Short Papers

A Periodic Spatial Power Combining MESFET Oscillator

Arul Balasubramaniyan, John Heinbockel,
Amir Mortazawi, and Tatsuo Itoh

***Abstract*— A planar periodic MESFET based spatial power combiner was designed and fabricated for X-band operation. In this combiner four MESFET devices driving a linear microstrip antenna array are periodically connected to a microstrip transmission line. A large-signal analysis of this combiner and experimental results thereon are presented. An effective radiated power of 484 mW was achieved for this structure at an oscillation frequency of 10.02 GHz with a power combining efficiency of 87%.**

I. Introduction

The need for high power millimeter-wave solid-state sources has led to extensive research into various power combining techniques [1]. Recently, a significant amount of research has focused on the use of two and three terminal devices in spatial power combining structures [2]–[4].

This paper presents the theoretical and experimental results for a periodic MESFET based combiner. The structure contains four MESFET oscillator cells which feed a uniform linear array of microstrip patch antennas. A large-signal analysis of this four-device combiner has been performed utilizing a non linear model for the device in PSpice™. The effect of circuit parameter variations on phase locking and power combining is investigated. These structures have promising application in Doppler motion sensors, microwave and millimeter-wave communication, and other applications employing array radiators.

II. Design and Analysis

Fig. 1 shows the circuit structure of the combiner. A transmission line is loaded with oscillator "cells" which are separated by λ_g, the guided wavelength at the oscillation frequency. This spacing allows for the widths of the antenna patches as well as the proper phasing of the feeds of the array. The individual "cells" are designed, using small-signal S-parameters for the transistors. A short-circuited inductive stub is used as a feedback element in series with the source of the FET to ensure instability. An open ended microstrip line, attached to the gate, is then used to set the resonant frequency of the oscillator to 10 GHz. This reduces the transistor to an equivalent "one-port," negative resistance device.

The commercial CAD software Libra™ was used to optimize the reflection coefficient at the drain port of the device. It then becomes a matter of matching the negative resistance to the given load (antenna) to ensure that the oscillation condition is satisfied and that maximum power is delivered to the load. The antennas are matched to the oscillator cells with the help of quarterwave transformers. The

Manuscript received May 22, 1992; revised August 22, 1994.
A. Balasubramaniyan is with Motorola, Fort Worth, TX USA.
J. Heilbockel, and A. Mortazawi are with the Department of Electrical and Computer Engineering, University of Central Florida, Orlando, FL 32816 USA.
T. Itoh is with the Department of Electrical Engineering, University of California at Los Angeles, Los Angeles, CA 90024 USA.
IEEE Log Number 9410346.

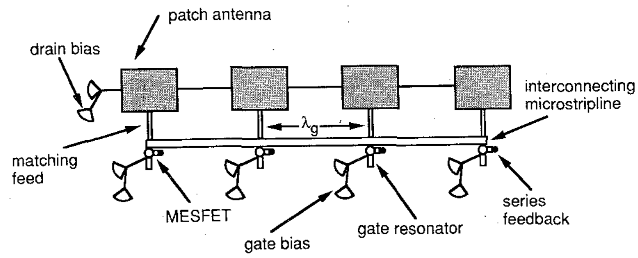

Fig. 1. Schematic of four-MESFET power combiner.

oscillators phase lock through the strong interaction of the devices connected to the coupling transmission line. The combiner was biased using stubs located at the gate of each cell and with a single bias stub connected to the transmission line coupling the devices together for drain bias. All the four devices are biased at the same gate and drain voltage.

The possibility of simultaneous multi-mode excitations for the combiner can be investigated using an eigenvalue-eigenvector analysis [5]. At the design frequency, where the periodicity of the structure is λ_g, the impedance matrix of the combiner, looking at the device ports, has the following form

$$\mathbf{Z} = \frac{Z}{4}\begin{bmatrix}1 & 1 & 1 & 1\\ 1 & 1 & 1 & 1\\ 1 & 1 & 1 & 1\\ 1 & 1 & 1 & 1\end{bmatrix}$$

where Z is the impedance of the patch antenna transformed through the quarterwave transformer. The resulting eigenvalues of the above matrix are 0, 0, 0, Z. This shows that only one mode of oscillation can exist at the design frequency [6]. In order for the mode associated with the nonzero eigenvalue to be excited, z should be equal to the negative of the device impedance to satisfy the oscillation condition. The eigenvector of the impedance matrix is given as $X = (1{,}1{,}1{,}1)$ which is proportional to the drain currents at each port and shows that the patch antennas are excited with the same phase.

In order to show that there are no unwanted modes of operation at other frequencies and to investigate the phase locking of the signal in this power combining structure, a large signal analysis of the structure using PSpice™ was performed. A non linear model for the GaAs chip available in PSpice™ was utilized for the analysis. The model parameters were chosen so that the device dc characteristics closely match those of the actual device. The package parasitics were then obtained comparing the S-parameters of the chip with the S-parameters of the Avantek GaAs MESFET ATF 26884 used in our experiments. The Libra™ optimization routines were used for this purpose.

