Transponder and Emergency Stop Integration Guide

Revision 2

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1. Overview

The SubT Challenge Competition Rules document describes a three-tiered emergency stop (e-stop) system that minimizes risk to humans, platforms, and the environment (Section 9.4.12 in Revision 1). The 2nd Tier of this emergency stop system is the "Recovery Wireless E-Stop", which is a DARPA defined and provided wireless receiver that teams must integrate onto all mobile platforms weighing more than 0.5 kg. The Tier 2 E-Stop will help ensure that platforms can be brought to a halt so that DARPA personnel may safely enter the course to recover the platforms after the run is over. The purpose of this document is to provide teams with specifications and integration guidelines for the DARPA-provided Tier 2 E-Stop receiver.

This document supersedes the *SubT Transponder and Emergency Stop Integration Guide, Revision 1* document dated March 25, 2019. Major revisions in this document are indicated by blue text. This document is subject to change and may be superseded by later versions. The latest official versions of all documents will be posted to the SubT Challenge Website and the SubT Community Forum.

The Tier 2 E-Stop system has been designed to minimize the integration and operational burden on teams. The system leverages low size, weight, and power (SWaP) radios that operate on a mesh network. The concept of operations for this system can be visualized in Figure 1 below. Each mobile platform will host the DARPA Tier 2 E-Stop receiver and will constantly monitor it for an emergency stop signal. Once the host platform detects the signal from the Tier 2 E-Stop receiver, it must bring itself safely to a halt within 30 seconds.

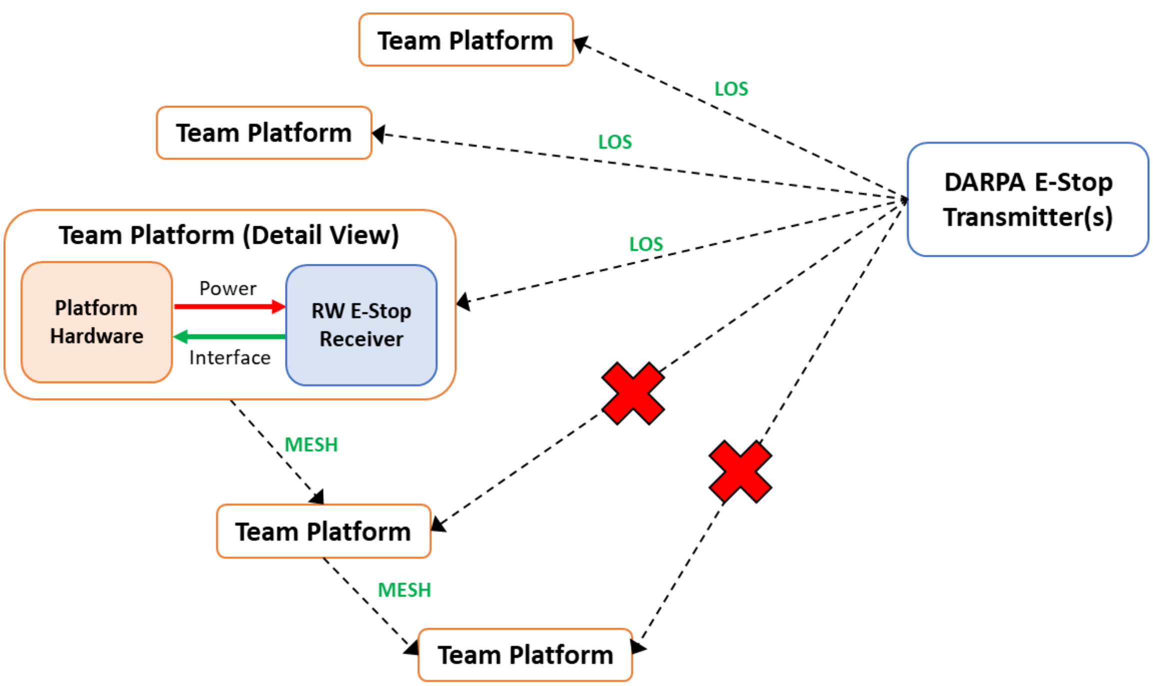

Figure 1: Concept of Operations for the Recovery Wireless E-Stop System

The SubT Challenge Competition Rules document additionally stated that teams will be required to integrate a transponder onto their mobile platforms that enables DARPA to track and monitor the progress of systems throughout the test course (Section 9.4.10 in Revision 1). To minimize the burden on teams, the Tier 2 E-Stop receiver will also function as the transponder. This means that teams will only have to integrate a single receiver into their platforms to meet both the Tier 2 E-Stop and Transponder requirements provisioned in the rules document. See Appendix E for additional details related to the transponder tracking gates.

