Journal of KIIT. Vol. 20, No. 1, pp. 121-128, Jan. 31, 2022. pISSN 1598-8619, eISSN 2093-7571 121
http://dx.doi.org/10.14801/jkiit.2022.20.1.121

A New E-Plane T-Junction Waveguide Power Divider Employing a Dielectric Insert

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Abstract

Waveguide power dividers or combiners are employed in microwave power distribution or summation systems, antenna feed networks, and signal multiplexers and demultiplexers. This paper presents a new waveguide T-junction power divider in the E-plane is presented. The proposed power divider consists of a mound for the compensation of junction discontinuity effects and a dielectric insert for impedance matching. Compared with existing structures, the power divider proposed in this paper has the advantage of structural simplicity and compactness. As an illustration, a design is presented for a power divider operating in the W-band from the parametric analysis using a commercial electromagnetic field simulation tool. The designed power divider shows reflection coefficient of less than -20 dB and transmission coefficient of greater than -3.04 dB at 75-95 GHz. Finally methods for the fabrication of the proposed power divider are presented.

요 약

도파관 전력분배기는 마이크로파 전력 분배 또는 합성 시스템, 안테나 급전회로망, 신호 멀티플렉서 및 디멀티플렉서에 사용된다. 본 논문에서는 전계면 상의 새로운 T-접합 도파관 전력분배기를 제안하였다. 본 논문에서 제안한 전력분배기는 접합의 불연속 효과를 보상하기 위한 돌출물과 임피던스 정합을 위한 유전체 삽입물로 구성된다. 기존의 구조에 비해 제안된 전력분배기는 구조의 단순성과 소형성의 장점을 제공한다. 예로서 상용 전자기장 시뮬레이션 툴을 이용한 파라미터 분석으로부터 W-대역에서 동작하는 제안된 전계면 T-접합 전력분배기의 설계를 제시하였다. 설계된 전력분배기는 75.5-95.7GHz에서 -20dB 이하의 반사계수와 -3.04dB 이상의 전달계수를 보인다. 마지막으로 제안된 전력분배기의 제작 방법을 제시하였다.

Keywords
power divider, rectangular waveguide, E-plane, T-junction, optimum design

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· Received: Dec. 31, 2021, Revised: Jan. 13, 2022, Accepted: Jan. 16, 2022
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I. Introduction

Waveguide power dividers are employed for applications where signal or energy needs to be distributed or combined in rectangular waveguide media [1]. Typical applications include the combining of microwave high-power sources [2]-[4], the antenna array feed network [5][6], and the waveguide multiplexer [7][8]. A waveguide power divider is implemented in the form of T-junction [9], Y-junction [10][11] or septum/bifurcation junction [12]. The T-junction offers the advantage of structural simplicity and compactness. Depending on the requirement, the T-junction divider can be realized either in the electric-field plane or in the magnetic-field plane.

Various approaches to the design of the E-plane T-junction power divider have been proposed. A half height (b/2) waveguide has been employed with a branching mound and stepped impedance transformers at the output branches [13][14], where the output ports have twice the input port's characteristic impedance. The output waveguides may have the same height (b) as the input waveguide [14][15]. In this case, stepped impedance transformers are employed either at the output ports or at the input port, and a mound or a similar structure is used to compensate for the junction effect [16][17]. A continuously tapered impedance matching structure can be used in place of a stepped transformer [18].

Another approach to the design of the divider is to use a metal post in the junction region and an impedance matching iris at the input waveguide [19]. The metal post can be replaced with a mound compensating for the junction effect [20].

This paper explains a new power divider in the electric-field plane that has a simply-shaped mound for junction-effect compensation and a dielectric insert for impedance matching. Compared with existing structures, the proposed design offers the advantage of structural simplicity and compactness while providing reasonably wideband performance. Optimum design of the proposed power divider is obtained from iterative parameter sweeps using the CST Studio Suite. Finally, fabrication methods of the proposed power divider are presented.

