A High Power Two-Dimensional Coupled-Oscillator Array at X-band

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Abstract — The design and construction of a high power X-band quasi-optical power combining array is described. This array extends our previous work to two dimensions using a coupled network of GaAs power MESFET oscillators. Preliminary measurements suggest that a 6×6 array produces a total power in excess of 30 Watts, with an effective radiated power (ERP) of greater than 2 kW.

1. Introduction

Quasi-optical coupled oscillator arrays have recently been demonstrated to achieve power combination on the order of watts [1-3]. This power generation is accomplished through the synchronization of many nearly identical solid state devices through mutual injection locking. An understanding of the behavior of these coupled oscillator dynamics has evolved [4], and was used to develop several linear coupled oscillator arrays [2]. This paper describes the design and construction of a 6×6 element, high power, two dimensional X-band power combining array. This two dimensional array represents a departure from the previous linear arrays constructed by the authors, and involves only a small modification of the circuit coupling techniques previously described [6].

2. Oscillator Design

A commercial packaged power MESFET, NE9008-11, was used. These devices have a saturated output power of 33 dBm, and a power added efficiency of approximately 20% at 8 V, and 900 mA. These devices are also internally matched at 11 GHz, so this was the design frequency for the oscillators. The small signal S-Parameters of the device were measured at the prescribed bias condition on an HP 8720 network analyzer. To extract the maximum oscillator power available from the device, the large signal S-Parameters of this device were extrapolated using an approach suggested by [5]. An X-band oscillator was then designed using these large signal S-parameters. Because the source flange of the package was designed to be grounded, only common source oscillator configurations were possible. After the oscillator was built, a triple stub tuner was used to further optimize the output power from the device. The optimum impedance presented by this tuner was then measured using an HP 8720B network analyzer and used to establish the proper matching conditions to the patch antenna.

This microstrip oscillator design was implemented using Rogers Duroid 5880 with a quarter inch thick (6.35 mm) aluminum ground plane. The thick aluminum was required to heat sink the NE9008-11. In a 50 Ω environment, the X-Band power oscillator was measured to produce over 1 Watt of power at 10.8 GHz, at a DC-RF conversion efficiency of 15%. A shunted varactor diode was integrated near the gate of the device to provide some frequency tunability. This tunability is often useful in correcting for device variations. An 11 GHz patch antenna for the oscillator was similarly fabricated on the Duroid 5880 with Aluminum ground plane. To insure maximum power transfer from the device to the antenna, the position on the patch with the optimum impedance was calculated. The output of the oscillator was then connected to the patch antenna at the proper position by feeding a short section of coaxial line through the ground plane.

3. Array and Coupling Network Design

The two dimensional array is comprised of 36 elements, arranged in a 6×6 fashion. The coupling circuits were designed to provide zero degree coupling, which ensures a stable in-phase mode of operation [6]. The elements within the array are coupled to one another using resisitively loaded, one wavelength long transmission lines, as shown in figure 1. Coupling between the different rows is achieved by interconnecting only the end-elements of each row; in other words, it is a parallel combination of linear arrays. Following the theory prescribed in [6], the strength of the nearest neighbor coupling was controlled by the value of the resistance, while the phase was determined by the length of the transmission line.

The patch antenna array is fabricated on a single Duroid substrate with integral heat sink. Once again, each patch antenna is fed at the position which presents the optimum load impedance to the device. Because the NE9008-11 device package was so large, the element spacing within the array was set to 22 mm, which corresponds to approximately $0.8\lambda_0$. The entire array consisted of 6 oscillator "palettes", with six oscillating elements each. These palettes are then secured to the antenna array panel. Each individual oscillator is then connected to its corresponding patch antenna using a coaxial feed through the antenna ground plane. An photograph of a single typical palette and corresponding patch array can be seen in Fig. 2.

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4. Measurements

A typical broadside radiation pattern from a single palette of this array is illustrated in Fig. 3. The highest sidelobes are seen to be approximately 12 dB below the main lobe, which correllates well with the array factor for this element separation. Using the Friis transmission equation, the effective radiated power from this single oscillator palette was measured to be 103 Watts, at 10.8 GHz. Using an array gain of approximately 13 [7] suggests a

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total radiated power of 7.92 Watts for each palette. The DC-RF conversion efficiency at this power level was approximately 15%, using 10 Volt bias and 5 A drive to the palette. Currently the 36-element array is still under construction, but will use identical palettes to that measured above, and hence a total power in excess of 30 Watts is expected.

