A MULTI-BAND MULTI-STANDARD RF FRONT-END FOR IEEE 802.16a and IEEE 802.11a/b/g APPLICATIONS

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Abstract—**This paper presents a multi-band multi-standard receiver architecture for wireless applications, such as 802.11 a/b/g WLAN, and 802.16a WMAN. The targeted frequency bands include licensed bands – 2.3 GHz, 2.5 ~ 2.7 GHz, and 3.5 ~ 3.7 GHz, and un-licensed bands – ISM 2.4 GHz and U-NII 5 GHz. The main advantages of the proposed receiver are using a single frequency synthesizer to perform entire frequency transferring, and each frequency band shares the identical LNA and mixer to reduce chip area. The maximum hardware shared LNA and Mixer design are also presented. The S_{11} of the proposed multi-band LNA is below -10 dB from 2 GHz to 6 GHz. The integrated NF of the RF-Front-End is 3.18 dB at 2.4 GHz, 3.47 dB at 3.5 GHz, and 5.47 dB at 5.4 GHz. The conversion gain and IIP3 are 35 dB and -16.7 dBm at 2.4 GHz, 34.3 dB and -17.4 dBm at 3.5 GHz, and 30.6 dB and -11.3 dBm at 5 GHz respectively. Using a 0.18μm CMOS process, the multi-mode RF front-end dissipates 56 mW from a 1.8V supply voltage.**

I. INTRODUCTION

The wireless market is growing rapidly. Being pushed by market demands, various wireless communication systems are emerging. Wireless local area networks (WLANs) have been introduced in ISM and UNII bands for indoor wireless access. IEEE 802.16a Wireless Metropolitan Area Networks (WMANs) standard [1] published on 1 April 2003 for urban area coverage wireless access as the "last mile" solution. IEEE 802.16a system addresses frequencies from 2 to 11 GHz, including licensed and un-licensed bands while the dominant bands [2] are licensed bands of 2.3 GHz (WCS), 2.5 to 2.7 GHz (MMDS), 3.5 to 3.7 GHz (ETSI), and un-licensed bands of 2.4 GHz (ISM) and 5.8 GHz (U-NII) where WLANs operates as well [3][4].

In order to increase flexibility on the market and functionality of RF transceivers, multi-band and/or multi-standard transceiver architecture solutions are pursued. A straight forward method is to use multi-input stage for each interested frequency. The advantage of the approach is that the performances of each RF front-end can be optimized for each frequency band, but it suffers from area and cost issues. In this paper, a multi-band multi-standard receiver architecture with maximum hardware sharing for IEEE 802.16a and IEEE 802.11a/b/g is developed. A single wideband input matching LNA and a multi-band down conversion mixer are proposed and implemented to save the chip area and cost.

The paper is organized as following: in section 2, the architecture and the particular frequency plan of receiver for IEEE 802.16a and 802.11a/b/g multi-band and multi-standard applications are proposed. The complete LNA and mixer design considerations are discussed in sections 3 and 4, respectively. The simulation results and performance summary are given in section 5. Finally, conclusions of this design are offered in section 6.

II. RECEIVER ARCHITECTURE

Fig. 1 shows the proposed multi-band multi-standard receiver for IEEE 802.11a/b/g and IEEE 802.16a. Dual-conversion architecture is used for IEEE 802.11a/b/g and IEEE 802.16a. But zero-IF technique is adopted for 3.5~3.7GHz the IEEE 802.16a ETSI band. Since IEEE 802.11b/g, and WCS and MMDS bands of IEEE 802.16a share adjacent frequency bands around 2.4 GHz, the RF filter can be used for these standards. For this band, the first local oscillator (LO) frequency is located at 3.45 to 4.05 GHz to convert the signal to IF band from 1.15 to 1.35 GHz and then the second LO frequency converts it to the baseband. IEEE 802.11a and U-NII band of IEEE 802.16a also share the same frequency band so that the RF filter can be used for these two standards. For the U-NII band, the first LO frequency is placed at 3.85 to 4.37 GHz to convert the signal to 1.282 ~ 1.457 GHz and then the second LO transfers the signal to the baseband. For the ETSI band, the received signal is directly converted to baseband through the first LO.

