2x2 QUASI-OPTICAL POWER COMBINER ARRAY AT 20 GHz

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ABSTRACT

Investigation of a power combiner made of two FET oscillators for an active array are reported. As an approach by a quasi-optical method, a two-dimensional planar array of strongly coupled oscillators by direct connection through a microstrip line is used. In-phase condition between the oscillators as well as in-phase condition of each radiation wave was accomplished by regulating length of feed microstrip lines. The radiation elements of 1λ-slot are embedded in a circuit ground plane. At an operation frequency of 20 GHz, in both H- and E-planes, reasonable Σ radiation patterns were obtained which have good agreement with theoretical patterns.

INTRODUCTION

Quasi-optical circuits have been of growing interest for compact and simple microwave and millimeter-wave systems. Among many solid-state devices, FETs are preferred as an active source for applications based on the MMIC technology[1]. However, due to low efficiency, individual FET has limited capability of the power generation at higher operating frequencies. Therefore, a power combining technique is essential for high power and high frequency systems. Further, the need for such systems has resulted in a variety of power combining configuration using FETs.

As one of such power combiners, the planar grid oscillator using MESFETs has been developed in a distributed fashion[2]. Also, the weakly coupling oscillator array in a periodic fashion supported by a reflector element has been reported[3]. Recently, using external injection locking, the power combiner array with feedback FET oscillators was made[4]. However, due to a multimoding problem, the power combiner array with strong coupling has not made great progress to date. Regarding linear spatial power combiner arrays with strong coupling, we have already reported a few results obtained under the stratified structure[5],[6]. Through these results, in-phase operation for high combining efficiency was facilitated.

In this paper, we describe design and experimental results of a quasi-optical spatial power combiner array made of two negative resistance HEMT oscillators and 4 slots. Radiation patterns from the slots aligned as 2x2 were compared with theoretical patterns in both H-plane and E-plane. Further, through these patterns, it was confirmed that the radiation waves from each slots were in-phase.

DESIGN

In order to demonstrate topology for the MMIC technology, the circuit was made in a layered structure by adopting slot radiators in a circuit ground plane. Fig. 1 shows the configuration of 2x2 spatial power combiner array designed at 20 GHz. The circuit structure made of two negative resistance oscillators and feed lines is etched on the top side of the substrate, while the slot radiators shown by cross-hatched sections in Fig. 1 are embedded in the ground plane of the bottom side of the same substrate. Each oscillator was designed with -50 Ω for an input impedance. Since both sides of the substrate can be effectively used, the slot radiators in the circuit ground plane increase design flexibility.

RF energy generated from one FET oscillator is divided and delivered to two slots aligned in the E-plane. In addition, a part of this energy is used to lock the other oscillator through a direct coupling between the two oscillators. The locked and amplified signal flows into another two slots aligned in the E-plane as well. Each pair of the slots aligned in the E-plane are connected in series. Therefore, this 2x2 array consists of two slots aligned in the E-plane and two slots aligned in the H-plane with 1λ separation between the centers of two slots. The direct connection of two slots in H-plane separated by a thin line enhances high packaging density.

