A Multifunction Transceiver RFIC for 802.11a/b/g WLAN and DVB-H Applications

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Abstract—We present a multifunction wireless transceiver RFIC for WLAN and DVB-H applications. The RF IC includes a super-heterodyne transceiver for IEEE 802.11a/b/g WLAN applications and a zero-IF receiver for DVB-H application. The WLAN and DVB-H transceiver share the down-conversion mixers, the baseband VGAs, filters, and the PLL synthesizer, resulting in a small silicon area of 20mm². Using a 3.3V supply, the power consumption of the WLAN transceiver and the DVB-H receiver are 462mW and 396mW, respectively.

I. INTRODUCTION

The boom of wireless and mobile networks leads to an ever-increasing request for multi-function, low power, and low cost RFICs. With wireless local network (WLAN) and digital-video-broadcasting (DVB) standards operating in very different frequency bands [1-5], future trends point to integrated wireless terminals that can support variety of modes such as TV and Internet browser. Wireless transceivers that can support multi-standards have not been reported so far. This work presents a low-cost hybrid wireless transceiver RFIC for WLAN and DVB coexistence. Combining multi-standards into a single wireless transceiver achieves high performance, low cost, low power, and small form-factor. It thus allows multi-mode interoperability with transparent worldwide usage.

II. HYBRID TRANSCEIVER RFIC DESIGN

As illustrated in Fig. 1, the implemented multifunction hybrid transceiver RFIC comprises multi-band radio front-ends that can cover the WLAN 802.11a/b/g at 2.4GHz and 5.2GHz bands and the DVB-H UHF band from 470MHz to 862MHz. The illustrated multi-band transceiver is a direct-conversion receiver for DVB-H and a super-heterodyne transceiver for WLAN. The WLAN transceiver utilizes a walking IF, where the RF LO is 4 times of the IF LO. Thus both LOs can be derived from a single synthesizer. The IF chooses the upper-side band of the RF mixer for 2.4GHz band and the lower side-band of the RF mixer for 5.2GHz band. Thus, the walking-IF topology not only saves a synthesizer, but also moves the IF frequencies of the 2.4GHz and the 5.2GHz bands close to each other, allowing sharing the IF filter and the IF mixer with the IF ranging from 804MHz to 1161.2MHz. This frequency plan also allows the DVB-H receiver to share the IF-mixer of the WLAN receiver with its UHF input frequency from 470MHz to 860MHz. The baseband filter is an 8th order tunable Chebyshev low pass filter (LPF), which is shared by WLAN and DVB-H receivers. The WLAN transmitter also uses the same baseband filter with a loop-back scheme shown in Fig. 1.

The multi-standard wireless receiver comprises multiple LNAs in order to cover the entire WLAN and DVB-H bands. Both 5GHz and 2.4GHz LNAs are designed with 25dB gain at high-gain mode and about 0dB gain at low-gain mode.

The WLAN LNAs with tuned single-ended cascade common-emitter structure is shown in Fig.2, which has high gain and low gain modes for a wider dynamic range. Inductive emitter degeneration is used for better noise performance with high linearity. For the high gain mode, the cascode amplifier (Q1 and Q2) is powered on while the common base amplifier (Q3) is off. For the low gain mode, the NMOS switch (M0) and common base amplifier (Q3) is turned on while the cascode amplifier (Q1 and Q2) is turned off. The two gain modes step the gain by 25dB.
Two image filters with more than 20 dB image rejection are inserted between the WLAN LNA and down-mixer to eliminate the images. Mixer output buffers are designed to be open-collector, sharing the same load to switch the WLAN and tuner functions. An on-chip bandpass filter with 300MHz bandwidth and 15dB rejection is employed to replace the off-chip SAW filters. In order to increase the dynamic range of the receiver, a variable gain amplifier (VGA) with selectable gain of 16/11.5/6/1.6 dB gain is inserted in the receiver RF path.

