# A GSM/EDGE Dual-Mode, 900/1800/1900-MHz Triple-Band HBT MMIC Power Amplifier Module

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*Abstract*—This paper describes a 3.5-V operation HBT MMIC power amplifier module for use in GSM/EDGE dual-mode, 900/1800/1900-MHz triple band handset applications. With diode switches and a band select switch built on the MMIC, the module delivers a $P_{out}$ of 35.5 dBm and a PAE of about 50% for GSM900, a 33.4-dBm $P_{out}$ and a 45% PAE for GSM1800/1900. While satisfying an error vector magnitude (EVM) of less than 4% and a receive-band noise power of less than -83 dBm/100 kHz, the module also delivers a 29.5 dBm $P_{out}$ and a PAE of over 25% for EDGE900, a 28.5 dBm $P_{out}$ and a PAE of over 25% for EDGE1800/1900.

## I. INTRODUCTION

With the increase of data communications as well as voice data, multi-mode, multi-band handsets, which enable users to automatically roam across different operating systems and operating frequencies, are strongly required for digital cellular phones such as GSM, DAMPS, DCS, and so on [1]-[8]. To address this requirement, the enhanced data rates for GSM evolution (EDGE) air interface [9,10] is being introduced to GSM systems, however, to our knowledge, there is no report on a power amplifier suitable for GSM/EDGE dual-mode handset applications.

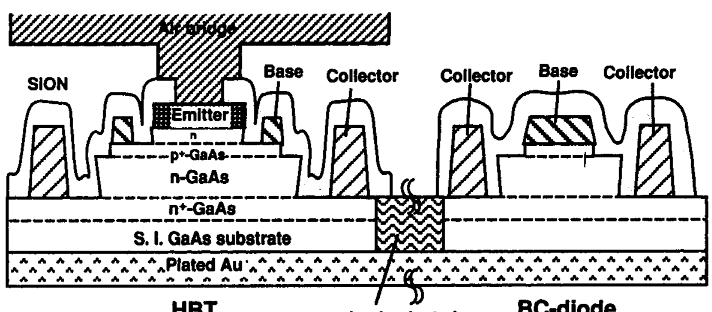
In this paper, we present a newly developed, 3.5-V operation HBT MMIC power amplifier module for GSM/EDGE dual-mode, 900/1800/1900-MHz triple-band applications. The circuit architecture using on-chip diode switches, proposed in this study, enables the GSM/EDGE dual-mode operation which requires much different behavior between the saturated amplification in GSM and the linear amplification in EDGE. In addition, the on-chip band select switch suppresses waste current of an inactive amplifier by the delicate current control. These techniques can realize a dual-mode MMIC amplifier module with good output power characteristics. This paper focuses on the architecture consideration and diode switch design.

## II. DEVICE AND PROCESS DESCRIPTION

In-house GaAs-based HBTs are used for the MMIC power amplifier module to deliver high output power density with single voltage operation.

Figure 1 illustrates a cross sectional view of the HBT and a base-collector diode. Typical DC characteristics are also listed in the figure. The diode is utilized for the diode switch as a detailed description will be given later. The HBT features an emitter air-bridge structure with individual thermal shunt paths, thereby reducing thermal resistance of great importance for practical use [7], [11]. The substrate thickness is as thin as 75 μm, and helps the reduction in the thermal resistance. The multi-finger HBT ($4 \times 20 \mu m^2 \times 100$ finger) achieves a low thermal resistance of 17°C/W, a 35-dBm $P_{out}$, and more than 60% PAE at 900 MHz.

As a passive element, several thin film resistors, MIM capacitors, and microstrip line inductors are integrated on the MMIC, together with substrate via-holes.




| Item | Typical value |
|---|---|
| DC current gain | 100 |
| Breakdown voltage | 15V (BVceo) |
| | 22V (BVcbo) |
| Equiv. series res. of BC diode | 6.5Ω /100μm² |

Fig. 1. Device structure of HBT and BC-diode, and typical DC characteristics.