II. Power Divider Design

The structure of a rectangular waveguide E-plane T-junction is shown Fig. 1 where only the inside surfaces of the waveguide are shown for simplicity. In Fig. 1 the background or exterior material is a perfect conductor and the interior material is air. A standard rectangular waveguide has the narrow wall width b that is 50 percent of the broad wall width a. The simple T-junction shown in Fig. 1 has poor input matching due to discontinuity effect. Fig. 2 is the coefficient of reflection (S1,1) and the coefficient of transmission (S3,1) of the structure of Fig. 1. In Fig. 2, one observes that input matching is poor.

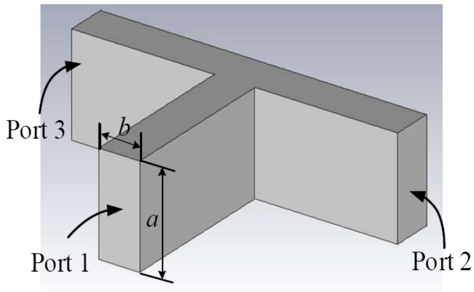


Fig. 1. Structure of a waveguide E-plane T-junction

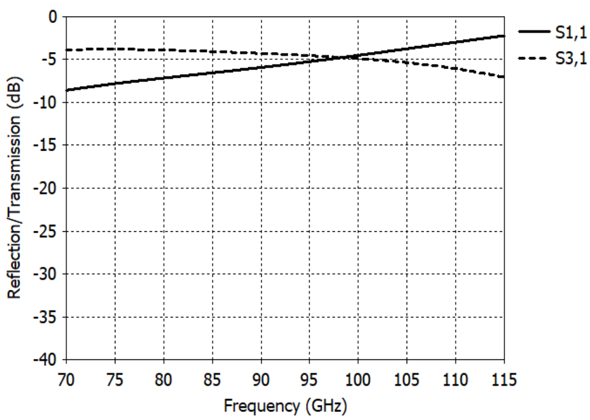
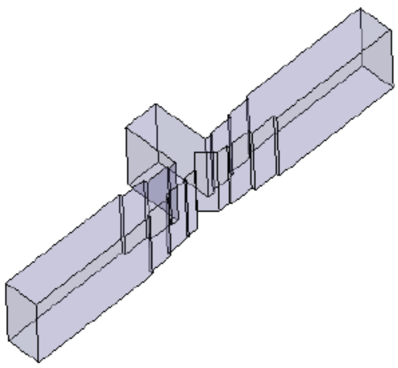


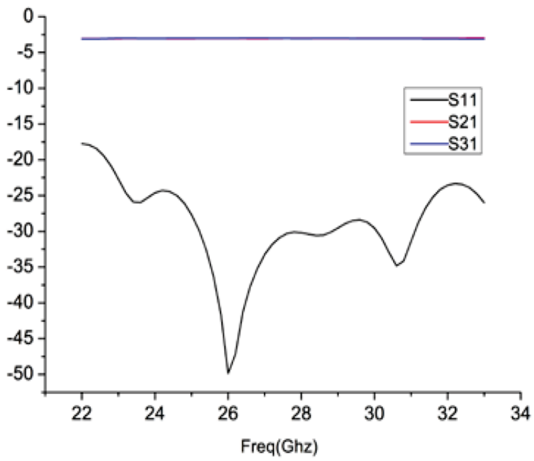
Fig. 2. Reflection (S1,1) and transmission (S3,1) coefficients of the uncompensated waveguide power divider in the electric-field plane

To improve input matching, various forms of the compensating structure can be employed. Fig. 3 shows the power divider proposed by Zou and co-workers [15] and its reflection and transmission coefficients. It has a mound and three -step impedance transformers at the output waveguides. The coefficient of reflection in the Zou's power divider is less than -20 dB at 23-33 GHz (42.9% bandwidth). It has a large bandwidth but with the structural complexity.

Fig. 4 shows the structure proposed in this paper, which consists of a mound for junction-effect compensation and a dielectric insert for impedance matching. Compared with the Zou's design, the proposed structure is simpler and thus easier to fabricate. The cost of structural simplicity is a reduced bandwidth of about 20%.



