# The Bifurcated E-Plane T-Junction and Its Application to Waveguide Diplexer Design

Jens Bornemann and Marjan Mokhtaari

Department of Electrical and Computer Engineering, University of Victoria, Victoria, BC, V8W 3P6, Canada

*Abstract*—**The bifurcated E-plane T-junction is presented. Its advantages with respect to waveguide diplexer design are: It allows full E-plane height operation, thus permitting good power handling capability, is simple to model, and provides additional tuning parameters for the computer-aided design. The performance of the junction is compared to those of other junctions and its advantages are demonstrated in a full diplexer design. The combined mode-matching and coupled-integral-equations code used for the design is verified by measurements and comparison with results obtained by commercially available software packages.**

***Keywords – waveguide junctions; T-junctions; bifurcations; diplexers; computer-aided design.***

## I. INTRODUCTION

The computer-aided design of waveguide diplexers has been a research topic for more than two decades, and a very large number of papers have been published. The synthesis and design of applicable channel filter structures is well understood. However, the overall diplexer design, which includes the waveguide junction joining filters and the common port, is not always a straightforward process.

Waveguide T-junctions are often used in diplexer configurations, and it was always felt that the T-junction required certain dimensional parameters to achieve an acceptable match within the relevant frequency ranges. Therefore, T-junctions with compensating elements are frequently employed either within the volume of the junction, e.g. [1] – [6], or just outside of it, e.g. [7], [8]. Other options include Y-shaped junctions in both H- and E-planes, e.g. [9] – [11] and E-plane bifurcations, e.g. [11], [12].

More recently, it was demonstrated that diplexers and multiplexers involving H-plane T-junctions can be designed without compensating elements - either as manifold designs, [13], [14], or even when the branching arm acts as the common port [15]. H-plane technology, however, is prone to passive intermodulation phenomena and, therefore, has limited applications in satellite systems where the E-plane manufacturing process is preferred, e.g. [16]. Possible leakage between transmit and receive channels also prohibits the use of standard E-plane bifurcations.

Thus the common E-plane T-junction (Fig. 1, left) is often used in front-end diplexer designs. Acceptable diplexer performance, however, seems possible only with reduced-height T-junctions that require matching waveguide transformers to full-height technology at all ports, e.g. [17]. Full-height E-plane junctions, i.e., without transformers, have only been used in manifold-type configurations, but they suffer from poor common-port return loss [18] or spurious resonances [19].

Therefore, this paper presents the bifurcated E-plane T-junction (Fig. 1, right) as an alternative to previous diplexers with the branching arm as common port. This junction not only allows full-height, high-power handling operation but also is much simpler to model than those containing elements within the junction volume and provides additional compensation elements for the computer-aided design. Leakage between transmit and receive channels, as known from classical bifurcated configurations ([11], [12]), is eliminated since the bifurcation is confined, thus excluding the channel filters.

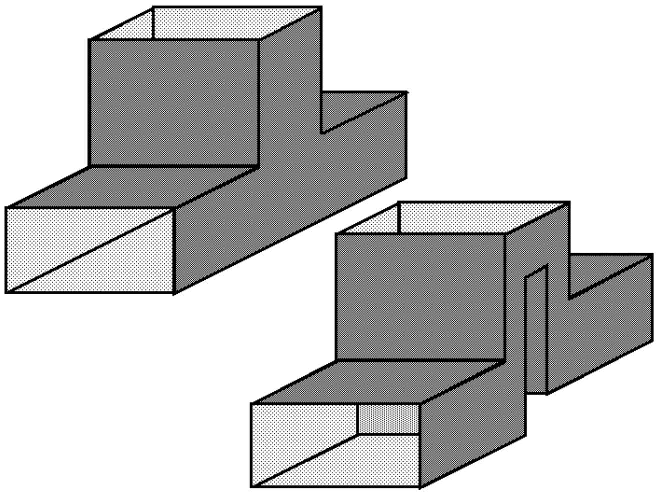


Figure 1. E-plane T-junctions: regular (left), bufurcated (right).

