

A Compact Flip Chip Single Die WiFi FEM for Smart Phone Application

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Abstract — A flip chip single die WiFi FEM is developed using Bi-FET (HBT+E/D-PHEMT) technology for smart phone application. High thermal conductive copper-pillar bumps were developed for the flip chip process. This FEM flip chip die consists of a high-pass filter (HPF), a 2GHz WiFi PA with on-chip regulator, PAON logic and detector circuit, and an SP3T. It showed good over-voltage and over-temperature performance when mounted on test LTCC module. Thermal modeling and design optimization kept junction temperatures comparable to wirebond versions of the design. A complete WiFi front-end LTCC module was developed using flip chip FEIC, integrated balun and SAW filter, with 3.2mmx3.2mm size for Smart Phone Application.

Index Terms — Flip Chip, Copper Pillar, Solder Bump, Front-End IC, LTCC, WiFi, FEM, Smart Phone.

I. INTRODUCTION

The WiFi FEM for Smart Phone application needs to meet small size, low cost and stringent cell coexistence rejection requirements. Figure 1 shows the block diagram of a typical WiFi FEM which consists of a power amplifier, an SP3T, a balun and a SAW filter.

To save cost, designers minimize die size and integrate as many features as possible on a die [1]. One way to reduce system size is to utilize flip-chip technology. Flip chip designs have a number of advantages over traditional chip-and-wire designs. These advantages include reduced overall cost, reduced module size, and simplified assembly.

II. FLIP CHIP FEIC DESIGN

A flip chip single die WiFi FEM is developed using Bi-FET (HBT+E/D-PHEMT) technology for smart phone application. High thermal conductive copper-pillar bumps were developed for the flip chip process [2]. This FEM die consists of a high-pass filter (HPF), a 2GHz WiFi PA with on-chip regulator, PAON logic and detector circuit, and an SP3T. The HPF provides rejection for WCDMA at 2.17GHz. The 3-stage PA provides 33 dB gain with good linearity (3% EVM, 17dBm) and good efficiency ($I_{cc}=135mA @ 18dBm$) for the FEM at the antenna port. The SP3T can be switched to connect the antenna port to the Tx port (PA output), Rx port, or BT port. A detector output is available to monitor FEM output power. The FEM is biased by a single battery supply (Vbat) from

2.3V to 4.8V. The digital command for PAON and SP3T Vex varies from 1.6V to 2.1V.

The design process of the flip-chip FEM included thermal modeling and design optimization to insure that maximum junction temperatures remained comparable to the wirebond version of the design.

Figure 2 shows the schematic of this flip chip FEM. The photograph of this flip chip FEM die using Cu-pillar bumps is shown in Figure 3. The die size is 1.5mm x 0.9mm.

The photograph of Flip Chip FEIC die mounted on a LTCC test module (3.2mm x 3.2mm) along with R, L, C SMD parts for PA & SP3T bias and command is shown in Figure 4.

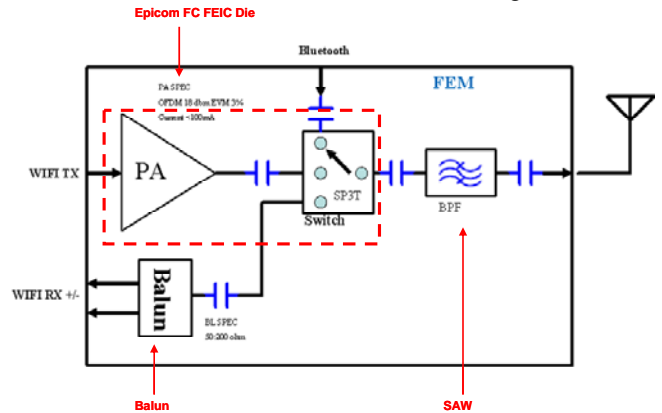


Fig. 1. Block Diagram of WiFi RF FEM for Smart Phone.

