

Aperture Tuning: An Essential Technology in 5G Smartphones

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Executive Summary

Antenna aperture tuning is essential to enable smartphones to operate efficiently over the ever-increasing range of RF frequency bands and support the transition to 5G. Smartphones need more antennas to support growing RF requirements such as new 5G bands, MIMO, and carrier aggregation (CA), but there is less space for these antennas due to changes in smartphone industrial design. As a result, antennas are becoming smaller, potentially reducing antenna efficiency and bandwidth. Aperture tuning compensates for this problem by allowing antennas to be tuned to operate efficiently on multiple bands and increasing Tx and Rx performance by 3 dB or more. Aperture tuning is implemented with switches combined with other tuning components; switches with low RON and low COFF are critical to maximize efficiency. Aperture tuning also lets antennas communicate on multiple bands simultaneously to support CA. Implementing aperture tuning requires in-depth knowledge of how to apply the technology for each application.

Introduction

Antenna efficiency plays a critical role in overall smartphone RF performance. However, current broad trends in RF requirements – especially the forthcoming transition to 5G – and in smartphone industrial design, mean that smartphones must fit more antennas into less space. As a result, antennas are shrinking in size, which reduces antenna efficiency. Without compensating for this problem, the reduced efficiency can impact Tx and Rx performance, causing shorter battery life, lower data rates and connectivity problems.

5G Handsets Need More Antennas to Deliver Faster Data Rates

The transition to 5G, which continues the quest to deliver higher data rates, will drive a significant increase in the typical number of antennas in each handset.

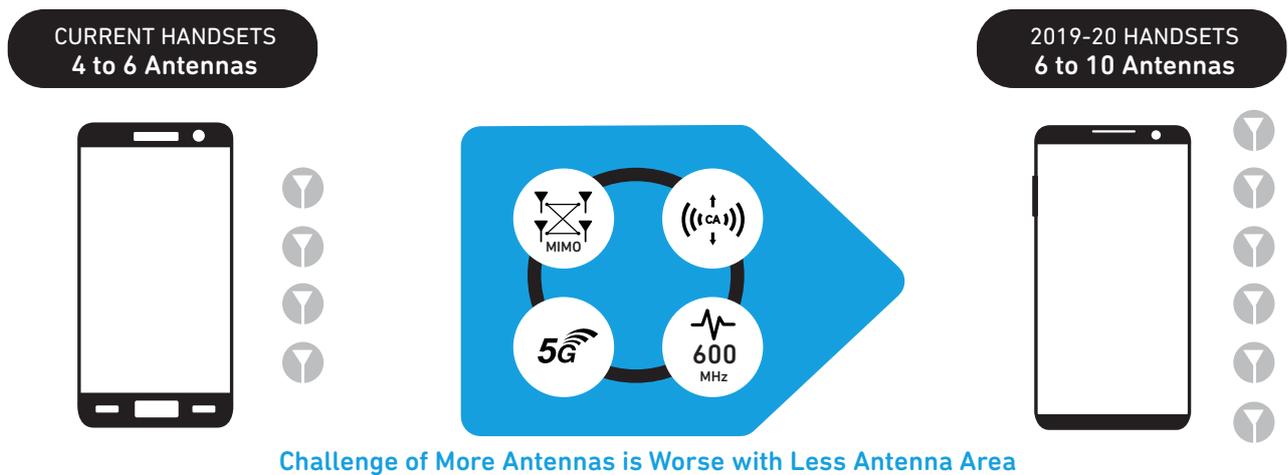
Two primary techniques for delivering higher data rates, CA and multiple input multiple output (MIMO), both require multiple antennas that operate simultaneously. 5G will further drive this trend because it mandates support for four independent downlink channels for most bands, requiring handsets to include at least four antennas for cellular communications.

“Increasing complexity required to support 5G coupled with industrial design constraints negatively impacts antenna performance resulting in degraded data rate and battery life”

At the same time, handset antennas will need to support a wider range of frequency bands, largely due to the introduction of new 5G bands. 5G handsets may need to support frequencies ranging from 600 MHz at the low end to as high as 6 GHz.

