A New Spatial Power Combiner Based on 32-way Ridged Waveguides

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Abstract

This paper presents a new spatial power combiner based on millimeter wave broadband multi-way ridged waveguides. The device is composed of a multi-step impedance transformer and 32-way ridged waveguides. Since the ridged waveguides provide a consistent impedance transformation and a broad band working frequency, a millimeter wave solid-state power amplifier based on the combiner demonstrates an output power of more than 34.6 dBm at 60 GHz and greater than 35 dBm over 49 GHz to 59 GHz band. Measured results show that all the ridged waveguides have the high uniformity of amplitude and phase, and the combiner has demonstrated operation over a broadband of 47 GHz to 60 GHz with more than 8 dB return loss and less than 0.8 dB insertion loss.

1. Introduction

Solid state power amplifiers are used in a wide variety of military and commercial applications requiring high power at microwave and millimeter wave bands because of highly reliable, small, lightweight and low coast [1]. However, the power level available today from solid state devices is limited. Currently, the output power per device or MMIC is limited to perhaps several hundred milliwatts. Therefore, to achieve higher power levels, power combining techniques must be employed.

Two types of power combining techniques are the planar power combiner and spatial power combiner. The planar combining technique has simpler design, but it will lead to very high combining loss when integrate large amount of amplifiers, while spatial power combining technique is proposed with the goal to combine a large quantity of solid-state amplifiers efficiently [2].

With the growing interest in spatial power combining technique, design of a variety of power divider and combiner structures, including both cavity structures such as waveguide devices and tree structures such as Wilkinson divider, has been paid enormous attention. Although the tree structures have simpler design, they have disadvantage of using multitude of transmission line segments, which add losses and degrade the performance of the structures significantly. Waveguide power combiners used in spatial power combining technique, on the other hand, have the lower insertion loss and higher combining efficiency [3].

In this paper, we present a new millimeter wave power combiner based on multi-way ridged waveguides. The combiner has demonstrated operation over a broadband of 47 GHz to 60 GHz with more than 8 dB return loss and less than 0.8 dB insertion loss.

2. Design of the Combiner

A new millimeter wave amplifier based on spatial power combining technique is presented in this paper. The power amplifier uses divider and combiner networks in pairs to first divide the input power, amplify and then recombine the outputs. Using simplified design methodology, a 32-way waveguide combiner has been designed with central feed and peripheral collecting ports structure. The device proved to be efficient for summing amplifiers when the number of ports is large, such as eight or more. Being in phase structures, their phase and amplitude stability depends upon symmetry, which in turn can be achieved easily with good mechanical design [4].

The overall structure of the combiner is composed of two cylinder TEM mode oversized radial waveguides terminated by an array of ridged rectangle waveguide that interface with the amplifier MMICs via microstrip probe array. The amplifiers, mounted on microstrip trays, are fitted on the outer surface of the device and cooled by conduction. By distributing the amplifier stages over the periphery of the combiner, the overall structure usually has better heat-dissipation characteristics than that of a binary-tree-combining structure. The mechanical design of the radial

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waveguide combiner is as simple as a common microstrip circuit. Also, the electrical design can be completely defined in terms of uniform transmission lines. With these structures, combined power of the order of up to 35dBm can be achieved. Necessary vector and scalar measurements were carried out for testing these designs.

The schematic diagram of the proposed divider or combiner and the EM field distribution in the waveguide combiner is shown in Fig. 1. We can see that all the ridged waveguides have the high coherence of amplitude and phase. Starting at the top, the input signal is transitioned from coaxial waveguide to the central radial-line section. The wave expands outward radially, and then at a radius of approximately 5 mm, transitions to each ridged waveguide to reach the periphery and the MMIC carrier.

