An x-band waveguide orthomode transducer with integrated filters

Gao, Yang; Shang, Xiaobang; Wang, Yi; Lancaster, Michael J.

DOI:
10.1002/mop.31986

An X-band Waveguide Orthomode Transducer with Integrated Filters

Yang Gao,[1] Xiaobang Shang,[2] Yi Wang,[3] Michael J. Lancaster[3]
[1]Depardment of Information Engineering, Zhengzhou University, NO. 100 Science Road, Zhengzhou, China, 450000
[2]National Physical Laboratory, Teddington, TW11 0LW, UK
[3]Department of Electric, Electronic, and System Engineering, The University of Birmingham, Birmingham, B15 2TT, UK
Corresponding author: X. Shang, E-mail: xiaobang.shang@npl.co.uk

ABSTRACT: *This letter presents a novel waveguide orthomode transducer (OMT) with integrated filters. Resonator-based bandpass filters are used for the two channels forming a duplexing OMT. As an example, a two-channel duplexing OMT is designed with channels at 9.9-10.1 GHz and 10.9-11.1 GHz. A good filter response with 20 dB return loss is achieved for both the channels. The upper and lower bands are isolated to -80 dB due to the filtering elements and a transmission zero. This new multifunction compact filter-OMT design leads to the size reduction and improved inter-band isolation. A CNC machined waveguide OMT is demonstrated and its performance is verified with excellent agreement between the electromagnetic wave (EM) simulation and measured results.*

Key words: *filtering OMT, waveguide.*

1. INTRODUCTION

Orthomode transducers (OMT) have been widely investigated [1]-[4] and are used to split signal polarization. An OMT is employed in the transmitting or receiving of two orthogonally polarized signals (for example the uplink and downlink paths in satellites), which can double the channel capability [2]. Generally, a turnstile T-junction is used in OMTs to form a three-port device. The common port carries the orthogonal signals; the other two ports extract the individual polarizations and routes them to two different paths [3]. The T-junction structure in OMTs can be either symmetric or asymmetric. Symmetrical junctions provide higher isolation between orthogonal channels and a wider operating bandwidth. However, this can be at the expense of high mechanical complexity and large size. Asymmetrical junctions on the other hand offer smaller size and more convenient machining, nevertheless, have smaller operating bandwidth and lower isolation.

To improve the isolation level and suppress undesired higher order modes, auxiliary filters can be added to the signal paths. This normally requires additional units, larger size, and more cost. We propose a new design in this letter, where filters are integrated with the OMT through a slot coupled T-junction, forming a filtering OMT. This co-design approach allows for the reduction of the component count, and a reduction in the overall circuit size and weight. Channel isolation can also be improved due to the incorporated filters and the introduction of transmission zeros.

Conventionally, filtering elements in the branches are designed independently followed by the construction of the T-junction [5]-[8]. The T-junctions are usually analyzed and modelled using the equivalent circuits [7], [8]. In [8], the T-junction is analyzed and represented by the equivalent lumped circuit having complex loads, and then the filters are added to provide matching [8]. In [5], a filter is only added to the vertical polarized port, with the other port directly coupled to the waveguide. In [6], single resonators were integrated with both channels, but had limited bandwidth, poor in-band flatness and little design flexibility.

In our work, the integrated filter-OMT is designed as an entity. Two third-order resonator-based filters are integrated to the upper and lower channels. The novelty lies in the slot coupled T-junction construction: it is different from the conventional independent structure of junction cascaded to filters, which requires a connecting waveguide section between the T-junction and the filters [5], [6], [7], [9]. Instead, the filters are integrated to the input waveguide with coupling irises. This accounts for a further reduction in the overall size.

