BAW Flip-Chip Switched Filter Bank Delivers Dramatic Form Factor Reduction

By Steven Mahon, Joshua Zepess and Mark Andrews
TriQuint Semiconductor

This new switched filter bank combines BAW filter technology with GaAs pHEMT switches and flip-chip integrated circuit assembly techniques

Complex communications and radar systems often utilize an array of filters with switching ports at the input and output of the signal path. This arrangement is used for a variety of intents such as signal pre-processing, frequency hopping or anti-jamming. The architecture of a switched filter bank (SFB) is long established (Figure 1); however, for microwave frequencies from 1-8 GHz the size is often many tens of cubic centimeters, a fact that prevents or restricts the use of an SFB in size- and weight-constrained applications such as those in defense and aerospace markets. A new approach to the design and manufacture of SFBs has been developed by TriQuint Semiconductor that breaks through long-standing size and weight barriers, opening-up new opportunities for making the benefits of this device more widely accessible.

The enabling technology in creating a miniaturized SFB is the advanced bulk acoustic wave (BAW) filter, which provides the smallest form factor for microwave filters currently available. BAW filters exploit the same advantage of converting high velocity electromagnetic (EM) waves to very slow acoustic waves as seen in surface acoustic wave (SAW) devices. This allows the required signal processing to occur on a much smaller dimensional scale, thereby creating filter functionality. BAW filters offer the advantage of wide frequency range serviceability and do not run up against the practical limit SAW devices face at about 2.5 GHz. This allows the delay function required in reactive components to be realized in a space several orders of magnitude smaller than in EM-based filters.

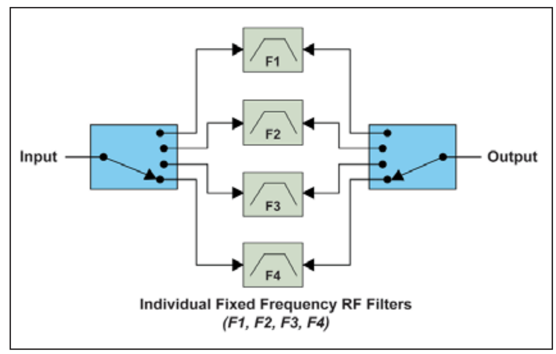

Figure 1 · Switched filter banks schematic.

Long used in defense applications and more recently seeing explosive growth in consumer handset applications, the most common BAW architecture is a ladder configuration where multiple resonators are connected in a series and shunt arrangement. Although still very small, a ladder can contain 5 to 11 resonator sections and consume 1-3 mm^2 in resonator space alone. The more compact variants and the most advance BAW architectures, coupled resonator filters (CRFs) or stacked crystal filters (SCFs), can reduce the area required even further [1] (Figure 2). The resonator areas are inversely proportional to the center frequency, which creates a practical limit around 1 GHz. This invention allows the volume of a given SFB subsystem to be reduced by three to four orders of magnitude, resulting in a dramatic size and cost savings to the system. BAW technology is most effective producing these size reductions for frequencies between 1 GHz and 8 GHz.

Developing a miniature SFB subsystem is

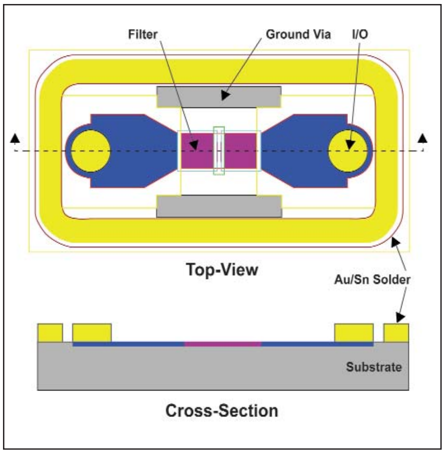

Figure 2 · CRF or SCF Bulk Acoustic Wave Filter (1.5 x 0.75 mm)

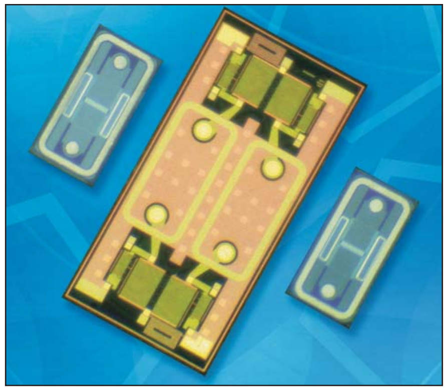

Figure 3 · Switch die with filter mating patterns. BAW filters (rectangular devices to the left and right of the pHEMT switch die), are flipped for mounting to their receiving points on the GaAs circuits.