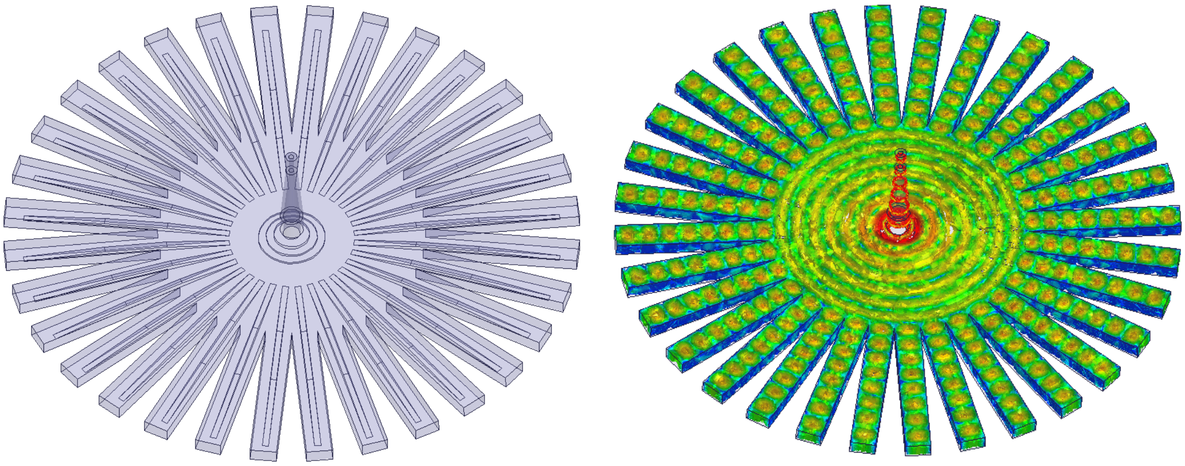

Fig.1. (a) The schematic structure of the combiner (b) The EM field in the combiner

3. The EM Field in the Radial Waveguide Combiner

The radial waveguide is a non-uniformity transmission line. Because of the radiate shape of the main body, the EM field in it can be described. The cross section is side and is the signal transmission direction. So, the EM field distribution of the radial waveguide divider in the coordinate can be described as follows.

$$-j\omega\mu H_r = \frac{1}{r}\frac{\partial E_z}{\partial \phi} - \frac{\partial E_\phi}{\partial z} \tag{1}$$

$$-j\omega\mu H_\phi = \frac{\partial E_r}{\partial z} - \frac{\partial E_z}{\partial r} \tag{2}$$

$$-j\omega\mu H_z = \frac{1}{r}\left(\frac{\partial\left(rE_\phi\right)}{\partial r} - \frac{\partial Er}{\partial \phi}\right) \tag{3}$$

$$j\omega\mu E_r = \frac{1}{r}\frac{\partial H_z}{\partial \phi} - \frac{\partial H_\phi}{\partial z} \tag{4}$$

$$j\omega\mu E_\phi = \frac{\partial H_r}{\partial z} - \frac{\partial H_z}{\partial r} \tag{5}$$

$$j\omega\mu E_z = \frac{1}{r}\left(\frac{\partial\left(rH_\phi\right)}{\partial r} - \frac{\partial Hr}{\partial \phi}\right) \tag{6}$$

After eliminating the radial part of the EM field, the transmission line equation can be described as follows.

$$\frac{\partial E_z}{\partial r} = -jk\zeta\left[-H_\phi + \frac{1}{k^2}\left(\frac{1}{r}\frac{\partial^2 H_z}{\partial\phi\partial z} - \frac{\partial^2 H_\phi}{\partial z^2}\right)\right] \tag{7}$$

$$\frac{1}{r}\frac{\partial}{\partial r}\left(rE_{\phi}\right)=-jk\zeta\left[H_{z}+\frac{1}{k^{2}}\left(\frac{1}{r^{2}}\frac{\partial^{2}H_{z}}{\partial\phi^{2}}-\frac{1}{r}\frac{\partial^{2}H_{\phi}}{\partial\phi\partial z}\right)\right] \tag{8}$$

