User's Manual and Data Sheet

PulsON® 412

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Overview

This document is the user's manual and data sheet for the Time Domain PulsON 412 ("P412") Ultra Wideband (UWB) ranging radio transceiver. The document is divided into the following sections.

1 Summary and Theory of Operation

The P412 is an Ultra Wideband (UWB) radio transceiver that provides the following functions:

- It accurately and reliably measures the distance between two P412s and provides these measurements at a high update rate.
- It supports two different range measurement techniques (Two-Way Time-of-Flight and Coarse Range Estimation).
- It communicates data between two or more P412s.

Time Domain's PulsON P412 is a ruggedized, industrial UWB platform. The most obvious and important characteristics of the device relative to industrial operation are listed below:

- The electrical interface to the unit through USB, Serial or CAN
- All components are rated for industrial temperature (-40C to +85C)
- Fan is not required for cooling.
- For best performance, the user must provide a heat sink to insure that the unit does not overheat
- The board is provided with nine large (#6) mounting holes that insure that the unit will survive and operate in most high vibration environments
- RF filtering provides superior operation in the presence of 2.4GHz and 5.8GHz
- The UWB emissions have been tested and comply with FCC 15.519 which is the most stringent of the FCC UWB limits
- The digital emissions have been tested and comply with the FCC 15.109(b) ("Class A digital device") which limits use of the P412 to commercial and industrial uses only

The P412 is an Ultra Wideband radio that coherently transmits and receives trains of individual RF pulses at a nominal rate of 10 MHz. **Figure 1** provides a notional example of a typical UWB pulse in both the time and frequency domain. Pulses are transmitted as coded trains of pulses. Coding is accomplished either by pseudo-randomly shifting the pulse phase or inter pulse transmission time. By transmitting and receiving pulses coherently, the P412 can integrate multiple pulses and thereby increase the received signal to noise ratio. Integration can therefore be used to increase robustness and or operational range.

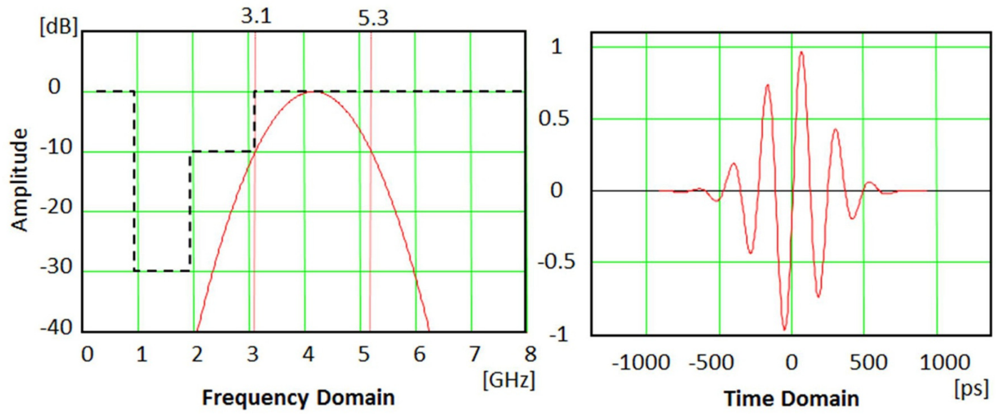


Figure 1: Notional UWB pulse in both time and frequency domain.

The P412 measures distance using a technique called Two Way Time of Flight. In this approach the radio requesting the range measurement (the Requestor) will transmit a packet of pulses that will be received by one or more units (the Responders). The responder will then measure the leading edge of the waveform relative to the radio lock spot and transmit this information in a return (or responding) packet. The Requestor will then measure the difference in phase between the transmitted and received PN code and compensate this phase measurement by the leading edge measurement. Dividing the result by two and multiplying by the speed of light yields a measurement of the distance between the Requestor and Responder.

The user controls and monitors the P412 through a straight forward Application Programming Interface (API) over USB, Serial or CAN connections. USB driver support is provided for Vista 32, Vista 64, Win7 32 and Win7 64 operating systems. The API provides all the commands and capabilities required by a user to design a network tailored for operating multiple P412s as ranging radios. For details on the API see the following document:

- *Ranging and Communications Module API Specification*

For details on the USB and serial interfaces refer to

- *USB and Serial Interfaces*

To assist the user in demonstrating the performance of the P412 as a ranging radio, Time Domain also provides a PC based Graphical User Interface (GUI). These GUI allows the user to exercise all of the API commands and offers the following capabilities:

- They provide programmers with a visual example of a host application which interfaces to the P412 through the API.
- They allow users to evaluate ranging and communications performance.
- They allow system analysts to visualize, collect and log raw ranging data such that it is possible to develop algorithms/strategies tailored to a given application

Time Domain also provides sample C and Matlab for demonstrating the interface and performance of the hardware.

For details on these GUIs refer to the following document:

- *Ranging and Communications Module Reconfiguration and Evaluation Tool (RCM – RET) User Guide*

Additional information including all of the documents referenced in this section can be found on the web at www.timedomain.com. This includes: the API, software manuals, applications notes, white papers, examples, published papers, sample C code, sample Matlab, etc.

2 Using a P412 as a Ranging Radio

The P412, shown in **Figure 2**, is a small, low power and affordable device which provides accurate, high rate range measurements and has superior operational performance when compared to conventional RFID/RTLS devices. The device is intended for use as an OEM module. When used as a ranging radio it is typically referred to as a P412 RCM.

