Q- and V-Band Planar Combiners

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Abstract

Millimeter-wave planar power combiners have been developed at frequencies of 44 GHz and 60 GHz. These combiners are 3-way and 5-way and are of tapered line construction. They show transmission loss of 0.6 dB, VSWR of 1.5:1 and isolation of greater than 15 dB.

Introduction

In the past few years significant progress has been made in the development of millimeter wave three terminal power devices which are capable of very high efficiency and output power [1-3]. These include high electron mobility transistors (HEMT) and the heterojunction bipolar transistors (HBT). These devices are being used to construct monolithic wideband power amplifiers for improved producibility and reliability of the entire solid state amplifier (SSA). Due to the limited power achievable from each device, a large number of these HEMT or HBT amplifiers are required to achieve the necessary output power of a practical transmitter amplifier. There is thus a need for efficient millimeter wave planar power combiners that are compatible with MMIC HEMT or HBT amplifier chips. A planar microstrip power combiner reduces the required output power of the device thus relaxing the thermal design and ensuring better reliability. The small size and lightweight planar combiner also reduces the order of the subsequent combining component such as a waveguide radial line combiner thus reducing overall SSA size and weight. The well-known Wilkinson combiner can be used for two way combining [4]. It is however difficult to construct for more than a two way planar combiner using the Wilkinson approach since the isolating resistors must be connected in a star configuration. An improvement on this is the Nagai version in which the resistors are planar connected [5]. The steps in impedance level of the lines however give rise to discontinuity susceptances which cause unacceptable deterioration in performance at millimeter-wave frequencies. A better planar combiner is one that has tapered line impedances. Tapered line combining at Ku band has been documented by Schellenberg and Yamasaki [6] and a 2 to 18 GHz tapered line combiner has been reported by Yau et al [7]. This paper describes the design and performance of MMIC compatible Q- and V-band tapered line planar combiners. To the best of our knowledge these are the first reported millimeter wave planar combiners.

V-Band Three-Way Planar Combiner Design

A schematic of the three-way planar tapered line combiner is shown in Figure 1. It shows three tapered lines that connect to a common junction at the output. Each of the three microstrip lines transforms its 50 ohm source to 150 ohms which becomes 50 ohms at the parallel connection.

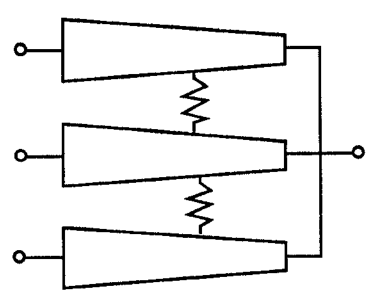

Figure 1. Schematic of 60 GHz 3-Way Combiner.

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The combiner is then matched both at its output port and its input ports when they are fed in phase . Also shown are two deposited thin film resistors which bridge between the tapered lines. They are spaced at a distance of approximately quarter-wavelength from the common junction at the center working frequency. These resistors give the combiner its input-to-input port isolation and low VSWR on the input ports when fed singly. A feature of this combiner was that the input arm spacing was set to 60 mil to allow for power combining of three MMIC HEMT power amplifiers. A Dolph-Chebychev impedance taper and an initial length were chosen for the transmission lines. The line widths and spacings were obtained by using a static capacitance analysis program. It was necessary that all the lines phase track along their lengths: otherwise the splitter/combiner combination would have combining losses. In this combiner the outer lines were longer than the inner ones but their effective dielectric constant was lower. There was an optimum length of lines such that the phase tracking was obtained. For this combiner the required line length was in excess of two wavelengths. The complete combiner was characterized using even and odd mode analysis. The value of resistor was optimized for best isolation and input port VSWR. A photograph of two combiners back-to-back is shown in Figure 2. The combiner was fabricated on 5 mil thick Quartz. The resistors were made of deposited Tantalum Nitride having a resistance value of 100 ohms/square.

V-Band Three-Way Planar Combiner Test Results

Figures 3 through 5 show the combiner back-to-back transmission and return loss, transmission unbalance and isolation over the frequency range 54 to 66 GHz. The loss per combiner is within 0.6 dB over most of the band. The transmission unbalance is within 1 dB. The isolation between the input ports is greater than 16 dB. The input port return loss is greater than 10 dB.

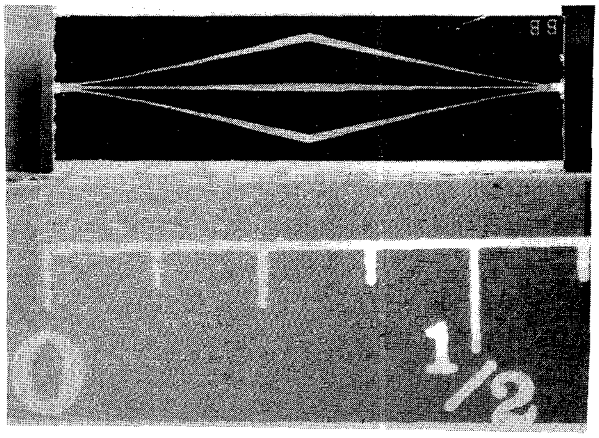

Figure 2. Photograph of two 60 GHz 3-Way Combiners back-to-back.

