APS017 APPLICATION NOTE

MAXIMISING RANGE IN DW1000 BASED SYSTEMS

Version 1.0

This document is subject to change without notice

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1 Introduction

1.1 Overview

This application note is concerned with how to maximise the effective communications range in DW1000 based systems. It examines all parts of the communications link between two DW1000 based nodes and discusses the optimisations that can be made in each area to maximise the effective range between the two nodes.

There are a number of other application notes available on www.decawave.com dealing with particular aspects of the subject of this application note and these are referenced during the course of this application note where relevant. www.decawave.com also contains details of Decawave's products as well as a range of additional support material.

1.2 What do we mean by "Range"?

In this note it is important to understand the distinction between the following terms: -

Term	Description	Primarily depends on
Communications range	The range between two DW1000 nodes at which successful communication takes place (as defined by acceptable packet error rate for a given application).	The **total energy** transmitted into the channel by the transmitter and received at the receiver over all paths between the two nodes. If this is above the receiver sensitivity then communications can occur.
Direct path detection range	The range between two DW1000 nodes at which the DW1000 can correctly detect and timestamp the direct path signal between the two nodes rather than any multipath.	The energy received at the receiver only over the **direct path** between the transmitter and receiver. This energy must be above a dynamically adjusted threshold in order for it to be detected by the DW1000.

These ranges may or may not be equal, depending on the channel. They are usually equal where there is a line-of-sight (LOS) between DW1000 nodes but for non-line-of-sight (NLOS) cases they may not be.

The DW1000 operates by deriving the impulse response of the communications channel between the transmitter and receiver for each received frame. It does this by processing the preamble sequence which comes at the start of every IEEE802.15.4-2011 UWB frame.
This allows the IC to: -

- Detect the signal from below the noise floor.
- Extract the direct path signal and any multipath signals that follow it.
- Process the impulse response and timestamp the first peak in this response that exceeds a dynamically adjusted detection threshold.

The DW1000 reports the time-stamp of this first peak in the impulse response via registers to which the application software has access. This value can then be used in a variety of different ways to implement location and ranging schemes.

1.3 Overview of the document

This document begins by presenting an overview of the key determinants of communications range and goes on to investigate each of those determinants in detail.

The results of that investigation are presented as a set of “rules” that can be applied to your design to ensure performance is maximised.

The document is organised as outlined in Table 1.

Table 1: Document overview

Section	Title	Description
Section 2	What determines range?	Gives an overview of the key elements that determine range in a radio communications system.
Section 3	System Parameter choices	Discusses how the choice of operating parameters for the DW1000 influences the range that can be achieved.
Section 4	Optimising the transmitter	Deals with the various aspects of the transmitter that need to be considered in order to maximise range.
Section 5	Optimising the receiver	Deals with the various aspects of the receiver that need to be considered in order to maximise range.
Section 6	Channel effects	Deals with the impact of various channel effects on range.
Section 7	Conclusion	Presents a summary of rules for getting maximum range.
Section 8	References	Lists the sources cited in this application note.
Section 9	Document history	Presents the revision history of this application note.
Section 10	Major changes	Lists the changes between revisions of this application note.
Section 11	About Decawave	Presents basic information about Decawave including contact information

2 What determines communications range?

2.1 Introduction

The communications range between two DW1000 ICs is determined by: -

1. the signal power that arrives from the transmitter of one DW1000 IC via the communication channel to the receiver of the other DW1000
2. the sensitivity of the receiver in the receiving DW1000

The signal power that arrives at the receiver depends on a number of factors as seen by examining Friis' path loss formula: -

$$P_R\ [dBm] = P_T\ [dBm] + G\ [dB] - L[dB] - 20\ \log_{10}(4\pi f_c d / c)$$

Where: -

- P_R is the received signal level;
- P_T is the transmitted power.
- *G* includes the antenna gains of the transmitting and receiving antennas, as well as any other gain from external amplifiers.
- L includes any PCB, cable, connector and other losses in the system
- *c* is the speed of light, 299792458 m/s;
- f_c is the center frequency of the channel used, expressed in Hertz;
- *d* is the distance in meters between the transmitter and receiver.

Provided P_R is greater than the receiver sensitivity, the signal will be correctly received.

The difference between the value of P_R and the receiver sensitivity is known as the **Link Margin** and gives an indication of the robustness of communications over the channel. A large link margin means that communications are robust and can handle additional attenuation without causing communications loss and vice versa.

Friis' formula clearly shows that: -

- For a given distance, as the signal frequency increases so does the path loss
- For a given frequency as the distance between transmitter and receiver increases so does the path loss.

2.2 The importance of each of the individual elements in the system

To maximise range: -

- Transmit power needs to be kept at the maximum allowable limit to ensure the maximum energy is transmitted into the channel.
- Losses due to PCB and antenna effects need to be kept to a minimum.
- The configuration with the best receiver sensitivity should be used
- The lowest channel frequency possible should be used if maximum range is the overriding requirement.

We'll deal with each of these in subsequent sections of this note.

3 System parameter choices

3.1 Introduction

This section discusses the impact of system operating parameter choices on achievable range.

The DW1000 is highly configurable. For each chosen configuration the operating characteristics of the device and its interaction with the physical world will be different so it is very important to understand the influence these configuration parameters have on device performance.

3.2 Channel Frequency

Perhaps the parameter that has the most obvious influence on range performance is the selected channel of operation. Friis' formula tells us that, for constant TX power, RX sensitivity and other hardware losses or gains, the range reduces with increasing channel frequency: -

$$P_R\,[dBm] = P_T\,[dBm] + G\,[dB] - L[dB] - 20\log_{10}(4\pi f_c d / c)$$

Choosing a representative set of parameters, we can observe the impact of channel frequency on range by plotting the link margin vs. distance using this formula as shown in Figure 1.