To support these requirements as well as Wi-Fi, GPS, and **Bluetooth**® technologies, the typical number of antennas will increase from 4 to 6 in today’s LTE handsets to 6 to 10 in 5G smartphones. It is becoming increasingly difficult to fit all these antennas into the limited space available.

Figure 1. The number of antennas is increasing, particularly with the transition to 5G, to support new frequency bands as well as MIMO and CA requirements.

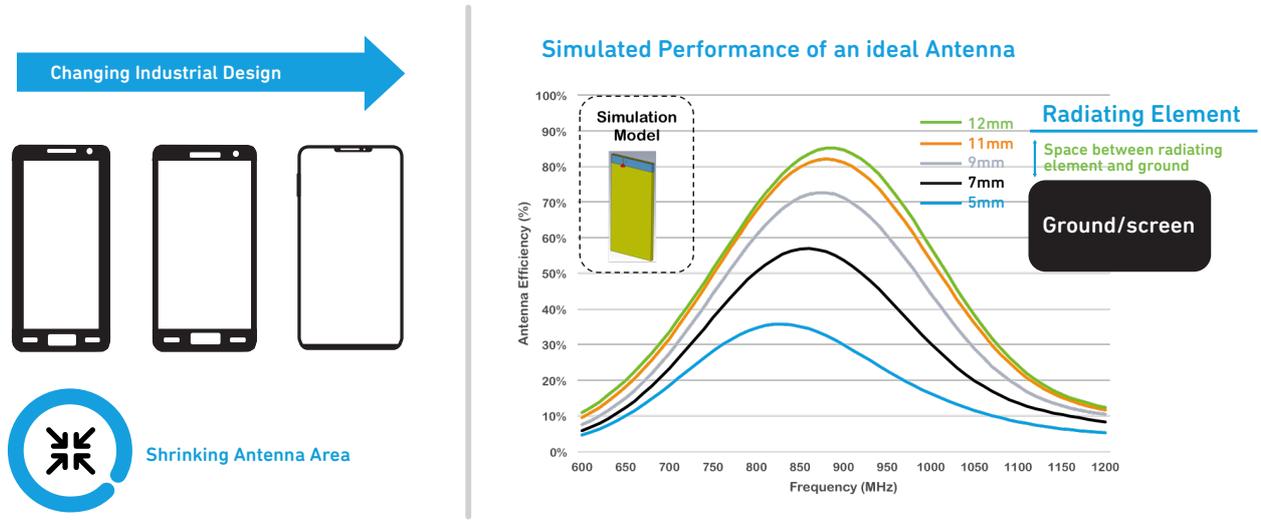


Reduced Antenna Area

Exacerbating the problem, the space available for antennas is shrinking as manufacturers make industrial design changes and add new features. One key change is the shift to full-screen handsets, in which the display occupies nearly the entire face of the phone; as a result, there is less space available outside the screen for cellular antennas. Manufacturers are also adding more cameras, further reducing the space available within the handset.

The need to fit more antennas into less space means antennas are becoming smaller, and the reduced antenna size results in lower antenna efficiency. Figure 2 shows how antenna efficiency decreases in full-screen designs as the space between the radiating element at the top of the phone and the ground (located at the screen edge) shrinks.

Figure 2: Full-screen smartphone designs shrink the available antenna area, reducing antenna efficiency.



