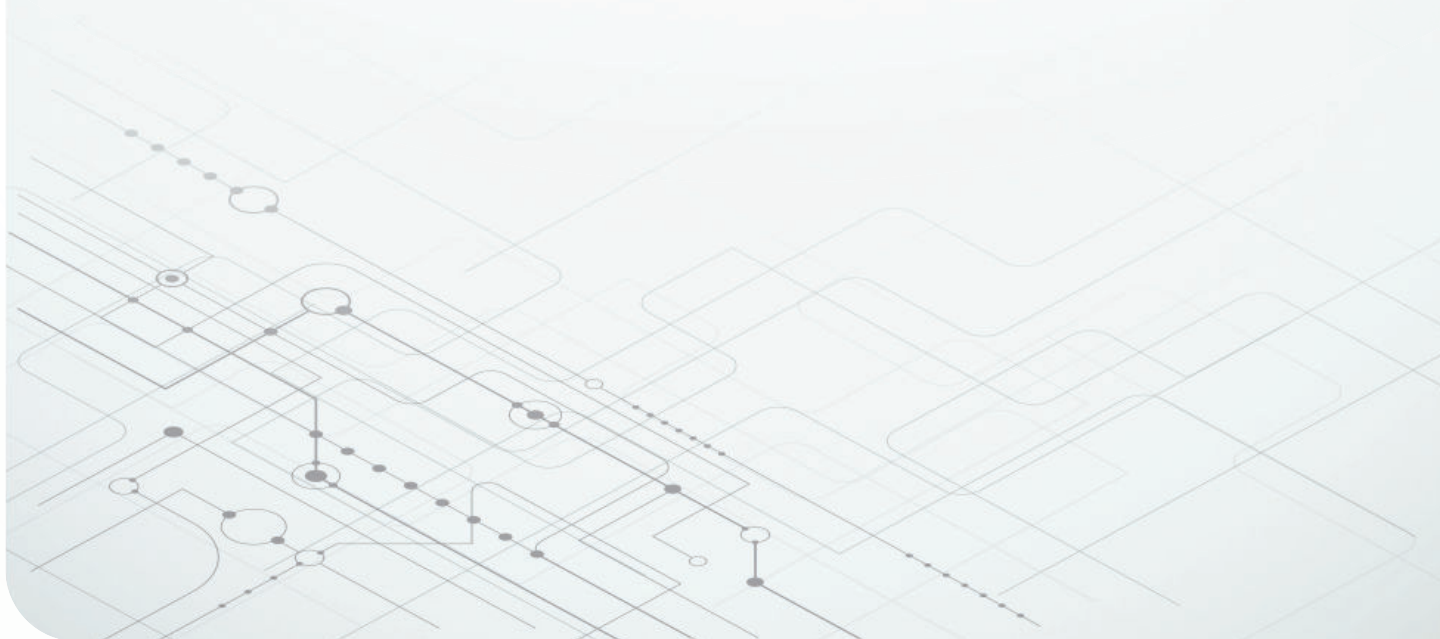


Powering Up the Power Downs – RF System and Transceiver Innovations for 5G Radio Energy Efficiency



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At a glance

This paper provides an overview to the modern 5G radio networks, the network deployment trends, and the overall efforts to reduce power consumption. By the end of this paper, you will learn about:

- **Different types of radios within the 5G radio network:** Radios such as macro base-stations, massive multiple-inputs-multiple-outputs (mMIMO), and small cells
- **5G network radio protocols that enabled power savings:** Frequency division or time division duplexing to allow idling of the unused transmitter or receiver channels
- **Innovations in radio component levels that enabled power savings:** RF transceivers and the associated digital, analog, and power saving capabilities such as digital pre-distortions, idling of the unused channels with fast wake-up time, and adjustments to optimize power supply load transients

