WHITE PAPER

A New Generation of 5G Filter Technology

Introduction

5G implementation is accelerating worldwide, creating new challenges for wireless technology in mobile devices. The drive to deliver higher data rates with 5G has resulted in an enormous increase in RF complexity: the use of new higher-frequency bands, increasing complexity of modulation schemes, increasing number of antennas, carrier aggregation (CA) and E-UTRA New Radio Dual Connecticity (EN-DC) are all being used extensively to increase bandwidth. These trends increase the probability of interference in mobile devices, to mitigate this, advances in RF filtering technology are required. Space available for the RF front end (RFFE) is shrinking, which means filters must also become smaller and more highly integrated. If that wasn't enough, filters also need to handle higher power to maintain adequate design margins and maximize handset operating range.

Bulk acoustic wave (BAW) filters are evolving to address these challenges, along with other approaches such as antenna routing and antenna tuning. BAW technology is advancing toward handling higher frequencies up to 7 GHz – the upper limit of 5G frequency range 1 (FR1). BAW filters provide low insertion loss that helps maintain RF output power and steep skirts to avoid interference, which makes them extremely efficient at dissipating heat at high power levels. A new generation of BAW technology, called micro-BAW (uBAW), saves board space by making filters smaller and easier to integrate into RFFE modules that support 5G requirements.

5G Filtering Challenges

Table 1 illustrates how RF complexity in mobile infrastructure and devices has increased with each generation of wireless technology. 5G adds yet another level of complexity, intensifying the challenges for mobile device design engineers. RFFEs in 5G devices must support many more RF paths, higher power output and much greater bandwidth, all while occupying less space – minimizing link losses and efficiently removing heat are vital. Advances in filter technology are critical to achieving all these goals.

Table 1. Band and feature developments over time.

			LTE Advanced	5G
Features	**2015**	**2017**	**2019**	**2020**
Number of total RF paths	14	22	>100	>300
Number of filter-band paths	7	12	18	>25
Maximum number of filters combined at one node for carrier aggregation	2	6	8	15
Critical isolation specifications required to meet standard	2	36	51	74
Max bandwidth of transmit signal	20 MHz	40 MHz	60 MHz	100 MHz
Power class 2 (3 dB higher power)	No	No	Yes	Yes
LNA integration	No	No	Yes	Yes
Envelope tracking or average power tracking (ET or APT)	APT	ET	ET	ET & APT
Incremental RF PCB size change	Baseline	+25%	+50%	-35%

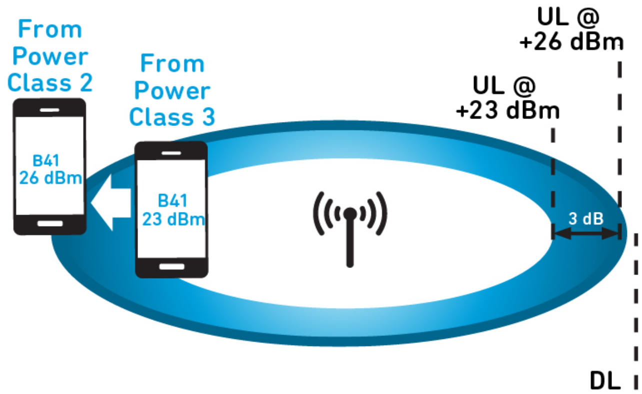
Power Handling and Heat Dissipation

Rising RF power requirements have increased overall system heat. To maintain handset reliability and performance, filters must be able to handle higher power levels and efficiently dissipate the additional heat.

RF power output in mobile devices has increased due to requirements such as Power Class 2, a specification introduced by 3GPP to improve 2.5 GHz TDD-LTE coverage worldwide. Power Class 2 raises power output at the handset antenna by 3 dB, as shown in Figure 1, to increase uplink (UL) range. This specification is also being used to support new higher frequency 5G bands, such as n77, n78 and n79.

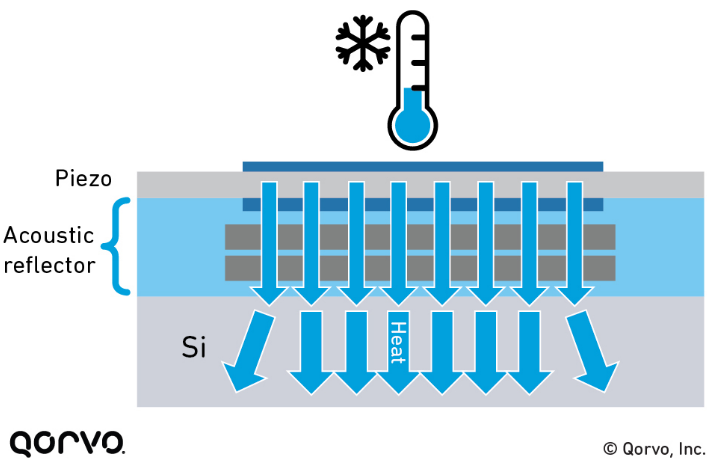
Furthermore, handset manufacturers require RFFE components that handle higher power in order to maintain adequate design margins as system losses increase due to growing RF complexity. In today's mobile and infrastructure devices, filters must handle power levels as high as 33 dBm or more. By effectively dissipating the heat caused by these higher input power levels, filters can maintain performance and avoid lifetime degradation.

