APU007 APPLICATION NOTE

AN INTRODUCTION TO AUTOMOTIVE KEYLESS ENTRY SYSTEMS

Automotive Keyless Entry schemes and their implementation with DecaWave's DW1000 Wireless Transceiver

Version 1.00

This document is subject to change without notice

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

This is one in a series of notes on application areas for DecaWave's DW1000 Ultra-Wideband wireless transceiver technology.

This note considers the use of DecaWave's DW1000 in Automotive Keyless Entry Systems.

Other notes in this series on www.decawave.com examine the application of DecaWave's technology to other market areas such as Process Automation, Healthcare, Agriculture and so on.

2   IMPLEMENTATION OF KEYLESS ENTRY SCHEMES

The following are some general comments and notes on the implementation of Keyless Entry Schemes; in particular, wireless schemes based on DecaWave's Ultra Wideband technology.

DecaWave will be pleased to explore these issues with customers who wish to implement these or any other schemes.

2.1   Requirements for a Keyless Entry System

There are a number of fundamental requirements for a Keyless Entry System that can be summarized as follows: -

Table 1: Requirements for a Keyless Entry System

Parameter	Requirement
Communications Performance	Must be capable of operating in crowded car parks both indoors and outdoors
Communications Range for vehicle access	Generally required to be limited to within a relatively short distance of the vehicle
Communications Range for vehicle start	The must be able to determine when the key fob is inside the vehicle so that the engine cannot be started until the driver is inside the vehicle
Conformance with local regulations	The technology employed must conform to regulations in all geographies the manufacturer's vehicles are sold
Long Battery Life	Batteries need to last a significant length of time – typically 5 years depending on amount of use.
Cost	The system should be as low cost as possible
Reliability	The system must reliably open / start the vehicle
Security	It must be difficult for potential thieves to "hijack" communications between the key fob and the vehicle and thereby gain entry to the vehicle

2.2   How to meet these requirements with the DW1000

2.2.1   Distance from the vehicle

Measuring the distance of the fob to the vehicle is not a problem. DecaWave's technology allows distance to be measured to an accuracy of +/- 10cm (+/- 4")

A single transceiver in the vehicle can conduct a 2-way ranging exchange with the key fob, when the appropriate key fob button is pressed and calculate the distance from the fob to the vehicle to an accuracy of +/- 10cm. See Figure 1

A single unit in the vehicle can conduct a two-way ranging exchange with the fob and calculate the distance between the fob and the vehicle

Fob
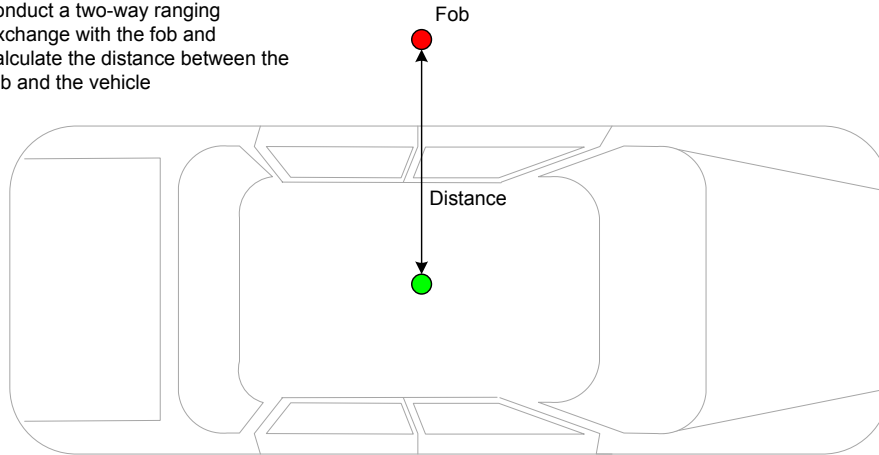
Distance

Figure 1: Measuring the distance from the fob to the vehicle

2.2.2 Operation only within a given distance from the vehicle

DecaWave's technology allows Line-of-Sight ranges of greater than 250m however the in-vehicle unit can be configured to only take action when the measured distance is less than a certain vehicle manufacturer-defined value.

