Application Note

mmWave Production Testing Overview

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ABSTRACT

This application note is meant to act as a guide to testing Radar sensors built using TI's Radar chips. This document is expected to act as a high-level guide to help setup testing of radar sensor units during production. It captures generic requirements of radar testing; the actual test set up and software required to run the tests varies depending on the actual application of the radar. The user is expected to design the test software and determine the appropriate limits for any tests based on the application of the radar.

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1 Sensor RF Performance Validation

Described below are the basic production checks done on a radar module at high-level:

- Basic power-on checks
  - Current drawn at power up
  - Digital Interface checks
- Factory Calibrations
  - Antenna beam tilt measurement
  - Range bias and receiver channel gain/offset compensation
- Parametric checks – Corner Reflector setup
  - Transmitter-receiver loopback SNR

Sensor performance validation can cover the entire range of sensor hardware and software subsystems. This document is not intended to serve as a reference for hardware bring up or validation. Instead, this section describes a high-level overview of the production line testing done on fully validated and characterized hardware to screen for issues on a production ready sensor. These issues generally arise from handling defects, environmental factors, assembly defects, and manufacturing defects.

1.1 Basic Power-on Checks

After the assembly, the sensor board is powered up. The boot-up current drawn from the supply is measured and made sure that it is within the limits. The test program is executed which takes the sensor board through the sequence of tests described in the following sections.

The Radar Test GUI is a program that controls the Radar chip and processes the data that the Sensor captures. It is a custom program developed by the user suiting their end application and test hardware interface available.

1.2 Factory Calibrations

Described below are key factory calibrations that help improve the performance of the sensor by compensating for imperfections introduced by the manufacturing process.

1.2.1 Antenna Beam Tilt Measurement

A transmitter antenna designed to generate peak power at bore-sight may show the peak power tilted away from bore-sight in practice, thus the antenna beam pattern can exhibit a tilt (skew). The magnitude of tilt depends on the antenna and feed design. The tilt could change monotonically with the RF frequency, and the tilt could also change with variations in the PCB. For example, the pattern of glass fabric that is inherent in some of the PCB dielectric materials can interplay with the antenna transmission line geometry and can cause alteration in the radiation pattern, including beam tilt. This is especially true with low-cost PCB materials. Beam tilt is also more pronounced for a high-gain antenna.

The frequency-dependent tilt may be systematic and quantifiable, but the tilt due to PCB artifact may be somewhat random. Beam tilt on the final sensor can include effects of radome and casing. This beam tilt may be a parameter used as a pass/fail criterion or can be corrected in the mechanical mounting of the Radar sensor if required such that the beam tilt of the mounted sensor is effectively zero.

The beam tilt can happen for both transmit and receive antennas. It is typically measured for the required combination (or every combination) of Tx and Rx antennas by using the loopback measurement setup shown in Figure 2-2 explained in the next section.

Procedure: The beam tilt can be measured either in azimuth or in elevation. In this example, assume that the beam tilt is in elevation for the sensor that is being tested. The procedure involves stepping through the elevation angle and measuring the signal strength at each step.

The target (corner reflector) is kept at a distance so that it generates an IF of around 1 MHz. The chirp parameters are chosen appropriately. A narrow-band RF sweep is chosen that sweeps in the center of the band. Narrow band is chosen to minimize the frequency-dependent beam tilt.

Next, the elevation angle is swept. In this example, we use a sweep of 40 degrees. Using a turn-table, position the sensor at one end of the elevation angle sweep at +20 degrees. Use one of the transmitters for generating the chirp. ADC output from all receiver chains are simultaneously captured and processed to measure the signal strength. The signal amplitude from the receivers are averaged. This procedure is repeated by stepping through the elevation angle by some incremental value, such as 0.5 degrees, until the end of the elevation sweep at -20 degrees. The angle corresponding to the maximum received signal strength is the beam tilt for that transmitter.

The above procedure is repeated for each of the transmitters. The sequence may be re-arranged to optimize the procedure. For example, Tx 1-3 measurements can be done for each elevation position before changing the elevation position. This reduces the mismatch in measured beam-tilts between Tx. Sufficient averaging is done to improve the accuracy.

