DUAL-BAND (S & C) NESTED CONCENTRIC CAVITY CONICAL SCANNING RF FEED FOR AUTO-TRACK TELEMETRY SYSTEMS

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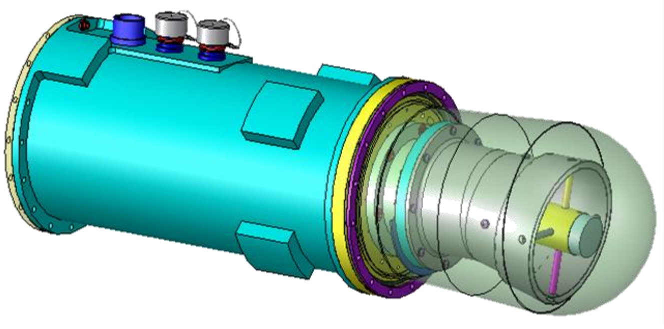
ABSTRACT

Recognizing the need for dual band tracking in missions where mobility and weight are crucial factors, Orbit Communications Ltd. has successfully designed and tested an S & C dual band, dual polarized feed with a total system bandwidth greater than 80%. The feed uses high RPM conical scan auto-track technology combined with two co-located concentric apertures that is able to achieve excellent tracking accuracy in a small volume that can efficiently feed small dishes, starting from 1.2 meter. This solution meets the needs of field deployment and tactical forces looking for compact and easy-to-assemble field telemetry.

The outermost cavity operates at S-Band and the inner cavity at C-Band. The antenna is fed with orthogonally polarized inputs, enabling polarization diversity in all bands. The coaxial cavities provide nearly uniform feed beamwidths as well as coincident phase centers in both bands, which make it an optimal feed for a parabolic dish. The conical scan rotates at up to 3000 RPM, giving excellent tracking fidelity. The entire feed system has a low blocking diameter of just 18 cm (7”) that make it possible to feed the entire range of parabolic dish diameters.



INTRODUCTION

Multiband functionality is a growing need in the next generation of tracking and telemetry antennas. Current solutions make use of dichroic sub-reflectors to meet this requirement. Dichroic sub-reflectors are difficult to design and manufacture and require very large main reflectors. Alternatively, electronic scanning antennas may be used to generate sum and difference patterns but require a large feed that is not always compatible with the smallest of reflectors.

ORBIT's innovative conical scan design is able to overcome current limitations by having two co-located concentric apertures. This innovative concept takes ORBIT's patented Tri-Band electronic scanning antenna one step further by having the coaxial cavities physically separated from the elements that excite them. This allows the concentric apertures to spin freely at a high RPM, independently of the feed network.

FEED CONCEPTS

The feed consists of two waveguide apertures. The outer one, which works at S-Band, is a coaxial waveguide, while the inner one is a simple circular waveguide that operates at C-Band. The S-Band coaxial waveguide is excited by 4 probes located 90 degrees apart. 4 probes are used for better impedance matching, axial ratio performance and pattern balance. Return Loss results for the antenna feed can be seen below in Figure 1. Return Loss is a measure of the portion of the input signal reflected back to the source. By reducing the Return Loss, more power is coupled into the antenna resulting in higher gain and G/T.

