Touch Panel System Using MC33794 E-Field Sensor

Reference Manual

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PREFACE

This Reference Manual provides all the design guidelines and considerations when designing a touch panel application using E-field sensors. The manual also includes the installation and setup instructions for the Touch Panel System using MC33794 E-Field Sensor, MC68HC908QB8 Embedded MCU and the MC33993 Multiple Switch Detection Interface. It describes how to easily program the embedded MCU and the basic hardware configurations to start the demo.

AUDIENCE

This document is intended for application developers who are setting up Freescale's RDMC33794 Reference Design.

SUGGESTED READING

- Additional documentation may be found at www.freescale.com
- Design Reference manual for RDMC33794.
- Application note, AN1985: Touch Panel Applications using The MC33794 E-field IC

CONVENTIONS

This document uses the following conventions:

Term or Value	Definition	Examples
Terminal Names	Terminal names are the physical connections and are shown in text as all upper case.	... the external supply voltage VSUP1.
Terminal Values	Terminal values are the currents to/from a terminal and are shown as upper and subscripted text.	In Stop Mode the voltage regulator still supplies the MCU with V_{DD}
Decimal Values	No special symbol attached to the number	1.0 34
Numbers	Considered positive unless specifically noted as a negative value	5.0 -10
Blue Text	Linkable on-line	... refer to Table 1, page 2

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MC33794RM Touch Panel System, Internal Rev. 0.2

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Chapter 1 Touch Panel System using the MC33794 E-field Sensor

1.1   Designer Reference Manual

This printed copy may be out of date. To verify you have the latest information available please refer to http://www.freescale.com for the most current revision.

1.2   Introduction and Setup

1.3   Introduction

The Touch Panel System (TPS) is a development platform for the MC33794 E-field sensor and MC68H908QB8 low cost 8-bit micro controller:

- MC33794 can detect electric field variations in up to 9 electrodes and transform these variations into an analog signal. This signal can be interfaced directly with a 5V micro controller A/D module. Based on this E-Field sensor, this reference design detects human presence through glass or other dielectric materials.

- Uses Freescale's MC33993 for cost effectiveness.

- MC33993 is also called a multiple switch detection interface and can drive 22 outputs using its configurable internal current sources.

- Communicates directly with the MCU using a 4 wire SPI communication with no external components required.

- User interface consists of an audio transducer (piezoelectric horn), two seven segments displays and six general purpose LED's. The MC33993 device is used to drive both displays and the 6 LED's directly.

- Serial communication interface (SCI) is used for communication between the MCU and the PC and programs the micro controller using the serial bootloader software.

- Platform works with an external power supply or 9V battery.

- TPS is an enhanced version of KIT33794DWEVM. In addition to a battery operation option, user feedback is improved through 6 LED's, two seven segment displays and an audio transducer. The main MCU is upgraded to a MC68H908QB8 micro controller which has a 10 bit resolution ADC, SPI and ESCI modules on chip.

- TPS consists of two boards: the Analyzer Board (AB) and the Touch Panel Board (TPB). The Analyzer Board (AB) includes the E-field sensor, the micro controller, the MC33993, LED's, serial port, displays and all hardware required for the application. In essence, the Analyzer Board (AB) is responsible for processing data and control of the application.

- Second board is the Touch Panel board, which consists of the electrodes and a 15 terminal SMD connector to Analyzer Board.

- Analyzer Board was designed with flexibility in mind allowing several different boards to be connected to it. This allows different Touch Panel Board configurations to be substituted easily through the SMD connector.

- Demonstration software provides the electrode selection (multiplexing E-field inputs), output reading, calibration routines and user feedback control when a pressed condition is detected.

Figure 1-1 below shows the TPS concept. The populated board is called the Analyzer Board (AB) while the electrodes board is called the Touch Panel Board (TPB).

Analyzer Board
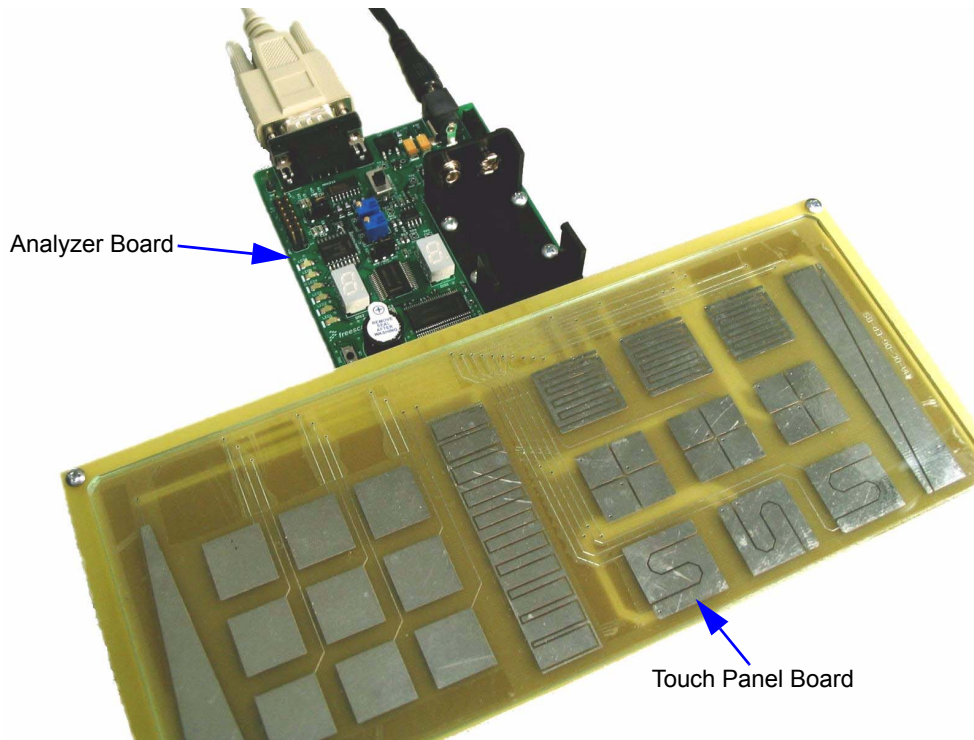
Touch Panel Board

Figure 1-1. Touch Panel System concept

1.4   Analyzer Board (Key Features)

The Analyzer board is a general-purpose board composed by a MC68HC908QB8 low cost micro controller, a MC33794 E-field sensor, a multiple switch detection interface (MC33993) and various other peripherals. The features of this development tool are:

- 10V power supply using integrated voltage doubler (charge pump)
- MC33993 Multiple switch detection interface
- MC68H908QB8 low-cost, low-terminal micro controller
- DPDT Monitor mode/User mode selection switch
- MON08 connector for debug and programming
- Op-amp with amplitude and offset adjustment
- One audio-transducer (piezoelectric horn)
- Serial port (ESCI hardware module)
- Two seven-segments displays
- Jack for External power supply
- MC33794 E-field sensor
- SPST ON/OFF switch
- 15-terminal AB connector
- 5V Power supply
- 9v Battery holder
- Six LED's
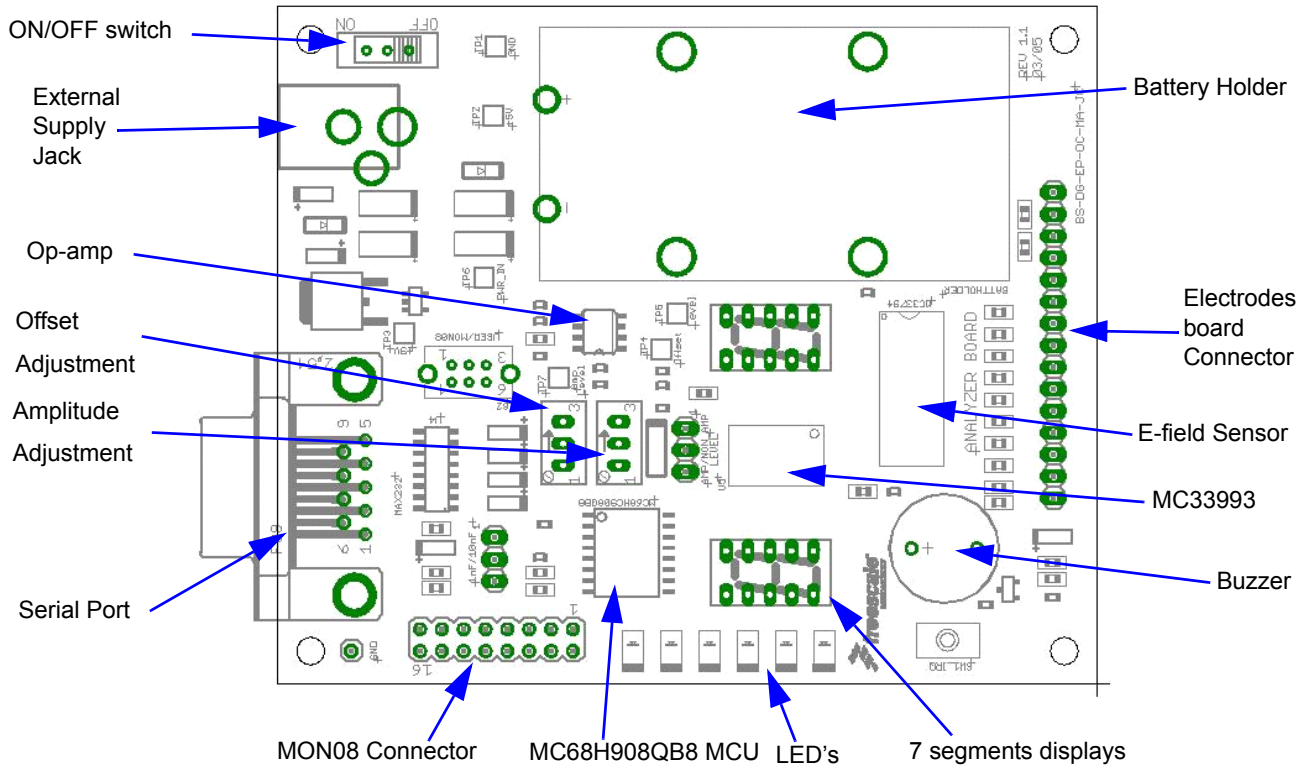
Figure 1-2. MC33794 Analyzer Board features

Touch Panel Connector (bottom side)

Single Slider Bar

Single Pads

Multiplexed Slider Bar

Multiplexed Pads

Multiplexed Slider Bar
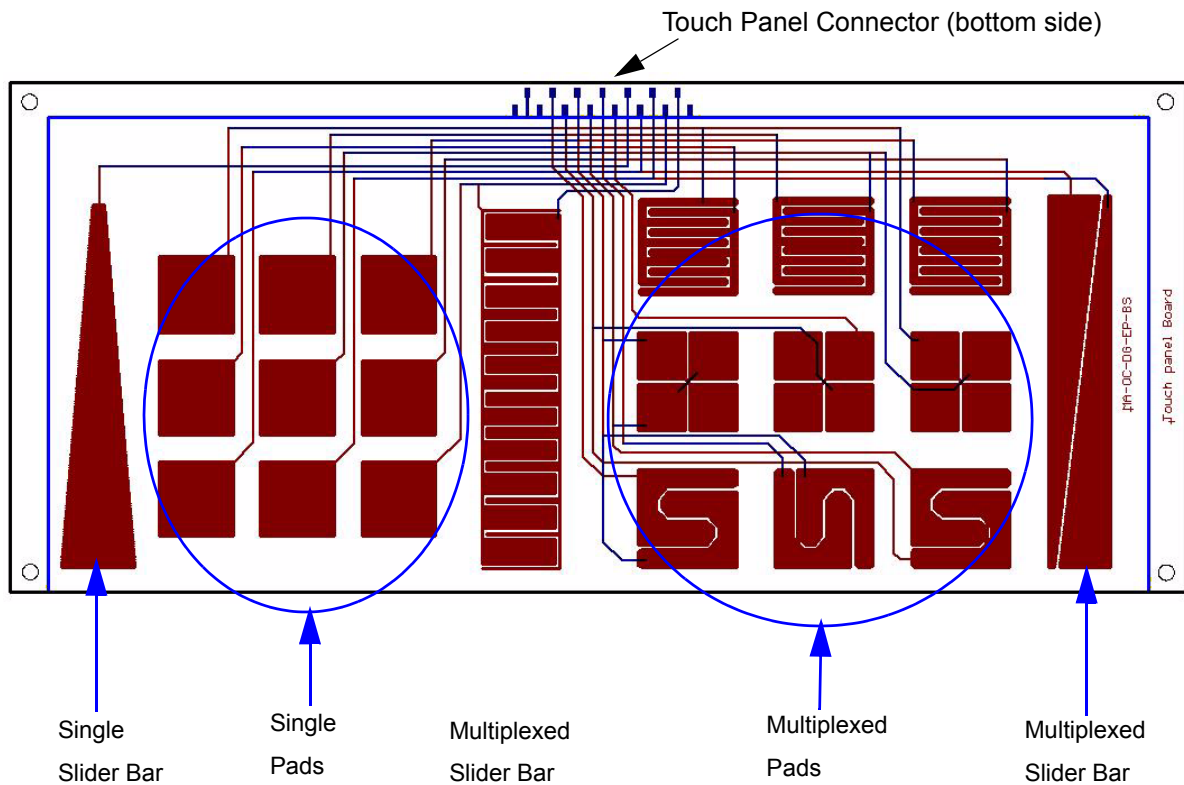
Figure 1-3. Touch Panel Board

1.5 E-field solution advantages

Advantages when using E-field sensor in touch panel applications compared to other solutions:

- Lower cost since a single chip might control a wide range of pads depending on multiplexing
- A wide range of objects and materials can be detected (people, metallic, non metallic, etc)
- No switches or mechanical parts to wear out or corrode
- Physical wear and chemicals exposure protection
- Lower power consumption
- 3-D position determination
- Higher temperature range
- Reliable solution

1.5.1 Touch panel basics

The following points give an introduction to the basic principle of detecting human presence in a touch panel application.

Almost anything conductive can be part of an electric field sensor by being one of the capacitor plates. An electric dipole field created between an oscillating transmit electrode and virtual ground receiver electrode is intercepted by a hand.

The hand can be modeled as a capacitor to a "virtual ground". In this case, the human finger is the grounded capacitor plate while Touch panel electrode forms the other capacitor plate.
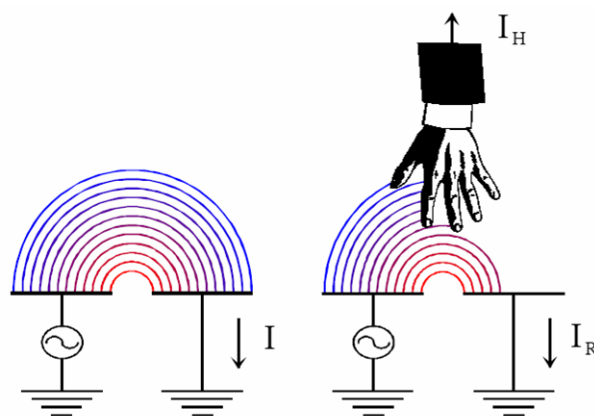
Figure 1-4. Touch Panel Basics

Recommended electrode size should be close to the size of a finger. The bigger the plate's area and the lower the distance between them, the higher the sensitivity. The size of the electrode should correspond to the size of the object operating the panel. The area of the electrodes should be made as large as possible within this constraint.

