Texas Instruments

Application Report

SLOA167–May 2012

TRF7960A RFID Multiplexer Example System

Josh Wyatt *Embedded RF Applications/Systems*

ABSTRACT

The purpose of this application report is to describe in concise detail the 16-channel high-frequency (HF) (13.56 MHz) RFID Reader System (based on the TRF7960A RFID IC) designed by Texas Instruments for customer use. The system hardware is comprised of one (1) RFID controller board and four (4) antenna boards, along with their associated cables (power, RF, GPIO, and host communication). The system firmware resides on Texas Instruments MSP430F2370 and supports the ISO/IEC15693 protocol in addition to communication with a host. The host software resides on the controller, and the host command details are also described in this document for reference during development and integration.

Contents

List of Figures

1 System Theory of Operation and Concepts

The purpose of the system is to read individual RFID transponders (or tags) in up to sixteen different locations. This system goal is accomplished by using one RFID reader controller board and four identical antenna boards (with four antennas on each board), each of which is cascaded. See Figure 1 for the main system block diagram.

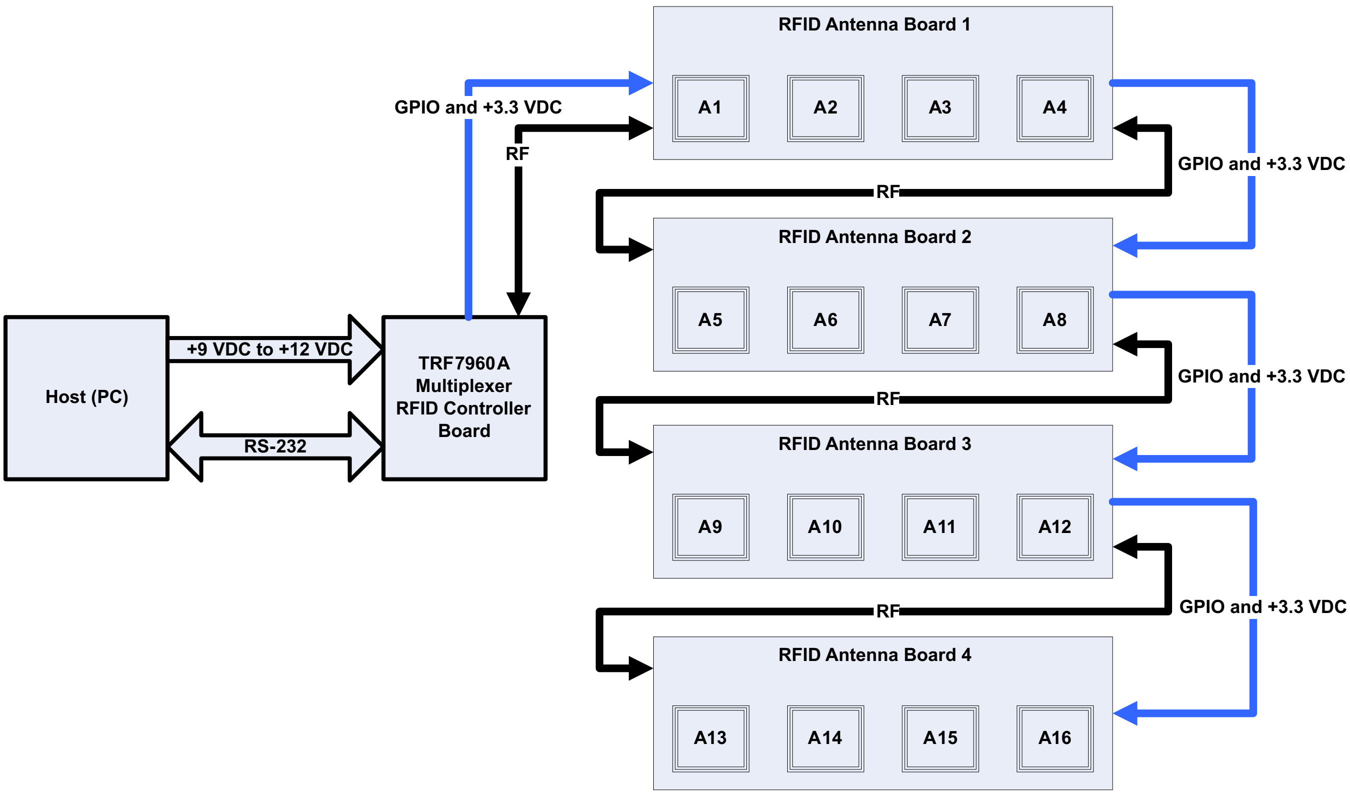


Figure 1. TRF7960A Multiplexer RFID System Block Diagram

The system design shown above in Figure 1 was done to the project requirements for one antenna board design (with four addressable antennas onboard) and a simplified wired connectivity scheme which allows for four of these identical antenna boards to be connected to each other and the RFID controller board with the absolute least amount of cabling physically possible.

The system works by first initializing the RFID IC (TRF7960A) upon power up. Antenna 1 (on Antenna Board 1) is selected by default. The host would then issue a series of commands to:

1. Turn on the RFID IC transmitter
2. Issue a single slot ISO/IEC15693 Inventory Command
3. Receive a response from the transponder in the field (if one was present)
4. Turn off the transmitter
5. Switch to the next antenna and then repeat steps 1-5 until all sixteen antennas in the system are addressed and the transponders in their respective fields are read.

These steps are described in much greater detail later in the document and a flow chart is also provided in this document to clearly show the example application process.

2 System Hardware

2.1 RFID Controller Board

The RFID controller board main components consist of one TRF7960A RFID IC, one MSP430F2370 microcontroller, one SN65176B RS-485 transceiver, two MAX3232E RS-232 drivers/receivers, and one REG117-5 (+5 VDC, 800 mA) linear regulator. The MSP430 holds the firmware that is required to communicate with the host via its UART channel and to initialize and communicate with the TRF7960A via its SPI channel. The MSP430 firmware also takes properly formatted commands from the host and controls the RF switches located on the antenna boards via its GPIO ports, then reports the results back to the host via the UART channel. The linear regulator takes the +9 VDC to +12 VDC from the power supply and down converts this voltage to +5 VDC for the TRF7960A to operate at full power. The TRF7960A provides +3.3 VDC (via VDD_X) and a 6.78-MHz system clock (via SYS_CLK) to the MSP430 for high-speed operation. The TRF7960A also provides +3.3 VDC to the RF switches via VDD_X. One of the RS-232 drivers/receivers is for direct host (that is, PC) RS-232 communications with the MSP430 (UART side). The second RS-232 driver/receiver is connected to the first RS-232 driver transceiver (DB9 side) and the RS-485 transceiver to create a simple RS-485 to RS-232 converter that simplifies the connection to the MSP430F2370. Minor components consist of one 18-position Micro Mate-N-Lok connector, one RJ-45 connector, one SMA connector, one DB9 connector (optionally populated for TI testing), a power connector, along with the required passive and active components necessary for proper power supply filtering, impedance matching, and charge pump voltage generation of the circuits on the board. A full schematic and layout of the RFID controller board is shown in Appendix A. Data sheets for the components that are used on this board can be found in References.

2.2 RFID Antenna Board

The RFID antenna board main components consist of four PCB trace loop antennas (tuned for 13.56 MHz, Q < 20), one Peregrine Semiconductor PE42440 SP4T RF switch, and one Peregrine Semiconductor PE4257 SPDT RF switch. The minor components on the board are two 18-position Micro Mate-N-Lok (for GPIO and +3.3 VDC in and GPIO and +3.3 VDC feedthrough to next antenna board), and two SMA connectors (for RF in and RF out to next antenna board). There are four of these boards (total) in the system. A full schematic and layout of the RFID antenna board is shown in Appendix A. Data sheets for the components that are used on this board can be found in References.

2.3 System Cables and Connections

2.3.1 Host Communication

Host communication is achieved via either RS-232 or RS-485. The RS232 cable should be pinned out according to industry standard for DCE to DTE (RS-232 DB9 pins 2, 3 and 5). The RS-485 cable is a custom nonstandard implementation using CAT5 cable (uses TX/RX_1, TX/RX_2 and RTS).

