Single-chip Dual-band WLAN Power Amplifier using InGaP/GaAs HBT

Chien-Cheng Lin[1], Yu-Cheng Hsu[2]

Computer & Communications Research Laboratories, Industrial Technology Research Institute,
195 Sec. 4, Chung Hsing Rd., Chutung, Hsinchu 310, Taiwan R.O.C., Phone: +886-35915554,

E-mail[1]: peter.cclin@gmail.com, E-mail[2]: YCH@itri.org.tw

Abstract — **A single-chip dual-band power amplifier monolithic microwave integrated circuit (MMIC) operating at 3.5V single supply has been developed for both WLAN 2.4GHz and 5.2GHz with IEEE 802.11b/g/a standards applications. The MMIC utilizes the process of WINs Corp. with an InGaP/GaAs HBT process. The dual-band power amplifier constructed based on the design of adaptive RF bias choke circuits and proper output matching networks. The proposed WLAN PA chip provides low current consumption and high power added efficiency. The WLAN-PA is implemented as a two-stage MMIC with active bias and input pre-matching and inter-stage matching networks integrated. In addition, the PA is a broadband power amplifier with above 20dB flat gain between the frequency bands of 2.2GHz to 5.5GHz.**

I. INTRODUCTION

Wireless Local Area Network (WLAN) applications in wireless communication systems are developed rapidly, and it has driven the innovation of the RF integrated circuit designing techniques. In wireless communication market, the key factor we concerned is cost down. Fully discrete RF front-end solutions, although requiring more board space, are often less risky and give the end user the opportunity to choose among several suppliers achieving both the best performance and lower cost. In contrast, partial integration of multiple front-end components or critical RF tuning, such as in the case of a matched PA, may shorten system design time, provide faster time-to-market.

In this paper we present one cost-effective, fully input and interstage matched chip of WLAN power amplifier MMIC that could be applied to 2.4GHz and 5.2GHz two frequency bands, and we only need to design an adaptive bias choke circuit with specific frequency on the module board, and then it help us to reduce much design time and design cost.

II. MMIC CIRCUIT DESIGN

Heterojunction Bipolar Transistor (HBT) technology is an advanced transistor technology for high frequency and high performance applications. InGaP/GaAs-based HBT benefits from a wide bandgap material in the emitter layer, particularly at the emitter-base junction. As a result, high base doping concentration makes the GaAs HBT with a very high current gain, a relatively low base resistance, and a high Early voltage. The high base doping concentration also allows the base region to be made quite thin. This has two important effects: the transit time across the base is very short; and the base transport factor, α_T, is very high, allowing for high operating frequency and increasing the current gain, respectively.

The proposed WLAN-PA is a power amplifier optimized for the FCC Unlicensed National Information Infrastructure (U-NII) band applications in the 5.15-5.35 GHz frequency range. The device is manufactured by WINs Corporation with an InGaP/GaAs HBT MMIC process. To achieve over 20dB of gain and 25dBm of P_{1dB}, a two-stage topology was selected. This power amplifier MMIC is designed for two stages, using two power transistors of different size combinations, and integrated with two base bias circuits, and broadband RF input and inter-stage matching networks for dual bands. The driver stage is composed of eight transistor cells with each emitter area of 2.8umX6um. The power stage is composed of thirty-two power cells with each emitter area of 2.8umX12um, and the total chip size is 1150um X 850um within 6 I/O pins, as shown in Fig. 1. We only need to implement a quarter-wavelength RF bias choke and a simple output matching circuit on a printed circuit board (PCB) to obtain the optimum output power for 2.4GHz or 5.2GHz. The RF bias choke in the circuit is adaptive by using different scales of bypass capacitors C1 and C2 to fit optimum performance for 2.4GHz or 5.2GHz, as shown in Fig. 1. In order to reduce losses in the matching networks, 1mil bond wires connected with external high-Q quarter-wavelength RF bias chokes were uesd instead of on-chip spiral inductors. The schematic of the WLAN PA MMIC is shown in Fig.2.

