デザイン・ガイド：*TIDA-020032*
カー・アクセス *Bluetooth®+ CAN* 衛星モジュールのリファレンス・デザイン

TEXAS INSTRUMENTS

概要

この衛星モジュールのリファレンス・デザインは、*Bluetooth®* Low Energy のパッシブ・エントリ／パッシブ・スタート (PEPS) および PaaK (電話をキーとして使用) デジタルキー・カー・アクセス・システムに適しています。このデザインは、広帯域の車内ネットワーク通信を必要とするシステム向けに、TI の Bluetooth ワイヤレス・マイコン (MCU) を使用して CAN-FD (Control Area Network with Flexible Data Rate) 通信機能を実装する方法を示しています。他の利点として、スリープ状態での消費電力の低減、CAN 自動アドレッシング方式による製造の改良、接続監視機能による Bluetooth の位置識別精度の向上、Bluetooth の到来角 (AoA) と受信信号強度インデックス (RSSI) を測定できるコンパクトなプリント基板 (PCB) を挙げることができます。
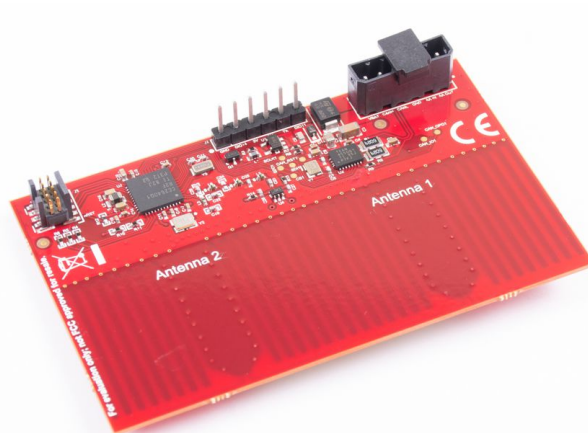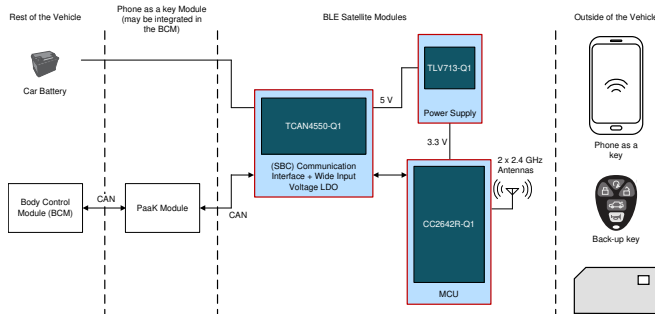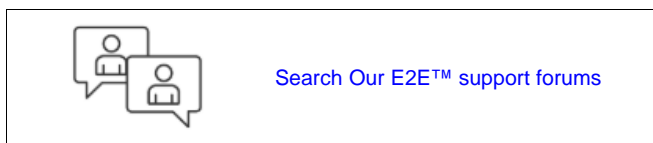
リソース

TIDA-020032	デザイン・フォルダ
CC2642R-Q1	プロダクト・フォルダ
TCAN4550-Q1	プロダクト・フォルダ
TLV713P-Q1	プロダクト・フォルダ

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特長

- CAN、CAN-FD 通信
- CAN の自動アドレッシング
- システムがスリープ状態で 25µA (標準値)
- Bluetooth の AoA と RSSI の測定が可能
- 47.625mm × 76.2mm (1.875 インチ × 3 インチ) の小型 PCB
- Bluetooth の接続監視機能によるシステム性能の向上

アプリケーション

- Phone-as-a-key (PaaK)、デジタルキー
- パッシブ・エントリ／パッシブ・スタート (PEPS)

カー・アクセス *Bluetooth®+ CAN* 衛星モジュールのリファレンス・デザイン　　　1

1 System Description

The TIDA-020032 Bluetooth Low Energy with CAN design is targeted for Bluetooth passive entry passive start (PEPS) and phone as a key, digital key systems. These car access systems may require higher in-vehicle data communication speeds and thus use CAN or CAN-FD communications between the satellite modules and the central car access module located in the body control module (BCM) or a separate electronic control unit (ECU). The higher network bandwidth allows for raw measurement data, such as angle of arrival IQ data, to be sent directly to the central car access module for processing. A unique feature implemented in the TIDA-020032 design is the ability to auto-address. Auto-addressing allows all satellite modules to be flashed with the same firmware instead of requiring each module to be flashed with a different CAN ID and thus simplifies manufacturing. When the car access system is first powered on during manufacturing, each satellite module will receive a unique CAN address associated to the satellite modules location around or in the vehicle so the central car access module can identify whered the localization measurement data is being received based off the CAN ID. For improved localization, multiple Bluetooth low energy methods are available for system designers to implement including AoA and RSSI. Having the capability to evaluate or implement both methods in a compact solution size is desired to allow car access system designers to test their best methods for Bluetooth localization and add their own combination of techniques to their system.

1.1 Key System Specifications

表 1. Key System Specifications

PARAMETER	SPECIFICATIONS	DETAILS
Input voltage range	5.8 V–30 V	12-V car battery
Sleep state current consumption	25 µA (typ.)	All devices powered off excluding the TCAN4550-Q1
Form factor	47.625 mm × 76.2 mm (1.875 in × 3 in)	PCB size including all devices and 2 × dipole antennas
Operating temperature range	−40°C to 105°C	