Figure 1. Power Class 2 increases handset uplink power and range compared to Power Class 3.



As shown in Figure 2, the structure of solidly mounted resonator (SMR) BAW filters removes this heat much more efficiently than other filter technologies, like film bulk acoustic resonator (FBAR). SMR BAW uses an acoustic reflector comprised of solid layers below the piezoelectric resonator. These solid layers provide a direct link to the silicon substrate below, allowing the heat generated within the filter to efficiently move away from the piezo resonator through the reflector layers to the substrate. In contrast, FBAR devices use an air cavity as the acoustic reflector. Because air is a poor heat conductor, heat must travel around the cavity rather than through it. Therefore, SMR devices are more efficient at moving heat into the silicon substrate, as shown in Figure 3. Increased system heat only has a minimal effect on SMR BAW filter and system performance, in comparison to FBAR, because of these structural differences.

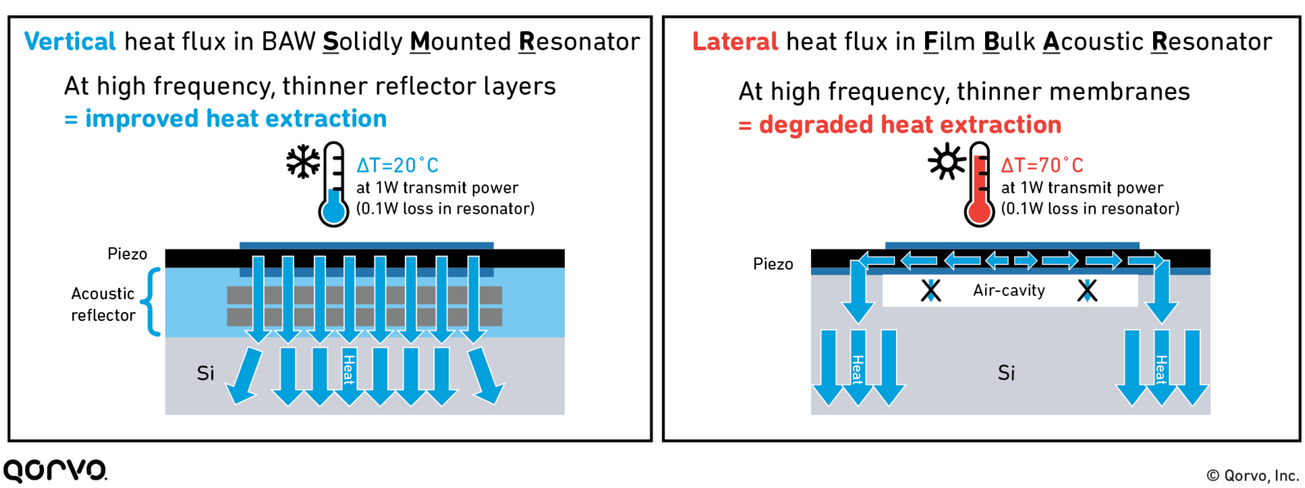
Figure 2. SMR BAW power and heat handling.



Heat Dissipation at Higher 5G Frequencies

The advantages of SMR BAW over FBAR are even more pronounced at the higher frequencies used for 5G. Power handling in filters becomes more challenging at these frequencies due to the smaller resonator size. However, with SMR BAW, the reflector layers also become thinner, which further improves heat extraction (Figure 3). In contrast, with FBAR, the membrane above the air cavity becomes thinner, reducing its ability to move heat away from the resonator. As a result, with SMR BAW the temperature rises 20°C per Watt of transmit power, compared to 70° C rise per watt with FBAR. Less temperature variation means better performance, which enables SMR BAW filters to meet system requirements for insertion loss and out-of-band (OOB) attenuation under high-power and temperature conditions.

Figure 3. SMR BAW versus FBAR filter power and heat handling.



SMR BAW filters also have high quality (Q) factors due to their low insertion loss and steep skirts, which also helps to reduce dissipated power and associated thermal issues.

