LTE RF Front-End Architecture for Mass Market

MediaTek White Paper

October 2014

1 Introduction

Cellular mobile communication technology has undergone a rapid evolution from GSM, WCDMA, TD-SCDMA to the current LTE standard. With dramatically increased frequency bands, radio front-end architecture is becoming ever more complex, particularly as it needs to support the carrier aggregation (CA) of LTE Advanced (LTE-A) . We need to find a good RFFE topology applicable for the LTE mass market and scalable for multiple variants. This means increasing the front end units supply ecosystem, so as to reduce costs with economies of scale.

2 LTE RF Front-End Design Challenges

LTE is the fastest developing mobile system technology to date. According to the September 2014 Global Mobile Suppliers Association's "Evolution to LTE Report, 331 commercial LTE networks launched in 112 countries to date, which includes 40 LTE TDD networks in 27 countries.[1, 2] Today's quad-band GSM + dual-band UMTS handsets no longer meet the needs of LTE requirements in most markets; LTE handset standards vary in different markets. Telecommunication regulators face the pressure of new spectrum resource requirements to meet the exponential demand of mobile data service. The GSA's report notes that network phone operators are deploying multiple LTE spectrum bands under LTE TDD or FDD modes. A scalable RFFE design is needed to both meet the radio performance requirements and the potential cost competition evident in industry trends.

2.1 Increasing LTE Bands

The complexity of LTE spectrum is significant when compared with UMTS. The defined 3GPP (LTE) TDD & FDD bands are summarized here.

Table 1. FDD LTE Bands & Frequencies

FDD LTE BANDS & FREQUENCIES					
LTE BAND NUMBER	UPLINK (MHZ)	DOWNLINK (MHZ)	WIDTH OF BAND (MHZ)	DUPLEX SPACING (MHZ)	BAND GAP (MHZ)
1	1920 - 1980	2110 - 2170	60	190	130
2	1850 - 1910	1930 - 1990	60	80	20
3	1710 - 1785	1805 -1880	75	95	20
4	1710 - 1755	2110 - 2155	45	400	355
5	824 - 849	869 - 894	25	45	20
6	830 - 840	875 - 885	10	35	25
7	2500 - 2570	2620 - 2690	70	120	50
8	880 - 915	925 - 960	35	45	10
9	1749.9 - 1784.9	1844.9 - 1879.9	35	95	60
10	1710 - 1770	2110 - 2170	60	400	340
11	1427.9 - 1452.9	1475.9 - 1500.9	20	48	28
12	698 - 716	728 - 746	18	30	12
13	777 - 787	746 - 756	10	-31	41
14	788 - 798	758 - 768	10	-30	40
15	1900 - 1920	2600 - 2620	20	700	680
16	2010 - 2025	2585 - 2600	15	575	560
17	704 - 716	734 - 746	12	30	18
18	815 - 830	860 - 875	15	45	30
19	830 - 845	875 - 890	15	45	30
20	832 - 862	791 - 821	30	-41	71
21	1447.9 - 1462.9	1495.5 - 1510.9	15	48	33
22	3410 - 3500	3510 - 3600	90	100	10
23	2000 - 2020	2180 - 2200	20	180	160
24	1625.5 - 1660.5	1525 - 1559	34	-101.5	135.5
25	1850 - 1915	1930 - 1995	65	80	15
26	814 - 849	859 - 894	30 / 40		10
27	807 - 824	852 - 869	17	45	28
28	703 - 748	758 - 803	45	55	10

FDD LTE BANDS & FREQUENCIES					
LTE BAND NUMBER	UPLINK (MHZ)	DOWNLINK (MHZ)	WIDTH OF BAND (MHZ)	DUPLEX SPACING (MHZ)	BAND GAP (MHZ)
29	n/a	717 - 728	11		
30	2305 - 2315	2350 - 2360	10	45	35
31	452.5 - 457.5	462.5 - 467.5	5	10	5

Table 2. TDD LTE Bands & Frequencies

TDD LTE BANDS & FREQUENCIES		
LTE BAND NUMBER	ALLOCATION (MHZ)	WIDTH OF BAND (MHZ)
33	1900 - 1920	20
34	2010 - 2025	15
35	1850 - 1910	60
36	1930 - 1990	60
37	1910 - 1930	20
38	2570 - 2620	50
39	1880 - 1920	40
40	2300 - 2400	100
41	2496 - 2690	194
42	3400 - 3600	200
43	3600 - 3800	200
44	703 - 803	100

Several additional bands are addressed here.