Using this model, a single cell oscillator at 10 GHz was designed and a large-signal analysis was performed. Fig. 2 shows the build up of oscillation from the noise level. In the next step, a four-MESFET combiner was formed by connecting the drains of the devices by λ_g-long transmission lines. The large-signal analysis was repeated and no other modes of oscillation were observed.

To study the interaction of the devices via the coupling transmission lines, simulations were performed where the characteristic impedances of the coupling lines were varied from 20–150 ohms. The

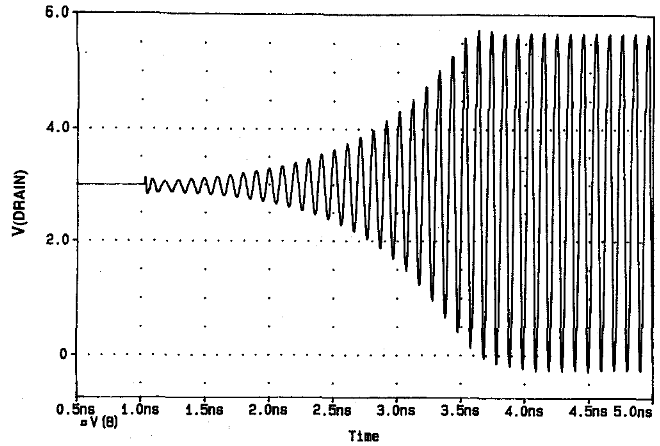

Fig. 2. Build-up of oscillation from noise level.

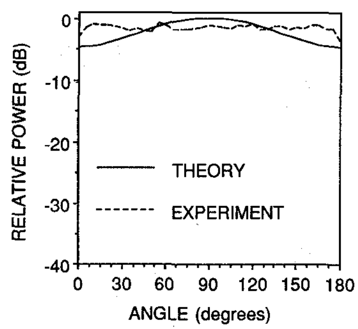

Fig. 3. Comparison of theoretical and experimental E-plane pattern.

analysis indicates that at high values of line characteristic impedances, the oscillators no longer have sufficient interaction to maintain phase locking. It was also observed that at low values of line characteristic impedances phase locking cannot be obtained and other modes are excited at different frequencies.

III. Experimental Results

As a first step a "cell" consisting of only one active device was designed and fabricated on a Duroid™ substrate of relative dielectric constant of 2.33 and thickness of 0.031 inches. The active device used was a GaAs MESFET Avantek ATF 26884, biased at $V_{DS} = 3.0$ V and $I_{DS} = 10$ mA. An effective isotropic radiated power of 36.3 mW at a frequency of 9.97 GHz was obtained. The power produced by a single device was calculated to be 7.24 mW after correcting for the antenna directivity (6.92 dB). Next, the four device combiner was fabricated and all the devices were biased at the same point. An EIRP of 484 mW was achieved at a frequency of 10.02 GHz. No other modes of oscillation were observed.

After correcting for the array directivity (12.8 dB), the power generated by each device in a four-device combiner was 6.35 mW. Hence, the power combining efficiency was 87.7%. Figs. 3 and 4 show the comparison of theoretical and experimental E-plane and H-plane patterns. A close match between the theoretical and experimental patterns was observed.

IV. Conclusion

A four-MESFET planar periodic spatial power combiner was designed and fabricated. An EIRP of 484 mW was obtained at a frequency close to the design frequency of 10.02 GHz. A power combining efficiency of 87.7% was achieved with no other modes of oscillation. A large-signal analysis of the structure was performed to study the phase locking sensitivity of the combiner. These types of structures have applications in motion detection, communication and medical applications where radiating structures are desirable.

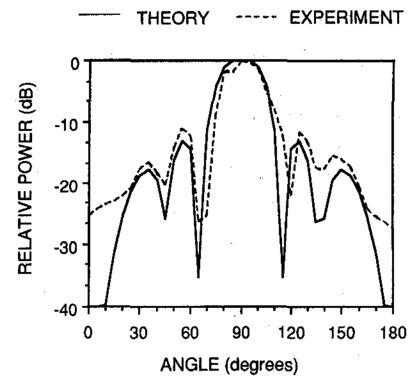

Fig. 4. Comparison of theoretical and experimental H-plane pattern.

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Proviso on the Unconditional Stability Criteria for Linear Twoport

Motoharu Ohtomo

***Abstract*— The proviso imposed by Rollett [1] on the well-known stability criteria for linear twoports is examined and redefined as the requirement that at least one set of immittance parameters must have no RHP (right-half plane) poles. It is shown that the proviso can be interpreted as the extreme cases of a newly introduced proviso that requires that the S-parameters defined for at least one pair of arbitrary positive reference impedances have no RHP poles. The new proviso means that the twoport must be stable for at least one pair of arbitrary positive resistance terminations. Since S-parameters are much easier to measure than immittance parameters at microwaves and their direct measurability is an indication of the absence of RHP poles, the new proviso allows us to apply the stability criteria to measured circuits less consciously of the proviso.**

Manuscript received October 27, 1993; revised September 21, 1994.
The author was with Toshiba Corporation. He is now with the Department of Electronics, Tokyo Engineering University, Tokyo 192, Japan.
IEEE Log Number 9410347.