WiFi™ Front End Module Design for Smart Phone Applications

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Abstract

Along with the explosive growth of smartphones, a new wave of the mobile device development is on the way, in which the WiFi enabled cellular phone has been taking an extremely important position. Unlike the desk top PC and notebook computers, integrating the WiFi radio within a cellular phone is much more complicated and challenging than simply putting two systems in a box with the form factor of a cellular phone. This paper will discuss the technical challenges and solutions regarding the integration of WiFi and cellular phone systems. Several examples of the WiFi front end module (FEM) will be given.

1. Introduction

The introduction of smartphones has, without a doubt, opened a new era of mobile communication, evidenced by the explosive growth in both customer subscriptions and available applications. Due to their application-intensive feature, the smart phone or smart-phone-alike devices are heavily Internet dependent. Although mobile devices can access the Internet via multiple means, WiFi technology is the most effective way due to its high data rate and low cost. Hence, WiFi capability is going to be offered as one of the most important default features for smartphones and smart-phone-alike mobile devices. On the other hand, integrating the WiFi system into the cellular phone presents new technical challenges from both system level implementation and hardware upgrade. In this paper, an overview about the issues and technical challenges regarding WiFi-cellular phone integration will be presented. After a brief discussion of the system level issues, the system hardware integration -- especially the radio front end -- will be discussed. In addition, a few examples of the WiFi FEM will be presented.

2. Basic System Level Description

Fig. 1a is a typical system block diagram of a smart-phone-alike mobile device. The system includes three major sections, radios, baseband processors and an application processor. As obvious as it is, the smart phone is actually an integration of a computer and a cellular phone, taking advantages of the latest powerful microprocessor technology. Basically, the application processor handles core computing functions while both cellular phone and WiFi, provide the mobile data communication interface between the application processor and the Internet. The most common issue of integrating multiple radios into a single platform is the interference and interaction. Without properly managing these interactions and inferences, the overall system performance will degrade. For example, let us assume that a system consists of a GSM/GPRS cellular radio and an 801.11g Wi-Fi radio. 1). When GSM and Wi-Fi are both transmitting, there will be cross modulation via system power supply and system VCO pulling, which will cause both GSM and WiFi burst waveforms to be no longer specification compliant. Furthermore the system may fail the FCC regulatory standard due to the out-of-band emissions resulting from these interferences. 2). When GSM is transmitting and WiFi is receiving, GSM signal will heavily de-sense the WiFi receiver resulting in the degradation of system S/N and BER. Thus multiple data
re-transmission is required in order to maintain the overall data transmission integrity. Consequently, overall data rate will be reduced. 3). When WiFi is transmitting and GSM is receiving, the GSM receiver will be desensed due to the WiFi transmit signal. Again the degraded S/N may cause either dropping a call or poor audio quality due to the compromised data transmission. In order to mitigate this system performance degradation, the integration of cellular phone radio and WiFi radio needs to address this interference issue from both system level and radio/RF front end level. At the system level, proper power supply design along with the enhanced filtering may reduce the power supply induced interaction during the transmission. Also data transmit timing and scheduling at the system level will be required. At the radio front end level, proper filtering and function partitioning can improve the overall system level performance.

3. WiFi Radio Front End Design

There are several constrains and limiting factors for integrating a WiFi radio front end into the smart phone. The obvious one is the form factor. Due to the size and height limitations the WiFi radio front-end has to be small and thin with higher level of integration. This is very different from the notebook based WiFi radio and poses new challenges to the component designer. Another issue is that the smart phone based WiFi radio front-end has to have higher output power and gain. Since a smart phone has to maintain concurrent operation of cellular phone and WiFi radio, a bandpass filter is typically inserted between the system antenna port and WiFi radio front-end to reject the cellular signal leaking into the WiFi side. This filter usually has high insertion loss (4-5dB). In order to maintain the total transmit power at the antenna port, WiFi power amplifier (PA) has to have linear power of 18-19dBm at the PA output port. By the same argument, the PA also has to have higher gain to keep the total gain of the transmission path the same. Finally, the WiFi radio front-end will be subject to the same harsh operation conditions as cellular phones, like high VSWR, extreme temperatures and other environment conditions.

