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Compact wideband bowtie dipole orthomode transducer

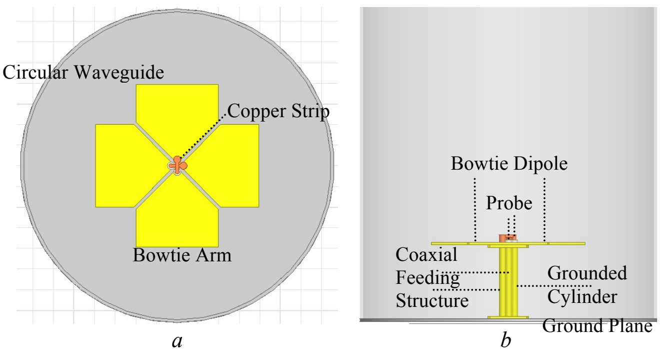
J. Fan, K. Zhu, J. Yang and Y. H. Yan

A compact wideband orthomode transducer (OMT) with an octave bandwidth is proposed for a 0.56-1.12GHz receiver system in the five hundred meter aperture spherical radio telescope (FAST). The OMT operates in a cryostat at a temperature of 70 K and therefore it is critical to minimize its dimension while insuring good electrical properties. The complete OMT comprises two bowtie dipoles orthogonally arranged in a circular waveguide. Because of the innovative structure, competing modes, TM_{01} TE_{21}, and TE_{01}, have been effectively suppressed, and the bandwidth of the dominate mode TE_{11} has achieved to 2.08:1. The final optimized OMT has a length of 300 mm (only 0.56 wavelength at the low-end frequency of 0.56 GHz), shorter than a half of the popular quardruple-ridged waveguide (QRWG) OMT. Measurements at room temperature agree well with simulation results, with a reflection coefficient below -10 dB for both polarizations and cross-coupling levels of -30.5 dB over the whole required frequency range.

Introduction: Orthomode transducers (OMTs) are one of key components in both radio astronomy and telecommunication systems. Different OMT technologies were reported, such as the coupled waveguide [1-2], the planar [3], the finline [4-5] and the quardruple -ridged waveguide (QRWG) [5-8] OMTs. For radio astronomy applications, the OMTs with low cross-polarisation, low ohmic loss and good impedance matching over a wide band are needed.

The coupled waveguide OMT in [2] has a simple structure and low reflection coefficient, but the bandwidth is limited by the single-mode bandwidth of waveguide. The planar OMT in [3] applies differential excitation that can broaden the single mode bandwidth to a value of 1.6:1 but two 180° hybrids and supporting dielectric substrates are needed, which leads to additional loss and therefore increases the noise. The finline OMT in [5] has a wide bandwidth of 1.7:1 but its asymmetric structure results in a high cross-polarization level. The QRWG OMT in [6] has a nearly symmetrical structure with a wider impedance bandwidth, but some trapped modes exist in the tapered QRWG structure, which can be suppressed by introducing shorting blocks and absorbers or offsetting the orthogonal ridges in the OMTs [8], where a large length about four wavelengths of the centre frequency is required.

In this letter, a novel bowtie dipole OMT for a cryogenic octave bandwidth (0.56-1.12 GHz) receiver used in the FAST (five hundred meter aperture spherical radio telescope) is presented. To reduce the total length while keeping good electrical performances, two orthogonal compact wideband bowtie dipoles have been introduced to excite the dual-polarized dominant modes in the transducer waveguide. The symmetrical structure and electrical field distribution characteristics of the optimized bowtie geometry increase the single-mode bandwidth and suppress the higher-order modes.

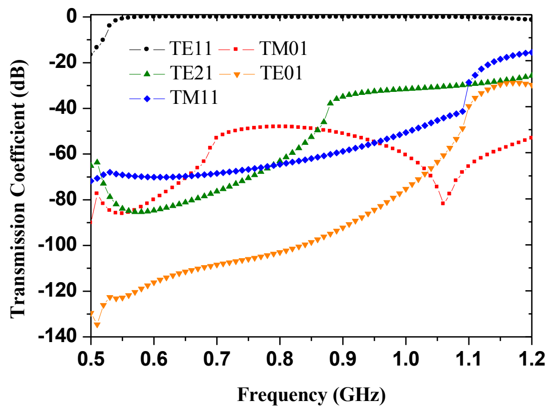


a *b*

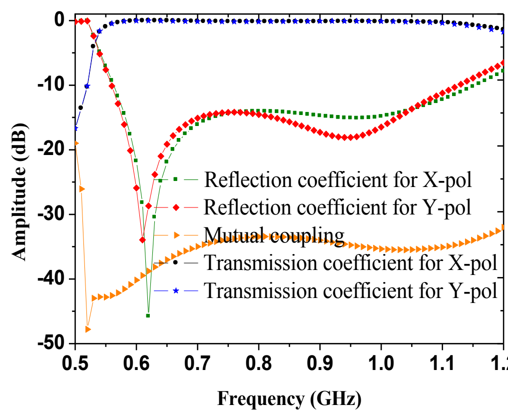
Fig. 1 *Structure of the purely metallic bowtie dipole OMT*
a Top view of the bowtie dipole OMT
b Side view of the bowtie dipole OMT

