RF FRONT-END CONSIDERATIONS FOR FUTURE MULTI-BAND MOBILE TERMINALS

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Keywords: Low noise amplifier, Multi-mode multi-band terminal, Multi-band power amplifier, RF filter, RF front-end.

Abstract: A Radio Frequency (RF) front-end (RF-FE) is one of the keys in multi-mode and multi-band mode mobile terminals. In conventional cellular phones, multiple RF-FEs are installed for multi-band use. There have been a lot of studies of achieving multi-band or broadband circuits that comprise a compact and cost-effective multi-band RF-FE with adequate RF performance. Reconfigurable or tunable RF-FEs are a way to provide multi-band function in future mobile terminals, which takes into consideration the capability to support a large number of wireless systems that use different frequency bands. However, the performance degradation should be considered if adaptive circuits are installed in the RF-FE. This paper presents considerations for the issues that might occur in a multi-band RF-FE for future mobile terminals. As an example, a concept of collaboration between a top RF filter and low-noise amplifier (LNA) is presented.

1 INTRODUCTION

After explosive growth of smart-phones, connecting to the Internet and/or someone else anywhere anytime is becoming necessary in modern lifestyle. To be able to connect from anywhere with adequate bit rate, mobile terminals must have multi-mode and multi-band operation capabilities. In other words, mobile terminals will be expected to function in all the required wireless systems and frequency bands. With regard to frequency bands for cellular systems, some reports indicate that the number of frequency bands required for a global mobile terminal is 3-5 for the third generation (3G) cellular system and it will be increased to 7-9 in the Long Term Evolution (LTE) era. A Radio frequency (RF) front-end (RF-FE) is one of the key components for the global mobile terminal, which should cover a vast number of frequency bands. In this paper, the RF-FE consists of power amplifier(s) (PA(s)), RF filters as a part of duplexers, antenna switches and low noise amplifier(s) (LNA(s)). In conventional cellular phones, multiple PAs, filters, and LNAs are installed for multi-band use, as shown in Figure 1. RFIC generally includes most of RF functions except PA, duplexer, band-pass filter (BPF) and antenna switch, and may have transceivers for wireless local area network (WLAN), Bluetooth and a receiver for the Global Positioning System (GPS).

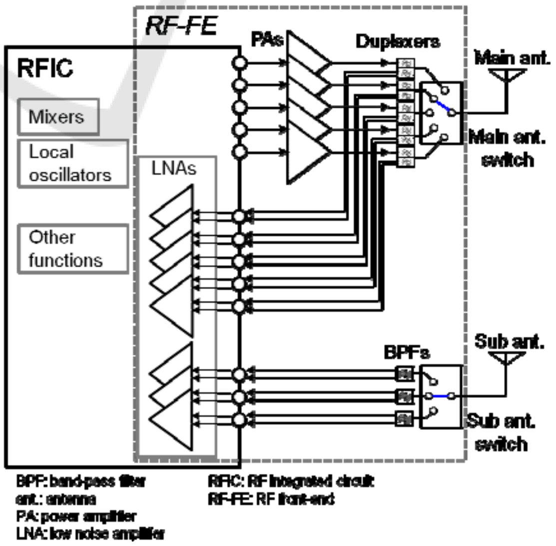

Figure 1: A conventional RF-FE configuration for frequency-division duplexing (FDD) systems.

Okazaki H., Furuta T., Kawai K., Takagi Y. and Narahashi S.
RF FRONT-END CONSIDERATIONS FOR FUTURE MULTIBAND MOBILE TERMINALS.
DOI: 10.5220/0004785300580061
In *Proceedings of the Second International Conference on Telecommunications and Remote Sensing (ICTRS 2013)*, pages 58-61
ISBN: 978-989-8565-57-0

