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Millimeter-wave waveguide-based out-of-phase power divider/combiner using microstrip antenna

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ABSTRACT

A millimeter-wave waveguide-based out-of-phase power divider/combiner using microstrip patch antenna has been proposed in this paper. The stepped rectangular waveguide provides smooth impedance matching from standard rectangular waveguide to oversized rectangular waveguide. In order to obtain good amplitude balance, four symmetrical microstrip patch antennas are utilized. A Ka-band four-way passive power combiner is designed and measured. The measured results show a reasonable agreement with the simulated ones.

1. Introduction

Millimeter-wave high-power solid-state amplifiers have been used widely in many systems such as satellite communication systems, commercial communication, and radar transmitters. However, the output power from single solid-state device drops significantly as the operation frequency increases. Therefore, it is necessary to combine RF power from multiple devices to meet the desired power levels. So, power-combining technologies attract more and more attentions in millimeter-wave power-combining amplifier design. Many power dividers/combiners have been proposed to design high power amplifiers. Such as substrate integrated waveguide power dividers [1–5], rectangular waveguide power dividers [6–12], radial waveguide power dividers [13–18], conical power dividers [19], coaxial waveguide power dividers [20–23], planar circuit power dividers [24–26] and ring-cavity power dividers [27,28].

In this paper, a millimeter-wave waveguide-based out-of-phase power divider has been proposed. Stepped rectangular waveguides are used to provide smooth impedance matching from standard rectangular waveguide to the oversized rectangular waveguide. Four microstrip patch antennas have been used to implement the out-of-phase power-dividing function. Finally, a Ka-band waveguide-based passive spatial power combiner has been designed, fabricated, and measured. The simulated and measured results have been discussed.

2. Analysis and design of the waveguide-based out-of-phase power divider/combiner

The sketch of the proposed waveguide-based out-of-phase spatial power-dividing/combining system is shown in Fig. 1(a), which is placing two identical power divider circuits back to back. Fig. 1(c) shows a waveguide-based power-combining amplifier that consists of an out-of-phase power divider, an out-of-phase power combiner, and four amplifiers. The single proposed waveguide-based four-way out-of-phase power divider with five ports (as shown in Fig. 1(a)) is constructed by stepped impedance transformer from standard rectangular waveguide to oversized rectangular waveguide, and coaxial probe-fed embedded antenna array which contains four microstrip rectangular patch antennas. The microstrip patch antenna array is placed at the end of the oversized rectangular waveguide. The structure of the antenna array is shown in Fig. 1(b). Four rectangular patch antennas are symmetrical with respect to plane AA′ and plane BB′ simultaneously. The microwave signal is coupled from the oversized rectangular waveguide to the antennas array, and divided into four ways to four coaxial lines. These four signals are then collected by output antenna array to combine power to the right output oversized rectangular waveguide. It can be seen that the input and output ports are aligned, which can simplify the structure of the active power-combining system.

The detailed structure of the proposed stepped rectangular waveguide is shown in Fig. 2. The microwave signals are fed into standard rectangular waveguide, and then transmitted into the oversized rectangular waveguide. A stepped waveguide impedance transformer has been used to provide smooth impedance matching

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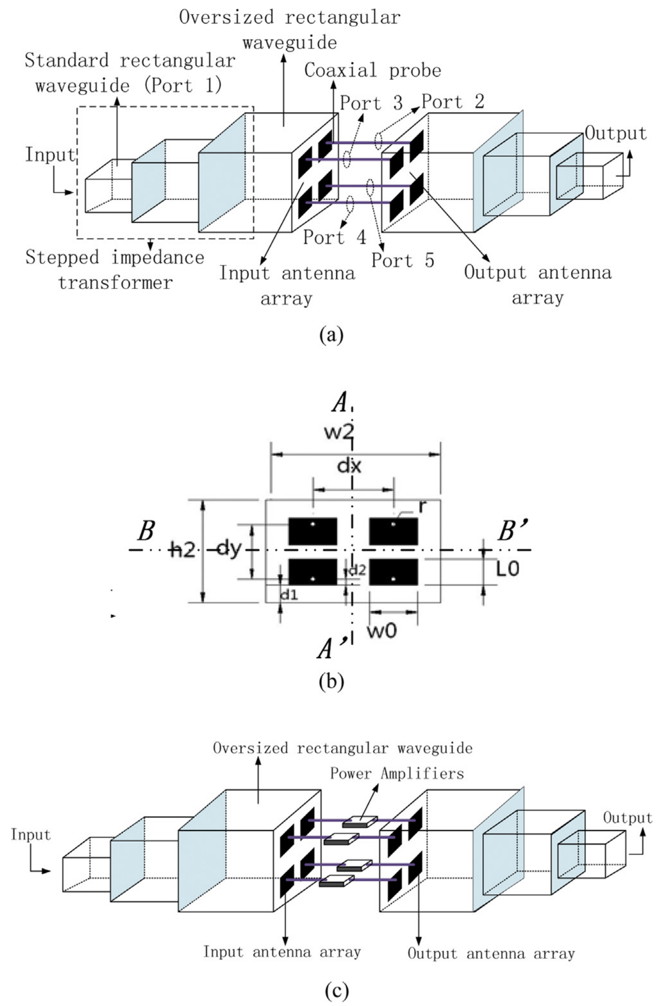