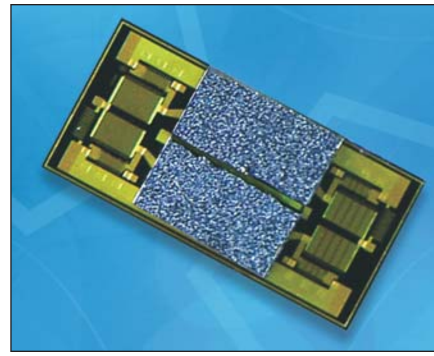

Figure 4 · The assembled miniature switched filter bank with two filters

enabled by combining three different technologies: BAW Filters, GaAs pHEMT switches and Au/Sn flip-chip assembly. A configuration of an SFB with 4 filters is approximately 5 × 5 × 1 mm in a surface mount module package. Using E/D pHEMT technology affords the capability of adding digital switch decoders to minimize the number of control lines required.

Configuration

BAW filter die are fabricated for the specific frequency responses desired. The die can be tested in advance of assembly to assure a known good filter. The switch IC die is designed such that there is a top level metal pattern matching the solder ring and I/O of the acoustic filter. A key requirement of a BAW filter is the necessity for a hermetic cavity environment to allow proper acoustic resonance and long-term stability. A hermetic seal can be accomplished with a high temperature solder stand-off that can be made as part of the BAW filter itself. This standoff is electroplated around the perimeter of the die and provides I/O and ground connections (Figure 2). The switch die can also be pre-tested to assure functionality. The BAW die is flip-chip assembled to its matching pattern on the switch IC and put through a solder reflow process. The flip-chip attach not only provides the hermetic capability but provides for minimal parasitics. The resulting assembly is then ready for the next level of board or module chip and wire assembly.

A miniature SFB offers several key benefits that resolve size, weight and performance challenges compared to existing, large form factor SFB assemblies. Currently, the most "compact" approach is to use existing filters of various architectures and route to external switches in a module or printed circuit board. Using die-to-die, flip-chip assembly solves three issues at the same time. First, the size can be made much smaller, which allows several orders of magnitude in volume reduction. Second, the close proximity of the filter to the switch allows for a minimization of parametric losses in the RF circuit where switch-to-filter routing is an issue. Third, minimizing the list of materials and the smaller size will result in a lower cost per filter bank function.

Two major challenges, one in system design and the other in flip-chip assembly, had to be resolved in order to create fully functional miniature SFBs. An example of one system design challenge can be found in the fact that a BAW device requires robust grounding, as common ground inductance can degrade the filter performance. The pHEMT switch die creates one more interface between the filter and the application board, thus creating a potential problem. This was addressed by using a significant number of through-wafer via ground connections, available as a benefit of using the pHEMT process. The assembly process offers challenges due to the small scale and the requirement for a complete seal around the perimeter of the filter. The exact metallurgical balance of the gold and tin must be maintained as well as time, temperature and attach pressure. An example of the importance of balance in this situation can be found in the fact that excessive tin can cause shorting between ground and I/O nodes, whereas insufficient tin will result in a weak mechanical attach. Modern IC and flip-chip assembly technology and equipment provide sufficient capability to maintain these process parameters to the tolerances required.

Test Results

A two-channel miniature SFB prototype was fabricated around the GPS L1 frequency (Figure 4) of 1.575 GHz. Two SCF BAW filters were fabricated for frequencies 30 MHz apart. These filters are 1.50 × 0.75 mm in size. Their performance, when assembled with the pHEMT switches as a

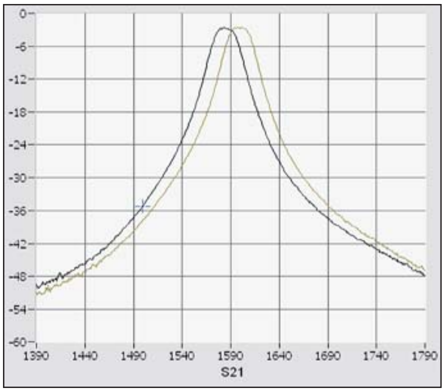

Figure 5a · Magnitude of S21 for both channels overlaid.

