Wi-Fi/WiMAX Dual Mode RF MMIC Front-end Module

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***Abstract* — A dual-mode RF front-end module is designed and implemented for Wi-Fi/WiMAX applications. It consists of a front-end MMIC and a dual-band power amplifier MMIC, both fabricated by 0.5μm E/D-mode p-HEMT process. The front-end MMIC integrates a single-pole triple-throw antenna switch, two low noise amplifiers, a low pass filter and a diplexer in single chip. Overall module size is compact 7 mm x 10 mm, well tested with Wi-Fi/WiMAX OFDM signals.**

***Index Terms* — Wi-Fi, WiMAX, dual band, RF front-end, power amplifier, pHEMT.**

I. INTRODUCTION

The development of WiMAX brings a revolution in wireless broadband communications. WiMAX covers many popular applications such as cellular, wireless LAN and last-mile Internet-access technologies. Because of the complicated modulation scheme of WiMAX signal, the RF front-end module requires high linearity and high power handling capability. InGaAs E/D-mode p-HEMT technology is an attractive solution for WiMAX RF circuit[1]. Enhanced-mode pHEMT is suitable for RF amplifiers due to its low noise, high trans-conductance and high linearity. Depletion mode pHEMT is favorable for antenna switch due to its low turn-on resistance, high isolation and high power handling capability.

In this paper, an RF front-end module comprised of a front-end MMIC and a dual-band power amplifier both fabricated by WIN semiconductor 0.5μm InGaAs E/D-pHEMT process is demonstrated. As shown in Fig.1, it is designed for 2.4-2.5 GHz Wi-Fi and 3.4-3.6 GHz WiMAX bands. Dual-mode solution ensures full access to wireless environment. In section II we present a front-end MMIC which integrates a single-pole triple-throw (SP3T) antenna switch, two low noise amplifiers , an RF low-pass filter and a diplexer. The MMIC size is 1.65 mm x 1.35 mm.

Next, in section III we present a dual-band class-AB power amplifier with fully-integrated input and inter-stage matching circuits. Dual-band matching circuits are designed to optimize the gain and power performance of each mode. The MMIC size is 1.0 mm x 2.0 mm.

Finally, a complete RF front-end module including the two MMICs is demonstrated and tested with standard Wi-Fi and WiMAX OFDM signal. The measured results will be discussed in section IV.

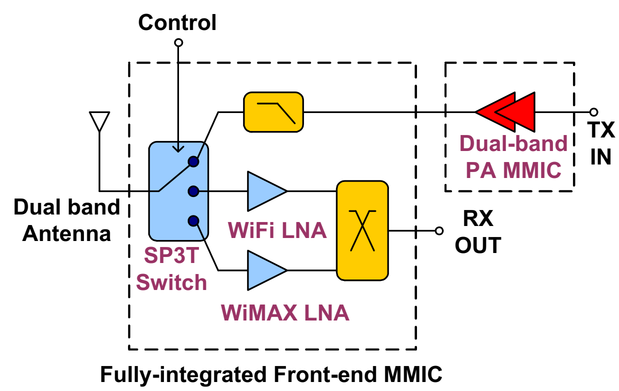


Fig. 1. Proposed Wi-Fi/WiMAX RF MMIC front-end module.

II. FRONT-END MMIC DESIGN

The proposed front-end MMIC includes an SP3T antenna switch, two low noise amplifiers, a low pass filter and a diplexer, as shown in Fig.1. For dual band operation, two independent low noise amplifiers are designed at Wi-Fi and WiMAX bands separately to avoid interference. A diplexer for receiver signal separation and filtering is also integrated on chip. The low pass filter on transmitting path is used to filter out harmonics from power amplifier.

A. Low noise amplifiers

In this work, enhancement-mode p-HEMT transistors are used in low noise amplifiers to earn low noise figure and drain current. Additionally, high quality integrated passive devices can be built due to low-loss characteristic of GaAs substrate. Fig.2 shows circuit schematic. The input port is matched to the output port of antenna switch and the output is optimized for maximum power transfer to diplexer. Bias and stabilization circuits are designed to minimize noise figure with low current, high gain and high linearity. The drain current of the cascoded transistors is limited below 5 mA to save power without linearity degradation.

