Analysis of a Spatial Power Combining Structure At Ka band

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***Abstract*-A spatial power combining structure based on radial waveguide at Ka band is analyzed and the power combining characteristic is simulated. Rectangular-radial waveguide adapters are used as input and output ports of the radial waveguide power dividing and combining network. Simulation presented show good performance. It is also discussed that how the power combining efficiency of the power combiner is affected by the inconsistencies of the amplitude, phase and circuit loss of the structure.**

I. INTRODUCTION

A single solid-state power amplifier output power at millimeter waves is limited, power combining techniques have to be used to improve the output power [1]. Though many power combining methods have been proposed and studied, spatial power combining technique has important practical significance because its low insertion loss in power dividing and combining networks. In recent years, the radial waveguide used for power dividing and power combining is reported in some papers[2][3].With the advantage of compact structure and radial symmetry, the wave path of each way will be same when radial waveguide used in power divider/combiner, so the radial waveguide is ideally suited for high-power combiner.

In this paper, a spatial power combining structure based on radial waveguide at Ka band is analyzed, and the power combining characteristic is simulated. Simulation results are presented to show its performance.

II. POWER COMBINING STRUCTURE AND ITS PERFORMANCE

A six ways power combining structure studied is shown in Fig.1. More ways power combining structure also can be obtained with similar structure. Rectangular-radial waveguide adapters are used as input and output ports of the radial waveguide power dividing and combining network.

Coaxial-line probe is used as the transition between radial waveguide and microstrip line. Power amplifier is developed in microstrip line. Input signal power is fed into radial waveguide through the rectangular-radial adapter, and then it is divided equally to six ways and feed into six microstrip power amplifier through six coaxial-line probes. The output power of six amplifiers are transmitted into radial waveguide and converged to the rectangular-radial adapter, finally it is transmitted into output waveguide.

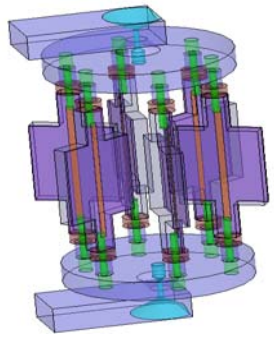

Fig.1 Six ways power combiner based on radial waveguide

We denote input waveguide as 1 port and output waveguide as 2 port of the power combining network in Fig.1. The simulated S parameters of the network are given in Fig.2. It can be seen that the performance of the network is good. The combining efficiency of the power combing network is given in Fig.3 under the condition that the output of every amplifier has same amplitude and phase.

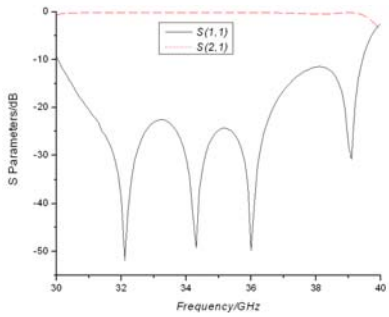

Fig.2 S parameters of the six ways power combining network

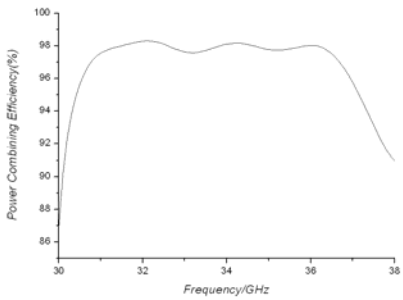

Fig.3 Combining efficiency of the power combing network

III. ANALYSIS OF COMBINING EFFICIENCY

The power combining is a vector combining, so it follows vector algorithm. The power combiner efficiency is affected by the discrepancy of the amplitude and phase of each way signal. To design a power combiner with high combining efficiency, it is essential to reduce the discrepancy of the amplitude and phase from every way.

As early as in 1969, J.R.Nevarez and G.J.Herskowitz had qualitatively analyzed the combining efficiency of a octal combiner affected by inconsistencies of the amplitude, phase and circuit losses [4] .

