Theoretical Design of a Simultaneous S/X/Ka Feed System with Monopulse Tracking in all Receive Bands

Christophe Granet[1], Robert A. Hoferer[2]

[1] Lyrebird Antenna Research, Sydney, Australia, Christophe.Granet@lyrebirdantennas.com

[2] Spacetime Engineering, Los Angeles, USA, Robert.Hoferer@spacetimeengineering.com

***Abstract*—The landscape of the SATCOM industry is changing due to the proliferation of satellites launched in LEO or MEO orbits, while the launch of GEO satellites has been vastly reduced in favor of multi-band, multi-orbit feed and antenna solutions. The theoretical design of a simultaneous S/X/Ka feed system with monopulse tracking in all receive bands is presented.**

***Index Terms*— feed system, horn antenna, reflector antenna, satellite communication, tracking, SATCOM, multi-band.**

I. INTRODUCTION

The landscape of the SATCOM industry is changing due to the proliferation of satellites launched in LEO or MEO orbits, while the launch of GEO satellites has been vastly reduced in favor of multi-band, multi-orbit feed and antenna solutions. There are advantages in using LEO and MEO satellites, due to the reduced latency and power requirement, BUT, the main disadvantage is that there is now a need to have a tracking antenna and the need to have a constellation of satellites to maintain connectivity at all time with the user, along with a terminal that can quickly switch from one satellite to the next in the constellation. To cater for these changing antenna requirements, new user terminals in phased-array technology are replacing standard parabolic dishes pointed at LEO and MEO satellites; however, there is still a need for TT&C and high data rate applications for high-performance, gateway reflector antenna systems.

Satellite and Teleport operators are now almost mandating that new reflector systems be multiband and, if possible, allow tracking of fast-moving LEO or MEO satellites.

Such a multiband application, that we have been asked to provide a bid-response to, is a simultaneous S/X/Ka antenna system with the following target specifications:

- Antenna Size: 15m dual-reflector system with a nominally Gaussian feed pattern taper of -18dB at 20°.
- S-Tx (Transmit): 2.025 - 2.120 GHz, Polarization: RHCP & LHCP (Right-Hand and Left-Hand Circular Polarization). Target directivity: 48.0 dBi (2.073 GHz → Aperture efficiency: 59.4 %)
- S-Rx: 2.200 - 2.300 GHz, RHCP & LHCP, TE21 Tracking (2-port). Target directivity: 48.7 dBi (2.250 GHz → Aperture efficiency: 59.3 %)
- X-Rx: 7.900 - 8.500 GHz, RHCP & LHCP, TE21 Tracking (2-port). Target directivity: 60.6 dBi (8.200 GHz → Aperture efficiency: 69.1 %)
- Ka-Rx: 25.500 - 27.000 GHz, RHCP & LHCP, TE21 Tracking (2-port). Target directivity: 69.8 dBi (26.250 GHz → Aperture efficiency: 56.1 %)

All in all, such a feed network would have 14 ports, which is a very challenging engineering endeavor.

There is very little information on the few existing S/X/Ka designs in the open literature. The triaxial system described in [1] has some interesting design features, but we have not been able to find more information in the open literature. Other triaxial systems, without TE21 tracking, are discussed in [2] and [3]. A system developed in India [4], uses a multimode Ka-band dielectric rod and 2x2 square arrays of dielectric rods for X-band and S-band.

Our approach is different from all these concepts. To respond to a bid, we have looked at the theoretical design of a feed system that could be used on a 15m shaped Cassegrain (or shaped ring-focus) antenna system.

Instead of a triaxial configuration, we use a coaxial configuration, where the S-band signals (communication and tracking) are processed through the coaxial part of the horn while the simultaneous X/Ka signals are processed through the circular part of the horn. We nickname this system a simultaneous S/X&Ka feed-system.

Such a design project has required the use of numerous analysis techniques, such as mode-matching for the coaxial horn design as well as a body-of-revolution code (QuickWave V2D) for sanity checks, Mician's MWave Wizard for filter and component designs, 3D EM solvers (CST MWS), in-house reflector shaping software, and GRASP for the reflector performance analysis. It is standard practice to check and cross-check theoretical performance with different software packages and analysis methods to try to catch as early as possible any possible glitch or trap mode that would cause immense pain at testing time.