The fob and in-vehicle unit can communicate up to the maximum ability of the technology (450m LOS) BUT the in-vehicle unit only takes action when the measured distance is 2m or less

Fob 1 can communicate with in-vehicle unit and in-vehicle unit takes action

Distance <2m to vehicle
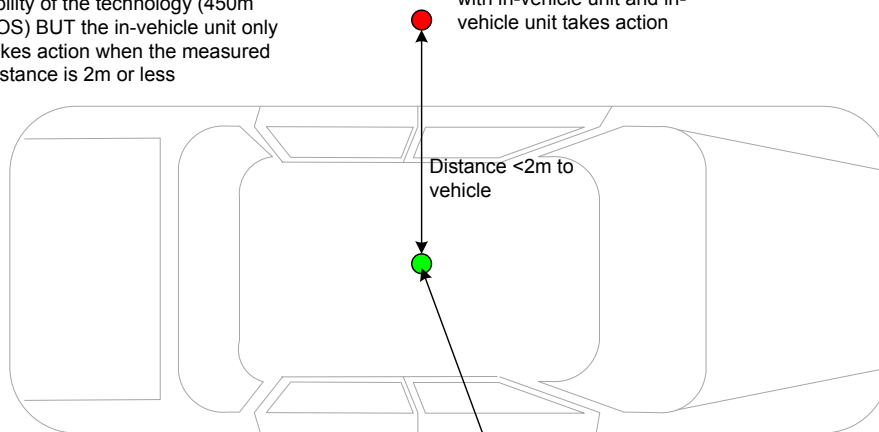
Distance >defined value to vehicle

Fob 2 can communicate with in-vehicle unit but in-vehicle takes no action

Figure 2: Operation only within 2m of the vehicle by allowing communications

2.2.3 Detecting on which side of the vehicle the fob is located

A single two-way ranging exchange between 1 in-vehicle unit and a fob, while sufficient to measure how far away the fob is from the vehicle, is not sufficient to determine on which side of the vehicle the fob is located because only one piece of information – a single distance – is available.
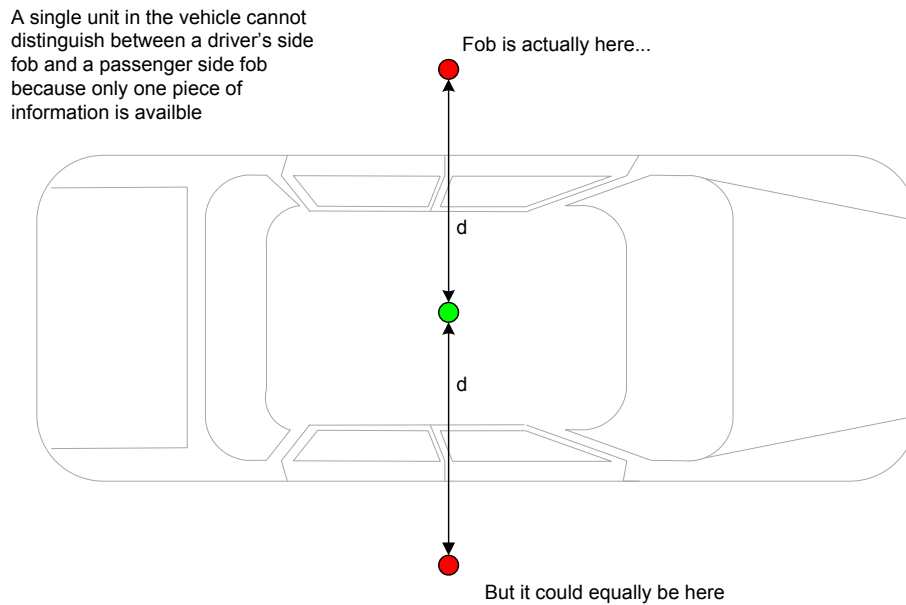
Figure 3: Detecting on which side of the vehicle the fob is located

