# A 6.5–16-GHz Monolithic Power Amplifier Module

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*Abstract* —A miniaturized 6.5–16-GHz power amplifier module, which includes T/R switch, dual polarity power supply, switch driver, and gate functions, was designed using two types of broad-band MMIC amplifiers. The two cascade designs were a 900–1200-μm FET amplifier and a 300–300-μm feedback amplifier which were used to provide large and small gain functions, respectively. The module exhibits 35 dB of gain, 1-W power output, and 55-dB T/R switch isolation.

## I. Introduction

MODERN SYSTEM requirements of increased reliability, reduced cost, and component miniaturization is driving the microwave industry to incorporate MMIC (microwave monolithic integrated circuit) technology into current and future systems. Some of the next generation of EW systems being developed require quantities of modules that are several orders of magnitude greater than the current production capacity and experience of the industry. Present approaches for building microwave broad-band power amplifiers using MIC techniques are extremely labor intensive and sensitive to variations in assembly methods. However, MMIC technology has the advantage of reducing labor intensive activities and circuit sensitivity to critical tuning elements, thus improving reproducibility and module yield. This paper describes the use of two types of MMIC amplifiers in the development of a miniature power amplifier module targeted for future high-volume production. The first amplifier type is a cascade two-stage feedback amplifier, shown in Fig. 1, used to develop small-signal gain, while the second amplifier type is a cascade design, shown in Fig. 2, used for driver and output stage applications.

## II. Circuit Description

The use of controlled feedback in the design of microwave amplifiers is well established and is used extensively in amplifier designs. Some of the advantages of using feedback are improved gain flatness, reduced input/output port VSWR, increased stability, and reduced device count. The performance goals for the feedback amplifier were to achieve a gain of $10 \pm 0.7$ dB per chip, and a VSWR of less than 2.0:1 on both input and output ports. The amplifier design approach [1]–[3] consisted of accurately modeling a feedback loop for maximum available gain across the desired band. Fig. 3 shows the measured power and gain performance of the feedback amplifier at the 1-dB gain compression point.

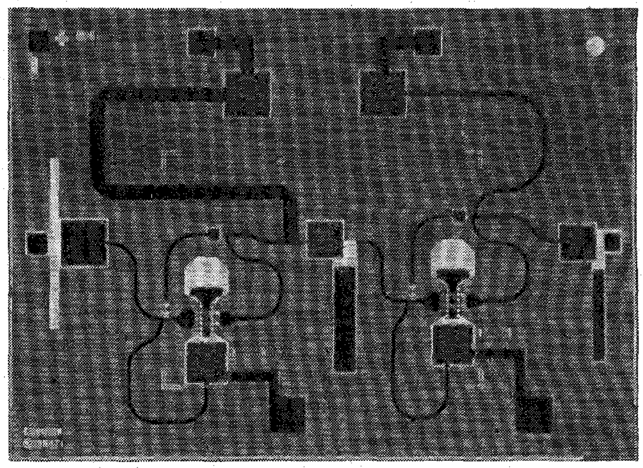

Fig. 1. 300–300-μm monolithic feedback amplifier.

The 900–1200-μm monolithic amplifier, called a power monolithic, was designed for optimum power performance throughout the 6.0–18-GHz frequency range [6]. A computer analysis of the 1200-μm FET's large-signal behavior was performed to determine the optimum termination impedance for maximum output power. Using the calculated impedance, the output matching networks were designed to present the optimum load to the FET. The input networks were designed to maintain a flat gain response using mismatch and equalization techniques. Both the input and output matching networks were of the high-pass form, which allowed for an easy method of biasing the amplifier. The measured power performance of the 900–1200-μm FET amplifier at the 1-dB gain compression point is shown in Fig. 4.

Both the feedback and power amplifiers were fabricated using similar techniques. The amplifiers were constructed on a 0.1-mm-thick semi-insulating GaAs substrate, with the active layers being formed by ion implantation. Via hole processing was accomplished using reactive ion etching. The MIM capacitors are of the metal/silicon–nitride/metal type, which have approximately 2000 Å of dielectric thickness. Resistors for the feedback amplifier were formed using the Mesa layer, while the power amplifier used alloyed AuGeNi resistors.