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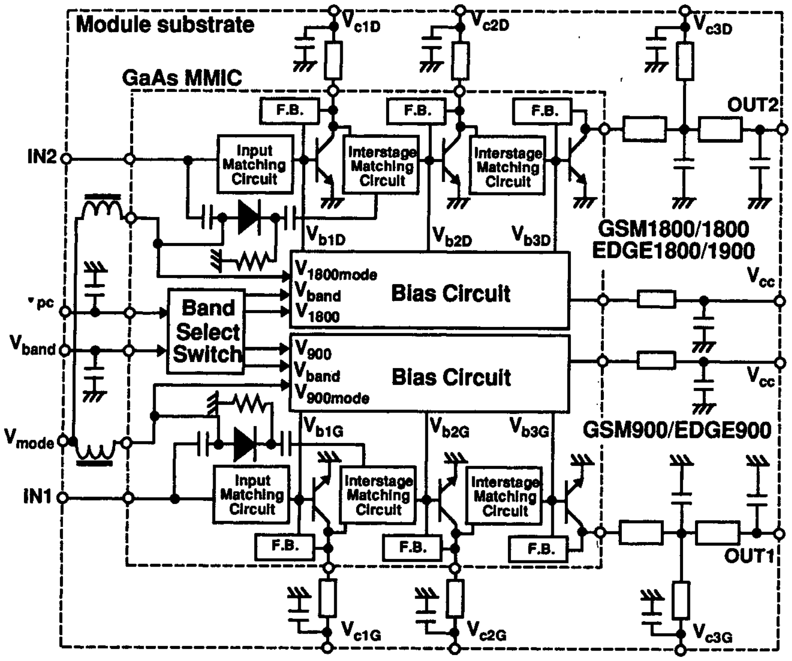



Fig.2. Block diagram for dual-mode, triple-band MMIC power amplifier module.

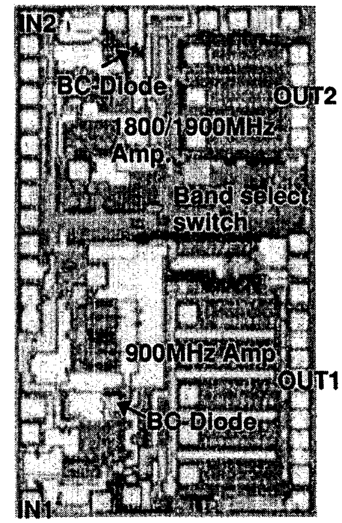



Fig. 3. Chip micrograph for dual-mode, triple-band MMIC power amplifier.

## III. Circuit Design

### *A. Amplifier Architecture*

A simplified block diagram of the MMIC power amplifier module is shown in Fig. 2. Two amplifier solution in the same chip is adopted for the MMIC amplifier module architecture, because the solution allows each amplifier to be optimized independently for the bands of interest, and the incorporation of analog HBT switches onto the chip is difficult under a low-operating voltage condition [5,7]. As shown in Fig. 2, interstage matching circuits, bias circuits, and a band select switch [7] are integrated on the chip. Matching elements were determined based on source/load-pull measurement results. In each amplifier stage, an RC-feedback circuit (F.B.) is employed for more stable operation. In GSM/EDGE systems, an isolator is often placed between an antenna switch and an amplifier in order to suppress the output load impedance variation for the amplifier. Therefore, higher output power is required for the amplifier, compared to that of conventional GSM/DCS dual-band amplifiers. To attain high output power of more than 35 dBm and 33 dBm required for the GSM900 and 1800/1900 operation mode, a $4 \times 20 \mu m^2 \times 100$ emitter-finger HBT is utilized for the final stage of a GSM/EDGE900 amplifier, and a $4 \times 20 \mu m^2 \times 60$ emitter-finger one for a GSM/EDGE1800/1900 amplifier.

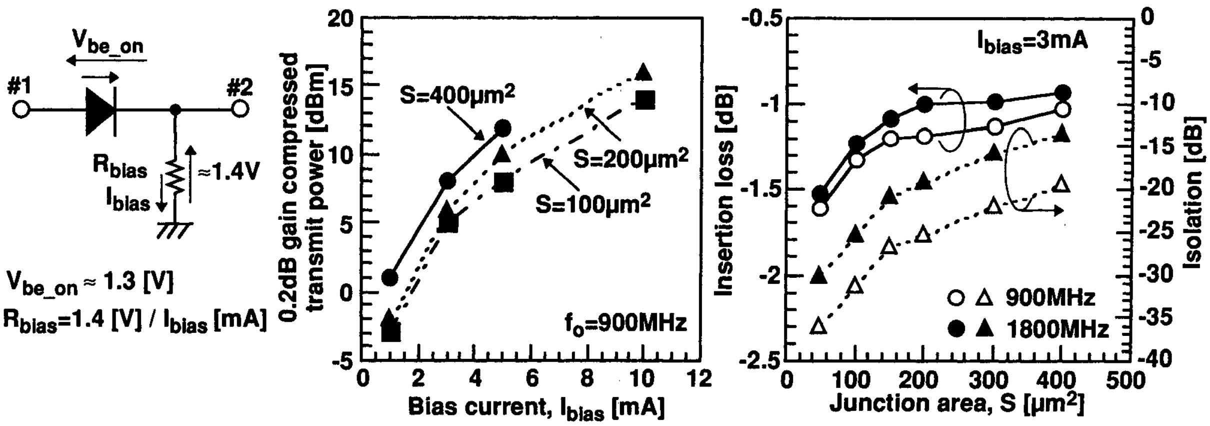
The essential technical issue of a GSM/EDGE dual-mode amplifier is to suppress the noise power in the receive band (RX-noise) within -79 dBm/100kHz (system specification) while the amplifier keeps high efficiency operation [9]. In the GSM/EDGE systems, the receive band is allocated in the 20 MHz upper band from the carrier. Generally, the RX-noise (N) in GSM is given by the following formula

