decaWave

APS009 APPLICATION NOTE

OPERATING THE DW1000
UNDER LAES REGULATIONS

Using the DW1000 with an
external power amplifier to
increase transmit power and
communications range

Version 1.3

This document is subject to change without
notice

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Overview

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 when UWB is permitted and provide some margin to allow for PCB and enclosure losses.

Needless to say, this restriction of output power along with the sensitivity of the DW1000 receiver results in a finite link budget which is the primary determinant of communications and location range – in the case of the DW1000 the maximum range is approximately 280 m.

Certain scenarios have recently emerged, particularly in the area of first responders to emergency situations, where it is desirable to considerably extend this range given that the location to which the first responders are deployed will most likely not have any UWB RTLS infrastructure deployed so they will need to deploy their own when they arrive.

1.2 Compliance with regulations

As a result of the above, ETSI, the regulatory body in Europe, has drawn up a new standard denoted LAES (**L**ocation tracking **A**pplications for **E**mergency **S**ervices) that applies only in the case of first responders and other specific use cases where the transmit power limits have been increased from the nominal -41.3 dBm / MHz by 20 dB to -21.3 dBm / MHz. This represents a significant increase in link budget and therefore communications range.

1.2.1 LAES compliance

The European LAES regulations specifically restrict operation to the frequency range of 3.4 to 4.2 GHz.

In order to be fully compliant with the ETSI LAES spec it is necessary to modify the pulse shape used in the DW1000 transmitter so that the resulting spectrum fits correctly within the LAES spectrum mask. Contact Decawave for further details on this topic.

1.2.2 Caution advised

While the DW1000 can be used with an external power amplifier, as detailed in this note, to increase transmit power by +20 dB and the DW1000 includes control signals to ease such a design, Decawave cannot guarantee that such levels of transmit power will be permitted in a particular geographic area under the regulations currently in force in that area.

Before commencing a design based on this application note, the user should satisfy themselves that it will be legally possible to operate the final product in their end-market.

Decawave accepts no responsibility should it transpire that the +20 dB transmit power level is not permitted in a particular geography.

It is important to note also that the upper frequency range of the external amplifier used in this application note limits the operation of this circuit to the low-band channels (Channel 2, 3, 4) which may have additional regulatory implications in certain regions and in particular may require the use of low duty cycle operation. Again, the user is advised to check the local regulations in their end-market.

1.3 Hardware and software modifications

Adding an external power amplifier to the transmitter of the DW1000 is relatively simple; the DW1000 has been designed to provide the necessary control signals and provided the external circuitry is implemented with care bearing in mind the frequencies & bandwidths involved then very good results

can be achieved.

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

There are basically three aspects to the use of an external power amplifier with the DW1000 as follows: -

1.   Control signals
2.   Power supplies
3.   RF circuitry and the integrity of the RF path

2.2   Control signals

The DW1000 provides all the signals necessary to control and enable an external power amplifier. The key ones are highlighted in the table below.

Table 1: DW1000 pins associated with the control of an external PA 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.
GPIO5 / EXTTXE / SPIPHA	33	DIO	General purpose I/O pin. On power-up it acts as the SPIPHA (SPI phase selection) pin for configuring the SPI mode of operation. Refer to the DW1000 data sheet and User Manual for further information. After power-up, the pin will default to a General Purpose I/O pin. It may be configured via programming to act as EXTTXE (External Transmit Enable). When configured in this way, this pin goes high when the DW1000 is in transmit mode.
GPIO4 / EXTPA	34	DIO	General purpose I/O pin. It may be configured via register programming for use as EXTPA (External Power Amplifier) enable.

2.3   Power Supplies

The power amplifier, when enabled, typically requires 130 mA from a 5 V DC supply rail. This requires an additional supply not normally required by the DW1000. It is important that this supply is sized with this current in mind and that adequate decoupling is provided to deal with turn-on transients as the amplifier is enabled for each transmission

2.4   RF Path

2.4.1   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 amplifier only in the transmit 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 transmit mode
- Provide a direct path from the antenna to the RF port on the chip when the DW1000 is in receive mode.