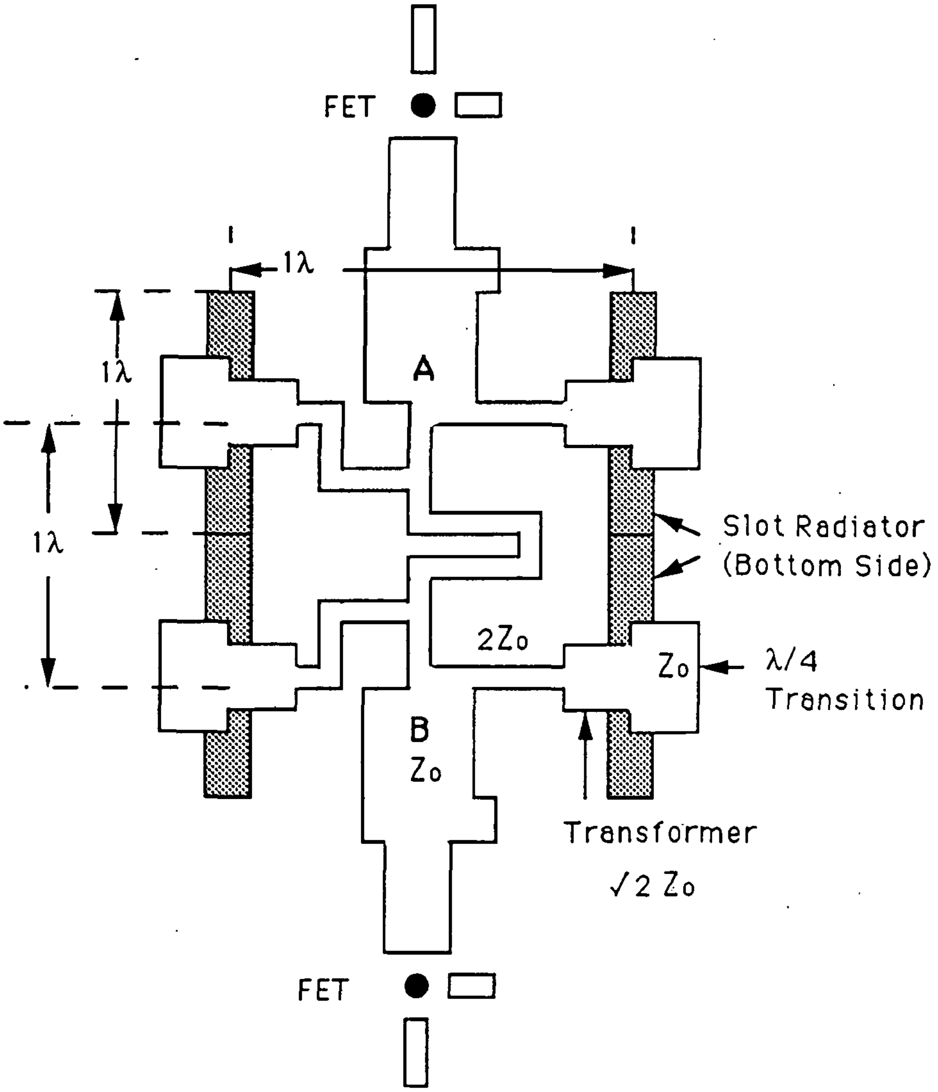


Fig.1 Circuit Configuration

According to the previous results about the direct connection of oscillators[6], when the distance between two branch-points from the oscillators (shown as A and B in Fig. 1) is an odd number of half wavelength, the radiation waves from the two branching points A and B are in-phase. Since the length of a straight line between A and B is 1λ, a microstrip line with λ/2 should be added. As a result, the radiation waves from the slots in H-plane can have the same phase.

The distance between two centers of slots is 1λ. Thus, the divided energy from one branching point A or B can reach the centers of both slots at the same time. This results in an anti-phase radiation. For the in-phase condition, one of these pass must have additional λ/2 to invert the phase on one of the slots. By means of this control of pass length between an oscillator and a slot as well as between two oscillators, the in-phase condition was obtained in both H-plane and E-plane.

In addition to the consideration of phase condition, input matching condition needs to be taken into account. A one-stage λ/4 transformer is inserted from a center of a slot toward a branched feed line connected to the branch-point A or B. In order to electromagnetically couple a feed line with a slot radiator, a λ/4 microstrip-to-slotline is adopted.

On the other hand, the slot radiators were also designed at 20 GHz with a 1λ slot length and a 0.081λ slot width. Since input impedance of the center feed 1λ slot radiator provides the circuit with 50 Ω load, the slot and the 50 Ω feed line are matched in the steady state oscillation condition.

EXPERIMENTAL RESULTS

The circuit were fabricated on 31 mil thick substrate with ε_r=2.33, using NEC NE32484 package HJFETs. The negative resistance FET oscillator was optimized at 21 GHz with 5 % margin by using small signal S parameters so that the actual circuit can also be operated at 20 GHz. The maximum operation frequency of 19.5 GHz was observed from the fabricated circuit as shown in Fig. 2.

