & Decoy Simulator consists of the following main subsystems;

X-Y Positioner

- 2 Curvilinear Vertical Rails
- 2 Curvilinear Horizontal Rails with carriage
- Manual roll positioner with coaxial rotary joint and horn attachment bracket
- Associated Motors, Drive Mechanisms and Encoders
- Associated Control and RF Cables
- Cable Management Hardware
- Limit Switches and End Stop shock absorbers
- Absorber treatment

Position Controller

- MI-710 Position Controller
- Local Control Terminal

Figure 2 is a block diagram of the system showing the main subsystems and interfaces to the flight simulation computer and associated equipment. Figure 3 shows the layout of the chamber with the System installed.

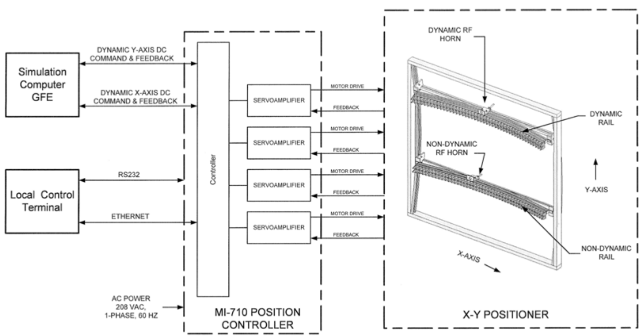

Figure 2 RF Target & Decoy Simulator Diagram

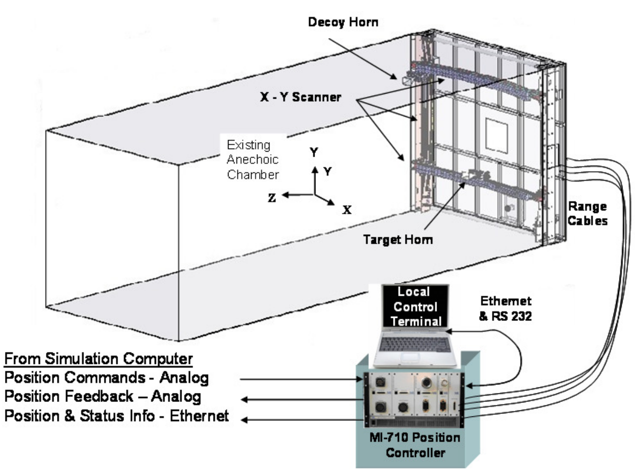

Figure 3 Chamber Layout

The Position Controller receives commands from the simulation computer to move the horns and closes the servo loop to precisely respond to static positioning commands (via Ethernet link) or dynamic positioning commands (via real-time analog signals). The controller reports current position and other status information back to the simulation computer via Ethernet at rates up to 1,000Hz. It also reports current position via analog signals.

The horns can be pre-positioned to simulate a variety of engagement scenarios. In a typical scenario, the horns are placed initially at essentially the same position (same position in X with a small offset in Y). As the engagement begins the decoy is moved away from the target, first slowly and then with increasing acceleration and velocity as missile closure is simulated. The target can stay stationary or be commanded to move to another position. The decoy races to the end of the test area achieving its maximum acceleration and velocity as it reaches the maximum travel in the X and/or Y direction.

The roll position of each horn can be manually adjusted to change its polarization. Rotary joints are used to facilitate this operation. The user interface to the simulator is via web pages that are generated by the controller. Therefore, any computer with a web-based browser can be used to control the simulator and/or monitor its operation. The installed system uses a laptop computer as a local controller to compliment the simulation computer.

The Missile Seeker or counter-measures developer can utilize the system to test counter-measure or counter-counter-measure techniques. Various target engagement scenarios can be implemented achieving target or decoy velocities of 24 and 32 in/sec (Y-axis, X-Axis respectively) accelerations of 12 and 20 inches/sec^2 (Y-axis, X-axis respectively), dynamic positioning accuracy of 0.2 and 0.5 inches (Y-axis, X-axis respectively) and squint accuracies (angle of main lobe from horn to seeker) of 0.5 degrees. The RF simulator currently supports testing up to 26.5 GHz. An upgrade to 40 GHz is available.

