Qorvo's Innovative BAW Filters for 5G

Timeline of BAW at Qorvo

- 1996 — First production BAW filter shipped (TFR Technologies)
- 2004 — TriQuint acquires TFR Technologies (Bend, OR)
- 2009 — First commercial BAW products shipped (Richardson, TX factory)
- 2015 — Merger between TriQuint & RFMD: Qorvo
- 2017 — The 10 billionth BAW filter shipped, introduction of complex multiplexer products for 4G LTE
- 2018 — Production release of BAW5 (5th gen. BAW), expanding frequency range of BAW filters to 6 GHz 200 mm wafer manufacturing release
- 2019 — Production release for BAW filters up to 6 GHz

The onset of 5G is materializing much faster than predicted. Newly developed innovations in the 5G supply chain are being requested now. Consumers and businesses are expecting and asking for an increase in data capacity and data link speeds.

RF component suppliers are also caught in this wave. One of the key 5G enabling components, RF filters, is being asked to do more. As a component that mitigates out-of-band interference to allow only the desired data to pass from transmitter to receiver, or visa-versa, the filter provides both system quality of service and reliability. In 5G however, it is being asked to do this job with less space, in a smaller form factor, with higher Power Class 2 requirements, while providing higher overall performance. In some phone models the size of a 5G phone battery can be twice the size of previous LTE phones. For example, the Samsung Note 5G S10 phone has a battery that is 20% larger than the legacy Note LTE S10 model. While this increase in size helps increase the mA/h capacity of the 5G phone by about 32%, the battery now inhabits a larger area of the PCB previously occupied by other components like the RF front end (RFFE).

System Advantages Low Insertion Loss Qorvo BAW Provides

Transmit Insertion Loss - 0.5 dB

- 25 ~ 50 mA savings for PA
- Longer talking time
- Higher antenna transmit power than previous generations
- Better thermal performance
  - Reduces overall device temperature
  - Reduces requirement for additional thermal solutions

Receive Insertion Loss - 0.7 dB

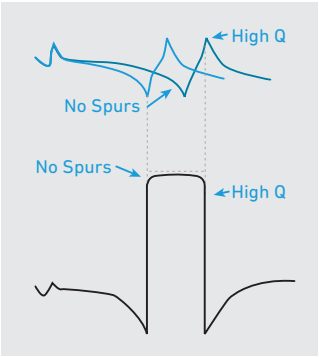
- Better RF signal range coverage
- Lower drop call rate
- Improved receiver signal power

...resulting in an increase in data throughout and overall better user experience

Not only is size becoming a constraint, 5G high frequencies are also affecting RFFE design. To meet the demands of 5G, frequency spectrum is required. 5G acquires this additional spectrum from the higher frequency bands found above 3 GHz – both in the sub-7 GHz and mmWave ranges (i.e. the more familiar "sub-6 GHz" terminology is included in "sub7 GHz" to support potential frequency allocations up to 7 GHz). The higher the frequency of a design, the greater the challenge of meeting parameter requirements.

One system parameter RF filters must meet is passband insertion loss. Line lengths, matching components, filter components and connecting trace lines have an added effect on insertion loss, especially at the higher frequency ranges above 3 GHz. To optimize a system's link budget, low insertion loss is required. As the frequency range increases into the sub-7 GHz realm and above, meeting this insertion loss gets increasingly challenging. Filter target insertion losses of 1 or 2 dB have now moved to below 1 dB, as manufacturers want to increase system margin and efficiency at the higher frequencies of 5G.

Qorvo BAW Technology



Qorvo has been solving filtering challenges since 1996 when BAW production began, and has over 240 patents on BAW technology to date. We have shipped over ten billion BAW filters globally and increased filter complexity by creating multiplexers that maximize carrier aggregation (CA) performance in a small form factor. Qorvo BAW performs in the 1 GHz up to 20 GHz range; Qorvo filters supplied in the higher mmWave ranges above 9 GHz are used mostly for defense and aerospace applications, such as radar systems. For mobile devices, consumer premise equipment or automotive products, BAW filter technology is focused up to the 9 GHz range.

Our BAW has many attributes that outperform competitor SAW or FBAR technologies – such as high Q, low spurs and steep skirts. Additionally, Qorvo BAW has superior thermal properties compared to other filter products found in the marketplace.

These thermal properties come in handy with 5G Power Class 2 (PC2) requirements. The PC2 requirement increases the maximum output power previously defined by Power Class 3. PC2 increases the transmit output power of the RFFE to compensate for greater propagation losses at the higher 5G frequencies. Ultimately, an increase in power creates more system thermal heat.

