A LAYERED NEGATIVE RESISTANCE AMPLIFIER AND OSCILLATOR USING A FET AND A SLOT ANTENNA

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ABSTRACT

Prototypes of quasi-optical transmitter components (oscillator and amplifier) using FET's as 1-port devices are reported. By using a slot antenna and microstrip to slotline transition, the circuit portion and the antenna are separated on different interfaces. The oscillator exhibited 1% electrically tuned range and the amplifier had a 2% locking range. The radiation patterns are also reported.

INTRODUCTION

Recently, with a view to developing low-cost, small-size and multi-function circuits, extensive research work on quasi-optical components has been carried out[1-3]. These circuits are compact, simple and efficient. In order to make these circuits even smaller, a multi-layered configuration will be considered. Although 1λ slot antennas with a short-circuited 50Ω microstrip feed line have been reported in [4], based on this concept, we propose a layered configuration that has a slot antenna and circuit components on each side of a common substrate.

In this paper, we report experimental results of two prototype circuits for layered quasi-optical trasmitter components. A MESFET 1-port oscillator[5] loads a slot antenna electromagnetically by using λ/4 microstrip to slotline transition[6]. The frequency of the negative resistance oscillator can be tuned by changing the bias voltages. A negative resistance amplifier made of a MESFET[7] also loads a slot electromagnetically. The injection locking mode of the negative resistance amplifier was confirmed through the anti-phase antenna pattern of the negative resistance amplifier circuit.

DESIGN

(a) Negative Resistance Oscillator Circuit

We use 1λ slots designed to match an electromagnetically coupled 50Ω microstrip feed line (see Fig.1 (a)). Without a soldered connection, a negative resistance oscillator will excite the slot electromagnetically through the crossover point at the center of the slot and cause the slot to radiate.

A negative resistance oscillator is designed to have an input impedance of -50Ω, as the slot antenna provides a 50Ω load to the oscillator. Using Touchstone microwave CAD program, the configuration shown in Fig.1 (b) was obtained. The feed line of the negative resistance oscillator has a λ/4 microstrip to slotline transition with radial stub configuration.

(b) Negative Resistance Amplifier Circuit

In order to ensure that the negative resistance amplifier operates in an injection locking mode, we design the slot like Fig.2 (a). It has four discontinuities at λ/4, 3λ/4, 5λ/4, 7λ/4 from one end of the slot. Each low impedance section has the length of λ/2 and the crossover point at its center where the microstrip on the other side of the substrate is electromagnetically coupled the slot through a λ/4 microstrip to slotline transition. The high impedance section at the center has the length of λ/2 in order for two crossover points to be 1λ apart. The width of the low impedance section is the same as that of the 1λ slot in Fig.1 (a), to match the 50Ω feed line. The width of the high impedance section is determined to insure injection locking. If its width is too small (lower impedance), multi-coupling occurs, and its circuit has multi-spectrum. If its width is too large (higher impedance), the coupling is weak, and locking does not occur.

The input impedance of the negative resistance amplifier should also be -50Ω. To use a FET as a 1-port device, the FET gate with feed back inductor should be shortened to reflect RF energy, but to control the undesired low frequency oscillation. The circuit configuration is shown in Fig.2 (b).

We initially designed the negative resistance amplifier with in-phase injection locking mode to operate at 10 GHz. The expected field distribution is shown in Fig.3. Due to the high impedance section, the amplitude of the propagation waves from one crossover point to the other one is reduced when waves pass through it. According to the simulation, the variation of phase of the reflection coefficient around 10 GHz was steep with respect to frequency. In this case, as the frequency band-width for the in-phase condition is very narrow, it is difficult to adjust the circuit to confirm the injection locking mode.