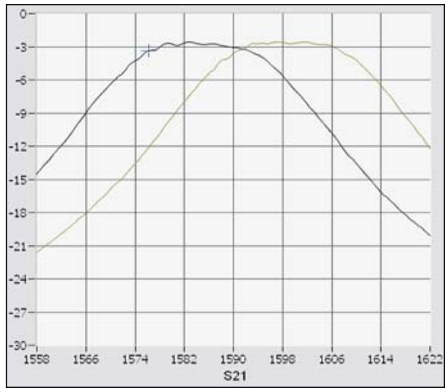

Figure 5b · S21 (passband magnification) for both channels overlaid.

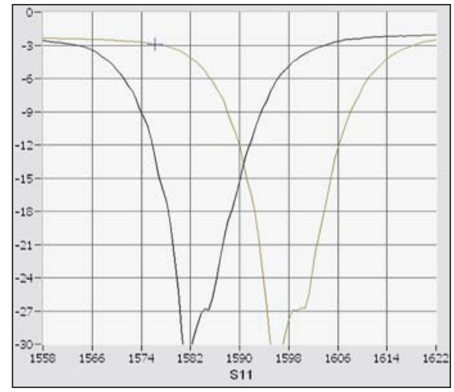

Figure 5c · Return Loss of both channels overlaid.

two-filter system, is shown in Figure 5. The stand alone BAW filters maintain an insertion loss (IL) of 1.5 dB. Each switch contributes about 0.6 dB, resulting in a system insertion loss of less than 3 dB. The interconnection and other parasitics have little additional contribution to overall loss. The crossover interaction between filters is particularly low. This demonstration provides solid insight and direction as a means to build more complex SFB designs. Figure 6 shows the demonstrated wideband performance of a single channel.

Summary

The integration of TriQuint's compact BAW filters and GaAs pHEMT switches has resulted in the creation of a miniature switched filter bank (SFB) that can enable new approaches to system architectures for advanced RF systems. Immediate applications expected to benefit from this advancement include a variety of intents such as signal pre-processing, frequency hopping or anti-jamming functions for defense and aerospace markets. Because such devices provide a dramatic reduction in size while retaining essential performance capabilities it's possible to envision switched filter bank functionality in applications far beyond their current range. A miniature SFB's size and performance also opens new doors for markets and applications by simplifying integration both at architecture and system levels.

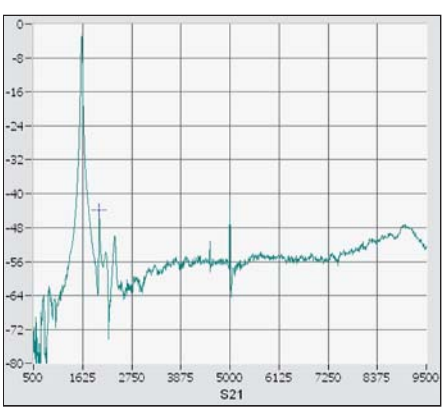

Fig. 6: Wideband performance of a single channel of the miniature switched filter bank

Cost and yield will improve as this technology advances. Such advances will also help enable new capabilities tied to the number of channels that can be switched by a single device. For example: pHEMT switches with single pole, nine-throw (SP9T) designs are now used in wireless handsets. As more designers are exposed to the possibilities of using miniature switched filter banks, one can imagine a standard pHEMT switch die that allows a wide range of custom filter combinations to be made with modest development. A limit on the number of filters possible in a bank is not set in a literal sense, but is typically governed by classical system partitioning needs. Growing the number of channels that can be switched by a single device in mobile handset applications points to the possibility that miniature SFBs will also advance in such a way, offering new solutions to designers of advanced RF systems.

The size and cost advantages provided by miniature SFBs compared to current technology leads the imagination to jump from obvious first-generation applications in defense and advanced aerospace markets to commercial intents. Competitive pressures in commercial markets will also drive development and speed product evolution. As the market has demonstrated with other breakthrough technologies, a range of initial applications grows very quickly once the ingenuity of systems designers is brought to bear, which will enable miniature SFBs to serve an ever-increasing universe of applications.

References

1. K.M. Lakin, J. Belsick, J.F. McDonald, and K.T. McCarron, "High Performance Stacked Crystal Filters for GPS and Wide Bandwidth Applications," *IEEE 2001 Ultrasonics Symposium,* October 9, 2001

TriQuint Semiconductor
Tel: +1 541-382-6706
E-mail: baw-sfb@tqs.com
www.triquint.com