(a) Structure of the Zou's power divider



(b) Reflection coefficient/transmission coefficient

Fig. 3. Structure and coefficients of reflection/transmission of the Zou's divider [15]

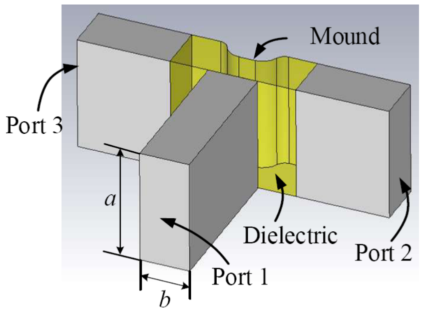


Fig. 4. Structure of the authors' power divider

Fig. 5 shows the dimensional parameters of the divider. Design parameters of the divider are as follows. L_2: mound length, L_3: mound height, R_1: mound edge radius, R_2: mound corner radius, L_1: dielectric insert length, ε_r: relative permittivity of the dielectric insert.

The power divider design will be illustrated for a power divider operating in W-band where a and b are 2.54 mm and 1.27 mm respectively. The cyclic olefin copolymer (COC) is chosen as the material of the dielectric insert for low dielectric constant (ε_r = 2.30 and low loss (tanδ = 0.0002 at W-band), good dimensional stability, excellent precise moulding property, low moisture absorption, high rigidity/strength/hardness and good machinability [21][22]. Other dielectric materials can be used as far as its dielectric constant is not too high.

Starting from initial values obtained by guess work, design parameters R_1, R_2, L_2, and L_1 are iteratively adjusted for low reflection over a wide frequency range.

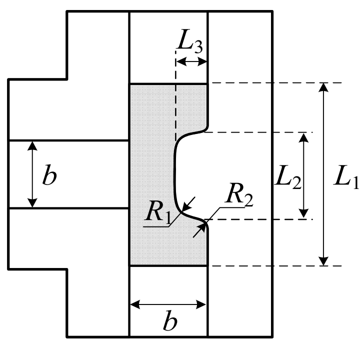


Fig. 5. Design parameters of the divider

Table 1 shows the result where reflection coefficient of less than -20 dB is obtained at 75.5-95.7 GHz (23.6% bandwidth). Fig. 6 shows the H-plane cross-sectional view of the divider. Fig. 7 shows the reflection and transmission coefficients of the power divider. The coefficient of reflection is less than -20 dB and the coefficient of transmission is greater than -3.04 dB at 75.5-95.7 GHz.

For power dividers to be operated at a lower or higher frequency range, L_1/b is increased or decrease respectively and other parameters are optimized. The bandwidth of the optimally designed power dividers is about 20% (a little smaller and larger than 20%) throughout W-band.

Table 1. Normalized dimensions of the divider

Frequency (GHz)	BW (%)	L_1/b	L_2/b	L_3/b	R_1/b	R_2/b
Initial values	–	2.00	1.00	0.50	0.30	0.20
75.5–95.7	23.6	2.406	1.229	0.457	0.376	0.20

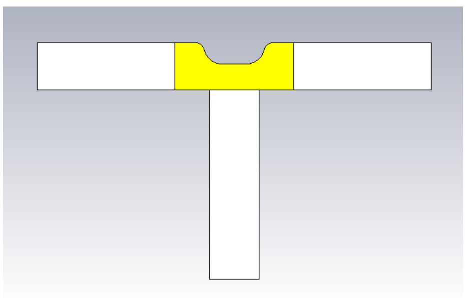


Fig. 6. H-plane cross-sectional view of the designed power divider

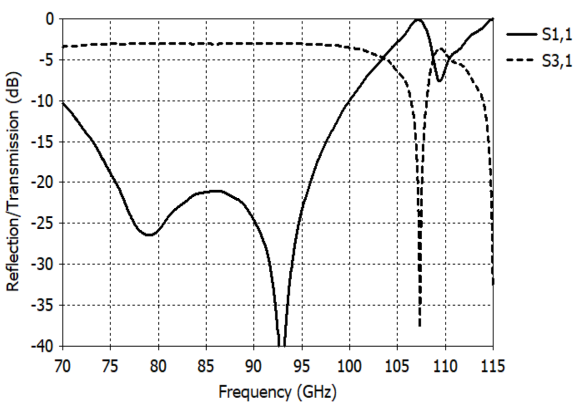


Fig. 7. Reflection (S1,1) and transmission (S3,1) coefficients of the divider

In the following we illustrate the dependence of the divider's input reflection coefficient on each design parameter. Fig. 8 to 12 shows the reflection coefficient S11 at the input port versus each design parameter (one of L_1, L_2, L_3, R_1 and ε_r) with all the other parameters remaining at the optimum value in Table 1.

