*Application Note*

# *Cascade Coherency and Phase Shifter Calibration Application Note*


**ABSTRACT**

Multiple AWR2243 radar devices can be cascaded to realize a larger antenna array sensor. In such a system, the firmware routines controlling and calibrating the individual devices' analog sections must operate in tandem to ensure good angular accuracy performance. This application note describes recommendations to improve a cascade system's coherence across time, temperature and its antennas, and involves more control of AWR devices by the host processor on the sensor. The recommended procedures may also be used in advanced single chip applications which desire stability of the radar return signal's absolute phases across radar frames, devoid of abrupt jumps. This note also describes recommendations wrt TX phase shifter calibrations, which are applicable in single chip as well as cascade usages, and are relevant to AWR1843 and AWR2243.


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# 1 Introduction

Gen1 (AWR1243, AWR1843, AWR1642, and AWR1443) and Gen2 (AWR2243) radar devices include self-calibrations to mitigate process and temperature effects on analog performance. The calibrations include RF INIT (i.e., boot time) calibrations to mitigate manufacturing process variation effects, and Run Time calibrations to mitigate temperature effects. These calibrations mostly involve optimizing the RF register settings for TX, RX, and LO-based on the temperature read by the built-in temperature sensors. In simple single-chip usage context, these self-calibrations achieve the purpose of analog performance stabilization without compromising on inter-channel imbalances due to inherent channel matching within each device.

Maintaining inter-channel matching in multi-device cascaded sensors is more challenging due to manufacturing process mismatches across devices and independence of the self-calibration procedures running in the multiple devices. This note describes recommendations to improve a cascade system's coherence across time and temperature and involves more control of AWR devices by the host processor on the sensor. Further, the recommended procedures may also be used in advanced single chip applications which desire stability of the radar return signal's absolute phases across radar frames, devoid of abrupt jumps.

Further, the recommendations in this note also address the topic of avoiding corruption of the self-calibration results when the device operates in interference-prone environments. Note that the same is also briefly explained in *Self-Calibration in TI's mmWave Radar Devices* (SPRACF4), applicable in single chip usages. Finally, another important topic addressed in this note is TX phase shifters (AWR1843 and AWR2243). Their accuracies can be improved with calibrations at customer factory as well as in field, and this note describes relevant recommendations.

## 1.1 Background – Simple Single-Chip Applications

In single chip usage context, in interference-free environments, all self-calibrations can be enabled, including the RF INIT calibrations and Run Time calibrations. Typically, the host is expected to trigger RF INIT calibrations once at the beginning of each power cycle. The host also enables run-time calibrations by configuring the device to self-trigger calibration updates at a configurable periodicity (for example, once in N number of frames, amounting to ~1 second). The device then schedules auto-periodic calibrations, with a 10°C hysteresis to avoid unnecessary successive retriggers. Alternately, the host may also explicitly trigger Run Time calibration after it senses a significant temperature change (for example, ~30°C).

These calibrations do not disturb any inter-channel imbalances in single-chip context due to inherent channel matching within each device. But the situation is different in cascade systems and in advanced single-chip usages. In cascade usage, this note provides guidelines to mitigate process and temperature variation effects without disturbing inter-channel imbalances. This note also provides guidelines to enable advanced single chip usages that desire stability of radar return signal's absolute phase over time across frames.

Further, in typical automotive usages, where interference from other radars can be expected, some of these calibrations are discouraged to be used in field, to avoid interference corrupted calibration results. The recommendations in this note avoid running in-field those RF INIT or Run Time calibrations that are susceptible to interference corruption. Instead, some calibration procedures in interference-free customer factory (one time per device) and other temperature adjustment procedures in-field are recommended.

TX phase shifter accuracies can also be improved with similar calibration approaches. These are relevant in interference and cascade contexts.

# 2 Cascade Incoherence Sources and Mitigation Strategies

This section describes potential sources of cascade incoherence. It also provides a brief overview of the mitigation strategies. The solution procedures are elaborated further in a later section.

## 2.1 PCB Routing Imbalances and Device Processes

Slight imbalances in the PCB routing of the 80-GHz TX and RX lines as well as the 20-GHz (FMCW Sync LO) lines are possible in cascade sensors with large antenna arrays. The TX, RX, and 20-GHz LO circuits in different devices can also have manufacturing variability. These can result in inter-channel imbalances across devices in the cascade systems.

It is common for customers to perform factory calibrations to measure the cascade's inter-channel imbalances and TX phase shift errors, and store them in a non-volatile memory (NVM) for use in error compensation in-field. For this to be effective, the devices' analog configurations (i.e., RF register settings) during in-field operation need to match those during factory calibration.

RF INIT calibrations can converge to different analog configurations each time they are executed due to measurement noises and temperature differences across executions. Therefore, triggering RF INIT calibrations in-field on every power cycle (as in single-chip context) can render the devices' analog configurations to be different from those during factory calibration and make the factory calibration based compensation ineffective. As a way to avoid such a situation, TI recommends that each AWR device's RF INIT calibrations are triggered only during the customer factory calibration process. Those results may be stored in a non-volatile memory on the sensor and restored to the AWR devices upon each power up during in-field operation.

## 2.2 Temperature Drifts

The cascade sensor's inter-channel imbalances can smoothly vary with temperature due to mismatches in temperature-coefficient of delays of the 80-GHz and 20-GHz PCB routings. It is expected that the DSP or the host processor controlling the AWR devices accounts for this using higher layer algorithms (e.g. refining inter-channel imbalance estimates using crude estimates of real-life object directions). There can be similar smooth imbalance drifts due to manufacturing variability in the TX, RX, and LO paths in different devices and can be mitigated by the same algorithms.

## 2.3 Scheduling of Run Time Calibrations

In single chip usage, the self-calibrations/run time calibrations reconfigure the analog sections in 10°C temperature bins to mitigate temperature effects. If the devices in a cascade system are allowed to calibrate independently (e.g. in automatic periodic calibration mode), it is possible that they make calibration updates at different times, depending on their individual temperatures. Because each device's analog reconfiguration can change its phase responses, these calibration updates can cause abrupt jumps in inter-channel imbalances of the cascade system (see graphs illustrating this in later sections of this note). They also cause abrupt changes in the radar return signal's absolute phase over time and corrupt advanced single-chip algorithms.

To avoid such jumps, TI recommends that the customer use a factory calibration procedure for the sensor (described in subsequent sections) and during the live operation in the field, the host processor take control of the calibration triggers by using a certain Temperature Index Update sequence to reconfigure the AWR devices and compensates for the expected phase jump in the processing.

# 3 Enabling Cascade Coherence and Improved Phase Performance

The following measures are proposed to ensure that inter channel imbalances remain predictable across time, power cycles, and temperature. First shown is a solution summary and it is followed by detailed descriptions of the steps involved in it.

**Note**

Most focus in all the subsequent sections is on inter-channel imbalances but information / procedures relevant to TX phase shifter accuracy improvement are interspersed in each of the below sub-sections.

## 3.1 High-Level Summary

1. Process variation: To account for manufacturing process variation, the devices must perform RF INIT self-calibrations, but only once, at the customer factory. The ambient temperature (called factory calibration temperature) may be 25°C or the middle of the expected in-field temperature range.
2. Save restore: Let the RF INIT calibration results be saved in a nonvolatile memory and restored later into the devices before each RF INIT during in-field operation.
3. Offsets measurement at customer factory: the customer factory calibration procedures must measure the offsets (such as inter-channel imbalances and phase shift nonlinearity). These offsets must be stored in a nonvolatile memory and used during in-field operation by the DSP.
4. Multiple front end settings: the customer factory calibration procedure must be performed with the AWR device in multiple (3) calibration settings, optimized for various operating temperatures. The ambient temperature is still kept the same while only varying the devices' analog configurations, according to other temperature settings.
5. Temperature compensation in-field: the host must use its real-time knowledge of temperature trends (such as increasing or decreasing, expected operating range) and based on it, simultaneously communicate its chosen temperature index to all the AWR devices in the cascade. To minimize jump magnitudes, this transition is recommended to be near the factory calibration temperature.
6. DSP compensation: in tandem with the calibration settings change, the DSP layer processing must also use the corresponding offsets data from factory calibration.

### 3.1.1 Sequence of Proposed Steps and Introductory Flow Diagrams

The steps of the recommended procedure at the customer factory and in-field operations are listed below. Reference to the relevant flow diagram in the Appendix section has been provided for each step.

1. Saving RF INIT calibration results at customer factory.
   - The flow diagram for this step is conceptually illustrated by Figure A-1.
2. Offsets measurement at customer factory
   - Inter-channel imbalances measurement concept is illustrated by Figure A-2.
   - TX phase shifter error measurement concept is illustrated by Figure A-3.
3. Restoring customer factory calibration results in-field.
   - The flow diagram for this step is conceptually illustrated by Figure A-4.
4. Host based temperature drift effects mitigation in-field.
   - Mitigation of inter-channel imbalances is conceptually illustrated by Figure A-5.
   - Mitigation of TX phase shifter error is conceptually illustrated by Figure A-6.

Each of the above steps is elaborated with details in the following sections.

## 3.2 Saving RF INIT Calibration Results at Customer Factory

During the customer factory calibration process, TI recommends that the host trigger RF INIT calibration in each device in each cascade board with all the RF INIT calibrations enabled (exceptions for some calibrations are mentioned below). This allows the devices to self-calibrate to account for manufacturing process variation. The ambient temperature (called factory calibration temperature) may be 25°C or the typically expected in-field temperature of the sensor. The factory calibrations should be done at the RF frequency range of interest for the sensor.

The RF INIT calibrations can be triggered one after another (non-overlapping) for the devices in the cascade sensor to prevent mutual interference from corrupting the RF INIT calibrations.

The relevant messages for enabling various calibrations and triggering them are AWR RF INIT CALIBRATION CONF SB and AWR RF INIT SB. The RF INIT calibration frequency can be controlled using AWR CAL MON FREQUENCY LIMITS SB.

After each AWR device in the cascade completes its RF INIT calibrations, the host is recommended to fetch each device's calibration data and store in a nonvolatile memory. This data is to be used during in-field operation, without the need to rerun the RF INIT calibrations in-field.

The relevant message for saving the calibration data is AWR CAL DATA SAVE SB. This message does not save the TX phase shifter calibration results and that is explained later in this note.

### 3.2.1 Note on LODIST Calibration

In Gen1 devices (AWR1243, AWR1843, AWR1642, AWR1443), TI recommends that the field “Enable LODIST calibration” in AWR RF INIT CALIBRATION CONF SB be set to 0 during customer factory calibrations for advanced single chip use cases where coherence across time and frames is desired. This keeps the configurations of the LO distribution buffers to the TX and RX sections constant (it is a measure to avoid abrupt phase jumps arising from their reconfigurations). As a result, the calibration report API messages (AWR AE RF INITCALIBSTATUS SB) will also report “LODIST calibration” status as 0.

In AWR2243, TI recommends that LO DIST calibrations are enabled while performing factory calibrations, i.e. the field “Enable LODIST calibration” in AWR RF INIT CALIBRATION CONF SB should be set to 1. The LO DIST calibration results are stored into NVM. During the field operation, the LO DIST calibration results are restored and LO DIST Temp Index can be forced (Low Bias, Mid Bias, and High Bias) to have corresponding LO DIST configurations.

### 3.2.2 TX Phase Shifter Calibration and Saving Results at Customer Factory

The TX phase shifters can have inherent errors which have process and temperature variation. There are two possible methods to mitigate the process variation (temperature variation is addressed in later sections).

1. Using RF INIT TX phase shift calibrations.
   - This is described in this section.
   - This option requires the TX phase shifter calibration in RF INIT to be enabled.
2. Using customer factory corner reflector.
   - This is described in the offsets measurement section later in this document.
   - This option requires the TX phase shifter calibration in RF INIT to be disabled.

The AWR devices' self-calibration of TX phase shifters gets executed in the process of RF INIT. These use the device's internal TX loopback paths and algorithms. The results from these may be used as the baseline for all in-field TX phase shifter error mitigation.

The message AWR PHASE SHIFTER CAL DATA SAVE SB can be used to save the data into the sensor's non-volatile memory, for each TX in the cascade. This data can be restored to the AWR device and that part is explained later in the document.

If deriving the phase shifter calibration values from the devices' internal RF INIT TX phase shifter calibrations in customer factory:

$$\text{PS Cal Result Array}_{TXn}\ (0 \text{ to } 63) = \text{Result of AWR PHASE SHIFTER CAL DATA SAVE SB API(TXm)at factory} \quad (1)$$

$$\text{PS Cal Result Array Degree}_{TXm}\ (0 \text{ to } 63) = (360° / 1024) \times \text{PS Cal Result Array}_{TXm}\ (0 \text{ to } 63) \quad (2)$$

The user should account for the API's phase indexing format, which may differ across TXs; refer to Section 7.5.

$$\text{Factory Measured Phase Shift Array}_{\text{RF INIT TX PS Cal},TXm}\ (0 \text{ to } 63) = \text{PS Cal Result Array Degree}_{TXm}\ (0 \text{ to } 63) \quad (3)$$

The arrays Factory Measured Phase Shift Array$_{\text{RF INIT TX PS Cal},TXm}$ (0 to 63) collected at factory temperature are necessary for restoring back to the device (explained later in this document). Example values for the Measured Phase Shift Array of Equation 1: [0, 5, 11, … 356] degrees, corresponding to [0, 5.625, 11.25, … 354.375] degree phase shifter settings. These correspond to INL error values of [0, 0.625, 0.25, … –1.625] degree, i.e. the deviation from ideal expectations. The term INL error refers to Integrated Non Linearity error (it is used in many places in this note).

The raw analog TX phase shifter's INL as measured by internal RF INIT calibration at 25C is represented in Figure 3-1(a). The post-calibration residual PS INL is also represented in Figure 3-1(a) to illustrate the efficacy of RF INIT TX phase shift calibration. Further, Figure 3-1(b) illustrates the raw analog TX phase shifter's INL as measured using external/independent method. The graphs in Figure 3-1(a) and Figure 3-1(b) are fairly matching, illustrating the efficacy of internal calibration. These have been obtained in TI lab evaluation of a few nominal process based devices.