Please note that teams are still required to implement and demonstrate their own Tier 1 wireless e-stop system as well as the Tier 3 on-platform e-stops. Teams that have an alternate or custom Tier 2 E-Stop configuration must receive official approval to use a non-DARPA configuration. Special cases will be evaluated on an individual basis including considerations such as safety and additional burden for competition staff.

2. Receiver Specifications

The Tier 2 E-Stop receiver will be an XBee Pro 900HP radio module mounted on a SparkFun XBee Explorer USB carrier board. The XBee radio will provide wireless communication with DARPA transmitters, and the recommended carrier board will enable simple mounting and integration onto teams' mobile platforms. Additional specifications and configuration information is provided in Appendix A.

The fully assembled Tier 2 E-Stop receiver is pictured below in Figure 2. It weighs 9 grams and has dimensions of 37 x 29 x 10 mm. The receiver operates on the 900 MHz ISM band frequency range, and typically consumes approximately 10 mW of power. The low SWaP of the receiver, along with its simple electrical interface, is intended to simplify integration of the receiver onto a wide range of mobile platforms.

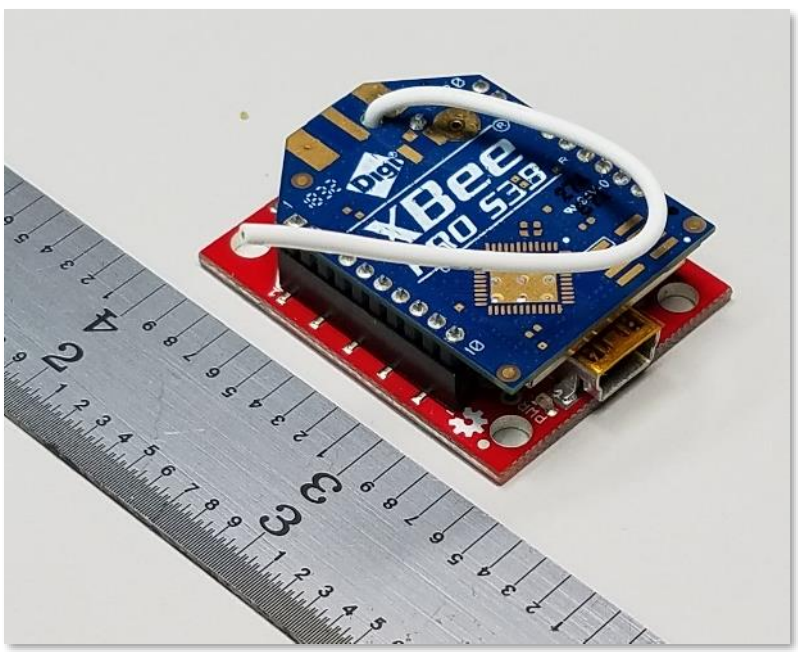

Figure 2: Tier 2 E-Stop Receiver

The XBee-Pro 900HP radio module operates on the 902 MHz – 928 MHz ISM frequency band with frequency hopping spread spectrum. Transmit power for each module can be up to 24 dBm

(250 mW). Please read Appendix E for more detailed information on the RF transmission behaviors of the Tier 2 E-Stop receiver with the E-Stop Transmitters and Tracking Gates.

3. Receiver Integration Guidelines

3.1. Mounting Options

Teams may physically mount the Tier 2 E-Stop to their platform receiver in any configuration as long as the following requirements are met:

1. At least 90% of the receiver's wire antenna length is exposed to the open air surrounding the mobile platform. This antenna may not be encapsulated by any material.
2. The receiver should be physically accessible on the platform in a reasonable timeframe (e.g., <60 seconds) to enable easy access for troubleshooting or replacement. Any covers or other obstructions to the receiver should be removable in this timeframe.
3. Reasonable steps are taken to ensure that the receiver will not be damaged by physical contact with a surface or with moisture during typical use.