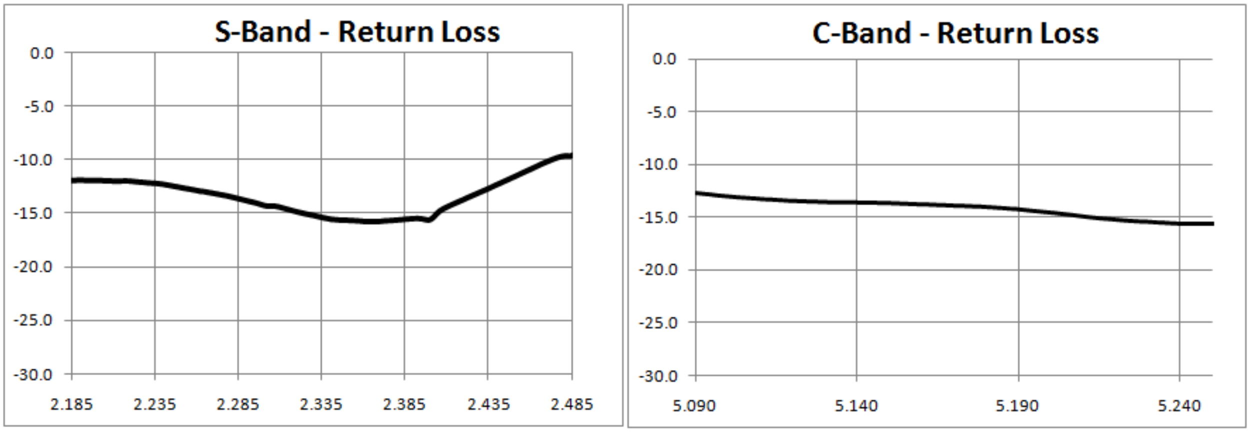


Figure 1 – S and C Band Return Loss

The S-Band probes excite the primary non-TEM mode of the waveguide, the TE_{11} mode. The cutoff frequency of the waveguide is approximately where the mean circumference between the inner and outer conductor is one wavelength. The equation that defines the cutoff frequency for the TE_{nm} mode in coaxial waveguide is given below:

$$f_c = \frac{p'_{nm}}{2\pi a} c \qquad [1]$$

$$J'_n(p'_{nm}) Y'_n(p'_{nm} b/a) - J'_n(p'_{nm} b/a) Y'_n(p'_{nm}) = 0 \qquad [2]$$

Where,

f_c - The cutoff frequency for the TE_{nm} mode in coaxial waveguide

p'_{nm} - Location of the mth zero of the nth order equation given above

$J'_n(x)$, $Y'_n(x)$ - The derivative of nth order Bessel function of the first and second kind

a, b - Inner and outer diameter of the coaxial waveguide, respectively

Proper balancing of waveguide diameters is necessary to ensure that only the desired TE_{11} mode will propagate, and that the undesired TE_{21} mode will remain below cut-off over the entire bandwidth as defined as 2.185 – 2.485 GHz. Furthermore, the inner waveguide acts as both the center of the S-Band waveguide as well as the C-Band waveguide, balance must be achieved so that only the TE_{11} mode of the C-Band cylindrical coax is able to propagate, over the proscribed bandwidth of 5.091 – 5.250 GHz, while not harming the modes of the S-Band waveguide. An image of the desired modes can be seen below in Figure 2. The dotted and solid lines in the outer ring are the orthogonal linear E-fields of the S-Band coaxial waveguide. The inner lines represent a single linear polarization of the C-Band circular waveguide.

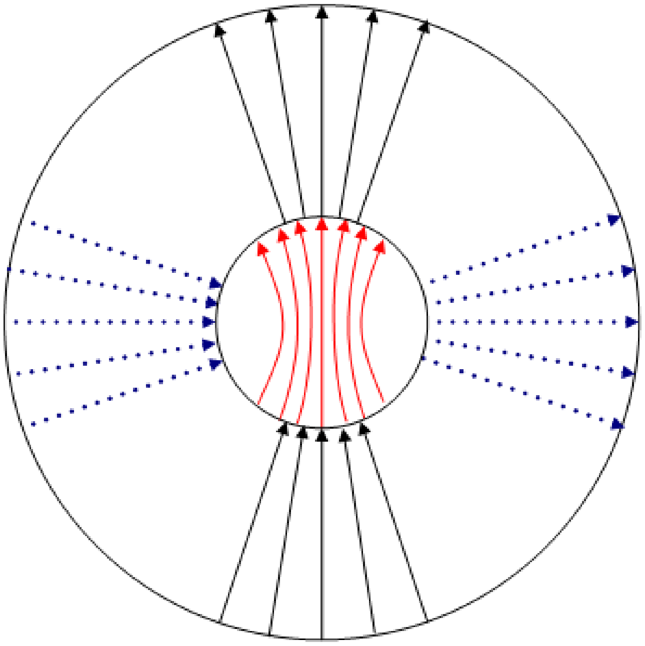


Figure 2 – E-Field Lines in TE$_{11}$ Waveguide Modes for S & C Bands

Each consecutive probe is then fed with a feed network that gives a 90 degree phase lag relative to its right hand neighbor to generate RHCP (Right hand circular polarization). When they are excited with a

90 degree phase lead LHCP (left hand circular polarization) is generated. Proper feed network design allows for reception of both polarizations simultaneously. Alternative feed networks could also generate dual orthogonal linear polarizations. Simultaneous orthogonal polarizations allow the system to be sensitive to all signals from all transmitters.