2 System Overview

2.1 Block Diagram

図 1. TIDA-020032 Block Diagram
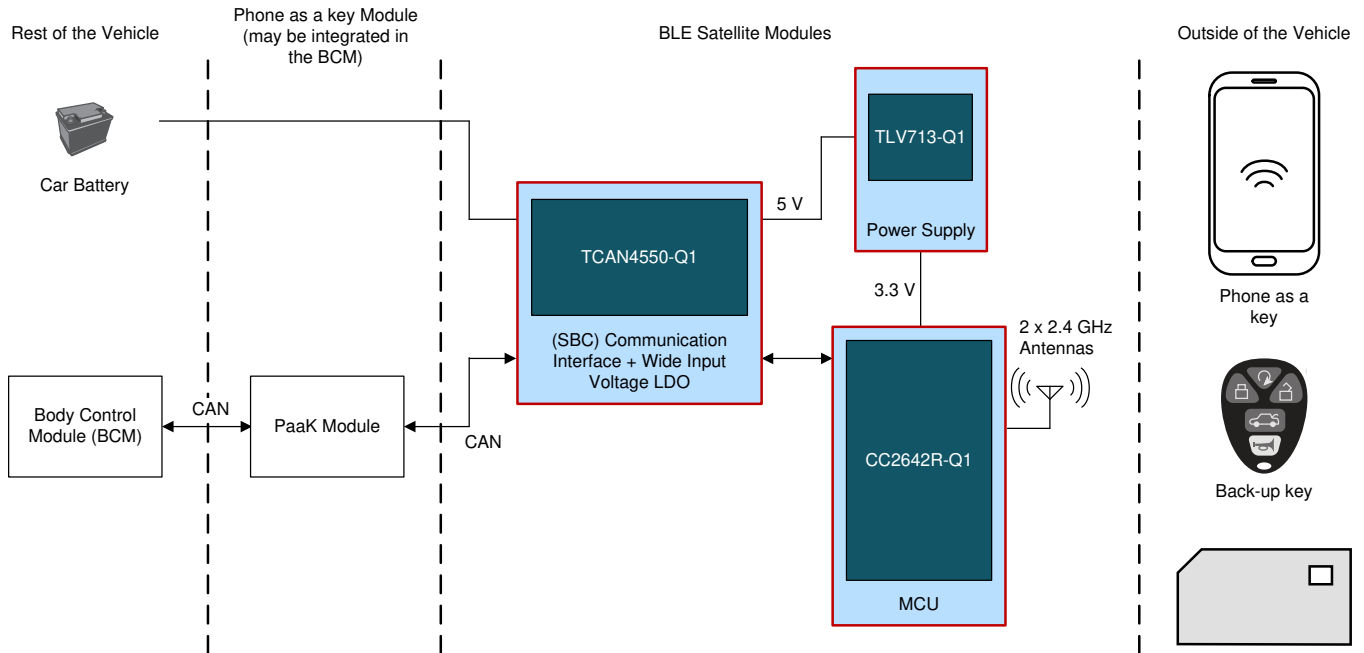
2.2 Design Considerations

The TCAN4550-Q1 CAN-FD controller with integrated transceiver implements SPI-to-CAN conversion that allows the CC2642R-Q1 Bluetooth MCU to implement CAN without an integrated CAN controller. The CC2642R-Q1 device can implement a CAN stack with the MCAL layer implementing SPI to the TCAN4550-Q1 CAN controller.

For system power, the TCAN4550-Q1 device also implements a wide input voltage 5-V out LDO. This allows the system to run off the TCAN4550-Q1 LDO and use the cost-effective TLV713P-Q1 low voltage input LDO to provide the 3.3-V rail from the 5-V rail. Due to the system power relying on the TCAN4550-Q1 5-V LDO, the system can completely disable the 5-V LDO by transitioning the TCAN4550-Q1 to the sleep state. This enables the system to reduce sleep state power consumption. When a CAN wake message is received, the TCAN4550-Q1 controller will enter the standby state and enable the 5-V LDO to power the system.

The TLV713P-Q1 device was selected due to its small package, low cost, and its ability to operate without input and output capacitors saving cost and board space. The TLV713P-Q1 device is used to step the 5-V rail down to 3.3-V for the CC2642R-Q1 device.

The SimpleLink™ CC2642R-Q1 device was selected due to its flexibility, since it is a software-defined radio with integrated memory, has low power consumption, its compliance to Bluetooth 5.0 standard, and its automotive qualification. The CC2642R-Q1 MCU is used to take multiple Bluetooth localization measurements and share the data via CAN to the central car access module.

To measure angle of arrival, two dipole antennas are used. Read the *Bluetooth® Angle of Arrival (AoA) Antenna Design* application note for more information on the antenna design and AoA performance. If AoA is not desired, one antenna and the RF switch can be removed. In addition, a different antenna can be used such as an inverted-F or patch antenna to further reduce PCB size.

2.3 Highlighted Products

2.3.1 TCAN4550-Q1 Automotive System Basis Chip (SBC) With Integrated CAN FD Controller and Transceiver

The TCAN4550-Q1 device is a CAN FD controller with an integrated CAN FD transceiver supporting data rates up to 8 Mbps. The CAN FD controller meets the specifications of the ISO11898-1:2015 high-speed controller area network (CAN) data link layer and meets the physical layer requirements of the ISO11898–2:2016 high-speed CAN specification. The TCAN4550-Q1 device provides an interface between the CAN bus and the system processor through serial peripheral interface (SPI), supporting both classical CAN and CAN FD, allowing port expansion or CAN support with processors that do not support CAN FD. The TCAN4550-Q1 device provides CAN FD transceiver functionality: differential transmit capability to the bus and differential receive capability from the bus. The device supports wake up via local wake up (LWU) and bus wake using the CAN bus implementing the ISO11898-2:2016 Wake Up Pattern (WUP). The device includes many protection features providing device and CAN bus robustness. These features include failsafe mode, internal dominant state timeout, wide bus operating range, and a timeout watchdog as examples.

2.3.2 CC2642R-Q1 Automotive Qualified SimpleLink™ Bluetooth® low energy Wireless MCU

The SimpleLink™ CC2642R-Q1 device is an AEC-Q100 compliant wireless microcontroller (MCU) targeting Bluetooth 5 Low Energy automotive applications. The device is optimized for low-power wireless communication in applications such as car access including passive entry passive start (PEPS) and remote keyless entry (RKE), battery management systems (BMS), car sharing, piloted parking, cable replacement, and smartphone connectivity. The highlighted features of this device include:

- Support for Bluetooth® 5.1 features: LE Coded PHYs (Long Range), LE 2-Mbit PHY (High Speed), Advertising Extensions, Multiple Advertisement Sets, CSA#2, as well as backwards compatibility and support for key features from the Bluetooth® 5 and earlier Low Energy specifications.
- Fully-qualified Bluetooth® 5.1 software protocol stack included with the SimpleLink™ CC13x2 and CC26x2 Software Development Kit (SDK), which enables Angle of Arrival (AoA).
- Longer battery life wireless applications with low standby current of 0.94 µA with full RAM retention.
- AEC-Q100 qualified at the Grade 2 temperature range (–40 °C to +105 °C) and is offered in a 7-mm x 7-mm VQFN package with wettable flanks.
- Dedicated software controlled radio controller (Arm® Cortex® -M0) providing flexible low-power RF transceiver capability to support multiple physical layers and RF standards, such as real-time localization (RTLS) technologies.
- Excellent radio sensitivity and robustness (selectivity and blocking) performance for Bluetooth® Low Energy (-105 dBm for 125-kbps LE Coded PHY).

The CC2642R-Q1 device is part of the SimpleLink™ MCU platform, which consists of Wi-Fi® , Bluetooth Low Energy, Thread, Zigbee® , Sub-1 GHz MCUs, and host MCUs that all share a common, easy-to-use development environment with a single core software development kit (SDK) and rich tool set. A one-time integration of the SimpleLink™ platform enables you to add any combination of the portfolio's devices into your design, allowing 100 percent code reuse when your design requirements change. For more information, visit SimpleLink™ MCU platform.

