POWER-COMBINING GRIDS FOR FREQUENCY TUNING AND BEAM CONTROL APPLICATIONS

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Abstract — **Two new quasi-optical power combining architectures are presented. A coplanar waveguide (CPW)-fed bowtie antenna array is used to combine the outputs of 16 FET's at 4.7 GHz with a dc-to-RF conversion efficiency of 17%. The arms of the bowtie antennas provide space to accommodate planar tuning and matching networks. A second power-combining array, consisting of 16 FET chips, uses integrated varactors for frequency tuning at 20 GHz. Experimental results for both types of power-combining grid are presented.**

I. Introduction

RECENTLY, scientists and engineers have renewed their efforts to develop reliable and efficient solid-state sources operating at millimeter wavelengths. A significant part of this effort has focussed on quasi-optical techniques as an alternative to more traditional power-combining methods based on microstrip and waveguide structures [1]–[3]. Although many different power-combining arrays have been investigated to date, few quasi-optical grid topologies have exhibited the design flexibility needed for integrating multiple devices or realizing multifunctional circuits. This feature is of particular importance due to the increasing interest in frequency agile and beam steerable sources for radar and communication systems.

A number of investigators have demonstrated microstrip oscillator arrays with beam scanning circuitry [4],[5]. Others have presented patch antenna oscillators with electronic frequency tuning [6],[7]. Mader *et al.*, in 1993, reported a varactor-controlled grid oscillator with tuning bandwidth of 10% at 6 GHz. The varactor tuners were integrated into a separate array fabricated on the backside of a grid oscillator [8].

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This paper presents two new power-combining grid architectures: a coplanar-fed bowtie antenna array and a varactor-tuned gate feedback grid oscillator.

II. CPW-Fed Bowtie Array

A diagram of the CPW-fed bowtie grid is shown in figure 1. The arms of the bowtie antennas provide space to accommodate planar transmission lines and semiconductor devices. As a result, impedance tuning circuits and control elements such as varactor diodes can be integrated directly into each cell of the array. The devices embedded in the grid are coupled to free space through CPW lines that feed the antennas. Unlike the more traditional quasi-optical arrays based on dipoles [3], the CPW feed lines can be adjusted to provide impedance matching without significantly disturbing the overall grid structure. In addition, the geometry of the array is fully compatible with standard coplanar HEMT layouts, making this array configuration a good candidate for monolithic integration.

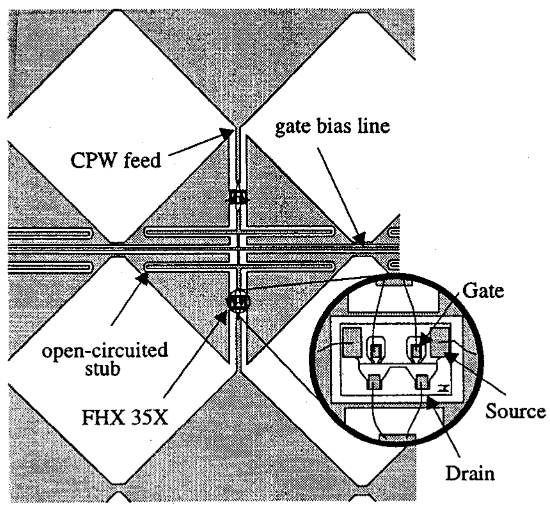

Fig. 1. Diagram of the bowtie oscillator grid. Coplanar feed lines couple the oscillator circuits to the antennas.

Bowtie Array Design

A 4×4 version of the grid illustrated in figure 1 was built as a proof-of-concept demonstration. The array was fabricated on a copper-clad Rogers *RT/Duroid* substrate with dielectric constant 10.5 and thickness of 1.27 mm. Each bowtie antenna is 8 mm square and is fed by a 100 μm wide coplanar line with impedance of 75 Ω and electrical length of 30° at 5 GHz. GaAs HFET's (FHX35X, manufactured by *Fujitsu, Inc.*) are attached to the array with silver epoxy and wire bonded to the grid metallization. A pair of open-circuited CPW stubs are placed 600 μm from the gate of each HFET. The characteristic impedance and length of the stubs (50 Ω and 3 mm, respectively) are chosen to give a reflection coefficient looking into the drain that is greater than unity.

Bias to the drains and sources is provided through the arms of the bowtie antennas. The HFET gates are biased through dc feed lines that run between adjacent rows of bowtie antennas (see figure 1). Due to the array symmetry, these gate bias lines are modelled at RF frequencies as 50 Ω, open-circuited CPW stubs.

