A Power Amplifier Module with Harmonics Suppression for Digital Mobile Communication

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ABSTRACT

A 1.9GHz miniaturized power amplifier module with a single low voltage supply of 3.0V, which was able to suppress second and third harmonics outputs, was developed. The volume of the module is 0.039 cc (3.4 x 5.8 x 2.0 mm). Good RF performance (adjacent channel leakage power of -55.5 dBc in the 600 kHz offset band, second harmonic power of -45.0 dBc, and third harmonic power of -46.2 dBc) was observed during operation at the desired maximum output power of 19.8 dBm. This module makes it possible to produce an RF transmission section without an external filter, that is, one having a small volume and a thin structure.

INTRODUCTION

Mobile radio communication systems are proliferating and the L-band digital mobile radio systems, such as Personal Digital Cellular (PDC) and Digital European Cordless Telephone (DECT), are spreading rapidly. In Japan the Personal Handy-phone System (PHS) has been introduced. This system utilizes a 1.9 GHz band π/4-shifted DQPSK (differential quadrature phase shift keying) signal. Power amplifier modules for transmitters are required to have small size, low voltage operation, high linearity, and low cost. Another desired characteristic is harmonics suppression. The people of several researchers [1, 2] have been referenced for the abouve requirements. We have developed a 1.9 GHz miniaturized power amplifier module with a single low voltage supply of 3.0 V, which is able to suppress second and third order harmonic outputs.

POWER AMPLIFIER MODULE

To achieve a small size, the power amplifier module is designed with optimum distribution of circuit components on a monolithic microwave integrated circuit (MMIC) and a substrate. For instance, the long transmission lines and large capacitors for the bias circuits have been constructed on the substrate rather than on the MMIC. Figure 1 shows the circuit block diagram of the power amplifier module.

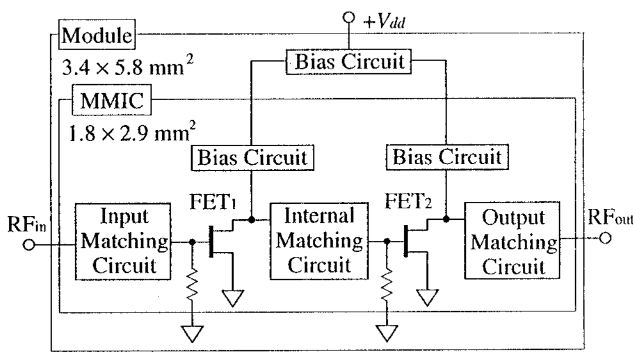

Figure 1. Block diagram of the power amplifier module.

1. MMIC Design

Refractory WNx/W self-aligned gate GaAs power MESFETs were used for the MMIC. This type of power MESFET, which operates in class AB bias with a single low voltage supply of 3.0 V and without an additional negative voltage supply, has a fully ion-implanted planar asymmetric self-aligned structure[3]. The two power MESFETs, a bias circuit, matching circuits for the input-stage, inter-stage and the output-stage were integrated on an MMIC chip. The total gate width of the power MESFETs was 0.6 mm in the first stage and 4.0 mm in the final stage.

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The output matching circuit of the MMIC is shown in figure 2. The output matching circuit including harmonics suppression is included on the MMIC, the additional loss through this circuit is designed to be 2 dB, which is reasonably low considering the advantage of the whole module's small volume. The additional loss is equivalent to the insertion loss and the assembly loss of the conventional external filter. The output matching circuit has both impedance matching and low-pass filter characteristics, and suppresses the output power of the second and third harmonics. The filter characteristics have been designed based on the biquadratic Chebyshev function[4]. We have carried out load-pull measurements for the final-stage MESFET to determine the load impedance which satisfies the requirements. The chip size was 1.8 x 2.9 mm. There was a 30% increase in chip area relative to similar MMIC chips with conventional matching circuits [3].

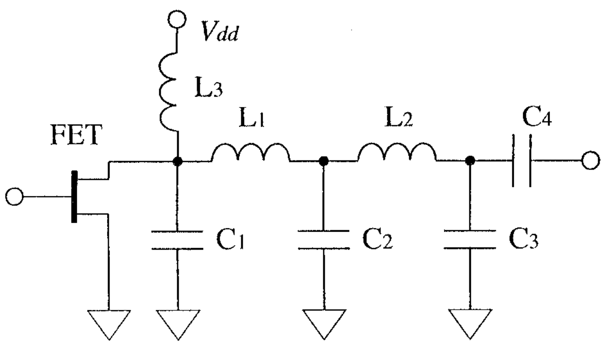

Figure 2. Output matching circuit.