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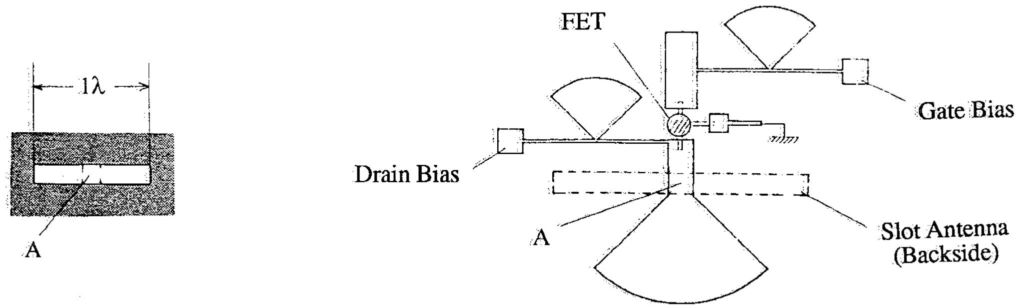
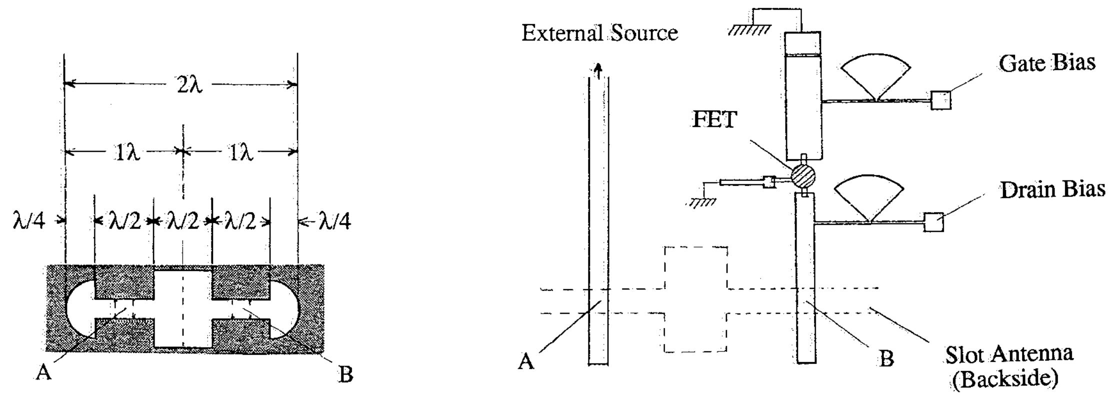


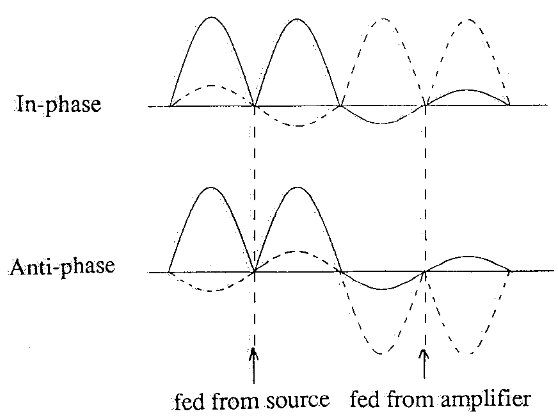
(a) Antenna portion (b) Oscillator circuit portion

Fig.1 Negative resistance oscillator circuit



(a) Antenna portion (b) Amplifier circuit portion

Fig.2 Negative resistance amplifier



—— by an external source
- - - by a negative resistance amplifier

Fig.3 Field distribution on the negative resistance amplifier slot

As another approach to confirm the injection locking mode of the negative resistance amplifier, we have chosen the anti-phase mode of its reflection coefficient. It was found that we should choose about 9.5 GHz as the operation frequency. In this anti-phase case, according to the simulation, the restriction of frequency band-width to accomplish the anti-phase mode and to adjust the circuit is not so severe. Hence, we are able to observe the antenna patterns with a minimum at the broadside direction. The expected field distribution of the anti-phase locking is also shown in Fig.3.

EXPERIMENTAL RESULTS

(a) Negative Resistance Oscillator Circuit

By controlling applied DC voltages, the frequency of the negative resistance oscillator was varied. Its variations were over a range of 100 MHz as shown in Fig.4. This tuning range corresponds to about 1 % of the designed frequency. It is noted that the main contribution to this tuning comes from the change of the drain voltage (Vds) rather than that of the gate voltage (Vgs). Regarding the power, we were able to measure the effective radiated power (ERP) of 13.2 dBm at Vds=3.5 V, Vgs=-0.7 V.

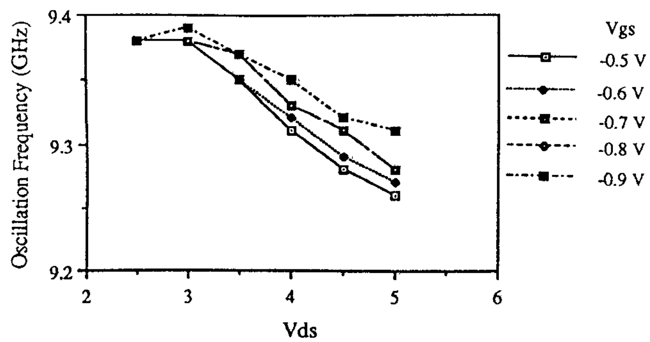


Fig.4 Vds dependence of oscillation frequency

Fig.5 shows the radiation patterns of the negative resistance oscillator circuit. Its beam-width is similar to but a little wider than that of a slot antenna with a feed line from an external source. The asymmetry in the antenna patterns was believed due to the effect of the bias line close to the antenna (see Fig.1 (b)). No dependence on antenna patterns of bias voltages was observed. From this, we can conclude that the variation of the reactance as well as that of the frequency by bias variation does not cause an appreciable change in antenna pattern.