The basic hardware scheme is shown in Figure 1 below. The balanced RF interface to the DW1000 is converted to un-balanced by the Balun.

In transmit mode, the external PA is enabled via GPIO4 while GPIO5 is set to switch the RF path through the amplifier. In receive mode the external PA is disabled (to save power) and GPIO5 is set to switch the RF path directly from the antenna to the DW1000.
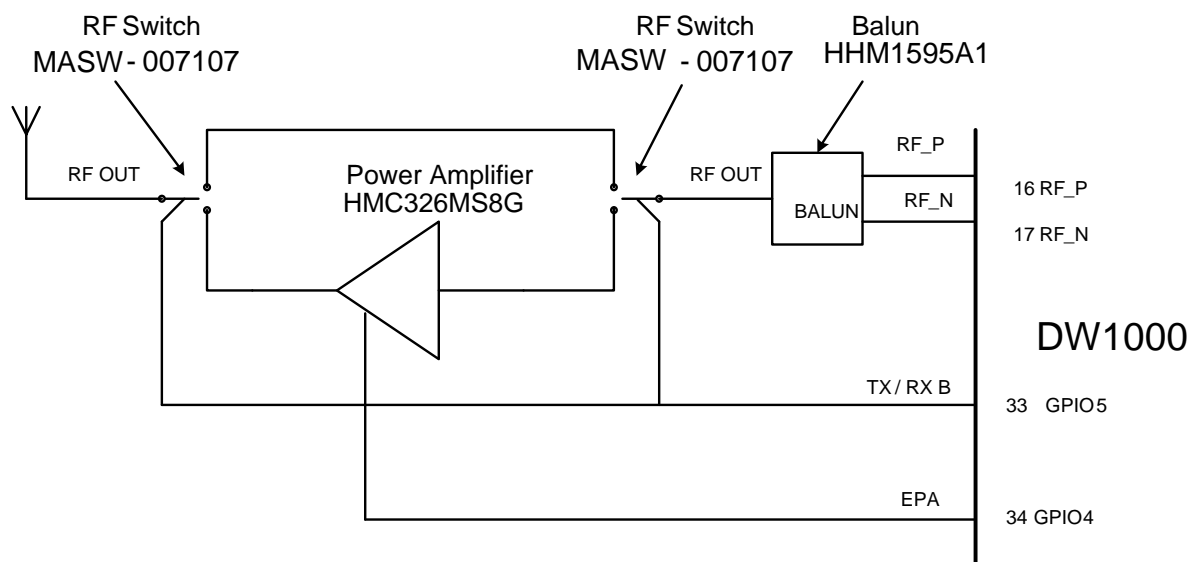

Figure 1: Basic scheme

2.4.2 Detailed schematic

The detailed schematic is presented in Figure 2 – essentially this directly implements the scheme shown in Figure 1.

Control signals from the DW1000 are nominally 3.3 V DC so these must be level shifted into the 5V domain before being used to control the RF switches & the PA.

Each RF switch requires two controls, one to enable the TX path and the other to enable the RX path. The TX path control is generated from the RX path control via inverter U5 thereby avoiding the possibility of both paths being enabled at the same time.

The transmit path can clearly be seen as the lower RF path in Figure 2 from the common RF port on RF-switch U8, through the RF2 port on U8, into the PA, U7, on pin3, out of the PA on pin 6, into the RF1 port on RF-switch U6 and finally out of the common RF port on U6 to the antenna.

The receive path is the upper RF path in the schematic from the antenna through the common RF port on U6, through the RF2 port on U6, into the RF1 port on U8 through the RFC port on U8 and then to the balun.