- **Low Bands (<1GHz),** with improved network coverage for macro cell.

  Band 31, 450-470MHz. Brazil's Telecom proposed this frequency to the 3rd Generation Partnership Project (3GPP) mobile broadband standards body and created a 3GPP "Work Item" in September 2012. The smallest duplex gap analyzed at 3GPP is 5MHz between uplink (at 452–457 MHz) and downlink (at 462–467 MHz), making the 450MHz the most challenging Band ever.

  600MHz Band, the spectrum released from broadcast TV airwaves for mobile broadband access in the USA. The American regulator FCC plans a spectrum auction in mid-2016, with the possible uplink frequency range 663-698MHz, and downlink frequency range 617-652MHz.

B44, 703-803MHz TDD mode operation overlaps Band 28.

B29, for the use of supplemental downlink in unpaired spectrum. The spectrum of 716-728MHz was initially planned for mobile TV but later proposed to be used only for LTE SDL.

- **Mid Bands (1-3GHz)**, provides balanced coverage/capacity suitable for macro or micro network.

  New AWS Band, the US auction of 2x25MHz spectrum in addition to the existing Band 4. The possible new band frequency spectrum in uplink is 1710-1780MHz, and downlink 2110-2180MHz.

- **High Bands (>3GHz)**, high network capacity performance but short coverage, mainly for use in micro/hotspot networks.

  3.5GHz Bands could potentially become the global harmonized spectrum, in that it has the frequency characteristics for small cell deployment for traffic offloading and the large bandwidth able to fulfill the requirement of increasing capacity.

2.2 Special Band Challenges

As ever more increasing bands are introduced, two key issues emerge to affect the design RFFE difficulty level: the frequency duplex gap and spectrum allocation, and the co-existence requirement.

The **frequency duplex gap** between uplink and downlink represents the RFFE filtering sharpness. For example as in Band 13, specific to Verizon Wireless in USA, the minimum gap between DL and UL is only 12MHz. This gap makes the duplex filter design really difficult for Band 13 and may need additional transmit power reduction with relaxed received receive sensitivity requirement.

Frequency Band allocation is also an issue. The digital divided Band 28 has relatively wide range low band frequency, uplink 703-748MHz and downlink 758-803MHz. The duplex filter has limited relative bandwidth (frequency gap/center frequency = relative bandwidth) thus the Band 28 duplexer usually is separated as two, the Band 28A & 28B, which results in

The **coexistence** issue can occur not only between cellular bands, but also between cellular bands and other air interfaces, such as GPS, Wi-Fi, Bluetooth or FM. Generally the solutions require more complex filtering, additional max power reduction, or relaxation of expected performance. Because the Bands 7, 38, 40, and 41 are the bands closest to the ISM Band, the RFFE design needs to contain a filter to avoid the interference, which impacts the transmit path link budget and also increases the switch usage for band selection.

2.3 Global LTE Design

Various LTE definitions must be examined when designing a universal global mobile device. The global UMTS bands are clear as Band 1, 8 or Band 2, 5, but LTE bands are much more complex. Band 3 is reportedly the most widely used band for LTE deployment. The reasons that network operators deploy 1800MHz LTE network are obvious: good coverage, and the available spectrum of re-farming from 2G service, or existing sufficient bandwidth in 1800MHz. And most importantly user device ecosystem is fairly mature with 1800MHz terminals. The next most frequently utilized bands are 2.6GHz (Band 7), and followed by 800MHz (Band 20), in wide use in Europe and Russia, and AWS (Band 4). In addition, two other frequency bands with potential of becoming the global harmonized spectrum are worth monitoring. The APT700 group, the 700/800MHz digital dividends Band 28 has been adopted in Asia Pacific countries, in almost all South American countries, and also two nations in Africa. And 900MHz (3GPP Band 8), where industry interest as a LTE Band is growing, as many GSM licenses are approaching expiration dates. In such cases regulators usually allow for technology neutrality license renewal or auction.