Fig. 8 shows the reflection versus the dielectric insert length L_1 with the case S1_1(L_1) corresponding to the optimum value of L_1.

Similarly, Fig. 9 and 10 are the coefficient of reflection with various values of the mound length L_2 and height L_3 respectively. In Fig. 8 to 10, one can observe that the coefficient of reflection is sensitive to these parameters.

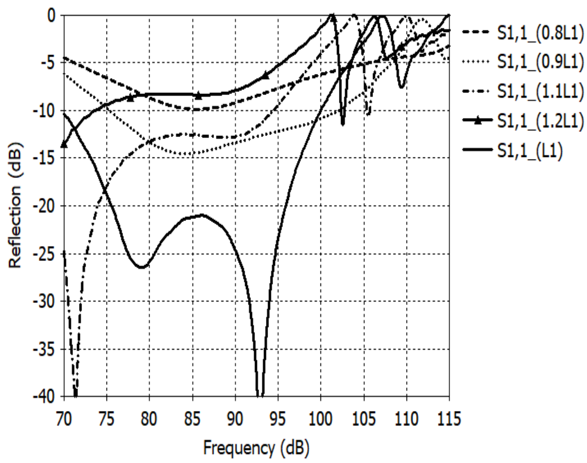


Fig. 8. Reflection versus the length L_1 of the dielectric insert

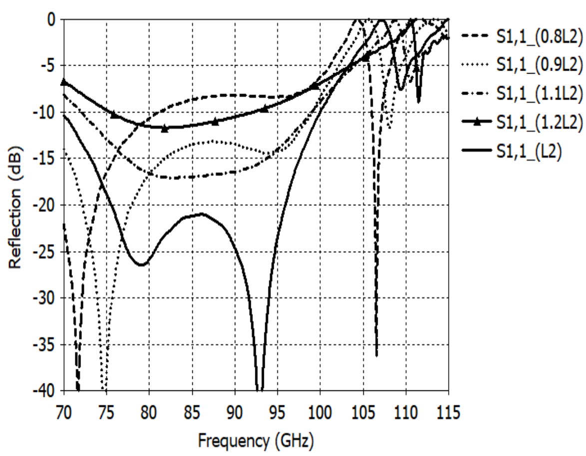


Fig. 9. Reflection versus the length L_2 of the mound

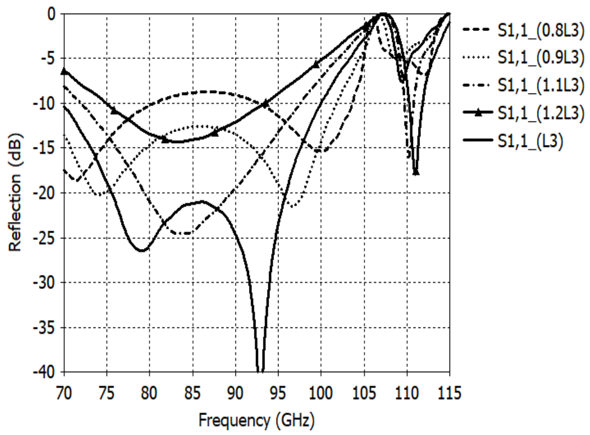


Fig. 10. Reflection versus the height L_3 of the mound

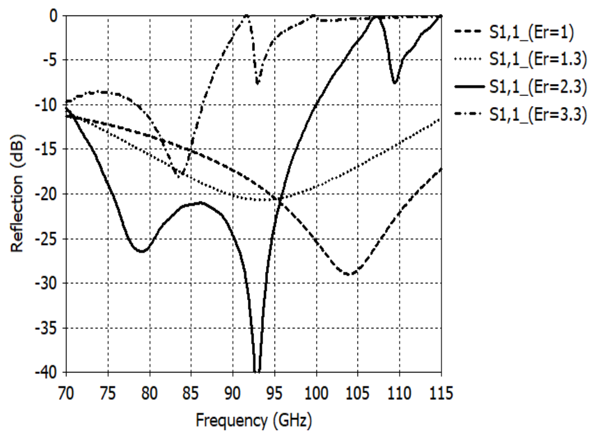


Fig. 12. Reflection versus the relative permittivity of the dielectric insert

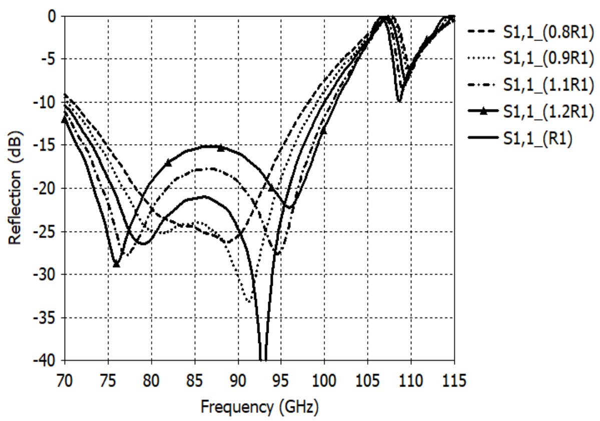
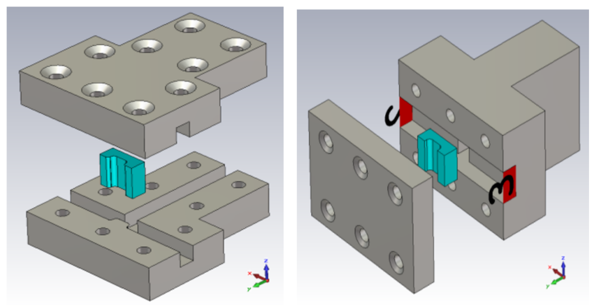


Fig. 11. Reflection versus the edge radius R_1 of the mound



(a) Split-block method (b) Top-surface split method

Fig. 13. Fabrication methods for the divider

Fig. 11 is the variation in the reflection coefficient with different values of the mound's edge radius R_1. The reflection coefficient at middle frequencies can be further reduced by using smaller values of R_1. This, however, results in reduced 20-dB bandwidths. The divider's reflection is not sensitive to the mound's corner radius R_2 so that the result is not presented. Finally Fig. 12 shows the reflection versus the relative permittivity ε_r of the dielectric insert. Again, the reflection is sensitive to ε_r.

