New Distributed Amplifier Design Using Transmission-Gate FET's

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***Abstract*—We propose a new distributed amplifier design using a transmission-gate FET (TGFET) whose gate is embedded in the gate-artificial line. The new technique greatly simplifies the gate-artificial-line design, with no meandering or T-junction lines. The test TGFET distributed amplifier, using 0.1-μm-gate-length InP HEMT's showed a promising bandwidth performance of 100 GHz.**

I. Introduction

DISTRIBUTED amplifier IC's are widely used as broadband gain blocks in many applications [1], [2]. In a distributed amplifier, the transmission line is periodically connected to the unit-section field-effect transistors (FET's) to form a wideband impedance- and velocity-controlled artificial line. A meandering line is usually used for this purpose because it obviates the need for extra T-junction lines for FET connection, which often causes design inaccuracies and complications. As the operating frequency increases, however, the periodic interval in the distributed amplifier becomes smaller until finally it is comparable to the size of the unit-section FET electrode pattern. At such high frequencies, we can no longer use the meandering line because it requires a relatively long line, as compared with a straight-line arrangement, which is used in other monolithic microwave integrated circuits (MMIC's) such as low-noise amplifiers. For the drain side, we can effectively replace the meandering-line design with an M-derived-type filter design [3] in which series transmission lines connected to the FET's are incorporated to form the artificial lines. When used for the gate side, however, this design usually degrades amplifier performance. So, we need a new design for the gate-artificial line to replace the meandering-line design.

In this letter, we propose a new design using a transmmision-gate FET (TGFET) whose gate is embedded in the gate-artificial line. The new technigue greatly simplifies the gate-artificial-line design with no meandering or T-junction lines. The test TGFET distributed amplifier using 0.1-μm-gate-length InP HEMT's showed a promising 100-GHz bandwidth performance.

II. Design Principle

Fig. 1(a) and (b) shows schematics of a transmission-gate FET (TGFET). The TGFET has the same structure as the conventinal FET except that it has two gate ends. Fig. 1(c) shows a schematic of the distributed amplifiers unit-section layout using a TGFET. In this figure coplanar waveguides are used for transmission lines, but a microstrip-line version is also available. As shown in this figure, a signal from the gate line is fed to one end of the gate, passed through, and extracted from the other end of the gate. In this way, the gate is embedded in the gate artificial line of the distributed amplifier. This enables us to make a very efficient gate-artificial-line design with short and straight lines, which is particularly suited to high-frequency-edge distributed amplifiers. On the other hand, the transmission-line effect in the drain electrode was neglected because of its typical electrode geometries [4]. We simply used a conventinal M-derived-type filter circuit for the drain-artificial line, which provided the flexibility to optimize overall transmission-line layout.

III. Experiments and Discussion

We made TGFET's for S-parameter characterization and a test distributed amplifier using TGFET's. They were fabricated using 0.1-μm-gate-length InP HEMT's and coplanar-waveguide technology [5]. The HEMT's had T-gate structures and threshold voltages of about -0.4 V. The TGFET's for S-parameter characterization had coplanar waveguides for two gate ends to measure gate-transmission characteristics. The measures S parameters were analyzed by an equivalent circuit model. The gate-transmission characteristics are shown in Fig. 2(b). Drain and gate biases were 1.5 and 0 V, respectively. We used an equivalent circuit model including distributed gate effects [4]. The gate inductance L_g was especially important to resemble the measured S parameters. We used an inductance of about 0.5 nH/mm. The differences between the measured and calculated results were small, but the phase of S_{11} was not well resembled compared with other parameters. Fig. 3 shows gate-width dependencies of gate-transmission characteristics at 40 GHz. S_{21} was better than 0.6 dB for 10-μm gate width. The matching, S11, was kept better than -10 dB with a gate width below 75 μm. This good matching characteristic was resulted from the distributed gate effect.

The performance of the test distributed amplifier using TGFET's is shown in Fig. 4. The amplifier had eight unit TGFET's with 10-m gate widths. The measurement was made using on-wafer radio frequency (rf) probes. For frequencies of 75 to 110 GHz, we used waveguide-rf probes. The initial design of the amplifier did not include the gate-distributed effect because TGFET-equivalent circuit models were not available at design time. S_{21} was about 5 dB and its 3-dB bandwidth was around 100 GHz. S_{11} and S_{22} were better than -10 dB within the measured frequency range. These results show that