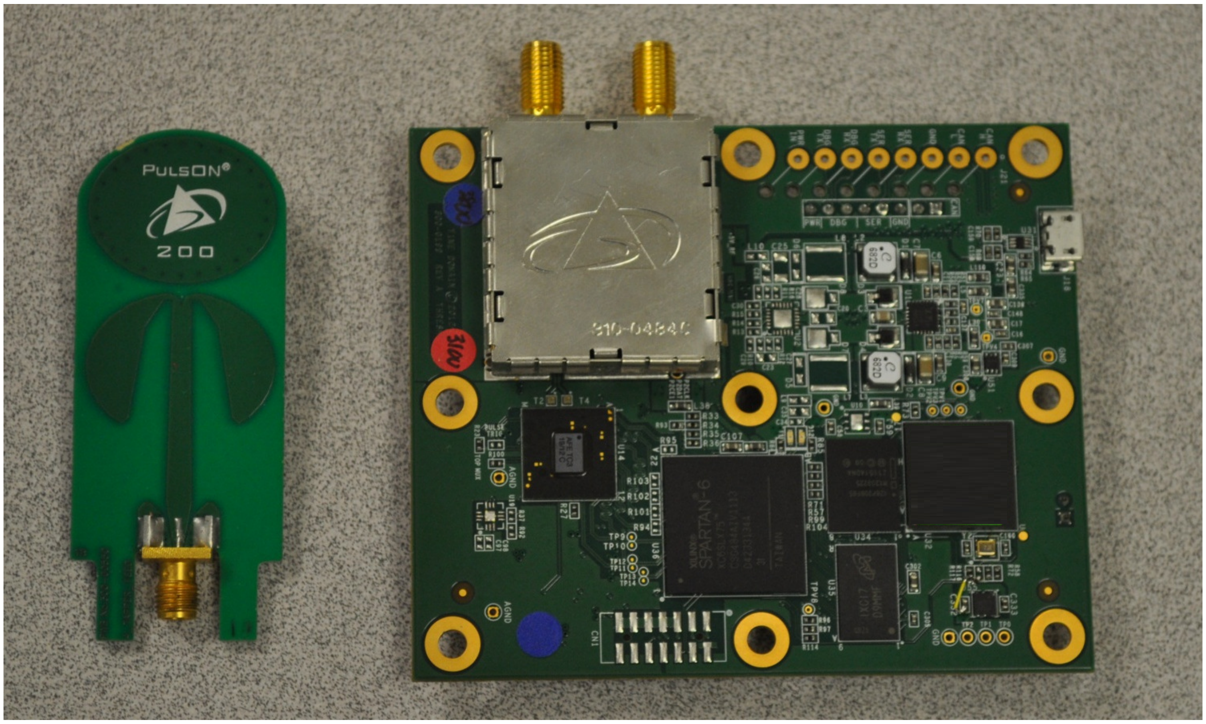


Fig. 2: P412 RCM with Broadspec antenna

Time Domain does not provide a standard network as part of the API. Instead, Time Domain is focused on providing a robust platform and a full featured, flexible interface. This focus includes all aspects of the physical and link layers as well as a few additional mechanisms to support implementation of a wide variety of network architectures. A block diagram showing operation of a ranging system is provided in **Figure 3.**

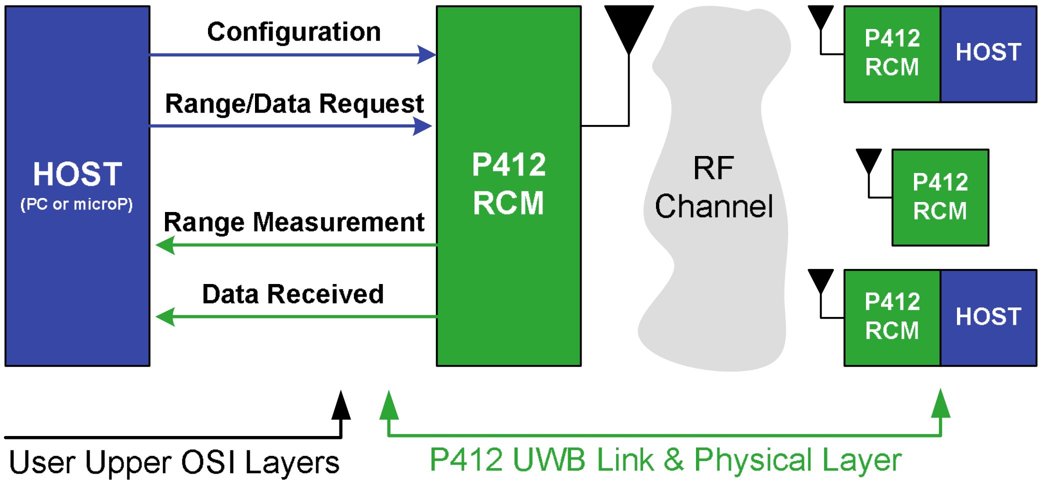


Fig. 3: Illustration of the interface with a system of P412 RCMs

Key Features of the P412 RCM

- Excellent performance in high multipath and high clutter environments
- Coherent signal processing extends operating range
- Direct sequential pulse sampling allows measurement of received waveform (resultant waveform is available to the user for ranging optimization)
- Two-Way Time-of-Flight (TW-TOF) ranging technique provides highly precise range measurements with industry-leading update rate
- Coarse Range Estimation (CRE) technique estimates the range from a transmitting unit by using the received leading edge signal strength and periodically recalibrating the estimate based on infrequent TW-TOF range measurements
- UWB chipset enables low cost, small size, and low power operation
- UWB waveform and pseudo random encoding ensures noise-like transmissions with a very small RF footprint
- RF emissions compliant with FCC limits
- Each unit is a full transceiver
- Single 3.1"x 3.7" (7.9 x 9.4 cm) board
- USB or Serial interfaces or CAN
- Several sleep modes allow user to reduce power consumption

Typical Applications of the P412 RCM

- Peer-to-peer ranging with moderate-rate wireless communications
- GPS augmentation for multipath resistance
- Inertial augmentation for drift removal
- Robotics navigation and tracking, precision formation
- Autonomous vehicle convoys
- First responder tracking and man-down locator
- Asset tracking, especially in applications that preclude the use of fixed infrastructure or involving moving frames of reference
- Distributed sensor automatic survey and dynamic mapping with fused data communications
- Wireless channel impulse response (CIR) measurements

- Wireless noise-like / covert data communications

3 Hardware Block Diagram

This section provides and discusses at a high level the P412 functional hardware block diagram, as shown in **Figure 4**. Additional detail on the various interfaces is provided in **Section 4**.