Table 2: Representative parameter set for illustration purposes

Parameter	Value	Units
TX Power	-16	dBm / 500 MHz channel
TX PCB Loss	0	dB
TX Antenna Gain	0	dBi
RX PCB Loss	0	dB
RX Antenna Gain	0	dBi
RX Sensitivity	-102	dBm / 500 MHz channel

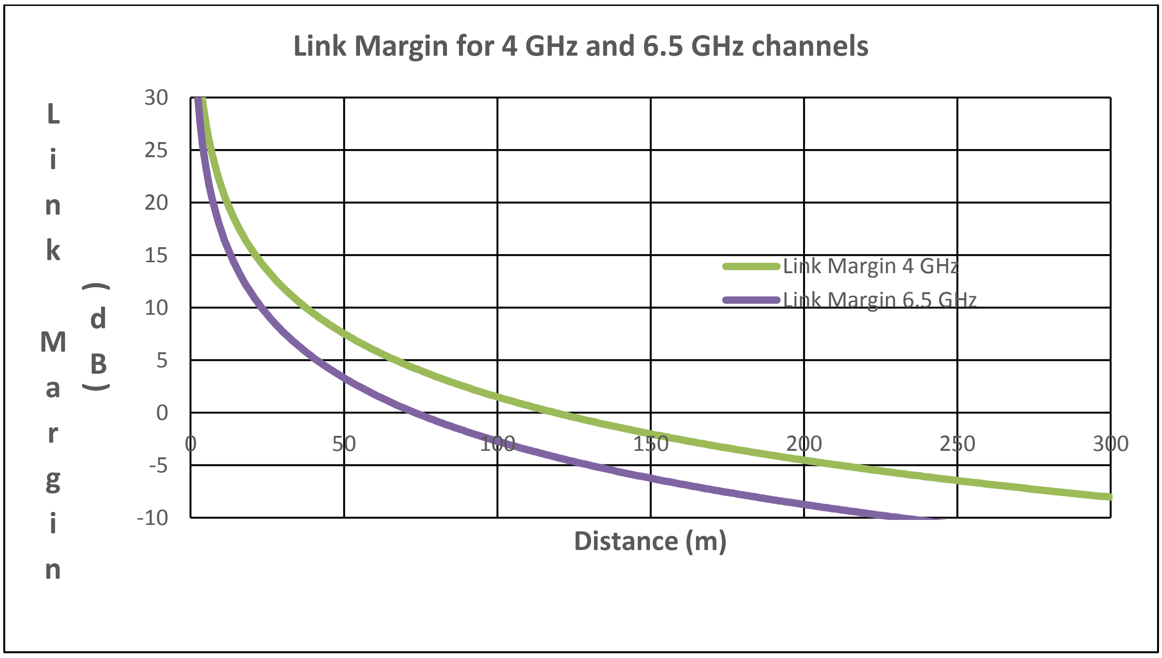

Figure 1: Link Margin vs distance for two channel frequencies

Figure 1 shows that the link margin in the 4 GHz channel reaches 0 dB at approximately 120 m while in the 6.5 GHz channel it reaches 0 dB at approximately 73 m. This comparison is somewhat unrealistic in that in practice the other system parameters are unlikely to remain the same at the two different channel frequencies but it does serve to illustrate the point.

Clearly if range is the overriding concern then the lowest available channel frequency should be used.

RULE 3.1: To maximise range use the lowest available channel frequency.

3.3 PCB losses

The example in section 3.2 assumed no antenna gain and no losses on the transmitter & receiver printed circuit boards (PCB). Let's assume our PCB design is poor and there is 2 dB of loss (very bad!) between the chip and the antenna. In a system context, if transmitter and receiver PCBs have the same front-end design, that represents a 4 dB loss in link margin. We can plot the same curves as in Figure 1 but this time based on the following parameters: -

Table 3: Representative parameter set with PCB losses

Parameter	Value	Units
TX Power	-16	dBm / 500 MHz channel
TX PCB Loss	2	dB
TX Antenna Gain	0	dBi
RX PCB Loss	2	dB
RX Antenna Gain	0	dBi
RX Sensitivity	-102	dBm / 500 MHz channel

