A 26-MESFET Spatial Power-Combining Oscillator

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***Abstract*— Several spatial power-combining oscillators based on an extended resonance technique was designed and fabricated. Experimental results for these combiners are provided and their performance is compared. An effective isotropic radiated power (EIRP) of 19.9 W at 9.923 GHz was obtained from a 26-MESFET spatial power combiner. The total radiated power for this combiner was 160 mW. The measured and predicted radiation patterns in E- and H-planes are also compared.**

***Index Terms*—Microstrip patch antenna, phase locking, quasi-optical power combining, spatial power combining.**

I. Introduction

MILLIMETER-WAVE communication and radar systems require more power than a single solid-state device can produce. At millimeter-wave frequencies, the power output from the solid-state devices drops as $1/f^2$. Therefore, it is desirable to combine power from many devices in order to meet the system requirements. Since conventional hybrid-type power combiners are quite lossy at millimeter-wave frequencies, an attractive approach is to use spatial or quasi-optical power-combining techniques where power produced from many devices is combined in free space. These spatial power combiners do not suffer from losses associated with conventional hybrid-type combiners. In recent years, extensive research [1]–[11] has been conducted in this area.

Several spatial power-combining oscillators based on an extended resonance technique were reported in [10] and [11]. In [10] the individual oscillators were phase locked to each other by strong interaction of the MESFET's through their gates. Rectangular patch antennas were used as radiating elements. To fit the antennas, extra half wave length lines were added between the unit cells. In this letter we are reporting the extension of the work reported in [11], where phase locking is achieved by interaction of the devices through their sources. Results obtained from a 26-MESFET spatial power combiner, designed to operate at 10 GHz, will be presented. Here, circular microstrip patch antennas are used as radiating elements. In this circuit no extra lines are required to fit the antennas, hence more compact structures can be constructed. (The size of the unit cell for this structure is approximately 72% of the equivalent unit cell for the nine-device oscillator reported in [10].) To date, this is the largest reported spatial power-combining oscillator array based on this technique.

Manuscript received October 11, 1996.

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Publisher Item Identifier S 1051-8207(97)02510-5.

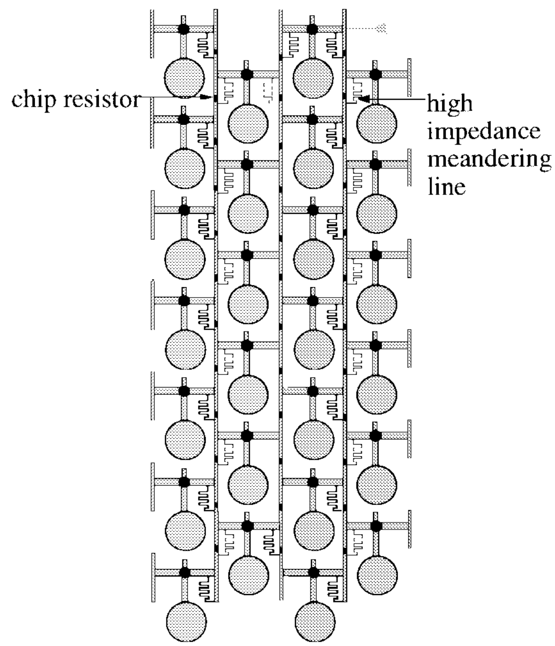

Fig. 1. Twenty-six-device extended resonance spatial power combiner.

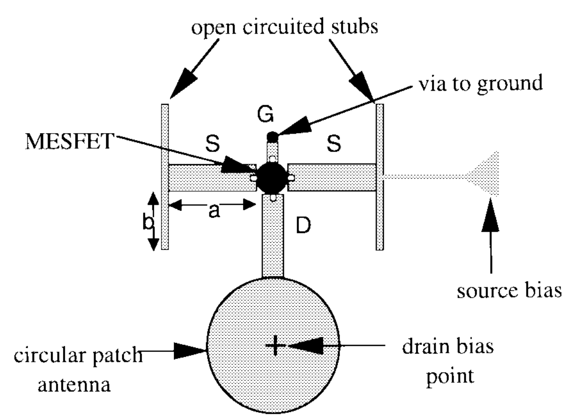

Fig. 2. The unit cell for the spatial power combiner.

