A Novel Ka-band 1 to 8 Power Divider/Combiner

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***Abstract* — In this paper, a 1-to-8 traveling wave power divider/combiner design at Ka-band is presented. This power divider/combiner is composed of eight units coupling power from rectangular waveguide to microstrip lines. Coupling is achieved through longitudinal slots in the broad wall of the waveguide. Shorting posts inside the waveguide are used to adjust the coupling values. Experiments on the eight-way passive divider/combiner back-to-back design demonstrates a minimum overall insertion loss of 1.8 dB at 32.5 GHz with a 3 dB bandwidth of 15%.**

I. Introduction

To realize solid-state microwave power amplification at high power levels and frequencies, power dividing and combining techniques are indispensable. An efficient multi-way power divider circuit requires equal power division over a wide bandwidth, good isolations and little phase deviations between the branches [1]. Most power divider/combiner circuits fall into two categories: resonant type and non-resonant type. Resonant designs usually have high combining efficiencies over narrow bandwidths, while non-resonant designs can obtain wide bandwidths at the cost of higher insertion losses [1]-[6]. The N-way traveling wave design belongs to the non-resonant type and each branch of this kind of power divider/combiner has different coupling coefficients to achieve equal power dividing/combining. Although this requirement increases the design complexity, the bandwidth can be greatly enhanced. In [2], an eight-way waveguide to coax traveling wave power divider at X-band was presented, and its measurement results showed great improvements in bandwidth and a low insertion loss compared to a similar resonant design in [3].

The work presented in this paper focuses on the transitions from a slotted rectangular waveguide to microstrip lines. In review of previous works, the waveguide to microstrip splitters are realized by inserting a microstrip probe inside the waveguide [7] or by coupling power through a longitudinal slot in the broad-wall of the waveguide [8]. In our previous work[4], a resonant power divider/combiner was designed at X-band with a 3 dB band-width of 0.5 GHz, and an insertion loss of 1.15 dB at 10 GHz.

This paper presents a novel traveling wave power divider/combining design, which consists of couplers from the slotted rectangular waveguide to microstrip lines. The coupling coefficients are adjusted by changing the positions of each shorting post inside the slotted waveguide (Fig. 1). The power divider/combiner presented in this paper provides wide bandwidth, low insertion loss, and efficient heat-sinking for solid-state amplifiers.

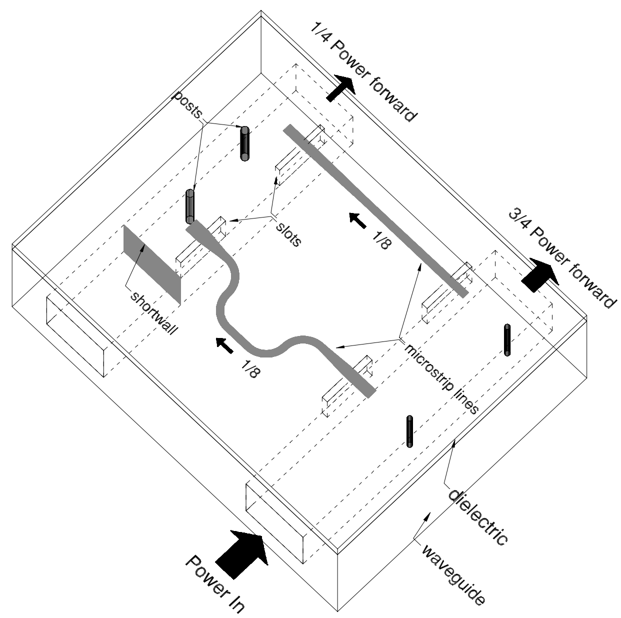

Fig. 1: The first two stages of the power divider and the last two stages of the power combiner. (i.e. divider stage 1 connected to combiner stage 8, divider stage 2. connected to combiner stage 7.)