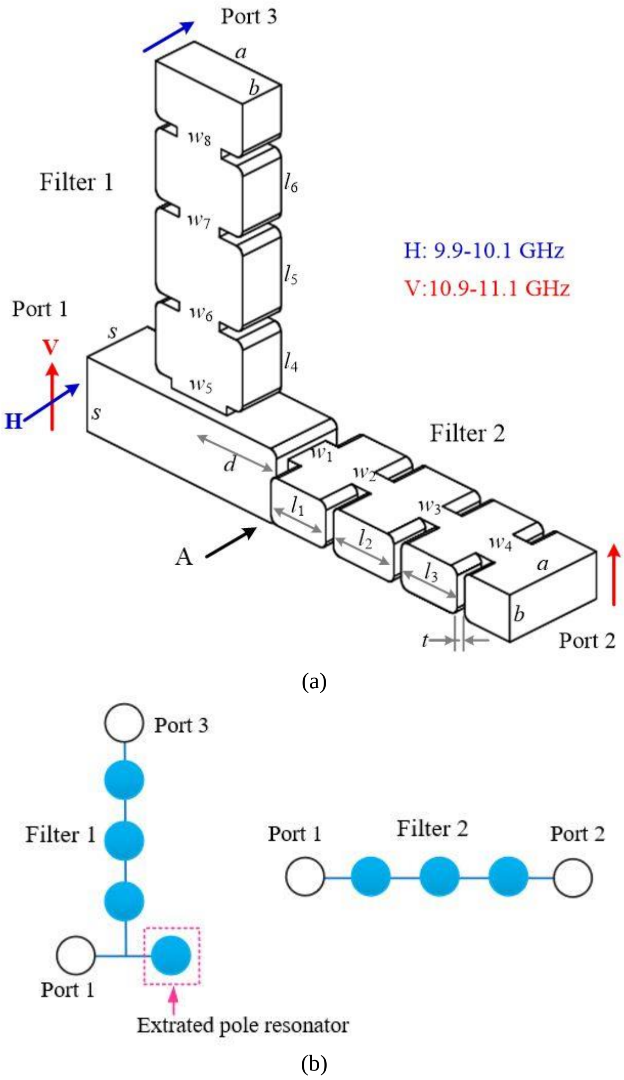


Figure 1 Diagram of the OMT. (a) Physical schematic. (b) Topology representation with the filled circles representing resonators. a=22.86, b=10.16, s=16, l_1=14.46, l_2=15.961, l_3=14.649, l_4=15.346, l_5=18.311, l_6=15.161, w_1=9.984, w_2=6.128, w_3=6.128, w_4=9.855, w_5=14.606, w_6=10.642, w_7=10.642, w_8=11.639, d=23.353, t=2, Unit: millimeter. All the inner corners have the same radius of 1.6 mm.

2. DESIGN OF THE OMT

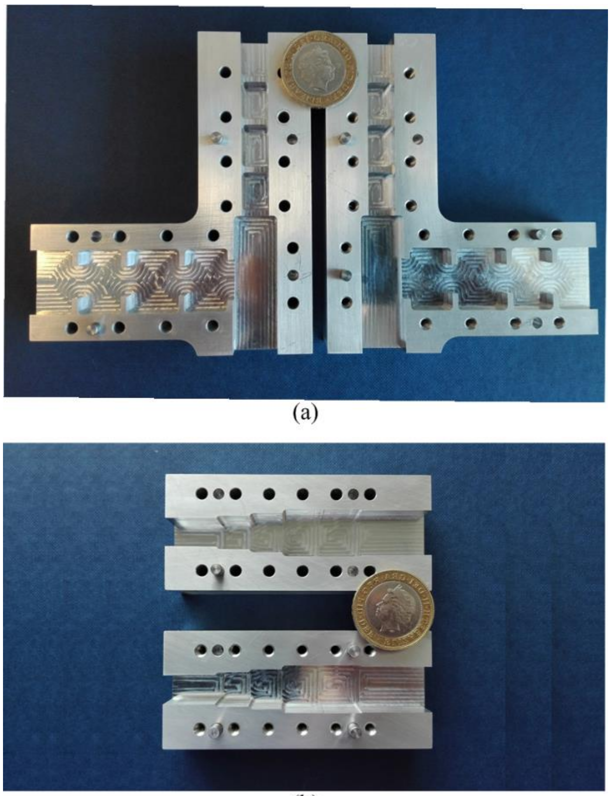
In principal, this new filter-OMT can have any frequency and bandwidth, however we will describe it through an example.

