

APS004 APPLICATION NOTE

INCREASING THE RANGE OF DW1000 BASED PRODUCTS USING AN EXTERNAL LNA

Using the DW1000 with an external Low Noise Amplifier to increase receiver sensitivity and communications range

Version 1.6

**This document is subject to change without
notice**

TABLE OF CONTENTS

LIST OF TABLES	2
LIST OF FIGURES.....	3
1 INTRODUCTION.....	4
1.1 OVERVIEW	4
1.2 HARDWARE AND SOFTWARE MODIFICATIONS	4
2 HARDWARE IMPLEMENTATION	5
2.1 OVERVIEW	5
2.2 DESIGNING LNA SCHEME	5
2.2.1 <i>Calculating Noise Figure</i>	6
2.2.2 <i>Example Noise Figure calculation</i>	6
2.2.3 <i>Calculating Attenuator Value</i>	7
2.2.4 <i>Example of calculating the required attenuation of the attenuator</i>	8
2.3 CONTROL SIGNALS	8
2.4 POWER SUPPLIES.....	8
2.5 RF PATH.....	8
2.5.1 <i>Overview / Basic scheme</i>	8
2.5.2 <i>Detailed schematic</i>	9
2.5.3 <i>PCB layout</i>	10
3 SOFTWARE IMPLEMENTATION.....	11
3.1 INTRODUCTION	11
3.2 REGISTER PROGRAMMING	11
3.3 CODE CHANGES	11
4 OTHER CONSIDERATIONS.....	13
4.1 EFFECT ON ANTENNA DELAY & ITS CALIBRATION.....	13
4.2 RECEIVER SIGNAL-BASED EFFECTS.....	13
4.2.1 <i>Effect on range bias and its correction</i>	13
4.2.2 <i>Potential receiver saturation</i>	13
5 REFERENCES.....	14
6 DOCUMENT HISTORY	14
7 MAJOR CHANGES.....	14
8 FURTHER INFORMATION.....	16
9 APPENDIX 1: CANDIDATE COMPONENTS LIST	17
9.1 BALUN.....	17
9.2 LNA.....	17
9.3 RF SWITCH.....	17

LIST OF TABLES

TABLE 1: EXAMPLE RX STAGE SPECIFICATIONS.....	6
TABLE 2: DW1000 PINS ASSOCIATED WITH THE CONTROL OF AN EXTERNAL LNA SCHEME.....	8
TABLE 3: TABLE OF REFERENCES.....	14
TABLE 4: DOCUMENT HISTORY.....	14

LIST OF FIGURES

FIGURE 1: BASIC SCHEME 5
FIGURE 2: SCHEME WITH TX PATH INCLUDED 5
FIGURE 3: CASCADE OF N DEVICES 6
FIGURE 4: PROPAGATION LOSS PER CHANNEL 7
FIGURE 5: HARDWARE SCHEMATIC 10

1 INTRODUCTION

1.1 Overview

In any wireless communications system, the range at which one can receive signals is determined by a number of factors. These are:

- Transmitted power level
- Transmitter antenna gain
- Losses in the propagation channel (e.g. over the air)
- Receiver antenna gain
- Receiver sensitivity

DW1000 has a receiver sensitivity of between -94 dBm to -107dBm depending on chosen configuration parameters (data rate), hardware setup (carrier frequency offset between Tx and Rx nodes) and the acceptable system performance limits for any particular application (acceptable packet error rate for example).

The transmit output power of the DW1000 is limited by design to a maximum value of approx. -35dBm / MHz. This is more than adequate to meet the regulatory maximum limit of -41.3dBm / MHz that applies in the vast majority of geographies where UWB is permitted and provides margin to allow for PCB, balun, temperature, antenna and enclosure losses.

The receiver sensitivity of DW1000 based products can be improved to increase communications range by the addition of a suitable low noise amplifier (LNA). The insertion of an LNA amplifier into the receive path between the receiver antenna and the RF pins on the DW1000 can typically result in a 3-4 dB improvement in receiver sensitivity. This is achieved by lowering the receiver noise figure.