The RF-FE configuration shown in Figure 1 is based on a conventional scheme, which is selecting the most suitable circuit combination from among several built-in circuits for each frequency band. The RF-FE in the figure can process 5 different frequency bands, and also have a diversity or 2-stream multiple-input and multiple-output (MIMO) receiving capability at 3 out of the 5 bands by using a sub receiver. However, the conventional configuration will reach impasse, and the terminal employing the configuration will be bulky and expensive. This is because the terminal handling *m* bands and *n* spatial streams for MIMO should have ($m \times n$) transceivers in it. Therefore, there have been a lot of studies of achieving multi-band or broadband circuits that comprise a compact and cost-effective multi-band RF-FE with adequate RF performance (Hueber and Staszewski (Ed.), 2011), (Bezooijen, Mahmouji, and Roermund, 2011). A reconfigurable or tunable technique seems to be a way to provide a multi-band RF-FE that supports a large number of frequency bands. An example is shown in Figure 2. However, the performance degradation should be considered if adaptive circuits are installed in the RF-FE. This paper presents considerations for the issues that might occur in a multi-band RF-FE for future mobile terminals. As an example, a concept of collaboration between a top RF BPF and LNA is presented.

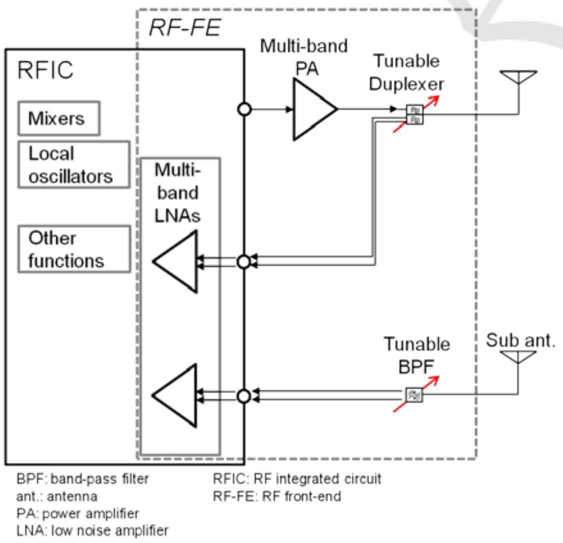

Figure 2: An example of RF-FE configuration employing multi-band circuits for FDD systems.

2 CONSIDERATIONS ON MULTI-BAND CIRCUITS

In this section, some considerations on each component in RF-FE are presented.

2.1 PA

In conventional configuration shown in Figure 1, highly sophisticated PAs are employed. Each of those PA is optimized for a specific frequency band and modulation scheme (mode) operation, thus, it is called as a single-band PA. The main concern of the PA for the mobile terminal is efficiency at required output power levels and spurious specifications at an operating frequency. Generally, efficiency versus frequency characteristics show a peak. That means frequency range where the PA works at high efficiency is limited. There are trade-off relationship between efficiency and frequency range. Figure 3 shows a rough comparison of the efficiency characteristics with PA design schemes.

A single-band PA is usually designed by a narrow-band matching scheme. A multi-band PA based on wide-band matching (wide-band PA) can cover closely-located frequency bands, such as 800, 850 and 900 MHz bands, in compensation for some efficiency degradation from the single-band PA. A wide-band PA is becoming popular because it can merge several PAs which should be required for the conventional RF-FE in a multi-band terminal. However, the wide-band PA is not practical to merge the PAs for widely spread frequency bands, such as 800 and 1900 MHz bands. The PAs based on broadband or distributed matching generally achieve lower efficiency than the wide-band PA, and they are not suitable to use in the mobile terminal.

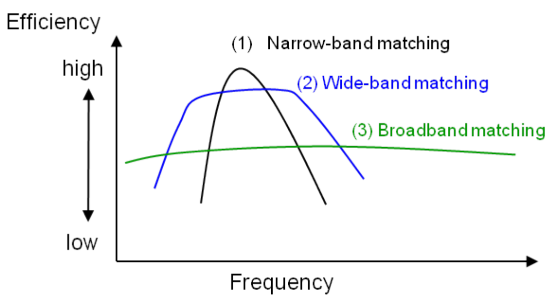

Figure 3: A comparison of design schemes of PA on efficiency versus frequency characteristics.

