A Ka-Band 4-way Power Combining Amplifier using Coplanar-Arms Waveguide Magic-T

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***Abstract*—A Ka-band 4-way power combining amplifier using coplanar-arms waveguide magic-T is presented in this paper. By using an E-plane power divider and a ridge waveguide coupler, the four arms of the magic-T are placed in the same E-plane, which has greatly simplified the assembly. Based on the coplanar-arms waveguide magic-T, a back-to-back structure of 4-way power divider/combiner is designed and fabricated for achieving power combining amplifier. Over the frequency band of 27.5 to 32.5 GHz, measured insertion loss of the back-to-back is less than 1.5dB. The measured saturated power (Psat) of the 4-way power com-bining amplifier is more than 8W, while the combining efficiency is over than 85%.**

Keywords—Coplanar-arms; Ka-band; Magic-T; HMC906; Power combing amplifier.

I. Introduction

Millimeter-wave solid-state power amplifiers with high power and compact size are becoming much more interest in many applications such as satellite communication systems. However, the output power from a single solid-state device is often insufficient, especially in millimeter-wave frequency. Therefore, it is necessary to combine power from power combiner to obtain the desired power level.

In [1], a full Ka-band waveguide-based power combining amplifier by using E-plane anti-phase probes is studied. In [2-4], different structure of the power combining amplifier has been developed. However, due to the excellent features in port matching, isolation, amplitude and phase balance, the magic-T is still one of the most commonly used power combiner. A four-way power combiner based on magic-T has been researched in [5]. The conventional waveguide magic-T is a four-port network which consists of an *E*-plane tee junction and an *H*-plane tee junction. To achieve broadband characters, the matching components are required, like a cone, wedge, post, pin or iris, such designing cases were proposed in [6-7]. In [9], two waveguide arms are forked to achieve the *E*-plane forked hybrid-T. However, since the four arms of the conventional magic-T are in different planes (*E*-plane and *H*-plane), it may bring inconvenience to the assembly and fabrication and the size of the matching components are so small that requires a relatively higher machining precision.

In [10], a *K*a-and *E*-plane waveguide magic-T with coplanar arms was proposed. The *E*-plane power divider coordinates with the waveguide-to-microstrip transition utilized the magic-T with four arms in the same *E*-plane. The advantage of this structure is obvious: for the four arms now locates in the same plane, the cascaded binary power divider is more compact. In addition, the conventional matching components are not included in this structure, which makes the fabrication and assembly more convenient. However, the microstrip section brings additional transmission loss and mismatching tolerance, and the power handling capability is limited.

The goal of this paper is to present a power combining amplifier with high combining efficiency and compact size. Replaced the microstrip section in [10] by the ridge waveguide transition, a full-metal coplanar waveguide magic-T is proposed to achieve a power combining amplifier. Due to the good features in full-metal structure, loss and size, the power combing amplifier can provide a higher power handing capability, high combining efficiency and compact size.

II. DESIGN OF THE POWER COMBINING AMPLIFIER

A. Design of the Magic-T

The coplanar-arms waveguide magic-T can be considered as an E-plane power divider and a ridge waveguide transition. The ridge waveguide probe is inserted into the E-plane tee junction in the center of the waveguide wall to excite the proper electric field, then the ridge waveguide is matched to the

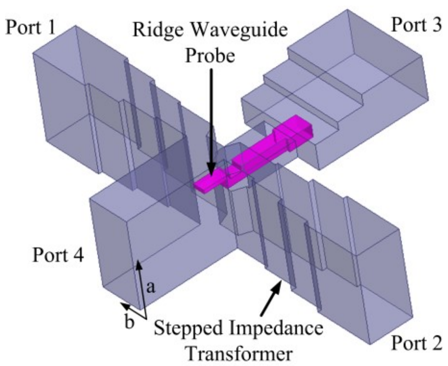


Fig. 1. Three-dimensional structure of the waveguide magic-T

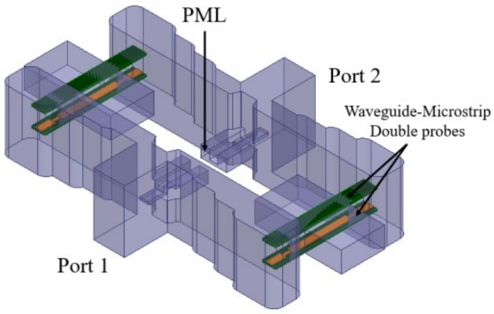


Fig. 2. Back to back structure of the 4-way power divider/combiner

standard waveguide by using the ridge waveguide-to-rectangular waveguide transition based on stepped impedance transformer.