## II. BIFURCATED E-PLANE T-JUNCTION

The bifurcated E-plane T-junction is shown in Fig. 1 (right) and, as far as computer analysis is concerned, consists of an E-plane bifurcation and two connected E-plane corners. In order to highlight some of the advantages of this junction, Fig. 2 compares its performance with those of the standard E-plane T-junction and a ridged junction. Shown is the input reflection coefficient in dB seen into the branching port (usually the common port in a diplexer design).

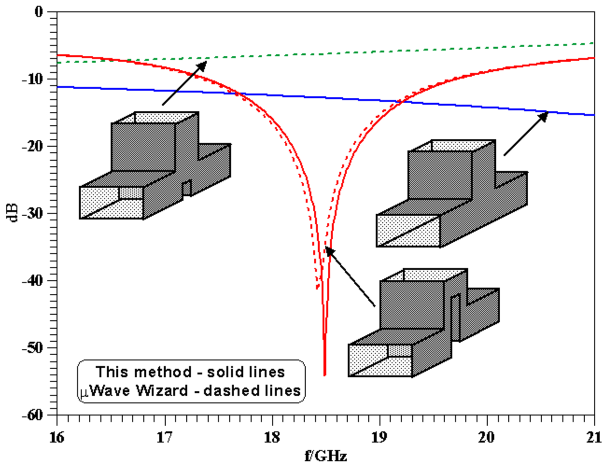



Figure 2. Reflection coefficient in dB of the branching (upward) port of ridged, standard and bifurcated E-plane T-junctions.

Both standard and ridged junctions show nearly constant reflection coefficients over the frequency range. Whereas the standard T-junction is simply modeled using a Mode-Matching Technique (MMT) or Coupled-Integral-Equations Technique (CIET), the ridged junction either requires a complex modal analysis [20] or more general numerical schemes such as the Finite-Element Method (FEM) used in the µWave Wizard®. In contrast, the bifurcated T-junction is not only easily modeled using modal techniques; it also creates a very acceptable return loss over a bandwidth usually wide enough for diplexer applications. This is achieved by offsetting the left and right arm for a given thickness of the bifurcation. The excellent agreement between the results obtained with our MMT-CIET code and those from the µWave Wizard® verifies the basic performance of the bifurcated E-plane T-unction.

## III. Diplexer Design

The basic steps in a computer-aided design of a diplexer are well known. In the first step, individual channel filters are separately synthesized and/or optimized employing either singly or doubly terminated filter theory. In the second step, the filters are combined at the respective ports of a three-port junction, and junction and filter dimensions are iteratively optimized according to given diplexer specifications.

A conventional E-plane T-junction diplexer with inductive-iris filters in reduced-height waveguide technology and matching transformers to WR75 waveguide at all three ports is shown in the inset of Fig. 3. The performance computed with this method is in good agreement with measurements within a dynamic range of approximately 70 dB. Thus Fig. 3 verifies the MMT-CIET code in a diplexer arrangement. Note that a loss analysis based on perturbation theory and Q-efficiency is included but shows little effect, as the inside of the entire component is silver-plated.

Various diplexer designs are now presented for 18/19 GHz using WR51 waveguides. Specifications call for 24 dB in-band return loss and 60 dB attenuation in the respective bands. Based on the channel bandwidths of 17.9GHz – 18.4GHz and 18.8GHz – 19.2GHz, seven- and six-resonator inductive-iris filters, respectively, are employed.

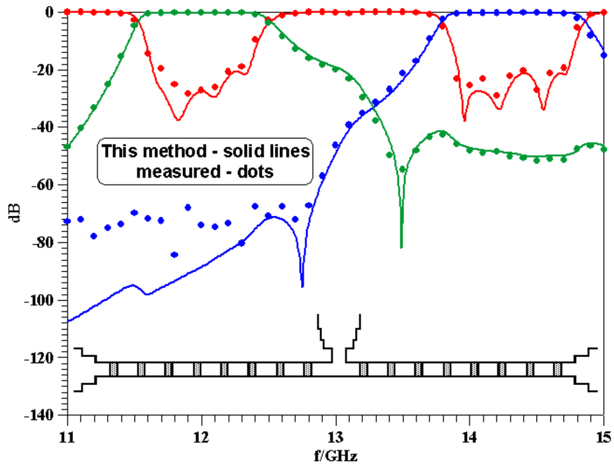



Figure 3. Computed and measured [17] performance of a traditional E-plane T-junction diplexer in reduced-height waveguide technology with matching transformers to WR75 waveguide.