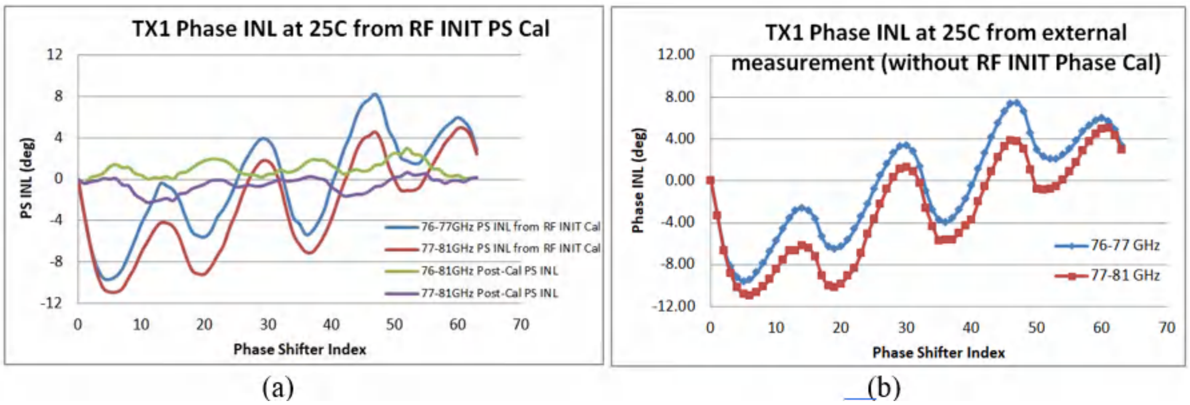


**Figure 3-1. Phase Shifter INL Plots at 25C for AWR2243 nominal devices information: (a) With internal RF INIT phase shifter calibration (b) With external waveguide loopback based measurements**

The above addressed the mitigation of process variation, and a strategy to mitigate temperature drift effect is recommended later in this note.

## 3.3 Corner Reflector-Based Offsets Measurement at Customer Factory

TI recommends that the offsets or non-idealities in the cascade system (such as inter-RX and inter-TX imbalances, and TX phase shift nonlinearity) be measured at customer factory. All the run time calibrations are recommended to be disabled during this procedure to ensure predictable analog state.

### 3.3.1 Corner Reflector-Based Inter-Channel Imbalances

The imbalance measurements should be done with the AWR device in multiple calibration settings, optimized for various operating temperatures. To mitigate in-field temperature drifts, the analog settings must be reconfigured based on operating temperature. TI recommends that offset measurements at factory be done at three configurations (temperature index/indices):

- Low Bias setting – i.e., RF settings optimized for low temperatures, such as –40°C to 10°C
- Mid Bias setting – i.e., RF settings optimized for mid temperatures, such as 0°C to 50°C (approximately the factory calibration temperature)
- High Bias setting – i.e., RF settings optimized for high temperatures, such as 40°C to 140°C

The ambient temperature is still kept the same while only varying the devices' analog configurations according to other temperature settings. The customer may fix the temperature ranges corresponding to Low Bias, Mid Bias, and High Bias settings based on the sensor's expected in-field temperature range, allowing a small overlap for transitions.

The measurements procedure is as follows.

1. Issue profile, chirp, and frame configuration APIs to set the desired chirp sequences, including RX gain, TX power, RF frequency, and so forth.
2. Perform these measurements at 0° TX phase shift to avoid TX phase shift nonlinearity effects.
3. Set the TX gain codes, RX gain codes (and LO DIST codes for the AWR2243) with temp index corresponding to the Low Bias, Mid Bias, and High Bias settings, iteratively. An example with recommended temp indices is illustrated in Table 3-1. The recommended steps for setting the codes with desired temp indices are described below for TI's mmWave MMICs.

- For AWR1243, AWR1843, AWR1642:
    a. Use the AWR RX GAIN TEMPLUT GET SB API and AWR TX GAIN TEMPLUT GET SB API to know the results of each device's self-calibration algorithms for this gain, power, and RF. The output is an LUT, which is a function of temperature (in 10°C resolution).
    b. Based on the results of the above APIs, choose the RX and TX gain codes for the Low Bias, Mid Bias, or High Bias setting.
    c. Use the AWR RX GAIN TEMPLUT SET SB API and AWR TX GAIN TEMPLUT SET SB API to set the desired analog setting to each AWR device in the cascade (each device to have its individual values).
- For AWR2243:
    a. Use AWR RUN TIME CALIBRATION CONF AND TRIGGER SB with temperature index override enabled for TX, RX, and LODIST along with respective temperature indices corresponding to Low Bias, Mid Bias, or High Bias setting.

4. Use a corner reflector at 0° direction to estimate the inter-channel imbalances across all $TX_m$-$RX_n$ combinations. Measure this for each bias setting (Low Bias, Mid Bias, High Bias). An example structure of the imbalance data for a two-chip cascade is shown in Table 3-2.
5. Store the imbalance data for each index (Low Bias, Mid Bias, High Bias) in the sensor's non-volatile memory for in-field usage.

**Table 3-1. Example (Device) Temperature Ranges and TX/RX Gain Codes**

| Setting | Temp. Range (e.g.) | Recommended Temp Index for TX Gain Codes | Recommended Temp Index for RX Gain Codes | Recommended Temp Index for LO DIST Codes (Applicable for AWR2243 only) |
|---|---|---|---|---|
| **Low Bias** | –40°C* to 10°C | 10°C | –40°C (lowest of temp range to ensure P1dB) | 10°C |
| **Mid Bias** | 0°C to 50°C | 50°C | 25°C (mid temp range) | 50°C |
| **High Bias** | 40°C to 140°C* | 140°C | 140°C (highest of temp range to ensure noise figure) | 140°C |
| **Guidance** | * Limit to sensor's in-field expected operating range | Highest of each temp range to ensure output power | | |

1. With this, RX gain drifts with temperature within each temperature range but without adversely impacting noise figure and P1dB.
2. The above is an example assuming that the device temperature is 25°C during the factory measurements. Suitable adjustments may be considered if the device temperature is significantly higher and also if the application needs a different temperature range of operation.
3. The device temperature can be known from the RF INIT calibration status report (AWR_AE_RF_INITCALIBSTATUS_SB) or through device's temperature monitoring API.
4. The transition temperatures between the settings should not be too away from the factory calibration temperature. This ensures more accurate calibration at low and high bias conditions.

**Table 3-2. Example Structure of Inter-Channel Imbalance Data in a 2-Chip Cascade**

| **Device 1** | | | | | | | **Device 2** | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | RX1 | RX2 | RX3 | RX4 | RX1 | RX2 | RX3 | RX4 |
| **Low Bias** | Device 1 | TX1 | 0 | A12 | A13 | A14 | A15 | A16 | A17 | A18 |
| | | TX2 | A21 | A22 | A23 | A24 | A25 | A26 | A27 | A28 |
| | | TX3 | A31 | A32 | A33 | A34 | A35 | A36 | A37 | A38 |
| | Device 2 | TX1 | A41 | A42 | A43 | A44 | A45 | A46 | A47 | A48 |
| | | TX2 | A51 | A52 | A53 | A54 | A55 | A56 | A57 | A58 |
| | | TX3 | A61 | A62 | A63 | A64 | A65 | A66 | A67 | A68 |
| **Mid Bias** | Device 1 | TX1 | 0 | B12 | B13 | B14 | B15 | B16 | B17 | B18 |
| | | TX2 | B21 | B22 | B23 | B24 | B25 | B26 | B27 | B28 |
| | | TX3 | B31 | B32 | B33 | B34 | B35 | B36 | B37 | B38 |
| | Device 2 | TX1 | B41 | B42 | B43 | B44 | B45 | B46 | B47 | B48 |
| | | TX2 | B51 | B52 | B53 | B54 | B55 | B56 | B57 | B58 |
| | | TX3 | B61 | B62 | B63 | B64 | B65 | B66 | B67 | B68 |
| **High Bias** | Device 1 | TX1 | 0 | C12 | C13 | C14 | C15 | C16 | C17 | C18 |
| | | TX2 | C21 | C22 | C23 | C24 | C25 | C26 | C27 | C28 |
| | | TX3 | C31 | C32 | C33 | C34 | C35 | C36 | C37 | C38 |
| | Device 2 | TX1 | C41 | C42 | C43 | C44 | C45 | C46 | C47 | C48 |
| | | TX2 | C51 | C52 | C53 | C54 | C55 | C56 | C57 | C58 |
| | | TX3 | C61 | C62 | C63 | C64 | C65 | C66 | C67 | C68 |

### 3.3.2 Corner Reflector-Based TX Phase Shifter Errors

Customers may choose to calibrate the TX phase shifters (e.g. for better accuracy) using corner reflectors in the factory. This procedure is an alternative to using the devices' self-calibration of TX phase shift using RF INIT. An example measurement procedure is as follows.

1. RF INIT should have been performed before this step with TX phase shift calibration disabled. This is so to measure the raw analog's nonlinearity, which is what's compensated in-field.
2. The devices should be configured to use per chirp phase shift mode.
3. Use profile config API to set the RF frequency at the sensor's in-field operating range, and configure the TX/RX for good SNR.
4. Configure multiple chirps with different phase shift index/indices. E.g. 0, 1, 2, 3, 4, … 63, 0 (effects of temperature drifts during measurements, if any, should be mitigated). Configure multiple TXs to transmit these chirps in sequence, one at a time, within a frame, to avoid significant temperature drift during successive phase measurements. An example chirp configuration for such a calibration frame is shown in Table 3-3.
5. Collect RX ADC data, and process it to find the corner reflector tone's phase for each phase shift index for each TX. This data must be stored in the sensor's non-volatile memory for each TX in the cascade.

If deriving the phase shifter calibration values from corner reflector measurements in customer factory:

$$\text{Factory Measured Phase Shift Array}_{\text{CornerReflector,TXm}}\text{(0 to 63)} = \text{Measured Corner Reflector tone phase in RX ADC output for phase shifter settings 0 to 63} \quad (4)$$

The arrays Factory Measured Phase Shift Array$_{\text{CornerReflector,TXm}}$ (0 to 63) collected at factory temperature are necessary for restoring back to the device (explained later in this document). Example values for the Measured Phase Shift Arrays of Equation 2: [0, 5, 11, … 356] degrees, corresponding to [0, 5.625, 11.25, … 354.375] degree phase shifter settings. These correspond to INL error values of [0, 0.625, 0.25, …, –1.625] degree, i.e. the deviation from ideal expectations. Here, INL error refers to Integrated Non Linearity error.

Here are some APIs relevant for achieving this:

1. AWR RF INIT CALIBRATION CONF SB (field: "Enable TX Phase calibration" = 0 to disable the device's self-calibration of TX phase shift errors at RF INIT).

2. AWR RF RADAR MISC CTL SB (field: PERCHIRP PHASESHIFTER EN) and AWR PERCHIRPPHASESHIFT CONF SB for controlling the phase shift values.

**Table 3-3. Example Chirp Configuration for Factory Calibration of TX Phase Shifter Errors**

| Device 1 | | | | Device 2 | | | |
|---|---|---|---|---|---|---|---|
| **Chirp Index** | **Enable TX1** | **Enable TX2** | **Enable TX3** | **Enable TX1** | **Enable TX2** | **Enable TX3** | **Phase Shift Index (common to all TXs)** |
| 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 (0o) |
| 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 (5.625o) |
| 2 | 1 | 0 | 0 | 0 | 0 | 0 | 2 (11.25o) |
| : | 1 | 0 | 0 | 0 | 0 | 0 | : |
| 63 | 1 | 0 | 0 | 0 | 0 | 0 | 63 (354.375o) |
| 64+0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 (0o) |
| 64+1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 (5.625o) |
| 64+2 | 0 | 1 | 0 | 0 | 0 | 0 | 2 (11.25o) |
| 64+: | 0 | 1 | 0 | 0 | 0 | 0 | : |
| 64+63 | 0 | 1 | 0 | 0 | 0 | 0 | 63 (354.375o) |
| 2*64+0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 (0o) |
| 2*64+1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 (5.625o) |
| 2*64+2 | 0 | 0 | 1 | 0 | 0 | 0 | 2 (11.25o) |
| 2*64+: | 0 | 0 | 1 | 0 | 0 | 0 | : |
| 2*64+63 | 0 | 0 | 1 | 0 | 0 | 0 | 63 (354.375o) |
| 3*64+0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 (0o) |
| 3*64+1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 (5.625o) |
| 3*64+2 | 0 | 0 | 0 | 1 | 0 | 0 | 2 (11.25o) |
| 3*64+: | 0 | 0 | 0 | 1 | 0 | 0 | : |
| 3*64+63 | 0 | 0 | 0 | 1 | 0 | 0 | 63 (354.375o) |
| 4*64+0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 (0o) |
| 4*64+1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 (5.625o) |
| 4*64+2 | 0 | 0 | 0 | 0 | 1 | 0 | 2 (11.25o) |
| 4*64+: | 0 | 0 | 0 | 0 | 1 | 0 | : |
| 4*64+63 | 0 | 0 | 0 | 0 | 1 | 0 | 63 (354.375o) |
| 5*64+0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 (0o) |
| 5*64+1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 (5.625o) |
| 5*64+2 | 0 | 0 | 0 | 0 | 0 | 1 | 2 (11.25o) |
| 5*64+: | 0 | 0 | 0 | 0 | 0 | 1 | : |
| 5*64+63 | 0 | 0 | 0 | 0 | 0 | 1 | 63 (354.375o) |

At 25C, the measured phase shift array from corner reflector-based experiments from TX1 of typical AWR2243 device (nominal process) is tabulated in Table 8 in the Appendix section. The same in the form of phase shifter INL plot at 25C is represented in Figure 3-1(b). These have been obtained in TI lab evaluation of few nominal process based devices. They provide representative information and can be used for example in initial sensor development. There can be some amount of process variation in the INL but the trend is expected to be roughly similar (based on evaluation of DoE devices in TI lab).

For post-calibration phase shifter accuracy with 25C factory calibration using corner reflector, refer to Figure 5(b).

## 3.4 Restoring Customer Calibration Results In-Field

The following are recommended to be done in-field to ensure that all devices are restored to the same state as during customer factory calibration.

### 3.4.1 Restore RF INIT Calibrations Results In-Field

At the time of power up in the field, the host processor in the sensor may restore each device to the same RF INIT calibration state as at the customer factory. This can be done using the following procedure. It has slight deviations from the normal RF INIT call and start up sequence.

1. Restore the RF INIT calibration results from the sensor's non-volatile memory for each device.
   - Use AWR CAL DATA RESTORE SB for this step.
   - This is an additional step to normal start up sequence.
2. Configure all RF INIT calibrations to be disabled.
   - Use AWR RF INIT CALIBRATION CONF SB for this step.
   - This is an additional step to normal start up sequence
3. Trigger RF INIT.
   - Use AWR RF INIT SB for this step.

The above restoration does not include TX phase shift calibrations and digital delay compensation settings.