1.2.2 Range Bias and Receiver Channel Gain/Offset Compensation

Due to imperfections introduced in the manufacturing process of the PCB and the SoC calibrations can be applied to compensate for bias in the range and receiver gain and phase introduced from the RF path delays. At a high level, this goal of this procedure is to determine the range bias offset common to all Tx-Rx paths and the gain and phase mismatch of each virtual Tx-Rx pair of an object placed at boresight at a fixed, known distance in the far field. The calibration coefficients generated from this procedure can be applied in post processing to compensate for the relative delay between the Rx paths so that each receiver interprets an object placed at boresight as being at a zero-angle and eliminates any bias in the detected range. The delays are unique to each PCB and sensor and thus each board/sensor pair has a unique set of calibration coefficients. Depending on the placement and orientation of the antennas, the applied correction could be correcting either azimuth or elevation angle. For example, if the receiver antennas are placed horizontally, then it is the azimuth angle that is zero'ed out during this calibration.

Procedure: For this example, assume that the radar sensor has four receiver antennas laid out horizontally so that the zero-angle calibration zero'es out azimuth angle error. The set up used is shown in Figure 2-2. A corner reflector is a preferred target to use for this test as it shows up as a single point, whereas a metal plate can be interpreted as multiple points, which can impact the accuracy of the calibration. The target is kept at a distance large enough so that the difference in azimuth angle from the target to each of the four receivers is negligible. The chirp parameters are chosen appropriately so that it generates an IF of around 1 MHz. The RF sweep is chosen to be within the specified operating range of Radar. One of the transmitters is used for this calibration. ADC output from each receiver chain is simultaneously captured.

First, using a turn-table the elevation beam tilt, if any, is compensated so that the sensor beam is made horizontal. Next the radar sensor is kept at zero-degree azimuth angle from the target. The ADC output is captured and is processed to get the FFT and further the relative phase difference between each Rx path. The range bias coefficient is computed based on the peak position and the known target distance of X. The gain and phase mismatch between each virtual Tx-Rx pair is computed and the coefficients are generated such that each of the virtual channels is forced to zero phase for the object at boresight. The coefficients can then be stored in a LUT and used in angle of arrival computations. Sufficient averaging is done to improve the accuracy. Confirmatory readings are taken at a couple of known angles on either side of zero to confirm that the calibration works.

The mmWave SDK provides a method for generating the calibration coefficients over the command line interface via the Out of Box Demo. For more details, refer to the mmWave SDK User's Guide. Additionally, the procedure and implementation of the calibration routine in the data-path processing chain can be found in the mmWave SDK install folder at mmwave_sdk_<ver>\packages\ti\datapath\dpc\objectdetection\<chain_type>\docs\doxygen\html\index.html. The user can use the OOB directly to perform the calibration or can port the provided source code into their own custom application.

1.3 Parametric Tests

Described below are the key parametric tests done during production.

1.3.1 Transmitter-Receiver Loopback SNR

In this test, the SNR of a target object is measured in a radiated Tx-Rx loopback and validated against the link budget analysis. This test combines the Tx output power and Rx Noise Figure into one test and helps to correlate the sensor to the calculated link budget. Any issues in transmitter gain, output power, or receiver gain can be detected by this test. Additionally, this test helps to verify the two-way path losses and noise figure of the system.

Procedure: The corner reflector is placed at a far-field distance inside the anechoic chamber as shown in Figure 2-2. The chirp parameters are chosen appropriately so that it generates an IF of around 1 MHz. The RF sweep is chosen to be within the specified operating range of Radar. One transmitter and all receivers are selected first. The SNR of the FFT signal corresponding to the target is measured for each receiver. This is repeated for all the transmitters. The expected SNR can be calculated from the Radar equation below.

$$SNR = (P_t * G_{Rx} * G_{Tx} * c^2 * \sigma * N * T_r) / (f_c{}^2 * (4\pi)^3 * kT * NF * R^4) \quad (1)$$

P_t = TX output power

R = Range of object

G_{Rx}, G_{Tx} = RX and TX antenna gain

σ = RCS of the object

f_c = Center frequency of the chirp ramp

N = Number of chirps

T_r = Chirp ramp time in seconds

NF = Noise figure of the receiver

SNR = Signal to noise ratio

k = Boltzman constant

T = Effective noise temperature

The Radar equation helps to estimate the expected SNR for a given an object of a given RCS. The RCS of the corner reflector used in the test must be known correctly. Any variables that can impact the SNR such as a radome enclosure or a car bumper should be considered in the calculation. The temperature also impacts the performance of the radar, thus testing should be performed in a controlled environment.

The SNR test should be done for different RF frequencies to cover all the frequencies of operation. The calculated SNR based on the link budget analysis and the measured SNR should be compared to confirm that the radar is operating within the specified bounds.