Fig. 4 presents the conventional design similar to that in Fig. 3. All design specifications, as depicted by the thin solid lines, are met, but the design is complicated by E-plane waveguide transforms and a relatively low power handling capability due to the reduced waveguide height in the channel filters.

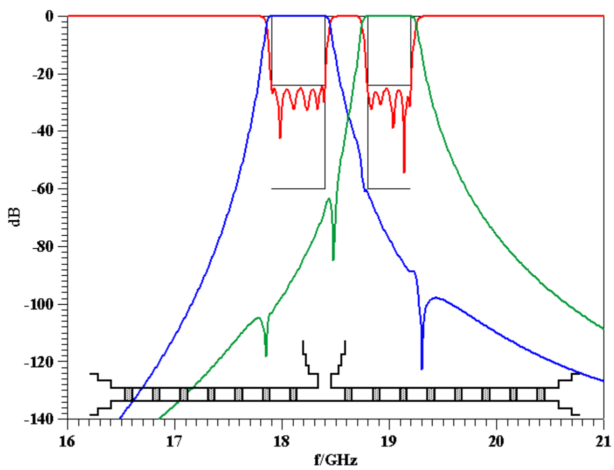



Figure 4. Performance of traditional E-plane T-junction 18/19 GHz diplexer.

In order to eliminate the disadvantages of this component, a straightforward design without transformers and full-height filter channels is attempted in Fig. 5. After extensive optimization, which includes the entire parameter sets of both filters, the specifications are still not quite met. Further optimization might improve the return loss behavior but only at the expense of further detuning the filters and, consequently, failing to meet the isolation specifications. Additional filter components (cavities) will have to be incorporated for this design to satisfy specifications without additional matching elements.

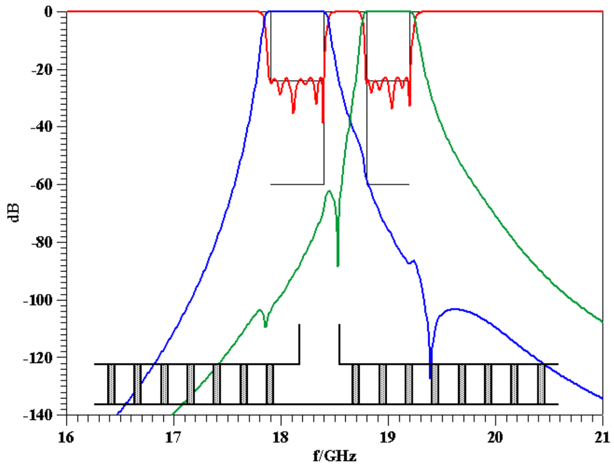
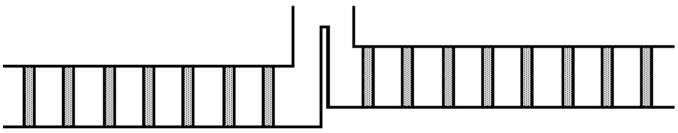
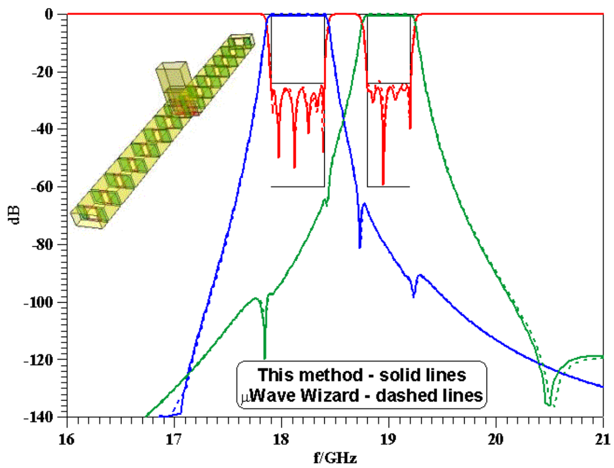



Figure 5. Performance of full-height E-plane T-junction 18/19 GHz diplexer.

