
Mobile Filter
Innovation is Alive
and Well in Extending
the Reach of 4G

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Mobile Filter Innovation is Alive and Well in Extending the Reach of 4G

Resonant is designing sub-3GHz filters to meet the need to rapidly reduce RF filter costs while delivering high power performance for 4G.

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Introduction

Mobile data consumption has grown rapidly and is expected to keep on growing. Cisco, in its Visual Networking Index[1], projects a 46% compound annual growth rate between 2017 and 2022 with total mobile data traffic growing to 77 Exabytes per month in 2022. Users in Asia-Pacific countries will account for more than half of that 2022 mobile data traffic.

This growth in data volume is leading mobile network operators (MNOs) to make many changes to how they operate their networks to be able to deliver that bandwidth. One of these changes is to acquire spectrum in higher RF frequency bands where more bandwidth is available. This move to higher frequency bands, which is actively being pursued for 4G devices, is the only way for 5G networks to deliver promised bandwidth. In 2019, the US Federal Communications Commission voted to auction spectrum in the 2.5GHz frequency band for 4G and 5G networks.

Higher frequency networks have shorter data transmission distances, which could mean more radio access network (RAN) infrastructure to maintain coverage levels. Instead, MNOs that are most aggressively adopting these higher frequency networks are also adopting high-power user equipment (HPUE) standards in order to boost signal range. Figure 1 demonstrates the shrinking cell size that accompanies higher-frequency RF signals.

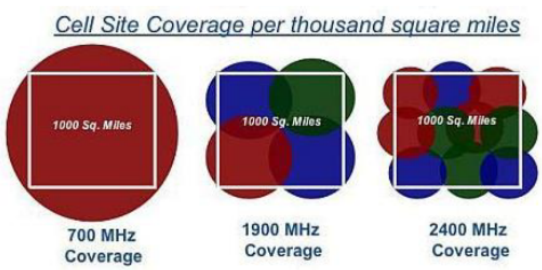


Figure 1: Figure 1: How cell coverage shrinks with higher frequency RF signals. 3G used low frequencies (700-900MHz), 4G mid-band frequencies (1700-2000MHz). 5G will use significantly higher frequency spectrum (3400-5000MHz).

To help MNOs adopt this technology in a cost effective way, Resonant Inc. has developed designs for HiPower temperature compensated surface acoustic wave (TC-SAW) filters that utilize Resonant's Infinite Synthesized Network® (ISN®) software platform to optimize filter designs for higher power, while using the lowest cost acoustic wave technology.

We believe, these HiPower filters are only possible using the company's ISN simulation tool, which precisely simulates the complex interactions within each device, making it possible to manufacture the filters cost effectively and with a short time to market.

This whitepaper reviews the industry momentum behind HPUE, presents the ISN technology and how it is used to develop HiPower filters.

Growth in HPUE

High power user equipment (HPUE) was originally approved in 3GPP Release 11 in 2011 to extend the range of 700 MHz (band 14) networks used for public safety agencies. AT&T was contracted by First Responder Network Authority (FirstNet) to create a HPUE public safety network. Release 11 defined HPUE as power class 1, which has +31 dBm power output as opposed to power class 3, the standard for most user equipment, which operates at +23 dBm.

In 2016, Sprint announced[2] its own version of HPUE for 4G/LTE consumer mobile devices.

[1]https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white-paper-c11-738429.html#_Toc1455212

[2] https://newsroom.sprint.com/sprint-unveils-breakthrough-technology-innovation-to-deliver-

Sprint's HPUE version is considered power class 2 and operates at +26 dBm. The new service helps to make up for propagation losses on higher frequency 4G/LTE networks which have much higher attenuation and thus shorter transmission range. Sprint said its tests show that HPUE expands the coverage range of the company's 2.5GHz (band 41) service by up to 24% (see Figure 2) which the company says gives users on a 2.5GHz 4G/LTE network the same reach as those on the 1.9GHz network. The tests also showed that the 2.5GHz frequency network also delivered 49% higher[3] average download speeds than the 1.9GHz network. Sprint is working with China Mobile, which also operates a band 41 service and is aggressively rolling out services across China.