The number of possible touchpads can be increased by multiplexing electrodes. Potentiometers and slider bars can be simulated by changing the contact area within the electrode. For more information about multiplexing and continuous electrodes, See "Continuous Pads" on page 21.

1.6   Demonstrating Firmware

The demonstration firmware performs three tasks:

1.   Reads electrode values.
2.   Sends values to the SCI interface.
3.   Display electrode changes in LED's and buzzer interfaces.

1.7   Setup Instruction User Guide

The following steps provide a basic procedure to run firmware within the Touch Panel System.

1.   Unpack Touch Panel Board (TPB)
2.   Unpack Analyzer Board (AB)
3.   Connect the AB with the TPB using the 15-terminal connector "JP2" and the TPB connector.
4.   Configure AB jumpers

The configuration jumpers in the analyzer board are JP1 and JP3.

JP1 selects if the input to Micro controller's AD channel is fed directly from the MC33794 output terminal (LEVEL) or if the output signal is first amplified by the on-board op-amp with offset and amplitude adjustments.

JP3 selects between two values of LP_CAP, 10nF and 1nF, the recommended value in the datasheet is 10nF.

The default jumper configuration is shown in Table 1-1 and Figure 1-5.

Table 1-1. default jumpers configuration

JP1	Position 1-2 (10nF)
JP3	Position 1-2 (Non-amp LEVEL)
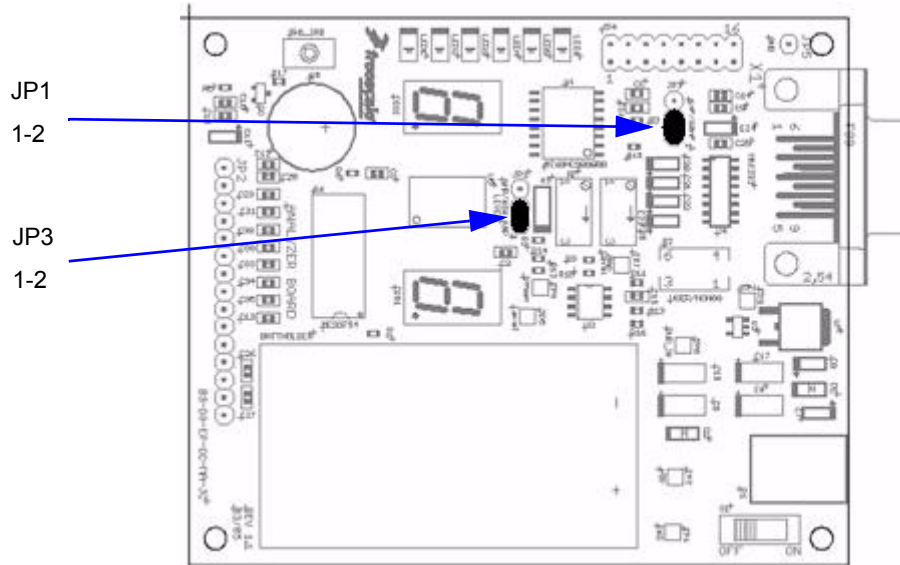
Figure 1-5. Default jumpers setup

5. Power On AB
- To power the AB make sure the battery or the external power supply does not exceed 15V
- Place a common 9 volt battery on the battery holder with the appropriate polarity,
- Or connect +9V center positive on the jack for external power supply.
- Move "S1" to the "ON" position.

NOTE: In order to avoid short circuit condition when connecting battery and external supply at the same time, the external power supply jack will disconnect the battery VCC terminal.

6. Configure User mode/MON08 Switch

When running the loaded program in the demo, the USER/MON08 switch "S2" should be on the USER position; USER mode is also used when programming the micro controller using the serial bootloader tool. MON08 position of "S2" is used to program or debug the MC68H908QB8 using a MON08 programming pod.

1.8 On Board Test Points

The Analyzer Board includes test points of the main signals. The purpose of these test points is for both testing the electrical performance of the board and to easily access the main signals involved in the application.

Table 1-2 shows a description of the signals that can be observed in the test points.

Table 1-2. Test points description

Test point number	Signal name	Description
TP1	GND	System Ground, electrical reference test point.
TP2	+5V	5V power supply output.
TP3	+9V	External power supply or battery voltage. After ON/OFF switch and reverse battery protection stages.

TP4	Offset	DC signal entering Op-amp non-inverter inputs. Output of potentiometer R8.
TP5	Level	MC33794's output. Check Figure 1-9.
TP6	PWR_IN	Charge pump output, 10 volts typically measured
TP7	Amp_Level	Amplifier stage output, MC33794's output with adjustment in offset and amplitude. Check Figure 1-9 and Figure 1-1

1.9 Downloading software to Demo

To download the firmware using the bootloader tool:

1. Make sure all the required programs are available in the programmer PC. You must have the *. S19 file to be downloaded into the MCU, software used for serial communications (i.e. TeraTerm), and the required bootloader already programmed into the demo board MCU.

2. Open and configure serial communications software (i.e. TeraTerm), setting serial port baud rate at 9600 bps, 8 bit, no parity, 1 stop bit and flow control set to none. Make sure the transmit delay is set to 3ms/char and 3ms/line in order to ensure a proper communication.

3. Make sure demo board jumpers are configured as desired and that the USER/MONO8 switch is set to USER.

4. Turn on the demo board while holding the SW1_IRQ button pressed, a "(p)rogram (w)ipe e(x)it" message should appear into the terminal screen.

5. Press "w" to wipe any data already loaded into the MCU flash. Note: this operation does not erase the bootloader code.

6. Press "p" and a "waiting…" message will appear. Use the terminal's "Send File" option to send the.S19 file, a progress dialog will show up.

7. After code download the "(p)rogram (w)ipe e(x)it" message will appear again. Press "x" and the downloaded code will start running.

8. Each time the demo board is turned on without pressing the sw1_irq button at the same time the user code will be run directly.

To download the firmware using a MONO8 pod:

1. Make sure the USER/MONO8 switch is set to MONO8 position.

2. Hook the MONO8 adapter into the X1 connector. Make sure the connector terminal alignment is correct to avoid any MCU damage.

3. Using CodeWarrior download the code to the demo board. Since this operation will erase the bootloader, make sure the interrupt vectors are located on the standard interrupt vector area.

4. Unplug the MONO8 connector and set the switch to USER position.

1.10 Operational Description

1.10.1 Introduction

This section describes the electrical characteristics, user interfaces and connections for the Touch Panel System using E-field Sensors (TPS).

1.10.2 Analyzer Board Electrical characteristics

Table 1-3. AB Electrical Characteristics

Inputs/outputs	Min	Type	Max	Unit
Input voltage (battery and external power supply)	7.2	9	15	V
Board current consumption	-	43	-	mA
Charge pump output voltage (PWR_IN)	-	10	-	V
Op-amp output	0.6	-	5.1	V

1.10.3 Jumpers and Switches description

Table 1-4. Analyzer Board jumpers and switches description

Jumper name	Functional description
JP1	• Position 1-2: Connects micro controller A/D input channel 3 to E-field output "LEVEL" directly. • Position 2-3: connects micro controller A/D input channel 3 to the Op-amp output. Op-amp adjusts gain and offset of "LEVEL" (E-field output). • Other: NOT valid
JP3	• Position 1-2: E-field LPF filter capacitor = 10nF. • Position 2-3: E-field LPF filter capacitor = 1nF. • Other: NOT valid
S1	• OFF: Power supply or battery is disconnected internally to all modules. • ON: Power up all AB modules
S2	• USER: Microprocessor in user mode, firmware running. Also used when programming using serial bootloader. • MON08: microprocessor is ready to be programmed using the MON08 connector.

1.10.4 MON08 Connector

MON08 Connector is a 16 terminal (8x2) male header, used for programming and debugging using the Multilink MON08 interface. The MON08 terminal header terminals are connected directly to some specific MCU terminals; those specific terminals are used by the micro controller to enter monitor mode and allow the flash programming and debugging modes. On the MC68HC908QB8 the MON08 connector follows the configuration shown in Table 1-5.

Table 1-5. MONO8 Interface to MC68HC908QB8

MON08 terminal number	MC68H908QB8 terminal number	MC68HC908QB8 terminal description
1	NC	-
2	16	VSS/GND
3	NC	-
4	NC	-
5	NC	-
6	9	IRQ/PTA2
7	NC	-
8	13	PTA0
9	NC	-
10	5	PTA4
11	NC	-
12	12	PTA1
13	4	PTA5/OSC1
14	NC	-
15	1	VDD
16	NC	-

1.10.5 TPB Connector

The external connector JP2 is a 15x1 male terminal connector that extends electrodes terminals (E1-E9), Ref_A, Ref_B and Shield from the E-field sensor out the board. This connector is called TPB connector, since it is compatible with the 15 terminals female connector in the TPB.

Table 1-6. TPB connector terminal-out

terminal#	Description	terminal#	Description	terminal#	Description
1	GND	6	E3	11	E8
2	SHIELD	7	E4	12	E9
3	SHIELD	8	E5	13	REF_A
4	E1	9	E6	14	REF_B
5	E2	10	E7	15	GND

1.10.6 Power supply

There are two ways to power up the board; using a 9V battery or using a center positive 9V external power supply through the P1 jack.

When a 9V external power supply is used to power up the analyzer board, the battery holder is disconnected from the board to avoid a short circuit condition.

1.10.7 Charge Pump

The MC33794 E-field sensor has a minimum requirement of 9.0V on Vpwr terminal. When using a 9V battery or an external power supply, fluctuations on the input voltage might make Vpwr voltage go out of specification.

An Integrated switched capacitor voltage converter, LM2767, is used to ensure VPWR terminal 1 has the required 9V . The LM2767 converts power from the regulated 5V power supply (MC7805) to a 10V power supply. If the 9V external supply or battery goes down, the E-field sensor will work correctly as soon as the minimum input voltage requirements of MC7805 are met.

NOTE: VPWR is the power supply of the analog portion of MC33794

1.10.8 E-field Sensor (MC33794)

Freescale Semiconductor's MC33794 is intended for applications where non-contact sensing of objects is desired. When connected to external electrodes, an electric field is created.

The main features of MC33794 include:

- Shield Driver for Driving Remote Electrodes Through Coaxial Cables
- High-Purity Sine Wave Generator Tunable with External Resistor
- Critical Internal Nodes Scaled and Selectable for Measurement
- Support for up to 9 Electrodes and 2 References
- +5.0 V Regulator to Power External Circuit
- Watchdog and Power-ON Reset Timer
- ISO-9141 Physical Layer Interface
- Lamp Driver Output

E1 through E9 are the E-field terminals designated for electrode placement. These terminals are responsible for detecting changes in the surrounding electric field. When a specific electrode channel is selected, all other unselected electrodes are grounded by an internal switch.

REF_A and REF_B are used as electrodes as well; Unlike E1 through E9, these terminals are not grounded when not selected. These terminals allow known capacitors to be measured. By using capacitors at the low and high end of the expected range, absolute values for the capacitance on the electrodes can be computed. In this specific application, no absolute capacitance measurement is required; so REF_A and REF_B are used as electrodes as well.

Communication with the MCU is done via A, B, C, D and LEVEL terminals; A, B, C and D are 5V logic terminals that select the specific electrode while LEVEL terminal, analog output, outputs a DC value proportional to the electric field present in the electrode.

Other features of MC33794, such as the ISO-9141 physical layer interface, the lamp driver, watchdog reset and Power-on time are not used in this application.

1.10.9 Op-amp

Depending on glass thickness, dielectric material or the specific application, the output voltage of the E-field sensor might require software algorithms or higher A/D resolution.

Based on the above, the Touch panel system using E-field Sensors (TPS) incorporates a low cost op-amp, TS972, in order to provide amplification and offset to the LEVEL signal before entering MCU A/D channel. An additional explanation of the op-amp configuration used can be found "Hardware Design Considerations" on page 15.

1.10.10 Multiple Switch Detection Interface MC33993 (MC33993)

LED's are connected directly to SGx and SPx terminals (no external resistors are needed), configuring the wetting current, either on SG and SP terminals. A certain amount of current to the LED's (16mA or 2mA) is injected and consequently they are turned On. To turn LED's On/OFF the MC33993's (MC33993) tri-state command is used.

1.11   Touch Panel Board

The Touch Panel Board (TPB) is a passive board that ties directly to some of the MC33794 E-field sensor terminals. A 4mm glass covering the electrodes is used as the touch pad. The TPB includes different kinds of pads using E-field electrodes for experimentation. The design of these electrodes is described in , "Hardware Design Considerations" on page 15.

1.11.1 AB connector

Table 1-7 shows AB connector JP2 terminal-out. AB connector is a 15x1 female terminal header that connects TPB with AB.