Because all calibrations are disabled in the above procedure, the calibration report API messages (AWR AE RF INITCALIBSTATUS SB) also reports all calibration statuses as 0. The mandatory calibrations (e.g. to keep the PLLs in lock) are done without host control. Unlike the timing constraint on issuing RF INIT API to all devices in the cascade in a non-overlapping manner during factory calibration and saving (to avoid mutual interference), there is no special timing constraint in the restore phase (because calibration measurements are actually disabled here).

### 3.4.2 Restore TX Phase Shift Calibration Results In-Field

The TX phase shift factory calibration results (found in Equation 1 or Equation 2) can be restored to the AWR device using AWR PHASE SHIFTER CAL DATA RESTORE SB.

For restoring customer factory corner reflector based phase shifter calibration values, send the following to the above API:

$$\text{modulo}\ (1024/360° \times \text{Factory Measured Phase Shift Array}_{\text{CornerReflector,TXm}}\ (0\ \text{to}\ 63),1024) \quad (5)$$

For restoring values based on RF INIT TX phase shifter calibration executed in customer factory in to the device, send the following to the above API:

$$\text{modulo}\ (1024/360° \times \text{Factory Measured Phase Shift Array}_{\text{RF INIT TX PS Cal,TXm}}\ (0\ \text{to}\ 63)) \quad (6)$$

The user should account for this API's phase indexing format, which may differ across TXs (refer to Table A-5 and Table A-6.

For simplicity of explanation, it is assumed here that the temperature at power up matches the factory calibration temperature. This assumption is not necessary and if wrong, the required steps are explained in detail in Section 3.5.4.

## 3.5 Host-Based Temperature Calibrations In-Field

After ensuring that the devices are restored to their customer factory calibration state (wrt RF INIT calibration results), TI recommends that the host control the devices' run time temperature calibrations as described here.

### 3.5.1 Disabling AWR Devices' Autonomous Run Time Calibrations

In the recommended procedure, many of AWR devices' internal autonomous run time calibrations are kept disabled, and some are enabled. The exceptions are:

1. The mandatory calibrations (such as to keep the PLLs in lock) are done without host control.
2. Power detector calibrations must be enabled. This is because monitoring functions use them and they need continual calibration for temperature drifts. They do not have an effect on the functional chirps if the other TX and RX calibrations are disabled.

The relevant API is AWR RUN TIME CALIBRATION CONF AND TRIGGER SB, and the power detector calibrations can be enabled by setting the field PD CALIBRATION EN to be 1. As mentioned earlier, the other calibrations should be disabled.

With these important run time calibrations disabled, the host processor in the sensor must configure the devices in the appropriate bias setting (Low Bias, Mid Bias, High Bias). That procedure is described next.

### 3.5.2 Enabling Host-Based Temperature Calibrations of Inter-Channel Imbalances

The host must monitor the device temperatures and, when needed, change the analog configurations in the AWR devices to mitigate temperature drift effects. The following steps illustrate the procedure.

1. Reading device temperature: use the AWR devices' temperature sensors to measure device temperatures. Use an average of all analog (TX, RX, CLK) temperature sensors in all devices to determine a single average temperature. The relevant APIs for temperature measurement are as follows:
   - AWR RF TEMPERATURE GET SB (it can be used as an on-demand temperature sensor reading and is useful before the first frame starts).
   - AWR MONITOR TEMPERATURE CONF SB (it can be used to pre-configure periodic temperature monitor reports).
2. Determining bias setting: determine which bias setting (Low Bias, Mid Bias, or High Bias) to use for the sensor using the average temperature and the host's knowledge of temperature trends (increasing or decreasing and expected long term temperature range).
3. Configuring TX, RX, and LO codes: based on the selected bias setting, configure TX, RX, and LO codes as follows:
   - For AWR1243, AWR1843, AWR1642: Set TX and RX gain codes stored in the non-volatile memory for the selected bias setting using AWR TX GAIN TEMPLUT SET SB API and AWR RX GAIN TEMPLUT SET SB API, respectively. The codes must be set to the same value for all the temperature bins (–40C to –30C, –30C to –20C, –20C to –10C … 120C to 130C, 130C to 140C) in both APIs, and the codes may be different for different devices.
   - For AWR2243: Override the temperature index corresponding to the selected bias setting for TX, RX, and LO DIST by issuing AWR RUN TIME CALIBRATION CONF AND TRIGGER.
4. Before the first radar frame: the host must execute the above procedure before triggering the first radar frame after RF INIT.
5. Transition timings and API sequences: after RF INIT, even after the frames have started, the host must continually monitor device temperatures and identify if bias setting transitions are needed. When needed, it must execute the above procedure, with timing constraints.
   - For the AWR1243, AWR1843, and AWR1642, the timing constraints are as follows:
     a. The above SET APIs must be issued to all devices in the cascade in tandem and when no frames/ chirps are ongoing.
     b. For this, AWR FRAMESTARTSTOP CONF SB API (stop) should first be issued to all the devices. The SET APIs must be then issued. The frames can then be resumed using AWR FRAMESTARTSTOP CONF SB API (start).
     c. The devices, upon receiving this API message, complete the ongoing radar frames before stopping further frames.
   - For AWR2243, AWR RUN TIME CALIBRATION CONF AND TRIGGER SB can be issued with appropriate temperature index override, even when frames are running. The host must observe the following timing constraints to ensure all the devices in the cascade honor and apply the necessary adjustments at the same frame and avoid any intermittent inter-device mismatches:
     a. The host should wait for monitoring report header API message corresponding to a monitoring period (say, monitoring period N). The message indicates that the previous monitoring period has ended and the next one is beginning.
     b. The host should then issue AWR RUN TIME CALIBRATION CONF AND TRIGGER SB and ensure that it reaches all the cascade devices in the same monitoring period, i.e. monitoring period N+1. The host should ensure that the cascade devices receive the new API before the next monitoring period (i.e. monitoring period N+2) begins (approximately a millisecond or earlier).
     c. The devices perform necessary computations related to the calibration adjustments in the next monitoring period (i.e. monitoring period N+2). The new calibration adjusted settings take effect in the subsequent monitoring period (i.e. monitoring period N+3). The timing is illustrated in Figure 3-2.
6. Transition temperature: the bias setting transitions are recommended to be near the factory calibration temperature. This can be done by appropriate choice of the temperature ranges for Low Bias, Mid Bias, and High Bias.

- Altering the TX, RX and LO DIST codes will cause phase jumps. These are expected to be compensated by DSP post processing (explained in later sections).
- To minimize the residual phase jumps after DSP post compensation, the jump magnitudes in the field must match those measured at factory. For this, the transitions are recommended when the temperature is as close as possible to the factory calibration temperature (typically the middle of Mid).

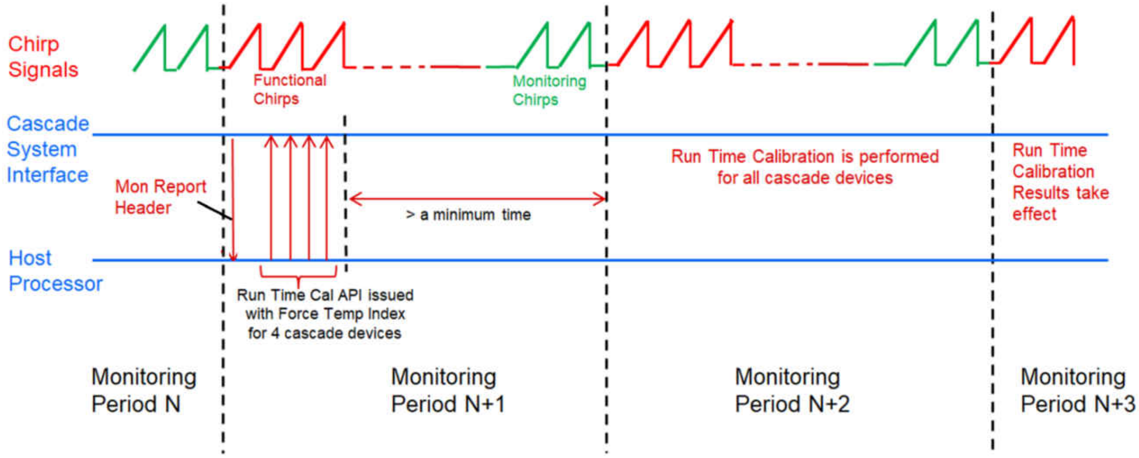


**Figure 3-2. AWR2243 RunTime Cal Temp Index Forcing Timing Diagram**

### 3.5.3 Switching of DSP Imbalance Data

In tandem with the AWR device temperature index transitions, the DSP must also transition to corresponding imbalance data that is stored in the sensor's non-volatile memory of the customer factory calibration results.

This ensures that even if the AWR devices switch analog settings, no significant phase jumps occur due to imbalance as the DSP algorithms are communicated the new imbalances from factory calibration data. The residual imbalances are expected to be small if the transition temperature matches the factory calibration temperature (typically the middle of Mid Bias temperature range).

### 3.5.4 Enabling TX Phase Shifter's Host-Based Temperature Calibrations

Even after the process variations in TX phase shift errors are mitigated using the methods described earlier in the document, there can be temperature drift induced residual TX phase shift errors. The following presents one typical strategy to reduce this residual error, derived from evaluation of a few devices (AWR1843 and AWR2243, nominal process) across temperature in TI labs.

Follow these steps:

1. Estimate the TX phase shift values at the "present" temperature. This includes recalling factory calibration values and temperature correction terms from LUTs.
2. Restore the estimated TX phase shift values to the device.

These are explained in the following sections.

#### *3.5.4.1 Estimating TX Phase Shift Values at Any Temperature*

The estimated phase shift values of the device's raw analog phase shifter at any temperature ($T_{present}$) can be derived as:

$$\text{Estimated Phase Shift Array}_{TXm}\text{ (0 to 63)} = \text{Factory Measured Phase Shift Array}_{CornerReflector,TXm}\text{ (0 to 63)} + \text{Temperature Correction LUT } (T_{present}) \quad (7)$$

Here, Factory Measured Phase Shift Array$_x$ denotes the measured phase shift values for each of the 64 raw analog's phase shifter settings obtained at factory for each TX, at the factory temperature ($T_{factory}$=25C), and comes from Equation 1 or Equation 2. Further, Temperature Correction LUT ($T_{present}$) denotes the temperature-related correction that must be applied to obtain the equivalent estimated phase shift values for $T_{present}$. It is explained in the following sections.

#### 3.5.4.2 Temperature Correction LUTs for AWR1843TX Phase Shifter

Assuming that $T_{factory}$ = 25C, Temperature Correction LUT ($T_{present}$) at $T_{present}$ = -40C, 25C, 85C, 130C for AWR1843 is provided in Table 7 in the Appendix. The same is represented in the form of a graph in Figure 3-3. These are derived from evaluation of a few nominal process based devices in TI labs. The LUT for any temperature is indexed with 0 to 63, corresponding to the 6 bit phase shift index and the output is the correction in the phase angle that is needed. linear interpolation/extrapolation over these temperatures can be used for other temperatures if needed. The data shown below is measured with a single TX been ON at a time. If multiple TXs are ON at the same time the Tx-Tx antenna coupling could cause secondary impact on phase.

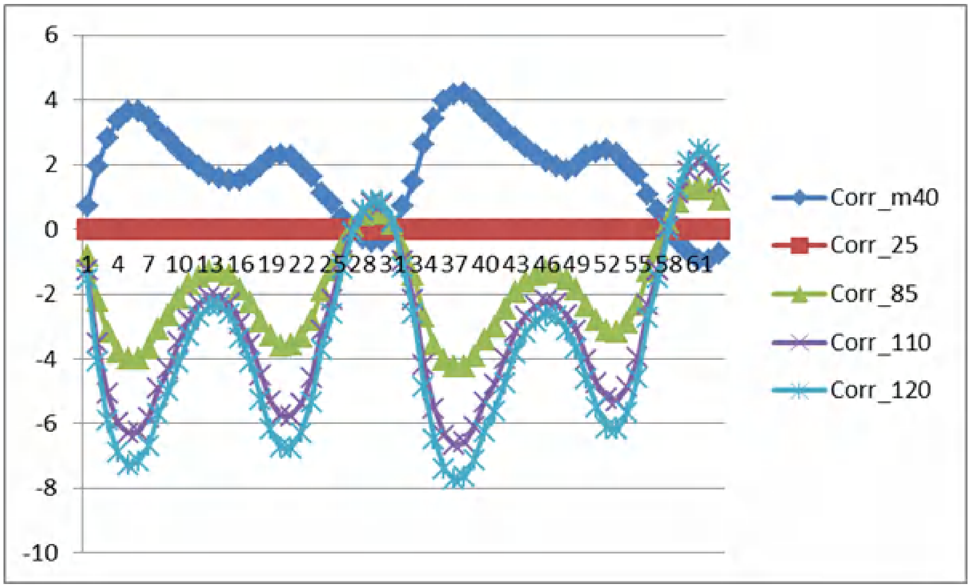


**Figure 3-3. Temperature Correction of TX Phase Shift Error for AWR1843** 1

1. Assuming 25C customer factory calibration, y-axis is phase error in degrees, x-axis is phase shift.

#### 3.5.4.3 Temperature Correction LUTs for AWR2243 TX Phase Shifter

Assuming that $T_{factory}$ = 25C, Temperature Correction LUT ($T_{present}$) at $T_{present}$ = -40C, 25C, 85C, 130C for AWR2243 is provided in Table 9 in the Appendix section. The same are provided in the form of graphs in Figure 3-4. These are derived from evaluation of a few nominal process based devices in TI labs. The evaluation was carried out on a radar system with waveguide loopback connecting TXs to RXs. The LUTs are provided separately for 76-77 GHz band and 77-81 GHz band for TX1, to capture slight differences across RF frequencies. The LUT for any temperature is indexed with 0 to 63, corresponding to the 6 bit phase shift index and the output is the correction in the phase angle that is needed. Linear interpolation/extrapolation can be used for other temperatures if needed. The data shown below is measured with a single TX been ON at a time. If multiple TXs are ON at the same time the Tx-Tx antenna coupling could cause secondary impact on phase.