In this paper, how the power combining efficiency of the structure is affected by the inconsistencies of the amplitude, phase and circuit losses is presented.

A. *Amplitude and phase inconsistent*

It is known that each way output of the power divider exist a certain inconsistency of the amplitude and phase due to their space position relative to the transition or adapter, but within acceptable range. It is interesting to know how the combining efficiency is affected by the amplitude and phase inconsistent.

(1) Laterally symmetry

The combining structure is shown in Fig.4. For this structure, S_{41} and S_{51} is same, S_{31} and S_{61} same, and S_{21} and S_{71} is same due to the symmetry. But the microstrip in port 2 and port 7 are crooked to extend 3mm length.

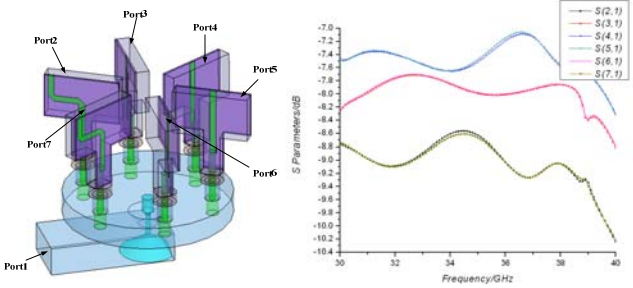

Fig. 4 The simulation model and result of the six-way laterally symmetry unequal path radial waveguide power divider

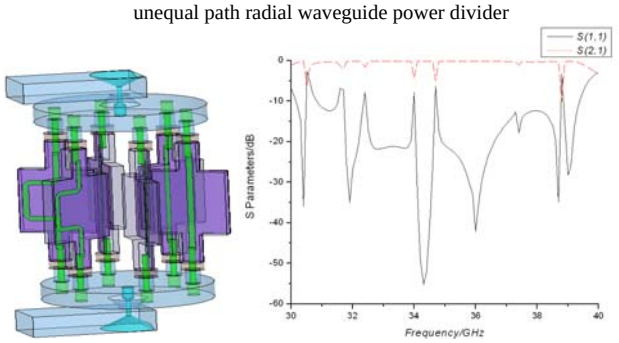

Fig.5 The simulation model and result of the six-way laterally symmetry unequal path radial waveguide power combiner

The extending of microstrip length in port 2 and port 7 make the amplitude and phase inconsistent worse, the return loss and the insertion loss shown in Fig.5 get worse compared with Fig.2.

Power combining efficiency is shown in Fig.6, in some frequency ranges, the power combining efficiency gets drastic decrease because of increasing the amplitude and phase inconsistent between the six ports.

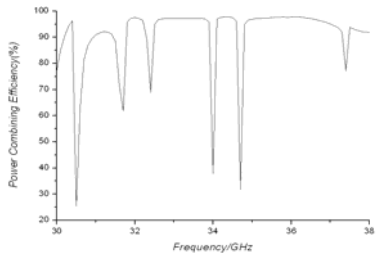

Fig.6 The power combining efficiency of the structure in Fig.5

(2) Laterally asymmetry

Fig.7 shows another combining structure, where the microstrip in port 5 and port 7 have been extended 3mm length, the amplitude imbalance of the six-ways power divider gets worse.

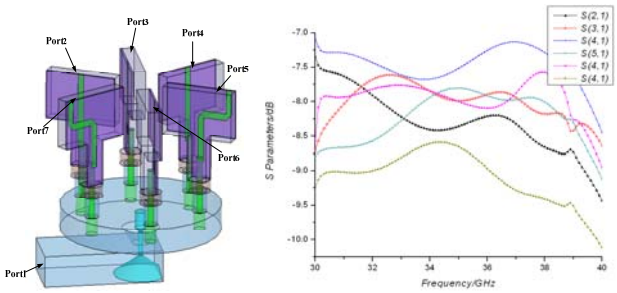

Fig. 7 The simulation model and result of the six-way laterally asymmetry unequal path radial waveguide power divider

Fig.8 shows the complete structure and S parameters. The return loss and the insertion loss get worse compared with Fig.2.