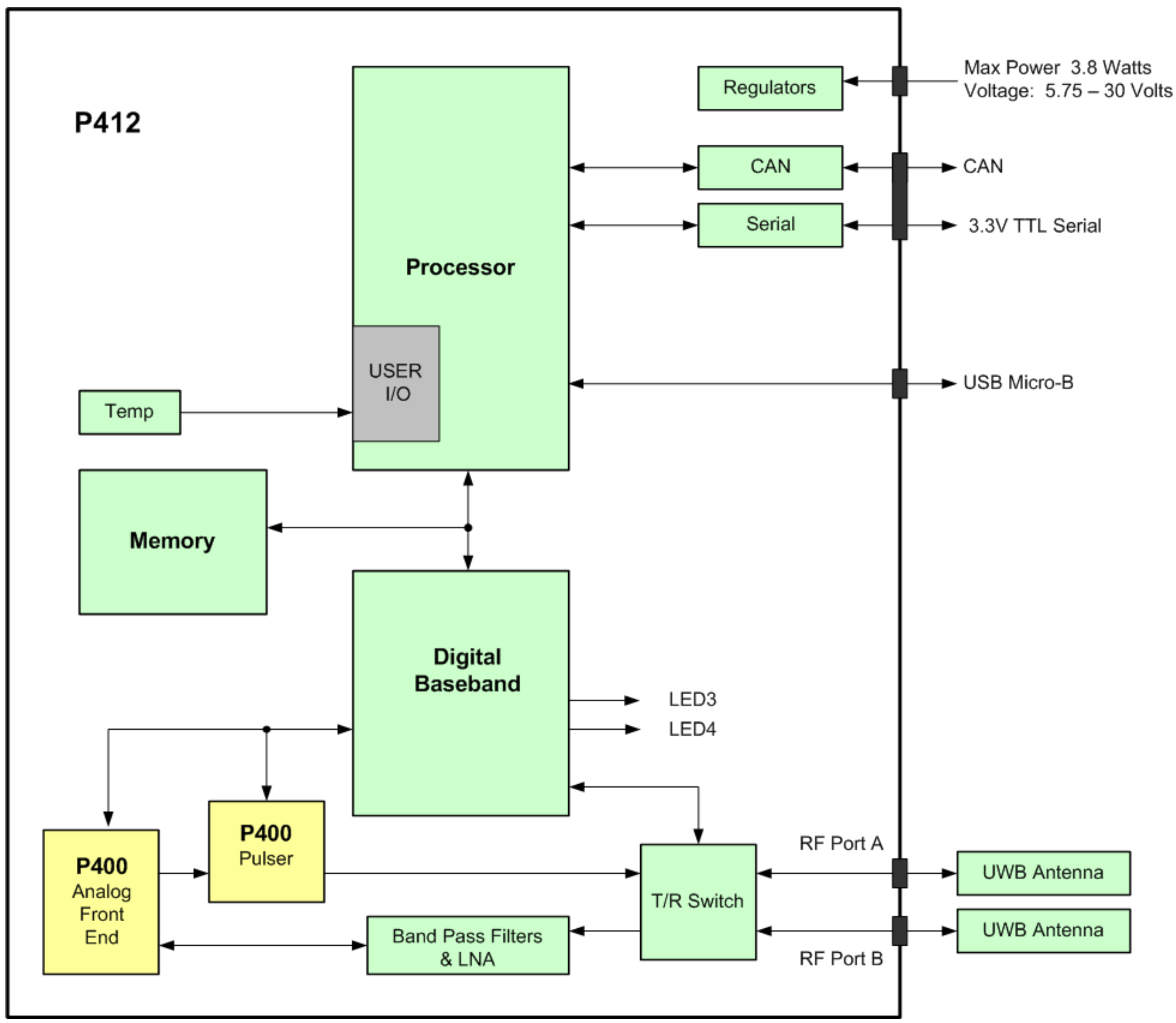


Fig. 4: P412 hardware functional block diagram

To power the board, the user must supply a maximum of 3.8 Watts at any voltage between 5.75-30V. This can be accomplished either with the provided power supply or from a battery. Indicating lights provide operating status information.

The user can interface to the P412 through either USB (standard USB Micro B connector), Serial connection, or CAN. In addition, the user can request the P412 to report the board temperature.

The physical interface to the P412 is through a pigtail (not provided). Provisions for soldering the pigtail to the board are provided. Each of the pigtail holes is also provided with a strain relief hole. If desirable, the user can lace each of the pigtail wires through the strain relief hole before soldering at the pad. Details are provided in Section 4.

The processor controls the UWB front end through a Digital Baseband FPGA interface. More specifically, the FPGA configures the Time Doman P412 Pulser chip (UWB transmitter) and P412 Analog Front End (AFE) chip (UWB receiver), provides timing signals and out-going data, receives incoming data and controls the position of the transmit/receive (T/R) switch.

There are three RF sections:

- The Pulser chip transmits a train of UWB pulses at the maximum allowable FCC transmit levels. The Pulser chip is also provided with a variable attenuator that allows the user to reduce the transmit power to as little as 19 dB below the FCC limit.
- Receive chain consists of gain stages and band pass filter.
- T/R switch supports two configurations: Transmit/Receive on Port A and Transmit on A, Receive on B.

4 Interfaces

This section provides a detailed description of the various P412 interfaces. The overall board image in **Figure 5** is referenced throughout this section. The user power, serial and CAN interfaces are all connected to the P412 via a soldered down pigtail (not provided). A set of strain relief holes is also providing. This allows the user to lace the pigtail wires through dedicated holes before soldering to the pad. This is detailed in **Figure 6**.