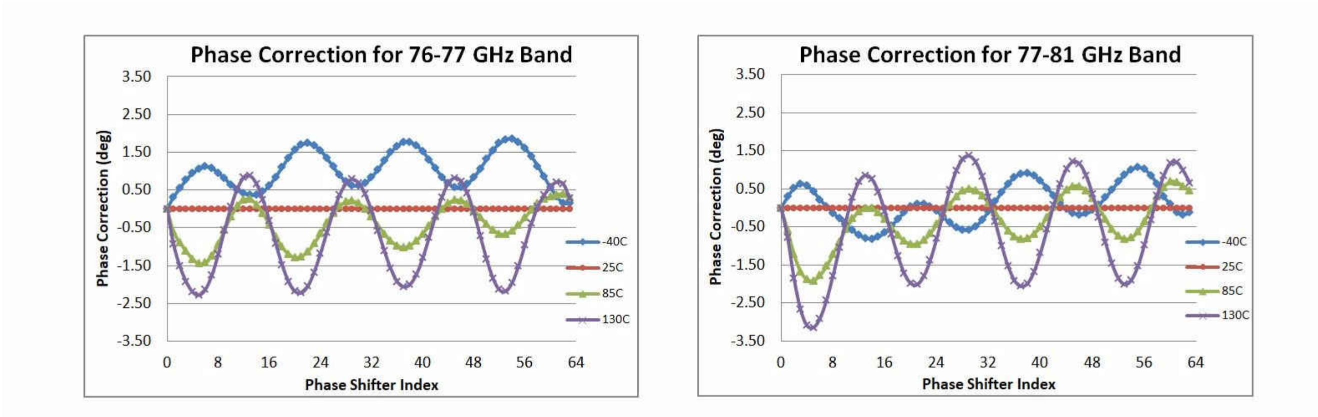


**Figure 3-4. Temperature Correction of TX Phase Shift Error for AWR2243**[1]

1. Assuming 25C customer factory calibration, y-axis is phase error in degrees, x-axis is phase shift index, unit = 360°/64.

### *3.5.4.4 Restoring TX Phase Shift Values – Format Conversion*

The API AWR PHASE SHIFTER CAL DATA RESTORE SB can be used to restore the TX phase shifter calibration data into the device in the field operation.

For restoring the estimated phase shift values of the raw analog for the present temperature, send the following to the above API:

$$\text{modulo } (1024/360°) \times \text{Estimated Phase Shift Array}_{TXm} \text{ (0 to 63),1024)} \quad (8)$$

The user should account for this API's phase indexing format, which may differ across TXs (refer to the Appendix Section 7.5).

### *3.5.4.5 Restoring TX Phase Shift Values – Transition Timing and Constraints*

The AWR PHASE SHIFTER CAL DATA RESTORE SB message should be issued to the device only when the radar frames are not ongoing, i.e. after issuing the issue the FRAME STOP command (using AWR FRAMESTARTSTOP CONF SB) and before issuing the next FRAME START command. If the customer desires to issue the AWR PHASE SHIFTER CAL DATA RESTORE SB without stopping the frame, then the host is responsible to ensure that the API is issued not when active frames are ongoing. This is true for both AWR1843 and AWR2243.

### *3.5.4.6 Typical Post-Calibration TX Phase Shifter Accuracies*

Representative TX phase shifter accuracy from a nominal AWR2243 device is shown in Figure 3-5 (with and without the calibration procedures using temperature correction LUTs explained above). In TI lab evaluation of a few DoE devices, the phase shifter INL has been observed to be < approximately +/- 2 degrees. The evaluation used a waveguide loopback between the TX and RX of an AWR2243 device and measured TX phase shifter errors by sweeping across TX phase shifter codes and processing the ADC data received on the RXs.

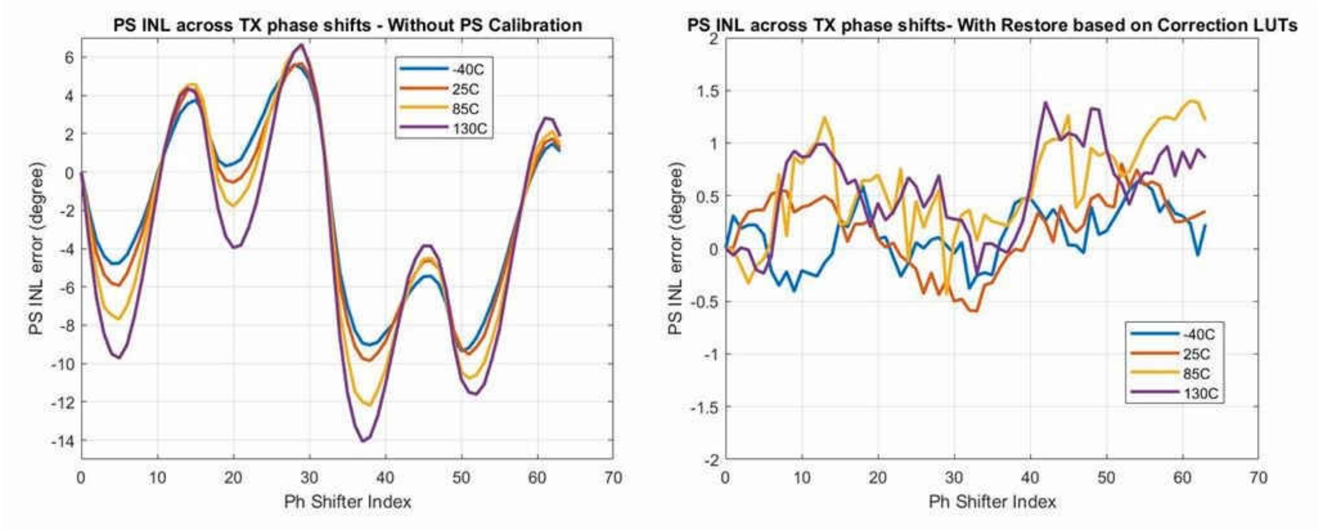


**Figure 3-5. TX Phase Shifter Accuracy in the AWR22431, 2**

1. (a) PS INL without any phase shifter calibration.
2. (b) PS INL with host based temperature calibration based on correction LUTs, shown for multiple temperatures.

#### *3.5.4.7 Correcting for Temperature Drift While Sweeping Across Phase Settings*

This section describes a minor aspect regarding temperature drift during factory calibrations and formation of Factory Measured Phase Shift Array$_{CornerReflector,TXm}$ (0 to 63). Even if ambient temperature is stable, if there is slight drift in the device temperature while sweeping the phase shifter setting from 0 to 63 due to self-heating, it can cause a drift in PS INL measurement for the device as the experiment progresses. If there is a significant amount of drift across phase settings, then the customer can consider repeating the 0 phase shifter setting measurement at the end during the customer factory measurements, i.e. measure the phase shifter INL for the settings 0, 1, 2, 3, …., 62, 63, 0. After deriving the phase shifter INL from the measurements, the host processor can apply a linearly increasing correction as described by the following formula, so that the phase shifter INL for 0 phase setting measurement at the end becomes 0.

Factory Measured Phase Shift Array (0 to 64) = Factory Measured Phase Shift Array (0 to 64) - Factory Measured Phase Shift Array (0). (9)

Factory Measured Phase Shift Array (0 to 63) = Factory Measured Phase Shift Array (0 to 63) + ((360° – Factory Measured Phase Shift Array (64))*[0:63]/64. (10)

Here, Factory Measured Phase Array (64) refers to the measured phase shift value when 0 phase setting is repeated at the end.

This can compensate for the impact of temperature drift while sweeping the phase shifter settings. Figure 3-6 illustrates the compensation of temperature drift impact on PS INL measurements by applying a linear correction across phase settings.

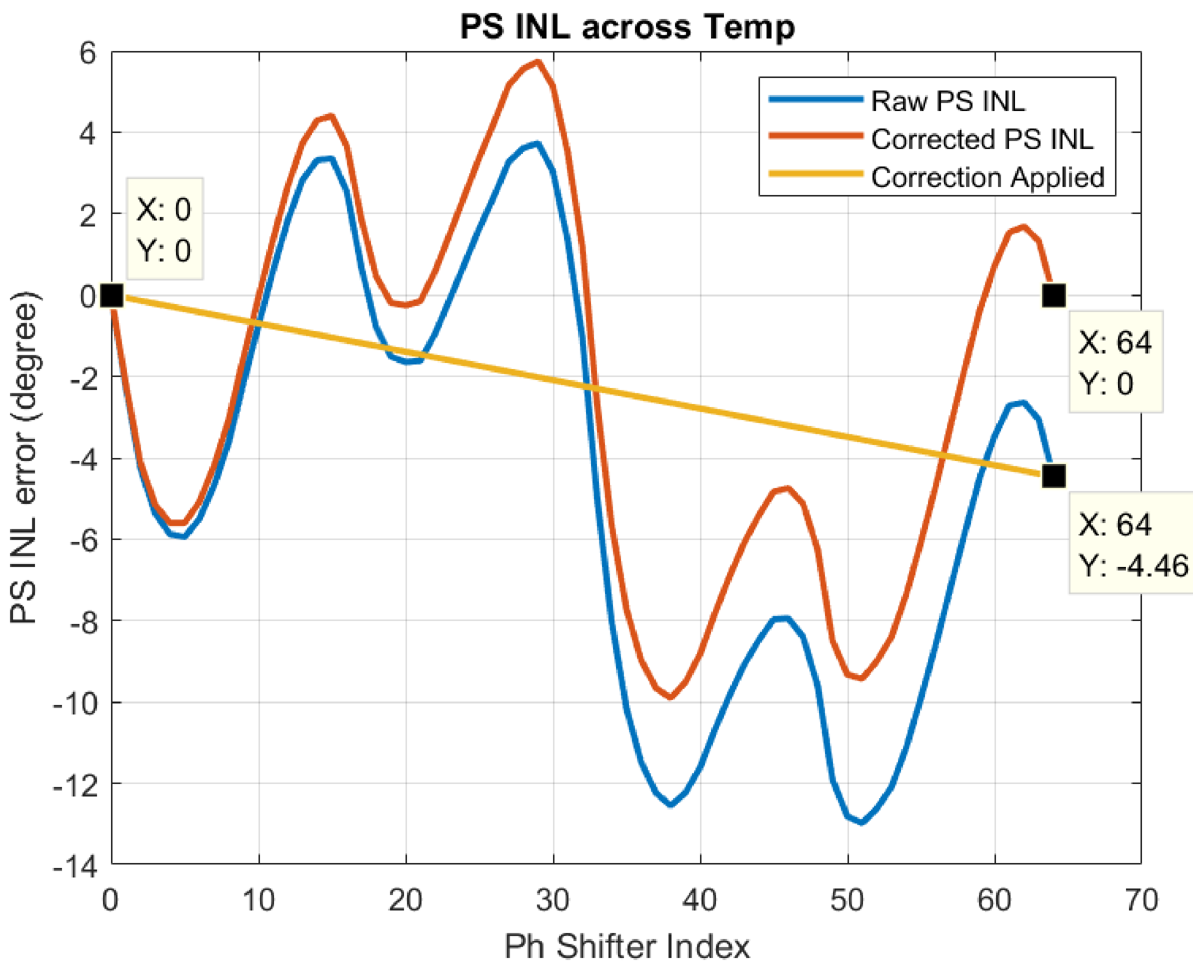


**Figure 3-6. Raw measured PS INL during the calibration procedure, and illustration of linear compensation for phase changes temperature drift during calibration measurements**

#### *3.5.4.8 Amplitude Stability Across Phase Shifter Settings*

Representative amplitude stability across TX phase shifter codes from a nominal AWR2243 device is shown in Figure 3-7 (with and without the calibration procedures using temperature correction LUTs explained above). In TI lab evaluation of a few DoE devices, the phase shifter INL has been observed to be < approximately +/- 0.3 dB. The evaluation used a waveguide loopback between the TX and RX of an AWR2243 device and measured TX phase shifter amplitude variation by sweeping across TX phase shifter codes and processing the ADC data received on the RXs. The data shown below is measured with a single TX been ON at a time. If multiple TXs are ON at the same time the Tx-Tx antenna coupling could cause secondary impact on amplitude.

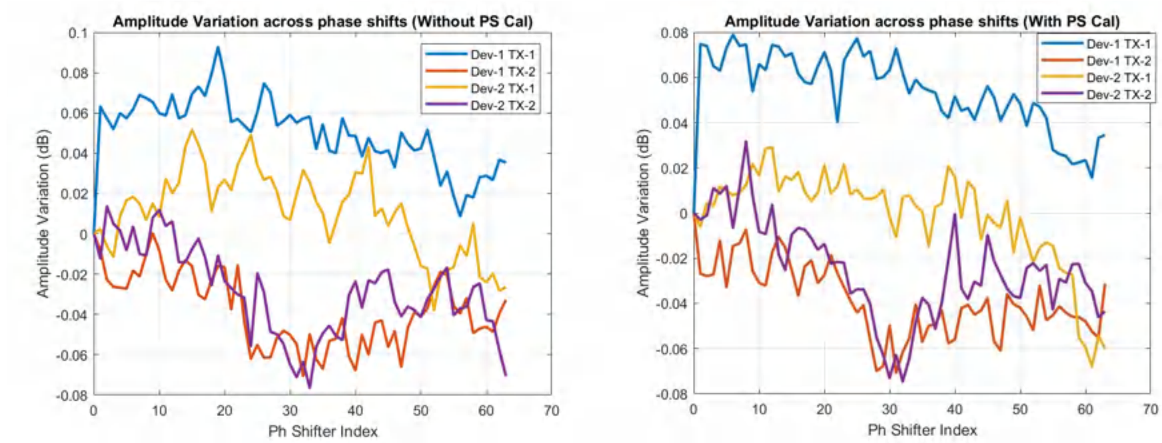


**Figure 3-7. Amplitude Variation Across Phase Shifter Settings at 25C[1]**

1. Without phase shifter calibration, as measured in a cascade sensor (2 TXs of 2 devices).

#### *3.5.4.9 Impact of Customer PCB's 20-GHz Sync Path Attenuation on TX Phase Shifters*

In the AWR2243 cascade system, the 20-GHz LO signal from ClockOut or SyncOut pin of Master is routed on the PCB and fed to the SyncIn pin of all the devices, to achieve RF synchronization. This PCB routing can lead to losses in the 20-GHz Sync Path, and the change in 20-GHz SyncIn power level can indirectly change the TX Phase Shifter properties.

In TI lab evaluation of few devices across DoE process corners and temperature, with SyncIn BGA power set at approximately -0.5 dBm to -4.5 dBm, the change observed in PS INL with all the above recommended procedures and LUTs has been observed to be <1 degree across all phase shifter settings.

Because the 20-GHz power levels are highly dependent on the customer's PCB design, if further TX phase shifter accuracy improvement is desired, the customer may consider characterizing the TX phase shifter over temperature across several of their own sensors, re-evaluating and re-deriving the LUTs mentioned in this note corresponding to their own sensor.

### 3.5.5 Ambient and Device Temperatures

The customer factory measurements should be done with the device temperatures sufficiently settled and constant (within ~5°C) throughout the measurements. Also, in the above, the term factory calibration temperature has been loosely defined as the ambient temperature, under the assumption that the device temperature is the same. But if the device is warmer during the calibration process (the average of analog temperature sensors), then the factory temperature should refer to the device temperature. The device temperature during the factory measurements can be obtained through the TEMPERATURE field in the RF INIT calibration status report message (AWR_AE_RF_INITCALIBSTATUS_SB), or by using the device's temperature monitor APIs.