Nomenclatures

1. 3GPP: 3rd Generation Partnership Project
2. ACLR: Adjacent Channel Leakage Ratio
3. BBU: Baseband Unit
4. CFR: Crest Factor Reduction
5. DPD: Digital Pre-Distortion
6. FDD: Frequency Division Duplex
7. LTE: Long Term Evolution 4th Generation 3GPP Standard
8. mMIMO: Massive Multiple-Input-Multiple-Output radios
9. Micro-DTX: Micro-Discontinuous Transmission
10. Micro-DRX: Micro-Discontinuous Reception
11. NR: New Radio 5th Generation 3GPP Standard
12. OFDM: Orthogonal Frequency Division Multiplexing
13. PA: Power Amplifier
14. PAR: Peak-to-Average Power Ratio
15. PCB: Printed Circuit Boards
16. PoE: Power over Ethernet
17. PoF: Power over Fiber
18. RANs: Radio-Access Networks
19. RF: Radio Frequency
20. RRU: Remote Radio Unit or Macro Unit
21. RFIC: Radio Frequency Integrated Circuits
22. SSB: 5G Radio Standard Synchronization Signal Block
23. TDD: Time Division Duplex

Introduction

The 3GPP 5G network delivers wider coverage and higher throughput for mobile communications. Since 2022, increased video conferencing, cloud computing, augmented reality, and artificial intelligence applications have driven demand for wireless data throughput, prompting mobile operators to expand their coverage. However, two significant challenges can impact the speed of deployment: rising global energy costs and the inherently higher power consumption of 5G radio systems. OFDM signaling in the 5G standard produces higher PAR, forcing power amplifiers to operate at lower efficiencies to accommodate signal peaks. Consequently, telecom operators now prioritize reducing operational electricity costs and seek innovative power-saving solutions from equipment vendors. This article addresses both system-level and silicon-level techniques for reducing power dissipation in 5G systems.

First, the authors discuss RF system-level power savings gained by leveraging 3GPP standard defined silent time slots for standby operations including disabling portions of the radio during non-peak hours. Micro-DTX and Micro-DRX operations exploit 5G NR's lean carrier design, where SSB transmissions typically occur every 20ms, allowing base stations to enter micro-sleep states between transmissions during low traffic periods. Further improvements focused at the RFIC level: the authors present a methodology to enable programmable, independent, staggered control of radio channels which significantly reduces current slew rates. By preventing simultaneous activation or deactivation of all channels, the authors show a load transient change of up to 75% in a 16-channel RFIC. This methodology reduces performance-degrading voltage transients and simplifies power distribution networks on the PCB. Advanced implementations include pre-staggering and overlap staggering between receive and transmit modes, strategically prioritizing minimal load transient changes to optimize power consumption while maintaining communication integrity. Overall, both the RF system and RFIC power savings reduce operation costs for 5G systems without sacrificing performance to large power supply transients.

5G Radio Deployment Trends

In wireless cellular networks, service operators have teams responsible for network planning to design typical hexagon cell size and coverage. Cell size is directly related to base station RF power and number of connections to be supported.

Figure 1 highlights the current trend for mMIMO, RRU, and small cell radio deployments. The two axes highlights the population density and data traffic, respectively. The population axis includes urban areas with high rise apartment and office buildings, suburban areas with typical 1-story to 2-story homes and shopping plazas, and rural areas such as farmland. The traffic axis includes high, medium, and low traffic.