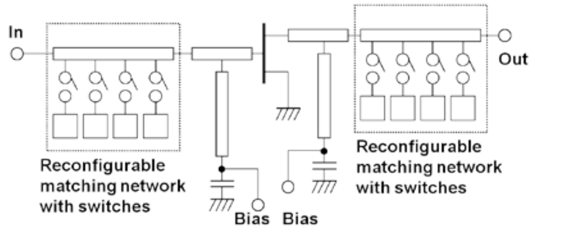

Figure 4: Circuit diagram of reconfigurable amplifier with switches in its matching networks.

On the other hand, a PA with reconfigurable or tunable matching network is expected to achieve high efficiency at each frequency band even if the bands are widely spread. The PAs have variable devices such as switches or varactors in their matching networks to change their operating frequency. Figure 4 shows a circuit diagram example of a reconfigurable amplifier. The status or parameters of the variable devices are set to optimized values for high efficiency based on narrow-band matching at each target frequency. However, efficiency degradation should be considered because the variable components have losses. In the case of the reconfigurable PA with switches, detailed evaluations were presented and it is reported that the degradation can be mitigated (Fukuda, *et al*., 2011).

2.2 Filters and LNAs

Figure 5 shows an example of a receiver RF-FE configuration, which is one generation earlier than that shown in Figure 1. With the progress of CMOS process and efforts on circuit technologies such as "SAW-less" technique (Darabi, 2007), it becomes natural that the LNA is integrated into an RFIC, and the BPF between LNA and RFIC shown in Figure 5 is removed. The main concerns of a LNA for the mobile terminal are sensitivity (gain and noise figure) and linearity, which includes immunity from out-of-band signals. Broadband or wide-band operation of the LNA itself seems to be easier than that of an efficient PA.

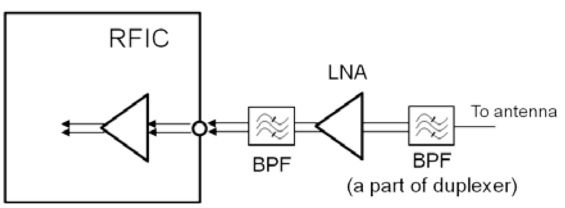

Figure 5: One generation earlier receiver RF-FE configuration example of receiver side.

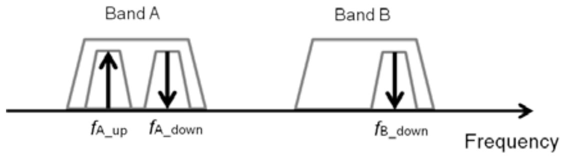

Figure 6: Inter-band CA.

Comparing the receiver configurations shown in Figures 1 and 2, only tunable BPF is required to configure the RF-FE shown in Figure 2. However, it is a considerable challenge to attain a tunable BPF with low-loss at pass-band, high isolation at suppression band, and a wide-tuning frequency range.

Carrier aggregation (CA) technology that employs several bands aggregately and concurrently will be utilized to obtain a wide operating band-width in the LTE-advanced era. Figure 6 shows an example of spectrum usage in inter-band CA. One technical issue for the CA is configuring a duplexer and BPF. Characteristics at the combination band should be considered in the duplexer design in addition to a conventional duplexer design scheme which mainly considers characteristics at an original frequency band for isolation between transmitter and receiver. Because so many combinations of pair-bands are considered for the inter-band CA, a conventional duplexer-bank scheme will make a global terminal more bulky, and using tunable BPFs and tunable band-elimination filers (BEFs) will become more valuable. Otherwise localized mobile terminals for a specific carrier, county, or region will revest.