The proposed power divider can be fabricated using the methods shown in Fig. 13. In the first split-block method, the structure is halved in the E-plane central surface. Each half block is fabricated using a suitable method such as CNC machining [23].

The dielectric insert is separately fabricated and installed between two blocks. Two half blocks are then joined together using screws.

In the second top-face split method, the structure is decomposed into the top surface of the branched waveguides and the remaining structure. The rectangular hole for the input waveguide is fabricated, for example, using the electrical discharge machining [24][25]. The remaining processes are the same as in the first method.

III. Conclusion

Authors of this paper have proposed a new waveguide divider in the electric-field plane and of the T-junction type. The divider design method has been presented. An uncompensated power divider shows reflection coefficient from -9 dB to -2 dB. In the proposed structure, the T-junction discontinuity is compensated using a simply-shaped mound and input-output impedance matching is obtained using a dielectric insert. To illustrate the divider's structure, a design of the proposed power divider has been presented that works in the W-band.

The proposed power divider shows reflection lower than -20 dB at 75.7-95.7 GHz (23.6% bandwidth). Using the proposed structure one can design a divider of T-junction type in the electric-field plane operating anywhere in the standard waveguide band with more than 20% bandwidth. The power divider proposed in this paper is simple and easy to fabricate offering a significant advantage over existing design for applications at high millimeter-wave and terahertz frequencies where machining tolerances of 0.02 mm or less are routinely required.