In the following sections, an equivalent network is introduced based on the traveling wave concept, and design formulas are given for each branch's coupling ratio in terms of S-parameters. The design procedure for determining branch's dimensions is described, and experimental results on the passive power divider/combiner are demonstrated and compared with the

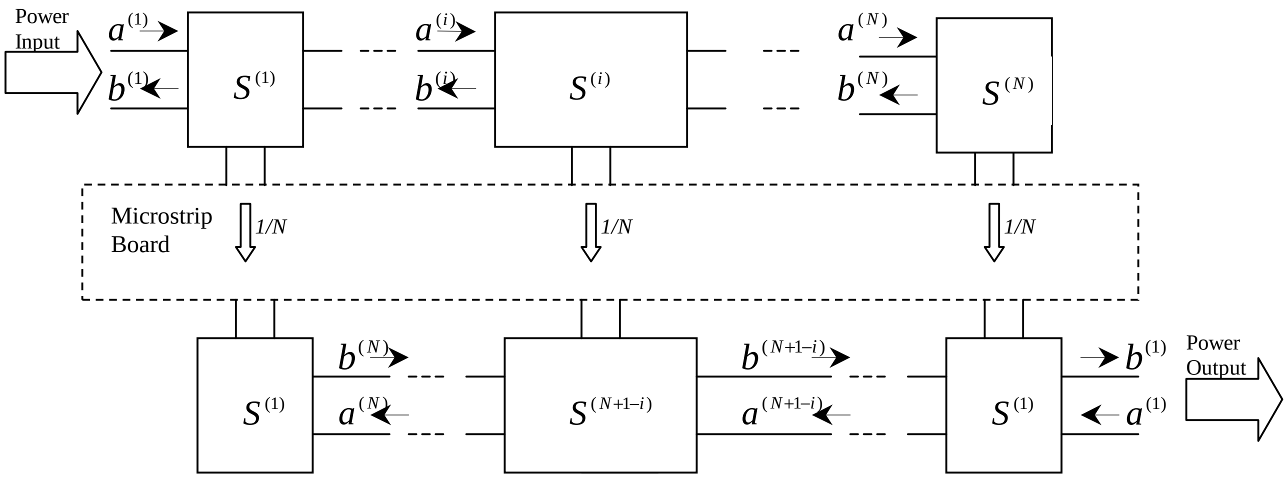

Fig. 2: N three-port network blocks for each stage of traveling wave N-way power divider/combiner.

simulation results obtained from a commercial software (Agilent- $HFSS^{TM}$).

II. THEORY AND DESIGN APPROACH

In a traveling wave power divider, the input power is equally divided into N branches, and it is designed to have no reflection from each branch's discontinuity. Therefore, each branch can be designed individually as a two-way power divider, i.e. a three-port network. In Fig. 2, the whole structure is simplified into eight three-port network blocks. The port 1 and 3 of each unit are the waveguide ports, and port 2 is for microstrip line port (Fig. 3).

In this traveling wave design approach, only the dominant propagating mode exists between each stage in the rectangular waveguide, and the distance between these units is large enough to neglect the evanescent modes coupling between the stages. If a_i to be the incident wave to the i^{th} stage, and b_i to be the reflected wave, the power delivered into this three-port junction is: $(i = 1,2,..., N)$

$$|a_i|^2 - |b_i|^2 = (N - i + 1)P_{in} / N. \quad (1)$$

For an ideal traveling wave power divider, the following design goals should be achieved [2,3]:

$$|b_i|^2 = 0\,; \quad (2)$$

$$|a_i|^2 = (N - i + 1)P_{in} / N. \quad (3)$$

Therefore, the design of an eight-way power divider is simplified into eight individual designs of three-port power dividers with the following S-parameters: $(i = 1,2,..., N)$

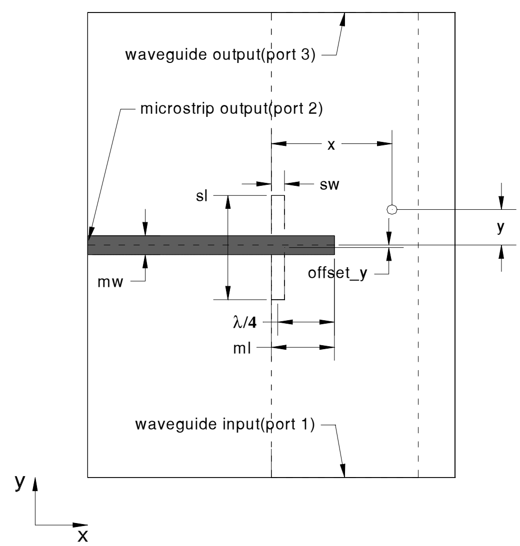

Fig. 3. Single stage top view with design parameters.

