Technical White Paper

Enabling Triple-Band Base Station Radio Design Using AFE7769D Featuring Skyworks Power Amplifiers

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ABSTRACT

Multi-band radios have become more and more important for modern wireless network infrastructure, as they make the network equipments and radio deployments more cost effective, power efficient, flexible and scalable. Designing multi-band radios faces many challenges on optimizing the radio size, weight, power consumption and performance. This paper discusses the critical features required from the RF transceivers perspective for multi-band radios. As an example, the Crest Factor Reduction (CFR)/Digital Pre-Distortion (DPD) performance results of AFE7769D, a quad-channel RF transceiver with integrated CFR/DPD in a triple-band use case with Skyworks power amplifiers are presented, which show how AFE7769D can enable a compact and efficient multi-band radio design.

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1 Introduction

Nowadays, there is an increasing demand for base station radios to support multiple frequency bands with a single radio, for both cellular public networks and private networks This demand is driven by many factors such as:

- **Reducing network footprint and cost**: Multi-band base stations can potentially reduce the number of physical radios and antennas required at a cell site, leading to a smaller footprint, lower facility rental and utility cost, and reduced installation expenses.
- **Flexibility and adaptibility**: Multi-band radios offer greater flexibility for network operators, as they can adapt to evolving network conditions. Multiband radios are valuable when migrating existing networks to new technologies, facilitating a smoother and more gradual migration process. For example, it is not unusual to see the co-exisiting of 4G and 5G service, or 2G and 4G service for some developing countries and regions.
- **Spectrum availability and efficient utilization:** Different frequency bands have different characteristics. Some offer better coverage over longer distances, while others provide higher data rates and capacity in denser areas. Multi-band base stations allow operators to make the most of the available spectrum across these various bands, catering to different needs and environmental conditions.
- **Neutral host network**: Operators focus on network densitification, when it comes to the last mile and/or in-buidling coverage, neutral host has been playing a more and more essential role. Neutral host network offers overall network cost reduction by sharing the infrastructure, deployment and management cost, meanwhile, it also provides enhanced user experience with improved network coverage and capacity. Multi-band support is a must-have for neutral host network.

Designing a multi-band radio faces many challenges including increased size and weight, high power consumption, additional inter-band interference, and so on. This white paper shows how TI's RF transceiver AFE7769D can be used to enable a compact triple-band radio design, as shown in Figure 1-1, where 1T1R operating at 3GPP frequency band B3, 1T1R operating at frequency band B1 and 2T2R operating at frequency band N41. The Crest Factor Reduction (CFR) and Digital Pre-Distortion (DPD) results of the AFE7769D transceiver in conjunction with the following power amplifiers (PA) from Skyworks: SKY66391-12, SKY66394-11, and SKY66522-11 are presented.