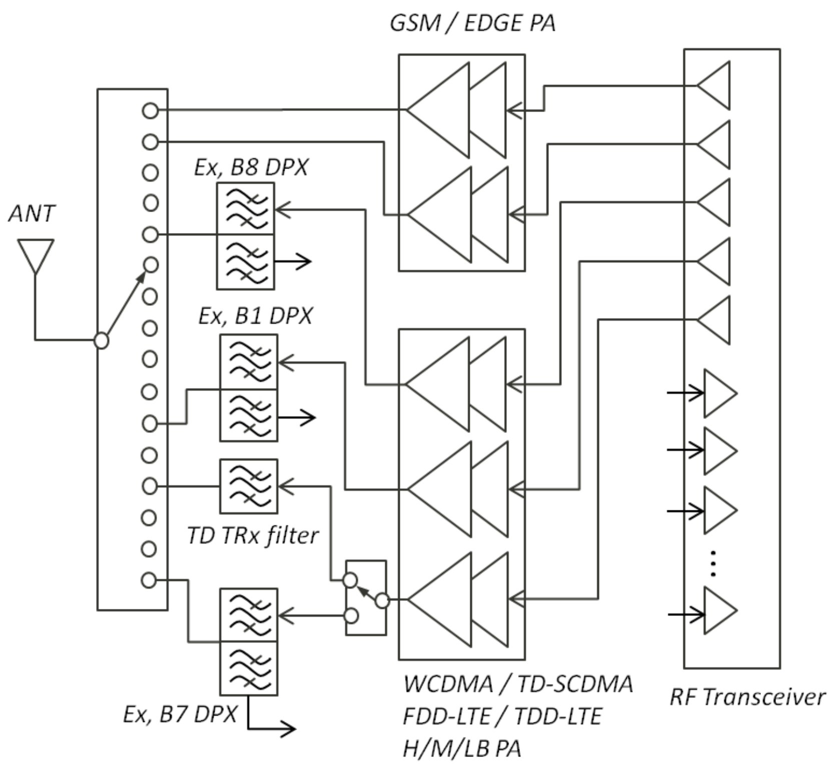
If the LTE RFFE is customized for each specific region, the components economies scale will be limited for multiple variants and would slow the cost reduction. To ensure cost efficient LTE terminal devices, a scalable LTE RFFE design is essential. This insures maintaining system flexibility but also unifying the front-end components eco-system.

3 Trends of Industry Development

Important industry development issues include wideband and high efficiency PA design, filter requirements, switch development, and integration.

As shown in the simplified diagram below, the key front end components are power amplifiers (PA) and transmit/receive path or duplex filters and switches for band selection or antenna switch module.

Figure 1. Simplified Front-End Block Diagram



From UMTS to LTE and beyond, the RF component technologies are developed not only to perform the radio conformance test but also to reduce LTE RFFE complexity. The LTE power amplifier is targeted to broad-banding and tunability, which enables the power amplifier to be shared usage of a specific frequency range operation. Of course, because the power saving is always the top priority of power amplifier design, the high load-line power amplifier is optimized with Envelope Tracking technique adoption. The frequency selective filters are needed for each band, which can be used on transmit path to eliminate the noise level or interference level, or the receive path to ensure the radio blocking performance, or the duplex filter to provide the Tx to Rx isolation. Usually the surface acoustic type filter has a lower process cost when compared to the bulk acoustic type filter. Therefore the lower cost solution is typically favored when component specification is not too difficult and can be handled by the SAW filter. But some difficult bands still need bulk technique to deliver promising performance. The mainstream market has adopted the switch with SOI due to cost efficiency and the promising performance-- the insertion loss, isolation, or the harmonics are all acceptable in LTE system.

Since each module vendor has its own competition landscape, the RFFE integration can take different paths. A summary of module-building topologies, shown in table below, can be a guide in the selection of a suitable scalable RFFE architecture strategy.

