Efficient Design of a Novel Wide-illumination-angle Ku/Ka-band Feed for Reflector Antennas

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Abstract - **A novel wide-illumination-angle feed for satellite communication which could operate simultaneously in Ku/Ka uplink and downlink bands is proposed in this paper, based on a highly efficient design routine. Excellent radiation performances and high reflection loss are achieved by employing multi scalar rings, hybrid mode launcher and coaxial structure. Cylindrical modal matching method is employed for generalized scattering matrix calculation inside the feed, while spherical mode expansion is adopted for the feed aperture discontinuity. Key specific parameters are finally compared with the full wave simulation results. Good consistency confirms the validity of our numerical approach and the proposed antenna.**

Index Terms — **Ku/Ka-band satellite communication, multiband feed, cylindrical modal matching method, spherical mode expansion.**

1. Introduction

Due to the increasing communication traffic, antenna systems are required to have greater capacity than ever before. There has been a considerable interest to reduce the number of antennas on different platforms in the past few years. However, numerous functional requirements make the development of such antennas quite challenging.

Crucial component in reflector antennas is the feed system. In certain applications, dual-band feed systems have to offer simultaneous transmitting and receiving operation in both bands. Once Rx/Tx sub-bands are widely separated, the feed systems should be treated as tri-band or quad-band systems. BAE Systems Australia proposed several multiband feed systems covering S/X-bands and X/Ka-bands [1]. The band separation is large enough so that the upper-band horn can be embedded into the center conductor of the lower-band coaxial horn. A smaller band ratio, however, results in a different configuration, where the inner waveguide should be loaded with low-loss dielectric. Stephen presented a compact feed which could operate in Ka/Q bands simultaneously [2]. A constant beamwidth and phase center over the desired frequencies was realized. A similar prototype was proposed to cover X/Ku-bands [3]. Full-wave simulation tools were employed referring to the two abovementioned primary feeds. It's the same case for future Ku/Ka-band feeds, which actually function as quad-band antennas. As is known, Ka-band operation is very useful for high data-rate communication but subject to large attenuation by atmosphere. Thus, combination of lower bands with Ka band makes such satellite communication more robust.

To investigate the possible application of wide-illumination-angle primary feeds in Ku/Ka-band satellite communications, a novel feed configuration is proposed in this paper. A method combining cylindrical modal matching method (MMM) and spherical mode expansion is utilized for optimization [4]. The computational efficiency will be checked in comparison with full-wave solvers. Numerical optimization leads to the feed with expected performances including low cross-polarization level, low VSWR, etc. in 12.25-12.75GHz, 14.0-14.5GHz, 19.6-21.2GHz and 29.4-31.0GHz simultaneously.

2. Hybrid Numerical Algorithm

The remarkable separation between different frequency bands has made the feed synthesis extremely challenging. Commercially available full-wave EM simulation solvers, such as those based on finite-element or finite-difference approaches, could offer very accurate results, but the cost is long computation time and high memory requirements. Modal matching method, however, is often preferred, since they are computationally more efficient and provide physical insight [5].

The radiation patterns can then be computed by a Kirchhoff-Huygen integration of the tangential fields over the waveguide aperture, which will bring in significant error referring to wide-illumination-angle feed since the aperture is not electrically large, where the influence of the aperture discontinuity is considerably high. For accurate radiation pattern and overall scattering matrix prediction, Wiener-Hopf method or spherical mode expansion should be employed for calculating the aperture discontinuity [6].

3. Feed Design

A cross-sectional view of the proposed feed is shown in Fig. 1. The feed features a three-port coaxial junction, where the HF-band signals are transmitted or received by the inner dielectric-loaded circular waveguide, and the LF-band signals by the coaxial waveguide formed by fitting outer and inner metallic pieces together. The feed operates as a fundamental-mode horn in Ku band and K band, and as a hybrid-mode horn in Ka-band.

Fixed phase center at each band could be guaranteed by this configuration, which always locates at the aperture. High cross-polarization discrimination within the illumination angle is required over all bands, generally better than 30 dB.

Combination of multiple scalar rings for Ku/K bands and hybrid-mode junction for Ka band is chosen thereafter.