In order to determine on which side of the vehicle the fob is located two pieces of information are required – two distances from two in-vehicle units for example provided of course that these in-vehicle units are positioned in an appropriate way.
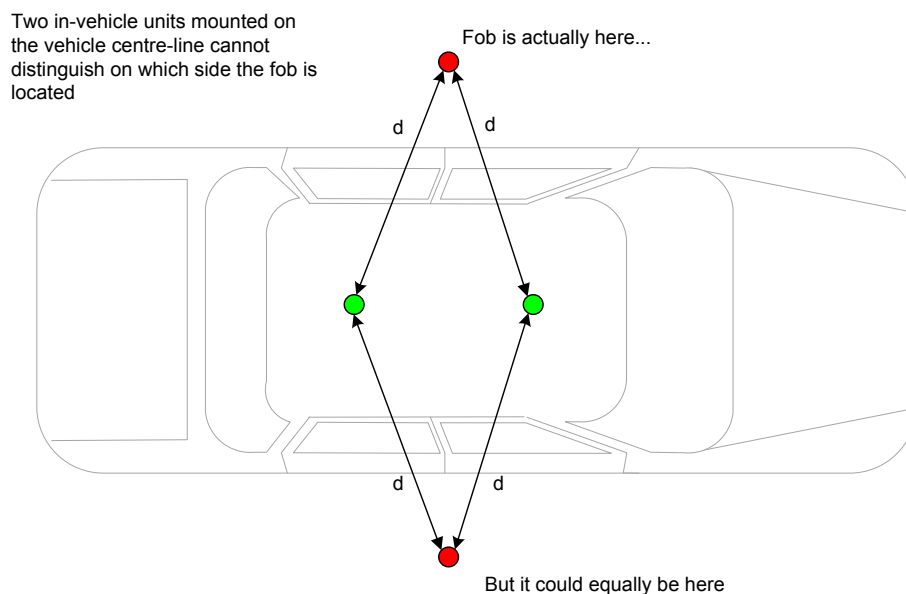
Figure 4: Two in-vehicle units on vehicle centre line

If, however, the two units are mounted across the vehicle as shown in Figure 5 then it becomes possible to uniquely identify the side of the vehicle on which the fob is located.

Two in-vehicle units offset across the vehicle can distinguish on which side the fob is located by examining d1 and d2
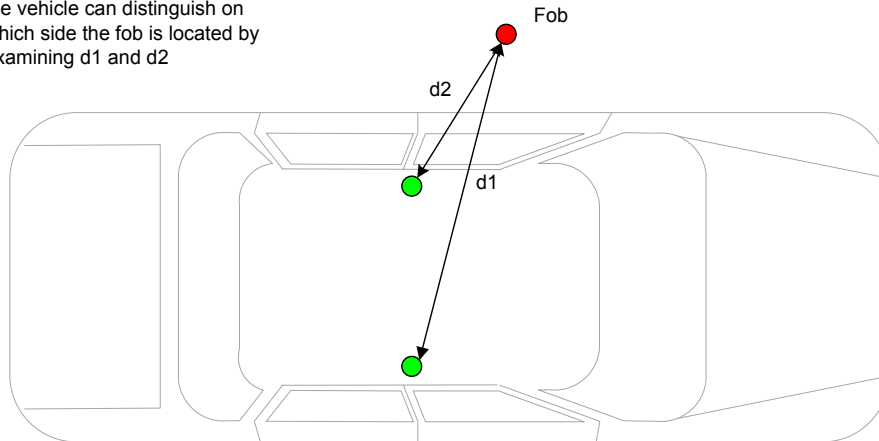
Figure 5: Two in-vehicle units mounted across the vehicle

Table 2: Analysis of measured distances

Condition (in Fig 6)	Conclusion
d1 > d2	Fob on driver's side (USA)
d1 < d2	Fob on passenger's side (USA)
d1 = d2	Fob on center line of vehicle
d1 AND d2 both less than distance to opposite edge of vehicle	Fob inside the vehicle

The question then arises; how close together can the in-vehicle units be located? If they can be mounted close enough together then it becomes possible to fabricate them as one unit for ease of installation into the vehicle. This is where the +/- 10cm distance measurement accuracy comes into play.