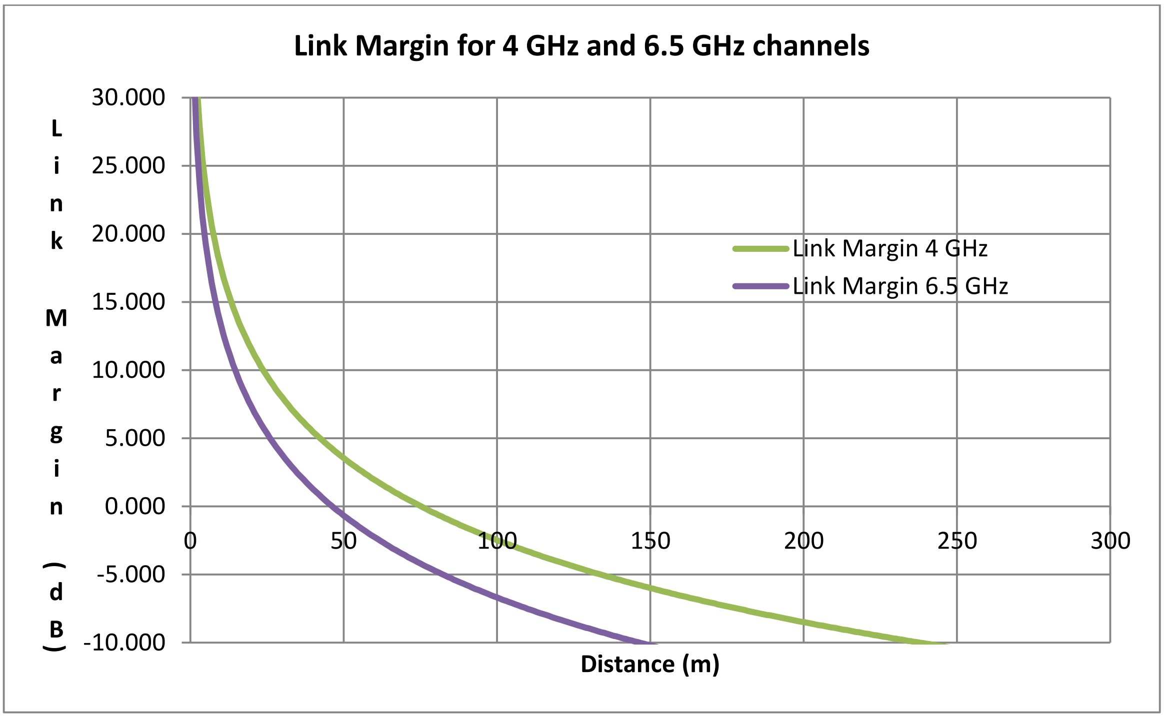

Figure 2: Link Margin vs distance for two channel frequencies with additional losses

Figure 2 shows that the link margin in the 4 GHz channel reaches 0 dB at approximately 75 m while in the 6.5 GHz channel it reaches 0 dB at approximately 46 m. Clearly poorly designed PCBs have a significant impact on achievable range.

RULE 3.2: For best range performance follow the Decawave PCB layout guidelines closely and ensure the circuit between the DW1000 and the antenna is correctly matched.

3.4 Antenna Gain

The example in section 3.2 assumed that the antennas used had a gain of 0 dBi. It is possible to design antennas such that they have greater gain at the frequency of operation.

As far as the transmitter is concerned, regulations limit the amount of power that can be radiated into the channel. Therefore any gain in the transmitting antenna must be calibrated out so that the radiated power from the product is set to the desired limit (-41.3 dBm / MHz in most cases). The only real benefit of gain in a transmitting antenna in UWB is that we do not need to output as much signal power from the DW1000 and can thereby reduce power consumption in the device.

However antenna gain is very useful on the receiver side since it directly contributes to our link budget. Let's assume our antenna has 2 dBi gain at our centre frequency and that the radiated transmit power is correctly calibrated. We can plot the same curves as in Figure 1 but this time based on the following parameters: -

Table 4: Representative parameter set with receive antenna gain

Parameter	Value	Units
TX Power	-18	dBm / 500 MHz channel, taking the antenna gain into account
TX PCB Loss	0	dB
TX Antenna Gain	2	dBi, but gain is calibrated out to give same radiated TX power
RX PCB Loss	0	dB
RX Antenna Gain	2	dBi
RX Sensitivity	-102	dBm / 500 MHz channel

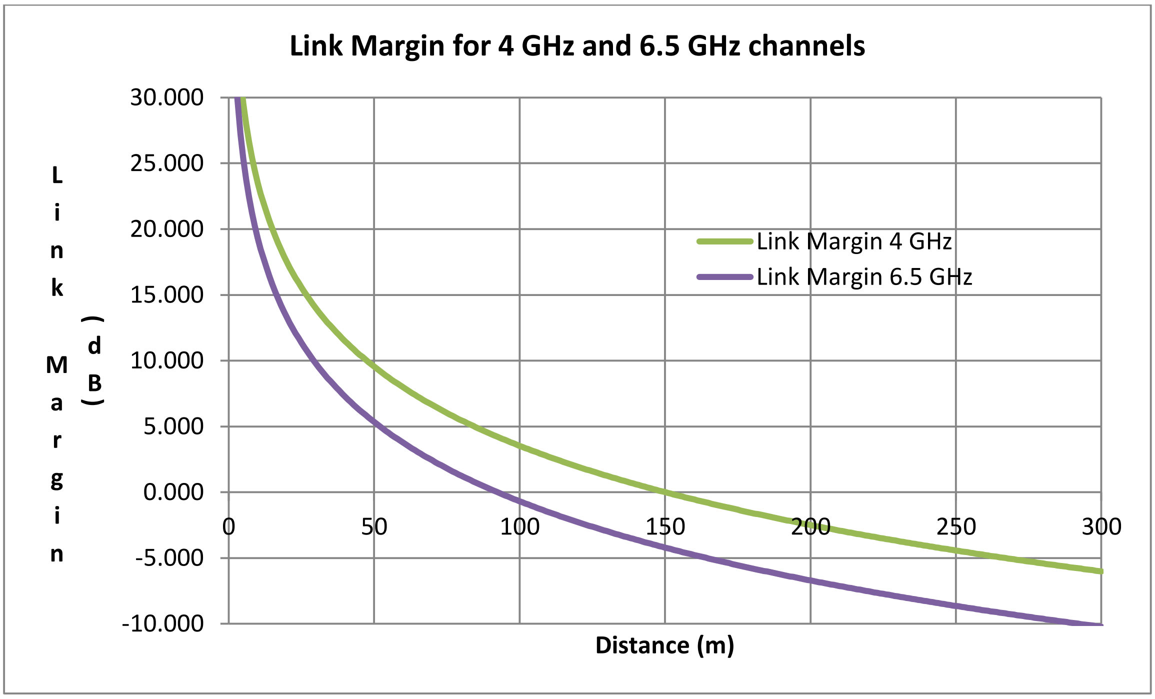

Figure 3: Link Margin vs distance for two channel frequencies with antenna gain

Figure 3 shows that the link margin in the 4 GHz channel reaches 0 dB at approximately 150 m while in the 6.5 GHz channel it reaches 0 dB at approximately 92 m. Receive antenna gain has a considerable impact on achievable range.

