

# High Frequency Resonator is Foundation for High- Throughput 5G Services – And Much More

WHITE PAPER



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# Executive Summary

After years of promise and hype around 5G, at CES 2020 the industry came to grips with the fact that today's 5G service does not deliver the full bandwidth that the technology promised. After CES, industry pundits proclaimed that while there is some benefit delivered by today's services, 5G will continue to roll out in multiple phases. In fact, significant 5G traffic isn't expected until the year 2022 (Figure 1).

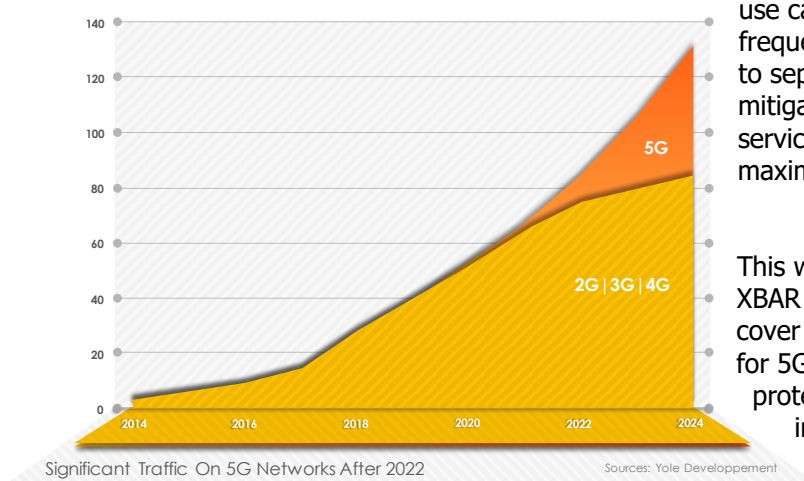


Figure 1: Traffic growth on 4G and 5G networks.

What underlies the future phases of 5G is the utilization of higher radio frequencies to deliver the hundreds of gigabits per second performance that will fulfill the promise of 5G. Some of today's services operate at these frequencies but the infrastructure is not yet built out and the devices are in limited supply. This is similar to previous generations of wireless technology (Figure 2), which continue along the adoption curve even though initial performance may disappoint.

3GPP is the organization that develops standards for new wireless technologies, with each generation of standards structured in the form of Releases. The main subset of standards for the air interface is designated as 5G New Radio or 5G NR. The 3GPP Release 15 is the most current 5G standard and it features a number of bandwidth-boosting features from the use of higher frequency RF bands to small cells that provide better signal receptivity. RF filters are a core technology that needs to

evolve to produce high-bandwidth 5G mobile devices. RF filters depend on resonating structures to pass signals in targeted frequencies, and the acoustic wave filters that were created for 4G do not have the performance needed for 5G frequencies. In addition, there is a new filter requirement for RF filters in applications 5G is used in close proximity to Wi-Fi.

5G and Wi-Fi must successfully co-exist in a wide range of use cases. But in many of these use cases, 5G and Wi-Fi are in adjacent frequency bands with very little guard band to separate them. This means the filter must mitigate the interference between each service to prevent signal bleed and to allow maximum bandwidth operation.

This whitepaper explores both the use of XBAR resonating structures as a new way to cover all of the frequency bands proposed for 5G and to offer the interference protection to ensure 5G and Wi-Fi co-exist in all mobile devices in addition to their use for other applications because

of the inherent flexibility of this structure.

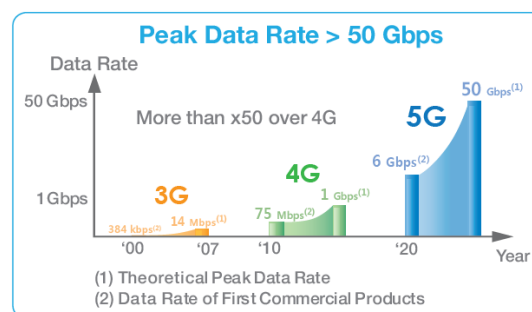


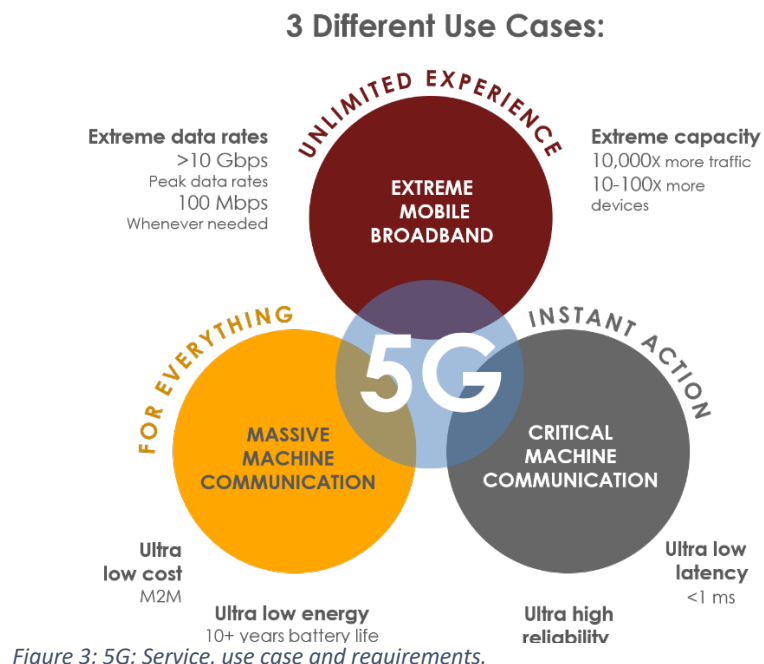
Figure 2: 5G peak data rates.