To maximize the level of the hardware sharing, the LNA is designed for multi-band reception. The mixers can also be

shared for all the standards because of the wide-band characteristics of the transconductance. The low-pass channel select filters are programmable to change the cutoff frequency corresponding to each standard. To adjust the signal at appropriate level at the input of the ADCs, the gain range of the PGAs is determined considering the sensitivity and maximum input power for each standard. The ADCs are programmable for multi-standards. The digital baseband extracts DC offset level and feeds back to analog baseband through DACs (not shown in this figure) to subtract DC offset.
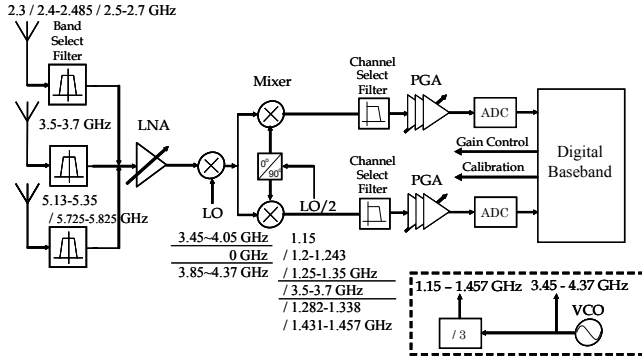

Fig. 1. Proposed multi-band multi-standard receiver

The developed frequency planning of each band is illustrated in Fig. 2. The feature of this architecture is the frequency synthesis for multi-band operation can be achieved by only one voltage control oscillator (VCO) operating from 3.45 to 4.37 GHz, which can be easily implemented by digitally switching binary weighted capacitances in current CMOS technology. In additional, The Local Oscillator 2 (LO$_2$) can be generated by a divide-by-three circuit from the LO$_1$ in this architecture.
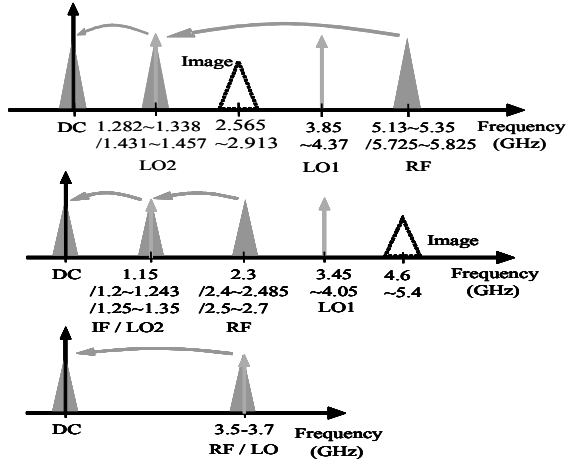

Fig. 2. Frequency planning

III. LNA DESIGN

One of the difficulties in the design of a multi-band application transceiver is how to realize a multi-band LNA. Many LNA topologies for multi-band applications have been

proposed. The most popular method [5] is to use an LNA for each band. The advantage of this approach is that the performances of each LNA can be optimized for each interested band, but this technique may suffer from area and cost issues. The common-gate stage is the other way to realize a wide-band LNA [6]. However, the common-gate topology usually has relative higher noise figure than the previous approach. A concurrent multi-band LNA [7] based on inductor degeneration technique can achieve a relative lower NF, therefore, this topology is usually adopted especially for the systems with less noise figure budget. Thus narrow-band CMOS LNA designs have employed inductive source degeneration technique to achieve good input matching, and yield nearly optimal noise performance at the high operating frequency of the input network.

A. Input Matching

In order to receive the desired frequencies operating at 2.4 GHz, 3.5 GHz and 5.8 GHz, LNA design adopts wide-band input matching topology. In Fig. 3, the input impedance Z_{in} is embedded in 2nd-order band-pass LC-ladder filter to resonate its reactive part over the whole band, from 2 GHz to 6 GHz [8]. For flexibility of the design, an inductor (L_g) is placed in series with the gate, and a capacitor (C_{par}) is added in parallel with the gate-source of the amplifying transistor. The cascode configuration improves the reverse isolation and the frequency response of the amplifier.
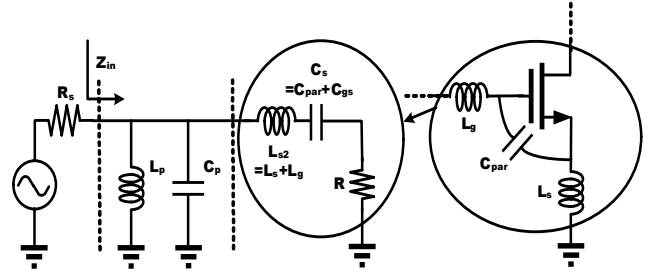

Fig. 3. Input matching network using a 2nd-order band-pass LC-ladder filter

The source degeneration topology synthesizes an input impedance with a real part equal to $g_m L_s / C_p$, where $C_p = C_{par} + C_{gs}$, to be matched with the source resistance R_s.

