A 2-18GHz MONOLITHIC VARIABLE ATTENUATOR USING NOVEL TRIPLE-GATE MESFETS

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ABSTRACT

A monolithic variable attenuator requiring only a single positive external bias/drive voltage and capable of handling 0.4W input power has been developed using novel triple-gate MESFETs. The IC exhibits greater than 13dB attenuation and less than 2:1 VSWR from 2-18GHz with a maximum insertion loss of 2.7dB at 18GHz. It was developed from a lower power single-gate version using a unique scaling approach that preserves the circuit electrical property while enhancing the power handling almost nine-folds.

INTRODUCTION

In recent years, broadband amplifier designs covering multi-octave or decade bandwidths are becoming very prevalent. Systems incorporating these amplifiers will generally require stabilization over temperature. Conventional temperature compensation schemes using PIN diodes together with quadrature couplers are not very appropriate for covering such broad bandwidths. Previous GaAs MESFET attenuators have been designed covering 2-18GHz frequency range and beyond[1,2]. These circuits required external negative control voltages employing operational amplifiers and dual-polarity power supplies. One other MESFET attenuator design did not require negative power supply[3], but covered only 1-6GHz. Furthermore, all these MESFET attenuators are very sensitive to frequency as well as control voltage change at their maximum attenuation. This behavior may require additional comparator or limiter circuitry.

In our previous work, we developed a variable attenuator[4] that eliminated the above mentioned drawbacks. It employed MESFETs in a Pi configuration, with some additional features : 1) A pair of series R and L was connected in parallel with the series FET to improve bandwidth, 2) only one positive control voltage was required, applied to the drain/source nodes of the series FET and the gate nodes of the shunt FETs. The IC demonstrated very good performance in VSWR, variable attenuation, and bandwidth, although the power handling was limited to about +18dBm which is typical of MESFET control circuits including switches and phase shifters[5,6].

To further increase the power handling, one could resort to the use of larger devices. But it may not be very effective for the following reasons: The increased intrinsic capacitance will degrade bandwidth at the high frequency end, and the reduced channel resistance will change input and output matchings over the entire frequency range requiring probably a significant redesign of the circuit. One another approach is to use newer devices or processes capable of higher breakdown voltage and current such as the semi-insulated-gate FETs (SIGFETs)[7], yet this will require significant effort in process development and device characterization.

This paper presents a different approach for higher power attenuator design. A unique scaling method which provides higher power handling without requiring a circuit redesign is proposed. Novel triple-gate MESFETs are used replacing the single-gate FETs in [4]. The higher power version, except for MESFET gate metalization pattern change, does not require any additional process or circuit changes.

SCALING METHOD FOR MESFET POWER ENHANCEMENT

To increase the power handling , a

new scaling and modeling approach was investigated : By increasing the number of gates and the gate width by the same ratio N, where N is an integer, in comparison to a single-gate FET, the power handling of the multi-gate FET, for control applications in general and attenuator design described here in particular, can be increased without significant deviation of the multi-gate FET's small signal RF characteristics from that of the single-gate FET; and the resultant power improvement is 20(log N) in dB. In other words, by doubling the gate width of a single-gate FET and replacing it with dual-gate FET, one can increase power handling by 6dB without affecting the small signal characteristics. Similarly, a triple-gate FET with gate width three times of a single gate FET will have 9dB higher power without significant small signal performance degradation.

To illustrate this, the schematic diagram of a single-gate MESFET, along with its equivalent circuit, is shown in Figs. 1a and 1b. The representation of the FET by a two-port R-C model is a valid approximation because the third port, the gate of the device, is RF blocked although DC-connected for most control applications. The letters W, Vm, and Im in Figs. 1a and 1b designate the FET's total gate width, maximum voltage, and maximum current respectively. The RF small signal performance is mainly determined by the equivalent circuit's R and C's; while the power handling is determined by Vm and Im. A dual-gate FET and its equivalent circuit, using the above scaling method, are shown in Figs. 1c and 1d. The dual-gate FET is basically two single-gate FETs cascoded together. With the external gate terminals RF removed, the equivalent circuit of the dual-gate FET is simplified to two series-connected R-C circuits. By doubling the gate width as shown, each of the two series-connected R-C circuits will have half the series impedance of that in Fig.1b and the equivalent circuit shown in Fig.1d becomes exactly the same as that in Fig.1b; while the power handling increases by $4V_1 x I_1/(V_1 x I_1)$, i.e., 6dB. With this approach, the power handling of MESFET attenuators or switches can be increased several-folds with changes only made to the active devices. This approach also can be implemented by using single-gate FETs in cascode connection. But the use of multi-gate FETs has advantages in achieving more compact IC chip size and simpler layout change from lower power single-gate FET control circuits.