Table 1-7. TPB to AB connector terminal-out

terminal#	Description	terminal#	Description	terminal#	Description
1	GND	6	E3	11	E8
2	SHIELD	7	E4	12	E9
3	SHIELD	8	E5	13	REF_A
4	E1	9	E6	14	REF_B
5	E2	10	E7	15	GND

1.11.2 TPB Electrodes Distribution

Figure 1-6 shows the electrode layout within the Touch panel board (TPB).
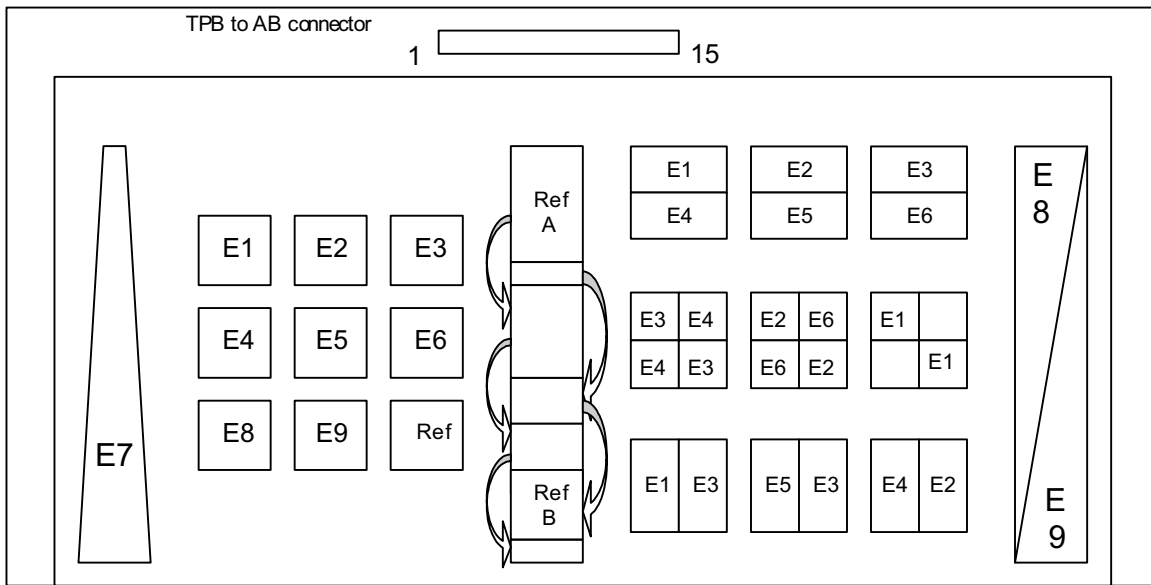
Figure 1-6. Touch Panel Board electrodes distribution

1.11.3 Block Diagram

This section shows the block diagram of the Touch Panel System.
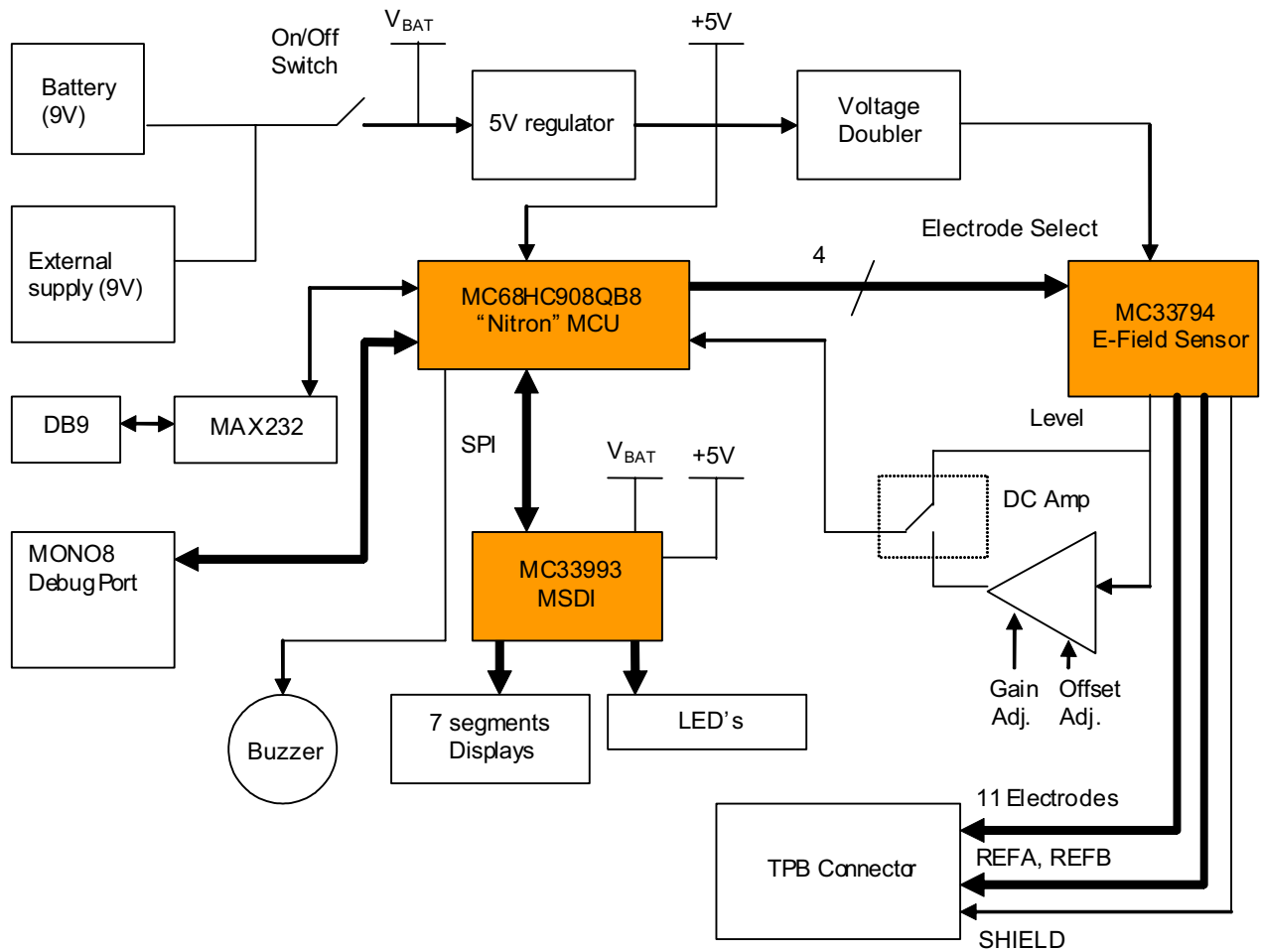
Figure 1-7. Touch Panel System block diagram

The main blocks are shown in Figure 1-7, orange blocks correspond to Freescale Semiconductor devices. A more detailed description is performed in "Hardware Design Considerations" on page 15.

1.12 Schematics

1.12.1 Analyzer Board Schematics

Figure 1-8. Schematics
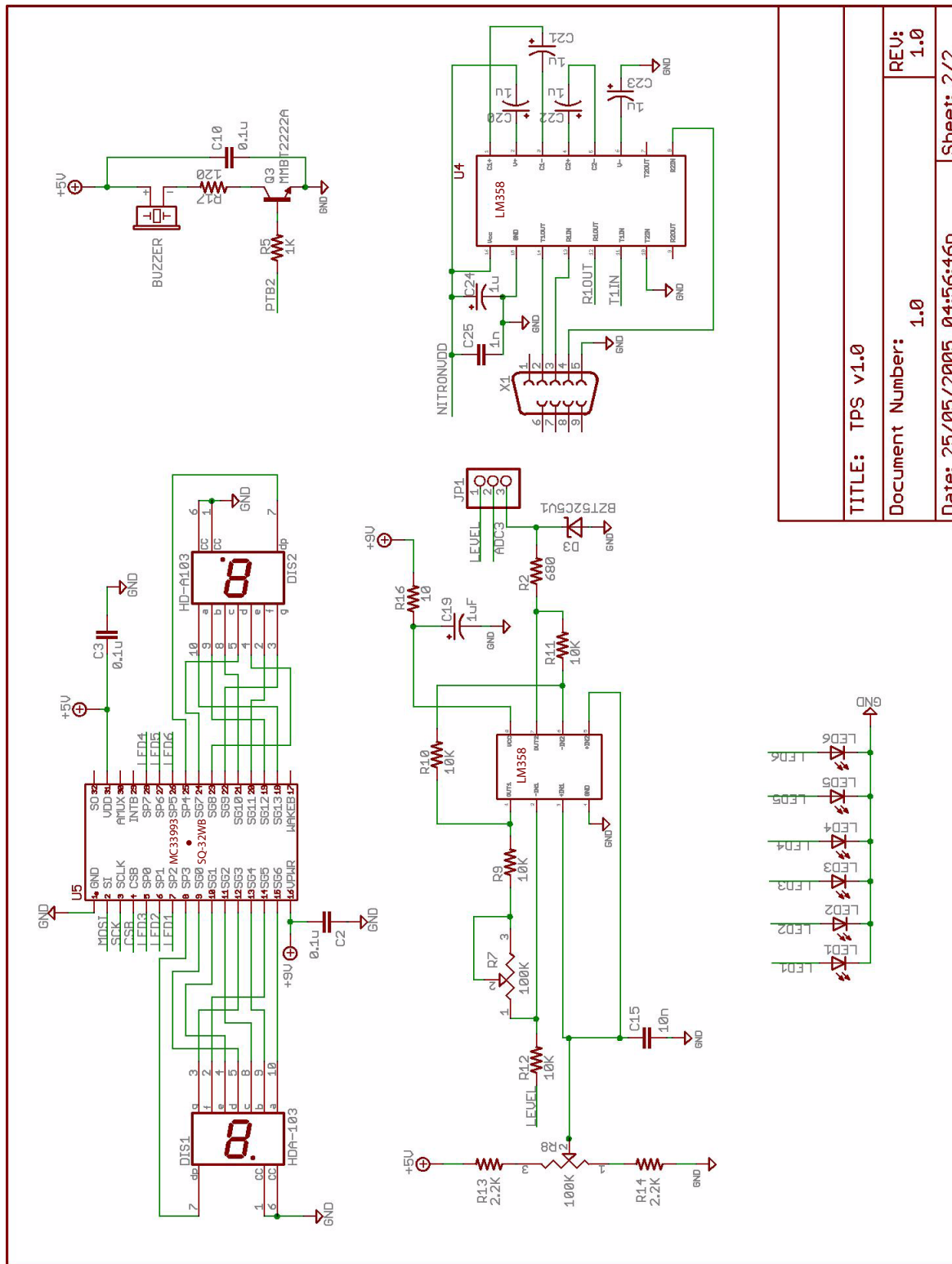
Figure 1-9. Schematics Continued

1.13   Hardware Design Considerations

1.13.1 Analyzer Board

1.13.1.1   Introduction

The Analyzer Board uses the E-field sensor, the MC68HC908QB8 MCU, MC33993, audio transducer, serial port, etc. This section gives a quick explanation of each hardware block.

1.13.1.2   Op-Amp

The Analyzer Board includes an amplifier with offset and gain adjustment. The reason for this amplifier is to provide higher sensitivity to the signal read by the MCU ADC converter. The amplifier circuit enables the user to zoom in the voltage range of interest and consequently achieve higher electrode reading changes for easier detection.

Op-Amp provides offset adjustment and gain adjustment; offset adjustment is done by the potentiometer R8 while gain adjustment is by potentiometer R7.
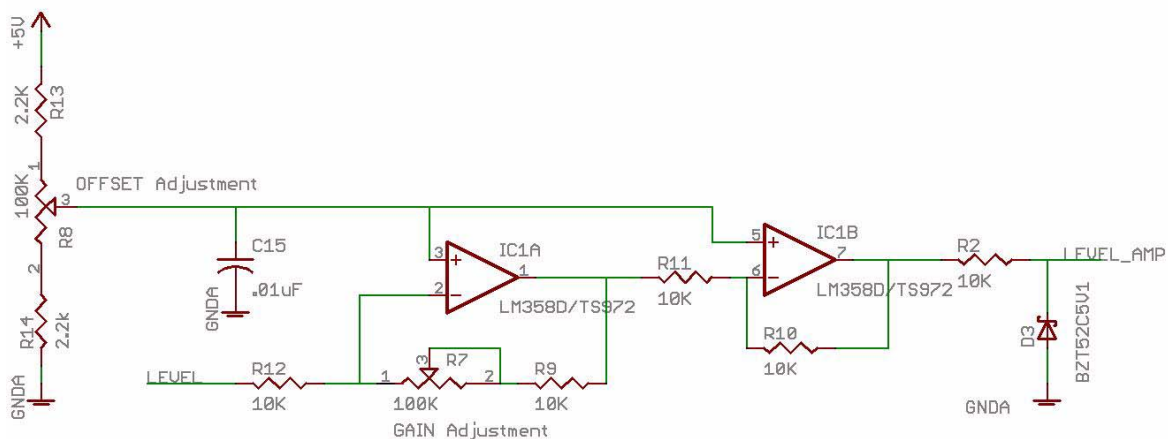
Figure 1-10. Op-Amp Circuitry

The amplifier follows the configuration of an inverter amplifier (IC1A). The gain adjustment (Av) goes from 1 to 11, while the offset adjustment goes from 0.1V to 4.89V. A unitary gain inverter (IC1B) is added after the first stage to reestablish signal polarity.

R2 and D3 are added at the op-amp output to protect MCU AD channel from voltages higher than 5.1V.

Sometimes the output signal cannot be amplified as high as the op-amp allows due to its intrinsic characteristics. The multiplexed signal varies over time and amplitude; these variations are dependent on the switching speed of the A, B, C and D signals and on the electrodes construction itself.

Figure 1-11 shows an oscilloscope graph of the "Level" and "Amp Level" test points in the Analyzer Board after adjusting op-amp offset and amplitude. It can be observed that the signal is periodic due to the constant reading of the different electrodes; the voltage steps observed are proportional to the electric-field detected on each electrode.

LEVEL

1.0 V/div

LEVEL_AMP

1.0 V/div

Figure 1-11. E-field sensor output LEVEL and its amplified version LEVEL_AMP

MC33794RM Touch Panel System, Rev 1.0

Op-amp power supply is a derivation of +9V after a Low-pass filtering used for DC coupling.

1.13.1.3 Power Supply

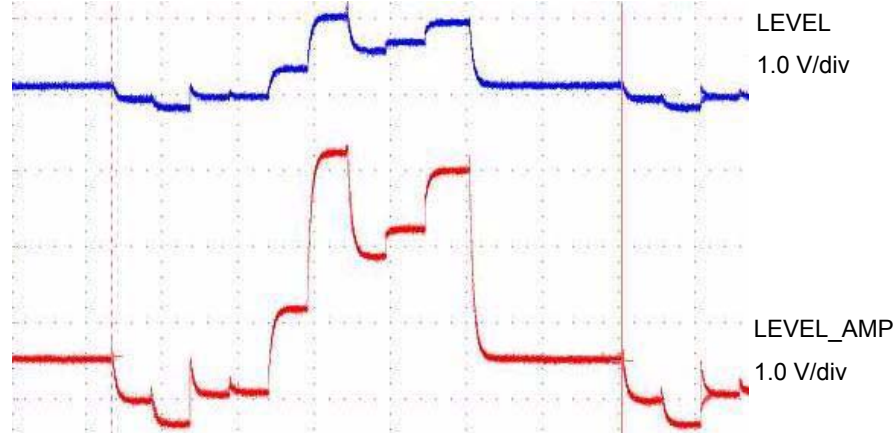The board has two power supply sources, the +9V battery and external power supply. A charge pump after the +5V terminal generates the 10 volts input for the E-field sensor.

When the external jack is connected, the negative terminal of the battery holder is disconnected to prevent a short circuit.

+5V is used to power up the micro controller and RS232 transceiver when in USER mode. It is also the logic power supply VDD of MC33993, the piezo-electric buzzer and most of the 5V requiring circuitry.

The non-regulated +9V signal is used to power up op-amp and MC33993 power side.

For extra information about the charge pump, See "Charge Pump Circuitry" on page 18.
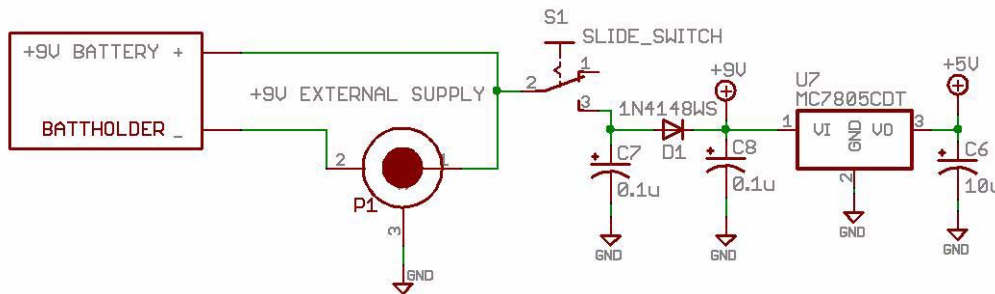
Figure 1-12. Power Supply Circuitry

1.13.1.4 Multiple Switch Detection Interface

The MC33993 Multiple Switch Detection Interface is designed to detect the closing and opening of up to 22 switch contacts. The switch status, either open or closed, is transferred to the microprocessor unit (MCU) through a serial peripheral interface (SPI); whenever a switch changes state, the micro controller is automatically alerted.