Bowtie Array Measurements

The output of the power-combining array was measured using a ridged horn antenna in the far field. A planar mirror placed behind the array provided the external feedback needed for mutual injection-locking and served as a tunable backshort. With a drain bias of 3 V, the backshort position and gate bias were adjusted until an oscillation at 4.7 GHz was observed. The oscillation frequency could be tuned over a 125 MHz bandwidth with mirror position. Figure 2 shows the measured H-plane radiation pattern for the array for different mirror positions. As the mirror is moved towards the array, the directivity and radiated power decrease.

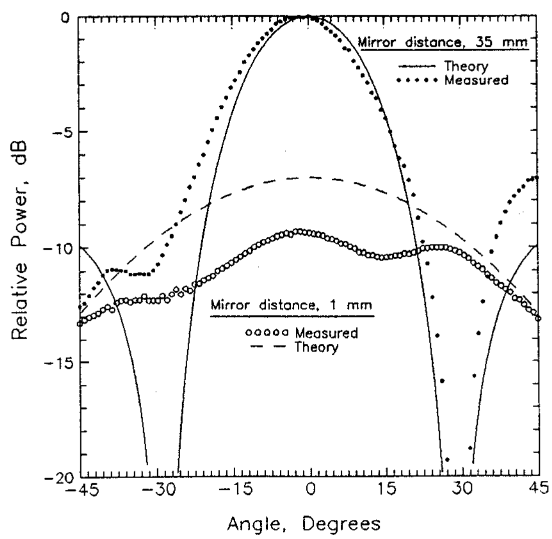

Fig. 2 H-plane radiation pattern of the bowtie array for different position of the backshort.

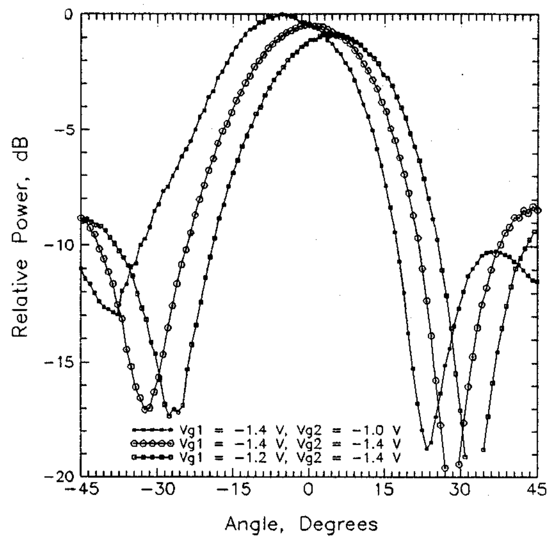

Fig. 3 Beam steering of the bowtie oscillator array in the E-plane. Each antenna pattern corresponds to a different set of gate dc bias voltages.

Figure 3 demonstrates the effect of altering the dc gate bias of different rows of the array. Because adjacent rows of devices share a gate bias lead, the dc operating point of pairs of rows can be tuned independently by adjusting the gate voltage. Adjusting the dc bias of the different rows in the array has the effect of detuning the oscillators' free-running frequencies. Consequently, adjacent rows of devices experience a phase shift that results in beam steering [9]. Using this method, the main beam of the bowtie array can be steered in the E-plane by approximately ± 6° off boresight.

The antenna gain of the array is estimated from the measured E-plane and H-plane patterns to be 16 dB. Using this estimated gain and the Friis transmission formula results in a net radiated power of 40 mW and an overall dc-to-RF conversion efficiency for the array of 17%.

III. Varactor-Tuned Oscillator Grid

Grid oscillators, in essence, are frequency selective surfaces into which active devices have been embedded. Consequently, the bandwidth over which these grids operate is often small. Varactor diodes included in the grid structure can be used to tune the embedding impedance presented to the active devices and, in principle, extend the operating bandwidth.

Grid Geometry and Design

Figure 4 shows a diagram of the varactor-tuned grid oscillator. This array is based on the "gate-feedback" grid configuration [10] and includes a single varactor tuner for each FET. The array, containing 16 FET's, is fabricated on a 1.27 mm thick *RT/Duroid* substrate with dielectric constant of 10.2. Chip transistors (FHX35X manufactured by *Fujitsu*) are mounted and wirebonded to the array metallization. The tuning diodes are CVG9800-001 hyperabrupt varactors manufactured by Alpha Industries, Inc. These diodes have a measured capacitance tuning range of 920 fF (at zero bias) to 64 fF (at a bias of -20 V). The varactor chips are mounted on a meander line that provides bias to the FET gates and are wirebonded to the horizontal bias line, as shown in figure 4.

