THE APPLICATION OF RADAR ENVIRONMENT SIMULATION TECHNOLOGY TO TELEMETRY SYSTEMS

Anand Kelkar
Malibu Research Associates

Luc Gravelle
Malibu Research Associates

ABSTRACT

Complete real time testing of a telemetry tracking system typically requires the use of a cooperative target operating under conditions specially set up to simulate actual flight scenarios. This is a very expensive, time-consuming process and does not necessarily exercise all of the functions and capabilities available in new digital antenna controllers. This paper introduces Radar Environment Simulator technology and its application to testing of telemetry tracking systems. Measured results are shown, demonstrating that operational environment simulation is a valuable approach to quickly and effectively characterize the real time operation of a telemetry tracking system.

KEY WORDS

Environment simulation, autotracking, pedestal performance envelope, real time

INTRODUCTION

The tracking functions of a telemetry antenna rely on a handful of inputs that are made available to the Antenna Control Unit (ACU). These signals originate from a set of interactions that the antenna/pedestal has with the target during a tracking event. Natural phenomena such as weather and multipath then modulate the signal before it passes through the antenna and is applied to the receiver terminals and then the ACU.

In the Telemetry Environment Simulator (TES), a virtual environment is created by accounting for all these phenomena in an overall environment model, and concatenating the effects along with the effects of dynamic beam scan to produce an output for consumption by the ACU. The result is that the antenna/pedestal system performs its functions in a controlled environment that is designed to test the limits of the tracking system performance envelope. This technique has long been used in Radar Environment Simulators, for which the technology was developed.

The immediate benefit of the TES is that the performance envelope of a pedestal can be thoroughly measured and characterized by a stand-alone device. This applies to new pedestals coming off the manufacturing line as well as to pedestals that have been in service and require quantitative characterization of performance for a variety of reasons.

A second benefit relates to the newer Antenna Control Unit (ACU) capabilities. Sophisticated control algorithm development which can be now supported in the ACU can be effectively implemented using the TES as an integration tool to measure the dynamic response characteristics of the antenna/pedestal and iterate towards an optimal solution. This allows the controller to squeeze more performance out of an antenna/pedestal system than a classical linear approach would allow.

Considerations For A Virtual Environment

There is a minimal set of signals that need to be considered to create a virtual environment for an ACU:

1) Scan reference signal(s) to indicate the instantaneous scanned position of the beam.

2) The average strength of the received signal (AGC).

3) The modulation imparted to the received signal by the scanning beam (AM).

4) The position of the antenna as reported by some position feedback device, be it encoder, resolver or synchro.

Signals 2 and 3 emanate from the TES and are fed to the ACU under test, while signals 4 and 5 are fed to the TES. Signal(s) 1 depend(s) on the specifics of each unique antenna feed and can emanate from or be provided to the ACU under test.

The application and operation of the Telemetry Environment Simulator (TES) is best described in block diagram fashion.

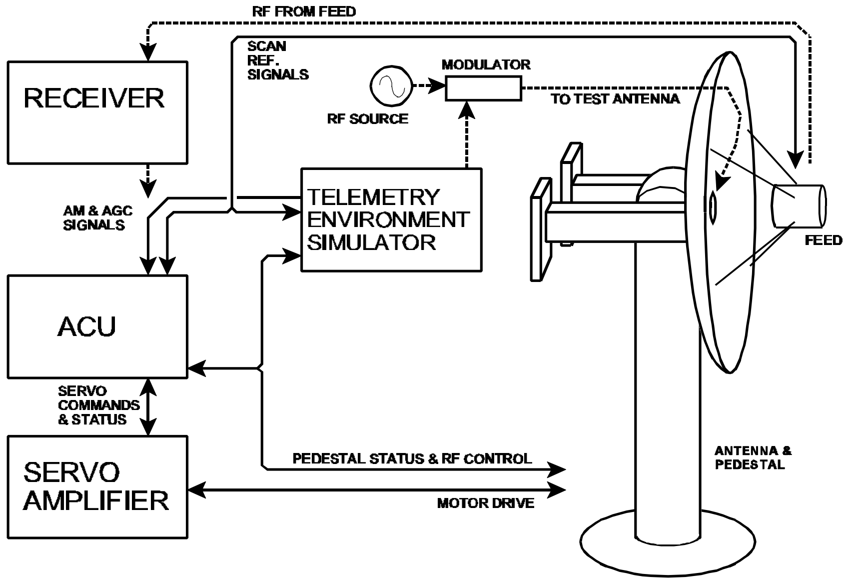

Figure 1 - **Typical Application of Telemetry Environment Simulator (TES). Dotted Lines Show RF Signal Injection Path.**