For wide band reception over the DVB-H UHF band, inductorless wide band LNAs is used. Fig. 3 shows the tuner front-end with variable gain LNA circuits. The fixed gain LNA is differential cascade amplifier with shunt feedback. Variable gain LNA supplies a large dynamic range for the system with the gain tuning range of from 5dB to 25dB with automatic gain control (AGC) based on the input power level. An adaptive biasing circuitry is used for automatic linearity compensation. The input referred 3rd-order intercept-point (IIP3) of the tuner front-end increases automatically for a strong input signal. Following the LNA is a VGA that is designed to have 0dB to 17dB gain control.

The WLAN transmitter baseband VGA provides negative gain from -32dB to -26dB with a step size of 2dB. The receiver baseband variable gain range is 48.8dB from 11.4dB to 60.2dB with a step size of 1dB. Transmitter IQ modulator includes two mixers similar to the receiver IF mixers with image rejection.

The baseband filter is designed as an 8th order Chebyshev filter with temperature compensated programmable corner frequency. The cut-off frequency of baseband filter for WLAN can be programmed from 6.3MHz to 12MHz, while that for DVB-H tuner can be adjusted from 2.6GHz to 7.4GHz.

The power amplifier driver consists of a differential cascode amplifier, an emitter follower, and a common-emitter amplifier as shown in Fig.4. The cascode amplifier stage acts as a differential to single-ended converter. The cascode structure employed here can supply good inverse-isolation and wide bandwidth. A tank is used as the load to provide narrow-band gain with good out-of-band filtering. The common-emitter amplifier provides additional gain with good linearity and sufficient voltage headroom. In a two-tone test, the IIP3 of the power amplifier driver is +10.2dBm.

The power amplifier driver is designed to drive the 50Ω input of the off-chip 5.2GHz/2.4GHz power amplifier. The tank is resonated at 5.2GHz/2.4GHz, which also provides image rejection for out-of-band tones. The bypass Cb and Rb provide an ac path for the signals. The current dissipation of the power amplifier driver is 28mA.

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**Fig. 3 DVB-H tuner front-end circuits with fixed gain LNA and AGCs.**

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**Fig. 4 Schematic of the PA driver with image rejection.**

The pre-PA driver is designed to have 8dB gain at 5GHz and 11dB gain at 2.4GHz. An odd order harmonic filter is designed to remove the harmonics after the IQ modulator. With the pre-PA tanks, the filters in the Tx chain provides more than 40dB emission rejections for harmonics and spurs rejections, with the IIP3 of +10.2dBm.

The multi-band phase-locked-loop (PLL) comprises a 9-bit programmable multi-modulus divider (MMD) constructed with 8 cascaded divided-by-2/3 cells. With an additional control bit, the divide ratio can be programmed from 128 to 511. A divided by 1/2/6/8 programmable divider is employed at the output of PLL to generate the LO frequencies from 470MHz to 4.8GHz. Five wide-band VCOs are employed to cover the bands from 2900MHz to 4800MHz bands. Wide-tuning range PMOS VCOs are designed to allow the tank referenced to the ground, which leads to lower phase noise.

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**Fig.5 Wide-band fractional-N PLL synthesizer with a PMOS VCO**
The VCO design also employs an automatic amplitude control (AAC) circuitry that can keep the VCO in current limit region and alleviate the AM and AM-to-PM noise. AAC also provides perfect ambient-proof characteristics over process, temperature and frequency variations. VCO buffer utilizes the Darlington structure in order to sustain the large VCO output swing. VCO buffer has an open-collector with the load resistors laid out close to the mixer. Porting the LO in current mode through long distance avoids the interference and voltage decay. The phase frequency detector (PFD) employs a totally differential structure for symmetric and noise rejection. The charge pump (CP) is also differential and its current can be programmed from 140uA to 1190uA for adjusting the loop gain and bandwidth for different applications.

III. MEASURED RESULTS

The die photo of the WLAN/DVB-H hybrid transceiver RFIC is shown in Fig. 6. To our best knowledge, this design is the first multifunction hybrid transceiver RFIC with a compact die size of 4×5mm².