CONICAL SCAN CONCEPTS

For proper operation an amplitude based tracking antenna must create an amplitude modulated (AM) signal that the receiver can interpret as an error signal that tells the controller how far off boresite the target is located. The controller will then command the pedestal to move to new coordinates that cause the error signal to approach zero. In a conical scan antenna this AM signal is achieved by steering the main beam of the antenna slightly off boresite. The main beam is steered by having the phase center of the feed antenna displaced axially from the focal point of the parabolic reflector. The steering angle of the antenna is defined by the following equations for small angular deviations:

$$\theta_B = BDF \cdot \tan^{-1}\frac{\delta}{F} \tag{3}$$

$$BDF = \frac{1 + 0.36\left(4\frac{F}{D}\right)^{-2}}{1 + \left(4\frac{F}{D}\right)^{-2}} \tag{4}$$

Where,

θ_B	-	Steering angle of the main beam
δ	-	Axial displacement of the feed phase center from the focal point
BDF	-	Beam deviation factor
F/D	-	Focal length divided by diameter of the parabolic dish

As the nutating feed goes about a 360° rotation the signal will oscillate sinusoidally due to the corresponding rotation of the main beam about the boresite of the reflector. The amplitude of the sinusoid gives the magnitude of the error signal which is proportional to the angular offset of the target to the boresite of the antenna. The frequency of the sinusoid is equal to the rotational speed of the feed. By sampling the error signal at four points, error values can be calculated for both azimuth and elevation and corresponding corrections can be made. Figure 3 shows an Azimuth cut of the main beam taken during feed nutation. It can be seen that at 0 degrees the error approaches zero and increases continuously as the antenna moves further from boresite.