1.2 Hardware and software modifications

DW1000 has been designed to provide the necessary control signals to allow the use of an external LNA. These signals include controls for switching LNA DC power and controlling RF switches to switch between transmit and receive paths if required.

The hardware required is discussed in section 2 while the software modifications to enable the operation of the external circuitry are discussed in section 3.

2 HARDWARE IMPLEMENTATION

2.1 Overview

The basic scheme for incorporating an LNA into the DW1000 receive path is illustrated in Figure 1 below.

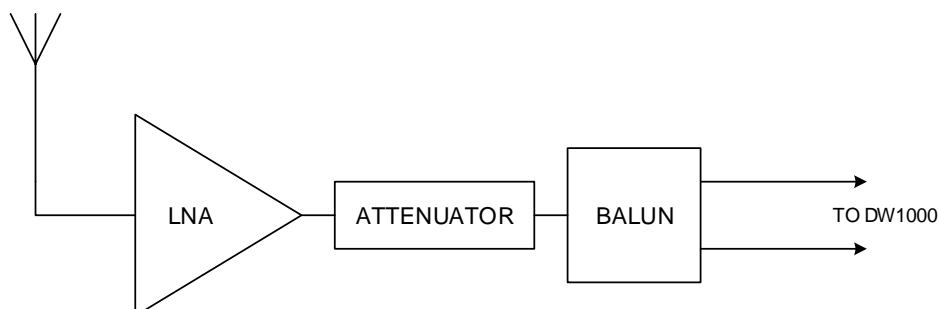


Figure 1: Basic scheme

The LNA has a lower noise figure than the DW1000 and can provide in the region of 10 – 30 dB of gain depending on the channel frequency and the particular amplifier used. This level of gain is sufficient to saturate the on-chip DW1000 receiver at high receive signal levels at the antenna so to prevent this from occurring, an attenuator is typically included between the LNA output and the DW1000 input.

The basic scheme illustrated above does **not** include a transmit path from the DW1000 to the antenna. Decawave recommends that a transmit path **should** be included because it permits Decawave's recommended method of antenna delay calibration to be used (refer to [6] for a detailed discussion of antenna delay calibration). See Figure 2 below.

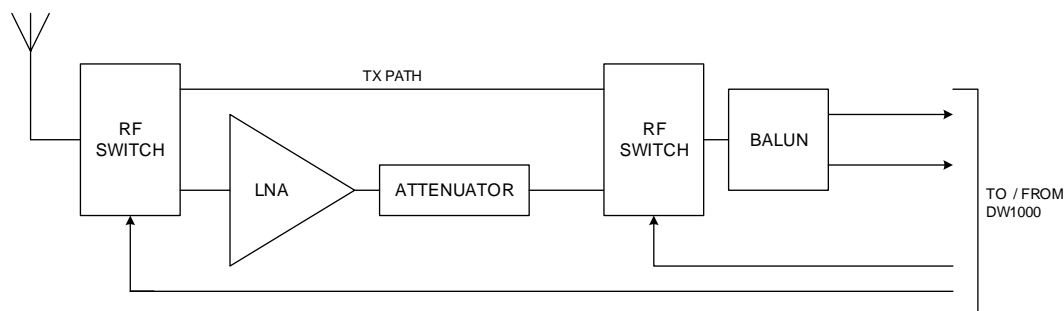


Figure 2: Scheme with Tx path included

2.2 Designing LNA scheme

Receiver sensitivity is mainly determined by the receiver noise figure (NF). Typically DW1000 has a noise figure of 5 dB. When a balun is included, this figure increases to approximately 6 dB. When designing the external LNA scheme the following criteria should be met:

- The overall receiver noise figure needs to be reduced
- The strongest receiver signal presented to the DW1000 IC should not exceed -39 dBm

The LNA circuitry should be designed to give the lowest noise figure while not compressing the DW1000 receiver.

