Challenges of integrating a 4G receiver front-end on chip

From LTE to LTE-"Advanced"

Long Term Evolution (LTE) has been a fast growing cellular communication standard over the past five years as the next generation of the 3rd generation Wide Code Division Multiple Access (WCDMA) network. The downlink rate in LTE can be as high as 300Mbps theoretically due to the introduced technologies like Orthogonal Frequency Division Multiple Access (OFDMA), higher order modulation scheme, large channel bandwidth and the use of multiple antennas [1]. The first commercial LTE network was launched in Sweden and Norway in December 2009 and is now spreading all over the world. It is estimated that the global LTE market revenue will be as high as $997 billion by 2020 [2].

Even though often marketed as 4G technology, LTE does not fulfill the target downlink speed of 1Gbps for a 4G system as announced by the International Telecommunication Union (ITU) in its IMT-Advanced requirement [3]. LTE-Advanced (LTE-A) is an enhancement of LTE, which was proposed by the 3rd Generation Partnership Project (3GPP) to be a candidate 4G system [4]. One of the main advancement of LTE-A is the technique of Carrier Aggregation (CA) in which the user terminals can use multiple channels (carriers) at the same time to use wider bandwidth for data transmission. The concept is illustrated in Figure 1, which depicts 3 cases of multiple carriers: Contiguous intra-band, non-contiguous intra-band and inter-band.

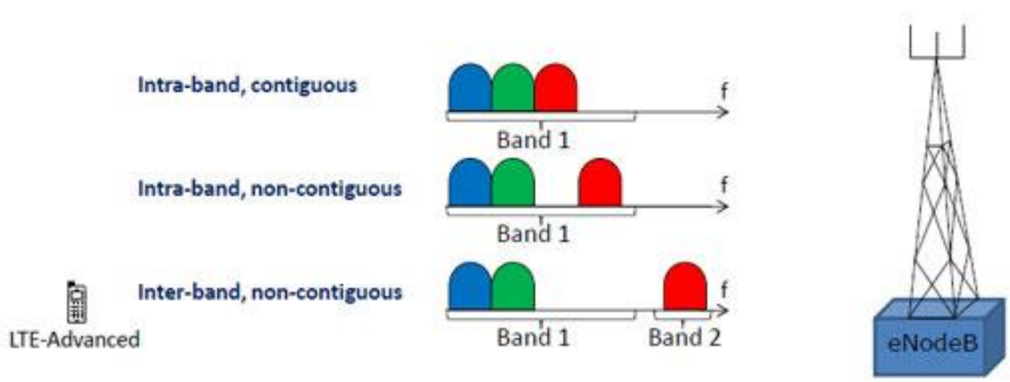

Figure 1: 3 scenarios of Carrier Aggregation for user terminals in LTE-A network [4].

The first LTE-A network was run in South Korea in June 2013 [5]. The network supported user terminals to use 2 carriers simultaneously with the first LTE-A smart phone Samsung Galaxy S4. It is announced that at the end of 2014, there were 49 commercially available LTE-A networks around the world, which provided service to 100 million people [6]. The number of LTE-A users is predicted to reach 1 billion at as early as 2018 [6].

LTE-A Challenges for Receiver Front-end

From the perspective of receiver front-end, the main challenge of LTE-A is the required high linearity for the low-noise amplifier (LNA), which is the first block in the whole receiver. Linearity is the ability of the amplifier to keep a constant gain in amplifying a small signal from the air to a stronger one for easier signal processing. As the amplifier becomes less linear, it can combine (or intermodulates) interferences at its input to produce spectrum components at its output to overlap and ruin the wanted signal. In LTE user terminals, the transmitter (Tx) shares the same antenna with the receiver (Rx) so a portion of Tx signal leaks into Rx (called Tx leakage). As the Tx signal can be strong if the terminals are far from the base station, the Tx leakage becomes a strong interference for the Rx. In LTE-A system with multiple carriers, the situation is even worst as an in-band interference of one carrier can combine with Tx leakage of another carrier and their intermodulation product can fall on top of signal of the first carrier. The interference cannot be removed by filter (which would remove the signal as well) so can be strong to destroy the signal. The LNA linearity must be high enough to suppress the intermodulation products and sustain the signal.