## 5G Vision

The 5G vision is for dramatic improvements over 4G for performance metrics: capacity, number of mobile connections, latency, cost, data rates and coverage. As with every new generation of mobile technology, the performance targets are ambitious, some would say impossible, but the advances in technology and performance will drive new revenue streams, applications,

penetration, and an increasingly mobile world.

reason that mobile network operators (MNOs) are racing to build out their networks.



In many ways, the drivers for 5G are conflicting because of the differing use case requirements: increased data rates and capacity for a richer visual experience (HD video, augmented reality (AR) and virtual reality (VR)), but also ultra-high reliability, low device cost and massive increase in the number of connected devices (IoT, smart cars, smart cities and smart homes).

But for mobile phones, tablets, always connected PCs and other mobile devices, the main benefit of 5G is dramatically increased data-rate – with a theoretical limit of up to 10 Gbps, a 10 times increase over 4G theoretical maximum bandwidth. A variety of factors will influence these theoretical figures, but in real life 5G will be a significant speed upgrade to 4G / LTE.

This throughput (combined with low latency) enables a new range of services including streaming high-definition video, virtual reality/augmented reality (VR/AR), autonomous vehicles and other applications. It's these new revenue generating services that are the main

But this long-term vision, is indeed only a vision and during the early stages of 5G the reality is that users will not notice a significant change from 4G. However, mobile broadband remains the primary emphasis for this technology transition and is the focus of this White Paper.

In many ways the need for 5G is a prediction of wireless user and usage change that is not satisfied by 4G. These requirements are:

#### Capacity

Capacity is required to accommodate the number of users that want simultaneous network access from a particular cell site.

Capacity is a function of both the number of users and the amount of data they are consuming. Consequently, in a wireless network, where spectrum bandwidth is a finite resource, and where demand is growing, MNO must make the most of their capacity through techniques such as spectrum re-farming and the use of small cells to create more capacity for a given area than a macrocell. The network capacity goal for 5G is 10,000 times the current network capacity.

#### Coverage

As with previous generational technology upgrades, along with increased capacity requirements comes increasingly ubiquitous coverage. There is no point in having local areas with very high data rates if the wireless link is continually dropped due to poor coverage. Wireless technologies are limited in their reach from an antenna, based upon propagation over the air, and through obstacles and walls. Because much of the low-frequency spectrum (which has better propagation characteristics, and can penetrate further) is already allocated, much of the additional capacity for 5G is targeted by use of higher frequency spectrum – 3.3GHz to 5GHz (designated frequency range 1 (FR1)) and mmWave (FR2). However, these high frequencies present a significant coverage

challenge as signal strength drops off rapidly with distance.

Thus, a network is envisaged with many more radiation points and different transmission frequencies. This naturally leads to the concept of heterogeneous networks, which combine low

using “re-farmed” 4G spectrum or at FR2. However, FR2 has extremely limited coverage and so will be limited to local “hot spots” or fixed wireless.

### Key Technologies

In order to meet the challenging targets for data rates, coverage and connections set for 5G, new technologies will be required. Identified technologies include:

- 1) New frequencies, especially so-called sub 6GHz (FR1) for most of the world and mmWave (FR2) for US
- 2) Network densification
- 3) New and adaptive air

interfaces (see Figure 5)

- 4) Massive multiple input/multiple output (MIMO) and beamforming
  - a. To increase data-rates and improve coverage at the higher frequencies
- 5) Dual connectivity
  - a. Essential for non-standalone deployments

frequency, tall antenna macro cell sites for large area coverage, with high frequency, local points of presence (small cells), providing high data rates where needed. In addition, in the early stages of 5G deployments 4G will be used as an “anchor” for the 5G signal – so-called non-standalone (NSA) architecture.

US MNOs have a distinctly different 5G deployment strategy compared to operators in other countries based on spectrum availability. Outside of the US, FR1 spectrum is available for greenfield 5G deployments. Although propagation is less than 4G at these higher frequencies, by implementing some of the new technologies and deployment strategies, coverage can be similar. FR1 spectrum is not available in the US, so 5G can only be fulfilled