A default mounting option is described below, with additional mounting options presented in Appendix B. Teams may use any combination of these options or custom options of their own. Most of these mounting options make use of the SparkFun XBee Explorer USB carrier board detailed in Appendix A.

Default Mounting Option: Adhesives

Adhesives such as tape, foam pads, 3M Dual Lock, Velcro, etc., may be used to attach the carrier board directly to the surface of a mobile platform. The bottom of the carrier board is flat with no electronic components soldered to the bottom. This provides a smooth surface for attaching adhesives to the bottom of the carrier board. It is important to note that teams may have to solder wire connections to the 5V, GND, and DIO1 pins (see Sections 3.2 and 3.3), which would constrain the placement of adhesives on the bottom of the carrier board.

3.2. Power Provisioning

Teams are required to provide power to the XBee radio module from the hosting mobile platform. A default option is described below with additional options listed in Appendix C. Teams may implement any power integration scheme as long as appropriate power is provided to both the XBee and Sparkfun carrier boards. Furthermore, teams should consider the latching behavior of the E-Stop (see Section 3.3 for additional details). When an emergency stop signal is received by the XBee radio module, the DIO1 pin will permanently latch into a HIGH state (signaling e-stop) until one of the two conditions are met:

Condition 1: The XBee radio module is restarted. This can be accomplished by any one of the following methods:

a. Pressing the RESET button on the SparkFun carrier board. This requires that the RESET button on the carrier board is readily accessible while mounted on the hosting mobile platform.
b. Power to the radio module is cut and then momentarily restored using an electrical or mechanical method for disconnecting the power circuit. It is suggested to implement a

simple SPST/NC push button or switch. This can also be accomplished electrically with a relay or other electronic switch.

c. Power for the entire platform is cycled, which will ultimately cut and restore power to the XBee radio as well.

Condition 2: DIO1 is reset to a LOW state via serial communication, as further defined in Appendix D.1.

Teams that are not able to meet Condition 2 directly above must be able to satisfy either Condition 1.a or Condition 1.b in order to reset their platforms' Tier 2 E-Stop from emergency stop mode to running mode.

Default Power Provision Option: Carrier Board Pin Connections

Power may be provided directly to the board using the 0.1" spaced pin connections on the carrier board itself. To provide power, simply connect the 5V pin and one of the GND pins to a stable 5 VDC power source. This power source must be able to provide at least 1 W of power (200 mA @ 5 V) continuously. Connection can be accomplished via male pin headers or via wire. If using wire, no thinner than 24 AWG wire is recommended.

CAUTION: Do NOT attempt to provide 3.3 VDC power to the 3.3 V pin on the carrier board. This pin is connected to the output of a MIC5219 linear regular on the carrier board, which is not reverse-current protected.

3.3. Monitoring for E-Stop Signals

Teams are required to continuously monitor the Tier 2 E-Stop receiver for emergency stop signals. This is accomplished by monitoring the state of the DIO1 pin on the XBee radio module. A HIGH state on DIO1 will always signify an emergency stop signal, while a LOW state will always signify normal operation (e.g. no e-stop signal). Several options for monitoring the state of DIO 1 are presented below. Teams may monitor the DIO1 pin using any method, as long as they meet the requirement that the hosting mobile platform will safely come to a complete stop within 30 seconds of receiving a wireless emergency stop signal via the Tier 2 E-Stop receiver. This implies that the platform must be able to sense the transition of the DIO1 pin from the LOW state to the HIGH state in much less than 30 seconds, giving the platform enough time to come to a safe stop within the required 30 second window.

The behavior of the DIO1 pin is described as follows. Upon initial power-on, the DIO1 pin will default to the LOW (normal operation) state. It will remain in the LOW state until a wireless e-stop signal is received by the XBee radio module, after which DIO1 will immediately transition to and latch at a HIGH (e-stop) state. DIO1 will remain latched in the HIGH state until one of the following conditions are met:

Condition 1: The XBee radio module is restarted by one of the methods discussed in Section 3.2.

Condition 2: DIO1 is reset to a LOW state via serial communication, as further defined in "SparkFun Carrier Board: Serial via USB or TX/RX Pins" of this section.