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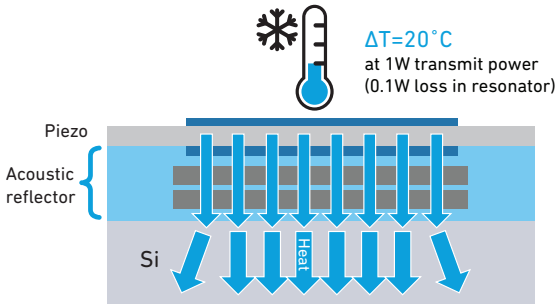
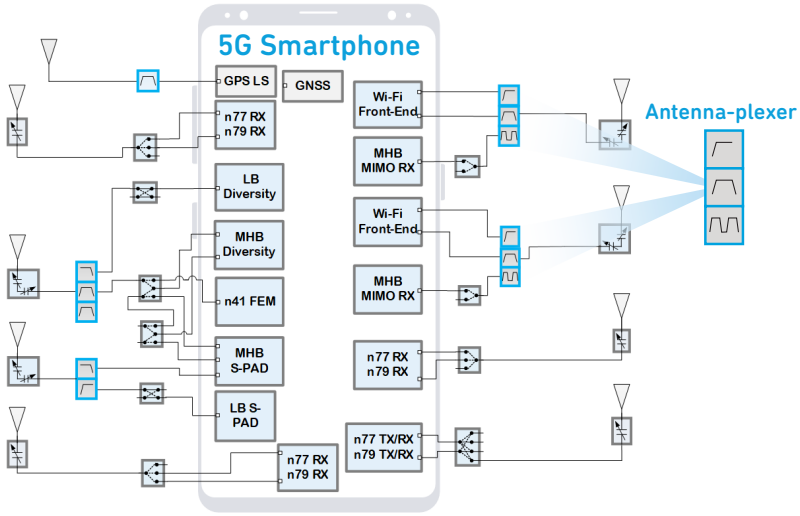
To make efficient use of additional 5G spectrum, a filter cannot degrade bandwidth while operating over a wide range of temperatures. BAW has a vertical heat flux acoustic reflector that allows thermal heat to quickly and efficiently dissipate away from the filter. The topology of BAW provides a lower resistance and prevents resonators from overheating. BAW exhibits very little frequency shifts, making it ideal for 5G applications that are prone to self-heating due to higher transmit power.



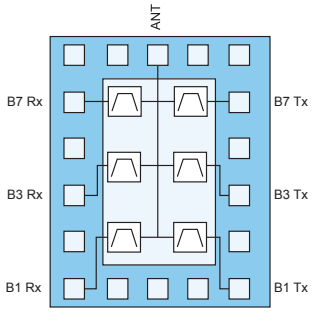
In all 5G use case categories, devices are becoming more complex. Engineers must negotiate their way through designs efficiently without compromising system performance. One complexity, as noted above, is spectrum, another is designing a device with a minimum number of antennas, line connections and lead lengths. Device manufacturers try to create products with the highest amount of functionality in the simplest way. To help reduce the number of antennas in a system, engineers use filters integrated into antenna-plexers.. Antenna-plexers reduce antenna complexity by allowing one antenna to transmit a large bandwidth. This large bandwidth is then split by the antenna-plexer into multiple different bands. For example, the triplexer shown below splits the Wi-Fi, mid-band and ultra-high bands going to one antenna while providing the out-of-band (OOB) rejection needed for optimal coexistence.

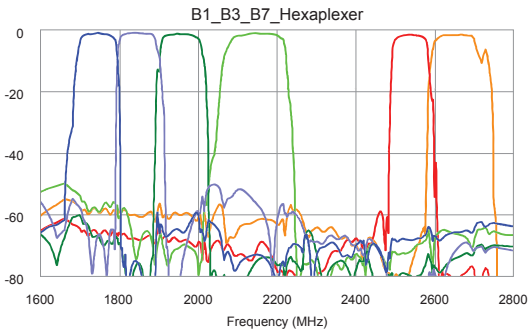
Carrier aggregation (CA) is another complex function of the RFFE. CA allows microwave devices to create higher data rates by combining two or more carrier signals. Linear multiplexer filters with OOB rejection allow for multiple CA combinations. For example, bands n77 and n79 in 5G New Radio designs or LTE bands 1, 3 and 7. These OOB rejection challenges in CA exist in many regions throughout the globe. Using BAW, engineers have access to multiplexers featuring minimal insertion loss below or around 1 dB. This low insertion loss minimizes any negative effect on the power amplifier current drain and device battery life. BAW also provides best-in-class band isolation and cross-isolation for optimal system-level performance.



The number of bands in 5G use cases will continue to grow. The mobile device market has used SAW, BAW and FBAR filter technologies for decades. However, 5G will alter the alloted spectrum in mobile and non-mobile devices like handsets, Wi-Fi, automotive V2X, radar and infrastructure and presumably others not yet known. With all the possible 5G applications, discrete and integrated BAW will help engineers resolve complex antenna systems and coexistence challenges.

B1+B3+B7 Hexaplexers - Enabling Carrier Aggregation





As a proven longtime industry leader, Qorvo understands that each device manufacturer creates unique products. By providing RFFE design flexibility, device manufacturers can more easily layout and design products for multiple 5G use cases. Qorvo's portfolio of filters helps customers find the best product for their design to meet stringent certification and design parameters.

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