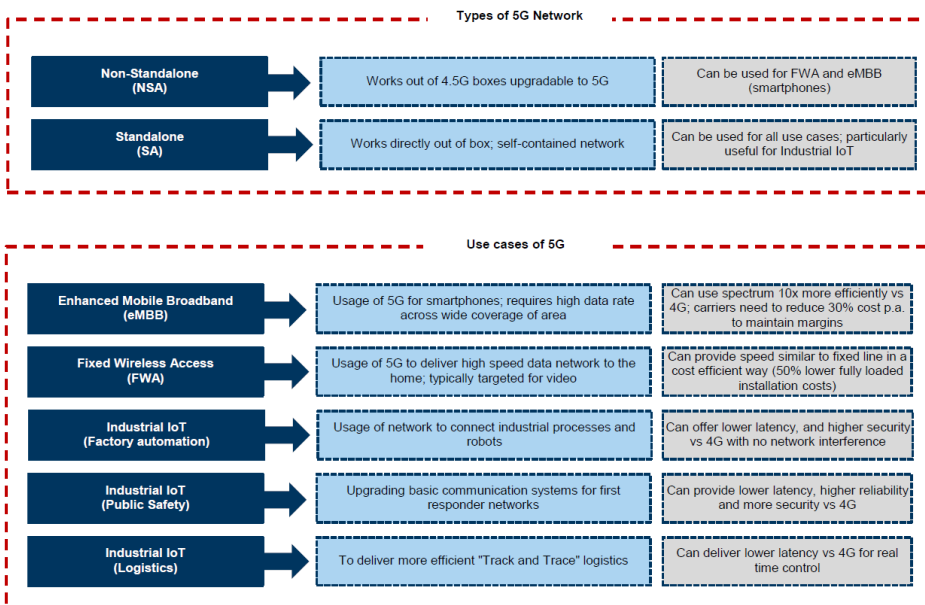
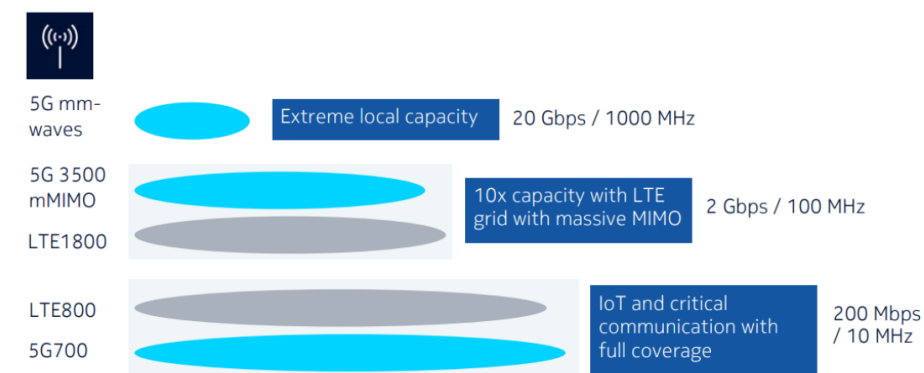


Figure 4: Types of 5G networks and use cases.

### 5G Coverage Footprint



Source: Nokia

Figure 5: 5G coverage footprint for different frequencies.

# The Importance of Spectrum

Radio frequencies occupy the range of electromagnetic spectrum designated for broadcasting over distance. RF signals are broadcast over the air, received by a device's antenna(s), and 'sorted' into the appropriate circuit path by the RF filter.

Wireless carriers purchase spectrum through auctioning of different frequency bands. And it is on these frequency bands that carriers can transmit and receive wireless signals. Consequently, the performance of any wireless network is critically dependent upon the amount of spectrum owned by any particular wireless operator.

Spectrum not only supports commercial wireless, but also a vast array of other applications. Consequently, allocating new spectrum, particularly below 3GHz, is very difficult.

Due to the lack of wide bandwidths of new spectrum, 5G spectrum will become available at different times globally.

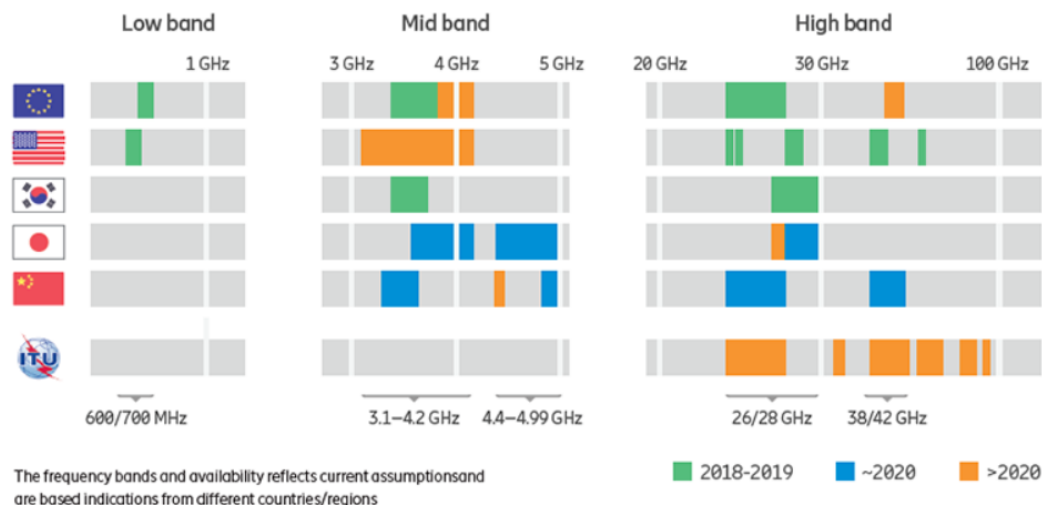
To make the story even more complex, different frequencies have very different coverage and capacity characteristics.

