Traveling-wave power divider with coplanar waveguide probes inserted into rectangular waveguide

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TRAVELING–WAVE POWER DIVIDER WITH COPLANAR WAVEGUIDE PROBES INSERTED INTO RECTANGULAR WAVEGUIDE

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The new traveling–wave power divider with the coplanar waveguide probes is investigated. The divider is composed by connecting successively the dividing units which consist of the coplanar waveguide probe–pair inserted into the rectangular waveguide and the thin narrow section. By the experiments on the four- and six-way dividers, the wideband characteristics comparable to the divider with the coaxial probes is demonstarted.

1 Introduction

In order to realize a high output solid–state microwave power amplifier comparable to the traveling–wave tube, power combining techniques are necessary, because the output power of the single solid–state device in microwave frequency range is much less than that of the tube. The amplifying system using power combining usually consists of three stages: dividing the input signal, amplifying the divided signals, and combining the amplified powers. Thus, multiple–port power dividers and combiners with low insertion loss and wideband characteristics are required. Several kind of dividers and combiners have been developed[1]. A "chain" structure[2] in which a number of hybrids are successively connected can exhibit a wideband traveling–wave operation with flexibility of increasing or decreasing the number of output ports. Previously the authors proposed the traveling–wave power divider with coaxial probe–pair inserted into the rectangular waveguide and demonstrated the broadband characteristics[3].

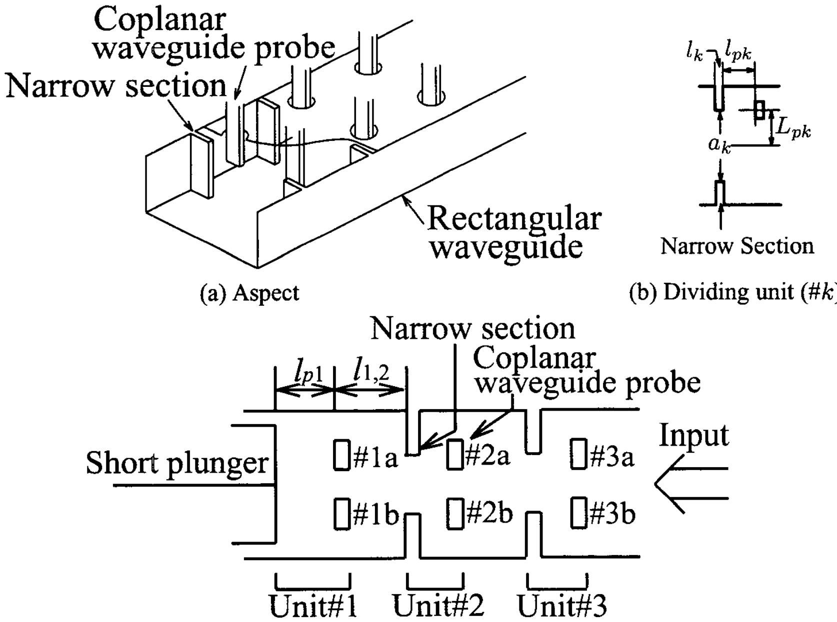
In this paper, we investigate a new traveling–wave power divider with coplanar waveguide probes as the branching ports instead of the coaxial probes. The output lines of the divider are coplanar waveguides, so that it is considered that connection between the solid–state amplifiers and the divider/combiner is easy.

2 Structure of divider

Figure 1 shows a traveling–wave divider which is composed of N dividing units. The dividing unit consists of a waveguide section with a coplanar waveguide probe–pair followed by a thin narrow section. Each unit is numbered starting with the last unit. If the reflected waves generated by the probe–pair and by the narrow section are canceled out with each other, the input port of the unit is matched. Thus, the reflected wave does not exist on the waveguide between the adjacent units, and the behavior of the divider can be considered the traveling wave operation.