2.3.2 Power Cable

Custom power cable is required for delivering +12 VDC to RFID controller board.

2.3.3 RF Cables

Industry standard 50-Ω coaxial cables with SMA plugs on both ends are required for this system. RG-316 is recommended cable type.

2.3.4 GPIO and +3.3 VDC Cables

GPIO cables to be used in this system are terminated into 18-position Micro Mate-N-Lok connectors. The wires in these cables are terminated with receptacle contacts for mating to Micro Mate-N-Lok board header.

2.4 ISO/IEC15693 Transponder

The requirement for this system was for ISO15693 compliant transponder with 2048 or 256 bits of user memory. The Texas Instruments transponder and inlay offerings fit exactly this requirement and are what is used in this application. Data sheets for these components can be found in References.

3 System Firmware

MSP430F2370 firmware used for this project is based on TRF7960A EVM firmware (see References). This firmware project that is provided with this application report (now named _MUX_TRF7960A) has been modified for use in this application to support extended GPIO port control of up to 16 antennas and exclude (but not remove support for) the other ISO protocols. The firmware has also been modified to return the unique identifier (UID) of the transponder as one would read it (versus the way it is returned over the air). For example, the transponder UID is returned over the air LSByte first, so then the firmware file uart.c was modified to manipulate the returned UID so that any host controller software is relieved of this task. (that is, the UID is now returned to the host as E00781BCC1912470 rather than 702491C1BC8107E0).

3.1 MSP430F2370 Setup

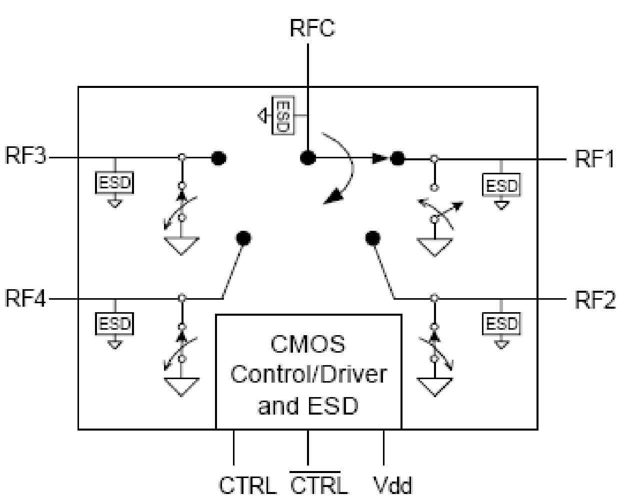
The MSP430F2370 firmware initializes the TRF7960A RFID Reader IC and configures it for ISO/IEC15693 operation using the default settings for the IC (full power out (+23 dBm), high transponder data rate (26.4 kbps), and 1 of 4 data coding).

3.2 ISO/IEC15693 Support

The MSP430F2370 firmware supports all ISO15693 commands currently known to be relevant to this project and allows for all mandatory and optional commands listed in the standard that do not apply to this project currently, but could be used later.

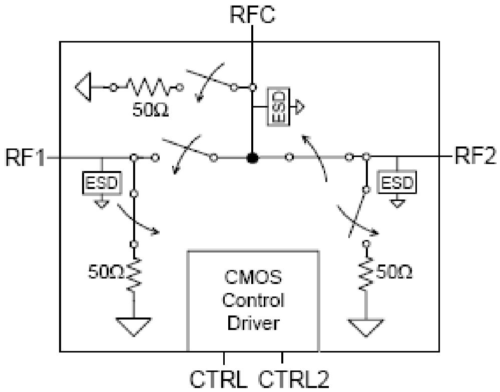
3.3 GPIO Control

The firmware provides support for the hardware to control up to 16 antennas via the GPIO available on the MSP430F2370 directly driving the control lines on the PE42440 and PE4257 RF switch ICs used on the antenna boards. One PE42440 switch and one PE4257 switch are mounted on each antenna board to accommodate the four PCB trace antennas and provide for output to next antenna board. The PE42440 and PE4257 switch functional diagrams and truth tables are shown in Figure 2 and Figure 3, respectively, for reference. Table 1 is the combined (PE42440 + PE4257, as connected on each antenna board) truth table. Figure 4 shows the block diagram of this circuit arrangement. The details about the switches and the circuit arrangement are important to understand before looking at entire system arrangement.



Path	V2	V1
RFC – RF1	0	0
RFC – RF2	1	0
RFC – RF3	0	1
RFC – RF4	1	1

Figure 2. PE42440 Functional Diagram and Truth Table



CTRL1	CTRL2	RFC – RF1	RFC – RF2
Low	Low	OFF	OFF
Low	High	OFF	ON
High	Low	ON	OFF
High	High	N/A[1]	N/A[1]

Figure 3. PE4257 Functional Diagram and Truth Table

Table 1. TRF7960A Multiplexer Antenna Truth Table (One Board)

RF Switches Used	Channels Used	PCB Antenna and Switch Port Selected	Notes
PE42440	RFC → RF1	1	Default on power up
PE42440	RFC → RF2	2	
PE42440	RFC → RF4	3	
PE42440	RFC → RF3	To PE4257 RFC	For antenna 4 or RF OUT
PE42440 + PE4257	RFC → RF2 (PE4257)	4	
PE42440 + PE4257	RFC → RF1 (PE4257)	RF OUT	To next antenna board

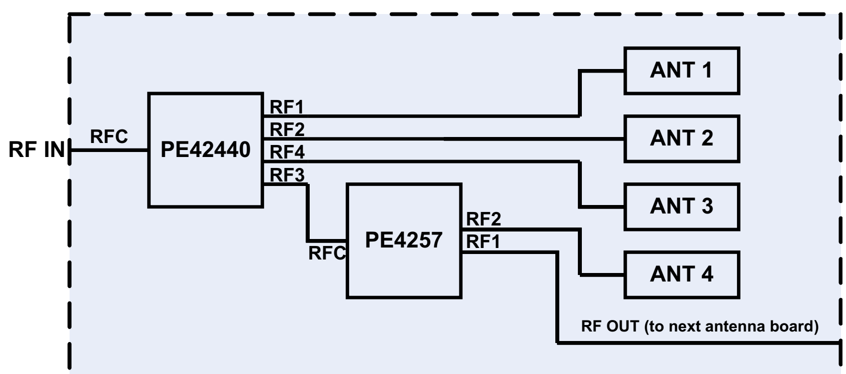


Figure 4. PE42440 and PE4257 Antenna Circuit Arrangement Detail Diagram

The full switch logic matrix is shown in Table 2 and can be viewed in the firmware by opening the msp430f23x0.h file where they are defined and the host.c file where they are called (using 0xC0:0xCF and 0xD0:0xDF host commands).

Table 2. MSP430 GPIO Switch Logic Matrix (Full System)

ANTENNA BOARD	1				2				3				4		
GPIO USED	**P4.6**	**P4.5**	**P4.3**	**P4.4**	**P4.2**	**P4.1**	**P3.7**	**P4.0**	**P1.7**	**P1.6**	**P1.4**	**P1.5**	**P1.3**	**P1.2**	**P1.1**
ANTENNA	**V2**	**V1**	**CTRL 1**	**CTRL 2**	**V2**	**V1**	**CTRL 1**	**CTRL 2**	**V2**	**V1**	**CTRL 1**	**CTRL 2**	**V2**	**V1**	**CTRL 1**
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
5	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
6	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0
7	0	1	0	1	1	1	0	0	0	0	0	0	0	0	0
8	0	1	0	1	0	1	1	0	0	0	0	0	0	0	0
9	0	1	0	1	0	1	0	1	0	0	0	0	0	0	0
10	0	1	0	1	0	1	0	1	1	0	0	0	0	0	0
11	0	1	0	1	0	1	0	1	1	1	0	0	0	0	0
12	0	1	0	1	0	1	0	1	0	1	1	0	0	0	0
13	0	1	0	1	0	1	0	1	0	1	0	1	0	0	0
14	0	1	0	1	0	1	0	1	0	1	0	1	1	0	0
15	0	1	0	1	0	1	0	1	0	1	0	1	1	1	0
16	0	1	0	1	0	1	0	1	0	1	0	1	0	1	1

In Table 2, the green shaded blocks follow the 13.56-MHz signal path through the system and show the antenna selected as well as the GPIO used in the process. Table 3 shows the Host Command Codes that are used to turn the antennas on or off. The complete Host Command format is described in Section 4.