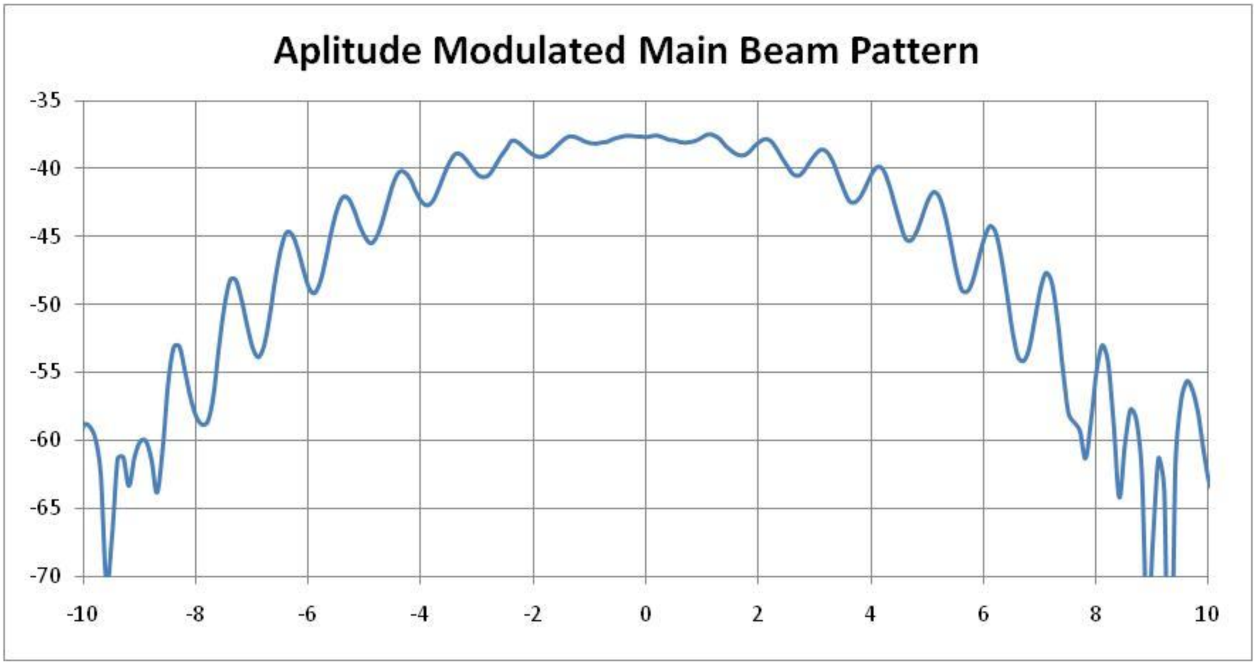


Figure 3 – Antenna Pattern During Feed Nutation

It is important to properly steer the main beam to optimize tracking gain versus boresite gain loss. As seen by equations 3 and 4 the greater the feed offset the greater the steering angle of the main beam. As the main beam steering angle increases, the boresite gain of the antenna will decrease. The degree of beam peak steering is not frequency dependant, whereas the beamwidth is frequency dependant. Consequently, for a given fixed feed offset, the difference between the boresite gain to the peak gain will increase as a function of frequency, resulting in reduced system boresite gain and G/T. Conversely, if the main beam is not steered enough there will be insufficient delta between beam peak and boresite gain, leaving the AM error signal with too little resolution for accurate auto-tracking function. Figure 4 illustrates these concepts.

When dealing with a conical scanning feed that operates over the range of 2.185 to 5.250 GHz, there can be no suitable delta that will satisfy both conditions over the entire band. To compensate for this the phase center of both apertures are not co-located. There is a slight offset in the axial displacement of the phase center between S and C band. Consequently, the two conductors of the S-Band waveguide are not concentric which can cause impedance matching and axial ratio difficulties. The angular offset was carefully selected to ensure that the S-Band performance was not harmed by correcting the C-Band steering angle. Figure 5 below shows resulting measured axial ratio values.