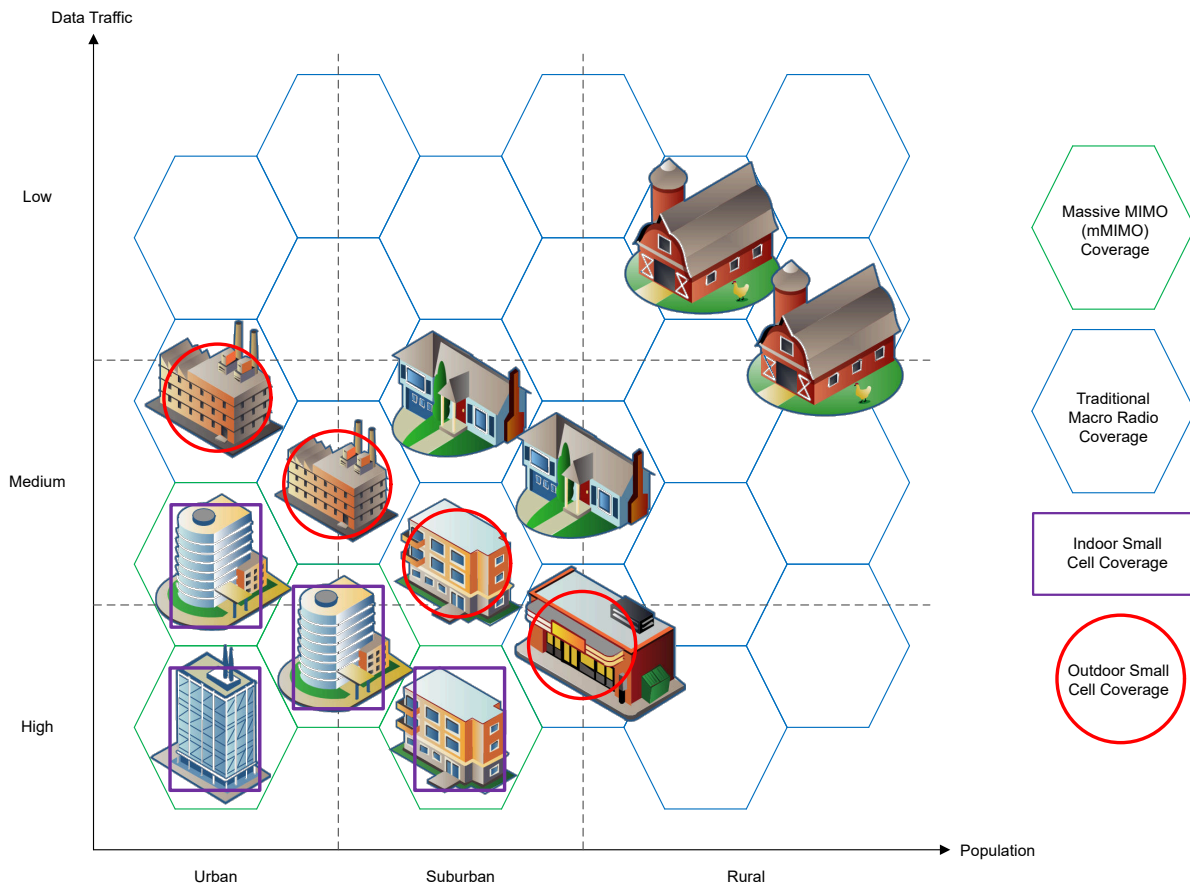


Figure 1. 5G Radio Deployment Strategies

To optimize overall network power consumption, the industry's current deployment trend utilizes mMIMOs in urban areas, RRUs in suburban and rural areas, and uses small cell radios to fill areas with gaps in coverage. This strategy aligns with the current trend of 80% of mobile data originating indoors. ^{[1][2]} The service providers generally deploy MIMO in the urban and high traffic area. The area benefit from mMIMO's ability to provide vertical domain beamforming necessary to cover high rise buildings beyond the traditional horizontal area coverage. For sites in dense urban areas with tall buildings, either mMIMO where the traffic load is high or RRUs where the traffic load is low.

MIMO and Macro RRU Trends

While TDD bands remain as the main data traffic transfer for mMIMO, FDD bands based MIMO radios are emerging as supplementary path. Since FDD bands have dedicated uplink frequencies, the FDD mMIMO can improve the general uplink traffic quality in dense areas. Per [Table 1](#), the majority of the FDD bands are less than 2.7GHz (for example, the 3GPP band 1, band 3, and band 7 cases) when compared to higher frequency ranges of TDD bands such as N77 and N78 bands of greater than 3.3GHz. As result, the antenna size of FDD based mMIMO system has some inherent limitations due to physical properties of the wavelength. However, with innovations in RFICs (such as TI's [AFE8030](#), [AFE8128](#), and [AFE8192](#) family of RFICs) in terms of channel count density and overall power consumption, designers can decrease the overall size of the electrical components of the radio to ensure ease of field installations.