Fig. 7 shows the measured WLAN LNA S11 in the 802.11a and 802.11bg mode separately. The measured baseband filter V~F characteristics are shown in the Fig. 8. It shows that the filter in WLAN mode has a cut-off frequency at 9.8MHz with stopband rejection larger than 31dB at 12MHz. In DVB-H tuner mode, cut-off frequency is measured as 4MHz with rejection larger than 36dB at 4.8MHz. Passband ripple are all less than 1dB.

The measured tuner front-end linearity is shown in Fig.9. When the input power increases, the linearity compensation circuitry automatically boosts the front-end IIP3. When the power reaches a saturation level (around -3dBm), the IIP3 begins to drops. The measured IIP3 result agrees with the simulation well.

Fig. 10 shows the VCO tuning curves for VCO1 to VCO5 when the tuning voltage is changed from 100mV to 3.3V. The five VCOs can cover the 2.9GHz to 4.8GHz range with tuning voltage from 500mV to 3.0V. The measured PLL settling times with VCO frequency is changed from 3504MHz to 4056MHz, the settling time is about 250us with charge pump output current set as 170uA. The typical PLL phase noise measurement using VCO5 in the WLAN mode. The carrier frequency is 4608MHz and the measured phase noise in locked state is: -93 dBc/Hz @ 1kHz; -100 dBc/Hz @ 100kHz; -112 dBc/Hz @ 1MHz.
Fig. 12 shows the measured EVM of 4.26% rms for DVB-H tuner Rx. Fig. 13 gives a complete DVB-H tuner demo test configurations. A DVB-T/H media stream modulator is placed in the back to modulate MPEG2 stream into DVB-H format and transmit the modulated signals at about 0dBm power level. In the front-end, apart about 4 meters from the back-end transmitter antenna, there is a 75ohm receiver antenna which is connected to the 802.11a/b/g and DVB-H multifunction RFIC board. The output signals of the RFIC transceiver IC are fed into the DVB-H digital baseband which is connected to a PC through the USB interface IO port. The PC receives the raw media stream signals and performs software processing to de-code the MPEG2 streams, and then the application program can play the video and audio on the PC. The RFIC is controlled by another serial-port-interface (SPI) control program which loads the control data bits into RFIC through RS232 interface to a MCU and then to the RFIC in SPI timing.

Table 1 summarizes the transceiver performances and compares them to previous work. This work presents a high performance, lower power, and smaller size multi-function transceiver RFIC that covers WLAN a/b/g and DVB-H bands. The prior solution for multi-standard radio implementation is to use multiple single-band transceivers with large die size and form factor. By integrating multi-standard radio functions into a single RFIC, this work gains great advantages over previous designs. The present work allows sharing of radio functional blocks such as the frequency synthesizer, mixers, VGAs and baseband filters. In addition to a complete WLAN a/b/g transceiver, a DVB-H tuner front-end with only 0.9×1.2mm² size was added to form a multi-function hybrid transceiver RFIC with 20mm² total die size.

Table 1. Measured WLAN/DVB-H performance and comparison with others. Test conditions: (1) Simulated LNA NF/Measured Front-end NF, DVB-H: max gain, WLAN Rx front-end: 22dB gain; (2) Rx IIP3, WLAN: 39dB gain, DVB-H: max gain; (3) Tx OIP3, -10 dB gain; (4) 64QAM, 54Mbps; (5) @6 dB gain; (6) @-20dB gain; (7) @64 dB gain.

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IV. CONCLUSION

In conclude, this paper presents a single-chip multi-function, multi-standard hybrid transceiver RFIC for WLAN 802.11a/b/g and DVB-H applications that has not been reported before. The hybrid transceiver RFIC was implemented in a 0.5um SiGe BiCMOS technology with 20nm² total die size. The power consumption is only 462mW and 369mW for WLAN and DVB-H operating modes, respectively.

REFERENCES