# 4 Concept Illustrations

The below graphs illustrate solution concepts explained in this note. These are based on experiments on AWR1243 cascade sensor with two devices, with one RX and one TX from each considered for analysis.

The results with AWR2243 are expected to be similar in the context of this note. With this, there are 4 virtual channels or TX-RX combinations. The temperature in the experiments is varied and the absolute phase of the radar return signal for various TX-RX combinations is plotted. One of the graphs is with the AWR devices configured with their independent and autonomous periodic Run Time (temperature) Calibrations running (as would be typically recommended in single chip usages). The devices potentially can self-trigger calibration updates in 10°C resolution and create phase jumps of unknown magnitudes at different temperatures, as illustrated in this graph. The next graph illustrates the same but with externally triggered temperature calibrations with 3 bias settings (Low Bias, Mid Bias, and High Bias, as explained earlier). The last graph illustrates the same with additional post-compensation of the phase jumps across Low-Mid-High based on prior measurements of the jumps at 25°C ambient, and is devoid of phase jumps.

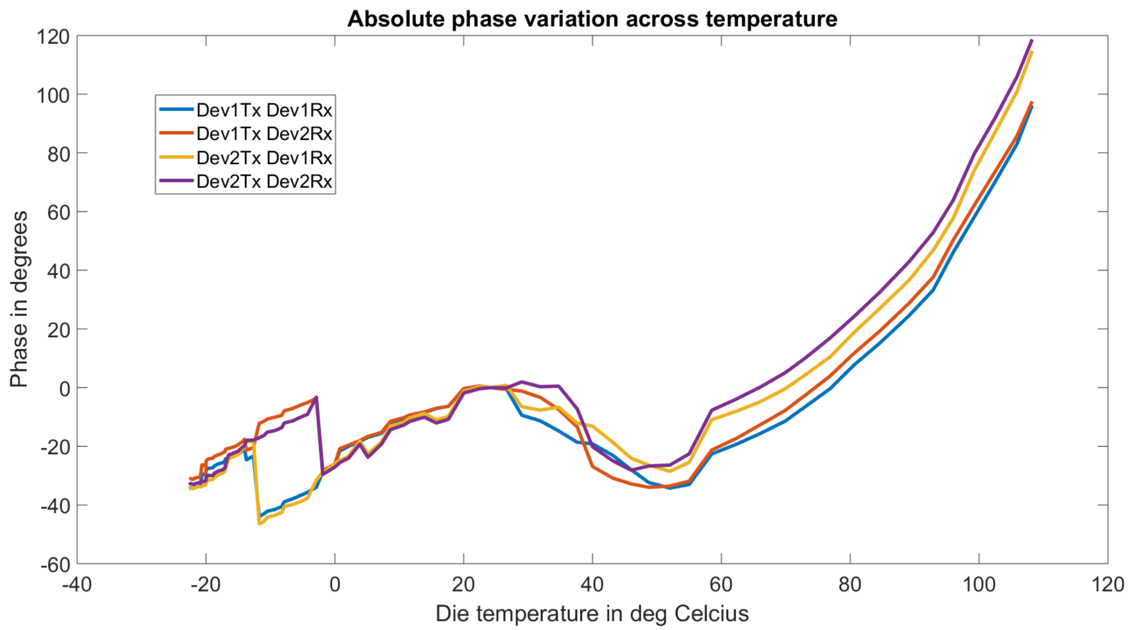


**Figure 4-1. Absolute Phase Variation with Independent, Autonomous Periodic Run Time Calibrations in the Devices**

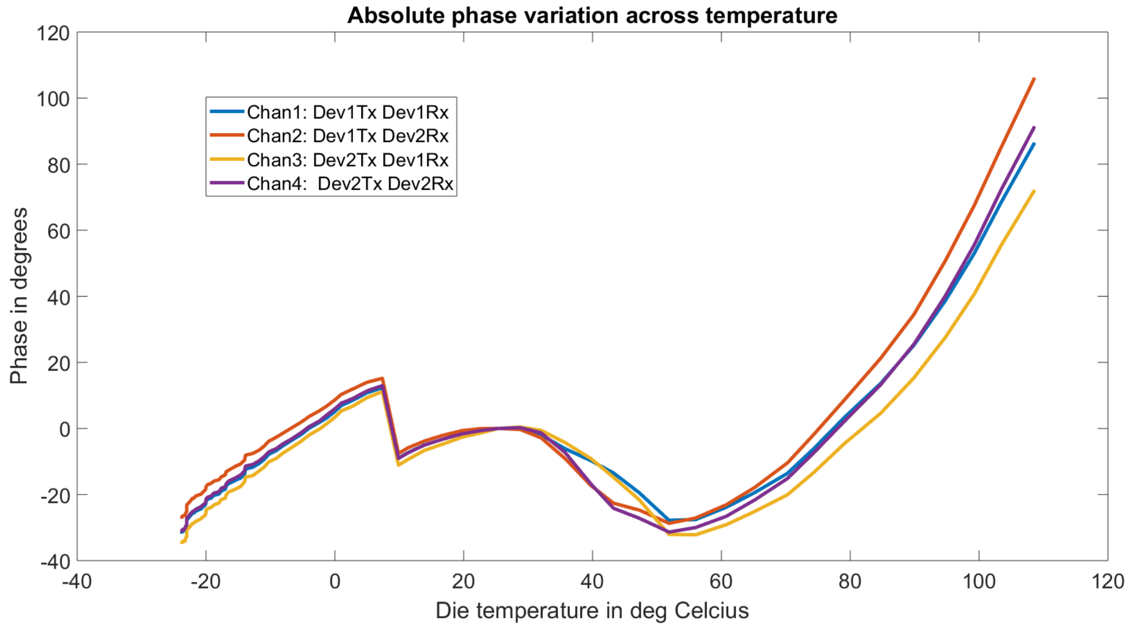


**Figure 4-2. Absolute Phase Variation with External Triggering of Calibration Updates**1

1. Based on Low Bias, Mid Bias, and High Bias temperature ranges.

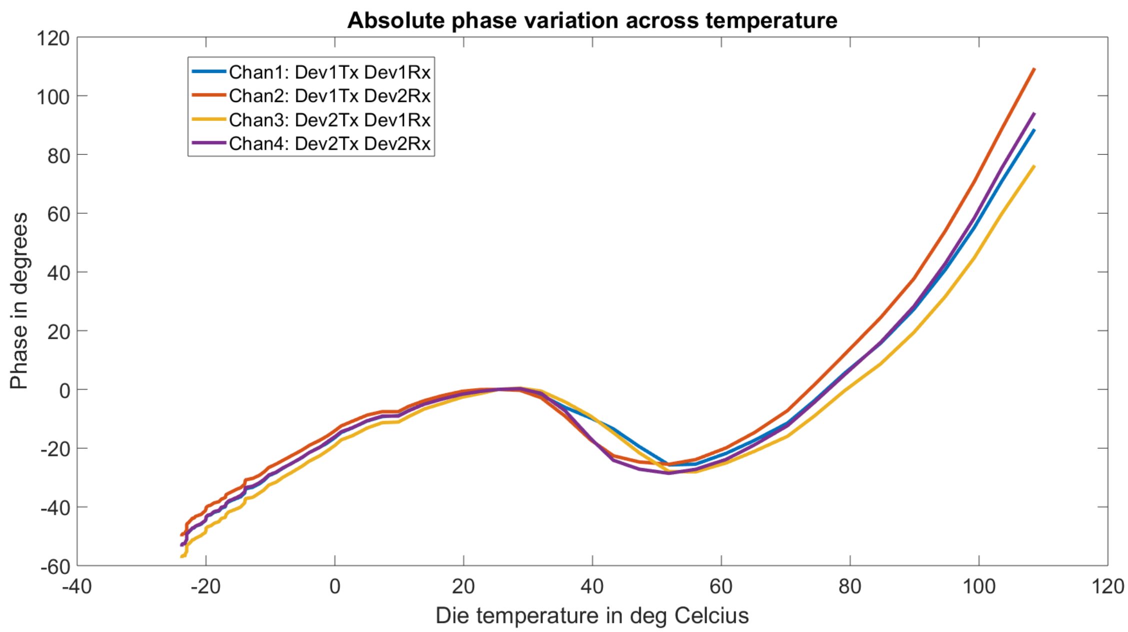


**Figure 4-3. Absolute Phase Variation with External Triggering of Calibration Updates**1

1. Based on Low Bias, Mid Bias, and High Bias temperature ranges with associated post-compensation using prior 25°C estimation of the jumps.

# 5 Miscellaneous (Interference, Gain Variation, Sampling Jitter)

## 5.1 Handling Interference In-Field

The device's internal calibrations and monitoring functions can be impacted by external interference. The mitigation strategies, similar to cascade coherence related strategies, include performing RF INIT at customer factory in interference-free environment, saving those results and restoring them into the device during in-field operation, using the calibration save and restoring APIs. The device's self-calibration application note contains some more details (see reference section).

## 5.2 Information on TX Power and RX Gain Drift with Temperature

In general the strategies recommended above keep the RF-analog bias settings constant over large temperature ranges (e.g. ~50C to 140C may use the same TX and RX bias settings). With this, the radar return signal strength varies with temperature, depending on the bias setting choice. This section provides information (nominal AWR2243 design based expectations) regarding how the TX power and RX gain vary with temperature. It is provided as a table for different bias settings, given that the host has API based control on the temperature/bias settings.

**Note**

This information is from nominal device simulations and there can be some deviation across manufacturing process.

**Table 5-1. TX Power versus Device Temperature (use for deriving relative "drift" over temperature)**

| | TX Output Power (dBm) | | | | |
|---|---|---|---|---|---|
| **Temperature** | **-40C Settings** | **10C Settings** | **25C Settings** | **50C Settings** | **140C Settings** |
| -40 | 13.11 | 13.48 | 13.57 | 13.77 | 14.43 |
| -30 | 13.00 | 13.38 | 13.5 | 13.66 | 14.41 |
| -20 | 12.87 | 13.28 | 13.41 | 13.56 | 14.38 |
| -10 | 12.71 | 13.17 | 13.31 | 13.46 | 14.34 |
| 0 | 12.54 | 13.05 | 13.2 | 13.36 | 14.28 |
| 10 | 12.35 | 12.93 | 13.08 | 13.27 | 14.21 |
| 20 | 12.14 | 12.79 | 12.95 | 13.17 | 14.13 |
| 30 | 11.91 | 12.65 | 12.8 | 13.06 | 14.04 |
| 40 | 11.65 | 12.50 | 12.64 | 12.95 | 13.94 |
| 50 | 11.38 | 12.34 | 12.47 | 12.83 | 13.82 |
| 60 | 11.09 | 12.16 | 12.29 | 12.71 | 13.69 |
| 70 | 10.78 | 11.96 | 12.1 | 12.57 | 13.55 |
| 80 | 10.45 | 11.76 | 11.89 | 12.43 | 13.4 |
| 90 | 10.09 | 11.54 | 11.67 | 12.29 | 13.24 |
| 100 | 9.72 | 11.26 | 11.44 | 12.11 | 13.06 |
| 110 | 9.33 | 11.01 | 11.2 | 11.94 | 12.87 |
| 120 | 8.92 | 10.76 | 10.95 | 11.77 | 12.67 |
| 130 | 8.49 | 10.48 | 10.68 | 11.58 | 12.46 |
| 140 | 8.03 | 10.17 | 10.4 | 11.36 | 12.24 |

**Table 5-2. RX Gain Across Temperature for Various Settings**

| | RX Gain (dB) | | |
|---|---|---|---|
| **Temperature** | **-40C Settings** | **25C Settings** | **140C Settings** |
| -40 | 37.53 | 40.07 | 43.35 |
| -30 | 37.09 | 39.59 | 42.85 |
| -20 | 36.65 | 39.13 | 42.37 |
| -10 | 36.24 | 38.68 | 41.9 |
| 0 | 35.83 | 38.24 | 41.44 |
| 10 | 35.44 | 37.82 | 40.99 |
| 20 | 35.06 | 37.41 | 40.56 |
| 30 | 34.69 | 37.01 | 40.14 |
| 40 | 34.34 | 36.62 | 39.73 |
| 50 | 33.99 | 36.25 | 39.32 |
| 60 | 33.66 | 35.89 | 38.93 |
| 70 | 33.33 | 35.53 | 38.55 |
| 80 | 33.01 | 35.19 | 38.17 |
| 90 | 32.69 | 34.85 | 37.79 |
| 100 | 32.38 | 34.51 | 37.42 |
| 110 | 32.07 | 34.17 | 37.05 |
| 120 | 31.76 | 33.84 | 36.68 |
| 130 | 31.45 | 33.5 | 36.31 |
| 140 | 31.14 | 33.16 | 35.94 |

## 5.3 Jitter Between Chirp Start and ADC Sampling Start

Due to data synchronizers in the synthesizer chirp starting path, there can be 0/1.1 ns bimodal jitter in the starting of each RF chirp wrt RX ADC sampling. This can lead to a small chirp to chirp phase jitter whose magnitude depends on IF frequency. For example, this translates to 360° x 1.1 ns x 1 MHz = 0.4° at 1-MHz IF in range dimension; 4° for 10-MHz IF, and 8° for 20-MHz IF. This chirp to chirp phase jitter can result in a slight leakage of tones in velocity dimension at the same IF frequency during Doppler processing. The behavior is expected to be random, varying with time, temperature, and device to device.

## 6 Conclusion

Simple single-chip applications in interference-free environments, which are concerned only with inter-channel imbalances can continue to use the device's self-calibrations (RF INIT as well as run time calibrations) in-field fully. But for those single-chip applications where stability of absolute phase is also desired, devoid of abrupt jumps, and for cascade sensors, where inter-channel balance across all devices is desired, this note has documented the necessary recommendations. It has also provided information on TX phase shifter accuracy and improvement methods.

# A Appendix

## A.1 Terminology

Table A-1 briefly explains some terms used in this note.