$$N[dBm/100kHz] = -174dBm/Hz \cdot 100kHz + F[dB] + G[dB],$$

where 100 kHz is the measurement bandwidth, F and G are noise figure and gain of the amplifier in receive band. Conventional GSM amplifiers have a high linear gain of 40 dB or more to realize high efficiency operation in a large gain compression state exceeding at least 5 dB. On the other hand, an EDGE amplifier needs a linear operation to prevent signal distortion. This means that a high linear gain amplifier cannot be applied to the EDGE amplifier, because the high gain leads to a high RX-noise as estimated in the above formula.

To overcome this technical issue, we have changed the linear gain of the amplifier using the diode switches between the GSM and EDGE modes, as shown in Fig. 2. This architecture enables a high gain for GSM mode and a low gain for EDGE mode, thus allowing the amplifier to operate with high efficiency in both modes while satisfying the RX-noise specification.

The chip micrograph is shown in Fig. 3. To assemble a module, the chip was mounted on a glass-ceramic sub-




(a) (b) (c)

Fig. 4. RF characteristics for diode switch: (a) circuit diagram, (b) 0.2dB gain compressed transmit power versus bias current, and (c) insertion loss, isolation versus diode junction area.

strate with a small size of 7.5 x 7.5 x 1.8 $mm^3$ together with several surface mount type elements.

*B. Diode Switch*

The insertion loss of the diode switch which bypasses the first stage in the EDGE mode should be as low as possible. In contrast, the isolation should be as high as possible. We used the simple diode switch with a resistor load, $R_{bias}$, as shown in Fig. 4(a). Fig. 4(b) shows the measured transmit power characteristics versus bias current. In Fig. 4(b), 0.2-dB gain compressed transmit power is plotted as a parameter of the total junction area, S, where $R_{bias}$ is varied so as to maintain a turn-on voltage of the diode switch of 2.7 V as shown in Fig. 4(a). As shown in Fig. 4(b), a bias current of over 3 mA is necessary to transmit an input power of over 5 dBm without distortion. The measured insertion loss and isolation versus the junction area are depicted in Fig. 4(c), where the bias current is 3 mA. The results indicates that the maximum diode junction area is 200 μm for the isolation level of about 20 dB at 900 and 1800 MHz. Thus, we determined the diode junction area of 200 μm and its bias current of 3 mA.

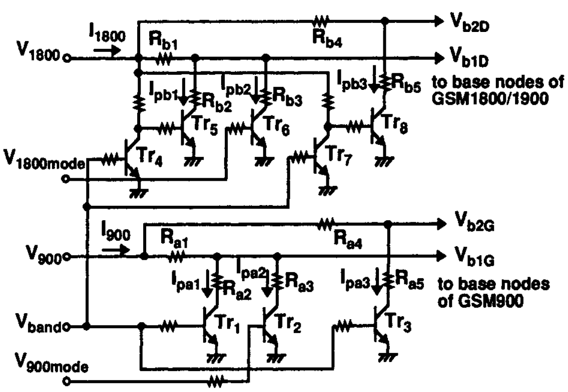



Fig. 5. Bias pull-down circuit for current injection.

*C. Bias Circuit*

In the GSM mode, output power has to be gradually controlled by a control voltage, $V_{pc}$, to suppress transient spurious emission for the rise and fall duration of the power output. To meet this requirement, we have adopted a current injection bias scheme for the first and second stages, while the final stage is driven by a conventional emitter follower to prevent the increase of an unnecessary control current, $I_{pc}$, and attain high output power.

Figure 5 shows the bias circuit diagram for the first and second stages. The additional transistors, $Tr_1$ *to* $Tr_8$, implements the pull-down of the bias voltage for the inactive amplifier, thereby greatly reducing the waste current through the inactive amplifier. This delicate current control is useful for enhancing the signal isolation between both amplifiers as well as helping high efficiency operation of the whole amplifier.