RULE 3.3: For best range performance use the highest gain antenna available at your frequency of operation but make sure all its other performance parameters are within specification also. See APH007 [4] for a more detailed discussion on this topic.

3.5 Clock sources and clock offset between nodes

Receiver sensitivity is maximised when there is no frequency error between transmitted signal and receiver's local oscillator. Typical performance curves in the DW1000 datasheet [1] show that sensitivity degrades significantly as frequency error in ppm is introduced. Crystals should be characterised for your design to determine the correct DW1000 trim code to use. You should use one of the recommended crystal parts listed in the datasheet.

RULE 3.6: Minimise the clock offset between the nodes in your system.

3.6 Data rate selection

Receiver sensitivity is dependent on the data rate being used. As can be seen in the receiver sensitivity characteristics section of the DW1000 datasheet [1], the sensitivity improves as you go from the highest supported data rate (6.8 Mbps) to the lowest (110 kbps). Using the lowest data rate will therefore maximise link margin and range.

The disadvantage of a lower data rate, however, is that frames take a longer time to be transmitted and so there is a power consumption penalty.

See section 4.3 for further implications of using short messages.

RULE 3.7: Select the data rate that gives longest range while also meeting the other requirements of your system.

3.7 Preamble selection

The choice of preamble code and preamble length affects the ability of the receiver to detect the incoming signal in the noise and accurately determine the first path. The minimum length preamble receivable by the DW1000 is 64 symbols. The maximum supported by the DW1000 is 4096. Generally speaking the preamble needs to be long enough for the receiver to detect the signal and lock its carrier and timing recovery loops. Having a preamble that is longer than necessary takes up air time and unnecessarily increases system power consumption for no appreciable increase in performance.

Recommended preamble sequence lengths for different data rates are given in the operational design choices section of the DW1000 user manual [2].

RULE 3.8: Select the preamble length that gives longest range while also meeting the other requirements of your system.

3.8 Other factors

3.8.1 Attenuation introduced by product packaging

Most products are encased in some sort of housing or enclosure with the antenna mounted inside the enclosure. Therefore it is vital to ensure that the enclosure material introduces as little attenuation as possible. On the transmit side this attenuation can be calibrated out (by increasing transmit power) during production test since it is the radiated power from the product that is of interest in terms of regulations. However, on the receiver side, the attenuation subtracts directly from the link budget. The attenuation of any enclosure material should be one of the key choice criteria when selecting the enclosure for your product.

RULE 3.4: Minimise attenuation introduced by product packaging.

3.8.2 Power supplies

The DW1000 requires relatively high peak currents for very short durations of time. It is very important that your power supply design be capable of effectively supplying these peak currents so that the supply voltage does not “droop” and go out of spec.

The receiver of the DW1000 is very sensitive, typically in the -98 to -101 dBm region. While it is not unduly sensitive to power supply noise, care should be taken with the design of the power supply so that noise on the supply rails is minimised. Decoupling should be used on all supplies as shown in the DW1000 datasheet [1].

RULE 3.5: Keep power supplies quiet through the correct use of decoupling.

4 Optimising the transmitter

4.1 Introduction

This section deals with the transmitter and how it can be optimised to ensure it radiates the maximum allowable power into the communications channel.

4.2 The importance of transmitter calibration

4.2.1 Introduction

Because transmit power levels are restricted to -41.3 dBm / MHz by regulation in the vast majority of geographies (and lower in some regions) it is very important to ensure that the maximum permitted signal power is being radiated into the channel. The DW1000 provides more than enough RF signal power to overcome any PCB or antenna losses, trim out any inter-device variations and ensure that the maximum permitted transmit power is radiated from your product.

4.2.2 Mean power

The calibration of mean transmit power is discussed in the DW1000 user manual [2] and in APS012 [9]. You should consult these references to see how to calibrate the DW1000 to ensure that the correct power level is radiated from your product and to ensure that you are compliant with the relevant regulations in your region. You should refer to the APR series of application notes for information on the regulations relevant to your specific geography.

RULE 4.1: Ensure your transmit power is correctly calibrated.

4.2.3 Spectral mask

The other important parameter to consider when calibrating the transmitter is the spectral mask profile. Ideally the radiated power would completely fill the spectrum mask so as to ensure the maximum power is being radiated into the channel. In Figure 4, a typical transmit spectrum measurement is compared to an ideal, rectangular profile occupying a 500 MHz bandwidth. If the actual transmit spectrum could extend towards the corners of the rectangular ideal profile, then the integrated power would be higher and longer range could be achieved.

In reality it is not possible for the transmit spectrum to be perfectly rectangular but DW1000 has configurable TX parameters to increase the power towards the edges of the spectrum so that the profile is more rectangular. For example, TC_PGDELAY is used to tune the width of pulses and hence the spectrum bandwidth. Information on the relevant TX parameters and how they can be tuned can be found in the DW1000 user manual [2].

