APS012 APPLICATION NOTE

PRODUCTION TESTS FOR DW1000-BASED PRODUCTS

Typical production tests that should be applied to DW1000-based products

Version 1.8

This document is subject to change without notice

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1 OVERVIEW

1.1 Introduction

This document is intended to be used as a guide for the production testing of DW1000-based products. The tests suggested in this document refer only to tests associated with DW1000; 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 DW1000 use case.

1.2 General test scope

These tests assume the main active component in the product is the DW1000 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, EU or other spectral mask regulations are met.

Calibration data can be programmed into non-volatile memory (OTP) on the DW1000 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 DW1000 during product operation.

For brevity throughout this document it is assumed that calibration data is programmed into the DW1000 OTP.

2   TEST ENVIRONMENT

2.1   Test setup overview

Table 1 below shows the general test conditions.

Table 1: Test setup – general 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 because some calibration parameters vary with supply voltage as detailed in [1].	2.8 – 3.6	V DC
2	*Voltage for programming calibration data into on-chip non-volatile memory.* Note: this is required to program the DW1000 on-chip OTP memory. If your product design does not support this voltage then calibration data recorded during the tests in section 3.3 below will need to be stored in some other non-volatile memory in your product	3.7 to 3.9	V DC
3	*Test temperature* Note: you should record the temperature of the DW1000 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

Figure 1 below shows the test set up for testing DW1000-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 <u>does</u> 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
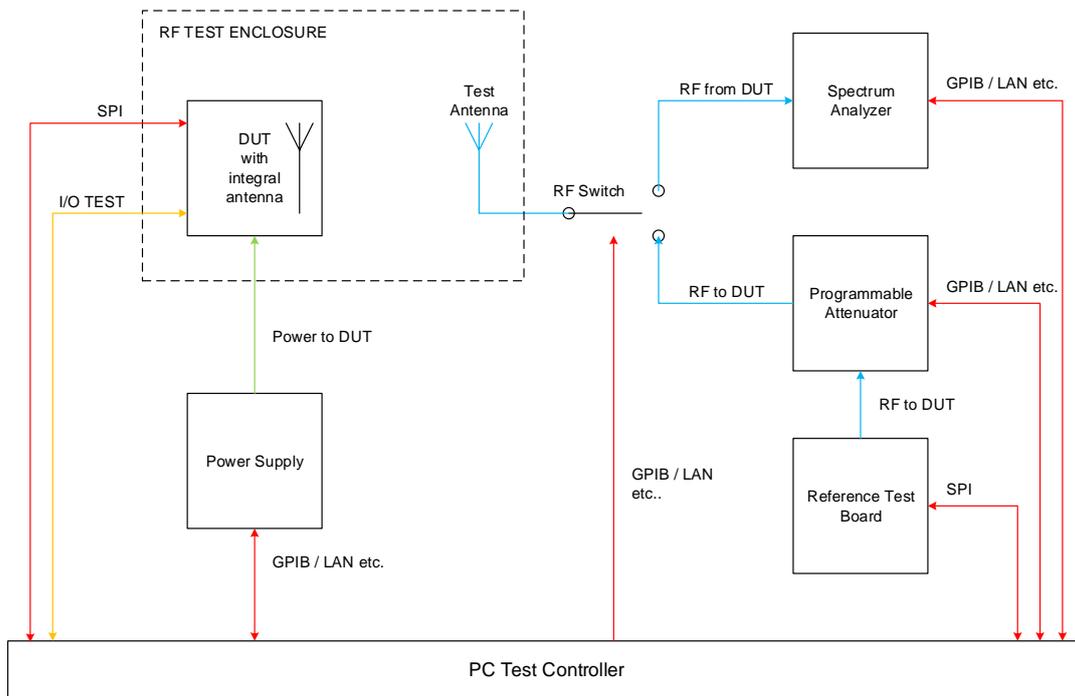
Figure 1: Customer product test setup block diagram

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

Table 2: Suggested test equipment

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

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 level optimization / 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 [5] for a detailed discussion on this topic).

Table 3: Measurements related to losses in the test setup

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

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

2.2.2 DW1000 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 capable of being connected to the test setup via coax cable.

Decawave uses its own EVB1000, correctly calibrated using a spectrum analyzer, as an RTB for in-house testing.

2.2.3 Calibrating the transmit path losses from the DUT to the spectrum analyser

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.
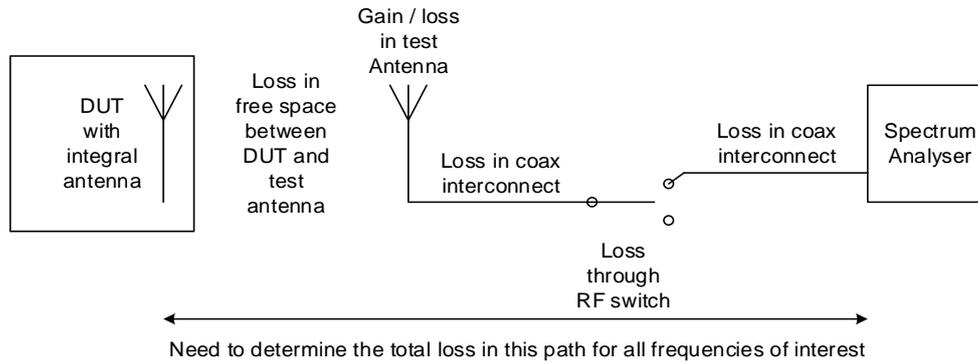
Figure 2: Identification of DUT test setup transmit path losses

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
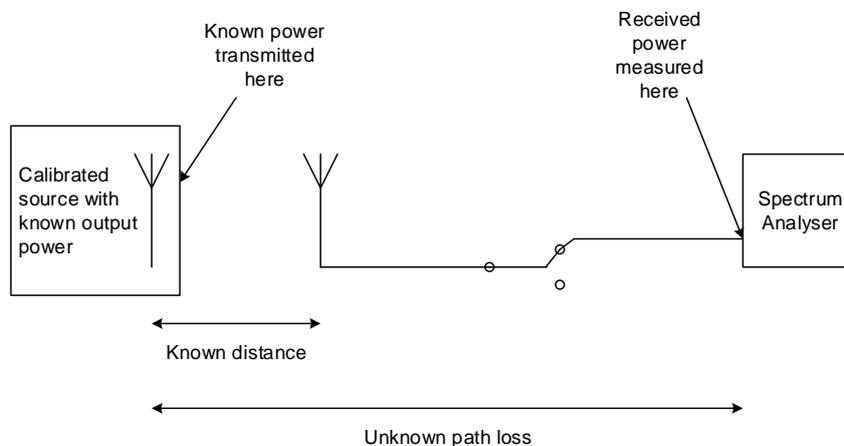
Figure 3: DUT test setup transmit path loss measurement