2.3.3   TLV713P-Q1 Capacitor-Free, 150-mA, Low-Dropout Regulator With Foldback Current Limit

The TLV713P-Q1 series of low-dropout (LDO) linear regulators are low quiescent current LDOs with excellent line and load transient performance and are designed for power-sensitive applications. These devices provide a typical accuracy of 1%. The TLV713P-Q1 series of devices are designed to be stable without an output capacitor. The removal of the output capacitor allows for a very small solution size. However, the TLV713P-Q1 series is also stable with any output capacitor if an output capacitor is used. The TLV713P-Q1 also provides inrush current control during device power-up and enabling. The TLV713P-Q1 device limits the input current to the defined current limit to avoid large currents from flowing from the input power source. This functionality is especially important in battery-operated devices. The TLV713P-Q1 series is available in a standard DBV package and provides an active pulldown circuit to quickly discharge output loads. The TLV713P-Q1 is suited for automotive applications because the devices are qualified for AEC-Q100 grade 1.

2.4   *System Design Theory*

The TIDA-020032 Bluetooth satellite module implements the CC2642R-Q1 device to take localization measurements from a smart phone or key fob. Using the TCAN4550-Q1 device, the CC2642R-Q1 MCU can transmit this data via SPI to the CAN controller in the TCAN4550-Q1 device and then transmit the CAN data to the central, or smart key module. Therefore, in systems that require higher bandwidth communications, the CC2642R-Q1 device can still meet their requirements.

The system power tree is very simple, consisting of the TCAN4550-Q1 internal wide input voltage 5-V out LDO and the TLV713P-Q1 device for 5 V to 3.3 V. Overall system current consumption is very low considering the CC2642R-Q1 MCU has very-low RF and MCU current consumption. Furthermore, in the sleep state, the 5-V rail can be disabled and only the TCAN4550-Q1 device will consume current, typically around 25 µA, in the sleep state. At start-up (when 12 V is applied), the TCAN4550-Q1 LDO will be brought up first, followed by the 3.3-V LDO shown in 図 2. For more information on the TCAN4550-Q1 LDO performance, see Understanding LDO Performance in the TCAN4550-Q1.

図 2. Start-up Diagram
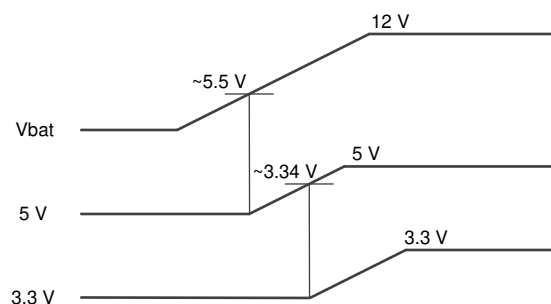
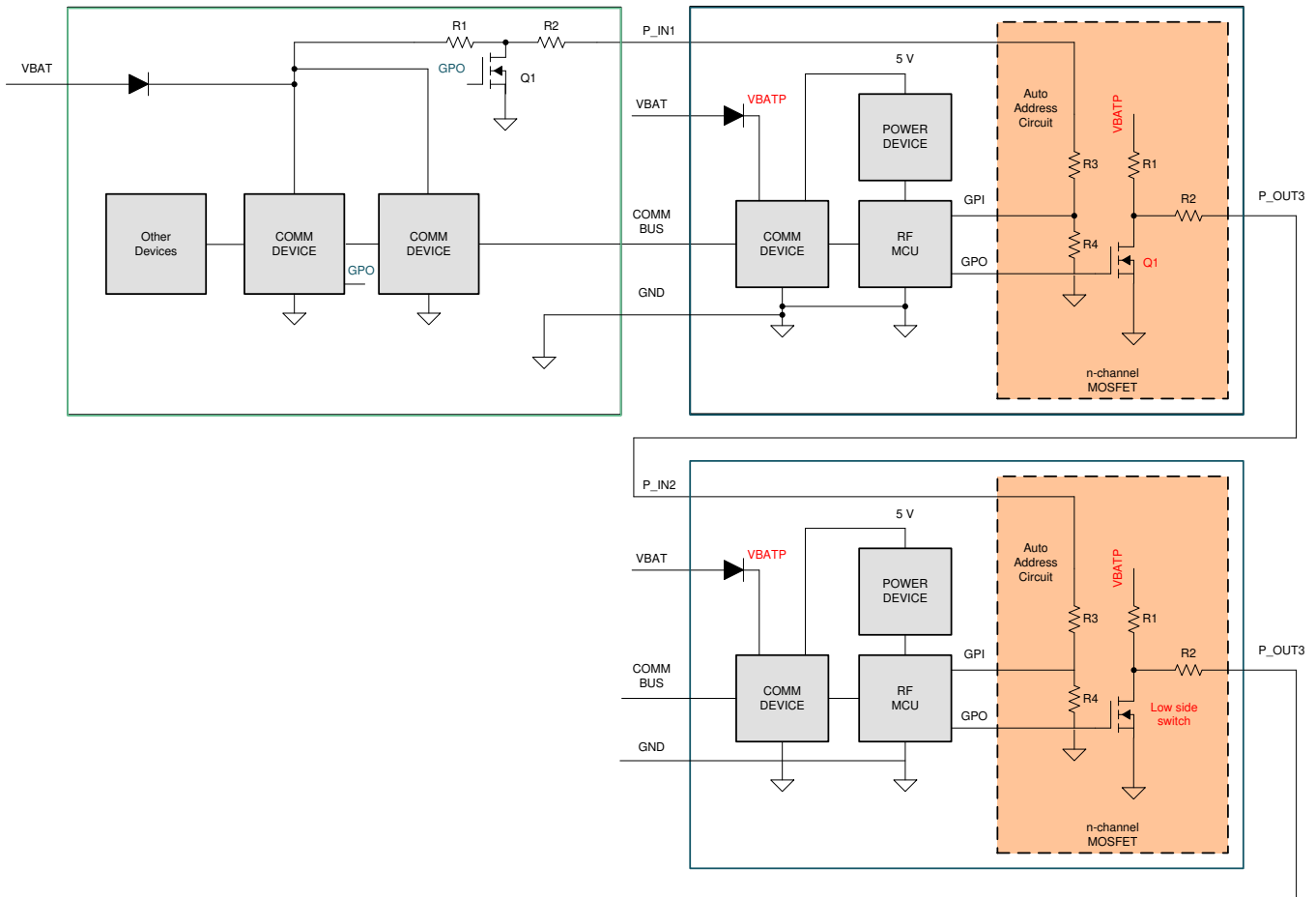### 2.4.1 Auto-addressing Scheme

The auto-addressing scheme is very simple and only requires some discrete circuitry and one cable to be daisy-chained between the central car access module and each satellite module. 図 3 shows the auto-addressing setup from a system perspective.