Considering a tunable filter as a part of the tunable duplexer, one of the serious problems for receiver chain is to generate gain and phase modulation caused by strong out-of-band signals. The LNA will be required to enhance its frequency selectivity in order to prevent the performance degradation from undesired out-of-band signals in a multi-band receiver that yields non-optimum RF filter performance. Frequency response adjustment of the LNA will be a solution.

Figure 7 shows small signal frequency responses of the reconfigurable LNA that has a same circuit topology shown in Figure 4. The responses were obtained in two different switch states (0 and 1) at a class A bias condition. Figure 8 shows the results of the gain suppression measurement at 3.1 GHz with out-of-band signals of 2 GHz. From the results above, the input power of 3.1 GHz for each state is set to -20.3 dBm, which lies in a linear region. In the figure, "gain difference" and "gain diff. at 3.1-GHz," correspond to the difference in gain at 3.1 GHz between with and without the 2.0-GHz signal input power indicated on the horizontal axis, respectively. The gain of the 2.0-GHz signal without the 3.1-GHz input is also shown for comparison. The gain suppression is observed at a higher level of 2.0-GHz input power, and is mitigated in state 1. Thus, the frequency response adjustment of the LNA is effective in the gain suppression problem caused by out-of-band signals as well as filter response improvement. (Okazaki, *et al*., 2010)

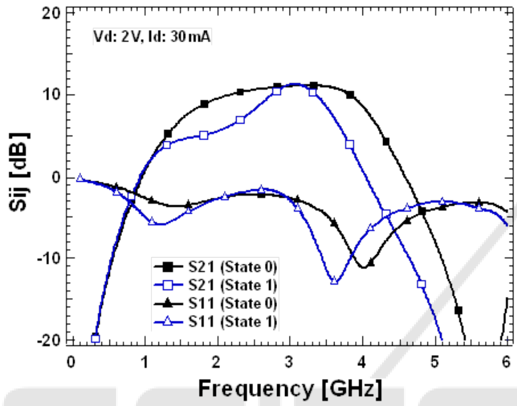

Figure 7: Frequency response of reconfigurable LNA.

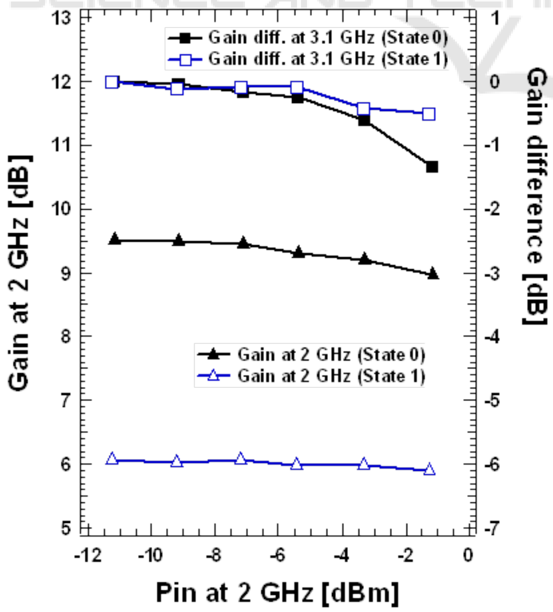

Figure 8: Results of the gain suppression measurement.

3 CONSIDERATIONS ON OVERALL RF-FE

One of the main issues for the overall RF-FE is known collectively as RF coexistence, which is a hot topic (Sahota, 2012). A modern mobile phone has different kind of RF systems such as cellular, WLAN, Bluetooth, GPS, etc., which will be activated at the same time. Each of them may become a source of interference and also a victim of that. Moreover, the MIMO and intra-band CA require also simultaneous operation within multiple transceivers for cellular systems. It seems to be difficult to work all the RF transceivers and receivers installed in a multi-band mobile terminal with expected performance in RF quiet environment.

4 CONCLUSIONS

Several RF-FE considerations for future multi-band mobile terminals are described. Some of them will be solved but others such as ideally tunable filters are remained as issues to be solved and the problems of RF coexistence are still growing. Continuous efforts and innovations are really needed.

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