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 4 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.
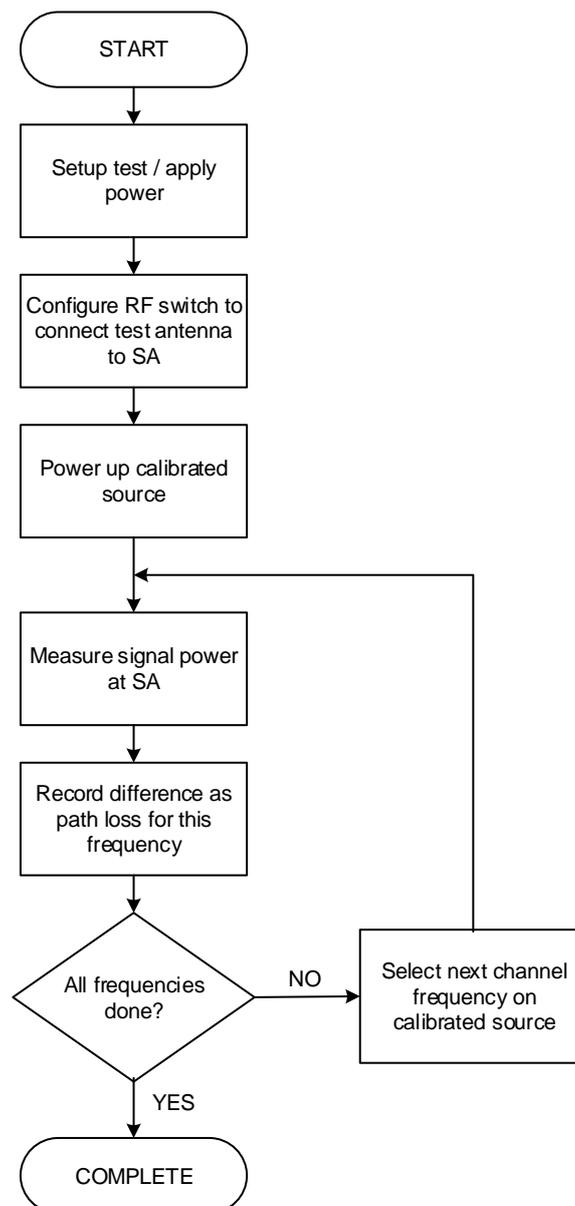
Figure 4: DUT test setup transmit path loss measurement procedure

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.

2.2.4 Calibrating the receive path losses from the RTB to the DUT

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.
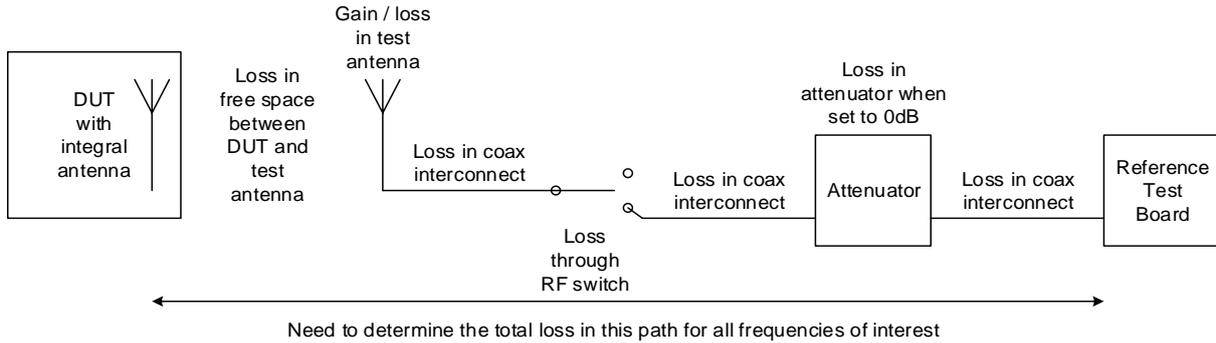
Figure 5: Identification of DUT receive path losses

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.
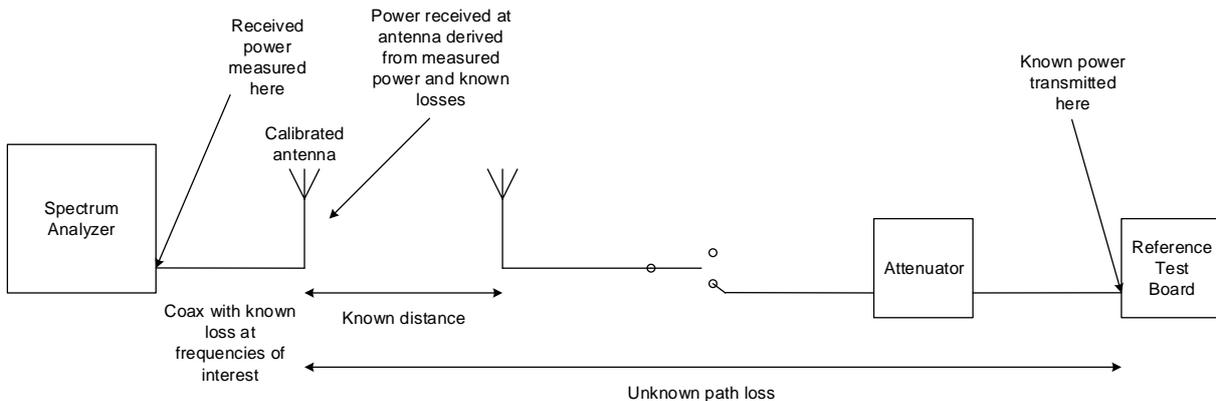
Figure 6: DUT receive path loss measurement setup

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 7 below describes the measurement procedure.

```
            ┌──────────────┐
           (    START       )
            └──────────────┘
                   │
            ┌──────────────┐
            │  Setup test  │
            └──────────────┘
                   │
            ┌──────────────┐
            │Configure RF  │
            │switch to     │
            │connect RTB to│
            │test antenna  │
            └──────────────┘
                   │
            ┌──────────────┐
            │Configure     │
            │in-line       │
            │attenuator to │
            │0 dB          │
            └──────────────┘
                   │
            ┌──────────────┐
            │ Power up RTB │
            └──────────────┘
                   │
            ┌──────────────┐
            │Measure signal│
            │power at SA   │
            └──────────────┘
                   │
            ┌──────────────┐
            │Record        │
            │difference as │
            │path loss for │
            │this frequency│
            └──────────────┘
                   │
              ╱─────────╲         NO    ┌──────────────┐
             ╱ All        ╲──────────── │Select next   │
             ╲ frequencies╱             │channel       │
              ╲ done?    ╱              │frequency on  │
               ╲───────╱               │calibrated    │
                   │                    │source        │
                  YES                   └──────────────┘
                   │
            ┌──────────────┐
           (   COMPLETE     )
            └──────────────┘
```
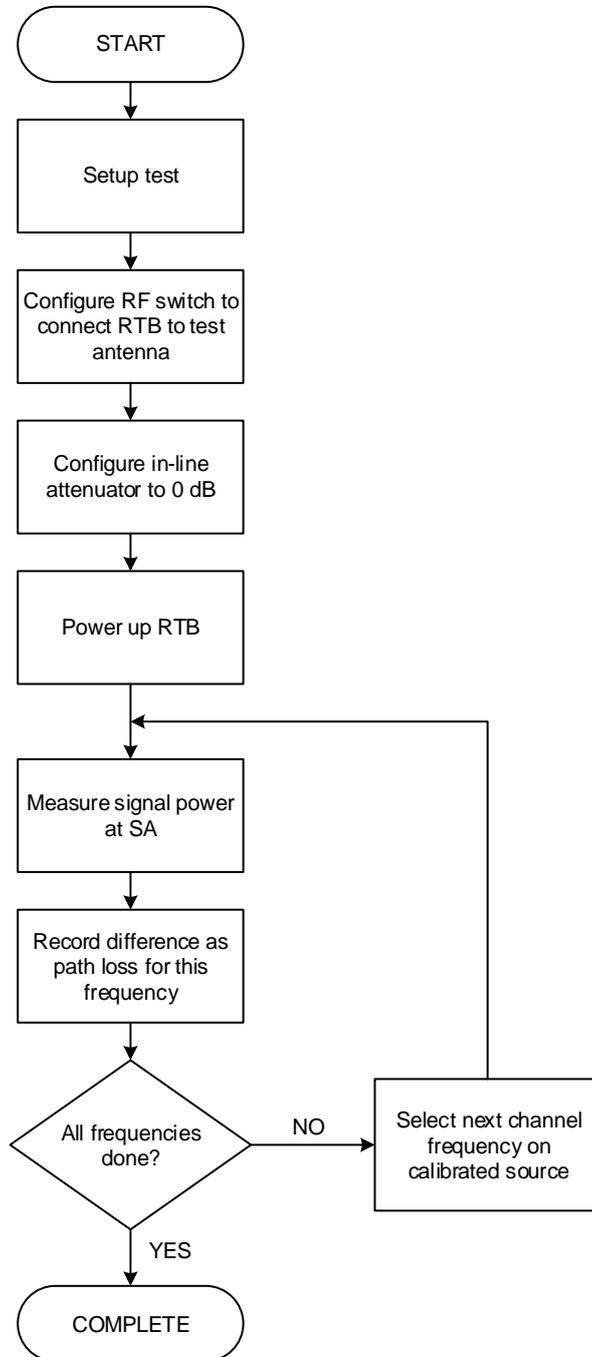
Figure 7: Receive path loss measurement procedure

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 Determining the antenna delay of the test setup using the two-way ranging method

Two-way ranging (TWR) between two DW1000-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 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.