図 3. Auto-addressing Overview

Every satellite module is programed with the same software and ignores the CAN bus until signaled to listen via the P_IN line. To start addressing, the master module sends a VBAT level PWM signal on the P_IN1 line using the FET Q1 and begins transmitting the first CAN ID on the CAN bus. The first satellite module receives this VBAT level signal and uses a simple voltage divider to step the signal down to a reasonable IO voltage. Once this PWM signal is detected by the MCU, the satellite module will listen to the CAN bus for an address sent from the master module. Once the address is received and stored in memory, the first satellite module will send a CAN message to the master to acknowledge that it has correctly received an address.

The master module will then begin transmitting the second CAN ID on the bus. Next, the first satellite module will send a VBAT level PWM signal on P_IN2 using its own FET. Once the second satellite module receives this signal, The MCU begins listening to the CAN bus for an address from the master module. Once the address is received, the second satellite module will send the acknowledge message on the bus so the master knows to begin transmitting the 3rd CAN ID. After the acknowledge message is sent, the second satellite module sends the VBAT level PWM signal to the third satellite module and the process continues until all modules are addressed.

If there is a fault on one of the auto-addressing cables such as a short to GND or battery, the master will recognize that an error has occurred because the satellite module being addressed will never send the acknowledge CAN message to the master. Therefore, the master can specifically identify which module did not get addressed and can send an error flag to the body control module. It is important to note that in a particular vehicle model, each satellite module in a specific location of the vehicle will always be addressed in the same order depending on the wiring harness of the vehicle. This is also how the central module knows which CAN ID is associated to which satellite module location (rear bumper, passenger side, driver side, and so forth).

For auto-addressing, a simple discrete circuit is required on all satellite modules as shown in 図 4.

図 4. Auto-addressing Circuit
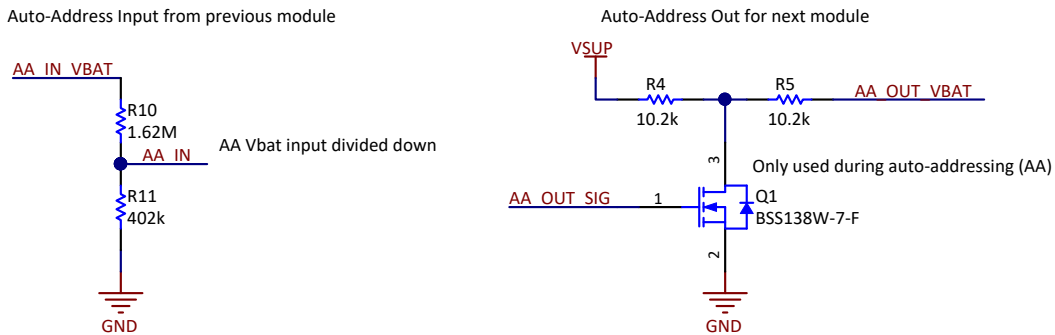
A small FET Q1 with current limiting resistors R4 and R5 are used for transmitting a 12-V PWM signal. R5 is added for limiting current for the fault condition that the AA_OUT_VBAT/P_IN wire is shorted to VBAT. For receiving the 12-V PWM signal, R10 and R11 provide a simple voltage divider to step the voltage down to a reasonable voltage for the CC2642R-Q1 GPIO pins.表 2 shows the auto-addressing circuit parameters.

表 2. Auto-addressing Circuit Parameters

PARAMETER, OR COMPONENT	MIN	TYP	MAX
R4		10.2 kΩ	
R5		10.2 kΩ	
R10		1.62 MΩ	
R11		402 kΩ	
Diode Drop		0.3 V	
VBAT	9 V	12 V	18 V
Vsup (after diode drop)	8.7 V	11.7 V	17.7 V
CC2642R-Q1 Vgpio Input High Minimum			1.17 V
Vgpio	1.71 V	2.30 V	3.48 V
Vgpio cable short to VBAT	1.79 V	2.39 V	3.58 V
CC2642R-Q1 Vgpio range	–0.3 V		3.6 V
Idivider	4 µA	6 µA	9 µA

The following equations were used to calculate the voltages and currents from the auto-addressing resistors:

$$V_{gpio} = V_{sup}\left(\frac{R_{11}}{R_{11}+R_{10}+R_4+R_5}\right) \tag{1}$$

$$V_{gpio(short\ to\ Vbat)} = V_{bat}\left(\frac{R_{11}}{R_{11}+R_{10}+R_4+R_5}\right) \tag{2}$$

$$I_{divider} = \frac{Vsup}{(R_4+R_5+R_{10}+R_{11})} \tag{3}$$

3 Hardware, Software, Testing Requirements, and Test Results

3.1 Required Hardware and Software

3.1.1 Hardware

For testing auto-addressing and CAN communications, the Vector VN1630A CAN and LIN Network Interface with CANalyzer Pro software was used to verify and monitor the CAN bus communications. To test the auto-addressing functionality, three boards were used, where one was programmed to act as the auto-addressing master and the other two were programmed as auto-addressing slaves. A harness was made using the 1778874 Phoenix Contact male connector to provide power, ground, CAN high, CAN low, auto-addressing IN, and auto-addressing out. A 12-V power supply was used to power the system. 図 5 shows the connections between the boards.

図 5. Harness Connections
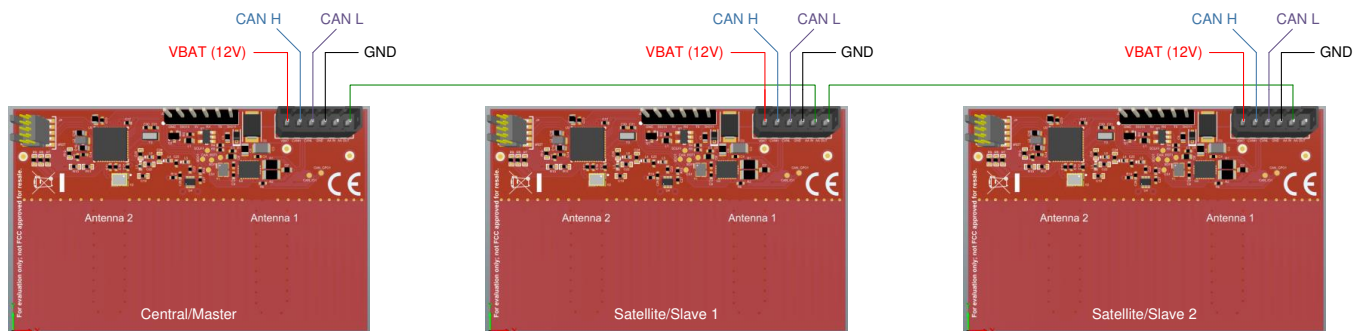
3.1.2 Software

The CC2642R-Q1 software was developed based off the SimpleLink SDK version 3.30. For analyzing CAN communications, the Vector CANalyzer Pro software was used.