II. REFLECTOR AND HORN DESIGN

A view of the optimized S/X&Ka horn is shown in Fig. 1 as a cut-view. The outer coaxial horn is corrugated and optimized for S-band while the inner smooth-wall horn is optimized for simultaneous X&Ka operation. The theoretical radiation pattern of the horn in circular polarization is shown in Figs. 2 and 3. The horn by itself, assuming a TE11 excitation at either the coaxial port or the circular port, is well matched with nominally better than 25dB return loss at S-band and better than 30dB return loss in both X-band and Ka-band.

The antenna is an optimized 15m-diameter shaped Cassegrain reflector system with a 2.25m-diameter subreflector and a half-subtended angle of 20°. The reflector shaping (in-house Matlab code) is done assuming a theoretical Gaussian feed with a -18dB taper at 20°, hence this is the design goal for the radiation pattern of the horn in each frequency band.

From an antenna performance point of view, using the theoretical radiation pattern of the horn to feed the reflector system in GRASP, we can see in Fig. 4 that the directivity and aperture efficiency targets are met.

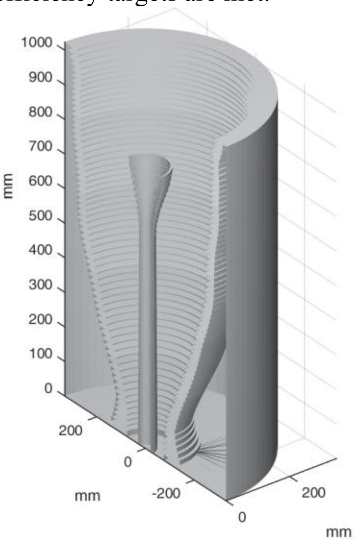

Figure 1: The S/X&Ka horn concept: -18dB@20deg.

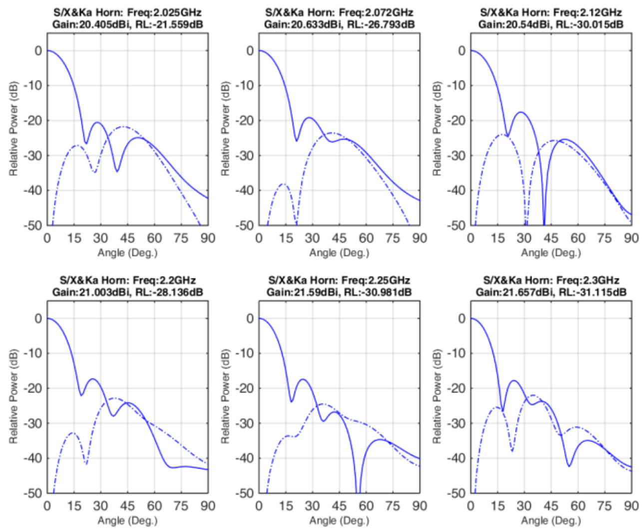

Figure 2: Horn pattern at S-Tx and S-Rx.

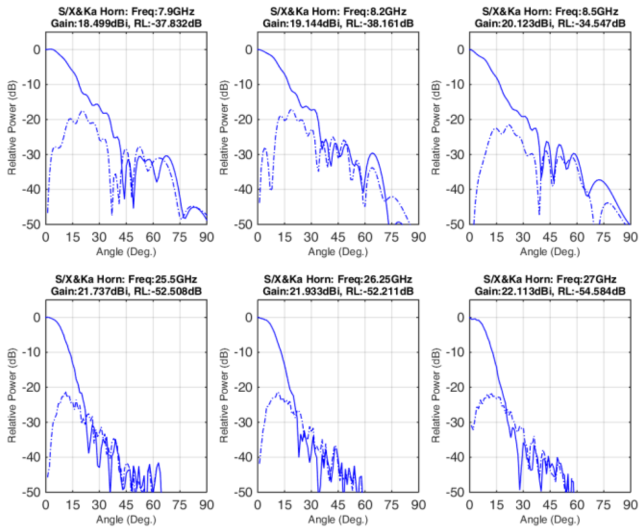

Figure 3: Horn pattern at X-Rx and Ka-Rx.

