AN EXTENDED RESONANCE SPATIAL POWER COMBINING OSCILLATOR

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ABSTRACT

A new circuit topology is presented for a spatial power combining oscillator based on an extended resonance technique. This oscillator uses annular slot antennas as the radiating elements and is more compact than the extended resonance circuits previously reported. A nine device power combining oscillator has been designed, fabricated and tested at the operating frequency of 10.11 GHz. The radiation patterns in both E and H plane have been measured and compared with the theoretical patterns. An effective isotropic radiated power of 2.4 W has been obtained from the nine device combiner.

INTRODUCTION

Due to the inability of a single solid state device to produce enough power to meet the demand of communication systems at millimeter and submillimeter wave frequencies it is often necessary to combine the power generated from many solid state devices for such systems. An attractive approach is to use spatial or quasi-optical power combining techniques where the power produced from individual active devices is combined in free space instead of using conventional combining techniques based on hybrids. In recent years an extensive work has been conducted in this area [1-11].

In [11] spatial power combining oscillators based on the extended resonance technique were presented. In these combiners several individual MESFET oscillators were phase locked to each other by their strong interaction through the microstrip lines connecting their gates. Microstrip patch antennas were used as the radiating elements. To fit the antennas extra half wave length lines were placed between the unit cells. Furthermore, five port junctions were created where the gate transmission lines joined the interconnecting transmission lines. This task was complicated due to the fact that the modeling of such five port junctions is difficult using commercially available CAD tools.

In this paper a new circuit topology is presented, where phase locking is achieved by the strong interaction of MESFET oscillators through their source leads. Here annular slot antennas are used as the radiating elements. These antennas can be easily accommodated without inserting any extra half wave microstrip lines in-between the unit cells making this circuit more compact. Furthermore, five port junctions that were present in former designs are eliminated.

THEORY

Fig. 1 shows the circuit topology for the implementation of the spatial power combining oscillator using three terminal devices in an extended resonance structure. First a unit cell for this combiner can be identified by using the theory of extended resonance which

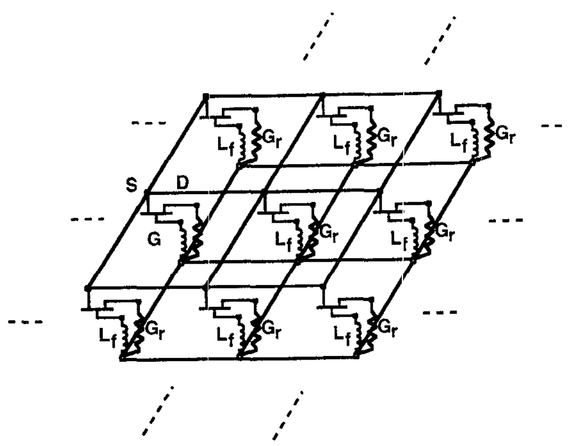

Fig.1 A MESFET based spatial power combiner based on the extended resonance method. Inductors are used to make the device unstable. Gr represents antenna's radiation conductance.

is described in detail in [11]. G_r represents the radiation conductance of the antenna connected to the drain of each device and it is chosen such that it compensates the negative conductance of the active device under steady state operation. Therefore, the admittance seen by looking into the source of each device is purely imaginary (e.g. -jB) and can be resonated with the susceptance of the four

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adjacent active devices through interconnecting transmission lines. The length of the lines connecting the sources is chosen such that -jB/4 seen by looking into the source of each device is transformed to jB/4 at the source of adjacent devices. In this manner each device is made resonant with its four adjacent devices. A unit cell can be identified for this power combiner by placing virtual shorts or opens at the center of the interconnecting transmission lines. Virtual shorts can be used if the devices have capacitive susceptance otherwise, virtual opens are employed.

The microstrip realization of the nine device spatial power combining oscillator is shown in Fig. 2 and the unit cell which is the building block for this combiner is identified in Fig. 3.

