RF interference has always been an inhibitor of communications, requiring designers to perform major feats to keep it in check. Today’s wireless devices must not only reject signals from other services but from themselves, too, as the number of bands packed inside each device increases.

A high-end smartphone must filter the transmit and receive paths for 2G, 3G, and 4G wireless access methods in up to 15 bands, as well as Wi-Fi, Bluetooth and the receive path of GPS receivers. Signals in the receive paths must be isolated from one another. They also must reject other extraneous signals whose causes are too diverse to list. To do so, a multi-band smartphone will require eight or nine filters and eight duplexers. Without acoustic filter technology, it would be impossible.

SAW: Mature but Still Growing
Surface acoustic wave (SAW) filters are used widely in 2G receiver front ends and in duplexers and receive filters. SAW filters combine low insertion loss with good rejection, can achieve broad bandwidths and are a tiny fraction of the size of traditional cavity and even ceramic filters. Because SAW filters are fabricated on wafers, they can be created in large volumes at low cost. SAW technology also allows filters and duplexers for different bands to be integrated on a single chip with little or no additional fabrication steps.

The piezoelectric effect that exists in crystals with a certain symmetry is the ‘motor’ as well as the ‘generator’ in acoustic filters. When applying a voltage to such a crystal, it will deform mechanically, converting electrical energy into mechanical energy. The opposite occurs when such a crystal is mechanically compressed or expanded. Charges form on opposite faces of the crystalline structure, causing a current to flow in the terminals and/or voltage between the terminals. This conversion between electrical and mechanical domains happens with extremely low energy loss, achieving exceptional efficiency of 99.99% in both directions.

In solid materials, alternating mechanical deformation creates acoustic waves that travel at velocities of 3,000 to 12,000 m/s. In acoustic filters, the waves are confined to create standing waves with extremely high quality factors of several thousand. These high-Q resonances are the basis of the frequency selectivity and low loss that acoustic filters achieve.

In a basic SAW filter (see Figure 1), an electrical input signal is converted to an acoustic wave by interleaved metal interdigital transducers (IDTs) created on a piezoelectric substrate, such as quartz, lithium tantalite (LiTaO3) or lithium niobate (LiNbO3). Its slow velocity makes it possible to fit many wavelengths across the IDTs in a very small device.
SAW filters, however, have limitations. Above about 1 GHz, their selectivity declines, and at about 2.5 GHz their use is limited to applications that have modest performance requirements. SAW devices also are notoriously sensitive to temperature changes: the stiffness of the substrate material tends to decrease at higher temperatures and acoustic velocity diminishes.

An alternative approach is to use temperature-compensated (TC-SAW) filters, which include overcoating of the IDT structures with layers that increase stiffness at higher temperatures. While an uncompensated SAW device typically has a temperature coefficient of frequency (TCF) of about -45 ppm/oC, TC-SAW filters reduce this to -15 to -25 ppm/oC. However, because the process doubles the number of required mask layers, TC-SAW filters are more complex and thus more expensive to manufacture, but still less expensive than bulk acoustic wave (BAW) filters.

**High-Performance BAW**

While SAW and TC-SAW filters are well suited for up to about 1.5 GHz, BAW filters deliver compelling performance advantages above this frequency (see Figure 2). BAW filter size also decreases with higher frequencies, which makes them ideal for the most demanding 3G and 4G applications. In addition, BAW design is far less sensitive to temperature variation even at broad bandwidths, while delivering very low loss and very steep filter skirts.
Figure 2: BAW filters provide compelling performance advantages above 1.5GHz

Unlike SAW filters, the acoustic wave in a BAW filter propagates vertically (see Figure 3). In a BAW resonator using a quartz crystal as the substrate, metal patches on the top and bottom side of the quartz excite the acoustic waves, which bounce from the top to bottom surface to form a standing acoustic wave. The frequency at which resonance occurs is determined by the thickness of the slab and the mass of the electrodes. At the high frequencies in which BAW filters are effective, the piezo layer must be only micrometers thick, requiring the resonator structure to be made using thin-film deposition and micro-machining on a carrier substrate.
To keep the waves from escaping into the substrate, an acoustic Bragg reflector is created by stacking thin layers of alternating stiffness and density. The result of this approach is called a solidly-mounted resonator BAW or BAW-SMR device (see Figure 4). An alternative approach, called a film bulk acoustic resonator (FBAR), etches a cavity underneath the active area, creating suspended membranes.
Both types of BAW filters can achieve very low loss because the density of their acoustic energy is very high and the structures trap acoustic waves very well. Their achievable Q is higher than any other type of filter of reasonable size employed at microwave frequencies: 2,500 at 2 GHz. This results in superb rejection and insertion loss performance even at the critical passband edges. **BAW, FBAR and the Future**

Although BAW and FBAR filters are more expensive to manufacture, their performance advantages are well suited for the most challenging LTE bands in addition to the PCS band, which has a narrow transition range of only 20 MHz between transmit and receive paths. BAW and FBAR filters also have no tiny IDTs, so they can handle higher RF power levels of 4W at 2 GHz. BAW devices have inherently high resistance to electrostatic discharge, and the BAW-SMR variant has a TCF of about -17 ppm/oC at 2 GHz.

Demand for high-performance filters is increasing significantly as spectral crowding drives the trend toward reducing or even eliminating guard bands. BAW technology makes it possible to create narrowband filters with exceptionally steep filter skirts and high rejection along with very little temperature drift, ideal for addressing the most vexing interference rejection problems between adjacent bands. Here at TriQuint, as well as at other filter manufacturers, engineers are working to achieve BAW-SMR filters with bandwidths of 4% or greater, very low loss, and a TCF of essentially zero.

BAW devices require 10 times more processing steps than SAW, but because they are fabricated on larger wafers, about 4 times more devices can be harvested per wafer. Even so, the cost of BAW remains higher than for SAW. However, for some of the most challenging frequency bands being allocated above 2 GHz, BAW is the only viable solution. As a result, the share of BAW filters in 3G/4G smartphones is growing rapidly.

Our design team at TriQuint focuses on optimizing BAW and BAW-SMR architectures rather than FBAR. The acoustic reflectors used below the bottom electrode of a BAW-SMR filter allow them to be optimized for wideband performance in frequency regions where FBAR faces challenges. The SiO2 used in the reflector also reduces the overall temperature drift of BAW significantly below what SAW or even FBAR can achieve. Because the resonator sits on a solid block of material, it can dissipate heat very effectively in comparison to FBAR, which employs a membrane that can dissipate heat only laterally at its edge. This allows BAW devices to achieve higher power densities that will soon lead to devices that can handle 10 W for small-cell base station applications.

**Summary**

SAW, TC-SAW and the various permutations of BAW filters and duplexers will become even more important components of all types of wireless devices in the years to come. RF interference rejection will become ever more challenging as emitters of all types proliferate, more wireless bands are allocated at higher frequencies and global spectrum management remains a fragmented process.

**About Robert Aigner**