The Power Amplifier used in this implementation is a Hittite part (HMC326MS8G) with a frequency range of 3 to 4.5 GHz. As such, this circuit operates only with the low band channels of the DW1000 (Channel 2, 3, 4) and will not operate with the high band channels (Channel 5, 7). The amplifier needs to be specifically tuned to the desired channel of operation. This is achieved by altering the electrical lengths of the traces between the amplifier output, C55 and L1 by physically moving the location of C55 as appropriate.

Note the extensive decoupling throughout – this is crucially important to the correct operation of the design.
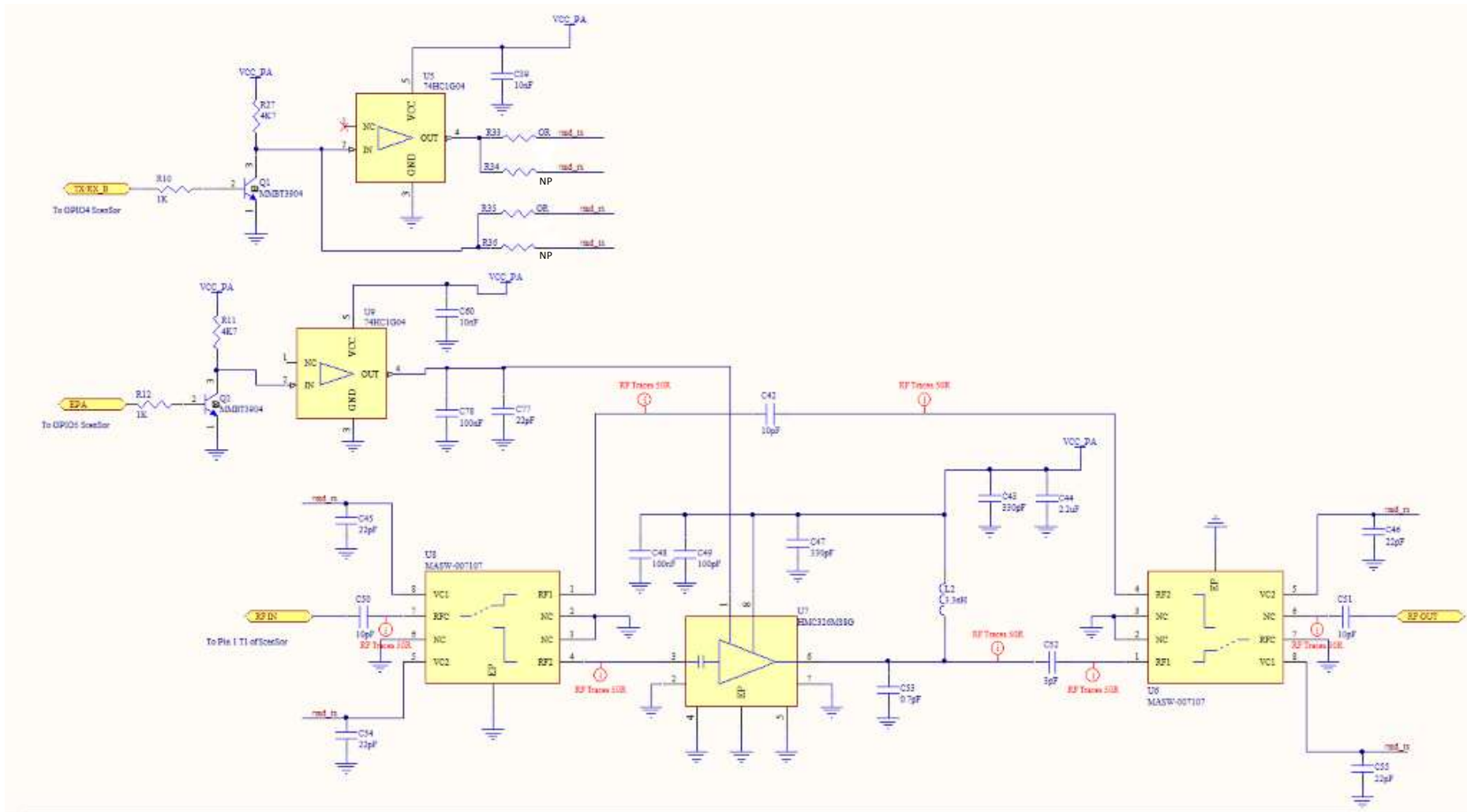