For the two in-vehicle units to reliably determine correctly the side of the vehicle on which the fob is located the separation between the two in-vehicle units must be greater than the maximum possible error in the distance measurement. So, with +/-10cm accuracy, in the worst case, the measurement from one in-vehicle unit to the fob could be +10cm in error while the measurement from the other could be -10cm in error. To avoid drawing incorrect conclusions from the measured data a minimum separation between the two units of 20cm is required. We can illustrate this by drawing an error boundary of +/-10cm around the distance measured from each in-vehicle unit to the fob.

Provided the in-vehicle units are separated by more then the max measurement error it is possible to determine the side of the vehicle on which the fob is located

Fob

d2

d1 - Correct distance

-ve error

+ve error
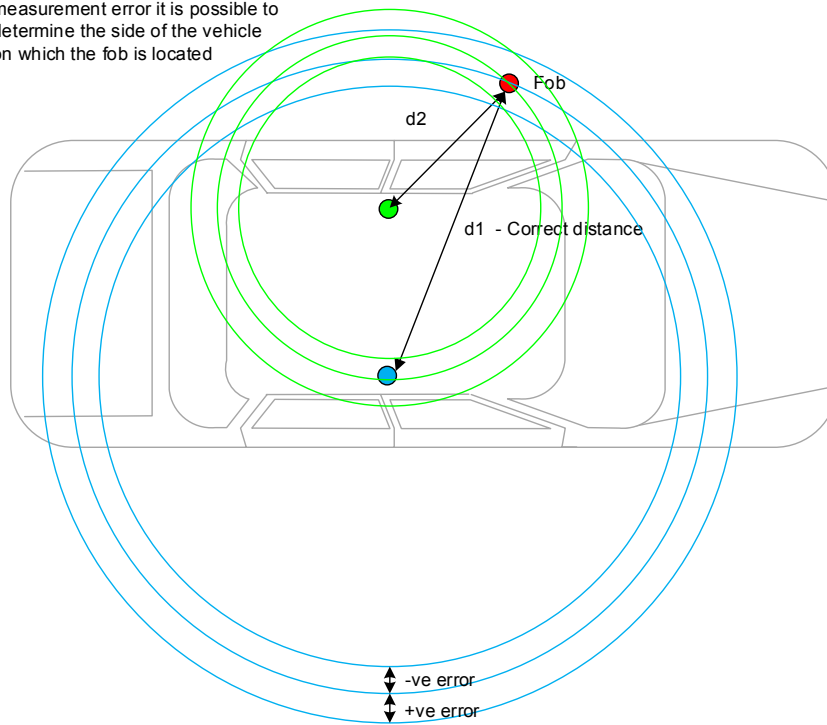
Figure 6: Maximum measurement error determines physical separation of in-vehicle units

If the in-vehicle units are mounted closer together than the maximum measurement error then it is not possible to reliably determine on which side of the vehicle the fob is located.

If the in-vehicle units are separated by less than the maximum measurement error there is a possibility of incorrectly determining the side of the vehicle on which the fob is located

Fob is here...

d2

d1

But could be inside this area of intersection also

Figure 7: In-vehicle units separated by less than the max measurement error

The conclusion from this analysis is that the two in-vehicle units must be separated by at least 20 cm.

2.2.4   Physical Implementation of the in-vehicle unit

So given that it is clear that two units are required inside the vehicle the question then arises as to how best to implement those units.

In its basic form a unit consists of the DecaWave transceiver, a microcontroller and an antenna. The microcontroller controls the transceiver and implements the two way ranging exchange with the fob.