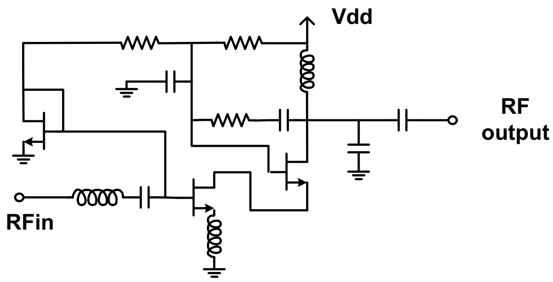


Fig. 2. Schematic of low-noise amplifiers.

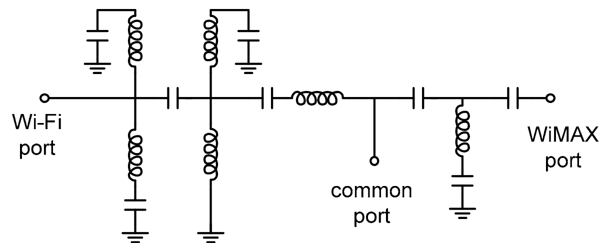


Fig. 3. Schematic of on-chip diplexer.

B. Antenna switch

Depletion-mode pHEMT transistors exhibit low turn-on resistance and high power handling capability. It is desirable for antenna switch. In this work, the switch transistors are put in series-series configuration to provide high isolation. Multi-gate transistor structure further improves isolation without increase in circuit area and linearity degradation. Additionally, the power handling capability is higher because the voltage distribution is more uniform[2]. The corresponding transistor size is determined by the requirement of Wi-Fi and WiMAX standards. Larger transistor provides higher power handling capacity but poor isolation because of more parasitic capacitance in off-state.

C. Integrated passive device - low pass filter and diplexer

Integrated passive device has been developed to reduce cost and size of RF modules[3]. It is applicable in proposed MMIC because GaAs substrate has lower loss. To meet Wi-Fi and WiMAX standard simultaneously, the insertion loss in the transmitting path of the proposed RF front-end module is limited to 1.8 dB and the noise figure in receiving path is limited to 3 dB. On these constraints, the low pass filter is designed in parallel resonant circuit, with spiral inductor and parallel MIM capacitors. The transmission zeros are allocated in second and third harmonic frequencies of WiMAX band. Parasitic inductances and capacitances of GaAs substrate and metal lines are EM simulated to optimize the performance.

An on-chip diplexer is designed to separate Wi-Fi and WiMAX signals. In Wi-Fi mode, a low pass network plus a second-order band-pass network is synthesized to suppress signal below 1.8 GHz and provides isolation in the WiMAX band. Simulated insertion loss is 3.6 dB and isolation is more than 20 dB. In WiMAX mode, a high-pass architecture is synthesized to suppress signal at Wi-Fi band. Simulated insertion loss is 1.4 dB and isolation is more than 20 dB, too.

The front-end MMIC is optimized for Wi-Fi and WiMAX bands, respectively. On-chip routing between antenna switch, low noise amplifiers and integrated passive devices is matched for better noise and linearity.

III. DUAL-BAND POWER AMPLIFIER DESIGN

To minimize chip size, power consumption and meet various wireless applications, multi-band power amplifier architecture is investigated. Engineers may use one broad-band matching circuit to cover multiple standards[4]-[5]. Nevertheless, a more straight approach is applying multi-band matching circuit in desired bands.

In this work, a dual-band power amplifier MMIC is designed and fabricated by enhancement-mode p-HEMT technology. The cut-off frequency is above 30 GHz. According to [6], the ability to operate from a single power supply and good power handling capability at low bias voltages makes enhance-mode pHEMT transistor attractive for RF power generation in portable wireless applications. Its high thermal stability and linearity are also superior for high-power application such as WiMAX.

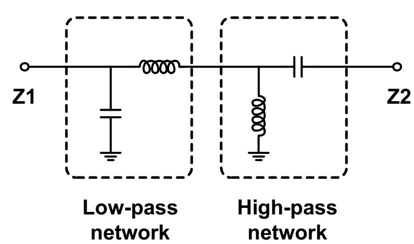


Fig. 4. Proposed dual-band matching network

Fig.4 shows the proposed dual-band matching network comprised of a high-pass and a low-pass network in series connection. The matching network transforms the impedances at two different frequencies to 50Ω. Fig.5 illustrates the operation mechanism and the corresponding impedance loci of dual-band matching network. In this case for example, two different impedances at different frequencies $Z1\_hi=250\Omega$ and $Z1\_lo=150\Omega$ are both matched to 50Ω using four lump elements. The matching network can be optimized for best RF performance.