Table 3. Host Command Codes for Antenna Selection

Antenna Number	Command Codes (on / off)
1	N/A (DEFAULT ANT)
2	0xC0 / 0xC1
3	0xC2 / 0xC3
4	0xC4 / 0xC5
5	0xC6 / 0xC7
6	0xC8 / 0xC9
7	0xCA / 0xCB
8	0xCC / 0xCD
9	0xCE / 0xCF
10	0xD0 / 0xD1
11	0xD2 / 0xD3
12	0xD4 / 0xD5
13	0xD6 / 0xD7
14	0xD8 / 0xD9
15	0xDA / 0xDB
16	0xDC / 0xDD

4 System Host Commands

The System Host Commands provide the method by which the host controller communicates with the RFID controller board. The host controller in the system (that is, the PC) sends specifically formatted commands as defined in the following section to accomplish a task. The MSP430F2370 firmware on the RFID controller board echoes back the command sent along with any data that is relevant to that command (for example, the Unique ID with RSSI value or transponder block data).

4.1 Host Commands Structure Definition

The Host Commands have a general protocol structure that is shown in Figure 5.

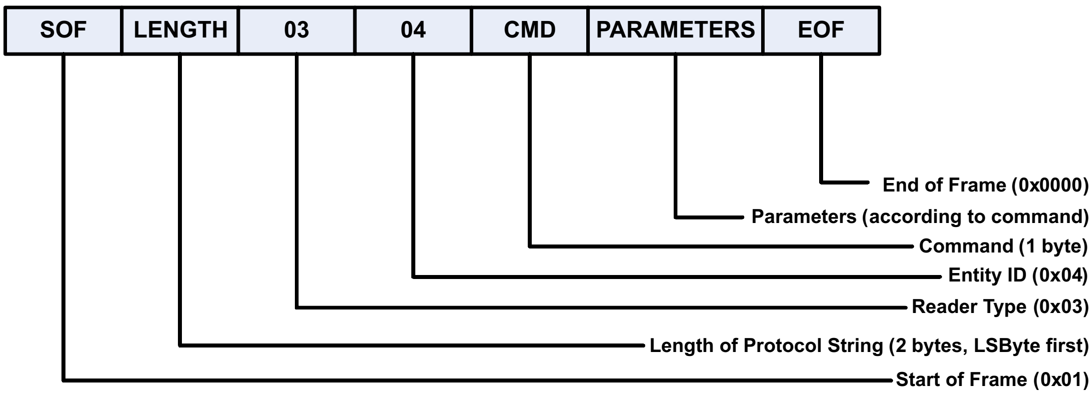


Figure 5. RFID Controller Host Protocol General Format

For simplification purposes and for brevity of this system document, the Host Commands are fixed examples and should be used as explained in the following subsections. For further reading on the other Host Commands possible with the ISO/IEC15693 protocol supported by this firmware, see the *TRF7960 Evaluation Module ISO 15693 Host Commands* (SLOA141).

4.2 Initiate Communication With RFID Controller Board

To initiate communication with the RFID controller board firmware from the host terminal, the following command should be sent:

0108000304**FF**0000

Where **FF** is the command, with no parameters being sent.

The controller board echoes this command string, followed by text string in ASCII of:

TRF7960A_MUX_RFID

****COM Port found! ****

4.3 Set Protocol

The set protocol command is issued to configure the TRF7960A reader IC for operation with the ISO/IEC15693 standard based transponders. In the ISO/IEC15693 standard, there are multiple settings for this allowed. For best performance, the command string example used here in this document will be for TRF7960A operating with +5VDC, full power out (+23dBm), 100% modulation depth on the downlink with ISO15693 high transponder data rate (26.48kbps) with single subcarrier transponder response and 1 of 4 data coding used/expected back on the uplink. This is a register write request to the TRF7960A Chip Status Control and the ISO Control Registers. (Registers 0x00 and 0x01) The command string example used here to be sent from a Host Terminal would be:

010C000304**10****00210102**0000

Where **10** is the command, and **00210102** are the parameters.

This string echoes from the RFID Controller Board, followed by the ASCII string:

Register Write Request

4.4 Inventory Command

The Inventory Command is used by the TRF7960A to retrieve the unique ID (UID) from the transponder. The command string example used here (Single Slot Inventory) to be sent from a Host Terminal would be:

010B000304**14260100**0000

Where **10** is the command, and **002100** are the parameters.

This string echoes from the RFID Controller Board, followed by the ASCII string:

ISO 15693 Inventory request

And then the UID is sent back to the host along with a received signal strength indicator (RSSI) value, which indicates relatively how close the transponder is to the energizing antenna:

[UID,RSSI]

For example, [E00781BCC1912470,77]

Where E00781BCC1912470 is the UID (for this transponder in the field), and 77 is the RSSI value (as the transponder is very close to the antenna. The RSSI values can range from 0x40 to 0x7F.

4.5 Turn Off RF Transmitter

Turning off the transmitter before switching channels is a recommended practice in any RF application as it reduces the amount of stress on the switch or relay in a given system, providing for a potentially longer service life. This is a register write request to the TRF7960A Chip Status Control Register (Register 0x00) and more specifically a toggle of bit 5 in that register. The command string example used here to be sent from a Host Terminal would be:

010A000304**100001**0000

Where **10** is the command, and **0001** are the parameters.

This string echoes from the RFID Controller Board, followed by the ASCII string:

Register Write Request

4.6 Switch Antenna

Switching antennas is the main feature highlight of this system. The MSP430 firmware has been modified (as explained in previously in this document) to allow the host to choose any of the sixteen antennas in the system by using the host commands shown in Table 3 and outlined in Table 2. The command string example used here to be sent from a Host Terminal would be:

0108000304**C0**0000

Where **C0** is the command, with no parameters being sent.

This string echoes from the RFID Controller Board, followed by the ASCII string:

Switch 2 On

The other Switch Antenna commands are shown in Table 3 and have similar messaging in ASCII corresponding to the operation performed. For example, sending 0108000304**C1**0000 results in that string being echoed back, followed by the ASCII string: Switch 2 Off.

4.7 Turn On RF Transmitter

The transmitter of the TRF7960A RFID IC must be turned on prior to issuing any commands to transponders in the field. Otherwise, they will not be energized and will not respond. This is a register write request to the TRF7960A Chip Status Control Register (0x00) and more specifically a toggle of bit 5 in that register. The command string example used here to be sent from a Host Terminal would be:

010A000304**100021**0000

Where **10** is the command, and **0021** are the parameters.

This string echoes from the RFID Controller Board, followed by the ASCII string:

Register Write Request

4.8 Read Transponder Data Blocks

The Read Single Block Command is used by the TRF7960A to retrieve the transponder memory data preprogrammed onto the transponder. The command string example used here to be sent from a Host Terminal would be:

010B000304**18****022000**0000

Where **18** is the command, and **022000** are the parameters. 02 are the request flags for the command, 20 is the Read Single Block command, and 00 is the block # to be read (in this example) (block range with this transponder is from 0x00 to 0x3F)

This string echoes from the RFID Controller Board and, if the read was successful, it is followed by:

[0078563412]

Where 78563412 is the transponder memory block data (in this example), note that the data is returned MSByte first and the 00 in the return indicates no error. The data in this block could be programmed to any value between 0x00000000 to 0xFFFFFFFF.

4.9 Write Transponder Data Block

The Write Single Block Command is used by the TRF7960A to write data (program) to the transponder memory. The command string example used here to be sent from a Host Terminal would be:

010F000304**18****42210078563412**0000

Where, **18** is the command, and **42210078563412** are the parameters. 42 are the request flags for the write operation, 21 is the Write Single Block command, and 00 is the block to be written (in this example). 78563412 is the data block to be written (in this example). User memory (data blocks) range on the transponder being used is from 0x00 to 0x3F. Data can be any value desired in hexadecimal format (from 0x00000000 to 0xFFFFFFFF). Note this block data is sent MSByte first.