**Table A-1. Terminology**

| | |
|---|---|
| *Device* | *TI's radar system on chip, such as AWR1243or AWR2243* |
| *Single chip* | *A usage scenario where a radar sensor includes only one AWR device and performs coherent processing of data only within frames and not across frames.* |
| *Cascade* | *A radar system operating multiple AWR devices together to improve sensing* |
| *Advanced single chip* | *A usage scenario where a single chip radar sensor performs coherent processing across multiple frames, thereby needing phase stability across frames.* |
| *Host* | *The processor or microcontroller that controls the cascade's multiple AWR devices* |
| *DSP* | *The (internal or external) processor which processes the AWR devices' RX ADC data* |
| *Analog* | *Mm-wave, RF, analog circuits and subsystems in the device* |
| *Analog configurations* | *Bias currents, voltages, capacitor, resistor values that control the analog operation* |
| *Offsets* | *A collective term for errors, such as inter-channel imbalances, TX phase shifter nonlinearity errors.* |
| *Customer* | *The customer of the AWR devices who manufactures the radar sensor PCB using them.* |
| *Non-volatile memory (NVM)* | *A memory element in the sensor which can be populated during the factory calibration process (e.g. with calibration results) and which can be read in field.* |
| *Factory calibration temperature* | *Temperature at which Customer factory is performed (typically 25C).* |
| *Cold, Mid, Hot settings* | *A nomenclature to illustrate the AWR analog settings corresponding to broad temperature ranges.* |
| *DoE, DoE devices* | *Design of Experiments, and associated devices. This refers to intentional skewing of device manufacturing process parameters to manufacture a few devices for TI lab evaluation, in order to capture/understand the effect process variation in mass manufacture of devices.* |
| *INL error* | *Integrated Non Linearity error, referring to TX phase shifter's deviation from ideal 0 to 360o characteristics.* |

## A.2 References

These references provide useful background to support this note.

1. *AWR1xx and AWR2243 Radar Interface Control Document* ()
2. *Programming Chirp Parameters in TI Radar Devices* ()
3. *Self-Calibration in TI's mmWave Radar Devices* ()

## A.3 Flow Diagrams for Proposed Cascade Coherence Scheme

This appendix section consists of flow diagrams describing the procedure for customer factory calibration and in-field operations for proposed scheme.