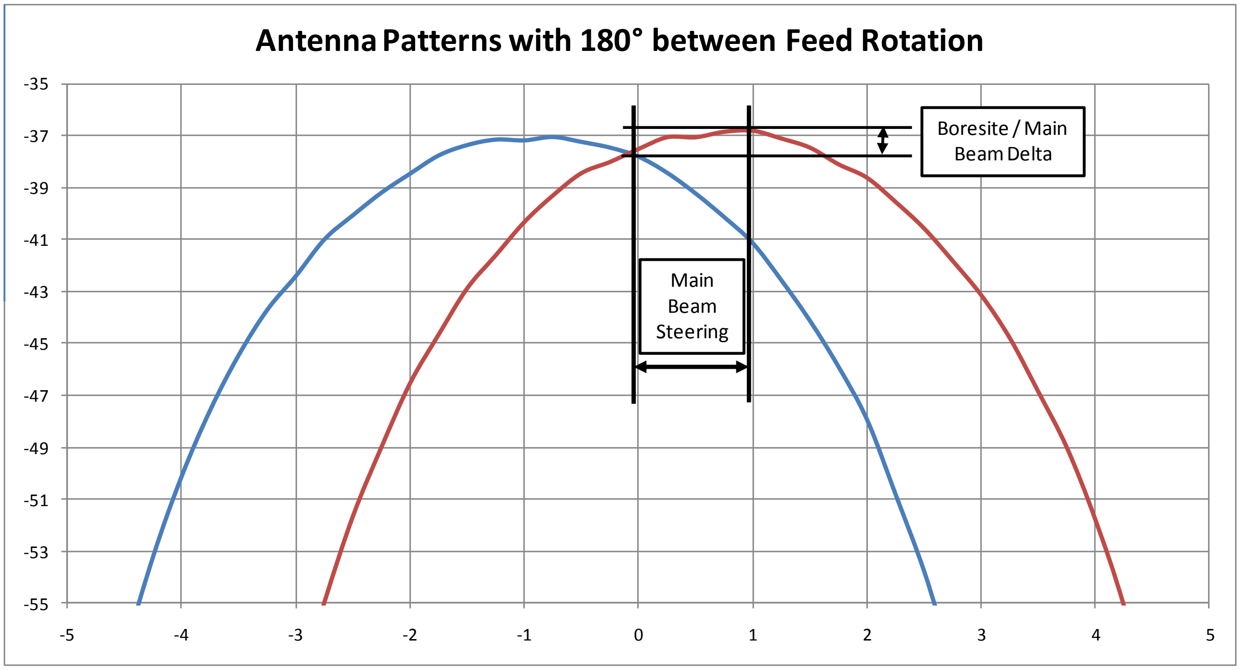


Figure 4 – Antenna Patterns of Opposite Steered Beams

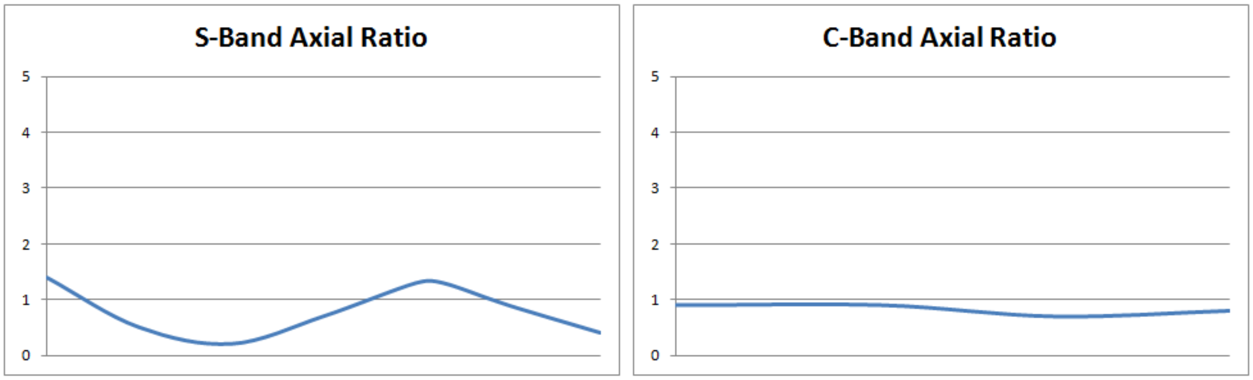


Figure 5 – Axial Ratio Results for S and C Band

CAVITY FEED DESIGN – MECHANICAL CONSIDERATIONS

Two central principals in the design of the conical scan antenna were that the antenna should be able to rotate at a very high RPM, but that no rotary joint be required. The components of the antenna that are connected to the stator and the components that are connected to the rotor must be totally separated to avoid friction and drag that can lead to damaged parts and reduced performance. The parts that are attached to the stator include all waveguide probes and feeds that are in turn connected to the static coaxial cables. The coaxial waveguide cavities that cause the main beam steering, must be attached to the rotor and therefore physically disconnected from the stationary parts.

REFLECTOR & FEED BLOCK DESIGN

For the program to which the S & C Conical Scan antenna was designed a 1.2m dish was selected. The focal length of the reflector is 0.546m, which corresponds to an f/D ratio of 0.455. The feed was designed such that the angular range of +/- 57.5° should be between 8 and 12 dB down from the feed peak gain for optimal reflector efficiency.

A 1.2 meter dish is less than 9 wavelengths in diameter at the lowest frequency of operation, making it very small electrically. Complicating matters is the blocking caused by the feed and RF frontend housing, which was a significant fraction of the overall reflector diameter. This blockage causes a reduction of the gain in S-Band. The housing was redesigned to reduce the blocking diameter. The final outer diameter of the S & C feed housing was reduced to 18cm (7”).

RANGE TESTING

The 1.2m S & C conical scan antenna was tested on Orbit’s outdoor farfield test facility. 360 degree Azimuth patterns were taken with the feed in static and dynamic states. Figure 6 shows patterns taken in S Band. The upper graph is a plot of the main beam that displays both static and dynamic patterns. It can be seen from the graph how the upper envelope of the dynamic pattern conforms to the static pattern on one side of boresite and to the lower envelope on the other side of boresite. This is due to the feed offset being oriented along this plane. The peak of the static beam is steered toward the left hand side of the graph, which will represent the maximum edge of the rotating pattern. Conversely, the right side of the graph will then coincide with the minimum of the rotating pattern, since the beam is steered away from that side. The lower graph is a full 360 pattern of the antenna for the static case.

Tracking error curves, or S-Curves, were also measured. ‘S-Curve’ is a nickname for a curve representing the relation between the actual boresight error of a tracking antenna and the antenna error value reported by the tracking system. Normally the curve is expected to be almost linear in the 3-dB range of the antenna boresight. Another important characteristic of the tracking antenna, closely related to the S-curves, is the crosstalk. When the antenna is displaced from the boresight along one of its axes, ideally, the antenna error should report only for this axis. With a practical tracking antenna some false error values will be reported in the orthogonal axis. This phenomenon is referenced to as a ‘crosstalk’. The crosstalk should be minimized by proper antenna design and calibration.