This string echoes from the RFID Controller Board, and if write was successful, it will be followed by the ASCII string:

Request mode

And then the Error Flags are returned in the following manner:

[00], where 0x00 equals no error (write operation was successful)

Other possible responses here are:

[0103] = Option not supported (option flag not set, should be set for TI tags (0x42)

[010F] = Unknown error

[0110] = Block not available (memory block range is 0x00 to 0x3F)

[0113] = Programming was not successful (memory block could be locked or too far away)

4.10 Example Application Flow Chart

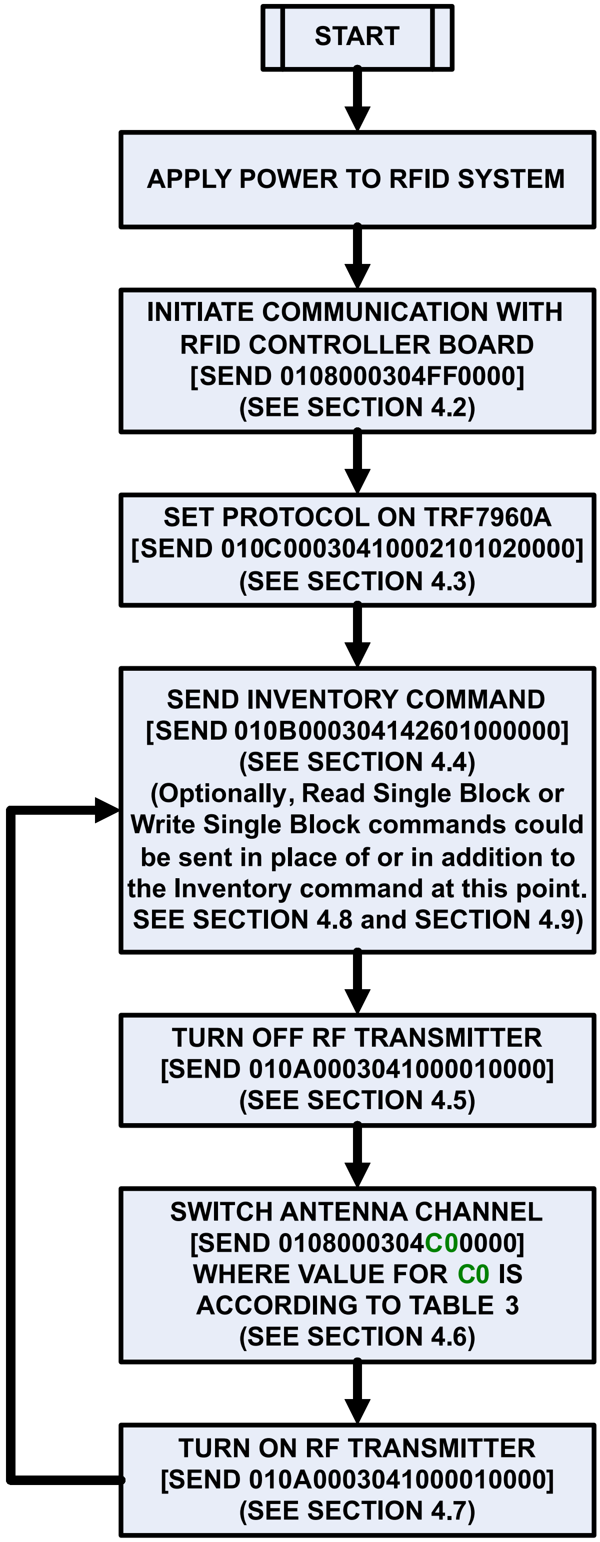


Figure 6. Example Application Flow Chart

5 Performance Measurements and Testing

In antenna multiplexing and switching applications such as this example, close attention should always be paid to the potential of RF signal loss and crosstalk between channels. The switches that were chosen for this application have a 50-Ω characteristic impedance, are made for the frequency of operation (in this case 13.56 MHz), are rated for more than the maximum output power level possible from the transmitter (in this case +23 dBm (200 mW)), and have good isolation between channels.

In this reference design, the Peregrine Semiconductor devices PE42440 and PE4257 were used and meet these criteria. These were lab tested with TRF7960A EVM, PE42440, and PE4257 EVMs. Loss measured was within expected levels as the PE42440 and PE4257 data sheets indicate that 0.45-dBm and 0.7-dBm loss should be expected from these parts, respectively. RF-HDT-DVBB read range was also checked here with the different power output levels with same antenna 6.5-cm diameter coils. Read range was minimally affected, where observed read range varied approximately 0.25 cm. Figure 7, Figure 8, and Figure 9 show the spectrum analyzer captures for the bench-top hand-wired prototype.

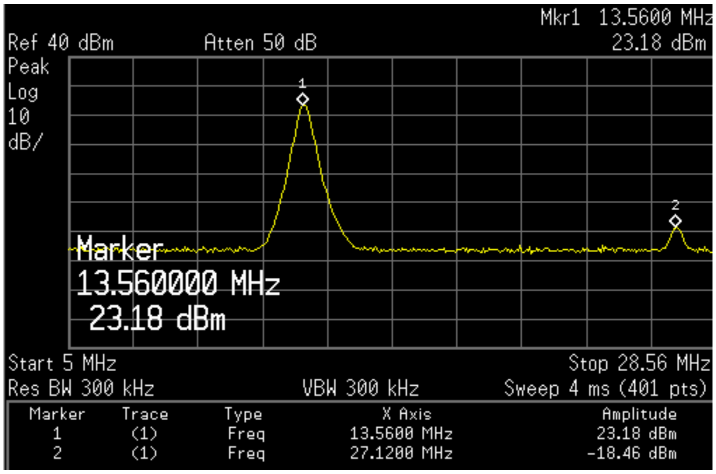


Figure 7. TRF7960A Out (Approximately +23 dBm)

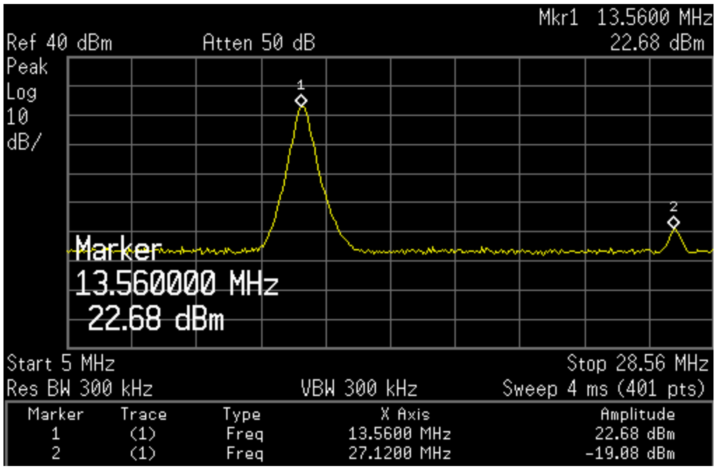


Figure 8. TRF7960A to PE42440 Out (Approximately 0.5-dBm Loss)

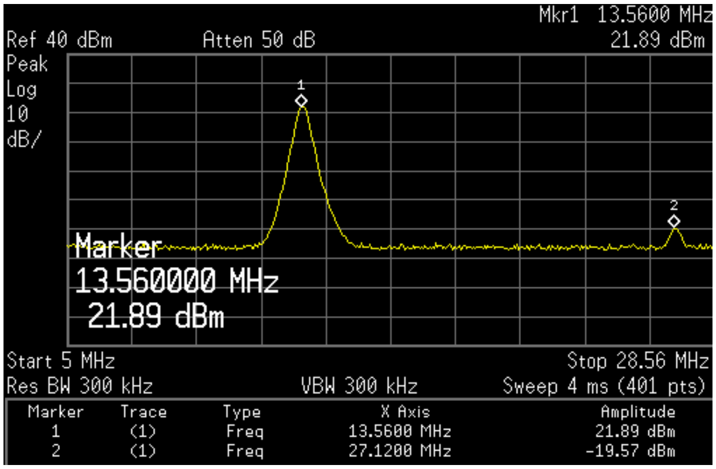


Figure 9. TRF7960A to PE42440 to PE4257 out (Approximately 0.8-dBm Loss)

