# A Passive Double-Layer Microstrip Array for the Construction of Millimeter-Wave Spatial Power-Combining Amplifiers

Toni Ivanov, Sean Ortiz, Amir Mortazawi, Erich Schlecht, and John Hubert

***Abstract*— A passive double-layer microstrip array for the construction of millimeter-wave quasioptical amplifiers has been demonstrated. A total insertion loss of 3.1 dB was measured for a 138 element divider/combiner at 35.1 GHz. The 3-dB bandwidth is larger than 1 GHz. The array incorporates microstrip-slot-microstrip transitions with an insertion loss of 0.2 dB at the design frequency and microstrip patch antennas with an estimated efficiency of approximately 72%.**

***Index Terms*— Horn antenna, ka-band, microstrip antenna, MMIC, spatial power combining.**

## I. Introduction

SPATIAL power-combining amplifiers have been proposed to replace vacuum tubes with solid-state devices at millimeter-wave frequencies. Different approaches have been used to realize circuits that coherently combine the power produced from an array of solid-state devices. First, grid amplifiers [1], [2] were introduced. Subsequently, power combining architectures based on discrete antenna arrays and dielectric slab combiners were reported [3]–[6].

In [7], we demonstrated a double-layer circuit used to construct one- and two-stage spatial amplifiers at X band. A new feed for spatial amplifiers was proposed [8] in order to provide a uniform excitation of the unit cells in the spatial array. In this letter, we investigate the losses of the double-layer microstrip architecture at millimeter-wave frequencies. The circuit studied herein is a 138-element array of microstrip patch antennas excited with phase corrected pyramidal horns at 35 GHz. The structure is passive in order to estimate accurately the divider/combiner losses. Another objective of this study was to estimate the contributions of the structure's building blocks to the total loss of the divider/combiner. The dimensions of the unit cells, forming the array, are such that they can be populated with existing 1.0-W monolithic microwave integrated circuit (MMIC) power amplifiers.

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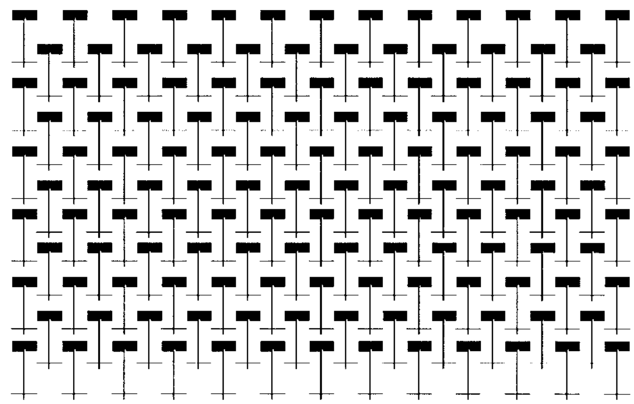

Fig. 1. Schematic of the passive double-layer microstrip array.

## II. Design and Experimental Results

A schematic of the passive double-layer microstrip array is shown in Fig. 1. The circuit was fabricated on a 0.381-mm-thick Duroid substrate with $\varepsilon_r = 6.15$. This substrate was chosen in order to emulate the performance of the circuit on a diamond substrate with $\varepsilon_r = 5.6$. When the array is populated with active devices, a considerable amount of heat will be generated. Therefore, a substrate with a good heat conductivity should be used, and diamond is considered a possible candidate.

Two microstrip boards were placed back to back with a shared ground plane to form a double-layer architecture. The array is formed from identical unit cells each consisting of a receiving and a transmitting rectangular patch antenna, microstrip-slot-microstrip transition, and interconnecting microstrip lines. The microstrip-slot-microstrip transition is used to couple energy from the receiving layer to the transmitting layer. The area of the circuit was determined by the aperture size of a standard Ka-band horn (69 $\times$ 52 mm). Since the circuit is double sided, a driver stage can be mounted on the input side and power stage on the output side.