Typical Telemetry Environment Simulator (TES) Application

Figure 1 provides a schematic representation of how the TES fits into a typical application. The characterization of the antenna/pedestal can happen by using either video signals to inject into the ACU, or at the RF level, injecting signals directly into the feed by means of a small antenna placed in the shadowed region of the feed. In either event the ACU operates in its normal mode, and is unaware of the presence of the TES.

Signal Generation At Video. Here the TES paints the RF environment for the ACU in the form of AM and AGC signals only, based on the feedback from the pedestal position sensor and the RF state of the feed. The RF chain is assumed to be a perfect transmission medium, with negligible contribution to the overall performance of the antenna/pedestal dynamics.

In most Telemetry applications the link is of sufficient fidelity (high SNR and bandwidth >> antenna/pedestal positioner bandwidth) that this level of test is sufficient to characterize the operational envelope of the ACU-pedestal.

Signal Generation at RF. When the overall RF-to-video response needs to be considered in the performance assessment, the TES is used to modulate an RF source and is fed into the antenna feed by means of a small antenna placed in the center of the reflector.

Some antenna systems have a small test antenna used to simulate the downlink. This is an ideal place to inject TES modulated RF signals.

Functional Description of the TES

The functional description of the TES can be broken into 2 portions. The hardware is best described in block schematic fashion as in Figure 2. The computer is a Pentium-100 single board computer. There is a Malibu Research developed pedestal interface board used to translate the pedestal signals, the same as would an ACU, and the multi channel D/A converter board is commercially available. The standard PC power supply, hard disk, floppy and display are used in conventional fashion. A software description of the TES is shown in Figure 3. The code segments are broken in modular fashion to the task level as indicated in the diagram. The simulator has been built in both DOS and Windows 95 environments and uses COTS software to the maximum extent possible. Data display, analysis and database management is provided through a commercially available program suite customized to the TES.

