ADVANCED TELEMETRY TRACKING
SYSTEM FOR HIGH DYNAMIC TARGETS

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ABSTRACT
A new advanced 2.4 meter telemetry tracking antenna system allows for successful autotracking of high dynamic targets. The system is designed to work at C, S, and L bands. One of these systems at L/S-band was recently implemented and tested in the field. The testing included tracking aircraft during maneuvers such as rolls, spins, and antenna tower fly-by at high rates of speed.

This paper examines test results and some of the features of the new system that allow for continuous tracking.

KEY WORDS
Flight Test; Telemetry Link; ESCAN; Dynamic Test; L/S-band.

INTRODUCTION
A new telemetry tracking antenna system was developed by ViaSat in partnership with Orbital Systems in order to meet increasing demands in the telemetry field. This system utilizes a 2.4 meter reflector above an Elevation over Azimuth positioner. The system examined in this paper currently uses an ESCAN L/S-band prime focus feed. However, with the shift to the C-band spectrum on the horizon, the system was designed to easily add a cassegrain C-band feed and downconverter for operation at C-band. Features of the new system will be examined, followed by the review of tests performed on the system, which include dynamics testing prior to any aircraft mission and tracking results from test flight campaigns.
SYSTEM OVERVIEW

The outdoor equipment (Figure 1) consists of an L/S-band feed, spars, 2.4 meter reflector, camera, and an Elevation over Azimuth positioner (which houses the tracking receivers, antenna controller, servo amplifiers, motors, and associated electronics). The indoor equipment includes a computer for controlling the system and accessing the camera, a Lumistar receiver, a dehydrator, and a video recorder. A single fiber cable is connected between the indoor and outdoor equipment for communication, along with RF cables for the telemetry data.

Figure 1 - Telemetry Tracking System Outdoor Equipment

SYSTEM FEATURES

The system operates in the traditional L/S-band between 1.4-2.4 GHz, and is designed to work in the new C-band telemetry band between 4.4-5.25 GHz. A prime focus feed is used for L/S-band operation. ViaSat has been providing S-band autotracking antenna systems for over 50 years, and utilized a previous feed design to facilitate autotracking for this new system.

The positioner for the new system (Figure 2) was developed in partnership with Orbital Systems. This new design has improved performance characteristics for both axes in order to autotrack high dynamic
targets. A slipring is used in the azimuth axis (Figure 3) to allow for continuous rotation so that autotrack is not interrupted. The entire positioner is pressurized (along with the rest of the outdoor equipment) via a dehydrator located indoors, allowing for operation of the system in harsh environments for many years.

The indoor computer is used primarily to control the system and access the video stream from the camera. Users control the system by accessing the outdoor antenna controller through a Graphical User Interface (GUI - Figure 4). The computer can also be used to check the status of the outdoor tracking receivers via web interface, as well as check the temperature and humidity within the outdoor positioner.

**SYSTEM DYNAMICS TESTING**

Prior to any tests involving the tracking of targets, automated tests were performed via the controller GUI to ensure that the system could handle tracking high dynamic targets. The system was designed to have performance characteristics of ±60°/s velocity in the azimuth axis, ±45°/s² acceleration in the azimuth axis, ±30°/s velocity in the elevation axis, and ±30°/s² acceleration in the elevation axis. Along with the results of the automated tests displayed on the controller GUI, servo control data from the system itself was recorded during the tests to further analyze the system’s performance.
The results displayed on the controller GUI after the automated velocity testing are shown in Figures 5 and 6. The measured absolute velocities in azimuth and elevation were respectively 59.98 °/s and 30.02 °/s.
For independent verification of the true system performance, the servo control data was examined from all 10 time slices (s₁ through s₁₀ of Figure 5) at steady speed (i.e. ±60°/s and ±30°/s respectively for the azimuth and elevation axes). The measured mean speed (Vm) of each slice was then computed as:

\[ V_m = \sum_{t_k \geq t_{sm}}^{t_k \leq t_{fm}} \left( \frac{V(t_k)}{n} \right) \quad m=[1:10] \]  

(eq. 1)

Where:

- m is the slice number (m = [1:10]);
- Vm is the mean speed of the mth slice;
- t_sm, t_fm are respectively the starting and finishing time of the mth slice (S_i); and
- n is the number of samples of each slice