2.2.5.1 Step 1: Free space measurements
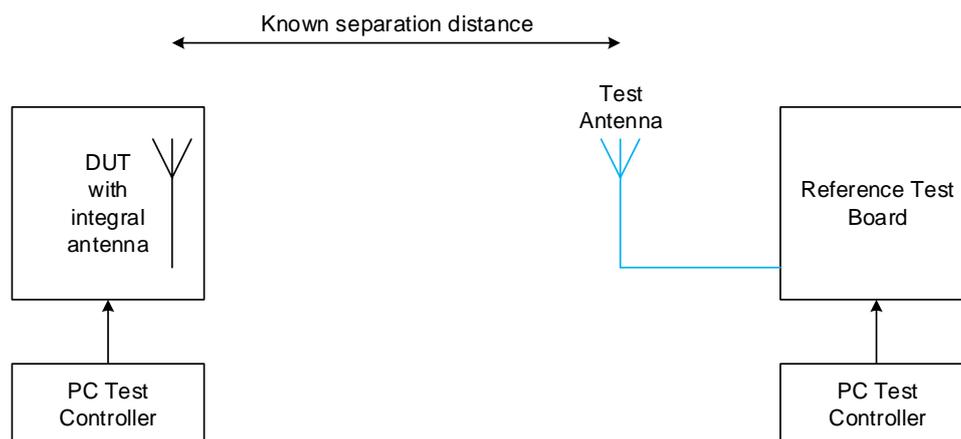
Figure 8: Two-way ranging calibration block diagram for step 1

The separation distances used in the free space measurements must take account of sources of error in two-way-ranging. See [3] for a detailed treatment of ranging accuracy vs. received signal level and range bias. The range bias correction as applied in the DUT must be accounted for in the calibration process. In Table 5 below, the distances given are the points at which the range bias correction is chosen to be zero in the configuration described.

Table 5 below shows the separation distance used between the two DW1000 devices for this step 1. These distances are based on Decawave's EVB1000 and they assume: -

- A 1 dB loss between the RF port on the DW1000 and free space (i.e. a 1 dB RF circuitry loss and a 0 dBi antenna gain).
- The radiated power from both nodes is at the regulatory limit of -41.3 dBm / MHz

If your design has different losses or uses an antenna with different gain then please refer to [3] for a more detailed discussion of this topic.

Table 5: Separation distance used for step 1 calibration

Channel	PRF	Distance (m)
1	16	14.75
1	64	9.3
2	16	12.9
2	64	8.1
3	16	11.5
3	64	7.2
4	16	8.7
4	64	8.7
5	16	7.9
5	64	5.0
7	16	5.3
7	64	5.3

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.
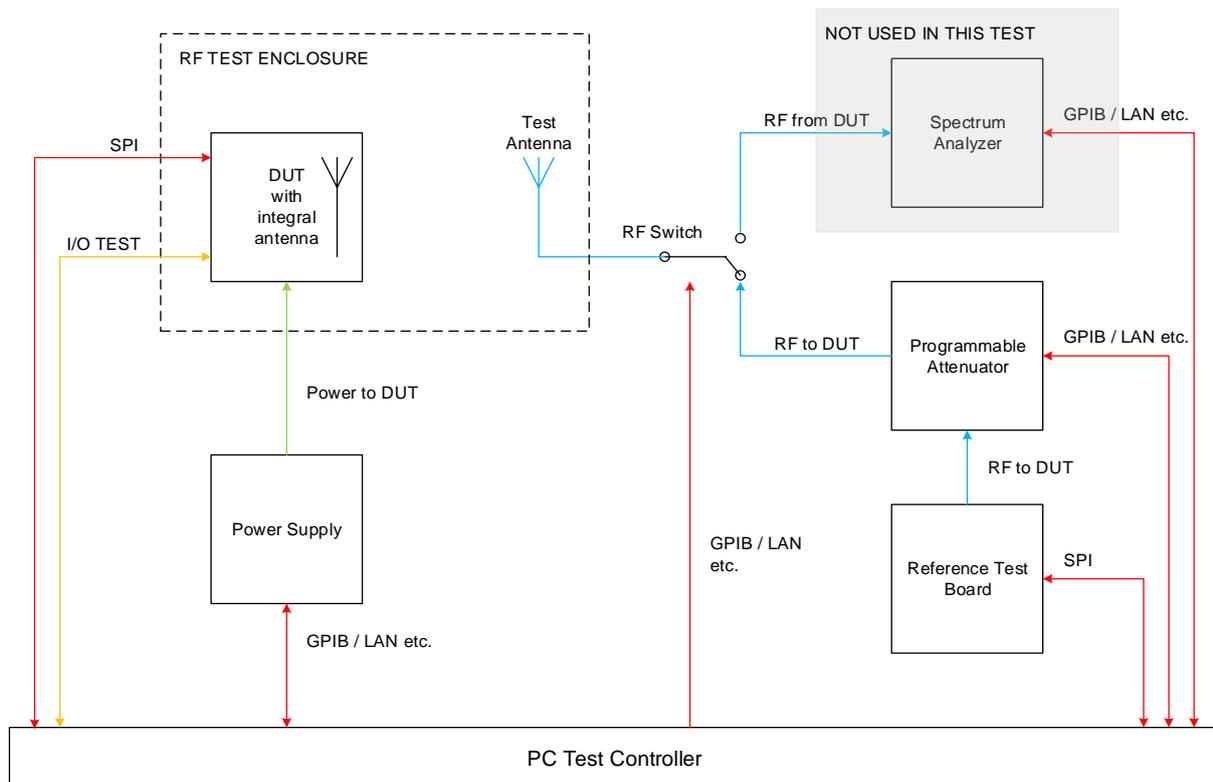
Figure 9: Test setup for antenna delay measurement using two-way ranging – step 2

