APPLICATION NOTE

APS312

Production Tests for DW3000-Based Products

Typical production tests for products using DW3000 series ICs

Referenced Documents

The reference documents below take precedence over the contents of this application note, and should always be consulted for the latest information.

DW3000 Data Sheet

DW3000 User Manual

Table of Contents

1 Overview

1.1 Introduction

This document is intended to be used as a guide for the production testing of DW3000-based products. The tests suggested in this document refer only to tests associated with DW3000; you will need to include additional tests to cover the other aspects of your product's functionality. The tests can be reduced or edited depending on the particular DW3000 use case.

1.2 General test scope

These tests assume the main active component in the product is the DW3000 IC. This IC is delivered pre-tested however a number of product tests are required to ensure that the product is assembled correctly. For some tests the product also needs to be calibrated for correct operation and to ensure that FCC, ETSI or other spectral mask regulations are met.

Calibration data can be programmed into non-volatile memory (OTP) on the DW3000 IC as part of your production test or into off-chip non-volatile memory (NVM) so that firmware in the DUT can subsequently access it and use it to configure the DW3000 during product operation.

For brevity throughout this document it is assumed that calibration data is programmed into the DW3000 OTP.

2 Test Environment

2.1 Test Setup Overview

Table 1 below shows the general test conditions.

Item	Condition	Value	Units
1	*Test voltage* Note: You should use the nominal voltage that is intended to be used in your product during its normal operation. You should record the actual voltage used during test.	2.4 – 3.6	V DC
2	*Voltage for programming calibration data into on-chip non-volatile memory.* Note: This is required to program the DW3000 on-chip OTP memory. If your product design does not support this voltage then calibration data will need to be stored in some other non-volatile memory in your product.	2.75 – 3.6	V DC
3	*Test temperature* Note: You should record the temperature of the DW3000 during test using the on-chip ADC and store the resulting value in OTP. Some calibration parameters vary with temperature as detailed in [1].	Should be recorded and stored in OTP	°C

Table 1: Test setup – general conditions

Figure 1 below shows the test set up for testing DW3000-based products. The diagram assumes that the product contains an integral antenna, i.e. there is no RF connector and therefore the product must be tested in an over-the-air (OTA) test set up. Typically, this setup consists of an RF absorber-lined screened box in which the Device-Under-Test (DUT) and the test antenna are installed at a known distance apart.

If the DUT does have an RF connector, a coax cable should be used to directly connect the DUT to the RF Switch – the test setup will need to be calibrated in this configuration.

This setup allows three different test modes: -

- DUT tests, where the RF section on the DUT is not used.
- DUT transmitter tests, where the DUT is connected via the RF switch to the spectrum analyzer so that the transmit output of the DUT can be observed, measured and adjusted.
- DUT receiver tests, where the DUT is connected via the RF switch to the Reference Test Board (RTB) so that a known signal can be provided to the DUT and the signal observed by the DUT can be analyzed.

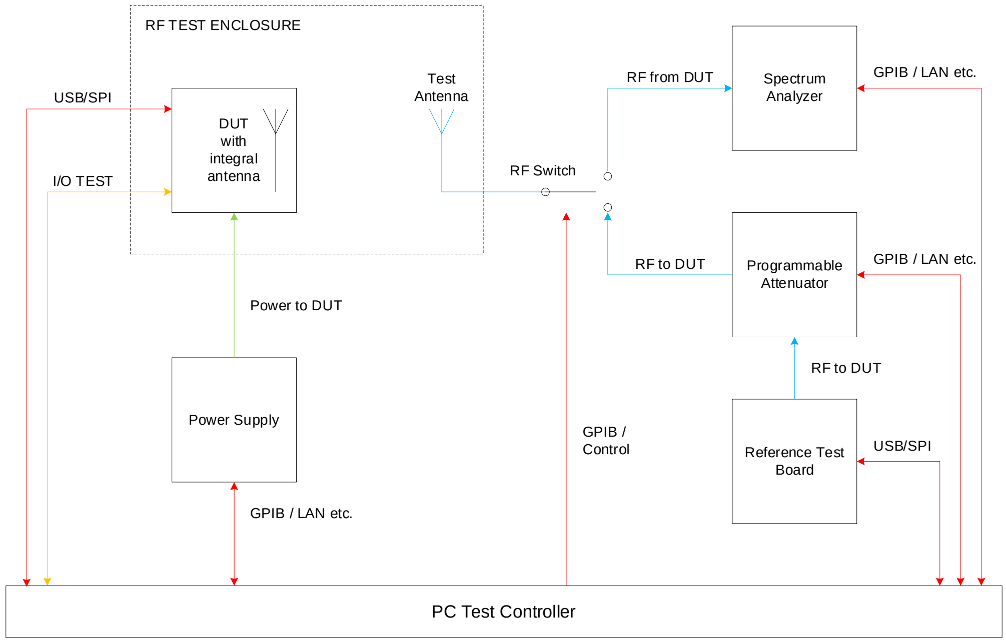


Figure 1: Customer product test setup block diagram

The following is a list of suggested test equipment. Where particular manufacturers' equipment is suggested, equipment with similar specifications should be perfectly acceptable.

Item	Test Equipment	Comment
1	Programmable Power Supply	Any supply capable of providing the required voltage and current and which supports remote control over GPIB / LAN etc.
2	GPIB Controller	Any GPIB controller with the requisite number of ports and which is compatible with the other equipment being used is acceptable.
3	RF Switch	e.g. Mini Circuits USB-1SPDT-A18 or similar.
4	Spectrum Analyser	Any analyser with the appropriate frequency range and an RMS detector is acceptable.
5	Programmable Attenuator	e.g. Agilent 11713A controller / Agilent 8495H 70 dB attenuator / Agilent 8494 11dB attenuator.
6	Shielded Test Cell	e.g. Tieok TK-B1332M (see Figure 2)

Table 2: Suggested test equipment

Note: Equipment vendors such as Litepoint (IQgig-UWB) and Rohde&Schwarz (CMP200) are now developing dedicated IEEE802.15.4A/Z UWB testers which will be capable of replacing the reference board, programmable attenuators and spectrum analyser shown in Figure 1.

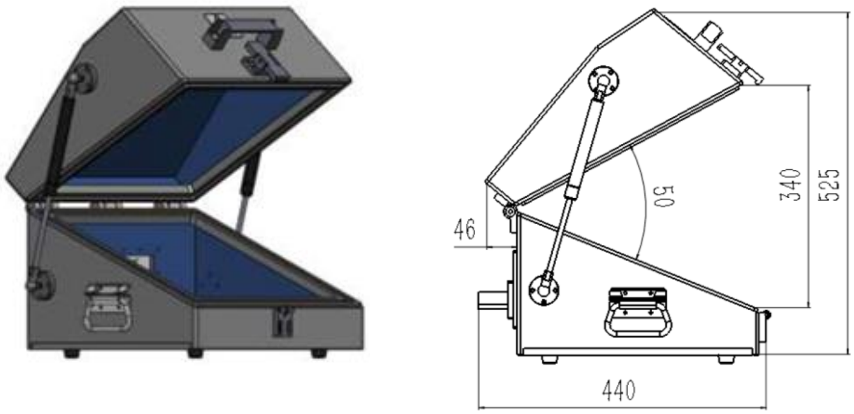


Figure 2. Example shielded test cell for DUT and test antenna (dimensions in mm)

2.2 Calibrating the Test Setup

2.2.1 Overview

In general, test setup calibration should be regularly carried out until such time as the test setup is proven to be stable. Thereafter the calibration interval can be extended.

Tests requiring the test setup to be calibrated fall into two categories.

1. Those that deal with absolute power levels transmitted or received by the DUT (e.g. transmit power calibration, receiver sensitivity).
2. Those that deal with calibrating the antenna delay of the DUT (e.g. if your product is intended to be used in or as a location system or range measurement device and you have decided that antenna delay calibration is necessary to achieve the accuracy you require in your application. See [4] for a detailed discussion on this topic).

If you intend performing this test in production: -	Then the test setup needs to be measured for: -
DUT transmit spectrum optimization	Losses between the DUT and the spectrum analyser
DUT receiver sensitivity tests	Losses between the Reference Test Board (RTB) and the DUT

Table 3: Measurements related to losses in the test setup

If you intend calibrating: -	Then: -
DUT antenna delay	The “Calibration Distance” of the test setup needs to be determined.

Table 4: Measurements related to the antenna delay in the test setup

2.2.2 DW3000 Reference Test Board (RTB)

Any test in which the DUT needs to receive a calibrated UWB signal requires the use of an RTB. This RTB needs to be capable of being connected to the test setup via coax cable.

Qorvo uses its own DW3000 development board, correctly calibrated, as an RTB for in-house testing.

2.2.3 Calibrating Transmit Path Losses

2.2.3.1 Components of the Path Loss

This section describes the method used to calibrate the losses in the transmit path from the DUT to the spectrum analyzer such that the observed measurement at the spectrum analyzer can be corrected for the path loss to give the actual transmit signal from the DUT.

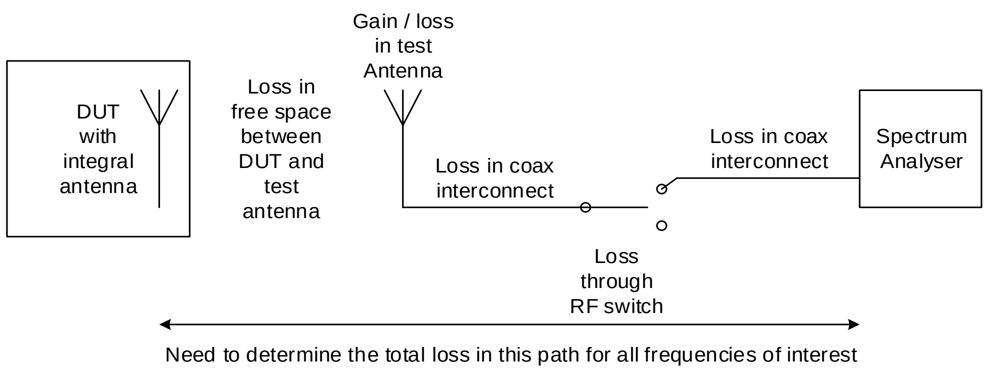


Figure 3: Identification of DUT test setup transmit path losses

The transmit power observed at the spectrum analyzer, P_{SA}, is given by: -

$$P_{SA} = P_{DUT} – \text{PATH LOSS}$$

$$P_{SA} = P_{DUT} – (L_{FREESPACE} – L_{TA} – L_{I1} – L_{RFSW} – L_{I2}) \text{ or;}$$

$$P_{DUT} = P_{SA} + (L_{FREESPACE} + L_{TA} + L_{I1} + L_{RFSW} + L_{I2})$$

Where: -

P_{DUT}	=	Actual signal power transmitted by DUT
$L_{FREESPACE}$	=	Attenuation in free space between the DUT antenna and the test setup antenna
L_{TA}	=	Loss in the test antenna. If the test antenna has any gain this need to be subtracted
$L_{I1, 2}$	=	Losses in the coax interconnect
L_{RFSW}	=	Loss in the RF switch

2.2.3.2 Measuring the Path Loss

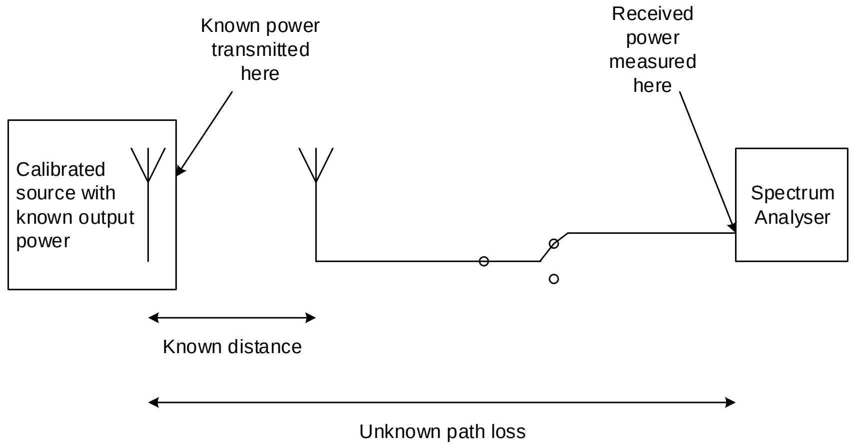


Figure 4: DUT test setup transmit path loss measurement

Calibrating the test setup involves inserting a DUT that has been previously calibrated in an anechoic chamber and whose radiated output power is known. By observing the power measured at the spectrum analyzer and knowing the power transmitted by the calibrated source, the path loss can be determined by subtraction.

