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Temperature-Compensated Filter Technologies Solve Crowded Spectrum Challenges

Phil Warder, David Schnaufer
TriQuint Semiconductor
Note: TriQuint and RFMD have announced plans to merge under the name of Qorvo.

The extraordinary growth in mobile wireless data is generating a continuous need for new spectrum bands in which operators can deploy LTE services to accommodate the traffic. As a result, global spectrum has become increasingly crowded, with a highly fragmented and complex array of spectrum licenses spread across multiple operators

Manufacturers are now creating smartphones that support many bands, as they seek to minimize the number of different handset models and enable global roaming. Some of these LTE bands are very close to bands used for other wireless applications such as Wi-Fi and satellite radio. Due to these trends, devices must include a growing number of high-performance filters to prevent interference between these closely spaced frequency bands.

As frequency bands squeeze closer together, filter temperature drift has emerged as a significant challenge. Traditional filter technologies, in which the frequency response shifts as the temperature changes, are often not able to meet the challenging requirements in mobile devices that must operate over a wide temperature range. Solving these challenges requires new filter processes with a much more stable response to temperature variation.

Another challenge facing device designers is limited space, as they seek to pack more filters into each device. This applies not just to smartphones but also to the growing range of other mobile and fixed wireless devices including automotive electronics and small-cell base stations. New packaging technologies play an important role in reducing filter size, making it easier to fit more of them into each device. These packaging technologies are particularly valuable for components such as LTE diversity filters in which compact size is the primary consideration.

Filtering requirements will become even more stringent in the future as more new bands are defined and operators deploy faster LTE Advanced networks to support escalating demand for video and other bandwidth-intensive applications. The data rate increases provided by LTE Advanced will depend in part on Carrier Aggregation (CA), an LTE Advanced feature that enables operators to combine fragments of spectrum to create wider channels. CA will need high-performance filters to meet the requirements for low insertion loss and isolation of each component carrier.

Also on the horizon are new 3.5 GHz bands that will open up wide expanses of a previously unexploited spectrum, and the proposed use of LTE Advanced in an unlicensed 5 GHz spectrum (LTE-U). These developments will be important in enabling operators to support more users via network densification.

▲ *Fig. 1 Band 13 and public safety coexistence challenge.*

THE NEED FOR TEMPERATURE-COMPENSATED FILTERS

The key filter performance parameters are low loss of the desired signals in the passband and sufficient attenuation of undesired interference in the stopband. These parameters must be met over environmental and production variations. Historically, designers have built allowances for each of these sources of variation into the system. However, the design challenges have increased as bands have become more closely spaced.

In some cases, the transition between the passband and stopband is as small as 2 MHz. In such cases, it is almost impossible to meet the requirements using traditional filter technologies. This is because the variation in response, which is dominated by temperature drift, can exceed the width of the transition band. The result is unacceptable interference, high insertion loss, or both.

The solution is to design filters using a process that greatly reduces temperature drift. TriQuint has developed such fabrication processes for both of the primary filter technologies: surface acoustic wave (SAW) filters, which are most effective for lower frequencies up to about 1.9 GHz; and bulk acoustic wave (BAW) filters, which are typically used for higher frequencies above 1.5 GHz. As shown in ***Table 1***, these new processes produce filters with dramatically reduced temperature sensitivity. For example, the standard SAW process produces filters with temperature variation of -35 to -45 ppm/°C. In comparison, temperature variation for NoDrift™ SAW filters is almost eliminated, at 0 ± 2 ppm/°C. For LowDrift™ BAW filters, temperature drift is -17 to -22 ppm/°C; with NoDrift™ BAW, this is reduced to 0 ± 2 ppm/°C.

These new SAW and BAW filters are effective within the same frequency ranges as standard SAW and BAW. The reduced sensitivity to temperature change makes these processes a good choice for challenging specifications including several new 3G and 4G duplexers and filters.