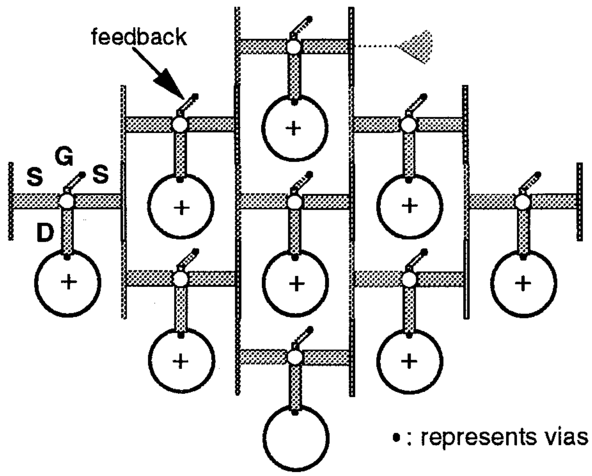

Fig.2 A Microstrip realization of the nine device spatial power combining oscillator.

An annular slot antenna was chosen as the radiating element for this combiner due to its compactness (the patch antenna requires approximately 2.0 times more real estate than the annular slot) and greater bandwidth compared to microstrip patch antennas. This facilitates the design of a frequency tunable power combining oscillator The slot antennas are excited by shorting the end of the microstrip feed line to the ground plane side. This allows us to bias the drains from the circular patch created by the annular slot. The slot antenna employed has a perimeter of $1\lambda_s$ (where λ_s is the guided slot wave length) and a slot width of 0.05**r** (where **r** is the mean radius of the annular slot).

A commercially available CAD tool, LIBRA^{TM} was used to design the unit cell. A short circuited inductive stub was added in series with the gate as a feedback element to generate negative resistance at the drain port. The transmission line length "**a**" and open stub length "**b**" in the source circuit (Fig. 3) were adjusted in order to fit the slot antenna while maintaining a reasonable negative resistance in the drain circuit. A quarter wave transformer is used to match the radiation resistance of the antenna to one third of the negative resistance seen looking into the drain, in order to maximize the output power. Since the annular slot antenna radiates in both directions, a metal

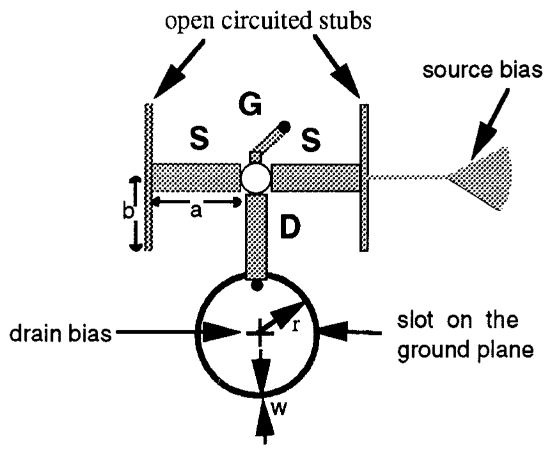

Fig.3 The unit cell for the spatial power combining oscillator.

reflector was placed behind the annular slot to make the radiation unidirectional. The drains are biased via wires connecting the reflector plate to the center of the circular patch created by the slot.

EXPERIMENT

As a first step an annular slot antenna was fabricated on RT Duroid substrate with a relative dielectric constant of 2.33 and thickness of 31 mils. It had a mean radius of 160 mils and a slot width of 8 mils. A reflector was placed a quarter of a free space wavelength apart from the antenna surface. The measured radiation resistance at the resonant frequency was approximately 400 Ohms. Subsequently a unit cell for the combiner was designed and fabricated using the same substrate. The computer simulation for the drain admittance is shown in Fig. 4, where resonance is achieved at the design frequency of 10 GHz. The active device used is an Avantek ATF26884 packaged MESFET, biased at V_{ds}=3 V and I_{ds}=10 mA. An oscillation at 9.87 GHz was measured. The measured oscillation frequency is slightly lower than the design frequency, probably because the oscillator design was performed using the small signal S-parameters of the active device.