$$|S_{11}^{(i)}|^2 = 0\,; \quad (4)$$

$$|S_{21}^{(i)}|^2 = 1/(N + 1 - i)\,; \quad (5)$$

$$|S_{31}^{(i)}|^2 = (N - i)/(N + 1 - i)\,. \quad (6)$$

As can be seen, the transition coefficient $|S_{21}|^2$ from the waveguide to microstrip line for the last stage is 1. Inspired by [9]'s application of posts in waveguide, these large transmission ratios were realized by introducing shorting posts in the waveguide. For an individual stage shown in Fig. 3, the slot offset (*offset_y*), slot width (*sw*), microstrip line impedance, post position (*x*,*y*) and radius of the post (*radius)*, can be adjusted to obtain the specified S-parameters. The open-circuited microstrip lines were extended a quarter of the microstrip's wavelength beyond each slot to achieve a virtual short at the microstrip plane. In addition, at the slots, the microstip-line impedance values are transformed to 50 Ohms by tapered transmission lines.

For each waveguide-microstrip coupler, an optimal design of the above parameters should simultaneously satisfy the following conditions [8]:

i). The least reflections back to the input of waveguide (*port 1.* in Fig. 3);
ii). Minimum radiation from the coupling slot into the free space (i.e. radiation boundary);
iii). Power division at specified ratio (S_{21}) from the waveguide to the microstrip line.

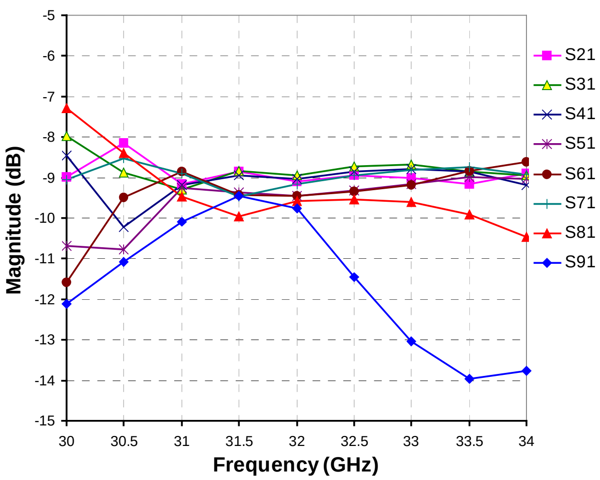

Fig. 4: Eight-way power divider's insertion loss at each branch. (S_{91} is the transmission coefficient for the last stage. Agilent- $HFSS^{TM}$ simulation results)

The last coupler stage must have a transition coefficient of 1. For this stage, a resonant design using a shorting waveguide wall at the end is chosen. Due to its resonant nature, the overall bandwidth for the dividing circuit is slightly reduced (Fig. 4).

According to the reciprocity theory, the power divider design also can be used as a power combiner. In this case, phase deviations due to different shorting posts' positions at each stage are critical for a coherent power combining. Most of these phase deviations can be corrected by simply cascading the combiner back-to-back with the divider, i.e. the divider's 1_{st} branch connected with the combiner's 8_{th} branch, the divider's 2_{nd} branch connected with the combiner's 7_{th} branch, etc. And because of the last stage's special requirement, i.e. the total power of the waveguide coupled into the microstrip line, additional phase delay had to be introduced by adding extra microstrip length (as shown in Fig. 1). Fig. 5 shows the phases of transmission coefficients for the different branches, whose values are close to each other over a wide bandwidth.