Figure 2: Hardware schematic

2.4.3   PCB layout

It is vital to bear in mind that all of these RF lines need to operate at very high frequency (4 GHz) and with very wide bandwidth (500 MHz). 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 using as short a trace as possible and without any discontinuities. Note the tapered trace to avoid any step discontinuity. The receive path trace width is chosen and referenced to one of the internal PCB ground layers so as to provide a 50 Ω match. Similarly the path from the antenna to the antenna-side RF switch is similarly matched. The matching of the path from the RF switches to / from the PA 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 match.
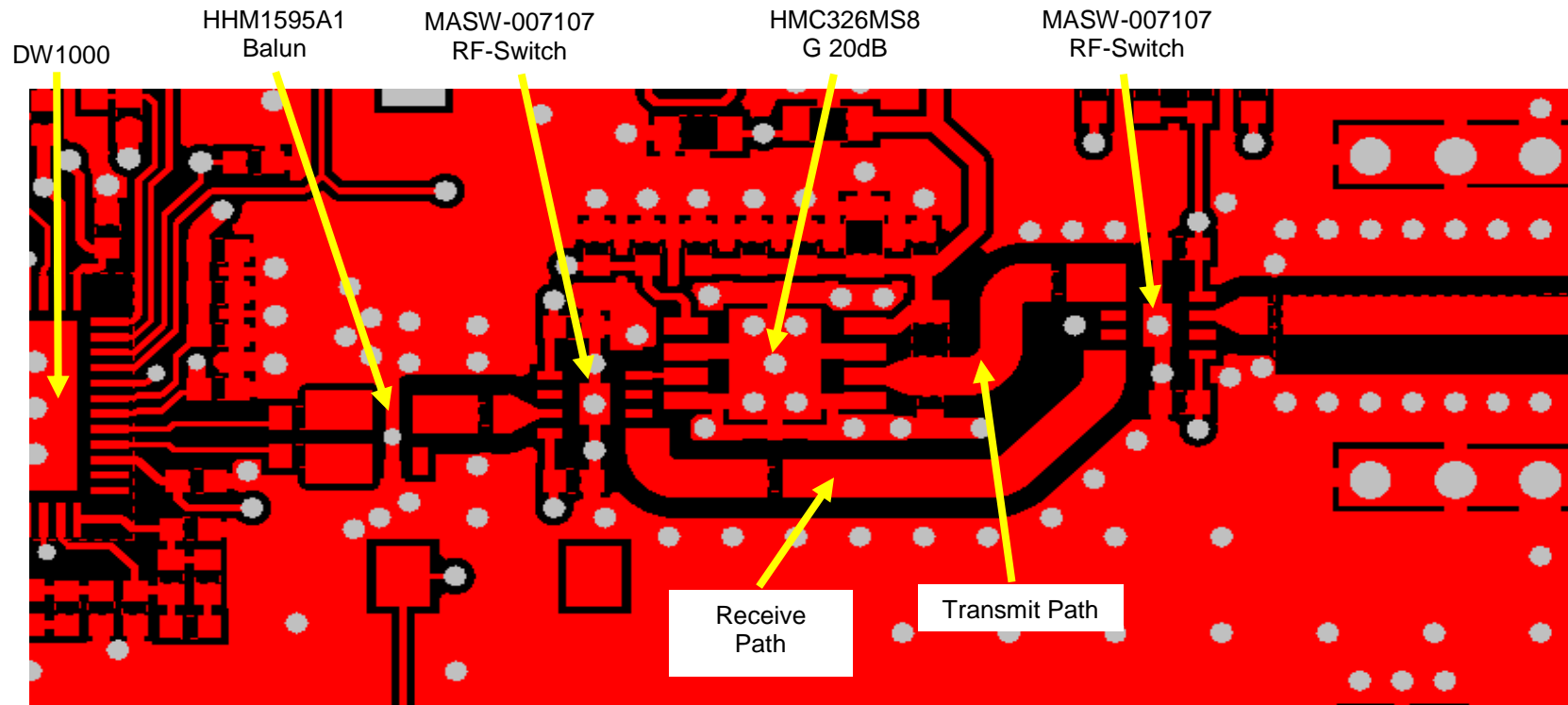