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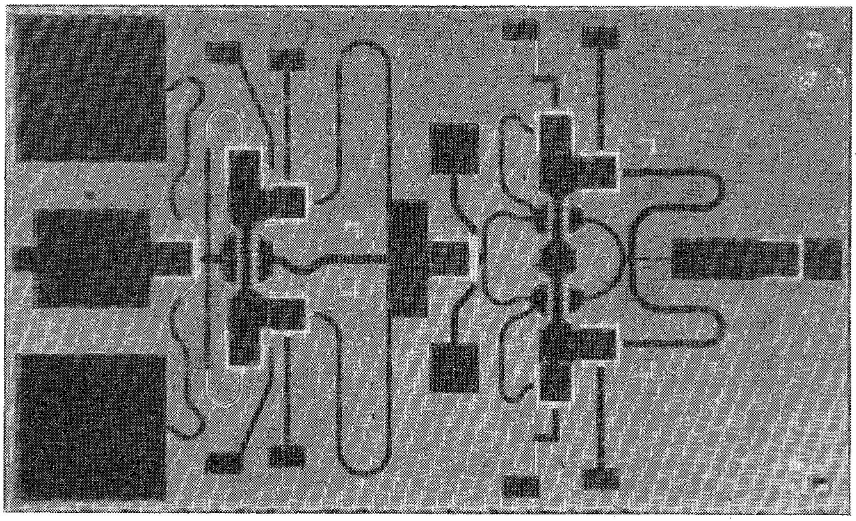
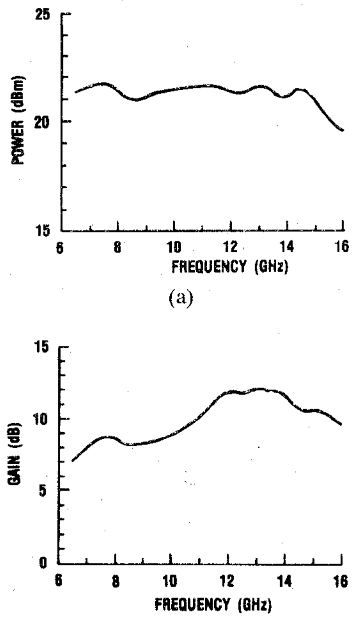


Fig. 2. 900–1200-$\mu$m monolithic power amplifier.




(a)

(b)

Fig. 3. Feedback amplifier MMIC (a) power and (b) gain at 1-dB gain compression.

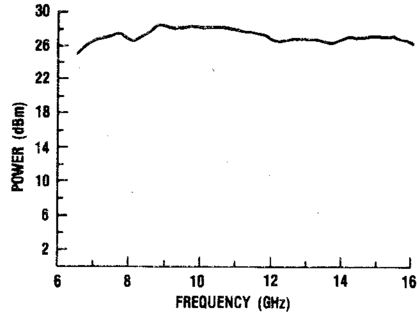



Fig. 4. Power amplifier MMIC power at 1-dB gain compression.

A four-stage power amplifier module, shown in Fig. 5, was designed using two feedback and six power amplifier MMIC's. The module dimensions were .75×2.2×.19 in. The first two stages of the module were used to develop small-signal gain and consisted of two cascaded feedback amplifier MMIC's. The feedback amplifiers were selected from the same GaAs slice and the $V_p$ and $g_m$ of the two stages were chosen to be nearly the same. However, the $I_{dss}$ of the second stage was chosen to be at least 20 mA higher than that of the first stage in order to obtain a high 1-dB compression point for the amplifier. The amplifier chain developed over 20 dB of small-signal gain and 19 dBm of saturated power. The feedback amplifiers were followed by a pair of power amplifier monolithics, balanced using Lange couplers. The balanced amplifier had a saturated output power of 25–27 dBm and was used as a driver for the module's final amplifier stage, called an output amplifier. The output amplifier was composed of four power monolithics arranged in parallel, using Lange couplers to balance the four monolithics in sets of two and Wilkerson power combiner/dividers to combine the balanced monolithics pairs. The output amplifier had a saturated output power of 31–33 dBm. The power monolithics used in the construction of the output and driver amplifiers came from the same GaAs slice and were chosen to have approximately the same $I_{dss}$, $V_p$, and $g_m$ characteristics. These criteria constrained the amplitude and phase of the power monolithics to track one another very closely, which resulted in excellent power-combining efficiency at the amplifier level. Fig. 6 illustrates the functional block diagram of the power amplifier module.

The power amplifier module was designed to operate in two modes: transmit and receive. In the transmit mode, all the amplifiers were turned on and the T/R switch connected the output amplifier to the output port. In the receive mode, the T/R switch connected the output port to the receive port, while the transmitted signal was blocked by shorting the output amplifier and turning off the feedback amplifiers.

