A Ka-band Perpendiculary-fed Patch Array for Spatial Power Combining

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Abstract — **A Ka-band spatial power combining amplifier array employing a perpendicular feed structure is presented. The amplifier array utilizes perpendicularly-fed, aperture-coupled microstrip patch antennas with a unique feed structure for both the input and output antennas. This feed places the devices and antennas on separate planes, allowing for a smaller unit cell size, a simplified layout, and a minimum interaction between the devices and fields. A 7x7 passive and active amplifier array have been designed and fabricated at Ka-band. Experimental measurement results for both arrays are given.**

I. Introduction

Many papers [1]-[8] have been presented which demonstrate spatial power combining utilizing grids, CPW fed slots, tapered slotlines, and microstrip patch based spatial amplifiers. The typical spatial amplifier array is formed from individual unit cells. The unit cells can limit the size of the devices or the complexity of the matching circuit used, since both the amplifiers and matching circuits, as well as the antenna, must be contained within the area determined by the array spacing. This is typically on the order of 0.6 to 0.7λ in air and is necessary to avoid grating lobes and to provide an efficient excitation of the amplifiers using hard-horn feeds [9]. One design, which alleviates this problem, is found in [7], where the amplifiers are placed between the input and output tapered slotline antennas. In this paper, the amplifiers are also placed on a separate layer located between the input and output antennas. This was first introduced in [10] for a 5x5 X-band array using perpendicular-fed patch antennas [11].

The general concept for this array configuration is shown in Fig. 1, where the patch antennas on the left of the diagram receive an incident signal radiated from the feeding hard-horn antenna. The signal is then coupled through apertures in the groundplane to the microstrip transmission lines located perpendicularly to the antenna groundplane. After amplification, the signal is then radiated through the aperture coupled patch antennas on the last layer and is collected by the receiving horn. This implementation utilizes the perpendicularly-fed patch antenna as the radiating element and the application of a novel microstrip-to-waveguide transition for coupling energy from a microstrip line within the array to the dielectric filled waveguides, which are terminated by the aperture coupled patch antennas.

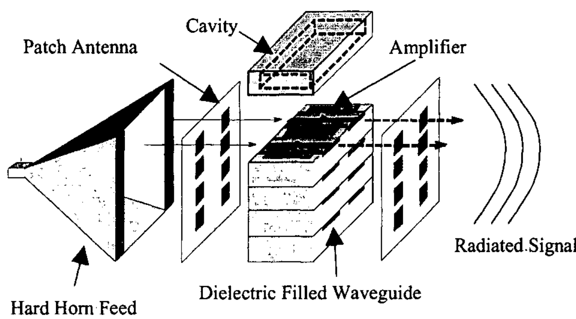

Figure 1: Perspective view of the quasi-optical array employing perpendicular feed structures.

This array topology has several advantages over tile-based arrays and also other tray-based arrays. The most notable advantage is the reduced unit cell size, which is difficult in high power tile-based arrays but common among tray-based arrays. As can be seen in Fig. 1, the amplifiers and biasing networks are located on trays, which are stacked to form the array. In addition, the amplifying portion of the unit cell occupies the space between the input and output microstrip patch antennas. By placing the amplifying circuitry between the input and output antennas, the unit cell size has been reduced to its smallest possible dimensions, since a 3-dimensional approach has been taken. Furthermore, the amplifying elements have been isolated from the radiating elements, through the microstrip patch antenna groundplane (only slot apertures are present in this groundplane as seen on the right side of the figure). The groundplane with the slot apertures, shown in Fig. 1, has been formed by stacking the individual trays on top of each other. Stacking the trays also forms the dielectric filled waveguide on either side of the array. This dielectric filled waveguide is the conduit between the microstrip transmission lines in the center of the tray and the microstrip patch antennas on the left and right sides of the array. The isolation formed between the amplifying

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circuitry and the radiating elements simplifies the system design. In addition, the radiation characteristics of the antenna array are no longer influenced by finite size substrates, bias lines, bondwires, etc. More importantly, the isolation reduces the possibility of potential oscillations. Finally, the stacked trays provide thick groundplanes for the removal of heat. Each groundplane may be half or more of the unit cell size. At Ka-band, this is on the order of 2.54-mm for a $0.5\lambda_0$ spacing. Furthermore, the groundplane need not remove the heat from as many unit cells, since each tray carries only a fraction of the total number of unit cells.