Basic in-vehicle single unit. The micro provides measured distance information to other in-vehicle systems for processing and analysis

Antenna

decaWave
"Thinking outside the band"

DecaWave Transceiver DW1000

SPI

Micro-controller

Distance Info to in-vehicle systems
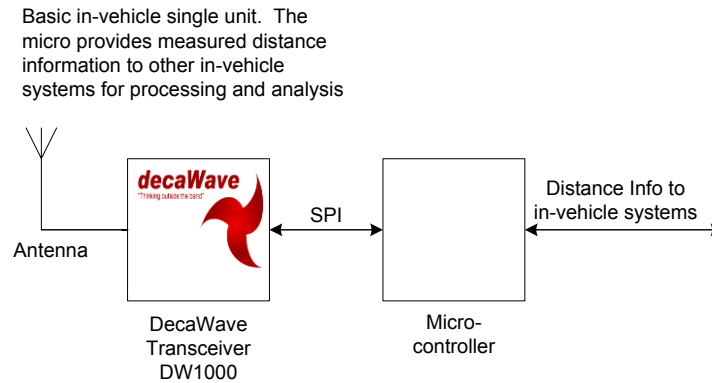
Figure 8: Basic Single Unit Implementation

There are a number of possibilities in terms of implementing the two units: -

- Separate antennas but only one transceiver and one micro-controller
- Separate antennas and transceivers but only one micro-controller
- Entirely separate units

2.2.4.1   Separate Antenna Implementation

Antenna 1

Two unit system based on two antennas, and a single transceiver + micro

decaWave
"Thinking outside the band"

DecaWave Transceiver DW1000

SPI

Micro-controller

Distance Info to in-vehicle systems

Antenna 2

Figure 9: Possible Two-Unit Implementation by switching antennas

This implementation has the advantage that the comparison between the two distance measurements to the fob can be made in the micro and the conclusion advised to the relevant in-vehicle systems. At first glance it would also appear that this implementation would be cheaper to implement.

The primary drawback with this system is the difficulty in switching antennas at the high frequencies involved and the inaccuracies that are introduced by the antenna connection and switching mechanisms.

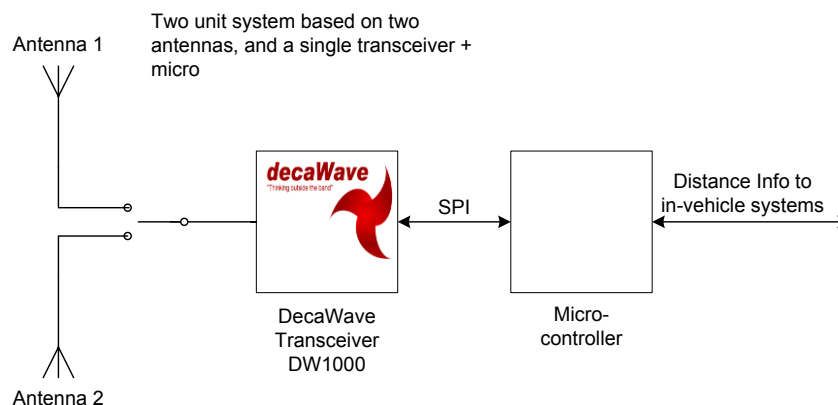Switching radio signals at the frequencies of interest (3.1 – 10.6GHz) is difficult at best and should be avoided if at all possible. The switching components are generally expensive given the frequencies at which they are operating. Switching antennas necessitates a settling period before messages can be transmitted or received since there is no guarantee that the potential at one antenna is the same as the other at switching time so a transient may result which requires time to settle. This will limit the number of transmissions / receptions that can be made with each antenna. Without system modelling it is impossible to say what impact this might have on overall performance.

For this system to work reliably the delays introduced by the antenna connections must be known and very tightly controlled. This is difficult to do repeatably in cable environments but is much more controlled using printed circuit board connections.