The performance of the T/R switch is critical to the performance of the module. In the transmit mode, the T/R switch must have very low loss to avoid attenuating the transmitted signal while maintaining 55-dB isolation be-

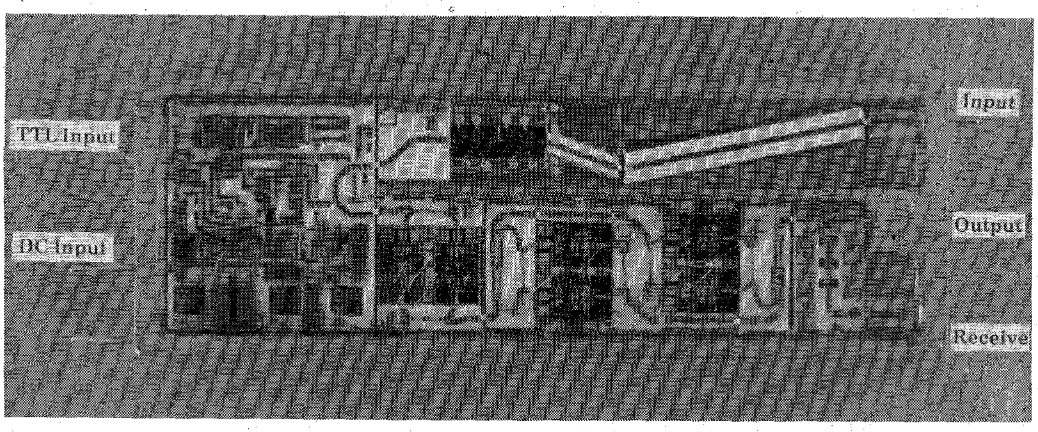



Fig. 5. Power amplifier module.

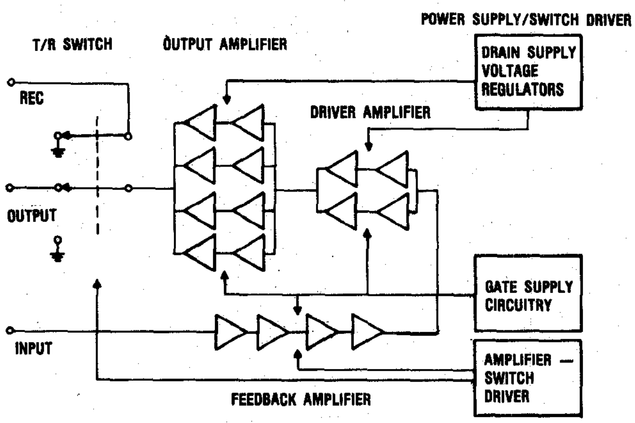



Fig. 6. Power amplifier module block diagram.

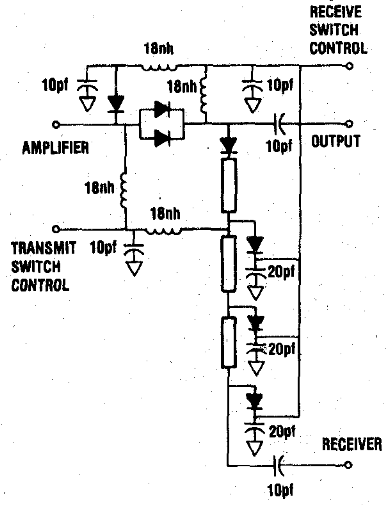



Fig. 7. Circuit schematic of transmit–receive switch.

tween the output and receiver port. Conversely, in the receive mode, the T/R switch must attenuate the transmitted signal by 20 dB while providing low insertion loss between the output and receiver ports. Finally, the time spent in transition between the receive and transmit modes must be kept to a minimum. The required performance was achieved by using a combination of series and shunt p-i-n diodes as shown in Fig. 7. RF energy radiating to the receiver port from the output port was blocked by bridging the receiver arm of the T/R switch with a small brass block. The negative supply available in the module did not have adequate current to drive the p-i-n diodes. As a result, a diode biasing network was used in which the diodes were connected in series between two positive switch drivers. The biasing scheme is illustrated in Fig. 7, where the signal from one switch driver enters the receive switch control line and the signal from the second switch driver enters the transmit switch control line. The switch drivers, controlled by a TTL signal, switched inversely from one another between 0 and +1 V, driving the diodes on and off. To isolate the dc bias from ground, the shunt p-i-n diodes were mounted on 20-pf chip ceramic capacitors. The 20-pf capacitor and shunt p-i-n diode combinations were placed in vias cut in the alumina substrate.

The dc regulation and switch driver functions required for module operation were performed inside the module by circuitry on a power supply/switch driver hybrid circuit. The inputs to this hybrid were a dc voltage of 10–14 V and a switch timing TTL signal. A bank of voltage regulators reduced the dc input to the 8-V drain voltage required by the power monolithics. The negative gate voltage for biasing the monolithics was produced by a dc/dc converter and its associated circuitry. High-power MOSFET switch drivers connected to the drains of the feedback amplifiers and the T/R switch were controlled by the input TTL timing signal. The internal processing of the dc and TTL input signals by the power supply/switch driver hybrid resulted in an amplifier module requiring a minimum of external interface.

