Application Note

Multi-AFE Synchronization using AFE7769D for Large Phased Array Antenna Systems

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ABSTRACT

Beamforming is an advanced signal processing technique where large, phased array antenna systems focus radio waves into targeted beams directed at specific users, improving range and signal to noise ratios while minimizing interference. Beamforming requires consistent phase alignment to steer and shape the beam in a predictable manner. Deviation in phase directly degrades beamforming performance, reduces signal strength widens beamwidth, and ultimately, diminishes system range and capacity.

The scalability of phased array is intrinsically tied to the ability to maintain precise and deterministic phase control across all elements in the system. This challenge is particularly acute in large, multi-element phased arrays where maintaining phase coherence across numerous data converters becomes increasingly difficult due to manufacturing process variations and temperature drifts.

The AFE7769D RF transceiver addresses this key limitation by ensuring deterministic phase control across multiple devices through a System Reference (Sysref) signal. The Sysref synchronizes the local oscillators and sampling clocks, effectively establishing a common timing and phase reference for the entire array.

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1 Introduction

The AFE7769D, based on zero-IF sampling architecture, offers a Digital Pre-Distortion (DPD) algorithm for improved signal quality. Additionally, the device features proven results for next-generation base stations and adjacent communications infrastructures, making it preferred for massive MIMO and beamforming technologies.

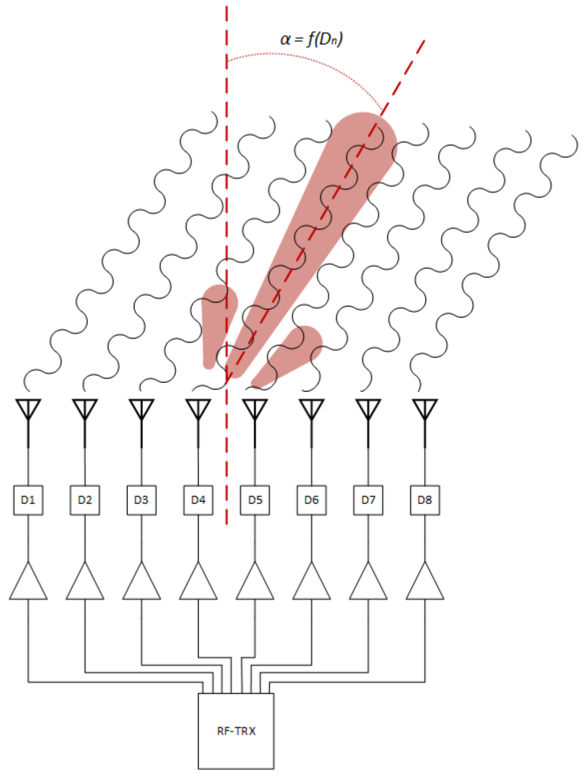

Figure 1-1. Beam Formed by Adjusting the Phase Between Time-Synchronous Antennas

The AFE7769D is a pin-compatible family of high performance, multichannel transceivers, integrating four direct up-conversion transmitter chains, four direct down-conversion receiver chains, two wideband RF sampling digitizing auxiliary chains (feedback paths) along with low-power Digital Pre-Distortion (DPD) engine for Power Amplifier (PA) linearization. The integrated DPD engine corrects the distortion due to PA nonlinearity for signals up to 300MHz instantaneous bandwidth and 730MHz DPD expanded bandwidth. The high dynamic range of the transmitter and receiver chains enables wireless base stations to transmit and receive 2G, 3G, 4G, and 5G signals.

The device also facilitates integrated QMC (quadrature mismatch compensation) algorithm which is capable of continuously monitoring and correcting I and Q imbalance mismatch without the need to inject any specific signals or perform offline calibration.

The synthesizer section integrates four fractional-N RF PLLs that can generate four different RF LOs, allowing the device to support up to three different bands.

For phased array applications, the device verifies deterministic and reliable phase using Sysref. Sysref helps synchronize multiple AFEs, thus proving it to be useful in applications like ground stations, satellite communications, and wireless infrastructures.