1.4 Golden Sensor Unit

In a production calibration setting, it is important to have a 'golden' unit that can be used as a reference and to calibrate the test setup. The golden unit is a sensor that has been tested and proven to provide accurate results and as such can be used to help uncover issues in the test setup or to help calibrate a test setup. The link budget of the golden unit should be correlated to the measured SNR using the procedure described in the Tx-Rx Loopback SNR test.

When the golden unit has been tested and verified to provide accurate results, this unit can be used to periodically calibrate the test setup or to help debug any potential issues in the test setup. For example, in the event that many sensors begin to fail a test, the golden unit can be tested, and if the golden unit fails it is an indication that there could be an issue with the test setup itself. In some cases, the golden unit can be damaged, making it difficult to calibrate the test setup or debug any test setup issues. For this reason, it can be valuable to have multiple golden units in the given event that the original golden unit is damaged.

2 Low-Cost Manufacturing Setup

When testing any RF parameters or performing calibrations, it is important to ensure that the tests are performed in a clutter free environment. Ideally, tests should be done in an anechoic chamber to minimize clutter and ensure that the corner reflector is easily identifiable. However, as long as the noise created by the clutter is low enough so that there is no chance for a competing object to be used for calibration, an anechoic chamber is not necessarily required. In the event that an environmental object is accidentally used in calibration, this could cause the sensor to malfunction and underperform in the field. This section describes the typical hardware needed for a radar production test environment.

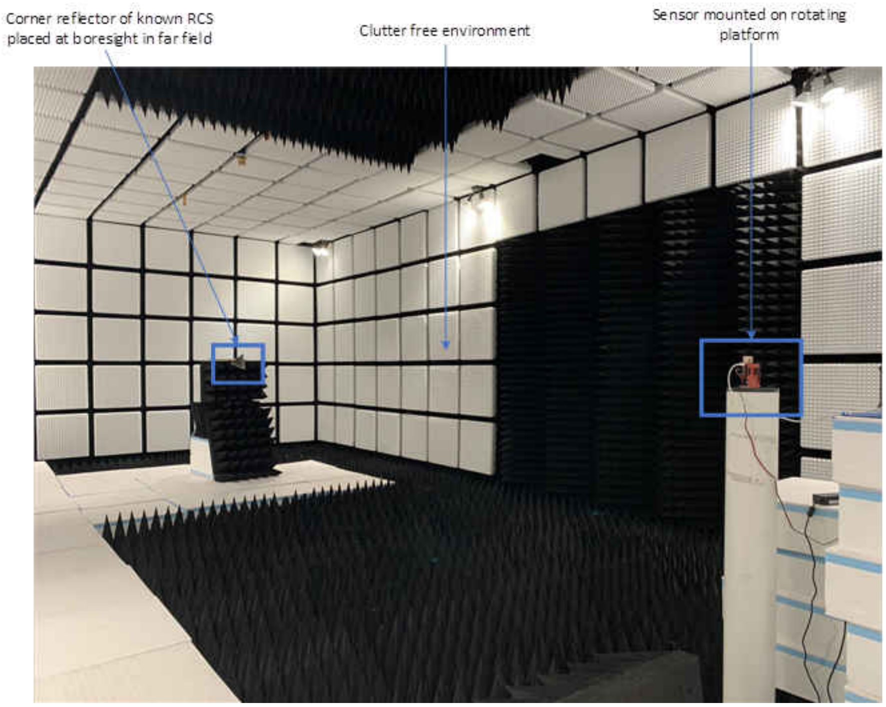

Figure 2-1. Example Test Environment

2.1 Hardware

The hardware for testing Radar is shown below. It comprises of the following components:

- Anechoic chamber with turn-table
- Corner reflector
- DC supply with ammeter
- Computer for data & control interface to the Radar unit and also for controlling the turn-table