2G and 3G networks use low frequency spectrum for voice and low-speed data application where coverage is critical. 4G and 5G networks require larger bandwidths, necessitating higher frequencies and different deployment strategies to compensate for the much poorer coverage.

## Bandwidth

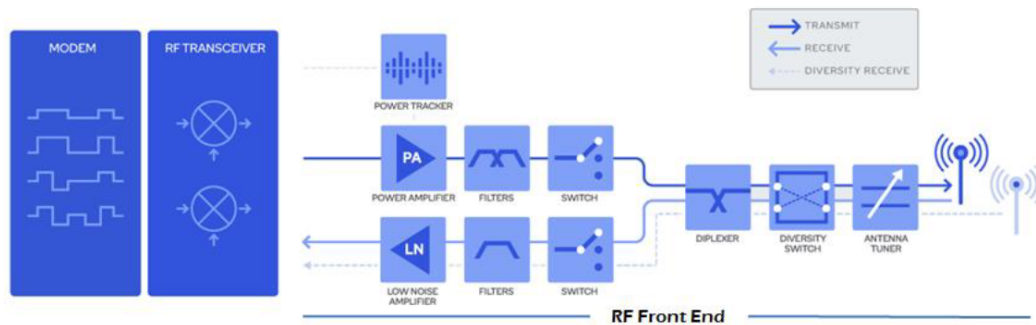
5G is set apart from previous cellular generations by the fact that it encompasses a broad range of use cases from high-bandwidth mobile devices and last mile to machine-to-machine (M2M) communications and high-reliability communications.

But like the previous cellular generations, the driver for consumer-oriented mobile devices is increasing mobile broadband bandwidth broadband driven by the increasing demand for mobile high-definition video and other new use cases. That makes delivery of high bandwidth the critical job of the 5G network.



Different spectrum bands are being made available for 5G NR around the world, on different timescales.

Figure 6: Variable air interface bandwidth and spacings for different use cases.



Source: Qualcomm

Figure 7: Schematic of mobile phone architecture.

Data rate is the key metric for bandwidth and that is expressed by the Shannon–Hartley theorem which determines the maximum data rate through a pipe.

The theorem is:

$$C = M \cdot H \cdot \log_2 (1 + \text{SINR})$$

where,

- C = channel capacity in bits/second
- M = number of channels
- H = bandwidth in Hertz
- SINR = signal-to-(interference + noise) ratio

5G equipment firms and MNOs are utilizing each of these variables, as shown below, as they seek to deliver maximum bandwidth:

- Higher Frequencies: To increase bandwidth involves tapping into higher frequency RF bands where the passbands offer hundreds of megahertz of bandwidth compared to tens of megahertz in 4G / LTE frequency bands. Currently defined frequency bands for mobile devices include n77, n78 and n79, which operate in the 3GHz and higher frequency bands.
- More Channels: Supporting multiple antennas has been a trend in high-bandwidth wireless devices for some time now – and more antennas means more channels. 5G is ushering in “massive MIMO” increasing base station antennas from four or eight to tens or even hundreds of antennas. Mobile devices won’t support that many antennas, but the number will grow.
- Better Reception: Poor signal reception due to signal attenuation increases the

noise in the SINR and reduces throughput. A denser network built using small cells will improve signal reception and increase the signal aspect of this ratio resulting in higher throughput.

- Higher Power: 5G uses a higher power version of the orthogonal frequency division multiplexing (OFDM) modulation scheme. This higher power helps to compensate for the signal attenuation that is more pronounced in higher frequencies.

All of these promise more throughput, but the gatekeeper / enabler for all of these is the RF filter, which must support the higher frequency and also be designed to accommodate the amount of bandwidth required.

## RF filter and 5G Throughput

A filter allows desired signals to pass and blocks unwanted interfering signals. Acoustic filters use the piezoelectric effect to convert RF signals into electrical energy that causes minute fluctuations in a substrate. These fluctuations determine which frequencies are processed. Filters are able to select designated signals from specific frequency bands while rejecting unwanted signals that interfere with the reception of the intended frequency.

Currently there are between 50-90 filters in a tier 1 4G/LTE mobile device allowing operation anywhere in the world. A new filter is needed

for every antenna and frequency band supported by the device. That number will increase as the number of antennas grow along with support for multiple 5G frequency bands in the device.

RF filters have always been an important part of mobile devices, but in the 5G era, they are the key to unlocking the promised high bandwidth that will drive many of the 5G use cases. 5G networks operate in higher frequency bands, requiring new underlying technology and performance standards for RF filters. The industry must develop new resonating structures in order to filter at these high frequencies. In the case of the 3G to 4G transition, and the associated increase in frequency (around 2GHz) and bandwidth (~3.5% fractional bandwidth) requirements, new resonating structures, FBAR and SMR-BAW, were developed.

compensated SAW (TC-SAW), film bulk acoustic resonator (FBAR) and Solidly Mounted Resonator bulk acoustic wave (SMR-BAW).

As operating frequencies increase, the physical dimensions decrease, making it more demanding on the processing technologies. Higher frequency signals have higher signal attenuation which means filters need to support high-power RF signals to boost signal strength.