3. Keeping the Main Lobe on Seeker

It is important to keep the centerline of the main lobe of the horns always pointing at the Seeker. Two possible configurations were considered to achieve the desired directivity as the Decoy and Target horns traverse across the test area: (1) Straight linear rails where the squint angle of the horns are dynamically adjusted in two axes to always point to the seeker and (2) Curvilinear rails with a radius of curvature such that the seeker is at the center of curvature. Design considerations that needed to be taken into account in making the decision included the dynamic motion requirements, the maximum allowed depth of the scanner (18 inches), the complexity of the cable management system and the complexity of the drive assembly.

Straight rails have the advantage of simplicity in the drive mechanism and depth of scanner. Straight rails allow use of highly responsive linear drives. They would also take up the least amount of depth. The disadvantage is that a squint mechanism would be necessary adding two more axes of motorized control per horn, in order to keep the horns pointed at the seeker. This would add much mass to each horn's carriage and add complexity to the cable handling, both to the detriment of dynamic positioning. The geometry of the commands for X and Y would be straight forward, but the geometry of the commands for the squint axes would be complex. The proper squint commands would be a function of actual X and Y position with the possibility then of compounding errors.

Curvilinear rails preclude the need for motorized squint axes and hence minimize the mass of the carriage. The number of cables required at the carriage is reduced, but the complexity of the cable management remains due to carriage motion along a curved path. It allows the geometry of the X and Y commands to remain reasonable and keeps error sources in each axis independent of each other. However, the curvature of the rails adds depth to the system and the drive mechanism becomes more complex.

The solution was to use a hybrid of the two candidate approaches. The X-axis motion for each horn was achieved using a carriage that rides along a curvilinear rail. The mass of the carriage is minimized containing the horn, a waveguide to coax adapter, an RF path thru a rotary joint and a small rotary motor and drive mechanism. The drive mechanism consists of a curved rack mounted to the curved rail in a rack and pinion implementation. Minimum weight is critical to dynamic performance. To achieve the necessary stiffness at minimum weight, the rail and rack are mounted to a structure made of carbon composite material. In order to provide highly dynamic and responsive motion in the Y direction, the entire X-axis assembly, rail and carriage must be capable of being easily moved up and down.

A hybrid solution was used for the Y motion. The drive mechanism was implemented along a linear axis using highly responsive and powerful linear motors. However, the carriage rides along a curvilinear rail and is connected to the linear drive mechanism via a coupling that allows it to rotate as it rides the curved rail. In this way, the advantages of a linear drive mechanism are achieved without the disadvantage of needing a motorized squint mechanism. As the carriage rides the rail driven thru the coupling by the linear drive, its squint position in the Y-axes is automatically and correctly adjusted mechanically.

The X-axis implementation is identical for both horns. Both X-axis rail assemblies ride up and down on the same pair of Y-axes curvilinear rails. In this way, each horn maintains its directivity toward the seeker throughout the simulator travel range.

There is another advantage of the selected approach using curved rails. Since the target and decoy horns travel the test area along a common sphere with a constant radius to the target, the phase front of the RF signals emitted by the target and decoy horns will be the same and constant when positioned anywhere on the sphere as received by the seeker. This would not be the case if the target and decoy moved along linear rails. Their phase front as seen by the seeker would be constantly changing as they moved to different positions. Though constant phase front was not a requirement in this implementation, the selected design approach provides this feature allowing the developer to take advantage of it should it become useful or necessary.

