A Monolithic MEMS Switched Dual-Path Power Amplifier

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***Abstract*—RF MEMS switches have been successfully integrated with HEMT MMIC circuits on a GaAs substrate to construct a dual-path power amplifier at X-band. The amplifier uses two MEMS switches at the input to guide the RF signal between two paths. Each path provides single-stage amplification using different size HEMT devices, one with 80-μm width and the other with 640-μm. Depending on the required output power level, one of the two paths is selected to minimize the dc power consumption. Measurements showed the amplifier producing similar small signal gains of 13.2 and 11.5 dB at 10 GHz for the small and the large devices, respectively. The best PAE was 28.1 percent with 8.5 dBm of output power for the small device, and 15.3 percent with 14.6 dBm for the large device.**

***Index Terms*—HEMT, MEMS switch, MMIC, power amplifier.**

I. INTRODUCTION

IN personal communication systems, improving battery lifetime by optimizing the dc efficiency of the transmitter is an important issue. For mobile transmitters, the required output power level is proportional to the distance to the nearest base station. The probability distribution of the required power from mobile transmitters in a suburban environment shows that the power generated from small size transistors is sufficient in most cases. Occasionally, however, a significantly larger amount of power may be necessary when the distance between the transmitter and the base station is increased. Consequently, a dual-path output stage amplifier can be used to improve efficiency by choosing either a small or a large size transistor depending upon the amount of output power required.

The recent demonstration of a four-bit, true-time delay network [1] using sixteen metal-to-metal contact RF MEMS switches has confirmed the maturity of the MEMS technology in passive RF components. The switches developed at Rockwell Science Center display very small RF insertion loss and do not dissipate any dc power. They are fabricated with a movable metal shunting bar to connect two RF signal lines when the dc activation voltage of approximately 70 V is applied. Measurements on discrete Rockwell switches show typical dc/RF contact-resistances of 1.0 Ω while the off-switch coupling capacitance is only 1.75 fF. A more detailed discussion on discrete switch performance can be found in [2]. In order to extend the MEMS switch application to high-speed GaAs circuits, the switch fabrication process must be amenable to integration with active devices [3]. The integration sequence developed at Rockwell starts with the front-side 0.18-μm HEMT fabrication on 3-in GaAs substrates, followed by placing the MEMS switches, based on a low-temperature ($T < 250$ C), thin-film process, on top of the HEMT circuits which are protected with a layer of polyimide. The substrate is then thinned to 75-μm before the via holes are etched. Finally, the protection over the HEMT circuits is removed and the switches released. Measurements performed on HEMT circuits before and after the switch integration show no degradation in RF performance. Unlike most other popular switches, the Rockwell switch completely isolates the RF lines from the dc control lines, eliminating interference issues between the high-voltage dc and low-voltage RF circuits. We believe the switchable output power amplifier introduced in this paper is the first example of monolithically integrating MMIC's with MEMS switches to obtain enhanced circuit performance.

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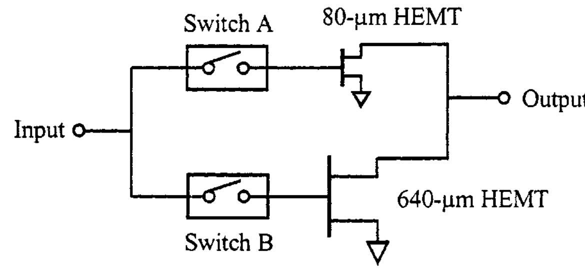


Fig. 1. Sketch of the dual-path power amplifier. The large drain impedance change of the HEMT device with dc on-bias eliminates the need for the switches on the output.

II. AMPLIFIER DESIGN

Ordinarily, a dual-path amplifier design requires two switches at the input and two at the output. In our design, however, we simplified the circuit by using the switches only at the input, thus reducing the number of switches by half (Fig. 1). This is possible because the drain impedance of an unbiased HEMT device is quite different compared to the biased case. Therefore, with a proper matching network, the drain terminal of the off-biased device can be essentially isolated from the output port of the amplifier. The gate impedance of the HEMT, on the other hand, displays minimal change, because the small dc gate bias has only a negligible impact on the gate-to-source capacitance. Consequently, two switches are still required at the input to isolate two paths.