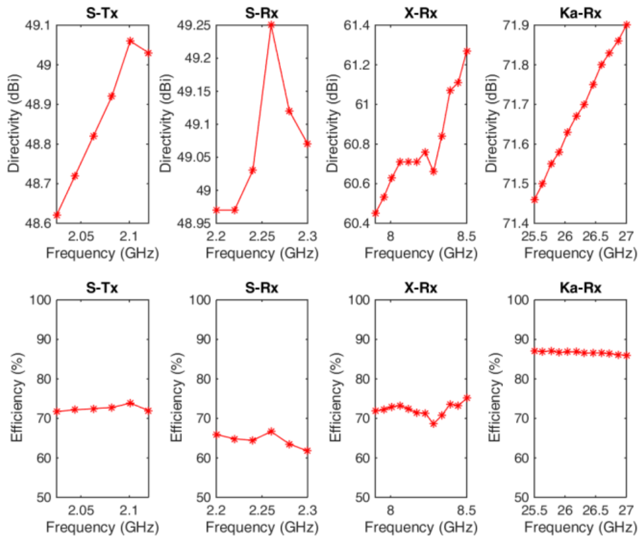

Figure 4: Reflector directivity and aperture efficiency.

III. Feed Network Concept

The S-band signals are processed using a completely new concept where the communication signals (TE11) in the coaxial waveguide part of the feed are extracted first and the tracking signals (TE21) extracted after: a complete reversal of what is usually done in TE11/TE21 tracking couplers. This is done using a coaxial mode-filter that provides a better than 30dB rejection of the TE11 modes (>60dB in S-Rx) while passing the TE21 modes with less than 0.25dB of loss over S-Rx. The mode filtering concept is circular symmetrical, so less complicated to manufacture than the traditional multi-hole coupler system as described in [5]. The advantages of this new concept are its compactness, that the TE21 network is now isolated from the TE11, and that it can be recombined either in waveguide, as in [5], or using an 8-probe network, and six 180°-hybrids and a 90°-hybrid for the CP generation. This provides the two CP tracking ports at S-Rx. The TE11 network is basically a coaxial quadrature junction that is recombined and connected to an E-plane 90° waveguide coupler, generating the combined S-Tx and S-Rx CP signals. An S-band diplexer then finishes the TE11 network.

The X&Ka network is more conventional (but still very complex), i.e., an inline feed network with a Ka-band OMT, a Ka-band TE21 coupler, a 4-port X-band OMJ, an X-band TE21 coupler and the inner horn of the coaxial horn. Of specific challenge here, is the requirement for a rather non-standard approach to the X-Band tracking coupler due to the total supported frequency band required, which exceeds historically achieved bandwidths.

IV. Feed Network Analysis

The block diagram of this feed is displayed in Fig. 5.

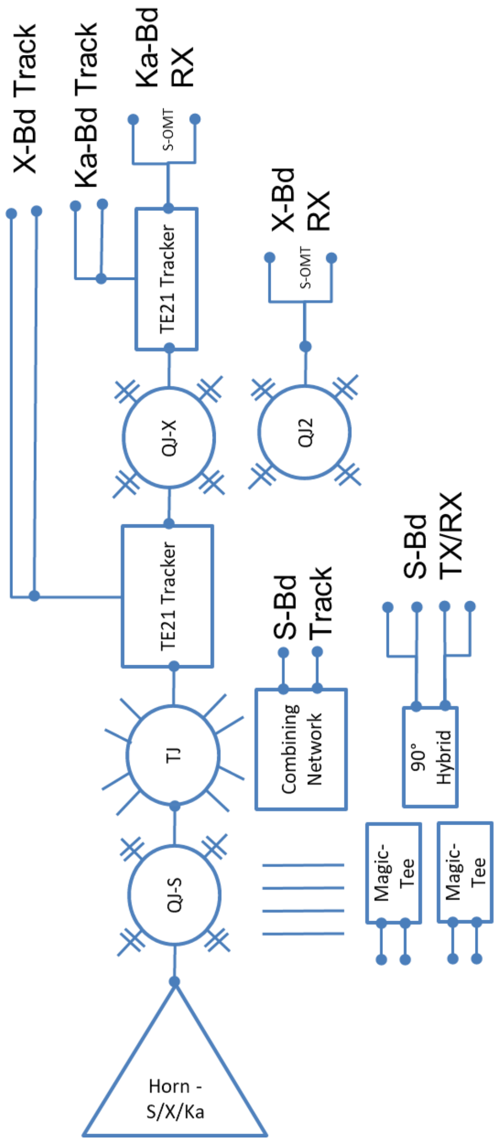

Figure 5: Feed Block Diagram.

