High Speed Target C-Band Feed Upgrade for Autotracking High Dynamic Targets

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ABSTRACT

A new common aperture autotracking C-band feed, specifically designed to accurately track fast moving targets such as the Lance missile, is reviewed. Measured data demonstrates exceptional tracking modulation required for good tracking performance while simultaneously providing excellent data channel performance for high G/T over the entire 4.40-5.25 GHz band. The new patent applied for feed design allows users to maintain existing L/S-band capability with a cost effective field upgrade which adds high performance C-band capability to an existing telemetry tracking system.

Key Words

Telemetry, Reflector Antenna, C-band, Autotrack, Dual band, L/S-band, ESCAN, Dichroic, High Performance Tracking

Introduction

A novel dual band L/S and C-band feed was described (1) for exceptionally demanding autotracking applications. ViaSat has been providing high performance S-band autotracking antennas for over 50 years and has leveraged its high power C-band monopulse radar antenna product line for use in the new 4.4-5.25 GHz telemetry band. ViaSat supplies a wide variety of autotracking feeds that include single and three channel monopulse, mechanical conscan, and TE21 mode monopulse techniques that are applicable for different autotracking missions. For fast moving targets, the use of an autotracking feed with good tracking error gradient is essential compared with less demanding missions such as LEO, MEO, or GEO satellite autotracking. The tracking error slopes of several popular feed topologies are compared. Recent critical C-band component developments associated with the new feed are also discussed.

Available Autotrack Feed Topologies

Autotrack antenna feeds may be mechanically or electronically scanned. ViaSat offers both types of feeds. Mechanically scanned (conscan) feeds (Figure 1) typically use dominant mode waveguide that is displaced from the nominal boresight axis of the antenna. Mechanically scanned feeds are limited by the available motor speeds (<60 Hz typical) and the inability to quickly vary the scan rate to reduce the susceptibility to target scintillation effects resulting in a possible loss of autotrack. Conscan systems do not have the ability to have separate data and tracking channels, tracking modulation is always present with the telemetry data.

Electronically scanned autotrack feeds include the use of a TE21 multimode coupler, a four horn phased array, or a five horn phase array. ViaSat provides tracking antennas that use all of the above techniques. The ViaSat TE21 multimode coupler (shown in Figure 2) approach provides good aperture efficiency and works well with low dynamic targets such as inclined orbit satellites. The multimode coupler design autotrack performance is unacceptable when used with highly dynamic, linearly polarized targets since the tracking modulation varies with the polarization tilt angle causing potential loss of autotrack. However, when used with larger reflector diameters, the TE21 feed approach can offer impressive aperture efficiencies for inclined orbit satellite (GEO) applications.

Figure 1 ViaSat L/S-band Conscan Autotrack Feed

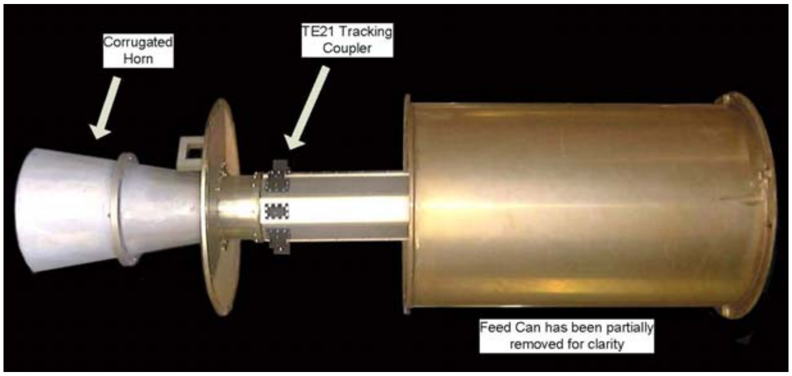

Figure 2 ViaSat S-band TE21 Mode Autotrack Feed

Figure 3 shows a ViaSat five horn array autotracking feed. These feeds are used in many LEO satellite applications. They do not suffer the effect of tracking modulation variation with incident linear polarization angle changes like the TE21 feeds. Five horn feeds can offer high aperture efficiency comparable to the TE21 design, however the autotracking modulation slope is inferior to the four horn feed. The reduced autotracking slope is caused by the increased tracking horn displacement from the boresight axis as compared with the four horn design. The effect of tracking error slope and tracking element offset will be examined in greater detail in later paragraphs in this paper.