It is important to perform this calibration for all UWB channel frequencies and values of PRF intended to be used in your final product since the path loss will vary depending on frequency and PRF.

These path loss figures should be recorded for subsequent use in production testing.

The flowchart in Figure 5 below describes the measurement procedure.

2.2.3.3 Obtaining a Calibrated Source

A DUT should be calibrated in an anechoic chamber in a calibrated measurement setup. Once calibrated there, it can be used as a “golden unit” to calibrate the test setup.

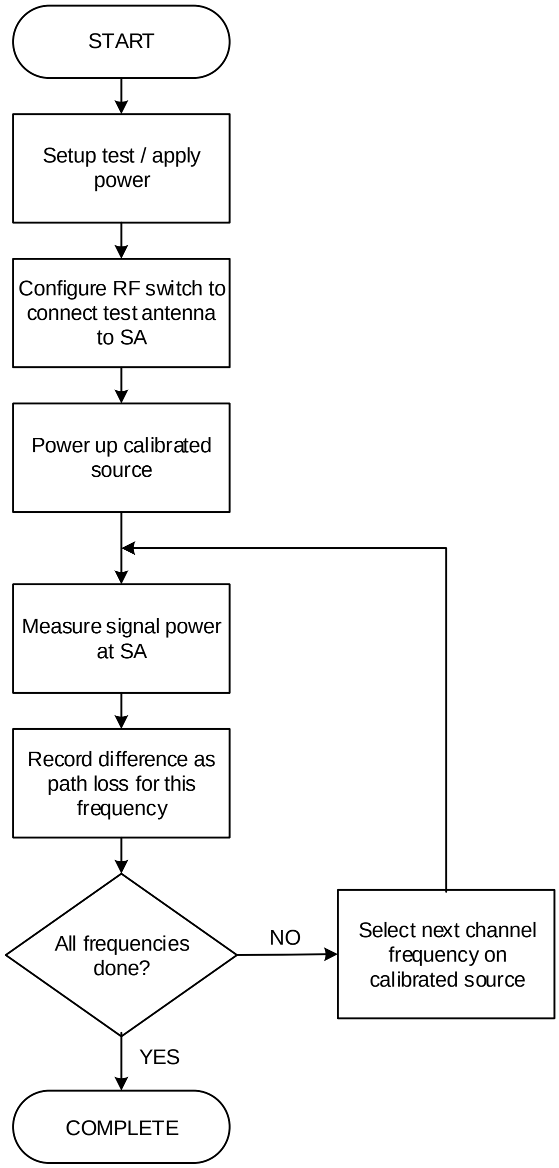


Figure 5: DUT test setup transmit path loss measurement procedure

It is recommended that the transmit path loss of the test setup be calibrated at regular intervals and it **must** be carried out if any part of the transmit path in the test setup is replaced or modified.

2.2.3.4 Transmit Configuration for Test Station

When calibrating the golden unit in the anechoic chamber, the device is configured to transmit a repeated sequence of a single UWB frame per millisecond. This is consistent with how your product should be configured during radio emissions testing in a test house for certification purposes.

When calibrating the production test station, it can be found that, when transmitting a single frame per millisecond, small spurs can sometimes be seen in the spectrum and that a smoother spectrum is seen when transmitting continuous frames, i.e. back-to-back frames with a short duration between frames. It is desirable to have a signal trace that is as smooth as possible, avoiding random spurs which can make power calibration less accurate. For this reason, it can be better to use continuous frame mode for transmit power calibration in the production station. Although the measured power increases with the increased duty cycle in continuous frame mode, this can be calibrated out (note the amplitude offset applied in Figure 6).

Note that the transmit configuration should be the same for golden units and DUTs passed through the test station.

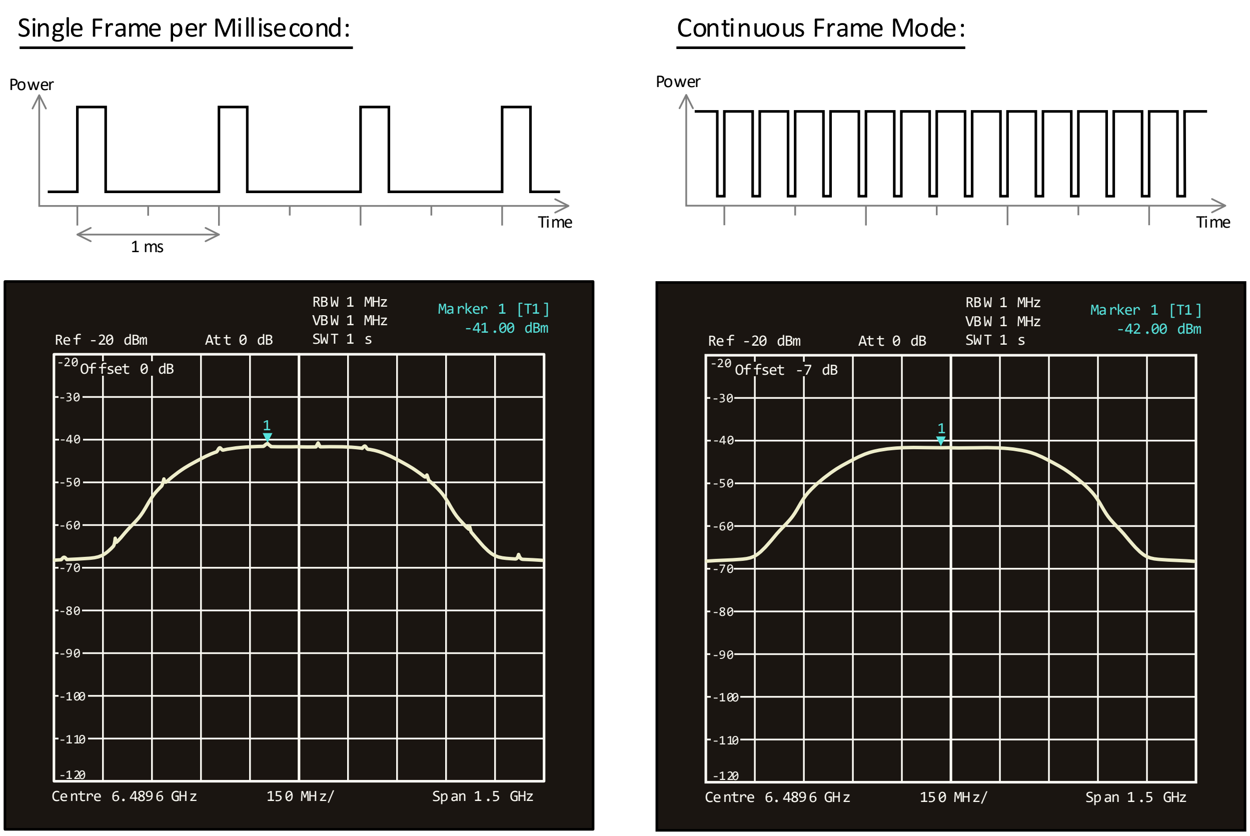


Figure 6. Rendering of Transmit Signal on Spectrum Analyser

2.2.4 Calibrating the Receive Path Losses

This section describes the method used to calibrate the loss in the receive path from the RTB to the DUT such that the received signal level at the DUT can be determined for a given transmit signal level from the RTB.

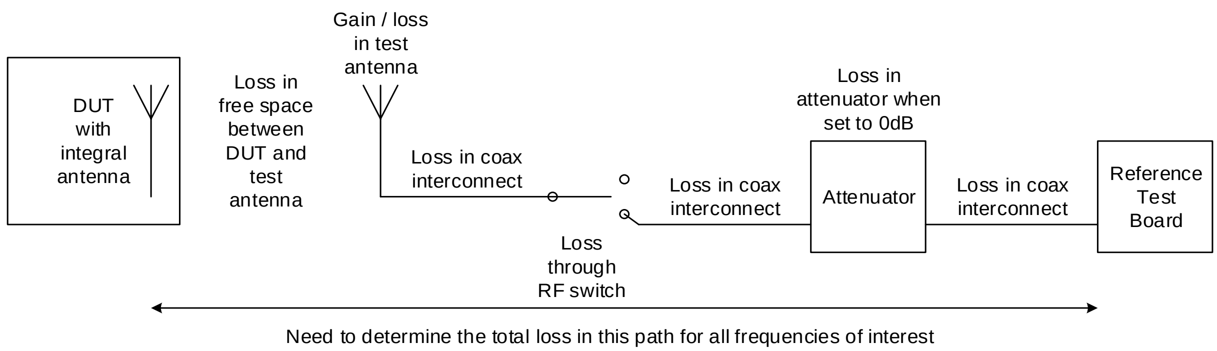


Figure 7: Identification of DUT receive path losses

The receive signal power observed at the DUT, P_{RDUT}, is given by: -

$$P_{RDUT} = P_{RTB} - \text{PATH LOSS}$$

$$P_{RDUT} = P_{RTB} - (L_{I1} + L_{ATT} + L_{I2} + L_{RFSW} + L_{I3} + L_{TA} + L_{FREESPACE})$$

Where: -

P_{RDUT}	=	Signal power received at DUT
P_{RTB}	=	Signal power transmitted by reference test board
$L_{I1, 2, 3}$	=	Losses in the coax interconnect
L_{ATT}	=	Losses in the attenuator
L_{RFSW}	=	Losses in the RF switch
L_{TA}	=	Losses in the test antenna. If the test antenna has any gain this needs to be subtracted
$L_{FREESPACE}$	=	Attenuation in free space between the test setup antenna and the DUT antenna

Calibration involves the physical substitution of the DUT with a calibrated measurement setup. A spectrum analyzer is connected to an antenna of the same type as that used in the DUT (or to an antenna whose performance has been correlated with the DUT antenna) via coax interconnect whose loss is known at the frequencies of interest.