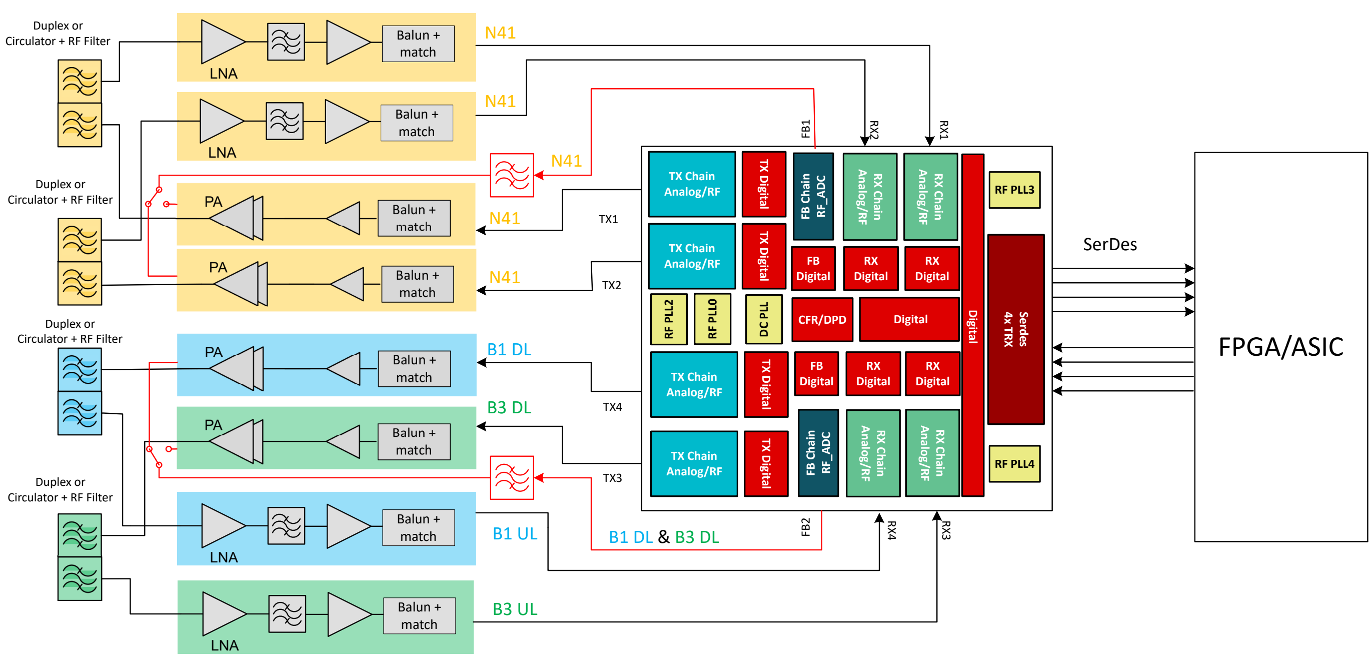

Figure 1-1. Example Block Diagram of a Triple-Band Radio (2T2R N41 + 1T1R B1 + 1T1R B3)

2 Enabling Compact and Efficient Multi-band Radios

2.1 TI RF Transceiver With Integrated CFR/DPD: AFE7769D

The AFE7769D (4T4R2F) is a family of high-performance, multichannel transceivers, integrating four direct up-conversion transmitter chains, four direct down-conversion receiver chains, two wide-band RF-sampling digitizing auxiliary chains (feedback paths), and a low-power CFR/DPD for PA linearization. The AFE7769D has the following features to enable a low-power and small size multi-band radio design.

- The AFE7769D integrates **four fractional RF PLLs** to synthesizes the Local Oscillator (LO) signals for the transmitter or receiver to up-converter or down-converter mixers. In addition, each transmitter and receiver chain has an optional **low-IF mixer**, which can be used along with the LOs for frequency up-conversion or down-conversion.
- The direct RF sampling-based feedback path in AFE7769D offers an inherently wideband receiver chain to observed the PA output signal for DPD estimation, and also simplifies the calibration of TX chain impairments. Each feedback path has **two switchable NCOs**, which can be used to switch between two different RF frequencies when the two transmitter paths are operating at different RF frequencies, as in the example of this document. The NCO phase can be maintained during the switching.
- The **integrated DPD** engine in AFE7769D can linearize PAs with various output power level up to 50dBm+ (average power) and PA technologies (GaAs, LDMOS, GaN) with fast converging and tracking, and low power consumption. With DPD, power amplifies can operate with higher power efficiency while still meeting the transmitter RF emission requirements.

2.2 Skyworks Power Amplifiers

Skyworks' SKY66394-11, SKY66391-12 and SKY66522-11 fully matched, highly efficient power amplifiers are equipped with integrated active bias for temperature compensation. Made for 5G NR and 4G LTE wireless infrastructure applications requiring +28dBm up to +30dBm of average output power, these power amplifiers are packaged into compact 5mm x 5mm modules and are designed to operate with digital pre-distortion techniques, such as those integrated in the Texas Instruments AFE7769D transceiver. The SKY66394-11, SKY66391-12, and SKY66522-11 power amplifiers are available now.