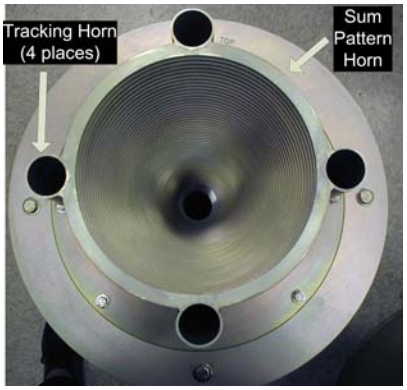

Figure 3 ViaSat X-band Five horn Autotrack Feed

A four horn autotrack feed used by ViaSat for C-band is shown in Figure 4. This approach uses a closely spaced square array of four dominant mode waveguides to generate the required sum, azimuth difference, and elevation difference beams. This feed typically generates excellent tracking error gradients near boresight since the tracking element offset distance is closely spaced from the antenna optics centerline. This offset distance is a major contributor to the tracking error slope. For fast moving targets such as missiles, a feed tracking output that provides good amplitude resolution and high signal to noise ratio (SNR) near boresight is a major advantage. The ViaSat C-band feed uses the four horn aperture approach to provide the excellent tracking error performance. It adds an additional aperture section to counteract the inherit non-symmetrical radiation patterns. Symmetrical feed radiation patterns are critical for good reflector efficiency and spillover performance.

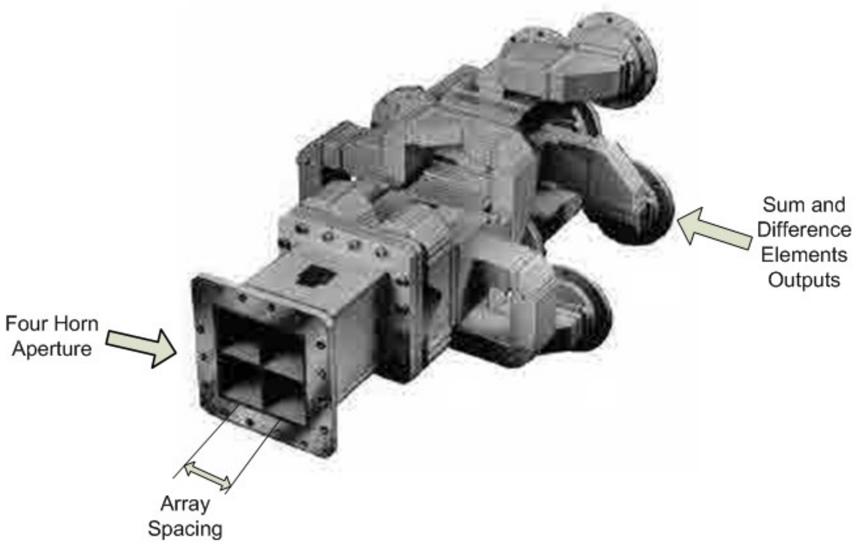

Figure 4 Four Horn Autotrack Feed used in ViaSat C-band Feed

Significant disadvantages of the standard four element array include the non-symmetric E-plane and H-plane pattern responses inherent for dominant mode horns. The dominant mode horns have a uniform electric field distribution in one axis of each horn and a cosine distribution in the orthogonal axis. This results in non-symmetric primary radiation patterns. The sum pattern that is formed by the array of all four horns has the disadvantage of relatively high primary pattern sidelobes. The high sidelobes are caused by the uniform array illumination which results in significant subreflector spillover losses and also higher antenna noise temperature.

The four horn feed primary advantage is the inherent close horn spacing from the tracking axis centerline. Figures 4-7 show the skewed secondary pattern from a representative 10 foot reflector with a single square horn Cassegrain feed that is displaced on both sides of the tracking axis for various offset distances. Notice that the available amplitude level decreases as the horn separation is increased around the crossover point (boresight axis) resulting in lower signal to noise ratio for the tracking receiver. The figures also show that the tracking voltage gradient versus target offset angle degrades with increased horn spacing. This is shown by the reduced absolute pattern level near boresight (zero degree). This results in lower tracking error resolution for the autotracking controller. The effect of both the lower signal to noise ratio and less error slope is reduced autotracking performance.