4. Collision Avoidance and End of Travel

Since the X axis rail assembly of each horn travels the same path on the same pair of Y axis rails there is opportunity for them to collide. Both horns can be positioned at the same X position simultaneously but obviously not in Y. There is always a minimum Y separation that must be maintained. The controller software dynamically monitors the position of each horn. If the horns violate the safe minimum separation distance, even when moving at maximum velocity and acceleration, the servo system is designed to stop motion before collision. Limit switches and inter-axis constant force shock absorbers are used as a back-up to prevent damage as shown in Figure 4.

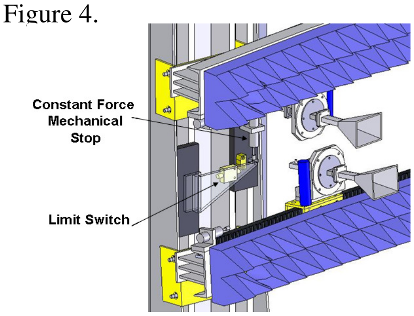

Figure 4 Collision Avoidance Hardware

The X-Y dimensions of desired simulator travel uses up most of the available space in the chamber. Therefore, the horn has very little space in which to stop, only 1 inch, after reaching the end of travel in either the X or Y direction. When an end of travel limit switch is encountered, a high deceleration routine is performed to bring the horn to a quick stop. Constant force shock absorbers are used as a backup to prevent damage.

5. Co-ordinate System

The FMS on which the Seeker is mounted, is an Elevation-over-Azimuth positioner:

FMS Elevation Angle = ELF_{MS}
FMS Azimuth Angle = AZF_{MS}

The above angles can be transformed into k-space direction cosines as follows,

$$k_x = \sin(AZ_{FMS}) \cdot \cos(EL_{FMS})$$

$$k_y = \sin(EL_{FMS})$$

$$k_z = -\cos(EL_{FMS}) \cdot \cos(AZ_{FMS})$$

The Curvilinear XY Scanner, on which the Target and Decoy are mounted, is an Azimuth-over-Elevation positioner:

Scanner Azimuth Angle = AZ_S
Scanner Elevation Angle = EL_S

The scanner angles can be transformed into k-space direction cosines as follows,

$$k\prime_x = \sin(AZ_S)$$

$$k\prime_y = \sin(EL_S) \cdot \cos(AZ_S)$$

These direction cosines can be related to the FMS direction cosines as follows,

$$k\prime_x = k_x \cdot \frac{R}{A} = \frac{R}{A} \cdot \sin(AZ_{FMS}) \cdot \cos(EL_{FMS})$$
$$k\prime_y = k_y \cdot \frac{R}{A} = \frac{R}{A} \cdot \sin(EL_{FMS})$$

Where, A is the distance from the scanner focal point to an arbitrary point on the spherical surface of the XY scanner and R is the distance from the FMS gimbal point to the same arbitrary point. R is computed as follows,

$$R = -12k_z + \sqrt{144k_z^2 + 102736.5625}$$

The curvilinear coordinates (along the X-curved and the Y-curved axes) are defined as follows,

$$X_C = 328.80 \cdot AZ_S$$

$$Y_C = 331.75 \cdot EL_S$$

Where 328.80" is the radius of the X-curved axis, and 331.75" is the radius of the Y- curved axis (feedback for the respective axes are read at these radii.)

From the above equations, the relationship between the curvilinear coordinates and the FMS pointing angles are derived as follows,

$$X_C = 328.80 \cdot \sin^{-1}\left[\frac{R}{A} \cdot \sin(AZ_{FMS}) \cdot \cos(EL_{FMS})\right]$$

$$Y_C = 331.75 \cdot \sin^{-1}\left[\frac{R}{A} \cdot \frac{\sin(EL_{FMS})}{\cos\left\{\sin^{-1}\left[\frac{R}{A} \cdot \sin(AZ_{FMS}) \cdot \cos(EL_{FMS})\right]\right\}}\right]$$

Equations for X_C and Y_C can be used by the simulation computer to command the RF target simulator to place the target and Decoy at desired positions relative to the FMS azimuth and elevation angles (AZF_{MS} and ELF_{MS}).