Fig. 2 shows the unit cell layout of the divider/combiner. The layout of the second layer is identical. The antenna is fed from the radiating edge. It was designed to have 90-$\Omega$ input resistance at 33 GHz. The inset into the patch is 0.508 mm long, the width of the microstrip line is 0.16 mm, and the gaps in the inset region have widths of 0.1 mm. The antenna has a resonant length of 1.676 mm and a width of 2.54 mm. The comparison between the antenna's simulated and measured input impedance is given in Fig. 3.

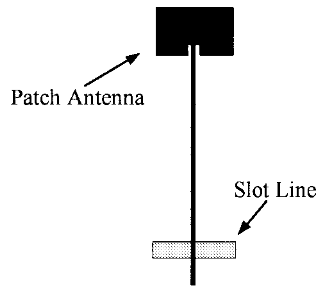


Fig. 2. Layout of the unit cell of the passive double-layer microstrip array.

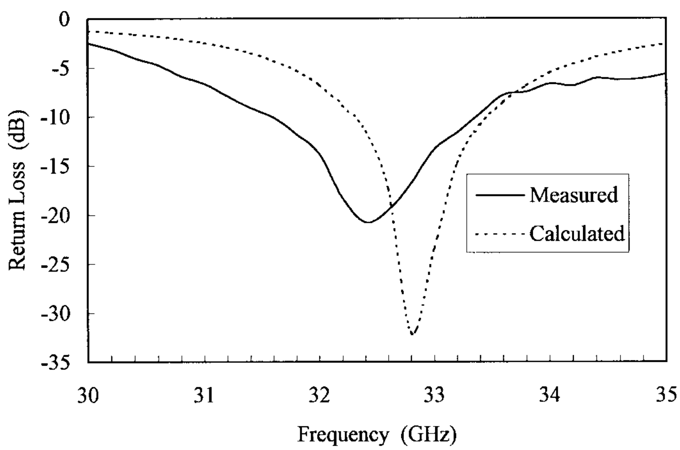


Fig. 3. Measured and calculated return loss of the patch antenna.

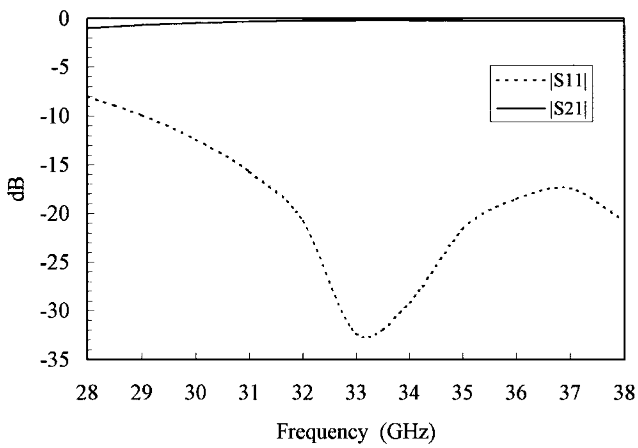


Fig. 4. Calculated $S$ parameters of the microstrip-slot-microstrip transition.

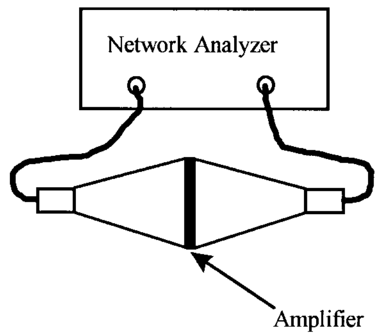


Fig. 5. Measurement setup.

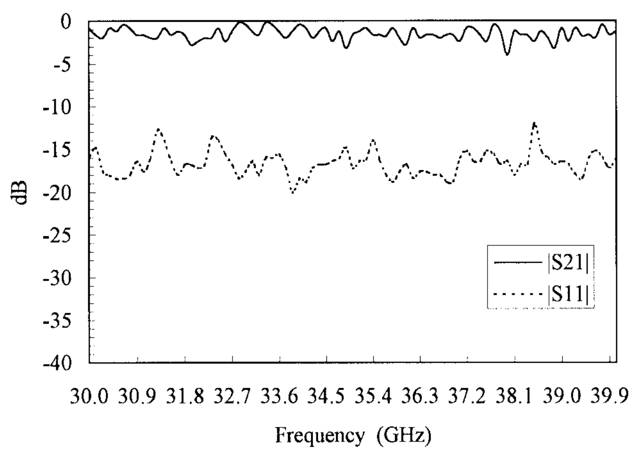


Fig. 6. Measured $S$ parameters of two phase-corrected pyramidal horns placed back to back.