B. Band Selection

Load inductors, L_{multi} as shown in Fig. 4, are switched for the desired band to tune the parasitic capacitor at the output node. To reduce the area occupied by the inductors, they are lumped together using a 5.5-turn spiral inductor with multi-tap. The schematic of the proposed multi-band LNA is shown in Fig. 4. The digital codes of $D_1 D_2 D_3$ control the switches for the resonance frequency at each band, namely, for 5 GHz the U-NII band, $D_1 D_2 D_3 = 111$, for 3.5 GHz the

ETSI band, $D_1D_2D_3 = 011$, and $D_1D_2D_3 = 001$ is for 2.3 GHz (WCS), 2.5~2.7 GHz (MMDS).

Due to the equivalent gate-source capacitor C_p of input device, the gain in 5 GHz band does not satisfy the specification, thus noise figure degrades. The broadband second amplifier stage is intended to solve this problem and relax specification budgets of circuit blocks. The inductance L_l and resistance R_l are designed to achieve that the overall LNA circuit has equal gains in all the frequency bands.
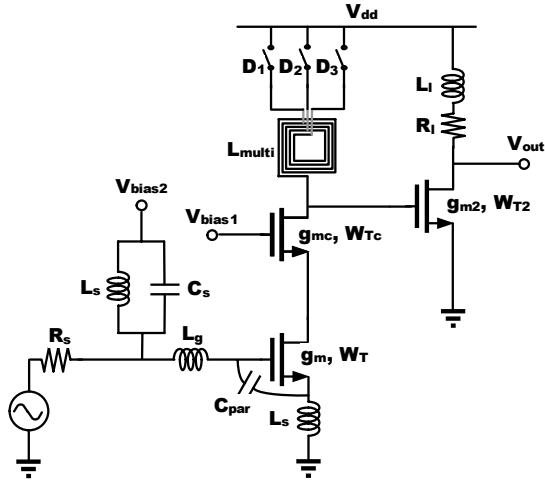
Fig. 4. Simplified schematic of the proposed multi-band LNA

IV.   MIXER DESIGN

Fig. 5 shows the schematic of the proposed dual-conversion mixer. The proposed mixer is composed of a double-balanced Gilbert-type mixer cascaded by two additional double-balance PMOS switching pair. The incoming RF voltage signal is firstly converted into a current signal by transistors M_1 and M_2 and then multiplied by transistors $M_3 \sim M_6$ in current domain to perform frequency translation. The transistors $M_3 \sim M_6$ are biased slightly above their threshold voltage. This results in the LO alternately switching M_3 (M_6) and M_4 (M_5) on and off. The first Gilbert-type stage translates the 5 GHz (U-NII band) and around 2.4 GHz (WCS, MMDS and ISM bands) signal to IF at 1.15 ~ 1.457 GHz and thus, the spiral inductors, L_{l1} and L_{l2} , are used as load to amplify the IF signal. Then the IF signal is folded into the two PMOS switching pairs, $M_7 \sim M_{14}$, to generate the quadrature baseband signals. PMOS has less flicker noise than NMOS does, so it can relax the noise specification budget. The baseband load uses poly resistors, $R_{l1} \sim R_{l4}$, due to lacking for flicker noise. For the 3.5 GHz (ETSI band) signal, M_4 and M_5 are turned off and M_3 and M_6 are biased as cascoded devices. The second stage down-converts it to baseband signal through LO_2 at 3.5GHz. The tank of the load in the first stage resonates at 3.5 GHz when the switch is off; otherwise, the resonance frequency is at 1.3 GHz.
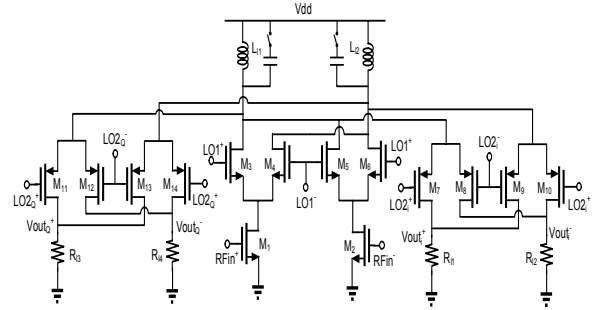
Fig. 5. Schematic of the proposed dual-conversion mixer