Fig. 1. Proposed waveguide-based spatial power-combining system (a) structure of the power combiner; (b) layout of the antenna array; (c) topology of the waveguide-based power-combining amplifiers.

from standard rectangular waveguide to oversized rectangular waveguide, which is easy to fabricate at millimeter-wave frequency. The equivalent-circuit model of the stepped impedance transformer is shown in Fig. 3. According to the transmission-line theory, the input impedance Z_{in} of stepped impedance transformer can be expressed as

$$Z_{in} = \frac{Z_1(Z_B + jZ_1 \tan \ \beta L)}{Z_1 + jZ_B \tan \ \beta L + jB_1(Z_1 + jZ_B \tan \ \beta L)} \tag{1}$$

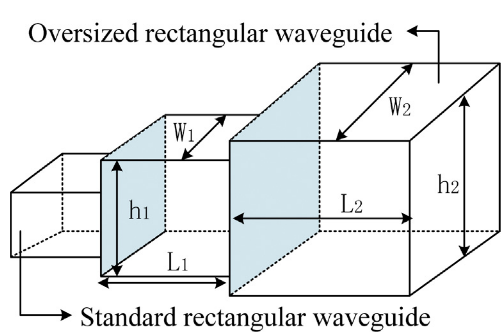

Fig. 2. Stepped impedance transformer.

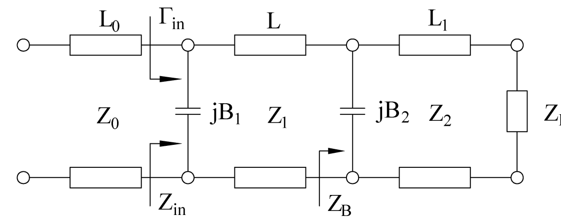

Fig. 3. Equivalent-circuit model of the stepped impedance transformer.

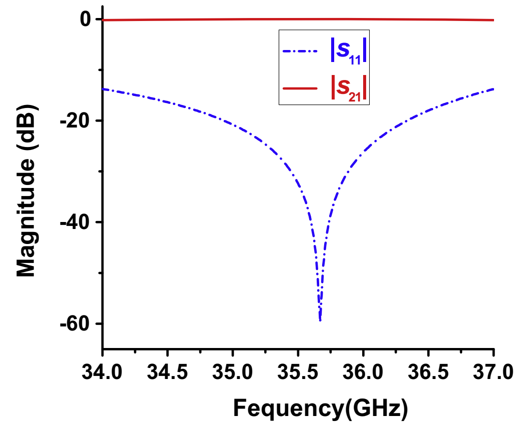

Fig. 4. Simulation results of the stepped impedance transformer.

where β is the propagation constant and Z_B can be expressed as

$$Z_B = \frac{Z_2(Z_L + jZ_2 \tan \ \beta L_1)}{Z_2 + jZ_L \tan \ \beta L_1 + jB_2 Z_2(Z_L + jZ_2 \tan \ \beta L_1)} \tag{2}$$

where Z_L is the input impedance of the oversized rectangular waveguide including four microstrip patch antennas, which can be obtained by using the simulation tool. So, the input reflection coefficient of the proposed waveguide-based power divider can be expressed as

$$\Gamma_{in} = \frac{Z_{in} - Z_0}{Z_{in} - Z_0} \tag{3}$$

Fig. 4 gives the simulation results of the stepped waveguide impedance transformer. It can be seen that the input return loss is more than 20 dB range from 34.5 GHz to 36.5 GHz.

The dominant mode of the rectangular waveguide is TE10, so the electromagnetic field distribution is symmetrical with respect to plane AA′, as illustrated in Fig. 5. Meanwhile, four rectangular patch antennas are symmetrical with respect to plane AA′ and plane BB′ simultaneously. Then, signals with equal magnitudes can be received by four patch antennas, while the phase between signals received by two antennas above or below plane BB′ are same. However, there is 180° phase difference between signals received by two antennas between above and below plane BB′.

As shown in Fig. 1, four symmetrical microstrip patch antennas fed by coaxial lines are utilized in the design of waveguide-based out-of-phase power divider/combiner. The transmission-line

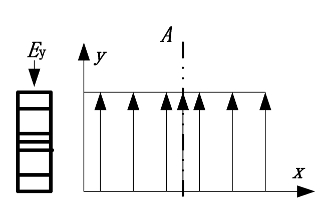

Fig. 5. Current distribution of rectangular waveguide.