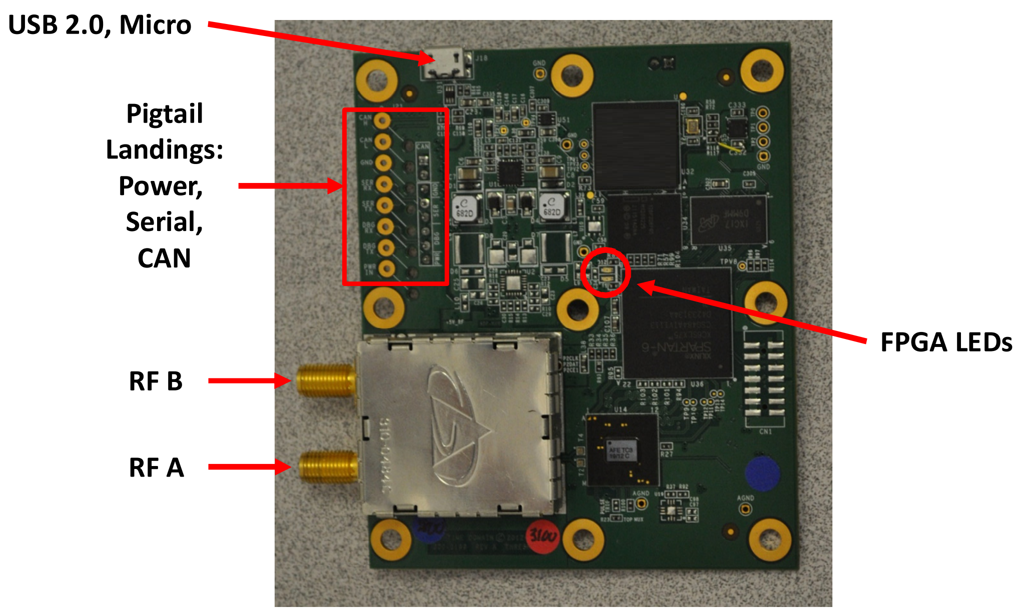


Fig. 5: Photo of the P412 highlighting key interfaces

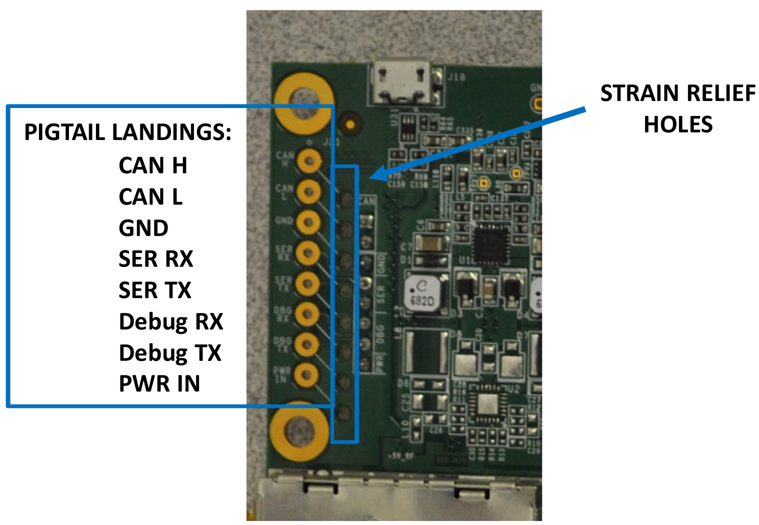


Fig. 6: Pigtail mounting and strain relief holes.

Note that Debug RX and Debug TX are for manufacturing test only.

4.1 Indicator Lights

The P412 is provided with two indicator LEDs mounted adjacent to the Digital Baseband FPGA. See **Figure 5** for exact locations.

The amber LED toggles at 1Hz to indicate that the FPGA has passed Built-In Test (BIT). If the FPGA fails BIT, then the amber LED will blink at approximately 10 Hz. The green LED is initially off indicating that the FPGA has not been loaded. It blinks rapidly to indicate that the FPGA has been loaded and is getting a clock. After that, a steady on or off indicates a failure.

4.2 USB, Serial and CAN Interfaces

The P412 offers three different interfaces that allow users to control the module according to their specific application needs. The standard interfaces supported by the system are: USB 2.0 through a Micro-B USB connector, a 3.3V TTL-level serial interface and a CAN interface. The Serial and CAN interfaces are physically connected to the board through a user supplied pigtail. The details of the pigtail connection are shown in Figure 6.

Note the USB connection does not provide enough power to support the RCM.

The protocol used to communicate with the P412 is fully defined in the *API Specification*. Connection to the Serial and USB interfaces are described in Time Domain application note *Using the P4xx USB and Serial Interfaces*.

4.3 Antenna Ports

The P412 has two antenna ports, designated Port A and Port B. The connector used on each port is a standard polarity female SMA connector (Digi-Key part number J801-ND). The two ports enable single and dual antenna modes of operation.

An RF transfer switch on the P412 controls how the RF electronics are connected to the SMA connector. Normal operation is either 1) Transmit/Receive on Port A or 2) Transmit of A, Receive on B. Use of a transfer switch allows for future operational capability.

The P412 is intended to be used with the Broadspec antenna. Using any other antenna will require FCC recertification. However, it is possible to add passive extension cables between the antenna port and the antenna. Be aware that using alternate UWB antennas will likely change the RF time-of-flight electrical distance between the antenna port and the phase center of the antenna. Failure to account for such changes will result in an offset or bias error in range measurements. See the RCM *API Specification* for details on how the electrical distance is defined and calibrated.

5 Mechanical

Board outlines and mounting hole locations are indicated in **Figure 7** and the hole dimensions are shown indexed in **Figure 8**. The nine mounting holes are sized for a #6 screw. It is anticipated that the number of mounting holes, size of the holes and placement separations are sufficient to satisfy most vibration requirements. All units are English/Imperial.