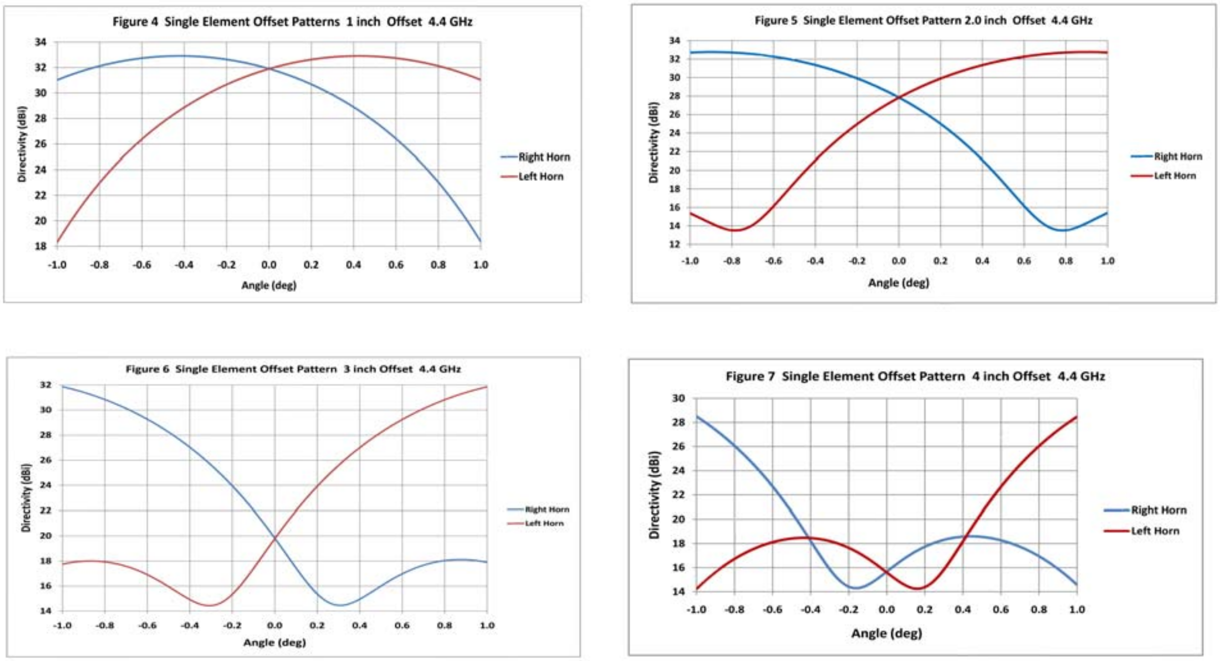

Figure 4-7 Individual Horn Scan Patterns for Various Horn Offsets

The monopulse error pattern is created when the two horn patterns are combined in a 180 degree hybrid to form the composite difference pattern. Figures 8 show the resulting secondary patterns (near boresight) when the individual horn patterns are combined using the 180 degree hybrids for various horn offsets. Note the error slope near boresight for the closely spaced horns are significantly steeper than the horns that have a wider spacing. The 2 inch horn-horn spacing (1 inch offset) is representative of ViaSat's new C-band feed while the 14 inch spacing is more typical of the five horn autotrack feed configuration shown in Figure 3 that are used for satellite tracking applications. The steeper error slope of the 2 inch design improves autotracking performance by supplying the tracking controller with more amplitude change versus target angular offset. The steeper tracking gradient also improves the signal/noise ratio since the signal strength is higher for targets near boresight. The result is a superior autotracking servo response that improves autotracking error performance.