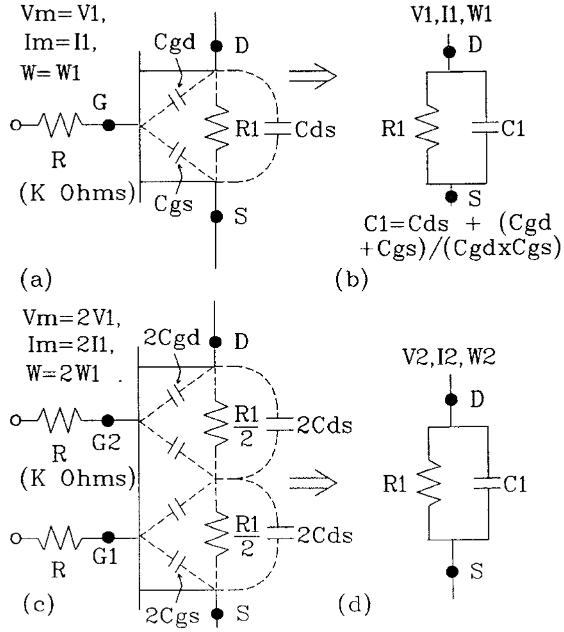

Figure 1. Proposed Scaling Method for MSEFET Power Enhancement.
a) Schematic of a single-gate MESFET
b) Equivalent circuit of a),
c) Schematice of a dual-gate MESFET,
d) Equivalent circuit of c), where Vm means the maximum voltage, Im the maximum current, and W the total gate width.

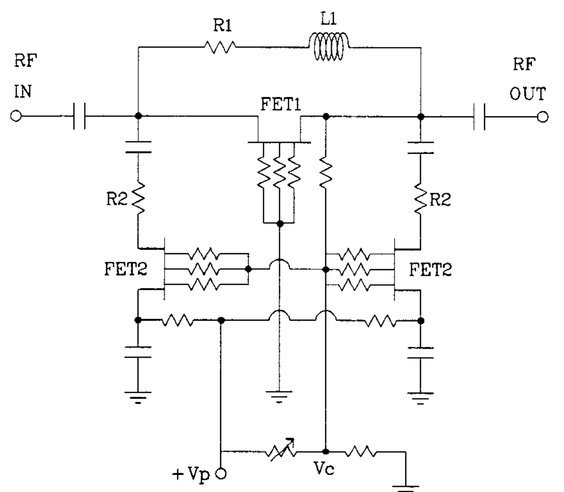

Figure 2. Schematic Diagram of the 2-18 GHz Triple-Gate MESFET Attenuator

CIRCUIT DESIGN AND FABRICATION

To validate the above concept, a variable attenuator was designed and processed using triple-gate FETs. The circuit schematic of the triple-gate variable attenuator is shown is Fig.2. It was developed using the aforementioned scaling and modeling method from a lower power single-gate attenuator described in[4]. Except for the active devices, the layout and components of the two ICs are almost identical. The two ICs have very similar chip size, measuring 0.062x0.057 mil^2 and 0.057x0.057 mil^2 each respectively. The increased chip size of the triple-gate attenuator is due to the gate width of the triple-gate FETs being three times of the gate width of the single-gate FETs in [4]. The triple-gate IC was fabricated using ion-implanted material. The IC processes included MIM capacitors, GaAs and metal resistors, and via-holes. A photograph of the finished MMIC chip is shown in Fig. 3.

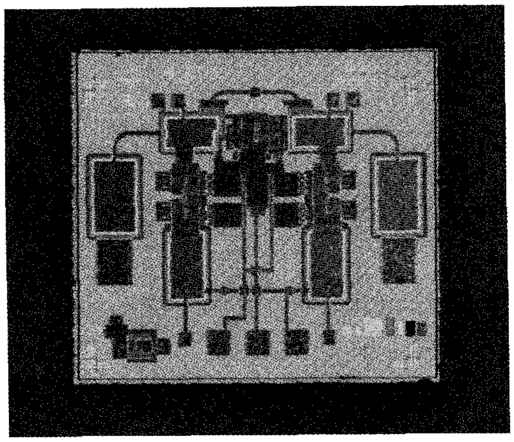

Figure 3. Photograph of the Triple-Gate Variable Attenuator MMIC Chip

MEASURED RESULTS

The measured results of the IC are presented in Figs.4-6. Fig.4 shows the minimum insertion loss and return loss vs. frequency at Vc = 0.0V. The insertion loss is 1.7 dB at 2GHz and 2.7dB at 18GHz. The return loss is greater than 10dB. Fig.5 shows the variable attenuation versus the positive control voltage Vc. The IC has a maximum attenuation of 16.5dB at 2GHz and 13.0dB at 18 GHz respectively, at a single control voltage of +3V. The input and output VSWRs are better than 2:1 over the entire control and frequency range. The attenuator's small signal performance is similar to that of the lower power single-gate version. The power performance versus frequency of the IC is shown in Fig.6, together with that of the lower power single-gate version. It can be seen that the triple-gate variable attenuator has about 8-9dB higher power handling than that of the single-gate version.