The amplifier module requires adequate heat dissipation to prevent failure of the amplifiers. Considerable attention was paid to the materials and assembly techniques used to build the amplifier module. The module components were epoxied to molybdenum carrier plates and the carrier plates were epoxied to the module floor. The module housing was made out of KOVAR with several copper inserts placed in the floor beneath the areas of high-power dissipation. The carrier plates were made of molybdenum because of its high thermal conductivity; KOVAR was used for the module housing because it is easily machinable and has a coefficient of thermal expansion close to that of

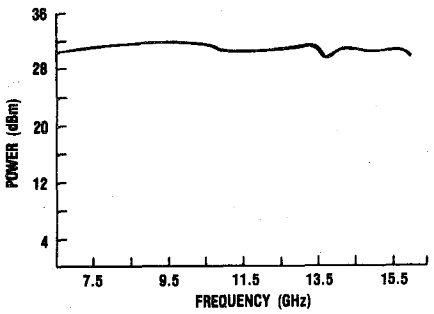



Fig. 8. Saturated output power of power amplifier module.

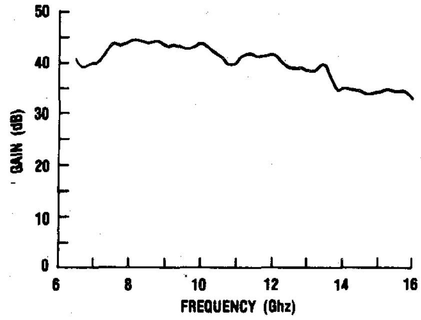



Fig. 9. Small-signal gain of power amplifier module.

molybdenum. Since the first iteration of the power amplifier module, a process for soldering the components and carrier plates into the module housing has been used with a resultant reduction in the modules thermal impedance. The components were assembled on separate carrier plates to allow for an easy circuit test prior to module integration. For extended operation, the amplifier module was mounted on an aluminum plate to provide a heat sink.

The small size of the module presented special problems in making adequate RF connection to the RF ports and in maintaining good isolation to prevent oscillations during testing. Two special connectors were developed to test the module. The receiver and input ports used a connector with a compressible, conductive gasket, which made a pressure contact fit, for ground, and a slip-in pin for RF. The output port used a slip-in connector which was inserted into a recess in the module housing.

## III. Module Performance

Module assembly and test were greatly simplified through the use of monolithic amplifiers. Since all the monolithic amplifier's RF components are on chip, assembly consisted of placing the monolithics on carrier plates, epoxying bypass capacitors by the drain and gate bias pads and bonding the monolithics to the gate and drain bias sources. This is a significant reduction in assembly effort when compared to that required for hybrid assemblies. An additional advantage was that no tuning was required during the unit test. Each amplifier assembly was simply turned on and the RF parameters evaluated. Repair of the amplifier assemblies was similarly facile. In the event of a monolithic amplifier failure, repair consisted of replacing the damaged chip and reconnecting the chip bias. These three advantages of monolithic technology greatly reduced the time and effort required to build and test each amplifier module.

Performance of the module was measured at room temperature with the module mounted in its test fixture. Cable losses in the test setup were removed through calibration. The saturated output power and small-signal gain, which were measured while the module was in the CW transmit mode, are shown in Figs. 8 and 9. Receiver isolation was determined by measuring the RF leakage at the receiver port during the transmit mode. The measured isolation was greater than 60 dB through the entire frequency range. Switching speeds, for the module changing between the receive and transmit modes, were less than 100 ns.

## IV. Conclusion

This paper has described the development of a miniaturized power amplifier module using several microwave monolithic circuits, demonstrating that monolithic technology can reduce the size and cost of producing difficult microwave designs. The MMIC circuits proved to be simpler and smaller than their MIC counterparts, and are well suited for high-volume production. The resulting module design demonstrates the promise that monolithic technology is a step closer to meeting the demands of the growing microwave industry.

## Acknowledgment

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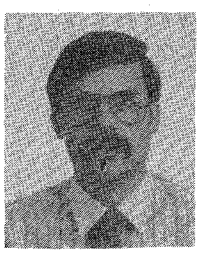

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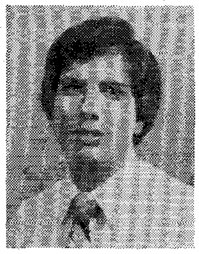

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