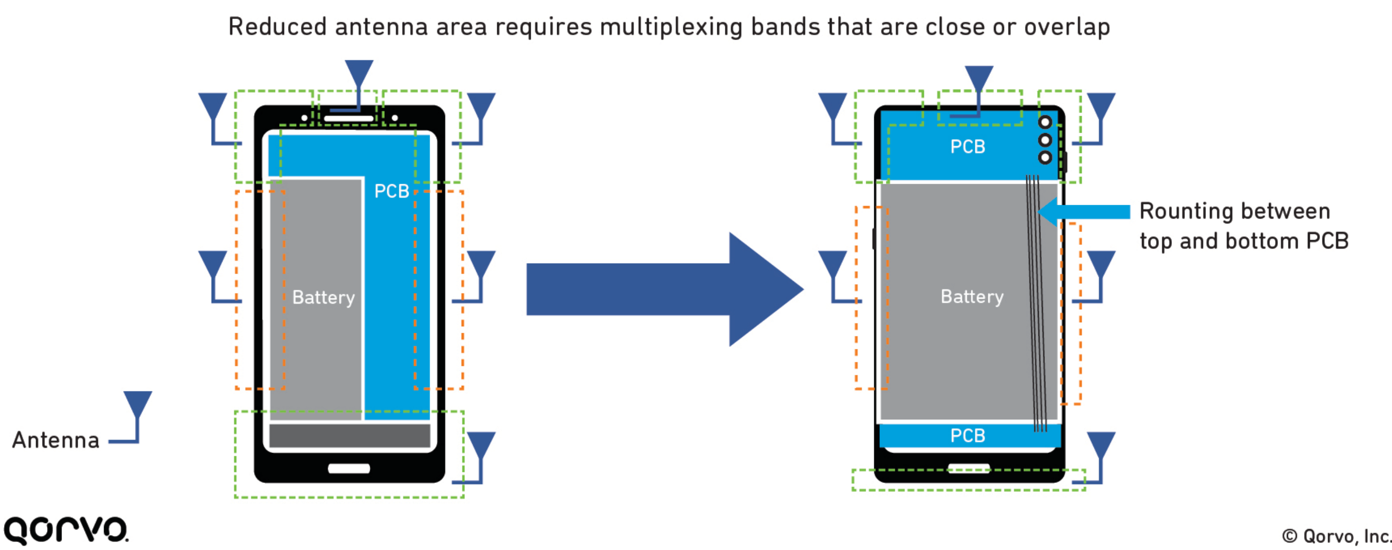
Insertion Losses

As Table 1 shows, the number of RF and filter band paths has increased dramatically in LTE-Advanced Pro and 5G smartphones. These additional paths increase insertion loss as signals pass through the system. Any increase in insertion loss reduces RF output, especially in the higher 5G FR1 ranges above 3 GHz. PA output can be increased to compensate for these incurred losses, but it comes at the cost of higher system current consumption. A better way to mitigate the system link budget increase is to use lower-loss switches and filters, integrate individual components into modules and reduce PC board line lengths. New SMR BAW generations offer reduced insertion loss to help design engineers meet link budget specifications in today's 5G devices.

Small Form Factor

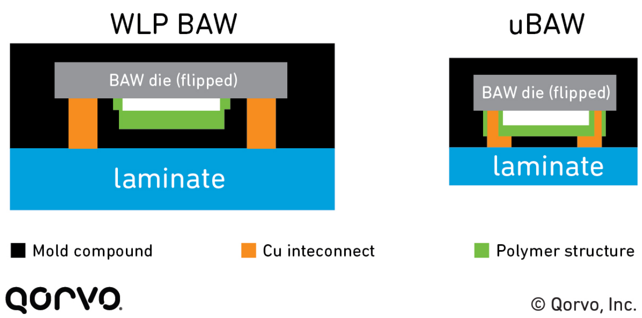
As illustrated in Figure 4, PC board area in 5G smartphones is shrinking due to several factors. Phone manufacturers are increasing battery size to support 5G and other new features. To support broad range frequencies and new wireless standards including Wi-Fi, low-band, mid-band, high-band, ultra-high band and millimeter wave, more antennas are also being added. Therefore, system designers need the RFFE to occupy less area on the PCB. As a result, this drives semiconductor manufacturers to make filters and other components smaller and integrated into increasingly dense, complex RFFE modules.

Figure 4. Larger batteries in 5G phones reduce the available RF related PCB space.



The development of uBAW technology is a key step toward addressing these challenges in 5G smartphones. Like previous BAW generations, uBAW uses wafer level packaging (WLP) with Cu-Sn-pillars. uBAW reduces the die peripheral area by placing the device input and output terminals on top of the WLP-roof, overlapping with the active area. As shown in Figure 5, uBAW shrinks the vias needed to connect the input and output pads to the BAW filter. This also means the distance between the active resonators can be further reduced when compared to previous BAW generations.