The RTB is configured to transmit a known signal power and the power received at the spectrum analyzer is measured and adjusted for gain / loss in the calibrated antenna and coax interconnect to give the actual received power.

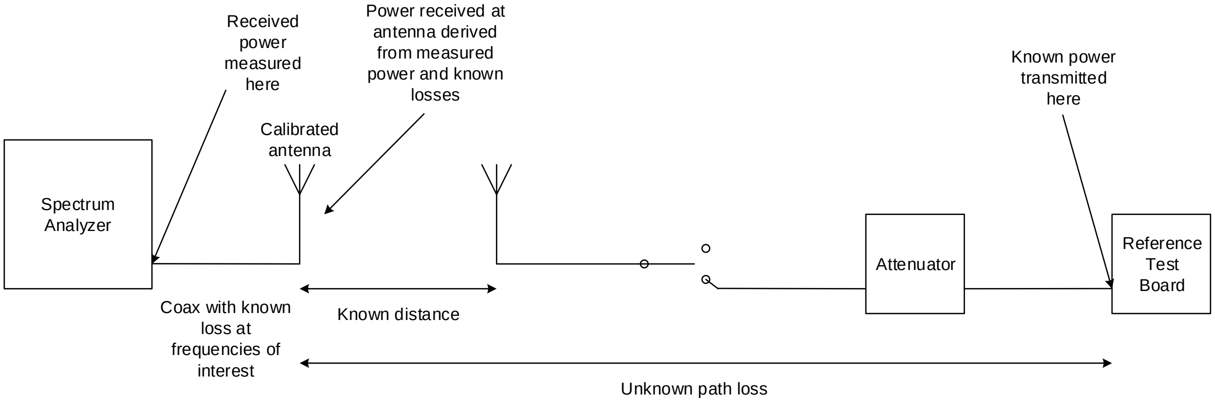


Figure 8: DUT receive path loss measurement setup

The difference between the signal power received at the calibrated antenna and the power transmitted by the reference test board is the path loss.

It is important to perform this calibration for all UWB channel frequencies and values of PRF intended to be used in your product since the path loss will vary depending on frequency and PRF. These path loss figures should be recorded for subsequent use in production testing.

The flowchart in Figure 9 below describes the measurement procedure.

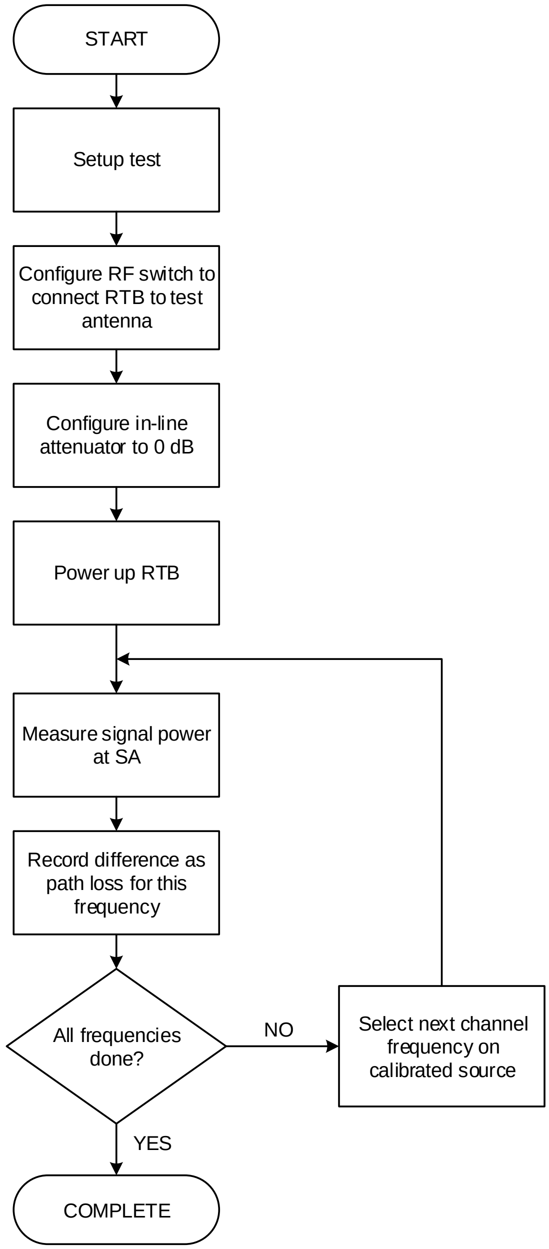


Figure 9: Receive path loss measurement procedure

It is recommended that the receive path loss of the test setup be calibrated at regular intervals and it **must** be carried out if any part of the receive path in the test setup is replaced or modified.

2.2.5 Calibrating for Antenna Delay

Two-way ranging (TWR) between two DW3000-based units determines the time of flight between the two units by exchanging messages, noting transmit and receive times and using an algorithm to remove turn-around times at each node. TWR can be used to derive the delay in the test setup.

Calibrating the test setup involves two steps as follows.

- **Step 1:** Two-way ranging is performed between a DUT and the RTB in free space, outside the test setup. The units are separated by a known distance and the antenna delay of the DUT is adjusted until the reported distance is correct. The units are now correctly calibrated to report ranging measurements.

- **Step 2:** The DUT and RTB are then inserted into the test setup and the process is repeated. The reported distance, which will be larger than the actual separation between the test antenna and the DUT, reflects the fact that the test setup introduces some additional delay. This difference in the reported distance should be noted as the "calibration distance" of the test setup.

The test setup can now be used for production testing. During production testing of DUTs the distance reported using two-way ranging with the DUT should be adjusted by this "calibration distance". The antenna delay in the DUT can then be adjusted to give the correct distance measurement thereby correctly calibrating the antenna delay in the DUT.

It is recommended that the antenna delay of the test setup be calibrated at regular intervals and it **must** be carried out if any element of the path between the RTB and the DUT is replaced or modified.

The subject of antenna delay calibration is covered in detail in [4].

2.2.5.1 Step 1: Free Space Measurements

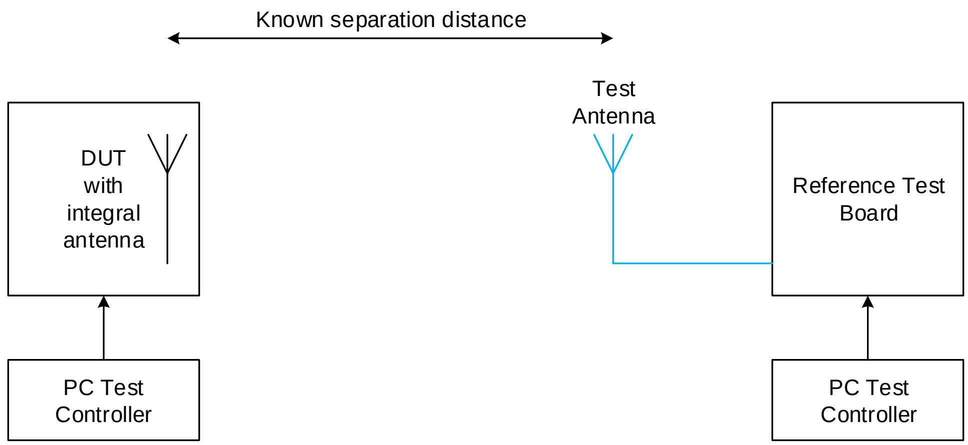


Figure 10: Two-way ranging calibration block diagram - Step 1

Setting up a TWR exchange between DUT and RTB at a known distance allows the DUT to be calibrated by adjusting its antenna delay setting. The separation distance should be that which gives a channel power at the input of either receiver of approximately -88 dBm. The distance is determined using the Friis transmission equation and is different for Channel 5 and Channel 9.

2.2.5.2 Step 2: Measurements in the Test Setup

Step 2 puts the DUT and RTB from step 1 into the test setup.

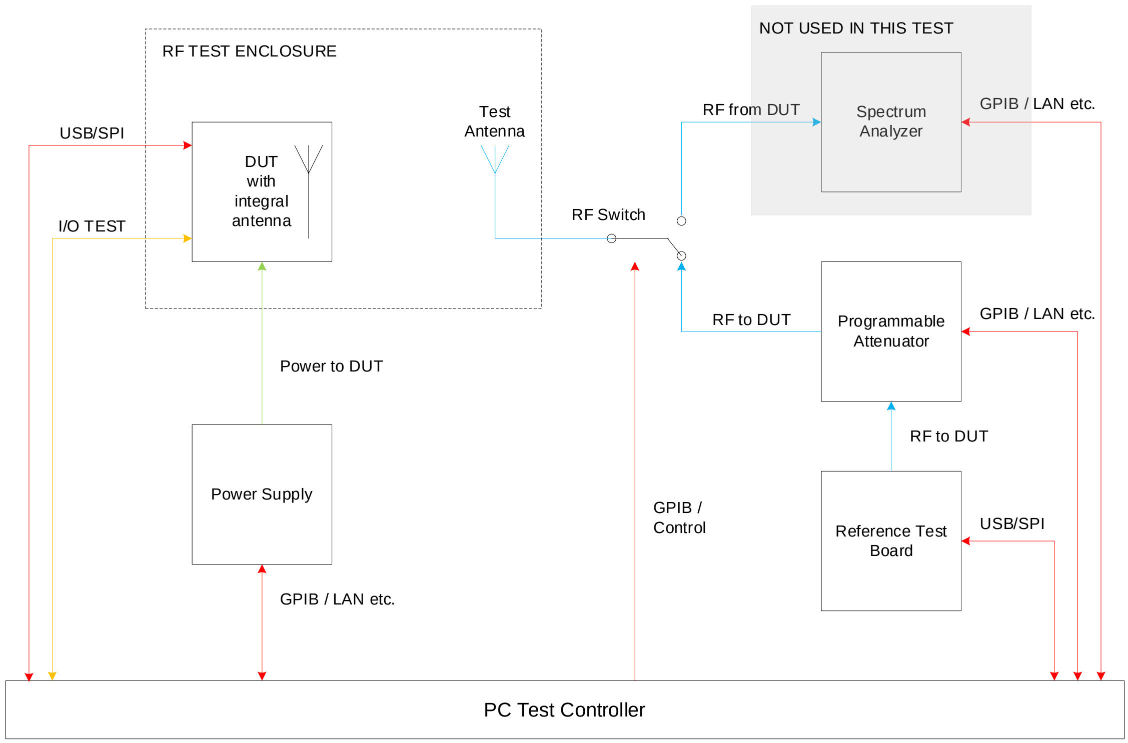


Figure 11: Test setup for antenna delay measurement using two-way ranging – Step 2

The flowchart in Figure 12 below describes this two-step process.