The multiple switch detection interface (MC33993) was specially designed for automotive applications, nevertheless its features allows it to be used on aircraft, industrial control, process control, security systems and on critical systems requiring switching status verification for safety or control purposes. In this application we use the internal configurable current sources (2mA or 16mA depending on the programmed wetting current) to drive LED's. The MC33993 communicates with MCU using just 4 wires SPI (3 wires if no feedback from the MC33993 is required).

Using the MC33993 to drive LED's have several advantages since just few MCU wires are used. Board space is reduced, no external polarization resistances are needed and current consumption and LED's brightening can be changed configuring the wetting current.

Figure 1-13. MC33993's SPx and SGx terminals internal diagram

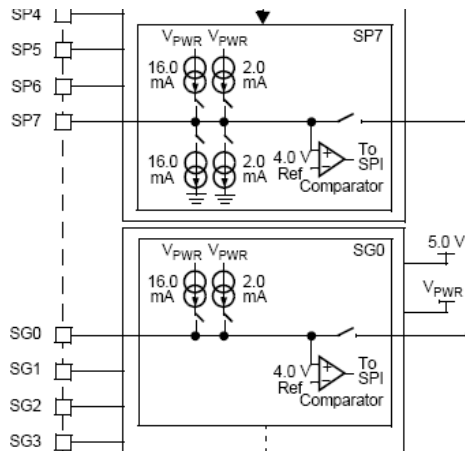Figure 1-14 shows the connection of the two 7 segments displays, and the general purpose LED's. Three SPI wires are used in the application (SI, SCK and CSB), SO is not used since we are just configuring MC33993 (sending commands through Slave input terminal) without feedback or status reading.

MC33993 is supplied by +5V for the logic side and unregulated +9V which is the internal voltage of the SGx and SPx terminals.
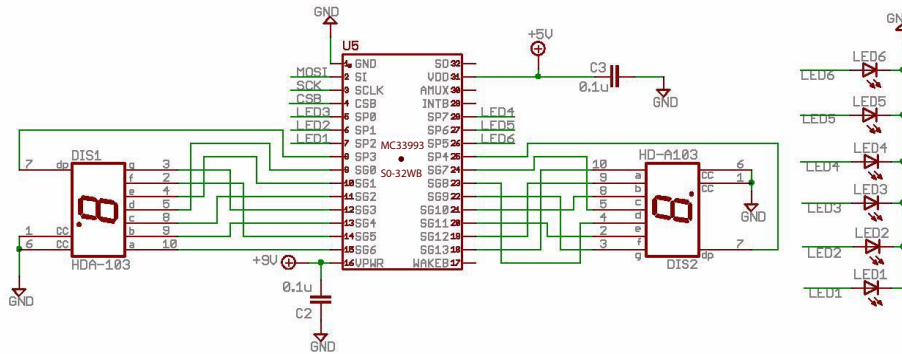

Figure 1-14. MC33993 driving LED's circuitry

1.13.1.5   E-field Sensor

The MC33794 E-field sensor generates internally a 120Khz sine wave signal in an AC array to measure capacitance variations on each of the electrode channels. REFA and REFB terminals are used as electrodes terminals, as total 11 channels; REFA and REFB terminals can be individually selected to measure a known capacitance value. Unlike E1-E9, these two inputs are not grounded when not selected.

LP_CAP terminal requires an external capacitor which is used within a low pass filtering stage to condition the output signal. This terminal can be used to determine the detected level before amplification or offset is applied. A 10 nF capacitor (recommended value) connected to this terminal will smooth the rectified signal and more capacitance will increase the response time. By changing the position of JP3 two different capacitors can be selected; if JP3 is on position 1-2, LP_CAP will have a 10nF capacitor and by moving jumper JP3 to the 2-3 position the selected LP_CAP value is 1nF.

MC33794's supply terminal (PWR_IN) is connected to the charge pump output, Charge pump assures a minimum 10V supply to the E-field sensor keeping the chip on its specified operational range regardless variations of the system power supply.

Other features like the lamp driver or the ISO-9141 transceiver available on MC33794 are not used in this application.

E1 through E9, REFA, REFB, GND and Shield terminals are tied to the external connector JP2, which is a standard 15x1 terminal connector for attaching Touch panel board or any other customized electrodes board.

Figure 1-15 shows the basic connections of the MC33794 E-field sensor within the application.
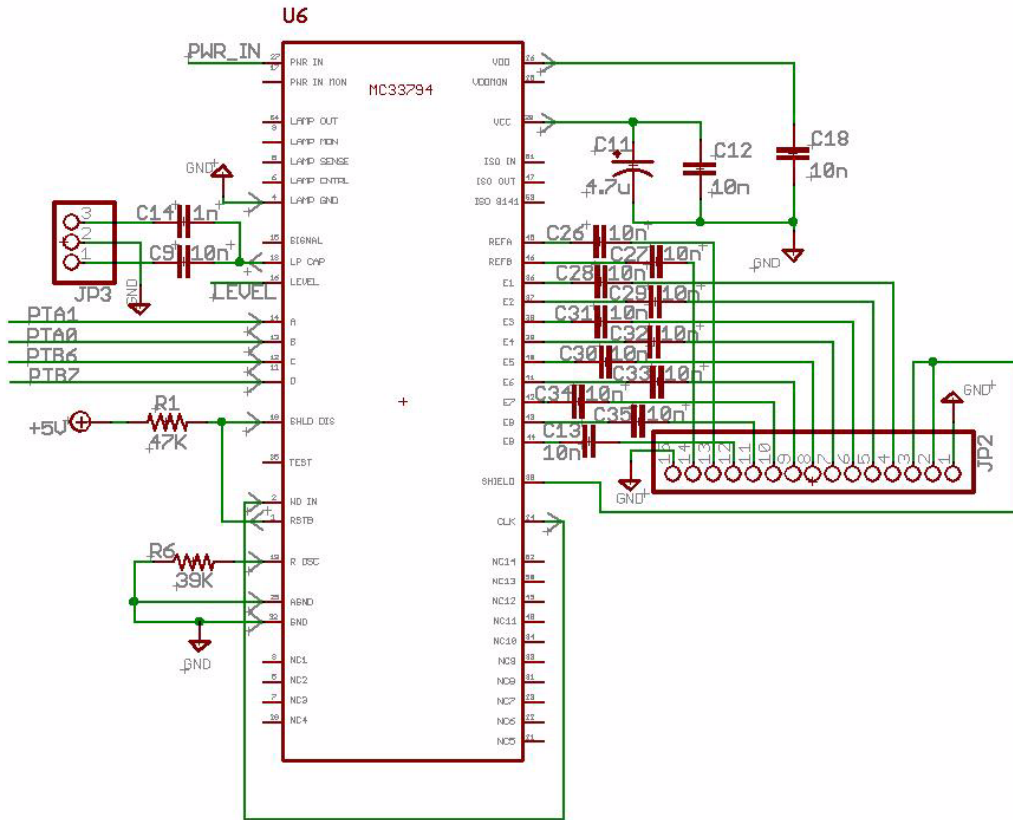
Figure 1-15. MC33794 Circuitry

1.13.1.6   Charge Pump Circuitry

As mentioned in MC33794 documentation, VPWR should be higher than 9V. In this case the Touch Panel System using E-field sensors is supplied either for an external power supply or a 9V battery. Fluctuations on this input voltage or simply low battery conditions may result in malfunction of MC33794. The charge pump produces 10V to assure a proper supply to the device.

The charge pump is based on National Semiconductor's LM2767. This IC doubles the 5V regulated signal having 10V nominal voltage at Vout (Pwr_in signal to MC33794).
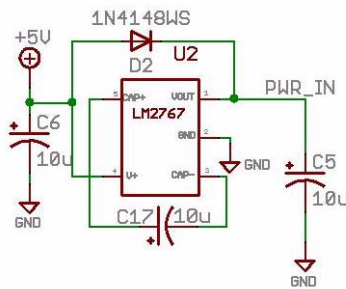
Figure 1-16. Charge pump circuitry

1.13.1.7   Buzzer (piezoelectric horn) Circuitry

The buzzer is controlled directly by a GPIO terminal of the microprocessor (PTB2), an NPN transistor is used as buffer switching ON/OFF.
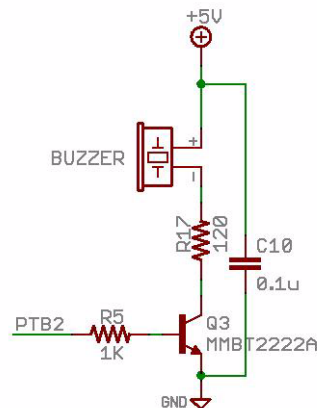
Figure 1-17. Buzzer circuitry

1.13.1.8   Serial Communication

In case it is necessary to share data with the PC or for programming flash using serial bootloader tool, serial communication interface (SCI) is included in the system.

Serial communication uses the ESCI module of the MC68H908QB8 micro controller, a RS232 transceiver and a DB9 connector.
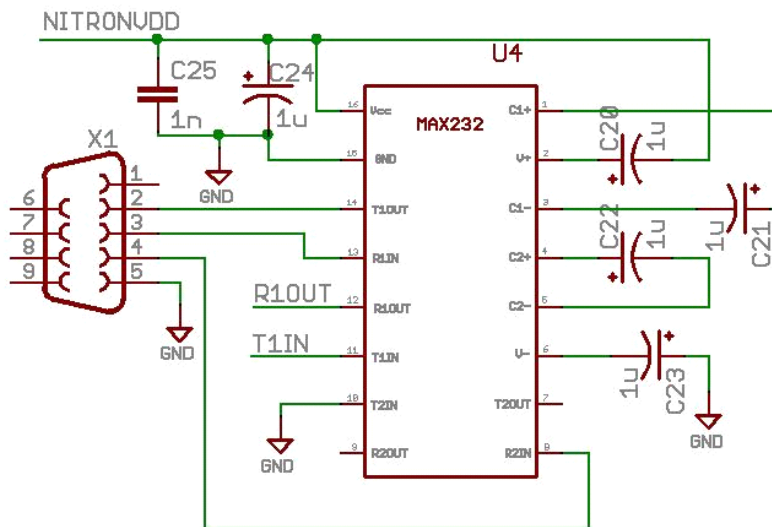
Figure 1-18. Serial communication circuitry

NOTE: Communication is allowed only in USER mode.

1.13.1.9   Micro Controller Programming and Debugging Circuitry

The system is based on a MC68HC908QB8, 8-bit, low cost micro controller. MCU selects each specific E-field channel, reads the output of the E-field sensor, and decides whether a touch or no-touch condition is present on each specific channel. It also sends commands to the MC33993 to drive the LED's, toggle ON/OFF buzzer, and perform serial communication.

The micro controller can be programmed using interface MON08 with the 16 terminals connector within Monitor mode or using serial bootloader tool in User mode. Selection between USER mode and MONITOR mode can be performed by switch "S2".

MC68HC908QB8 is used at 5V, no external crystal or oscillator is required running with internal oscillator.

Figure 1-19 shows connection between MCU and the MON08 debug and programming interface.
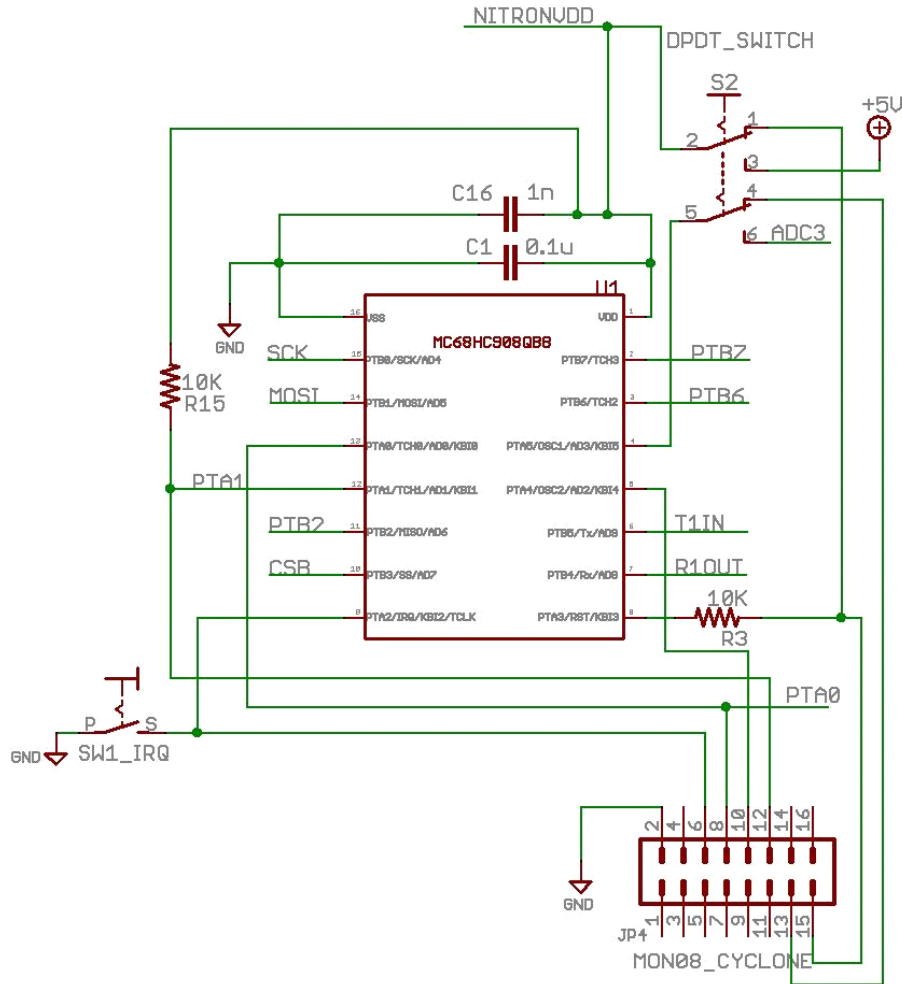
Figure 1-19. MCU debugging and programming circuitry

1.14   Touch Panel Board

1.14.1 Introduction

The Touch Panel Board has no components except for a 15x1 female terminal connector that attaches to the Analyzer Board. The TPB is just a simple double sized PCB with cooper traces. This section describes most of the considerations when designing electrodes for applications with MC33794 and particularly the design of the touch pads.

1.14.1.1   Pads Design

The TPB uses tree types of pads: single, multiplexed and continuous pads. Each one of these types is described in this section.