The flowchart in Figure 10 below describes this two-step process.
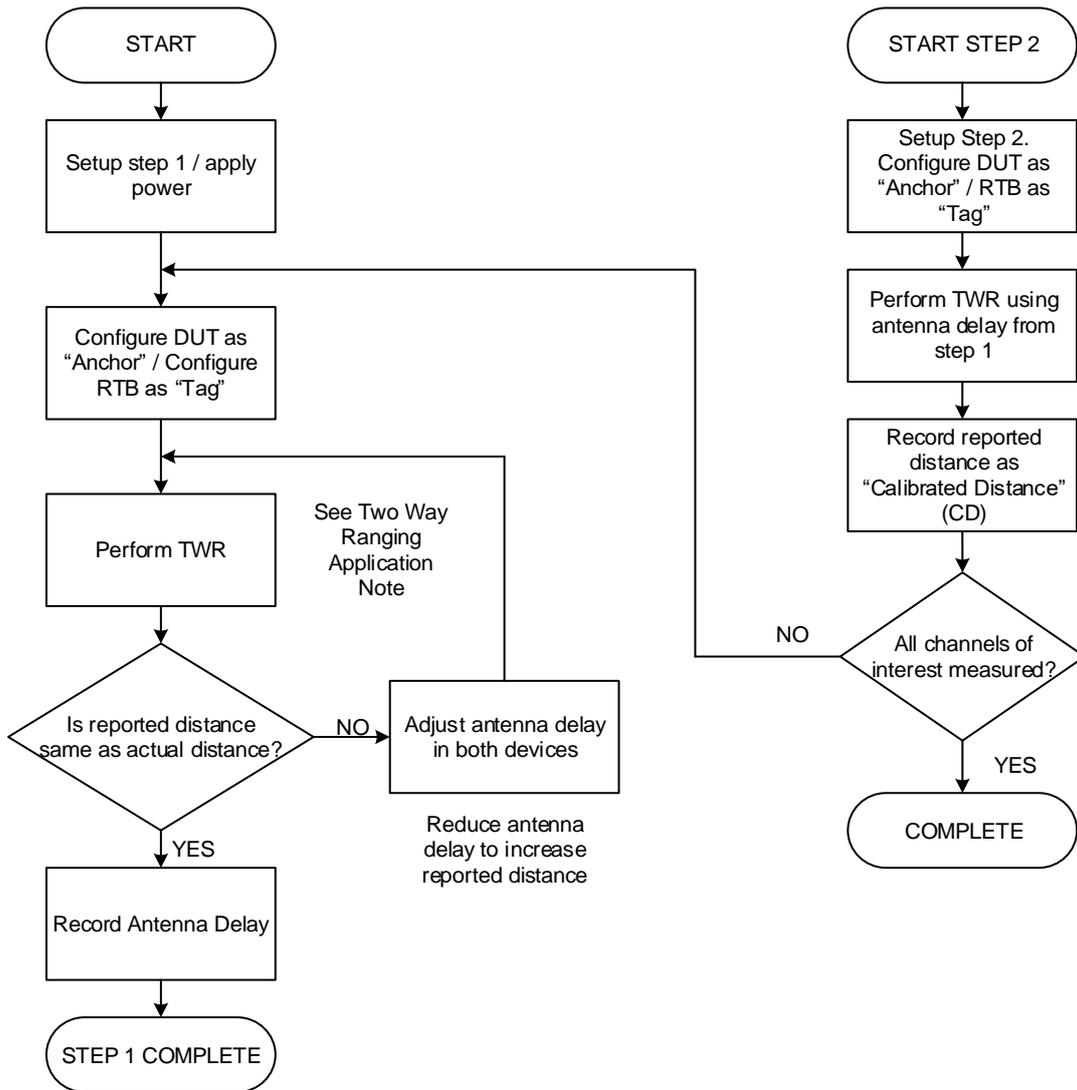
Figure 10: Using two-way ranging to determine the antenna delay of the test setup

3 PRODUCTION TESTS

3.1 Overview

The full list of production tests described in this document is shown in the table below. The selection of which tests to run depends on the intended application of the DW1000 product. For example if you are not using GPIO lines in your application then there is no need to test their functionality.

Table 6: Summary list of production tests

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 DW1000 device ID	DUT Only
1.3	GPIO strobe test	Use SPI commands to run GPIO strobe routing Verify that all GPIO, IRQ and SYNC lines are asserted correctly.	DUT Only
1.4	RSTn test	Check that the RSTn line goes high after power is applied.	DUT Only
1.5	WAKEUP test	Use SPI commands to set the DUT into SLEEP mode. Assert WAKEUP pin to bring device out of SLEEP.	DUT Only
1.6	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

3.2 Operational Tests

3.2.1 Tests Summary

Table 7: Production tests prior to checking / calibrating the transmitter and receiver

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 25 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 100 mA Max 150 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
1.6	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	
1.7	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
1.8	WAKEUP test	Using SPI commands to DUT set 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
1.9	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

3.3 DUT optimization

3.3.1 Crystal trim optimization

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

Table 8: Production tests – crystal trim

Test	Test Name	Test Description	Limits	Comments
2.1	Xtal 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].

3.3.1.3 Test description

The crystal trim test setup is shown in Figure 11 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: for the purposes of performing this test you should ensure that your product software provides a **test mode** that enables the DW1000 to output a CW signal on your primary operating channel. Decawave's software API includes a function to do this.
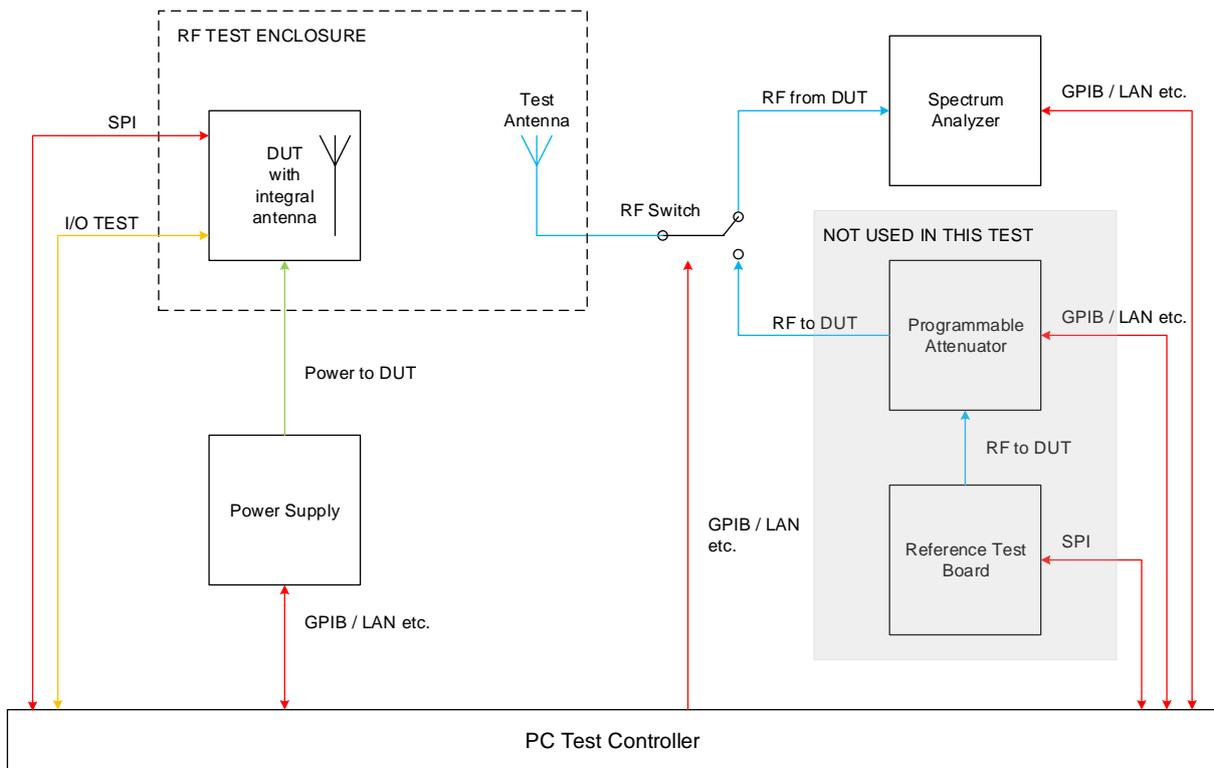
Figure 11: Crystal trim test setup block diagram

3.3.1.4   DUT configuration

The DUT Configuration for this test is shown in Table 9 below.

Table 9: DUT configuration for crystal trim test

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

3.3.1.5   Procedure

You should refer to section 8.1 in [2].