6. Performance Measurements

A series of tests were performed during Factory Acceptance and On Site Acceptance to verify functionality across the complete range of performance requirements. The data included in this paper are results associated with the accuracy of directing the RF signal of the Target and Decoy horns to the seeker.

A Faro Tracking Laser X was used as the independent measuring system to measure positioning accuracy. The FARO Laser Tracker (by FARO Technologies, Inc.) is a portable measurement system that uses a laser beam to accurately measure distances. The tracker utilizes a laser distance meter and two high accuracy rotating axes to track the exact position of a mirrored spherical probe (Spherically Mounted Retro-reflector, SMR) that is in contact with the object being measured. The high accuracy encoders measure the azimuth and elevation angles of the laser beam, while the state of the art laser technology determines the distance from the tracker head to the SMR. Figure 5 shows a typical FARO Laser Tracker system and a SMR. The system, along with dedicated software, aids in the measurement and alignment of parts, assemblies, and systems.

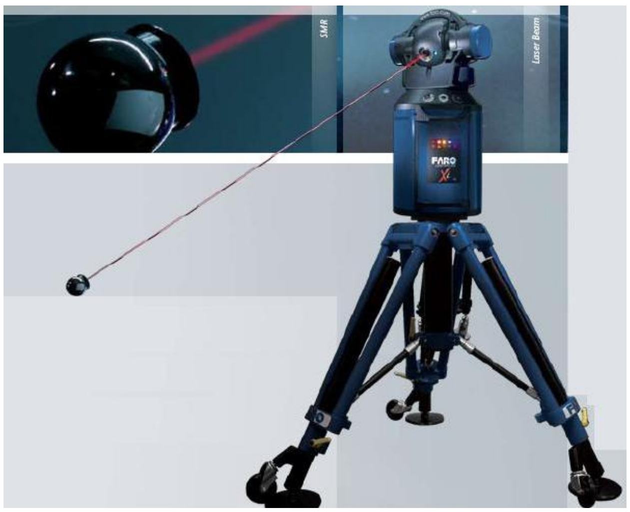

Figure 5 Laser Measurement System

The Faro's retro-reflector was mounted to the coax to waveguide adapter on the manual roll axis using a bracket and an SMR nest, as shown in the following picture. This was done for both the Target and the Decoy. The Faro laser tracker is then used to measure the actual position of the SMR.

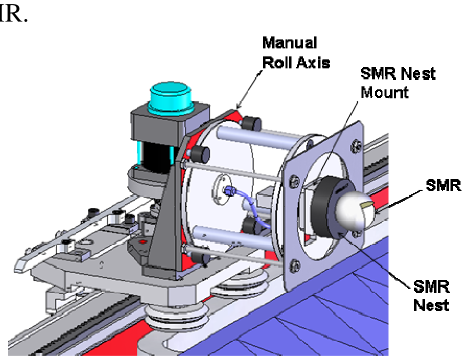

Figure 6 SMR Placement

For static positioning accuracy testing, each horn was commanded to various positions in their travel range on a grid of approximately 6 inches in each axis. The X-Y position measured by the laser was compared to the commanded position to verify accuracy within acceptable limits (X $\leq$ 0.2 in., Y $\leq$ 0.5 in. with repeatability of $\leq$ 0.1 and 0.2 in. respectively).

Table 1 Measured X & Y Positioning Error

Measured	**Error**	**Repeatability**
X-Axis Positioning	$\leq$ 0.10 in.	$\leq$ 0.014 in.
Y-Axis Positioning	$\leq$ 0.19 in.	$\leq$ 0.020 in.

Using the position measurements the axial line of sight for each RF horn for each position was calculated verifying that the squint angle to the seeker was in acceptable limits (Squint angle $\leq$ 0.5 deg with repeatability of $\leq$ 0.1 Deg.).