In addition to the novel approach to extract TE11 and TE21 modes in S-band, several other non-standard components also deserve additional explanations.

The X-band Tracking coupler requires a non-standard geometry (when compared to [5]) for coupling apertures to ensure the extraction of the TE21 modes in X-band, but while leaving the TE21 modes in Ka-band as well as the TE11 modes in X- and Ka-band undisturbed.

Representative S-Parameters analyzed using CST MWS of a design operating over 8.4 – 8.5 GHz are shown in Fig. 6, consisting of the TE11 and TE21 return loss (bottom red and pink curves), TE21 coupling into the side channels (top blue curve), and TE11 and TE21 backward coupling (bottom blue curves). The performance as shown is consistent with a feed, once installed into the antenna, to display a sum-to-delta peak difference of <10 dB.

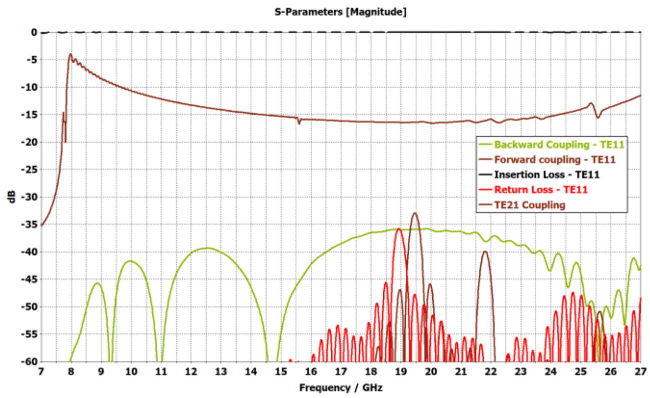

Figure 6: X-Band tracking coupler – representative S-Parameters.

In comparison, a more standard Ka-band tracking coupler analyzed also with CST MWS follows the design guidelines in [5], and the same collection of representative S-parameters are displayed in Fig. 7.

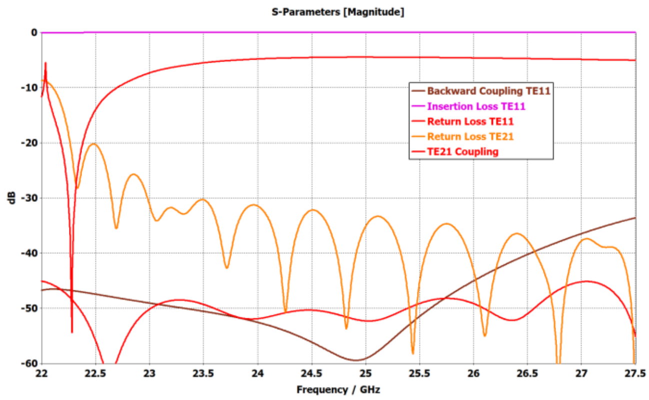

Figure 7: Ka-Band tracking coupler – representative S-Parameters.

The Tx/Rx isolation requirements in these complex multiband systems typically exceed the standard -85 dB found in regular SatCom systems and need to exceed -110 dB in all bands. As such, the S-Parameters of the S-band diplexer design (needed in this application), and as examples for possible upgrades, X-band, and Ka-band diplexer designs, are shown in Figs. 8, 9, and 10, respectively, which were designed using Mician's mWave Wizard.

Of note for the diplexer design is also the goal to achieve lowest possible ohmic losses not only for the obvious G/T and EIRP reasons, but also to minimize the dissipated power for elevated Tx power levels.

