A Low Phase-Error 44-GHz HEMT Attenuator

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***Abstract*— Radio frequency (RF) subsystems for emerging millimeter-wave applications require monolithic microwave integrated circuit (MMIC) attenuators with constant phase over the attenuation range. In this letter, we present the results for a 44-GHz stepped attenuator implemented in high electron mobility transistor (HEMT) MMIC technology. Use of a switched-path topology provides a high attenuation range (>30 dB) with good phase flatness ($<7^\circ$ p-p) and return loss (>14.5 dB) over the attenuation range. The same design topology should be well suited for other frequencies throughout the upper microwave and lower millimeter-wave range.**

***Index Terms*—Attenuator, millimeter-wave, monolithic.**

I. Introduction

COMMUNICATIONS systems in the millimeter-wave frequency range are of increasing interest as the microwave region becomes more congested, and as solid state technology for implementing the radio frequency (RF) electronics becomes increasingly available. The band in the vicinity of 44 GHz is of particular interest, having been assigned for use by military communications satellite uplinks.

In this letter, we report on a high-performance stepped attenuator, implemented in 0.15-μm HEMT MMIC, at 44 GHz. The design provides an attenuation range of over 30 dB. With good phase flatness over this range, the circuit can be used for vector applications in addition to the more traditional scalar applications.

II. Design

The schematic of the attenuator is shown in Fig. 1, and a photograph is shown in Fig. 2. The four attenuation bits are implemented by the use of the "switched path" topology, in which FET (HEMT) switches steer the signal to a nonattenuating through path, or an attenuation path containing a resistor network. The topology provides a design with excellent phase flatness over attenuation. Switched-path attenuators have been previously demonstrated in the microwave frequency range (e.g., [1]). In the current design, a series-shunt switch approach is used. The series switch (with inductive parallel resonator) provides a compact circuit layout, while the shunt switch, placed behind the series switch, provides improved isolation and suppresses loop resonances [2]. In order to achieve the desired amplitude steps even if the attenuation values are slightly inaccurate, the individual bit attenuators are incremented by a factor of 1.8 instead of 2.

III. Results

The insertion loss as a function of attenuator state of the circuit is shown in Fig. 3. Attenuation increments are approximately 2.5 dB. Note that, due to the 1.8-stepping factor, the step to the second most significant bit (MSB) state is smaller than the others, and the step to the MSB state actually steps backward in attenuation. Consequently, one of the 16 attenuator states (the one in which only the MSB attenuator is on) would be designated as a disallowed state for practical operation. Fig. 4 shows the input and output return loss for all 16 states. Worst case return loss is about 15 dB. Fig. 5 shows the insertion phase as a function of attenuation state. Over the large dynamic range of the circuit, the phase range is less than 7°.

IV. Conclusions

We have demonstrated a stepped attenuator with over 30-dB range, low phase error, and good return loss. The design should be readily scalable to other millimeter-wave frequencies.

Acknowledgment

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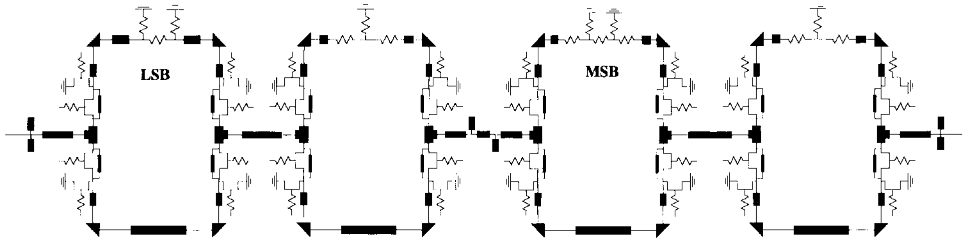

Fig. 1. Schematic of the 4-bit attenuator. Gate bias hookups and bypass capacitors for control of the HEMT switches are not shown to avoid cluttering the schematic.