Figure 3: PCB Layout

3 SOFTWARE IMPLEMENTATION

3.1 Introduction

There is very little software interaction required to allow the use of an external power amplifier. Because the DW1000 hardware supports this mode of operation, the software merely 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 pins to act as controls for the PA and the external RF switches as detailed in section 2. These GPIOs are 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 GPIO4 & 5; MSGP4 and 5 respectively.

Field	Description of fields within REG:26:00 GPIO_MODE
MSGP4 reg:26:00 bits:15,14	Mode Selection for GPIO4/EXTPA. Allowed values are: 00: The pin operates as GPIO4– This is the default (reset) state. 01: The pin operates as the EXTPA output. 10: Reserved. Do not select this value. 11: Reserved. Do not select this value.
MSGP5 reg:26:00 bits:17,16	Mode Selection for GPIO5/EXTTXE. Allowed values are: 00: The pin operates as GPIO5 – This is the default (reset) state. 01: The pin operates as the EXTTXE output. 10: Reserved. Do not select this value. 11: Reserved. Do not select this value.

From the above description we can see that we need to set MSGP4 to 01 and MSGP5 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 MSGP4 & 5. Examining the register details above gives an OR mask of 0x00014000.
3. Write the modified value back to the control register

There is one other step we need to take and that is to disable what is known as fine-grain sequencing. It is not necessary to go into the details of this here. Suffice to say that the DW1000 allows very fine control of the switching on and off of individuals blocks and circuits inside the chip to save power. However, if this switching was allowed to occur when using an external power amplifier incorrect

operation would result. Therefore we disable it.

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 DW1000 Software API Guide [7] 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 |= 0x00014000;                      // set the appropriate GPIOs
    dwt_write32bitreg(GPIO_CTRL_ID,reg);    // write the modified value back