1.14.1.2 Single Pads

Single Pads are designed using one E-field electrode channel per pad. This design is very simple and limits the touch panel to 11 pads (E1, E2…, E9, REFA and REFB).
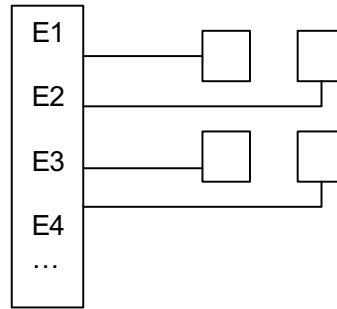
Figure 1-20. Single Electrodes concept

1.14.1.3 Multiplexed Pads

Multiplexed pads are formed by forming combinations of two or more electrodes per pad; this system is analogous to a matrix key pad where the number of touch pads can be increased using just a few electrodes terminals.
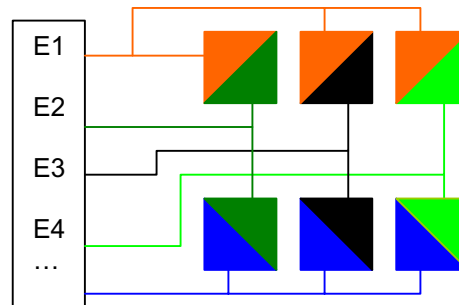
Figure 1-21. Multiplexed Electrodes Concept

For example, using two electrodes per pad, E1 and E2 form a touch pad, E1 and E3 form other pad, as well E1 and E4, and then the same with all other electrodes combinations, this way, a total of 57 pads using the 9 electrodes and 2 references can be archived.

Using "N" Electrodes per touch pad and "E" Electrode channels on the IC, the number of possible unique touch pads is given by:

$$\frac{E\,!}{N\,!\,(E\,-\,N\,)!} \;+\; N$$

The advantage of multiplexing electrodes is clear: the number of pads using a single E-field sensor can be highly increased. The major disadvantage is when multiplexing electrodes per pad, the area of the capacitor formed by each electrode is reduced and consequently reducing sensitivity.

1.14.1.4 Continuous Pads

Continuous electrodes can be designed either Single or multiplexed; the main characteristic of this kind of pad is that the value of the capacitance read is different depending on where specifically the electrodes are touched. The idea is to create a change in the DC value read as a finger is moved within the pad. Slider bars are used like slide potentiometers.

Figure 1-21 shows an example of continuous electrodes in both modalities: multiplexed and single.
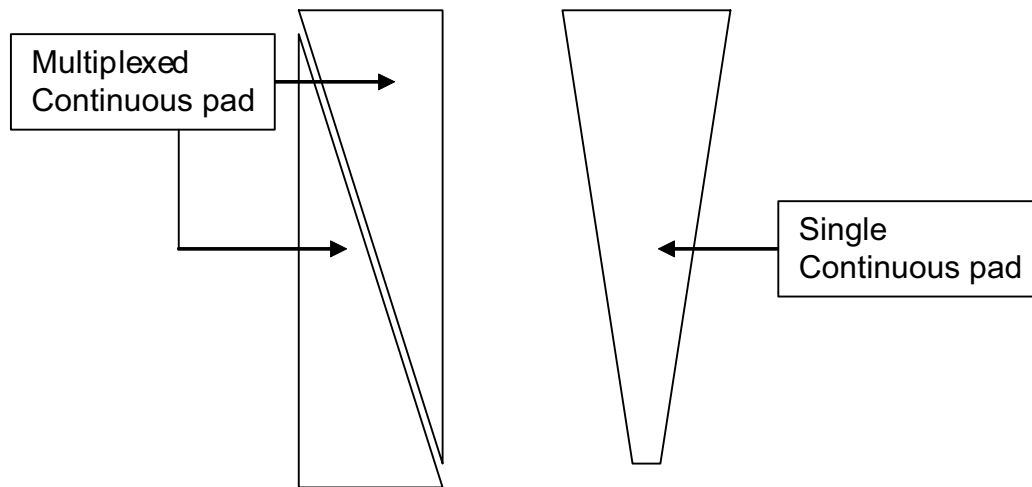
Figure 1-22. Continuous Pads concept

1.15 PCB Considerations

1.15.1 Electrode Size

When designing the electrodes for any application, one must take into account the physical size of the conductive electrode.

The larger the electrode, the more range and higher sensitivity will be obtained. However, as the electrode size is increased, so is its susceptibility to interference, electrical noise, and "stray" electric-field paths in its surroundings. One of the key practices regarding electrode design is for the electrode's area to correspond to the surface area of the object being detected. Touchpad applications, for example, would only require a size that suits the surface area of a finger.

The size of the electrode should correspond to the size of the object operating the panel, such as a finger. The area of the electrodes should be made as large as possible within this constraint.

1.15.2 Routing

The electrodes of a touchpad can be formed directly on Printed Circuit Boards (PCB) using copper circuit traces. When routing pads to electrode terminals, each trace must be the same distance from the others and routed following a star configuration. Following this recommendation output of the different channels is almost the same and reduces capacitive loading.

1.15.3 Grounding

The hand can be modeled as a capacitor to a "virtual ground", being the first plate of the capacitor. The E-field electrode or touch pad is the second plate. The dielectric material is the glass or acrylic between the two plates.
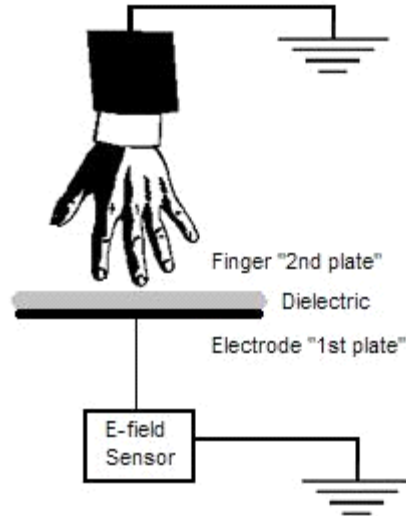
Figure 1-23. electrical grounding considerations

When a finger approaches the touch pad, it has to be referenced to the same E-field ground in order to find a return pad to the E-field sensor.

When running with external power supply most of the time this reference is intrinsic since external power supply is physically grounded, as well as human body in contact with a physical ground.

When running on external batteries this "reference" must be set externally since the battery is not physically grounded. It is recommended to reference the human body to the same Ground potential of the board. Analyzer board includes a GND terminal on the left upper corner as shown in Figure 1-24, GND terminal might be touched with left hand while the touch pads are used with the right one.

GND terminal

Note: Should be touched when running on batteries.
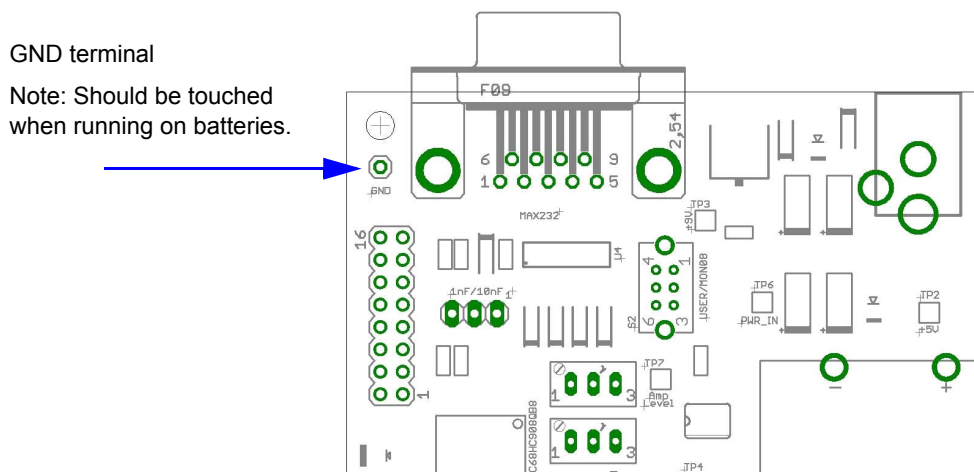
Figure 1-24. GND terminal within AB board; running on batteries effect

1.15.4 Shield

Shield terminal within the e-field sensor provides a buffered version of the returned AC signal from the electrode. Since it has nearly the same amplitude and phase as the electrode signal, there is little or no potential difference between the two signals thereby canceling out any electric field.

In touch pads applications "Shield" is used to drive a ground plane that is used behind the touch sensors electrodes at the backside layer of PCB, to cancel out any virtual grounds that could attenuate the AC signal.

Typical application is to connect the Shield Drive to the shield of a coaxial cable used to connect an electrode to the corresponding electrode terminal. With correct shielding, coaxial cables or PCB layers can be used to connect remote electrodes up to a few meters away, while obtaining measurements as accurately as if the electrodes were directly connected to the IC.

1.16 Mechanical Considerations

1.16.1 Glass

**Touch panel system using E-field sensors (TPS) was tested with common glass as the dielectric; using the system without amplifier an accurate detection through a 4mm glass was obtained. Using the amplifier with approximately a gain of two and a proper offset adjustment the detection was through approximately 10mm.**

Glass is mounted over the PCB with the copper pads, the dimensions of the glass are shown in Figure 1-25.

For testing purposes, the glass was patched with the PCB using a thin double sided tape. In the final application, the mechanical designers should determinate the best way to mount the dielectric with the electrode pads.

The gap between glass and dielectric material and the PCB should be as constant as possible, even after a touch condition. Many times, when the panel is touched, variations in other electrodes or noise in the measurement can be presented if the gap is not constant. Minor changes in the gap between the plates of the capacitor will represent a considerable change in the E-field measurements; therefore mechanical design should be very strict regarding this constant.
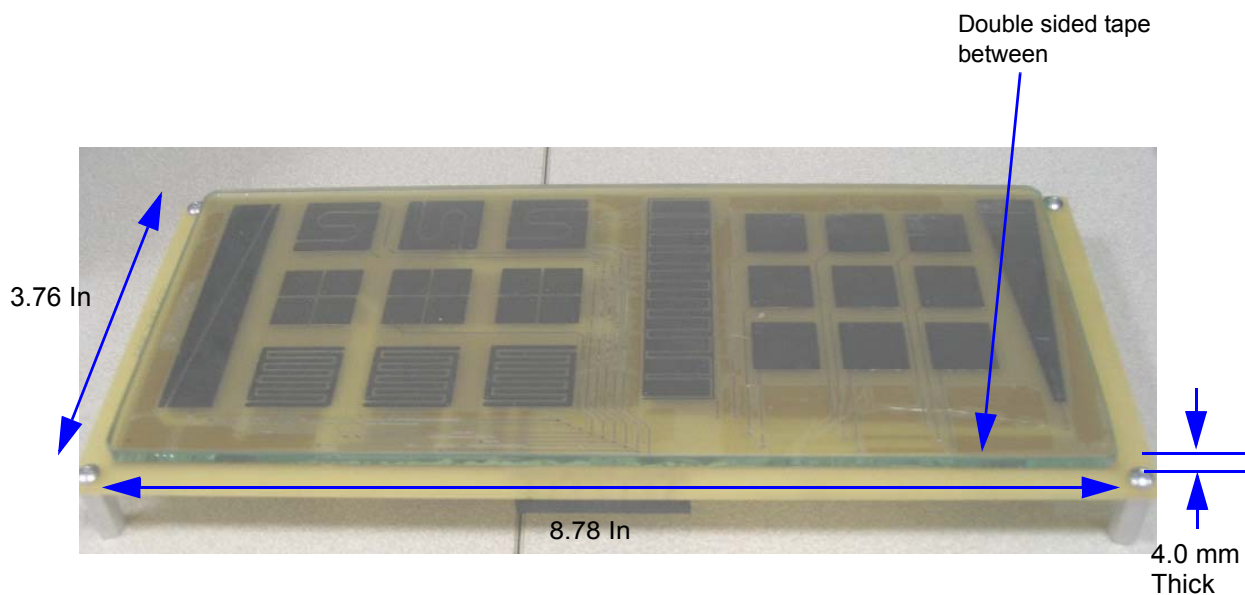
Figure 1-25. Touch panel board mechanical considerations

1.16.2 *TPB connector*

The TPB connector is an SMD 15 terminal connector mounted on the back side of the touch panel board (TPB). The TPB connector fits and is compatible with the 15 terminal connector JP2 in the analyzer board.

Special care must be taken when the two boards are attached to each other, bending or moving the Touch panel board from Analyzer board might detach the connector from the PCB.

1.16.3 Other Considerations

Many of the problems presented when noise is present in the reading of the electrodes are related with mechanical design. Some important mechanical considerations are listed below.

The electrodes board should have a flat surface for the dielectric material mount . If vias are used on this board, shouldn't be manufactured manually to avoid solder joints to hinder the mounting of the dielectric material. For the same reason, if components are required on the back of electrodes board, all those should be Surface Mount Technology (SMT).

Touch pad electrode to glass gap must be constant, even after touch condition since small gap changes represent a considerable change in the output of the E-field sensor.

If using fumed or painted glass, the dielectric constant of the glass is affected, testing must be performed for any new variable or material applied to the touch panel.

1.17 Software Design Considerations

Demo board firmware demonstrates the functionality of the MC33794DW device. Using the device as the main sensor for a 16 key keypad application, shows the possibilities of a larger system by multiplexing the electrodes. Two types of electrode configuration where used, a single electrode key configuration and two electrodes per key configuration.

- Electrode value reading is done by the MCU device, by selecting the appropriate channel lines and then reading the value on the MCU A/D module. Differences on the read value represent changes on the electrode field meaning the electrode might be near the presence of a human finger.

- Mixing different types of key configurations, multiplexed and not multiplexed results in a more complex software algorithm, for this project the routines where designed to get the best of both types of electrodes, but it is important to note that due to the mixed configuration the first thing to check is the key pressed configuration. And then use a different routine to find out the represented key according to the multiplexed or not multiplexed algorithm.

- The Demo board is designed to be used as a stand alone application by giving user feedback through on board displays and buzzer, the board can also be connected to another device via the SCI port.

- On Board displays are managed using an MC33993 device, which communicates to the MCU via an SPI bus while SCI communications are handled by the internal modules of the MCU.

- Demo firmware is grouped in 2 files communications.c and main.c.

- Communications.c is used for the SCI and SPI communication routines, as well as some timing delay routines.

- Main.c is where the main routines are located, along with the functions more related to the core functionality of the E-Field keypad application.

- ReadElectrode function is used to read the electrode values. This function will configure the electrode select lines PTA0, PTA1, PTB6 and PTB7 according to the desired electrode, and will wait to give some time to the electrode signal to stabilize, if needed this dead time can be used to send SCI data.

- 32 samples of the electrode channel level are acquired to make an average of this value; the resulting value is stored in the appropriate INT16evalues location.

- Sending data to the SCI interface is accomplished while waiting for the electrode value to stabilize in the function readElectrode. This implementation takes advantage of the periodicity in which the electrodes are readied in this application and at the same time improves the application using the dead time to accomplish this task. The standard SCI configuration is 8 bits, 9600 no parity, 1 stop bit.

- The displayData function is used to display electrode changes in the on-board displays . In order to display the correct electrode changes, this function requires some tasks to be accomplished before calling this function.

- Steps to make a valid use of displayData function:

- The call readValues() function read the electrode value of each channel using readElectrode function; after readValues is completed, actual electrode values of all channels will be present on the INT16evalues array.

