A Grid Amplifier

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Abstract—**The first demonstration of a grid amplifier is reported. A 50-MESFET grid has shown a gain of 11 dB at 3.3 GHz. The grid isolates the input from the output by using vertical polarization for the input beam and horizontal polarization for the transmitted output beam. The grid unit cell is a two-MESFET differential amplifier. A simple calibration procedure allows the gain to be calculated from a relative power measurement. This grid is a hybrid circuit, but the structure is suitable for fabrication as a monolithic wafer-scale integrated circuit, particularly at millimeter wavelengths.**

I. Introduction

PERIODIC grids loaded with active devices offer the possibility of greatly increasing the power and dynamic range of solid-state components by quasi-optical power combining. A variety of active grids have been demonstrated, including phase shifters [1], multipliers [2], oscillators [3], and mixers [4]. In all these grids, circuit power scales with total area, but circuit impedances are determined by the unit cell. This allows a designer to optimize for efficiency and noise performance independently from power. Another attractive feature of the grids is that they can be made as monolithic wafer-scale integrated circuits [1], [2]. These devices could serve as building blocks for radar, communications, and imaging systems. Until now, however, the critical component has been missing—the amplifier.

II. Approach

Fig. 1 shows the approach. Vertically polarized power is incident from the left, and passes through a polarizer. The grid amplifies the beam and radiates it as horizontally polarized power, which passes through an output polarizer to the right. The polarizers are thin circuit boards with etched copper strips. These polarizers provide isolation between the input and the output. In addition, they enable independent tuning of the input and output circuits.

Fig. 2 is a diagram of our unit cell. The vertical leads pick up the incident radiation. These leads are attached to the gates of two MESFET's. These two transistors have their sources connected together, so that the pair acts as a differential amplifier. The amplified signal radiates from the horizontal drain leads. There are 25 transistor pairs in a 5-by-5 grid. The transistors are FSC10LG packaged MESFET's manufactured by Fujitsu. The substrate is a 2.54-mm thick Duroid board ($\epsilon_r = 10.5$) manufactured by the Rogers Corporation. A second Duroid board with the copper removed was placed behind the amplifier to help tune the circuit.

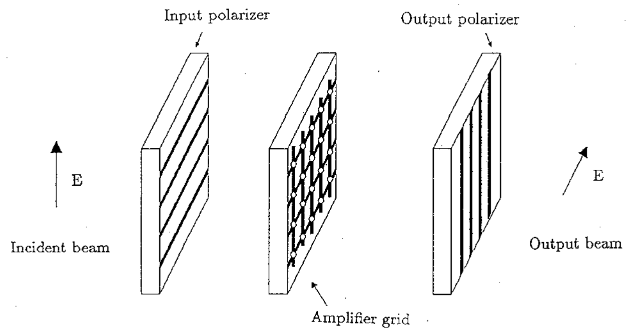

Fig. 1. Grid amplifier.

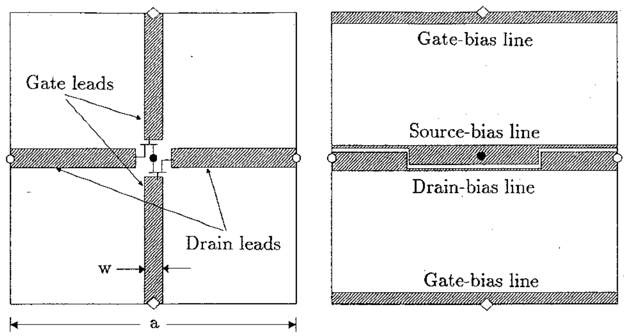

Fig. 2. Unit cell of a grid amplifier. (a) Front view. (b) Back view. Symbols indicate different connections between the front and the back of the grid amplifier. ●: 120-Ω source-bias resistor, ◇: 1-kΩ gate-bias resistor, ○: drain-bias pin.

The bias lines are copper strips etched on the back of the substrate, parallel to the output electric field. Holes were punched in the substrate so that connections could be made to the front. The drain-bias connections are metal pins at the cell boundaries, and the gate-bias connections are 1-kΩ carbon resistors. The source-bias connections are made with 120-Ω resistors to suppress common-mode oscillations. The resistors do not affect differential gain, which determines the overall grid gain.

We can draw a simple equivalent circuit for the unit cell (Fig. 3). Free space is represented as a transmission line with a characteristic impedance of 377Ω. The Duroid substrate

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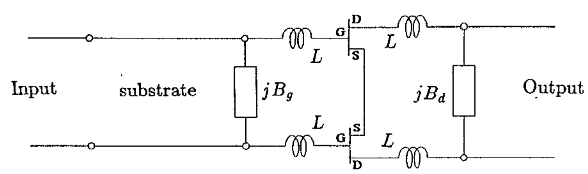

Fig. 3. Transmission-line model for the unit cell.

appears as a section of line with an impedance of 116 Ω. The gate and drain leads are taken into account by an inductance that can be calculated from a quasi-static formula [5].

$$L = \left(\frac{\mu_0 a}{4\pi}\right) \ln\left[\csc\left(\frac{\pi w}{2a}\right)\right], \tag{1}$$

where a is the period, and w is the lead width. For our grid, $a = 16$ mm and $w = 2$ mm, so that $L = 2.6$ nH. The susceptance B_g represents the output polarizer, and B_d accounts for the bias lines and the input polarizer. A circuit simulation of this model using the manufacturer's scattering parameters, but neglecting the polarizers, predicts a peak gain of 8.4 dB at 3.3 GHz, with a 3-dB bandwidth of 2.4 GHz.