2. Module Design

The power amplifier module consists of an MMIC, a substrate, and a conventional 1005-type chip capacitor. To achieve low module cost, the substrate has a single ceramic layer with gold and copper thick metal printed patterns, which were all baked at the same time. Gold pads are required for the bonding-wire connections between the MMIC and the substrate. Copper pads are required for soldering connections between the chip capacitors and the substrate, and between the printed circuit board (PCB) and the module. It was important to minimize the size of the module as well as the assembly area on the PCB. For the supply of signals and DC power, ground connections between the module and the PCB, a land grid array (LGA) structure on the bottom of the module is used. The assembly area is reduced by 60% compared with conventional packages with lead frames[5]. Additionaly, the LGA structure has better RF performance and heat radiation characteristics[5, 6]. Photographs of the power amplifier module are shown in figure 3. The module size with a cap is 0.039 cc (3.4 x 5.8 x 2.0 mm), which is 65% smaller than the previous module we had made[7]. The drain bias circuit consists of coplanar transmission lines, which have 100 μm line widths and gaps of 50 μm on both sides, and a conventional 1005-type chip capacitor(1000 nF). The bias circuit was determined by simulated results of electromagnetic analysis by the moment method and measured characteristics of the chip capacitor. Figure 4 shows the simulated result of the isolation between the bias circuits of first stage and final stage MESFET. This module made it possible to produce an only DC bias line from PCB to the module by the above techniques.

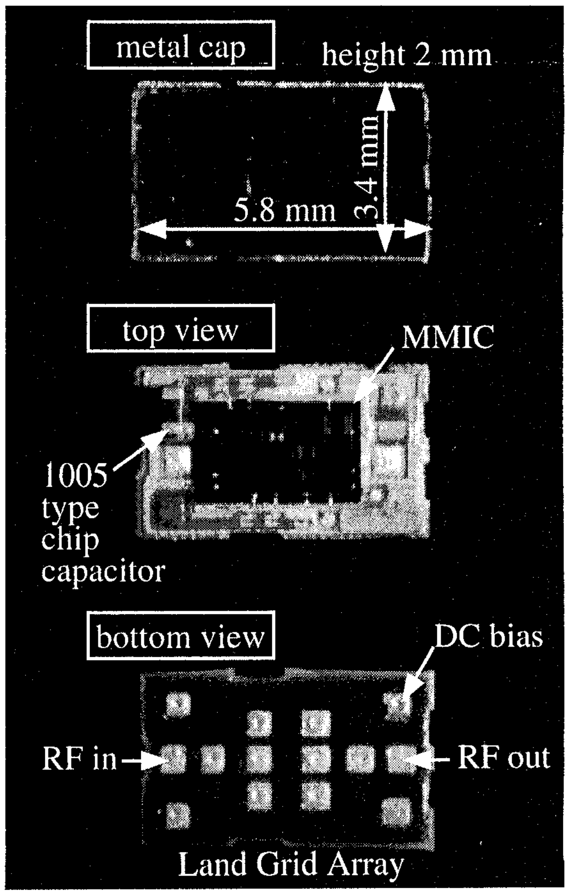

Figure 3. Photograph of the power amplifier module.

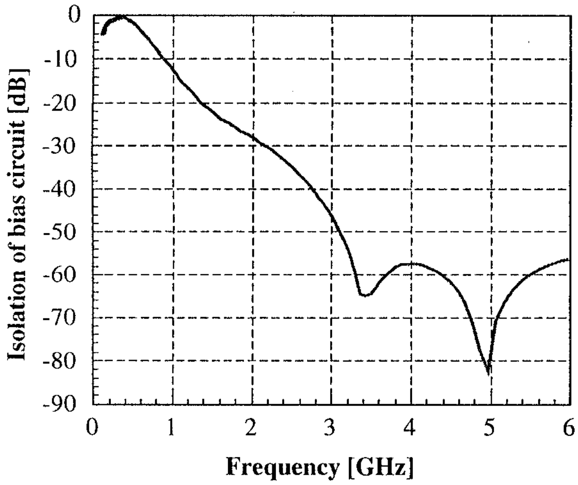

Figure 4. Simulated results of isolation for bias circuit between the first stage and final stage MESFET.