The E-plane power divider is a three-port network. The signal is input from the standard waveguide, and then divided into two half-height waveguide branches. Then, the half-height waveguide transits to the full height waveguide via the stepped-impedance transformer.

The ridge waveguide transition can be divided into two parts: the ridge waveguide probe and the transition from ridge waveguide to standard rectangular waveguide. The ridge waveguide probe is an all-metal probe inserted into the tee junction for coupling the wave from the E-plane power divider to the ridge waveguide.

B. *Design of the 4-way Power Combining amplifier*

Based on the coplanar-arms waveguide magic-T and waveguide-microstrip double probes, the 4-way power combining amplifier can be designed.

The coplanar-arms waveguide magic-T is modified to achieve a compact power combining amplifier. The stepped-impedance transformer in the E-plane power divider is designed at signal side to meet fabricated requirements. The transition from the ridge waveguide to standard rectangular waveguide is replaced by the perfectly matched layer (PML) to minimize the structure without deteriorating the performance. In the actual assembly, the perfectly matched layer can be available by using absorbing materials.

The back to back structure of the minimized coplanar-arms waveguide via waveguide-microstrip double probes is designed, as shown in Fig. 2. The signal is input from rectangular waveguide and divided into two ways by E-plane power divider. Then, the two-way signal is finally divided into two ways to microstrip via waveguide-microstrip double probes, respectively. Finally, the signal is combined along the opposite path.

The active power amplifiers(PA) can be placed at the midpoint of the signal transmission path to amplify the signal. The distribution of the electric field lines is drawn in Fig. 3.

By using four commercially available power amplifiers HMC906, the 4-way power combining amplifier can be designed and fabricated as shown in Fig. 4. The HMC906 is a

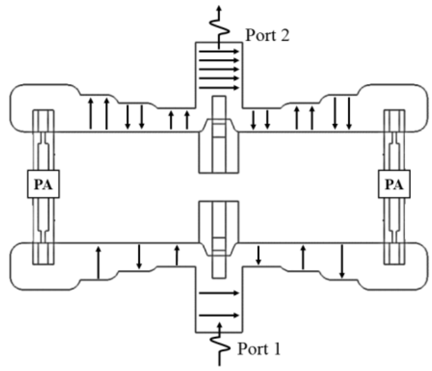


Fig. 3. Spreading wave front into the magic-T from Port 1

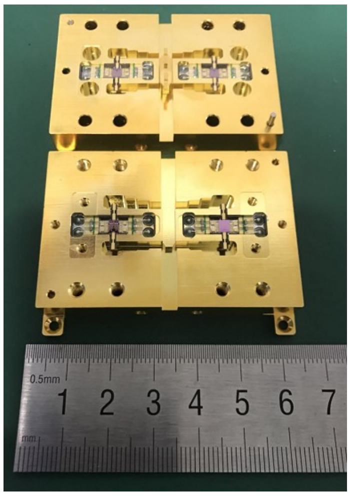


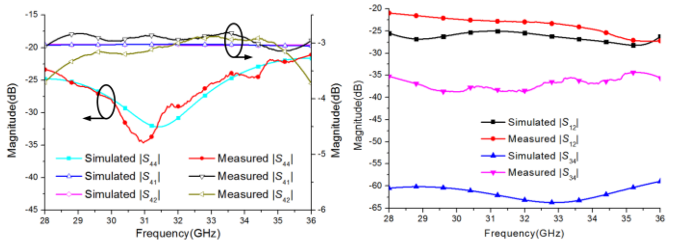
Fig. 4. Prototype of the 4-way power combining amplifier.

four stage GaAs pHEMT MMIC power amplifier which operates between 27.3-33.5GHz, and the saturated output power can reach 34dbm (2 watts).