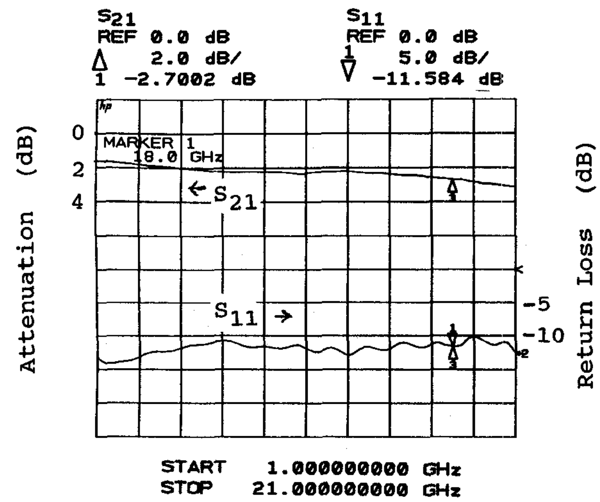

Figure 4. Measured Attenuation and Return Loss at Minimum Attenuation

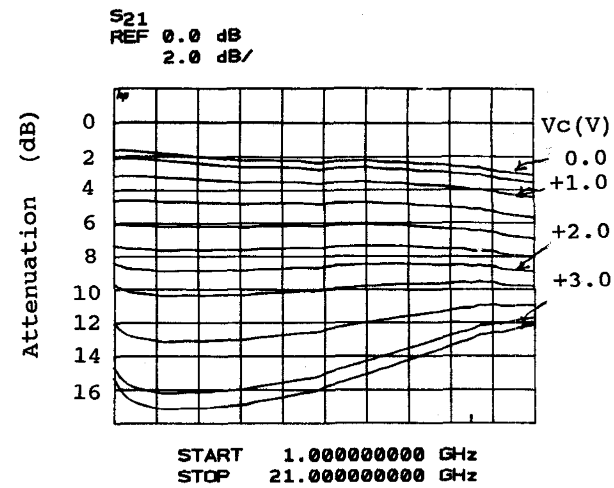

Figure 5. Measured Variable Attenuation as Function of Control Voltage Vc

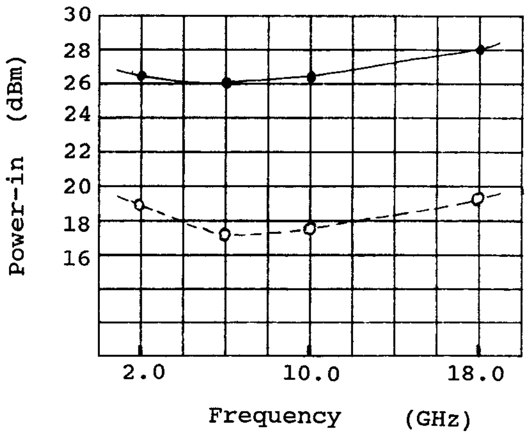

Figure 6. Measured Input Power vs. Frequency at 1dB Attenuation Deviation from 10dB Attenuation
• ———— this paper
o --------- the attenuator in [4]

CONCLUSION

In conclusion, a new FET scaling and modeling method has been investigated for microwave higher power control circuit designs. It allows significant power improvement from a lower power circuit without circuit redesign and the small signal performance degradation except the replacement of the active devices. A MESFET variable attenuator IC has been developed, based on the proposed scaling and modeling method, using novel triple-gate MESFETs. The circuit was designed from a lower power single-gate attenuator IC, with changes made on the active FETs only. It has exhibted a power handling improvement by almost 9dB without significant small signal RF performance degradation. The power enhancement has been demonstrated for an attenuator using MESFETs , but the proposed scaling and modeling method should be equally applicable to many other types of control circuits as well as different types of solid-state devices.

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REFERENCES

1. Y. Tajima, T. Tsukii, R. Mozzi, E. Tong, L. Hanes, and B. Wrona, "GaAs Monolithic Wideband (2-18 GHz) Variable Attenuators," IEEE MTT-S Digest, pp.479-481, 1982.
2. H. Kondoh, "DC-50 GHz MMIC Variable Attenuator," IEEE MTT-S Digest, pp.499-502, 1988.
3. G. Lizama T. Andrade, and R. Benton, "1-6GHz GaAs MMIC Linear Attenuator," IEEE MIMIC-S Digest, pp.105-107, 1987.
4. H. Sun, W. Wu, and J. Ewan, "A 2-20GHz GaAs MESFET Variable Attenuator Using A Single Positive External Drive Voltage," 19th European Microwave Conference Proceedings, pp.1270-1275, 1989.
5. M. J. Schindler, and A. M. Morris, "DC-40GHz and 20-40GHz MMIC SPDT Switches," IEEE MIMIC-S Digest, pp.85-88, 1987.
6. D. Levy, A. Noblet, and Y. Bender, "A 2-18GHz Monolithic Phase Shifter for Electronic Warfare Phased Array Applications," IEEE GaAs IC Symposium Digest, pp.265-268, 1988.
7. Y. H. Yuan, and R.J. Gutmann, "GaAs Semi-insulated-gate FETs as High Power MMIC Control Devices," IEEE MTT-S pp.997-1000, 1988.