3.1.2.1 *Auto-addressing Software*

For auto-addressing purposes, one board was programmed as the auto-addressing *central* or *master* (central/master) and the other two as *satellites* or *slaves* (satellites/slaves). 図 6 shows the central/master auto-addressing state diagram and 図 7 shows the satellite/slave auto-addressing state diagram.
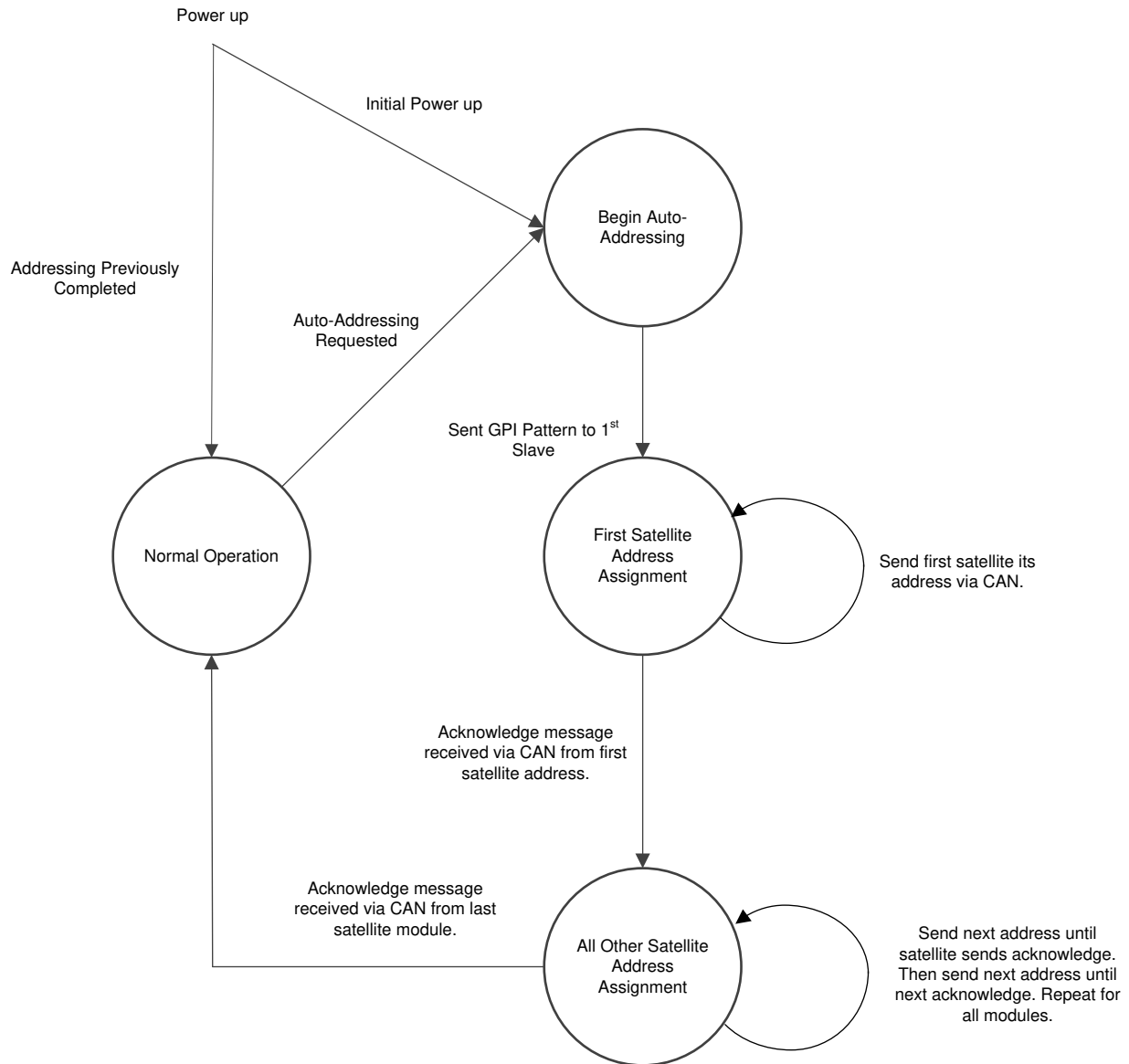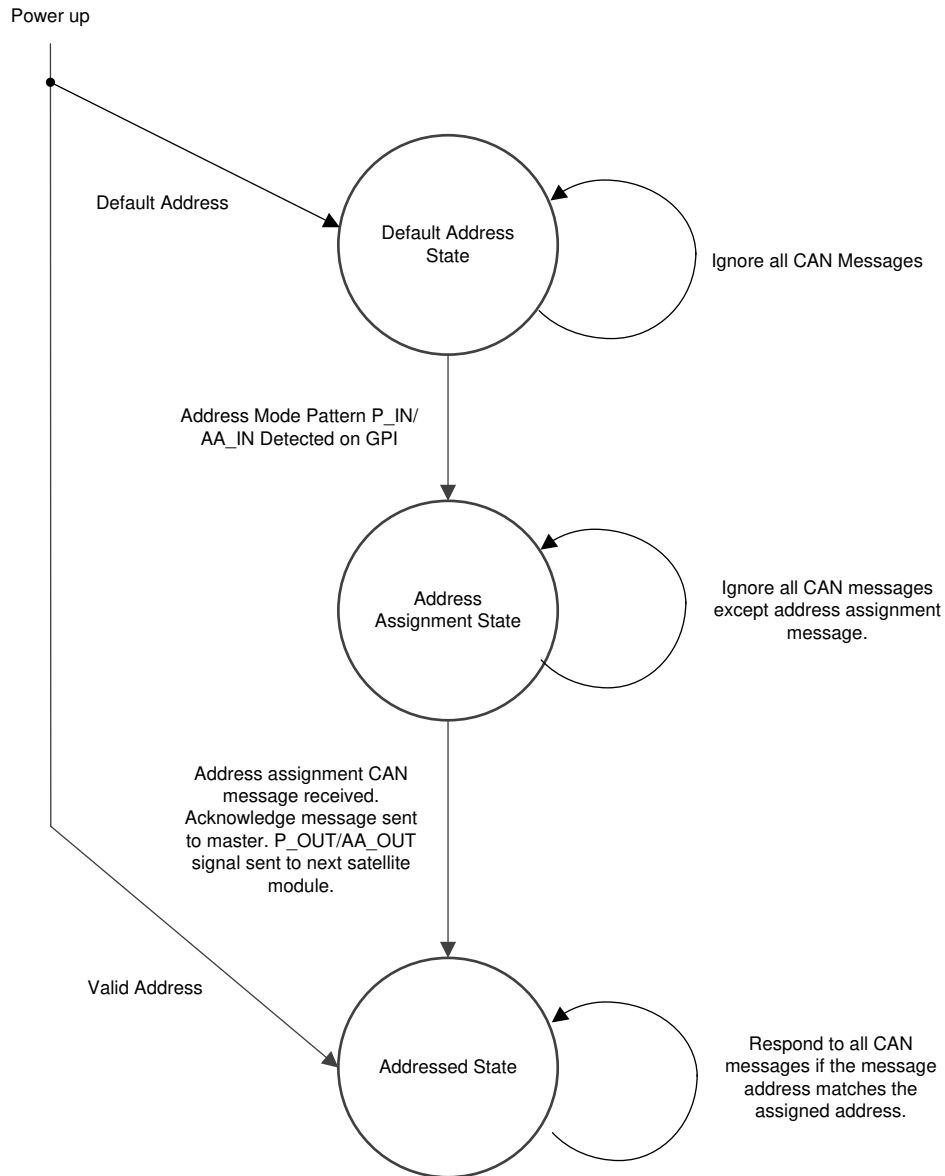
図 6. Central/Master Auto-addressing State Diagram