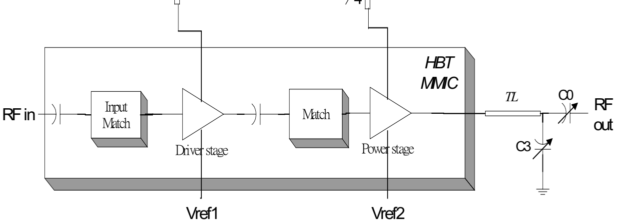


Fig. 1 Functional block diagram of the proposed WLAN power amplifier

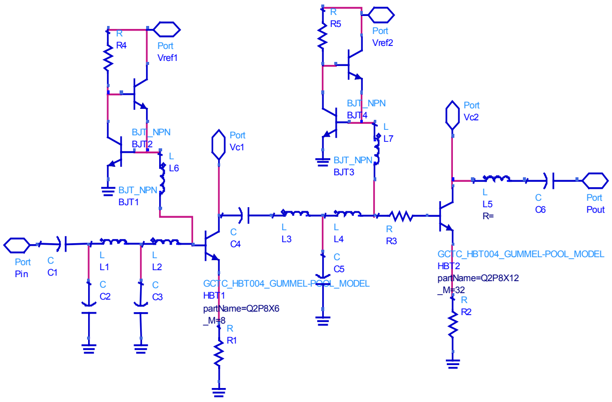


Fig. 2 Schematic of the dual-band WLAN power amplifier HBT MMIC

III. EXPERIMENTAL RESULTS

The proposed power amplifier MMIC is measured on a printed circuit board (PCB) with external quarter-wavelength RF bias chokes and simple output matching networks. There are two paths on the PCB; one is for 2450MHz path, and the other is for 5200MHz path, however, both paths use the same PA chip. The major differences between these two paths are the bias choke bypass capacitors and the output decoupling capacitor. The WLAN PA evaluation PCB is shown in Fig.3. First, we add the appropriate DC supply voltage 3.5V to Vcc and Vref respectively on PCB, and the quiescent DC current is below 50mA. To achieve high efficiency, the WLAN PA operates in class AB mode. Figure 4(a) shows the simulated and measured small signal S parameters in the 5200MHz path. It could be easily observed that the power amplifier was broadband and with 20dB of flat gain between 2.2 to 5.5GHz, but S11 and S22 were optimized for 5.2GHz. After replacing two bias bypass capacitors and an optimum output decoupling capacitor for 2450MHz, the overall performance was so different, and the circuit within 27dB of gain was optimized for 2450MHz. Figure 4(b) shows measured small signal S parameters in the 2450MHz path.

Single tone performance was assessed to verify the basic design of the PA. Figure 5 shows measured gain and output power and PAE versus single tone input power, demonstrating that original design targets were successfully achieved at the bands of 2450MHz and 5200MHz respectively. The 30dB of gain and 25dBm of P_{1dB} and about 40% of PAE are measured at the path of 2450MHz. Fig. 5(b) shows the 24dB of gain and 25dBm of P_{1dB} and over 50% of PAE and operating total current at the path of 5200MHz. Next, linear performance was evaluated through EVM (Error-Vector Magnitude) measurements using an OFDM modulated signal. The EVM measurements in this work have been performed using Agilent Vector Spectrum Analyzer system. Figure 6 shows the Power Mask of OFDM modulated signal on Spectrum at 5.2GHz. Figure 7 shows EVM measurements of proposed WLAN PA on 802.11b, 802.11g and 802.11a respectively. The EVM of 2450MHz path and 5200MHz path are 3.37% and 3.77% respectively at linear output power on OFDM 64QAM/54Mbps modulated signal.

IV. CONCLUSION

The single-chip dual-band WLAN power amplifier operates at a frequency of 5200MHz under a single low supply voltage of 3.5V with a very low quiescent DC current of 50mA, and with +25dBm of P_{1dB}, and 24dB RF power gain, and over 50% P.A.Eff. at P_{1dB} between 5.15 to 5.35 GHz. For +18dBm OFDM output power (64 QAM, 54 Mbps), it provides a very low EVM of 3.77%, and consumes less than 200 mA total current. While at the frequency of 2450MHz, the PA module could be also applied to IEEE 802.11b/g standards with +25dBm of P_{1dB}, 30dB of RF power gain, about 40% P.A.Eff. at P_{1dB}, 250mA of total current(CW), and 3.37% of EVM for +18dBm OFDM output power (64 QAM, 54 Mbps). The WLAN PA is an ideal solution for broadband, medium-gain power amplifier requirements for IEEE 802.11a/b/g WLAN applications.