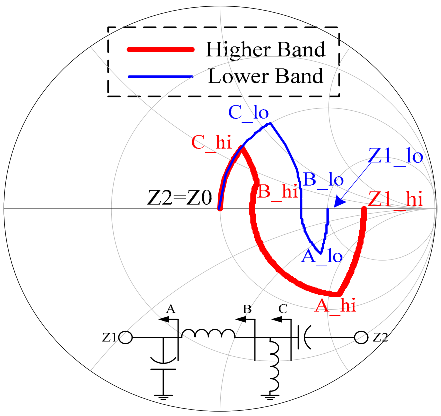


Fig. 5. The impedance loci of dual-band matching network.

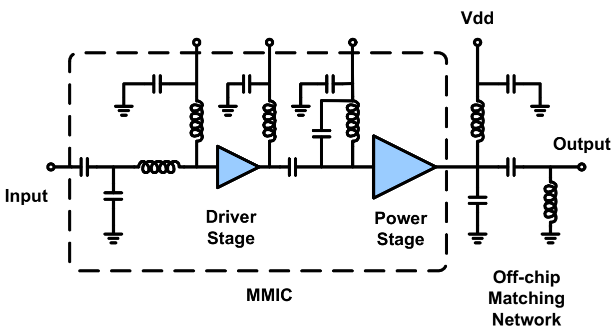


Fig. 6. Schematic of dual-band power amplifier.

The schematic of the dual-band power amplifier is shown in Fig.6. The input and inter-stage matching circuits are fully-integrated on chip. Output matching circuit is implemented by off-chip surface mount devices for lower loss. The bias conditions for WiMAX mode is V_{dd}=5 V and I_{dd}=744 mA. For Wi-Fi mode, it is V_{dd} =3.3 V and I_{dd} =166 mA.

IV. MEASUREMENT RESULTS

A. Front-end MMIC

The front-end MMIC is measured without external matching or biasing circuits. In transmitting mode, the insertion loss is 1.4 dB in Wi-Fi and 1.8 dB in WiMAX bands. Input P1dB is more than 34 dBm, sufficient to operate with typical Wi-Fi/WiMAX power amplifier without power and linearity degradation.

The receiving mode exhibits 11.2 dB of gain, 2.5 dB of noise figure and 0.5 dBm of input P1dB at Wi-Fi band. In WiMAX band, the receiving mode exhibits 13 dB of gain, 2.8 dB of noise figure and -1 dBm of input P1dB. The return losses are more than 10 dB in each mode. Power consumption of receiving mode in continuous-wave operation is 15 mW. The isolation of receiving mode in both bands is excess 30 dB, provided by diplexer and matching circuits of low noise amplifiers. Measured S-parameters are shown in Fig.7.

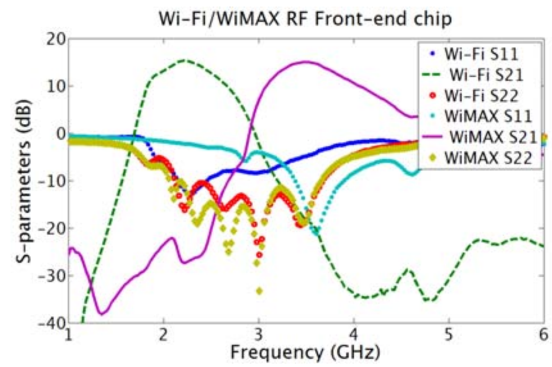
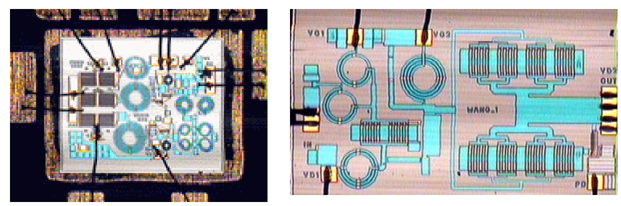


Fig. 7. Measured S-parameters of front-end MMIC.



(a) (b)

Fig. 8. The photographs of (a) front-end MMIC and (b) dual-band power amplifier MMIC.

B. Dual-band power amplifier

The dual-band power amplifier is measured on board. Power gain is more than 25 dB and the return loss is better than 10 dB in both Wi-Fi and WiMAX modes. Fig.9 and Fig.10 show measured RF power performance. The output P1dB for Wi-Fi and WiMAX modes are 25.5 and 32.9 dBm, respectively.