References

[1] J. Uher, J. Bornemann, and U. Rosenberg, "Waveguide Components for Antenna Feed Systems: Theory and CAD", Boston: Artech House, pp. 341-371, Dec. 1993.

[2] W. Qi, S. Qiang, W. Yidong, Z. Xiaodi, and X. Baosen, "Design of N-way high power combiner based on E-plane stepped waveguide T-junction", Proc. 2018 IEEE MTT-S Int. Wireless Symp. (IWS), Chengdu, China, 6-10 May 2018. https://doi.org/ 10.1109/IEEE-IWS.2018.8400957.

[3] Y. Zhang, K. Huang, D. K. Agrawal, T. Siawecki, H. Zhu, and Y. Yang, "Microwave power system based on a combination of two magnetrons", IEEE Trans. Electron Dev., Vol. 64, No. 10, pp. 4272-4278, Oct. 2017. https://doi.org/10.1109/TED.2017.2737555.

[4] L. W. Epp, D. J. Hoppe, A. R. Khan, and S. L. Stride, "A high-power Ka-band (31-36 GHz) solid-state amplifier based on low-loss corporate waveguide combining", IEEE Trans. Microw. Theory Tech., Vol. 56, No. 8, pp. 1899-1908, Aug. 2008. https://doi.org/10.1109/TMTT.2008.927299.

[5] X. Zhang, Y. Chen, Y. Xie, and L. Liu, "An improved E-plane waveguide power divider design for 94GHz dual-pyramidal horn antenna", ACES Journal, Vol. 34, No. 12, pp. 1897-1903, Dec. 2019.

[6] Q. You, Y. Lu, Y. You, Y. Wang, Z. C. Hao, and J. Huang, "Wideband full-corporate-feed waveguide continuous transverse stub antenna array", IEEE Access, Vol. 6, pp. 76673-76681, Nov. 2018. https://doi.org/10.1109/ACCESS.2018.2883590.

[7] J. Bornemann and M. Mokhtaari, "The bifurcated E-plane T-junction and its application to waveguide diplexer design", Proc. German Microw. Conf. (GeMiC), Karlsruhe, Germany, 28-30 Mar. 2006.

[8] Y. Rong, H. Yao, K. A. Zaki, and T. G. Dolan, "Millimeter-wave Ka-band H-plane diplexers and multiplexers", IEEE Trans. Microw. Theory Tech., Vol. 47, No. 12, pp. 2325-2330, Dec. 1999. https://doi.org/10.1109/22.808978.

[9] H. H. Zheng, J. Xu, and Z. H. Wang, "A novel E-plane T-junction power divider with ultra-wideband and high isolation", Proc. 2019 Int. Conf. Microw. Millimeter Wave Tech. (ICMMT), Guangzhou, China, May 2019. https://doi.org/10.1109/ICMMT45702.2019.8992421.

[10] A. R. Kerr, "Elements for E-plane split-block waveguide circuits", ALMA Memo 381, Jul. 2001.

[11] H. Chen, X. Xie, and R. Xu, "An ultra wide band power divider/combiner based on Y-junction waveguide", Proc. 2010 Int. Conf. Microw. Millimeter Wave Tech. (ICMMT), Chengdu, China, 8-11 May 2010. http://dx.doi.org/10.1109/ICMMT.2010.5525182.

[12] R. Malmqvist, A. Gustafsson, J. Svedin, B. Beuerle, U. Shah, and J. Oberhammer, "A 220-325 GHz low-loss micromachined waveguide power divider", Proc. 2017 IEEE Asia Pacific Microw. Conf. (APMC), Kuala Lumpur, Malaysia, pp. 291-294, 13-16 Nov. 2017. https://doi.org/10.1109/APMC.2017.8251436.

[13] G. Narayanan and N. R. Erickson, "A novel full waveguide band orthomode transducer", Proc.

10th Int. Symp. Space Terahertz Tech., Harvard University, USA, pp. 505-514, 26-28 Mar. 2002.