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 8):

- Surface acoustic wave (SAW): Simple to design and low cost technology for 3G/4G networks; offers good performance with precise filter design.

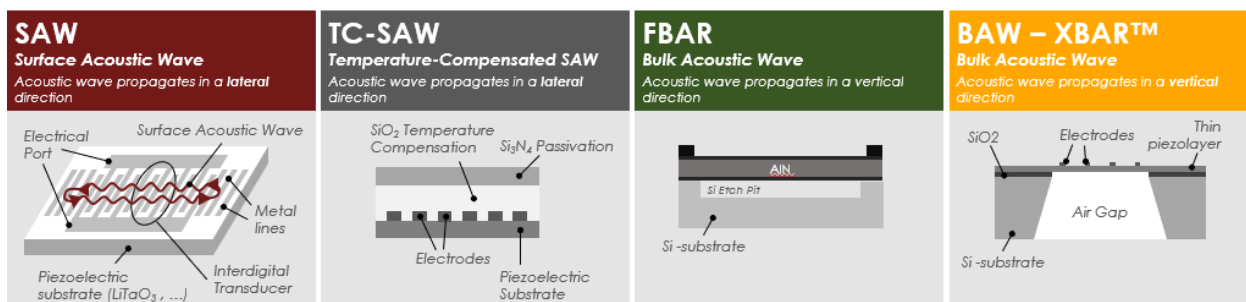


Figure 8: Acoustic wave filter technologies.

## XBAR-based Filters Realize the Potential of 5G

### Acoustic Wave Resonators

The foundational material underlying all RF filters are resonating structures, so called because they support resonance oscillation at defined frequencies. Acoustic wave resonating structures are the most popular structures because of their performance, small size and low cost.

Four acoustic wave filter technologies have been developed for 3G and 4G applications including surface acoustic wave (SAW), temperature-

- Temperature compensated SAW (TC-SAW): Use a higher cost process than SAW, but deliver increased temperature stability that is suited for HPUE applications.
- 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.
- Solidly Mounted Resonator- Bulk Acoustic Wave (SMR-BAW): 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.

These technologies differ in simplicity and cost, but when it comes to 5G most are practical in frequency bands up to about 2.7 GHz, which is lower than wide bandwidth 5G bands.

#### What is an XBAR resonator?

XBAR resonators consist of a single crystal, piezoelectric layer, with a metal interdigital transducer (IDT) on the top surface. The metal traces excite a bulk acoustic wave within the piezoelectric, the primary frequency and coupling characteristics being determined by the physical dimensions and properties of the piezoelectric.

- high power handling – more than 30 dBm (1 Watt) at the edge of the band
- Low loss (to maximize the signal efficiency)

The inherent flexibility of XBAR resonators allows tailoring for different requirements by changing the piezoelectric layer and its orientation. So, for these 5G applications z-oriented lithium niobate of ~ 400nm is preferred, providing the correct coupling (bandwidth) at the right frequency.

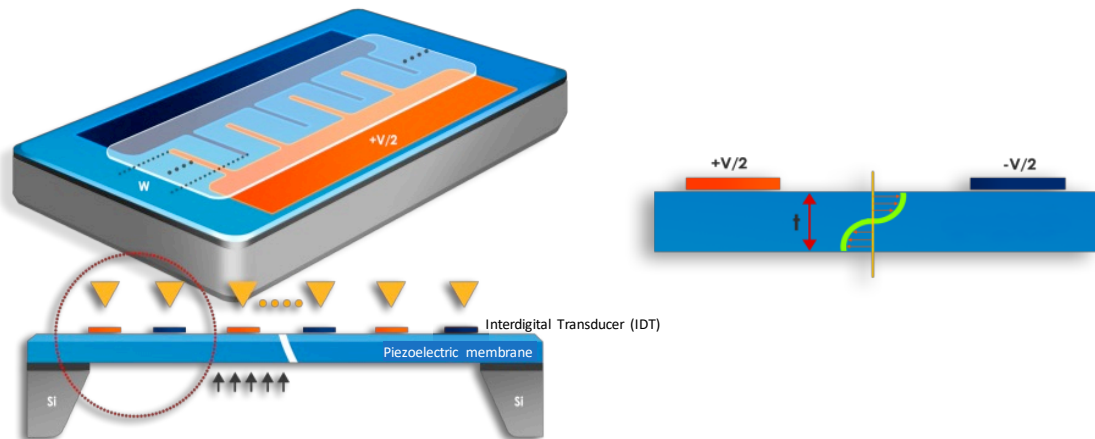


Figure 9: XBAR resonator, showing cross section of basic structure and bulk wave excited by IDT fingers.

#### New Filter Requirements for 5G - XBAR

As mentioned earlier in the white paper, wide bandwidth is critical to realize high data-rates. In the case of instantaneous bandwidth this is only available above 3GHz. Hence the filter requirements for these new bands is quite different from 4G.