Design and simulation: Sketches in Fig. 1 show the geometry of the OMT, composed of a circular waveguide, a pair of crossed bowtie dipoles, a ground plane, two grounded cylinders and two coaxial (air filled) feeding structures with outer conductors grounded and inner conductors (probes) connected to the opposite metallic arm plate via copper strips at one end, and connected to SMA connectors underneath the ground at the other end. Then, single-end LNAs can be connected directly to the OMT.

In a circular waveguide, the theoretical maximum purely single-mode bandwidth is 1.31:1, limited by the first higher-order mode TM_{01}. Therefore, in order to increase the single-mode bandwidth in practice, the excitation to the waveguide should be in such a way that all higher-order modes are not excited. By the proposed bowtie dipole feeding in this OMT, the electrical field distribution has a good symmetry with electric field line starting from one patch and terminating at the opposite as well as relatively strong electric field at the axial direction line, which allows the existence of the TE_{11} and TM_{11} modes. However, TM_{01}, TE_{21} and TE_{01} modes with zero E-field at the cross section centre are not excited since these modes cannot satisfy the properties of the bowtie dipole electrical field distribution. Therefore, the single-mode bandwidth of the proposed OMT is determined by the cut off frequencies of the fundamental mode TE_{11} and the higher-order mode TM_{11}, for the low end and the high end of the band, respectively, with a value of 2.08:1.



a



b

Fig. 2 *Simulated data of the bowtie dipole OMT*
a Transmission coefficient from TEM mode of coaxial port to the first five modes of circular waveguide port
b S-parameters of the complete OMT for the dominate mode TE_{11}

A circular waveguide with a radius of 170 mm is chosen in order to have the same dimension as the horn waveguide used for the FAST dish. Then, according to the analysis above, the single-mode bandwidth is from 0.52 GHz to 1.08 GHz, which is a bit different from the required band of 0.56-1.12 GHz. The reasons for this choice of the waveguide dimension, in addition to the size of horn waveguide, are: i) With the cut-off frequency of TE_{11} mode at 0.52 GHz, we have a margin to the low end of our operating band of 0.56-1.12 GHz so the reflection coefficient can achieve to be below -10 dB; ii) Even the cut-off frequency of TM_{11} mode is at 1.08 GHz, the upper band edge 1.12 GHz is very close to the cut-off frequency and the transmission coefficient from coaxial TEM mode at the coax port to TM_{11} mode at the waveguide port is under -20 dB, as shown with the simulation results in Fig. 2(a).

Transmission coefficients from the coaxial input port with the TEM mode to the first five modes in the circular waveguide port (defined as a multimode port) have been simulated using Ansys HFSS and shown in Fig. 2(a). As expected, transmission coefficients from the TEM mode to TM_{01}, TE_{01} and TE_{21} modes are extremely low, below -50 dB at low frequencies and -30 dB at the high frequencies, which means these higher-order modes have not been excited by this tight bowtie dipole geometry. The simulated S-parameters of the complete OMT for the dominate mode TE_{11} are shown in Fig. 2(b), with the mutual coupling between two polarizations below -33 dB, the reflection coefficients for both polarizations below -10 dB and the transmission coefficient above -0.45 dB over the frequency band. Wherein, the reflection coefficients of orthogonal polarized ports are below -14 dB and the transmission coefficients are above -0.2 dB from 0.58 GHz to 1.04 GHz.

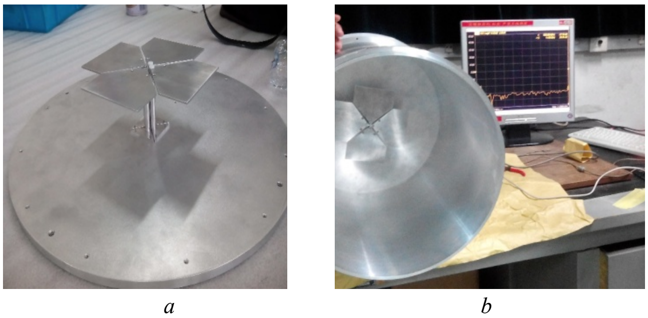


Fig. 3 *Photograph of the OMT prototype*
a Bowtie dipole part with a ground plane
b Bowtie dipole OMT under test