ACKNOWLEDGEMENT

The authors would like to thank Wins Semiconductor, Corp. for their contribution to MMIC fabrication. They also wish to acknowledge the assistance and support of all those who contributed for their valuable comments and encouragement throughout this work.

REFERENCES

[1] S. C. Cripps, RF Power Amplifier for Wireless Communications, Artech House, Inc., 1999.

[2] M. S. Shirokov, E. S. Gray, D. A. Little, G. Hau, and J. A. Roche Jr., "Low-Cost Wide-Range Low-Current Consumption Linear HBT MMIC Power Amplifier for Portable 2.4GHz WLAN Applications," in *Proceedings of the 12th GAAS Symposium*, Amsterdam, NL, October 2004, pp. 13-16.

[3] G. Gonzalez, Microwave Transistor Amplifiers Analysis and Design, 2nd ed., Prentice-Hall, Inc., 1997.

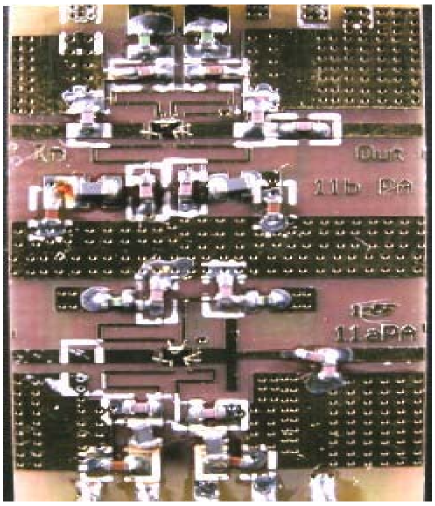


Fig. 3 Photograph of the dual-band WLAN PA module evaluation PCB

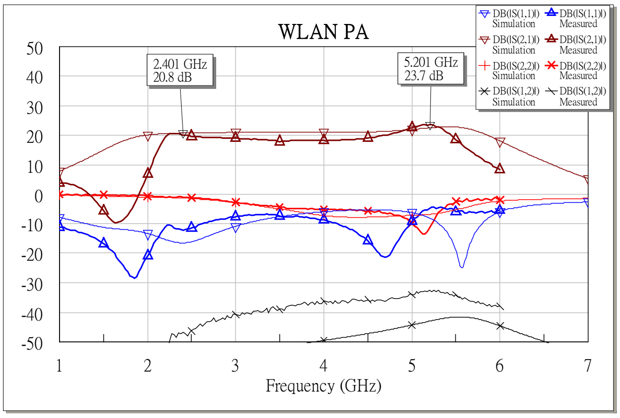


Fig. 4(a) simulated and measured small signal S parameters in the 5200MHz path

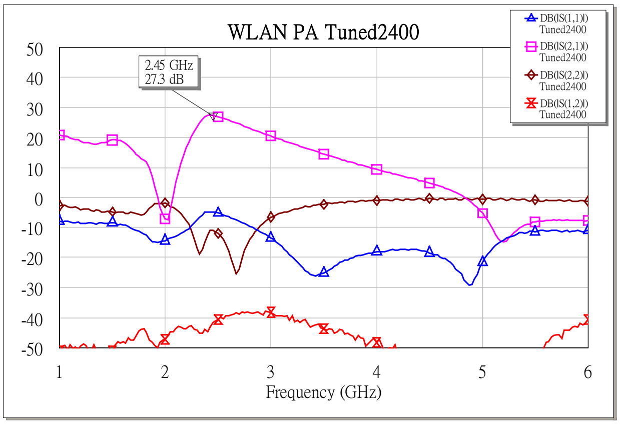


Fig. 4(b) measured small signal S parameters in the 2450MHz path

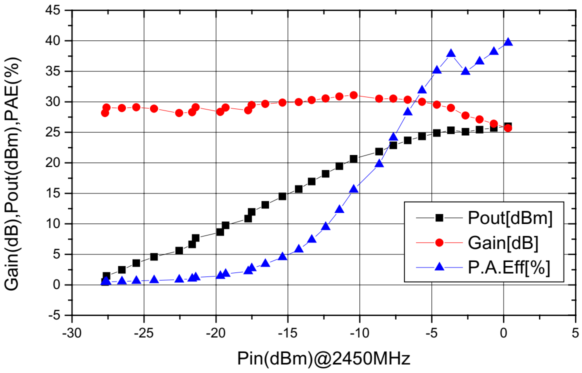


Fig. 5(a)

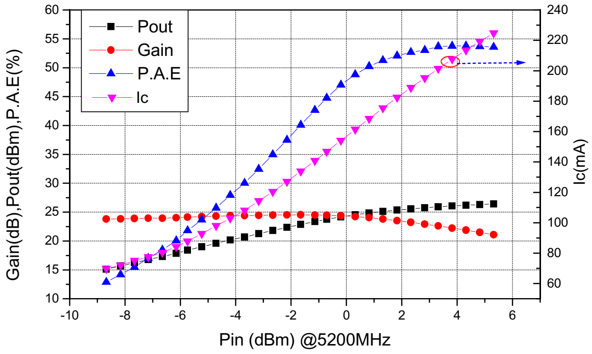


Fig. 5(b)

Fig. 5 Measured Gain, Pout, and P.A.E. versus Pin of power (Fig.5 (a) measured at 2450MHz; and Fig.5 (b) measured at 5200MHz).

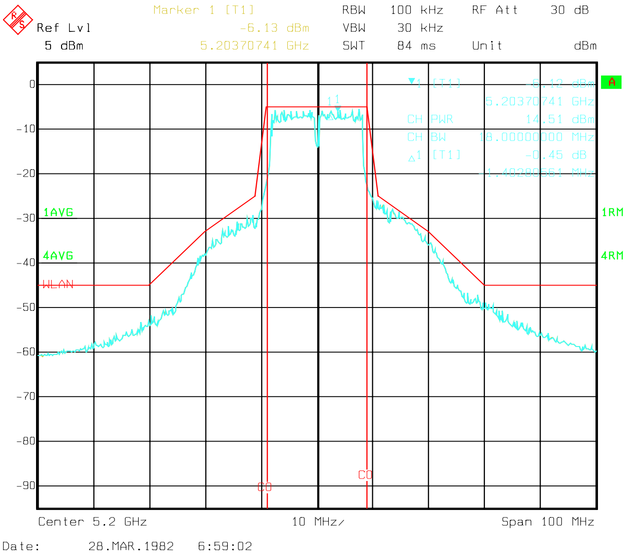


Fig. 6 Power Mask of OFDM modulated signal on Spectrum at 5.2GHz

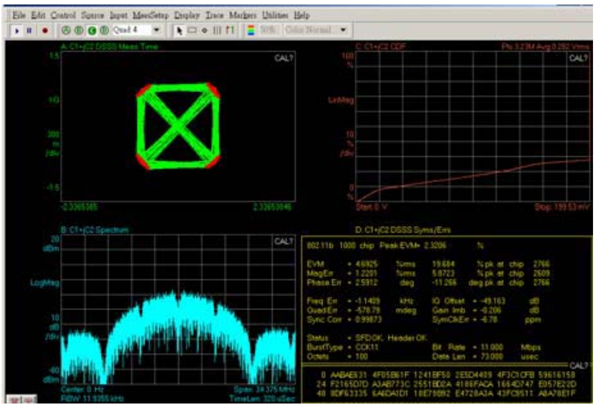
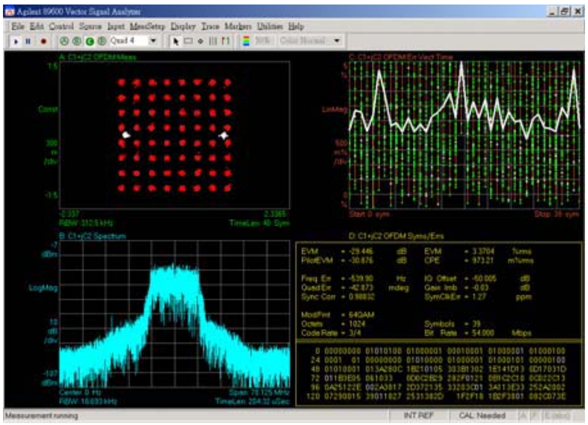