図 **7. Satellite/Slave Auto-addressing State Diagram**

The central/master module initiates auto-addressing after 5 to 6 seconds at first power up. Once addressing has taken place, the central/master will not initiate auto-addressing again unless it is requested from the vehicle system. All satellite modules are programmed with a default CAN ID but will ignore the CAN bus until the P_IN/AA_IN pattern is received. This ensures that only one module is listening to the CAN bus to receive a CAN ID at a time. If auto-addressing is run again due to a replacement satellite module and the satellite module being addressed has its CAN ID previously stored in memory, the module can simply send the acknowledge CAN message to the master and send the P_OUT/AA_OUT signal to the next module.

For testing, each passive module is programmed with 121 as the CAN ID. To start auto-addressing, the central/master was programmed to send a 50-Hz PWM for 200 ms and repeat that nine times every 500 ms to make sure the first slave module detects the PWM P_IN/AA_IN signal correctly. After sending the P_IN/AA_IN signal to the first satellite module, the master then begins transmitting the new CAN ID (721) for the first satellite module on the CAN bus. When the first passive stores the ID, it sends an acknowledge message back to the master (CAN ID 221) and sends the 50-Hz PWM signal for 200 ms to the next satellite module. The master begins broadcasting the next address (722) for the next satellite module on the CAN bus after receiving the acknowledge message from the first satellite module. Once the second satellite module sends the acknowledge message, the CAN bus is quiet for 5 seconds and then the system enters normal operation.

3.1.2.2   *Bluetooth® Software*

After auto-addressing occurs, the system enters the normal operating condition. Each satellite module acts as a Bluetooth passive with the central/master module programmed as the central. The key fob or phone (LaunchPad™ used for testing) acts as a peripheral , establishing a Bluetooth connection with the central module. Each satellite module tracks or monitors the connection between the key fob and the central module using our Micro BLE-Stack in connection monitoring mode, taking AoA and RSSI measurements each connection event. The central module shares the Bluetooth connection information such as access address, connection interval, channel map, and so forth, with the satellite modules (acting as passives) via the CAN bus. Once the passive modules are tracking the connection between the central and the peripheral (key), each satellite module shares the Bluetooth localization data (AoA and RSSI) via CAN to the central module. By using the connection monitor capabilities, the passives can actively track a Bluetooth connection enabling any Bluetooth data channel to be used besides using only advertising channels. This adds to overall system robustness in terms of Bluetooth localization accuracy. If some Bluetooth channels have high interference, the system can adjust and use different data channels that have less interference. To reduce power, the passive modules can be put to sleep and be awakened from the CAN bus when the central establishes a Bluetooth connection. This makes sure that only one module is needed to scan and connect with the key or phone to reduce vehicle current consumption. For more information on the roles used (central, peripheral, and passive) and information on our real time localization system demostration, see RTLS Toolbox Fundamentals in the SimpleLink Academy.

3.2 *Testing and Results*

3.2.1 Test Setup

図 8 shows the test setup.

図 8. Auto-addressing, CAN Test Setup
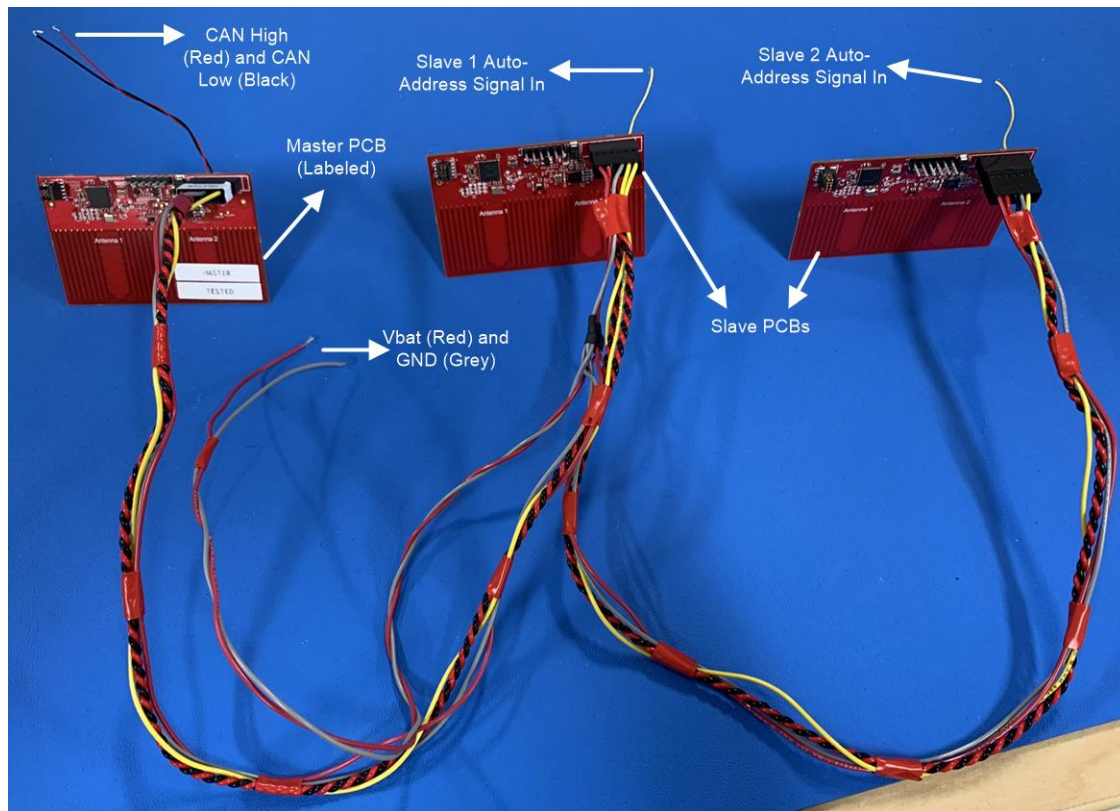
All three boards are connected via the wiring harness for power, CAN communications, and auto-addressing In/Out. Two wires were added to the master board to easily probe the CAN bus with an oscilloscope or the Vector VN1630A CAN and LIN Network Interface. The master board is programmed as the Bluetooth central and the two slave/satellite modules are programmed as passives.