Then, in conformance with EA-4/02 Standard (EA, 2002), the axis speed error (∆V_j) of each jth stabilized measurement, the associated uncertainty (σ_v) within 1σ confidence level and the mean speed of the entire test (V_t) were computed using:

\[ ∆V_j = \left[ V(t_k) \right]_{t_{sm} \leq t_k \leq t_{fm}} - V_m \quad m=[1:10] \]  

(eq. 2)

\[ σ_v = \pm \sqrt{\frac{\sum_{j=1}^{n} (\Delta V_j)^2}{n} - \frac{1}{n} \left( \sum_{j=1}^{n} (\Delta V_j) \right)^2} \]  

(eq. 3)

\[ V_t = \frac{\sum_{m=1}^{10} [(-1)^{m+1} \cdot V_m]}{m} \pm σ_v \]  

(eq. 4)
Then using acquired data shown in Figures 7a and 7b, the resulting computed absolute speed measurements were 59.99 °/s ± 0.18°/s @ 1σ and 30.00 °/s ± 0.04 °/s @ 1σ respectively for the azimuth and elevation axes.

![Figure 7 - Measured Absolute Speed Results During Velocity Testing, (a) Azimuth; (b) Elevation.](image)

The results of the automated acceleration testing displayed on the controller GUI are shown in Figure 8, yielding 44.91°/s² and 29.68 °/s² respectively for the azimuth and elevation axes.

![Figure 8 - Automated Acceleration Test Results, (a) Azimuth; (b) Elevation.](image)

For independent evaluation of the pedestal acceleration using the measured servo control data, it was necessary to compute the first derivative of the actual pedestal speed and select the slices where the pedestal acceleration was constant (i.e. ±45°/s² and ±30°/s² respectively for the azimuth and elevation axes). This procedure was required due to the lack of direct acceleration measurement in the servo control data set. Therefore:

\[ A(t) = \frac{dV(t)}{dt} \quad \text{(eq. 5)} \]

With data provided from equation 5 the measured mean acceleration \( A_m \) of all 10 time slices (Figure 9) was computed using:  

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6
\[ A_m = \sum_{t_k \leq t_{em}}^{t_k \leq t_{fm}} \frac{A(t_k)}{n} \left|_{m=[1:10]} \right. \] (eq. 6)

Figure 9 - Acceleration Test Slices, (a) Azimuth; (b) Elevation

Then, the axis acceleration error \((\Delta A_j)\) of each \(j\)th stabilized measurement, the associated uncertainty \((\sigma_A)\) within 1σ confidence level and the mean acceleration of the entire test \((A_t)\) were computed using:

\[ \Delta A_j = \left[ A(t_k)|_{t_{sf} \leq t_k \leq t_{ef}} - A_m \right]_{m=[1:10]} \] (eq. 7)

\[ \sigma_A = \pm \sqrt{\frac{\sum_{j=1}^{n} (\Delta A_j)^2}{n} - \frac{1}{n} \left( \sum_{j=1}^{n} (\Delta A_j) \right)^2} \] (eq. 8)

\[ A_t = \sum_{m=1}^{10} \left[ \frac{(-1)^{m+1} A_m}{m} \right] \pm \sigma_A \] (eq. 9)

Using acquired data shown in Figure 10, the resulting computed accelerations are 45.04 °/s² ± 2.01°/s² @ 1σ and 29.94 °/s² ± 2.92°/s² @ 1σ respectively for the azimuth and elevation axes.

Figure 10 - Measured Absolute Acceleration During Acceleration Testing, (a) Azimuth; (b) Elevation

Comparing the results of the automated tests to the desired characteristics of the system, it was confirmed the system could move quickly enough and had enough acceleration to keep up with intended targets. Looking over the velocity and acceleration errors, the acceleration errors do appear high, but this should not affect the intended system performance, and the velocity errors were considered satisfactory.
After the automated tests were performed, it was necessary to verify the system tracking capabilities under high dynamics. The pedestal was slaved to computer generated trajectory that simulates the aircraft path in order to exercise the pedestal dynamics under maximum acceleration regimen for both axes. Then the tracking error was computed as the difference of pedestal actual position and the required position (i.e. computer-generated command). The test results that include the pedestal command and position response, its speed and estimated tracking error are presented in Figures 11, 12 and 13.