Once one of these conditions are met, DIO1 will reset back to the LOW (normal operation) state. Platforms are required to enter and remain in an emergency stop state **as long as** the DIO1 pin is in a HIGH (e-stop) state. A DIO1 LOW state should never prevent the platform from entering an emergency stop state if a Tier 1 or Tier 3 E-Stop signal is detected.

Default Interface Option: Logic via DIO1 Pin

The carrier board includes direct electronic access to the DIO1 logic pin via a standard PCB pin hole. Platforms may read the state of the DIO1 pin using a digital input pin on a microcontroller, digital acquisition component, or other related hardware. For more reliable performance, teams should wire the digital input on their platform to both the XBee's DIO1 and GND pins. The DIO1 pin can only be in one of two states:

- **Digital LOW**: Normal operation, e.g. no e-stop signal present
- **Digital HIGH**: Emergency stop signal detected

The DIO1 pin operates on 3.3 VDC CMOS logic levels, and compatibility is only guaranteed for platforms with digital inputs that are also using 3.3 VDC logic. Most 5 VDC logic systems use TTL logic, which accepts inputs above 2 VDC as a HIGH signal. This is not guaranteed, and teams should test for proper functionality. A logic level shifter may be required for a 5 VDC logic digital input on the platform to successfully read a HIGH signal from the 3.3 VDC logic on the DIO1 pin.

It is recommended that teams use no thinner than 28 AWG wire to connect the DIO1 and GND pins from the carrier board to the digital input on the platform. Teams may instead interface with the DIO1 pin through the breadboard mounting configuration described in Appendix B. It is also recommended that platforms poll the DIO1 pin state regularly to meet the 30 second stopping requirement described at the beginning of Section 3.3.

Appendix A: Receiver Specification Detail

This appendix includes additional details on the specifications for the Tier 2 E-Stop receiver's two primary components: the XBee Pro 900HP Radio Module, and the SparkFun XBee Explorer USB carrier board.

A.1. XBee Pro 900HP Radio Module

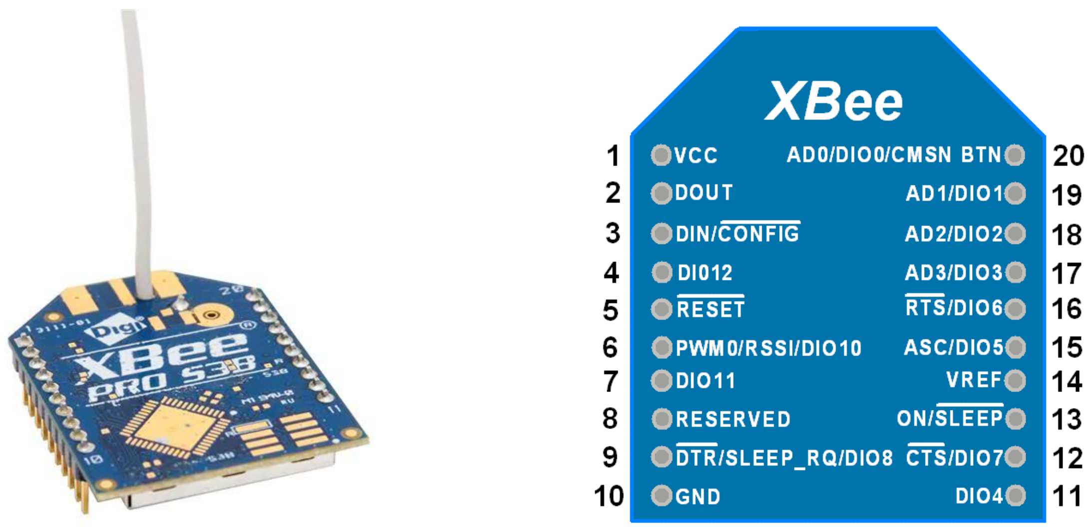

Figure 3: XBee Pro 900 HP Radio Module w/ Wire Antenna

Specifications:

Relevant specifications for the XBee Pro 900HP radio module are provided in Table 1 below. A full list of module specifications can be found in the datasheet.

Table 1: XBee Pro 900HP Radio Module Specifications

Parameter	Value
RF Frequency Band	902 to 928 MHz
Max LOS Range	Up to 9 mi (15.5 km)
Transmit Power	Up to 25 dBM (250 mW)
Antenna Configuration	Wire Antenna (24 AWG, 75 mm long)
Electrical Power	3.3 VDC (29 mA typical, 215 mA max)
Data Interface	3.3 V UART
Dimensions	33 mm x 25 mm x 8 mm
Weight	2 g

Configuration:

The XBee Pro 900HP modules have a wide array of parameters that can be configured to meet application requirements. DARPA will provide teams with pre-configured radio modules to integrate onto their platforms. The configuration information is provided here for team awareness.