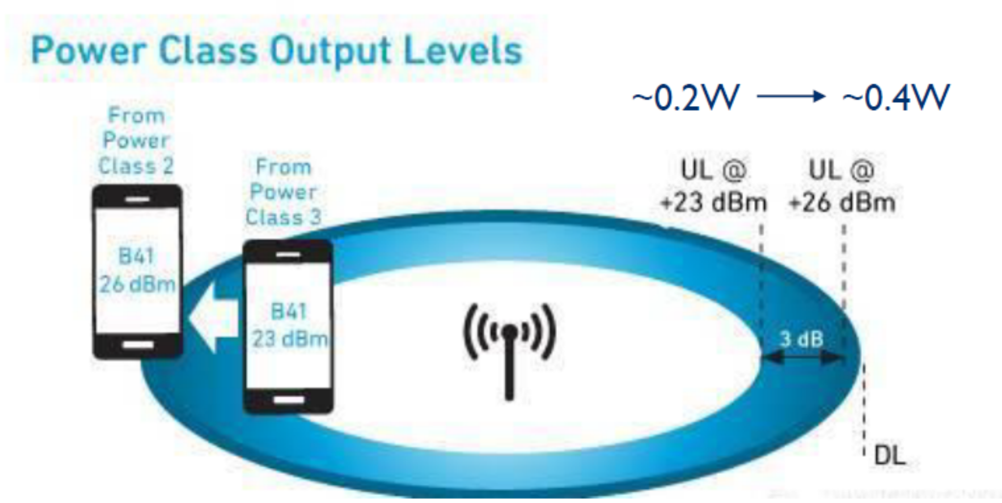


Figure 2: Expansion of cell coverage resulting from higher transmission power.

Sprint launched its first 4G/LTE HPUE device in 2017 and now has more than 10 devices in market that support the power standard. These Android-based devices are manufactured by leading OEMs including Samsung, LG, HTC, Motorola, and Google.

As MNOs deploy higher frequency networks to offer higher data rates without a need to change their tower and RAN infrastructure to fill in dead spots caused by the shorter transmission distances, they will demand increasingly higher power levels from mobile devices.

Impact of HPUE on RF Filters

A key challenge to the spread of HPUE is the RF front end, specifically the RF filter. RF filters act to separate the radio frequencies that are received and transmitted by a device's antenna(s) into the appropriate circuit path. Filters are engineered to allow specified frequencies to pass and to block other frequencies that are unwanted and interfere with the desired signals. More complex devices based on acoustic filters, called duplexers and quadplexers, are used to combine transmit and receive signal paths onto a single antenna, allowing combining of multiple frequencies to increase bandwidth and hence data-rate.

Acoustic wave filter technology has evolved over time to support the increasingly more complex filter requirements and meet the needs of the growing wireless industry, with trade-offs in performance and cost. The most popular acoustic technologies in use today include (see also Figure 3):

- Surface acoustic wave (SAW): Simple to design and low cost technology for 3G/4G networks; offers good performance with precise filter design.
- Temperature controlled SAW (TC-SAW): Higher cost process than SAW, but

better-coverage-and-faster-data-speeds-in-more-places.htm

[3] https://newsroom.sprint.com/new-hpue-report.htm

delivers increased temperature stability that is ideal for HPUE applications.

- Bulk acoustic wave (BAW): Low loss resonator using a reflector to minimize losses which requires high cost and complex manufacturing process.
- Film Bulk Acoustic Resonator (FBAR): A very low loss resonator with high rejection of interfering signals, that requires a high cost and complex manufacturing process.
- X-BAR Bulk Acoustic Wave (BAW): A technology with the performance for 5G networks offering best in class performance for ultra-wideband applications.

In addition to HPUE filter performance being able to survive increased power levels, other demands are placed on the filter performance, to minimize drift in filter stability because of the additional heating from the increased power, as well as isolating the transmit spectrum more effectively.

The implication for HPUE devices is that they must choose a filter technology based on an expensive, high-performance resonator technology to accommodate the high power, instead of using lower cost technology that now support the frequency bands in use.

This represents significant issues because there are between 50-90 filters in a Tier 1 4G/LTE mobile device. Reducing the cost of these filters has a significant impact on the device's bill of materials (BOM). It is important to note that even in early "5G phones" the majority of filters are for existing 2G, 3G & 4G technologies, since they will continue to carry the bulk of the RF signals until the networks become more fully evolved.