It is found that, in this two-device power combiner case, a frequency margin of 7.7 % is required under the design condition of -50 Ω for an input impedance. in reference [1], we investigated the frequency margin of a single quasi-optical oscillator with a single slot using the same NE32484. In this case, the frequency margin of 4.4 % was obtained.

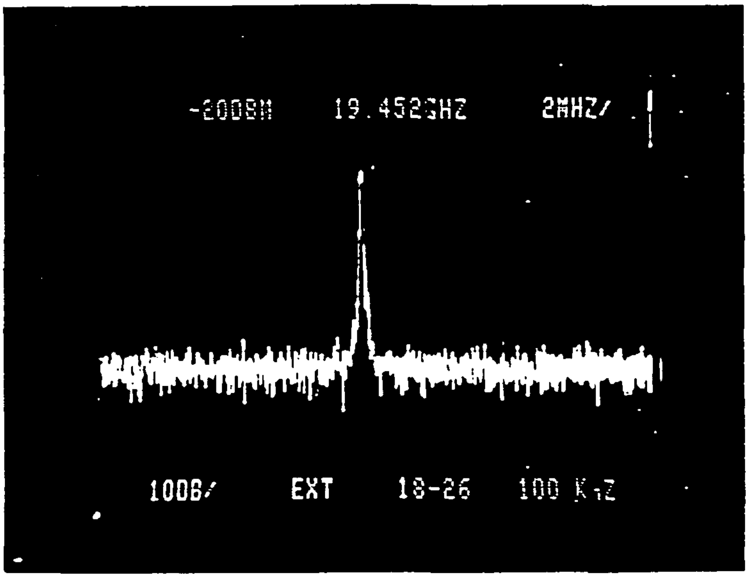
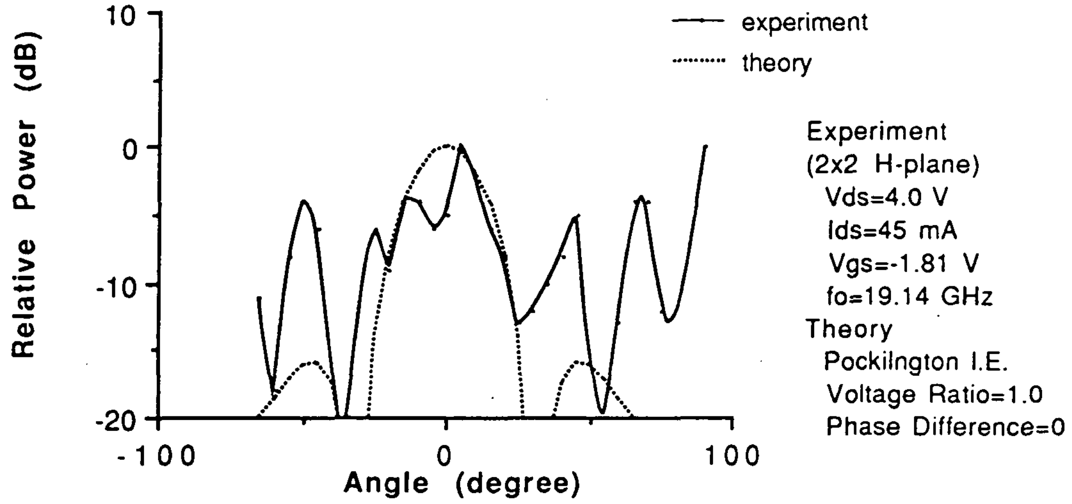