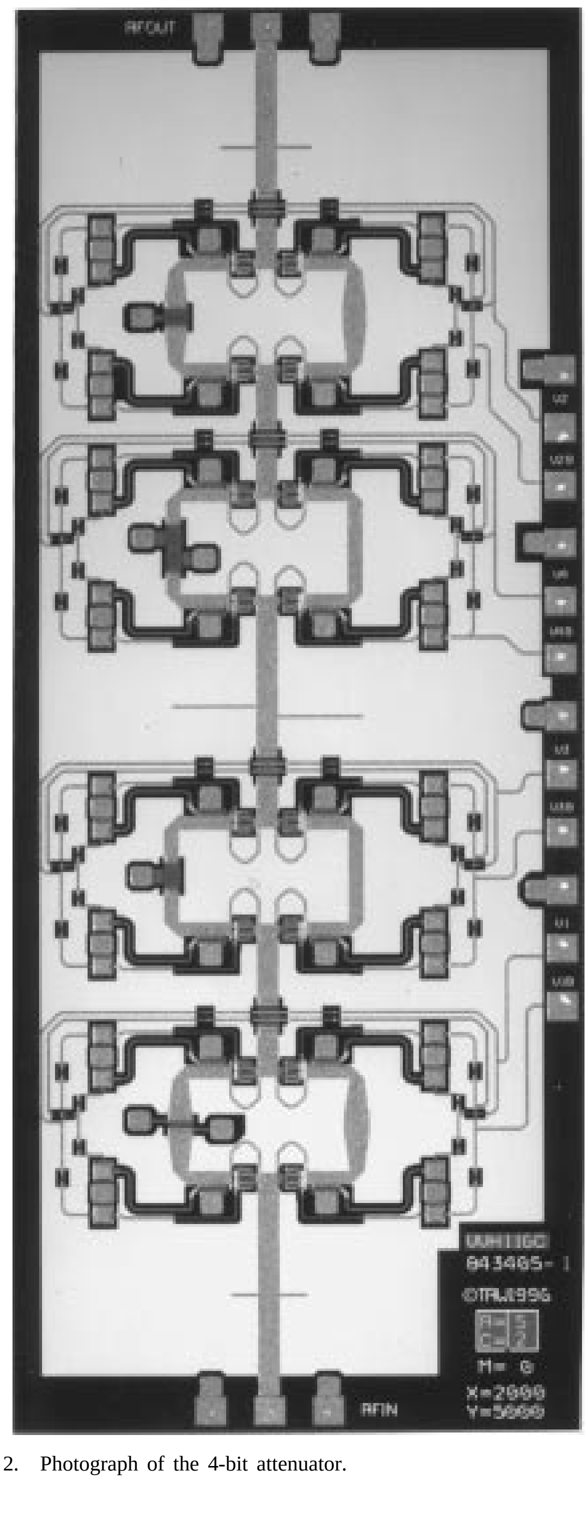

Fig. 2. Photograph of the 4-bit attenuator.

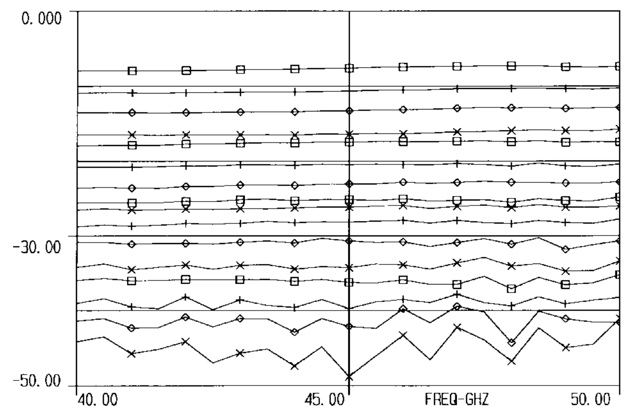

Fig. 3. Insertion loss (dedibels) of the 4-bit attenuator in its reference and attenuation states.

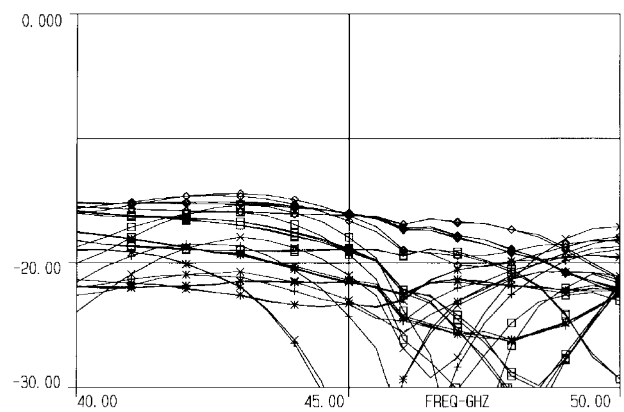

Fig. 4. Input and output return loss (decibels) of the 4-bit attenuator in all its states.

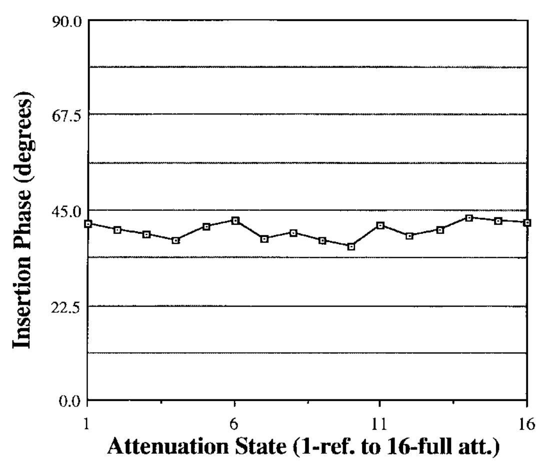

Fig. 5. Insertion phase of the 4-bit attenuator at 44.5 GHz as a function of attenuator setting.