    //disable fine grain sequencing
    dwt_write16bitoffsetreg(PMSC_ID, 0x26,0);
}
```

4 OTHER CONSIDERATIONS

4.1 Introduction

There are a number of effects that need to be taken into consideration when incorporating a PA into a node design.

4.2 Effect on antenna delay & its calibration

Incorporating a power amplifier and its associated RF switches into the signal path between the DW1000 and the antenna introduces additional delay between the time an outgoing message is timestamped in the DW1000 and time it leaves the antenna. Similarly in the receive path, additional delay is introduced by the RF switches.

It is important when choosing PA 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 receiving DW1000 will also vary.

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

4.3 Receiver signal-based effects

4.3.1 Effect on range bias & its correction

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

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

4.3.2 Potential receiver saturation

When a transmitter using a PA is in close proximity with a receiver the incident signal power at the receiver can be so strong as to saturate the 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 a PA is being used. Systems in which transmitting nodes come in close proximity to receiving nodes should not use a PA or should dynamically alter their gain to avoid receiver saturation.

4.4 Receiver accumulator wrap-around

The accumulator in the DW1000 receiver that is used to accumulate and analyse the channel impulse response of the received signal is a fixed length circular memory buffer that is designed to accommodate 1 µs of channel impulse response i.e. a distance of 300 m in a Line of Sight channel. If a signal is received over a path that is longer than 300 m this can cause the accumulator to "wrap around". This can give incorrect and confusing first-path timestamp results.

A location system using power amplifiers in mobile tags should incorporate filtering to remove such incorrect first paths.

5 REFERENCES

Table 2: 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
[7]	Decawave	Current	DW1000 Software API Guide

6 DOCUMENT HISTORY

Table 3: Document History

Revision	Date	Description
1.0	INTERNAL	Internal release for review.
1.1	3rd April, 2014	Initial release
1.2	15th January 2015	Updates as below
1.3	31st December 2015	Scheduled update

7 MAJOR CHANGES

Revision 1.2

Page	Change Description
All	Update of version number to 1.2
All	Correction of typographic error in page header
7	Modification of application schematic to show R33 / R35 as 0 Ohm and R34 / R36 as NP
9	Modification to section 3.2 to correct reference
11	Addition of document history table as section 4 and inclusion of this revision 1.2 Addition of this table and section heading as section 5 Renumbering of "About Decawave" heading to section 6

Revision 1.3

Page	Change Description
First	Update of version number to 1.3
All	Various typographical changes / update copyright notice to 2015
2	Update of Table of Contents / List of Tables / List of Figures