5. Conclusions

A two dimensional power combining array at X-Band is presented. The individual elements within the array are coupled to one another following the resistively loaded transmission line principles described in [6]. Preliminary measurements of one row of elements from this array indicate an ERP exceeding 100 Watts. The high directivity of a two dimensional array and the preliminary measurements of the single palette constructed suggest that a 6×6 array produces a total power in excess of 30 Watts, with an effective radiated power (ERP) of greater than 2 kW.

6. Acknowledgments

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7. References

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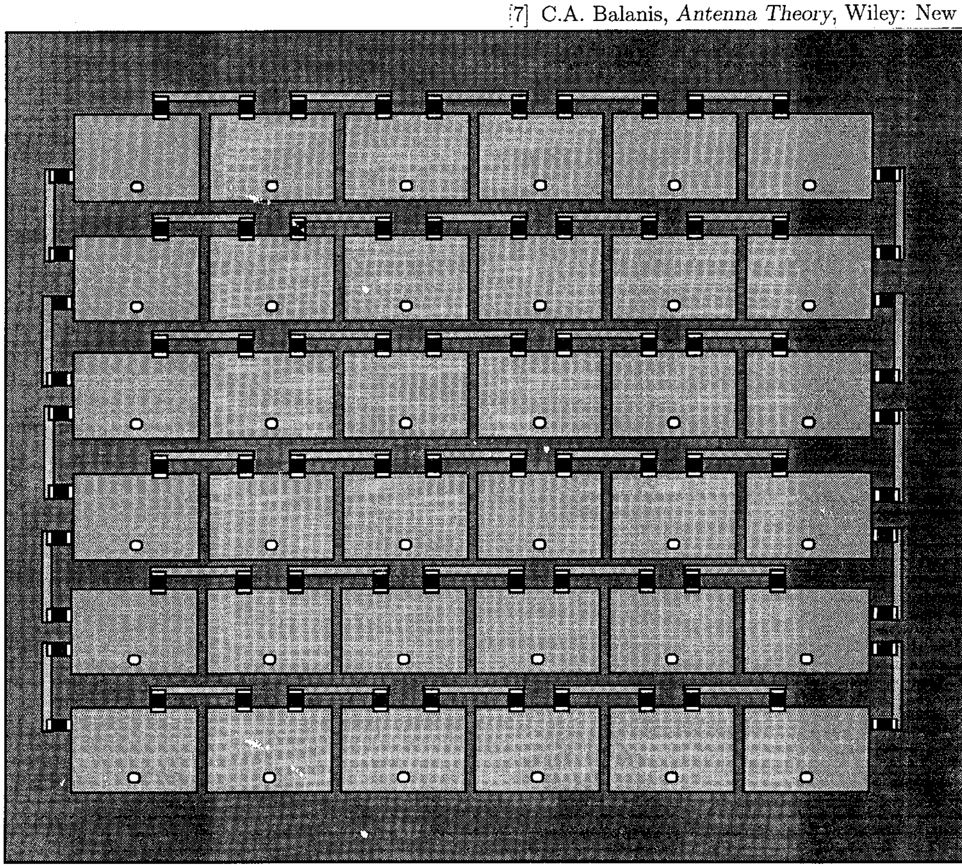

Figure 1. Proposed coupling scheme for 6X6 antenna array.
Holes indicate position of feed-thru from oscillator palettes.
Resistively loaded transmission lines couple indivual elements to nearest neighbors. End elements of each row are coupled to the end elements of subsequent row.

