Spatial Power-Combining Using CPW-Fed Bowtie Antennas

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***Abstract*—A new quasi-optical power-combiner geometry consisting of an array of bowtie antennas fed by coplanar waveguide is presented. The bowtie structure provides space to accommodate planar tuning structures as well as multiple devices. An oscillator circuit that includes a heterojunction field-effect transistor (HFET) and coplanar resonator is embedded in one arm of each antenna. Experimental results for a 4 × 4 array are provided and an equivalent circuit model used for the array design is described.**

***Index Terms*—Bowtie antenna, grid oscillator, power combining, quasi-optical spatial power-combiner.**

I. Introduction

EFFICIENT and high-power sources remain a critical need for a variety of millimeter-wave applications. Consequently, a significant part of the recent research effort in quasi-optical oscillators has focussed on optimizing arrays for maximum power output [1], [2]. The performance requirements, however, of modern radar and communication systems (particularly in regard to frequency agility and beam control) have given impetus to expand the functionality of quasi-optical oscillator arrays beyond simple power combining.

Many different power-combining arrays have been investigated, but few topologies have exhibited the design flexibility needed for integrating multiple devices or realizing multifunctional circuits. A number of investigators have demonstrated microstrip-based oscillator arrays that include beam scanning circuitry [3], [4]. Others have presented patch antenna oscillators with electronic frequency tuning [5]–[7]. In 1993, Mader *et al.* reported a varactor-controlled grid oscillator with tuning bandwidth of 10% at 6 GHz. The varactor diodes were integrated into a separate array fabricated on the backside of the grid oscillator substrate [8]. This letter presents a new power-combining grid architecture based on bowtie antennas fed by coplanar waveguide (CPW). The bowtie structure permits greater latitude in the grid design, allowing CPW tuning structures and matching networks to be included without disrupting the overall array geometry.

II. Array Geometry and Design

A layout of the bowtie grid is shown in Fig. 1. The arms of each bowtie antenna provide space to accommodate planar transmission lines as well as semiconductor devices. Impedance tuning circuits and control elements such as varactor diodes can be integrated directly into the array, leaving the bowtie structure undisturbed. As a result, each oscillator in the array is designed as a transmission-line circuit that is coupled to free space through a CPW-fed bowtie antenna. In contrast to the more traditional grid configurations based on crossed dipoles [9], the bowtie antennas and CPW feed lines can be adjusted to present an optimum output impedance without greatly disturbing the oscillator circuits. In addition, the coplanar configuration of the array is directly compatible with standard high electron mobility transistor (HEMT) layouts.

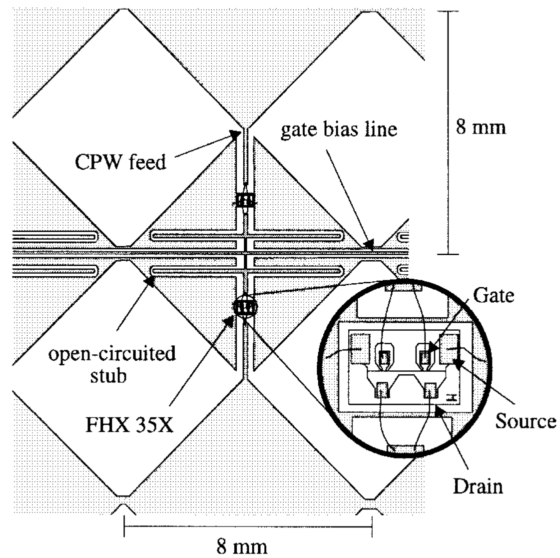

Fig. 1. Diagram of the bowtie oscillator grid. Coplanar feed lines couple the oscillator circuits to the antennas.

A 4 × 4 version of the grid shown in Fig. 1 was fabricated as a proof-of-concept demonstration on a Rogers *Duroid* 6010 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. Gold bond wires are used to bridge the ground planes of the coplanar lines. Heterojunction field-effect transistors (HFET's) (FHX35X, manufactured by *Fujitsu*, Inc.) are attached to the array with silver epoxy and wire bonded to the grid metallization. To facilitate bonding, the entire array is gold plated. A pair of open-circuited CPW stubs are placed 600 μm from the gate of each HFET. The impedance and electrical length of the stubs (50 Ω and 43° at 5 GHz, respectively) are chosen to give a reflection coefficient looking into the drain that is greater than unity.

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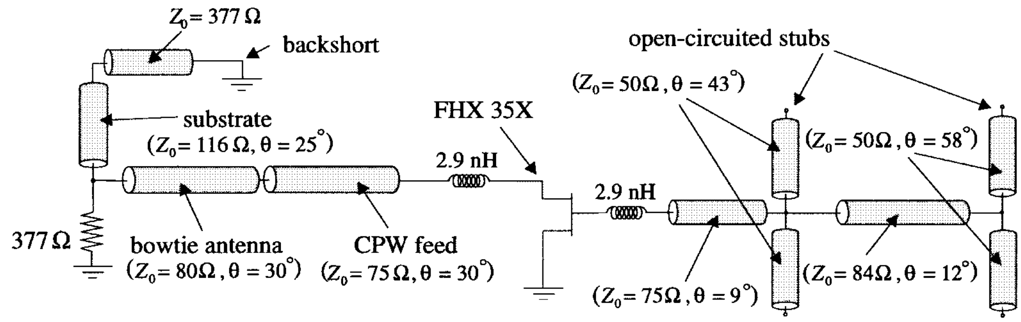

Fig. 2. Equivalent circuit model for an infinite array of bowtie oscillators. Free space is represented as a 377-Ω load and bond wires as lumped inductors. The electrical parameters for each transmission line at 5 GHz are given in parentheses.