- Call verifyElectrodes() searches for 3 electrode channels with greater value change using a delta value from the actual value and the calibration value of each channel. The electrodes will be registered on the MaxIndex1, MaxIndex2 and MaxIndex3 variables, the delta value will be stored according on the Max0,Max1 and Max2 variables.

- The calibration value is a register of the value of the electrodes with out any change applied. This calibration routine is called in the initialization routine.

- After MaxIndex variables are updated displayData function see if the keys are a valid combination and if the change is enough to consider the electrode touched. The functions verifyKeys() try to find a single electrode touched and if a possible multiplexed electrode is detected it will return the value 30 so verifyMuxKeys() must be called to find the multiplexed "button" value.

- dispalyData() will then call the display function which will be responsible for sending the correct MC33993 commands to the MC33993D device to display in the on board display the change registered on the electrodes.

- The VerifyKeys and VerifyMuxKeys parameters can be adjusted in the settings.h file.

- Note: The firmware is designed to be downloaded into the board via serial port or using a MONO8 programmer. Using the serial boot loader requires a different interrupt vector location, for this propose the define of

SERIAL_DOWNLOADER modifies the standard interrupt vectors location to a new location where the code is compatible with the serial boot loader. This change is not compatible if a MONO8 programmer is used so SERIAL_DOWNLOADER must not be defined if no boot loader is used.

1.17.1 Firmware Functional Description

Module:	main.c
Function:	barGraph
Syntax:	void barGraph(unsigned char led)
Parameters:	led
Return:	none
Description:	Routine to handle the six led bar, if WALKING_LED is defined just one LED is turned on at a time; else all the LED's below the received value are turned on.

Module:	main.c
Function:	calibrateElectrodes
Syntax:	void calibrateElectrodes(void)
Parameters:	none
Return:	none
Description:	Read each electrode value and store the result in the calibration register of each electrode.

Module:	main.c
Function:	display
Syntax:	void display(unsigned char left, unsigned char right)
Parameters:	left, right
Return:	none
Description:	Displays the hex value contained in the left and right bytes into the 7 segment displays using the MC33993 via SPI If a 255 value is received the display is turned off.

Module:	main.c
Function:	displayData
Syntax:	void displayData(void)
Parameters:	none
Return:	none
Description:	This function uses verifyKeys and verifyMuxKeys functions to find out if there is a key pad pressed. If a value different from 0 is found the corresponding value is displayed into the 7 segment displays and a beep is generated.

Module:	main.c
Function:	initPorts
Syntax:	void initPorts(void)
Parameters:	none
Return:	none

Description:	Initialize GPIOs, Oscillator, A/D module, Timers and external MC33993 chip.

Module:	**main.c**
Function:	main
Syntax:	void main(void)
Parameters:	none
Return:	none
Description:	Set up peripherals, get calibration value of electrodes and continuously scan the keys and take the appropriate action.

Module:	**main**
Function:	readElectrode
Syntax:	void readElectrode(unsigned char channel)
Parameters:	channel
Return:	none
Description:	Reads the selected channel and places the result into INT16evalue, channel takes on value from 1 to NUMBER_OF_ELECTRODES

Module:	**main.c**
Function:	readValues
Syntax:	void readValues(void)
Parameters:	none
Return:	none
Description:	Reads all electrodes using the readElectrode function.

Module:	**main.c**
Function:	verifyElectrodes
Syntax:	void verifyElectrodes(void)
Parameters:	none
Return:	none
Description:	Finds the three highest electrode change values and the corresponding electrodes are stored in the global variables MaxIndex0..MaxIndex2. Delta values are stored in Max0..Max2

Module:	**main.c**
Function:	verifyKeys
Syntax:	unsigned char verifyKeys(void)
Parameters:	none
Return:	Key pad number if any are valid, or 30 if a multiplexed pad is detected.
Description:	Evaluates the data in Max0 and Max1 global variables, returns the represented electrode if valid, and a 30 if the combination seems to be a multiplexed electrode key.

Module:	**main.c**

Function:	verifyMuxKeys
Syntax:	unsigned char veifyMuxKeys(void)
Parameters:	none
Return:	Key pad number represented by the electrode delta combination if any valid.
Description:	Verifies the values of Max0 and Max1 to find out if a valid key pad combination is present, returns the number of the key pad is any found.

Module:	**main.c**
Function:	_TOF_Interrupt
Syntax:	interrupt void _TOF_Interrupt(void)
Parameters:	none
Return:	none
Description:	Handler routine for the timer overflow interrupt, this routine stops the timer and turns off the beeper.

Module:	**main.c**
Function:	_KBD_Interrupt
Syntax:	interrupt void _KBD_Interrupt(void)
Parameters:	none
Return:	none
Description:	Handler routine for the keyboard interrupt, makes a beep and recalibrates the electrodes.

Module:	**communications.c**
Function:	delay10mS, delay100mS, delay1mS
Syntax:	void delay10mS(void), void delay100mS(void), void delay1mS(void)
Parameters:	none
Return:	none
Description:	Functions to wait for the specified amount of time using a for cycle.

Module:	**communications.c**
Function:	sendSCIchar
Syntax:	void sendSCIchar(unsigned char u8serialValue)
Parameters:	u8serialValue
Return:	none
Description:	Sends via SCI the u8serialValue

Module:	**communications.c**
Function:	sendSCIValue
Syntax:	void sendSCIValue(int u16serialValue)
Parameters:	u16serialValue

Return:	none
Description:	Converts the 16 bit value into a 3 digit hex value, and sends the three digits via SCI.

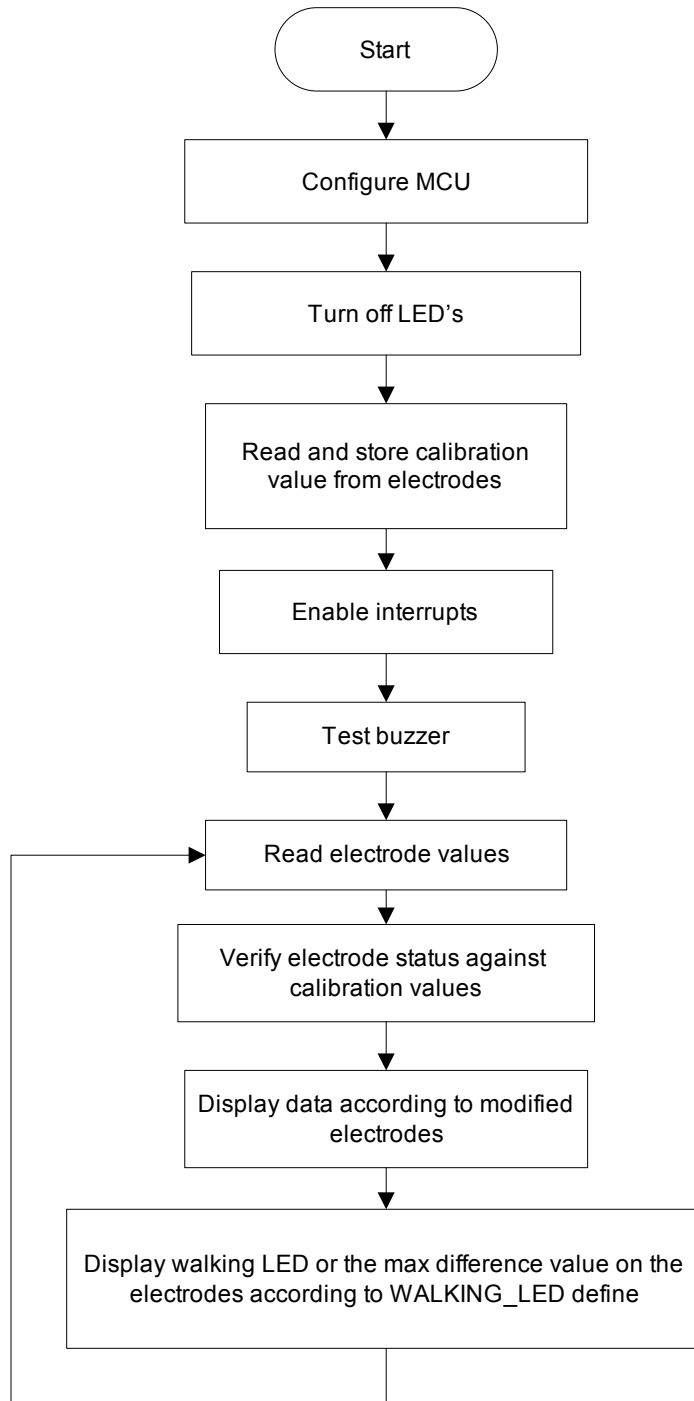| **Module:**	**communications.c**
Function:	sendSPI
Syntax:	void sendSPI(void)
Parameters:	none
Return:	none
Description:	Sends via SPI the bytes located on the global variable MSDI[0]..MSDI[2]

1.18 Flow Diagrams

```
                    ┌─────────────┐
                    │    Start    │
                    └─────────────┘
                           │
                           ▼
              ┌──────────────────────────┐
              │      Configure MCU       │
              └──────────────────────────┘
                           │
                           ▼
              ┌──────────────────────────┐
              │      Turn off LED's       │
              └──────────────────────────┘
                           │
                           ▼
              ┌──────────────────────────┐
              │  Read and store calibration│
              │    value from electrodes   │
              └──────────────────────────┘
                           │
                           ▼
              ┌──────────────────────────┐
              │     Enable interrupts     │
              └──────────────────────────┘
                           │
                           ▼
              ┌──────────────────────────┐
              │       Test buzzer         │
              └──────────────────────────┘
                           │
                           ▼
              ┌──────────────────────────┐
         ┌───▶│    Read electrode values  │
         │    └──────────────────────────┘
         │                 │
         │                 ▼
         │    ┌──────────────────────────┐
         │    │ Verify electrode status against│
         │    │    calibration values     │
         │    └──────────────────────────┘
         │                 │
         │                 ▼
         │    ┌──────────────────────────┐
         │    │ Display data according to modified│
         │    │        electrodes         │
         │    └──────────────────────────┘
         │                 │
         │                 ▼
         │    ┌──────────────────────────────────┐
         │    │ Display walking LED or the max difference value on the│
         │    │ electrodes according to WALKING_LED define │
         │    └──────────────────────────────────┘
         │                 │
         └─────────────────┘
```
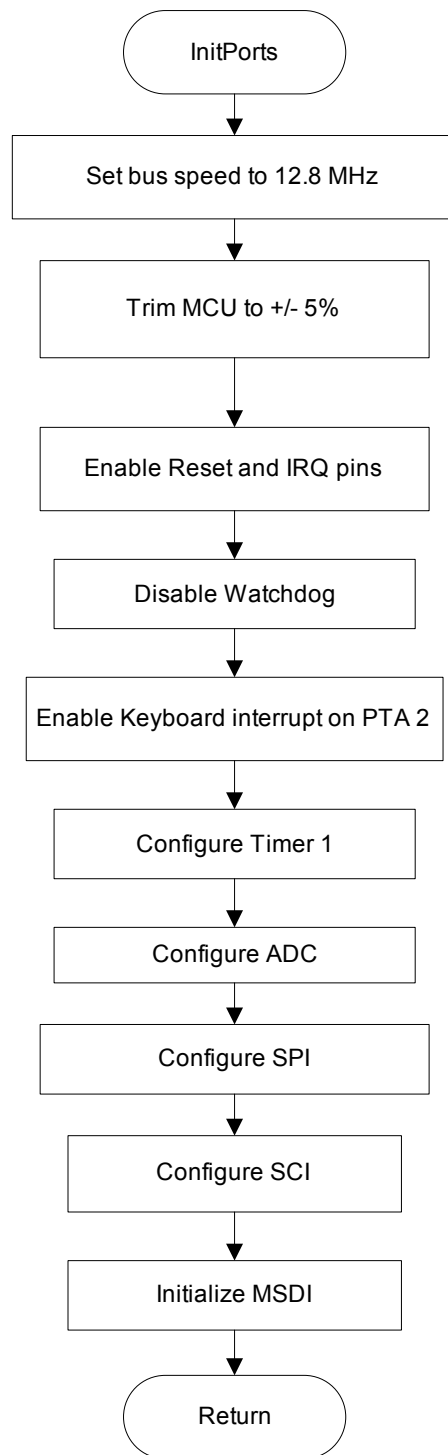
Figure 1-26. Main Program Flow