2.2.1 Calculating Noise Figure

A DW1000 product with a balun will have a typical antenna referenced noise figure of 6 dB. The design of the external LNA scheme should aim to reduce this NF to about 3 to 4 dB thus giving a corresponding 2 to 3 dB improvement in range.

To calculate the improvement (reduction) in NF we need to use the cascade formula for Noise Factor:

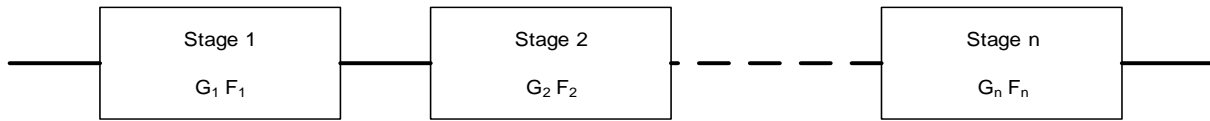


Figure 3: Cascade of n devices

In a general case of a cascade of n devices as depicted in Figure 3 the total noise factor is given by: -

$$F_{total} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \frac{F_4 - 1}{G_1 G_2 G_3} + \dots + \frac{F_n - 1}{G_1 G_2 \dots G_n}$$

Where:

- F_{total} = total noise factor (to be converted to noise figure)
- F_n = Noise factor of stage n
- G_n = Linear gain of stage n

Noise Factor (F) is converted to Noise Figure (NF) using the formula: -

$$NF = 10 \log_{10}(F)$$

Linear gain (G) is converted to gain in dB $G(dB)$ using the formula: -

$$G(dB) = 10 \log_{10}(G)$$

2.2.2 Example Noise Figure calculation

Taking the line-up shown in Figure 1, we have an LNA, attenuator and balun followed by the DW1000. The table below gives some typical gain and noise figure values for these stages and converts them to linear gain and noise factor.

Table 1: Example RX stage specifications

Stage	LNA	Attenuator	Balun	DW1000	Units
Gain	12	- 6	- 1		dB
Gain	15.85	0.25	0.79		Linear
Noise Figure	1.5	6	1	5	dB
Noise Factor	1.41	3.98	1.26	3.16	

Using the linear gain and noise factor values shown in the table above, we can now calculate the overall receiver Noise Figure: -

$$F_{total} = 1.41 + \frac{3.98 - 1}{15.85} + \frac{1.26 - 1}{15.85 \times 0.25} + \frac{3.16 - 1}{15.85 \times 0.25 \times 0.79}$$

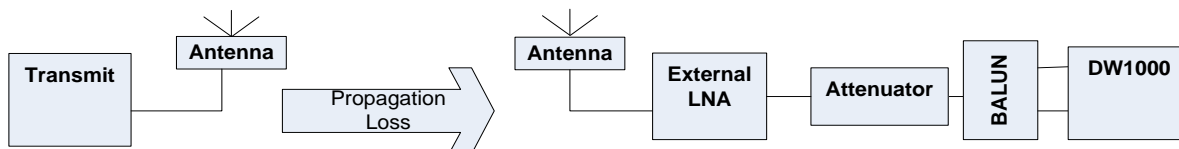
$$F_{total} = 2.35$$

$$NF(dB) = 3.71 \text{ dB}$$

This is a 2.29 dB reduction in overall noise figure compared to the case with no LNA since DW1000 plus the balun has a noise figure of 6 dB

2.2.3 Calculating Attenuator Value

In most cases when using an external LNA it will be necessary to add an RF attenuator after the LNA to avoid too high a level signal being presented to the DW1000 IC. This is mostly applicable when the transmitter and receiver are very close. The attenuator can be realised by using 3 surface mount resistors in a pie or tee configuration or by using an off-the-shelf fixed value RF attenuator.