The geometry of the microstrip-slot-microstrip transition is also shown in Fig. 2. Open-circuited microstrip stubs provide virtual shorts at the design frequency of 33 GHz. The stubs are 0.909 mm long (measured from the center of the slot line). The slot width and length are 0.142 and 1.965 mm, respectively. The performance of the transition was simulated using HP-HFSS. The input and output ports of the structure were set at the microstrip lines. Fig. 4 shows calculated magnitudes of S11 and S21 from 28 to 38 GHz. An insertion loss of about 0.2 dB is maintained in the frequency range of interest.

The circuit was measured using the setup shown in Fig. 5. Two standard phase corrected Ka-band pyramidal horns were used to couple the signal into and out of the passive array. The measurement setup was calibrated at the flanges of the horns, i.e., the loss contributions of the two horns and the two lenses were considered as a part of the overall divider/combiner loss. This gives the most realistic indication of the insertion loss for this technique used in the construction of practical millimeter-wave amplifiers. Initially, we measured the loss introduced by the imperfection of the phase-correcting lenses. The two horns were placed back to back (the horns were pressed against each other sharing a common aperture). The resulting closed structure was measured, and the response is presented in Fig. 6. Typically, the insertion loss is 1.0 dB and the return loss is better than 14.0 dB over the entire frequency range. The small ripples in the curves were attributed to partial reflections from the surface of the lens. As a next step, the array was placed between the two phase-corrected horns. The measured response is shown in Fig. 7. A minimum insertion loss of 3.1 dB was obtained at 35.1 GHz. The ripples in the insertion loss curve are about $\pm 0.5$ dB. Therefore, we choose an insertion loss of 4 dB as a conservative estimate for the circuit's response. The 3.0-dB bandwidth is more than 1 GHz. The microstrip circuit is enclosed by the exciting horns so that the spill over losses are eliminated and the total system length is equal to the length of the horns.

The measured results can be used to estimate the efficiency of the microstrip patch arrays. After accounting for the horn to horn insertion loss (approximately 1 dB) and microstrip-slot-microstrip insertion loss (0.2 dB), the loss due to the two

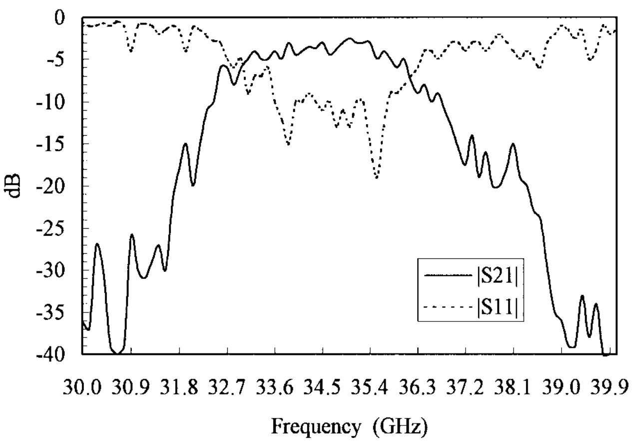


Fig. 7. Measured $S$ parameters of the passive double-layer microstrip array excited with two phase-corrected horns.

microstrip patch arrays is 2.8 dB. This corresponds to radiation efficiencies of approximately 72% for each patch array.

## III. Conclusion

A 138-element passive double-layer microstrip array for the construction of millimeter-wave spatial power-combining amplifiers was demonstrated. Monolithic microwave integrated circuit amplifiers can be readily mounted on the array. The circuit was excited with phase corrected standard Ka-band pyramidal horns. The structure does not suffer from spillover losses and the total length is equal to the lengths of the horns. The array provided 3.1 dB of insertion loss at 35.1 GHz. A useful 3-dB bandwidth of 1 GHz was obtained. The estimated patch antenna efficiency is approximately 72%.

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