WHITE PAPER

# Is Your Handset RF Ready for 5G?

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## Executive Summary

Accelerated 5G standards development has enabled mobile operators to advance their plans for 5G rollouts, creating pressure for smartphone manufacturers to add 5G New Radio (NR) support to handset designs even while 5G specifications are still evolving. 5G introduces multiple challenging requirements, including unprecedented bandwidth, 4x4 MIMO and higher peak-to-average power ratios together with very high PA linearity and extensive carrier aggregation-driven frequency congestion. Furthermore, initial mobile deployments will use the non-standalone (NSA) 5G New Radio specification, which creates additional complex RF challenges because of the need for simultaneous 4G LTE and 5G connectivity. While the specifications are still evolving it is necessary to draw on existing systems knowledge and expertise to estimate the impacts and the implications for RF design. As in previous major technology transitions, innovative new RF solutions will be required to solve the complex challenges of 5G.

## Introduction

The accelerated development of 5G standards has enabled mobile operators to advance their plans for 5G rollouts, with some planning early deployments within the next year. Once rollouts begin, 5G handsets are predicted to become the fastest-growing sector of the smartphone industry for the next decade, with shipments increasing from 2 million in 2019 to 1.5 billion in 2025, according to Strategy Analytics. A recent survey found that nearly 50 percent of consumers are likely to choose a 5G smartphone as their next mobile device, due in part to anticipated increases in data speeds.

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However, the rush toward 5G also presents significant RF challenges for handset design. Because of the compressed timeline for standards development, there are still uncertainties about key details of fundamental RF specifications, such as power backoff levels, regional band combinations, uplink MIMO and supplemental uplink (SUL).

With operators insisting that handsets include 5G content in time for their planned network deployments, smartphone manufacturers are under pressure to develop implementation strategies for meeting challenging 5G RF requirements, even as specifications are still evolving. These requirements include unprecedented bandwidth and peak-to-average power ratios together with very high power amplifier (PA) linearity and extensive carrier aggregation-driven frequency congestion.