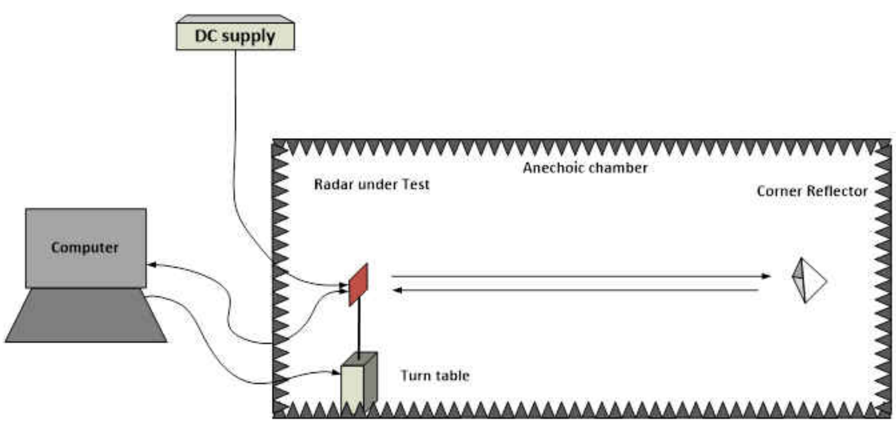

Figure 2-2. Hardware for Basic Radar Testing

The width and height of anechoic chamber can be typically with W × H = 60 cm × 60 cm. The length of the chamber should be such that the corner reflector can be placed well in far-field zone. The formula given below can be used to calculate the far-field zone.

Minimum Far-field distance, $d = 2.D^2 / \lambda$

Where D is the maximum dimension of the antenna array,

λ is the wavelength of the signal in air.

For example, a radar designed using a single mmWave sensor operating in 76-77GHz band with an antenna array that spans 24 mm will have d = 295 mm. After allowing space for turn-table and corner reflector and cabling, a 60-cm long chamber should suffice to test this Radar.

2.1.1 Low Cost Bench Top Anechoic Chamber

One option for a low-cost production testing environment is to build a custom bench top anechoic chamber with mmWave absorber materials. The chamber should be lined with a mmWave absorber material that provides sufficient absorption for the desired frequency of operation. Milliwave Silicon Solutions produces pre-built chambers, called a MilliBox, that are designed to provide -50 dB absorption at 60 GHz and 77 GHz at nominal incidence. These chambers are modular and can be configured to meet various different far field distance requirements and can be as small as 4’ x 3’ x 2’ to fit in space constrained environments or on a lab bench top. The chamber can be fit with a gimbal to rotate the DUT ±180 degrees along the horizontal and vertical axis. The gimbal can be automated using the test PC over a USB serial interface. A horn post can be mounted on the opposite side of the chamber to provide a location to mount a horn antenna or a corner reflector target.

Figure 2-3. Example Bench Top Anechoic Chamber

2.2 Software

The following software programs are required as part of the setup:

- Radar Test GUI: Application software to program the Radar device and analyze the data. This is a custom GUI specific to a sensor.
- Gimbal app: Application software to control the turn-table.

3 Advanced Test Setup

3.1 Target Simulator Setup

Using a Radar Target Simulator, additional parameters can be tested such as long range SNR. The Target Simulator takes in the TX signal from the DUT sensor and emulates a target at certain distance and velocity and sends the signal back to the DUT sensor. The target simulator can simulate a single object or multiple objects over multiple angles of arrival. The target simulator can also be programmed with various different scenarios that can be used to test target detection and classification algorithms.

Long-range SNR may be an essential production test for certain applications like long range radar. Figure 3-1 shows the hardware test setup using Target Simulator.

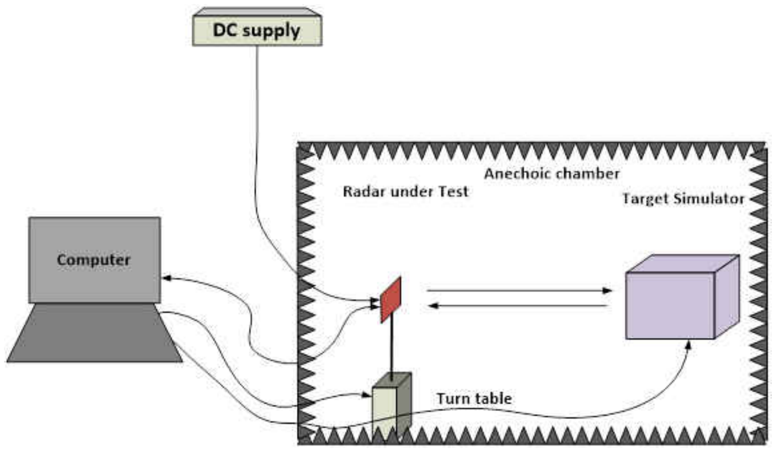

Figure 3-1. Hardware for Radar Testing using Target Simulator

4 References

1. Texas Instruments: *Programming Chirp Parameters in TI Radar Devices*
2. Texas Instruments: *TI mmWave Radar Sensor RF PCB Design, Manufacturing and Validation Guide*
3. Milliwave Silicon Solutions