The strongest receive signal appearing at the DW1000 input should be less than -39 dBm to avoid any signal compression in the IC. The following formula can be used to check that this condition is met and to calculate the value of attenuator required: -

$$RSL_{max} = Tx_{pwr} + Tx_{antgain} - Prop_{loss} + Rx_{antgain} + LNA_{gain} - Att_{loss} - Balun_{loss}$$

Where:

- RSL_{max} = maximum signal appearing at the DW1000 RF input
- Tx_{antgain} = gain of the transmitter antenna in dB
- Rx_{antgain} = gain of the receiver antenna in dB
- LNA_{gain} = gain of the external LNA in dB
- Att_{loss} = loss of the attenuator in dB
- Balun_{loss} = loss of the balun in dB

The propagation loss will depend on the channel being used and the distance between receiver and transmitter. The graph below can be used to find the propagation loss for each channel at distances from 10 cm to 2 m.

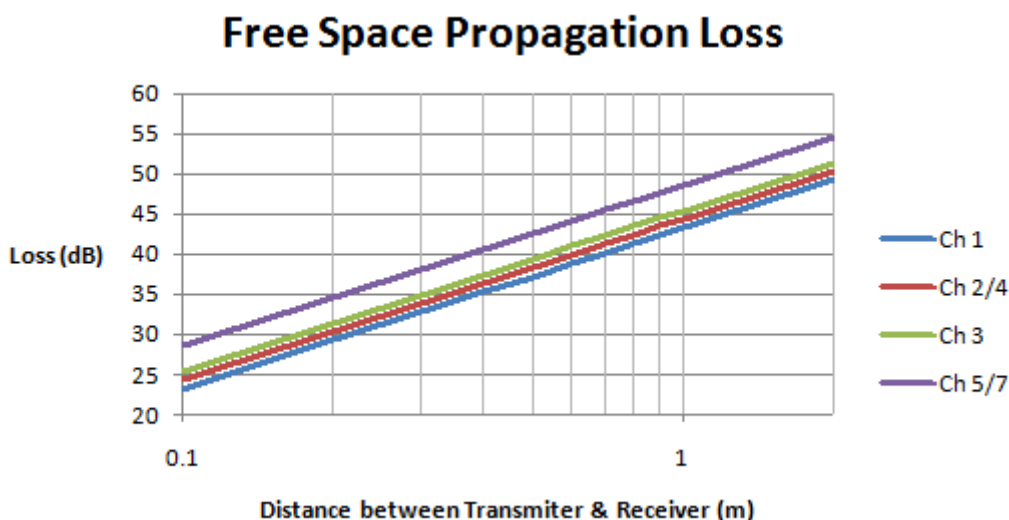


Figure 4: Propagation loss per channel

2.2.4 Example of calculating the required attenuation of the attenuator

Again taking the line-up shown in Figure 1, we have an LNA, attenuator and balun followed by the DW1000. If we use the LNA gain value from the previous example i.e. 12 dB and assume channel 2 operation at 1 m separation between receiver and transmitter, the transmitter operating at -14.3dBm and 0 dBi antenna gain for both transmitter and receiver then we have:

$$RSL_{max} = -14.3 + 0 - 44 + 0 + 12 - 6 - 1$$

$$RSL_{max} = 53.3 \text{ dBm}$$

This gives us a margin of: -

$$-39 - 53.3 = 14.3 \text{ dB}$$

Using this value of attenuator (6 dB) we could operate down to a minimum transmitter to receiver separation of 20 cm.

2.3 Control signals

The DW1000 provides signals necessary to control the switching of the path between the RF pins of the DW1000 and the antenna to include the LNA or not depending on whether the DW100 is in Rx or Tx mode.

Table 2: DW1000 pins associated with the control of an external LNA scheme

Signal Name	Pin	I/O	Description
GPIO6 / EXTRXE / SPIPOL	30	DIO	General purpose I/O pin. On power-up it acts as the SPIPOL (SPI polarity selection) pin for configuring the SPI operation mode. For details of this please refer to the DW1000 data sheet and User Manual. After power-up, the pin will default to a General Purpose I/O pin. It may be configured via programming to act as EXTRXE (External Receiver Enable). When configured in this way, this pin goes high when the DW1000 is in receive mode.