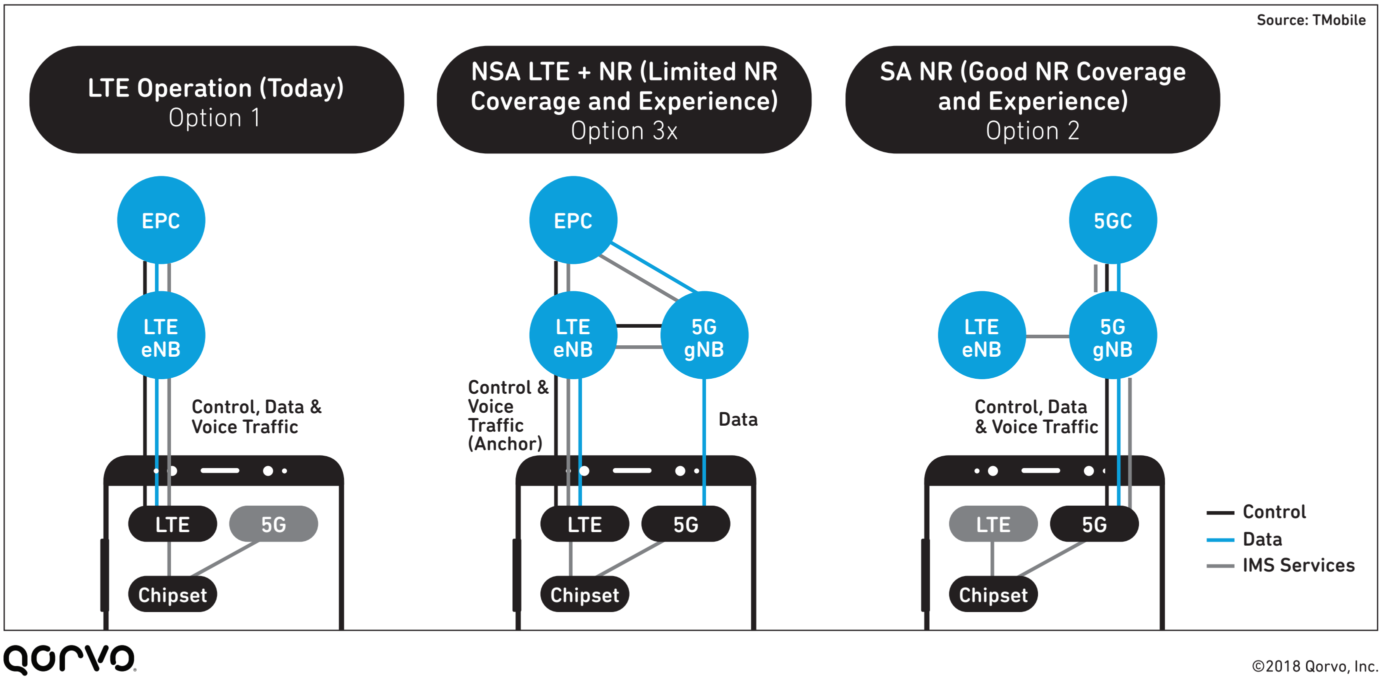
## Understanding What's Real

Ultimately, 5G will support an extraordinarily broad range of applications. However, mobile operators' initial implementation focus is on enhanced mobile broadband (eMBB), which is expected to deliver data rates of up to 20x today's 4G speeds.

Delivering true 5G requires new hardware in smartphones and infrastructure in the form of the 5G New Radio (NR) – not simply making 4G faster and rebranding it as 5G, as happened with the previous technology transition from 3G to 4G.

The initial set of 5G NR specifications were delivered in December 2017, in the first phase of 3GPP Release 15. They focus on mobile broadband deployment using the non-standalone (NSA) 5G NR, the technology that will be used in most of the early 5G network rollouts (Figure 1). NSA was devised to accelerate 5G deployments by using an LTE anchor band for control together with a 5G NR band to deliver faster data rates. This approach allows operators to deliver 5G speeds sooner by extending their existing LTE networks without the need to build out a whole new 5G core network. The 5G standalone (SA) specifications, which remove the need for an LTE anchor and will require a full 5G network buildout, are currently due for delivery about 1 year later in December 2018.

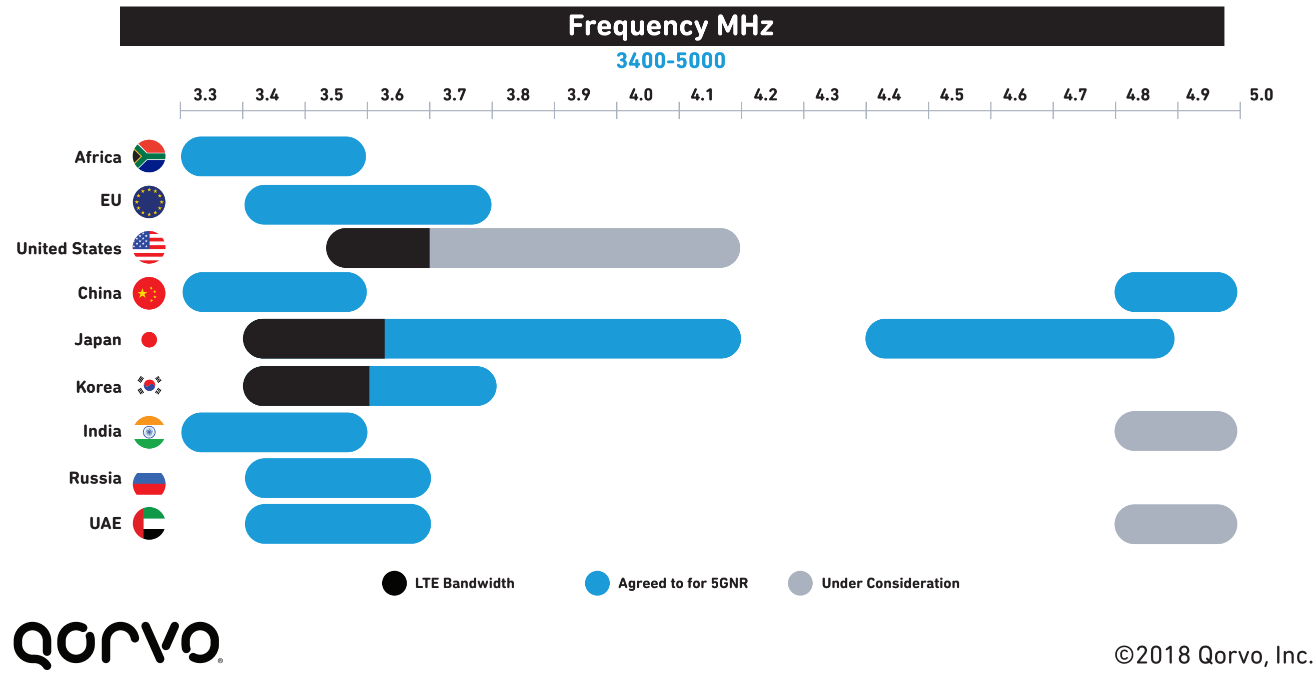
Figure 1. The progressive transition from LTE to 5G deployment.