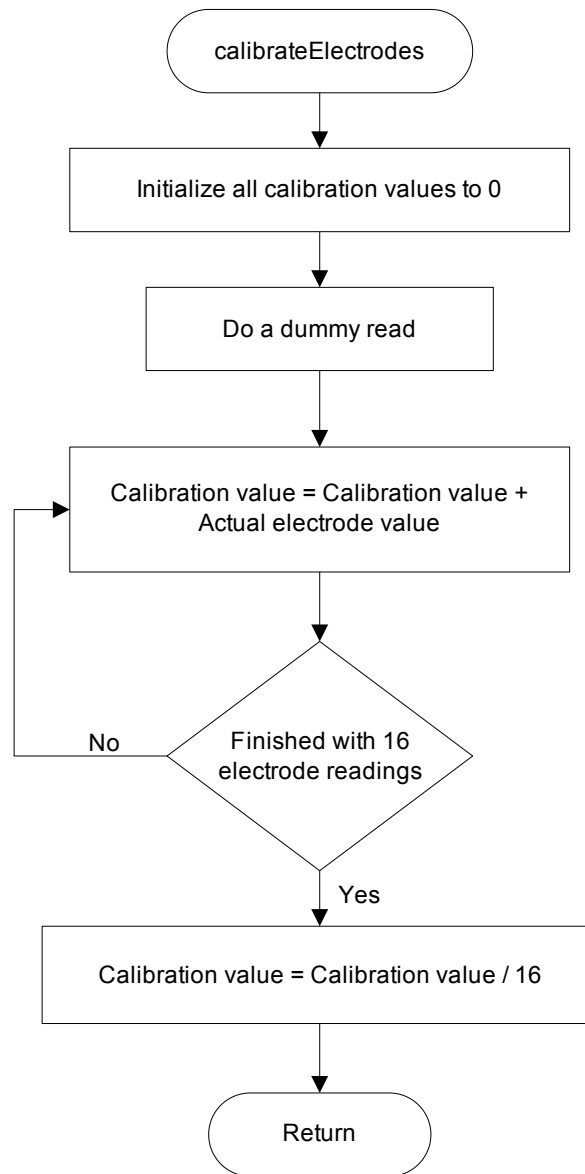**Figure 1-27. Initialization Ports**
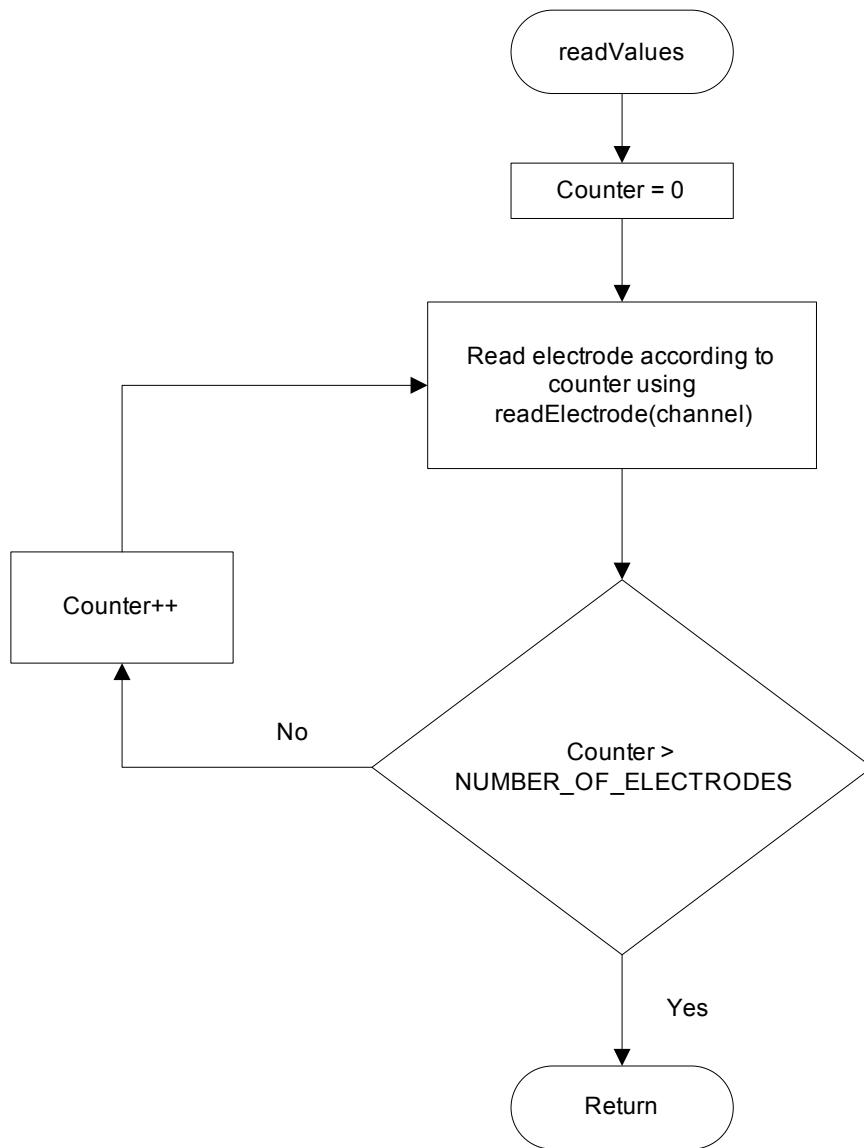
Figure 1-28. Calibrate Electrodes
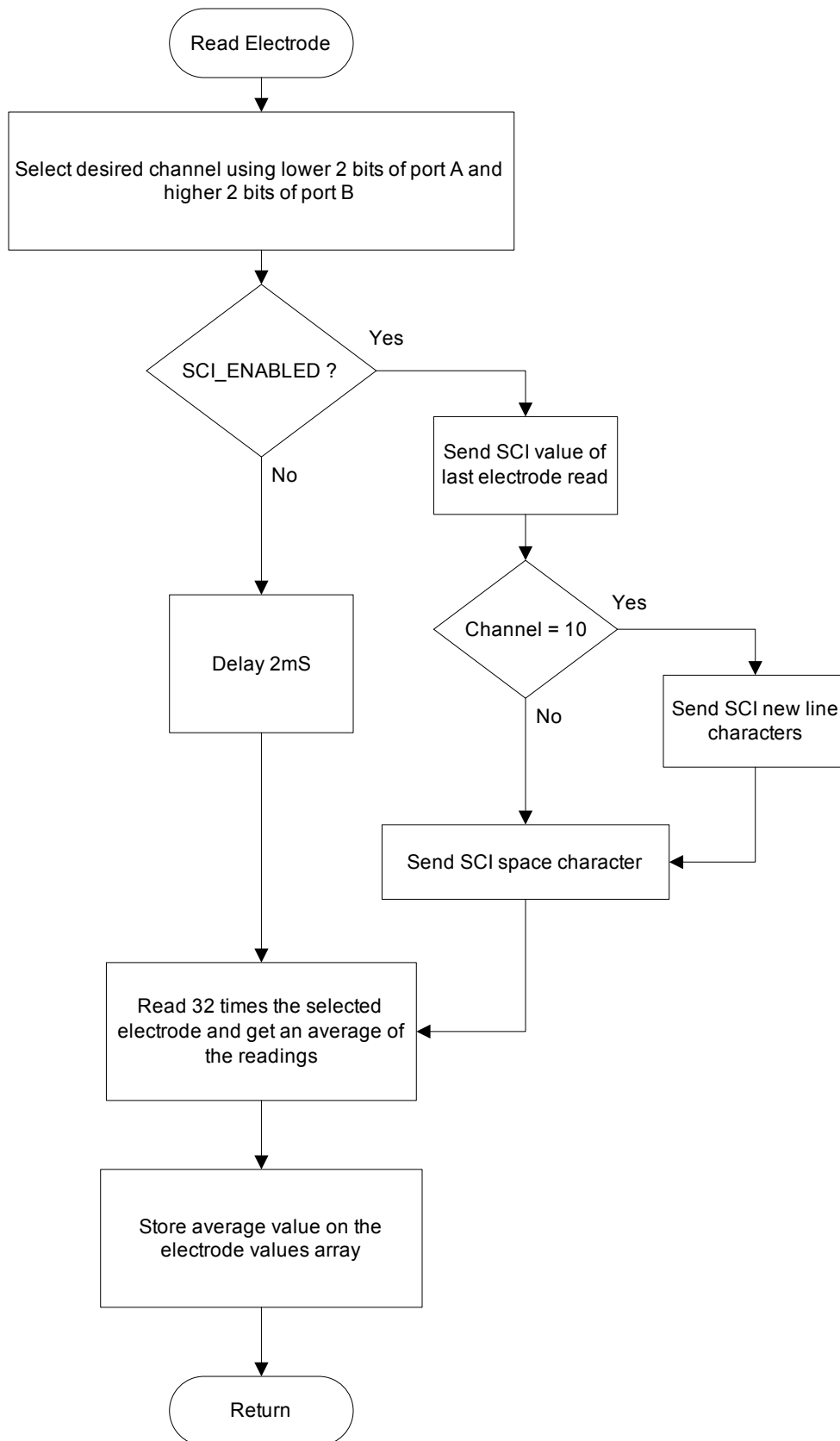
Figure 1-29. Read Values
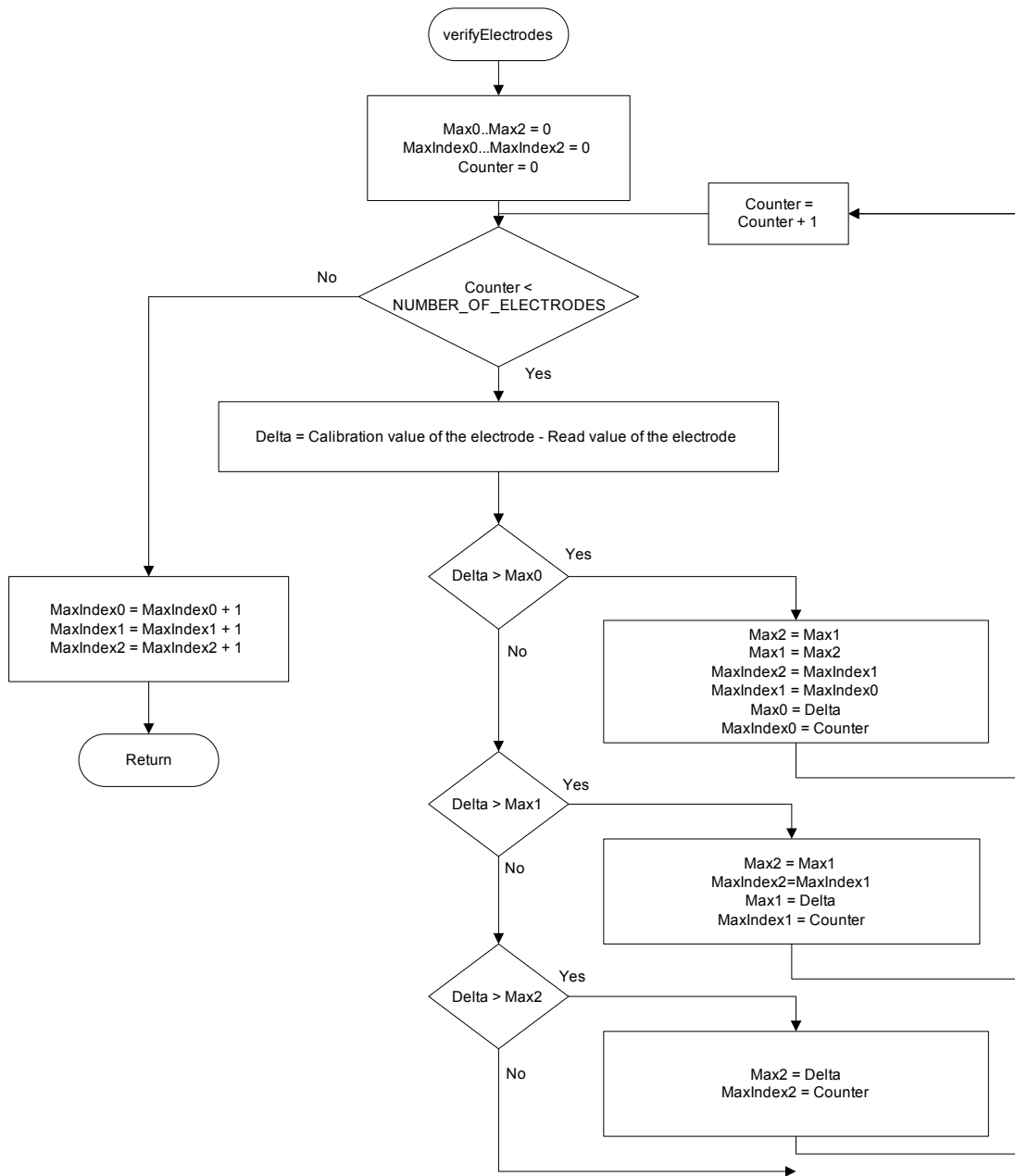
Figure 1-30. Read Electrode
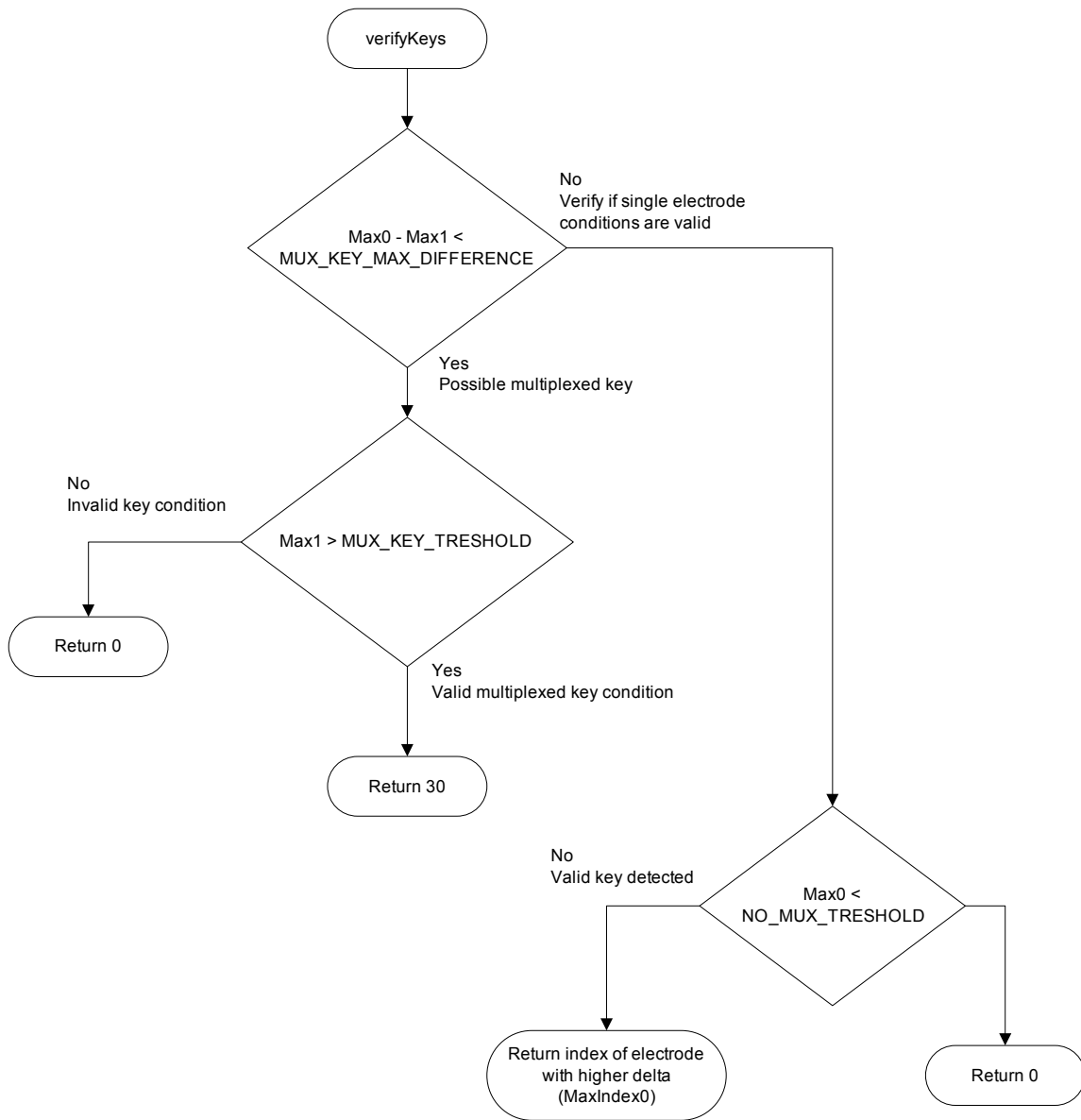
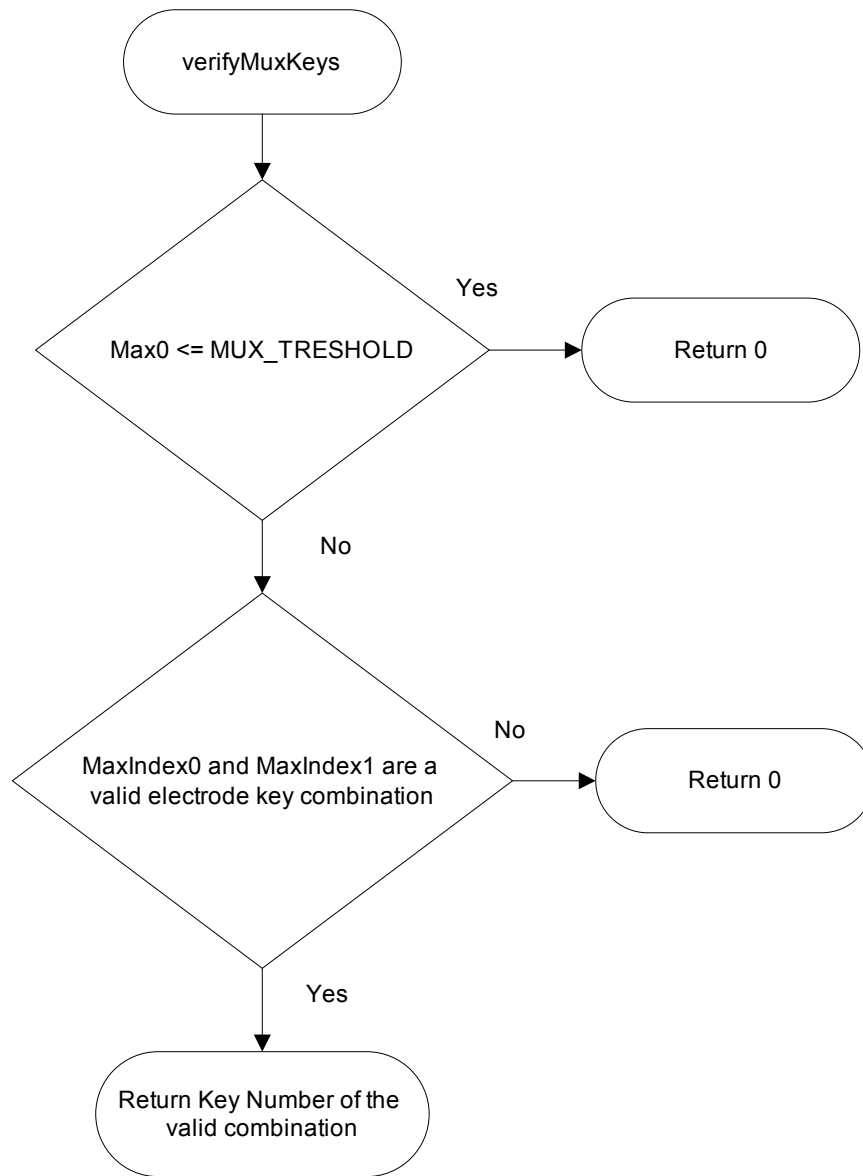**Figure 1-31. Verify Electrodes**