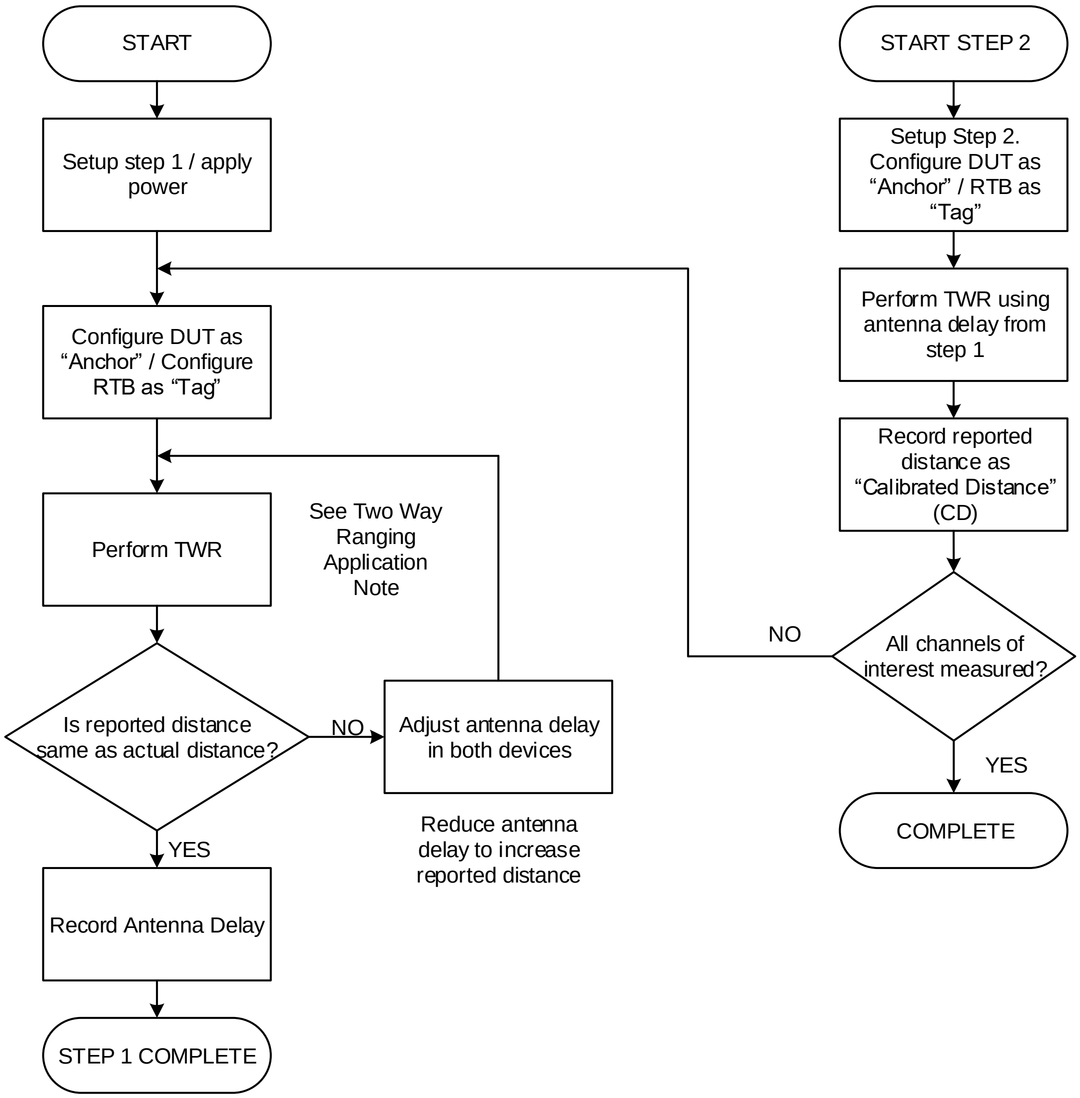


Figure 12: Using two-way ranging to determine the antenna delay of the test setup

3 Production tests

3.1 Overview

The full list of production tests described in this document is shown in the table below. Tests 1.1 to 1.7 check basic operation of the DW3000 IC and soldering integrity, whereas tests from 2.1 measure and calibrate UWB radio metrics.

The selection of which tests to run depends on the intended application of the DW3000 product. For example, if you are not using GPIO lines in your application then there is no need to test their functionality.

Test	Test Name	Test Summary	Test Setup Mode
1.1	Idle mode current	Apply supply voltage to product. Measure supply current after 10 ms.	DUT Only
1.2	SPI test	Read the DW3000 device ID.	DUT Only
1.3	Current consumption	Configure DUT as transmit or receive.	DUT Only
1.4	GPIO strobe test	Use SPI commands to run GPIO strobe routing Verify that all GPIO, IRQ and SYNC lines are asserted correctly.	DUT Only
1.5	RSTn test	Check that the RSTn line goes high after power is applied.	DUT Only
1.6	WAKEUP test	Use SPI commands to set the DUT into SLEEP mode. Assert WAKEUP pin to bring device out of SLEEP.	DUT Only
1.7	EXTON test	Check that the EXTON line goes high after power is applied.	DUT Only
2.1	Crystal trim	Configure the DUT to output a CW test mode signal. Adjust the DUT crystal trim register until the output signal is as close to the chosen carrier frequency as possible. Program the adjust crystal trim value into OTP.	DUT connected to Spectrum Analyzer or frequency counter
2.2-2.3	Channel spectrum	Configure the DUT to repeatedly transmit frames. Adjust transmit power until transmit spectrum meets spectral regulations. Program adjusted transmit power values into OTP.	DUT connected to Spectrum Analyzer
3.1	Receiver sensitivity	Configure DUT to receive mode and Reference Test Board to transmit mode. Transmit frames and check the receive rate for different receive signal power levels.	DUT connected to Reference Test Board
3.2	Antenna delay calibration using two-way ranging	Configure DUT to Anchor mode and Reference Test Board as Tag mode. Check reported distances to ensure correct operation.	DUT connected to Reference Test Board

Table 5: Summary list of production tests

3.2 Operational Tests

The tests listed in Table 6 are intended to check the fundamental operation and soldering integrity of the DW3000 IC.

3.2.1 Summary of Tests

Test	Test Name	Test Description	Limits	Test Applicability	Comments
1.1	Idle mode current consumption	Apply supply voltage to product and measure current after 10 ms.	Min 10 mA Max 13 mA	Recommended on a per-DUT basis.	These limits depend on what other circuitry is in your product and the supply voltage you are using during test.
1.2	SPI test	Run SPI Test.	Pass / Fail	Recommended on a per-DUT basis.	
1.3	Current consumption	Configure DUT as transmit or receive.	Min 30 mA Max 90 mA	Recommended on a per-DUT basis.	These limits depend on what other circuitry is in your product and the supply voltage you are using during test.
1.4	GPIO strobe test	Use SPI commands to run GPIO strobe routing. Verify that all GPIO, IRQ and SYNC lines are asserted.	GPIO, IRQ and SYNC lines go high then low as requested.	Only necessary if you are using these signals in your product.	
1.5	RSTn test	Check that the reset line goes high after power is applied.	Reset line goes high.	Recommended on a per-DUT basis.	Wait 5 ms after applying power.
1.6	WAKEUP test	Using SPI commands to set DUT device into SLEEP mode. Assert WAKEUP pin to bring device out of sleep.	Sleep mode current <1 µA then as per 1.1 above when WAKEUP asserted.	Only necessary if you are using WAKEUP functionality in your product.	Current after WAKEUP should be the same as Test 1.1 above.
1.7	EXTON test	Check that the EXTON line goes high after power is applied.	EXTON line goes high.	Only necessary if you are using EXTON functionality in your product.	Wait 5 ms after applying power.

Table 6: Production tests prior to checking / calibrating the transmitter and receiver

3.3 UWB Transmit Tests

3.3.1 Crystal Trim Calibration

3.3.1.1 Test Applicability

It is recommended that this test be carried out on a per-DUT basis to maximize range performance over the lifetime of each unit. This test is **not applicable** if your product uses a TCXO, OCXO or is intended to be driven by an external reference (e.g. an anchor node in an RTLS using wired clock distribution).

3.3.1.2 Test Summary

Test	Test Name	Test Description	Limits	Comments
2.1	Crystal Trim	Configure the DUT to output a CW test mode signal on your chosen channel center frequency. Adjust the DUT crystal trim register until the output signal is as close to the channel center frequency as possible.	Channel center frequency in MHz ± 3 ppm.	This test is used to trim the loading capacitance on the DUT crystal oscillator to center the carrier frequency. Refer to [1].

Table 7: Production tests – crystal trim

3.3.1.3 Test Description

The crystal trim test setup is shown in Figure 13 below. The DUT is connected to the spectrum analyzer. The spectrum analyzer allows the frequency of the CW signal from the DUT to be observed.

Note: To perform this test, your product software should have a **test mode** that enables the DW3000 to output a CW signal on your primary operating channel. Qorvo's software API includes a function to do this.

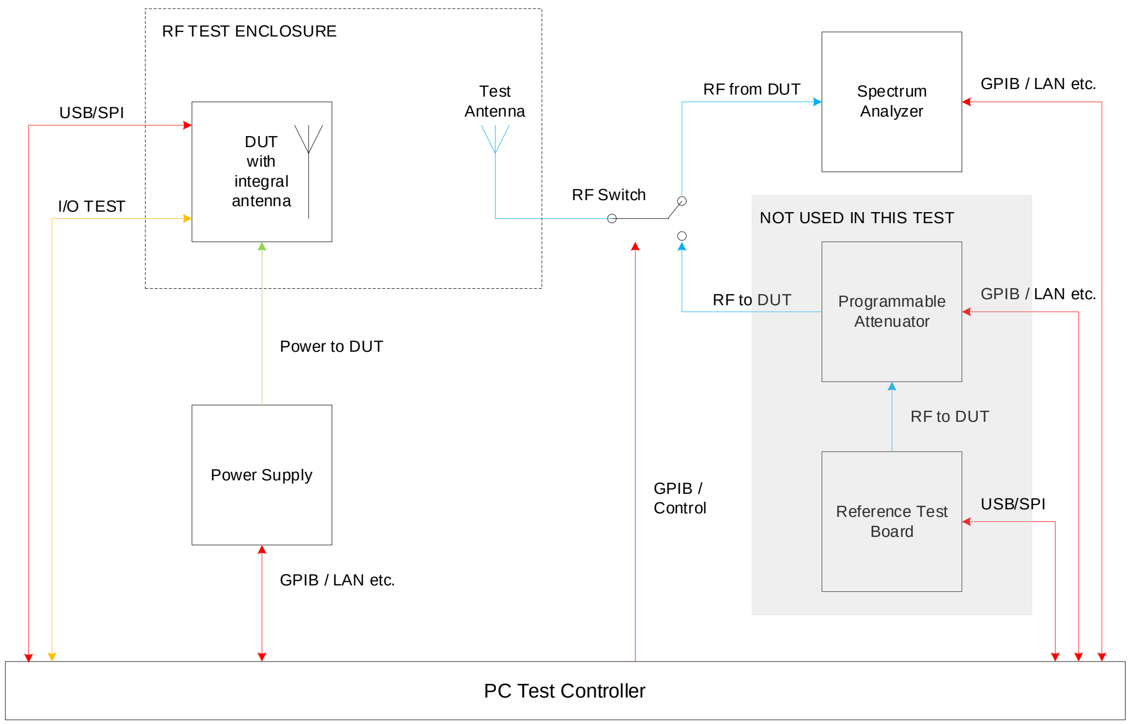


Figure 13: Crystal trim test setup block diagram

3.3.1.4 DUT Configuration

The DUT configuration for this test is shown in Table 8 below.