NOTE: Teams should **NOT** modify the configuration of the DARPA-provided and preconfigured receiver modules. If the configuration is changed or corrupted, teams should contact Competition Staff for assistance in restoring the module's configuration.

API Mode: API Mode without Escapes (0x01)
Using API mode enables more sophisticated control and communications with the XBee radio modules that is necessary to properly implement the Tier 2 E-Stop functionality.

Channel Mask: 0x00FFFFFFFFFF7FFFF
Selectively enables RF channels that the module may operate on. Teams using their own XBee networks may select their own channel masks to deconflict with the Tier 2 E-Stop channels.

Preamble ID: 0 (0x00)
The preamble ID allows XBee networks to be segmented, which ultimately minimizes interference between multiple XBee networks operating in the same vicinity. To avoid interference with the DARPA XBee network, teams should ensure that the Preamble ID(s) for their own XBee networks use a different value.

Network ID: 2015 (0x07DF)
The network ID specifies which network the XBee module is operating on. Only modules with matching network IDs are able to communicate with each other. All teams will use the same Network ID; however, different teams will be on separate virtual networks through differentiated AES Encryption keys.

MAC Address: Module Specific
Each XBee module has a hard-coded MAC address, which serves as the address for sending and receiving data packets. DARPA will maintain a catalog of modules and associated MAC addresses that are delivered to each team. Each module will have a sticker indicating it's hard-coded MAC address. DARPA will request that teams, after integrating the receivers, provide DARPA with platform identifier/name associations for each integrated receiver. This will allow DARPA to identify platforms by their receiver MAC address through the transponder tracking systems located throughout the course.

Encryption Enable: Enabled

AES Encryption Key: Team Specific
These configuration options are set to protect teams from errant emergency stop signals being sent to their platforms during a scored run. This ensures that DARPA will be the only entity able to send emergency stop signals to a team's platforms. A separate and private encryption key will be assigned to each team and preconfigured on the modules before delivering to teams.

DIO1: Digital Out (LOW)
Pin DIO 1 on the XBee will be used as a digital output pin that team platforms will monitor to ascertain the current emergency stop state. A signal that is LOW indicates "e-stop disabled", and a HIGH state indicates "e-stop enabled". The modules will be preconfigured so that the default state of DIO1 at power-on is a digital output LOW signal. The only time the DIO1 pin will change to the digital output HIGH state is when an emergency stop signal is received.

XBee Pro 900HP Resource Links:

Module Datasheet:
https://www.digi.com/pdf/ds_xbeepro900hp.pdf

Configuration and Usage Guide:
https://www.digi.com/resources/documentation/digidocs/pdfs/90002173.pdf