Fig. 2 Operation Spectrum

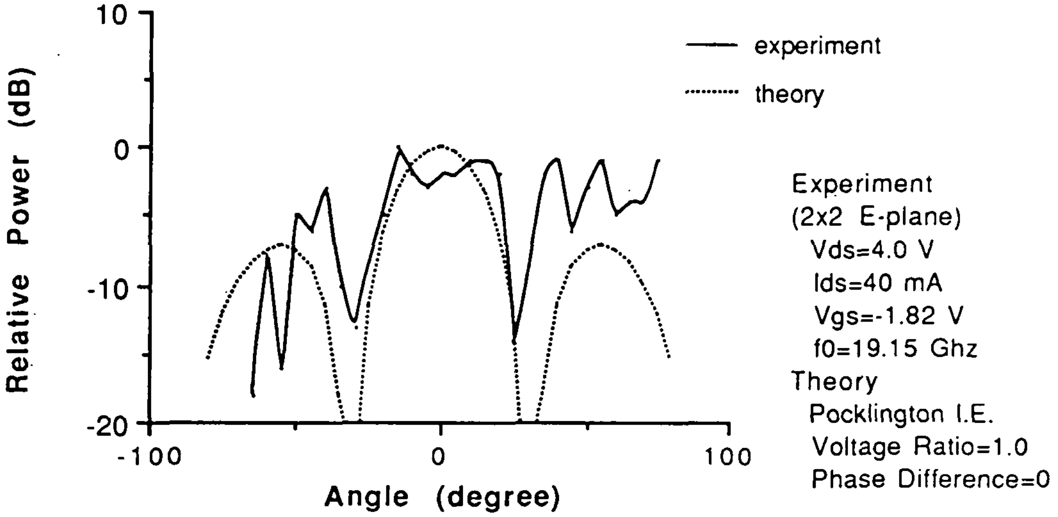
Compared with this previous results, the difference between the operation frequency and the design frequency is increased. This implies that, in the case of a large number of FET combiners, accumulation of a difference of input impedances due to such frequency difference becomes a cause of load pulling, and, due to this phenomenon, the frequency difference is increasingly enhanced. The tuning range obtained by changing the applied DC voltages, V_{ds} (2.6~5.0 V) and V_{gs} (-1.0~-1.6 V), was 121 MHz.

Radiation patterns in both the H-plane and the E-plane are shown in Fig. 3. In both cases, it is easy to find out null points around $\pm 30^{o}$ which result from array factor. For comparison, the theoretical analysis was carried out by using the point matching method to obtain numerical data from the Pocklington type integral equation. In the calculation, the voltage ratio of two source generators to excite each slot was set to 1, while the phase difference of these generators was set to 0. Using these data, theoretical radiation patterns



Experiment
(2x2 H-plane)
Vds=4.0 V
Ids=45 mA
Vgs=-1.81 V
fo=19.14 GHz
Theory
Pockilngton I.E.
Voltage Ratio=1.0
Phase Difference=0

Comparision in Radiation Pattern (H Plane)



Experiment
(2x2 E-plane)
Vds=4.0 V
Ids=40 mA
Vgs=-1.82 V
f0=19.15 Ghz
Theory
Pocklington I.E.
Voltage Ratio=1.0
Phase Difference=0

Comparision in Radiation Pattern (E plane)

Fig. 3 Radiation Patterns

are obtained as shown in Fig.3 for both the H-plane and the E-plane. Agreement around the main beams is good.

Sidelobes in the E-plane becomes lager than those in the H-plane because of a single element factor. This fact is shown in the theoretical patterns in Fig. 3. However, the sidelobes obtained from the experiment were still large in both H-plane and E-plane. These discrepancies may result from the inadequate experimental setup.

CONCLUSIONS

Design and experimental results of a 2x2 quasi-optical spatial power combiner was reported as a prototype of two dimensional quasi-optical power combiner array. Although the impedance matching conditions as well as the in-phase condition have been taken into account carefully, the difference of the operation frequency (19.2~19.5 GHz) to the design frequency (20 GHz) has increased. In the case of a large array, more attention should be paid to avoid increase of this frequency difference resulting in phenomena such as load pulling.

In both the H-plane and the E-plane of a 2x2 quasi-optical power combiner array, Σ radiation patterns were obtained by controlling the lengths of feed lines. Good agreement between the experiment and the theory was obtained about mainlobes in both radiation patterns.

It is believed that,through this prototype circuit, the fundamental data for a monolithic quasi-optical power combiner array were obtained.

ACKNOWLEDGEMENT

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