[14] D. Wu, X. Chen, G. Chen, and X. Liu, "Novel high efficiency broadband Ku band power combiner", Proc. 2010 Int. Conf. Microw. Millimeter Wave Tech. (ICMMT), Chengdu, China, pp. 258-261, May 2010. https://doi.org/10.1109/ICMMT.2010.5524923.

[15] M. Zou, Z. Shao, J. Cai, L. Liu, and X. Zhu, "Ka-band rectangular waveguide power dividers", Proc. 2011 Int. Conf. Comput. Prob.-Solving (ICCP), Chengdu, China, pp. 375-377, Oct. 2011. https://doi.org/10.1109/ICCPS.2011.6092239.

[16] Z. Xu, J. Xu, Y. Cui, and C. Qian, "A novel rectangular waveguide T-junction for power combining application", IEEE Microw. Wireless Comp. Lett., Vol. 25, No. 8, pp. 529-531, Aug. 2015. https://doi.org/0.1109/LMWC.2015.2440775.

[17] A. Gouda, C. D. López, V. Desmaris, A. B. Pavolotsky, and V. Belitsky, "Millimeter-wave wideband waveguide power divider with improved isolation between output ports", IEEE Trans. Terahertz Sci. Tech., Vol. 11, No. 4, pp. 408-416, Jul. 2021. https://doi.org/10.1109/TTHZ.2021.3078876.

[18] T. Su, C. Yu, and M. Zhao, "W-band four-way E-plane waveguide power divider", Proc. 2016 IEEE MTT-S Int. Microw. Workshop Series on Adv. Materials Processes for RF & THz Appl. (IMWS-AMP), Chengdu, China, Jul. 2016. https://doi.org/10. 1109/IMWS-AMP.2016.7588450.

[19] A. A. San-Blas, J. M. Roca, S. Cogollos, J. V. Morro, V. E. Boria, and B. Gimeno, "Compensation of the impact of low-cost manufacturing techniques in the design of E-plane multiport waveguide junctions", Radio Sci., Vol. 51, No. 6, pp. 619-628, Jun. 2016. https://doi.org/10.1002/2016RS006027.

[20] A. Pandey, "High-frequency (K-band) antenna feed network with waveguide", https://anilkrpandey.wordpress.com/2017/03/01/high-frequency-k-band-microstrip-feed-network-with-waveguide/. [accessed: Dec. 21, 2021]

[21] F. Pavanello, G. Ducournau, E. Peytavit, S. Lepilliet, and J.-F. Lampin, "High-gain Yagi-Uda antenna on cyclic olefin copolymer substrate for 300-GHz applications", IEEE Antennas Wireless Propagat. Lett., Vol. 13, pp. 939-942, May 2014. https://doi.org/10.1109/LAWP.2014.2322628.

[22] Topas Advanced Polymers Inc., "TOPAS® COC, Cyclic Olefin Copolymer", Product Brochure, https://topas.com/sites/default/files/files/Products_E_170406.pdf. [accessed: Dec. 22, 2021]

[23] N. Jastram, M. A. Al-Tarifi, L. Boskovic, and D. S. Filipovic, "On the split-block realization of millimeter-wave ridge waveguide components", IEEE Microw. Wireless Component Lett., Vol. 28, No. 4, pp. 296-298, Apr. 2018. https://doi.org/10.1109/LMWC.2018.2808420.

[24] D. H. Jun, M. S. Jung, and B. C. Ahn, "Design of a W-band groove polarizer", Journal of KIIT, Vol. 14, No. 4, pp. 79-84, Apr. 2016. https://doi.org/10.14801/jkiit.2016.14.4.79.

[25] L. Polo-López, P. Sanchez-Olivares, E. García-Marín, J. A. Ruiz-Cruz, J. Córcoles, J. L. Mas-Campos, J. R. Montejo-Garai, and J. Rebollar, "Waveguide manufacturing technologies for next-generation millimeter-wave antennas", Micro machines 2021, Vol. 12, No. 12, 1656, Dec. 2021. https://doi.org/10.3390/mi12121565.

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