Figure 1-32. Verify Keys

Figure 1-33. Verify Mux Keys
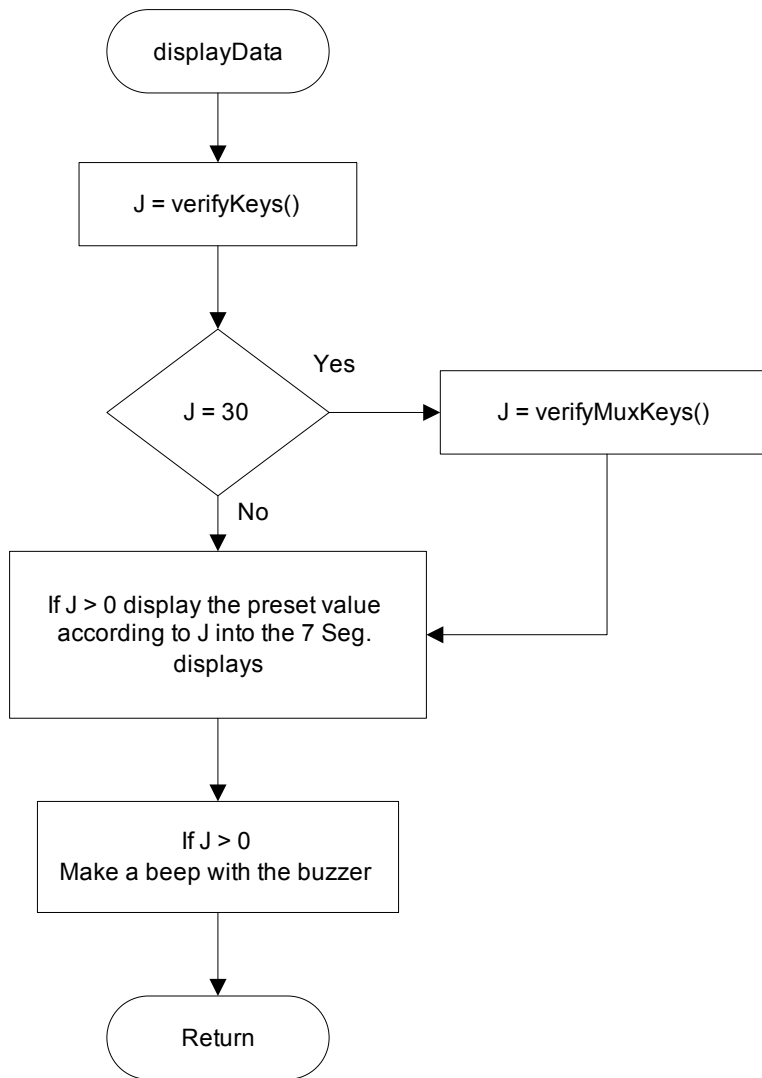
Figure 1-34. Display Data

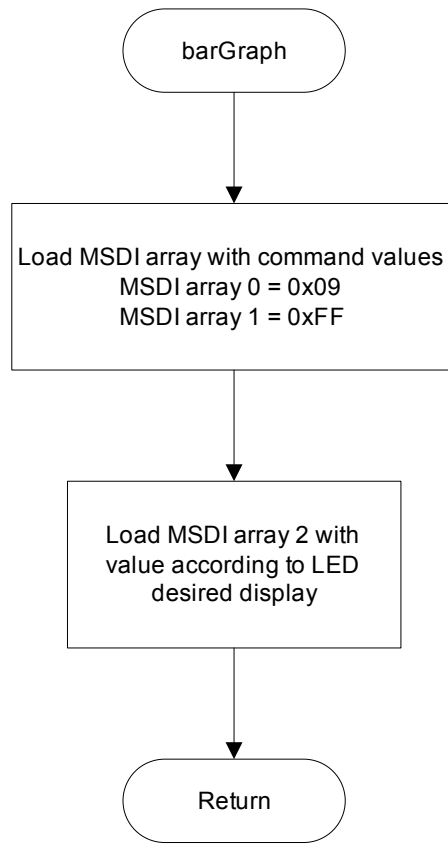**Figure 1-35. Display**

```
              ┌─────────────┐
              │   barGraph  │
              └─────────────┘
                     │
                     ▼
   ┌───────────────────────────────────┐
   │  Load MSDI array with command values │
   │       MSDI array 0 = 0x09          │
   │       MSDI array 1 = 0xFF          │
   └───────────────────────────────────┘
                     │
                     ▼
        ┌──────────────────────┐
        │ Load MSDI array 2 with │
        │ value according to LED │
        │    desired display     │
        └──────────────────────┘
                     │
                     ▼
              ┌─────────────┐
              │    Return   │
              └─────────────┘
```
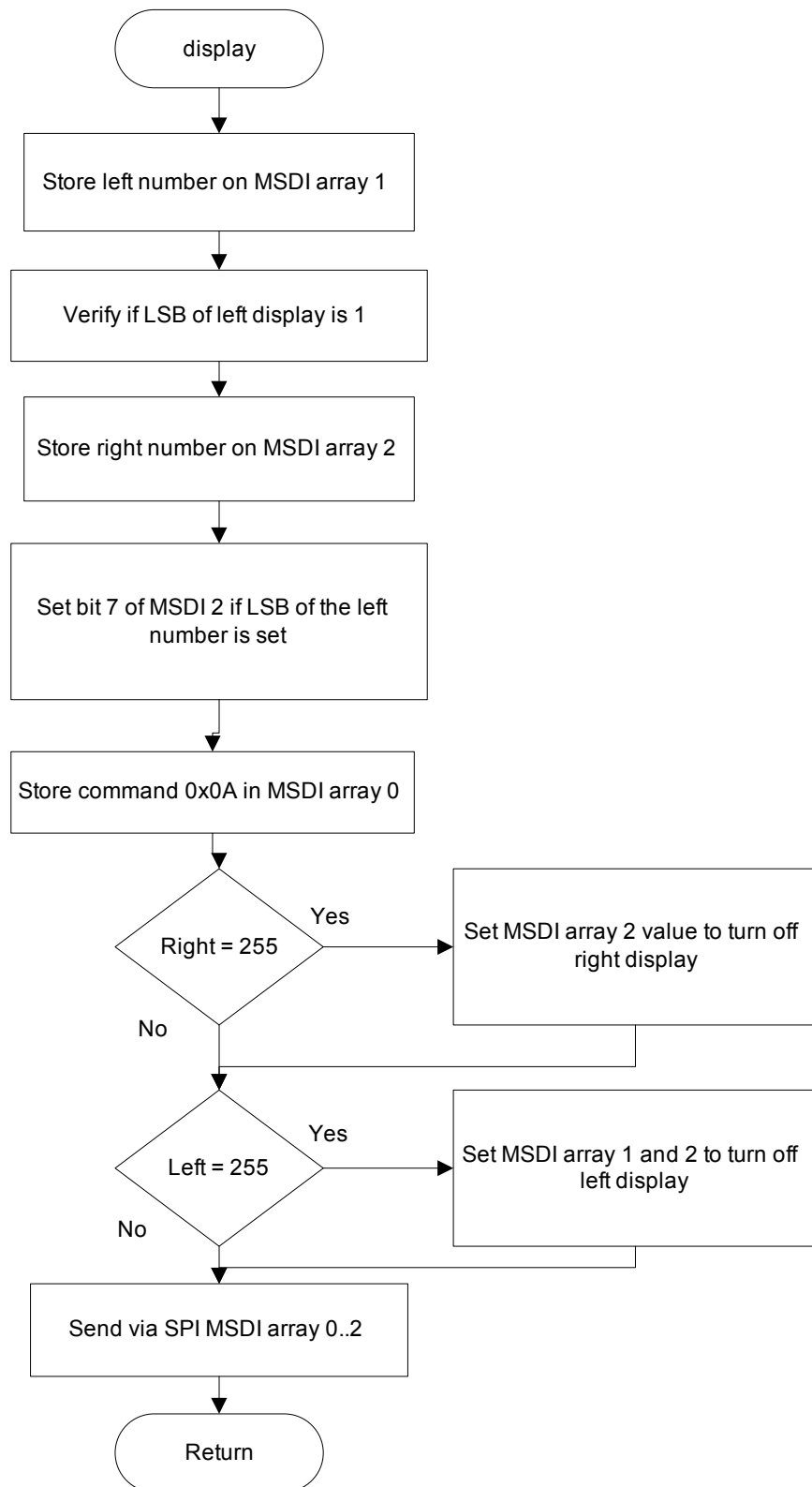
Figure 1-36. Bar Graph

Appendix A   Bill of Materials

Table A-1 shows the bill of materials for the Touch Panel System.

Table A-1. Bill of Materials

Part	Value	Manufacturer Part #	Package	Description	Manufacturer
C1, C2, C3, C10	0.1uF	06032R104K7B20D	C0603	Surface Mount Ceramic ChipCap	ANY
C5, C6, C17	10u	B45197A4106K309	C-EIA	Surface Mount Tantalum Electrolytic Capacitor	ANY
C7, C8	0.1uF	ECS-T1VY104R	A-EIA	Surface Mount Tantalum Electrolytic Capacitor	ANY
C9, C12, C13, C15, C18, C26, C27, C28, C29, C30, C31, C32, C33, C34, C35	10nF	06032R103K9B20D	C0603	Surface Mount Ceramic ChipCap	ANY
C11	4.7uF	ECS-T1AY475R	A-EIA	Surface Mount Tantalum Electrolytic Capacitor	ANY
C14, C16, C25	1nF	06032R102K9B20D	C0603	Surface Mount Ceramic ChipCap	ANY
C19, C20, C21, C22, C23, C24	1uF	ECS-T1CY105R	A-EIA	Surface Mount Tantalum Electrolytic Capacitor	ANY
D1, D2		1N4148WS	SOD323	Surface Mount Switching Diode	ANY
D3		BZT52C5V1	SOD123	5.1V SMD Diode	ANY
DIS1, DIS2		LSHD-A103		7 Segment LED Red Display	ANY
JP1, JP3		TSW-103-23-S-S		1x3 terminal Header	ANY
JP2		TSW-115-23-S-S		1x15 terminal Header	ANY
JP4		TSW-108-23-S-D		8x2 terminal Header	ANY
JP5		TSW-101-23-S-S		1x1 terminal Header	ANY
LED1, LED2, LED3, LED4, LED5, LED6		LNJ311G8TRU	1206	Surface Mount Green LED	ANY
P1		RAPC-722		Power Jack	ANY
R1	47K	ERJ-3GEYJ473V	R0603	Surface Mount Resistor	ANY
R2	680		R0603	Surface Mount Resistor	ANY
R3, R9, R10, R11, R12, R15	10K	ERJ-3GEYJ103V	R0603	Surface Mount Resistor	ANY
R5	1K	ERJ-3GEYJ102V	R0603	Surface Mount Resistor	ANY
R6	39K	ERJ-3GEYJ393V	R0603	Surface Mount Resistor	ANY
R7, R8	100k		3266Y-1-104	Trimming Potentiometer	ANY
R13, R14	2.2K	ERJ-3GEYJ222V	R0603	Surface Mount Resistor	ANY
R16	10		R0603	Surface Mount Resistor	ANY
R17	120		R0603	Surface Mount Resistor	ANY

MC33794RM Touch Panel System, Rev 1.0

Bill of Materials

S1		EG1218		SPDT Slide Switch	E-Switch
S2		EG2207		DPDT Switch	E-Switch
SW1_IRQ		KSR221G		SPST Surface Mount Switch	ANY
U1		MC68HC908QB8	SOIC16W	Micro controller	Freescale Semiconductor
U2		LM2767M5	SOT23-5	Switching Capacitor Voltage Converter	ANY
U3		LM358AD	8-SO	IC Opamp Dual	ANY
U4		MAX232CSE	16-terminal SOICN	RS-232 Interface	Maxim
U5		MC33993DWB	32-SOICW	WB MC33993 in SO-32WB	Freescale Semiconductor
U6		MC33794DWB	54-terminal SOIC	Electric Field Imaging Device (ODS)	Freescale Semiconductor
U7		MC7805CDT	D-PAK	5V Voltage Regulator	ANY
U8		PB-12N23P-05		Buzzer	Projects Unlimited
X1		182-009-212-531	D-type Female	RS-232 Connector	ANY
TPB connector		SSM-115-S-SV		SMD SOCKET STRIP, CENTERLINE: .100" (2,54MM), single row, 15 contacts	SAMTEC

Authors' Note: Freescale Competitor notation:

Freescale does not assume liability, endorse, or warrant components from external manufacturers that are referenced in circuit drawings or tables. While Freescale offers component recommendations in this configuration, it is the customer's responsibility to validate their application.

REVISION HISTORY

Revision	Date	Description of Changes
0.2	Sept, 2005	Initial Release

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