The filter-OMT is illustrated in Fig. 1. The common port is a square waveguide. One 3rd order filter is at the end of this square waveguide, whereas the other ortho-polarized waveguide filter is on the sidewall. Both filters are coupled to the square waveguide via a rectangular slot. Inductive irises are used within the two filters. Port 2 is to receive a vertically polarized signal over the frequency range 10.9 - 11.1 GHz, and Ports 3 is to receive the horizontally polarized signal over 9.9 - 10.1 GHz. Both filters have a bandwidth of 0.2 GHz with a 20 dB return loss. A transmission zero (TZ) is created at the center frequency (11 GHz) of the upper ban d, which improves the channel isolation.

The geometries of the coupling slots can be determined with the help of the external *Q* and coupling coefficient extraction approach for the conventional filter design [10]. That is, the coupling coefficients and external quality factors can be calculated from the standard *g*-values according to the filter specification and the iris sizes adjusted accordingly [10].

Fig. 1 illustrates the physical structure and the decomposed topology representation of the filter-OMT. The slot size w_1 and w_5, as shown in Fig. 1(a), can be determined by extracting the external quality factor Q_e of these two filters. The values of Q_e are the same as a conventional filter [10]. The center frequency of the resonator can be altered by adjusting the lengths of the resonators, l_1 and l_4. The external coupling at Port 2 and 3 are also obtained to fulfill the required Q_e, by adjusting the iris width w_4 and w_8.

The other characteristic dimensions are found from the inter-resonator couplings of the filters. The required coupling coefficients can be fulfilled by choosing appropriate sizes of w_2, w_3, w_6, and w_7 to match the calculated coupling coefficients.



(a)

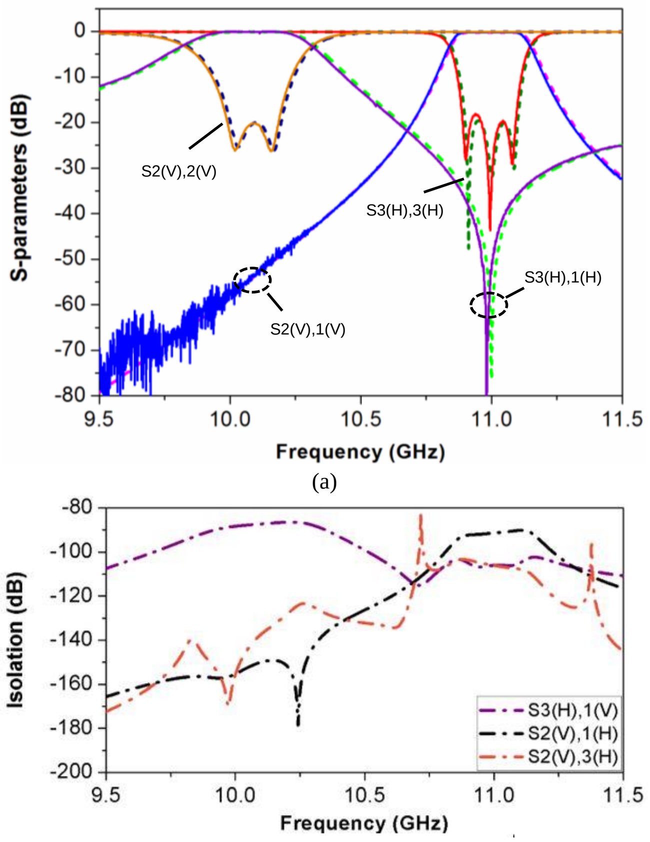
(b)

Figure 2 Photograph of (a) the split blocks of the OMT and (b) the stepped waveguide transformer.

3. FABRICATION AND MEASUREMENTS

The OMT is machined out of aluminium (AL5400), and a square-to-rectangular waveguide adapter is also made to facilitate the measurements [6]. The input waveguide flange is connected to port 1 using this stepped waveguide transformer which has a simulated insertion loss of < 0.1 dB. Both the waveguide transformer and OMT are cut along the E-plane. Fig. 2 shows a photograph the fabricated OMT and the waveguide transformer.