The Release 15 NSA specification solidifies many of the 5G specifications required to start designing 5G smartphones, including new bands, carrier aggregation (CA) combinations and key RF characteristics such as waveforms, modulations and sub-carrier spacing.

As anticipated, the specifications define two broad spectrum ranges at sub-6 GHz (FR1) and millimeter wave (FR2) frequencies. They include the first set of new 5G FR1 bands, including n77, n78 and n79, which will be used in many global 5G deployments (Figure 2). Many LTE bands have also been earmarked for refarming as 5G bands in the long term, but only a small number of those are expected to see near-term use, including n41, n71, n28 and n66. The Release 15 specifications also include over 600 new CA combinations.

Figure 2. New regional allocations of 5G FR1 bands n77, n78 and n79.




5G specifications define two alternative waveforms: CP-OFDM and DFT-s-OFDM. CP-OFDM offers very high spectral packing efficiency in resource blocks (up to 98%) and good support for MIMO. It is therefore likely to be used when operators' priority is to maximize network capacity, such as dense urban environments. DFT-s-OFDM, the same waveform used for LTE uplink, provides less efficient spectral packing but greater range (Table 1).

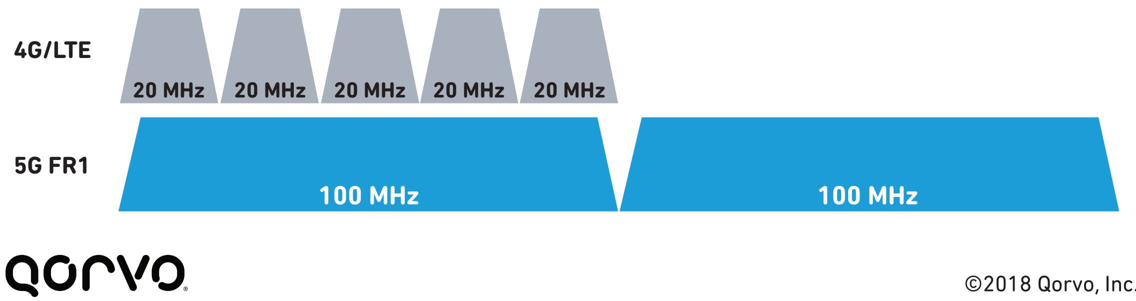
Table 1. Key 5G specifications.

| | UE Transmit Waveform Type | Modulation Order | Channel BW | Sub Carrier Spacing (SCS) |
|---|---|---|---|---|
| 4G | SC-FDMA | QPSK, 16QAM, 64QAM, 256QAM | 5-20 MHz | 15 KHz |
| 5G1 | DFT-s-OFDM | π/2 BPSK, QPSK, 16QAM, 64QAM, 256QAM | 5-50 MHz | 15 KHz |
| | DFT-s-OFDM | π/2 BPSK, QPSK, 16QAM, 64QAM, 256QAM | 5-100 MHz | 30 KHz, 60 KHz (optional) |
| 5G2 | CP-OFDM | π/2 BPSK, QPSK, 16QAM, 64QAM, 256QAM | 5-50 MHz | 15 KHz |
| | CP-OFDM | π/2 BPSK, QPSK, 16QAM, 64QAM, 256QAM | 5-100 MHz | 30 KHz, 60 KHz (optional) |

The specifications also confirm that despite the faster data rates, timing for 5G mobile broadband is like LTE and presents no additional impact for core RF implementation. However, latency has been substantially reduced in 5G, so there is much less time available for antenna swapping and antenna tuning. This is likely to result in the need for switching technologies that can perform 10x faster than 4G in certain applications.