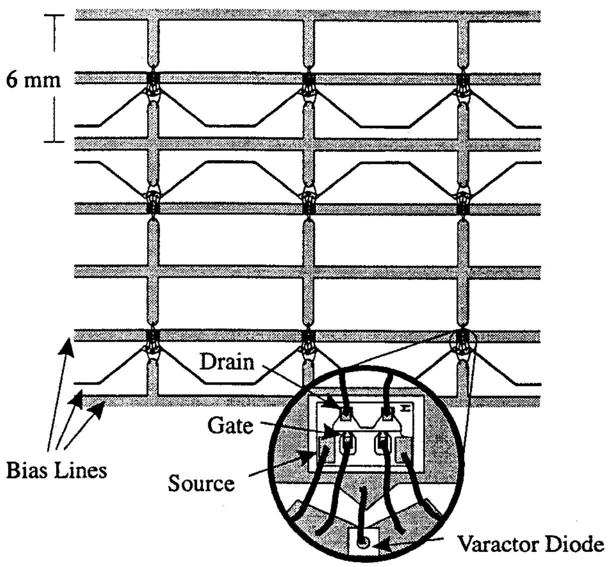

Fig. 4. Diagram of the varactor-tuned oscillator grid. Hyperabrupt varactor diodes are used to tune the embedding impedance seen by the FET chips.

Measurements

As with the CPW-fed bowtie array, the output of the varactor-tuned oscillator was measured with a ridged horn antenna placed in the far field. With the drain bias set to 3 V, the gate bias, varactor bias, and mirror position were adjusted until oscillation was observed. With a varactor bias of approximately -20 V and the total drain current adjusted to 105 mA, the grid oscillated at 19.8 GHz. As shown in Figure 5, the frequency tuning bandwidth with mirror position is approximately 40 MHz. For this measurement, the varactor bias is fixed at -21 V. Figure 6 shows the effect of the varactors on the oscillation frequency. The grid can be tuned over 100 MHz with the varactor bias. The bias range of the varactors is limited to -10 V to -21 V. Outside this range, the FET gates

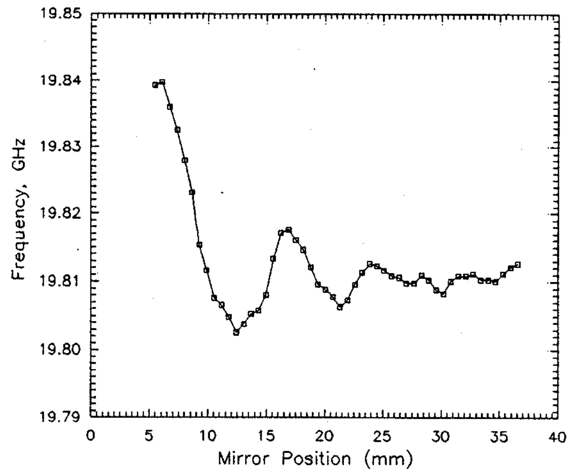

Fig. 5. Oscillation frequency of the varactor-tuned grid oscillator as a function of mirror position. The varactor bias is set to -21 V.

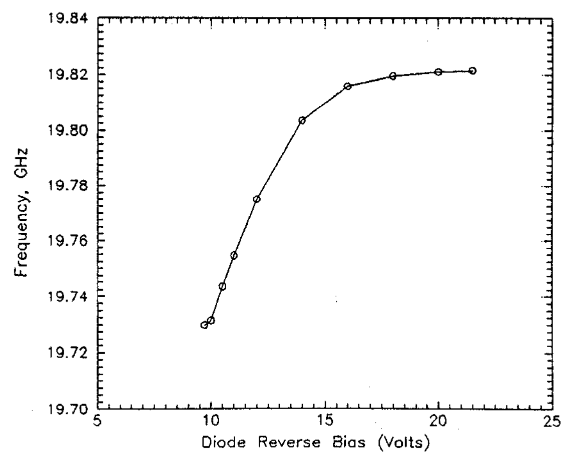

Fig. 6. Oscillation frequency of the varactor-tuned grid oscillator as a function of varactor bias.

become self-biased and the oscillators in the grid become unsynchronized.

IV. Summary and Conclusions

In this paper, we have presented two new quasi-optical oscillator configurations. As simple proof-of-concept demonstrations, these circuits were not optimized for maximum power output. Because coplanar matching networks can be embedded in the antenna arms, the CPW-fed bowtie array offers a more flexible architecture than previous grid oscillators based on crossed dipoles. This feature should allow future circuits to be designed for maximum dc-to-RF conversion efficiency without fundamentally disturbing the overall grid geometry. The arms of the bowtie antennas also may provide space for additional circuits and devices, such as varactor tuning diodes. Because the array structure is based on coplanar waveguide, it is fully compatible with the majority of HEMT device layouts. This feature should prove advantageous for any future monolithically integrated array. In addition, a new grid oscillator design that uses varactor diodes for frequency tuning has also been presented. This array proved to have a restricted tuning bandwidth. Future work will focus on developing a complete model for the array to aid in understanding the limitations of this structure.

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