Fig. 7(a) EVM < 2% @ Pout=22dBm, 11Mbps CCK, 2.4GHz(802.11b)



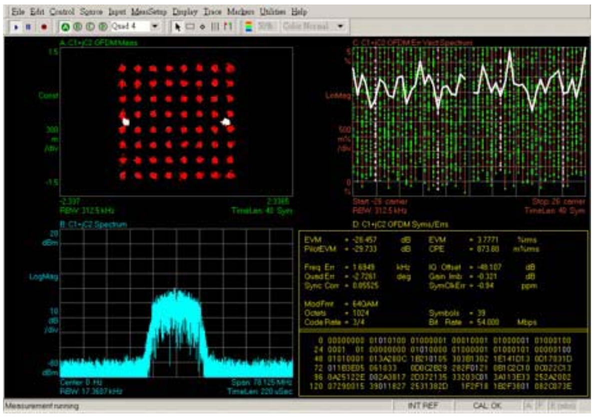
```
D: C1+jC2 OFDM Syms/Errs
EVM        = -29.446   dB     EVM       = 3.3704   %rms
PilotEVM   = -30.876   dB     CPE       = 973.21   m%rms

Freq Err   = -539.90   Hz     IQ Offset = -50.005  dB
Quad Err   = -42.873   mdeg   Gain Imb  = -0.03    dB
Sync Corr  = 0.98832          SymClkErr = 1.27     ppm

ModFmt     = 64QAM
Octets     = 1024             Symbols   = 39
Code Rate  = 3/4              Bit Rate  = 54.000   Mbps

  0 00000000 01010100 01000001 00010001 01000001 01000100
 24 0001   01 00000000 01010000 01000001 01000101 00000100
 48 01010001 013A280C 1B210105 303B1302 1E141D13 0D17031D
 72 011B3E05 061033   0D0C2B29 282F0121 0B1C2C10 0C022C13
 96 0A25122E 002A3817 2D372135 33203C01 3A113E33 252A2002
120 07290015 39011827 2531382D   1F2F18 1B2F3801 082C073E
```

Fig. 7(b) EVM = 3.37% @ Pout=18dBm, 64QAM/54Mbps OFDM, 2.45GHz (802.11g)



```
D: C1+jC2 OFDM Syms/Errs
EVM        = -28.457   dB     EVM       = 3.7771   %rms
PilotEVM   = -29.733   dB     CPE       = 873.80   m%rms

Freq Err   = 1.6949    kHz    IQ Offset = -48.107  dB
Quad Err   = -2.7261   deg    Gain Imb  = -0.321   dB
Sync Corr  = 0.85525          SymClkErr = -0.94    ppm

ModFmt     = 64QAM
Octets     = 1024             Symbols   = 39
Code Rate  = 3/4              Bit Rate  = 54.000   Mbps

  0 00000000 01010100 01000001 00010001 01000001 01000100
 24 0001   01 00000000 01010000 01000001 01000101 00000100
 48 01010001 013A280C 1B210105 303B1302 1E141D13 0D17031D
 72 011B3E05 061033   0D0C2B29 282F0121 0B1C2C10 0C022C13
 96 0A25122E 002A3817 2D372135 33203C01 3A113E33 252A2002
120 07290015 39011827 2531382D   1F2F18 1B2F3801 082C073E
```

Fig. 7(c) EVM = 3.77% @ Pout=17dBm, 64QAM/54Mbps OFDM, 5.2GHz (802.11a)