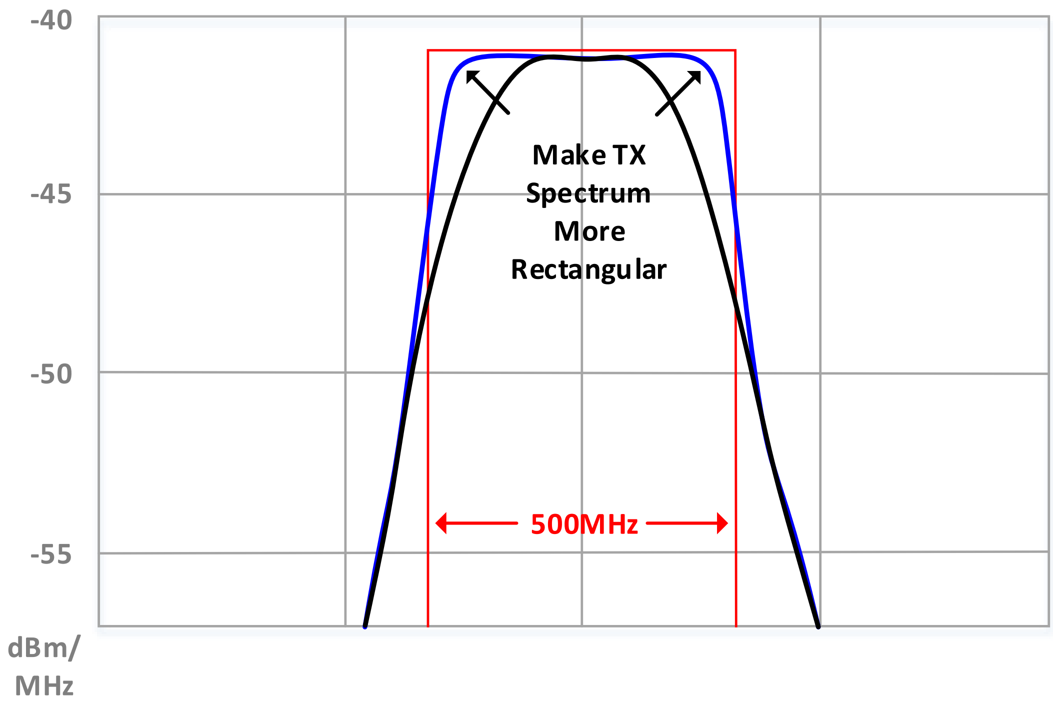

Figure 4: Ideal vs actual spectrum profiles

RULE 4.2 Ensure your spectral mask profile is optimised to fill as much of the spectral mask as possible.

4.3 Optimising transmit power using Smart Transmit Power Control

4.3.1 Introduction

Smart Transmit Power is a feature where transmit power can be increased if a message is transmitted in less than 1 ms. Since the regulations specify the maximum permissible power level averaged over a 1ms period, it follows that the power can be increased for shorter message durations. So, while a message that is 1 ms long may only be transmitted at -41.3 dBm / MHz to meet the regulatory limit, a message that is only 0.5 ms long may be transmitted at +3 dB above this level, a message that is only 0.25 ms long may be transmitted at +6 dB and a message that is only 0.125 ms long may be transmitted at +9 dB provided that only one such message is transmitted per ms. A more detailed description of Smart Transmit Power can be found in the DW1000 user manual [2].

4.3.2 Using Smart Transmit Power Control

You should ensure that the appropriate power level settings are selected and that your particular use case will allow Smart Transmit Power to operate. If, for instance, you are implementing a very fast update rate TDOA tag or a fast two-way-ranging exchange it may be the case that you transmit more than one message per millisecond. This needs to be taken into account when calculating the allowed power boost using Smart Transmit Power.

4.3.3 Taking Smart Transmit Power Control to the limit

The shortest possible transmission frame is used in the blink message which a tag sends to an anchor during the discovery phase of a two-way ranging (TWR) or time difference of arrival (TDOA) exchange. Data payload, including timestamp data used to calculate range, as well as destination address, and so on are omitted from the UWB frame but if this information can be sent by some other means, e.g. a link using some another wireless technology supported on the module working in harmony with the UWB link, then DW1000 transmit time can be minimised and transmit power can be maximised.

The blink frame structure is explained, along with the general TWR frame structure, in the DecaRanging ARM Source Code Guide [3].

RULE 4.3: Consider using Smart Transmit power to boost transmit power for short messages.

4.4 Increasing transmit power using an external Power Amplifier where permitted

For LAES (Location tracking Applications for Emergency Services) in Europe, an increase in transmit power above the nominal -41.3 dBm / MHz limit is permitted when using the spectrum between 3.4 and 4.2GHz. This increase can be as much as 20 dB which has obvious implications for link budget and range.

In order to achieve this additional transmit power an external power amplifier is required. The use of such an external power amplifier with the DW1000 is covered in application note APS009 [7].

Some additional design considerations are as follows: -

- Adding an external PA will increase power consumption.
- The increased transmit power will affect the range bias compensation factor (see application note APS011 [8]).
- If nodes are in close proximity, it's possible that the additional power could cause communication errors due to receiver saturation.

Before embarking on a development to incorporate a PA, you should satisfy yourself that the regulations in the markets into which you intend to sell your products permit this additional transmit power.

RULE 4.4: Consider using a power amplifier in the transmit path if regulations permit its use in your application.

4.5 Minimising losses in the transmit path from DW1000 to antenna

It is very important to ensure that the design of the RF path from the DW1000 RF pins to the antenna closely follows the recommendations in the DW1000 data sheet. In this regard: -

- Impedances should be carefully controlled and matched.
- There should be no step changes in trace widths.
- Component pads should be incorporated into PCB traces.
- If you are using an SMA connector to connect to the antenna then a through-hole SMA connector should not be used – these can introduce losses as high as 3 dB due partially to the right-angle between the central conducting element and the feed trace but also because of the stub created by the through hole mounting of the central conductor. In general, if you are using an SMA connector and end-launch type should be used.

You are recommended to follow the RF path layout given in the DW1000 data sheet. Autocad .dxf files are available as part of APH006 to assist you in doing this on your PCB.

RULE 4.5: Minimise losses in the transmit path from the DW1000 to the antenna.

4.6 Optimising the transmit antenna

The purpose of any transmit antenna is to radiate the energy fed to it by the transmitter as efficiently as possible. There are a number of other key criteria for UWB antennas, one of the most important of which is to ensure that pulses are not distorted as they are radiated – if they are then when they are recovered at the receiver they can give a distorted first path measurement.