Band	Duplex	RAT	Uplink (MHz)	Downlink (MHz)
B1/N1	FDD	LTE/NR	1920 to 1980	2110 to 2170
B3/N3	FDD	LTE/NR	1710 to 1785	1805 to 1880
B7/N7	FDD	LTE/NR	2500 to 2570	2620 to 2690
N77	TDD	NR	3300 to 4200	
N78	TDD	NR	3300 to 3800	

Table 1. Typical 3GPP Bands

Rise of Small Cells

Traditional cellular networks rely on RANs, in which baseband signal processing is carried out at the location of the cellular antennas. As traffic has increased, cell sizes are decreasing, dramatically increasing the number of cell sites and their capacity. In order to improve the scalability of these large numbers of access points, equipment vendors and network operators have proposed the separation of the RRUs and the BBUs. The general trend of decreased cell size and separation of RRUs and BBUs gives rise to the small cell radio deployments.

Small cells transmit substantially less power than traditional RRUs. The coverage area of small cells have the following benefits:

1. Sufficient cell size and power level to cover the necessary indoor or pre-defined outdoor area.
2. Utilizing optical network to cover the the bulk of data connection from BBU. Since the power required for transmission over the optical link can be less than that of the wireless link, the transmission power for a given bit rate can be smaller with small cells compared to the traditional macro cells.
3. Different RAN options have different BBU function split. Regardless of the split, small cells can improve the local area capacity through increased frequency reuse due to their smaller cell size, and reduce indoor coverage gaps by minimizing signal loss.
4. When multiple small cell radios are connected to a common BBU, the BBU can coordinate the radio resource allocation and interference management across cells, improving overall throughput and end-user-experience in a given area.
5. Service providers can choose to deploy aggregates of small cells and combination of power levels of each cell to achieve overall network level power efficiency. The service providers can use this as an alternative strategy, compared to the traditional strategy of high-power macro RRUs, to potentially improve network level energy efficiency.

On the other hand, network operators do have to exercise caution when deploying small cell networks to avoid possible interference with existing macro cells. The quantity of small cell radios depends on network coverage and performance. Based on estimate^[3], the range is from 4000 to 10000 square feet per radio. Moreover, within office buildings or apartment buildings where RF reception is poor, the building owner may choose to deploy combinations of small cells, repeaters, or distributed antenna system to expand the coverage. When designing for indoor coverage, typically 0.25W to 1W coverage per antenna may be sufficient. For areas such as suburban areas with medium to low traffic, the remote macro radio provides sufficient capacity and coverage. In between buildings or in areas where data traffic is high such as stadiums and shopping plazas, the building owner may choose to deploy outdoor small cells in the range of 5W to 10W to ensure coverage.

Radio Standard and Design Techniques to Fit Power Budget

Due to rising energy costs, building owners typically want to separate utility charges from rental charges, and demand service providers to deploy radios with independent power capabilities sourced from main grid as opposed to within the building. The independent power requires power-over-Ethernet (PoE) or power-over-fiber (PoF) solutions, which have limited wattage in transmission. The PoE standard defines multiple classes differentiated by allowable wattage. Radio designers strive to maintain total radio power within a targeted class to avoid the additional hardware and cost associated with upgrading to higher classes. Therefore, radio designers often investigate the following techniques to reduce power at the radio level.

- 5G standard from 3GPP has included micro-sleep feature in the physical layer. This feature allows a dynamic radio standby mode during operation and enables the radio to enter a power saving mode at a finer level per 5G waveform symbol. The micro-sleep feature includes TDD, FDD micro-DTX state, and FDD micro-DRX state. These standards enable radio designers to target specific receiver channels and/or transmitter channels to enter power saving modes.
- Transmitter Chain Efficiency: As most of the power dissipation is in the transmitter chain due to the power amplifiers (PA), the trend is to increase power amplifier efficiency through digital pre-distortion (DPD) linearization. Traditionally, small cell designers utilize linear amplifiers to achieve linearity at the cost of 10-15% reduced PA efficiency. The current trend in the industry is to utilize DPD to improve power efficiency of PA to upwards of 30%.