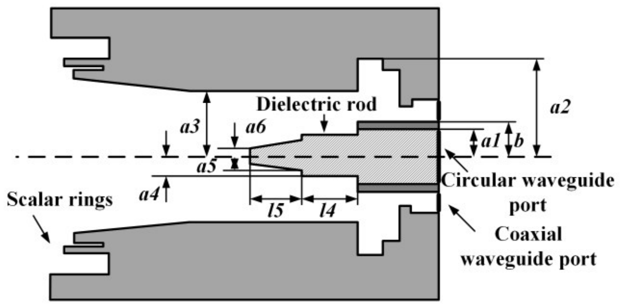

Fig. 1 Cross-sectional view of the proposed feed

The coaxial waveguide for Ku-band operation has inherently low return loss, due to the reflection at the coaxial-waveguide-to-horn junction. By multiple matching waveguide steps, impedance matching over dual bands are achieved. Moreover, low-pass-filtering function is also realized by setting these steps properly, in order to stop Ka-band signals from interfering the Ku-band operation.

A genetic algorithm optimization routine is written, which has been used together with the MMM and spherical mode expansion. The validation of our code is performed by comparison with FEM-based frequency-domain solver in CST Microwave Studio with the same precision criteria of 0.005. The wideband analysis (12-15 GHz and 17-33 GHz with a frequency step of 0.1 GHz) performed by our method required 10.5 min and 54.1 min on a Dell T7600 workstation respectively, which is limited to 8 CPU cores for comparison. To obtain the same accuracy, CST took 11.0 min and 315.7 min respectively. MMM save approximately 80% of the computation time.

Comparison with respect to reflection coefficient, and radiation patterns at corresponding center frequencies are shown in Fig. 2 and Fig. 3, respectively. As shown in Fig. 2, reflection coefficients by MMM are in excellent agreement with those by FEM over the whole frequency range, which are lower than –17 dB in Ku band, –21 dB in K band and –27 dB in Ka band. At 12.5 GHz, 14.3 GHz and 20.4 GHz, co-polarization radiation patterns in both principal planes coincide excellently within 90°, so as cross-polarization in 45°-plane, lower than -30 dB. Slight difference arises in Fig. 3 (d), but peak cross-polarization level is still in great agreement.

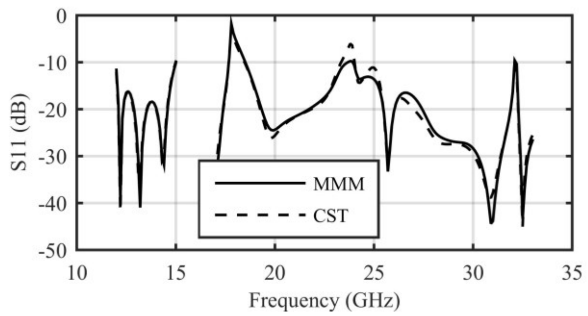

Fig. 2 Comparison of reflection coefficient versus frequency by MMM and CST

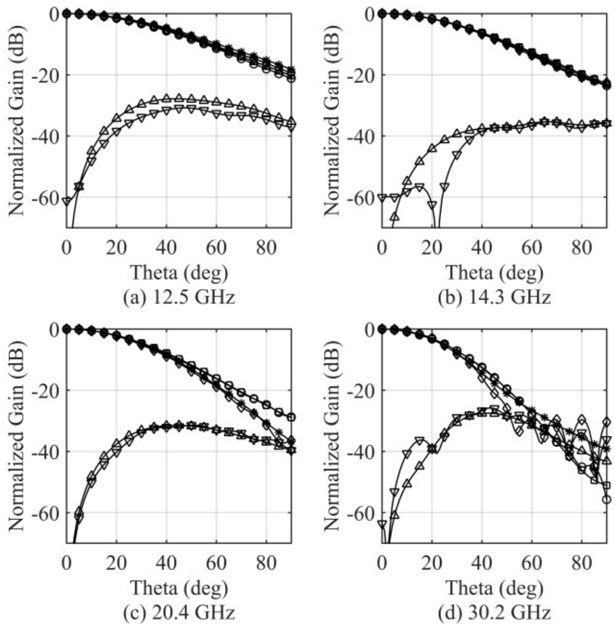

Fig. 3 Comparison of radiation patterns by MMM and CST at the center frequency of each band (MMM 0°-plane co-pol -□-, CST 0°-plane co-pol -○-, MMM 90°-plane co-pol -*-, CST 90°-plane co-pol -◇-, MMM 45°-plane cross-pol -△-, CST 45°-plane cross-pol -▽-)

4. Conclusion

A novel Ku/Ka-band feed antenna is proposed in this paper. It takes advantage of small flare angle for fixed phase center, which results in wide illumination angle. High computationally effective modal matching method is utilized for performance optimization. Radiation pattern prediction by spherical mode expansion results in a complete antenna diagram. The final design promises low cross-polarization and high return loss over all bands. Comparison between our method and CST Microwave Studio shows great agreement, but the computational time is significantly short.

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