Generally speaking, antennas in mobile nodes need to be omni-directional since the location of readers, anchors or other mobile nodes is unknown relative to the mobile node. For readers or anchors, antenna radiation patterns do not necessarily need to be omni-directional depending on the application – for example the antenna in a wall mounted anchor does not need to radiate into the ceiling cavity or into the wall on which it is mounted and so can be optimised to radiate only into a certain section of space.

RULE 4.6: Optimise the transmit antenna for your application.

5 Optimising the Receiver

5.1 Introduction

This section deals with the receiver and how it can be optimised to ensure its sensitivity is maximised so as to maximise the link budget.

5.2 Minimising losses in the receive path from antenna to chip

The same points from section 4.5 apply equally here. Unless your design uses an LNA in the receive path from the antenna to the DW1000 or uses a PA in the transmit path from the DW1000 to the antenna, the transmit and receive paths are actually one and the same

It is very important to ensure that the design of the RF path from the DW1000 RF pins to the antenna closely follows the recommendations in the DW1000 data sheet. In this regard: -

- Impedances should be carefully controlled and matched
- There should be no step changes in trace widths
- Component pads should be incorporated into PCB traces
- If you are using an SMA connector to connect to the antenna then a through-hole mounted SMA connector should not be used – these can introduce losses as high as 3 dB due partially to the right-angle between the central conducting element and the feed trace but also because of the stub created by the through-hole mounting of the central conductor. In general, if you are using an SMA connector and end-launch type should be used

You are recommended to follow the RF path layout given in the DW1000 data sheet. Autocad .dxf files are available as part of APH006 to assist you in doing this on your PCB.

RULE 5.1: Minimise losses in the receive path between the antenna and the DW1000.

5.3 Optimising the sensitivity of the DW1000

5.3.1 Introduction

Receiver sensitivity is quoted in the DW1000 datasheet and depends on a number of parameters including the selected channel and the data rate. For longest range the lowest data rate (110 kbps) should be used. See [1] and [2] for further information.

5.3.2 Using the receiver operating parameter sets

The DW1000 supports a number of what are termed “receiver operating parameter sets”, which modify how preamble signals are acquired and how data is decoded, depending on the choice of preamble length used in the system.

Selecting the ‘Tight’ parameter set configures the receiver for maximum range. See the DW1000 user manual [2] for more information.

RULE 5.2: Use a system configuration that maximises the receiver sensitivity of the DW1000.

5.4 Increasing the sensitivity of the DW1000 using an external LNA

It is possible to insert a low noise amplifier (LNA) between the antenna and the DW1000 to lower the noise figure and improve receiver sensitivity, thereby adding directly to the link margin. This technique is described in APS004 [5]. Typically a 2 to 3 dB reduction in noise figure can be achieved which adds directly to the link budget.

Some additional design considerations are as follows: -

- Adding an external LNA will increase power consumption.
- The increased receiver gain will affect the range bias compensation factor (see application note APS011 [8]).
- If nodes are in close proximity, it's possible that the additional gain could cause communication errors due to receiver saturation.

RULE 5.3: Consider using an LNA to reduce noise figure and improve receiver sensitivity but bear power consumption and system cost in mind.

5.5 Optimising the receive antenna

While gain in a transmit antenna is not of particular value because of the restrictions on radiated transmit power, gain in the receive antenna contributes directly to the link budget. You should select the antenna with the highest possible gain at your chosen channel frequency provided all other key parameters are maintained within specification. This is discussed in detail in APH0007 [8].

As mentioned in section 4.6, antennas for anchors mounted near reflecting surfaces such as walls shouldn't have omni-directional radiation patterns. A radiation pattern with its main lobe directing away from a wall and a null directing towards a wall is beneficial as reflections from the wall are attenuated.

RULE 5.4: Optimise the receive antenna for your chosen application to achieve maximum gain and most applicable radiation pattern. Use omni-directional patterns for receive antennas only where required by the application.

6 Channel effects

6.1 Introduction

The communications channel over which two DW1000 devices communicate has a significant impact on the achievable range. There are multiple channel effects to be considered. These include: -

- Whether the channel is a line-of-sight or non-line-of-sight channel.
- Whether multipath exists in the channel and to what extent

6.2 Line of Sight vs. Non Line of Sight

6.2.1 Introduction

When considering a channel between a transmitter and a receiver in a radio scheme one of the most important properties of the channel is whether it is either: -

1. Line of Sight (LOS); or
2. Non Line of Sight (NLOS)

A LOS channel has an unobstructed path between the transmitting antenna and the receiving antenna. A NLOS channel does not. Channels that may appear to be LOS can in fact be NLOS depending on what is termed the Fresnel Zone – see APS006 [6] for further details. For the purposes of the remainder of this discussion we will assume that NLOS channels are channels which are physically obstructed by a medium other than free space.

6.2.2 Reduction in range due to signal attenuation in a NLOS channel

The degree to which a signal is reflected or attenuated by any particular obstruction depends on the materials that make up the obstruction, the thickness of the obstruction and the frequency of the incident RF signal.

The signal power at the receiver, as well as being a function of the transmitted power, any antenna gains or losses in the system and the free-space attenuation, as in the LOS case, must now also account for the losses in the material causing the path to be a NLOS path.

If we assume there is no multipath we can represent this as follows: -

$$P_R\,[dBm] = P_T\,[dBm] + G\,[dB] - L[dB] - 20\,\log_{10}(4\pi f_c(d_1+d_2)\,/\,c) - L_{MATERIAL}[dB]$$

Where all quantites have the same meanings as in section 2.1 and: -

d_1 = free space distance from transmitter to attenuating material
d_2 = free pace distance from atttenuating material to receiver
$L_{MATERIAL}$ = loss in the attenuating material

In this situation, depending on the losses in the obstructing material, communications range between the two nodes can be severely reduced to the point where the material is impervious to radio signals and communications can no longer take place.