2.4 Power Supplies

If you decide to use an LNA in your product it is important that adequate decoupling is provided to keep the supply “quiet” so as to avoid injecting noise into the receiver.

You should follow the LNA manufacturer’s recommendation in this regard.

2.5 RF Path

2.5.1 Overview / Basic scheme

Because there is only a single RF port on the DW1000 which is used for both receive and transmit modes and as we wish to include an external LNA only in the receive path then, obviously, switching of the RF path is required between the DW1000 and the antenna to: -

- Switch in the amplifier when the DW1000 is in receive mode
- Provide a direct path from the antenna to the chip when the DW1000 is in transmit mode.

The basic hardware scheme is shown in Figure 2 above. The balanced RF interface to the DW1000 is converted to un-balanced by the balun.

In receive mode, the RF path is switched to include the LNA while in Tx mode the LNA is removed from the circuit and the balun is routed directly to the antenna.

2.5.2 Detailed schematic

The schematic using a typical low cost low current LNA (BGB707L7) is shown in Figure 5.

Each RF switch requires two controls, one to enable the Rx path and the other to enable the Tx path. The Tx path control is generated from the Rx path control via an inverter thereby avoiding the possibility of both paths being enabled at the same time.

The receive path is the lower RF path in the schematic; from the antenna through the common RF port on U1, through the LNA, U2, through the attenuator, U3, into the RF2 port of U4, out the common RF port of U4 and then to the balun.

The transmit path is the upper RF path in Figure 5, from the common RF port on U4, out the RF1 port of U4, into the RF2 port on U1 and finally out of the common RF port of U1 to the antenna.

AC coupling is used throughout to remove DC components in the signal.