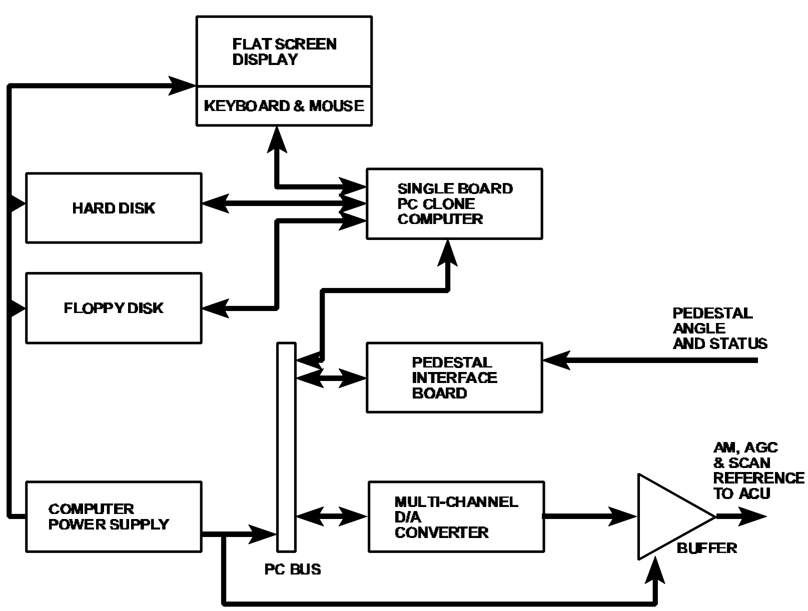

Figure 2 - Functional Block Diagram of TES Hardware

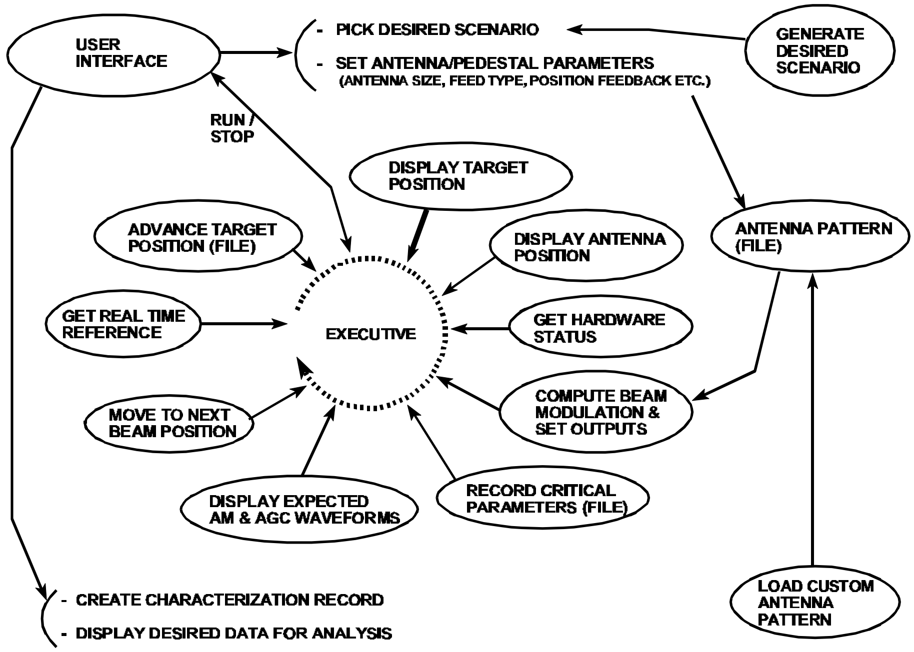

Figure 3 - Functional Description of Telemetry Environment Simulator (TES) Operation

A brief description of each code segment has been provided below.

Code Segment Description

User Interface - Provides all the tools necessary to pick scenarios, control TES functions, and display the collected data. This module is used to configure the TES to fit the application. The antenna size, pedestal type, feedback description and origin of scan reference signals is selected by the user.

Get Real Time Reference - Uses the real time clock to advance the scenario parameters. The present increment is set at 0.1 sec.

Advance Target Position - This advances the scenario that has been placed in program memory by the user interface. During each cycle the timer is consulted. Every 100 mS, the next position in the scenario file is used as the operating target position.

Display Target Position - Here, the target position is simply placed on the screen for user visual feedback.