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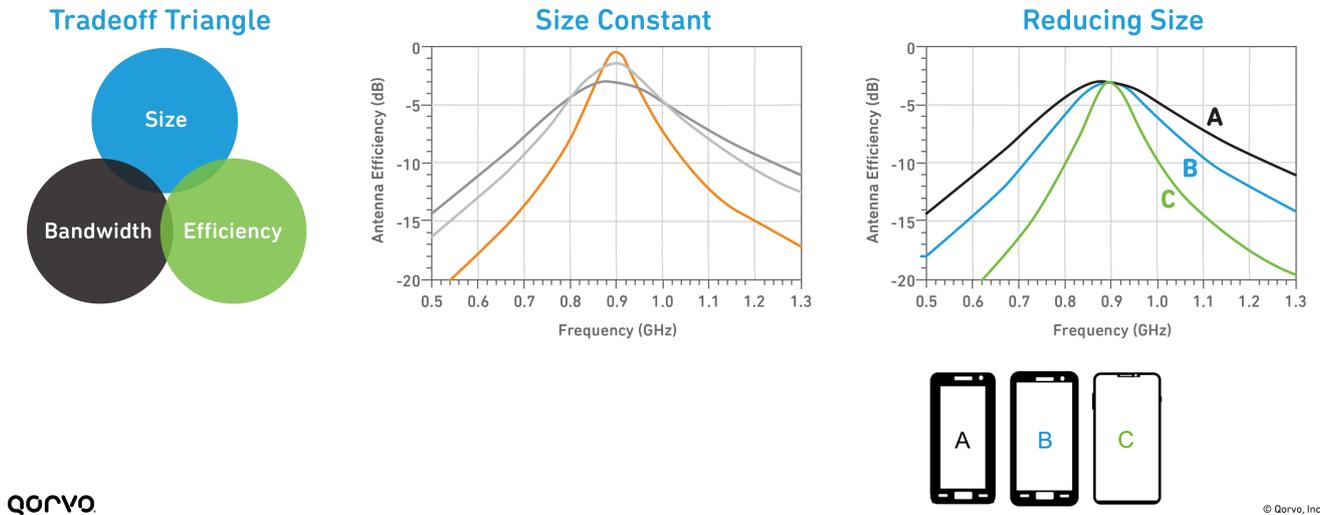
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The higher number of antennas, combined with their reduced size, also means the handset is more sensitive to transient effects caused by changes in its environment, such as handling the phone. These transient effects may include reduced efficiency and shifts in frequency response.

The Antenna Performance Tradeoff Triangle

The antenna “tradeoff triangle,” shown in Figure 3, illustrates the impact of reduced antenna size on efficiency and bandwidth. If the antenna size remains constant, efficiency can be traded in exchange for greater bandwidth. In older-generation phones with larger antennas, this tradeoff may be acceptable because the antenna may still be able to meet performance requirements while supporting a wider range of bands. But as the antenna size decreases, this tradeoff is no longer possible; with new full-screen designs, the antenna can only achieve the required level of efficiency over a narrow frequency range. Therefore, to support the wide range of frequencies supported in current handset designs, the antenna must be tuned to operate efficiently on each frequency.

Figure 3. The antenna performance tradeoff triangle.



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Aperture Tuning: Tuning with a Switch

Today, aperture tuning is the primary method used in handsets to overcome the problems caused by reduced antenna area and efficiency. It is essential to enable smartphones to support the ever-broadening range of frequency bands, especially with the transition to 5G.

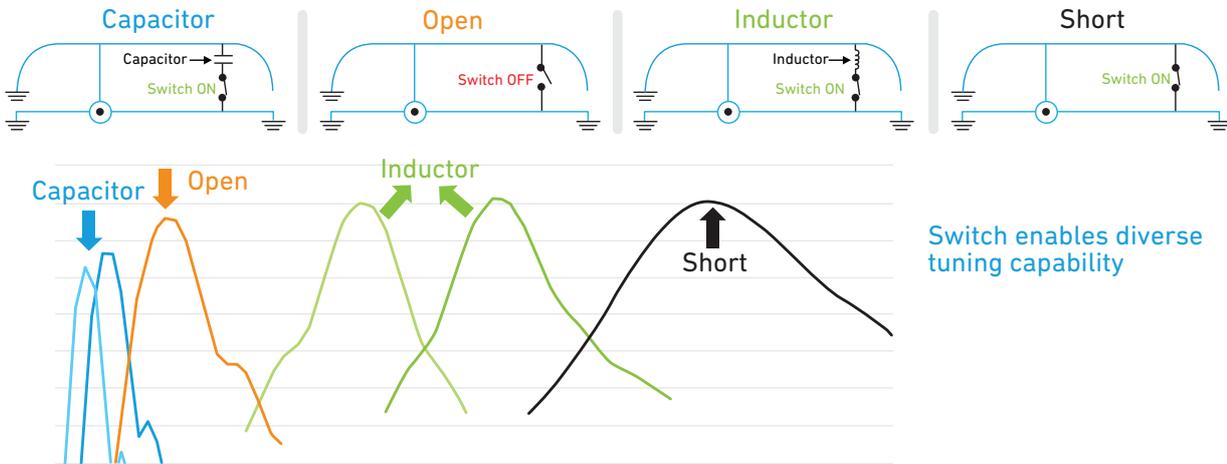
Aperture tuning can make a large impact on antenna efficiency for both transmit and receive communications, improving total radiated power (TRP) and total isotropic sensitivity (TIS) by 3 dB or even more depending on the application.