Another big challenge of LTE-A receiver is its large chip area. The traditional LNA often uses a resonator (an inductor in parallel with a capacitor) at its output to lower the noise floor [7] and to prevent noise folding effect caused by the odd harmonics of the local oscillator (LO) square wave used to drive the mixers [8]. The inductor is area-consuming, especially if the receiver is intended for low-frequency operation. As more carriers are used in LTE-A, more inductors are required which make the chip becomes too big and costly. An alternative solution of inductorless solution should be considered naturally to save chip area, but still good enough to deal with LNA noise and noise folding.

An Inductorless Receiver Front-end

An inductorless receiver front-end for low-band (600-960MHz) LTE-A network was investigated in Ericsson Modems, Lund as a master's thesis, with the target of supporting 3 carriers simultaneously. To do so, the LNA is designed with 3 outputs to drive 3 mixers and trans-impedance amplifiers (TIA) so that 3 signal paths are obtained. The LNA outputs can be turned on or off independently so the receiver can switch to 1 or 2 carriers when high data rate is not necessary. Figure 2 depicts the block diagram.

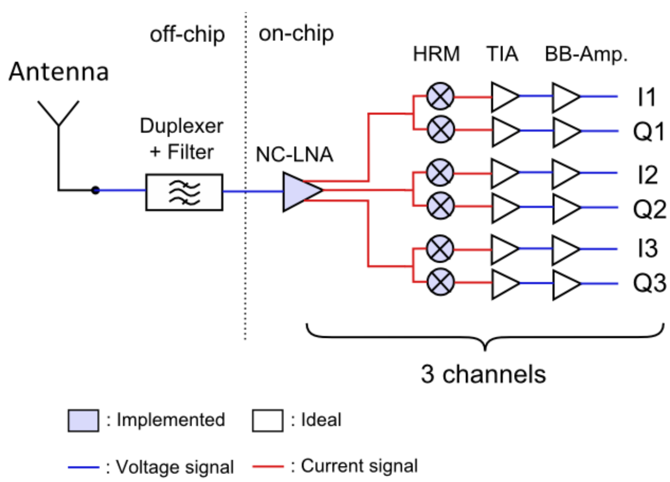

Figure 2: Front-end block diagram. Abbreviations: NC-LNA: Noise-cancelling LNA, HRM: Harmonic-rejection mixer, BB-Amp.: Baseband amplifier.

To solve the LNA noise issue, the technique of noise-cancelling is used. The technique was proposed in 2004 [9] in which an auxiliary amplifier is used to cancel the noise generated by the LNA main amplifier. The noise figure of noise-cancelling LNA was simulated to be 1.6 dB which is comparable to the traditional LNA with inductor included. The current-consumption of the new LNA is roughly 10mA when 2 carriers are used, and is good enough to compete with the traditional one.

The LNA linearity issue was solved by the used of push-pull stage as the LNA output stages. Push-pull includes one PMOS in parallel with one NMOS such that the nonlinearity of the PMOS cancels that of the NMOS, so a high composite linearity is obtained. The simulation results show very good linearity for LTE-A system.

The noise-folding issue was resolved by the adoption of harmonic-rejection mixer after the LNA. As its name suggests, this type of mixer uses LO signals with 6 phases to reject 3rd harmonic of the LO, hence eliminating folded noise. The noise folded reduces 0.5 dB by this technique, and the overall noise of the front-end is promising for LTE-A system.

Conclusion

The master's thesis done at Ericsson Modem aimed to investigate an inductorless receiver front-end for low-band LTE-A user terminals. The circuit combined noise-canceling technique and push-pull stage for LNA and harmonic-rejection technique for mixer, so 3 main issues of inductorless operation are solved. The issues include LNA noise and linearity, and noise folding effect caused by 3rd harmonics of LO signals.

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