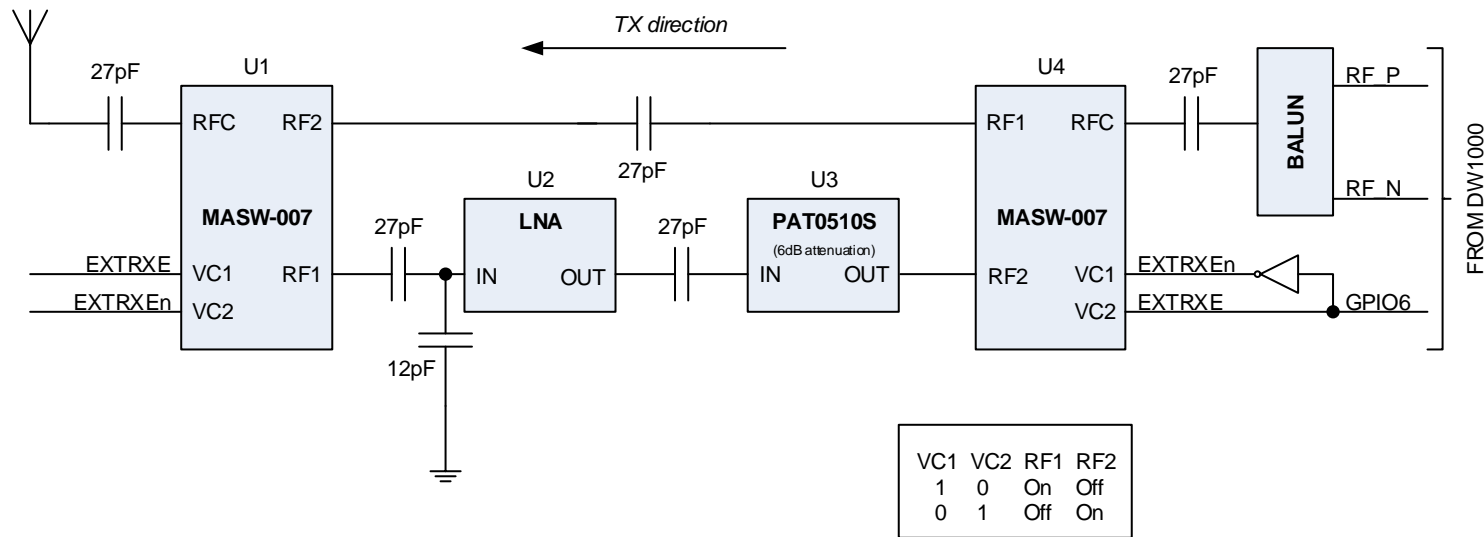


Figure 5: Hardware schematic

2.5.3 PCB layout

The frequency of the RF signals (3 – 7.5 GHz) and the bandwidths (500-900 MHz) are relatively high hence particular attention must be paid to the lay out of the RF signal traces. Switching RF signals of this type is challenging and great care must be paid to impedance matching and the avoidance of discontinuities if a significant reduction in performance is to be avoided.

The RF path from the DW1000 to the balun is as per the DW1000 datasheet. The unbalanced side of the balun connects directly to the RF switch, U4, using as short a trace as possible and without any discontinuities. A tapered trace should be considered here to avoid any step discontinuity. The transmit path trace width between U4 & U1 is chosen and referenced to one of the internal PCB ground layers so as to provide a 50Ω match. The path from the antenna to U1 is similarly matched. The matching of the receive path from the RF switches to / from the LNA is more difficult to achieve given the different component pad widths involved so a best compromise must be chosen that minimises discontinuity and most closely approximates the desired impedance match.

3 SOFTWARE IMPLEMENTATION

3.1 Introduction

There is very little software interaction required to allow the use of an external LNA. Because the DW1000 hardware supports this mode of operation, the software simply needs to enable the relevant portions of the hardware.

From then on no further interaction is required.

Enabling the hardware consists of correctly configuring the relevant GPIO pin to act as the control for the external RF switches as detailed in section 2. This GPIO is configured via the GPIO mode control register.

3.2 Register programming

The GPIO mode control register is a 32 bit register as follows: -

REG:26:00 – GPIO_MODE – GPIO Mode Control Register																															
31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
-	-	-	-	-	-	-	-	MSGP8	MSGP7	MSGP6	MSGP5	MSGP4	MSGP3	MSGP2	MSGP1	MSGP0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The relevant fields are those that control GPIO6; namely MSGP6.

Field	Description of fields within REG:26:00 GPIO_MODE
MSGP6 reg:26:00 bits:19,18	Mode Selection for GPIO6 / EXTRXE. Allowed values are: 00: The pin operates as GPIO6 – This is the default (reset) state. 01: The pin operates as the EXTRXE output. 10: Reserved. Do not select this value. 11: Reserved. Do not select this value.

From this description we can see that we need to set MSGP6 to 01.

3.3 Code changes

To program these GPIOs we proceed as follows: -

1. Read the current contents of the control register
2. OR in the desired changes for MSGP6. Examining the register details above gives an OR mask of 0x00040000.
3. Write the modified value back to the control register

The following code fragment illustrates the above: -

This code needs to be added to deca_device.c at the end of dwt_initialise().

Please also see the Decawave API document for details on the functions used.

```
{
    uint32 reg;

    // Set up GPIO

    reg = dwt_read32bitreg(GPIO_CTRL_ID); // read the current GPIO_CTRL_ID register
    reg |= 0x00040000; // set the appropriate GPIOs
    dwt_write32bitreg(GPIO_CTRL_ID, reg); // write the modified value back
}
```

4 OTHER CONSIDERATIONS

4.1 *Effect on antenna delay & its calibration*

Adding an LNA and its associated RF switches in the RF path between the antenna and the DW1000 introduces additional delay between the time the signal arrives at the antenna and the time the arriving frame is time-stamped inside the DW1000. Similarly in the transmit path, additional delay is introduced by the RF switches.

This additional delay needs to be calibrated out during the antenna delay calibration process discussed in [5] & [6].

It is important when choosing LNA and RF switch components that this additional delay remains constant over the expected operating parameter range (Voltage, Temperature) for a given channel otherwise the timestamps provided by the DW1000 will also vary.