Since the amplifiers do not share the same space with the antennas, this design can accommodate larger active devices. Moreover, large power amplifiers, which are often the size of the radiating elements, can be placed within the array with greater ease. As well as reducing the unit cell size, the design complexity is decreased by separating the antenna and amplifier networks into separate layers. The design and fabrication of both a passive and active 7x7 array utilizing this perpendicular configuration are presented.

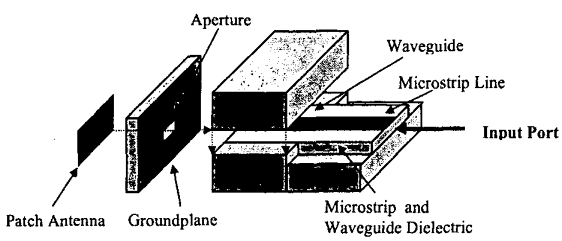

Figure 2: An aperture coupled patch antenna fed by a dielectric filled waveguide.

II. Design

The perpendicularly-fed patch amplifier array consists of 49 unit cells, each comprised of several components: input and output aperture coupled patch antennas, microstrip-to-waveguide transitions, amplifiers, and biasing networks. The antenna implementation, including the transition from the microstrip line to the dielectric filled waveguide is an essential part of the array topology. A conceptual view of the entire antenna implementation is shown in Fig. 2. In this figure, a signal input at the microstrip line is coupled to the dielectric filled waveguide through the microstrip-to-waveguide transition. Then the signal is radiated by the aperture coupled patch antenna, which terminates the dielectric filled waveguide. Since the dielectric filled waveguide separates the aperture coupled patch antenna from the microstrip-to-waveguide transition, the two components can be modeled separately.

By separating the antenna design into two parts, the aperture coupled patch antenna can be designed first using *Agilent HFSS™*. This simulation includes the dielectric filled waveguide, which serves as the input port for the simulation, but not the microstrip-to-waveguide transition. A more detailed discussion of the design process can be found in [11]. The resulting microstrip patch antenna is 2.159x3.0-mm, while the slot is 1.6x0.254-mm. The antenna substrate is a *Rogers TMM3™* dielectric material with an $\varepsilon_r = 3.27$, dissipation factor of 0.002, and thickness of 0.381-mm. A *Rogers RT6006™* dielectric material with an $\varepsilon_r = 6.15$, dissipation factor of 0.0027, and thickness of 0.254-mm was chosen for the dielectric filled waveguide. The microstrip-to-waveguide transition was then designed by correctly choosing the dimensions of the waveguide, which yields an impedance of 50 Ω. The dielectric filled waveguide height was chosen to be that of the slot, while its width was chosen to give a 50 Ω impedance as described in [11]. The resulting waveguide width and height are 2.286-mm and 0.254-mm, respectively.

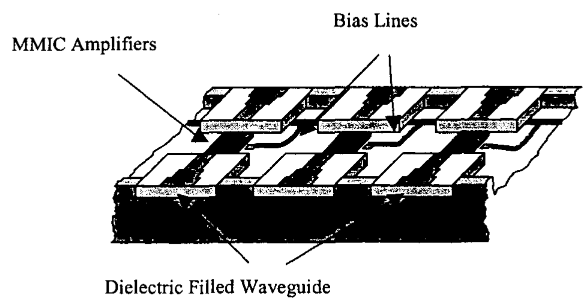

Figure 3: A perspective view illustrating several amplifying unit cells on one of the trays that are stacked to form the amplifying array.