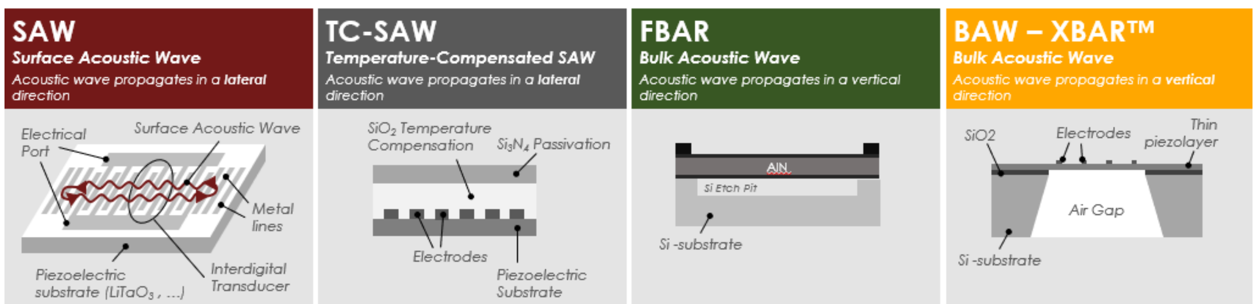


Figure 3: Acoustic wave filter technologies.

Historically, filters are designed, fabricated, tested and then refined and manufactured again in an iterative fashion using an approach called coupling of modes (COM) that can take tens of fabrication runs before an optimized filter is developed. The design of RF filters in this iterative way has put investigation of new topologies out of reach for the industry, and limited the market to a few vertically integrated filter manufacturers.

Resonant's ISN software platform enables filters to be accurately simulated and optimized before they are fabricated, allowing for new topologies to be tried to improve the performance including power performance. ISN incorporates a full finite element model module which only requires materials properties and physical dimensions in order to accurately predict final filter performance for even the most complex of filters.

ISN Precision Simulation Enables Low Cost HPUE Filters

Resonant's ISN provides precise simulation and design of acoustic wave RF filters. ISN brings together modern filter theory, finite element electromagnetic and acoustic modeling, and leverages the company's patented optimization algorithms. ISN uses circuit models that are computationally much faster, and physical models that are highly accurate because they are based entirely on fundamental material properties and dimensions.

ISN designs have demonstrated excellent predictability, enabling achievement of the desired product performance in just two or three turns through the fab. In addition, ISN's grounding in fundamental materials physics enables designs that are unconstrained by traditional acoustic wave filter design techniques. It is this capability that allows ISN to efficiently develop filters cost effectively for HPUE applications.

Thousands of designs can be developed and screened to maximize the ultimate performance of the device. ISN leverages the expertise of filter design engineers for an increasing number of more complex designs to be achieved using ISN.

We believe Resonant's ISN models are extremely accurate and reflect physical details of the filter structures matching the measured filter performance not only in loss and isolation but also in power handling. The accurate modeling of acoustic filters using ISN has the potential to enable the following:

- Reduced development time and cost: ISN performs the optimization without depending on multiple, expensive iterations in a fab.
- Solutions to challenging design problems: Empirical design techniques will ultimately be limited in headroom as more design parameters constrain the problem. This is particularly true for multiplexing and more complex filters. The flexibility and accuracy of the ISN tool suite is ideally suited for creating novel solutions to these increasingly complex requirements.
- Design for multiple temperatures: The ISN framework allows optimization over a range of temperatures, optimizing performance at the higher temperatures that are in use with HPUE.
- Designs optimized for high-power performance: LTE operates at higher power than CDMA, requiring designs that can withstand high power, at elevated temperatures, for extended periods of time. High bandwidth applications for 5G will continue this trend of higher power in order to achieve the highest data rates possible.
- Improved yield and lower cost of production: Resonant models help production engineers to create relevant fabrication parameters for reducing variability in the manufacturing process.

Another critical impact on filter performance is the fabrication process. Each fab has unique variations in their processing that must be captured in the simulation for it to deliver optimal performance. The ISN Foundry Program is designed to provide a vetted foundry supply chain that is stable and experienced. Through extensive testing, Resonant engineers capture a fab's unique characteristics which are incorporated into simulations.

Using the advanced simulation capabilities of Resonant's ISN, 4G RF filters can now be engineered and manufactured to optimize both power performance and cost for new 4G HPUE requirements.