- Wide bandwidth - >500MHz and up to 900MHz
- High frequency - >3GHz
- High power - to compensate for poor propagation at high frequency. It will be important for filters to demonstrate very

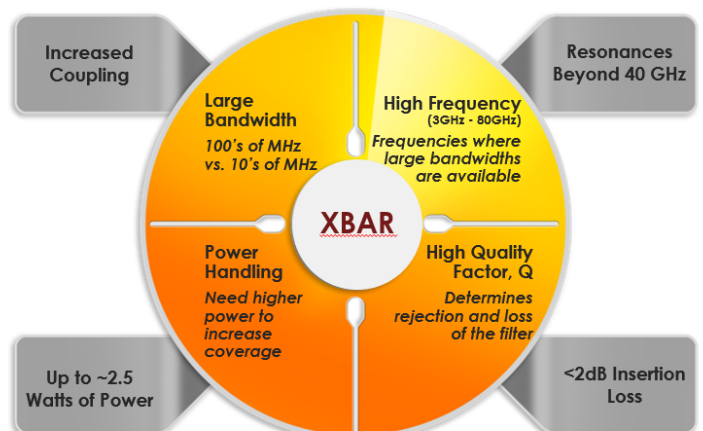


Figure 10: Key characteristics of XBAR resonator addressing 5G requirements.

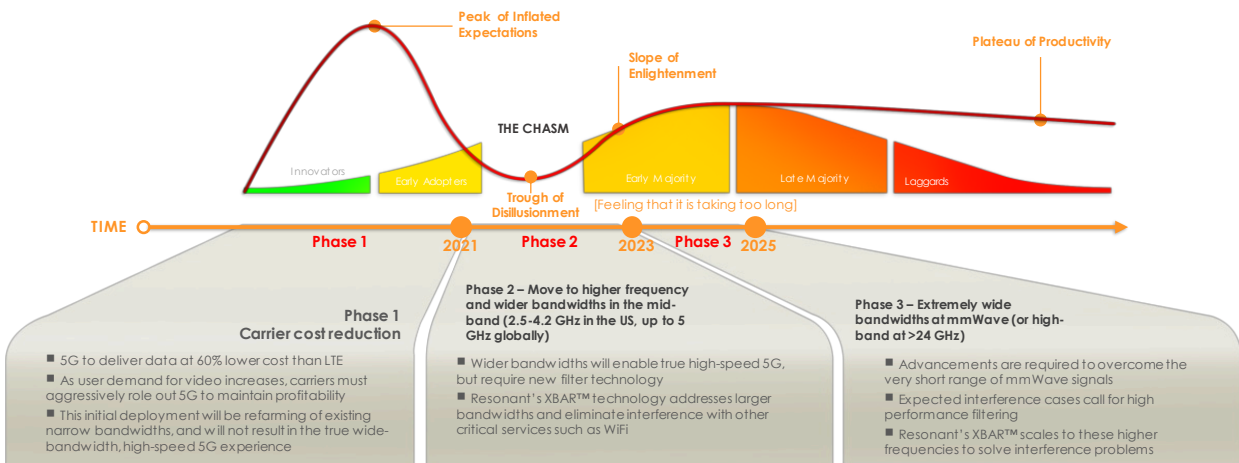


Figure 11: Phases of implementing 5G.

## Reality of 5G

In this early phase of 5G, the NR bands are

Early data-throughput testing shows some improvements over 4G, but these improvements are only marginal. As shown in Figure 12, with any new technology we must be careful to continue to implement all of the technologies

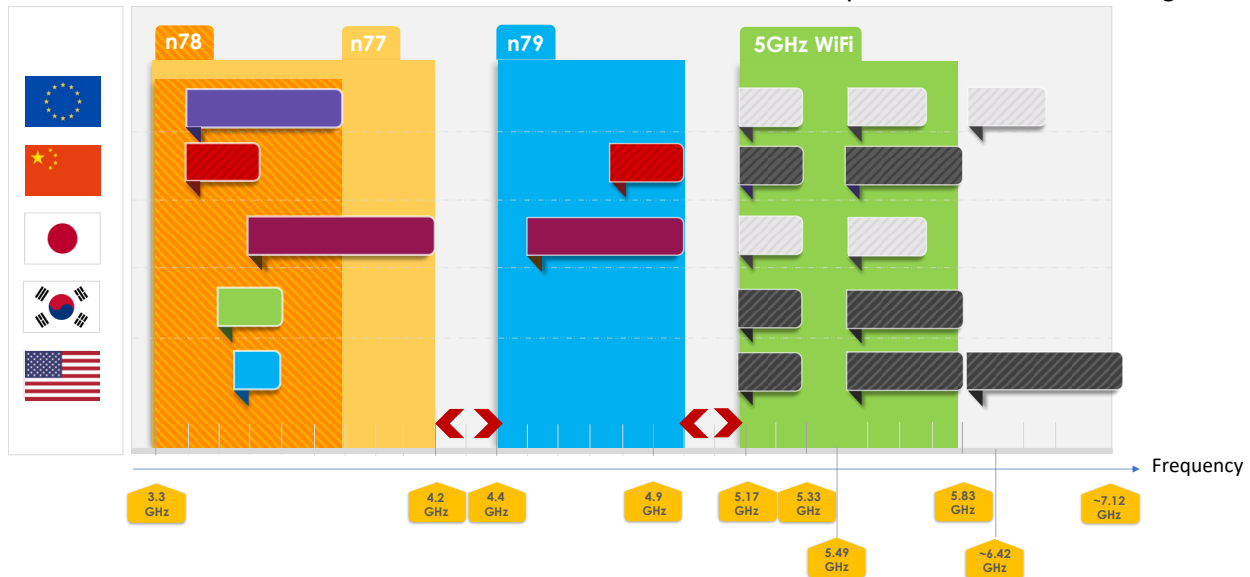


Figure 12: 5G sub-6GHz and Wi-Fi bands in the 3GHz to 7GHz frequencies.