Another major change in the transition from 4G to 5G is the unprecedented bandwidth that handsets must support. Increased bandwidth is a fundamental tenet of 5G: it is key to enabling the faster data rates targeted with new 5G bands. Single-carrier bandwidth can be up to 100 MHz – five times the LTE maximum of 20 MHz (Figure 3) – and in the FR1 range there can be two uplink and four downlink carriers for a total of 200 MHz and 400 MHz, respectively. The challenges of managing this bandwidth are expected to ripple through the entire RF subsystem, raising the bar for even the most innovative RF companies.

Figure 3. Maximum channel bandwidth comparison: 4G LTE vs 5G NR.




## Challenges for Handset Design

For smartphone manufacturers, the challenge is how to quickly add 5G support to handsets that are already densely packed with 4G LTE functionality – and to do so without delaying product release cycles or endangering their ability to meet global shipment volume targets.

### 5G NSA Dual Connectivity

While 5G NSA is the key to accelerating 5G deployment, it also adds significant RF complexity because it requires dual 4G LTE and 5G connectivity.

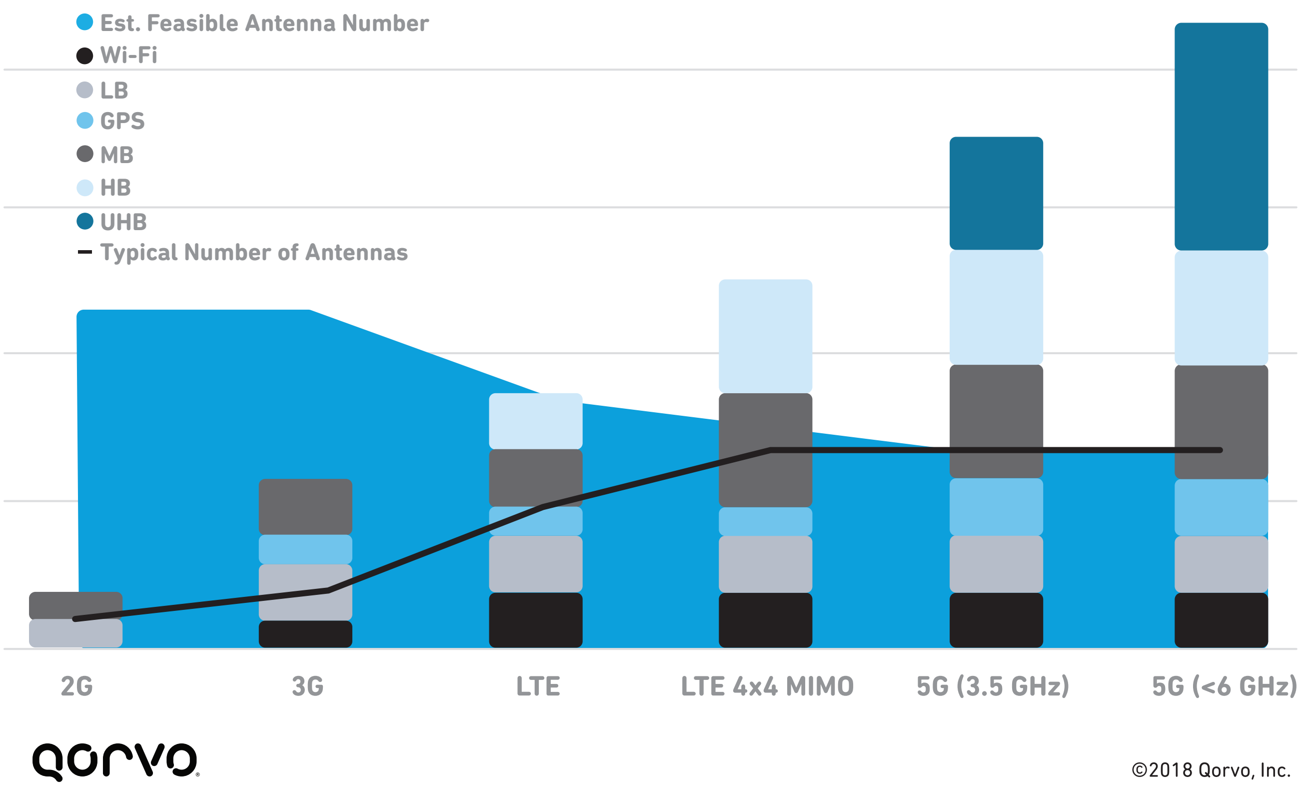
In many cases, operators are expected to combine 4G FDD-LTE bands with a 5G band. The NSA specification allows the handset to be transmitting on one or more of these LTE bands while receiving on a 5G band. This greatly increases the possibility that harmonics of the transmit frequencies will desense the receiver.