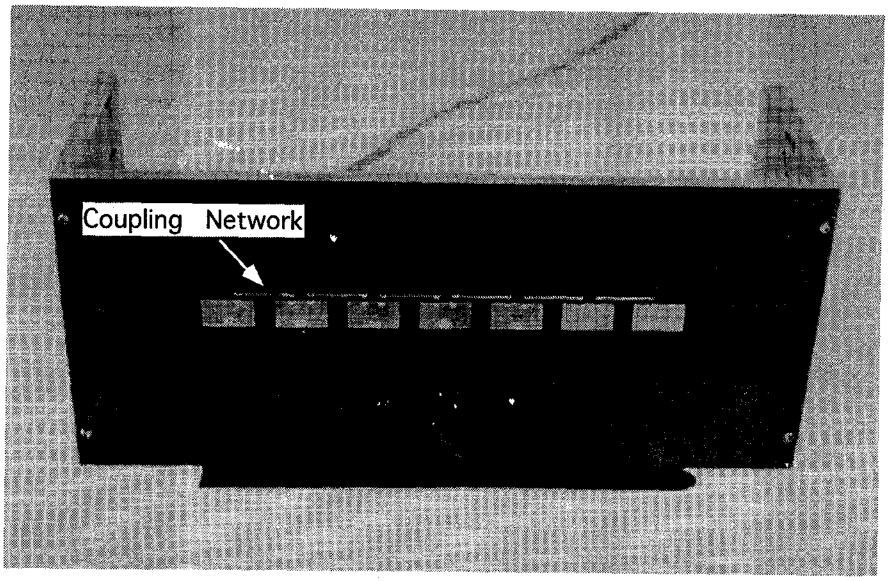

Figure 2a: Photograph of Antenna Palette

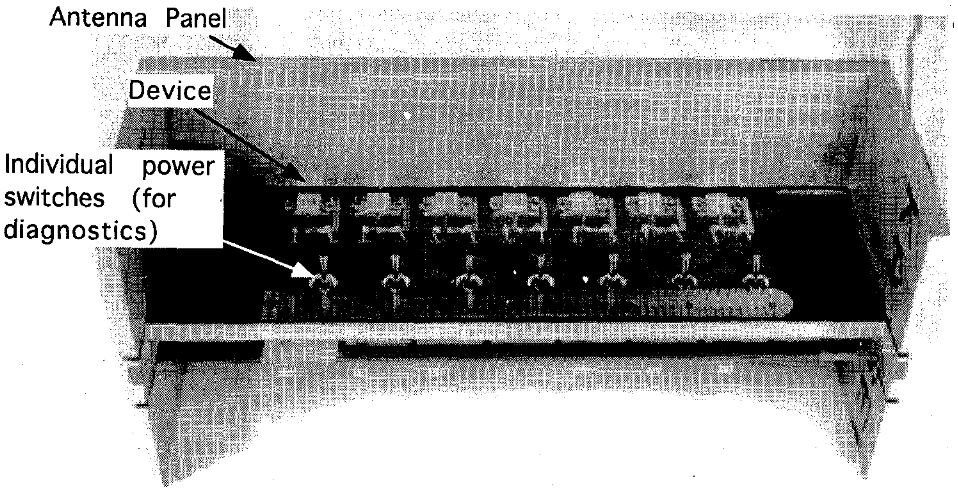

Figure 2b: Photograph of Oscillator Palette
Antennas are fed thru holes drilled in ground plane of antenna palette.

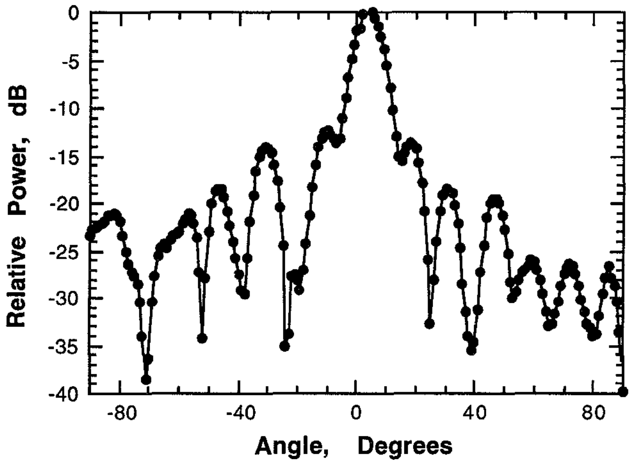

Figure 3. Broadside radiation pattern obtained from single palette of power combining array.