The antenna tuning concept is shown in Figure 4. A switch is connected between the antenna and the ground and used to adjust the resonant frequency of the antenna to match the frequency that the phone is currently using to communicate.

Adding different tuning components (a capacitor or inductor) between the switch and the radiating element can be used to further adjust the resonant frequency, to support different bands. Figure 4 shows the resonant frequency of an antenna when the switch is off, when it is on, and when an inductor or capacitor is inserted into the circuit.

In Figure 4, each component is connected to a simple switch, to illustrate the aperture tuning concept. However, in some applications, such as primary cellular antennas, more complex multi-throw switches may be used to connect multiple tuning components and support a broader range of frequency bands.

Figure 4. Aperture tuning.



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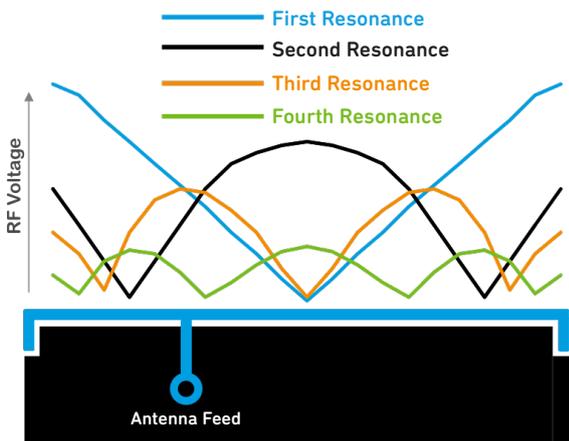
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Tuning an Antenna for Multiple Frequency Ranges

An antenna has multiple natural resonant frequencies. These are harmonically related: for example, an antenna may have resonant frequencies at 900 MHz, at 1800 MHz (2nd order harmonic), at 2700 MHz (3rd order harmonic) and so on. By using aperture tuning switches to tune each of these frequencies, a single antenna can support many bands distributed across a very wide spectrum range.

Figure 5 shows how this works. Each resonant frequency has a different voltage distribution along the antenna. The voltage pattern varies depending on the type of antenna; Figure 5 shows one example.

Figure 5. Voltage distributions for an antenna's different resonant frequencies.