Example of improved power performance

One typical test to characterize the power durability of transmit filters is to step-increase the input power (Pin) to the filter, while measuring the output power (Pout). The power test frequency is set to be performed at the most sensitive location – the edge of the passband, where the maximum power is stored in the filter.

Measured results and ISN simulations of two different designs are shown in Figure 4. The filters shown are band 3 transmit (Tx) filters, in this case one filter of a quadplexer used in 4G mobile devices for carrier aggregation. Quadplexers combine the transmit and receive of two frequency bands onto the same antenna and Band 3 is the most critical band in the quadplexer for power performance since the small duplex gap limits the max power of the filter. The ISN simulations match the

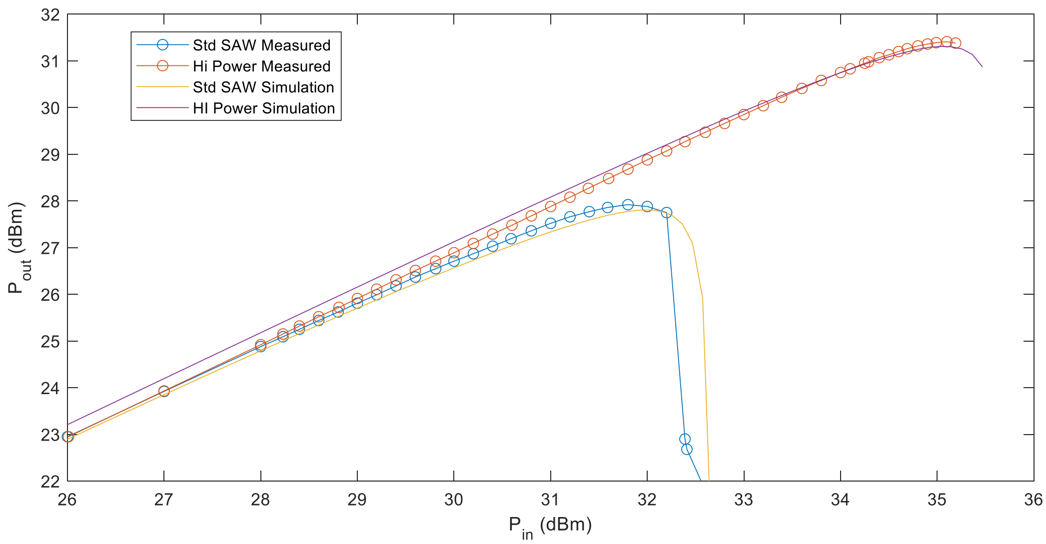
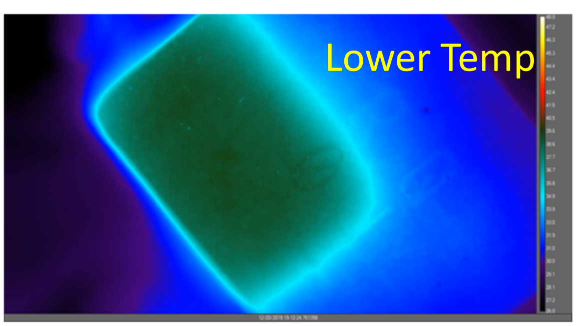


Figure 4 Measured vs simulation of standard SAW and HiPower SAW designs.

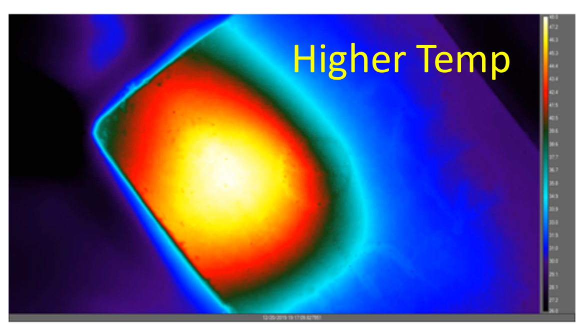
measurement for both designs. The HiPower design shows significant improvement in power vs. the standard SAW design.

All filters passing high RF power experience self heating that contributes to limiting the maximum power of the filter. The thermal images shown in Figure 5 are of the above two band 3 Tx filters with the same level of RF input power (+32dBm). The filters are each part of a quadplexer (four filters) and the images show the temperature difference between the two designs. The improved (HiPower) design provides for better thermal control to achieve 3dB power improvement.

