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A Periodic Spatial Power Combining MESFET Oscillator

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ABSTRACT

A planar periodic MESFET based spatial power combiner is designed and fabricated in X-band. A microstrip transmission line is periodically connected to four MESFET devices driving a linear microstrip antenna array. An effective radiated power of 3.2 Watts is obtained for this structure at an oscillation frequency of 11.2 GHz. A frequency tuning bandwidth of 36 MHz is achieved, by varying the gate bias, Vgs,

INTRODUCTION

The need for high frequency 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, 3]. The extra terminal available in three terminal devices facilitates greater flexibility in the design of these structures. In certain instances, these structures should also provide frequency tuning capability. Traditionally this is accomplished using varactor diodes. In this structure, varactorless frequency tuning via bias adjustment is studied.

Results of a periodic MESFET based combiner are presented here. The structure contains four MESFET oscillator cells which corporately feed a uniform linear array of microstrip patch antennas. Frequency tuning as well as power combining is investigated. These structures have promising application in doppler motion sensors, noninvasive medical imaging, and other array radiating applications.

DESIGN PROCEDURE

Figure 1. shows the circuit structure. A transmission line is loaded with oscillator "cells" which are spaced λ_g, the guide wavelength of the oscillation frequency, apart. This spacing allows for the geometry of the antenna array as well as the proper phasing of the feeds of the array. The individual "cells" are designed using a small signal iterative procedure, utilizing a commercially available microwave CAD package, to optimize the reflection coefficient at the output of each device. A short circuited series inductive stub is used as a feedback element with the FET to ensure instability. An open ended microstrip line, attached to the gate, is then used to set the resonance of the oscillator. This effectively reduces the transistor to a one-port, negative resistance device. It then becomes a matter of matching this output to the given load to ensure the oscillation condition is satisfied and that maximum power is delivered to the load.

Because the devices in this structure are separated by a whole wavelength, the possibility of an oscillation at half the design frequency, where the periodicity of the structure is one half wavelength, must be addressed. Originally, a stepped impedance low pass filter was connected to the gate. This filter was terminated with the proper load to eliminate negative resistance in the passband. However, undesired radiation at the oscillation frequency made this filter unattractive. The filter was then removed and replaced with an open circuit resonator as previously described. Using Touchstone™, a test oscillator was designed and fabricated. No low frequency oscillations were detected for both the test oscillator and the power combiner.

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At steady state , the condition for oscillation requires the device impedance to be the negative of the circuit impedance. By determining the impedance matrix of the combiner circuit looking into each device port and calculating its eigenvalues, it can be shown that under small signal conditions only one mode of oscillation can exist at the design frequency [4]. The impedance matrix for the four device structure is calculated as

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

where z is the impedance of the patch antenna, transformed through the feed line. The resulting eigenvalues of the above matrix are 0,0,0,z. The eigenvector of the impedance matrix is given as

$$\mathbf{X} = \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \end{bmatrix}$$

which is proportional to the drain currents at each port. This shows that the antennas are excited with the same phase.

The antennas are matched and fed via $\lambda/4$ transformers to the oscillator cells. The oscillators phase lock through their strong coupling via the main transmission line. The combiner is biased using stubs located at the gate of each cell with a single bias stub connected to the main transmission line to bias the drain. The gates are biased at the same voltage.

RESULTS

A single oscillator cell and a four device structure were designed and fabricated on Duroid™ substrate with a dielectric constant of 2.3 and thickness of 31 mils. Avantek ATF26884 general purpose GaAs MESFETs were used and biased for a 30 mA nominal drain current. The design bias voltages are -0.5 Volts for the gate and 5 volts for the drain. The oscillation frequency is 11.2 GHz for the four device combiner respectively.

The radiation patterns for the four device combiner are given in figures 2 through 4. Figure 2 shows the H-plane pattern. Figures 3 and 4 show the E-plane and cross polarized patterns. Sidelobe levels are -10 dB below peak power. The effective radiated power [5] for the four device combiner is 3.2 Watts. The isotropic DC to RF conversion gain [5] is 1.5 dB A single device oscillator matched to 50 Ohms delivers 17.5 dBm of power.

A frequency tuning bandwidth (±1 dB power variation) of 36 MHz is obtained for a fixed drain bias while the gate bias was varied from -.3 to -1.85 Volts. The limited tuning bandwidth of the combiner is likely due to the periodicity of the structure and the small bandwidth of the antennas. Presently, large signal analysis of this combiner is being done to determine its maximum frequency tuning bandwidth.

CONCLUSIONS

A four device spatial power combining oscillator is designed and fabricated. The effective radiated power measured at 11.2 GHz is 3.2 Watts. Frequency tuning of the four device structure is 36 MHz. Further investigation of this structure as well as alternate structures with enhanced frequency tuning is continuing. The structure presented also lends itself to integrated circuit fabrication. These types of structures have application in motion detection, communication and medical applications where radiating structures are desirable.