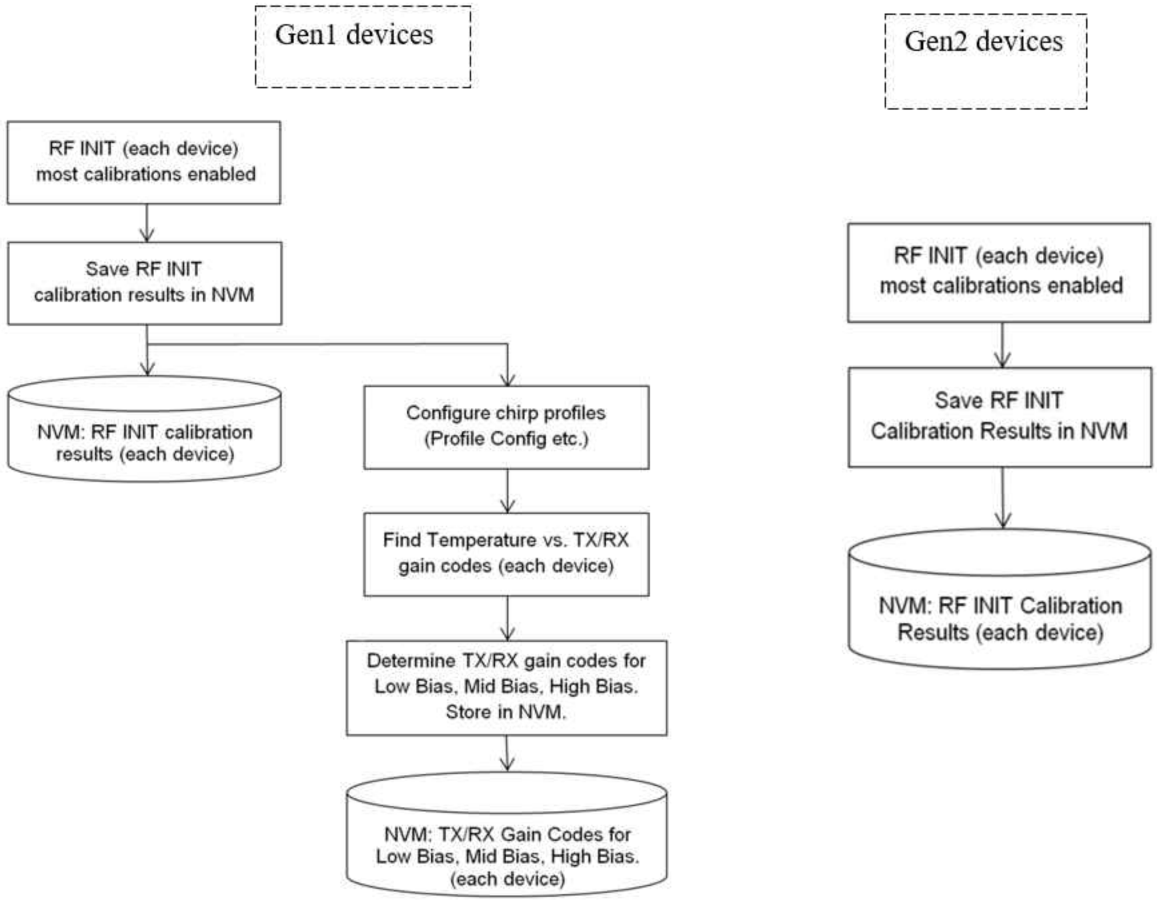


**Figure A-1. Customer Factory Calibrations: Saving (Process) RF INIT Calibration Results**

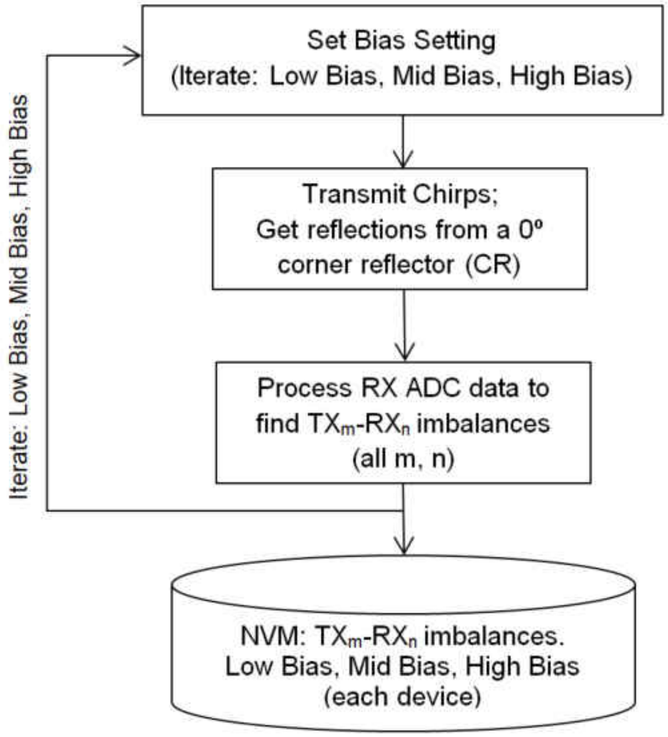


**Figure A-2. Measure Inter-Channel Imbalances at Customer Factory Across Bias Settings**

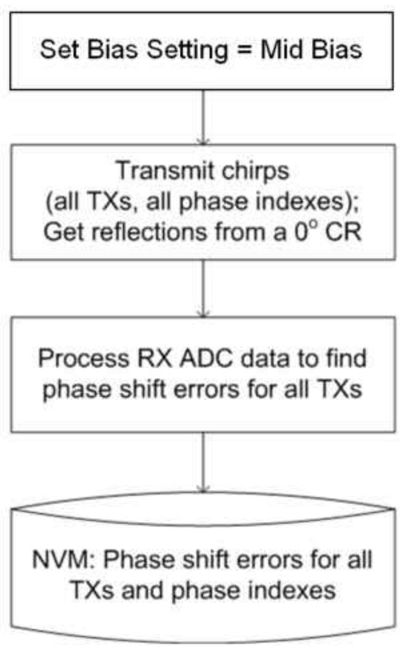


**Figure A-3. Measuring TX Phase Shifter Errors at Customer Factory**

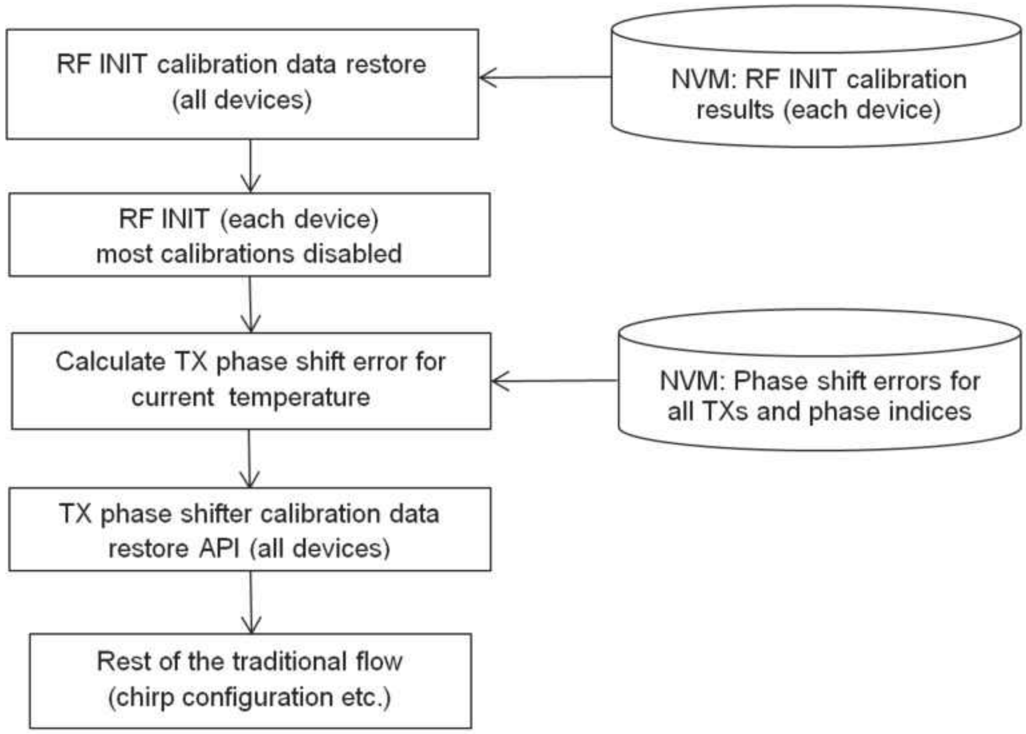


**Figure A-4. In-Field Operation: Restoring RF INIT Calibration Results from Factory to the Device**

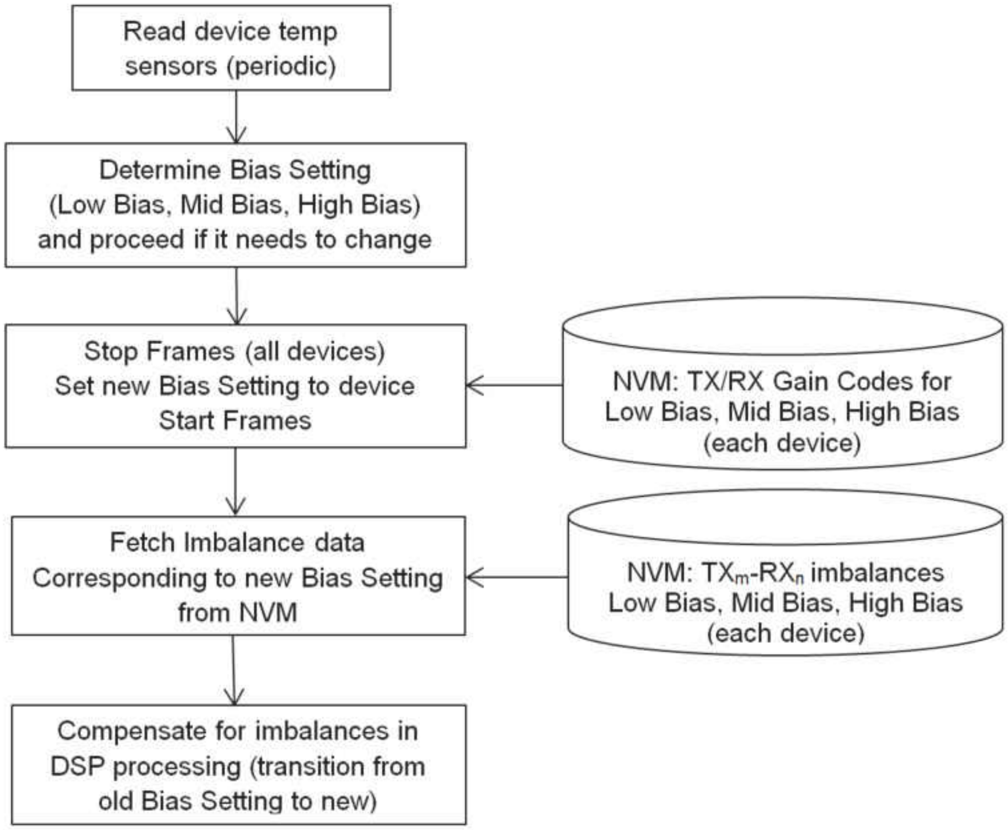


**Figure A-5. In-Field Operation: Handling Temperature Transitions wrt Inter-Channel Imbalances - Gen1**

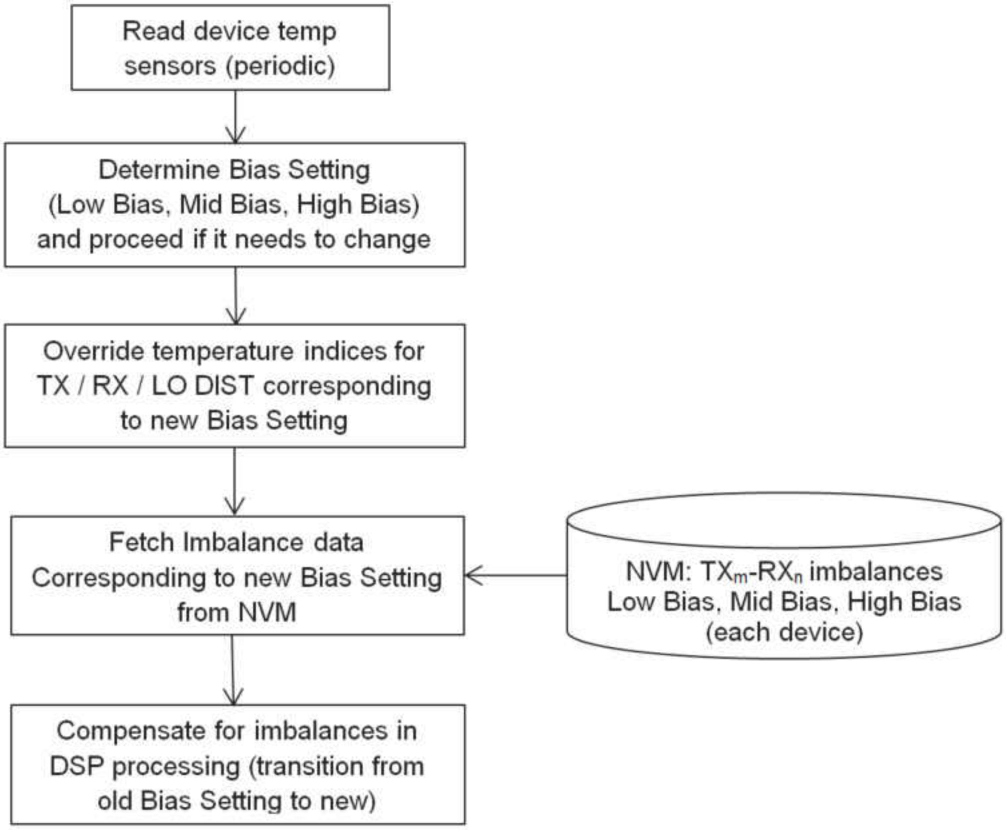


**Figure A-6. In-Field Operation: Handling Temperature Transitions wrt Inter-Channel Imbalances - AWR2243**

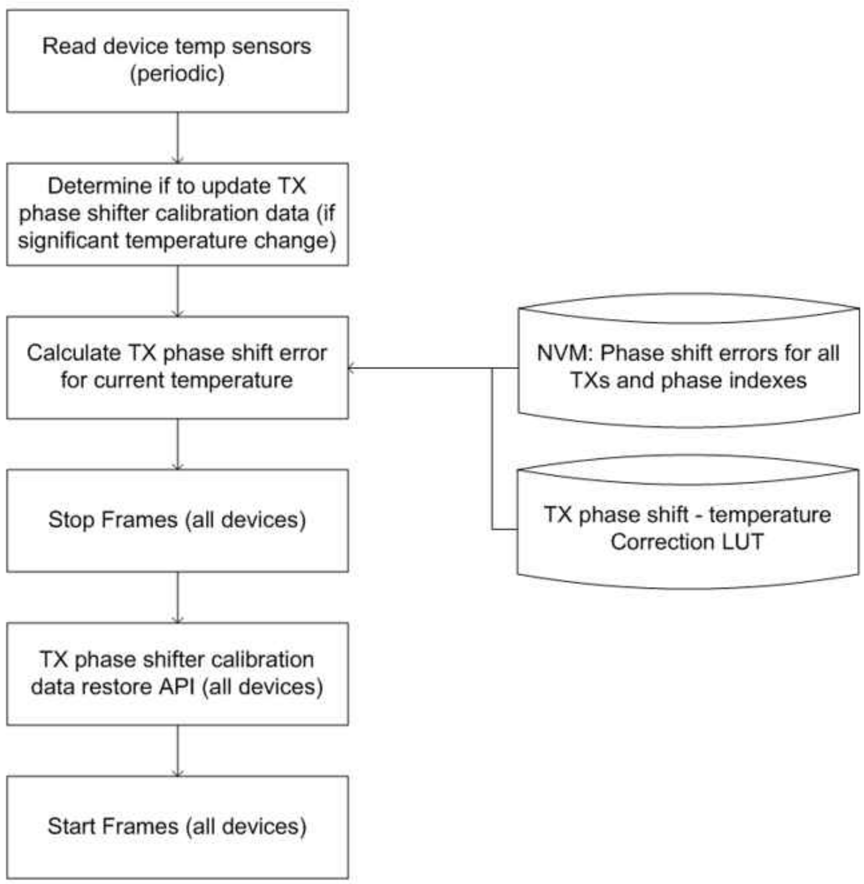


**Figure A-7. In-Field Operation: Handling Temperature Effects on TX Phase Shifter Errors**

## A.4 LUTs for TX Phase Shifter Temperature Drift Mitigation

This appendix section tabulates several Look-Up-Tables (LUTs) referred to in the rest of this note. The LUTs have common values, but indices differ slightly for TX1 and TX2/3. The values listed below are with single TX ON at a time. With multiple TX ON the antenna coupling between the TX could cause a secondary impact on the phase.

**Table A-2. TX Phase Shift Calibration Temperature Correction LUT for AWR1843**

| Phase Shift Index for TX1 | Phase Shift Index for TX2 and TX3 | Temperature Correction LUT (-40°C) | Temperature Correction LUT (25°C) | Temperature Correction LUT (85°C) | Temperature Correction LUT (110°C) | Temperature Correction LUT (120°C) |
|---|---|---|---|---|---|---|
| 0 | 32 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 | 33 | 0.73 | 0.00 | -0.82 | -1.28 | -1.53 |
| 2 | 34 | 1.95 | 0.00 | -2.21 | -3.53 | -4.07 |
| 3 | 35 | 2.81 | 0.00 | -3.19 | -5.06 | -5.91 |
| 4 | 36 | 3.38 | 0.00 | -3.81 | -5.98 | -6.91 |
| 5 | 37 | 3.63 | 0.00 | -4.02 | -6.29 | -7.29 |
| 6 | 38 | 3.64 | 0.00 | -3.99 | -6.27 | -7.18 |
| 7 | 39 | 3.45 | 0.00 | -3.70 | -5.82 | -6.70 |
| 8 | 40 | 3.07 | 0.00 | -3.10 | -4.92 | -5.70 |
| 9 | 41 | 2.82 | 0.00 | -2.67 | -4.32 | -4.99 |
| 10 | 42 | 2.46 | 0.00 | -2.15 | -3.48 | -4.11 |
| 11 | 43 | 2.18 | 0.00 | -1.72 | -2.79 | -3.29 |
| 12 | 44 | 1.94 | 0.00 | -1.46 | -2.28 | -2.69 |
| 13 | 45 | 1.72 | 0.00 | -1.31 | -2.11 | -2.39 |

**Table A-2. TX Phase Shift Calibration Temperature Correction LUT for AWR1843 (continued)**

| Phase Shift Index for TX1 | Phase Shift Index for TX2 and TX3 | Temperature Correction LUT (-40°C) | Temperature Correction LUT (25°C) | Temperature Correction LUT (85°C) | Temperature Correction LUT (110°C) | Temperature Correction LUT (120°C) |
|---|---|---|---|---|---|---|
| 14 | 46 | 1.60 | 0.00 | -1.30 | -2.13 | -2.37 |
| 15 | 47 | 1.50 | 0.00 | -1.41 | -2.31 | -2.63 |
| 16 | 48 | 1.49 | 0.00 | -1.85 | -2.93 | -3.38 |
| 17 | 49 | 1.65 | 0.00 | -2.24 | -3.55 | -4.12 |
| 18 | 50 | 1.94 | 0.00 | -2.86 | -4.50 | -5.25 |
| 19 | 51 | 2.23 | 0.00 | -3.29 | -5.29 | -6.19 |
| 20 | 52 | 2.29 | 0.00 | -3.60 | -5.76 | -6.75 |
| 21 | 53 | 2.26 | 0.00 | -3.58 | -5.78 | -6.77 |
| 22 | 54 | 1.95 | 0.00 | -3.34 | -5.41 | -6.30 |
| 23 | 55 | 1.64 | 0.00 | -2.83 | -4.61 | -5.33 |
| 24 | 56 | 1.11 | 0.00 | -1.90 | -3.13 | -3.71 |
| 25 | 57 | 0.78 | 0.00 | -1.29 | -2.19 | -2.62 |
| 26 | 58 | 0.36 | 0.00 | -0.51 | -0.98 | -1.23 |
| 27 | 59 | -0.02 | 0.00 | 0.07 | -0.04 | -0.13 |
| 28 | 60 | -0.26 | 0.00 | 0.44 | 0.57 | 0.59 |
| 29 | 61 | -0.41 | 0.00 | 0.57 | 0.81 | 0.89 |
| 30 | 62 | -0.36 | 0.00 | 0.50 | 0.74 | 0.81 |
| 31 | 63 | -0.07 | 0.00 | 0.17 | 0.23 | 0.24 |
| 32 | 0 | 0.71 | 0.00 | -0.61 | -0.98 | -1.19 |
| 33 | 1 | 1.48 | 0.00 | -1.41 | -2.19 | -2.60 |
| 34 | 2 | 2.62 | 0.00 | -2.68 | -4.20 | -4.88 |
| 35 | 3 | 3.42 | 0.00 | -3.55 | -5.54 | -6.48 |
| 36 | 4 | 3.95 | 0.00 | -4.05 | -6.38 | -7.42 |
| 37 | 5 | 4.16 | 0.00 | -4.25 | -6.67 | -7.74 |
| 38 | 6 | 4.18 | 0.00 | -4.23 | -6.59 | -7.64 |
| 39 | 7 | 4.02 | 0.00 | -3.94 | -6.11 | -7.13 |
| 40 | 8 | 3.65 | 0.00 | -3.39 | -5.33 | -6.26 |
| 41 | 9 | 3.39 | 0.00 | -3.00 | -4.78 | -5.61 |
| 42 | 10 | 3.05 | 0.00 | -2.46 | -4.00 | -4.74 |
| 43 | 11 | 2.80 | 0.00 | -1.94 | -3.18 | -3.84 |
| 44 | 12 | 2.53 | 0.00 | -1.63 | -2.69 | -3.20 |
| 45 | 13 | 2.29 | 0.00 | -1.44 | -2.37 | -2.83 |
| 46 | 14 | 2.09 | 0.00 | -1.31 | -2.22 | -2.65 |
| 47 | 15 | 1.95 | 0.00 | -1.33 | -2.29 | -2.69 |
| 48 | 16 | 1.82 | 0.00 | -1.55 | -2.65 | -3.13 |
| 49 | 17 | 1.95 | 0.00 | -1.87 | -3.13 | -3.68 |
| 50 | 18 | 2.25 | 0.00 | -2.39 | -4.03 | -4.63 |
| 51 | 19 | 2.39 | 0.00 | -2.83 | -4.77 | -5.52 |
| 52 | 20 | 2.45 | 0.00 | -3.12 | -5.23 | -6.13 |
| 53 | 21 | 2.32 | 0.00 | -3.17 | -5.31 | -6.19 |
| 54 | 22 | 2.00 | 0.00 | -2.91 | -4.87 | -5.66 |
| 55 | 23 | 1.68 | 0.00 | -2.32 | -3.97 | -4.58 |
| 56 | 24 | 1.05 | 0.00 | -1.29 | -2.33 | -2.72 |
| 57 | 25 | 0.61 | 0.00 | -0.63 | -1.25 | -1.51 |
| 58 | 26 | 0.08 | 0.00 | 0.18 | 0.07 | 0.01 |

### Table A-2. TX Phase Shift Calibration Temperature Correction LUT for AWR1843 (continued)

| Phase Shift Index for TX1 | Phase Shift Index for TX2 and TX3 | Temperature Correction LUT (-40°C) | Temperature Correction LUT (25°C) | Temperature Correction LUT (85°C) | Temperature Correction LUT (110°C) | Temperature Correction LUT (120°C) |
|---|---|---|---|---|---|---|
| 59 | 27 | -0.38 | 0.00 | 0.83 | 1.13 | 1.29 |
| 60 | 28 | -0.71 | 0.00 | 1.22 | 1.79 | 2.08 |
| 61 | 29 | -0.94 | 0.00 | 1.36 | 2.09 | 2.44 |
| 62 | 30 | -0.97 | 0.00 | 1.22 | 1.94 | 2.29 |
| 63 | 31 | -0.74 | 0.00 | 0.91 | 1.45 | 1.70 |

### Table A-3. Factory Measured Phase Shift Array at 25C for AWR2243

| Phase Shift Index | | Factory Measured Phase Shift Array at $T_{Factory}$ = 25C | |
|---|---|---|---|
| TX1 | TX2 and TX3 | 76-77 GHz Band | 77-81 GHz Band |
| 0 | 32 | 0.00 | 0.00 |
| 1 | 33 | 8.97 | 8.98 |
| 2 | 34 | 17.88 | 17.77 |
| 3 | 35 | 25.67 | 25.04 |
| 4 | 36 | 32.66 | 31.68 |
| 5 | 37 | 38.97 | 37.75 |
| 6 | 38 | 44.71 | 43.18 |
| 7 | 39 | 50.06 | 48.15 |
| 8 | 40 | 55.06 | 52.86 |
| 9 | 41 | 60.02 | 57.41 |
| 10 | 42 | 64.69 | 61.93 |
| 11 | 43 | 69.38 | 66.49 |
| 12 | 44 | 74.20 | 71.09 |
| 13 | 45 | 79.75 | 75.94 |
| 14 | 46 | 84.92 | 81.34 |
| 15 | 47 | 90.80 | 87.24 |
| 16 | 48 | 97.26 | 93.67 |
| 17 | 49 | 104.68 | 100.97 |
| 18 | 50 | 111.28 | 107.55 |
| 19 | 51 | 117.04 | 113.37 |
| 20 | 52 | 122.33 | 118.76 |
| 21 | 53 | 127.20 | 123.75 |
| 22 | 54 | 132.11 | 128.38 |
| 23 | 55 | 136.30 | 132.80 |
| 24 | 56 | 140.08 | 137.21 |
| 25 | 57 | 144.28 | 141.39 |
| 26 | 58 | 148.44 | 145.71 |
| 27 | 59 | 152.64 | 150.23 |
| 28 | 60 | 157.17 | 154.87 |
| 29 | 61 | 162.02 | 159.84 |
| 30 | 62 | 167.43 | 165.41 |
| 31 | 63 | 173.44 | 171.59 |
| 32 | 0 | 180.23 | 178.61 |
| 33 | 1 | 188.25 | 186.52 |
| 34 | 2 | 195.58 | 193.98 |
| 35 | 3 | 202.61 | 200.59 |
| 36 | 4 | 208.16 | 206.47 |