Program the resulting trim value into the on-chip one-time-programmable (OTP) memory in the location indicated in section12 Appendix E: One-time-programmable (OTP) memory map.

3.3.1.6   Test limits

The test limits for the crystal trim test are shown in the table below.

Table 10: Crystal trim test limits

Limit Name	Limit Description	Limit	Comments
Trim_Freq	The frequency of the debug CW signal should be within the limit	Center frequency in MHz ±3 ppm	Refer to [1]

3.3.1.7 Alternative method

An alternative test method is possible that does not require a spectrum analyzer. This method configures GPIO0 on the DW1000 to output a divided version of the internal system clock. This clock signal may be observed using a frequency counter.

To do this, power up in default mode and configure the GPIO0 to output the system clock as follows:-

- Power up in default mode.
- Set bit [7] in register 0x26:00 GPIO_MODE

You should see a 62.4 MHz clock on GPIO0. This is a divided-by-2 version of the internal system clock.

The crystal trim method is as described above.

Table 11: Alternative crystal trim method test limits

Limit Name	Limit Description	Limit	Comments
Trim_Freq	The frequency of the system clock signal should be within the limit	62.4 MHz ±3 ppm	Refer to [1]

3.3.2 Transmit spectrum optimization

3.3.2.1 Test applicability

During design verification and characterization, you should measure the nominal loss in the RF path between the DW1000 and the antenna to determine the **nominal transmit power value** required from the DW1000 to compensate for this loss.

With the DW1000 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 **strongly 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   Test summary

Table 12: Production tests – transmit spectrum test

Test	Test Name	Test Description	Limits	Comments
2.2	Spectrum	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 EU mask limits – see Appendix 1)	Set spectrum analyzer to: - Center frequency, Span = 1 GHz, Sweep time* = 1 s, VBW = RBW = 1 MHz, Detector = RMS

*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 12 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.
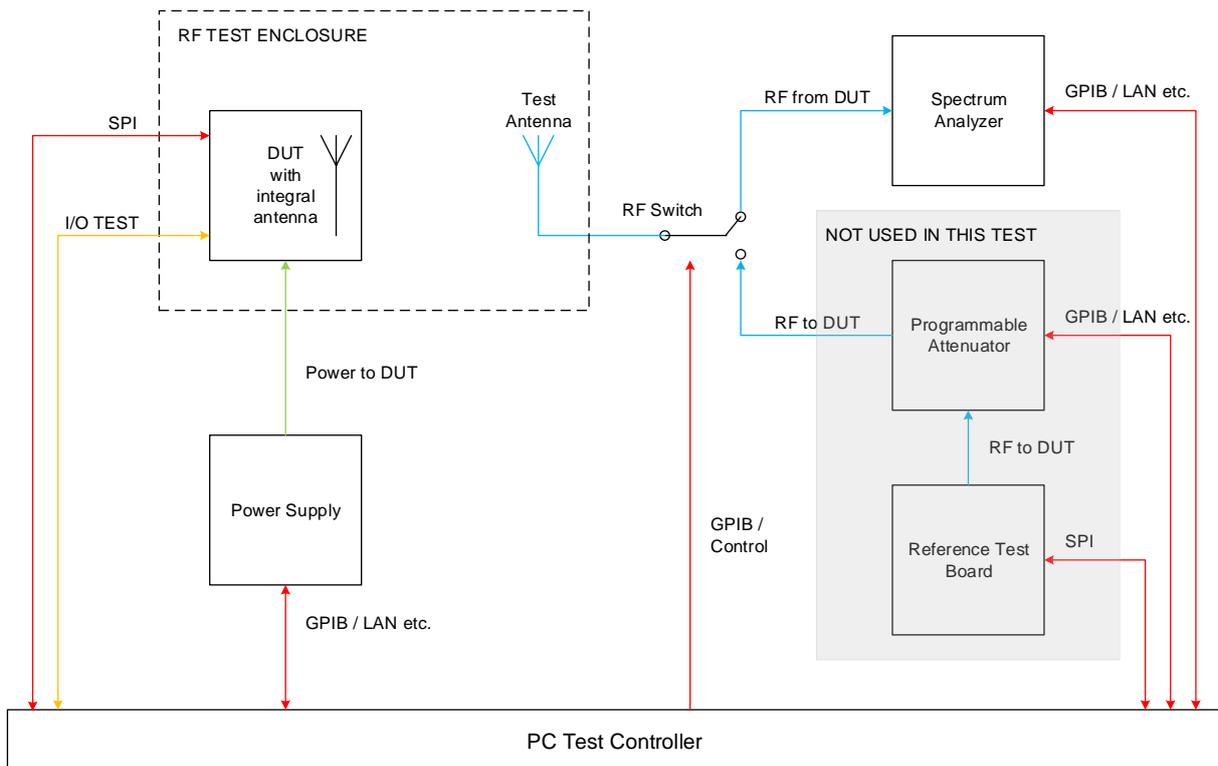
Figure 12: Transmit spectrum test setup block diagram

3.3.2.4   DUT configuration

The DUT configuration for this test depends on the intended application of the DW1000 product.

Table 13: DUT configuration for transmit spectrum test

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
Data payload	N/A

Note: For the purposes of performing this test you should ensure that your product software provides for a **test mode** that enables the DW1000 to transmit back-to-back repeated frames on each of your intended operating channels. Decawave's software API includes a function to do this.

3.3.2.5   Procedure

You should refer to section 8.2 in [2]. The flowchart in Figure 13 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.

Note for applications using a data rate of 6.81 Mbps, "Smart Tx Power" should be disabled (refer to [2]). See also section 3.3.2.7.

START

Setup test / apply power

Test setup calibrated? —NO→ Calibrate test setup

YES

See appendix for a description of how to configure the DW1000 using the API

Configure DUT for channel configuration of interest

See appendix for a description of how to configure the DW1000 transmit power using the API

Set Tx power to approx -41.3 dBm / MHz

Measure power on SA and correct for previously measured test setup path loss

DUT output power = -41.3 dBm / MHz? —NO→ Adjust Tx power in appropriate direction

YES

Program Tx power register value into appropriate OTP location

All channels of interest calibrated? —NO→

YES

COMPLETE

Figure 13: DUT transmit power calibration procedure

As shown in Figure 13, 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 section 12 Appendix E: One-time-programmable (OTP) memory map.

3.3.2.6 Test limits

The test limits for the transmit spectrum test are shown in the table below.

Table 14: Transmit spectrum test limits

Limit Name	Limit Description	Limit	Comments
Mask_Fit	Spectrum should be within the appropriate regulatory mask for your intended jurisdiction. See Appendix 1 for generally applicable FCC and EU mask limits. Refer to your certification test house or regulatory body for any specific regulations appropriate to your use case / application	Spectrum should be within the appropriate mask for your jurisdiction	As previously noted if you are calibrating the DUT before packaging in its enclosure you will need to compensate for any radiated power loss due to the enclosure.

3.3.2.7   Calibration for Smart Tx Power operation

3.3.2.7.1   Introduction

Refer to [2] for a detailed description of Smart Tx power operation.

This feature allows you to use a higher Tx power in your product than the regulatory limit provided the frame duration you are using in normal operation is less than 1 ms and a maximum of 1 frame is transmitted per ms. The increase in allowed Tx power depends on the length of the frame relative to 1 ms.

It is important to distinguish between the automatic and manual modes of Smart Tx power operation: -

- In automatic mode, Smart Tx power applies the appropriate power boost depending on the frame duration. There are four different power settings: -

    - Nominal (No boost)
    - Frame duration between 250 and 500 µs – approx. 3dB boost
    - Frame duration between 125 and 250 µs – approx. 6 dB boost
    - Frame duration less than 125 µs – approx. 9 dB boost

- In manual mode, Smart Tx power applies whatever power boost has been programmed into its registers and assumes the user has programmed the appropriate value for the frame duration being transmitted.