11	Inclusion of Section 4 and renumbering of subsequent sections
12	Inclusion of Section 5, table of references as Table 2 and renumbering of subsequent sections
12	Addition of revision 1.3 to table 3
12	Addition of this table

8 ABOUT DECAWAVE

Decawave is a pioneering fabless semiconductor company whose flagship product, the DW1000, is a complete, single chip CMOS Ultra-Wideband IC based on the IEEE 802.15.4 2011 UWB standard. This device is the first in a family of parts that will operate at data rates of 110 kbps, 850 kbps and 6.8 Mbps.

The resulting silicon has a wide range of standards-based applications for both real time location systems (RTLS) and wireless sensor networks (WSN) in areas as diverse as manufacturing, healthcare, lighting, security, transport, inventory & supply chain management.

Further Information

For further information on this or any other Decawave product contact a sales representative as follows: -

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e: sales@decawave.com
w: www.decawave.com
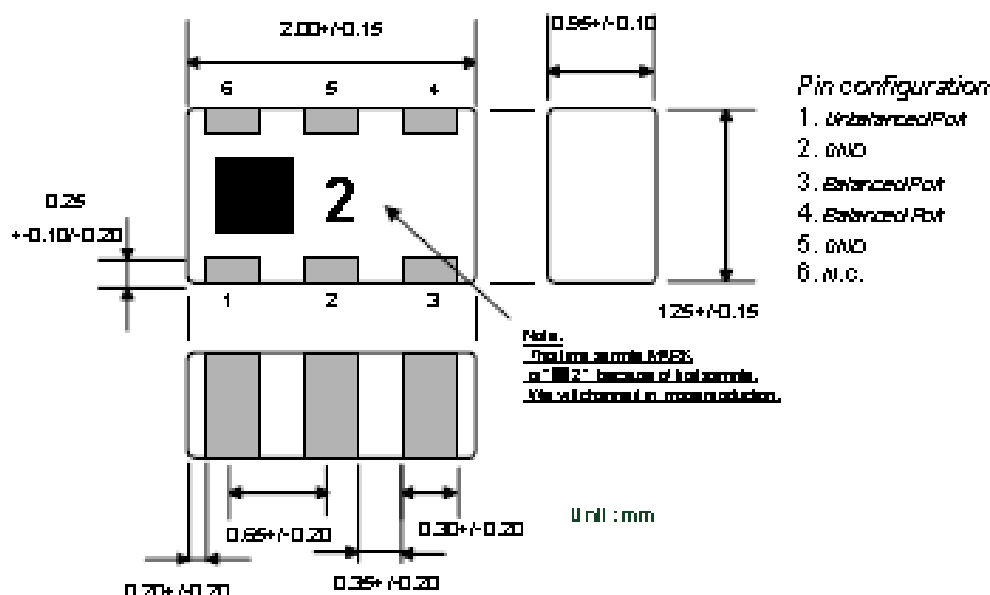
9 APPENDIX 1: COMPONENT SPECIFICATIONS

9.1 Balun

PRELIMINARY

March 2008 ver.2
TDK Corporation

MULTILAYER BALUN SPECIFICATION
P/N. HHM 595A1 For UWB

[MECHANICAL DIMENSIONS]

Pin configuration
1. Unbalanced Port
2. GND
3. Balanced Port
4. Balanced Port
5. GND
6. n.c.

Unit : mm

Note.
This line sample MARK is "2" because of test sample.
We will change in mass production.

[ELECTRICAL CHARACTERISTICS]

Unbalanced Impedance	50 ohm
Balanced Impedance	100 ohm
Frequency Range	3000 – 8000 MHz
Unbalanced Port Return Loss	8.0 dB min
Phase Imbalance at Balanced Port	180 +/- 20 deg
Amplitude Imbalance at Balanced Port	0 +/- 2.5 dB
Insertion Loss	1.5 dB max

[TEMPERATURE RANGE]

Storage Temperature	-40 - +85 degree C
Operating Temperature	-40 - +85 degree C

[STANDARD PACKAGING QUANTITIES]

2000 pcs./reel

Note: The above PRELIMINARY data are not guaranteed, and are subject to change without notice.

9.2 Power Amplifier

HMC326MS8G / 326MS8GE

v0.8.0808

GaAs InGaP HBT MMIC DRIVER AMPLIFIER, 3.0 - 4.5 GHz
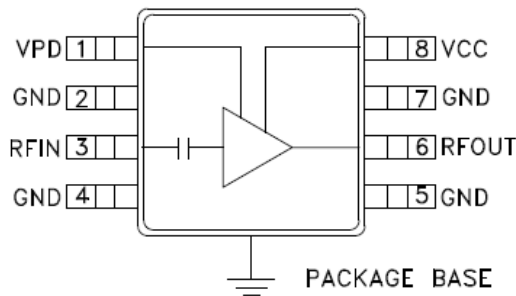
RoHS ✓

Typical Applications

The HMC326MS8G / HMC326MS8GE is ideal for:

• Microwave Radios

• Broadband Radio Systems

• Wireless Local Loop Driver Amplifier

Features

Psat Output Power: +26 dBm

> 40% PAE

Output IP3: +36 dBm

High Gain: 21 dB

Vs: +5V

Ultra Small Package: MSOP8G

Functional Diagram

VPD [1]   [8] VCC
GND [2]   [7] GND
RFIN [3]   [6] RFOUT
GND [4]   [5] GND

PACKAGE BASE

General Description

The HMC326MS8G & HMC326MS8GE are high efficiency GaAs InGaP Heterojunction Bipolar Transistor (HBT) MMIC driver amplifiers which operate between 3.0 and 4.5 GHz. The amplifier is packaged in a low cost, surface mount 8 leaded package with an exposed base for improved RF and thermal performance. The amplifier provides 21 dB of gain and +26 dBm of saturated power from a +5V supply voltage. Power down capability is available to conserve current consumption when the amplifier is not in use. Internal circuit matching was optimized to provide greater than 40% PAE.