In our single-stage dual-path microstrip amplifier, shown in Fig. 2, two devices with 80 and 640-μm gate widths provide

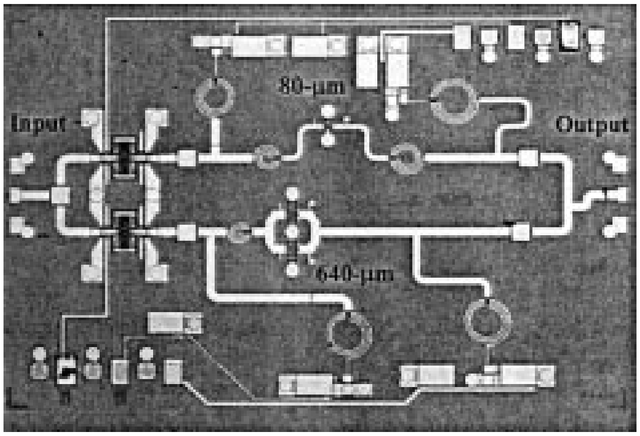


Fig. 2. Photograph of the X-band dual-path amplifier. The top path contains an 80-μm device while the bottom path has two 320-μm devices. Four dc bias lines are required for the HEMT's and two for the switches to operate the chip, 3.5×2.3 mm^2 in size.

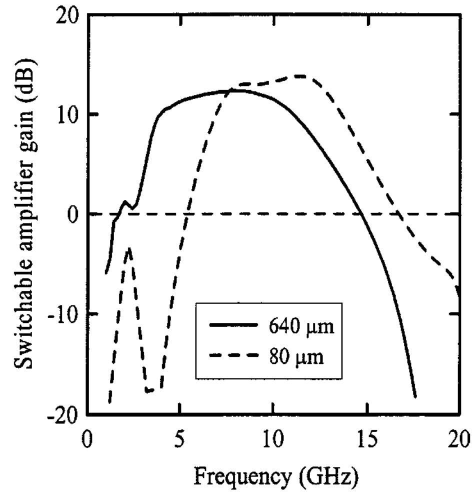
the gain at X-band, respectively. A conventional amplifier matching technique was used at the input, transforming the gate impedance to 50 Ω. On the output side, the matching network not only transforms the on-bias drain impedance to 50 Ω but also converts the off-bias drain impedance to an open circuit. Since the size of distributed matching circuits can be bulky at X-band, compact spiral inductors were introduced to provide the necessary matching at the input and output networks.

III. Amplifier Performance

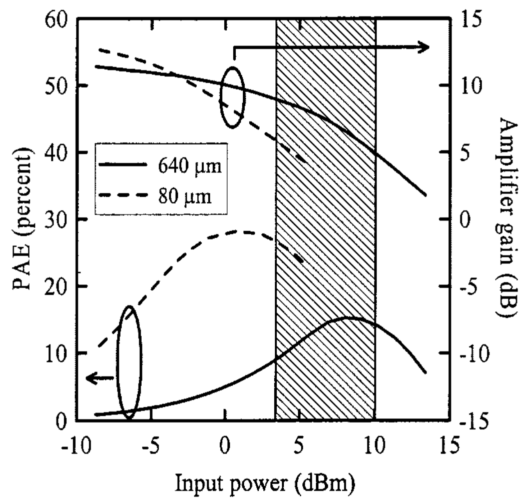
Both frequency and power measurements were performed using an RF probe station connected to an HP8510 Network Analyzer and power meters. During the measurements, the dc-bias pads for the unused device and switch were connected to ground. The small signal test showed approximately equal amplifier gain at 10 GHz for the two devices, 13.2 dB (small) and 11.5 dB (large), with a dc bias of 2.5 and -0.3 V at the drain and the gate, respectively [Fig. 3(a)]. The MEMS switches at the input path were controlled with a separate dc activation voltage of 98 V. The input and output matching was better than -5 dB at 10 GHz for both paths, and there were no oscillations at any frequencies. The power measurements [Fig. 3(b)] showed that the top path with the 80-μm device produces higher dc power-added efficiency than the bottom path with 640-μm device. However, the top path has a useful gain of better than 5 dB only up to an input power level of 3 dBm. By switching over to the bottom path, the usable input power range can be extended by 7 dB to 10 dBm. For optimum PAE, a different dc bias of 2 and -0.5 V at the drain and gate was needed. The small device showed a maximum PAE of 28.1 percent at 8 dB of gain with an input power of 0.5 dBm, and the large device showed a maximum PAE of 15.3 percent with 6.6 dB gain at 8 dBm input power.

IV. Conclusion

The monolithic dual-path amplifier was fabricated by successfully integrating RF MEMS switches with GaAs HEMT devices. The number of switches required in the design was reduced by half by utilizing the impedance change of the drain terminal of the HEMT devices in the on and off bias states. The 80 and 640-μm devices used in the circuit operate with 22 and 147 mW of dc power. By using the path with the smaller device when lower output power is required, the lifetime of the battery operating the amplifier can be increased by nearly seven times.



(a)



(b)

Fig. 3. Dual-path amplifier performance. The small-signal gain vs. frequency (a), and the gain and the PAE vs. input power at 10 GHz (b) are shown. The shaded area in (b) indicates the extended range in power handling capability by switching over from the 80 to 640 μm device.

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