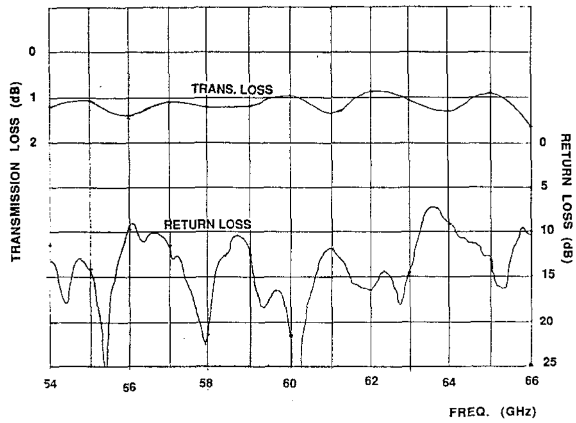

Figure 3. 60 GHz 3-Way Planar Combiner Back-to-Back Measured Transmission and Return Loss.

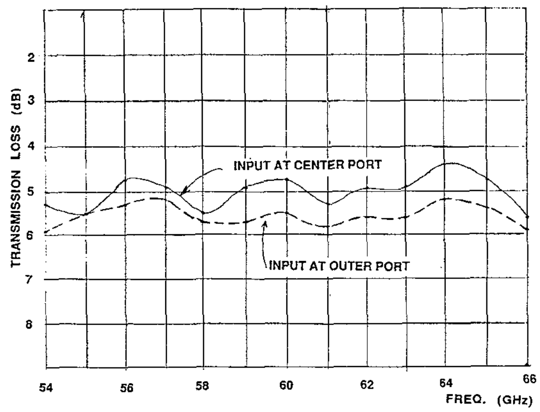

Figure 4. 60 GHz 3-Way Planar Combiner Measured Transmission Loss.

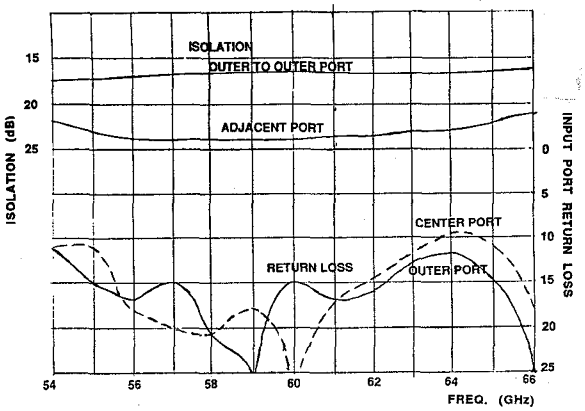

Figure 5. 60 GHz 3-Way Planar Combiner Measured Isolation and Input Port Return Loss.

V- and Q-Band Five-Way Planar Combiner Design

In the case of five-way combiners phase matching becomes a problem when combining separate chips. For this reason tight coupled five-way lines were designed to combine five MMIC amplifier outputs from a single chip. The schematic of the 60 and 44 GHz 5-way combiners is shown in Figure 6. The photographs of the combiners are shown in Figure 7a. and 7b. Since the 5-way combiners require a greater impedance transformation than the 3-way combiners the lines are narrower. For this reason part of the transformation is done in the common line connecting to the output. The design otherwise is similar to that of the three-way combiner. The 44 GHz combiner was fabricated on 10 mil thick Quartz and the 60 GHz combiner was fabricated on 5 mil Quartz.

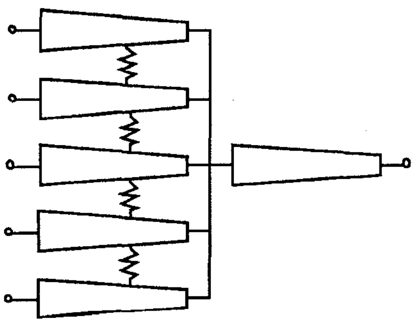

Figure 6. Schematic 60 and 44 GHz 5-Way Combiner.

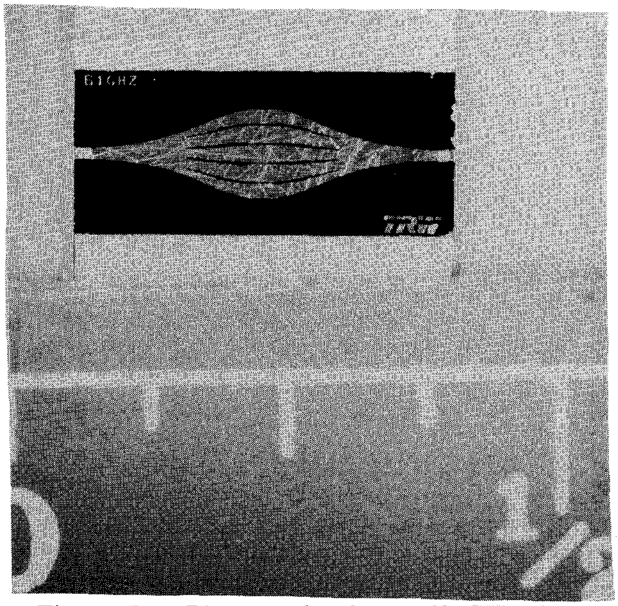

Figure 7a. Photograph of two 60 GHz 5-Way Combiners back-to-back.