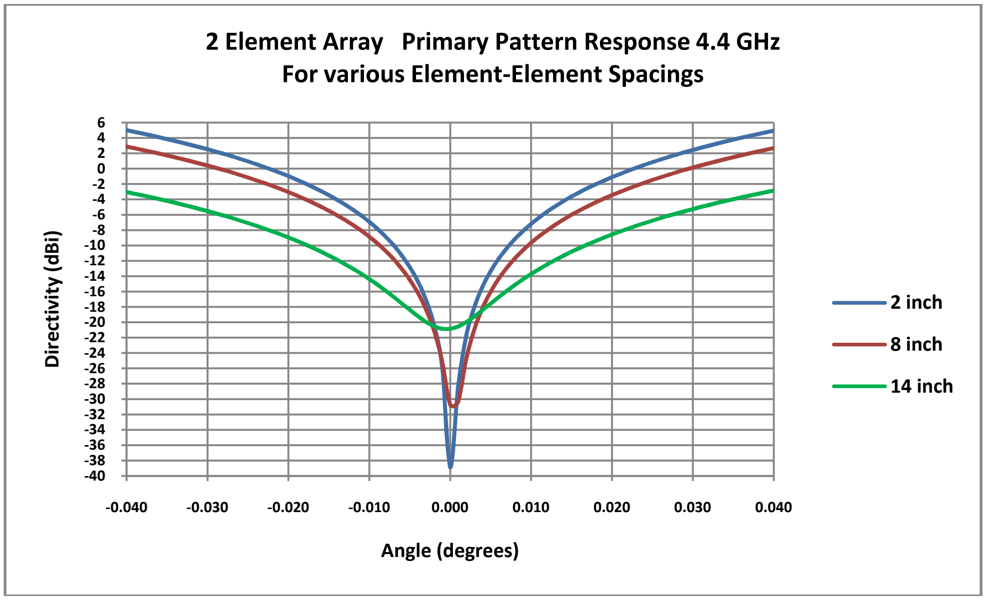

Figure 8 Predicted Tracking Channel Difference Patterns for Various Horn Spacings

The baseline ViaSat C-band feed is shown in Figure 9. Measured radiation patterns for both the sum and difference modes are shown in Figure 10. Note the near-equal E and H sum patterns along with the sharply defined difference pattern near boresight. Equal E and H plane patterns are desirable since the reflector aperture illumination may be more closely controlled which results in higher antenna aperture efficiency. Multi-horn monopulse arrays without the additional aperture section do not have E and H plane symmetry as shown in Figure 11. For fundamental mode horns, the E-plane is inherently narrower than the H-plane. For example, Figure 11 shows a 3dB beamwidth difference of over 34%. The additional horn aperture section shown in Figure 9 generates higher order waveguide modes. These higher order modes, when properly combined and phased with the fundamental TE10 waveguide mode, modify the horn E-plane pattern to more closely match the H-plane radiation pattern resulting in good pattern symmetry. Good pattern symmetry helps to control the main reflector illumination which results in increased secondary gain and improved secondary sidelobe levels.

ViaSat Additional Aperture Section

Figure 9 ViaSat Common Aperture C-band Feed

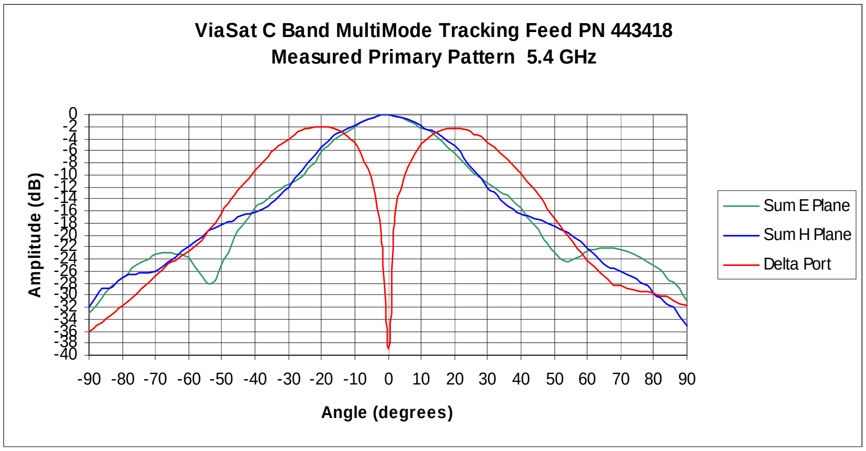

Figure 10 Measured Primary Pattern from ViaSat baseline C-band Horn (ref 1)