An example is the aggregation of LTE bands 1, 3, 7, and 20 with 5G band n78. Band n78 occupies a much higher frequency range than any of the LTE bands, and is also extremely wide (3.3-3.8 GHz). Because of this, there is a greater danger that harmonic frequencies generated by transmission on one of the LTE anchor bands will fall into the n78 frequency range, potentially causing receiver desense if there is insufficient attenuation of the frequencies. However, the filtering that is needed to achieve the requisite CA attenuation can lead to increased RFFE insertion loss, driving up PA output power requirements and driving down total system efficiency.

Dual connectivity also creates other challenges. For example, it will be desirable to accommodate two primary cellular antennas in a handset. Simultaneous transmission on LTE and 5G bands also creates power management concerns and requires an additional DC converter, which consumes even more space, leaving no room to further expand antenna volume.

Figure 4 illustrates this trend, showing the increase in key RF functional groups, the decrease in available antenna volume and the number of antennas in typical flagship smartphones. As shown, even with the relatively large form factor of some of today's 18:9 ratio smartphones, the available antenna volume has shrunk to the point where it is limiting the ability to add more antennas.

Figure 4. As handset RF content increases, the ability to add antennas is limited.




### 4X4 MIMO

5G MIMO requirements further exacerbate this problem. Unlike 4G LTE, where MIMO is optional, 5G handsets are required to support 4x4 MIMO in the downlink for bands above 1 GHz. This applies not only to new bands such as n77, but also to refarmed LTE bands. For example, if Band 3 is refarmed to 5G NR, becoming n3, handsets are now required to comply to the 5G NR specifications. Thus, the LTE requirement for receive diversity (i.e. two receive paths) instantly becomes a requirement for 4 receive paths.

For some handset designs that already support the optional 4x4 LTE MIMO, this change will not be significant. However, for many other handsets, the change will require a substantial increase in RF content, signal routing complexity and antenna bandwidth. Overall, this means squeezing even more content into the already crowded space allocated to the RF front end, since four antennas and four independent RF pathways will be needed. All this does not even consider the impacts of 2x2 uplink MIMO, as specified for n77, n78, n79 and n41.

This architectural shift has many implications. One of the most obvious, and critical, is that antenna tuning and antenna-plexers will become even more important. Today's smartphones have become dependent on antenna tuning to improve radiated efficiency, but antenna tuning will play an even larger role in the transition to 5G, helping smartphone makers keep the number of antennas within manageable limits by allowing each antenna to efficiently support a wider range of frequencies.

On a related note, diplexing signals is commonplace today (with low band and mid/high band signals, for example), but 5G will introduce a new level of signal routing complexity. Given the fact that the maximum number of antennas is leveling off (as shown in Figure 4), the addition of ultra-high band frequencies combined with dual connectivity uplink requirements will require significant changes in how signals are routed to antennas. Straightforward diplexers will quickly be replaced by high-performance antenna-plexers that maximize the number of signal connections while meeting tight CA rejection requirements and maintaining low insertion loss.

Another impact of all this new RF content is even though functionality is increasing, the area available for RF implementation is not. The trend is therefore likely to accelerate the adoption of integrated RF front end modules. Highly integrated modules that combine PAs, switches, filters and LNAs, such as Qorvo's RF Fusion™, require much less space while also reducing losses and supporting carrier aggregation.

**"Mandatory 4X4 MIMO has many implications."**

### Unprecedented Bandwidth and New Waveforms

The unprecedented bandwidth and new waveforms used to deliver high 5G data rates presents significant challenges for RF power output, power management and linearity.