When calibrating for either mode, you should first disable the Smart Tx power feature and calibrate the transmit power as described in 3.3.2.5 above. This establishes a correct baseline for the Tx power level.

During design verification you should calculate and verify the increase in Tx power relative to the nominal regulatory limit for the product's intended geographical region of operation (typically -41.3 dBm / MHz). Knowing these nominal values the DUT can then be calibrated.

The power boosts described are applied automatically based on a small set of frame parameters rather than the actual frame duration. See the description of Smart Transmit Power Control in [2] to check the detail of the functionality

3.3.2.7.2   Calibration procedure for automatic Smart Tx power operation

1. Disable Smart Tx power control bit DIS_STXP in Register file: 0x04 – System Configuration by setting to 1. Note that when using Smart Tx power mode in your application, DIS_STXP will be set to 0.

2. Configure the DUT for the nominal (-41.3 dBm/ MHz) transmit power case. Follow the procedure in section 3.3.2.5 and store the resulting register value. This value is the value used in Register 1E:00 bits 7-0 called BOOSTNORM.

3. Configure the DUT for the Tx power for frame durations less than 500 μs (approximately 3 dB boost). Follow the procedure in section 3.3.2.5 and record the resulting register value. This is the value to be used in Register 1E:00 bits 15 – 8 called BOOST500.

4. Configure the DUT for the Tx power for frame durations less than 250 μs (approximately 6 dB boost). Follow the procedure in section 3.3.2.5 and record the resulting register value. This is the value to be used in Register 1E:00 bits 23 – 16 called BOOST250.

5. Configure the DUT for the Tx power for frame durations less than 125 μs (approximately 9 dB boost). Follow the procedure in section 3.3.2.5 and record the resulting register value. This is the value to be used in Register 1E:00 bits 31 – 24 called BOOST125.

6. The values obtained from steps 2 – 5 can then be stored in DW1000 OTP (See section 12 Appendix E: One-time-programmable (OTP) memory map).

Note: If the product uses frames of a fixed duration then depending on that duration one or more of steps 3-5 can be omitted.

3.3.2.7.3   Calibration procedure for manual Smart TX power operation

In some products it may not be desirable to let DW1000 decide the Tx power boost based on the Tx frame duration but Smart TX power is still desired.

In this case Manual Smart TX power mode can be used. The calibration procedure is almost the same as for the automatic mode in section 3.3.2.7.2 above.

1. Disable Smart TX Power Control bit DIS_STXP in Register file: 0x04 –System Configuration by setting to 1. This will be the setting for normal operation using Smart TX power in manual mode.

2. Configure the DUT for the nominal (-41.3 dBm/ MHz) transmit power case. Follow the procedure in section 3.3.2.5 and store the resulting register value. This s the value to be used in Register 1E:00 bits 15-8 called TXPOWPHR.

3. Configure the DUT for the required Tx power boost as determined during design time depending on the Tx frame duration and regulatory limits in the geographical region of product operation. Follow the procedure in section 3.3.2.5 and store the resulting register value. This is the value to be used in Register 1E:00 bits 23-16 called TXPOWSD.

4. The values obtained from steps 2 – 3 can then be stored in DW1000 OTP (See section 12 Appendix E: One-time-programmable (OTP) memory map).

3.4 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

Table 15: Receiver sensitivity 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 error rate for different receive signal power levels Repeat for all relevant channels	Design dependent	

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 90% and 99% of frames transmitted by the RTB.

The test setup is shown in Figure 14 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.
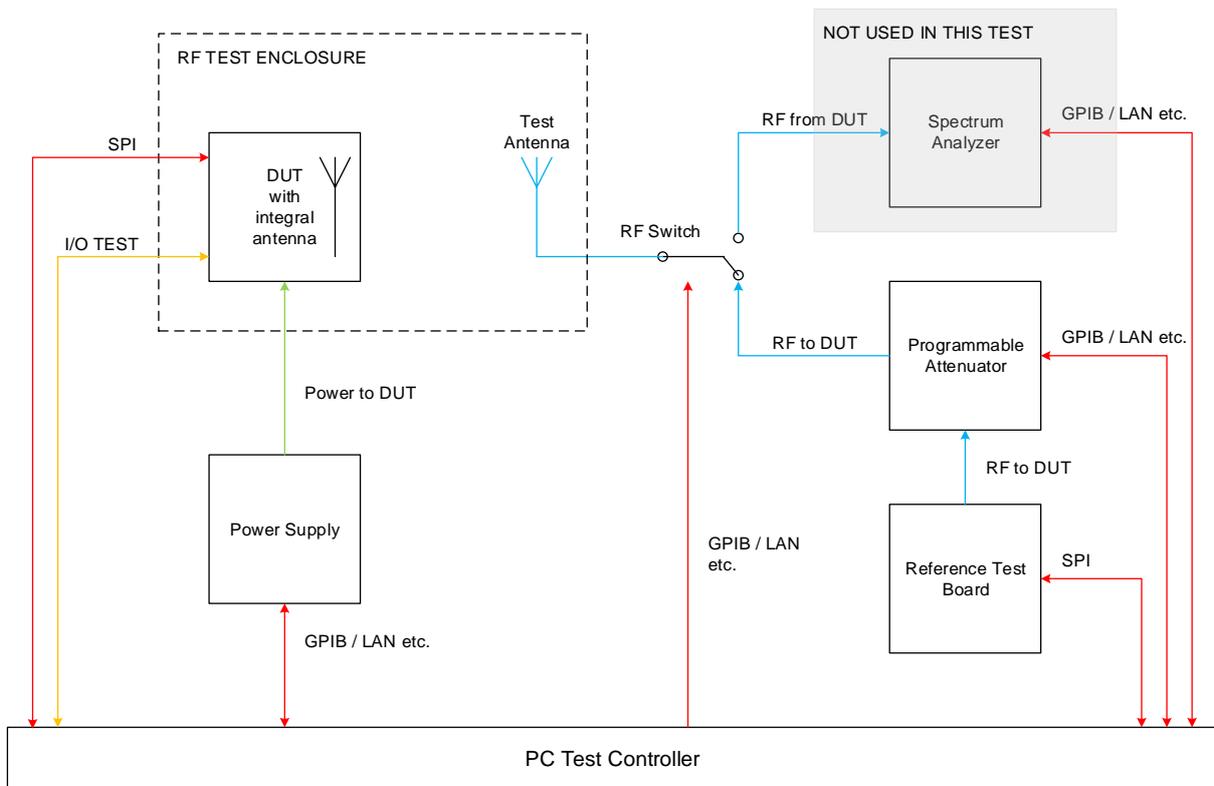
Figure 14: Receiver sensitivity test setup block diagram

The RTB, programmable attenuator, interconnect cables and test antenna must be calibrated as per section 2.2.4 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 16.