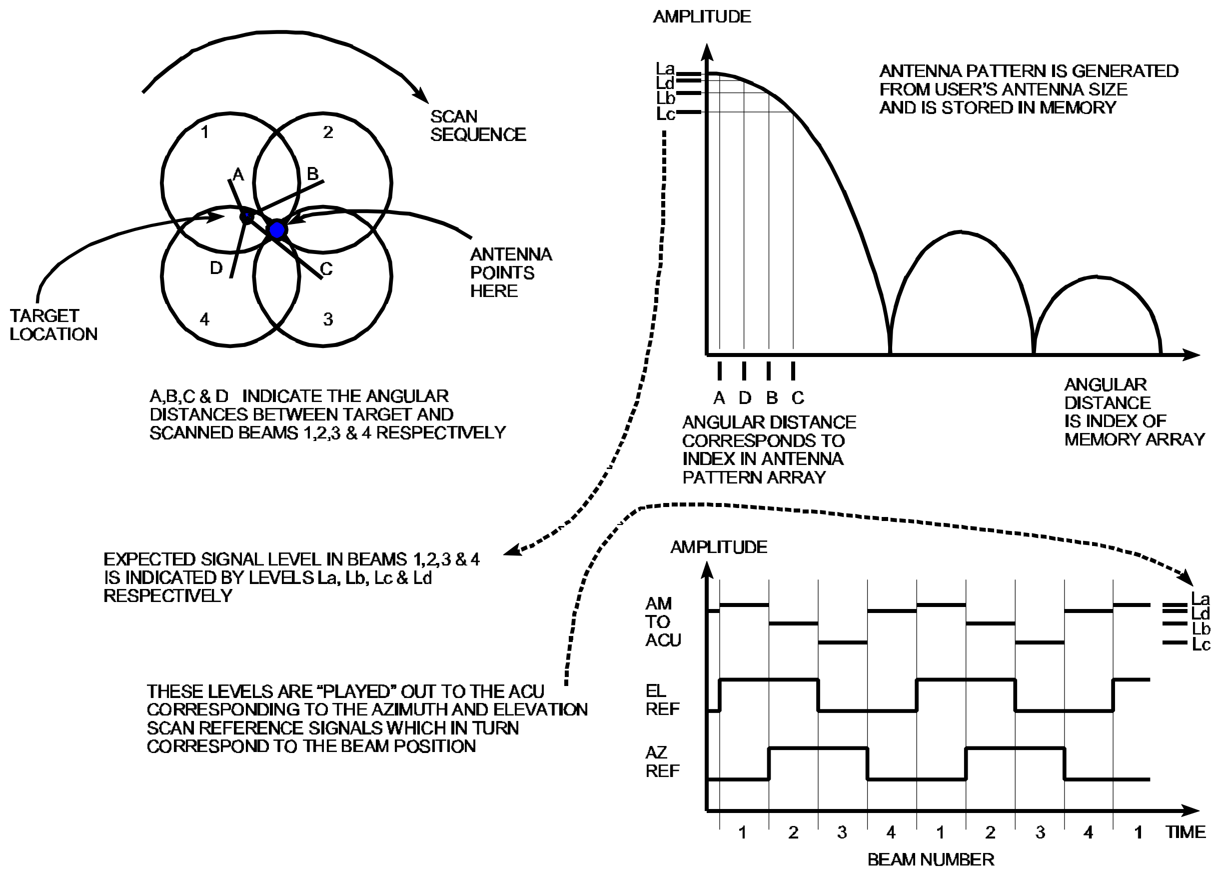

Figure 4 - Pictorial Description of AM Generation in the TES

Display Antenna Position - A similar function places the antenna position on the screen as well.

Get Hardware Status - Some Telemetry systems have multiple antennas, each with different characteristics. This routine allows selection of 1 of 5 antenna patterns on a real time basis.

Compute Beam Modulation and Set Outputs - This routine computes the angular distance between the beam position and the target position, and appropriately weighs the expected target intensity (as read from the scenario file) by computing an index corresponding to this distance and looking up the amplitude on the appropriate antenna pattern file to provide the value to the output port. Figure 4 describes this process. The AGC is derived by exponentially averaging the AM over user defined time constants.

Record Critical Parameters - This routine records the pertinent parameters for display and analysis. The following entities are recorded:

General parameters:	Date and time of test, name of scenario,
Target parameters:	Time, az, el, AGC
Pedestal parameters:	Az, el, antenna state (for multi-antenna systems)

The data is stored in memory and saved to storage media at the end of the scenario. The data is then recalled as desired by the user either through the user interface, or separately through any data analysis or spreadsheet program.

Display Expected AM & AGC Waveforms - The user is provided a visual indication of what he might see on an oscilloscope connected to the AM and the scan references. This display is invaluable during troubleshooting.

Move to Next Beam Position - The TES beam scan sequence emulates that of an electronically scanned feed. The TES is constantly sequencing between its 4 beams, whether the reference signals are provided from the feed or generated internally. This sequence is the basis for generating the AM, which is pictorially described in Figure 4.

How the TES is Used

The TES is driven from an ASCII scenario file that can be generated off-line. In this file, the target is “flown” through the desired path, using time, Az, El and signal strength to describe the target completely. In the development of the TES, we found a useful suite of scenarios that can characterize virtually any pedestal:

a) Stationary target - This scenario proves invaluable when the ACU/pedestal are first integrated as a set. This scenario is the first one that we use in our integration process. The target emulates an RF source at a fixed point in space.

b) Azimuth rate - The target is made to fly around the pedestal at a fixed elevation. Though different accelerations can be used as the target is first made visible to the TES, the most stressful is one where the target is moving at the full rate as soon as it becomes “visible” to the ACU.

c) Elevation rate - Same as “b”, but for the elevation axis.

d) Simultaneous azimuth, elevation operation... both axes simultaneously.

e) Multipath - Here, the target position is purposely dipped below the horizon periodically to simulate a low elevation angle track over water. Though our target has smooth angular behavior, the target position can be made to “glisten” using available surface scattering models, depending on the degree of realism desired.