6 References

1. MSP430F2370 data sheet (SLAS518)
2. TRF7960A data sheet (SLOS732)
3. TRF7960A MSP430F2370 Base Firmware Example (SLOC251)
4. TRF7960 Evaluation Module ISO 15693 Host Commands (SLOA141)
5. MAX3232E RS-232 Line Driver/Receiver data sheet (SLLS664)
6. SN75176B RS-485 Transceiver data sheet (SLLS101)
7. REG1117-5 +5VDC 800mA Linear Regulator data sheet (SBVS001)
8. PE42440 data sheet (http://www.psemi.com/content/products/switches/PE42440.html)
9. PE4257 data sheet (http://www.psemi.com/pdf/datasheets/pe4257ds.pdf)
10. RF-HDT-DVBB 2kbit ISO15693 Encapsulated Transponder data sheet (SCBS857)
11. ISO/IEC15693-2, -3 Standard (http://www.ieee.org/)

Schematics

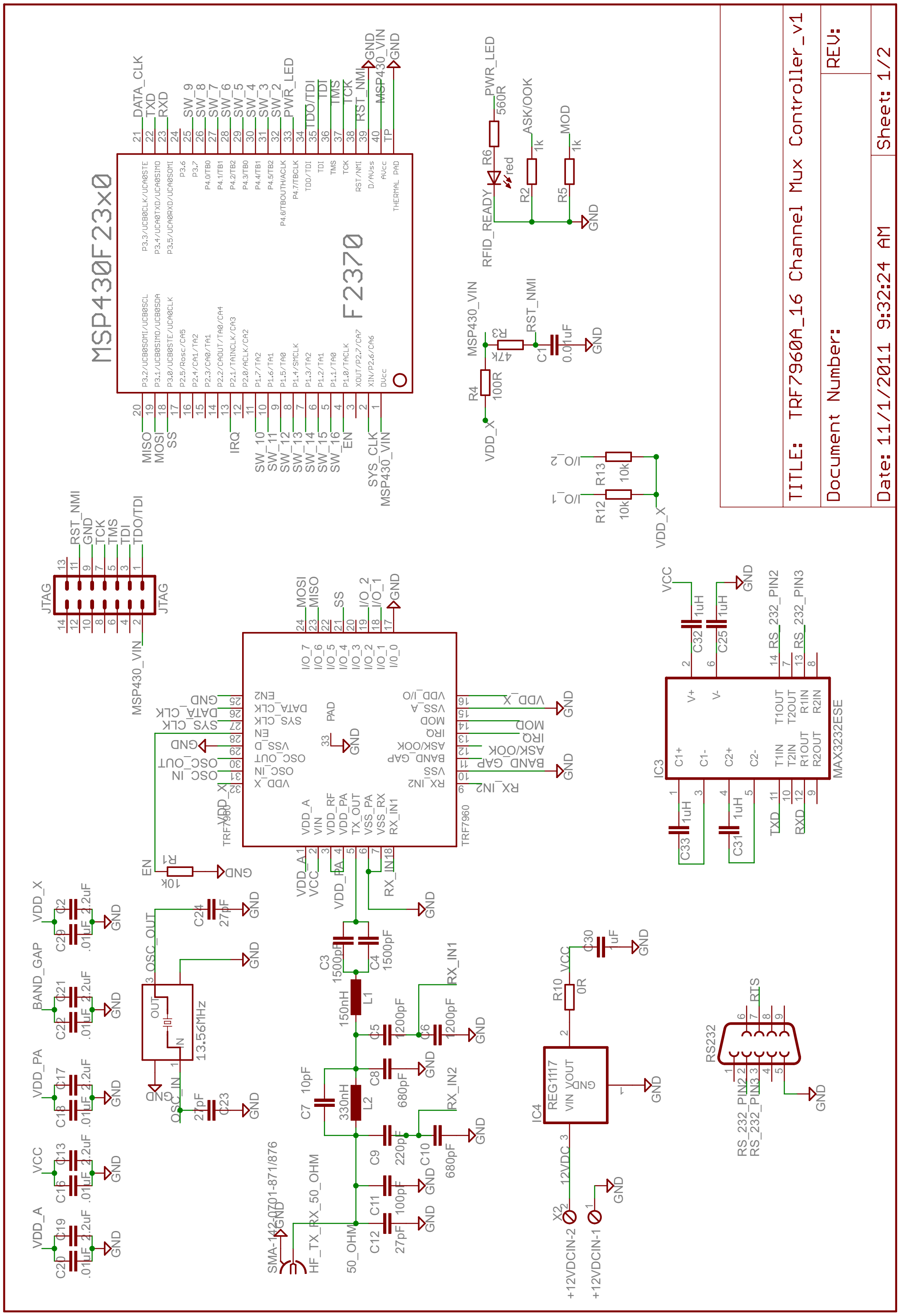


Figure 10. RFID Controller Board (1 of 2)

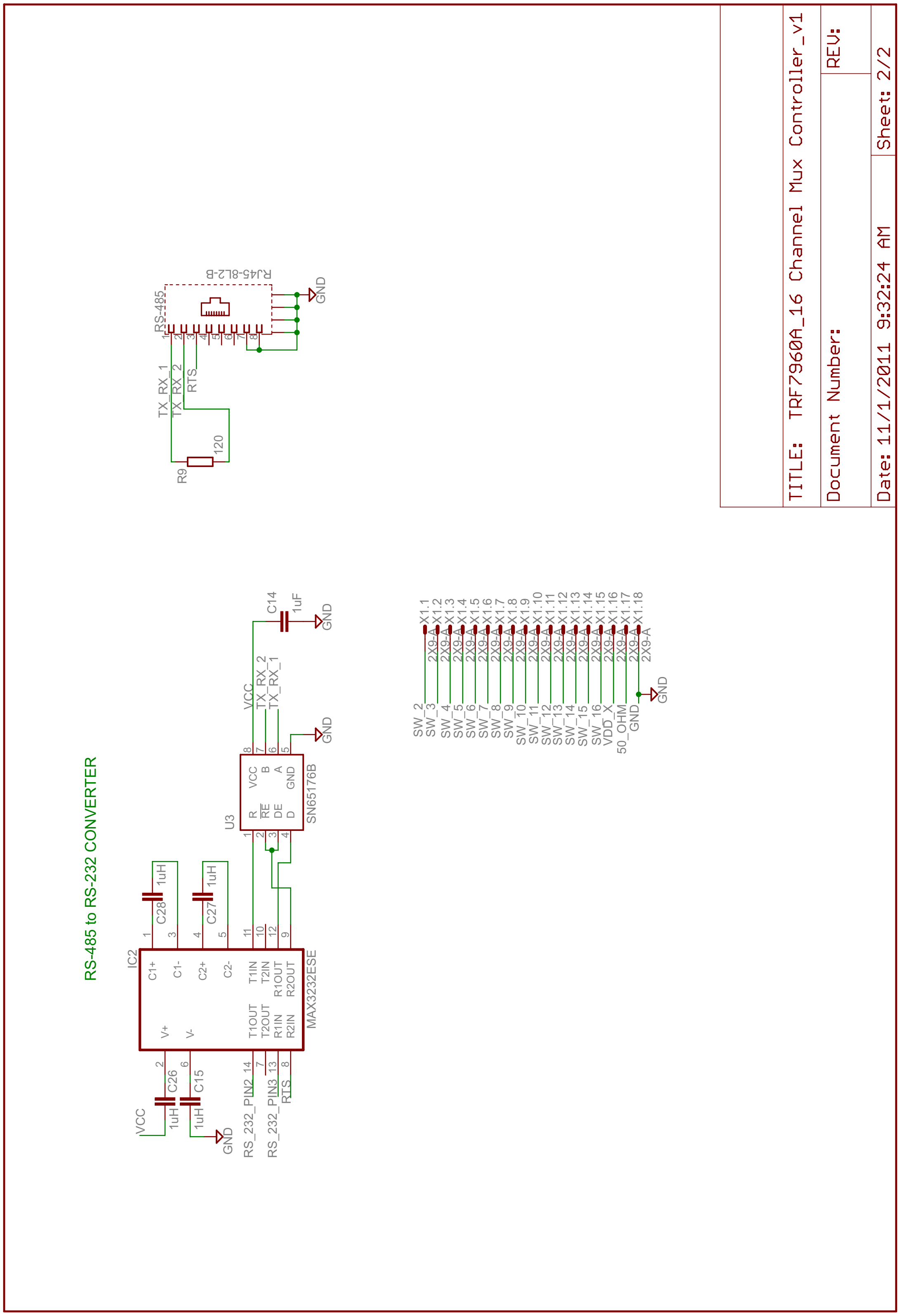


Figure 11. RFID Controller Board (2 of 2)