A diplexer design involving the bifurcated E-plane T-junction is presented in Fig. 6. For comparison with the insets of Fig. 4 and Fig. 5, Fig. 6a depicts the side view of this design; the inset of Fig. 6b shows a 3D view. Due to the advantages of the bifurcated T-junction, all ports have regular-height waveguide dimensions, thus avoiding the use of impedance transformers. Moreover, the filters are designed in full waveguide height, which reduces losses and increases power handling capability.



(a)




(b)

Figure 6. Sideview (a), performance (b) of a diplexer employing the bifurcated E-plane T-junction in WR51 waveguide technology and comparison with results obtained with the μWave Wizard®.

The performance of this diplexer is shown in Fig. 4b and satisfies specifications. A comparison with the professional software package μWave Wizard® shows excellent agreement, thus validating the principal design approach.

As shown in Fig. 2, the bandwidth of the bifurcated E-plane T-junction is narrow but acceptable for many diplexer applications. While the bifurcation is fairly wideband, the narrowband characteristic is mainly introduced by the two waveguide corners. In order to alleviate this restriction, mitered corners can be used. Such a diplexer design employing the bifurcated E-plane T-junction with mitered corners is shown in Fig. 7. This configuration has the potential of diplexing frequency bands which are further apart than the ones shown in this paper.

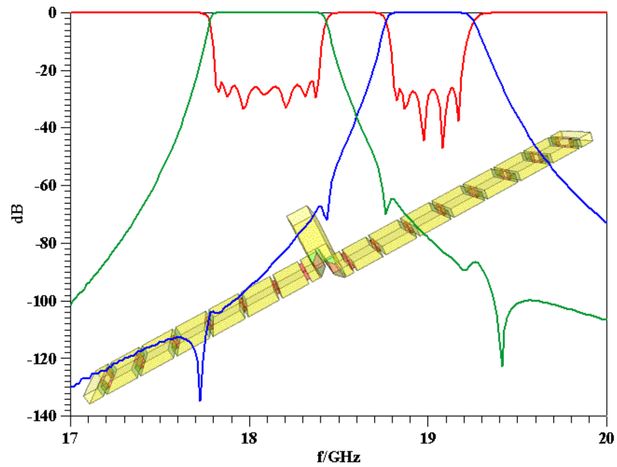



Figure 7. Diplexer design employing the bifurcated E-plane T-junction with mitered corners (μWave Wizard®).

## IV. Conclusions

The bifurcated E-plane T-junction presents a viable option for diplexer designs in E-plane waveguide technology. Through its full-height operation, it has the potential to accommodate a large variety of different channel filters. Compared to conventional designs, the bifurcated T-junction is easy to model, allows for better power handling capability and permits the offsets in side-arm locations to be used as additional optimization parameter. The simulation code is based on an efficient MMT-CIET combination and is verified by comparison with measurements and commercially available software. Mitered corners may be introduced for wide-band separation of individual frequency bands.

## Acknowledgment

The authors are greatly indebted to Dr. Jaroslaw Uher of MDA Space (formerly EMS Technologies), Ste-Anne-de-Bellevue, PQ, Canada for valuable discussions and helpful suggestions.

## References

[1] T. Shen, K.A. Zaki and T.G. Dolan, "Rectangular waveguide diplexers with a circular waveguide common port", IEEE Trans. Microwave Theory Tech., Vol.51, pp. 578 – 582, Feb. 2003.

[2] Y. Rong, H. Yao, K.A. Zaki and T.G. Dolan, “Millimeter-wave Ka-band diplexers and multiplexers”, IEEE Trans. Microwave Theory Tech., Vol. 47, pp. 2325-2330, Dec. 1999.

[3] E. Ofli, R. Vahldieck and S. Amari, “Novel E-plane filters and diplexers with elliptic response for millimeter-wave applications”, IEEE Trans. Microwave Theory Tech., Vol. 53, pp. 843-851, Mar. 2005.

[4] D.A. Cargill, T. Dolan and P. Pramanick, “Optimization of waveguide diplexers using shadow specification”, IEEE MTT-S Int. Microwave Symp. Dig., pp. 2107-2110, June 2001.