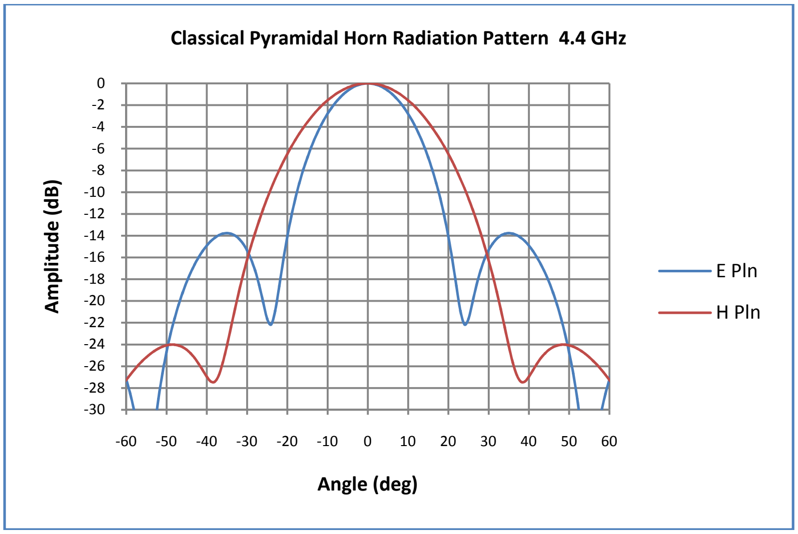

Figure 11 Calculated Primary Pattern for Classical Square Pyramidal Horn showing non-equal radiation patterns

The four horn outputs are routed through four slope septum waveguide polarizers to generate simultaneous RHC and LHC polarizations. Each of the polarizers outputs are routed into a bank of 180 degree waveguide hybrids that make up the monopulse comparator network. The monopulse comparator generates the data channel, azimuth difference channel, and elevation difference channel as shown in Figure 12 (highlighted). The comparator network outputs are routed to the low noise amplifiers. After amplification, solid state RF switches are used to time multiplex the azimuth and elevation error signals. These are then combined with a portion of the data channel to form a single channel monopulse tracking channel. A power divider after the data channel LNA provides a separate data channel that is completely free of tracking modulation, tracking boresight shifts, and also provides the highest possible G/T while also providing the reference component needed for the tracking channel. The polarizer and comparator designs are discussed in greater detail in subsequent paragraphs.

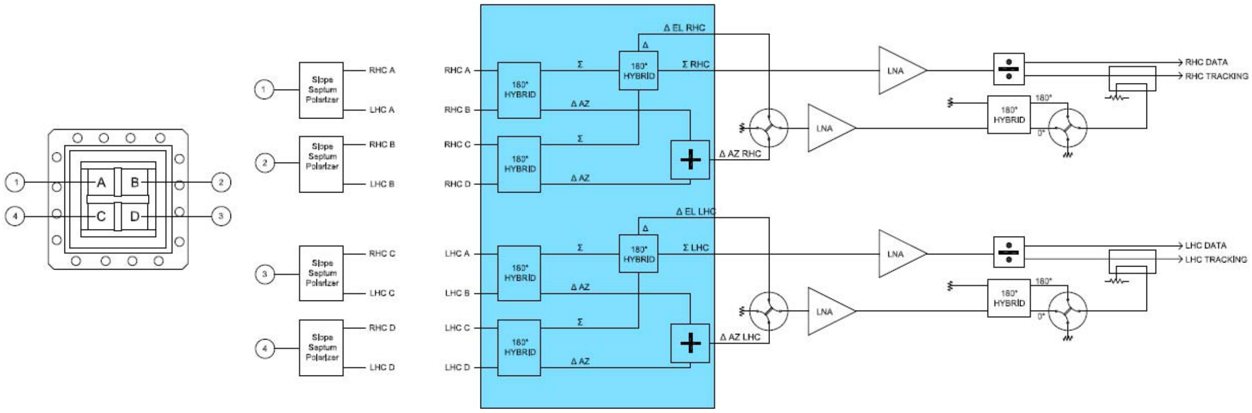

Figure 12 ViaSat Feed Topology
(Monopulse Comparator Network Highlighted)