Parameter	Setting
Channel	Primary operating channel
PRF	N/A
Data Rate	N/A
Preamble code	N/A
Preamble length	N/A
Data payload	N/A

Table 8: DUT configuration for crystal trim test

3.3.1.5 Test Procedure

Refer to section 10.1 in [2].

Program the resulting trim value into the on-chip one-time-programmable (OTP) memory in the location indicated in Appendix E.

3.3.1.6 Alternative Method – GPIO Clock

An alternative test method is possible that does not require a spectrum analyzer. This method configures a GPIO on the DW3000 to output a divided version of the internal system clock. This clock signal may then be observed using a frequency counter.

To configure GPIO0 to output the clock signal, write 0x3 to GPIO_MODE register Reg_0x05:00. The frequency of the clock signal is equal to the internal system clock divided by four, i.e. 31.25 MHz.

3.3.1.7 Alternative Method – Two-Way Ranging

It is possible to use carrier frequency offset calculations from two-way ranging exchanges to calibrate the crystal. The DUT can range with the reference test board in the production setup and the DW3000 can determine the frequency offset using the receiver's clock recovery circuit. By minimising the reported frequency offset in the ranging exchanges, the crystal frequency of the DUT can be tuned to match that of the reference test board.

Formulas for calculating frequency offset can be found in the carrier recovery integrator register description section of [2].

3.3.2 Transmit Power Calibration

3.3.2.1 Test Applicability

During design verification and characterization, you should measure the nominal loss in the RF path between the DW3000 and the antenna to determine the **nominal transmit power value** required from the DW3000 to compensate for this loss. With the DW3000 configured with this nominal transmit power value, the power radiated from the DUT antenna will **vary** between DUTs due to component tolerances etc.

It is **recommended** that this test be carried out in production on a per-DUT basis to ensure transmit power is as close to the allowed regulatory limit as possible to maximize range performance and compensate for any inter-unit variation. **Not doing** this test on a per-DUT basis will require the nominal Tx power setting to be "backed-off" from the regulatory limit to ensure that all units are **guaranteed** to meet that regulatory limit. This will result in some loss in performance. This may be acceptable depending on your intended application and you need to weigh up the cost of performing this test at manufacturing time vs. the resulting loss in performance for your intended application.

3.3.2.2 Summary of Test

Test	Test Name	Test Description	Limits	Comments
2.2	Tx Power Calibration	Configure DUT to transmit back-to-back repeated frames on the applicable channel(s). Adjust transmit power until transmit spectrum meets spectral regulations. Program adjusted transmit power values into OTP.	Spectrum should be within the appropriate mask for your jurisdiction (e.g. FCC and ETSI mask limits – see Appendix A).	Set spectrum analyzer to: - Center frequency, Span = 1 GHz, Sweep time* = 1 s, VBW = RBW = 1 MHz, Detector = RMS

Table 9: Production tests – transmit spectrum test

*It may be possible to reduce the sweep time and speed up this test. As you reduce the sweep time, the measured power changes. Provided there is good correlation between the power measured at the 1 s sweep time and the power measured at the faster sweep time and there is always a fixed offset between the two then the test can be carried out at the faster sweep time and can be adjusted by the fixed offset to give the actual transmit power.

Note: If you are calibrating the DUT before it is mounted in its enclosure you will need to take account of any attenuation caused by the enclosure. This enclosure attenuation should be measured during product design so that the transmit power of the DUT can be increased to compensate. It is recommended that transmit power calibration be done on the final packaged product to ensure maximum performance.

3.3.2.3 Test Description

The DUT transmit spectrum test setup is shown in Figure 14 below. The DUT is connected to the spectrum analyzer. The spectrum analyzer allows the transmit spectrum to be observed. The path loss from the DUT to the spectrum analyzer should be calibrated as per section 2.2.3.

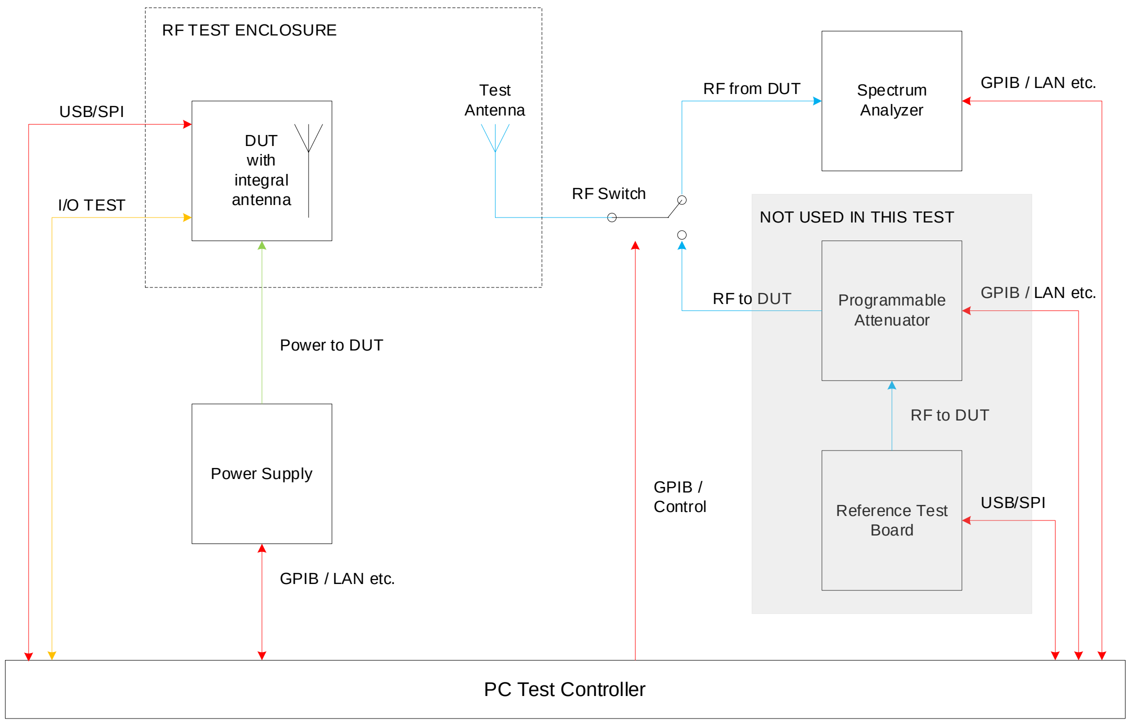


Figure 14: Transmit spectrum test setup block diagram

3.3.2.4 DUT Configuration

The DUT configuration for this test depends on the intended application of the DW3000 product.

Parameter	Setting
Channel	Each channel on which DUT is intended to operate
PRF	Each value of PRF intended to be used
Data Rate	N/A (assuming back-to-back repeated frames)
Preamble code	Depends on selected channel
Preamble length	Length intended for normal operation
STS length	Length intended for normal operation
Data payload	Bytes intended for normal operation

Table 10: DUT configuration for transmit spectrum test

Note: To perform this test, your product software should have a **test mode** that enables the DW3000 to transmit back-to-back repeated frames on each of your intended operating channels. Qorvo's software API includes a function to do this.

3.3.2.5 Test Procedure

Refer to section 10.2 in [2].

The flowchart in Figure 15 describes the procedure. The DUT is configured with the nominal Tx power value previously determined during design verification and characterization. The resulting DUT output power is measured and the configured Tx power value adjusted until the desired limit is reached.

This calibration process needs to be carried out for each of the channels on which you intend your product to operate. For each channel, program the resulting transmit power value into the on-chip OTP memory in the location(s) indicated in Appendix E.

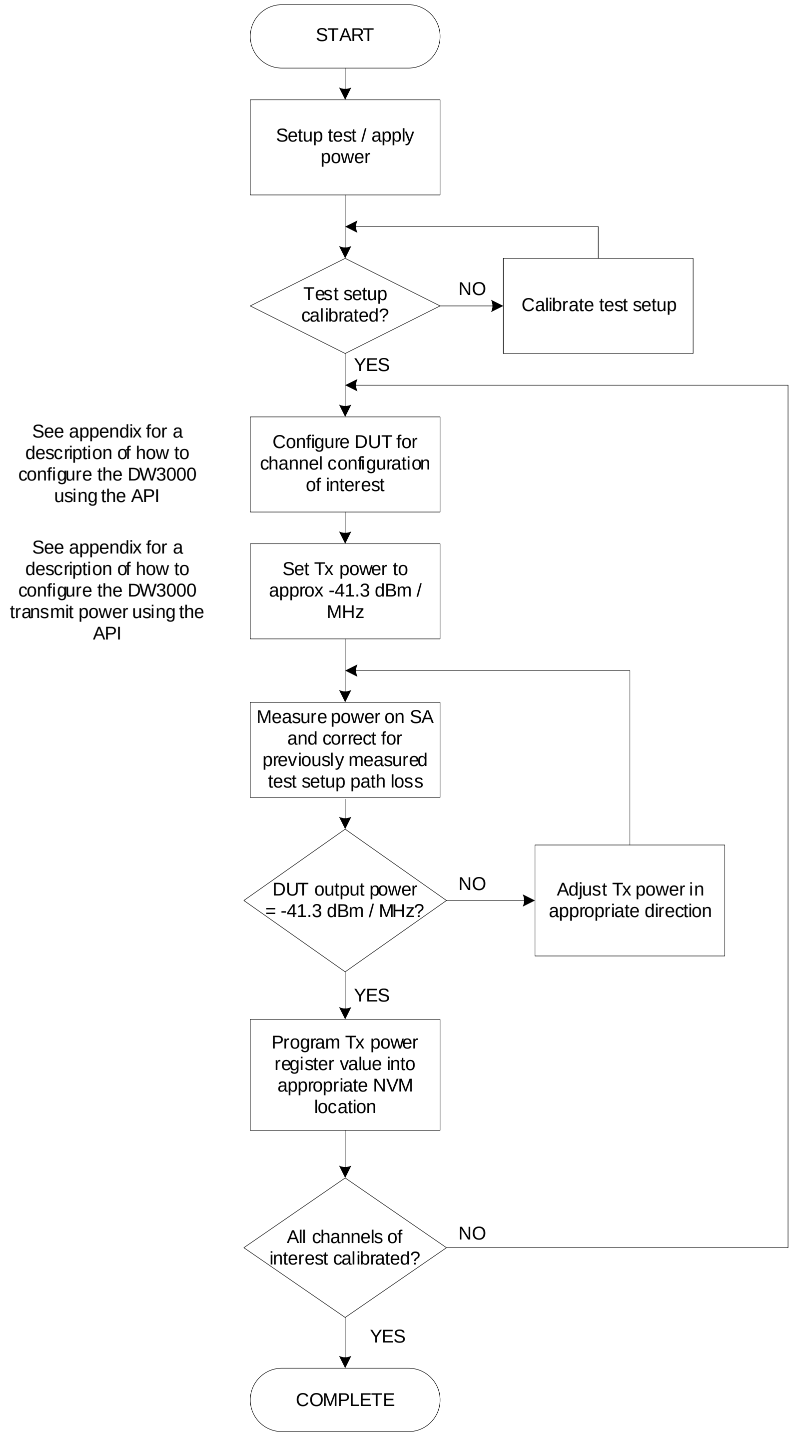


Figure 15: DUT transmit power calibration procedure

3.4 Receiver and System Tests

3.4.1 Receiver Sensitivity Tests

3.4.1.1 Test Applicability

Receiver sensitivity testing **must be carried out** at design verification and characterization to verify that the performance of that design is acceptable. It **should** then be run on a per-DUT basis in production to ensure the DUT receiver is operating correctly.