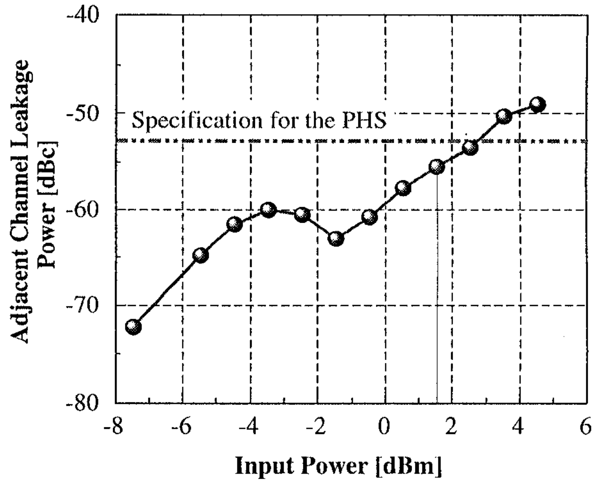

Figure 6. Adjacent channel leakage power in the 600 kHz offset band of the power amplifier module.

RF PERFORMANCE

The output power of the power amplifier module for π/4-shifted DQPSK modulated input signals (384 kbps, roll-off factor α=0.5) in the 1.9 GHz band was also measured at a drain bias of 3.0 V. The output power requirement of the PHS terminal is 80 mW (19 dBm). This requirement of this module without an external filter is 19.8 dBm because the loss of RF switch is less than 0.8 dB, typically. Figure 5 shows the output power of the module. The drain current for the desired maximum output power of 19.8 dBm was 242 mA. Figure 6 shows the adjacent channel leakage power characteristics in the 600 kHz offset band. The measurement results satisfied the specifications of in-band distortion for the PHS. The results indicate that the module performed with sufficient linearity. Figures 7 and 8 show the second and third harmonics in the output signal. The suppression of harmonics was improved by more than 15 dB in comparison to modules with conventional output matching circuits[7]. The measurements show that the module satisfied the specifications of out-band distortion for the PHS.

Table 1 shows the performance comparison between the proposed module and the conventional module. In the table, corresponding values for MMICs with conventional output

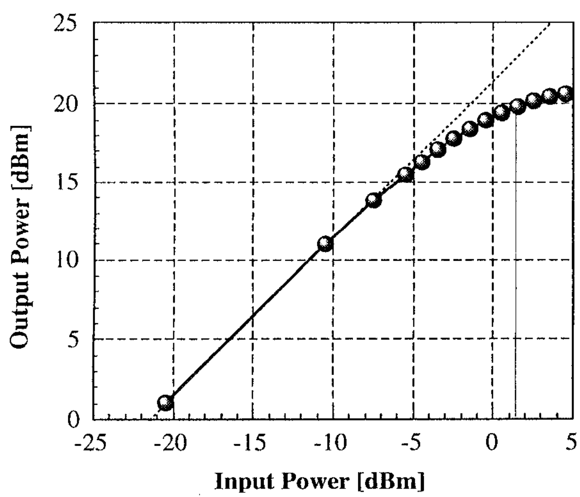

Figure 5. Output power of the power amplifier module for π/4-shifted DQPSK modulated input signals in the 1.9 GHz band.

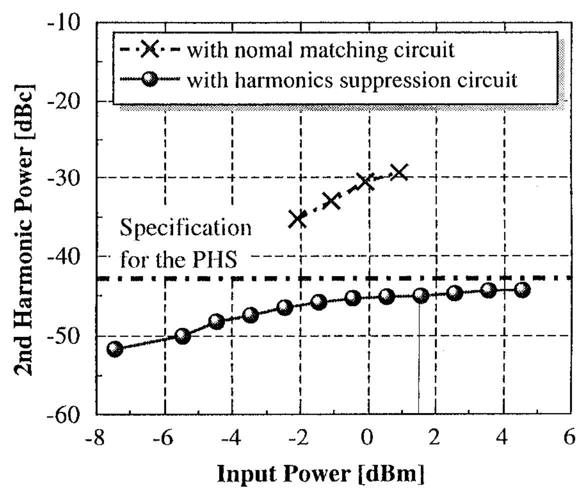

Figure 7. Second harmonic output power of the power amplifier module.