NLOS operation is covered in detail in the multi-part application note APS006 [6].

6.3 Multipath

6.3.1 Introduction

Multipath is the term used to describe the fact that there are multiple RF paths between the transmitter and the receiver depending on the environment. In addition to the direct path, the same transmitted signal can reach the receiver through other paths which involve reflection or refraction from surfaces in the environment.

UWB is highly immune to multipath because of the very short pulse used in the signalling scheme, however there are certain situations in which multipath interference can occur.

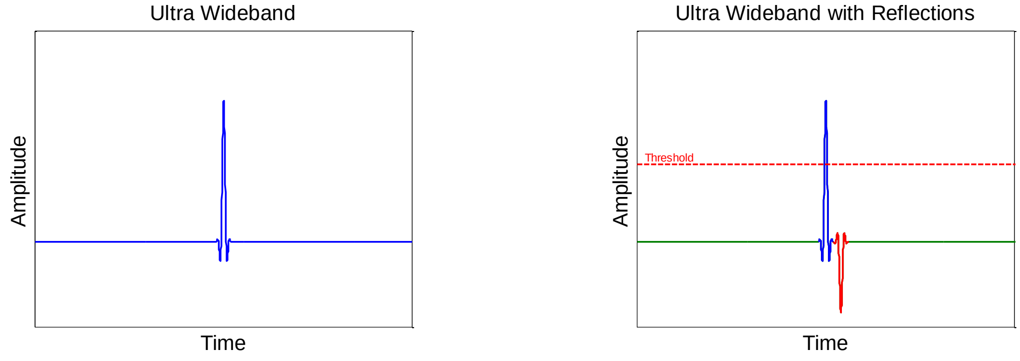

Figure 5: UWB pulse with and without reflections

In Figure 5 above we can see a UWB pulse in the left hand diagram and a UWB pulse in the presence of a reflected pulse in the right hand diagram. A reflected pulse experiences a phase inversion which can interfere destructively with the direct path pulse if it arrives at the receiver within the duration of the pulse (roughly 1 ns).

A more detailed study of multipath effects can be found in APS006 [6].

6.3.2 Multipath due to ground-bounce

In outdoor environments and large open indoor spaces the most common form of multipath is caused by RF reflections from the ground. Figure 6 illustrates the concept. It can be seen that there are an infinite number of such paths between the transmitter and receiver.

The primary concern here is how these multipath components interfere with the direct path (or not) as they both arrive at the receiver. As explained above, the multipath length must be within 1 ns of the direct path length for the multipath signal to interfere with the direct path signal. This is clearly a very specific case and represents the only situation where UWB is subject to fading as a result of multipath. This is obviously influenced by the height of the two nodes above the ground and the distance between the two nodes.

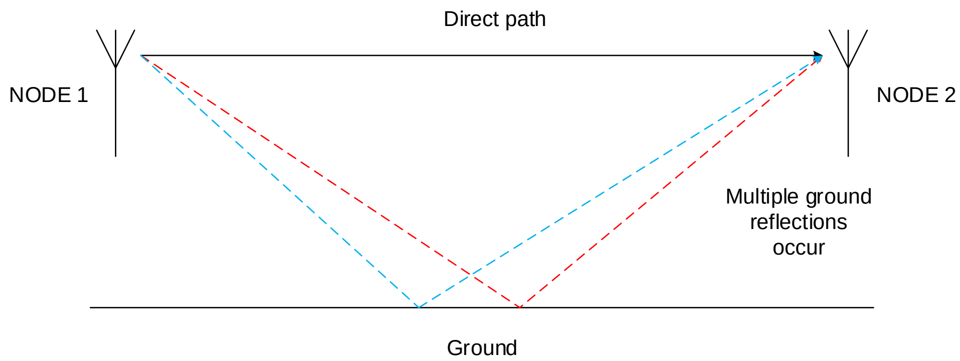

Figure 6: Multipath caused by reflections from the ground

A rough analysis of this scenario can be performed by considering how two sine waves at the channel center frequency might interfere (both constructively and destructively) as the direct and reflected path lengths vary.

If we return to the analysis we did in section 3.2 and apply this multipath fading we get a quite different link margin plot as shown in Figure 7.

Table 5: Representative parameter set for multi-path illustration purposes

Parameter	Value	Units
TX Power	-16	dBm / 500 MHz channel
TX PCB Loss	0	dB
TX Antenna Gain	0	dBi
TX Antenna height above Ground	2	m
RX PCB Loss	0	dB
RX Antenna Gain	0	dBi
RX Sensitivity	-102	dBm / 500 MHz channel
RX Antenna height above Ground	2	m