A.2. SparkFun XBee Explorer USB Carrier Board

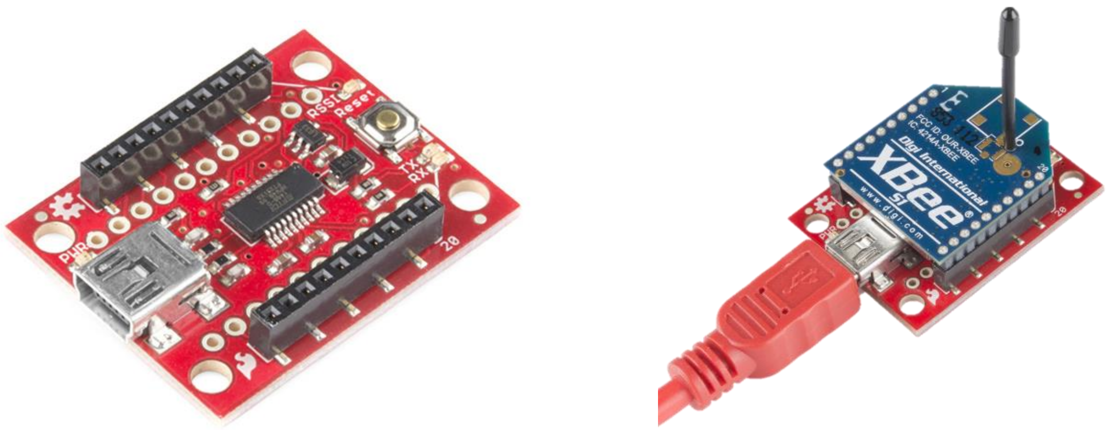

Figure 4: SparkFun XBee Explorer USB Carrier Board

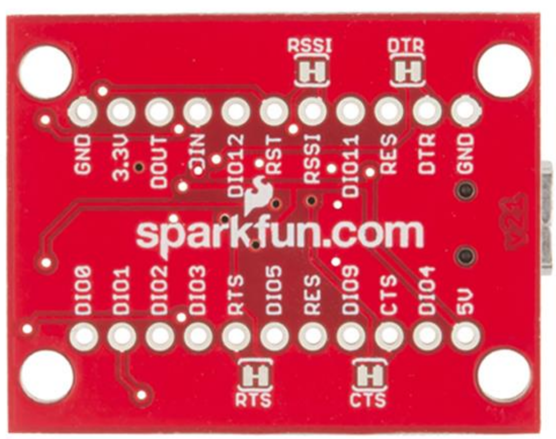

Figure 5: Bottom portion of the SparkFun XBee Explorer USB carrier board

Specifications:

Relevant specifications for the SparkFun XBee Explorer USB carrier board are provided in Table 2 below.

Table 2: SparkFun XBee Explorer USB Specifications

SPECIFICATIONS	
Electrical Power	5 VDC (0.5 mA typical, 20 mA max)
Data Interface	USB 2.0, 3.3 VDC UART, or 3.3 VDC DIO to XBee
Dimensions	33 mm x 25 mm x 8 mm
Weight	2 g

SparkFun XBee Explorer USB Resource Links:

Product Webpage:
https://www.sparkfun.com/products/11812

Board Schematic:
https://cdn.sparkfun.com/datasheets/Wireless/Zigbee/XBee-Explorer-v21b.pdf

Board CAD Model:
https://cdn.sparkfun.com/3D_Models/products/11812/stl.zip

Interface Tutorial:
https://learn.sparkfun.com/tutorials/exploring-xbees-and-xctu

Appendix B: Additional Mounting Options

B.1. SparkFun Carrier Board: Mounting Holes

The carrier board, as pictured in Figure 4 and Figure 5, has four mounting holes for attaching via screws. The mounting holes are 0.125” in diameter and are spaced in a rectangle with dimensions 0.8” x 1.2”. The PCB has a standard thickness of 1.6 mm. A full 3D CAD model of the board may be downloaded from the Resource Links provided in Appendix A.2. When creating mounting surfaces and choosing screws, make sure that enough clearance is given for components on the top surface as well as any soldered connections to the 5V, GND, and DIO1 pins if necessary (see Section 3.3).

B.2. SparkFun Carrier Board: Breadboard

The electrical pins on the carrier board, as seen in Figure 5, are 0.1” spaced and thus are breadboard friendly. Teams may mount the carrier board to a breadboard, protoboard, or other custom PCB using standard 0.1” male pins soldered onto the carrier board. Break-away male headers that are compatible with the carrier board can be purchased from this link: https://www.sparkfun.com/products/116.

B.3. No or Alternate Carrier Board

Teams also have the option of selecting an alternate carrier board to integrate the XBee radio module onto their platforms. The only requirement that must be met is that the XBee radio module can be powered and interfaced with as discussed in Sections 3.2 and 3.3, respectively. A number of other compatible OEM options exist; however, DARPA will only be providing the SparkFun XBee Explorer USB and teams will have to purchase any alternative carrier boards they select.

Appendix C: Additional Power Provisioning Options

C.1. SparkFun Carrier Board: USB

The SparkFun carrier board pictured in Figure 4 includes a single USB Mini B connection that provides power and data connectivity to BOTH the carrier board and the attached XBee radio module. Connecting the carrier board to a USB 1.1 or higher standard USB port on the platform will satisfy the power requirements for the Tier 2 E-Stop receiver.