Electrical Specifications, T_A = +25° C, Vs = 5V, Vpd = 5V

Parameter		Min.	Typ.	Max.	Units
Frequency Range			3.0 - 4.5		GHz
Gain		18	21		dB
Gain Variation Over Temperature			0.025	0.035	dB / °C
Input Return Loss			12		dB
Output Return Loss			7		dB
Output Power for 1dB Compression (P1dB)		21	23.5		dBm
Saturated Output Power (Psat)			26		dBm
Output Third Order Intercept (IP3)		32	36		dBm
Noise Figure			5		dB
Supply Current (Icc)	Vpd = 0V / 5V		0.001 / 130		mA
Control Current (Ipd)			7		mA
Switching Speed	tOn/tOff		10		ns

For price, delivery, and to place orders, please contact Hittite Microwave Corporation:
20 Alpha Road, Chelmsford, MA 01824 Phone: 978-250-3343 Fax: 978-250-3373
Order On-line at www.hittite.com

9.3 RF Switch

MASW-007107

GaAs Broadband SPDT Switch
DC - 8.0 GHz

Rev. V5

Features

- 802.11a + b/g and MIMO Applications
- Test and Measurement and Low/Medium Power Telecommunication Applications up to 8.0 GHz
- Broadband Performance: DC - 8.0 GHz
- Low Insertion Loss: 0.5 dB from 2.0 - 6.0 GHz
- High Isolation: 30 dB from 2.0 - 6.0 GHz
- Fast Settling for Low Gate Lag Requirements
- Lead-Free 2 mm 8-Lead PDFN Package
- 100% Matte Tin Plating over Copper
- Halogen-Free "Green" Mold Compound
- RoHS Compliant* and 260°C Reflow Compatible

Description

M/A-COM's MASW-007107 is a broadband GaAs pHEMT MMIC SPDT switch in a lead-free 2 mm 8-lead PDFN package. Typical applications are for WLAN IEEE 802.11a + b/g, and MIMO. Other applications include test equipment requiring ultra fast switching speeds. Designed for low insertion loss, this SPDT switch maintains low loss up to 8.0 GHz.

The MASW-007107 is fabricated using a 0.5 micron gate length GaAs pHEMT process. The process features full passivation for performance and reliability.

Ordering Information [1,2]

Part Number	Package
MASW-007107-TR3000	3000 piece reel
MASW-007107-000SMB	Sample Test Board
MASW-007107-000DIE[3]	Separated die on grip ring
MASW-007107-0GPDIE	100 piece gel pack

1. Reference Application Note M513 for reel size information.
2. All sample boards include 5 loose parts.
3. Die quantity varies.

Functional Schematic
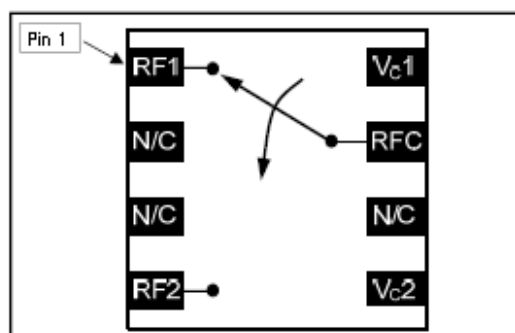
Pin Configuration [4]

Pin No.	Pin Name	Description
1	RF1	RF Output 1
2	N/C	No Connection
3	N/C	No Connection
4	RF2	RF Output 2
5	V_c2	Voltage Control 2
6	N/C	No Connection
7	RFC	RF Common
8	V_c1	Voltage Control 1
9	Paddle[6]	RF and DC Ground

4. M/A-COM recommends connecting unused package pins to ground.
5. The exposed pad centered on the package bottom must be connected to RF and DC ground.

Absolute Maximum Ratings [6,7]

Parameter	Absolute Maximum
Input Power @ 3 V Control	+32 dBm
Input Power @ 5 V Control	+34 dBm
Operating Voltage	+8.5 volts
Operating Temperature	-40°C to +85°C
Storage Temperature	-65°C to +150°C

6. Exceeding any one or combination of these limits may cause permanent damage to this device.
7. M/A-COM does not recommend sustained operation near these survivability limits.

* Restrictions on Hazardous Substances, European Union Directive 2002/95/EC.