$$\frac{\partial H_{z}}{\partial r}=-jk\eta\left[E_{\phi}+\frac{1}{k^{2}}\left(\frac{\partial^{2}E_{\phi}}{\partial z^{2}}-\frac{1}{r}\frac{\partial^{2}E_{z}}{\partial\phi\partial z}\right)\right] \tag{9}$$

$$\frac{1}{r}\frac{\partial}{\partial r}\left(rH_{\phi}\right)=-jk\eta\left[-E_{z}+\frac{1}{k^{2}}\left(\frac{1}{r}\frac{\partial^{2}E_{\phi}}{\partial\phi\partial z}-\frac{1}{r^{2}}\frac{\partial^{2}E_{\phi}}{\partial\phi^{2}}\right)\right] \tag{10}$$

The return loss of the input port simulated by HFSS is shown in Fig. 2. From the two figures we can see that the return loss of input port is better than -10dB from 40GHz to 68GHz. The insertion loss of the divider simulated by HFSS is shown in Fig. 3. From the simulated results we can see that the insertion loss is less than 15.4 dB.

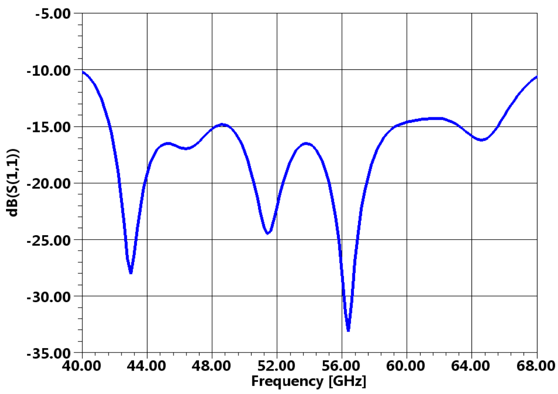

Fig. 2. The return loss of input port

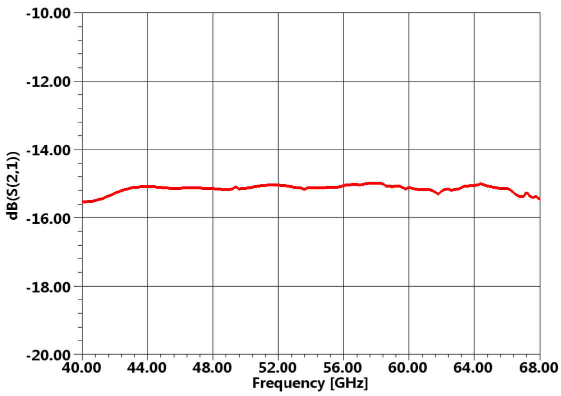

Fig. 3. The insertion loss of S_{21}

4. Measured Results of the Combiner

The photograph of the power combiner is shown in Fig. 4 and Fig. 5 is the endoscopic of the entire thirty two ridges.

Fig. 4. The entire structure of the divider/combiner

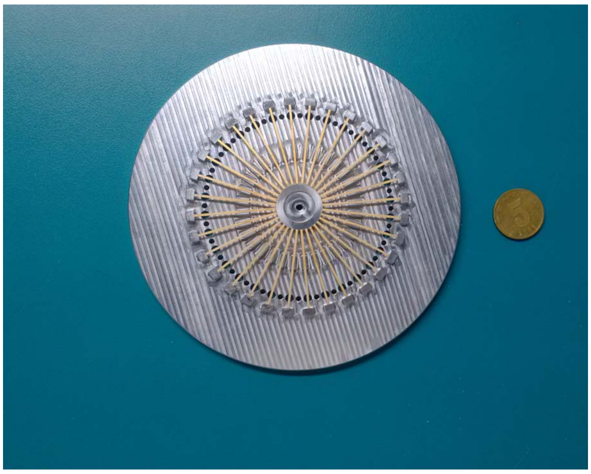

Fig. 5. The endoscopic of the entire thirty two ridges

The measured return loss and insertion loss of the entire structure are shown in Fig. 6 and Fig. 7. From the two figures we can see that the return loss of input port is better than -8dB from 47GHz to 66GHz, and the insertion loss of the combiner is better than -7.2dB. Considering of the 5.6 dB insertion loss of the microstrip connecting the divider and the combiner, the actual insertion loss of the divider and the combiner is less than 0.8 dB respectively.