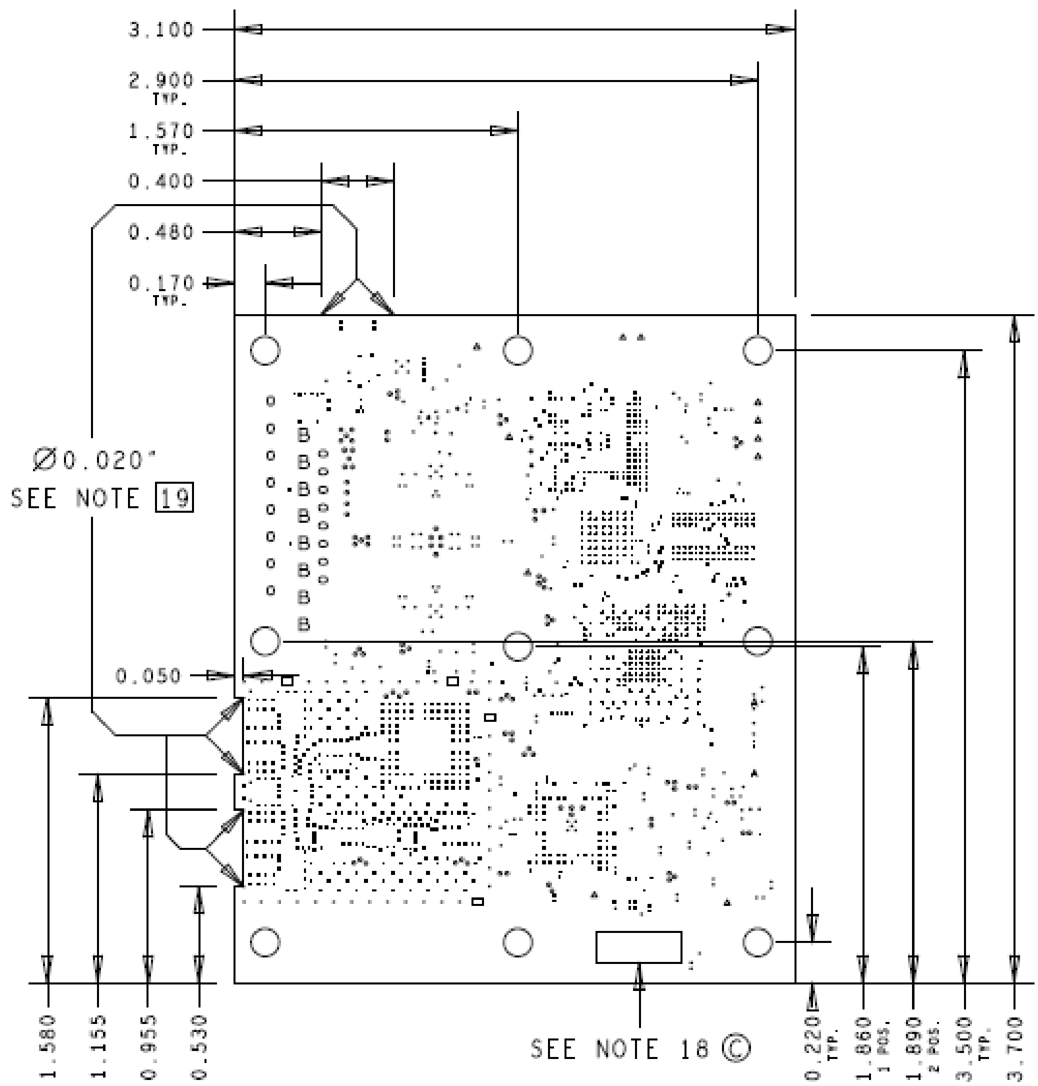


Fig. 7: P412 mechanical top view

DRILL CHART: TOP to BOTTOM				
ALL UNITS ARE IN MILS				
FIGURE	SIZE	TOLERANCE	PLATED	QTY
·	8.0	+4.0/-4.0	PLATED	333
·	8.0	+5.0/-5.0	PLATED	779
·	10.0	+5.0/-5.0	PLATED	231
·	16.0	+5.0/-5.0	PLATED	96
·	18.0	+5.0/-5.0	PLATED	6
▴	38.0	+5.0/-5.0	PLATED	11
▫	43.0	+5.0/-5.0	PLATED	8
▫	47.0	+5.0/-5.0	PLATED	8
▫	55.0	+5.0/-5.0	PLATED	4
○	156.0	+0.0/-0.0	PLATED	9
A	40.0	+5.0/-5.0	NON-PLATED	2
B	67.0	+0.0/-0.0	NON-PLATED	8

Fig. 8: Hole sizes: Index table

The user must provide a sufficiently sized heat sink such that the temperatures of the board can be kept below the maximum allowable temperature for the target deployment environment.

Most of the heat is generated by the AFE chip. There are two means by which this heat can be extracted from the board. First, a heat sink can be placed directly in contact with the AFE. While this will work, it should be noted that most of the heat generated by the AFE is transported to the board through the BGA balls on the AFE. While heat can escape through the top of the chip, the transfer characteristics of silicon are poor. Once the board begins to heat, the temperature of the RF shield will rise. This offers the second opportunity to extract heat from the board. Because the RF shield is tightly connected to the board ground plan, connecting the shield to the heat sink will greatly increase the rate at which heat is transferred from the P412.

Figure 9 shows the mechanical dimensions for both the AFE and the RF Shield. **Figure 10** shows a notional heat sink strategy and calls out dimensions of relevant structures. **Figure 11** shows relevant clearances.

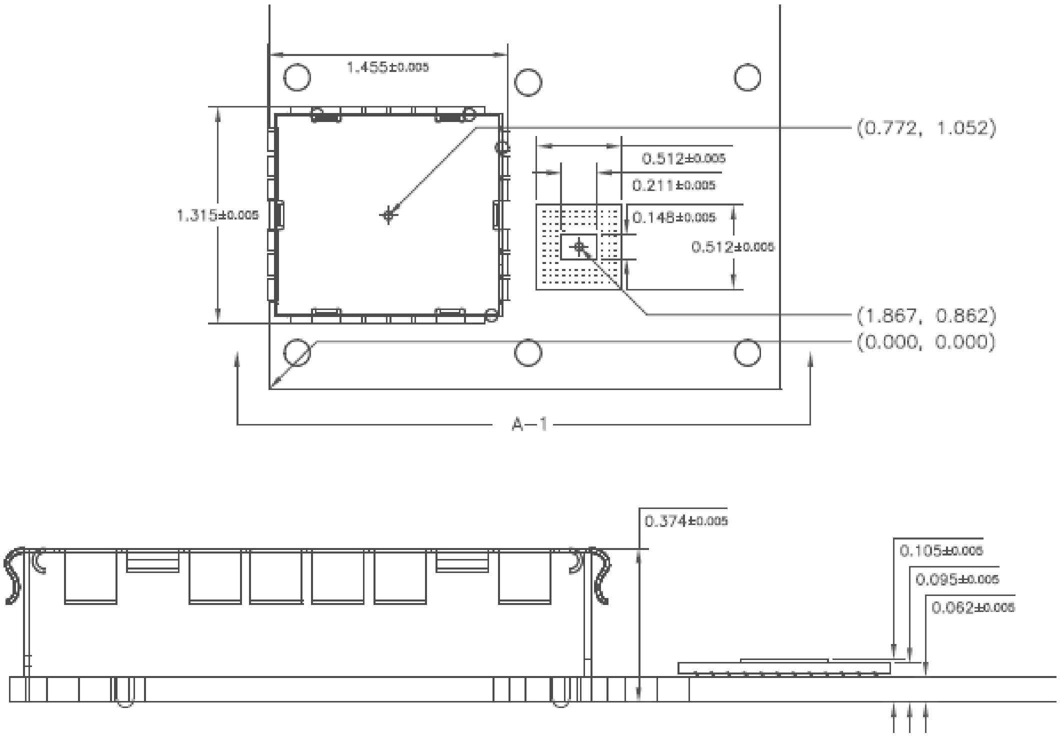


Fig. 9: Shield and AFE mechanical location and dimensions.