f) Fade - The signal strength is made to move through nulls of increasing duration. We have found 5 secs to be an acceptable fade duration in the community.

g) Overhead - Here, the target is made to fly through great circles so that the pedestal lies just outside the plane of the great circle in varying amounts. This set of scenarios are specially useful in testing the “plunge” mode on some of our controllers that can track at elevations above 90 degrees.

h) High performance craft - This scenario is especially useful in checking the efficacy of the tracking loop. An “airplane” is flown close to the pedestal so that the angular rates of the target exceed the pedestal’s capabilities, often in the near overhead condition. In some multi-antenna tracking systems, a wider beamwidth acquisition aid antenna takes over until the signal has re-appeared in the main antenna. The TES has the capability to switch antenna patterns as the antenna system wants to test the integrity of this plan. But, in cases where there is no acquisition aid antenna, the tracking loop can predict where the target will be and point the antenna accordingly so as to acquire the target after it has passed through the “caustic” point in the pedestal mechanism.

i) Step, ramp & impulse response - The target is made to go through maneuvers that are impossible in the real world so the classic pedestal responses can be recorded. The importance of this class of tests seems to be fading into the background as the ability to emulate actual scenarios has become available.

i) Frequency response - As the heading implies, the target position oscillates with increasing frequency. The classic “Bode Plot” parameters can be recorded.

Once the scenario suite is chosen, the TES is run with those scenarios and the output is analyzed. From this data set, the pedestal specification parameters are calculated and if satisfactory, the entire response profile is saved as a piece of the internal acceptance test data.

From an overall system sense, application of the TES becomes a powerful tool when an expected target path is programmed, and the tracking error is measured and plotted over the duration of the trajectory, revealing trends or systematic performance nulls in the pedestal coverage envelope.

The productization process of the TES has progressed to the point where the equipment (including the flat panel display) is contained in an equipment case that can be carried on board commercial aircraft. Malibu Research looks to the TES as a vital piece of equipment used to characterize field installations as they happen, and then as benchmarks for quality assurance as the equipment ages in the field.

Tracking Loop Optimization Using the TES

Presented below is a case where the TES has been used to optimize an autotracking loop. The application was a shipboard autotracking system without inertial stabilization. The target acquisition was assumed to have been provided through an external source by a commanded designation. Since the system was fixed on the ship deck, the apparent target position was expected to move corresponding to the motion of the ship.

Simulation of Sea State 5 Dynamics

A sea state 5 motion was simulated for a DDG class ship. This was done by inverse FFT operations performed on a set of random samples. The scenario duration was first chosen, then the expected frequency content was then determined (Ref.1).

Scenario length =	100 secs (arbitrary) = 1000 samples at .1 sec update rate
Expected roll period =	7 secs (Ref.1)
Expected pitch period =	14 secs

The 7 sec period corresponds to approximately 14.5 cycles of roll motion during a 100 sec period. Therefore, the first 145 filters of a 1000 filter frequency domain representation of the ship's roll would have content and the remaining filters would be zero amplitude (See Figure 5).

For computational convenience, 1024 samples were used. When played out this would correspond to 102.4 secs vs the planned 100 secs. Then, the first 145 filters were filled with spectrally weighted random numbers (for both I and Q components) and an inverse FFT was performed. The result was a time waveform representative of ship's roll motion. The peak amplitude was then scaled to the levels indicated in Ref.1.