(b) Negative Resistance Amplifier Circuit

We measured the voltage dependence of the self-oscillation frequency and the locking range of the negative resistance amplifier. In our circuit, the self-oscillation frequency did not depend on Vds and Vgs. As shown in Fig.6, its locking range was almost twice as wide as the tuning range of the negative resistance oscillator circuit. Meanwhile, the locking range dependence on Vds was similar to the case of the negative resistance oscillator circuit.

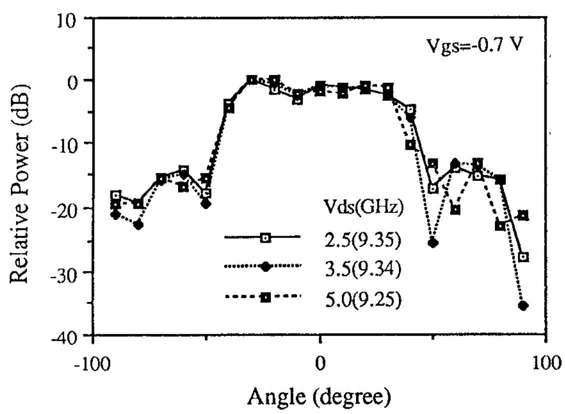


Fig.5 Antenna pattern
of negative resistance oscillator circuit

As expected, the antenna pattern of the negative resistance amplifier circuit has a minimum at the broadside direction shown in Fig.7 due to its anti-phase mode. The asymmetry is due to the difference of the radiation power from the external source and the negative resistance amplifier. The antenna pattern did not change because of the small variation of frequency when Vds and Vgs were changed.

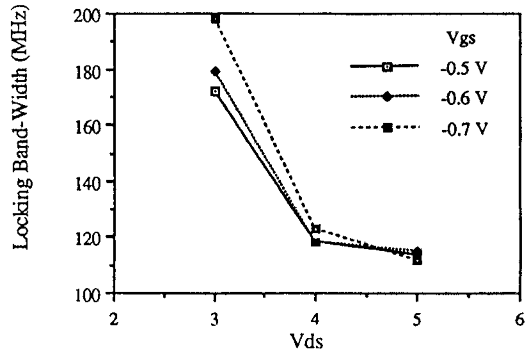


Fig.6 Vds dependence of locking band-width

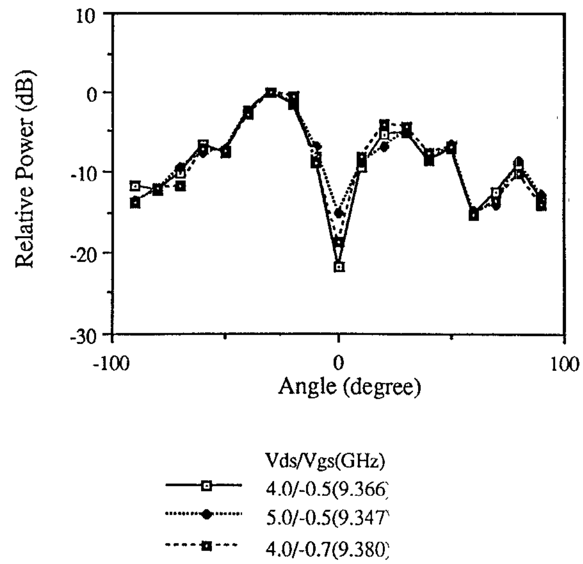


Fig.7 Anti-phase antenna pattern
of negative resistance amplifier circuit

CONCLUSION

The prototype circuits using slot antennas which specifically take into account the layered configuration in order to use MMIC technology are presented here. About 1% tuning range (100 MHz around 9.4 GHz) of the oscillation frequency on the negative resistance oscillator and about 2% locking range (200 MHz around 9.3 GHz) of locking frequency on the negative resistance amplifier were obtained by controlling applied DC voltages. By replacing the external feed line in Fig.2 (b) with a negative resistance oscillator and adding more amplifiers, it is feasible to make a spatial power combiner using a layered quasi-optical transmitter.

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