3 Triple-Band CFR/DPD Performance Test Setup and Condition

Figure 3-1 shows the CFR/DPD performance test with AFE7769D in a triple-band setup, where the transmitter channel TX1, TX3 and TX4 are configured to operate at band N41, B3 and B1 with three different Skyworks power amplifiers: SKY66522-11, SKY66391-12 and SKY66394-11, respectively. Note that channel TX2 is also configured to operate at band N41 as TX1, however, for test simplicity, the TX2 output is not connected for further amplification during the CFR/DPD performance test.

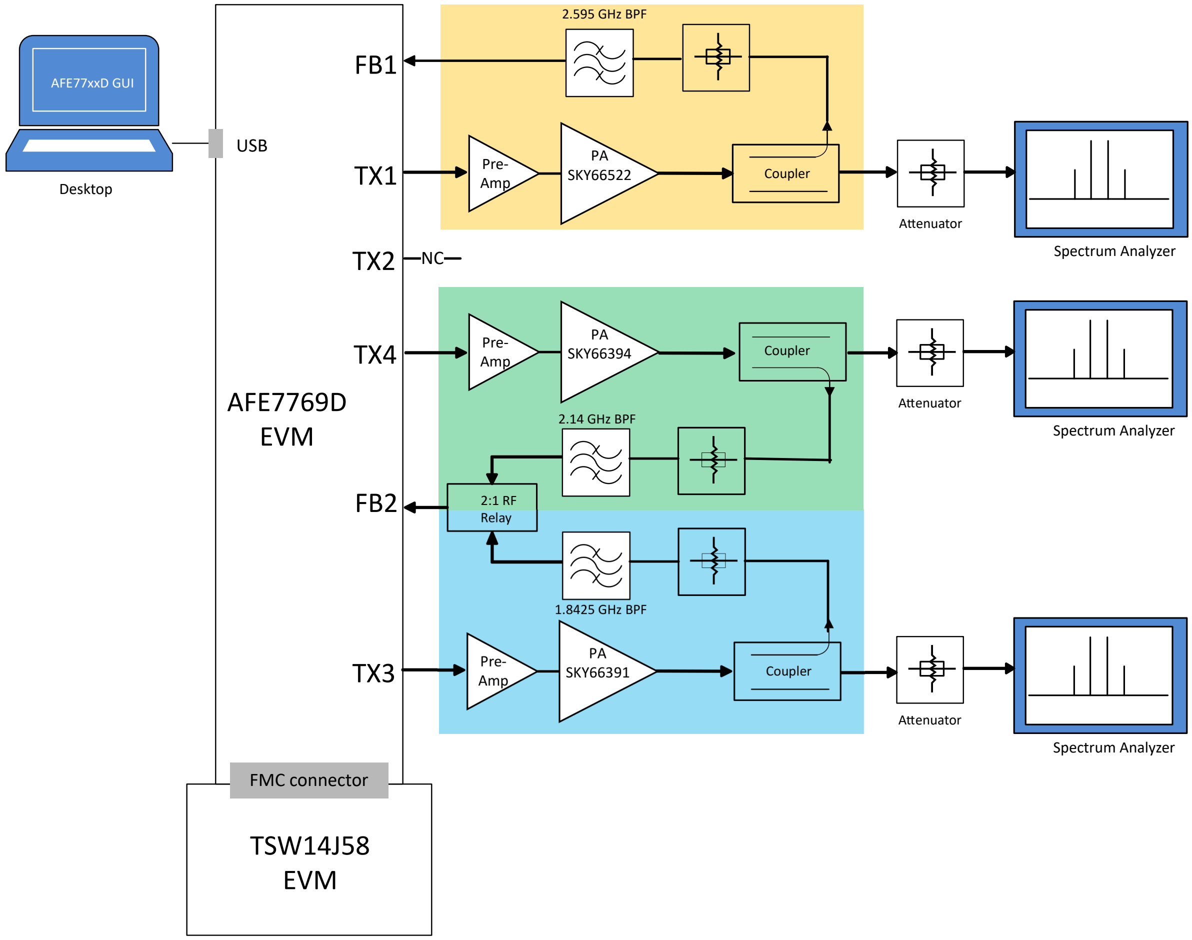

Figure 3-1. Block Diagram of AFE7769D Triple-Band DPD Performance Test Setup

Note

The TX RF front-end line-up is via connecting discrete stand-alone evaluation boards and passive components, instead of being soldered down on the same board. Therefore, the results shown in this report are the typical baseline performance with the specific EVM boards and under the specific test conditions as shown in Table 3-1 and Table 3-2. Device-to-device and board-to-board variations are expected. **Further DPD performance and PA efficiency optimization is possible through working with TI and Skyworks application teams.**

Table 3-1 to Table 3-2 give the test setup (front-end gain, carrier profile) and the final stage power amplifier details.