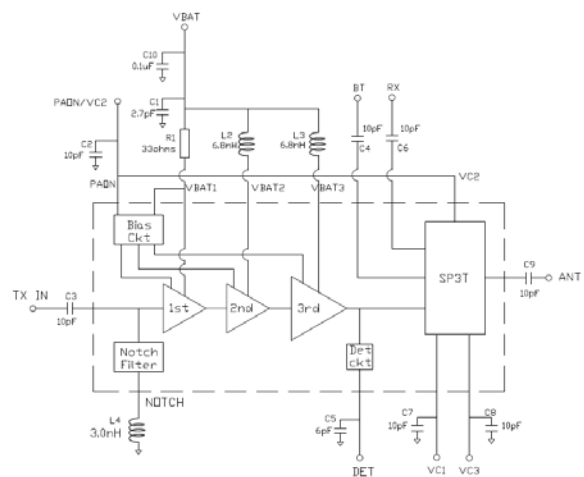


Fig. 2. Flip Chip FEM Schematics.

III. FLIP CHIP FEIC TEST DATA

The S-parameter data of Tx mode at nominal bias ($V_{bat}=3.3V$, PAON=SP3T $V_{c2}=1.8V$) is shown in Figure 5. The FEM has 33dB gain and better than 15 dB return loss in band. The 2.17 GHz rejection can be improved by adjusting the external high-Q notch inductor. Figure 6 shows the S-parameters of both Rx and BT modes. The insertion loss is around 0.7dB (at SP3T V_{c1} or $V_{c3}=1.8V$) and return losses are better than 15dB in band.

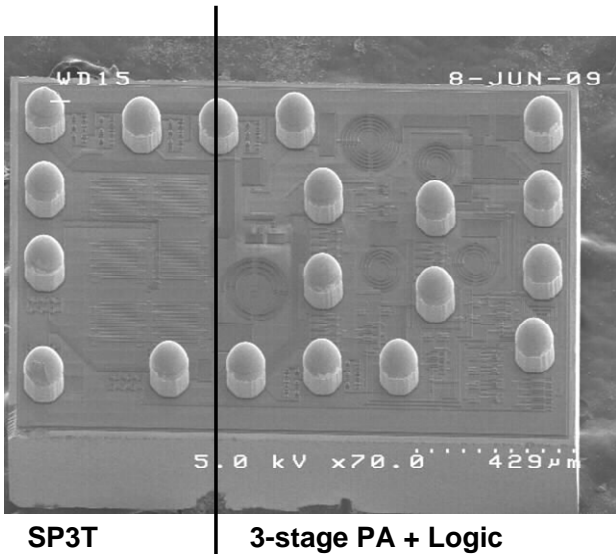


Fig. 3. Flip Chip FEM Die Photo, 1.5mmx0.9mm.

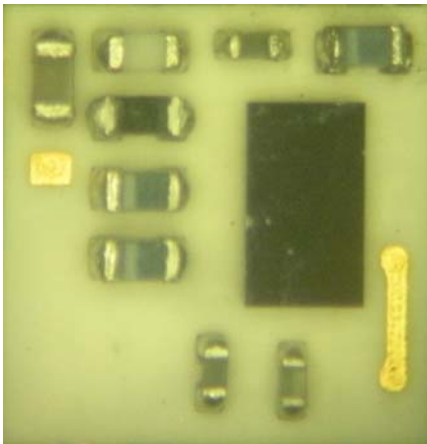


Fig. 4. Flip Chip FEIC on LTCC Test Module (3.2x3.2mm)

Figure 7 shows the EVM/Icc vs. Pout of the flip chip FEM at 2.412-2.484GHz. EVM is less than 3% up to Pout=17dBm. It has $I_{cq}=72mA$ and $I_{cc}=135mA$ @18dBm at $V_{cc}=+3.3V$. The Detector output vs. Pout plot over $V_{bat}=2.7V-4.8V$ and over digital command PAON=SP3T $V_{c2}=1.6V-2.0V$ variations is shown in Figure 8. The detector output is tightly bunched over bias supply variations.