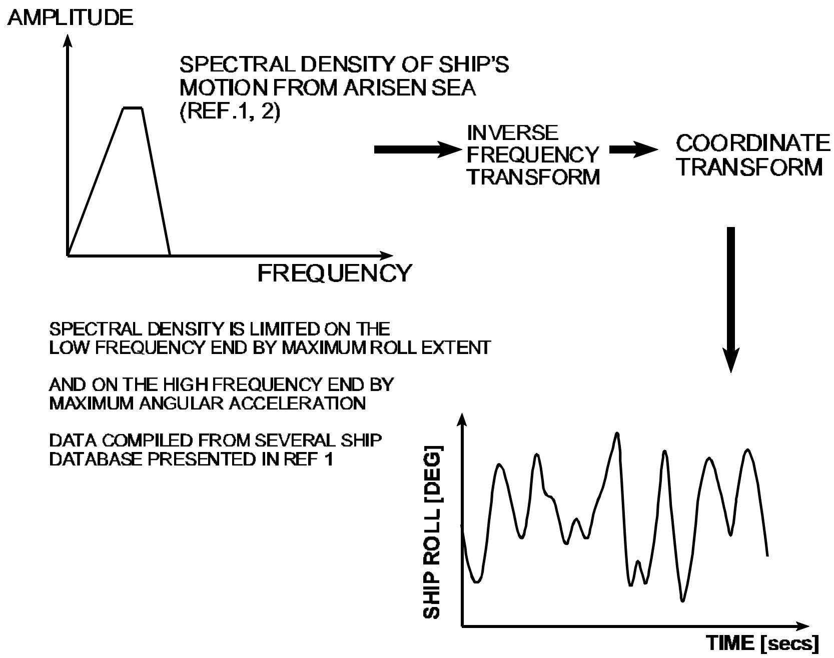

Figure 5 - Pictorial Description of AM Waveform Generation

A similar approach was used to create pitch motion. Then, the 2 axes were properly coordinate transformed to provide elevation and azimuth components relative to the pedestal reference frame. The target, which was relatively motionless for the duration of the test, then appeared to move in the elevation and azimuth antenna axes as a function of the ship's pitch and roll motion. This information was used to generate a scenario file and the autotrack loop was run while the antenna tracked the virtual target.

Figure 6 shows the performance of the tracking loop before it was optimized. The 2 larger magnitude traces describe the apparent path of the target and the antenna's path while tracking the target. The smaller magnitude waveform is the residual error in the track. The antenna beamwidth was approximately 5 degrees, and as can be readily seen, the error magnitude is large, and would cause significant modulation in the received signal, probably resulting in loss of data. In this instance, the tracking loop was purposely made sloppy (low forward gain) to demonstrate the operation of the TES. A typical pedestal autotracking loop properly matched to its mission would have less error residue.