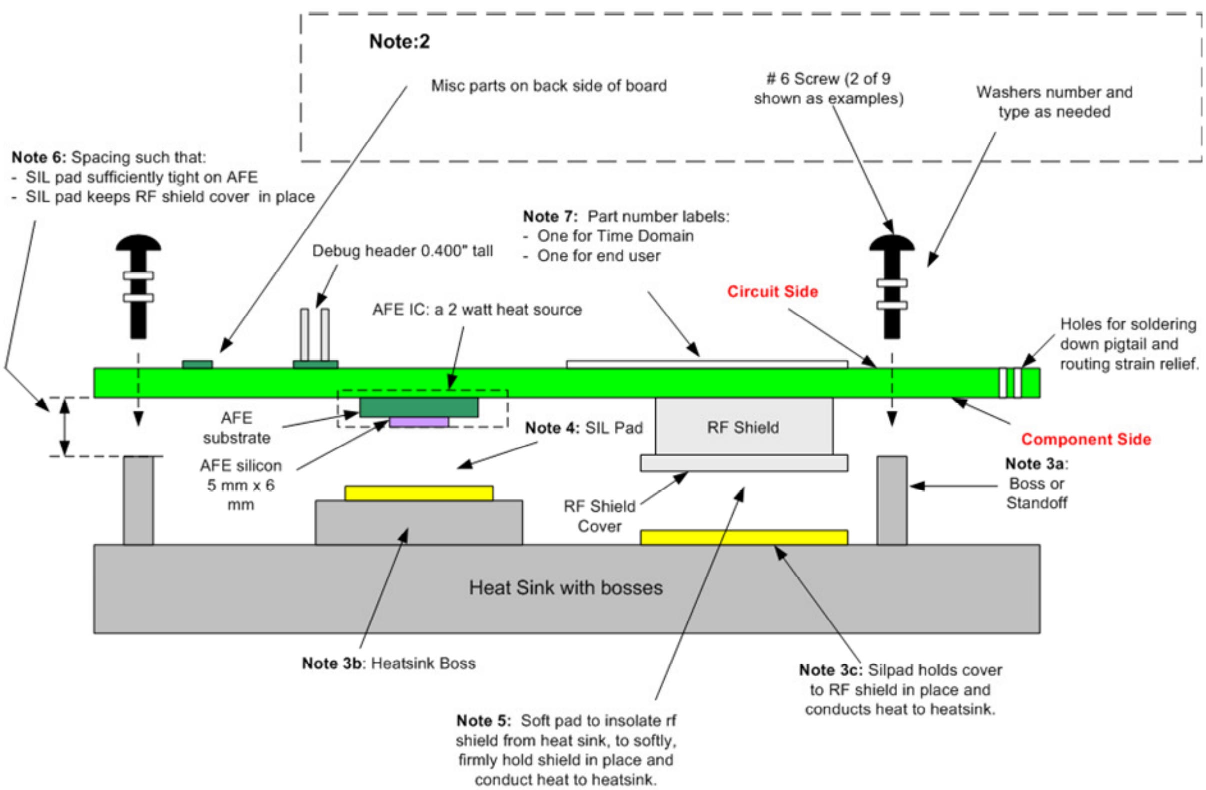
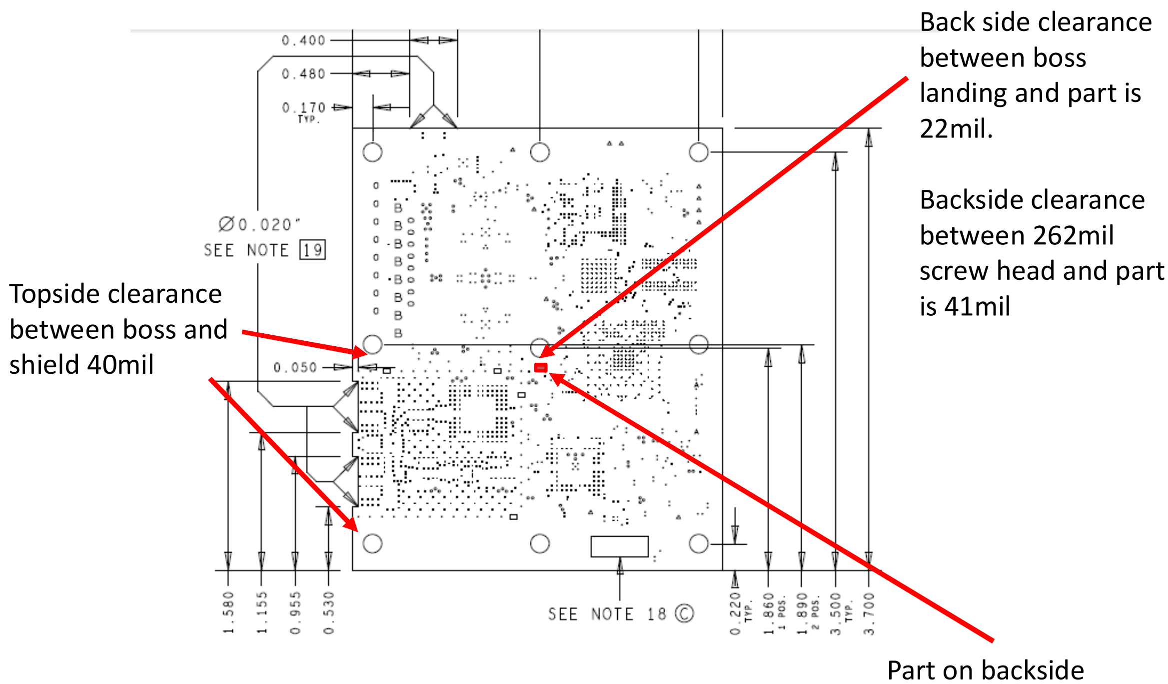


Fig. 10: Notional heat sink strategy.

Topside View



All other boss clearances (top and back) are at least 50mil

Fig. 11: Relevant clearances.

6 Performance Specs

Table 2 summarizes the P412 specifications and key performance parameters.

P412 Specs	Value
Physical Parameters	
Dimensions:	3.1"x 3.7" (7.9 x 9.4 cm)
Weight:	58 grams
Storage Temperature:	-40C to 85°C
Max component operating temperatures ratings:	-40C to 85°C (industrial range)
Max allowable board temperature:	75°C (as reported by on board temp sensor and using optimum heat sink)
Humidity:	Up to 95%, non-condensing
Input Power Range:	5.75V to 30V DC
Input Power Ripple:	100 mV pk-pk
Power/Temp operating as a Ranging Radio	
Maximum Power Consumption:	3.8 Watts
Typical Power Consumption and Transition times (power function of communications interface):	
- Active (requesting or receiving)	3.8 Watts
- IDLE	2.7 Watts (Enter: 1.2ms, Exit: 1.2 ms)
- Standby_E	2.6 Watts (Enter: 1.2 ms, Exit: 2.9 ms)
- Standby_S	2.6 Watts (Enter: 1.3 ms, Exit: 2.9 ms)
User Interfaces/Devices	
Standard PC/Laptop Interface:	USB 2.0A Client – Micro B connector
Serial Interface:	3.3V TTL Serial UART 115.2kbps, 8, n, 1
CAN Interface:	Tested up to 1 Mbps
On Board Temperature Sensor	-40°C to 125°C, +/- 2.0°C
RF Characteristics	
Operating Band:	3.1GHz to 5.3 GHz
Center Freq:	4.3 GHz
Max Transmit power density:	Meets FCC Limit (-41.3dBm/MHz)
Max power into base of antenna:	-13dBm
Adjustability range:	-32 to -13dBm (19 dB in 63steps)
Antenna Ports A&B:	Standard 50 Ohm SMA coaxial connector
Antenna Supported	Broadspec™ Toroidal Dipole Antenna
Antenna Control:	User cross-bar configured as either Tx/Rx on port A or Tx on A, receive on B. Other configurations may be supported in the future.
Noise Figure:	4.8 dB