V.   SIMULATION RESULTS

The LNA and the mixer are designed in 0.18μ m CMOS process using *ADS®* simulator. The active current of the multi-mode RF front-end is 31 mA from a 1.8 V supply voltage. The S-parameter simulation results of the proposed multi-band LNA are shown in Fig. 6. The insertion loss of each band is below -10 dB between 2 GHz and 6 GHz. The S_{21} is 14 dB at 2.7 GHz, 13.9 dB at 3.6 GHz, and 13.3 dB at 5.3 GHz.
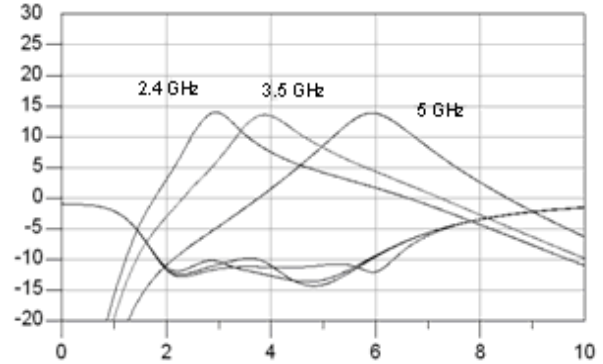
Fig. 6. Simulations of insertion gain and insertion loss

The noise figures (NF) for the three bands of the RF front-end is shown in Fig. 7. The NFs are 3.18 dB at 2.4 GHz, 3.47 dB at 3.5 GHz, 5.47 dB at 5.4 GHz, respectively.
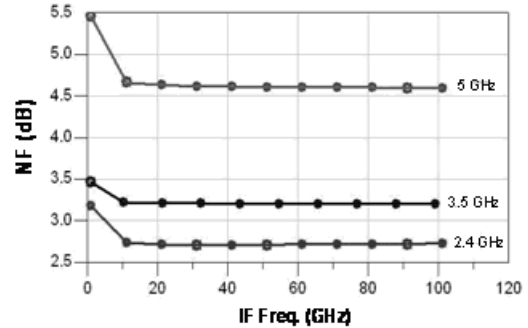
Fig. 7. Noise figure simulations

The linearity of the circuit characterized by the overall RF front-end is shown in Figs. 8. The conversion gain and IIP3 of the RF front-end are 35 dB and -16.7 dBm at 2.4GHz,

34.3 dB and -17.4 dBm at 3.5GHz, and 30.6 dB and -11.3 dBm at 5GHz, respectively.

The simulation results for the integrated multi-band RF front-end are summarized in Table 1.
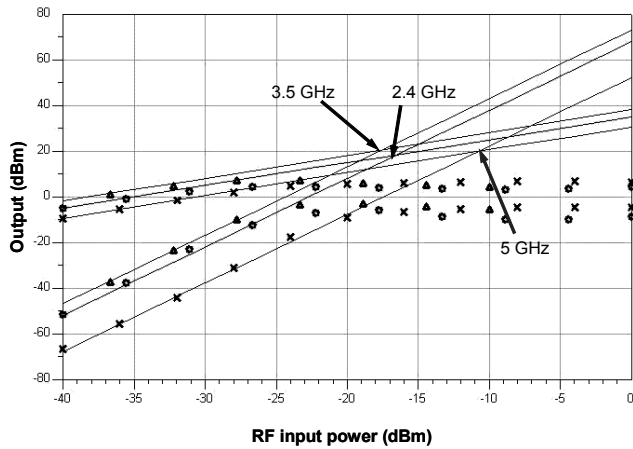

Fig. 8. IIP3 Simulations

Table 1. Performance summary of the RF Front-End simulated

LNA			
Bands (GHz)	S_{21} (dB)	NF (dB)	IIP3 (dBm)
2.4	14	2.3	-15
3.5	13.9	3.2	-10
5.25	13.3	4.4	-1.5
Mixer			
Bands (GHz)	Conversion gain (dB)	NF_{DSB} (dB)	IIP3 (dBm)
2.4	6.5	15.2	+5.7
3.5	10	14.3	+3.4
5.25	6.0	15.7	+6.24
RF Front-End			
Bands (GHz)	Conversion gain (dB)	NF (dB)	IIP3 (dBm)
2.4	35.0	3.18	-16.7
3.5	34.3	3.47	-17.4
5.25	30.6	5.47	-11.3

VI.   CONCLUSION

A highly integrated multi-band multi-standard receiver with dual-conversion/Zero-IF architecture for IEEE 802.16a and IEEE 802.11a/b/g is proposed. With proposed receiver architecture and frequency plan, only single frequency synthesizer is required for multi-standard application. To maximum the level of component share in the multi-band receiver, the targeted three frequency bands share an LNA and a mixer. The wide input matching LNA with adjustable load has been developed. The wide input folding cascaded mixer is also presented for dual-conversion and Zero-IF architecture. All the circuits and the proposed receiver configuration are suitable for area-efficient multi-band and multi-standard receivers.

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