The measured results are shown in Fig. 3(a) and compared with those simulated in CST. An excellent agreement can be observed without any tuning. The upper-lower bands isolation is up to -80 dB as the simulated S-parameters responses of $S_{2(V),1(H)}$, $S_{3(H),1(V)}$, and $S_{2(V),3(H)}$ are shown in Fig. 3(b).



(a)

(b)

Figure 3 Simulated (dashed lines) and measured (solid lines) S-parameters responses of the integrated filter-OMT. (a) Transmission and reflection responses; and (b) simulated isolation responses.

The occurrence of the TZ is due to the extracted pole resonator of filter 1, which is illustrated in Fig. 1(b). The distance between the coupling slot of filter 1 and the junction point A is shown as length *d*. At junction point A, the vertically polarized wave couples to filter 2 (as designed), however the horizontally polarized wave has an impedance close to a short circuit over a wide frequency range, even at the center frequency of filter 2. Thus, adjusting *d* to approximately a half wavelength provides the extracted pole resonator and the position of the TZ can be altered by changing the distance *d*. The whole structure is simulated and optimized in CST and the optimized *S*-parameters response is shown in Fig. 3. The 3rd-order response can be clearly observed at the upper channel, but the lower channel filter has one missing reflection zero. This may be caused by the cancelation of the reflected waves.

4. CONSLUSION:

A new duplexing OMT has been presented in this letter. The simulated and experimental performance exhibit excellent agreement, validating the co-designed filter OMT. The integration of this multi-functional structure brings advantages of the device in terms of simplicity, compactness and simplified design approach.

ACKNOWLEDGMENT

This work was supported by the U.K. Engineering and Physical Science Research Council under contract EP/S013113/1.

REFERENCES

1. M. A. Abdelaal, S. I. Shams, M. A. Moharram, M. Elsaadany and A. A. Kishk, "Compact full band OMT based on dual-mode double-ridge waveguide," *IEEE Trans. Microw. Theory Techn.*, vol. 66, no. 6, pp. 2767-2774, June 2018.
2. A. M. Bøifot, "Classification of ortho-mode transducers," *Eur. Trans. Telecommun.*, vol. 5, no. 2, pp. 503–510, 1991.
3. J. A. Ruiz-Cruz, J. R. Montejo-Garai, C. A. Leal-Sevillano and J. M. Rebollar, "Orthomode transducers with folded double-symmetry Junctions for broadband and compact antenna feeds," *IEEE Trans. Antennas Propag.*, vol. 66, no. 3, pp. 1160-1168, March 2018.
4. C. A. Leal-Sevillano, Y. Tian, M. J. Lancaster, J. A. Ruiz-Cruz, J. R. Montejo-Garai and J. M. Rebollar, "A micromachined dual-band orthomode transducer," *IEEE Trans. Microw. Theory Techn.*, vol. 62, no. 1, pp. 55-63, Jan. 2014.
5. P. J. Tatomir, L. Niguel, D. J., Hoppe, *el*, 'Coaxially configured OMT-multiplexer assembly', *U.S. Patent.*, Feb. 2000.
6. Y. Tao and Z. Shen, "Synthesis of single- and dual-band short-circuited waveguide orthomode transducers," *2014 44th Europ. Microw. Conf.*, Rome, 2014, pp. 452-455.
7. K. Wu and W. Meng, "A direct synthesis approach for microwave filters with a complex load and its application to direct diplexer design," *IEEE Trans. Microw. Theory Techn.*, vol. 55, no. 5, pp. 1010-1017, May 2007.
8. Y. Tao, Z. Shen and G. Liu, "Closed-form expressions for the equivalent circuit model of square-waveguide T-Junctions and its application in ortho-mode transducer design," *IEEE Trans. Microw. Theory Techn.*, vol. 58, no. 5, pp. 1167-1174, May 2010.
9. T. Sieverding and F. Arndt, "Field theoretical CAD of open or aperture matched T-junction coupled rectangular waveguide structures," *IEEE Trans. Microw. Theory Techni.*, vol. 40, no. 2, pp. 353-362, Feb. 1992.
10. J. S. Hong and M. J. Lancaster, *Microstrip Filters for RF/Microwave Applications*. New York, NY, USA: Wiley, 2001.