The amplifier layout was the last portion of the unit cell design to be performed. For this layout, *Triquint TGA1073A™* PHEMT MMIC amplifiers were used to provide gain. They provide a nominal 19 dB of gain with 25 dBm output power under 1-dB compression when biased at $V_{DS} = 6V$ and $I_{DS} = 220$ mA. The unit cell layout is illustrated in Fig. 3, and a photograph of the tray is shown in Fig. 4. The MMIC amplifier, as well as the microstrip lines, was epoxied to the aluminum tray using a two part silver epoxy *(EPO-TEK H20E™)* at 120°C for 15 minutes. Three gold bondwires were used to connect the input and output of the amplifier to the microstrip lines. In addition, several capacitors were placed on the gate and drain bias lines for stability, where the smaller capacitors are single layer types with a capacitance of 100 pF, and the larger capacitors are 0.1 μF chip capacitors. Furthermore, 47 μF capacitors were placed along both the gate and drain bias lines to suppress low frequency oscillations.

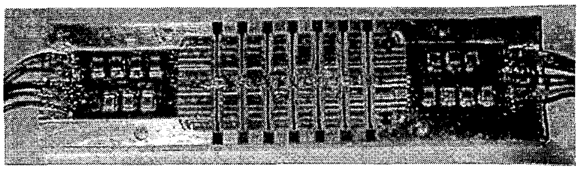

Figure 4: A photograph of a tray containing the amplififying unit cells. The gate and drain bias lines are seen on the left and right sides of the tray.

III. Experimental Results

Several experiments were performed on the active and passive versions of the array. These include measurements of the insertion loss and return loss of the passive array and the small signal gain and return loss of the active array. In both cases, the arrays were placed between two hard-horn feeds, such that the hard-horns were nearly in contact with the arrays. Thus the resulting insertion loss or gain includes the losses of the input and output hard-horn feeds and gives the closed system response.

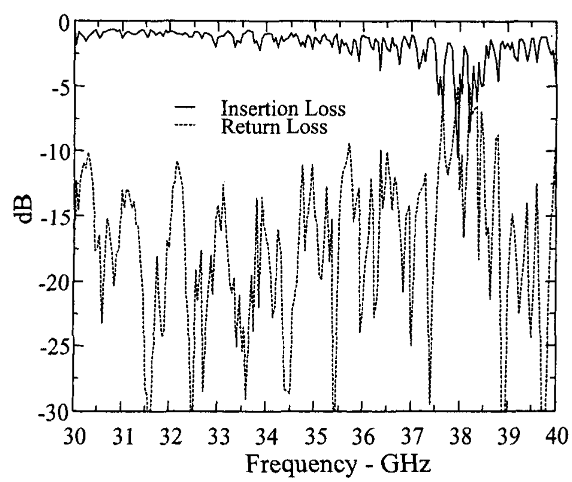

Figure 5: The insertion loss and return loss of two hard-horn feeds placed back-to-back.

Before performing these experiments with the passive and active versions of the array, the hard-horn feeds were characterized. As mentioned, the hard-horns distribute the power to the amplifier array with uniform amplitude and phase [9]. The performance of the hard-horn feeds is characterized by the uniformity of the electric field in both amplitude and phase at the aperture of the horn. One measure of this uniformity is the insertion loss of two hard-horn feeds placed back-to-back. The resulting insertion loss of such a measurement made at the input waveguide ports to the horns is shown in Fig. 5. The resulting insertion loss is less than 1.5 dB from 30.5 to 33 GHz with a corresponding return loss of better than 10 dB across this same band.

The passive array was then measured. This array is a simplified version of the active array, where the MMIC amplifiers have been replaced by microstrip transmission lines. A photograph of the array is shown in Fig. 6. The resulting insertion loss and return loss is illustrated in Fig. 7, where an insertion loss of 5.3 dB has been obtained at 32 GHz with a 3-dB bandwidth of 2.7 GHz. The measured array performance includes the loss of the hard-horn feeds and is the closed system response.