## IV. MEASUREMENT RESULTS

Measured power characteristics for 900/1800/1900-MHz-bands are shown in Figs. 6 and 7. Supply voltages, are all 3.5 V. The module delivers a $P_{out}$ of 35.5 dBm and a PAE of about 50% for GSM900, a 33.4-dBm $P_{out}$ and a 45% PAE for GSM1800/1900. While satisfying an EVM of less than 4% and a receive-band noise power (RX-noise) of less than -83 dBm/100kHz, the module also delivers a 29.5 dBm $P_{out}$ and a PAE of over 25% for EDGE900, a 28.5 dBm $P_{out}$ and a PAE of over 25% for EDGE1800/1900. The maximum $P_{out}$ slope versus $V_{pc}$ is less than 140 dB/V thanks to the current injection bias scheme. These good characteristics sufficient for GSM/

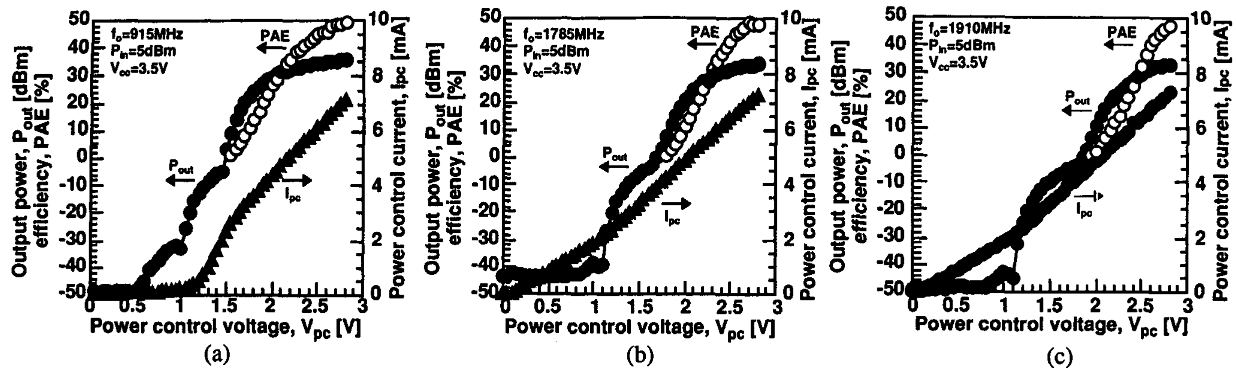



Fig. 6. Measured characteristics of power amplifier module in GSM mode: (a) 900MHz, (b) 1800MHz, and (c) 1900MHz.

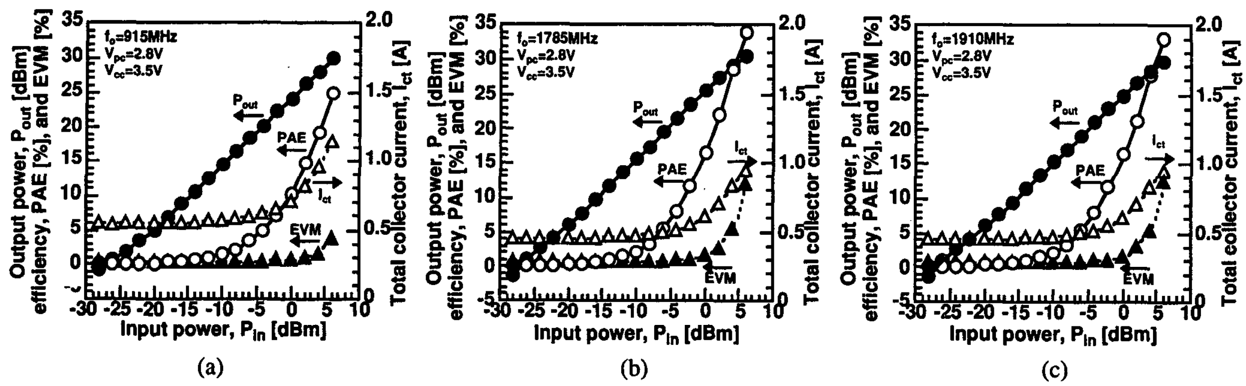



Fig. 7. Measured characteristics of power amplifier module in EDGE mode: (a) 900MHz, (b) 1800MHz, and (c) 1900MHz.

EDGE practical use are due to the proposed architecture and careful bias current control.

## IV. Conclusion

We have demonstrated the 3.5-V HBT MMIC power amplifier module for use in GSM/EDGE dual-mode, 900/1800/1900-MHz triple-band applications. To our knowledge, this module is the first to be reported in a 3.5-V operation GSM/EDGE dual-mode GaAs-based HBT MMIC power amplifier module including an on-chip HBT band select switch. The module will realize small-size, light-weight GSM/EDGE dual-mode handsets.

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