Wideband Polarizer Design

ViaSat has designed dozens of wideband waveguide polarizers for L- to Ka-bands. These designs provide excellent polarization purity with almost negligible insertion loss for minimal G/T degradation. Figure 13 shows the specifications for the new polarizer. Figure 14 shows the polarizer's axial ratio of better than 1 dB over the entire C-band telemetry band.

Parameter	Design Limit
Freq Range	4.40-5.25 GHz
Return Loss	> 20 dB
Axial Ratio	< 1 dB
Insertion Loss	< 0.05 dB

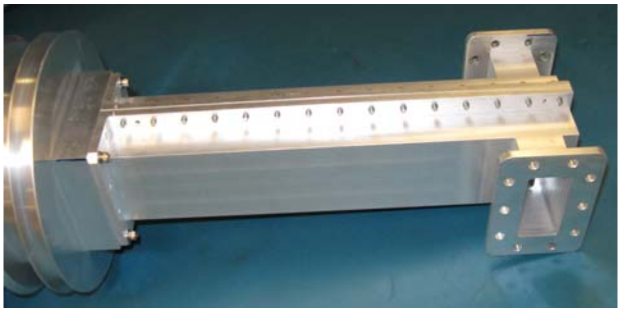

Figure 13 Electrical Specifications for ViaSat C-band Waveguide Polarizer

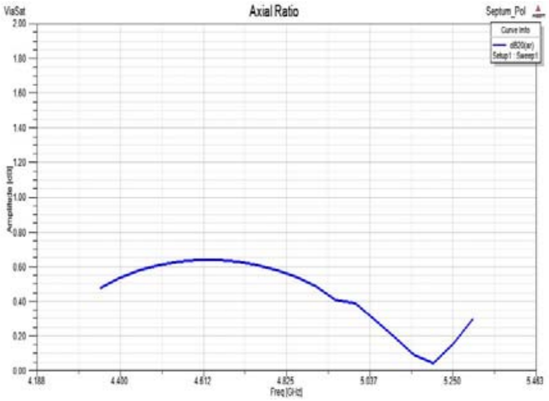

Figure 14 C-band Polarizer Axial Ratio

Wideband Monopulse Comparator Design

ViaSat has recently designed a low loss waveguide monopulse comparator network that covers the entire 4.40-5.25 GHz band. The comparator is made of a series of four 180 degree hybrids that are waveguide magic tee junctions. Magic tee junctions combine two inputs with simultaneous in-phase and anti-phase outputs. The comparator network integrated with the polarizer and feed is shown in Figure 15. Traditional magic tee designs typically only cover a 10%-15% bandwidth. The new ViaSat magic tee design achieves better than 20 dB return loss over the entire 4.40-5.25 GHz telemetry band (> 17% bandwidth) with less than 1 degree of phase error using a new optimized junction compensation element. Figures 16 and 17 show the predicted return loss and phase errors of the new magic tee junction.