TI's RFICs such as the [AFE8128](#), [AFE8192](#), [AFE8030](#), and [AFE7769D](#) RF transceivers enable engineers to achieve these goals: all of TI's RFICs have fast standby/wake-up functionality to enable the micro-sleep feature in the 3GPP spec. The standby to wake-up time is generally less than $2\mu\text{s}$ ¹ to meet the stringent 5G symbol level timing requirements. TI's [AFE7769D](#) RFIC with integrated DPD can improve the overall power efficiency of the radio system through advanced linearization of PAs independently without external digital processing upstream of the RFICs.

TI RFIC Fast Standby and Wake-up Feature

TI's RFICs feature fast standby/wake-up times to optimize radio system low-power modes while maintaining a $2\mu\text{s}$ wake-up time in many use cases. In FDD systems, this primarily enables micro-DTX and micro-DRX, and in TDD systems, the features enable maximum channel-disable time of the transmitter during uplink and the receiver during downlink.

Transmitter or downlink level standby can be a primary mechanism for reducing PA power consumption. The PA, which may consume more than 50% of radio unit power, is always the biggest target for energy savings. For FDD systems, the 5G standard introduced micro-DTX which allows the transmitter channel to be deactivated at the OFDM symbol level within data frames. Thus, engineers have more opportunities to put the radio into transmitter standby state during unused slots. Micro-DTX works by putting the power amplifier into a sleep state during empty OFDM symbols. The challenge of actual implementation is the stringent wake-up time of one OFDM symbol duration.

Referring to [Figure 2](#), wake-up all channels simultaneously in a multi-channel radio system can cause large current transients resulting in voltage ripple on RFIC supply rails. This can affect RFIC initial sampling performance due to power rail settling. Power supply designers also have to consider small interval of TDD guard time (not shown in [Figure 2](#)) where both uplink and downlink are disabled. This scenario creates even more transients as the current draw goes from

¹ Typical test conditions for standby to wake-up time. Please contact TI for specific standby to wake-up time based on optimized RFIC configurations for the applications.

high draw to low draw and then to high draw state. Moreover, the power supplies can also have more transient surge loss, therefore compromising the overall system efficiency.

To mitigate these issues, TI's RFICs can wake up in a staggered fashion for individual channels or certain group of channels, where the enable signals for each group of channels are staggered in time (T_s), as shown in **Figure 3**. Depending on the configuration, the RFICs allow programming the GPIO to control the channel enable signals independently, enabling flexible control of double, quad, or octet levels of channels.

Designers can apply the same standby and wake-up power saving strategy to receiver chain. The main focus for the power saving is the low noise amplifiers (LNAs) in the receiver uplink chain.