TABLE 1

COMPARING STANDARD AND TEMPERATURE-COMPENSATED SAW AND BAW FILTERS

SAW Processes	
Process	***Temperature Drift***
Standard SAW	-35 to -45 ppm/°C
LowDrift™ SAW	-22 ppm/°C
NoDrift™ SAW	0 ± 2 ppm/°C
BAW Processes	
Process	***Temperature Drift***
Standard FBAR	-22 to -31 ppm/°C
LowDrift™ BAW	-17 ppm/°C
NoDrift™ BAW	0 ± 2 ppm/°C

BAND 13

A specific example where temperature-compensated filters are needed is Band 13. The challenge, shown in ***Figure 1***, is that the Band 13 uplink at 777 to 787 MHz is very close to narrowband public safety communications in the 769 to 775 MHz region. This problem was anticipated by 3GPP, the organization responsible for LTE standards. To avoid interference problems, 3GPP defined a network signaling case (NS_07) whereby the network signals mobile devices when there is a narrowband public safety system in the area. In response to this signal, mobile devices must reduce emissions in the 769 to 775 MHz range by 22 dB.

In initial Band 13 deployments, the only feasible way to achieve this emissions improvement was to reduce the output power of the mobile device. The required power reduction is a function of the number and location of the reference blocks in the uplink transmission; worst-case reductions are significant, ranging as high as 12 dB.

Because a power reduction of this size significantly impacts system performance, the operators using Band 13 have long wanted a solution capable of addressing the interference issue without the reductions in output power. To meet the specification, filtering solutions need to provide 22 dB

TABLE 2

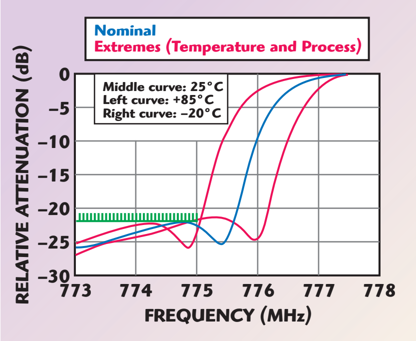
COMPARING TEMPERATURE DRIFT OF STANDARD AND TEMPERATURE-COMPENSATED BAND 13 UPLINK FILTERS

	Standard SAW	LowDrift™ SAW	NoDrift™ SAW
Temperature Coefficient	-40 ppm/°C	-20 ppm/°C	-2.5 ppm/°C
Drift cold (25° to -20°C)	1.40 MHz	0.70 MHz	0.087 MHz
Drift hot (25° to +85°C)	-1.87 MHz	-0.93 MHz	-0.116 MHz

TABLE 3

DRIFT OF TEMPERATURE-COMPENSATED BAND 30 BAW FILTERS AT 2324 MHz

	Standard FBAR	LowDrift™ BAW	NoDrift™ BAW
Temperature Coefficient	-27 ppm/°C	-17 ppm/°C	-1 ppm/°C
Drift cold (25° to -20°C)	2.9 MHz	1.78 MHz	0.10 MHz
Drift hot (25° to +85°C)	-3.9 MHz	-2.37 MHz	-0.14 MHz



▲ *Fig. 2 Band 13 NoDrift™ filter performance.*

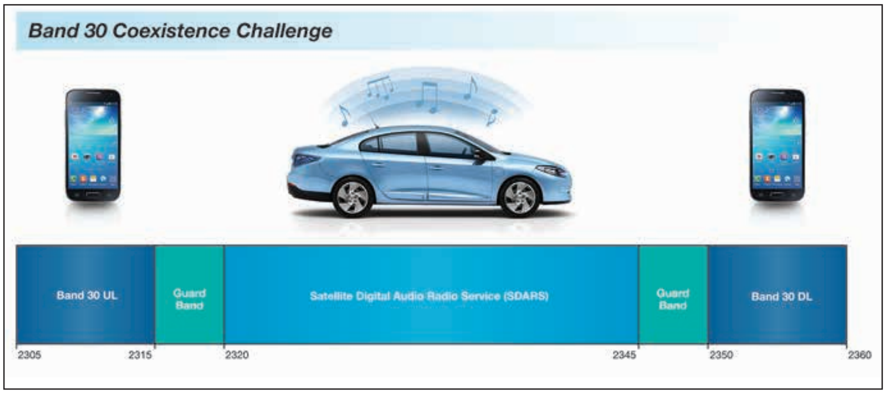
of attenuation at 775 MHz while still passing 777 MHz, the lower edge of Band 13. Complicating the problem is the need to provide this attenuation over a wide temperature range, typically from -20° to + 85°C.