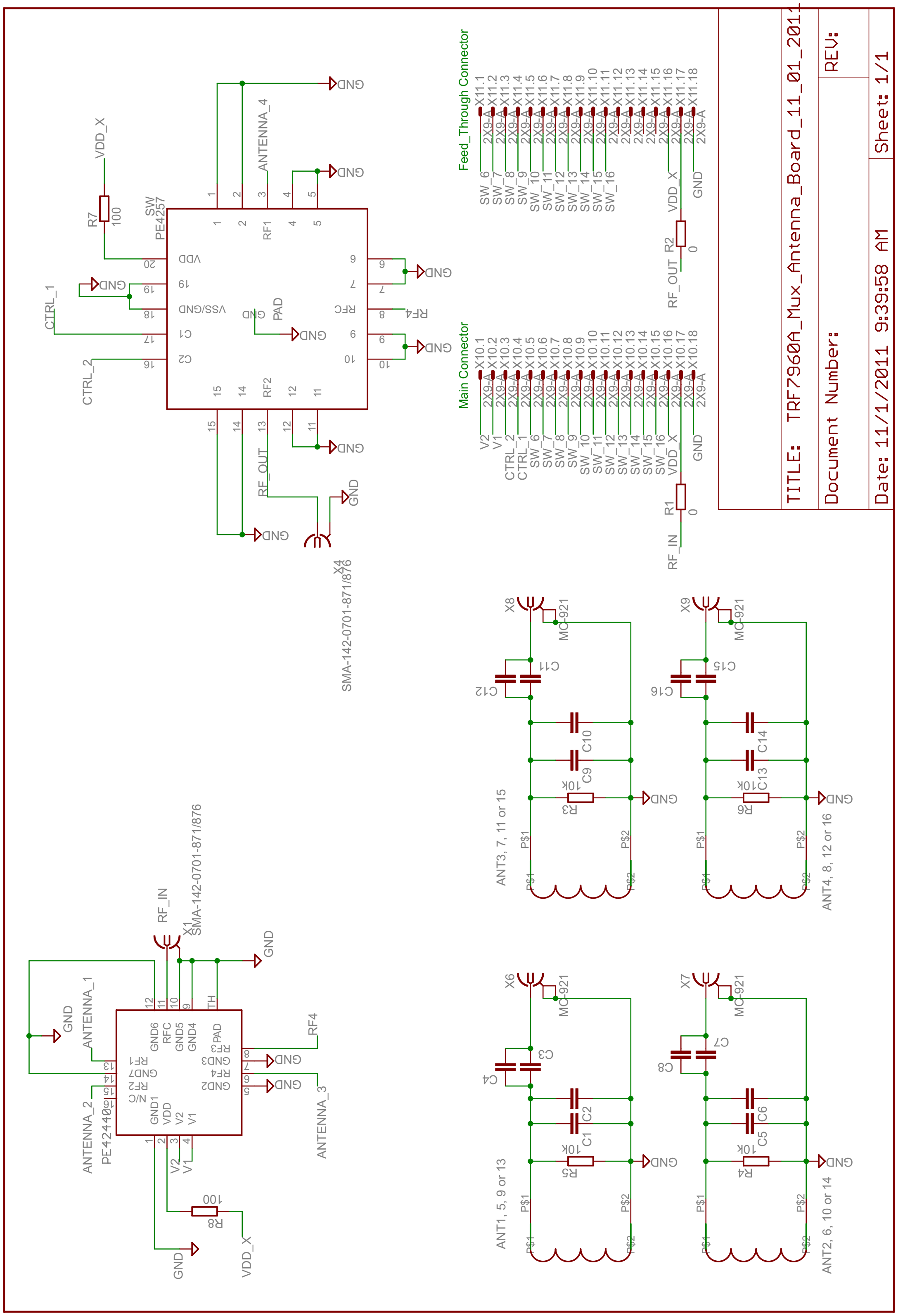


Figure 12. Antenna Board

Layout Images

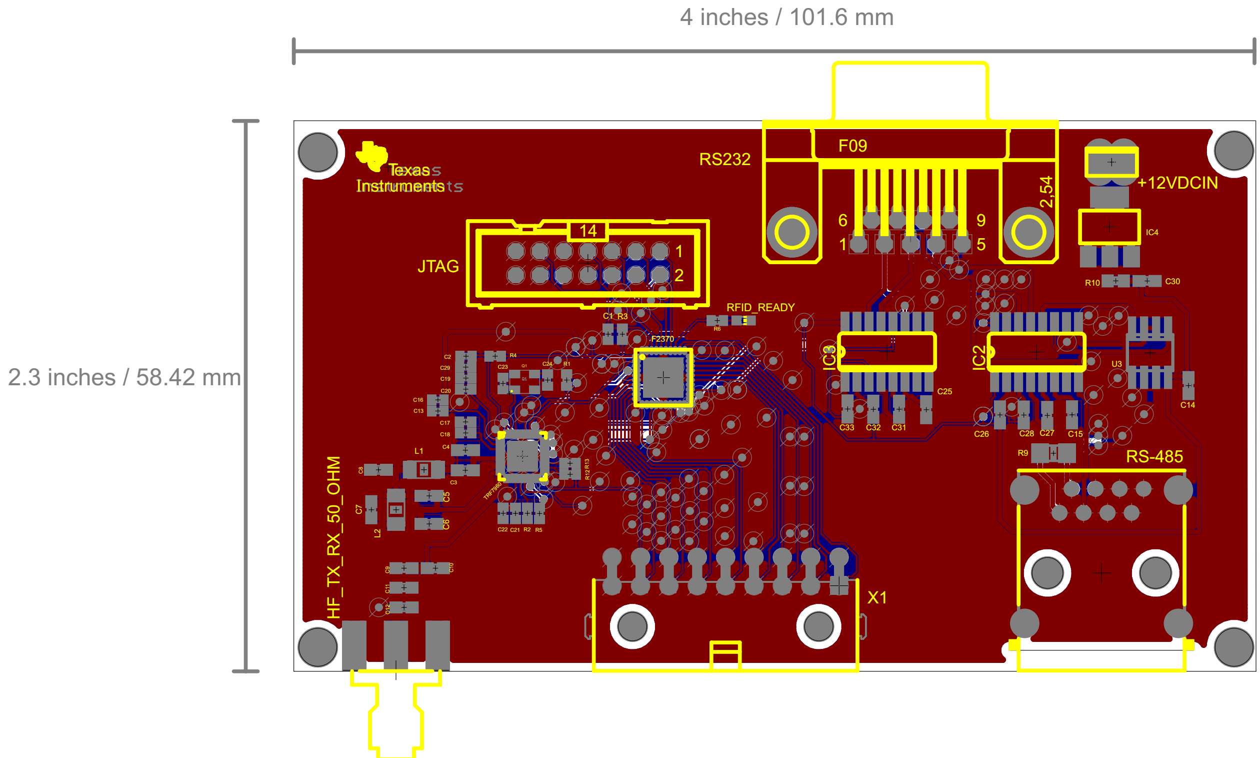


Figure 13. RFID Controller Board Layout

The dimensions of this board are 4.00 inches x 2.3 inches (101.6 mm x 58.42 mm). Original customer requirement was that this board be no larger than 110 mm x 220 mm. Mounting holes are M4.