Finally a nine-MESFET combiner was fabricated using the same RT Duroid substrate. A metal reflector was placed behind the plane of the antenna. After biasing the combiner the distance between the plane of antenna and the reflector was adjusted to maximize the power obtained in the broadside direction. This distance was found to be

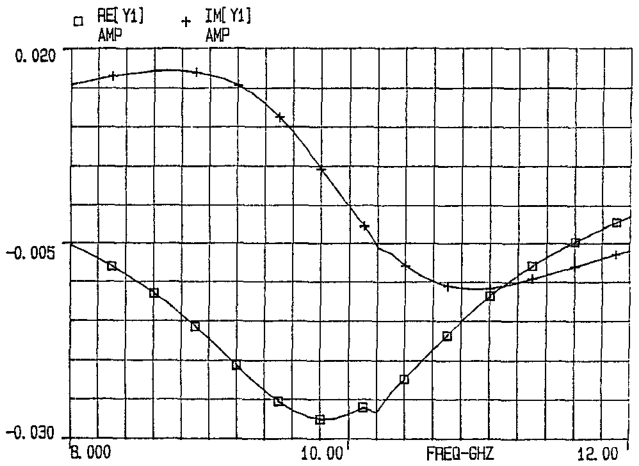

Fig.4 computer simulation results showing the drain admittance of the unit cell for the spatial power combining oscillator.

approximately one quarter of a free space wave length. The oscillation frequency of the combiner was 10.11 GHz which is higher than the oscillation frequency of the single oscillator. This is likely due to the fact that the end effect capacitance in the unit cell is eliminated when connecting several of the unit cells to form the multiple device combiner. Computer simulations show that this will increase the oscillation frequency slightly. The distance between the reflector and the combining circuit was adjusted from 0.6 to 1.2 cm, which caused a variation of less than 80 MHz in the oscillation frequency. This is consistent with our expectation that the phase locking should be entirely due to the strong coupling provided

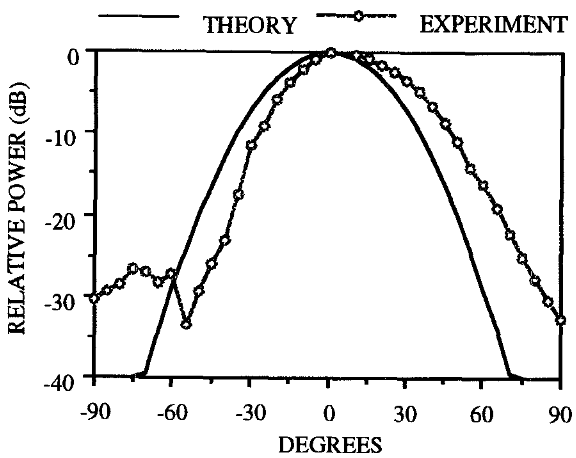

Fig.5 Theoretical and experimental E-plane pattern for the nine MESFET power combining oscillator.

by the extended resonance circuit. The 80 MHz variation in oscillation frequency is mainly due to load pulling effects, since the radiation resistance of the slot antennas depends on the reflector spacing. The theoretical and measured radiation patterns in E and H planes for the nine device combiner are compared in Figs. 5 and 6 respectively. There is good agreement in the main lobe

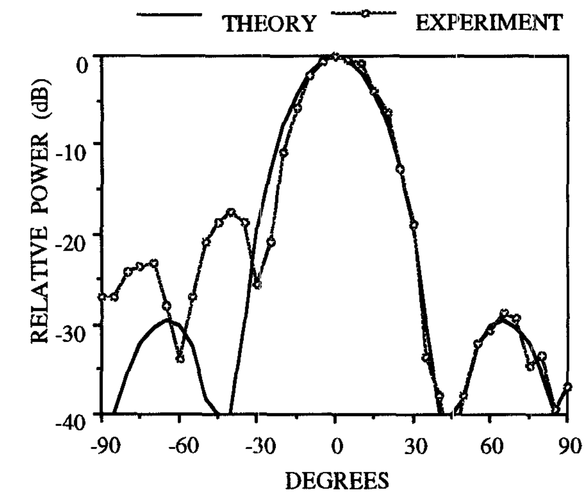

Fig.6 Theoretical and experimental H-plane pattern for the nine MESFET power combining oscillator.

region. The Effective Isotropic Radiated Power (EIRP) of the combiner was also measured using a standard gain horn antenna. An EIRP of 2.4 W and an isotropic conversion gain of 9.5 dB were measured for the nine device combiner.

CONCLUSION

A nine MESFET spatial power combining oscillator was presented. The circuit incorporates annular slot antennas as radiators and is more compact and easy to design using available CAD tools. The measured E and H plane antenna patterns are in good agreement with the calculated ones. Measured EIRP at 10.11 GHz is 2.4 W.

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