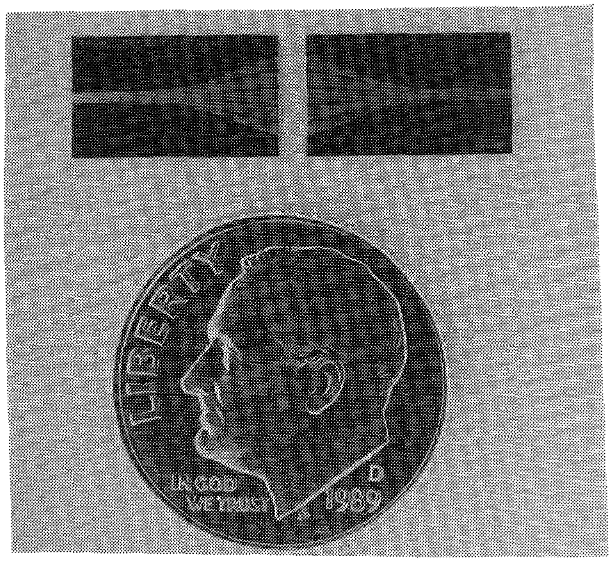

Figure 7. Photograph of two 44 GHz 5-Way Combiners..

V- and Q-Band 5-Way Planar Combiner Test Results

The measured back-to-back transmission loss of the 60 GHz 5-way combiner is shown in Figure 8. The loss per combiner is within 0.55 dB over nearly the complete waveguide band. Figures 9 and 10 show the 44 GHz 5-way combiner back-to-back transmission loss and input-to-input port isolation respectively. The loss is within 0.5 dB per combiner. The isolation is greater than 15 dB.

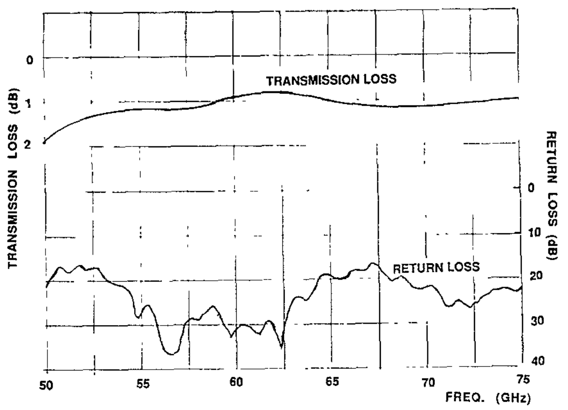

Figure 8. 60 GHz 5-Way Planar Combiner Back-to-Back Measured Transmission Loss and Return Loss.

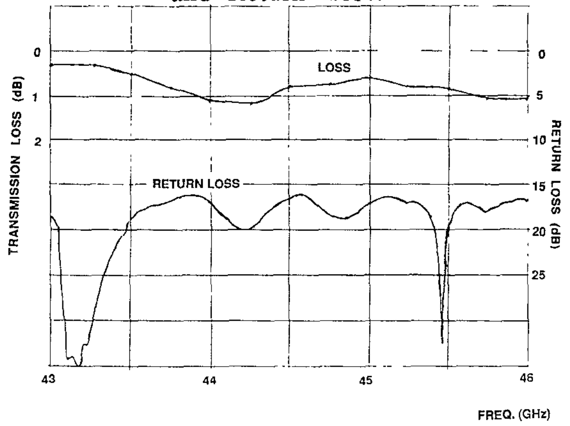

Figure 9. 44 GHz 5-Way Planar Combiner Back-to-Back Measured Transmission Loss and Return Loss.

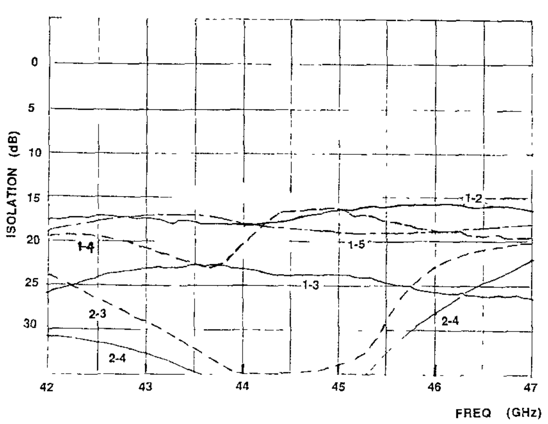

Figure 10. 44 GHz Planar 5-Way Combiner Measured Isolation.

Conclusion

This paper has described the design and performance of 3-way and 5-way planar combiners working in the 44 and 60 GHz frequency ranges. They have been shown to have less than 0.6 dB combining loss and greater than 15 db isolation. These planar combiners are eminently suitable for combining the outputs of MMIC, HEMT or HBT amplifier chips to form a one watt level amplifier module.

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