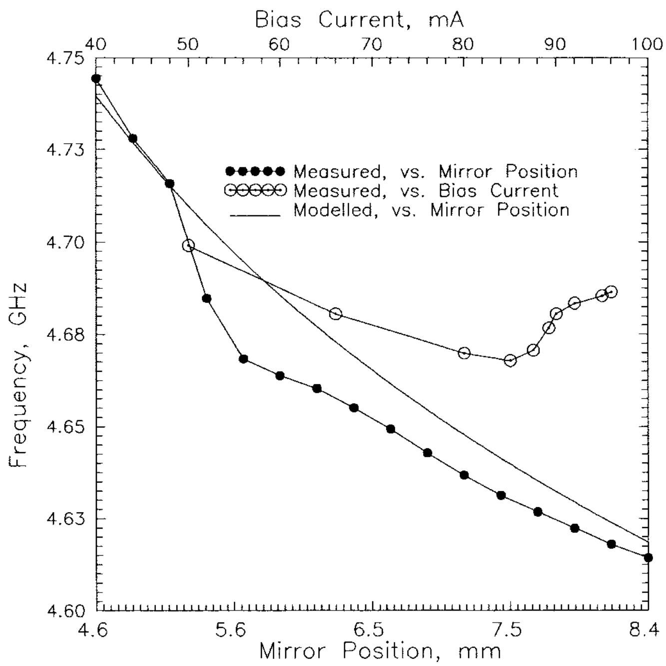

Fig. 3. Frequency tuning curves for the bowtie array versus mirror position and bias current.

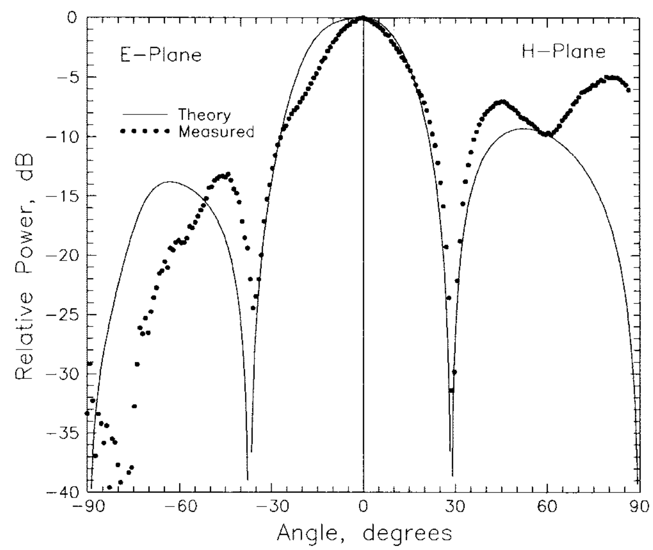

Fig. 4. E-plane (left side) and H-plane (right side) radiation patterns for the bowtie array.

Bias to the drains and sources is provided through the arms of the bowtie antennas. The gate bias is fed through bias lines running horizontally across the array between adjacent bowtie antennas, as shown in Fig. 1. At RF frequencies, these bias lines are treated as 50-Ω open-circuited CPW stubs. The open circuits result from image currents and appear along the vertical symmetry planes between adjacent columns of bowtie antennas.

An equivalent circuit model for an infinite array of bowtie oscillators is shown in Fig. 2. This circuit, which is based on symmetry and the induced electromotive force (EMF) method [10], models propagating modes with transmission lines. The capacitance between the bowtie arms and the inductance along the bowtie's length are distributed circuit elements. As a result, the bowtie antenna is also represented as a transmission line (with characteristic impedance of 80 Ω and electrical length of 30° at 5 GHz). This circuit has been used successfully to model bowtie arrays operating at frequencies up to the terahertz region [11].

III. 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 oscillation was observed. Fig. 3 shows the frequency tuning of the array as a function of mirror position and total bias current. Also shown is the theoretical mirror tuning curve obtained using the grid equivalent circuit model and transistor small-signal s-parameters. The s-parameters were obtained by measuring a single device in a 50-Ω test fixture.

Lumped inductors are included in the array circuit model to represent wire bonds from the HFET chip to the CPW lines. Because bond inductance is difficult to model accurately, these inductors are adjusted to bring the theoretical tuning curves into agreement with measurement. The fitted value of 2.9 nH for the drain and gate inductance is reasonable for the approximate length (1–2 mm) of bonding wire used.

Radiation patterns measured in the principal planes are shown in Fig. 4. The high sidelobe level in the H-plane is believed to be a reflection from the array mount and not due to the array itself. It is estimated from these patterns that the antenna gain of the array is 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 of 17%.

IV. Summary and Conclusions

In this letter, we have presented a new quasi-optical oscillator configuration consisting of an array of bowtie antennas fed by coplanar transmission lines. As a simple proof-of-concept demonstration, the circuit was not optimized for maximum power output. In addition, the transistors used in the array operate at a relatively low bias (typically, $V_D = 3$ V and $I_{DS} = 8$ mA). The flexibility of the array geometry, however, should permit future circuits to be designed for maximum dc-to-RF conversion efficiency without fundamentally disturbing the grid architecture. 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.

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