Figure 5. Comparing previous WLP BAW generations with uBAW.



Out-of-Band Attenuation with BAW Multiplexers

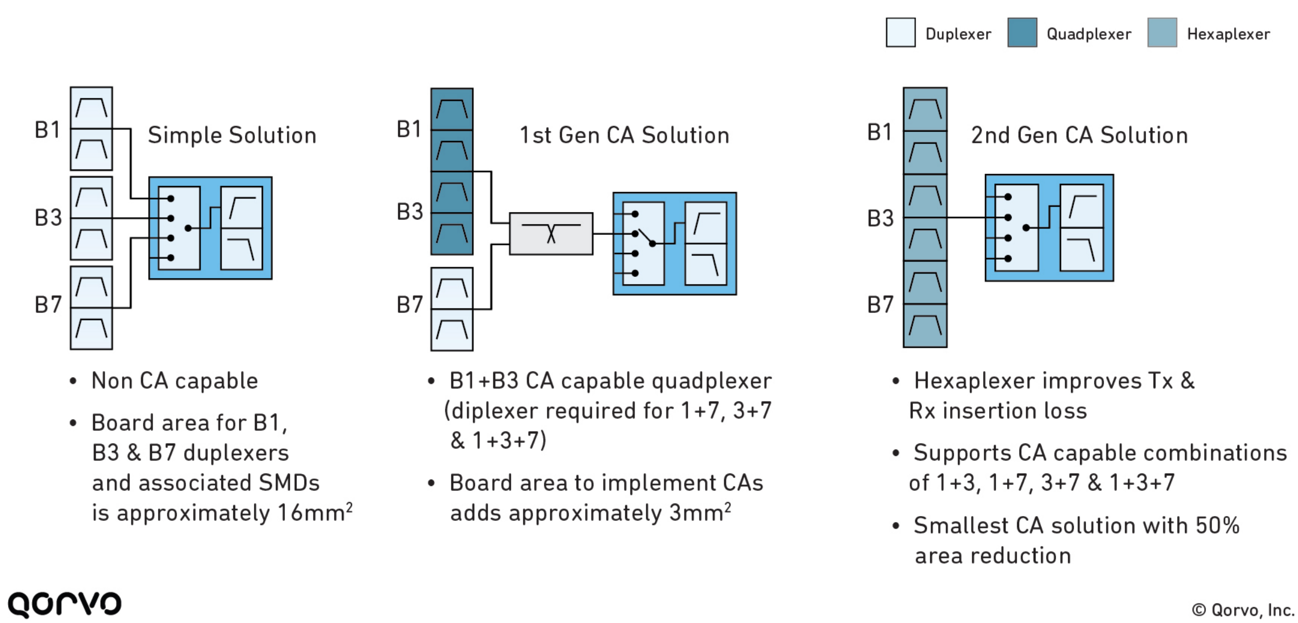
In the 5G ecosystem, attenuating adjacent signals is becoming more difficult as technologies such as CA are used to increase device data rates. CA, first introduced with LTE Advanced, enables mobile network operators (MNOs) to maximize the use of their existing mobile spectrum and bandwidth by combining multiple component carriers into one data channel. By increasing uplink and downlink data rates, CA enhances network performance and enables MNOs to ensure a high-quality user experience.

5G allows many more carrier combinations than LTE, which increases the out-of-band (OOB) attenuation challenges. Enabling CA requires simultaneous communication on multiple carriers, which may be different frequency bands. The system must include mechanisms to help achieve isolation between these RF paths. BAW multiplexers achieve the required cross-isolation between the aggregated RF pathways, allowing communication to occur simultaneously on all the aggregated carriers while attenuating OOB signals for each pathway. BAW filters are well suited to attenuating OOB signals thanks to their steep skirts.

Advancements in filter technology were critical to enabling the adoption of CA with LTE Advanced Pro, and are equally critical for 5G. Filter material advancements in coupling, aluminum nitride enhancement and material doping were important milestones to achieving high attenuation, low return loss and the cross isolation required for enabling CA.

Advances such as uBAW allow for the development of more complex integrated multiplexers, as shown in Figure 6. These highly integrated multiplexers reduce board space requirements and have the added benefit of reducing losses by eliminating the need for additional matching elements.

Figure 6. Tackling CA with advanced BAW multiplexer filter design.



Summary

SMR BAW filter technology has been critical to enabling successive waves of wireless technology and is playing equally important roles in 5G mobile devices. New advances in BAW technology are mitigating thermal issues, reducing board space requirements, enabling greater integration, supporting complex CA requirements and handling the higher frequencies used for 5G. Future BAW technology developments will continue to provide system designers with the tools to further enhance our mobile devices and networks.