By using new topologies derived from ISN, the power durability perfomance of a low cost, SAW design is shown to outperform the much more expensive FBAR filter in Figure 6. Because of their simple processing, SAW designs are also much more amenable to high volume foundries and the associated cost reductions in high volume.



HiPower SAW B3 Tx Filter



Standard SAW B3 Tx Filter

Figure 5. Images show the temperature of two parts as figure 4 with the same input power of +32dBm.

Summary

Resonant software tools enable new design techniques and topologies to address the needs for both increasingly complex filters, with more demanding requirements, fabricated at large capacity, high quality foundries. Resonant has demonstrated that improved power performance, over more expensive BAW and FBAR filters, is achievable using significantly lower cost resonator topologies. Commoditization of 4G filters is driving new approaches for low cost, while meeting BAW performance.

Demand for 4G filters will continue to grow, but will also become increasingly commoditized.

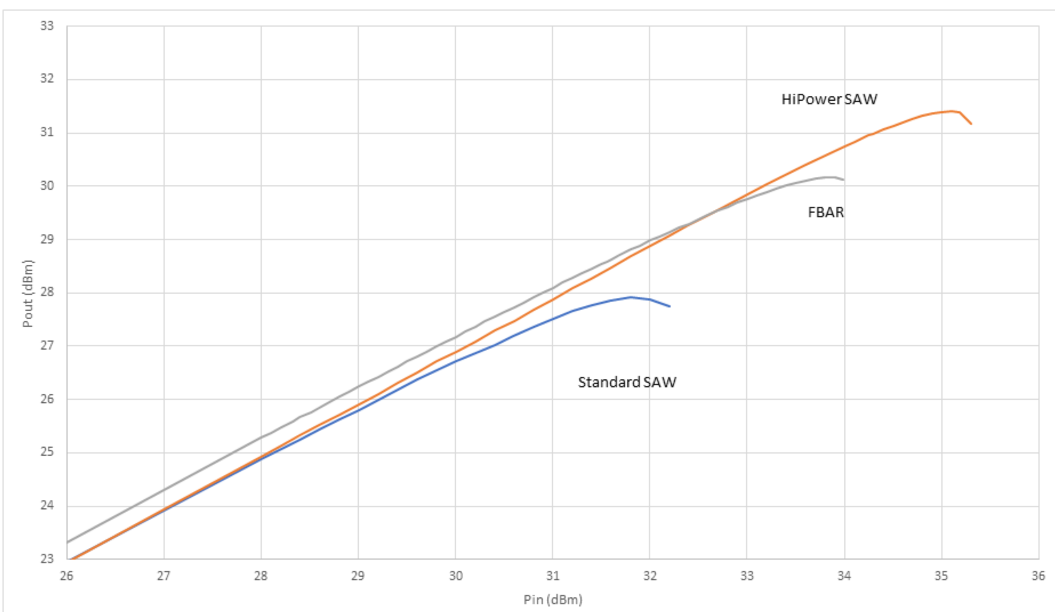


Figure 6: Shows the measured Pin vs. Pout response of the same quadplexer (band 3 Tx) as figure 4, but in this figure the measured performance of an FBAR quadplexer (band 3 Tx) is compared. The HiPower design has more than 1dB higher power performance.

Resonant has developed an acoustic wave filter foundry ecosystem, analogous to the ecosystem that exists for other RFIC components and sub-systems, such as power amplifiers, low noise amplifiers and switches. Only by changing the RF filter design process using ISN is this possible.

New higher frequency operation and high data-rate requirements for 4G are driving increased power in the mobile device, which in turn makes the filter requirements more challenging. At the same time, filter complexity is growing in order to aggregate multiple frequency bands. As an example the pre-fab simulation and measured performance of the (4) frequency bands for a band 1 / band 3 quadplexer is shown in Figure 7:

The pre-fab model is in excellent agreement with the actual measured performance of this very complex structure with 32 resonators. ISN is able to simulate this structure in this very complex device and predict the performance to very fine fidelity.