Table 16: DUT configuration for receiver sensitivity test

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
Data payload	Length intended for normal operation

3.4.1.5 Procedure

```
┌──────────┐
│  START   │
└────┬─────┘
     │
┌────┴──────────┐
│ Setup test /  │
│ apply power   │
└────┬──────────┘
     │
 ╱Test setup╲        ┌──────────────┐
╱ calibrated? ╲──────│ Calibrate    │
╲             ╱      │ test setup   │
 ╲           ╱       └──────────────┘
     │
┌────┴──────────┐
│ Set programmable│
│ attenuator to   │
│ highest         │
│ attenuation     │
│ setting         │
└────┬──────────┘
     │
┌────┴──────────┐
│ Configure RTB │
│ to Tx mode    │
└────┬──────────┘
     │
┌────┴──────────┐
│ Configure DUT │
│ to Rx mode    │
│ with auto-Rx  │
│ re-enable     │
└────┬──────────┘
     │
┌────┴──────────┐
│ Clear         │
│ statistics    │
│ registers on  │
│ DUT           │
└────┬──────────┘
     │
┌────┴──────────┐
│ Transmit min  │
│ 200 frames    │
│ from RTB      │
└────┬──────────┘
     │
┌────┴──────────┐
│ Read DUT      │
│ statistics /  │
│ Calculate     │
│ frame rate    │
└────┬──────────┘
     │
 ╱Attenuation╲  NO   ┌──────────────┐
╱ sweep       ╲──────│ Reduce       │
╲ complete?   ╱      │ attenuation  │
 ╲           ╱       │ by 1 dB      │
     │YES            └──────────────┘
 ╱Result within╲ NO  ┌──────────────┐
╱ limits?       ╲────│    FAIL      │
 ╲             ╱     └──────────────┘
     │YES
┌────┴─────┐
│  PASS    │
└──────────┘
```

See attenuation sweep section for details on how to determine the attenuation sweep

See appendix for a description of how to configure the DW1000 to transmit mode using the API

See appendix for a description of how to configure the DW1000 to receive mode using the API

See appendix for a description of how to Clear the DW1000 statistics registers using the API

Figure 15: Receiver sensitivity test procedure

3.4.1.6 Reading statistics and calculating the frame receive rate

The statistics from the DW1000 IC is used to calculate the frame receive rate. See Appendix D for a discussion of how to read the statistics from the DW1000.

Once the statistics are read from transmitting and receiving DW1000, the frame receive rate is

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

3.4.1.7 Test limits

The Test limits for the receiver sensitivity test are shown in Table 17 below.

Table 17: Receiver sensitivity limits

Limit Name	Limit Description	Limit	Comments
RSL_99%	The receive power level should be equal to or less than the limit value for correct frame reception of 99% of transmitted frames	Design dependent	
RSL_90%	The receive power level should be equal to or less than the limit value for correct frame reception of 90% of transmitted frames	Design dependent	

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 [5] 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

Table 18: Product tests – DUT antenna delay calibration using TWR

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 ±10 cm Std dev < 4 cm	Depending on the level of accuracy required in your application these limits may be relaxed

3.4.2.3 Test description
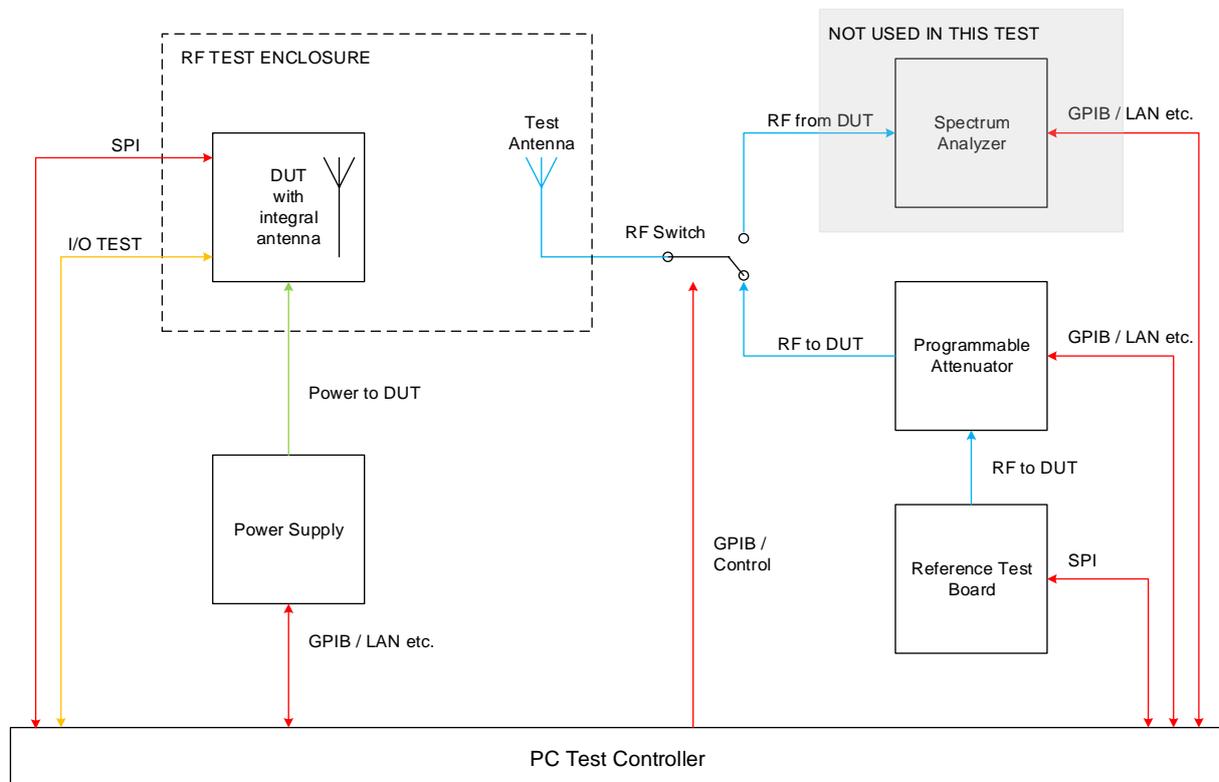
Figure 16: Two-way ranging test setup block diagram

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 DW1000 product. Refer to Table 19.

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.

Table 19: DUT configuration for antenna delay calibration

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
Data payload	As required by the two-way ranging process

3.4.2.5   Procedure

Use Decawave's DecaRanging software or your own product software to perform two-way ranging. You should refer to [4] for a discussion on Decawave's implementation of two-way ranging.
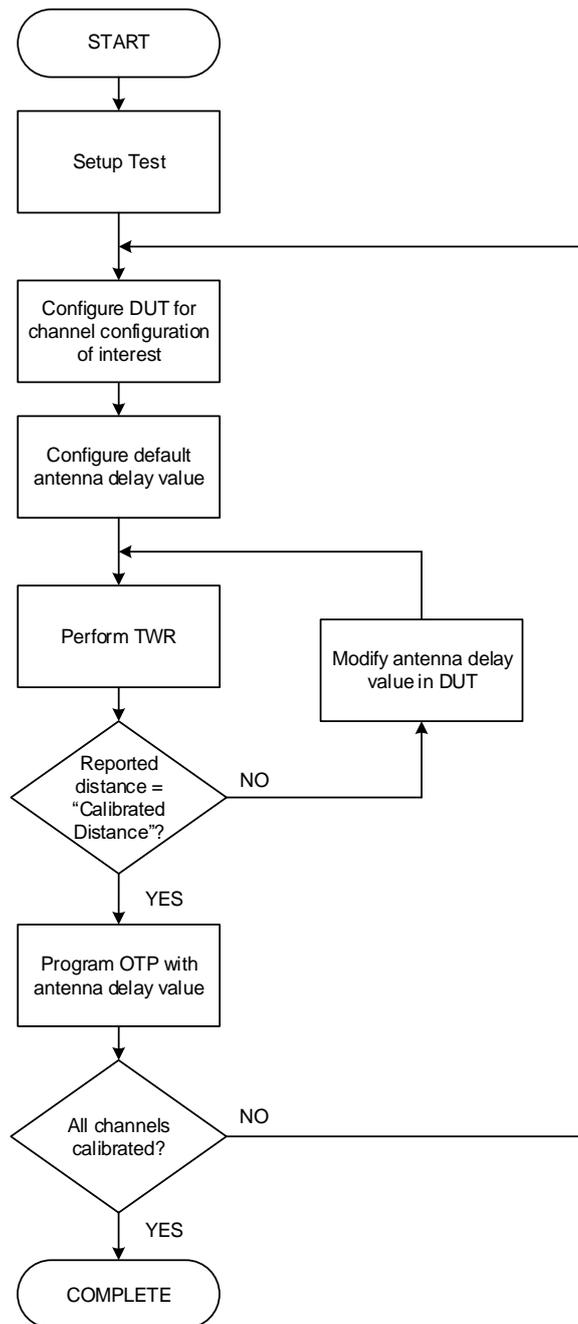
Figure 17: DUT antenna delay calibration using TWR

3.4.2.6 Test limits

The test limits for the two-way ranging test are shown in Table 20 below.