An equivalent circuit for the divider is shown in Fig.2. Let the equivalent admittance looking toward the narrow section at the output probe–pair of the unit #k be $y_k = g_k + jb_k$, and the equivalent admittance of the coplanar waveguide probe–pair be $y_{pk} = g_{pk} + jb_{pk}$, where all the admittance are normalized by the characteristic admittance of the waveguide. Assuming that the left side of the unit #k is matched, These admittances must satisfy the following equations for equal–power and reflectionless dividing[3]:

$$g_k = \frac{k-1}{k} \qquad (k = 2, \cdots, N) \tag{1}$$



(a) Aspect (b) Dividing unit (#k)

(c) Construction

Figure 1: Traveling–wave divider with coplanar waveguide probe–pair

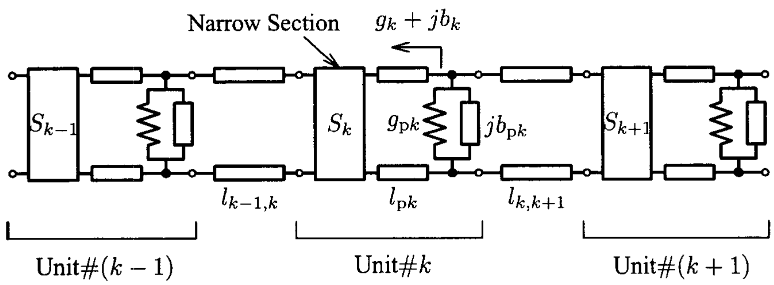


Figure 2: Equivalent circuit of the divider

$$g_{pk} = \frac{1}{k} \qquad (k = 2, \cdots, N) \tag{2}$$

$$b_k + b_{pk} = 0 \qquad (k = 2, \cdots, N) \tag{3}$$

Optimum structures of the dividing units with wideband characteristic were given by [3, 4]. Table 1 lists the structural parameters of the units with the design frequency 9.0GHz. In order to describe the frequency characteristic of the dividing unit, we define two kind of bandwidths. One is the bandwidth B_{d} in which deviations of both the delivered power and the transmitted power from the desired values are within ± 0.5dB. The other is the bandwidth B_{r} in which the reflection coefficient of the dividing unit is less than -20dB. B_{d} and B_{r} are also shown in Table 1. The unit #1 consists of the coplanar waveguide probe–pair whose conductance is unity and a shorting plate which should cancel out the susceptance of the probe–pair as shown in Fig.1(c). The structure of the coplanar waveguide probe–pair is shown in Fig.3. The hot conductor of the coplanar waveguide is extended with the dielectric and is inserted into the rectangular waveguide. For the probe–pairs of all the dividing unit, only the values of the admittance are specified. Thus, the distance L_p between the probe and the waveguide axis, the extension length d_p,

Table 1: Optimum values of the structural parameters and the bandwidth of the dividing unit[3, 4]

k	g_{pk}	b_{pk}	a_k[mm]	l_k[mm]	l_{pk} [mm]	B_d [GHz]	B_r [GHz]
2	1/2	0.522	14.90	1.00	3.20	4.20	2.20
3	1/3	0.311	16.84	1.00	3.20	5.65	3.05

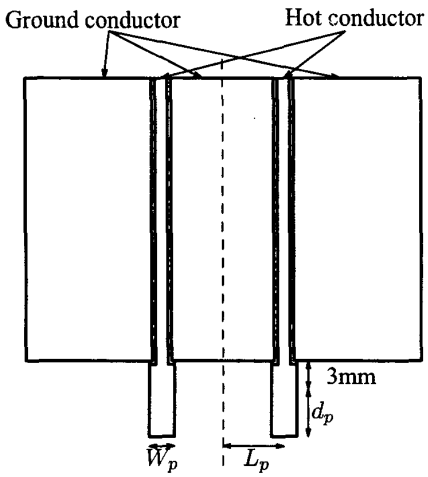


Figure 3: Coplanar waveguide probe–pair

Table 2: Structure of the probe–pair used in the experiment

k	L_p[mm]	W_p[mm]	d_p[mm]
1	6.45	2.1	7.0
2	6.45	2.5	5.5
3	6.45	2.1	4.7

and the width W_p of the probe–pair with the specified admittance may be found.