- Topology 1 is the conventional architecture. The 2G/3G/4G power amplifiers of low band and mid-band cores are integrated with several band select switches as a MMMB power amplifier module, and adopted with a high band power amplifier module if TD-LTE or Band 7 is supported. Another building block is the separated antenna switch module. The duplexer filters can be either discrete or integrated as a duplexer band. Or even further integration of ASM and DPXs is an available solution.
- Topology 2 integrates 2G power amplifier and ASM as a transmit module (TXM), and puts all other 3G/4G power amplifiers in a single package.
- Topology 3 integrates 2G/3G/4G low band & mid-band power amplifiers, band select switch, and partial of ASM as a single module. This is beneficial for SOI technology integration, but since there are still many duplex filters in between 3G/4G power amplifier and ASM, the IN/OUT pcb routing may be complex and needs to carefully handle the Tx-Rx paths in isolation.
- Topology 4 leaves the ASM outside, and integrates the power amplifier with duplex filters into the power amplifier + Duplexer (PAD) module. The partition is separated by low band, mid band and high band. The built-in duplex filter and power amplifier can minimize the impedance transfer loss. But since the embedded filters are costly, the number of integrated duplex filters depends on the device shipping target. This topology is more cost effective for the OEMs with large unit volume and clear shipping forecasts.
- Topology 5 is the fully integrated module, with the power amplifiers, duplex filters and ASM in the module as a single package or separated as different frequency groups.

Each topology offers multiple consideration issues, such as the design scalability for sku variants, end-user tuning flexibility for performance optimization, and also the supply chain eco-system, and RF layout area.

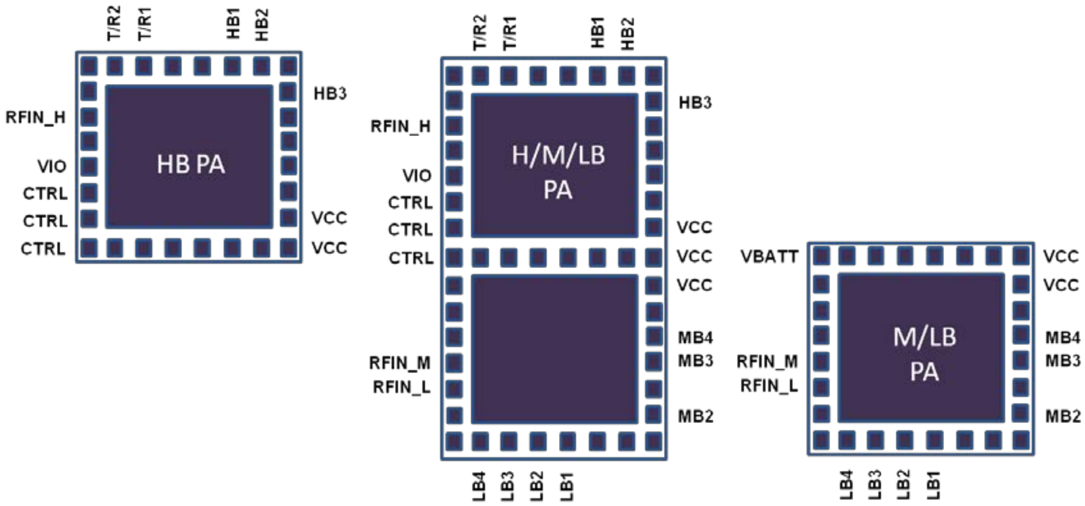
Table 3. Module Integration Solutions

Topology	**1**	**2**	**3**	**4**	**5**
Architecture	ANT switch filter, Duplexer HB PA, M/LB PA, 2G PA	TXM (switch+2GPA) filter, Duplexer HB PA, M/LB PA	ANT switch filter, Duplexer HB PA, M/LB 2G/3G/LTE PA + switch	ANT switch PAD, PAD, PAD	PAMID PAMID (All-in-One module)
Supplier	ASM, MMPA, DPX	TXM, MMPA, DPX	ASM, MMPA, DPX	PAD, ASM	AIO module
Scalability	◎	◎	X	X	X
Tuning flexibility	◎	◎	◎	X	X
Eco-system	△	◎	X	△	X
Layout area	X	△	△	◎	◎
◎ good, △moderate, X not good.					

4 RFFE Integration

Topology 2 shows good balancing of flexibility and has an especially lower entry barrier for not only the Tx module but also the 3G/4G multi-mode multi-band power amplifier (PA) design. For scalability, the module is defined with several variants to fit different SKU variants with cost optimized structure. The Tx module, which is the GSM PAs with integrated ASM, can be 8T, 10T, 12T or even up to 16T. Inside the MMMB power amplifier there are typically three PA cores which can support low band, mid band and high band 3G/4G application. And the correlated switches can also be integrated for band selection purposes. The duplex filters are left outside the PA module for better routing and tuning flexibility, but it's still available for further integration with a duplex bank module.