II. Design and Experimental Results

Fig. 1 shows the microstrip realization of a two-dimensional 26-device spatial power combining oscillator. The unit cell, which is the building block of the combiner, is shown in Fig. 2 and was designed using the commercially available CAD tool HP-EEsof LIBRA^{TM}. A short-circuited inductive stub (26.3 mil long) was used in the gate of the MESFET to provide negative resistance at the drain port. The transmission line length "a" and open-circuited stub length "b" were chosen such that only negative resistance is seen looking into the drain

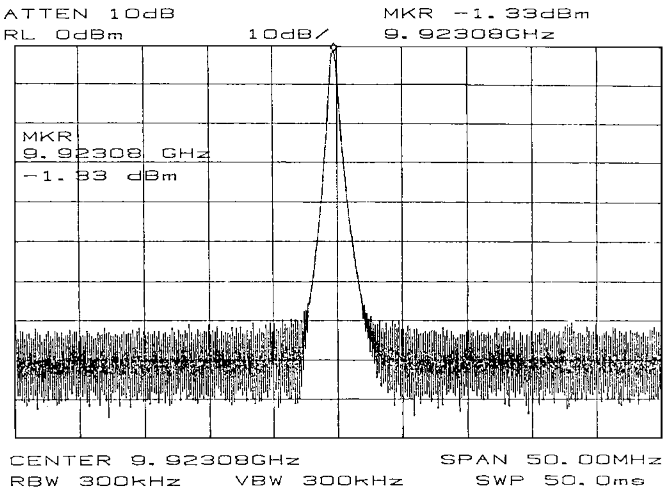

Fig. 3. Measured spectrum of the 26-device combiner.

TABLE I
SUMMARY OF THE RESULTS OBTAINED FROM A FOUR-, A NINE-, A THIRTEEN-, AND A TWENTY-SIX-DEVICE SPATIAL POWER COMBINER

Number of devices	Osc. Freq. GHz	Total radiated power mW	Calculated array directivity dB	EIRP W	Power combining efficiency
4	9.98	27.3	12.9	.53	—
9	9.91	59.8	16.05	2.41	97.3%
13	9.97	84.08	18.14	5.48	94.7%
26	9.923	160	20.95	19.91	90.2%

port, and at the same time the structure can accommodate the circular microstrip patch antenna with a radius of 210 mil. The length "a" and "b" were chosen to be 238 and 155 mil, respectively. Negative resistance was obtained from 7.2 to 11.8 GHz ($-41.8\,\Omega$ at 10 GHz). A quarter wave transformer was used to transform the radiation resistance of the antenna to one-third of the negative resistance looking into the drain to maximize the power output of the oscillator. Once the unit cell was designed, a two-dimensional oscillator was constructed by interconnecting many unit cells. To suppress the excitation of any undesired mode [10], 56-Ω chip resistors were connected at the point where the unit cells meet. The chip resistors do not absorb any radio frequency power since the points where unit cells meet act as virtual open for the desired mode of operation. To avoid dc voltage drop across the resistors, high-impedance meandering bias lines were used to provide dc bypass across them. These meandering bias lines prevent any RF leakage because they provide high impedance to RF. The drain bias was applied to the center of the circular patch antenna from the back of the substrate. The center of the patch was chosen because of having zero-electric field.

The circuits were fabricated on RT/Duroid substrate with a relative dielectric constant of 2.33 and thickness of 31 mil. The active devices used were HP ATF-26 884 MESFET's, biased at 3.0 V with a drain current of 10.0 mA per device. The spectrum of the 26-device power-combining oscillator is shown in Fig. 3. The measured frequency of oscillation was

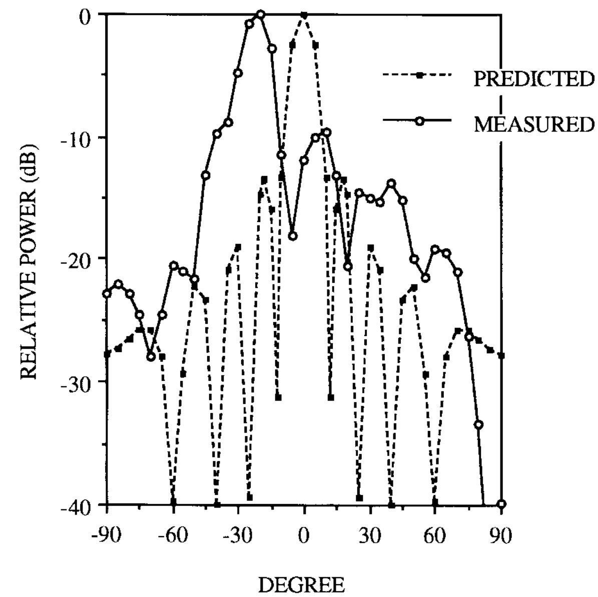

Fig. 4. Measured and predicted E-plane patterns for the 26-device combiner.