Dynamic Range:	
Integration: 1 (instantaneous)	30 dB
Integration: 16:1 (PII=4)	42 dB (Min Ranging Integration)
Integration: 64:1 (PII=6)	48 dB (Min Radar Integration)
Integration: 1024:1 (PII=10)	60 dB (Max Ranging Integration)
Integration: 32768:1 (PII=15)	75 dB (Max Radar Integration)
Pulse Repetition Rate (Nominal)	10 MHz
RF Communications	
Channelization:	7 user selectable pseudo-random pulse interval channels. Others available for special applications.
Raw Data (Symbol) rates:	See Table 3:
Max Range (max FCC Part 15 transmit power, standard Broadspec Antennas, free space, thermally noise limited environment, clear line of sight)	See Table 3:
Comms type:	Packet transmission
Max user bytes/packet:	1024
Pulse integration rates (PII):	4 (16:1), 5 (32:1), 6 (64:1), 7 (128:1) 8 (256:1), 9 (512:1), 10(1024:1)
Ranging Performance	
Ranging techniques:	Pulsed Two-Way Time-of-Flight (TW-TOF), Coarse Range Estimation (CRE)
Two-Way Time-of-Flight	
Line of Sight Range Performance	See Note 1
Precision (Standard Deviation)	2.3 cm
Accuracy (Bias error):	2.1 cm
Range Update Rate	See Table 3
Non-Line of Sight Performance	See Note 2
Coarse Range Estimation (LOS only)	See Note 3
Range update rate	See Table 3

Table 1: P412 performance characteristics

Note 1: Precision and Accuracy in LOS conditions. The Line of Sight (LOS) Precision and Accuracy specification is based on a measurement campaign that included 20,000 range measurements taken in an open field, over an operating range that varied from 2 ft. to 300 ft., for PIIs 4 through 8 inclusive, at minimum and maximum transmit gain, when the received signal was linear and also when it was in compression. The quoted values are the results of the composite of all of the measurements. This includes combinations of settings that may not be reasonable (e.g., operation at minimum range and maximum transmit power). It is believed to be a conservative estimate of the system's ranging Precision and Accuracy. When averaging many range measurements, users have reported precisions on the order of a few millimeters.

Note 2: Precision and Accuracy in NLOS conditions. Time Domain does not have a specification for accuracy in Non-Line of Sight (NLOS) environments. This is because of the wide variety of conditions that can be encountered. For example, if one is measuring range inside a building that is constructed of wood frame and drywall (aka sheetrock or gypsum board), then one will experience a level of performance that is less than but close to LOS conditions. This is because wood and drywall do not significantly attenuate or disperse RF signals at the P412's operating frequency. At the opposite end of the propagation spectrum would be operation inside a metal ship. Because metal blocks radio frequencies, the operating range would be limited to the size of the room. Operation in NLOS must be determined empirically. Having said that, we routinely measure range from one side of our office space to the other (a distance of 30 meters through an environment that is not only NLOS but is also occluded by large amounts of metal) with an accuracy of better than +/- 1 meter.

PII	Max Range (meters)	Data rate: (bps)	Precision Range Measurement (time, rate)
4	35	632k	6.5 ms, 154 Hz
5	60	316k	8.5 ms, 118 Hz
6	88	158k	12.5 ms, 80 Hz
7	125	79k	20 ms, 50 Hz
8	177	39.5k	36 ms, 28 Hz
9	250	19.7k	67 ms, 15 Hz
10	354	9.86k	132 ms, 8 Hz

Table 2: Data and ranging performance characteristics

Note that these are conservative estimates of range performance and have a healthy safety margin allowing robust performance. For example, with PII set to 9, Time Domain has routinely achieved 650 meters in clear line of sight conditions over open ground.

Note 3: Precision and Accuracy of CRE: There are three main factors that affect the Precision and Accuracy of a CRE measurement: stability of the RF channel, signal strength, and changes in antenna pattern. If RF channel characteristics are stable, then the accuracy of the CRE measurement should be close to that of the reference PRM range measurement. However, if the RCM is physically moving, with associated antenna pattern changes, then the RF channel will change with time. Therefore, the recalibrating PRM measurements should be taken frequently enough such that the rate of change ("drift") of the RF channel will be small. This rate of change will vary with node speed and change in orientation and must be determined empirically. Random effects, along with sampling variability, can cause a static node's signal strength measurement to vary as much as 10%. The CRE error is also a function of distance/SNR as a smaller/farther signal contains a higher proportion of noise elements. This translates into a CRE standard deviation error of approximately 10% at short distances growing up to 30% at very long distances.

Note 4: Setting the transmit power level: The maximum transmit power provided by the P412 will be at the limit allowed by the FCC. The user has the option to reduce the transmit power from this maximum and operate at levels as much as 19dB below the limit. This adjustment is made through the API "Set Configuration" command. Alternatively, this adjustment can be made through the Graphic User Interface (GUI) RCM RET by modifying the "Transmit Gain" setting on the Config Tab. **Figure 12** shows the relationship between the value selected for Transmit Gain and the radiated power when using a standard P412. This measurement was taken by directly connecting the output of the P412 to a power meter. The maximum level shown in **Figure 12** (-13 dBm at a gain setting of 63) corresponds to the maximum level permitted by FCC when used with the Broadspec antenna. It is not possible for the user to enter a value greater than 63. Using any antenna other than the Broadspec invalidates the certification.