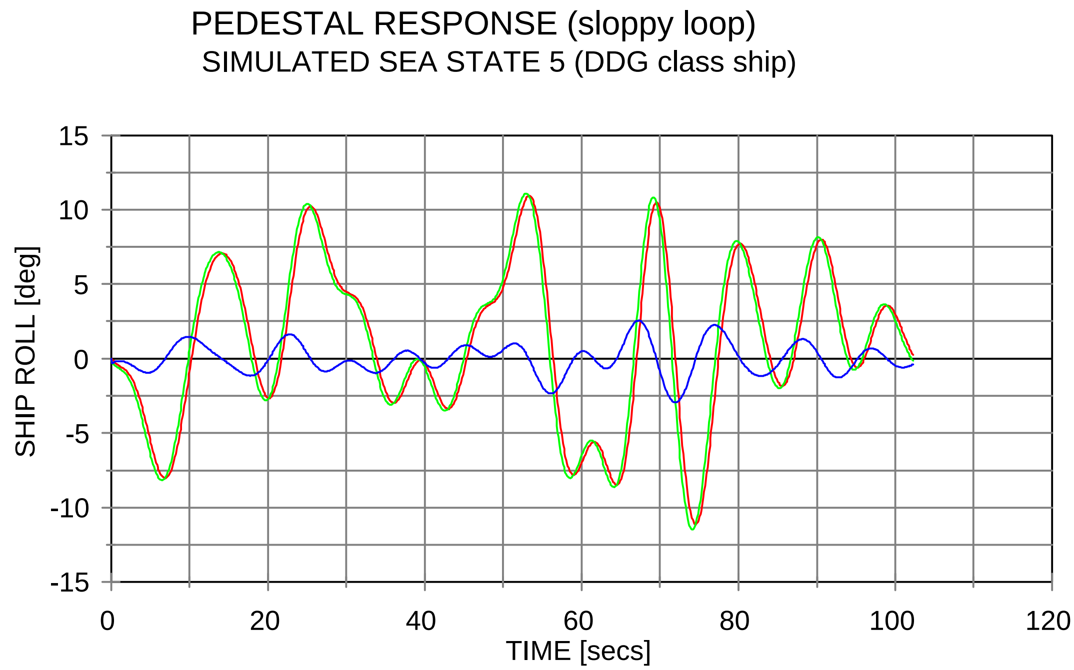

Figure 6 - Pedestal Response in Simulated "Sea State 5" Conditions

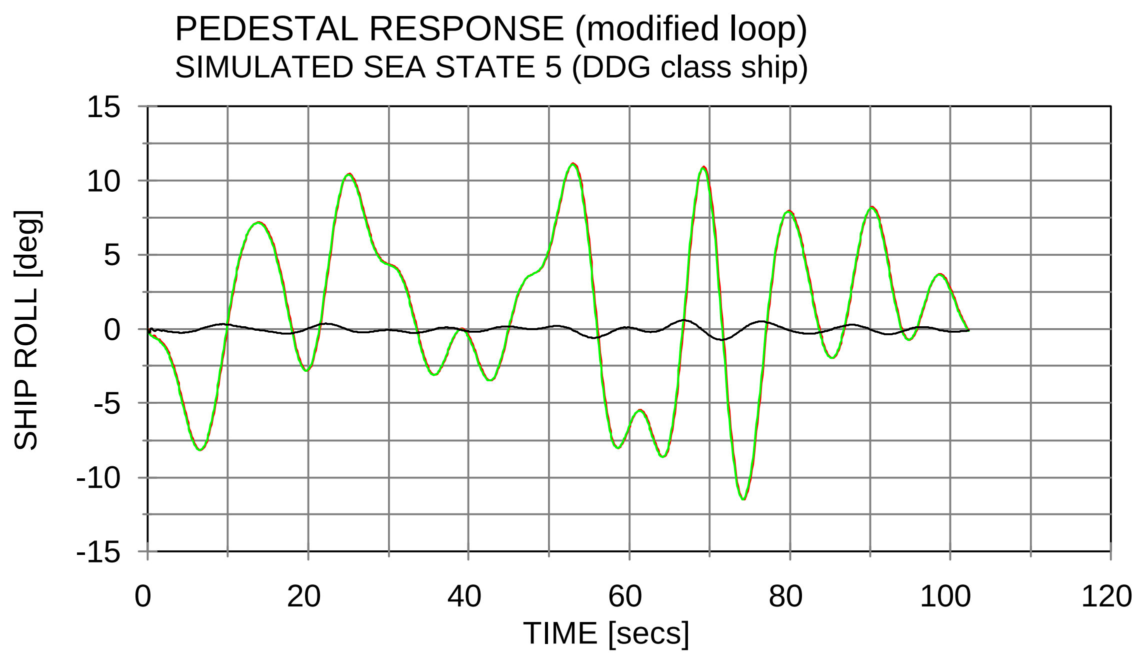

Figure 7 - Pedestal Response Quantifiably Improved With Modified Tracking Algorithm

When the tracking loop was modified to include velocity and acceleration estimates, the pedestal was able to “predict” a change in direction, and was able to keep up with the target even though the loop gain was far from optimal. Note that the two larger amplitude traces in Fig.7 are now virtual overlays, and the smaller amplitude “error residue” waveform is only 20% of what it was in the Fig.6.

This example illustrates how the TES was used to improve the track quality of resource limited pedestal, by iterating on the nature of the tracking loop. The TES was able to provide visibility to the critical parameter, the tracking error, to allow the developer to optimize the outcome.

CONCLUSION

The Telemetry Environment Simulator (TES) approach to Telemetry positioner analysis opens an easy path for exhaustive performance bench marking. A portable TES system not only serves as an efficient field integration tool, but allows quantitative comparison between pedestals. As performance history gets complied, the true “lifetime” of pedestal systems will become apparent, exposing the effects of age induced degradation. The overall quality of the tracking system positioner can then be maintained at a desired level by directly tying maintenance to performance.

REFERENCES

1. McDonald, M., “SHF SATCOM Terminal Ship-Motion Study,” Technical Report 1578, N.L.Hannon Associates, Oxnard, CA, March, 1993

2. “PEDESTAL DESIGN HANDBOOK FOR SHIPBOARD ANTENNAS”, NAVSHIPS publication 0967-303-7070, US Navy Ship Engineering Center, Washington DC.

3. “FIREFINDER RADAR ENVIRONMENT SIMULATOR (RES) SYSTEM”, Technical Proposal in response to US Army solicitation DAAB7-92-R-L622, Technology Service Corporation, Santa Monica CA.