carrying very little traffic, and so, filter requirements, particularly regarding interference protection are relaxed. However, as data traffic increases, co-existence of 5G bands and Wi-Fi becomes a serious issue that will require high performance filters. In addition, limited bandwidth from re-farmed spectrum, NSA implementations, lack of key technologies in the early stages of 5G will constrain the performance.

required to pass through the "trough of disappointment" and realize the full potential of 5G. It is fair to think that wireless carriers should wait for a more developed and optimized technology but it is a competitive world and all carriers are linked to the success of 5G.

### 5G - Wi-Fi Co-existence

5G and Wi-Fi will have a co-existence challenge unlike any other in the history of cellular

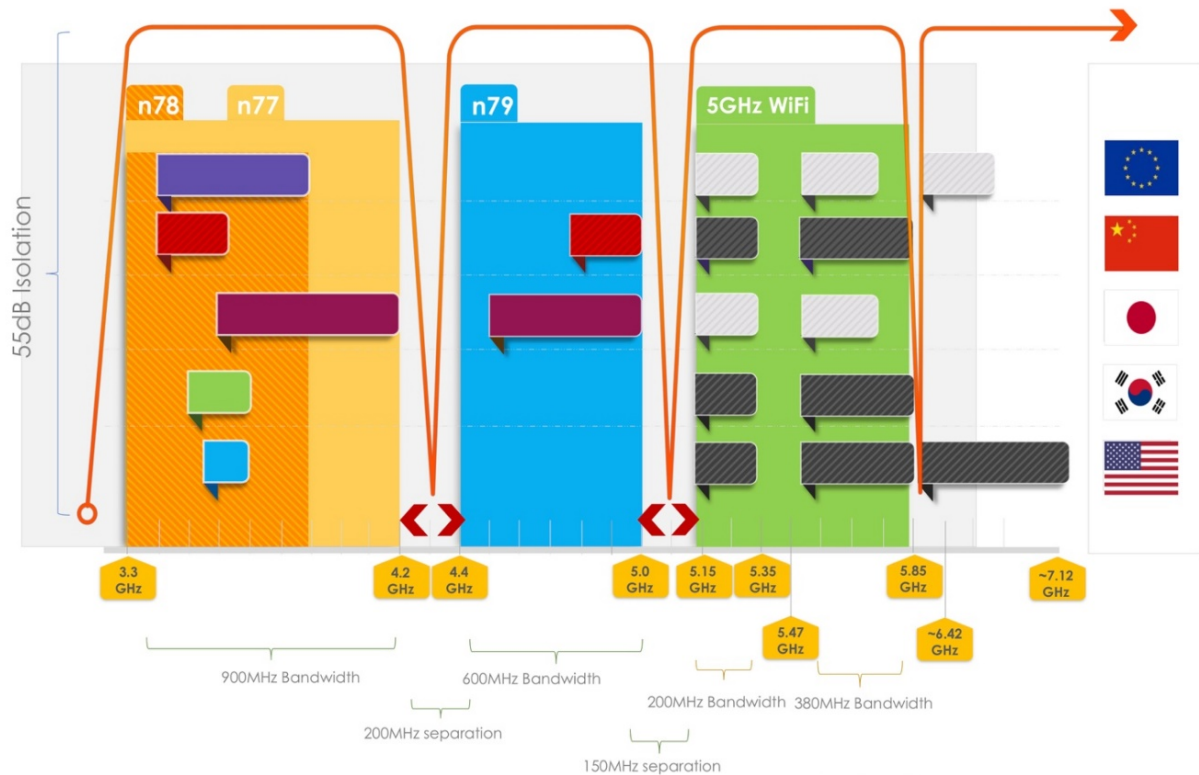


Figure 13: Filters required to prevent interference and allow co-existence/operation for these bands

technology. Bands n77, n79 and 5GHz Wi-Fi are adjacent in frequency with little guard band to separate them. The new Wi-Fi 6 (802.11ax) standard operates adjacent to the 5GHz Wi-Fi frequency band, which, in turn neighbors the n79 and n77. According to industry analysis firm Navian:

"5GHz band for Wi-Fi which is essential for smartphones sits between the 4.5GHz and 6-7GHz bands. If these frequencies are to be fully utilized, each bandwidth would need a steep filter. Also with n77 and n79, high-performance filters will be needed at the same time, since band gap of 200MHz is too narrow to be utilized fully."

As seen in Figure 13, there is only a 200MHz separation between n77 and n79, and a 150 MHz separation between n79 and 5GHz Wi-Fi. Filters for these bands will need to have a high Q to mitigate interference between the 5G and Wi-Fi bands, enabling maximum bandwidth operation, preventing Wi-Fi signals from bleeding into the n79 data path and vice versa.