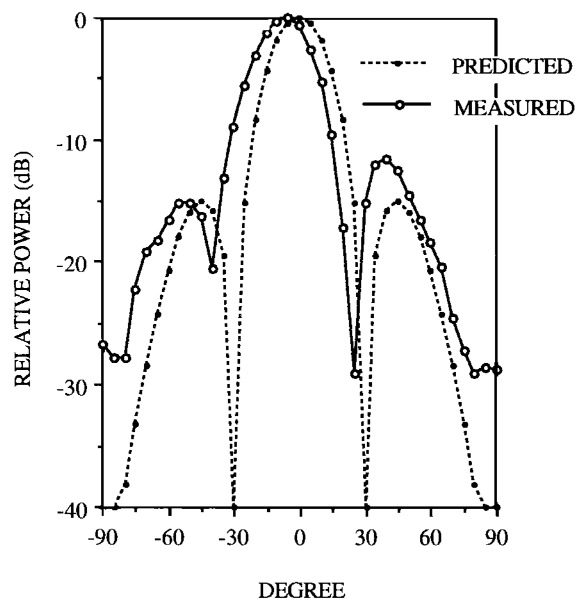

Fig. 5. Measured and predicted H-plane patterns for the 26-device combiner.

9.923 GHz, which is very close to the design frequency of 10 GHz.

The total radiated power of the spatial power combining oscillators was calculated using

$$P_r = P_o\left(\frac{4\pi r}{\lambda_o}\right)^2 \times \frac{1}{G_s D}$$

where P_o is the power received by a standard gain horn antenna placed at a far-field distance r away from the plane of the combiners. D is the calculated directivity of the array and was determined by assuming uniform amplitude and phase excitation for the array elements. G_s is the gain of the standard gain horn antenna and λ_o is the free-space wavelength.

Summary of the results obtained from a four-, a nine-, a thirteen-, and a twenty-six-device spatial power combiner is given in Table I. It should be mentioned that the power output from the unit cell when matched to 50 Ω was 7.45 mW.

The effective isotropic radiated powers (EIRP's) are calculated by multiplying the total radiated power with the array directivity. The power-combining efficiencies are calculated by comparing the estimated radiated power per unit cell for each combiner to the radiated power per unit cell for the four device combiner. As seen from Table I, the power-combining efficiencies are below 100%. One possible explanation is that the calculated directivity does not take into account the amplitude and phase errors involved in excitation of the array elements. This can be due to the device parameter variation across the array and should be alleviated in monolithic combiners where all the devices are uniform. The single side band phase noise for the four- and the twenty-six-device power-combining oscillators was measured at an offset frequency of 100 kHz from the carrier. The single sideband (SSB) phase noise for the four- and the twenty-six-device combiner was −83 and −89 dBc/Hz, respectively. This corresponds to a 6-dB improvement in phase noise.

Figs. 4 and 5 show the E- and H-plane radiation patterns for the 26-device combiner, respectively. There is a good agreement in the main lobe region between the measured and predicted patterns, except that the main beam is slightly shifted. As mentioned, the difference between the measured and predicted patterns can be due to the phase and amplitude errors across the array.

III. Conclusion

Results obtained from a four, a nine, a thirteen, and a twenty-six-MESFET spatial power combiners based on extended resonance technique were reported. The performance of these combiners was compared. A steady oscillation very close to the design frequency was achieved for all of the oscillators reported herein. An effective isotropic radiated power of 19.9 W at 9.923 GHz (with a directivity of 20.95 dB) was obtained for the 26-device combiner. This corresponds to a total radiated power of 160 mW. The radiation patterns for the 26-device combiner in both E- and H-planes were measured and compared with predicted data.

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