The results are measured by the vector network analyzer (VNA) AV36587A which was designed by the 41st institute of CETC. We found a good agreement between theory and experiment.

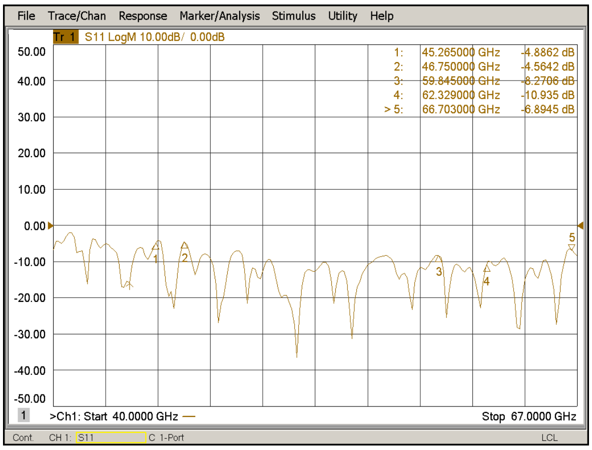

Fig. 6. The measured curve of return loss

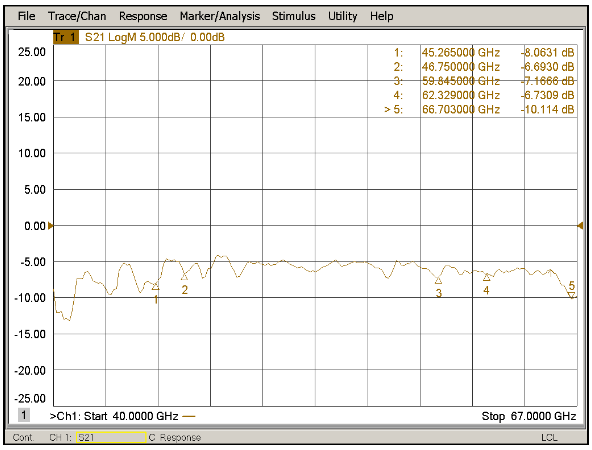

Fig. 7. The measured curve of insertion loss

The measured output power of the combiner is shown in Table I. We can see that it is more than 34 dBm in the whole working frequency from 47 GHz to 60 GHz.

Table I. The measured output power of the combiner

Freq.(GHz)	**Pout(dBm)**	**Freq.(GHz)**	**Pout(dBm)**	**Freq.(GHz)**	**Pout(dBm)**	**Freq.(GHz)**	**Pout(dBm)**
46	36.2	50	35.3	54	36.4	58	36.0
47	35.5	51	35.2	55	35.5	59	35.2
48	34.8	52	36.4	56	35.3	60	34.6
49	35.6	53	36.2	57	36.2	61	34.2

5. Conclusion

A 32-way broadband spatial power combiner based on novel broadband ridged waveguide from 47 GHz to 60 GHz is designed and constructed. The device is composed of thirty two ridged waveguides terminated by array of amplifiers that interface with the waveguides via microstrip probe array. Further, excluding combiner conductor losses, this combiner demonstrates an outstanding combining efficiency of 80% and output power of more than 34 dBm

We have successfully demonstrated the 32-way ridged waveguides have the high uniformity of amplitude and phase. It proves that the spatial power combining technique based on novel broadband ridged waveguide is the most effective approach to integrate a large quantity of devices over a broadband width with high power combining efficiency.

6. Acknowledgments

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