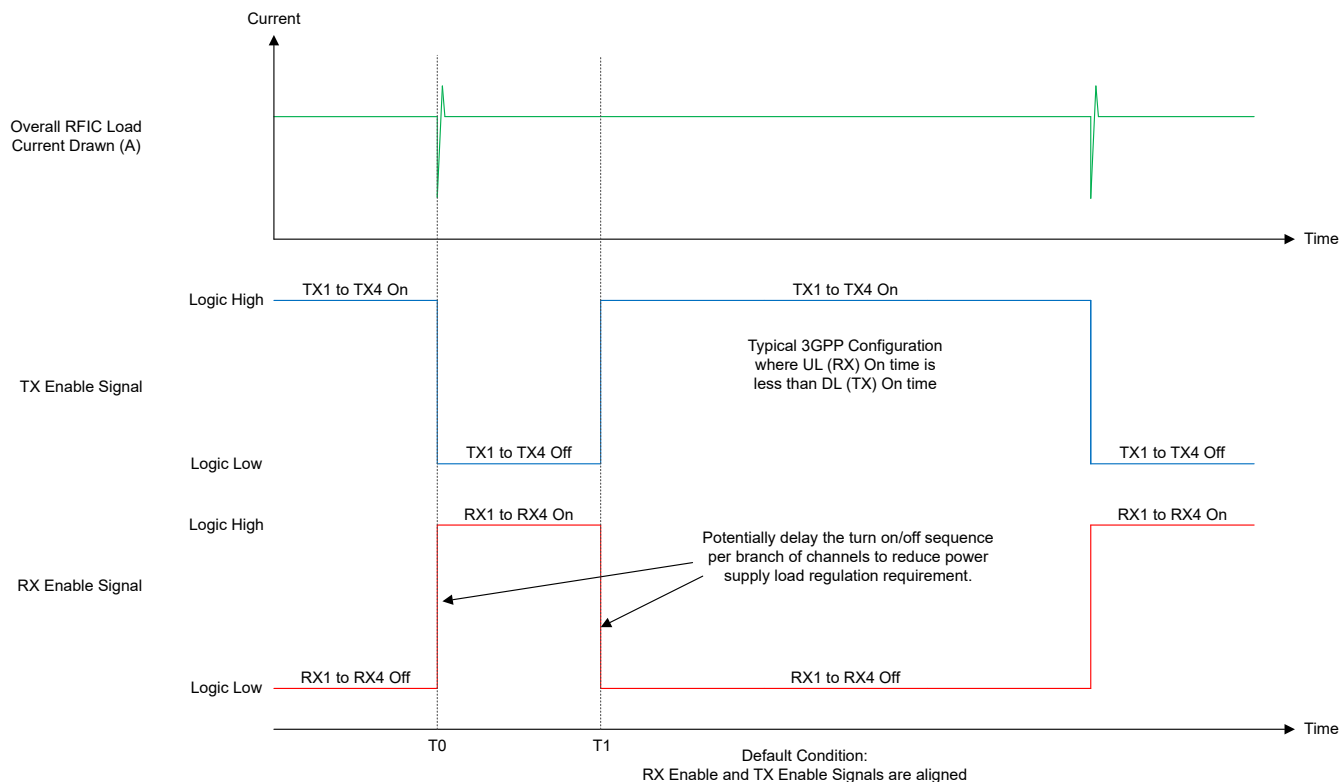


Figure 2. Typical Example Operation and Channel Idling Profile for TDD Based Radios: Staggering the Wake-up of RFIC Channel Groups - All Channels On/Off Simultaneously