2 Understanding the Architecture

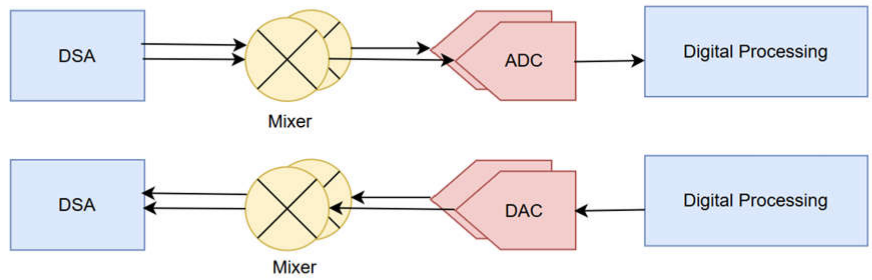

Figure 2-1. Data Path Architecture

Along the data path, there are two analog mixers for I and Q data streams, followed by two data converters for the respective streams before the digital processing as shown in Figure 2-1. Unlike digital NCOs (numerically controlled oscillators), analog PLLs can start at random phase every time. An analog PLL relies on continuous-time circuits (charge pumps, voltage-controlled oscillators, loop filters) whose behavior is inherently affected by component mismatches, temperature changes, supply voltage variations, and analog noise, introducing analog imperfections. These imperfections make it difficult to guarantee the exact same phase relationship every time.

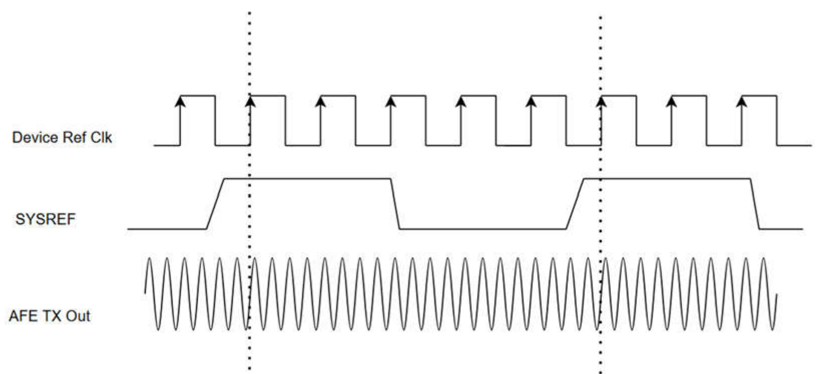

Figure 2-2. Timing Diagram of Phase Reset via Sysref

The AFE7769D is able to achieve deterministic phase using Sysref as shown in Figure 2-2 whenever the mixer frequency used for reception or transmission is an integer multiple of Sysref frequency. The Sysref signal is given to all the blocks and sub-blocks within the RF PLL mixer to align all the dividers in the path so they always start with deterministic phase. Sysref ensures that the RF PLL block is reset and aligned to achieve deterministic phase across all the channels within a device with reconfiguration/power-cycle.

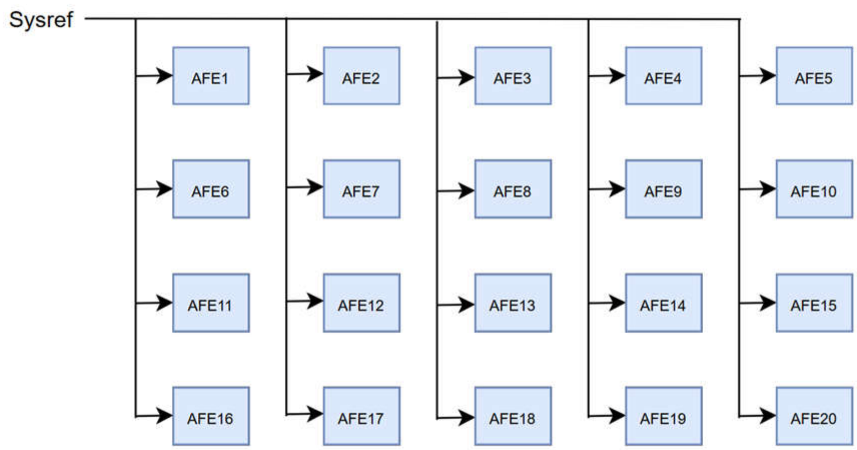

Figure 2-3. An Example Large Phased Array Setup with Multiple AFEs

For large phased array applications employing multiple devices as illustrated in Figure 2-3, the Sysref signal provides deterministic phase alignment within and across devices, ensuring phase consistency across the distributed system. This eliminates the additional effort of phase-calibration with every power up, as every time each device is brought up at a deterministic phase using Sysref.

3 Analyzing Phase Variation

The setup included two AFE7769D evaluation modules (EVM) for observing phase synchronisation with multiple reconfigurations and over a range of temperature. Device reference clock (Fref) and System Reference (Sysref) were derived from the same source for both the devices as shown in Figure 3-1.