Table 3-1. Test Setup Details

Parameter	TX1 Path	TX3 Path	TX4 Path
RF center frequency	2595MHz	1842.5MHz	2140MHz
Instantaneous bandwidth (IBW)	200MHz	75MHz	60MHz
Gain of the pre-amplify stage	16dB	19.7dB	19.2dB
Final stage power amplifier used	SKY66522-11	SKY66391-12	SKY66394-11

Table 3-2. Power Amplifier Details

Key Attribute	SKY66522-11	SKY66391-12	SKY66394-11
Operating frequency range	2300 – 2690MHz	1800 – 1900MHz	2000– 2300MHz
Rated output power	31dBm	28dBm	28dBm
Gain	36.5dB	35.9dB	38dB
Supply voltage	$5V_{DS}/12V_{DS}$	$5V_{DS}$	$5V_{DS}$

4 Triple-Band CFR/DPD Performance Test Results

For each tested channel, the Adjacent Channel Leakage Ratio (ACLR) and Error Vector Magnitude (EVM%) results at the PA outputs are shown. In the collected ACLR performance plots, the orange curves show the ACLR performance before the DPD is applied, and the blue curves shows the ACLR performance after the using the AFE7769D integrated DPD algorithm to linearize the PA.

4.1 TX1 Test Results (Band 41)

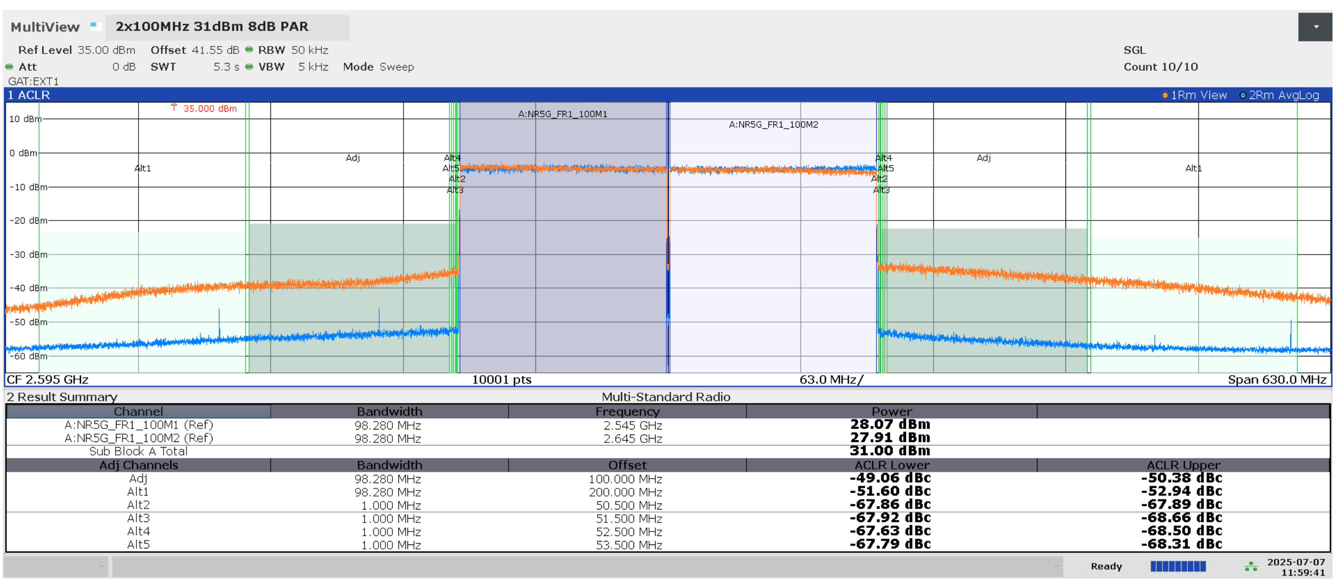

Figure 4-1. TX1 ACLR Plot: 2x100MHz Signal With 2.595GHz Center Frequency

Table 4-1. TX1: ACLR Summary

Parameter	PA Output Power	Adjacent Power Lower	Adjacent Power Upper	Alternate Power Lower	Alternate Power Upper	PA Efficiency
Without DPD	31dBm	–33.2dBc	–30.1dBc	–36.6dBc	–34.5dBc	–
With DPD	31dBm	–49.0dBc	–50.3dBc	–51.6dBc	–52.9dBc	31.0%

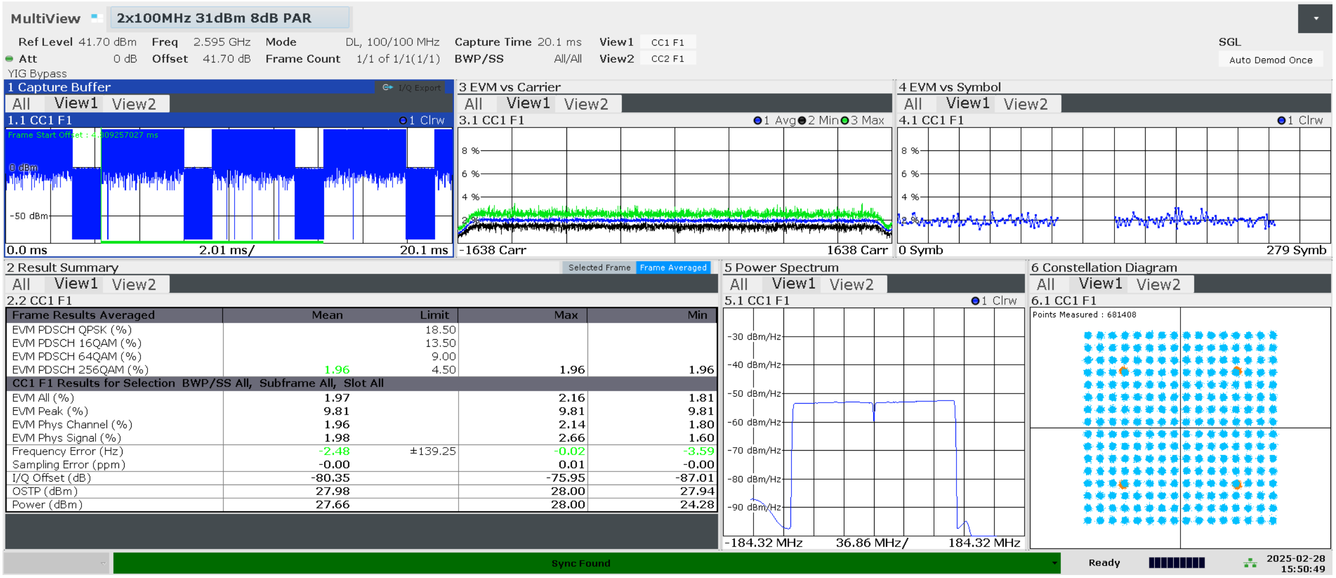

Figure 4-2. TX1 EVM% Plot: 2x100MHz Signal With 2.595GHz Center Frequency (PAR = 8dB)