Ideally these delays should be the same so that the same correction factor can be applied by the micro to remove the "antenna delay" from the calculations (the delay between the arrival / departure of the signal at / from the antenna and the instant it is time-stamped by the receiver / transmitter. If they are not the same (i.e. unit and one antenna located on one side of the vehicle and the other antenna located on the other side of the vehicle) then different correction factors will need to be applied and these may need to be calibrated at manufacturing time to take account of cable manufacturing tolerances.

It is our view that this implementation will lead to production difficulties and an unreliable system implementation and should be avoided.

2.2.4.2 Separate Antennas and Transceivers but only one Micro-controller

This system removes the antenna switching issues with the previous implementation. It allows for the remote location of one transceiver + antennas using the SPI interface (although this range is limited because SPI was intended as an on-circuit-board serial communications interface scheme).

Because both distance measurements are calculated by one micro it is also capable of analysing these distances and determining on which side of the car the fob is located. This information can then be provided to other in-vehicle systems. This may be a more orthogonal & "cleaner" partitioning of functionality and may simplify other in-vehicle systems.

The fact that one micro controls both transceivers means that only one can be actively communicating with a fob at any one time- in fact this is not an issue since that is the way the system works. The fob ranges to one in-vehicle unit followed by the second – it cannot range to both simultaneously.

It's our view that this is a good compromise solution provided the issue of communications between the micro and the two transceivers via SPI is handled correctly.
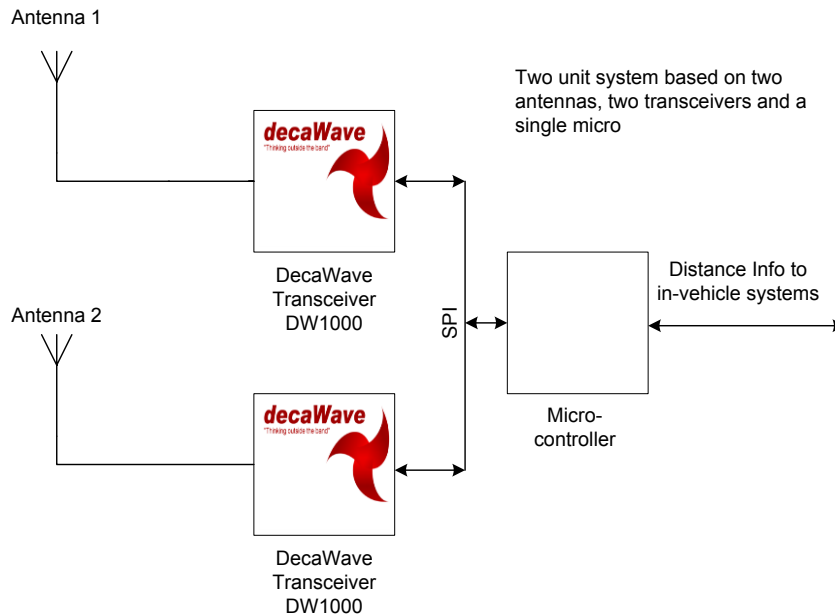
Antenna 1

Two unit system based on two
antennas, two transceivers and a
single micro

DecaWave
Transceiver
DW1000

Antenna 2

SPI

Distance Info to
in-vehicle systems

Micro-
controller

DecaWave
Transceiver
DW1000

Figure 10: Two Transceivers / Single Micro implementation

2.2.4.3   Entirely Separate Units

Antenna 1

Two unit system based on two
completely separate units

DecaWave
Transceiver
DW1000

SPI

Micro-
controller

Antenna 2

In-vehicle comms
bus (CAN)