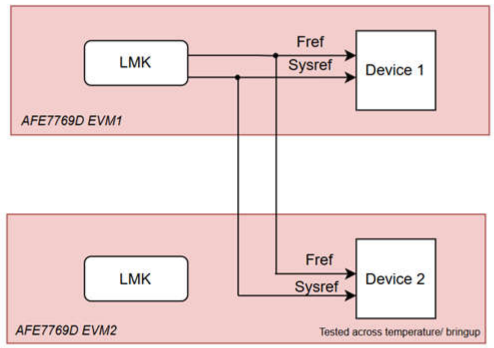

Figure 3-1. Clocking Structure for Phase Synchronization

The RF PLL frequency was set as an integer multiple of Sysref frequency. In this case, all the observations and plots were taken with RF PLL frequency set as 1728 MHz. After both devices were configured once, observations were made on EVM2 with mutiple reconfigurations and varied temperature.

The device maintained consistent phase across all channels with respect to external reference and the other device with multiple reconfiguration/power-cycle as illustrated in Figure 3-2 and Figure 3-3.

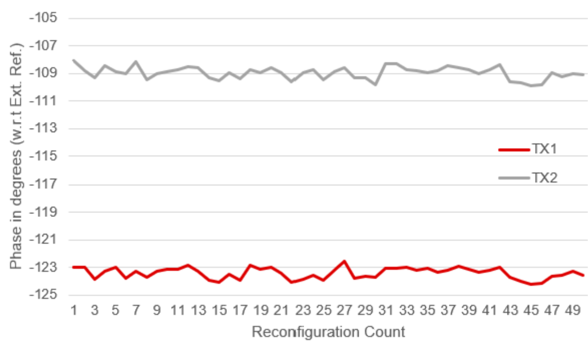

Figure 3-2. Phase Variation Across Channels with Multiple Reconfigurations

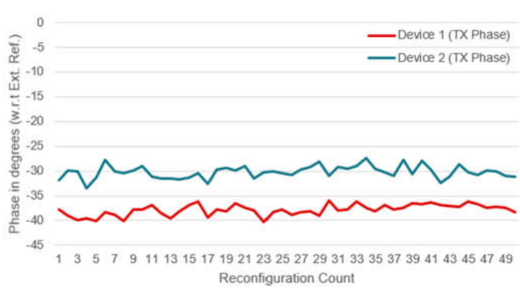

Figure 3-3. Phase Variation Across Devices with Multiple Reconfigurations

The phase was also observed with varying temperature over a range of 100°C. The phase degrades approximately 0.4°C for TX (Figure 3-4). For RX, it rises by 0.208°C (Figure 3-5). The user can account this change for calibration if needed with temperature variation.

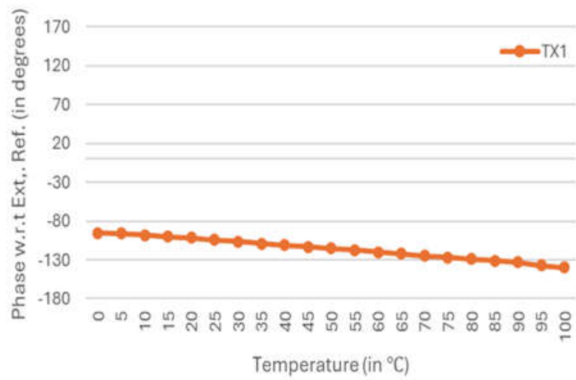

Figure 3-4. Phase Drift Across Temperature (TX) at PLL Frequency 1728MHz

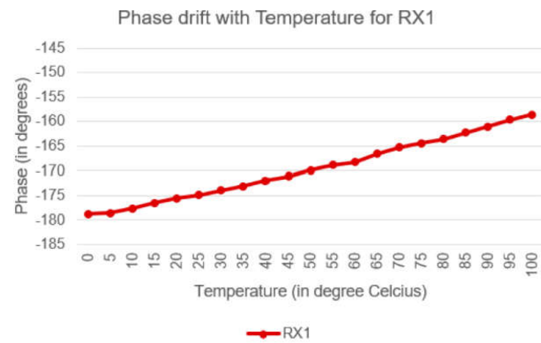

Figure 3-5. Phase Drift Across Temperature (RX) at PLL Frequency 1728MHz

However, the device maintains consistent phase across channels with temperature (for example, the relative phase between channels remains constant) as shown in Figure 3-6 and Figure 3-7.