New design techniques enabled by software tools improve performance and minimize the cost of 4G filters. Resonant's proprietary simulation software (1, 2) uses a Multiphysics approach built up from the physical dimensions and materials properties of the manufactured part. We use the physics of piezoelectricity, electromagnetism, and thermodynamics to construct accurate finite element models, then use our proprietary tools and methods to produce accurate simulations.

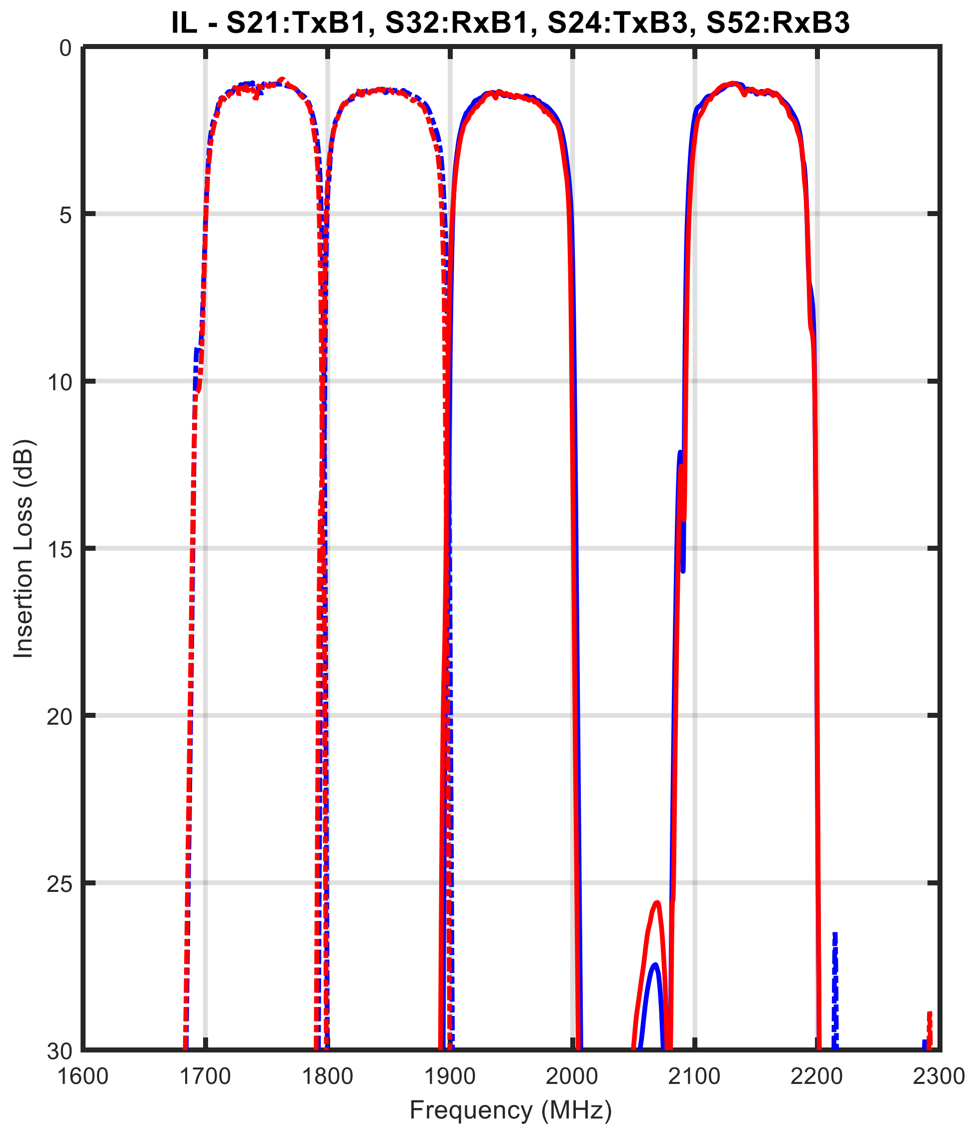


Figure 7 Pre-fab simulation vs measurement for a Band 1/Band 3 TCSAW Quadplexer. Prefab simulation (in blue) vs measurement (in red)

The combination of Resonant ISN design platform and qualified foundries is a perfect match to provide high performance filters at low cost and high quality as the requirements for 4G continue to require innovation while lowering the overall cost.

References:

1. Design and Characterization of SAW filters for High Power Performance
2. FEM modeling of an entire 5-IDT CRF/DMS filter