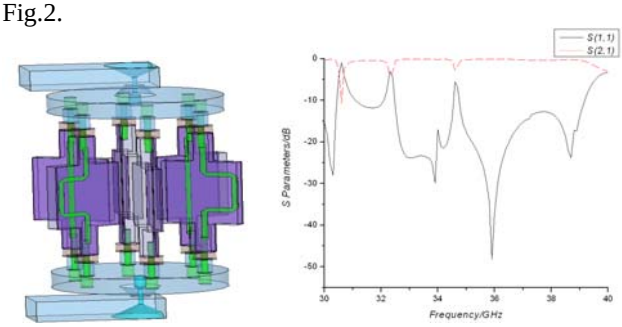

Fig.8 The simulation model and result of the six-way laterally asymmetry unequal path radial waveguide power combiner

Power combining efficiency is shown in Fig.9. As shown in Fig.9, in some frequency ranges, the power combining efficiency also gets drastic decrease because of the increasing inconsistent of the amplitude and phase between the six ports.

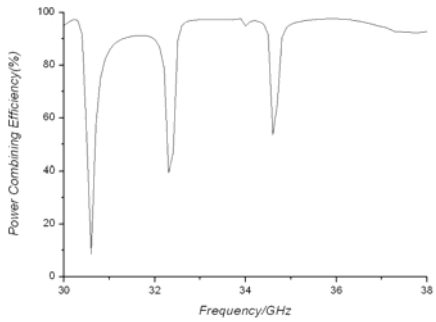

Fig. 9 The power combining efficiency of the six-way laterally asymmetry unequal path radial waveguide power combiner

B. *Circuit losses inconsistent*

(1) Laterally symmetry

The main loss of microstrip line is dielectric loss, conductor ohmic loss and radiation loss, in which the first two losses are dominant. Dielectric loss has no significant effect on the attenuation, while the ohmic loss is much greater.

The attenuation from the conductor loss is approximated as follows [5]:

$$\alpha_c = \frac{R_S}{Z_0 W} Np/m \tag{1}$$

W is the width of the microstrip. $R_S = \sqrt{\omega\mu_0 / 2\sigma}$ is the surface resistance of the microstrip conductor belt.

Fig.10 shows the combining structure with six-way laterally symmetry unequal circuit loss. The material of microstrip conductor belt of the port 2 and port 7 is assumed as graphite, whose conductivity is σ =70000 Siemens/m, while the others' material is PEC, whose conductivity is σ =1e+30 Siemens/m. As shown in the Fig.10, S_{21} and S_{71} decrease drastically because of the circuit loss.

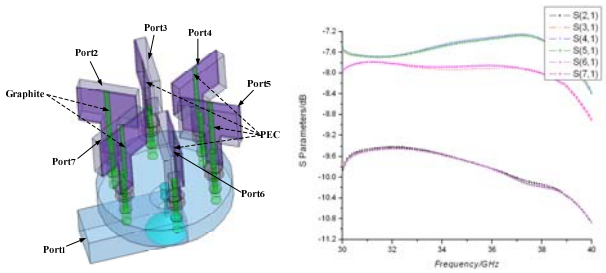

Fig.10 The simulation model and result of the six-way laterally symmetry unequal circuit loss radial waveguide power divider

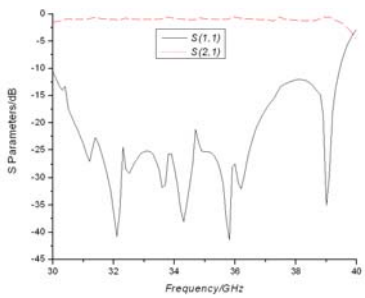

Fig. 11 The simulation result of the structure shown in Fig.10

The insertion loss of the structure gets worse because of the circuit loss as shown in Fig.11.

As shown in Fig.12, the power combining efficiency gets drastic decrease because of circuit loss.