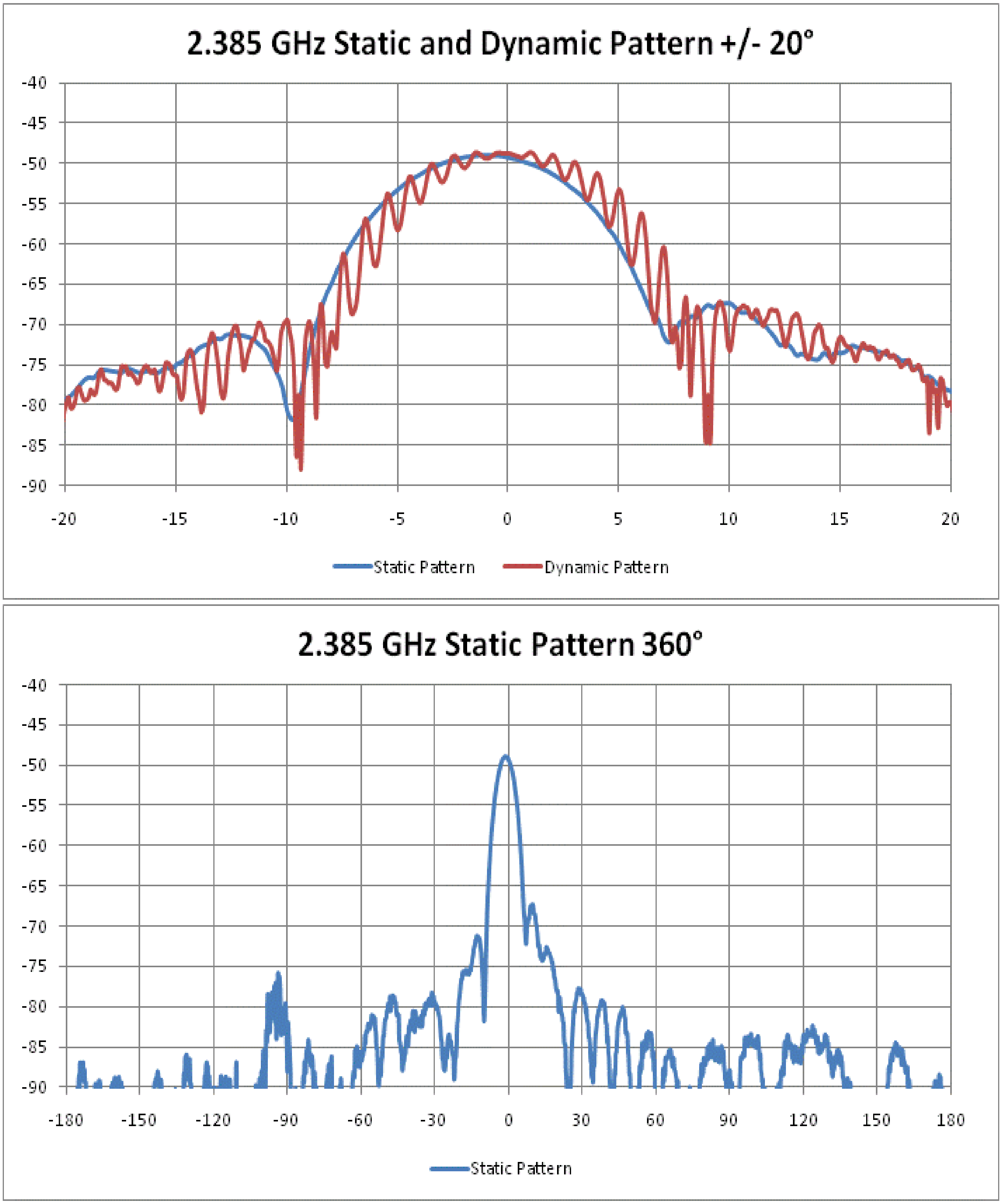
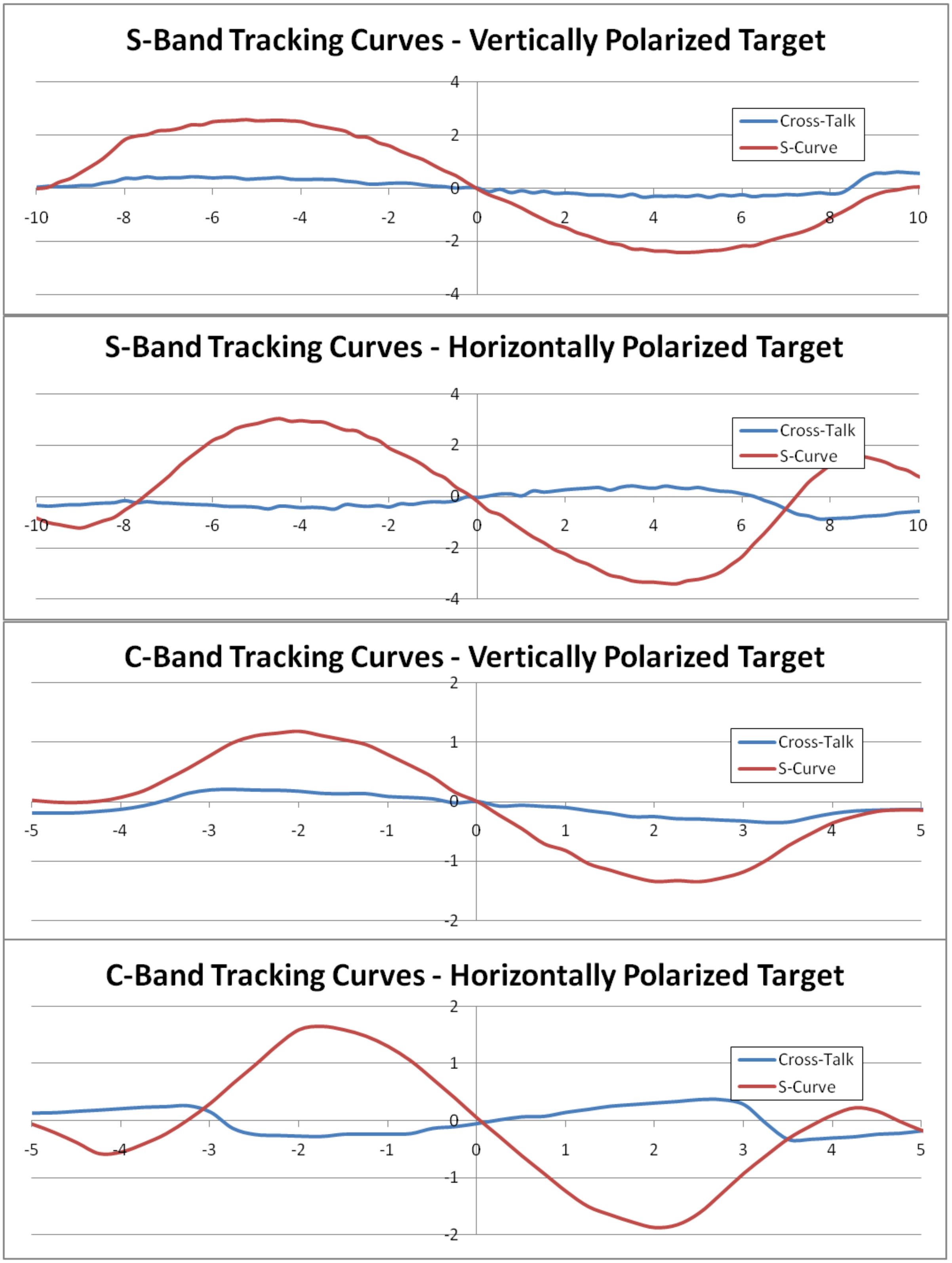


Figure 6 – S-Band Measured Patterns of Rotating and Fixed Feed


S-Band Tracking Curves - Vertically Polarized Target

S-Band Tracking Curves - Horizontally Polarized Target

C-Band Tracking Curves - Vertically Polarized Target

C-Band Tracking Curves - Horizontally Polarized Target

Figure 9 – S-Curves in S and C Bands, showing linear response in range of 3dB beam width for orthogonal polarizations

SUMMARY

We have shown the design essentials and the performance highlights of the novel Dual Band S & C conical scanning auto-tracking antenna. The final antenna was measured to have acceptable levels of return loss, axial ratio, gain and tracking accuracy. The final dual band feed was packaged to fit into a maximal outer diameter of 18 cm (7”) with a weight of 9 kg (20 lbs). Coupled with the successful mating with a 1.2m dish, the dual band conical scan has proven to meet even the most lightweight and mobile requirements. Larger reflectors could also take advantage of this technology with even greater efficiency.

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