![Figure 11 - Pedestal Azimuth Position at Dynamic Tracking Test, (a) Azimuth; (b) Elevation.](image)

![Figure 12 - Pedestal Speed at Dynamic Tracking Test, (a) Azimuth; (b) Elevation.](image)

![Figure 13 - Estimated Tracking Error at Dynamic Tracking Test, (a) Azimuth; (b) Elevation.](image)

The measured tracking error was 0.01° ±0.70° @2σ and 0.03° ±0.85° @2σ respectively for the azimuth and elevation axes (Figures 13a and 13b). This tracking error was compared to the 3 dB beamwidth of the system in order to verify the system dynamics would allow for successful aircraft tracking under high
dynamics regimen. For L/S-band operation, the 3 dB beamwidth at 2.4 GHz is 3.65° for this system, so tracking should not be an issue. For future C-band operation, the 3 dB beamwidth at 5.25 GHz is 1.67°, so there should not be any tracking issues in this band either due to system dynamics.

**DYNAMIC TARGET TESTING**

After successful on-site system installation, certain flight test profiles were chosen to verify system tracking at the highest possible speed for the system. One of these tracking tests was a tower fly-by test point used by the Brazilian Divisão de Formação em Ensaios em Voo (Flight Test School - EFEV) for the air data system (ADS) calibration flight test campaign. Therefore a particular test scenario was selected, where the elevation of the system was almost constant, but the azimuth axis would need to move near maximum speed and acceleration.

Test results for the XAT-29 (EMBRAER Super Tucano) aircraft flying at 255 kts (Figure 14a) shows that the antenna reached its maximum speed (i.e. +60°/s). Also at the same condition the measured tracking error (Figure 14b) shows that the maximum error was within the -3db beam width of L, S and C Bands. Therefore the measured azimuth tracking error of -0.13° ± 1.06° @2σ and the pedestal dynamic performance could be considered satisfactory.

![Figure 14 - Tower Fly-By Test Results, (a) Azimuth Speed; (b) Azimuth Tracking Error](image)

To evaluate both axes the EFEV 2014 class students performed an over-head pass of the XAT-29 aircraft, where the test bed flies almost directly over the system. Such profile would require both axes to move close to their maximum speeds (Figures 15a and 15b) and accelerations.
A detailed analysis of the over-head test point (Figures 16a and 16b) shows that the azimuth axis tracking error exceeded the 2.4GHz -3db beamwidth. With this condition we would expect to lose autotrack capability, however the antenna control system could maintain test bed tracking. One possible reason for such behavior could be attributed to the high RF signal strength, so the e-scan tracking signal could still be properly generated. At the other side the elevation tracking error was inside the 2.4GHz -3db beam width limits.

After the high dynamic testing, the aircraft performed a 6-turn normal and inverted spins test to determine if the system could successfully track the aircraft in a real test scenario where the RF polarization is changing fast due to the propagation effects of such maneuver. Due to some limitations, the system tracking error was not recorded during such tests; however the antenna front end was able to properly handle tracking and received all data without any noise and/or dropouts as expected.
CONCLUSIONS

The new design by ViaSat and Orbital Systems for an advanced 2.4 meter telemetry tracking antenna system can successfully track high dynamic targets. Utilizing a slipring, the system has continuous rotation in the azimuth axis which allows for continuous tracking of a target throughout its mission. The dynamics testing showed the system could handle tracking targets that required the system to move and accelerate quickly. With the help of IPEV and EFEV, flight profiles were executed to fully test the tracking capabilities of the system. During the tower-fly by test, the system never lost track and the tracking error was within the -3dB beamwidth for L, S, and C bands. Although the over-head pass had an azimuth test point for tracking error that was outside the -3dB beamwidth for S-band, the system did not lose track, and the rest of the data points were inside the beamwidth. Furthermore, reviewing the data from the flight tests, the results indicate that tracking at C-band should not be an issue. Some of the tracking errors for the over-head pass were outside of the -3dB beamwidth, but with some tracking gradient adjustments for the tracking receivers, future C-band tracking should be possible.

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