[5] K.-L. Wu and H. Wang, "Rigorous modal analysis of H-plane waveguide T-junction loaded with a partial-height post for wide-band applications", IEEE Trans. Microwave Theory Tech., Vol. 49, pp. 893-901, May 2001.

[6] H.-W. Yao, A.E Abdelmonem,.; J.-F. Liang; X.-P. Liang; K.A. Zaki, and A. Martin, “Wide-band waveguide and ridge waveguide T-junctions for diplexer applications”, IEEE Trans. Microwave Theory Tech., Vol. 41, pp. 2166 – 2173, Dec. 1993.

[7] J.M. Rebollar and J.R. Montejo-Garai, “Asymmetric H-plane T-junction for broadband diplexer applications”, IEEE AP-S Int. Symp. Dig., pp. 2032-2035, July 2000.

[8] T. Sieverding and F. Arndt, “Field theoretical CAD of open or aperture matched T-junction coupled rectangular waveguide structures”, IEEE Trans. Microwave Theory Tech., Vol. 40, pp. 353 - 362, Feb. 1992.

[9] F.M. Vanin, D. Schmitt and R. Levy, “Dimensional synthesis of wide-band waveguide filters and diplexers”, IEEE Trans. Microwave Theory Tech., Vol. 52, pp. 2488-2495, Nov. 2004.

[10] I.V. Bragin, S.E. Chadov, V.I. Gusevskii and E. Lavretski, “Waveguide diplexer using E-plane tee of improved symmetry”, Proc. 13th Int. Conf. Microwaves, Radar, Wireless Communications, Vol. 2, pp. 513-516, May 2000.

[11] A. Morini and T. Rozzi, "Constraints to the optimum performance and bandwidth limitations of diplexers employing symmetric three-port junctions", IEEE Trans. Microwave Theory Tech., Vol. 44, pp. 242-248, Feb. 1996.

[12] J. Dittloff and F. Arndt, “Rigorous field theory design of millimeter-wave E-plane integrated circuit multiplexers”, IEEE Trans. Microwave Theory Tech., Vol. 37, pp. 340 – 350, Feb. 1989.

[13] L. Accatino and M. Mongiardo, “Hybrid circuit-full-wave computer-aided design of a manifold multiplexers without tuning elements”, IEEE Trans. Microwave Theory Tech., Vol. 50, pp. 2044-2047, Sep. 2002.

[14] J.R. Montejo-Garai, J.A. Ruiz-Cruz and J.M. Rebollar, "Full-wave design of H-plane contiguous manifold output multiplexers using the fictitious reactive load concept", IEEE Trans. Microwave Theory Tech., Vol. 53, pp. 2628-2632, Aug. 2005.

[15] A. García-Lampérez, S. Llorente-Romano, M. Salazar-Palma and T.K. Sarkar, "Efficient electromagnetic optimization of microwave filters and multiplexers using rational models", IEEE Trans. Microwave Theory Tech., Vol. 52, pp. 508-521, Feb. 2004.

[16] J. Bornemann and J. Uher, “Design of waveguide filters without tuning elements for production-efficient fabrication by milling”, in Proc. 2001 Asia-Pacific Microwave Conf., pp.759-762, Dec. 2001.

[17] J. Bornemann, J. Uher and K. Patel, “Efficient full-wave CAD of waveguide diplexers”, Proc. ANTEM 96 Symp. Antenna Technology and Applied Electromagnetics, pp. 591-594, Aug. 1996.

[18] F. Arndt, J. Bornemann, D. Grauerholz, D. Fasold and N. Schroeder, “Waveguide E-plane integrated circuit diplexer”, IEE Electronics Letters, Vol. 21, pp. 615-617, July 1985.

[19] M. Guglielmi, “Simple CAD procedure for microwave filters and multiplexers”, IEEE Trans. Microwave Theory Tech., Vol. 42, pp. 1347-1352, July 1994.

[20] V.A. Labay and J. Bornemann, “Generalized modal scattering matrix of discontinuity-distorted waveguide multiport junctions”, *Int. J. Numer. Model.*, Vol. 10, pp.153-167, May-June 1997.