Table 2 compares the drift of standard, the new SAW filters over this temperature range. Given that the space between the passband and the stopband is only 2 MHz, it is clear that only these SAW filters, the most temperature-stable of the filter processes, can meet the requirements. ***Figure 2*** shows the performance of the Band 13 NoDrift™ uplink filter in more detail.

BAND 30 AND SATELLITE RADIO

Another example of a situation requiring temperature-compensated filters is the challenge of Band 30 coexistence with satellite radio services, which are widely used to deliver in-car entertainment. The problem is shown in ***Figure 3*** where the satellite radio spectrum is sandwiched into the duplex gap between the Band 30 uplink and Band 30 downlink. The Band 30 spectral emission mask is tightly constrained to protect the satellite radio service as well as government bands below Band 30.

Mobile device makers and operators are very concerned about interference from satellite radio service signals (primarily the signals emanating from



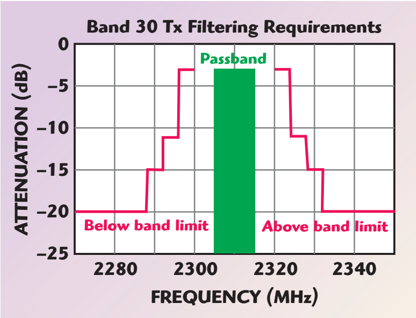
▲ *Fig. 3 Band 30 and satellite radio service coexistence challenge.*

powerful terrestrial repeaters), and about meeting the specified emission mask. Similarly, satellite radio operators are concerned about interference due to Band 30 communications from mobile handsets or base stations.

Figure 4 shows the response required in a Band 30 uplink filter to achieve the spectral emission mask. The passband is 2305 to 2315 MHz, and the most difficult attenuation points are at 2296 and 2324 MHz. These are both 9 MHz away from the passband edge and require 11 dB of absolute attenuation.

As in the example of Band 13, the challenge is complicated by the need to meet the attenuation requirements over a wide temperature range. In the case of Band 30, a temperature-compensated BAW filter is needed. ***Table 3*** shows the response of new BAW filters at the critical 2324 MHz point. Only the NoDrift™ filter is capable of meeting requirements over the complete temperature range.

Filtering requirements for satellite radios are similarly challenging, requiring a temperature-stable filter that passes the satellite band but rejects adjacent Band 30 frequencies. This requirement is met by embedding a bandpass filter based on NoDrift™ BAW process into the car's antenna. ***Figure 5*** illustrates the re-



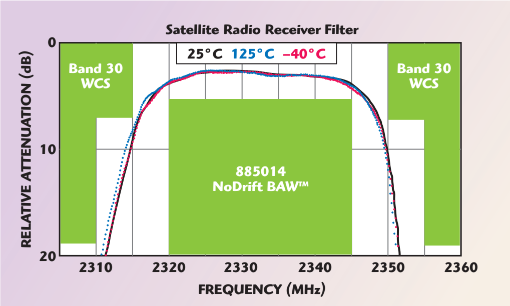
▲ *Fig. 4 Band 30 uplink filter requirements.*

sponse of this filter over a wide temperature range. As shown, the filter meets the requirements for low insertion loss across the entire passband, as well as the attenuation required to avoid interference with Band 30 uplink or downlink communications.

WI-FI COEXISTENCE IN CHINA

While the above two examples refer to filtering challenges in North America, similar challenging requirements exist in other regions. An example is LTE/Wi-Fi coexistence in China. The 2400 to 2482 MHz spectrum used by Wi-Fi lies between Bands 40 and 41, which are used to deliver TDD-LTE service in China. The upper edge of Band 40 (2400 MHz) directly abuts the Wi-Fi spectrum, with no transition band at all.

Solving this Wi-Fi coexistence



▲ *Fig. 5 Performance of NoDrift™ BAW satellite radio service filter over temperature range.*

challenge requires RF filters that are capable of rejecting closely adjacent frequencies. At the same time, the filters must minimize insertion loss in the WLAN transmission pathway, to help maintain the high signal-to-noise ratio and correspondingly low EVM required for 802.11n. BAW filters can achieve quality factors (Q values) that are superior to other traditional acoustic technologies. As a result of the high Q values, the filter skirts will be very steep while insertion losses remain low even at the edges of the passband, minimizing the need to sacrifice LTE or Wi-Fi bandwidth.