Table 2 Achieved Squint Accuracy

Measured	**Error**	**Repeatability**
Squint Angle in X	$\leq$ 0.031deg.	$\leq$ 0.007 deg.
Squint Angle in Y	$\leq$ 0.034 deg.	$\leq$ 0.007 deg.

The simulator is required to maintain this accuracy and repeatability during dynamic motion. Figure 7 shows the system during dynamic testing without absorber treatment applied.

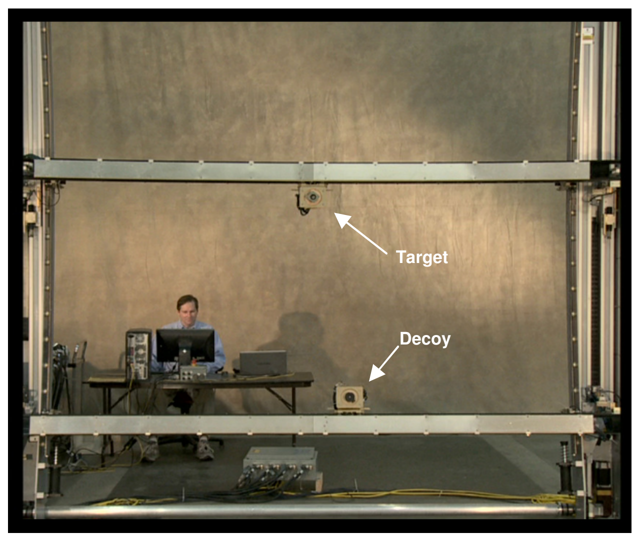

Figure 7 Dynamic Testing of the Simulator

For dynamic accuracy testing, pre-established position versus time commands were sent to the controller, representative of those that would come from the simulation computer in a typical target engagement that exercise the velocity and acceleration required of the simulator. The Faro Laser Tracker was used to measure achieved position versus time and this was compared to the commanded position. Weight was added as necessary to the carriage to properly simulate the mass of the horn.

Figures 8 and Figure 9 show plots of the flight path of the Decoy vs. Time in the X and Y Axes respectively, as measured by the laser. Also plotted in each figure are the Commanded Flight Path vs. Time and the flight path as measured by the scanner's encoder feedback. In Figure 8 the plots lie on top of each other through the simulation until the scanner's velocity limit is reached in the X-Axis. This occurs toward the end of the engagement when the simulated line of site rate from the seeker to the decoy grows very fast. At this point, the plot of the laser measured and encoder measured positions in the X-axis start to deviate from the commanded position as expected.