#### Future XBAR based Filter Applications

The most immediate application for these resonating structures is 5G, because no other solution exists. However, the simplicity of this bulk acoustic wave resonator lends itself to many other applications and markets.

For example, with lithium tantalate as the piezoelectric membrane, of the appropriate thickness and orientation, high performance (narrow/sub-band) Wi-Fi filters for consumer premises equipment (CPE) are achievable.

These both exhibit low-loss (<1.5dB) across the band and excellent rejection to neighboring, potential interfering frequencies (>50dB).

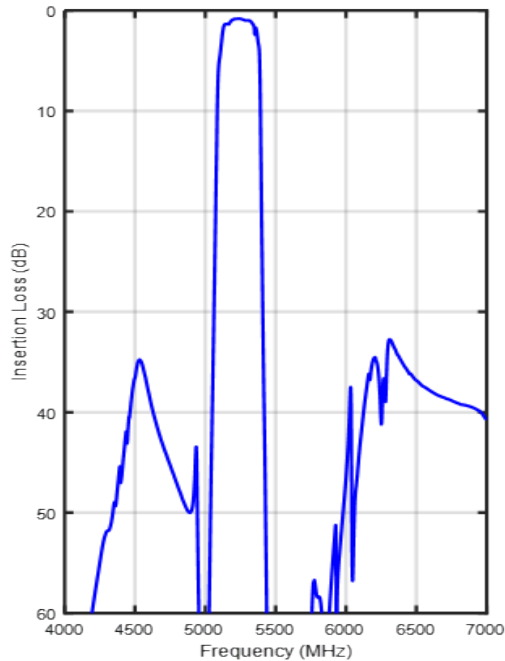


Figure 14: Simulation of a narrow band 5.2GHz Wi-Fi filter.

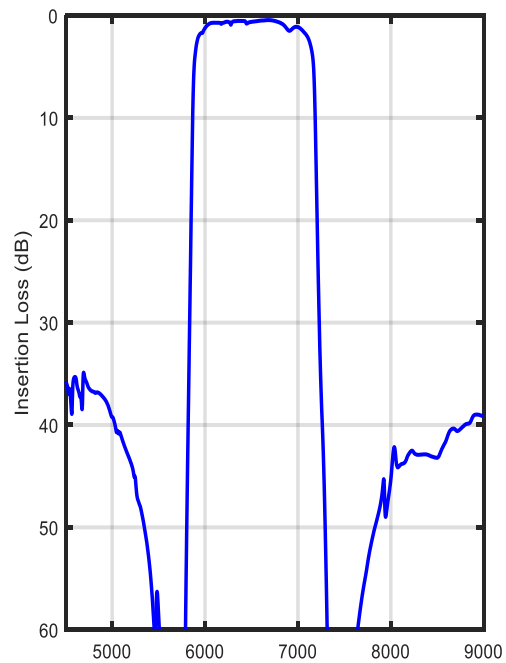


Figure 16: Simulation of a full-band Wi-Fi 6GHz filter.

For a full-band 5GHz Wi-Fi filter, a design with the appropriate piezoelectric can produce

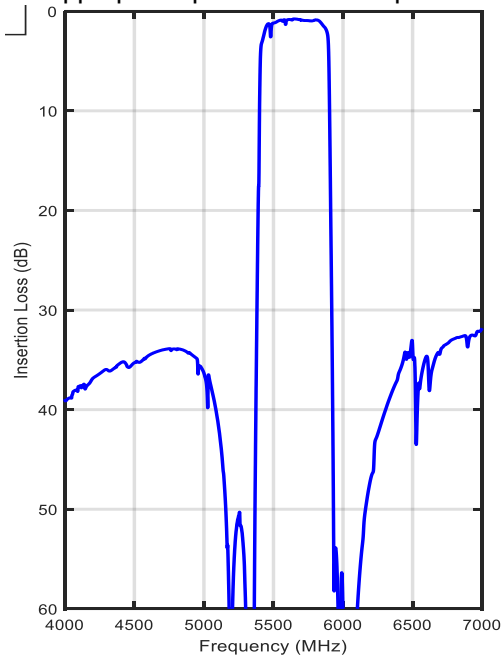


Figure 15: Simulation of a narrow band 5.6GHz Wi-Fi filter.

performance that is un-matched by any other acoustic wave technology (Figure 15).

It is important to note that the process steps are the same, only the piezoelectric material, thickness and orientation are varied. In addition, the ability to design these filters is enabled by Resonant's ISN software platform. The full finite element model for both acoustic and electromagnetic accurately predicts the measured filter performance. This allows optimization in software, which is even more critical for wider bandwidth passbands, to ensure that performance is maintained over the entire bandwidth.

## Conclusion

Delivering true 5G bandwidth means more than just faster video streaming and internet access, it is an enabler for a range of brand new wireless services. New XBAR resonators can be used to design an RF filter that supports the high frequency and high power and wide bandwidth needed for true 5G services. XBAR based filters also provide the high Q factor necessary to ensure the rejection of Wi-Fi signals that operate in adjacent bands. XBAR based filters provide a path for a simple, single resonating architecture to cover all of the recent wireless technologies.