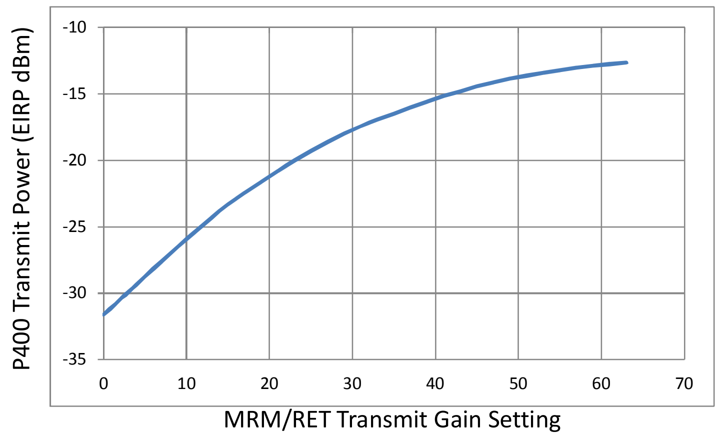


Figure 12: Transmit power as a function of Transmit Gain setting. (Setting 63 = FCC limit)

7 Broadspec Antenna

The P412 is designed to operate with the Broadspec P200 antennas shown in **Figure 13**. Use with *ANY* other antenna invalidates the FCC certification. Per FCC 15.203, the Broadspec antenna must be professionally installed and the installer has the responsibility to insure that the Broadspec antenna is used.

The P412 can be operated with a single antenna (used for transmit and receive) or with two antennas (where one is dedicated for transmit and the second for receive).

The Broadspec Ultra Wideband Antenna (~3dBi) provides an omni-directional transmit/receive pattern supporting a frequency range of 3.1-5.3 GHz. It has a standard SMA female connector and measures 1"x 2.5" x 0.125". Specifications available on the web at:

http://www.timedomain.com/datasheets/TD_Broadspec_Antenna.pdf

Figure 13: Broadspec Antenna with right angle connector

8 FCC Compliance

The P412 and associated Broadspec antenna have been designed to be in compliance with the Federal Communications Commission (FCC) regulations governing both UWB hand-held systems (Part 15.519) also known as "battery powered devices" and UWB Surveillance Systems (Part 15.511). This means that the device can be incorporated in a wide variety of products including mobile tracking systems, mobile locators, radar-based locators, guidance and position systems, radar fences and communication devices.

More specifically,

> This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

The label which provides the certification number is shown below in **Figure 14.**

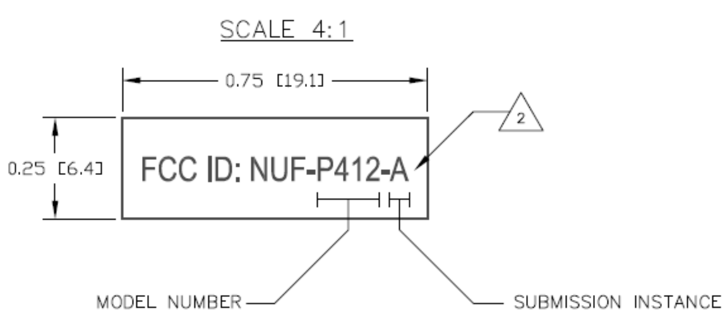


Figure 14: FCC ID number

This label is located on the back or bottom side of the P412. See **Figure 15.**

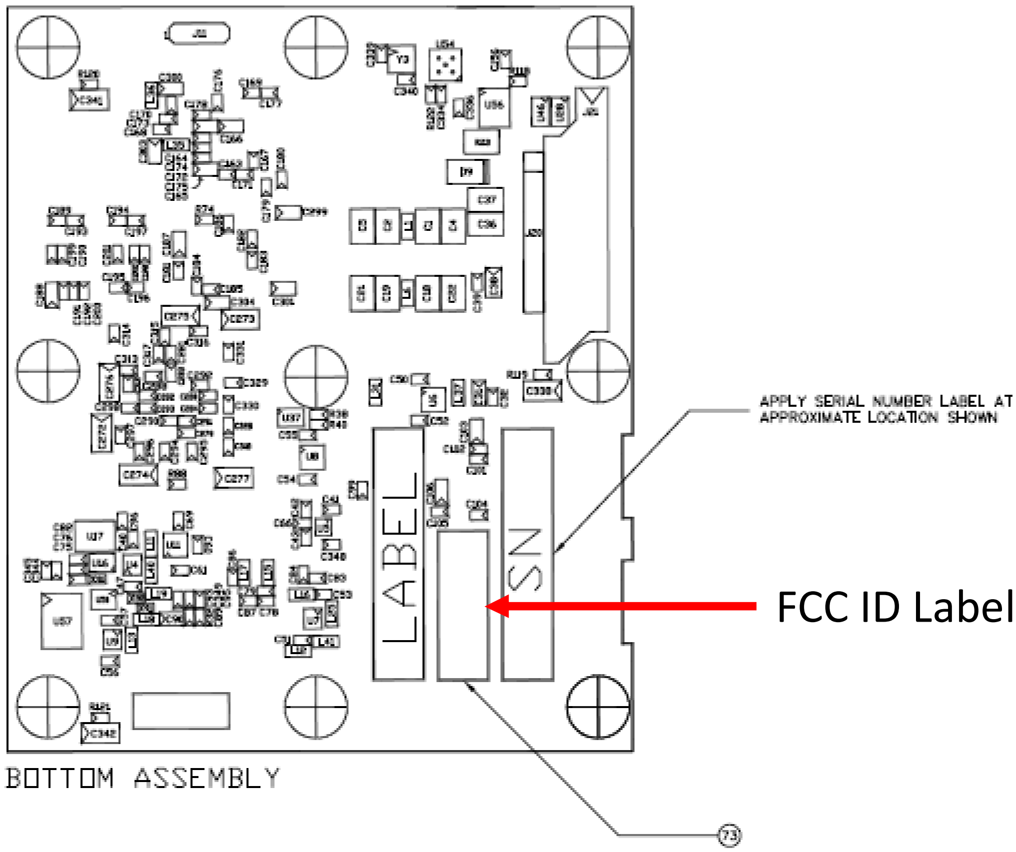


Figure 15: Location of certification number

9 Export Restrictions

Relating to export, the Department of Commerce's Bureau of Industry and Security has assigned the Export Commodity Control Number (ECCN) of 5A001b.4 to the P412. Products falling under ECCN 5A001b.4 are controlled for export purposes pursuant to the Commerce Control List for National Security and Antiterrorism. For the latest information from the Commerce Department on Export, please go to: http://www.bis.doc.gov/licensing/exportingbasics.htm.