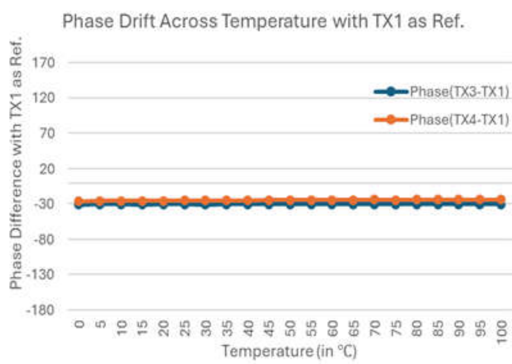

Figure 3-6. Phase Variation Across Temperature (TX)

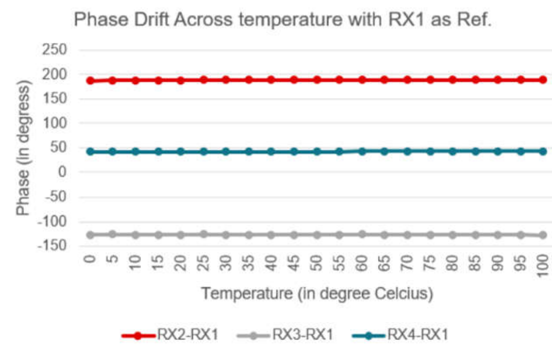

Figure 3-7. Phase Variation Across Temperature (RX)

4 Configuring the Device

When the system designers are configuring the device, they must ensure that the PLL frequency is a multiple of the Sysref frequency. Refer to the steps below:

1. Set the parameter *pllMuxMode* depending on the use case.
2. Set the PLL Frequency to operating frequency using the parameter *pllLo.* For reference, the PLL Frequency needs to be an integer multiple of the Sysref frequency.
3. Set other essential configuration parameters for your desired mode. Refer to AFE77xxD Configuration Guide (SBAU405A) for more details on the exact parameters.
4. Complete the device bring-up.

With every bring-up/reconfiguration, the device maintains consistent phase across channels and across devices with respect to the Sysref. Refer to the following *video* for more insights on how to bringup the device using AFE77xxD Latte software.

5 Frequency Hopping with Deterministic Phase

Frequency hopping is a technique where transmitters and receivers switch their frequency of operation for various applications. This method is widely used in communication systems to minimize interference and avoid congestion. When transitioning between frequencies, maintaining phase consistency is crucial. The phase relationship must remain predictable and controlled rather than jumping randomly.

This phase coherence becomes critical, expecially in large phased array systems, where multiple devices must maintain precise, deterministic phase relationships with each other to function correctly. Without phase coherence, the array would lose its ability to accurately steer beams or detect targets. Phase-coherent frequency hopping eliminates the need for any recalibration after each frequency switch. This allows the system to hop quickly between frequencies while maintaining continuous, accurate operation - essential for applications like beamforming base stations, and secure communications.

The PLL frequency can be switched dynamically after device bring-up without losing phase consistency provided the frequency to be switched onto is also an integer multiple of Sysref frequency. During frequency hopping, the PLL gets re-configured and the following sequence needs to be executed to ensure the phase alignment.

```
CAFE.dynamicLOChangeWrapper(0,rx12Lo,rx34Lo,tx12Lo,tx34Lo,iqmcDelayarr, dpdDelayArr)[1]
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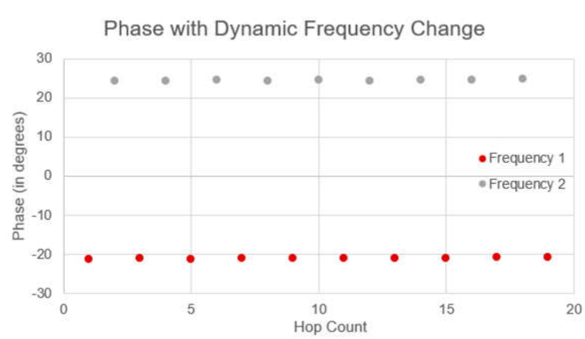

Figure 5-1. Device Phase with Dynamic Frequency Change

Thus, the system maintains a consistent phase even when switching between diferent frequencies as demonstrated above in Figure 5-1.

[1] IqmcDelayArr and DpdDelayArr can both be set to zero when DPD is not triggered. Whenever DPD is triggered, set them to appropriate delay values.

6 Summary

With every new telecommunications generation, the demand for higher data rates and lower latency increases substantially. 5G massive MIMO combined with beamforming enables high-throughput, low latency communication and ensures scalability . AFE7769D can be used for such massive MIMO applications where phase consistency is critical for precise antenna control and spatial filtering. It provides phase determinism within and across multiple devices. By maintaining predictable phase relationships with reconfiguration/power-cycle and frequency hopping techniques, AFE7769D eliminates recalibration requirements, reducing system complexity and supporting agile beamforming applications.

7 References

1. Texas Instruments, *AFE77xxD Quad/Dual-Channel RF Transceiver With Dual Feedback Paths Integrating CFR/DPD*, datasheet.
2. Texas Instruments, *Realizing 5G network potential through mMIMO and precise beamforming technology*, analog design journal.

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