If the DUT is a **transmit-only** device then this test is **not** applicable.

3.4.1.2 Test summary

Test	Test Name	Test Description	Limits	Comments
3.1	RX Sensitivity	Configure DUT to receive mode. Configure RTB to transmit mode. Transmit a fixed number of frames and check the receive packet error rate (PER) for different receive signal power levels. Repeat for all relevant channels.	Design dependent	

Table 11: Receiver sensitivity test summary

3.4.1.3 Test Description

The receiver sensitivity test sweeps the receiver power level at the DUT to determine the lowest power level at which the DUT correctly receives 99% of frames transmitted by the RTB.

The test setup is shown in Figure 16 below. The test setup is configured to connect the RTB to the DUT via the programmable attenuator. The RTB operates as the transmitter. The programmable attenuator controls the signal level presented to the DUT and is initially set to maximum attenuation. This attenuation is systematically reduced and the frame receive rate at each attenuation step is recorded.

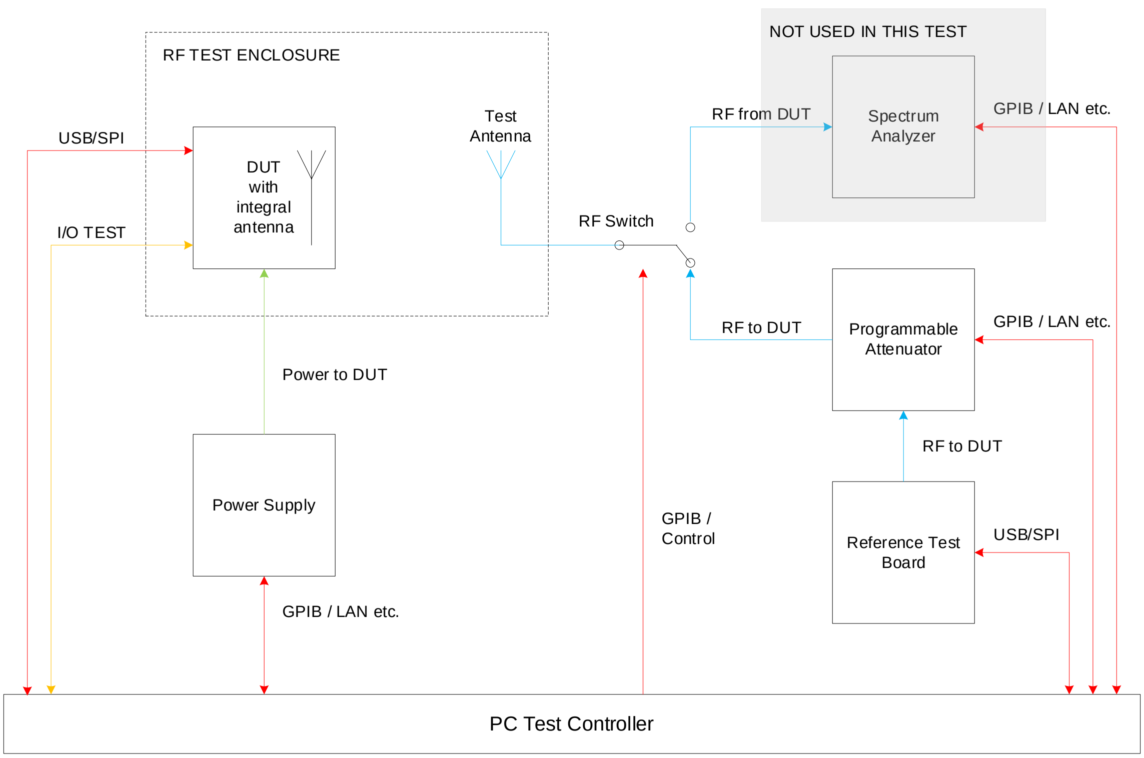


Figure 16: Receiver sensitivity test setup block diagram

The RTB, programmable attenuator, interconnect cables and test antenna must be calibrated as per section 2.2.3 so the signal power level presented to the DUT is known.

3.4.1.4 DUT Configuration

The configuration for this test depends on the intended application of the DUT. Refer to Table 12.

Parameter	Setting
Channel	Each channel on which the DUT is intended to operate
PRF	Each value of PRF intended to be used
Data Rate	Each data rate intended to be used
Preamble code	Depends on selected channel
Preamble length	Length intended for normal operation
STS length	Length intended for normal operation
Data payload	Bytes intended for normal operation

Table 12: DUT configuration for receiver sensitivity test

3.4.1.5 Test Procedure

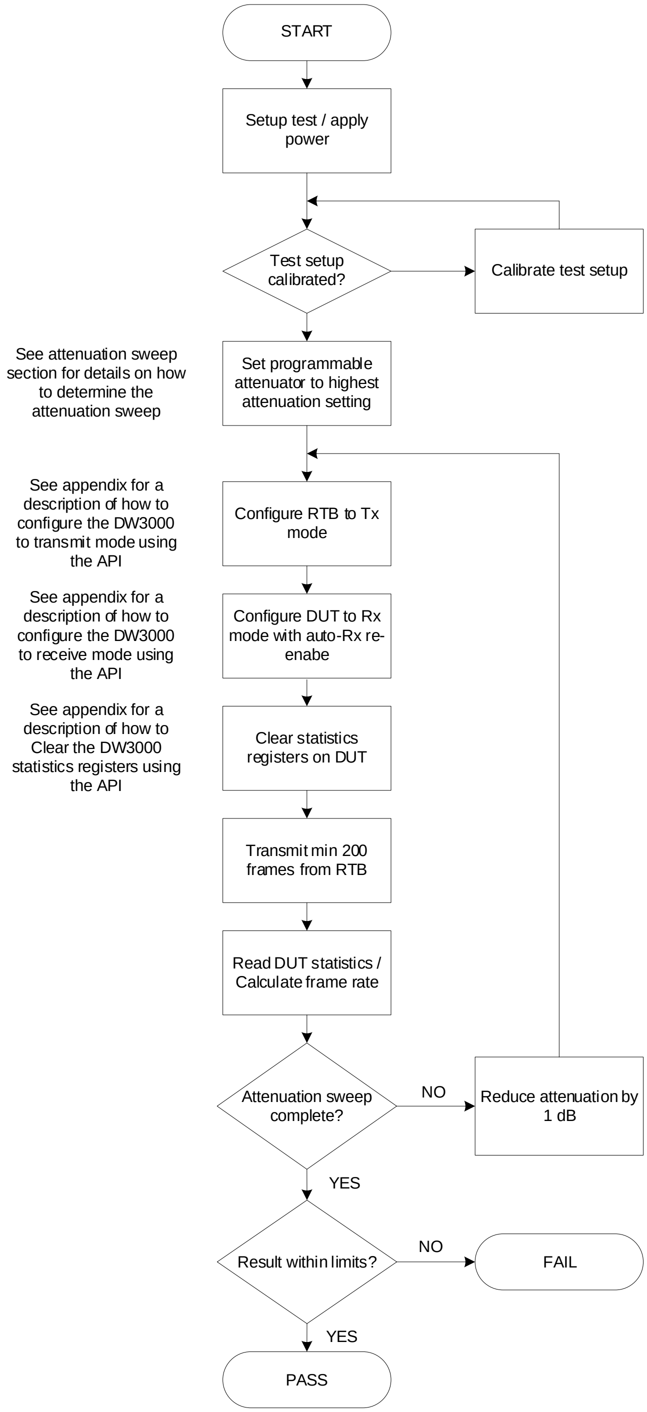


Figure 17: Receiver sensitivity test procedure

3.4.1.6 Calculating the Packet Error Rate (PER)

The statistics from the DW3000 IC are used to calculate the packet error rate (PER). See Appendix D for a discussion of how to read the statistics from the DW3000.

The PER is the following ratio.

$$\frac{ReceivedFrames}{TransmittedFrames} = PER$$

3.4.2 DUT antenna delay calibration using two-way ranging (TWR)

3.4.2.1 Test applicability

At design verification and characterization the nominal value of antenna delay for your design should be determined by testing over a sufficient sample of units.

During production testing antenna delay calibration may be **optionally** carried out on a per-DUT basis to remove any inter-DUT variation and so maximize the achieved ranging accuracy.

You should refer to [4] for a discussion of antenna delay calibration in general, the accuracy that can be achieved if you do not carry out this calibration step on a per-DUT basis and an explanation of how to make an RTB.

3.4.2.2 Test summary

Number	Test Name	Test Description	Limits	Comments
3.2	Ranging	Configure DUT and RTB for operation on applicable channel(s). Configure DUT to anchor mode and RTB to Tag mode. Perform Two Way Ranging.	Measured range = target ±4 cm Std dev < 4 cm	Depending on the level of accuracy required in your application these limits may be relaxed

Table 13: Product tests – DUT antenna delay calibration using TWR

3.4.2.3 Test description

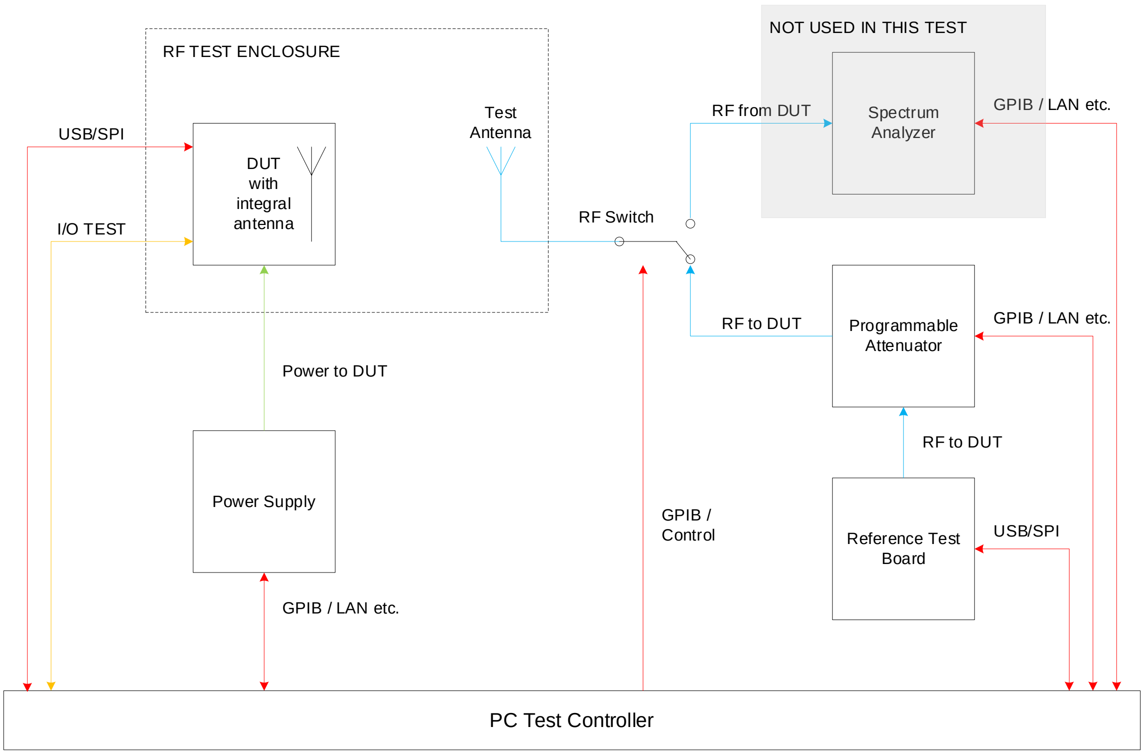


Figure 18: Two-way ranging test setup block diagram

The test setup must be calibrated as per 2.2.5 above so that its group delay is known.