4.2 TX3 Test Results (Band 3)

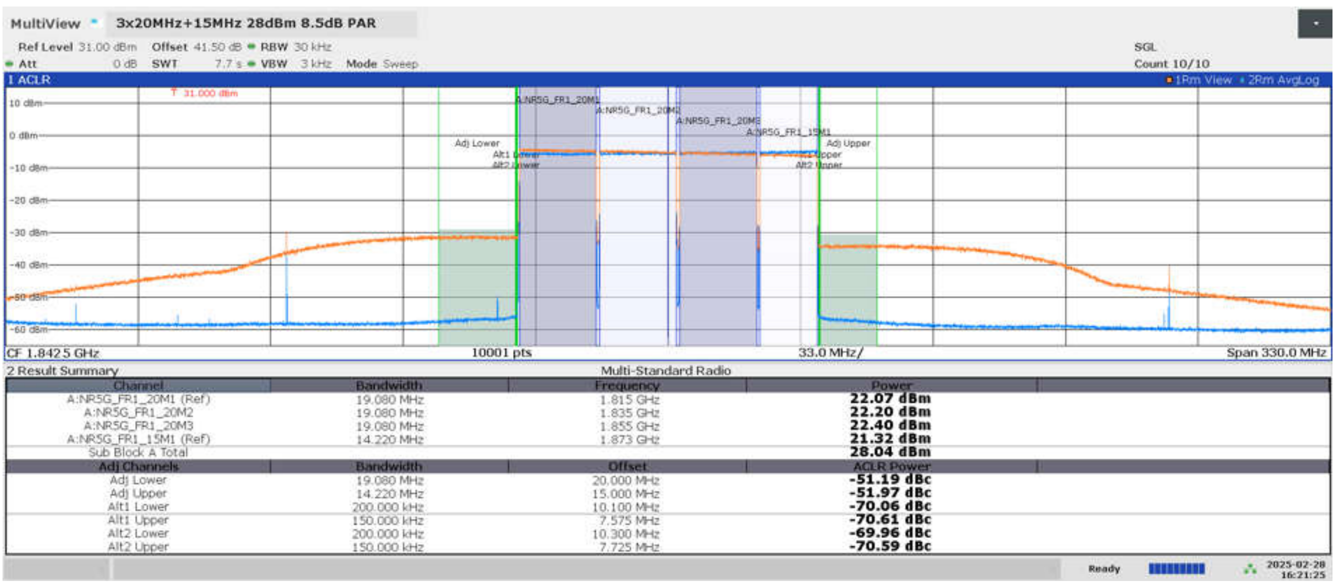

Figure 4-3. TX3 ALCR Plot: 3x20MHz + 15MHz Signal With 1.8425GHz Center Frequency

Table 4-2. TX3: ACLR Summary

Parameter	PA Output Power	Adjacent Power Lower	Adjacent Power Upper	PA Efficiency
Without DPD	28.0dBm	–27.0dBc	–24.0dBc	–
With DPD	28.0dBm	–51.2dBc	–52.0dBc	31.8%