Figure 2. Unified Land Pattern for the MMMB PA Definition

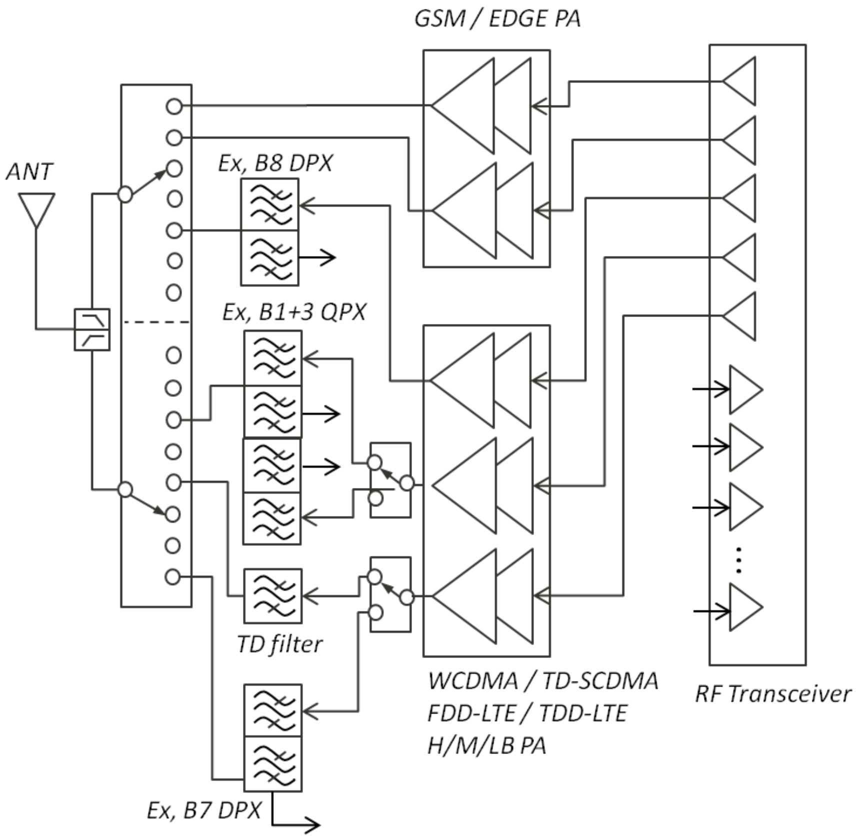


To save the pcb mounting area, the component packages should ideally keep the same footprint as a unified land pattern as Figure 2, which allows a single pcb design to accommodate different LTE sku variants. For example, a single pcb design to meet both CMCC's 5-modes 10-bands and TDD 3-modes 8-bands requirements, by changing the TxM 14T to 10T and MMMB power amplifier HMLB to HB power amplifier drop replacement. This proposal can easily achieve the efficient RFFE pcb area and offer the best cost optimization for different skus. This scalable RFFE topology is not only flexible for the China market but also for the worldwide market for either the FDD-LTE or TD-LTE terminals.

5 Extendable for LTE-A Application

This topology is extendable to support the next generation mid-low end CA, such as the intra-band aggregation, or most of inter-band downlink aggregation, with a reserved pin for the secondary TxM antenna port. The general RFFE architecture for LTE-A carrier aggregation is shown in Figure 3 below.

Figure 3. Architecture for LTE-A Carrier Aggregation



This module definition may face difficulty meeting the required system specification for some specific CA combinations, such as the uplink CA, or the harmonics-desensed CA. In general, however, this scalable RFFE topology is still workable for most mass market targets

6 Conclusion

In this white paper, we try to identify the suitable RFFE topology for the LTE mass market. The scalable architecture can be utilized widely with worldwide SKU variants, and can also achieve the efficient pcb area with the unified package definition. This concept has to be communicated to components vendors to enrich the eco-system environment.

7 References

1. “Evoluation to LTE,” Global Mobile Suppliers Association, September, 2014
2. “Whitepaper on Spectrum,” Huawei, February 2013