Fig. 2 is an ideal full duplex WiFi front end block diagram. A well designed radio front end includes the following functional blocks: 1) PA with high gain, high linearity output power and high efficiency; 2) Low noise amplifier with low noise figure and high linearity; 3) A high linearity T/R switch; 4) Low loss diplexer to ensure the concurrent operation of the dual-band radio; 5) A low loss filter for out of band emission rejection; 6) A low loss filter to reject the cellular phone transmitting signal; 7) A Bluetooth® path to the Bluetooth transceiver. 8) An optional low loss balun. This balun is only needed when the low noise amplifier (LNA) is integrated with a CMOS transceiver. Although there is no such radio front end module on the market yet due to cost issue and system optimization issue, a combination of different function blocks are available on the market or in development with the goal of performance optimization. All of these products offer pros and cons from the system design point of view.

3.1 PA-Switch Combination

Fig. 3 is a typical PA-switch combination diagram. It consists of a 2.5 GHz linear PA, a SP3T switch and a balun. It provides power amplification, WiFi Tx/Rx/BT switching and single end to balanced conversion for the off-chip LNA. The combination is very simple so it will be relatively easy to achieve high performance. Since the LNA is integrated with the CMOS transceiver, the total system cost will be lower.

However, a CMOS LNA is inferior to a pHEMT LNA in terms of performance which will affect the overall system sensitivity. Also in order to reduce the common mode noise/interference, the CMOS LNA adopts the

Bluetooth is a registered trademark of Bluetooth SIG.
balanced input. Therefore, an extra low loss balun is needed in the receiving path which introduces more loss.

3.2 PA-Switch-LNA Combination
Fig. 4 is the block diagram of the PA-switch-LNA combination. In order to achieve the highest WiFi performance, there is a trend to integrate the PA-switch-LNA by taking advantage of the pHEMT LNA. By using a pHEMT LNA the system sensitivity will be improved due to the low noise figure of the pHEMT device and removing the balun induced loss. It is more attractive for 5 GHz systems since it is more difficult to achieve decent low noise performance from a CMOS device. On the other hand, this approach may be perceived as the expensive one.

3.3 LNA-Switch Combination
The LNA-switch combination basically puts the system level emphasis on the receiver sensitivity. Fig. 5 shows the block diagram. It consists of a SP3T switch and a pHEMT LNA. It will also have a Bluetooth path and an optional LNA bypass path to avoid receiver saturation. The important advantage is that the matching between the SP3T switch and the LNA can be optimized without the constraints of the PA-switch-LNA combination. It may offer the highest system level sensitivity. On the other hand, the PA may be integrated with the WiFi transceiver which will further lower the total system cost.

3.4 2G PA-5G PA Combination
Although the dual band WiFi system is not very common, dual band PA development has been in process. Fig. 6 is a block diagram of a dual band WiFi PA. It consists of a 2 GHz WiFi PA, a 5 GHz WiFi PA, 2 T/R switches for TDD operation and a diplexer for band separation. This module will support full dual band WiFi operation.

3.5 Switch-Diplexer Combination
Fig. 7 is a block diagram of switch-diplexer combination. This combination offers another way of implementing the full duplex operation of a dual band WiFi system, which will produce the highest data throughput. It consists of 2 Tx/Rx switches for 2 GHz and 5 GHz bands. A diplexer is inserted between the switches and the antenna port to realize the full duplexing function. On the other hand, it offers more flexibility to system design in PA and LNA selection.

4. Summary
In summary, an overview of the WiFi radio front-end design is presented. With the explosive growth of smart phones, the integration of cellular phone and WiFi has become essential, which posts new technical challenges and opportunities to the engineering community. Also multiple ways of partitioning the WiFi front end can provide the system design more flexibility to maximize the performance and minimize the total system cost.

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