Table 20: Two-way ranging test limits

Limit Name	Limit Description	Limit	Comments
Range_Dist	The reported distance should be within limit	10 cm of target	
Range_Stddev	The standard deviation of the reported ranges should be within limit	4 cm	

The limits in Table 20 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 section 12 Appendix E: One-time-programmable (OTP) memory map.

When using the stored antenna delay value to program the DW1000, 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%

4 REFERENCES

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

Table 21: Table of references

Ref	Author	Version	Title
[1]	Decawave	Current	DW1000 Data Sheet
[2]	Decawave	Current	DW1000 User Manual
[3]	Decawave	Current	APS011 Sources of error in TWR
[4]	Decawave	Current	APS013 Two-way ranging implementation with the DW1000
[5]	Decawave	Current	APS014 Antenna delay calibration of DW1000-based products & systems

5 DOCUMENT HISTORY

Table 22: Document History

Revision	Date	Description
1.0	21th November 2012	Initial release for production device.
1.1	31st March 2015	Scheduled update
1.2	31st July 2015	Update to correct bit settings in section 3.3.1.7
1.3	31st December 2015	Scheduled update
1.4	30th June 2016	Scheduled update
1.5	1st October 2016	Scheduled update
1.6	1st August 2018	Logo update
1.7	25th September 2020	Logo update and Figure 18 to match DW1000 UM
1.8	17th of May 2024	Scheduled Update

6 MAJOR CHANGES

Revision 1.1

Page	Change Description
All	Update of version number to 1.1 / Copyright notice to 2015
All	Various typographical changes
2	Update to table of contents
3	Update to list of tables
6	Correction to OTP programming voltage to be consistent with DW1000 data sheet and user manual
21	Correction to note below Table 12 re spectrum analyzer sweep time
34	Addition of sections 5, 6, Table 22, this table, modification to numbering of section 7

Revision 1.2

Page	Change Description
All	Update of version number to 1.2
All	Various typographical changes
2	Update to table of contents
20	Correction to bit settings to output clock on GPIO0 in section 3.3.1.7
34	Addition of v1.2 to document history Table 22
34	Addition of this table

Revision 1.3

Page	Change Description
Front Page	Update of version number to 1.3
All	Various typographic corrections / Update of copyright notice to 2015
35	Addition of revision 1.3 to revision history Table 22
35	Addition of this table
41	Correction of reference to Figure 18

Revision 1.4

Page	Change Description
Front Page	Update of version number to 1.4
21	Correction to divided-by-2 system clock value to 62.4 MHz
35	Addition of revision 1.4 to revision history Table 22
36	Addition of this table
Appendix E	Update for consistency with DW1000 user manual

Revision 1.5

Page	Change Description
Front Page	Update of version number to 1.5
All	Various typographical corrections
21	Update procedure for Crystal Trim alternative method • Power up in default mode. • Set bit [7] in register 0x26:00 GPIO_MODE

Revision 1.6

Page	Change Description
Front Page	Update of version number to 1.6
All	Logo update

Revision 1.7

Page	Change Description
42	Update Figure 18 OTP table to match with DW1000 UM v2.18
All	Logo update

Revision 1.8

Page	Change Description
All	Modification to footer.

7   FURTHER INFORMATION

Decawave develops semiconductors solutions, software, modules, reference designs - that enable real-time, ultra-accurate, ultra-reliable local area micro-location services. Decawave's technology enables an entirely new class of easy to implement, highly secure, intelligent location functionality and services for IoT and smart consumer products and applications.

For further information on this or any other Decawave product, please refer to our website www.decawave.com.

8 APPENDIX A: TX POWER SPECTRAL LIMITS

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

Table 23: EU (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	-28.7
6,000	-28.7
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 DW1000 IN RECEIVER MODE USING API

When using Decawave's DW1000 driver source code the following API functions can be used to configure the DW1000 into receive mode. The user should study the current version of the DW1000 Device Driver API Guide available from Decawave 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 DW1000 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 DW1000 IN TRANSMIT MODE USING API

When using Decawave's DW1000 driver source code the following API functions can be used to configure the DW1000 into transmit mode. The user should study the current version of the DW1000 Device Driver API Guide available from Decawave 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 DW1000 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 Decawave's DW1000 driver source code then the following API function can be used to clear the DW1000 statistics register. The user should study the current version of the DW1000 Device Driver API Guide available from Decawave and familiarize themselves with individual API functions.

```
dwt_configeventcounters(1)
```

11.2 Reading

When using Decawave's DW1000 driver source code then the following API function can be used to read the DW1000 statistics register. The user should study the current version of the DW1000 Device Driver API Guide available from Decawave 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 Figure 18 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 Decawave'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 Decawave 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
Crystal trim	
Transmit power values per channel	
Antenna delay values by PRF	

Address	Size (Used Bytes)	Byte [3]	Byte [2]	Byte [1]	Byte [0]	Programmed By
0x000	4		64 bit EUID			Customer
0x001	4					
0x002	4		Alternative 64bit EUID			Customer
0x003	4					
0x004	4		LDO Tune			DW Prod Test
0x005	4					
0x006	4		PART ID / CHIP ID (32bits). See Appendix 4, DW1000 User Manual.			DW Prod Test
0x007	4		LOT ID (32 bits)			DW Prod Test
0x008	2	-	-	Vbat @ 3.7V	Vbat @ 3.3V	DW Prod Test
0x009	1 / 1	-	-	T_{meas} @ Ant Cal	T_{meas} @ 23ºC	Customer / DW Prod Test
0x00A	4		-			Reserved
0x00B	4		-			Reserved
0x00C	4		-			Reserved
0x00D	4		-			Reserved
0x00E	4		-			Reserved
0x00F	5		-			Reserved
0x010	4		CH1 TX Power Level PRF 16			Customer
0x011	4		CH1 TX Power Level PRF 64			Customer
0x012	4		CH2 TX Power Level PRF 16			Customer
0x013	4		CH2 TX Power Level PRF 64			Customer
0x014	4		CH3 TX Power Level PRF 16			Customer
0x015	4		CH3 TX Power Level PRF 64			Customer
0x016	4		CH4 TX Power Level PRF 16			Customer
0x017	4		CH4 TX Power Level PRF 64			Customer
0x018	4		CH5 TX Power Level PRF 16			Customer
0x019	4		CH5 TX Power Level PRF 64			Customer

Address	Size (Used Bytes)	Byte [3]	Byte [2]	Byte [1]	Byte [0]	Programmed By
0x01A	4	CH7 TX Power Level PRF 16				Customer
0x01B	4	CH7 TX Power Level PRF 64				Customer
0x01C	4	Tx / Rx Antenna Delay - PRF 64		Tx / Rx Antenna Delay - PRF 16		Customer
0x01D		-	-	-	-	Customer
0x01E		-	-	OTP Revision	XTAL_Trim[4:0]	Customer
0x01F		-	-	-	-	Customer
:	:	:	:	:	:	Reserved
0x400	4	SR Register (See DW1000 User Manual)				Customer

Figure 18: OTP memory map