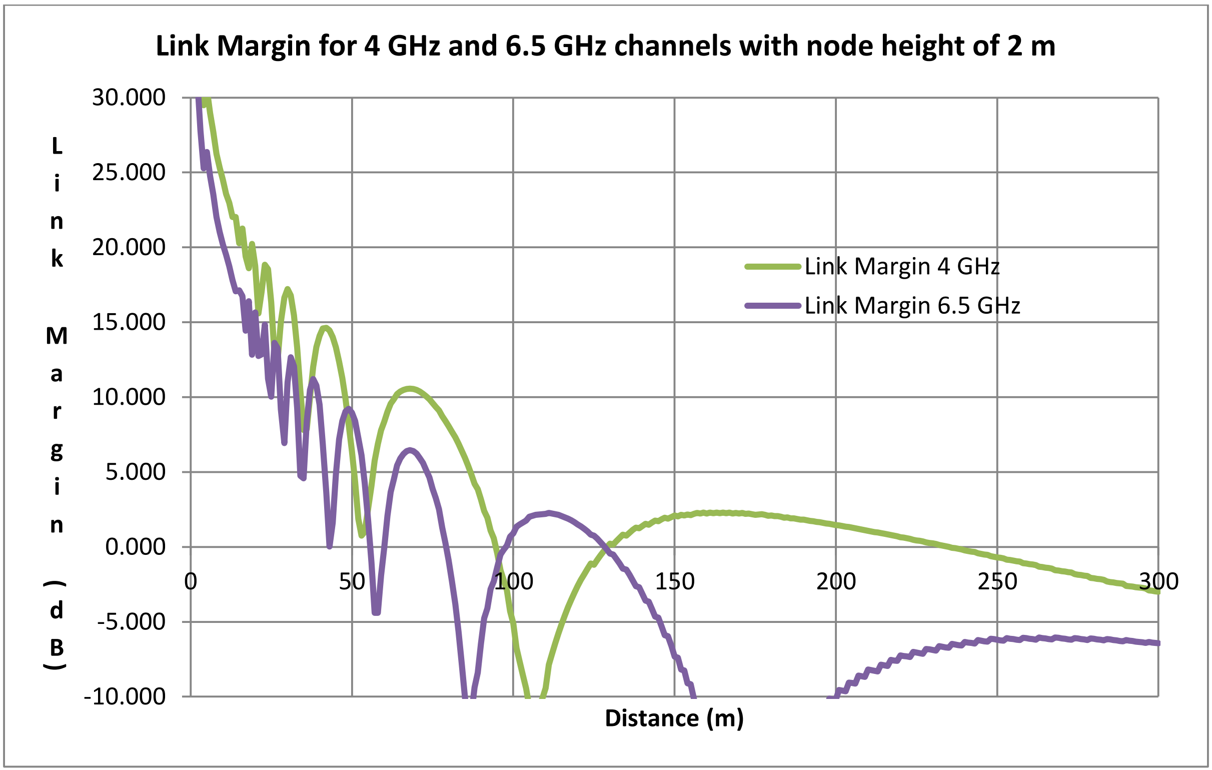

Figure 7: Link margin with ground bounce

If we consider the 4 GHz link margin plot we can see that it first reaches 0 dB at approximately 95 m but becomes positive again at approximately 130 m and remains positive until around 235 m. This "hole" between 95 m and 130 m is known as a "Fresnel hole".

This analysis is a gross over-simplification of the real world situation since a UWB transmission is not a single frequency but is spread across 500 MHz so even though some part of that bandwidth may be subject to fading at a particular multipath length, other parts of that bandwidth will not.

7 Conclusion

7.1 Introduction

This note presents an overview of all the issues to be considered when trying to maximise the range of your DW1000 system.

7.2 System parameter choices

Rule Number	Rule
3.1	To maximise range use the lowest available channel frequency.
3.2	For best range performance follow the Decawave PCB layout guidelines closely and ensure the circuit between the DW1000 and the antenna is correctly matched.
3.3	For best range performance use the highest gain antenna available at your frequency of operation but make sure all its other performance parameters are within specification also. See APH007 for a more detailed discussion on this topic.
3.4	Minimise attenuation introduced by product packaging.
3.5	Keep power supplies quiet by the correct use of decoupling.
3.6	Minimise the clock offset between the nodes in your system.
3.7	Select the data rate that gives longest range and meets the other requirements of your system.
3.8	Select the preamble length that gives longest range while also meeting the other requirements of your system.

7.3 Optimising the transmitter

Rule Number	Rule
4.1	Ensure your transmit power is correctly calibrated.
4.2	Ensure your spectral profile is optimised to fill as much of the spectral mask as possible.
4.3	Consider using Smart Transmit power to boost transmit power for short messages.
4.4	Consider using a power amplifier in the transmit path if regulations permit its use in your application.
4.5	Minimise losses in the transmit path from the DW1000 to the antenna.
4.6	Optimise the transmit antenna for your application.

7.4 Optimising the receiver

Rule Number	Rule
5.1	Minimise losses in the receive path between the antenna and the DW1000.
5.2	Use a system configuration that maximises the receiver sensitivity of the DW1000.
5.3	Consider using an LNA to reduce noise figure and improve receiver sensitivity but bear power consumption and system cost in mind.
5.4	Optimise the receiver antenna for your chosen application to achieve maximum gain and most applicable radiation pattern. Avoid omni-directional patterns unless required by the application.

8 References

8.1 Listing

Reference is made to the following documents in the course of this Application Note: -

Figure 8: Table of References

Ref	Author	Version	Title
[1]	Decawave	Current	DW1000 Datasheet
[2]	Decawave	Current	DW1000 User Manual
[3]	Decawave	Current	DecaRanging ARM Source Code Guide
[4]	Decawave	Current	APH007: Antenna Selection / Design Guide for DW1000
[5]	Decawave	Current	APS004: Increasing the Range of DW1000-based Products using an External LNA
[6]	Decawave	Current	APS006: Multi part Application note dealing with NLOS
[7]	Decawave	Current	APS009: Operating the DW1000 under LAES Regulations
[8]	Decawave	Current	APS011: Sources of Error in DW1000 Based Two-Way Ranging (TWR) Schemes
[9]	Decawave	Current	APS012: Production Tests for DW1000-based Products

9 Document History

Figure 9: Document History

Revision	Date	Description
1.0		Initial release.

10 Major Changes

Revision 1.0

Page	Change Description
All	Initial release.

11 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 Ultra Low Power Wireless Transceivers in areas as diverse as manufacturing, healthcare, lighting, security, transport, inventory & supply chain management.

Further Information

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