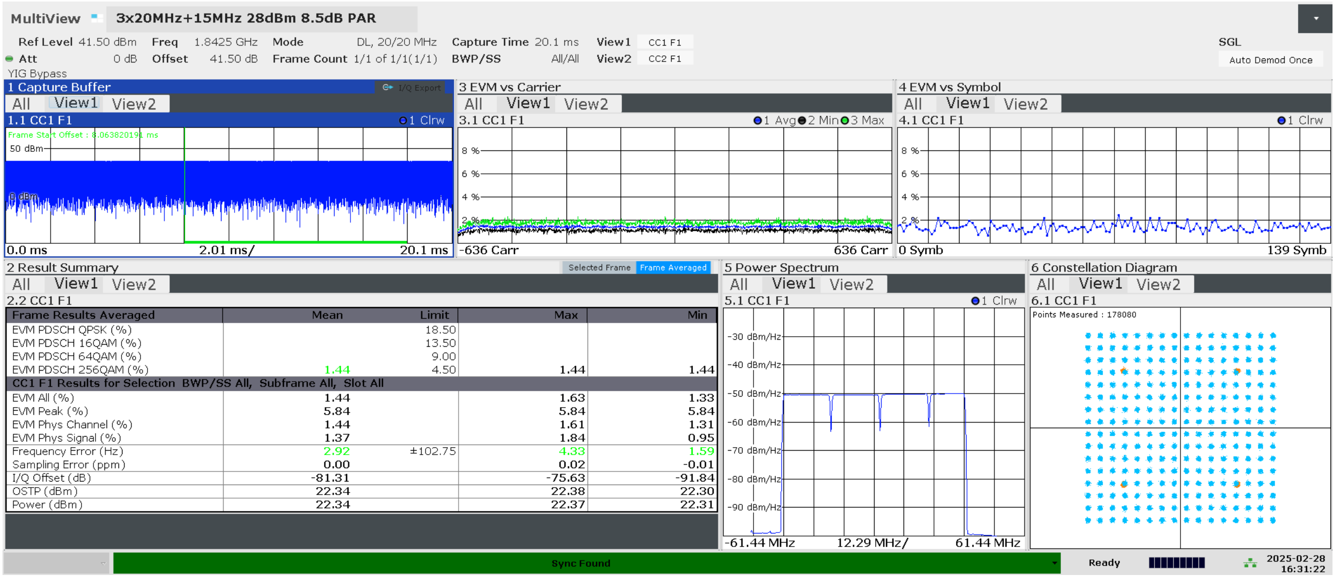

Figure 4-4. TX3 EVM% Plot: 3x20MHz + 15MHz Signal With 1.8425GHz Center Frequency (PAR = 8.5dB)

4.3 TX4 Test Results (Band 1)

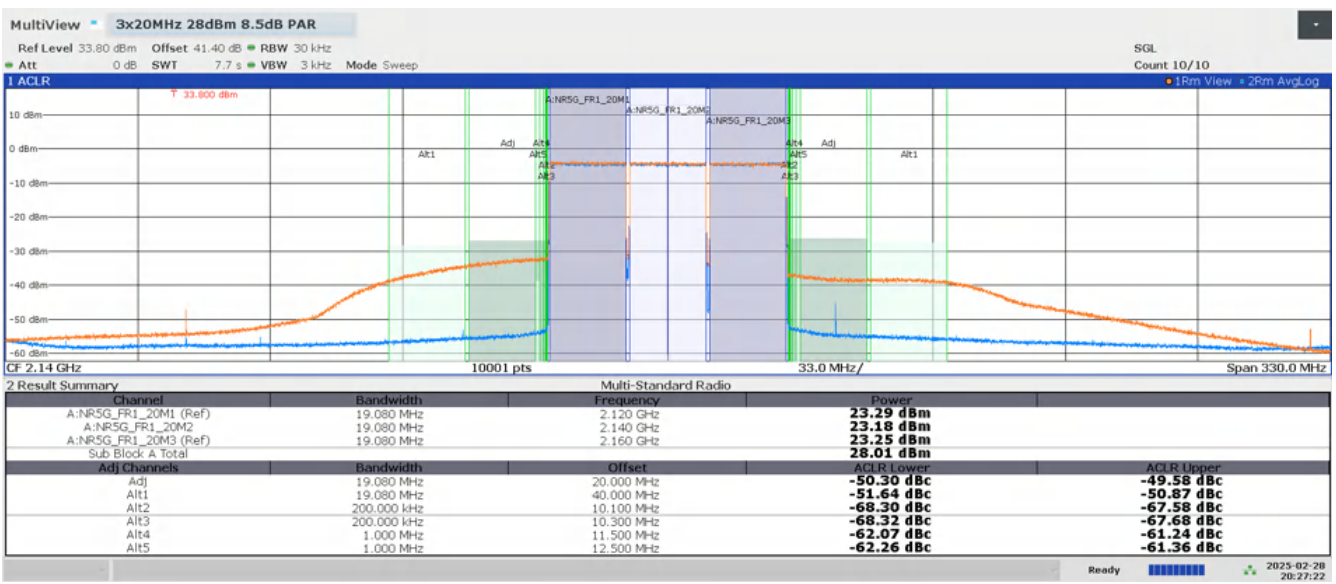

Figure 4-5. TX4 ACLR Plot: 3x20MHz Signal With 2.140GHz Center Frequency

Table 4-3. TX4: ACLR Summary

Parameter	PA Output Power	Adjacent Power Lower	Adjacent Power Upper	Alternate Power Lower	Alternate Power Upper	PA Efficiency
Without DPD	28.0dBm	–29.0dBc	–33.6dBc	–32.0dBc	–34.2dBc	–
With DPD	28.0dBm	–50.3dBc	–49.6dBc	–51.6dBc	–50.8dBc	30.0%