3.2.2 Test Results

3.2.2.1 *System Start-up*

The first test looked at the voltage rails to make sure all were starting as expected. 図 9 shows the system start-up oscilloscope trace capture.

図 9. Start-up Scope Trace
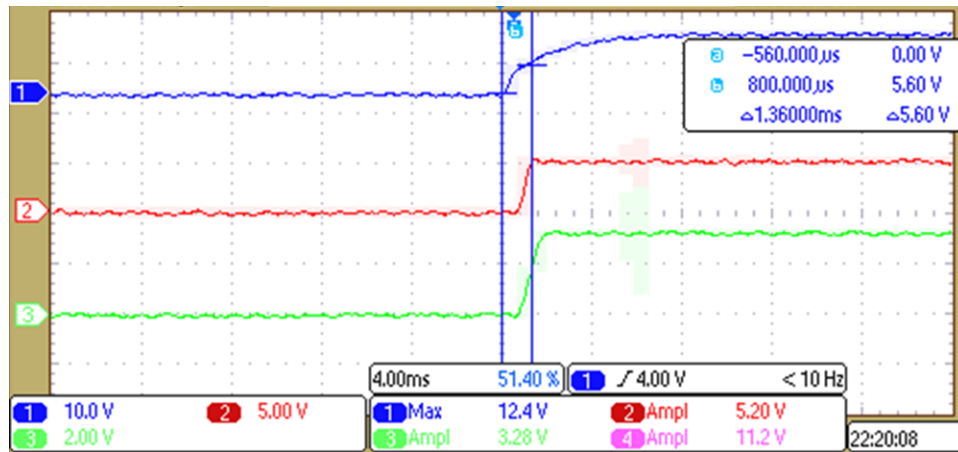
All voltage rails are stable and start-up when expected.

3.2.2.2 *Auto-addressing P_IN/AA_IN*

The first step for testing auto-addressing was to make sure that the correct auto-addressing signal (P_Out/AA_Out) was being sent correctly from the central/master to the first satellite module and from the first satellite module to the second satellite module. 図 10 and 図 11 show the P_IN/AA_IN 50-Hz PWM signals.

図 10. P_IN/AA_IN (P_Out/AA_Out from Master) Signal to First Satellite Module
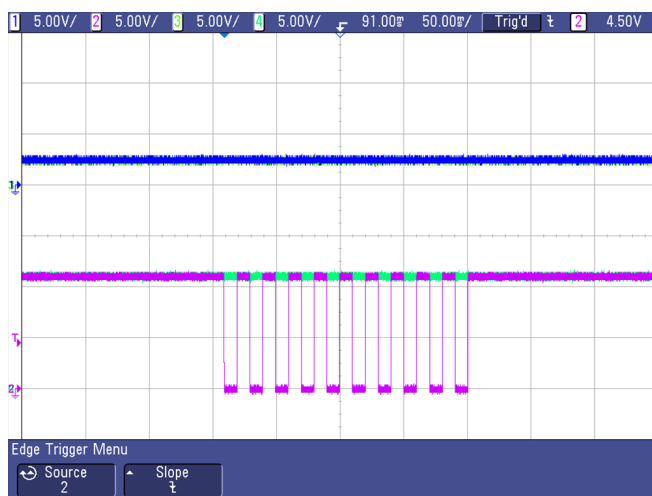
図 11. P_IN/AA_IN (P_Out/AA_Out from First Satellite) Signal to Second Satellite Module
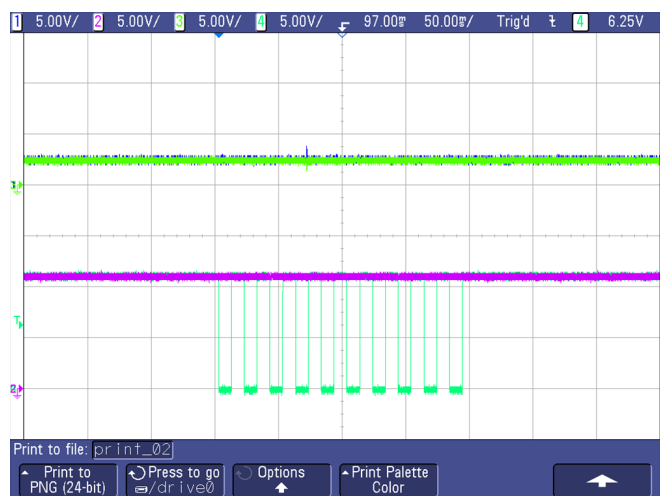
3.2.2.3 *Auto-addressing CAN Communications*

図 12 shows the full auto-addressing scheme including the auto-addressing signals (P_IN/AA_IN) to each module and the CAN bus.

図 12. Auto-addressing Scope Trace
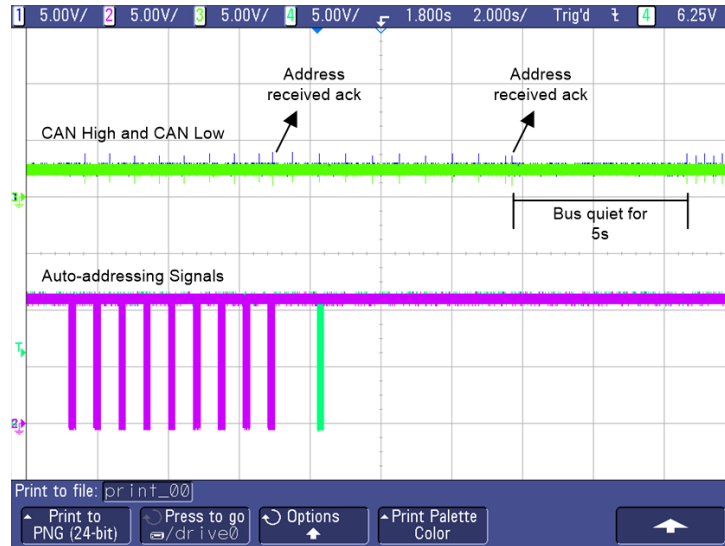
After the first auto-addressing signal (in green) is sent from the master, the master begins transmitting the first satellite models new CAN ID (0x721). After the acknowledge message, the next P_IN/AA_IN signal is sent (in pink) to the second satellite module. Again, the acknowledge message is received and the CAN bus goes quiet for 5 seconds. 図 13 shows the CAN bus trace and 図 14 shows the CAN bus log.

