A Nine-MESFET Two-Dimensional Power-Combining Array Employing an Extended Resonance Technique

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***Abstract*— A new spatial power combining circuit that forms a single resonant structure from many active devices is introduced. A large signal analysis of this power combiner was performed. Based on these results, a two- and a nine-MESFET two-dimensional combiner driving two- and nine-patch antenna elements, respectively, were designed and fabricated. Measured results are also presented. An effective radiated power of 6.06 W at 7.33 GHz was obtained from the nine-MESFET combiner.**

I. Introduction

At millimeter- and submillimeter-wave frequencies individual solid-state devices have a limited ability to produce microwave power [1], therefore, it is desirable to be able to combine the power generated from many separate devices [2]–[6]. The typical method used to combine microwave power from active devices employs some manner of locally resonating the individual active elements, which are connected together in some one or two-dimensional structure capable of adding their powers.

A new combining structure based of an extended resonance method is introduced in [7] and [8]. In this technique, the whole structure acts as a single resonant circuit. An advantage of this technique is that the oscillation is very stable and no simultaneous multimodes are excited. Wide-band frequency tuning of such an oscillator is possible. Here, we present two-dimensional spatial power combiners based on this technique that are capable of employing three-terminal devices [9].

II. Theory

The equivalent circuit for a two-dimensional spatial power combiner is shown in Fig. 1. The admittance of each device is $-G + jB$ under large signal operation. Here three terminal devices are represented by their two terminal negative resistance equivalent circuit. Each interior device is connected to four similar devices via sections of transmission lines with length L. G_r represents the radiation conductance of antennas connected to each port and must be equal to $-G$ under steady-state oscillation. Resonance is achieved by the proper choice of line length L so that $jB/4$ of each device is transformed to $-jB/4$ at the ports of adjacent devices, at the oscillation frequency. At the edges of the circuit, open circuited stubs of appropriate length can be used to partially resonate the edge devices.

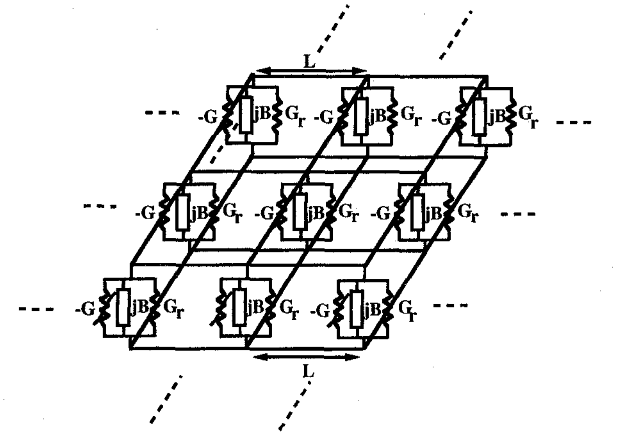

Fig. 1. Equivalent circuit model for a two-dimensional spatial combiner based on an extended resonance technique.

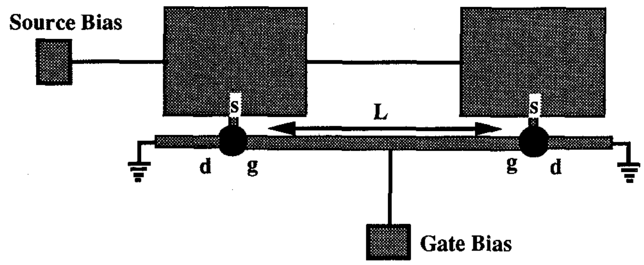

Fig. 2. Microstrip realization of a two-MESFET spatial combiner.

In order to incorporate three-terminal devices into this structure, a common method of three terminal oscillator design based on the negative resistance model can be used [10]. For example, a two-MESFET spatial combiner is shown in Fig. 2. The MESFET's are connected in a common drain configuration. Negative resistance is obtained by connecting a shorted transmission line in series with the drain of each FET. The source is connected to a microstrip patch antenna. The admittance seen by looking into each gate is purely inductive (since the device's negative resistance is compensated by the radiation resistance of the patch antenna). The length of the transmission line connecting the gates is chosen to transform the inductive susceptance of one device to a capacitive susceptance at the gate of the second device. An additional half

Manuscript received March 10, 1993. This work was support in part by the National Science Foundation under Grant No. ECS-9110155.

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IEEE Log Number 9210194.

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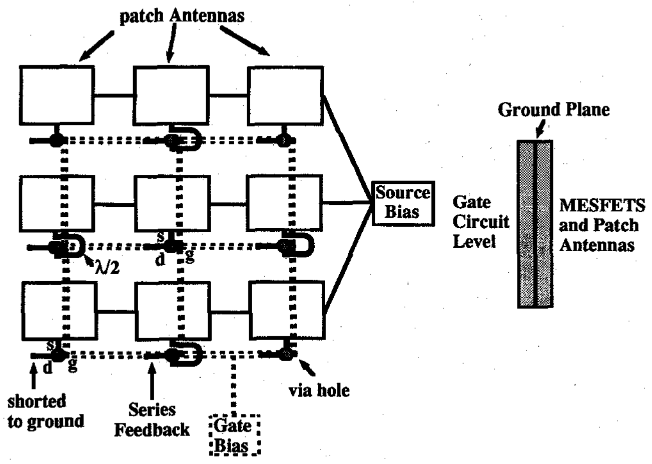

Fig. 3. Microstrip realization of a nine-MESFET spatial power combiner. Dashed lines represent the second microstrip layer.

wavelength line is added to this in order to create adequate separation between the patch antennas. Hence, two devices form a parallel resonant circuit at the design frequency.