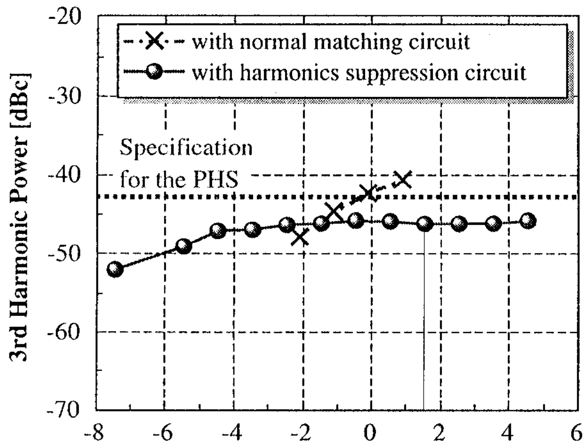

Figure 8.Third harmonic output power of the power amplifier module.

Table 1. Comparison of harmonics suppression with conventional module.

Module	New*	Conventional [7]	
Input power [dBm]	-1.4	-1.4	-4.5
Output power [dBm]	20.5	22.5	20.5
Second harmonic [dBc]	-49.1	-26.9	-31.6
Third harmonic [dBc]	-66.1	-44.2	-48.2
Drain current [mA]	242	240	

* with harmonics suppression circuit

matching circuits and a similar drain current are shown for comparison. The additional loss for the new output matching circuit of the module was thought to be 2 dB, which was the difference of the output power at the same input signal power. The harmonics suppression of this MMIC was, however, much better than that of conventional MMICs at 2 dB back-off. The power amplifier module with normal usage in the PHS (4ch-TDMA/TDD and the voice activty) predicted to consume about 20 mA, while the total current of a typical PHS terminal is approximately 100 mA. Thus the efficiency of the module is sufficiently good.

CONCLUSIONS

A 1.9 GHz miniaturized power amplifier module with a minimum single low voltage supply of 3.0 V, which is able to suppress second and third harmonics outputs, has been developed. The volume of the module is 0.039 cc (3.4 x 5.8 x 2.0 mm). This module made it possible to produce an RF transmission section without an external filter, and thus, having a small volume and a thin structure. The design technique will realize a 1 chip RF front-end MMIC. This is suitable for small terminals including those used in Personal Communications System (PCS), such as the PHS in Japan.

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REFERENCES

[1] S. Makioka, et al., "A High Efficiency GaAs MCM Power Amplifier for 1.9 GHz Digital Cordless Telephones", IEEE 1994 Microwave and Millimeter-Wave Monolithic Circuits Symposium, IV-2, pp. 51-54, June 1994

[2] M. Ida, "Microwave MCM using Ceramic Multi-layer Functional Substrate", MWE '96 Microwave Workshop Digest, WS2-4, pp. 67-71, Dec. 1996

[3] M. Nagaoka, et al., "High-Efficiency Monolithic GaAs Power MESFET Amplifier Operating with a Single Low Voltage Supply for 1.9-GHz Digital Mobile Communication Applications", Proc. of IEEE MTT-S, pp. 102-108, 1994.

[4] G. L. Matthaei, "Tables of Chebyshev Impedance Transforming Networks of Low-Pass Filter Form", Proc. of IEEE, pp. 939-963, Aug. 1964.

[5] N. Ono, et al., "Miniaturized Power Amplifier Module using LGA Structure", Proc. of International Microelectronics Conference '96, pp. 192-197, 1996.

[6] M. Konno, et al., "1.9 GHz Band Power Amplifier Module", Proc. of 1995 Microwave Workshops and Exhibition, pp. 256-261, Dec. 1995.

[7] E. Takagi, et al., "Miniaturized Power Amplifier Module for 1.9-GHz Digital Mobile Communication Applications", Proc. of 1994 Asia Pacific Microwave Conference, pp. 355-358, Dec. 1994.