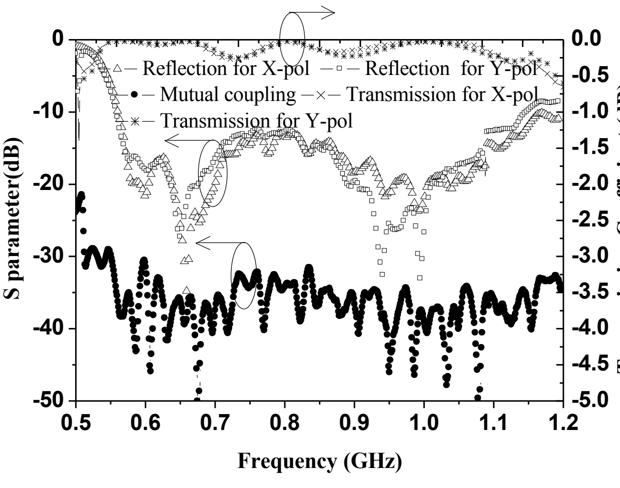


Fig. 4 *Measured data of the constructed OMT*

Experimental results: A prototype of the bowtie dipole OMT has been manufactured with the CNC machining on aluminium material, as shown in Fig. 3, and measured using an Agilent E5071C ENA Series network analyzer.

Fig. 4 shows the measured results of the reflection coefficients and the mutual coupling between the two orthogonal coaxial ports with matched load in the waveguide port. The measurement shows the reflection coefficient and the mutual coupling are below -10 dB and -30.5 dB respectively over 0.56-1.12 GHz. Measured transmission coefficient of the OMT at room temperature is presented in the figure, too, which was obtained by measuring two OMT units connected back-to-back and halving the measured data. The measured value is above -0.5 dB which agrees with the simulated data. In fact, the main part of the measured transmission coefficient is due to the reflection effect, while the Ohmic loss of this purely metal OMT is extremely low, which can be obtained by $-10*\text{Log}[|S_{21}|^2/(1-|S_{11}|^2)]$ with the maximum value of 0.15 dB and the average over the band below 0.05 dB. As predicted, no resonances of the trapped modes can be observed in the operating band.

Conclusion: A novel bowtie dipole orthomode transducer (OMT) with an octave bandwidth for cryogenic receiver system of FAST is presented. Due to the symmetrical OMT structure and electrical field distribution characteristics of the bowtie dipole, the single mode bandwidth of the OMT has been achieved to 2.08:1. The proposed OMT has a length of 300 mm, only 0.56 wavelength at the low-end frequency of 0.56 GHz. Measurements showed a reflection coefficient below -10 dB for both polarizations, cross-coupling levels below -30.5 dB and transmission coefficient above -0.5 dB over the operating band of 0.56-1.12 GHz. The purely metallic OMT is very compact, easy to fabricate and therefore, an excellent candidate for low frequency, high sensitivity, cryogenic integration and miniaturization application.

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J. Fan, K. Zhu and Y.H. Yan: *(Department of FAST, National Astronomy Observatory of China, Beijing 100012, China)*
E-mail: jfan@bao.ac.cn
J. Yang (*Department of Electrical Engineering [Antenna Group] and the Department of Earth and Space Sciences [Onsala Space Observatory], Chalmers University of Technology, Gothenburg, Sweden.)*

References

1. Bøifot， A. M., Lier， E., and Schaug-Pettersen， T.: ‘Simple and broadband orthomode transducer,’ *IEE Proc., Microw. Antennas Propag*., 1990, **137**, (6) pp. 396–400
2. Navarrini, A., and Plambeck, R. L.: ‘A turnstile junction waveguide orthomode transducer,’ *IEEE Trans. Microw. Theory Tech*., 2006, **54**, (1), pp. 272-277
3. Grimes, P. K., King, O. G., Yassin, G., and Jones, M. E.: ‘Compact broadband planar orthomode transducer’, *Electron. Lett*., 2017, **43**, (21)
4. Robertson, S. D.: ‘Recent advances in finline circuits,’ *IRE Trans. Microw. Theory Tech*., 1956, **MTT-4**, pp. 263–267
5. Skinner, S. J., and James, G. L.: ‘Wide-band orthomode transducers,’ *IEEE Trans. Microw. Theory Tech*., 1991, **39**, (2), pp. 294–300
6. G. M. Coutts: ‘Octave Bandwidth Orthomode Transducers for the Expanded Very Large Array,’ *IEEE Trans. Antennas Propag*., Vol. 59, No. 6, pp1910-1917, Jun 2011
7. Fan, J., Yan, Y. H., Jin, C, J., Zhan, D, Z., and Luo, J, R.: ‘Design of Wideband Quad-ridged Waveguide Orthomode Transducer at L-band,’ PIER C, 2017, **72**, pp.155-122
8. de Villiers, D.I.L., Meyer, P., Palmer, K.D.: ‘Broadband offset quad-ridged waveguide orthomode transducer,’ *Electron. Lett*., 2009, **45**, (1)