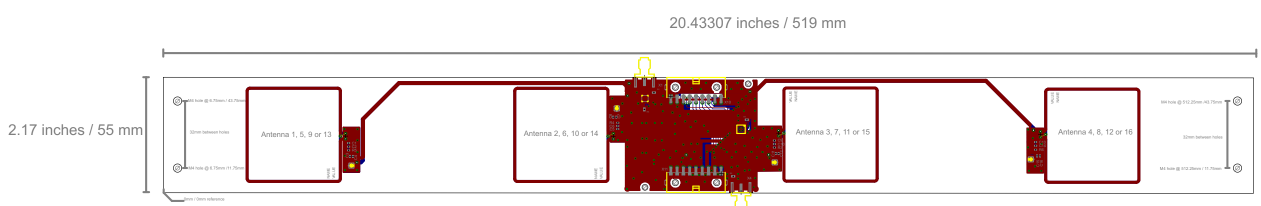


Figure 14. RFID Antenna Board Layout

The dimensions of this board are 20.433 inches x 2.17 inches (519 mm x 55 mm). Per original customer specification, two M4 size mounting holes are provided on either end of this board, spaced 6.75 mm from the board edge and 32 mm apart from each other vertically. With respect to the mounting hole spacing from each other horizontally, they are spaced 505.5 mm from each other, again, per original customer specification.

Cable Details

The system boards are designed with simplification of the cabling scheme in mind. Figure 15 shows the cascade concept for the signal flow from the controller board out to the first antenna array board, then from the first antenna array board to the second, and so on to the last antenna array board. The GPIO signals and the RF signals are cascaded through the boards as shown while the +3.3 VDC and ground are provided to each board directly. Figure 16 shows this in greater detail.

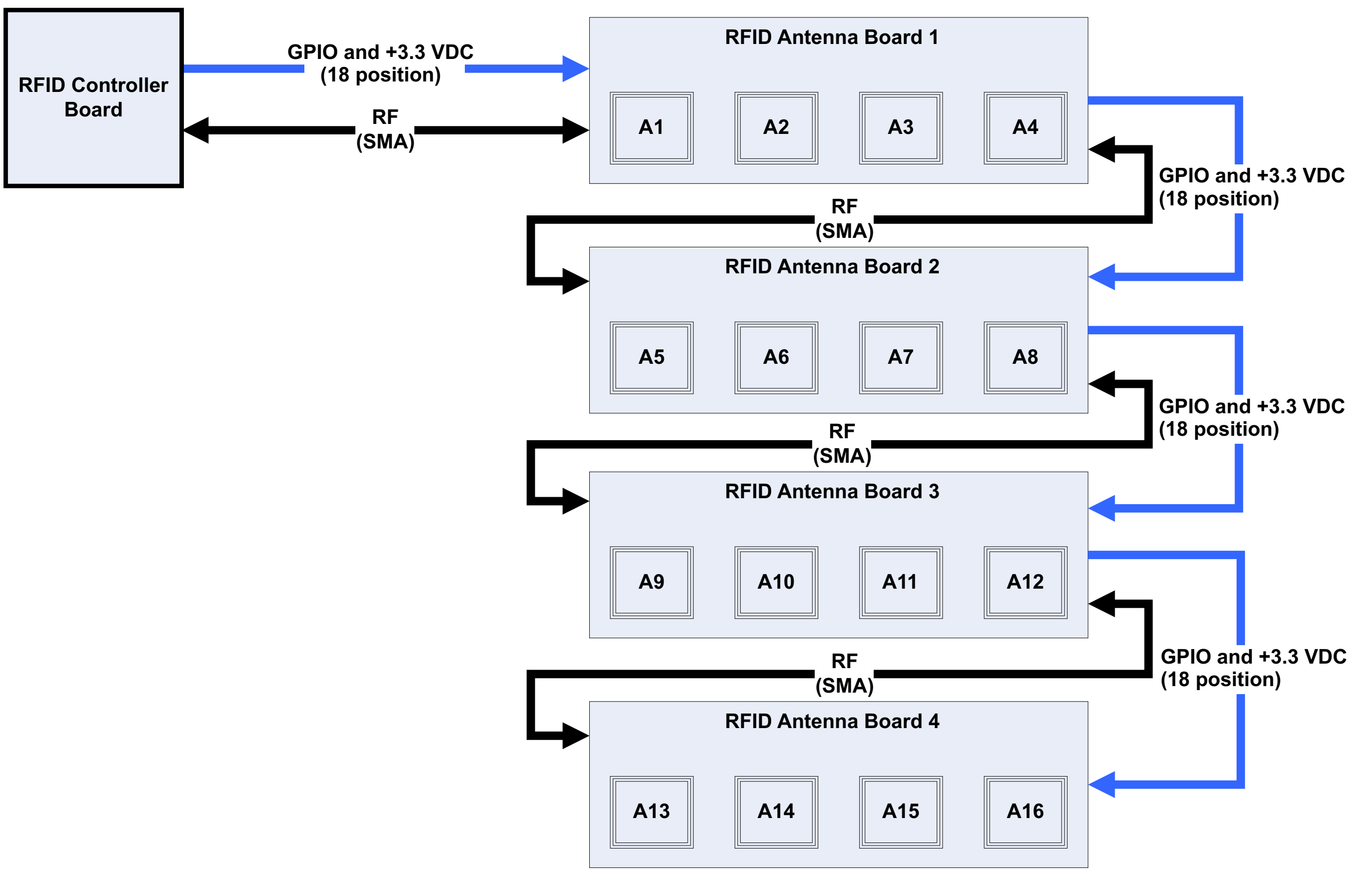


Figure 15. Signal Cascade Concept

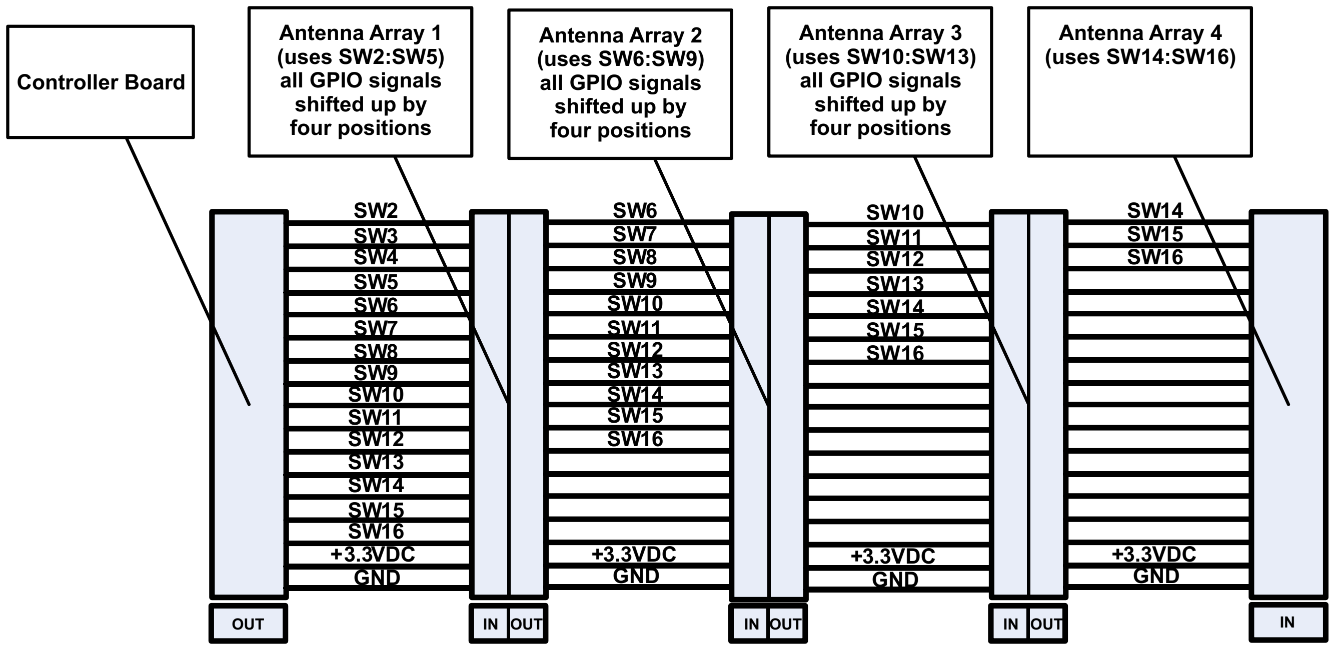


Figure 16. Cabling for Signal Cascade Concept

Table 4 shows the cable pin out of the signal distribution that is shown in Figure 16 for clarity and understanding. This cabling approach allows for one cable assembly to be created and then replicated four times for the system, which accommodates and distributes all of the signals that are required for command and control. Examination of the schematics and Figure 16 show that the cabling between the controller board and the antennas can all be the same, because the signal routing and shifting occurs on the boards.