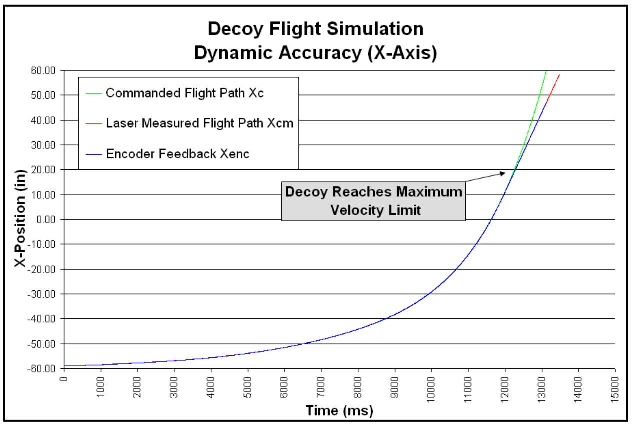

Figure 8 X Axis Position Vs Time Plot

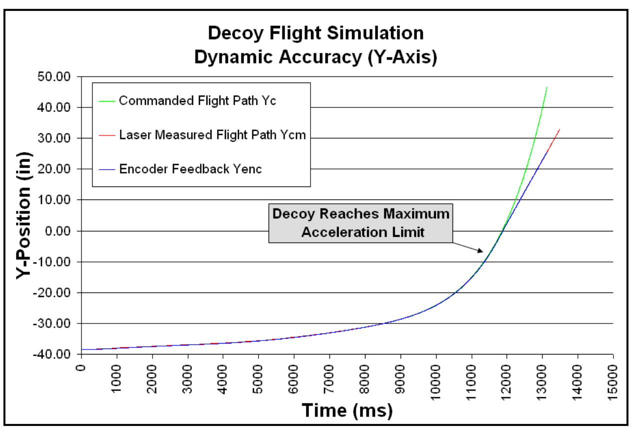

Figure 9 Y Axis Position Vs Time Plot

Similarly, in Figure 9, the plots lie on each other through most of the simulation until the scanner's acceleration limit is reached in the Y-Axis. Again this occurs toward the end of the engagement when the line of site rate from the seeker to the decoy grows rapidly. At this point the plot of the laser measured and encoder measured positions in the Y-axis start to deviate from the commanded position as expected.

Figures 10 and 11 give a better view of the dynamic positioning error vs. time. The data shows the system meeting its dynamic accuracy requirement of 0.2 inch in the X-Axis and 0.5 inches in the Y-Axis prior to reaching velocity or acceleration limits. It was necessary to plot the error with upper and lower bounds of uncertainty due to the latency of the laser measurement with respect to the commanded data.

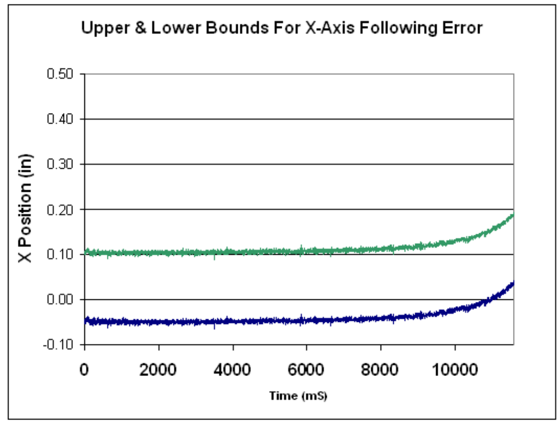

Figure 10 Dynamic Positioning Error X-Axis

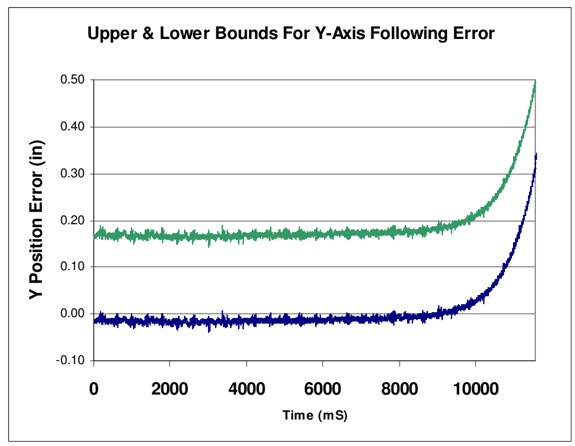

Figure 10 Dynamic Positioning Error Y-Axis

7. Summary

An RF Target and Decoy Simulator has been developed and installed that provides an affordable capability, in a compact area, that allows missile seeker developers to test counter-measure or counter-counter-measure techniques. Various target engagement scenarios can be implemented achieving target or decoy velocities of 24 and 32 in/sec (Y- axis, X-Axis respectively) accelerations of 12 and 20 inches/sec^2 (Y-axis, X-axis respectively), dynamic positioning accuracy of 0.2 and 0.5 inches (Y-axis, X-axis respectively) and squint accuracies of 0.5 degrees. Both the Decoy and Target horns maintain a constant radius to the seeker and therefore a consistent phase throughout the travel range. The RF simulator currently supports testing up to 26.5 GHz. An upgrade to 40 GHz is available.