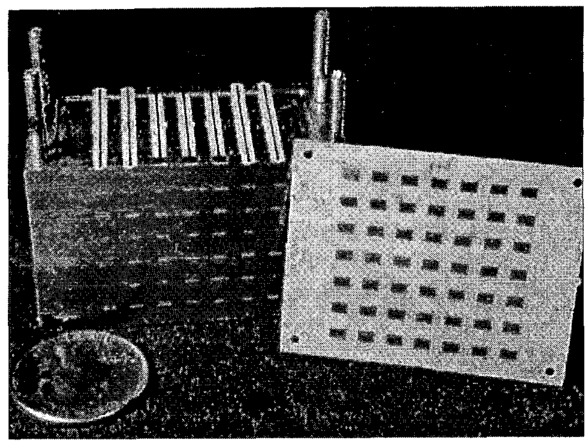

Figure 6: A photograph of the passive 7x7 array. The 7 trays are stacked to form the array of dielectric filled waveguides. The microstrip patch antennas are then glued to this groundplane.

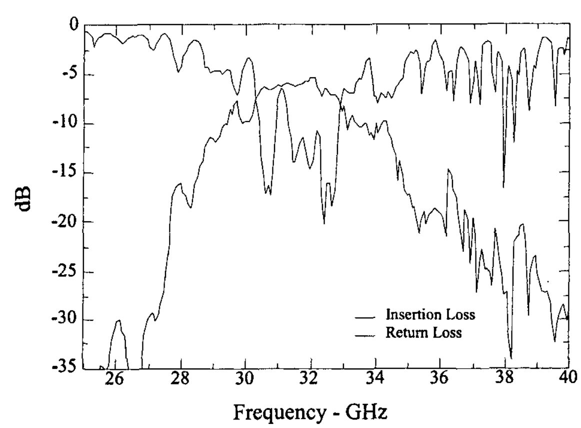

Figure 7: The insertion loss and return loss of the passive 7x7 array including the loss of the hard-horn feeds.

The active version of the array was then measured with hard-horn feeds placed at the input and output. The resulting small signal gain and return loss for the 49-element active array is shown in Fig. 8. A gain of 11.6 dB was obtained at 31.9 GHz with a corresponding 3-dB bandwidth of 1 GHz. This includes the losses of the hard-horn feeds. The maximum gain expected from the active array is 13.7 dB based on the passive array losses and the gain of the MMIC amplifier. However, amplitude and phase variations between active devices can significantly affect the overall system gain. Power measurements of this array should yield nearly 6.5 Watts under 1-dB compression with a power combining efficiency of 42%, based on half of the active array losses (3.7 dB) contributing to the degredation in output power.

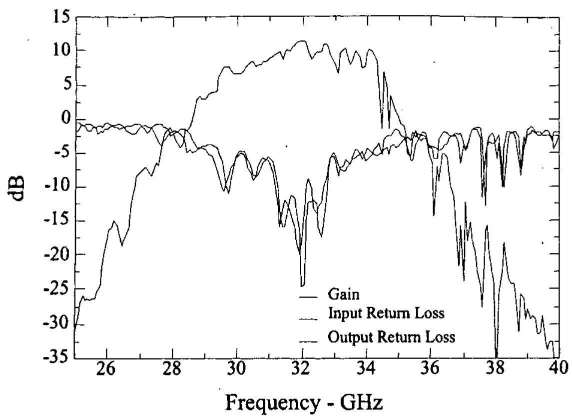

Figure 8: The small signal gain and return loss of the active 7x7 array including the loss of the hard-horn feeds.

IV. Conclusion

A 49-element, Ka-band spatial power combining amplifier array employing a perpendicular-fed patch antenna is introduced. A 7x7 passive and active array were designed and measured. The passive array demonstrated an insertion loss of 5.3 dB with a 3-dB bandwidth of 2.7 GHz. The active array yielded 11.6 dB of gain at 31.9 GHz with a 3-dB bandwidth of 1 GHz. A power combining efficiency of 42% is expected from this structure based on the active array losses. Preliminary measurement results have provided more than 5 Watts of power under 1-dB compression, giving a combining efficiency of 36%.

V. Acknowledgments

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