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COMPACT AND HIGH PERFORMANCE STEPPED TRUNCATED-CIRCULAR WAVEGUIDE BRANCHING ORTHO-MODE TRANSDUCER (STCWB-OMT)

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Abstract—This paper reports design and development of an innovative compact Stepped Truncated-Circular Waveguide Branching Ortho-Mode Transducer (STCWB-OMT) operating at 4.5–4.8 GHz for horizontal and vertical polarizations. STCWB-OMT is derived by introducing branch waveguide via coupling slot on a stepped truncated-circular waveguide. This configuration possesses inbuilt rectangular-to-circular transition; therefore it does not require any additional square-to-circular transition to combine it with horn antenna. The challenge in the design incorporated is to obtain a mechanically compact design with low mass while compliant with the specified electrical performances; since this device is developed for space-borne application. Achieved return losses at both direct and coupled ports are > 17 dB, insertion losses < 0.08 dB for both polarizations, isolation is < -60 dB and cross-polarization discrimination > 40 dB with the OMT length $= 1.98\lambda$ at center frequency and weight $= 250$ gm The agreement between measured and computed results provides a validation of the proposed OMT configuration.

1. INTRODUCTION

Limited space on spacecraft and enhanced communication capacity requirement stipulates the use of two orthogonal polarizations at the same frequency band facilitating exploitation of two same frequency channels, simultaneously. This frequency reuse can be achieved by one dual-polarized antenna, which consists of an ortho-mode transducer (OMT) as a constituent device. An OMT separates or combines two different polarizations (in this case, vertical and horizontal) at the

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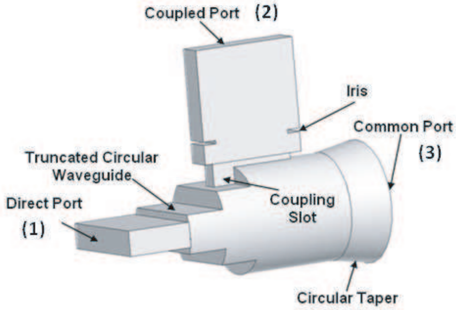
same frequency band. For space-borne application, it has required that the OMT should have low weight and volume, with a good match at all electrical ports, high cross-polarization discrimination between the independent waves, lower isolation and lower insertion losses. Another desirable feature of the OMT is the reduction of its axial length for an easy accommodation and enhancing mechanical natural frequency of complete feed system.

Several design variants of OMT are described by different researchers [1–6] that include slot-coupled branching OMT with stepped transformer, slot-coupled branching OMT with continuous taper function, slot-coupled septum branching OMT, probe-coupled OMT with taper transformer, probe-coupled septum branching OMT, OMT with short plate etc..

In this paper, a new compact Stepped Truncated-Circular Waveguide Branching Ortho-Mode Transducer (STCWB-OMT); is established to achieve the previously described, electrical as well as mechanical objective by means of an innovative design strategy. This OMT architecture is envisaged using ascertaining branch waveguide via coupling slot on a symmetrically-stepped truncated-circular waveguide. Truncated-circular waveguide has a cross-section intermediate between round and rectangular [7]. Thus, cross-section of common port of the STCWB-OMT is circular, which eliminates the requirement of square-to-circular transition to combine it with conical plane-/ corrugated-walled horn antenna and direct compatible with the horn. Apart from excellent electrical performance, this OMT also offers compactness, simplification in its mechanical design and alleviation in its manufacturing. The STCWB-OMT is designed for frequency band 4.5–4.8 GHz and linear horizontal and vertical polarizations for spacecraft application.

2. SYNTHESIS AND REALIZATION OF THE STCWB-OMT

The synthesized geometry and photograph of STCWB-OMT is given in Fig. 1. Direct and coupled ports of the OMT use rectangular half-height WR-187 waveguide. This OMT consists of a stepped inhomogeneous truncated-circular waveguide mode converter cum impedance matching section [7, 8]; providing symmetrical transition of circular waveguide to rectangular direct port of vertically polarized wave. This symmetrical transition reduces number of bends or twists required in waveguide plumb-line on the spacecraft. The stepped section is combined with a rectangular branching waveguide that is placed perpendicular to the longitudinal axis and placed on top of



(a)

(b)