DecaWave
Transceiver
DW1000

SPI

Micro-
controller

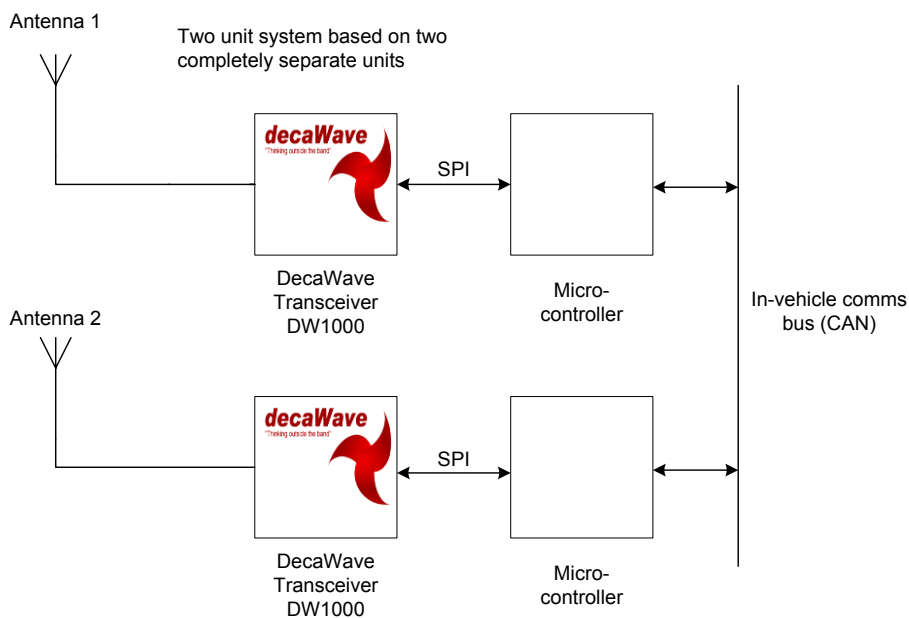**Figure 11: In-vehicle unit based on two entirely separate sub-units**

This is the obvious solution. Each micro deals with its own transceiver and supplies the
distance measurement data either to a processor elsewhere in the vehicle to perform the
data analysis or one of the two processors is designated as the data analysis processor and
the other processor provides its measurements to it for analysis.

In this situation the communications between the micro-controllers could be handled over the in-vehicle communications bus (CAN for example) or via a separate dedicated connection from one controller to the other.

The advantage of this implementation is that it allows much greater freedom in the location of the units (within the constraints of cost, manufacturability and so on)

2.2.5 Other Considerations

2.2.5.1 Location of the units in the vehicle

We have already seen how the in-vehicle units must be separated by more than 20cm to take account of the maximum possible ranging error. There is another consideration to be borne in mind – that of radio propagation.

DecaWave's technology is based on the propagation of radio waves from transmitter to receiver. The technology is exceptionally good in non-line-of sight- environments but like all radio schemes it will not propagate through metal plates; it can only propagate around them.

This has important implications for the location of the in-vehicle units. Positioning the units low down in the interior of the vehicle will severely restrict their "visibility" of the outside environment – behind dashboards, door panels etc. are all poor locations for this technology.

Positioning the units high up in the headlining, the courtesy light, the sun visor mounts or other such elevated position will give a much better view of the outside environment, via the windows glass, and will give better performance.

The appropriate location for an individual vehicle can only be found through testing
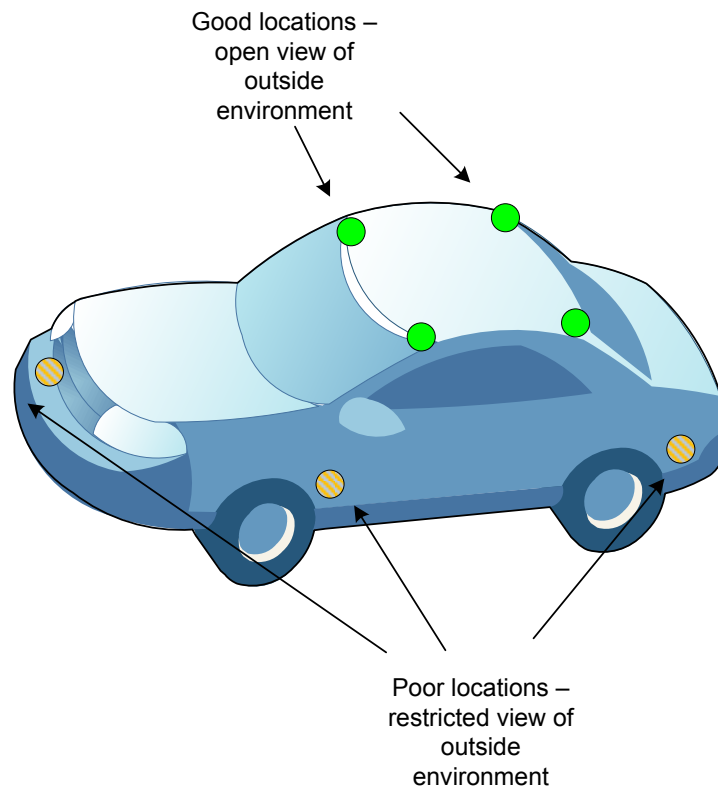
Good locations –
open view of
outside
environment