The divider is constructed by connecting the unit #k to the unit #$(k-1)$ with the line of length $l_{k-1,k}$. The optimum values of the lengths $l_{k-1,k}$ $(k = 2, \cdots, N)$ exist because the reflected wave propagates between the adjacent units in the frequency except for the design frequency. However, it is necessary to connect the coplanar waveguide to the coaxial adaptor due to the measurement in our experiment, so that the length $l_{k-1,k}$ must be be greater than the size of the coaxial adaptor, 12.7mm. Under this condition, $l_{k-1,k}$ was setted to 16.5mm so as to maximize the bandwidth of the divider.

3 Measured results

Experiments were carried out for four- and six-way ($N = 2$ and 3) dividers. The structure of the probe–pair was determined experimentally as shown in Table 2. Figure 4 shows measured results on divided power ratio and return loss of the six-way divider. Due to the attenuation on the coplanar waveguide, the insertion loss of about 1dB was larger than that of the divider with the coaxial probes. Table 3 shows the measured values of B_r and B_d in which the deviations of all the divided powers are within ± 0.5dB in both case of the four- and six-way dividers. The bandwidths comparable to the divider with coaxial probes were obtained. Isolation is important for the divider performance when the load VSWR of each output port is not small enough. Figure 5 shows the worst case of the isolation for the six-way divider. The isolations between paired probes of the dividing unit, especially the unit #1, were poor.

4 Conclusion

The new travleing–wave power dividers with the coplanar waveguide probes have been discussed. By the experiments on the four- and six-way dividers at X–band, the broadband characteristics and the poor

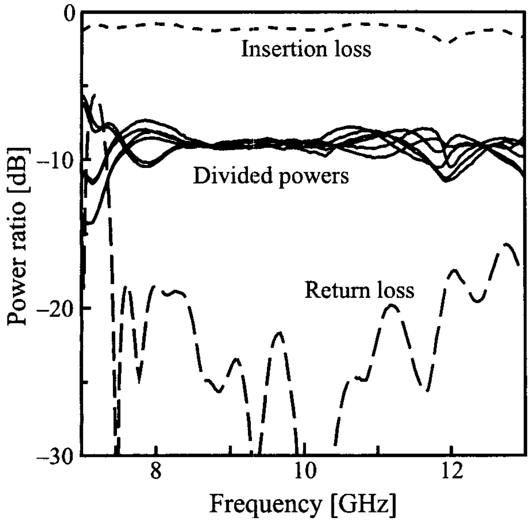


Figure 4: Frequency characteristics of six-way divider

Table 3: Measured B_r and B_d

	B_r[GHz]	B_d[GHz]
4 way	2.76	2.64
6 way	2.64	1.62

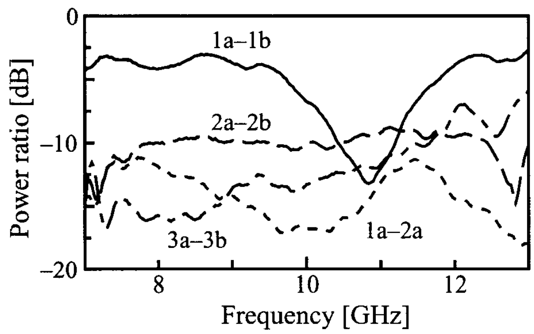


Figure 5: Worst case isolation of the six-way divider. 1a,1b,2a,$\cdots$ denote the port number (cf. Fig.1(c)).

isolation was obtained as well as the divider with the coaxial probes. The output lines of the paired probes of the dividing unit exist on the same substrate. Therefore, it is easy to install a circuit for improvement of the isolation between paired probes. The authors are studying this subject.

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