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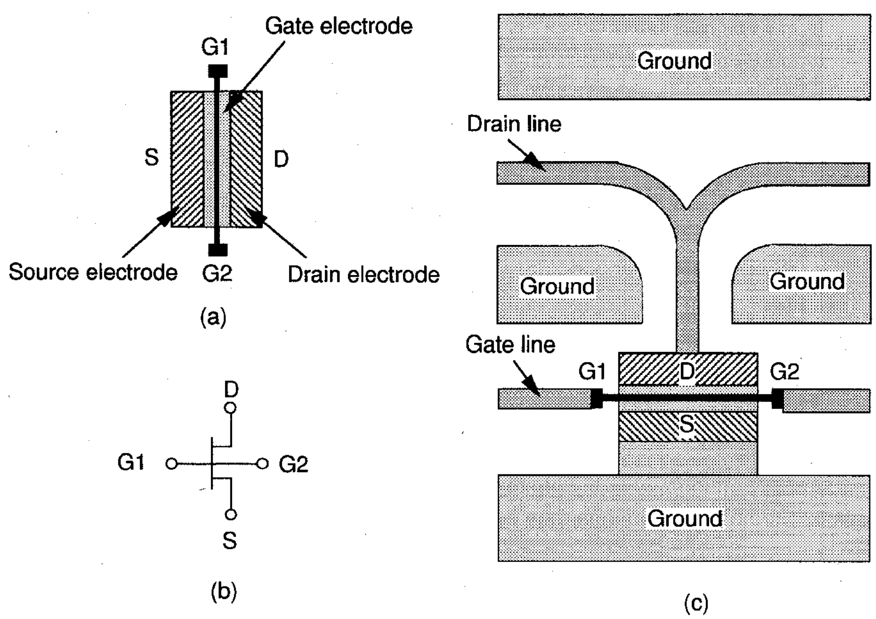

Fig. 1. (a) Schematic of TGFET. (b) Symbol for TGFET. (c) Schematic of the distributed amplifiers unit-section layout. Air-bridges are omitted.

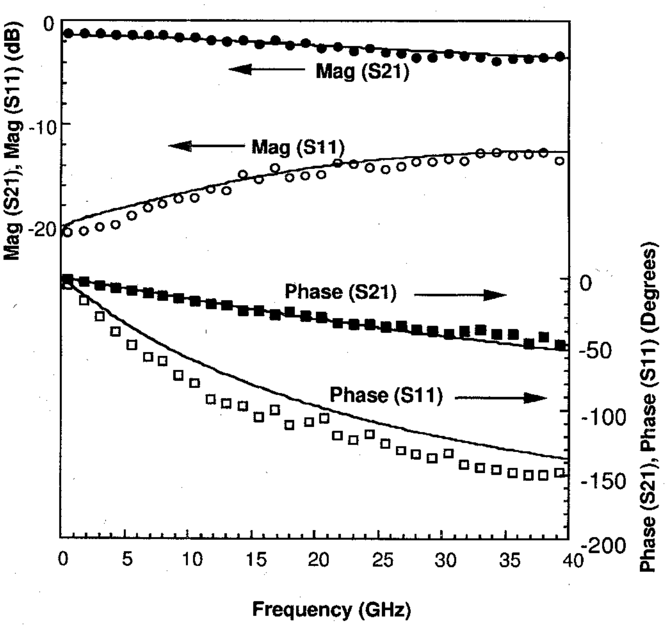

Fig. 2. S parameters of 50-μm-gate-width TGFET. Measured data are plotted and solid lines show simulated results.

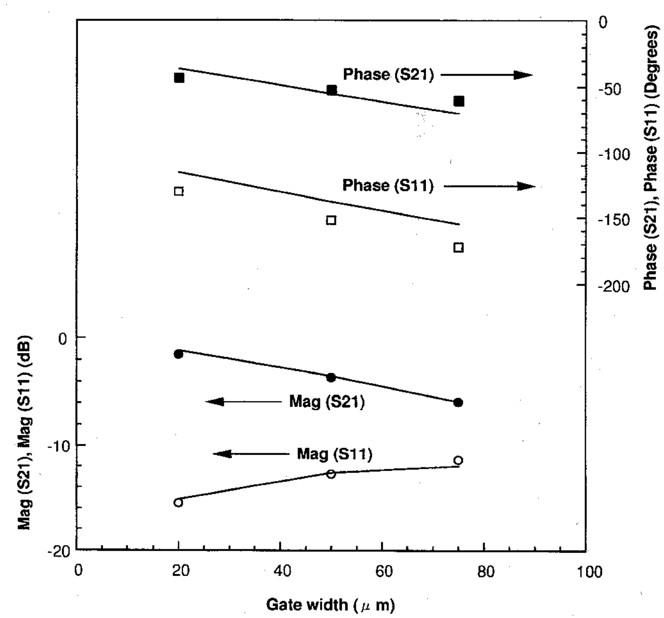

Fig. 3. S-parameter versus TGFET gate width at 40 GHz. Measured data are plotted and solid lines show simulated results.

the distributed amplifier with TGFET's has promising potential for millimeter-wave applications. The simulated results using the derived equivalent circuit are also shown in Fig. 4. The simulated S_{21} and S_{11} almost resembled the measured ones. However, S_{22} was not well resembled because the output impedance of the TGFET was not effectively characterized in our TGFET S-parameter measurement.