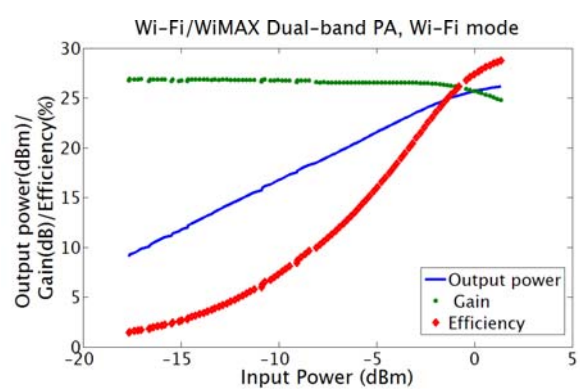


Fig. 9. Measured power performance of the dual-band power amplifier at Wi-Fi mode

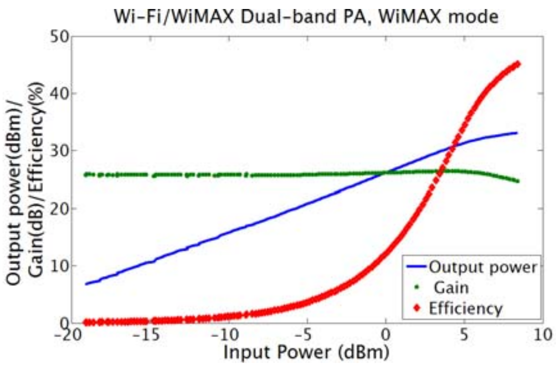
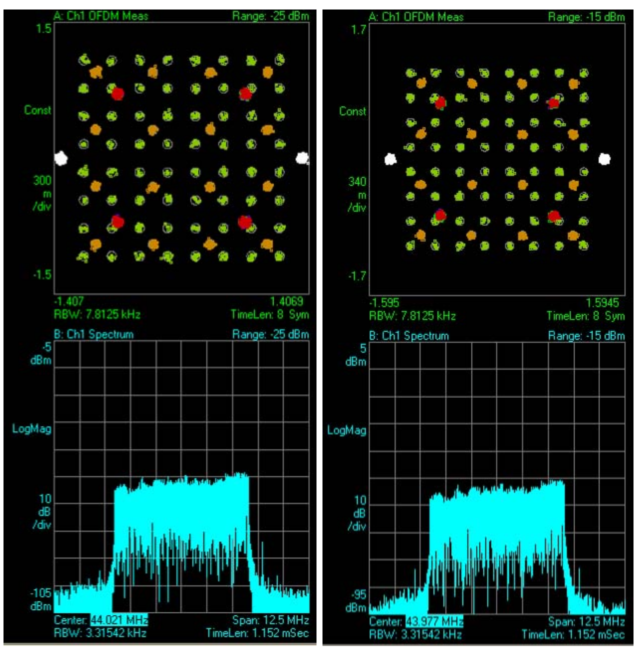


Fig. 10. Measured power performance of the dual-band power amplifier at WiMAX mode

C. Complete RF front-end module

The complete module in Fig.1 is implemented as shown in Fig.12. The proposed RF front-end module is tested with standard Wi-Fi and WiMAX OFDM signals. Fig.11 shows the test result of transmitting path on the criteria of 3% EVM in Wi-Fi mode and 2.8% EVM in WiMAX mode. The power delivered by the module exceeds 20 dBm in Wi-Fi mode and 25 dBm in WiMAX mode. The RF performance is well tested for Wi-Fi and WiMAX applications.



(a) (b)

Fig. 11. Constellation and spectrum diagrams in the EVM tests of proposed RF front-end module. (a) Wi-Fi mode, 3% EVM and (b) WiMAX mode, 2.8% EVM.

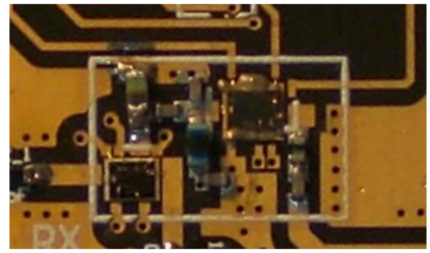


Fig. 12. Photograph of proposed RF front-end module. The area of the white-line rectangular block is 7 mm x 10 mm.

V. Conclusion

A dual-mode RF front-end module comprised of a front-end MMIC and a dual-band power amplifier MMIC both fabricated by WIN semiconductor 0.5μm InGaAs E/D-mode p-HEMT process is implemented and demonstrated. The front-end MMIC size is 1.65 mm x 1.35 mm and the power amplifier MMIC is 1.0 mm x 2.0 mm. The complete module size is 7 mm x 10 mm and is well tested for Wi-Fi and WiMAX applications.

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