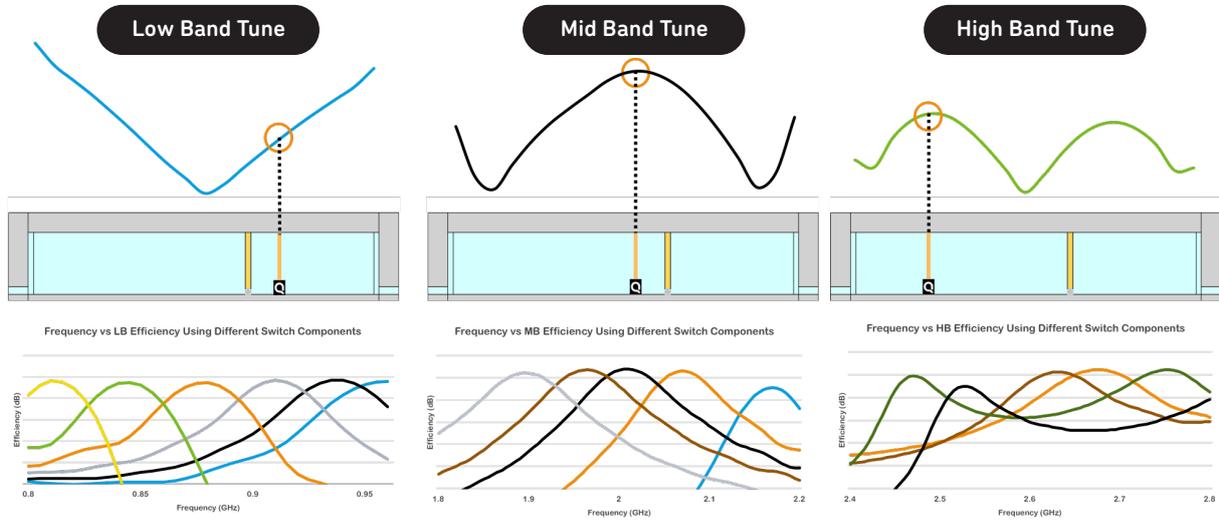
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Each of these resonant frequencies can be tuned independently by placing an aperture tuning switch at the point where it has the greatest effect, which is generally close to the apex of the voltage distribution for that frequency.

By positioning multiple switches in different locations along the antenna, and using multiple tuning components with each switch, a single cellular antenna can support a very wide range of low-, mid-, and high-frequency bands (Figure 6).

Figure 6. By placing tuning switches at multiple locations, a single antenna can support a wide range of low-, mid- and high-frequency bands.

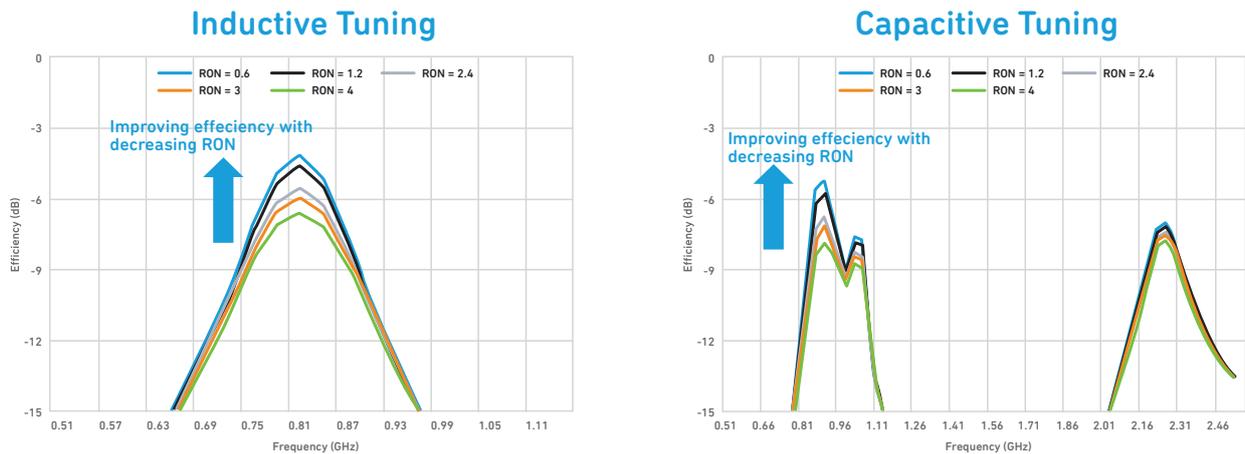


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The Importance of RON and COFF

Two critical characteristics of aperture tuning switches significantly affect antenna efficiency: on resistance (RON) and off capacitance (COFF). Decreasing RON can improve efficiency in both inductive and capacitive tuning by several dB (Figure 7), with a correspondingly large impact on a handset’s overall RF performance. Low COFF is similarly important.

Figure 7. Effect of decreasing RON on inductive and capacitive tuning efficiency.