SHRINKING FILTERS WITH NEW PACKAGING TECHNOLOGIES

Several factors are creating pressure to continuously reduce filter size. One is the trend for handsets to support an ever-growing number of frequency bands, requiring a corresponding increase in the number of filters. Another is the shift toward slimmer handset designs. Packaging technologies play important roles in reducing the size of filters and duplexers. Wafer-level packaging techniques that eliminate bulky ceramic packages mean filters occupy less PCB space. Flip-chip techniques, which replace wire bonds with more compact copper "bumps," also reduce horizontal space and height requirements. Together, these approaches can reduce space requirements by 50 percent and also reduce package height, facilitating slimmer designs. These can be particularly helpful for LTE RX diversity filters, in which small size is often an even more important concern than performance.

FUTURE FILTERING CHALLENGES

Demand for bandwidth is predicted to continue to skyrocket, largely due to growth in mobile video traffic. Globally, mobile data traffic is expected to increase 11-fold between 2013 and 2018 (Cisco Visual Networking Index, June 2014). Mobile video will grow at an even faster clip, increasing 14-fold over the same period and accounting for 69 percent of total mobile data traffic by 2018. Several developments are underway to help reduce – though not eliminate – the ever-growing pressure for more bandwidth. Each of these has implications for filtering requirements.

CARRIER AGGREGATION

One of these developments is Carrier Aggregation, a feature of LTE Advanced that helps operators create faster wireless data services. CA provides a method for overcoming the 20 MHz limitation on LTE component carrier bandwidth by enabling up to five fragments of spectrum to be combined into a single aggregate carrier that is up to 100 MHz wide. CA will be used to enable services faster than the 150 Mbps supported by a single component carrier (with LTE Category 4) today. Operators are rushing to put CA plans in place; by mid-2014, dozens of two-carrier and more than 50 three-carrier combinations had been proposed. CA will increase filtering challenges because each device will communicate simultaneously over multiple component carriers at different frequencies, requiring stringent attenuation and isolation of each signal to eliminate potential interference between them.

NEW 3.5 AND 5 GHz LTE BANDS

New LTE bands will play a key role in operators' plans to support more users through network densification, while adding capacity for bandwidth-intensive applications such as video download. Network densification entails deploying a large number of small cells (compact network infrastructure devices with limited range) to increase the total number of users that can be supported in densely populated or crowded areas.

3.5 GHz BANDS

TDD-LTE Bands 42 (3.5 GHz band) and 43 (3.7 GHz band) are each 200 MHz wide, representing a significant addition to the available LTE bandwidth. Because of the propagation loss at the high frequencies used by these bands, their biggest value may be for relatively short-range applications, such as enabling speedy video downloads in dense urban areas.

Band 42 may see its first sizable deployment in Japan around 2016, as part of the program to support the 2020 Olympics. In a pilot test using Band 42, a Japanese carrier has already demonstrated very high throughput of 1 Gbps. BAW filters will be well suited to this band, providing better performance in a smaller package size than other technologies. Band 43 is likely to enter use later than Band 42; it presents similar benefits and challenges, and will likewise be best served by BAW filters.

Also on the horizon is LTE Unlicensed – the proposed use of LTE in unlicensed spectrum, notably the 5 GHz range. As with the 3.5 GHz bands, propagation characteristics in this band will likely mean LTE-U is used primarily for shorter-range communications. Some of the 5 GHz spectrum is already used for Wi-Fi. Transmitting data over LTE rather than Wi-Fi may offer advantages for video and other traffic types that can benefit from LTE's enhanced quality of service (QoS) and scheduling capabilities.

CONCLUSION

New spectrum bands and application requirements are creating increasingly difficult filtering challenges. The need to meet these requirements over a wide temperature range has driven the development of new, more temperature-compensated SAW and BAW filters. These filters enable system designers to solve coexistence problems in crowded RF spectrum which are as yet unaddressed by any other technology.

Temperature-compensated Low-Drift and NoDrift filters enable operators and manufacturers to achieve new levels of wireless spectral efficiency. Their extremely precise selectivity means operators and manufacturers can deliver higher speeds and greater bandwidth by utilizing spectrum that might be lost with older filtering technologies due to the need for additional design allowances.

As packaging technologies help to shrink filter size and enable handsets to support the growing number of bands, filter technologies are also evolving to meet future challenges such as new LTE bands that use higher-frequency regions of the spectrum. ■