3.4.2.4 DUT configuration

The DUT configuration for this test depends on the intended application of the DW3000 product. Refer to Table 14.

You should configure the DUT for your intended channel(s) of interest and configure the nominal antenna delay for that channel determined during design time.

Parameter	Setting
Channel	Each channel on which DUT is intended to operate
PRF	Each value of PRF intended to be used
Data Rate	As intended for normal operation
Preamble code	Depends on selected channel
Preamble length	Length intended for normal operation
STS length	Length intended for normal operation
Data payload	As required by the two-way ranging process

Table 14: DUT configuration for antenna delay calibration

3.4.2.5 Procedure

Use Qorvo's DecaRanging software or your own product software to perform two-way ranging. You should refer to [3] for a discussion on Qorvo's implementation of two-way ranging.

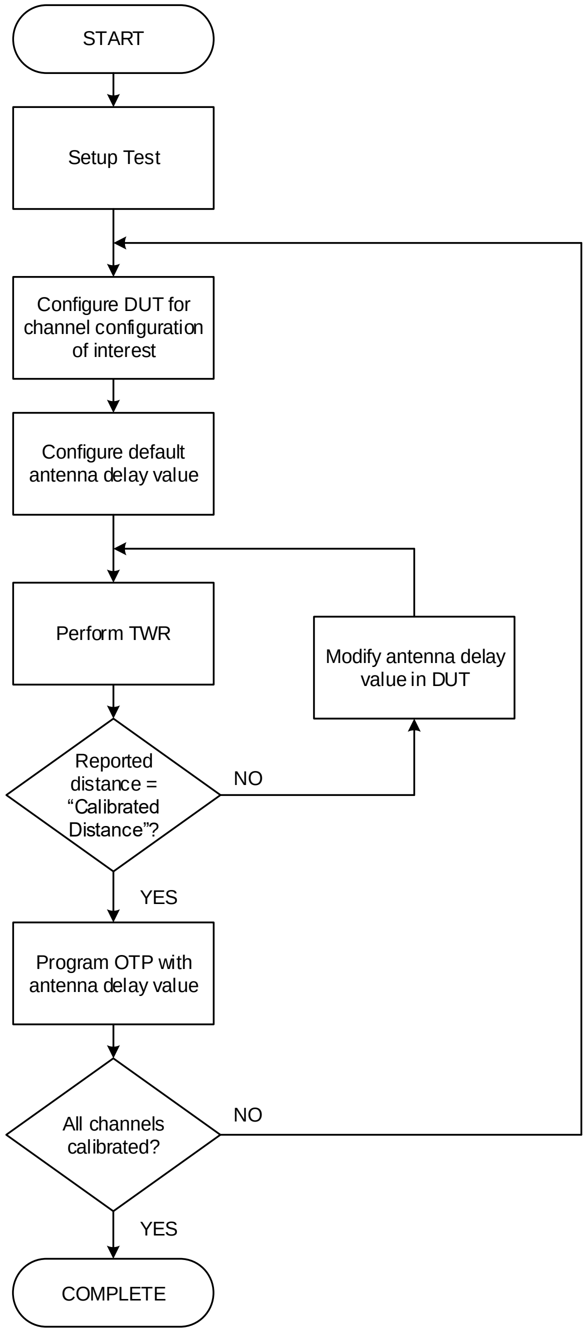


Figure 19: DUT antenna delay calibration using TWR

3.4.2.6 Test limits

The test limits for the two-way ranging test are shown in Table 15 below.

Limit Name	Limit Description	Limit	Comments
Range_Dist	The reported distance should be within limit	4 cm of target	
Range_Stddev	The standard deviation of the reported ranges should be within limit	4 cm	

Table 15: Two-way ranging test limits

The limits in Table 15 above are typical limits. Depending on your intended application, you may decide that looser test limits are appropriate.

The resulting antenna delay values should be programmed into the on-chip OTP memory in the locations indicated in Appendix E.

When using the stored antenna delay value to program the DW3000, it should be apportioned between the Tx and Rx antenna delay registers as follows: -

Tx Antenna delay = stored antenna delay * 44%

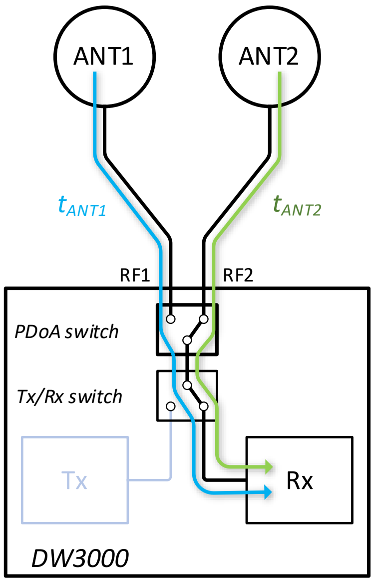
Rx Antenna delay = stored antenna delay * 56%

3.4.3 Phase Difference (PDoA) Calibration

Phase Difference of Arrival (PDoA) is a solution where a node with antennas connected to each of the DW3000 RF ports can be used to determine the position of a tag based on measurements of distance and angle.

There are differences in the propagation time of signals on the two RF paths, caused by process variation in the PCB, any front-end components such as RF switch ICs, the DW3000 IC, etc. These need to be calibrated out in order to ensure accurate results across devices.

Figure 20 illustrates the different signal paths in PDoA systems using two and four antenna elements.



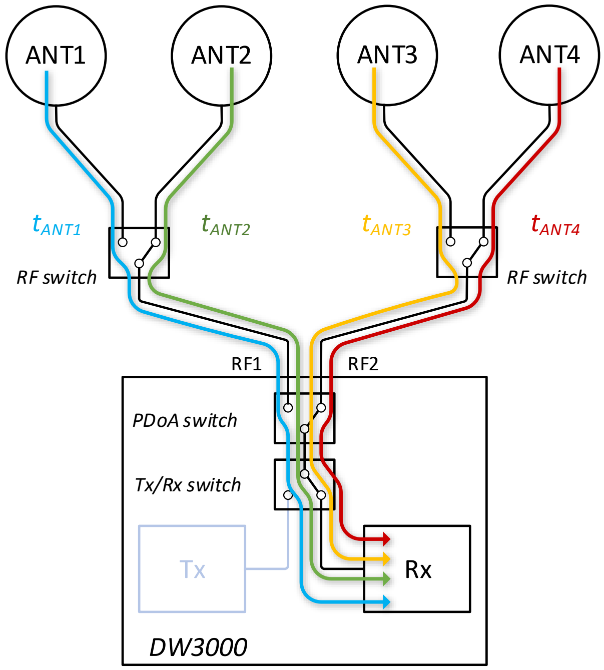


Figure 20. Delays on different paths in PDoA node

3.4.3.1 Factory Calibration

To calibrate the phase difference on each DUT in the factory, the device should be placed directly in front of a transmitting antenna. The resulting phase difference measurement for this 0 ° position can then be stored in OTP or flash memory and used as a fixed offset to correct each PDoA measurement.

As an optional extra verification step, a second transmitting antenna could be placed at another angle from the DUT. The test program can measure the angle and check that the raw PDoA measurement plus the 0 ° adjustment gives the correct angle, within a certain margin (say ± 5 °).

An illustration of a typical setup is shown in Figure 21. A large shielded test cell is recommended, with EM absorbing foam to limit reflections.

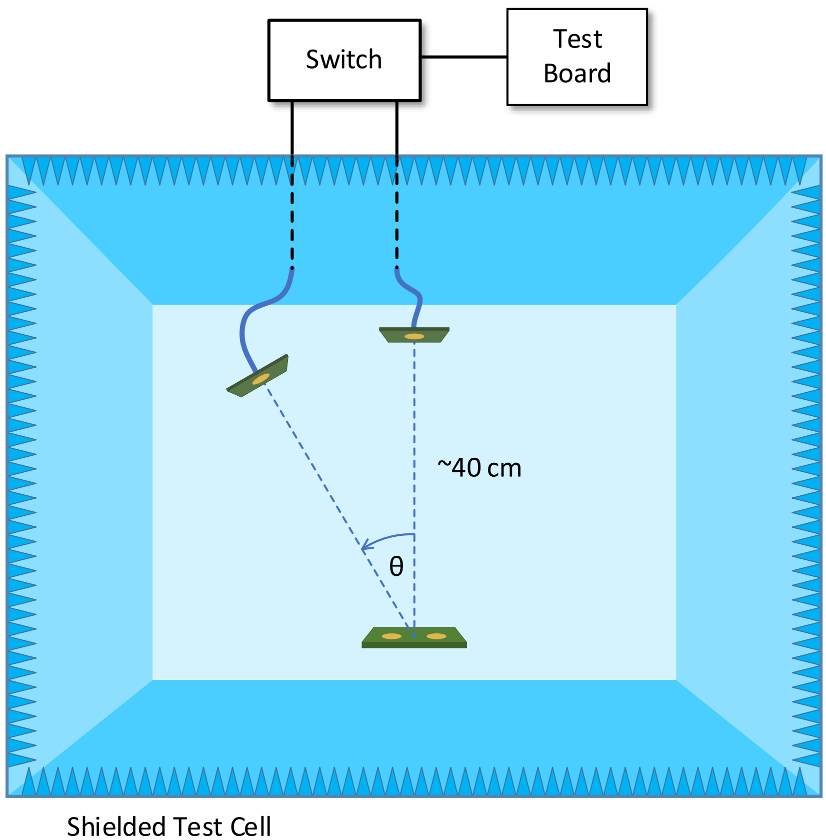


Figure 21. PDoA factory test setup

4 References

Reference is made to the following documents in the course of this application note: -

Ref	Author	Version	Title
[1]	Qorvo	Current	DW3000 Data Sheet
[2]	Qorvo	Current	DW3000 User Manual
[3]	Qorvo	Current	APS013 Two-way ranging implementation with the DW1000
[4]	Qorvo	Current	APS014 Antenna delay calibration of DW1000-based products & systems

Table 16: Table of references

5 Document History

Revision	Date	Description
A	July 2021	First release

Table 17: Document History

6 Contact Information

For the latest specifications, additional product information, worldwide sales and distribution locations:

Web: **www.qorvo.com**

Tel: **1-844-890-8163**

Email: **customer.support@qorvo.com**

7 FURTHER INFORMATION

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8 Appendix A: Tx power spectral limits

In tables below 0 dBr refers to -41.3 dBm/MHz.