C.2. No or Alternate Carrier Board

Teams may opt to use a different carrier board, or none at all, when integrating the XBee radio module to their platform. Should this be the case, teams must power the radio module by connecting its VCC and GND pins to a stable 3.3 VDC power supply. This power source must be able to provide at least 1 W of power (300 mA @ 3.3 V) continuously. If wire is used for this power connection, DARPA recommends no thinner than 24 AWG.

Appendix D: Additional Interface Options

D.1. SparkFun Carrier Board: Serial via USB or TX/RX Pins

The SparkFun carrier board provides direct serial communication with the XBee radio module via USB or the TX/RX pins pictured in Figure 5. Platforms will be able to read the state of the DIO1 pin through this serial connection. The XBee radio modules will be configured with the default serial settings listed in Table 3.

Table 3: XBee radio module default serial port settings.

XBee Radio Module Serial Port Configuration	
Baud Rate	9600 bps
Data Bits	8
Parity	None
Stop Bits	1
Flow Control	None

If using the TX/RX pins on the carrier board, it is important to note that these pins operate as 3.3 VDC UART. If the hosting platform is not 3.3 VDC UART (e.g. a 5 VDC UART), a logic level shifter must be used between the platform and the TX/RX pins on the carrier board.

The XBee radio modules are configured to operate in API mode (Appendix A.1: Configuration). This enables the platform to communicate with the XBee radio module through API frame packets over the serial connection. The full documentation of all API commands and responses can be found in Appendix A.1: Reference Links. Teams that communicate with the Tier 2 E-Stop via serial are expected to appropriately implement relevant XBee serial API protocols. The Tier 2 E-Stop specific API commands are provided for teams' reference below.

The ATIS command queries the state of all enabled digital and analog pins on the XBee radio module. To send this query command to the XBee, the platform must transmit the following packet to the XBee over the serial connection:

ATIS Frame Packet: 0x 7E 00 04 08 01 49 53 5A

The response (as long as the XBee remains in the DARPA default configuration) will be either:

Normal Operation: 0x 7E 00 0B 88 01 49 53 00 01 00 02 00 00 00 D7

Emergency Stop: 0x 7E 00 0B 88 01 49 53 00 01 00 02 00 00 02 D5

These two response packets ultimately describe the state of the DIO1 pin. If the DIO1 pin is in a LOW state (normal operation), then the XBee will return the first "Normal Operation" response packet indicated above. If the DIO1 pin is in a HIGH state (emergency stop signaled), then the XBee will return the second "Emergency Stop" response packet indicated above. Teams should regularly query the state of DIO1 to meet the 30 second stop requirement described at the very beginning of this section.

Platforms interfaced with the XBee radio module through serial will also have the ability to electronically reset the latched HIGH state of DIO1 to resume normal operation without power cycling the XBee. This coincides with Condition 2 listed in the beginning of this section. To accomplish this, the platform must send the following API frame packet via serial:

ATD1 Frame Packet: 0x 7E 00 05 08 01 44 31 04 7D

If the XBee received the command and DIO1 was properly reset to the LOW state, the following response will be sent from the XBee to the platform:

DIO1 Reset Success: 0x 7E 00 05 88 01 44 31 00 01

NOTE: While participating in an official run at a STIX or Circuit event, DIO1 may NOT be reset to a LOW state unless specifically permitted by DARPA staff. The intent is to prevent teams from resetting platforms from an emergency stop state to a normal operating state without DARPA's knowledge, which may put personnel, the platform, or the environment at risk.

There are a few important considerations teams must make to successfully interface with the Tier 2 E-Stop's XBee via serial:

- The XBee may respond to ATIS or ATD1 commands with response packets that instead indicate an error. Please read the "AT Commands", "Operate in API Mode", and "Frame Descriptions" sections of the XBee user guide listed under Appendix A.1: Resource Links to learn how to read and detect error indication messages. Relevant subsections are "I/O Settings Commands", "I/O Sampling Commands", "API Frame Format", "AT Command Frame", and "AT Command Response Frame".

- The XBee may transmit additional types of packets to the platform via serial. Platforms must be able to read all of these packets out of the receive buffer and process relevant packets in real time.

- The XBee may receive other types of packets from DARPA infrastructure during a run (see Appendix E.2 for more detail). Thus, the only reliable method for reading an emergency stop signal is to use the ATIS method described above.