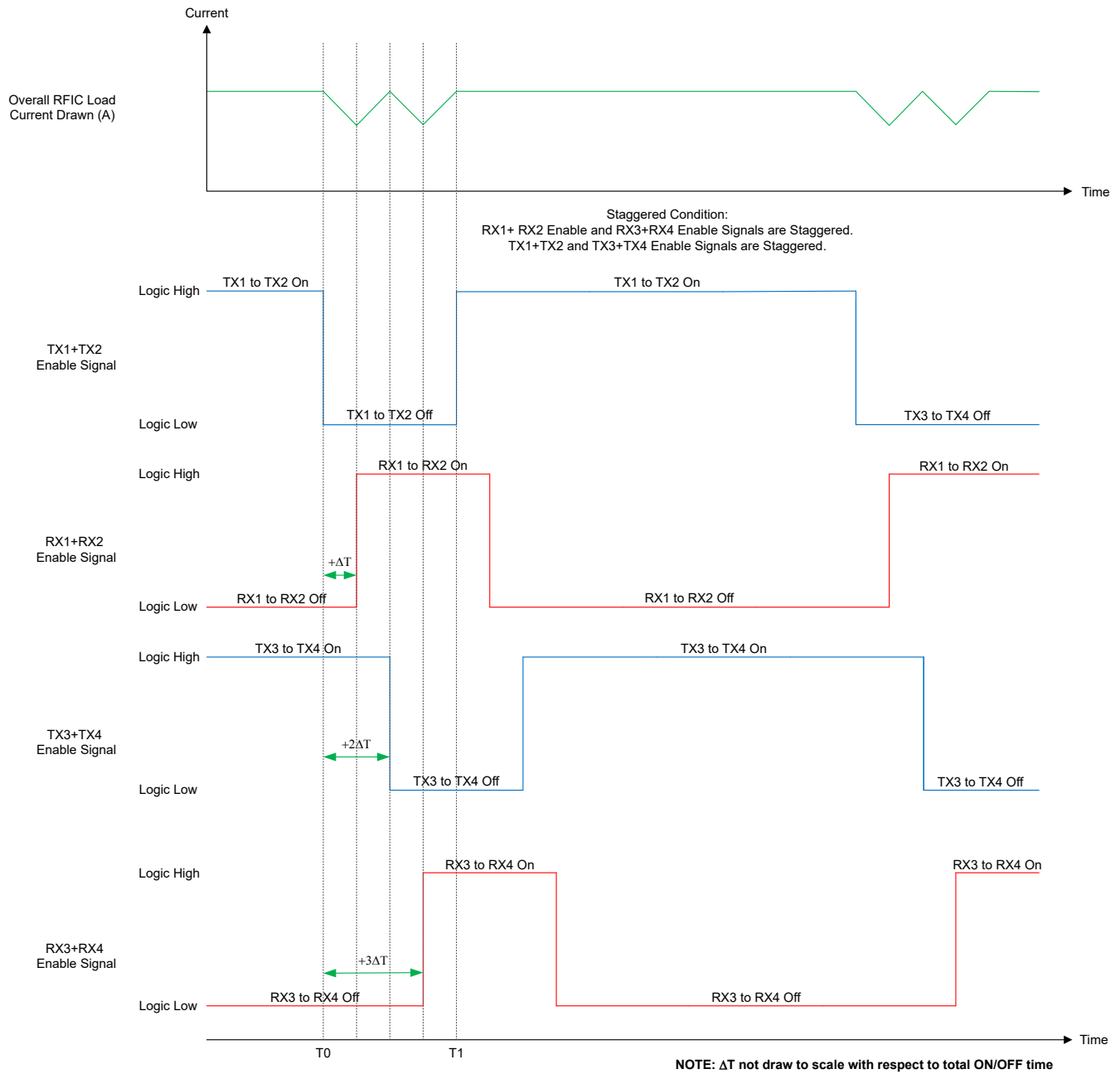


Figure 3. Enhanced Example Operation and Channel Idling Profile for TDD Based Radios: Staggering the Wake-up of RFIC Channel Groups - Channels Staggered with Respect to Time to Minimize Surge in Load Current

DPD to Improve Transmitter Chain PA Efficiency

PAs are often driven at high power to achieve optimal power efficiency at the trade-off of frequency response and linearity performance. Radio designers have traditionally utilized DPD to correct non-linearities introduced by driving high power PAs in a power efficient manner. MIMO and RRU systems almost ubiquitously utilize DPD to improve power efficiency on these high-power systems. Even in small cell systems, designers are gradually moving from the traditional linear amplifiers to more power efficient PAs (for instance, GaN) requiring DPD to meet 3GPP performance specifications². TI's DPD performance in many real world cases can achieve sufficient margin of ACLR (measurement for in-band and out-of-band emission) with the PA operating at typical biasing. For example, with two of the 100MHz 5G NR carriers at the typical N77 band, TI's DPD technology can achieve better than -51dBc³ of adjacent channel leakage ratio, which has a 6dB margin from the -45dBc of ACLR from 3GPP specifications. In such case, the designer can consider reducing the PA bias voltage to improve the efficiency of the PA, while letting the TI DPD engine to absorb the ACLR degradation from the PA itself. In such case, the overall performance may still be similar to the original performance while operating with reduced PA voltage bias and meeting the typical 3GPP specifications with some margin.

