Abstract — In this paper, a full-band millimeter wave waveguide magic tee design that is friendly to computer numerical controlled (CNC) machining, manufacturing assembly and industrial standard production processes is presented. Traditional magic tee designs either barely cover the full waveguide bandwidth or are difficult to fabricate with consistent electrical performance. An improved magic tee junction utilizes a simple post in the middle of the junction and stepped waveguide transformers to provide the mechanical mate with standard waveguide openings and flanges. The dimensions of the magic tee junction are EM simulated and optimized by considering the variations of the manufacturing process for optimal performance and high reproducibility. An E-band magic tee and a V-band four-way power divider are presented to demonstrate the improved designs. The newly developed magic tee and power divider have shown good performance for full band coverage with high production yields in manufacturing environments.

Keywords — waveguide, magic tee, power divider, full band, insertion loss, return loss, isolation, CNC machining, production.

I. INTRODUCTION

Waveguide magic tees and magic tee-based power dividers are widely used in monopulse comparator designs for tracking Radar systems, sub-system power distribution, and power combining of solid-state power amplifiers, etc. With the rapid development of millimeter wave communication, instrumentation, and other advanced systems, magic tees and power dividers covering full waveguide bands or multiple 5G bands are in great need. However, it is found that to design the basic building block, a magic tee, to cover full waveguide bandwidth operation while simultaneously easing the fabrication and assembly process is still a challenge.

The examples presented in Fig. 1. and Fig 2. are typical of numerous magic tee designs and applications, but they lack the full waveguide band coverage that is desirable in broadband applications. In [1], a magic tee composed of a septum and metallic platform is proposed for a broad bandwidth of 16% in the Ka-band. In [2], an X-band magic tee with a stepped conducting cone is optimized using a genetic swarm optimization to accomplish 20 dB return loss with bandwidth over 20%. In [3], an X-band H-plane folded magic tee with a bandwidth of 17% is proposed for a four-way power divider. In [4], a W-band E-faced-folded magic tee using a stepped regular triangular prism and a stepped waveguide transformer is proposed to cover the frequency band of 92-100 GHz, i.e., a fractional bandwidth of 8%. In [5], an X-band magic tee using an iris and a stepped post is presented, which serves as the power divider for solid-state power amplifiers. It exhibits a 10% fractional bandwidth. In [6], a compact magic tee with coplanar arms of the E port and H port is proposed for high power solid-state power combining. The manufactured magic tee with two coaxial ports, one ridge port and one rectangular port shows a bandwidth of 18%. In [7], a magic tee with four arms at the same plane is proposed, by using a ridge-waveguide transition and E-plane power divider. This design achieves an operating bandwidth of 25%. In [8], a Ku-band magic tee using a stepped post is designed by an MM/FE method. Its fractional bandwidth is around 14%. These magic tee designs are machined with an electro-discharge machining (EDM) process or computer numerical controlled (CNC) machining. However, as mentioned, they cannot cover the desired bandwidth of 40% over the full waveguide band. 3-D printing is another manufacturing technique that enables complex designs and wider bandwidth [9-10]. However, these
To solve the issues of traditional magic tee designs, we adapted the magic tee junction concept proposed in [11], but with reproducibility and repeatability of volume production requirements in mind while performing the design and analysis. The improved design adds waveguide step transformers to the ports of the magic tee junction to form a full waveguide band magic tee that mates with standard waveguide ports. The proposed magic tee with waveguide transformers in the H port and collinear ports is shown in Fig. 2, which utilizes the magic tee junction presented in [11]. There are four elements in this structure to enable good impedance match at the E and H ports: an iris in the E port, a simple post in the junction, width steps in the H port and collinear ports, and the reduced waveguide height of the H port and collinear ports. The iris and the waveguide width steps play the same role in the design as in Fig. 1 (b). The thickness of the iris in the E port is critical to the mechanical design of the power divider.

A minimum of 5 mils thickness of the iris is imposed during optimization to mitigate the fabrication difficulty for 50 GHz or higher bands. The reduced waveguide height provides better E-plane broadband impedance matching. In order to mate with standard waveguide height, 3-step waveguide transformers are added to the junction. Compared with the traditional designs shown in Fig. 1, the cuboid post in the junction can be machined on the waveguide housing using CNC machining, which makes this design a good candidate for production by eliminating additional machining and assembly steps. CST Microwave Studio with various optimization algorithms is utilized to determine the final dimensions of the magic tee junction. The dimensions of the four elements are used as parameters in the optimization.

III. MANUFACTURING AND TESTED RESULTS

The manufactured E-band full-band magic tee and V-band four-way in-line power divider are shown in Fig. 3. The magic tee has three ports, i.e., a top housing, a bottom housing, and a shim. The iris is made on the shim clamped between the top housing and the bottom housing. When an absorber with optimal shape is inserted into the E port to create a matched termination, the magic tee junction is converted to a two-way power divider. The four-way, in-line power divider is composed of three magic tee junctions. These magic tee junctions are connected through reduced-height waveguide. The E-band magic tee and V-band power divider are fabricated from aluminum alloy using CNC milling. Gold plating surface treatment is carried out to provide protection against corrosion.

Both the E-band magic tee and V-band power divider were tested using a vector network analyzer (VNA). The ports of the magic tee are indexed as shown in Fig. 2. The measured return loss, isolation and insertion loss of the E-band magic tee are presented in Fig. 4 for the full E-band frequency range. As shown in Fig. 4 (a), the H port and collinear ports show the minimum return loss of 20 dB, while the E port demonstrates the minimum return loss of 18 dB across the full waveguide band. As shown in Fig. 4 (b), the minimum isolation level
Fig. 3. Photographs of the manufactured (a) E-band magic tee, and (b) V-band four-way in-line power divider.

Fig. 4. Measured (a) return loss, (b) isolation, and (c) insertion loss of an E-band magic tee.

between two collinear ports is around 21 dB. Meanwhile, the minimum isolation level between E and H ports is around 29 dB. The insertion loss of two collinear ports to E port is shown in Fig. 4 (c). The maximum insertion loss of the two in-phase output ports is estimated to be 3.7 dB. The measured return loss, isolation and insertion loss of the power divider are presented in Fig. 5. Port 5 indicates the input port and ports 1, 2, 3 and 4 indicate the four output ports. The input port has a typical return loss of 20 dB, and minimum return loss of 14 dB, while the output ports have a minimum return loss of 20 dB. The minimum isolation between output ports is around 18 dB, while the maximum insertion loss is around 7.2 dB across the full frequency band. The improved magic tee junction is implemented in other waveguide bands up to WR-06 to cover 170 GHz with satisfactory and consistent performance in a manufacturing environment.

IV. CONCLUSION

A magic tee and a four-way power divider using an improved magic tee junction are presented. Waveguide step transformers are used at the ports of magic tee junctions to achieve a reduced-height waveguide to standard waveguide transition. The iris part in the magic tee junction is fabricated on a shim to ease the fabrication and assembly process. The proposed magic tee design solves multiple issues in the fabrication and assembly of traditional designs thus making production more efficient. The realized bandwidth of the magic tee is around 40%, which is sufficient to cover any waveguide full-band operation. The magic tee demonstrates satisfactory performance in terms of low return loss and high isolation. The presented four-way power divider using the magic tee design is an excellent candidate for high-power signal combining in solid-state amplifiers.
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REFERENCES