D.2. No or Alternate Carrier Board:

If a team opts to use no carrier board or a custom carrier board, they may still interface directly to the XBee module using the Serial TX/RX Pin or Logic DIO1 Pin methods described above. Please be sure to note the 3.3 VDC logic levels used by the XBee on all of its pins, including the serial TX/RX and DIO1 pins.

If teams use an alternate commercially available carrier board, then they must follow the carrier board's documentation for proper integration with the XBee's serial connection and/or access to the DIO1 pin.

Appendix E: DARPA Transmitter Specifications

The Tier 2 E-Stop receiver serves two purposes:

1. Wirelessly receiving Tier 2 emergency stop commands from DARPA personnel and relaying it to the platform

2. Serving as a transponder for tracking the locations of platforms throughout the test course

The Tier 2 E-Stop receiver will interact with two different types of radios to implement the purposes above: the E-Stop Transmitters and the Tracking Gates.

E.1. DARPA E-Stop Transmitters

The DARPA E-Stop Transmitters are handheld devices that will be carried by Competition Staff into the test course for platform recovery at the end of each run. These devices ensure that any platforms within line of sight of recovery personnel will wirelessly receive a Tier 2 emergency stop command from a safe distance.

The transmitters will also use an XBee-Pro 900HP radio module, which will enable transmission of emergency stop signals to the same XBee models used in the Tier 2 E-Stop receivers. These transmitters operate in only two states:

1. **Normal Operation**: During normal operation, when no emergency stop is required, the transmitter will be in an OFF state. No RF transmissions will be made in this state to minimize risk of interference with team platforms using the 902 MHz – 928 MHz frequency band.

2. **Emergency Stop**: When an e-stop is commanded by DARPA personnel, the transmitters will be switched into an ON state. While in this state, the transmitter's XBee radio module will continuously broadcast emergency stop signals at full power (24 dBm). These transmissions will be in the form of XBee API Frame Packets and will be repeated continuously in the range of 5 to 30 times per second.

It is also important to note that the Tier 2 E-Stop receivers operate in a mesh mode. This means that the receivers on the platforms may rebroadcast the received emergency stop signal to propagate it to other Tier 2 E-Stop receivers within line of sight.

The presence of multiple enabled DARPA E-Stop Transmitters, along with the meshing nature of the Tier 2 E-Stop receivers, may cause flooding of the RF environment in the 902 MHz – 928 MHz range. This is only anticipated during emergency stop events; the RF environment is expected to be unaffected during normal operation mode.

E.2. DARPA Tracking Gates

The DARPA Tracking Gates are devices that will be placed periodically throughout the test courses for tracking the location and movement of platforms. These devices use a microwave radar sensor to detect the presence of a platform, and then interrogate its Tier 2 E-Stop receiver for identification. Similar to the DARPA E-Stop Transmitters, the gates also use the XBee-Pro

900HP radio modules for communicating with the Tier 2 E-Stop receivers. The gates can operate in three modes:

1. **Standby Mode**: The gates continuously scan the nearby environment for the presence of one or more platforms using a microwave radar sensor. During this time, the gate's XBee radio module will be in a "sleep" state, meaning that no RF transmissions are made by the XBee.

2. **Interrogation Mode**: When a platform is detected, the gates will broadcast packets at the lowest transmit power (7 dBm) to interrogate all nearby Tier 2 E-Stop receivers. These packets will be in the form of an XBee API Frame Packet. The Tier 2 E-Stop receivers on platforms in the immediate vicinity will receive these interrogation requests and subsequently respond with a packet containing identifying information about the platform. This interrogation process may repeat continuously as long as the platform is within sensing range of the microwave radar sensor, which stays active at all times. NOTE: It is possible that platforms operating nearby–but not in the immediate vicinity of–tracking gates may receive broadcasted interrogation packets meant for another platform that is currently being tracked by the gate.

3. **Emergency Stop Mode**: During an emergency stop situation, the gates will transition to this mode to help propagate wireless emergency stop signals to the platforms in the test course. The gates will switch to maximum transmit power (24 dBm) and will broadcast the same emergency stop signal in the same exact manner as DARPA E-Stop Transmitter described in Appendix E.1.

The risk of RF interference in the 902 MHz to 928 MHz band is anticipated to be low while the gates are in the standby and interrogation modes. During emergency stop mode, the RF environment in this frequency range is expected to be crowded. The microwave radar sensor, which will operate at all times, emits 10.525 GHz at 13 dBm.