In order to verify the stability of oscillation and determine the circuits performance, a large signal analysis of the two MESFET combiner was performed using the Microwave Spice™ program. We chose Fujitsu FSX03FA/LG packaged MESFET's as the active devices in this analysis and in our experiments. The initial circuit design was performed based on the small signal parameters of these transistors and utilizing a commercial CAD Program (Libra™). To perform the large signal analysis, an approximate nonlinear model was derived for the MESFET's based on Curtice's cubic model [11] employing manufacturer supplied I–V data and S-parameters at a single bias point. The Curtice model obtained using only a single set of S-parameters cannot accurately represent the FET's used in our experiments. However, the large signal analysis of this combiner can be very useful in predicting potential moding and stability problems. This analysis shows that adjacent devices are out of phase. In order to obtain broadside radiation, a l/2 length of line can be inserted in the appropriate antenna feeds so that all antennas are excited with the same phase.

III. Experiment

To verify the results of the large signal analysis, A two-MESFET spatial power combiner based on the extended resonance technique was designed and fabricated (Fig. 2). As was mentioned it is expected that the two patch antennas will be out of phase. Measurement of radiation pattern of this combiner compares very closely with the calculated radiation pattern of two similar patches excited out of phase. A microstrip line realization of a nine-MESFET spatial power combiner is shown in Fig. 3. The circuit consists of two layers. MESFET's and patch antennas are on one layer with gate circuit transmission lines on the second. Individual MESFET devices are in a common drain configuration. The gates are connected to the microstrip lines of length L on the second circuit layer through via holes. This circuit is designed using commercially available microwave CAD tools (Libra™). The entire 3×3 structure was modeled. The design oscillation frequency is 8 GHz. A half-wavelength section of transmission line is connected to appropriate antennas in a multidevice combiner so that broadside radiation is obtained.

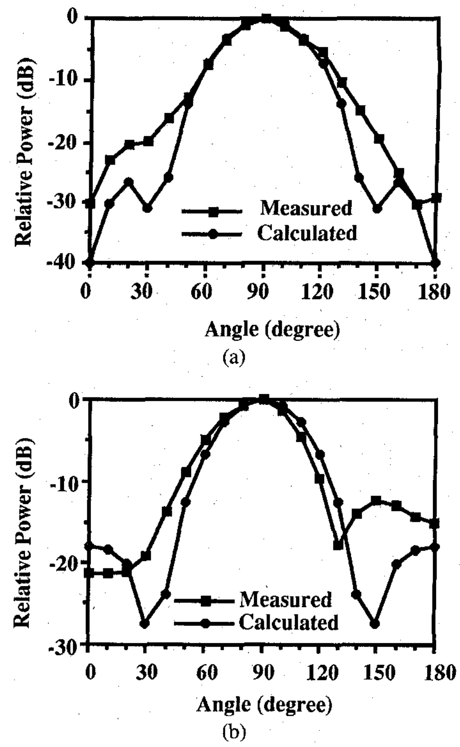

Fig. 4. (a) Measured and (b) calculated E-plane and H-Plane radiation patterns for a nine-MESFET combiner respectively.

This circuit is fabricated on Duroid™ substrates with a dielectric constant of 2.33 and a thickness of 31 mils. The measured oscillation frequency is 7.33 GHz and the effective radiated power obtained is 6.06 W. (It is believed that the discrepancy with the theoretical value is due to inaccurate modeling of the via connections between the two circuit layers.) The isotropic conversion gain is 8.3 dB [12]. The measured and calculated E and H radiation patterns are shown in Figs. 4(a) and 4(b). We believe that the proximity of the packaged devices to the patch antennas causes the lack of symmetry in the measured E-plane radiation pattern. The cross polarization on the broad side is determined to be −20 dB.

To determine the approximate power produced by each MESFET, the nine-element microstrip array's directivity was determined to be 13.3 dB. This means with the effective radiated power of 6.8 W, the total radiated power is approximately 282 mW, which indicates that power generated per device is 31.3 mW. This is approximately the power expected from these devices biased at 5 V with a drain current of 20 mA. This indicates that the combining efficiency of this combiner is close to 100%.

IV. Summary

Two-dimensional power-combining structures based on an extended resonance technique are described. The power-combining efficiencies of such structures are close to 100%. The large signal analysis of these structures indicates that, as expected each device experiences the same voltage amplitude but adjacent devices are out of phase.

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