Acoustic Filters and the Future of Smartphones: Carrier Aggregation and its Challenges

Robert Aigner

Qorvo Inc., Acoustic Technology R&D
1818 S. HW 441, Apopka, FL 32703, USA

robert.aigner@qorvo.com

Introduction:

The popularity of smartphones creates a tremendous demand for high-performance RF-filters based on the Bulk-Acoustic-Wave (BAW) and Surface-Acoustic-Wave (SAW) principle. Production numbers in year 2016 are estimated to exceed 50 billion RF-filter functions of which about 20 billion are high-performance filters such as FBAR, BAW or temperature compensated (TC)-SAW. The growth rate in the high performance RF-filter market dwarfs the overall market for RF components. The simple reason is that the number of frequency bands supported by the average smartphone keeps increasing, requiring additional filters. When a new band is released in one region of the world the top-tier smartphone brands will start adding this bands to their next flagship products. Existing bands will continue to be supported or may be re-farmed for more advanced communication standards – usually requiring even more advanced filters. As a consequence the latest models can require RF-filters for 15+ bands as well as additional filter for GPS and WiFi. For each of the bands an average of 3 RF-filters are deployed. For Frequency-Division-Duplex (FDD) bands there are 2 RF-filters constituting a duplexer and an additional receive (RX)-filter connected to a secondary (diversity) antenna. In Time-Division-Duplex (TDD) bands often there is one transmit (TX)-filter, one primary RX-filter and an additional RX diversity filter. The presentation will give an overview of system architecture of present and future smartphones.

Carrier Aggregation (CA) and MIMO (Multiple-Input-Multiple-Output) will increase the number of filters even further. The opportunity for the owners of wireless spectrum to increase data rates by Carrier Aggregation between different bands will see significant deployment in year 2016 and presents significant challenges for component suppliers as will be described in detail in the presentation. In RF frontend architectures supporting intra- and inter- band CA multiple filters must be impedance-matched to one common antenna port and provide TX to RX isolation for multiple use-cases. The most basic configuration for CA is a Quadplexer (two TX and two Rx filters matched together), but some architectures call for Hexplexers (three TX and three RX). Each RX output must be isolated from all TX inputs to prevent degraded receive sensitivity. As ownership and availability of bands varies geographically there is a huge number (≈100) of CA scenarios under serious consideration right now, each of which with has its own specific challenges and requirements. Considering the complexity of filter products for CA the ‘classical’ packaged stand-alone RF filter is obsolete, replaced by the same technology of RF filter embedded into integrated RF subsystems.

Miniaturization is mandatory in order to fit such a large number of RF filters into the limited space assigned to the RF section of a smartphone. Integration of RF filters for multiple bands into RF modules is an obvious choice as it will facilitate smaller footprint and tighter tolerances in assembly. Going forward all RF filters will feature a Wafer-Level-Package (WLP) and are directly attached to a functional substrate with inductors, lines and couplers embedded. Taking this one step further is to integrate multiple RF filters with switches, controllers and power amplifiers. This allows to design all components to achieve optimum system performance. The phone manufacturers appreciate the simplicity of using fully tested subsystems in a plug-and-play manner and they rely on the advantages in performance and size this approach offers. Examples of highly integrated products and their implementation will be shown in the presentation.

Design of RF filter products is the art to master the complexity of multi-physics problems appropriately. The design methodology for Multiplexers (Quad-, Penta-, Hexa-, Septaplexer) involves a rigorous use of EM simulations in addition to accurate acoustic resonator modeling. Cross-isolation between TX and all RX bands is a major challenge and too complex to solve by trial and error in hardware experiments. EM simulations have to include geometrical details as small as traces on the BAW filters and layers just a few µm thick, but also geometries as large as evaluation- or phone-boards. As a result the effort to set up those simulations is very high and the CPU time and memory demand is massive. The solution to reduce engineering effort is a full automation of geometry-definition which can be accomplished with proper interfaces between layout tools and EM solver. Definition of EM ports is automatic and the user is relieved from the chore to place ports manually and keep track of port numbers. Meaningful simplification of small geometries is necessary in order to improve the speed of simulations; each of the modifications applied must be fully verified. Another useful approach to reduce simulation time is to segregate parts of a Multiplexer into a several much smaller EM problems, optimize them individually and merge them back together for verification purposes.

Performance challenges arise because naturally Multiplexers will show higher insertion losses when the number of filters matched together grows. The native performance of a filter process is more important than ever, and criteria previously ignored are starting to play a critical role. Out-of-band losses of one filters can and will harm other bands. SAW filters are prone to suffer from bulk-radiation losses which set in 5 to 30% above the resonance frequency. Generally SAW and TCSAW is rich in out-of-band modes and ripple. This did not matter too much for most duplexers in earlier years. However, in most common band-combinations for future CA -Multiplexers the bulk-radiation losses in SAW will almost certainly hit one of the other bands. BAW generally has very clean out-of-band response and modes are few and far above the passband. Modes in BAW occurring below the passband are easily controlled and can be moved to other frequencies if needed. This is the reason FBAR and BAW are winning market share in high frequency bands even for bands SAW used to serve in the recent past. The dominant factor impacting out-of-band losses for BAW are the resistive losses in electrodes and interconnections. Those will be more relevant in Multiplexers than in Duplexers. Equally important are the losses introduced by matching inductors. Achieving the best possible Q-values in inductors is a high priority. Considering the number of inductors needed and the size constraints on RF modules this puts designers into a difficult position. One way out is to increase the number of layers available in the module substrate. This increases cost but also goes against the trend towards overall reduction of height. The presentation will summarize the present status and give an outlook on future generations of RF-filter products.

Robert Aigner was born in Mehrnbach, Austria on June 12th, 1968. He received his M.S. in 1993 and Ph.D. degree in 1996 both from Technical University Munich/Germany for research on micromachined chemical sensors. He was a visiting scientist at UC Berkeley Sensors and Actuators Center BSAC in 1996 where he worked on system design for MEMS inertial sensors.

After returning to Germany he joined the MEMS research group at Siemens Corporate Technology in 1997. Between 1999 and 2005 he was director of a MEMS R&D department at Infineon Technologies and worked on a variety of MEMS devices including Automotive MEMS and RF-MEMS. The team he built and directed became pioneers in commercializing Bulk-Acoustic-Wave (BAW) technology.

In year 2006 he joined TriQuint in Apopka/Florida to establish BAW. In year 2015 TriQuint and RFMD merged and created Qorvo, a leading provider or RF solutions for wireless communication. At Qorvo Robert Aigner is Sr. Director of Acoustic Technology. As such his focus is on driving technology innovations in the fields of SAW and BAW.

Robert Aigner has served in several European committees for Microsystem Technology and was nominated as MEMS-expert for European Commission. He served in the technical program committee of IEEE UFFC and serves as reviewer for JMEMS, Applied Physics Letters and other journals. He has more than 100 patents (from 65 patent families) in the field of BAW, SAW and MEMS granted on his name, he has published more than 110 articles and contributed chapters to three text books.