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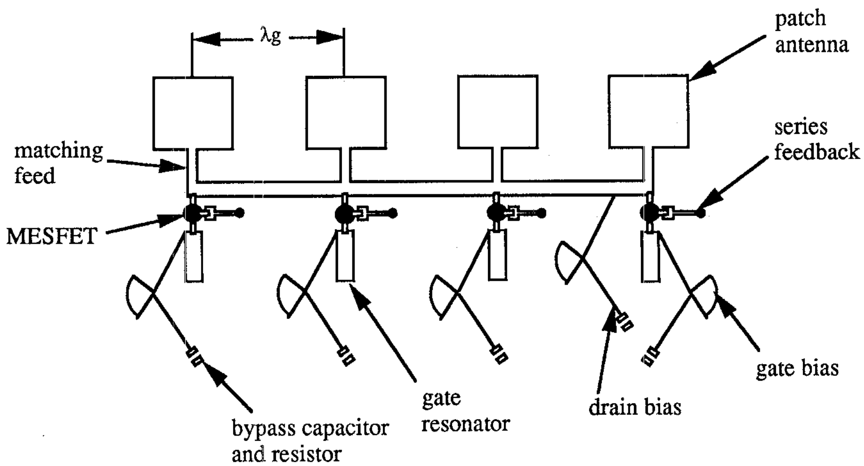

Figure 1.0 Four MESFET combiner

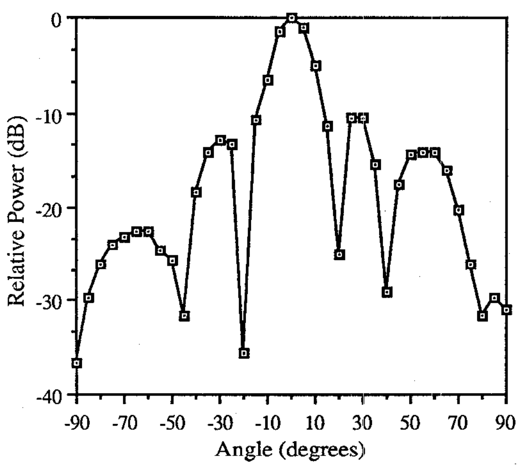

Figure 2.0 H plane pattern

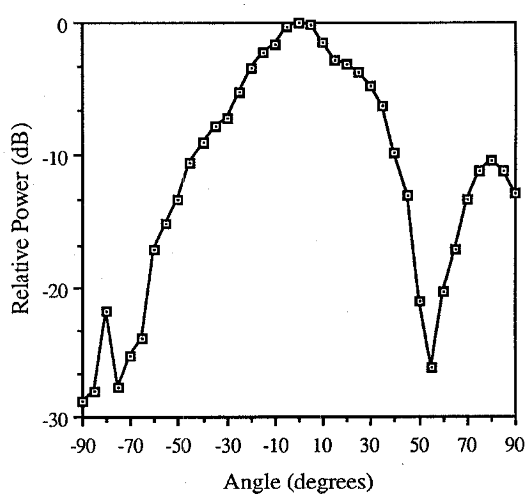

Figure 3.0 E plane pattern

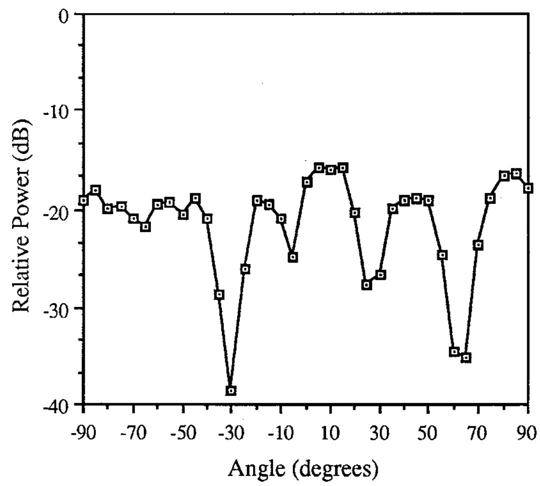

Figure 4.0 Cross Polarization

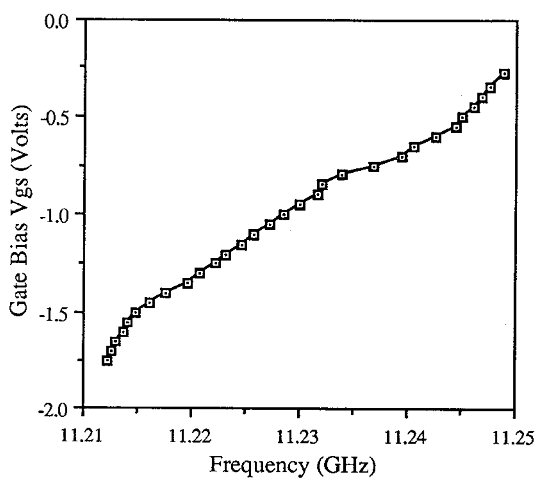

Figure 5.0 Frequency Tuning vs. Gate Bias