Today's flagship LTE handsets generally use envelope tracking (ET) with PAs to minimize power consumption. ET optimizes efficiency by continuously adjusting the PA supply voltage to track the RF envelope. However, envelope trackers are only expected to support up to 60 MHz bandwidth at the time of 5G deployments, while new 5G bands such as n77 and n79 will support single-carrier transmissions up to 100 MHz wide. Because of this, PAs will need to operate in average power tracking (APT) fixed-voltage mode for wideband 5G transmission, reducing efficiency.

The new 5G waveforms highlighted in Table 1 add to the challenge. The combination of the much higher peak-to-average power ratios (PAR) of CP-OFDM along with massive channel bandwidth requires greater PA backoff in 5G, compared to LTE, to avoid exceeding regulatory limits and to preserve the linearity required for high-quality data links. The upshot is a potential fall in efficiency for the transmit chain, along with a very challenging high linear power requirement for the PA design.

As if this wasn't complex enough, the RF front end (RFFE) may also need to support LTE for backward compatibility in regions where FR1 frequencies have already been used for LTE. To maximize precious battery life, handset makers want to use ET whenever possible, which means using ET for LTE transmissions and for 5G signals up to 60 MHz wide. Therefore, the PA must provide high saturated efficiency when operating in ET mode as well as high linear efficiency in APT mode. Balancing the operation of these PAs between high-bandwidth APT mode and lower-bandwidth ET mode presents additional complexities for RFFE suppliers. Furthermore, sophisticated power management will be required to switch between ET and APT mode.

### Complications of LTE Band Refarming

There are additional complications created by refarming LTE bands for 5G NR. Over the coming years, many existing 3G/4G spectrum allocations will be progressively refarmed for use as 5G NR bands. Until that transition is completed in every single market, smartphone PAs will need to efficiently support 4G as well as 5G transmissions in each of these bands. It is anticipated that full transition to 5G NR on all bands could take a decade or more. The need to support both LTE and 5G deployments in this frequency range therefore introduces additional complexity throughout the RFFE.

Band 41, for example, is among the initial set of bands to be refarmed (as n41). When used as an LTE band, the maximum bandwidth is 60 MHz (achieved by aggregating three 20 MHz carriers), and ET can potentially be used to conserve power. When used as a 5G band, the single-carrier bandwidth can be up to 100 MHz, requiring the PA to operate in APT mode; the increased signal bandwidth also has implications for RF filter design.

Additionally, in some cases, the number of resource blocks (RBs) for each channel bandwidth allocation is being reviewed as part of the refarming transition from 4G to 5G. Many RB limits were decided years ago when the LTE specifications were initially created; the technologies and knowledge have since then advanced to the extent that improvements are possible. Mobile operators are very interested in these potential improvements because they could enable more efficient spectrum use. For handset OEMs and RF front end suppliers alike, this creates yet another level of complexity, as RF chains may need to operate in ways for which they were not originally designed.

## Solving the Challenges

Thanks to accelerated standards development and aggressive deployment plans, 5G is unfolding faster than originally anticipated, increasing the pressure on smartphone manufacturers to quickly adapt handsets to support 5G. The new standard introduces unprecedented RF challenges, complicated by the fact that while the specifications are still evolving it is necessary to draw on existing systems knowledge and expertise to estimate the impacts and the implications for RF design. Add in smartphone form factor constraints, and the result is a set of challenges unlike any that the mobile industry has previously faced. As in previous technology transitions, innovative new RF solutions will be required to solve the complex challenges of 5G. RF suppliers must raise the bar in key areas such as PA design, RFFE module integration, antenna tuning and antenna-plexers. These core 5G functions will be of paramount importance in helping handset OEMs achieve on-time release of the data-centric mobile devices that have become essential to consumers' lives.

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## About the Author

Ben Thomas is Qorvo's Director of 5G Mobile Business Development. Prior to this, Mr. Thomas held various positions such as Director of Technical Marketing, Advanced Cellular Power Platforms, Director of Corporate Relations, Business Development Manager and other sales roles. He was instrumental in establishing the company's presence in Asia by opening and operating as the country sales manager in Taiwan, Korea and China. In addition to his current position at Qorvo, he also serves as the company's delegate to the 3GPP RAN4 standardization body. Mr. Thomas received his MBA from Wake Forest University's School of Business and his BSEE at the Georgia Institute of Technology.

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