4.2 *Receiver signal-based effects*

4.2.1 **Effect on range bias and its correction**

For a given physical separation between the transmitter and receiver, when using an LNA, the strength of the received signal level at the RF pins of the DW1000 will be higher than if an LNA is not used.

This has implications for range bias correction which is discussed in detail in [4]. When correcting for range bias the additional receiver sensitivity introduced by the LNA needs to be taken into account.

4.2.2 **Potential receiver saturation**

When a transmitter is in close proximity to a receiver that uses an LNA the incident signal power at the RF pins of the DW1000 can be so strong as to saturate the DW1000 receiver and drive it into compression. This can result in incorrect operation and an increase in packet error rate.

Care should be taken to ensure that such a situation does not arise if an LNA is being used. Systems in which transmitting nodes come in close proximity to receiving nodes should not use LNAs or should dynamically alter their gain to avoid receiver saturation.

5 REFERENCES

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

Table 3: Table of references

Ref	Author	Version	Title
[1]	Decawave	Current	DW1000 Data Sheet
[2]	Decawave	Current	DW1000 User Manual
[3]	Decawave	Current	APS009 DW1000 under LAES
[4]	Decawave	Current	APS011 Sources of error in two-way ranging
[5]	Decawave	Current	APS012 DW1000 production tests
[6]	Decawave	Current	APS014 Antenna delay calibration of DW1000-based products & systems

6 DOCUMENT HISTORY

Table 4: Document History

Revision	Date	Description
1.00	12 th December 2014	Initial release.
1.01	16 th December 2014	Scheduled update
1.02	31 st March 2015	Scheduled update
1.3	31 st December 2015	Scheduled update
1.4	30 th June 2016	Scheduled update
1.5	31 st March 2017	Scheduled update

7 MAJOR CHANGES

Revision 1.00

Page	Change Description
All	Initial release

Revision 1.01

Page	Change Description
Front page	Change in version number from 1.00 to 1.01
2	Update of table of contents
11	Inclusion of new section 3.4 Other Considerations
12	Update of table 3 to include Reference [5]

Revision 1.02

Page	Change Description
Front page	Change in version number from 1.01 to 1.02
2	Update to table of contents
10	Section 3.3. Change in mask value from 0x08 to 0x04
11	Change in mask value from 0x08 to 0x04
12	Addition of revision 1.02 to Table 4
12	Addition of this table

Revision 1.3

Page	Change Description
Front page	Change in version number from 1.02 to 1.3 – correction of version number format
All	Various typographical changes
2	Update to table of contents
13	Inclusion of section 4
14	Addition of revision 1.3 to Table 4
15	Addition of this table.

Revision 1.4

Page	Change Description
10	Modification to LNA label in Figure 5
17	Modification to list of LNA parts in section 9.2
14	Addition of revision 1.4 to Table 4
15	Addition of this table.

Revision 1.5

Page	Change Description
Front page	Change in version number from 1.4 to 1.5
All	Various typographical changes
17	Modification to list of RF switch parts in section 9.3
14	Addition of revision 1.5 to Table 4
15	Addition of this table.

Revision 1.6

Page	Change Description
Front Page	Change in version number from 1.5 to 1.6
All	Update of company logo
9	Replaced reference to BGA628 LNA (obsolete) with BGB707L7
15	Addition of this table.

8 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.

9 APPENDIX 1: CANDIDATE COMPONENTS LIST

9.1 Balun

Part Number	Manufacturer	Comments
BD3150L50100AHF	Anaren	Max freq specified is 5 GHz but may operate at 6.5 GHz with increased insertion loss.
HHM1595A1	TDK	Used on Decawave reference designs

9.2 LNA

Part Number	Manufacturer	Comments
BGB707L7	Infineon	
BFP840ESD	Infineon	
MAAL-011078	MACOM	Does not cover channel 5

9.3 RF Switch

Part Number	Manufacturer	Comments
MASW-007107	MACOM	
RFSW8000	RFMD	
Sky13320	Skyworks	Does not cover channel 5