Excellent EVM and Icc and Det-out over temperature data (at Cold [-25°C], Room Temp and Hot [+85°C]) are shown in Figures 9 and 10.

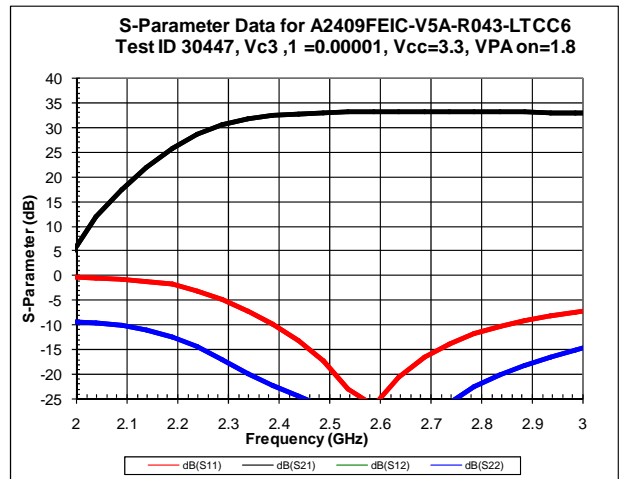


Fig. 5. Tx Mode S21/S11/S22

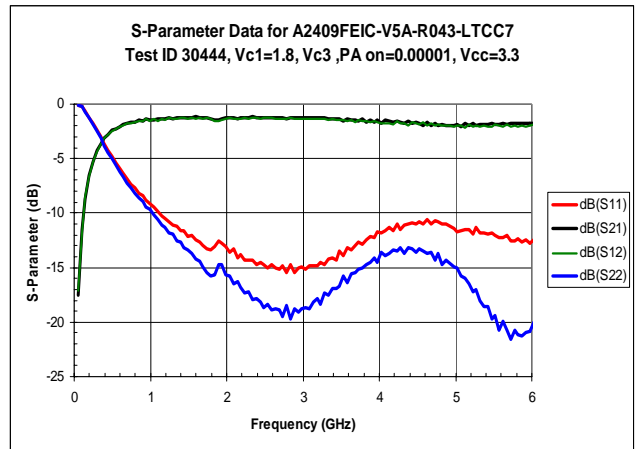


Fig. 6. Rx & BT Mode S21/S11/S22

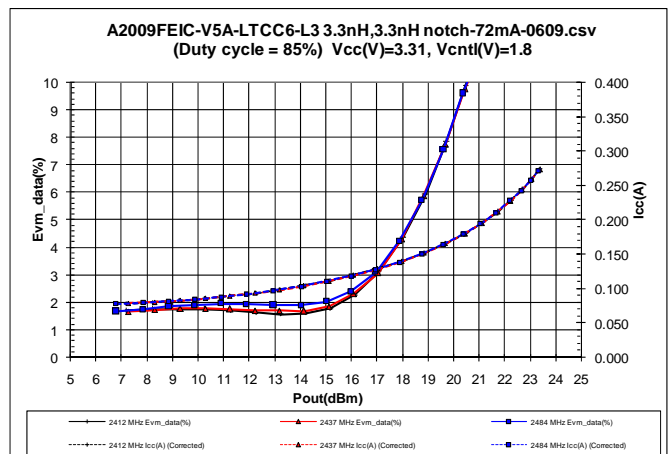


Fig. 7. Tx Mode EVM/Icc vs Pout, Over Freq, at RT

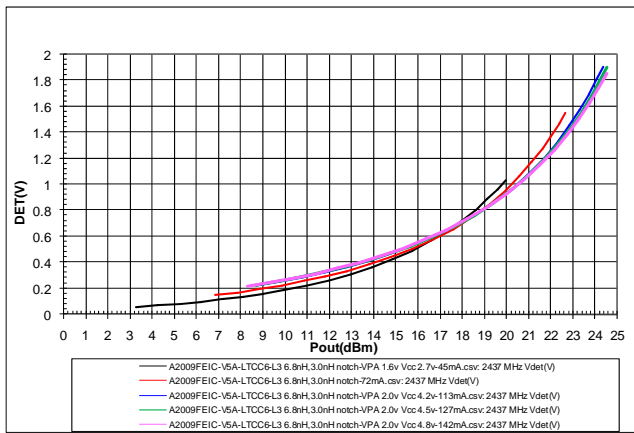


Fig. 8. Tx Mode Det-out vs Pout, Over Bias Supplies, at RT

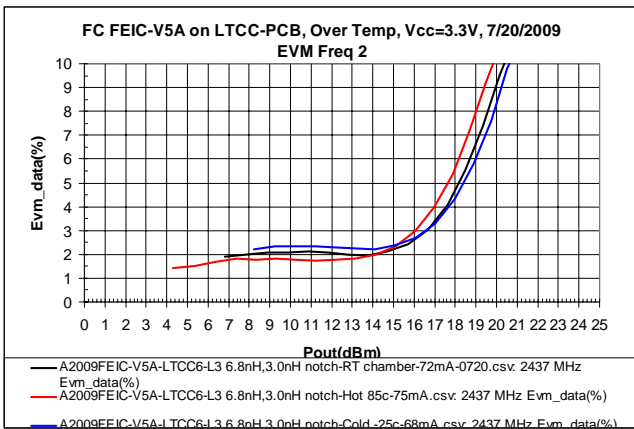


Fig. 9. Tx Mode EVM vs Pout, Over Temp, at 2.437GHz

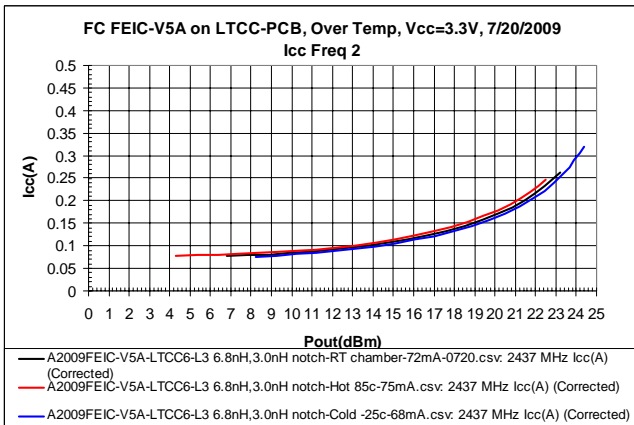


Fig. 10. Tx Mode Icc vs Pout, Over Temp, at 2.437GHz

IV. WiFi RF FEM USE FLIP CHIP FEIC

The described FEIC and its circuitry together with a coexistence bandpass filter and a receive balun was integrated into a complete FEM according to the block schematic shown in Fig. 1. The balun was completely integrated into the LTCC substrate.

Due to space and cost reasons, a common bandpass filter (BPF) filter is shared between the WLAN Rx, WLAN Tx and Bluetooth paths. Such filter should fulfill the attenuation requirements for both Rx and Tx modes at the same time.

In order to keep the insertion loss at a low level the filter was realized using a combination of two technologies – multilayer Low Temperature Co-fired Ceramics (LTCC) and surface acoustic wave (SAW) technology.

SAW resonators provide very high quality factors, having relatively small physical dimensions and a low profile. Therefore, SAW filters are widely used in multiband RF front-end modules realized on laminate or LTCC technology [3]. They provide a very good attenuation close to passband in combination with a low insertion loss, due to the very high Q-factors of SAW resonators. However, the attenuation farther from passband is often insufficient if the filter order is not very high.

A combination of LTCC and SAW filters was used to utilize the advantages of both technologies and obtain a high-performance and small size filter solution.

Figure 11 shows the measured performance of the Bluetooth path.