Table 4. GPIO Cable Pin Out

Pin	Name	Function
1	SW2 / SW6 / SW10 / SW14	SW2 from controller to first antenna board, SW6 for second antenna board, SW10 for third antenna board, SW14 for fourth antenna board
2	SW3 / SW/7 / SW11 / SW15	SW3 from controller to first antenna board, SW7 for second antenna board, SW11 for third antenna board, SW15 for fourth antenna board
3	SW4 / SW8 / SW12 / SW16	SW4 from controller to first antenna board, SW8 for second antenna board, SW12 for third antenna board, SW16 for fourth antenna board
4	SW5 / SW9 / SW13	SW5, SW9, and SW13 from controller to first antenna board for further routing
5	SW6 / SW10 / SW14	SW6, SW10, and SW14 from controller to first antenna board for further routing
6	SW7 / SW11 / SW15	SW7, SW11, and SW15 from controller to first antenna board for further routing
7	SW8 / SW12 / SW16	SW8, SW12, and SW13 from controller to first antenna board for further routing
8	SW9 / SW13	SW9 and SW13 from controller to first antenna board for further routing
9	SW10 / SW14	SW10 and SW14 from controller to first antenna board for further routing
10	SW11 / SW15	SW11 and SW15 from controller to first antenna board for further routing
11	SW12 / SW16	SW12 and SW16 from controller to first antenna board for further routing
12	SW13	SW13 from controller to first antenna board for further routing
13	SW14	SW14 from controller to first antenna board for further routing
14	SW15	SW15 from controller to first antenna board for further routing
15	SW16	SW16 from controller to first antenna board for further routing
16	VDD_X (+3.3VDC)	Voltage supply for digital switches
17	RF_OUT/RF_IN (50_OHM)	RF (coaxial or twisted pair) (optional, use based on testing)
18	GND	GND (coaxial or twisted pair)

The preliminary cable assembly diagram is shown in Figure 17.

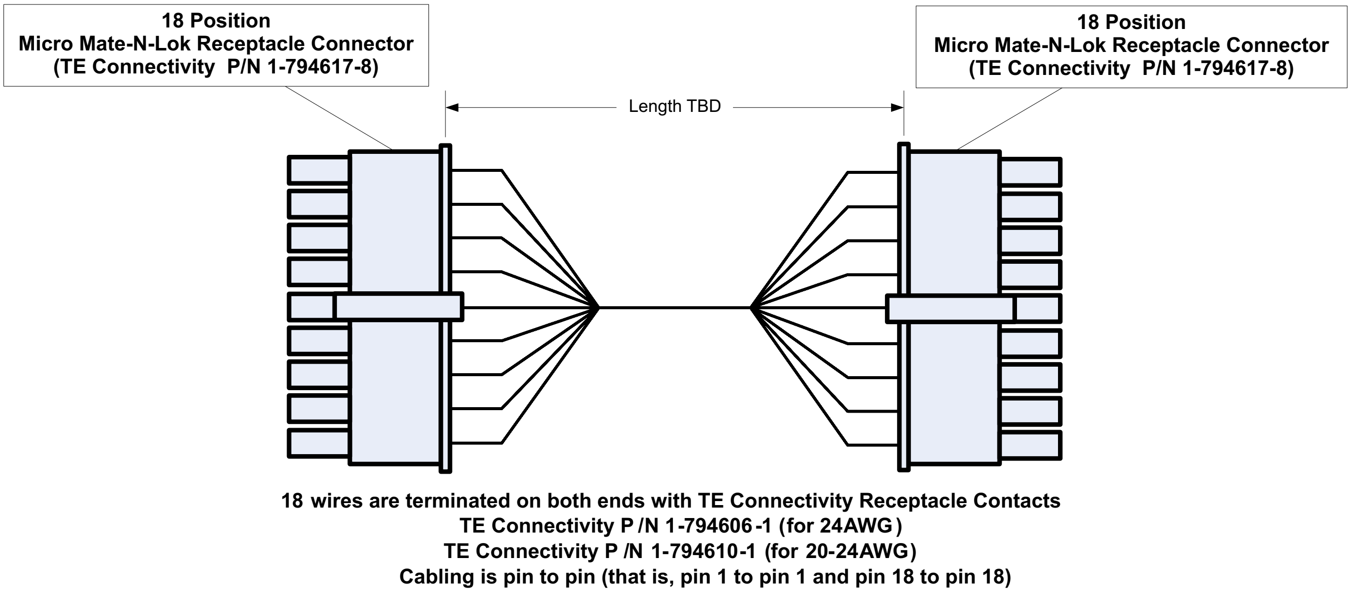


Figure 17. GPIO Cable Diagram

IMPORTANT NOTICE FOR TI DESIGN INFORMATION AND RESOURCES

Texas Instruments Incorporated ('TI") technical, application or other design advice, services or information, including, but not limited to, reference designs and materials relating to evaluation modules, (collectively, "TI Resources") are intended to assist designers who are developing applications that incorporate TI products; by downloading, accessing or using any particular TI Resource in any way, you (individually or, if you are acting on behalf of a company, your company) agree to use it solely for this purpose and subject to the terms of this Notice.

TI's provision of TI Resources does not expand or otherwise alter TI's applicable published warranties or warranty disclaimers for TI products, and no additional obligations or liabilities arise from TI providing such TI Resources. TI reserves the right to make corrections, enhancements, improvements and other changes to its TI Resources.

You understand and agree that you remain responsible for using your independent analysis, evaluation and judgment in designing your applications and that you have full and exclusive responsibility to assure the safety of your applications and compliance of your applications (and of all TI products used in or for your applications) with all applicable regulations, laws and other applicable requirements. You represent that, with respect to your applications, you have all the necessary expertise to create and implement safeguards that (1) anticipate dangerous consequences of failures, (2) monitor failures and their consequences, and (3) lessen the likelihood of failures that might cause harm and take appropriate actions. You agree that prior to using or distributing any applications that include TI products, you will thoroughly test such applications and the functionality of such TI products as used in such applications. TI has not conducted any testing other than that specifically described in the published documentation for a particular TI Resource.

You are authorized to use, copy and modify any individual TI Resource only in connection with the development of applications that include the TI product(s) identified in such TI Resource. NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT OF TI OR ANY THIRD PARTY IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information regarding or referencing third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of TI Resources may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI RESOURCES ARE PROVIDED "AS IS" AND WITH ALL FAULTS. TI DISCLAIMS ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESS OR IMPLIED, REGARDING TI RESOURCES OR USE THEREOF, INCLUDING BUT NOT LIMITED TO ACCURACY OR COMPLETENESS, TITLE, ANY EPIDEMIC FAILURE WARRANTY AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY YOU AGAINST ANY CLAIM, INCLUDING BUT NOT LIMITED TO ANY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON ANY COMBINATION OF PRODUCTS EVEN IF DESCRIBED IN TI RESOURCES OR OTHERWISE. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, DIRECT, SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF TI RESOURCES OR USE THEREOF, AND REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

You agree to fully indemnify TI and its representatives against any damages, costs, losses, and/or liabilities arising out of your non-compliance with the terms and provisions of this Notice.

This Notice applies to TI Resources. Additional terms apply to the use and purchase of certain types of materials, TI products and services. These include; without limitation, TI's standard terms for semiconductor products http://www.ti.com/sc/docs/stdterms.htm), evaluation modules, and samples (http://www.ti.com/sc/docs/sampterms.htm).