## Table A-3. Factory Measured Phase Shift Array at 25C for AWR2243 (continued)

| Phase Shift Index | | Factory Measured Phase Shift Array at $T_{Factory}$ = 25C | |
|---|---|---|---|
| TX1 | TX2 and TX3 | 76-77 GHz Band | 77-81 GHz Band |
| 37 | 5 | 213.73 | 211.70 |
| 38 | 6 | 218.76 | 216.51 |
| 39 | 7 | 223.63 | 221.11 |
| 40 | 8 | 228.68 | 225.45 |
| 41 | 9 | 232.61 | 229.50 |
| 42 | 10 | 236.79 | 233.56 |
| 43 | 11 | 240.95 | 237.74 |
| 44 | 12 | 245.26 | 241.95 |
| 45 | 13 | 249.87 | 246.49 |
| 46 | 14 | 254.93 | 251.41 |
| 47 | 15 | 260.59 | 256.92 |
| 48 | 16 | 266.96 | 263.38 |
| 49 | 17 | 274.53 | 271.07 |
| 50 | 18 | 282.01 | 278.27 |
| 51 | 19 | 287.73 | 284.56 |
| 52 | 20 | 293.27 | 290.42 |
| 53 | 21 | 298.63 | 296.05 |
| 54 | 22 | 303.61 | 301.29 |
| 55 | 23 | 308.49 | 306.35 |
| 56 | 24 | 313.18 | 311.19 |
| 57 | 25 | 317.76 | 315.91 |
| 58 | 26 | 322.49 | 320.97 |
| 59 | 27 | 327.42 | 326.12 |
| 60 | 28 | 332.57 | 331.51 |
| 61 | 29 | 338.08 | 337.42 |
| 62 | 30 | 344.39 | 343.85 |
| 63 | 31 | 351.40 | 351.02 |

## Table A-4. TX Phase Shift Calibration Temperature Correction LUT for AWR2243

| Phase shift index | | Correction LUTs for 76-77 GHz Band | | | | | Correction LUTs for band 77-81 GHz Band | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| TX1 | TX2 & TX3 | Temperature Correction LUT (-40C) | Temperature Correction LUT (25C) | Temperature Correction LUT (85C) | Temperature Correction LUT (130C) | | Temperature Correction LUT (-40C) | Temperature Correction LUT (25C) | Temperature Correction LUT (85C) | Temperature Correction LUT (130C) |
| 0 | 32 | 0.00 | 0.00 | 0.00 | 0.00 | | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 | 33 | 0.31 | 0.00 | -0.60 | -0.93 | | 0.29 | 0.00 | -0.58 | -0.77 |
| 2 | 34 | 0.54 | 0.00 | -0.89 | -1.52 | | 0.52 | 0.00 | -1.22 | -1.86 |
| 3 | 35 | 0.77 | 0.00 | -1.12 | -1.93 | | 0.63 | 0.00 | -1.67 | -2.67 |
| 4 | 36 | 0.94 | 0.00 | -1.33 | -2.20 | | 0.59 | 0.00 | -1.88 | -3.09 |
| 5 | 37 | 1.06 | 0.00 | -1.45 | -2.28 | | 0.43 | 0.00 | -1.91 | -3.14 |
| 6 | 38 | 1.12 | 0.00 | -1.43 | -2.13 | | 0.22 | 0.00 | -1.77 | -2.90 |
| 7 | 39 | 1.08 | 0.00 | -1.24 | -1.76 | | 0.04 | 0.00 | -1.53 | -2.42 |
| 8 | 40 | 0.95 | 0.00 | -0.93 | -1.20 | | -0.13 | 0.00 | -1.22 | -1.78 |
| 9 | 41 | 0.81 | 0.00 | -0.56 | -0.56 | | -0.28 | 0.00 | -0.88 | -1.05 |
| 10 | 42 | 0.63 | 0.00 | -0.20 | 0.05 | | -0.44 | 0.00 | -0.55 | -0.33 |
| 11 | 43 | 0.50 | 0.00 | 0.08 | 0.54 | | -0.58 | 0.00 | -0.28 | 0.28 |
| 12 | 44 | 0.41 | 0.00 | 0.24 | 0.83 | | -0.71 | 0.00 | -0.09 | 0.69 |

## Table A-4. TX Phase Shift Calibration Temperature Correction LUT for AWR2243 (continued)

| Phase shift index | | Correction LUTs for 76-77 GHz Band | | | | | Correction LUTs for band 77-81 GHz Band | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| TX1 | TX2 & TX3 | Temperature Correction LUT (-40C) | Temperature Correction LUT (25C) | Temperature Correction LUT (85C) | Temperature Correction LUT (130C) | | Temperature Correction LUT (-40C) | Temperature Correction LUT (25C) | Temperature Correction LUT (85C) | Temperature Correction LUT (130C) |
| 13 | 45 | 0.36 | 0.00 | 0.25 | 0.87 | | -0.79 | 0.00 | 0.00 | 0.86 |
| 14 | 46 | 0.37 | 0.00 | 0.11 | 0.66 | | -0.81 | 0.00 | -0.01 | 0.76 |
| 15 | 47 | 0.45 | 0.00 | -0.12 | 0.24 | | -0.76 | 0.00 | -0.12 | 0.42 |
| 16 | 48 | 0.62 | 0.00 | -0.42 | -0.31 | | -0.64 | 0.00 | -0.30 | -0.09 |
| 17 | 49 | 0.84 | 0.00 | -0.74 | -0.92 | | -0.47 | 0.00 | -0.51 | -0.69 |
| 18 | 50 | 1.10 | 0.00 | -1.01 | -1.48 | | -0.29 | 0.00 | -0.71 | -1.26 |
| 19 | 51 | 1.35 | 0.00 | -1.20 | -1.92 | | -0.11 | 0.00 | -0.87 | -1.72 |
| 20 | 52 | 1.56 | 0.00 | -1.29 | -2.18 | | 0.03 | 0.00 | -0.95 | -1.98 |
| 21 | 53 | 1.69 | 0.00 | -1.26 | -2.22 | | 0.11 | 0.00 | -0.95 | -2.01 |
| 22 | 54 | 1.73 | 0.00 | -1.13 | -2.05 | | 0.11 | 0.00 | -0.85 | -1.79 |
| 23 | 55 | 1.68 | 0.00 | -0.92 | -1.68 | | 0.04 | 0.00 | -0.67 | -1.37 |
| 24 | 56 | 1.54 | 0.00 | -0.65 | -1.18 | | -0.08 | 0.00 | -0.43 | -0.79 |
| 25 | 57 | 1.34 | 0.00 | -0.37 | -0.62 | | -0.24 | 0.00 | -0.16 | -0.14 |
| 26 | 58 | 1.11 | 0.00 | -0.12 | -0.08 | | -0.39 | 0.00 | 0.09 | 0.48 |
| 27 | 59 | 0.89 | 0.00 | 0.07 | 0.37 | | -0.51 | 0.00 | 0.31 | 0.98 |
| 28 | 60 | 0.72 | 0.00 | 0.19 | 0.67 | | -0.58 | 0.00 | 0.45 | 1.29 |
| 29 | 61 | 0.62 | 0.00 | 0.21 | 0.78 | | -0.57 | 0.00 | 0.50 | 1.37 |
| 30 | 62 | 0.61 | 0.00 | 0.14 | 0.68 | | -0.48 | 0.00 | 0.46 | 1.21 |
| 31 | 63 | 0.68 | 0.00 | 0.00 | 0.39 | | -0.31 | 0.00 | 0.33 | 0.83 |
| 32 | 0 | 0.84 | 0.00 | -0.21 | -0.05 | | -0.09 | 0.00 | 0.12 | 0.28 |
| 33 | 1 | 1.04 | 0.00 | -0.44 | -0.58 | | 0.16 | 0.00 | -0.12 | -0.36 |
| 34 | 2 | 1.27 | 0.00 | -0.66 | -1.11 | | 0.42 | 0.00 | -0.37 | -0.99 |
| 35 | 3 | 1.49 | 0.00 | -0.85 | -1.58 | | 0.64 | 0.00 | -0.59 | -1.53 |
| 36 | 4 | 1.66 | 0.00 | -0.97 | -1.92 | | 0.81 | 0.00 | -0.75 | -1.91 |
| 37 | 5 | 1.76 | 0.00 | -1.02 | -2.06 | | 0.90 | 0.00 | -0.82 | -2.06 |
| 38 | 6 | 1.76 | 0.00 | -0.97 | -2.00 | | 0.91 | 0.00 | -0.80 | -1.98 |
| 39 | 7 | 1.68 | 0.00 | -0.85 | -1.74 | | 0.84 | 0.00 | -0.68 | -1.67 |
| 40 | 8 | 1.52 | 0.00 | -0.66 | -1.30 | | 0.71 | 0.00 | -0.49 | -1.17 |
| 41 | 9 | 1.30 | 0.00 | -0.44 | -0.76 | | 0.53 | 0.00 | -0.24 | -0.56 |
| 42 | 10 | 1.07 | 0.00 | -0.21 | -0.19 | | 0.33 | 0.00 | 0.03 | 0.07 |
| 43 | 11 | 0.84 | 0.00 | 0.00 | 0.31 | | 0.13 | 0.00 | 0.28 | 0.63 |
| 44 | 12 | 0.67 | 0.00 | 0.15 | 0.67 | | -0.03 | 0.00 | 0.47 | 1.03 |
| 45 | 13 | 0.57 | 0.00 | 0.23 | 0.82 | | -0.13 | 0.00 | 0.57 | 1.22 |
| 46 | 14 | 0.57 | 0.00 | 0.22 | 0.73 | | -0.18 | 0.00 | 0.57 | 1.16 |
| 47 | 15 | 0.66 | 0.00 | 0.13 | 0.41 | | -0.15 | 0.00 | 0.46 | 0.86 |
| 48 | 16 | 0.83 | 0.00 | -0.03 | -0.10 | | -0.06 | 0.00 | 0.26 | 0.36 |
| 49 | 17 | 1.06 | 0.00 | -0.22 | -0.72 | | 0.09 | 0.00 | 0.00 | -0.26 |
| 50 | 18 | 1.31 | 0.00 | -0.41 | -1.33 | | 0.27 | 0.00 | -0.29 | -0.90 |
| 51 | 19 | 1.55 | 0.00 | -0.57 | -1.84 | | 0.48 | 0.00 | -0.55 | -1.46 |
| 52 | 20 | 1.73 | 0.00 | -0.66 | -2.14 | | 0.69 | 0.00 | -0.74 | -1.85 |
| 53 | 21 | 1.83 | 0.00 | -0.67 | -2.18 | | 0.88 | 0.00 | -0.82 | -2.01 |
| 54 | 22 | 1.85 | 0.00 | -0.58 | -1.95 | | 1.01 | 0.00 | -0.78 | -1.89 |
| 55 | 23 | 1.77 | 0.00 | -0.43 | -1.51 | | 1.07 | 0.00 | -0.62 | -1.53 |

**Table A-4. TX Phase Shift Calibration Temperature Correction LUT for AWR2243 (continued)**

| Phase shift index | | Correction LUTs for 76-77 GHz Band | | | | | Correction LUTs for band 77-81 GHz Band | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| TX1 | TX2 & TX3 | Temperature Correction LUT (-40C) | Temperature Correction LUT (25C) | Temperature Correction LUT (85C) | Temperature Correction LUT (130C) | | Temperature Correction LUT (-40C) | Temperature Correction LUT (25C) | Temperature Correction LUT (85C) | Temperature Correction LUT (130C) |
| 56 | 24 | 1.61 | 0.00 | -0.23 | -0.95 | | 1.02 | 0.00 | -0.35 | -0.97 |
| 57 | 25 | 1.39 | 0.00 | -0.03 | -0.39 | | 0.86 | 0.00 | -0.03 | -0.32 |
| 58 | 26 | 1.13 | 0.00 | 0.14 | 0.06 | | 0.62 | 0.00 | 0.29 | 0.33 |
| 59 | 27 | 0.85 | 0.00 | 0.25 | 0.36 | | 0.30 | 0.00 | 0.55 | 0.86 |
| 60 | 28 | 0.56 | 0.00 | 0.32 | 0.59 | | 0.10 | 0.00 | 0.69 | 1.17 |
| 61 | 29 | 0.32 | 0.00 | 0.37 | 0.71 | | -0.11 | 0.00 | 0.68 | 1.20 |
| 62 | 30 | 0.15 | 0.00 | 0.40 | 0.66 | | -0.18 | 0.00 | 0.57 | 0.98 |
| 63 | 31 | 0.15 | 0.00 | 0.31 | 0.27 | | -0.12 | 0.00 | 0.45 | 0.66 |

## A.5 Circular Shift of TX Phase Shifter Calibration Data Save and Restore APIs

As mentioned in the ICD, there is a circular shift of phase shift values needed in the saving and restoring of the phase correction codes to overcome some minor limitations inside the device's data storage and phase shifter circuits. This behavior is different across TXs. They are described here for each TX.

For TX2 and TX3, for phase shifter setting/index n=0 to 63 corresponding to functional APIs (e.g. Profile Config, Per Chirp Phase Shifter, and so forth), the calibration data must be retrieved from/restored to following byte locations of TX2 and TX3 phase calibration data save/restore API.

**Table A-5. Circular Shift for TX2 and TX3 Phase Shift Cal Data Save/Restore API**

| n | Desired Phase Shift | Byte Locations in the Save and Restore API Data Packets |
|---|---|---|
| 49 | 49*5.625deg | Byte[1], byte[0] |
| 50 | 50*5.625deg | Byte[3], byte[2] |
| 51 | 51*5.625deg | Byte[5], byte[4] |
| : | : | : |
| 62 | 62*5.625deg | Byte[27], byte[26] |
| 63 | 63*5.625deg | Byte[29], byte[28] |
| 0 | 0*5.625deg | Byte[31], byte[30] |
| 1 | 1*5.625deg | Byte[33], byte[32] |
| 2 | 2*5.625deg | Byte[35], byte[34] |
| : | : | : |
| 47 | 47*5.625deg | Byte[125], byte[124] |
| 48 | 48*5.625deg | Byte[127], byte[126] |

For TX1, for phase shifter setting/index n=0 to 63 corresponding to functional APIs (e.g. Profile Config, Per Chirp Phase Shifter, and so forth), the calibration data must be retrieved from/restored to following byte locations of TX1 phase calibration data save/restore API.

**Table A-6. Circular Shift for TX1 Phase Shift Cal Data Save/Restore API**

| n | Desired phase shift | Byte locations in the Save and Restore API data packets |
|---|---|---|
| 17 | 17*5.625deg | Byte[1], byte[0] |
| 18 | 18*5.625deg | Byte[3], byte[2] |
| 19 | 19*5.625deg | Byte[5], byte[4] |
| : | : | : |
| 62 | 62*5.625deg | Byte[91], byte[90] |
| 63 | 63*5.625deg | Byte[93], byte[92] |

**Table A-6. Circular Shift for TX1 Phase Shift Cal Data Save/Restore API (continued)**

| n | Desired phase shift | Byte locations in the Save and Restore API data packets |
|---|---|---|
| 0 | 0*5.625deg | Byte[95], byte[94] |
| 1 | 1*5.625deg | Byte[97], byte[96] |
| 2 | 2*5.625deg | Byte[99], byte[98] |
| : | : | : |
| 15 | 15*5.625deg | Byte[125], byte[124] |
| 16 | 16*5.625deg | Byte[127], byte[126] |