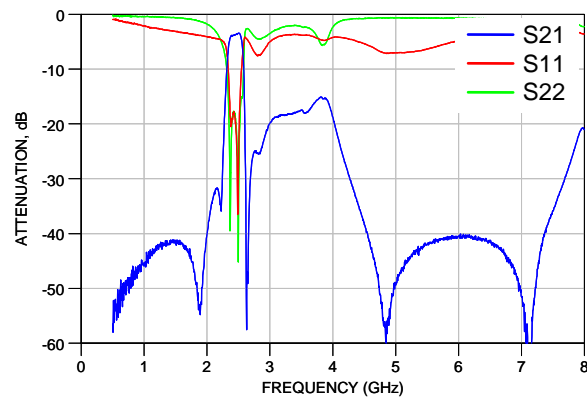


Fig. 11. Bluetooth path. Measured performance.

The combined insertion loss of the filter and switch is less than 3.5 dB, the attenuation in the WCDMA Band I RX (2170 MHz) is better than 30 dB and the attenuation of the other cellular bands is better than 40 dB. The attenuation at harmonic frequencies is >35 dB.

The achieved attenuation in the cellular bands is typically sufficient to protect the WLAN/Bluetooth receiver from cellular Tx band blockers and also to reduce the wideband noise generated by the WLAN/Bluetooth transmitter in the cellular Rx bands. Therefore, a reliable coexistence between the WLAN (or Bluetooth) and the cellular radios located within one mobile terminal can be ensured.

The Tx path small-signal performance is shown in Fig. 12. The overall Tx gain is ~30 dB and the attenuation at 2170 MHz (WCDMA Rx Band) is -45 dBc.

The complete FEM provides +14 dBm linear output power in 802.11g mode ($I_{cc}=120\text{mA}$) and +17 dBm linear output power in 802.11b mode ($I_{cc}=150\text{mA}$).

The 802.11g EVM performance of the complete FEM is demonstrated in Fig. 13.

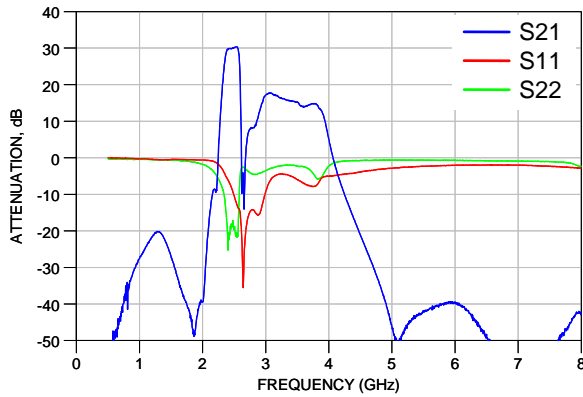


Fig. 12. WLAN Tx. Measured performance.

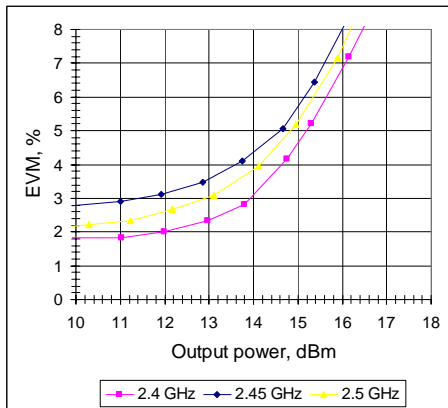


Fig. 13. Measured EVM performance of the complete FEM.

V. Conclusion

In summary, we have developed a flip chip WiFi FEM die with good performance. A complete WiFi RF FEM including SAW filter (between SP3T & antenna, for rejection at WCDMA 2.17GHz and harmonics), flip chip IC, Rx balun, coupler-detector and SMD R, L, C parts with module size 3.2 x 3.2 x 1mm is developed for Smart Phone application. The wire bond process and wire bond pads are eliminated. This flip chip FEM die enables size and cost reduction for Smart Phone application.

ACKNOWLEDGEMENT

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