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However, RON and COFF have differing impacts along the length of the antenna, depending on the voltage distribution. The impact of low RON is greatest where the voltage is low; the impact of COFF is greatest where the voltage is high. Strategic placement of switches with low RON or low COFF can be used to optimize tuning for different frequencies.

Aperture Tuning for CA

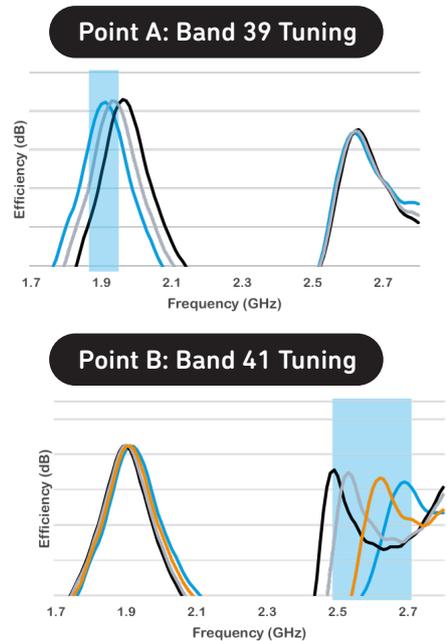
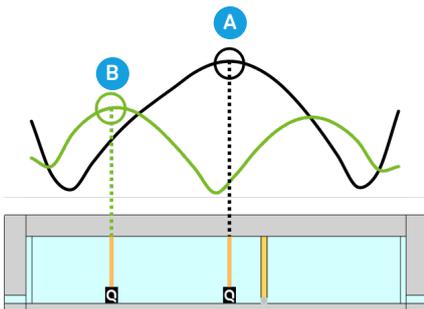
LTE operators worldwide are using CA to provide higher data rates. CA combines two or more LTE carriers, often in different frequency bands, to deliver increased bandwidth. Due to the limited total number of antennas in handsets, this often means that a single antenna must communicate on two bands simultaneously.

Carefully placed aperture tuning switches can meet this requirement. As previously described, placing a tuning switch near the peak voltage of a resonant frequency has the greatest tuning effect on that frequency. Conversely, placing a tuner at the null voltage of a resonant frequency has little tuning effect. By positioning a switch so that it is close to the peak voltage for one resonant frequency but near the null of a second frequency, the first frequency can be tuned without impacting the second.

Figure 8 shows aperture tuning used to support the combination of Band 39 and Band 41, which is commonly used in China. Placing a switch near each frequency’s peak voltage allows high-efficiency tuning of each band with minimal impact on the other band.

Figure 8. Aperture tuning for CA; placing a switch near the voltage peak for each resonant frequency allows high-efficiency tuning of each band with minimal impact on the other.

Antenna Switch Placement Combination Tuning: B39 + B41



Conclusion

Aperture tuning is essential in enabling today's smartphones to support the ever-growing range of frequency bands. It significantly increases Tx and Rx performance, overcoming the challenges caused by handset industrial design changes and making it possible to meet increasingly complex RF requirements. The effective implementation of aperture tuning requires considerable knowledge of how to apply the technology to optimize each application. The increasing number of antennas also means that aperture tuning solutions must be small to fit into the shrinking available space.

Qorvo is the recognized market leader in aperture tuning, with deep experience in helping leading manufacturers use aperture tuning to meet their goals. Qorvo's extensive portfolio of highly compact solutions offers the combination of ultra-low COFF and low RON necessary to maximize performance.

About the Author



Abhinay Kuchikulla is a Senior Marketing Manager at Qorvo, leading the product strategy and direction for antenna tuners. Abhinay supports Qorvo with a strong technical background in RF design engineering, enabling him to understand customer problems and solve them effectively. He works to define new products and manage their development, bringing optimum solutions to the market on time and meeting customer's future RF requirements. Abhinay was awarded the Marketing Person of the Year Award in 2016 for outstanding achievement in growing Qorvo's tuner business. He received his Master's degrees from the University of Kansas in Electrical Engineering, 2004, and Engineering Management, 2013.

For more information, please visit www.qorvo.com.

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