Poor locations –
restricted view of
outside
environment

Figure 12: Location of in-vehicle units

2.2.5.2 Antenna Radiation Patterns

All of the discussions so far have assumed simple spherical antenna radiation patterns. These may not be the best ones to use.

For example, in the fob it may be better to use a much-less omni-directional pattern so an element of directionality is introduced and the fob must be "pointing" in the general direction of the vehicle for communications to take place.

Similarly, for the in-vehicle units it may make sense to have oval radiation patterns rather than spherical because vehicles are generally longer than they are wide.

These decisions would require further analysis.

WHY DW1000 IS IDEAL FOR KEYLESS ENTRY SYSTEMS

DecaWave's DW1000 wireless transceiver uses Ultra Wideband radio technology, is compliant with the IEEE 802.15.4-2011 UWB standard and is implemented using CMOS technology. For a full suite of sales & technical information on the DW1000 see the DecaWave website www.decawave.com

Looking at the requirements discussed above let's see how DecaWave's DW1000 technology addresses them: -

Table 3: Meeting Keyless Entry System Requirements with the DW1000

Parameter	Requirement	What DW1000 brings
Communications Performance	Must be capable of operating in crowded car parks both indoors and outdoors	Because DW1000 uses Ultra Wideband technology it is very immune to fading due Multipath propagation. This is particularly important in indoor environments with significant amounts of metal such as in indoor car parks
Communications Range for vehicle access	Generally required to be limited to within a relatively short distance of the vehicle	DW1000 has excellent Non-Line-of-Sight and Line-of-Sight range – the system designer can decide on the distance within which the in-vehicle system should take action on receipt of a valid exchange
Communications Range for vehicle start	The must be able to determine when the key fob is inside the vehicle so that the engine cannot be started until the driver is inside the vehicle	DW1000's highly accurate distance measurement capability allows the system to reliably determine if the fob is inside the vehicle
Conformance with local regulations	The technology employed must conform to regulations in all geographies the manufacturer's vehicles are sold	DW1000 is based on Ultra Wideband which is allowed on an unlicensed basis in most major geographies worldwide. Consult DecaWave for more details
Long Battery Life	Batteries need to last a significant length of time – typically 5 years depending on amount of use.	DW1000's high data rates mean its on-air time can be kept shot and it's power consumption can be minimized
Cost	The system should be as low cost as possible	DW1000's low cost allows cost effective fobs and in-vehicle units to be constructed
Reliability	The system must reliably open / start the vehicle	The IEEE802.15.4-2011 UWB protocol incorporates a number of error checking methods to ensure communications is reliable.
Security	It must be difficult for potential thieves to "hijack" communications between the key fob and the vehicle and thereby gain entry to the vehicle	Because the distance measurement is based on the exchange of very accurate time stamps it is extremely difficult for a third party to hijack an exchange. The IEEE802.15.4-2011 UWB standard supports AES-128 encryption

3 REFERENCES

3.1 Listing

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

Table 4: Table of References

Ref	Author	Date	Version	Title
[1]	DecaWave		2.00	DW1000 Data Sheet
[2]	DecaWave		1.00	DW1000 User Manual

4 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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