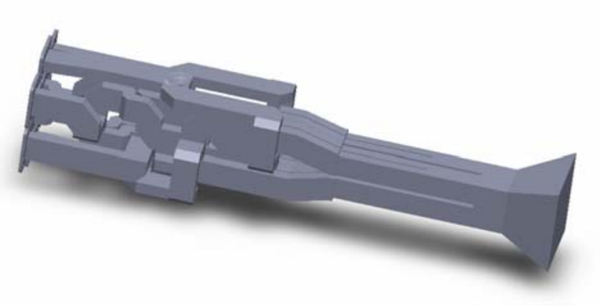

Figure 15 ViaSat Monopulse Comparator integrated with C-band Feed Horn

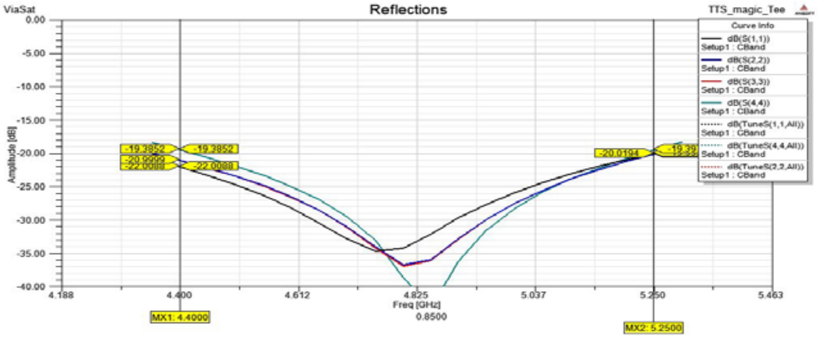

Figure 16 Predicted Return Loss of ViaSat Magic Tee Junction

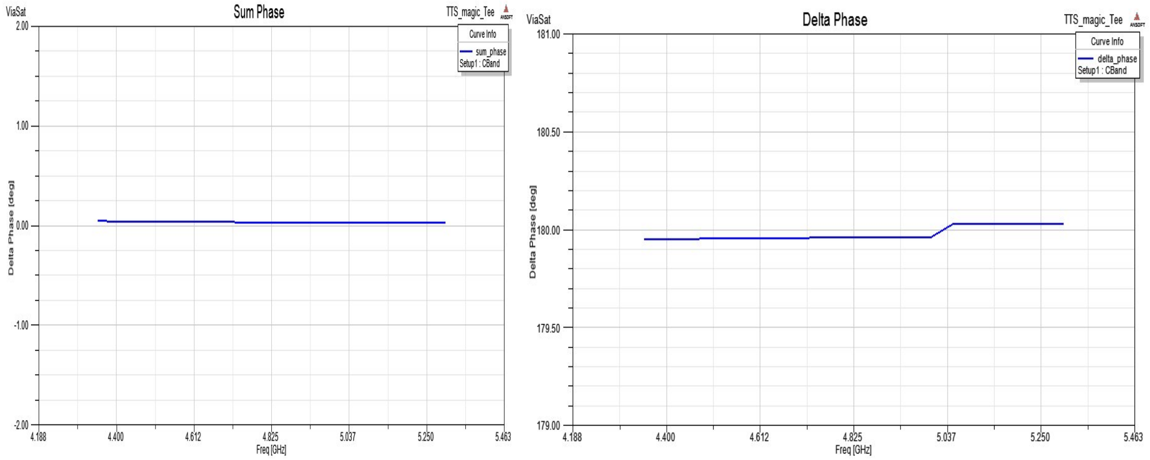

Figure 17 Predicted Phase Response of ViaSat Magic Tee Junction (sum and delta ports)

Dichroic Subreflector

ViaSat has designed and deployed many antennas employing an S and/or C-band dichroic subreflector. The subreflector employs a frequency selective surface (FSS) that allows the antenna to be used simultaneously in the prime focus and Cassegrain configurations. The subreflector is constructed from resonant printed circuit layers with specific spacing and dielectric losses that are conformal to the contour prescribed by the antenna optics. The resonant elements are mostly reflective in the Cassegrain mode (C-band) and nearly transparent in the prime focus mode (S-band). Figure 18 shows a photograph of the baseline S/C-band subreflector. Figure 19 shows calculated return loss of the subreflector when used for transmission across the 1.4-2.4 GHz bandwidth. The plot shows that the return loss is mostly better than 10 dB for incident angles up to 30 degrees with a design optimization frequency at 2.2 GHz. The corresponding reflection response from the subreflector is also shown. The predicted transmission loss for the subreflector at C-band is > 15 dB over the entire 4.40-5.25 GHz telemetry band resulting in minimal reflective losses for the Cassegrain operational mode.