Figure 1. Stepped Truncated-Circular Waveguide Branching Ortho-Mode Transducer (STCWB-OMT). (a) Synthesized geometry. (b) Photograph.

this region, near the common port of the OMT. The broad dimension of the branching waveguide is aligned with the axis of the transition. Horizontally polarized wave is coupled in branching waveguide through coupling slot. The dominant TE_{11c} mode at the circular common port is transformed into TE_{10r} mode by stepped truncated-circular waveguide mode transformer and supplied to direct port of the OMT. Applying quarter wave impedance matching theory, we can concurrently control impedance matching from circular to rectangular direct port. The stepped truncated-circular waveguide section, also acts as virtual short for the orthogonal dominant TE^*_{11c} mode and this mode become evanescent within the stepped truncated-circular waveguide section. Consequently, it is reflected and coupled to the branching coupled port (TE_{01r} mode). The location of coupling slot and branching waveguide, within the truncated-circular waveguide section, control coupling of wave in coupled port. In truncated-circular waveguide section, there is E-plane step discontinuity with reference to rectangular direct port. Thus, it offer capacitive discontinuity for the TE_{10r} (or TE_{11c}) mode at the wall of the common waveguide, which is compensated by proper location of branching waveguide with coupling slot and by introducing symmetrical inductive iris in coupled branching port to match its impedance.

Diameters of circular waveguide section and multi-stepped truncated waveguide are kept equal to broad wall dimension of rectangular direct port. For combining horn with the OMT a circular taper is used before common port. The longitudinal three-stepped truncated-circular waveguide is designed using design-guideline given in [8]. Length of each stepped section is kept equal to $\lambda/4$ (quarter wavelength transformer). Length and width of coupling slot are chosen $\lambda/2$ and $\lambda/10$, respectively [4, 5].

The stepped truncated-circular waveguide is optimized using mode-matching-technique (MMT) based software (Mician's μ Wave Wizard ®). Since, presently we cannot analyze complete OMT of this type using Mician, the STCWB-OMT is optimized using finite element method (FEM) based software Ansoft HFSS®. Coupling of TE_{01r} mode, isolation and return loss at coupled port are optimized using location of coupling slot/branching waveguide and symmetrical inductive iris. Thus, different electrical performance objectives (e.g., return loss and polarization purity etc.), are achieved by optimizing different parameters of the OMT. Length of the optimized STCWB-OMT is 1.98λ at centre frequency. The OMT is fabricated by using aluminium alloy 6061T6 with the help of computerized numerically controlled (CNC) wire-EDM (electrical discharge machining), CNC turning etc.. STCWB-OMT is fabricated into two pieces; viz. branching waveguide section and truncated-circular waveguide mode transducer.

3. RESULTS AND DISCUSSION

The return losses at direct and coupled ports, port-to-port isolations of STCWB-OMT are measured using Rohde & Schwarz vector network analyzer (VNA) (model: ZVA-40). VNA is calibrated using TOSM method at SMA coaxial connector of VNA. Figs. 2(a) and (b) compare measured and predicted (from HFSS) return losses at direct and coupled ports ($-S_{11}$ and $-S_{22}$ respectively). The return loss is better

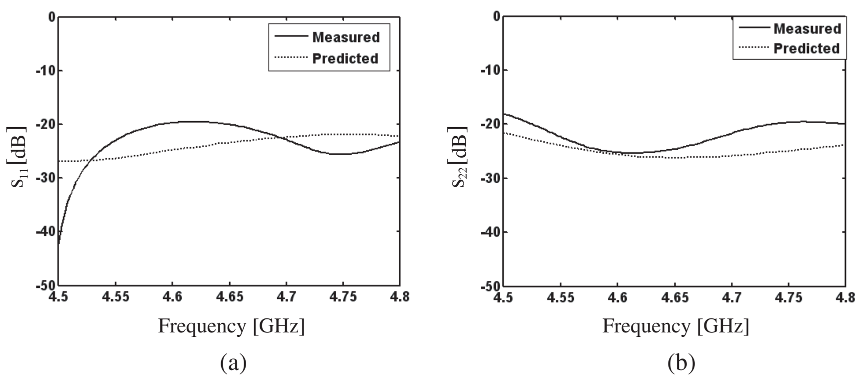


Figure 2. Predicted and measured return loss versus frequency of the STCWB-OMT at (a) direct port and (b) coupled port.