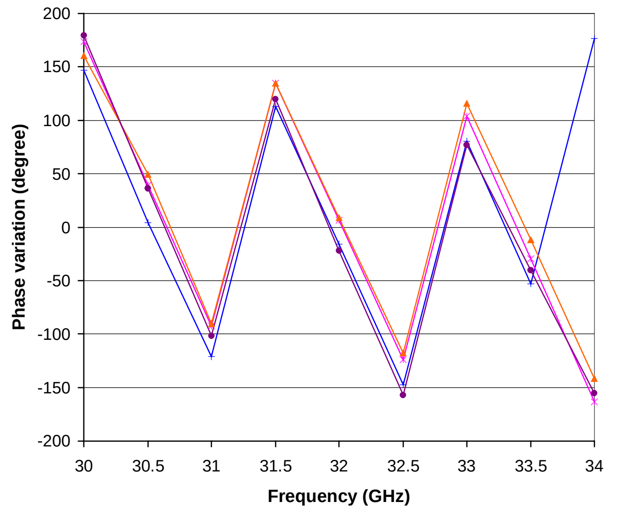

Fig. 5: Phase variations of each two branches connected from the divider to the combiner, i.e. divider stage 1 to combiner stage 8, divider stage 2 to combiner stage 7, divider stage 3 to combiner stage 6, divider stage 4 to combiner stage 5. (The other four branches connected from the divider to the combiner are symmetric with these four.)

III. RESULTS AND DISCUSSION

A passive cascaded eight-way power divider/combiner was fabricated and measured. The microstrip circuit was fabricated on Roger's 6006 $RT/Duroid^{TM}$ ($\varepsilon_r = 6.15$) with a thickness of 0.381 mm. The slotted Ka-band waveguide was machined from an aluminum block. Simulation results for the eight-way power divider/combiner are shown in Fig. 6's (a) and (b) together with measured results. A close agreement between simulation and measured results is observed. The simulated return loss of the whole divider and combiner is approximately 20 dB and its insertion loss is less than 2 dB over a 4 GHz bandwidth. And in measured results, the minimum insertion loss of the entire passive system is 1.8 dB at 32.5 GHz with an input return loss of 35 dB. The increased insertion loss compared with the simulation results is most likely due to the fabrication errors and the slight mismatches in each branch's phase.

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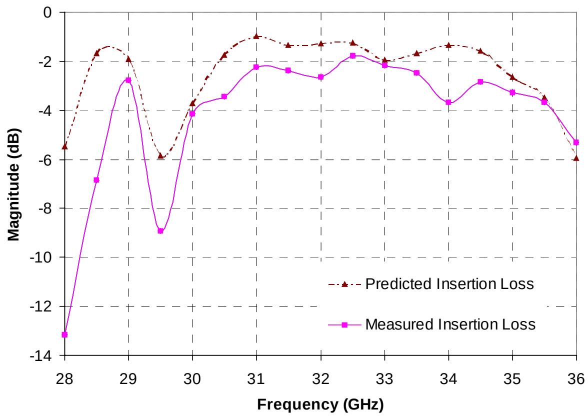
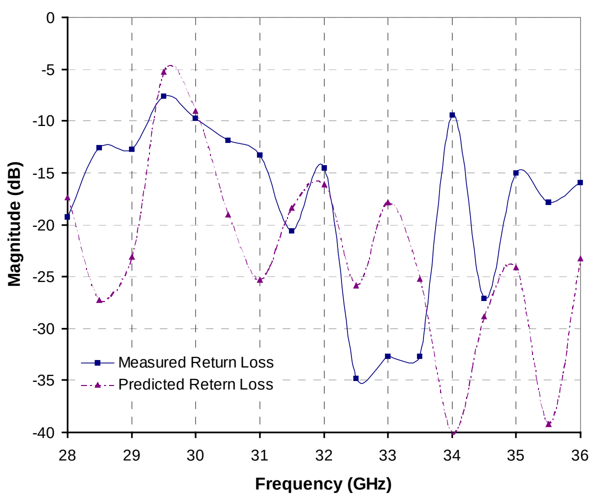


(a)



(b)

Fig. 6: Simulation and measured results for a passive 1 to 8 power divider/combiner: (a) Insertion loss; (b) Return loss;

IV. CONCLUSION

The design of a novel 1-to-8 power divider/combiner at Ka-band is presented in this paper. This passive power divider/combiner not only demonstrates a wide bandwidth with low insertion loss but also offers an efficient heat sinking structure for the design of solid-state power amplifiers. A 3 dB bandwidth of 15% (~5GHz at 32.5GHz) was obtained with an insertion loss of approximately 1.8 dB and a return loss better than 30 dB.

ACKNOWLEGEMENT

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