III. Simulated Results and Measured Results

To verify the performance of the coplanar-arms magic-T, a passive structure has been fabricated and measured. As show in Fig. 5, the simulated and measured results of the coplanar-arms magic-T with an operation frequency from 28 to 36 GHz. The return loss ($|S_{44}|$) at port-4 and the power dividing coefficient ($|S_{41}|$ and $|S_{42}|$) are illustrated in Fig. 5 (a). The measured $|S_{44}|$ better than -20 dB is realized, which agrees well with the simulated results. Considering an ideal power dividing coefficient of 3 dB, the insertion loss ($|S_{41}|$ and $|S_{42}|$) for excitation from the out-of-phase port is less than 0.7 dB, while the insertion loss ($|S_{31}|$ and $|S_{32}|$) for excitation from the in-phase port is less than 1 dB, which can be seen in Fig. 5 (b). Moreover, the return loss ($|S_{33}|$) at port-3 is better than -12 dB, the performance variation is mainly caused by the machining tolerance, especially some vital dimensions, including the length and thickness of the metal probe, etc.

Fig. 6 shows the measured and simulated results of the back-to-back structure of 4-way power divider/combiner from



(a) (b)

Fig. 5. (a) Return loss |S44|, |S41| and |S42|. (b) Return loss |S33|, |S31| and |S32|.

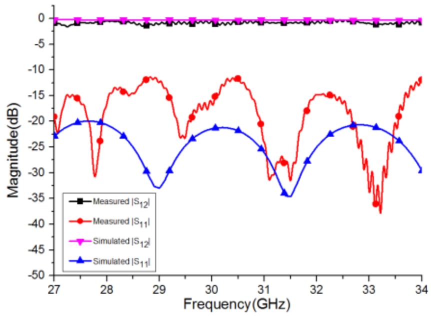


Fig. 6. Simulated and measured results of the back to back structure.

27 to 34 GHz, the operation frequency ranges of the power amplifier. The measured return loss is better than -15dB, while the insertion loss is less than 1.5dB.

The measured results of the power combining amplifier is shown in Table1. The Psat of a single amplifier can be available from the datasheet of HMC906. The measured small-signal gain is more than 16dB, while the amplifier working at 6V/0.8A as shown in Fig. 7. From 27.5 to 32.5GHz, the Psat is greater than 8 watts, while the combining efficiency is higher than 80%. The degradation of the output power between 33 to 34GHz is mainly caused by the limited bandwidth of the HMC906.

IV. Conclusion

This paper focuses on achieving a compact 4-way power combining amplifier. On the basis of completing the design of coplanar-arms waveguide magic-T, the 4-way power combining amplifier is designed and fabricated. The measured results of the coplanar-arms magic-T show good performance at insertion loss, isolation and size. Furthermore, the measured output saturated power of the 4-way power combining amplifier is over 8W with higher than 81% combining efficiency. All the features demonstrate the potential of achieving a power combining amplifier with compact size and high combing efficiency by using coplanar-arms waveguide magic-T.

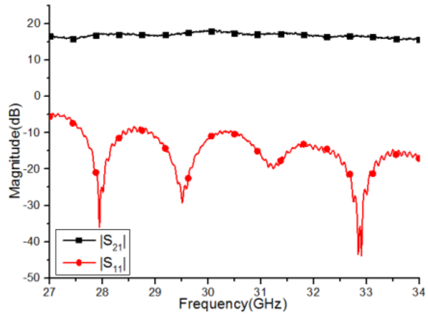


Fig. 7. Measured results of the small-signal gain.

Table 1. The measured Psat of the 4-way power combining amplifier.

Frequency (GHz)	Psat of single amplifier (Watts)	Psat of power combining amplifier (Watts)	Combining efficiency (%)
27	3.13	9.84	78.69
27.5	2.95	10.47	88.70
28	2.45	9.31	97.04
28.5	2.51	9.57	95.27
29	2.29	8.75	95.49
29.5	2.57	9.04	87.89
30	2.51	9.59	95.49
30.5	2.82	9.46	83.93
31	2.49	9.57	95.93
31.5	2.49	9.18	92.03
32	2.19	8.30	94.83
32.5	2.29	8.20	89.52
33	2.21	6.03	68.07
33.5	2.43	4.17	42.95
34	2.19	4.26	48.63

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