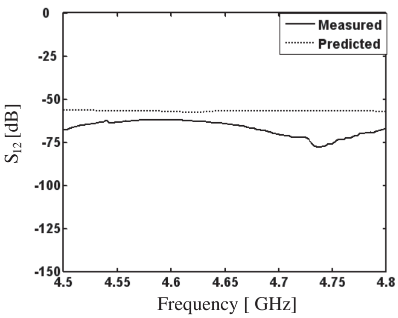


Figure 3. Predicted and measured port-port isolation versus frequency of the STCWB-OMT.

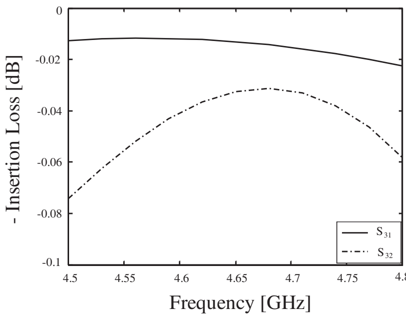


Figure 4. Insertion loss with respect to frequency of the STCWB-OMT for vertical and horizontal polarizations.

than 17 dB at both ports in desired frequency band. The port-to-port isolation (S_{12}) of the OMT is given in Fig. 3. The port to port isolation is better than -60 dB in desired frequency band. The deviation between measured and predicted results may be due to measurement inaccuracy such as calibration at SMA coaxial connector instead of waveguide adaptor etc..

Figure 4 depicts insertion losses from common port to direct port ($|S_{31}|$) and from common port to coupled port ($|S_{32}|$) from HFSS, respectively. The insertion loss from common port to coupled port is higher in comparison of those from common port to direct port due to iris at coupled port. Iris is tuned at near to centre frequency; therefore the insertion loss from common port to coupled port is lower at resonating frequency in comparison of other frequencies. The cross-polarization discrimination (XPD) [9] of the OMT describes the amount of depolarization or cross-coupling caused by asymmetry in the network. XPD is the ratio of a co-polar component to a cross-polar component. The cross-polarization discrimination (XPD) of the OMT should be very high (>40 dB) so that OMT does not deteriorate cross-polarization characteristics of horn antenna and hence of entire antenna system. Since, there is only single coupling slot (asymmetrical coupling technique), there are chances of mode conversion from TE_{10r} and TE_{01r} modes into TM_{01c} mode which may cause depolarisation. Fig. 5 depicts XPD (from HFSS) of the OMT for two polarisations. At optimized dimensions of the OMT, the XPD is better than 41.9 dB and 64 dB for vertical and horizontal polarisation; respectively.

Depending upon requirement, STCWB-OMT design can be easily

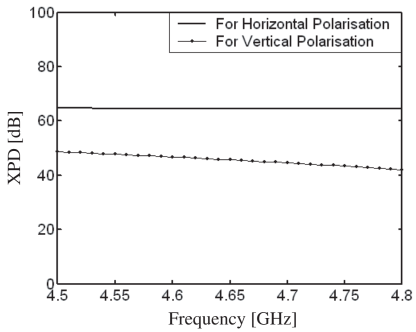


Figure 5. Cross-polarisation discrimination (XPD) with respect to frequency of the STCWB-OMT for vertical and horizontal polarizations.

modified (i) for dual-band application by higher frequency band coupling at coupled port, (ii) for higher mode purity at common port by combining paired branch-waveguide to the common waveguide by hybrid junction, and (iii) for larger diameter of common port by using homogeneous stepped-truncated-circular waveguide instead of stepped inhomogeneous one. These, features increase versatility of the STCWB-OMT.

4. CONCLUSION

A new simplified design strategy for a compact Stepped Truncated-Circular Waveguide Branching Ortho-Mode Transducer (STCWB-OMT) has been demonstrated for C-band (bandwidth = 6.45%) in this paper. Excellent electrical performance (return loss at direct and coupled ports >17 dB, port-to-port isolation (< -60 dB), low insertion losses < 0.08 dB, high polarization discrimination (> 40 dB) etc.,) and mechanical requirements (compactness, low weight and volume, easy to fabricate etc.,) are achieved with the STCWB-OMT.

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