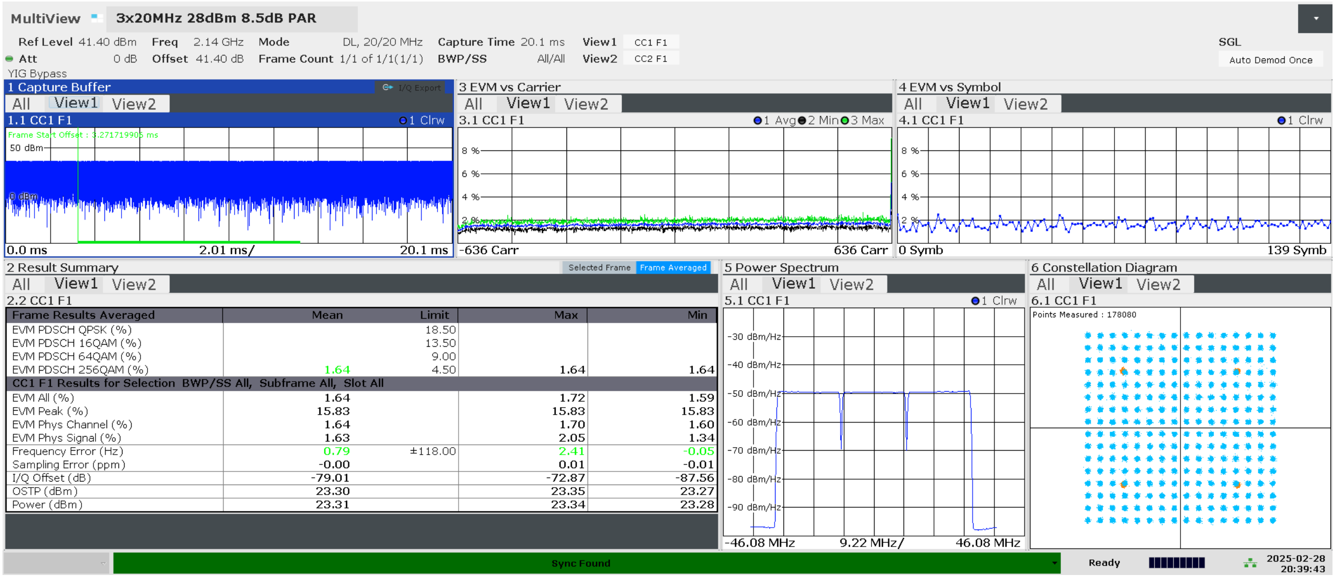

Figure 4-6. TX4 EVM% Plot: 3x20MHz Signal With 2.140GHz Center Frequency (PAR = 8.5dB)

5 Summary

Table 5-1 and Table 5-2 summarize the test conditions, and the ACLR and EVM% results for three different TX channels operating at three different RF frequencies with three different power amplifiers using AFE7769D in a triple-band setup.

The results demonstrate that with the integrated CFR/DPD algorithm and the richness on the LO synthesizers, AFE7769D can be used to realize an compact and efficient triple-band radio design.

Table 5-1. Summary of Test Cases

Test	Center Frequency	Carrier Profile	Power	PAR	V_{DS}
TX1: SKY66522-11	2.595GHz	2x100MHz	31dBm	8.0dB	5V, 12V
TX3: SKY66391-12	1.8425GHz	3x20MHz+ 15MHz	28dBm	8.5dB	5V
TX4: SKY66394-11	2.140GHz	3x20MHz	28dBm	8.5dB	5V

Table 5-2. Summary of CFR/DPD Performance Results

Test	PA Output Power	Adjacent Channel ACLR (Lower/Upper)	Alternate Channel ACLR (Lower/Uppper)	PA Efficiency	EVM%
TX1	31dBm	–49.0dBc/–50.3dBc	–51.6dBc/ -52.9dBc	31.0%	1.94%
TX3	28dBm	–51.2dBc/–52.0dBc	–	31.8%	1.44%
TX4	28dBm	–50.3dBc–49.6dBc	–51.6dBc/-50.8dBc	30.0%	1.64%