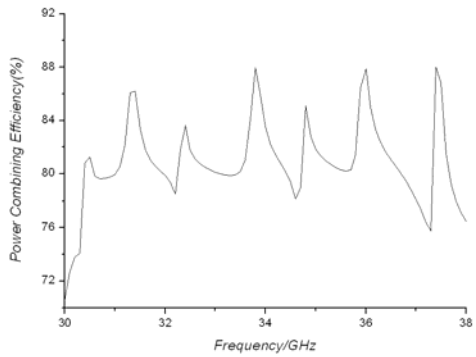

Fig.12 The power combining efficiency of the six-way laterally symmetry unequal circuit loss radial waveguide power combiner

(2) Laterally asymmetry

Fig.13 shows the six-way laterally asymmetry unequal circuit loss radial waveguide power divider. The material of the microstrip's conductor belts in the port 6 and port 7 is graphite, while the others' material is PEC. As shown in the Fig.13, S_{61} and S_{71} decrease drastically and become inconsistent because of circuit loss and laterally asymmetry.

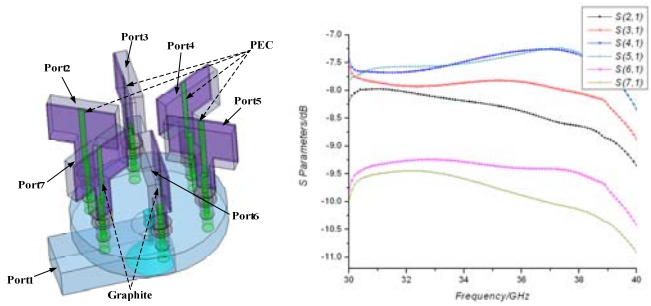

Fig. 13 The simulation model and result of the power combiner based on the radial waveguide

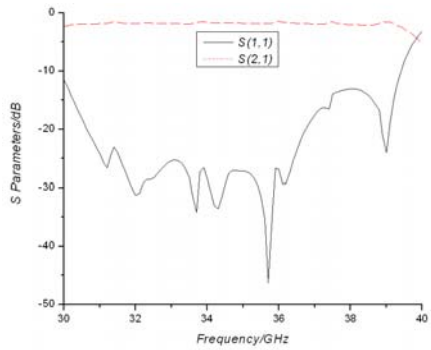

Fig. 14 The simulation results of the S parameters of the structure in Fig.13

Fig.14 shows the simulation results of S parameters of the structure in Fig.13. The insertion loss gets worse compared

with Fig.2 because of circuit loss and asymmetry unequal structure. The power combining efficiency shown in Fig.15 gets worse compared with Fig.3 because of the circuit loss and asymmetry unequal structure.

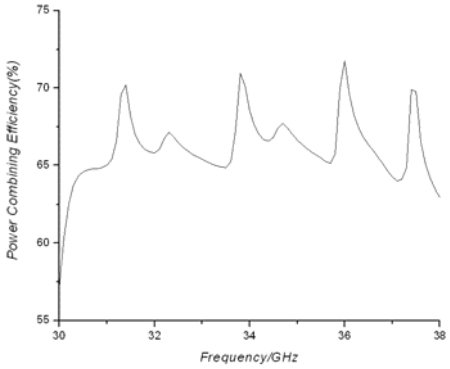

Figure 14. The power combining efficiency of the six-way laterally asymmetry unequal circuit loss radial waveguide power combiner

IV. Conclusion

In this paper, an analysis on six-ways spatial power combiner based on radial waveguide is carried out, and the simulation results of the power combiner characteristics are presented. Good performance has been obtained under the condition that the output of every amplifier has same amplitude and phase. Then, it is discussed that how the power combining efficiency of the power combiner is affected by the inconsistencies of the amplitude, phase and circuit loss, and the simulation results of the combining efficiency for different situation are given. It is of important for the development of the radial waveguide power combiner and will be referenced in the following works.

The power combiner hardware is being manufactured and experiments will be done in the near future.

Acknowledgment

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