Using a circuit simulation, we compared the performances of a conventional distributed amplifier and one with TGFET's. For the conventional amplifier simulation, we used the distributed gate model with one gate end treated as electrically open. The results were almost the same as those found using the lumped equivalent model with one-third previous values for L_g and R_g [4]. The simulated amplifiers had 10 to 20-μm-gate-width unit FET's with the total gate width below 160 μm. The transmmision line was treated as a coplanar waveguide with 75-Ω characteristic impedance. Using the ideally optimized line length for each case, the TGFET amplifiers had only 10% bandwidth penalty of conventional ones. This is because the effect of the transmission-gate loss was not significant when a small gate width was used for the unit FET. The amplifiers with TGFET's had better input matchings than the conventional ones because of the distributed gate effect. Fig. 5 shows the typical performance differences between the conventional and TGFET amplifiers. The amplifiers had eight unit TGFET's with 20-μm gate widths. This figure

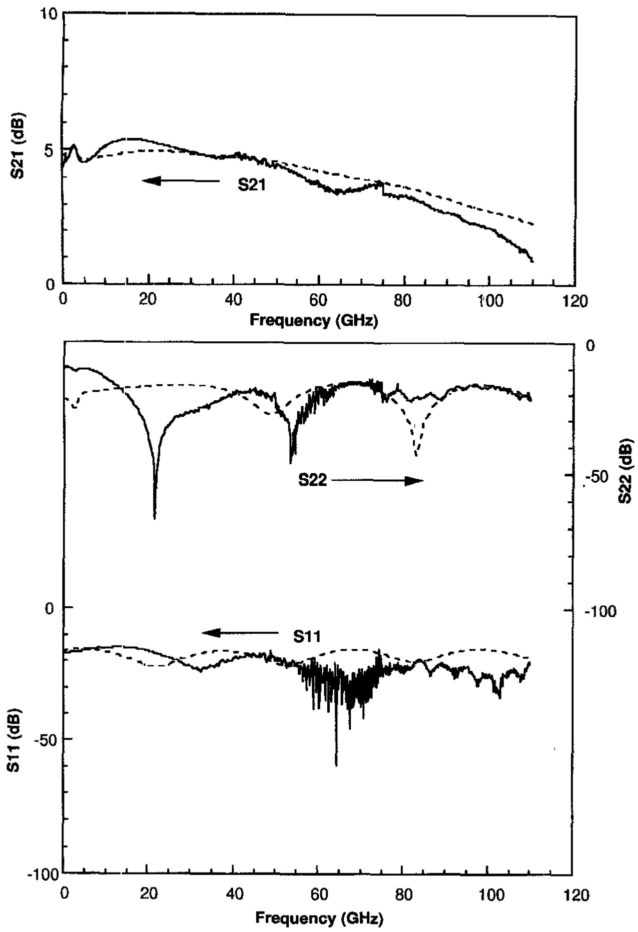

Fig. 4. Performance of TGFET distributed amplifier. Solid and dashed lines show measured and simulated results, respectively.

clearly shows the explained differences above. The distributed amplifier with TGFET's had good input matching with a very wide frequency range while the gain slope was slightly larger than that of the conventional one. With regard to the layout of the transmission lines, the distributed amplifier with TGFET's had an advantage over the conventional ones because of its potential for efficient layout. In fact, the unit gate-line length will decrease to below 100 μm for future high-frequency-edge amplifiers with bandwidths over 150 GHz. These amplifiers will almost fail using the conventional layout method.

IV. Conclusion

We present a new design using a transmission-gate FET whose gate is embedded in the gate-artificial line. The new

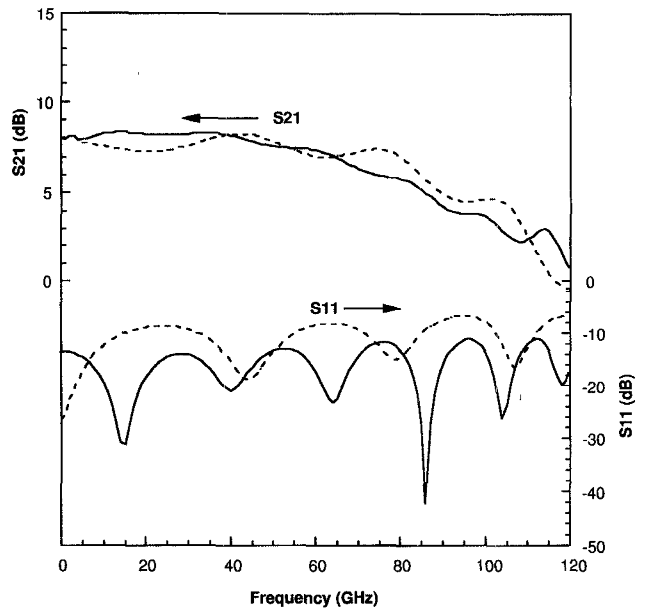

Fig. 5. Simulated comparison between TGFET and conventional distributed amplifiers. Solid and dashed lines show TGFET and conventinal amplifiers, respectively.

technique greatly simplifies distributed amplifier design. Because of its efficient layout, we believe that the design will have a great potential in the production of millimeter-wave amplifiers because of its efficient layout.

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