図 13. CAN Bus Trace
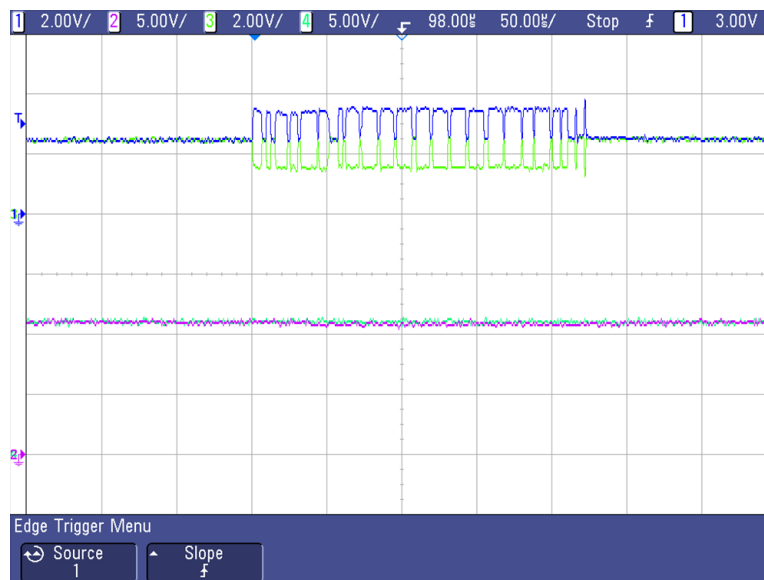
図 14. CAN Bus Log

```
                                        ID        Data
                         328.5409;RX;0x121;8;0x07;0x21;0x00;0x00;0x00;0x00;0x00;0x00;
                         329.2429;RX;0x121;8;0x07;0x21;0x00;0x00;0x00;0x00;0x00;0x00;
                         329.9449;RX;0x121;8;0x07;0x21;0x00;0x00;0x00;0x00;0x00;0x00;
Master sends 721 to      330.6469;RX;0x121;8;0x07;0x21;0x00;0x00;0x00;0x00;0x00;0x00;
ID 121 for Slave 1       331.3489;RX;0x121;8;0x07;0x21;0x00;0x00;0x00;0x00;0x00;0x00;
                         332.0509;RX;0x121;8;0x07;0x21;0x00;0x00;0x00;0x00;0x00;0x00;
                         332.7530;RX;0x121;8;0x07;0x21;0x00;0x00;0x00;0x00;0x00;0x00;
Slave 1 sends address    333.4550;RX;0x121;8;0x07;0x21;0x00;0x00;0x00;0x00;0x00;0x00;
received acknowledge     333.8379;RX;0x221;8;0x00;0x00;0x00;0x00;0x00;0x00;0x00;0x00;
message                  334.4070;RX;0x121;8;0x07;0x22;0x00;0x00;0x00;0x00;0x00;0x00;
                         335.1570;RX;0x121;8;0x07;0x22;0x00;0x00;0x00;0x00;0x00;0x00;
                         335.9070;RX;0x121;8;0x07;0x22;0x00;0x00;0x00;0x00;0x00;0x00;
Master sends 722 to      336.6570;RX;0x121;8;0x07;0x22;0x00;0x00;0x00;0x00;0x00;0x00;
ID 121 for Slave 2       337.4070;RX;0x121;8;0x07;0x22;0x00;0x00;0x00;0x00;0x00;0x00;
                         338.1570;RX;0x121;8;0x07;0x22;0x00;0x00;0x00;0x00;0x00;0x00;
                         338.9070;RX;0x121;8;0x07;0x22;0x00;0x00;0x00;0x00;0x00;0x00;
                         339.6570;RX;0x121;8;0x07;0x22;0x00;0x00;0x00;0x00;0x00;0x00;
Slave 2 sends address    340.4070;RX;0x121;8;0x07;0x22;0x00;0x00;0x00;0x00;0x00;0x00;
received acknowledge     340.5840;RX;0x221;8;0x00;0x00;0x00;0x00;0x00;0x00;0x00;0x00;
message                  345.5340;RX;0x721;8;0x01;0x01;0x00;0x00;0x00;0x00;0x00;0x00;
```

It is clear that the master sends 0x721 to ID 0x121 until the acknowledge message is received and then increments the data from 0x721 to 0x722 for the next satellite modules ID. Once the addressing is done, the first and second satellite module begin transmitting data via CAN after 5 seconds.

It is important to note that this is purely test code to show the functionality of the auto-addressing scheme. The addressing time can be greatly decreased to ensure that there is not a long wait time for the modules to be addressed.

3.2.2.4   *RF and Angle of Arrival Performance*

For test results on the TIDA-020032 antenna performance and angle of arrival (AoA) accuracy, see the *Bluetooth Angle of Arrival (AoA) Antenna Design* application note, specifically the *Dipole Antenna Array* and *Calculating AoA From IQ Measurements* sections.

4 Design Files

4.1 Schematics

To download the schematics, see the design files at TIDA-020032.

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-020032.

4.3 PCB Layout Recommendations

4.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-020032.

4.4 Altium Project

To download the Altium Designer® project files, see the design files at TIDA-020032.

4.5 Gerber Files

To download the Gerber files, see the design files at TIDA-020032.

4.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-020032.

5 Software Files

To download the software files, see the design files at TIDA-020032.

6 Related Documentation

1. Texas Instruments, *CC2642R-Q1 SimpleLink™ Bluetooth® 5.1 Low Energy Wireless MCU*
2. Texas Instruments, *TCAN4550-Q1 Automotive Control Area Network Flexible Data Rate (CAN FD) Controller With Integrated Transceiver Data Sheet*
3. Texas Instruments, *TLV713P-Q1 Capacitor-Free, 150-mA, Low-Dropout Regulator With Foldback Current Limit for Portable Devices Data Sheet*
4. Texas Instruments, *Bluetooth® Angle of Arrival (AoA) Antenna Design*
5. Texas Instruments, *CC13xx/CC26xx Hardware Configuration and PCB Design Considerations*
6. Texas Instruments, *Understanding LDO Performance in the TCAN4550-Q1*

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7   About the Author (Optional)

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