Example of the Design Requirements for 4T4R C-Band Macro RRU

DESIGN PARAMETERS	EXAMPLE VALUE
RF frequency band	3740MHz – 3940MHz
Instantaneous bandwidth	200MHz
PLL reference clock	491.52MHz
Maximum FPGA, ASIC SerDes data rate	10Gbps
JESD204 mode (encoding)	8b/10b
PA output power	47.5dBm

Table 2. Example of the Design Requirements for 4T4R C-Band Macro RRU

Key Attribute	Value
Power amplifier	GTRB424908FC
Operating frequency range	3700MHz – 3980MHz
Rated output power	47.5dBm
PA type	High Power RF GaN-on-SiC HEMT
Gain	12dB
Efficiency	40.4%
Supply voltage	48V _{DS}

Table 3. Power Amplifier Specifications

Parameter	Value
TX interface rate	245.76MSPS
DPD rate	737.28MSPS
CFR Target	8dB

Table 4. TX Interface, DPD Rate, and CFR Configurations

- (1) MACOM Technology Solutions Inc, [High Power RF GaN Amplifier 450 W, 48 V, 3700 - 4000 MHz](#), datasheet

² Refer to TI's DPD Test Reports in the References Section for Linearization Performance of Example PAs

³ Typical measurement conditions at room temperature.

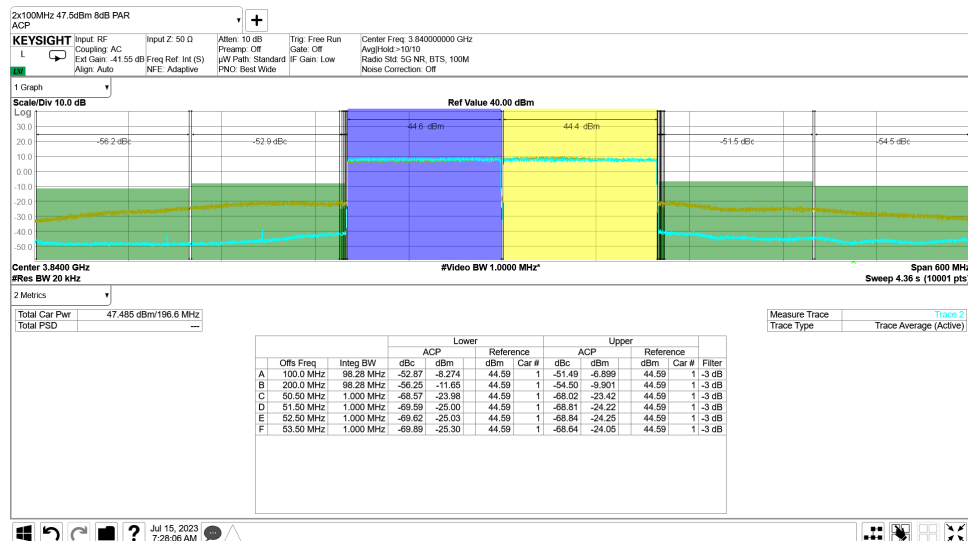


Figure 4. AFE7769D and Macom GTRB424908FC ACLR Performance for 2x100MHz NR Carriers at 3.84GHz N77 Band with 47.5dBm Output Power and 8dB of PAR

Parameter	PA Output Power	Adjacent Power Lower	Adjacent Power Upper	Alternate Power Lower	Alternate Power Upper
Without DPD (ORANGE)	47.5dBm	-30.16dBc	-32.15dBc	-35.87dBc	-36.62dBc
With DPD (BLUE)	47.5dBm	-52.87dBc	-51.49dBc	-56.25dBc	-54.50dBc

Table 5. ACLR Summary

Conclusion

Overall, operators are utilizing a mix of mMIMO, RRU, and small cell radios with the rollout of 5G to optimize the spectrum and power efficiency at the network level. At the radio level, TI's RFICs enable the radio designers' power saving opportunities during transmission and reception idle periods. Moreover, TI's integrated DPD RFIC solutions allow the use of higher power efficiency PAs while maintaining highly linear performance. Designers are able to address one of the highest power dissipation sub-systems of radios by utilizing DPD to optimize system efficiency while adhering to stringent 3GPP specifications.

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