Table 18: ETSI (left) & FCC (right) mask limits

Freq MHz	Max Mean Power dBr
-	-48.7
1,600	-48.7
1,600	-43.7
2,700	-43.7
3,100	-28.7
3,100	0
4,800	0
4,800	0
6,000	0
6,000	0
8,500	0
8,500	-23.7
10,600	-23.7
10,600	-43.7
11,000	-43.7

Freq MHz	FCC dBr
-	-24
960	-24
1,610	-24
1,610	-12
1,990	-12
1,990	-10
3,100	-10
3,100	0
10,600	0
10,600	-10
11,000	-10

9 Appendix B: Configure DW3000 in receiver mode using API

When using Qorvo's DW3000 driver source code the following API functions can be used to configure the DW3000 into receive mode. The user should study the current version of the DW3000 Device Driver API Guide available from Qorvo and familiarize themselves with individual API functions.

1. Power on the DUT.

2. Call dwt_initalise function passing relevant parameters, e.g. if reading of OTP saved values is needed or not

   dwt_initialise(DWT_LOADUCODE | DWT_LOADTXCONFIG | DWT_LOADANTDLY | DWT_LOADXTALTRIM);

3. Setup callback functions for the receive and/or transmit events

   dwt_setcallbacks(instance_txcallback, instance_rxcallback);

4. Set up interrupts

   dwt_setinterrupt(xxxxxx)

5. Configure the DW3000 with the required parameters for particular channel / PRF etc. settings

   dwt_configure()

6. Set the device's antenna delay

   dwt_setrxantennadelay()

7. Set any other receiver features/functions, rx auto re-enable, frame filtering, double-buffering etc.

8. Enable the receiver (with/without delay), if delay is used then need to set delay time first

   dwt_setdelayedtrxtime()

   dwt_rxenable(delay)

9. Wait for an interrupt event or poll the status register and process the receive event when one occurs.

10 Appendix C: Configure DW3000 in transmit mode using API

When using Qorvo's DW3000 driver source code the following API functions can be used to configure the DW3000 into transmit mode. The user should study the current version of the DW3000 Device Driver API Guide available from Qorvo and familiarize themselves with individual API functions.

1. Power on the DUT.

2. Call dwt_initalise function passing relevant parameters, e.g. if reading of OTP saved values is needed or not.

   ```
   dwt_initialise(DWT_LOADUCODE | DWT_LOADTXCONFIG | DWT_LOADANTDLY | DWT_LOADXTALTRIM);
   ```

3. Setup callback functions for receive and / or transmit events.

   ```
   dwt_setcallbacks(instance_txcallback, instance_rxcallback);
   ```

4. Set up interrupts.

   ```
   dwt_setinterrupt(xxxxxx)
   ```

5. Configure the DW3000 with the required parameters for particular channel / PRF etc. settings.

   ```
   dwt_configure()
   dwt_configuretxrf()
   ```

6. Set the device's antenna delay.

   ```
   dwt_settxantennadelay()
   ```

7. Set any other transmitter features / functions, continuous frame, Smart Tx power etc., then write Tx frame data.

   ```
   dwt_writetxdata(length, (uint8 *)  frame, 0);
   dwt_writetxfctrl(length, 0, 0);
   ```

8. Start the transmitter (with / without delay), if delay is used then you need to set delay time first.

   ```
   dwt_setdelayedtrxtime()
   ```

```
dwt_starttx(DWT_START_TX_IMMEDIATE or DWT_START_TX_DELAYED);
```

9. Either wait for an interrupt event or poll the status register and process the transmit event when one occurs.

11 Appendix D: Clearing and reading statistics register using API

11.1 Clearing

When using Qorvo's DW3000 driver source code then the following API function can be used to clear the DW3000 statistics register. The user should study the current version of the DW3000 Device Driver API Guide available from Qorvo and familiarize themselves with individual API functions.

```
dwt_configeventcounters(1)
```

11.2 Reading

When using Qorvo's DW3000 driver source code then the following API function can be used to read the DW3000 statistics register. The user should study the current version of the DW3000 Device Driver API Guide available from Qorvo and familiarize themselves with individual API functions.

```
dwt_readeventcounters()
```

12 Appendix E: One-Time-Programmable (OTP) memory map

The various values determined during the calibration process in 3.3.1 (crystal trim), 3.3.2 (transmit spectrum) and 3.4.2 (antenna delay calibration) should be programmed into the on-chip OTP for future use. The procedure for programming the OTP is given in [2]. The memory map of the on-chip OTP is shown in Table 19 below.

The locations assigned to storing the results of the various tests discussed in this document are highlighted as shown. These are the locations expected by Qorvo's API software. You are not required to use this memory map provided the device driver software you are using has been appropriately modified and care is taken not to use any of the Qorvo production test locations.

Also, depending on the intended operating channels of your product you may not have calibration values for all fields.

Test	Location highlighted like this
IC production test	
Crystal trim	
Transmit power values per channel and PRF	
Antenna delay values by PRF	

Address	Size (Used Bytes)	Byte [3]	Byte [2]	Byte [1]	Byte [0]	Programmed By
0x00	4	64 bit EUID				Customer
0x01	4					
0x02	4	Alternative 64 bit EUID (Selected via reg/SR register)				Customer
0x03	4					
0x04	4	LDO Tune				Prod. Test
0x05	4					
0x06	4	{"0001,0000,0001", "CHIP ID 5 nibbles (20 bits)"}				Prod. Test
0x07	4	{"0001", "LOT ID – 7 nibbles (28 bits)"}				Prod. Test
0x08	4		Vbat @ 3.0 V [23:16]	Vbat @ 3.62 V [15:8]	Vbat @ 1.62 V [7:0]	Prod. Test
0x09	2				Temp @ 22 °C +/- 2 °C [7:0]	Prod. Test
0x0A	0	BIAS Tune				Prod. Test
0x0B	4	Antenna Delay – RX RF Loop		Antenna Delay – TX RF Loop		Prod. Test
0x0C	2	AoA Iso CH9 RF2->RF1	AoA Iso CH9 RF1->RF2	AoA Iso CH5 RF2 -> RF1	AoA Iso CH5 RF1->RF2	Prod. Test
0x0D	0	W.S. Lot ID [3]	W.S. Lot ID [2]	W.S. Lot ID [1]	W.S. Lot ID [0]	Prod. Test

0x0E	0			W.S. Lot ID [5]	W.S. Lot ID [4]	Prod. Test
0x0F	0		W.S. Wafer Number	W.S. Y Loc	W.S. X Loc	Prod. Test
0x10	4	CH5 TX Power Level - PRF 16				Customer
0x11	4	CH5 TX Power Level - PRF 64				Customer
0x12	4	CH9 TX Power Level - PRF 16				Customer
0x13	4	CH9 TX Power Level - PRF 64				Customer
0x14	4					Customer
0x15	4					Customer
0x16	4					Customer
0x17	4					Customer
0x18	4					Customer
0x19	4					Customer
0x1A	4	*CH5 PGCNT (optional)*		*CH9 PGCNT (optional)*		Customer
0x1B	4					Customer
0x1C	4	RX Antenna Delay – PRF 64		TX Antenna Delay – PRF 64		Customer
0x1D	4	*RX Antenna Delay – PRF 16 (optional)*		*TX Antenna Delay – PRF 16 (optional)*		Customer
0x1E	2				XTAL_Trim [6:0]	Customer
0x1F					OTP Revision	Customer
0x20	4	RX_TUNE_CAL: DGC_CFG0				Prod. Test
0x21	4	RX_TUNE_CAL: DGC_CFG1				Prod. Test
0x22	4	RX_TUNE_CAL: DGC_CFG2				Prod. Test
0x23	4	RX_TUNE_CAL: DGC_CFG3				Prod. Test
0x24	4	RX_TUNE_CAL: DGC_CFG4				Prod. Test
0x25	4	RX_TUNE_CAL: DGC_CFG5				Prod. Test
0x26	4	RX_TUNE_CAL: DGC_CFG6				Prod. Test
0x27	4	RX_TUNE_CAL: DGC_LUT_0 – CH5				Prod. Test
0x28	4	RX_TUNE_CAL: DGC_LUT_1 – CH5				Prod. Test
0x29	4	RX_TUNE_CAL: DGC_LUT_2 – CH5				Prod. Test
0x2A	4	RX_TUNE_CAL: DGC_LUT_3 – CH5				Prod. Test
0x2B	4	RX_TUNE_CAL: DGC_LUT_4 – CH5				Prod. Test

0x2C	4	RX_TUNE_CAL: DGC_LUT_5 – CH5	Prod. Test
0x2D	4	RX_TUNE_CAL: DGC_LUT_6 – CH5	Prod. Test
0x2E	4	RX_TUNE_CAL: DGC_LUT_0 – CH9	Prod. Test
0x2F	4	RX_TUNE_CAL: DGC_LUT_1 – CH9	Prod. Test
0x30	4	RX_TUNE_CAL: DGC_LUT_2 – CH9	Prod. Test
0x31	4	RX_TUNE_CAL: DGC_LUT_3 – CH9	Prod. Test
0x32	4	RX_TUNE_CAL: DGC_LUT_4 – CH9	Prod. Test
0x33	4	RX_TUNE_CAL: DGC_LUT_5 – CH9	Prod. Test
0x34	4	RX_TUNE_CAL: DGC_LUT_6 – CH9	Prod. Test
0x35	4	PLL_LOCK_CODE	Prod. Test
0x36 – 0x5F		UNALLOCATED	Customer
0x60	1	**QSR Register (Special function register)**	Reserved
0x61	4	Q_RR Register [7:0]	Reserved
0x62 – 0x77	4	UNALLOCATED	Customer
0x78	4	AES_KEY [127:96] (big endian order)	Customer
0x79	4	AES_KEY [95:64] (big endian order)	Customer
0x7A	4	AES_KEY [63:32] (big endian order)	Customer
0x7B	4	AES_KEY [31:0] (big endian order)	Customer
0x7C	4	AES_KEY [255:224] (big endian order)	Customer
0x7D	4	AES_KEY [223:192] (big endian order)	Customer
0x7E	4	AES_KEY [191:160] (big endian order)	Customer
0x7F	4	AES_KEY [159:128] (big endian order)	Customer

Table 19. OTP memory map