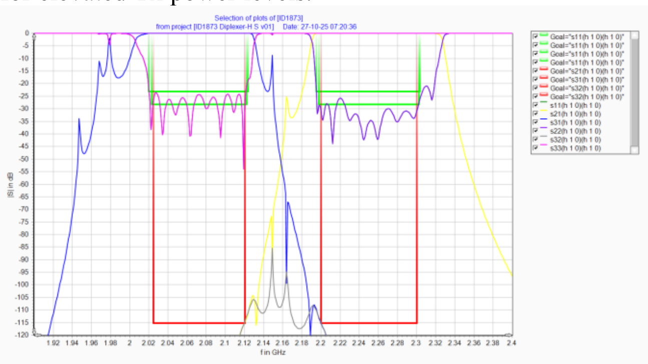

Figure 8: S-Band diplexer – representative Return Loss and port-to-port isolation.

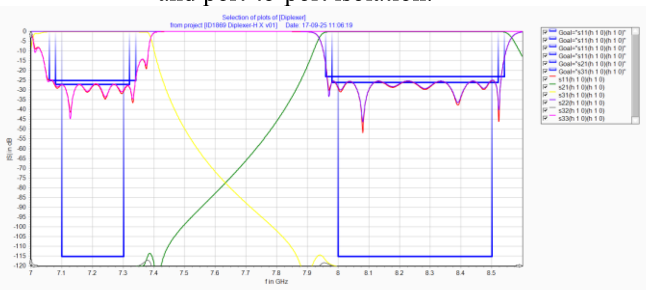

Figure 9: X-Band diplexer – representative Return Loss and port-to-port isolation.

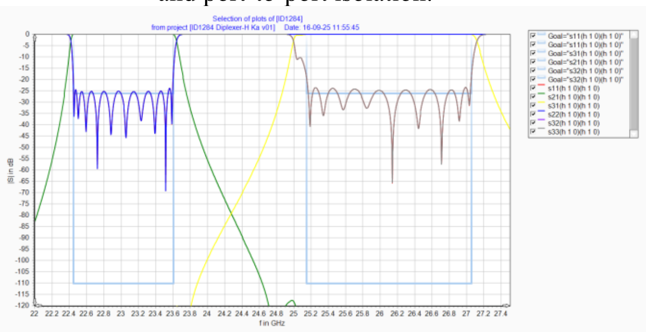

Figure 10: Ka-Band diplexer – representative Return Loss and port-to-port isolation.

V. Conclusion

This paper discussed a possible design approach for a tri-band S/X/Ka-band feed with simultaneous TE21 monopulse tracking in all three bands. Representative performance characteristics were shown and discussed here, establishing the feasibility of this approach.

While the feed configuration discussed here is geared towards a medium-gain horn application (-18 dB at 20°), a tri-axial horn configuration can be envisioned for a lower gain application, whereby the TE21 monopulse tracking by means of a mode filter (as discussed here for S-band) is similarly implemented in X-band.

In the feed configuration discussed here, the X-band and Ka-band paths are Rx-only, but can potentially be expanded into a Tx/Rx configuration by adding the aforementioned diplexers (Figs. 8 and 9) and a slight widening of the respective frequency bands compared to what is displayed here.

The design of such a complex system cannot be done unless a suite of software packages dedicated to specific tasks is used. Some of these software packages are commercial packages, while in-house software packages, written, checked and cross-checked over years and years of internal R&D are also required. Cross checking the performance of components of the system using different software packages that use different analysis methods, is, when possible, very important, as it allows catching possible issues early during the design phase, from a time and cost perspective, but mostly from a stress perspective.

[1] A. Karas, P. Cousin, G. Kipfer, A. Robert, A Triband Autotrack concentric Feed S, X, Ka for Ground Stations related to Earth Observation , 2018 SpaceOps Conference, Marseille, France.

[2] J. A. L pez-P rez et al, A tri-band low-noise cryogenic receiver for geodetic VLBI observations with VGOS radio telescopes , Preprints.org; 2019. DOI: 10.20944/preprints201912.0408.v1.

[3] C. Granet, M. Olszewska-Placha, Optimization of Triaxial Horns: A Simultaneous S/X/Ka Example , 5th Australian Microwave Symposium, Melbourne, Australia, 16-17 February 2023, 2 pages.

[4] https://www.nrsc.gov.in/sites/default/files/pdf/techtransfer/IEN_SXKa_triband_RFFeed.pdf

[5] Y.H. Choung, K.R. Goudey, L.G. Bryans, "Theory and design of a Ku-band TE21-mode coupler", IEEE MTT, Vol.30, No11, Nov.1982.