III. Measurements

Fig. 4(a) shows how the gain was measured. A signal generator transmits a vertically polarized beam from a small horn. The beam is incident on the grid, amplified, and transmitted with horizontal polarization. Another horn receives the amplified beam. We define the grid amplifier gain G by the equation.

$$P_r = GP_t\left(\frac{G_t A}{4\pi r^2}\right)\left(\frac{G_r A}{4\pi r^2}\right), \tag{2}$$

where P_r is the received power and P_t is the signal generator power. G_t and G_r are the gains of the transmitting and receiving horns, A is the geometrical area of the grid, and r is the distance between the grid and each horn. The terms in parentheses are the input and output space-loss factors. The grid gain G is the ratio of the power radiated by the grid to the incident power, reduced by the losses from amplitude and phase errors across the grid. This equation has quite a few parameters, but we can eliminate some of them by making a calibration measurement with the grid removed (Fig. 4(b)). The received power P_c is then given by

$$P_c = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 (2r)^2}. \tag{3}$$

From these two equations, we can write an expression for the amplifier gain as

$$G = \frac{P_r}{P_c}\left(\frac{\lambda r}{2A}\right)^2. \tag{4}$$

This simple formula allows us to calculate the gain from a relative power measurement and three well-known parameters. In our measurements, $r = 50$ cm and $A = 64$ cm^2.

Fig. 5 is a plot of the measured amplifier gain. The largest value is 11 dB at 3.3 GHz, with a 3-dB bandwidth of 90

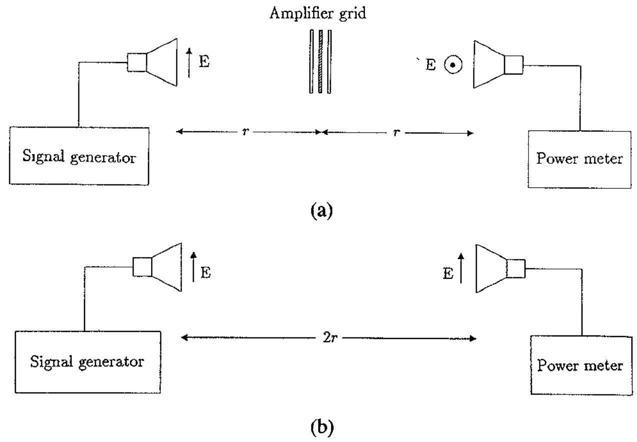

Fig. 4. (a) Measuring the amplifier gain. Gain of each horn is about 10 dB in this frequency range. (b) Calibration measurement with the grid removed and the receiving horn rotated 90° to match the transmitter polarization.

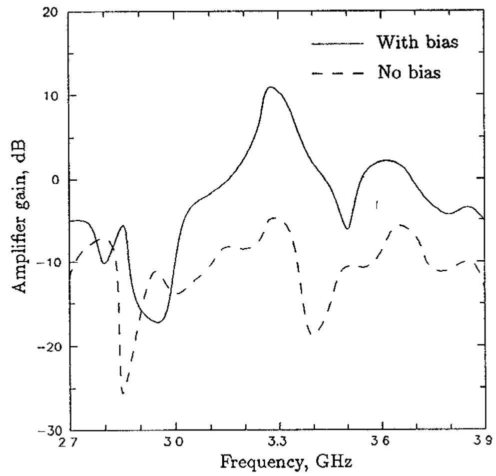

Fig. 5. Measured grid amplifier gain with bias (solid line) and without (dashed line). The total incident power was about 300 μW.

MHz. The tuning provided by polarizers is important; we did not see gain without them. At the same time, the polarizers may be responsible for the small bandwidth. The gate bias-line voltage was −0.25 V relative to the source bias-line, and the drain bias-line voltage was 4 V. The drain current was 6.6 mA per MESFET. For comparison, the gain was also measured with the bias turned off, and it was below −5 dB everywhere. The horns have a wide bandwidth, 2 GHz to 18 GHz, and this allowed us to monitor the received signal with a spectrum analyzer to insure that there were no spurious oscillations. As an additional check, the measurements were repeated at different power levels to make sure that the output power varied linearly with input power.

IV. Conclusion

We have demonstrated a hybrid grid amplifier with a gain of 11 dB at 3.3 GHz. Fifty MESFET's are arranged as 25 differential amplifiers that accept a vertically polarized input and transmit a horizontally polarized output. A simple calibration procedure allows the gain to be calculated from a relative power measurement. The design should be suitable for monolithic wafer-scale integration, particularly at millimeter wavelengths.

A grid amplifier is a multimode device, and should amplify beams at different angles. For example, it should be possible to place a grid amplifier after an electronic beam-steering array. The grid would amplify both single and multiple transmitted beams, while preserving propagation angles, sidelobe levels, and monopulse nulls. The amplifier could overcome losses in the beam steerer itself. A grid amplifier could also precede a receiving beam-steering array, allowing the noise performance to be determined by the grid, rather than by losses in the beam steerer.

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