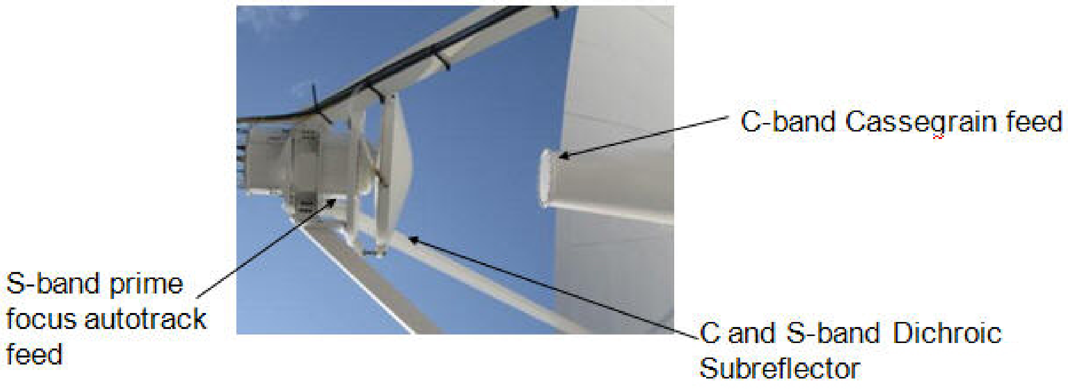

Figure 18 ViaSat Baseline L/S and C-band Dichroic Subreflector

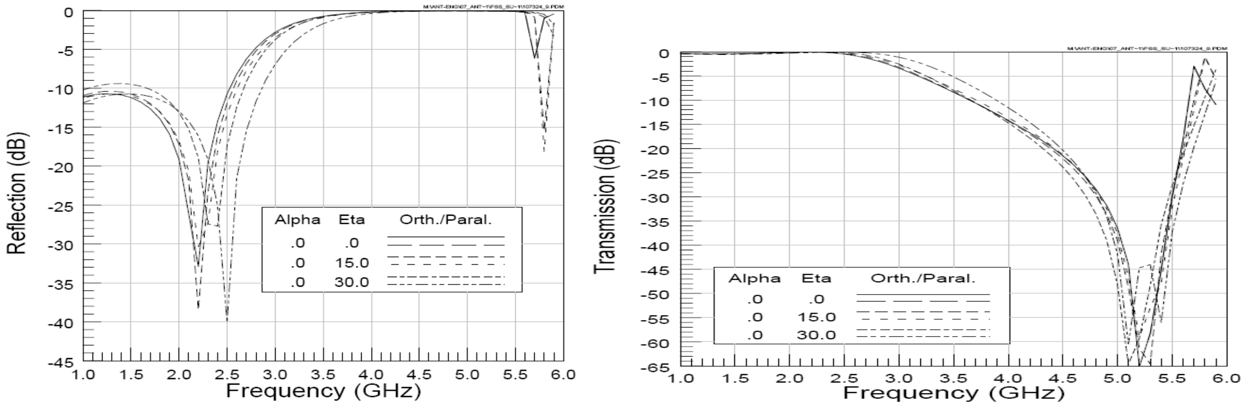

Figure 19 Dichroic Subreflector Reflection and Transmission Response

Conclusions

ViaSat's new High Speed Target C-Band Feed design has been shown to have significantly improved tracking error gradient performance compared with other feed topologies. Good tracking error gradient is especially important when autotracking high dynamic linearly polarized targets. The development of several key ancillary devices such as the polarizer, monopulse comparator, and dichroic subreflector assisted in achieving this performance to cover the entire C-band telemetry band. Finally, the use of ViaSat's existing C-band high performance Cassegrain feed is the key to obtaining secondary patterns with sharp tracking error slopes, high signal/noise performance, and near equal E-H plane beamwidths that result in excellent sum channel performance. These desirable characteristics allow the antenna to autotrack difficult targets such as rockets during launch.

This design approach demonstrates that it is not necessary to sacrifice L and/or S-band capability in order to achieve high tracking performance on C-band. ViaSat's upgrade design uses independent L/S- and C-band feeds retaining existing L/S band assets. Re-use of the existing RF chain minimizes cost and retains legacy capability with minimal performance impact. Streamlining installation, the new C-band feed upgrade is a field retrofit which minimize range downtime and maximizes mission availability.

Acknowledgments

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References

(1) "High Performance S and C-band Autotrack Antenna" Ray Lewis, International Telemetering Conference 2011