AN1102

Layout and Physical Design Guidelines for Capacitive Sensing

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INTRODUCTION

This application note describes the layout and physical design guidelines used for the capacitive sensing solution proposed in *AN1101 "Introduction to Capacitive Sensing"*. The layout and physical design of your capacitive system is an important part of the design process. A good layout will make the software implementation simpler. Depending on the application, the layout may be very simple, or more complex, but the same simple guidelines govern all layouts.

PAD SHAPE AND SIZE

General Guidelines

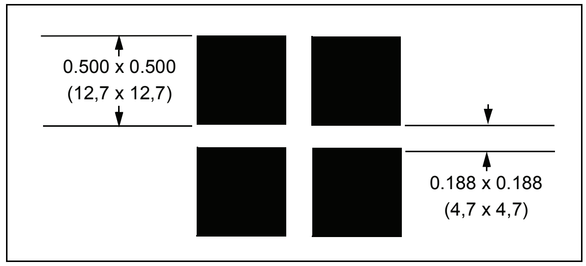
When designing a capacitive button, the shape of the pad is not very important. The area of the pad is the parameter to design for. A larger pad area will allow better detection and sensitivity. A smaller pad has poorer detection capability. Also, a greater distance, between capacitor plates reduces capacitance as in Equation 1. As a rule of thumb, the area should be about the size of an average person's finger when pressed against the button; for example, a square 0.5" x 0.5" (12,7 mm x 12,7 mm) makes a good sensor. This very simple shape is easy to design and easy to implement in a grid of buttons.

EQUATION 1: CAPACITANCE EQUATION

$$C = \frac{\varepsilon_0 \varepsilon_r A}{d}$$

Another related concern is the proximity of a button to adjacent buttons. When a person touches a sensor, or its covering plate (plastic, glass, etc.), the person's finger introduces additional capacitance, not only to the current sensor, but to other nearby sensors at a lesser effect. Maintaining a gap between adjacent sensor pads provides insulation from the finger's capacitance. Usually a gap of 3/16" (4.7 mm) is sufficient. Figure 1 illustrates the suggested layout; the black squares are copper pads which act as buttons.

FIGURE 1: EXAMPLE PAD SIZES AND SHAPE



Again, the shape is not the key parameter; a circle of approximately the same area will function comparably to the square shape suggested.

Sometimes a button is shaped for aesthetic purposes. A simple way exists to make a very nice looking interface to a person. By putting a printed paper with graphic designs between the pad and a clear touch surface, the user will see the graphic paper while the actual pad is hidden below. The paper may have the complex shape on it, meanwhile below the paper, a simple, less artistically demanding copper pad can exist with a simple shape. An example is shown in Figure 5.

EFFECTS OF COVERING PLATE

Window glass and Plexiglas® are common materials for use as the surface which a person touches. These common materials come in various thicknesses, and the thickness and composition of the material between the pad and touching surface affects sensitivity. When comparing window glass to Plexiglas, or another brand acrylic, the window glass will allow detection through a thicker piece of material given identical testing conditions. This is because the dielectric constant of window glass is higher than the dielectric of acrylics. Numerous specifications for a particular acrylic or type of glass exist, but the dielectric constants are on the order of 2-3 for acrylics and about 7 for window glasses. Other notable substances have dielectric constants of 1 for air and 80 for water.

From a capacitive sensing perspective, an extremely thin plate is ideal because it increases sensitivity and enables better accuracy. The thinner a covering plate is, the more sensitive the system will be. The two materials mentioned before have been tested with a commonly available thickness of 2 mm, and both acrylic Plexiglas and window glass work well in a variety of conditions. Thicker, 5 mm Plexiglas has also been found to work acceptably.

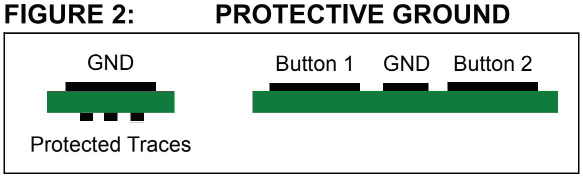
Conductive materials, such as metal, will not work as a covering plate. Metal plates absorb the field lines created by the oscillating pad. A person's finger press may be too weak to disturb the oscillator enough, or if it does create enough change, the press will trigger all of the buttons which are beneath the plate, which is equally as bad. All buttons covered will fire because the metal is conductive and charge moves freely through it.

GROUND

Because the sensing method is dependent on the parasitic capacitance of a sensor to ground, placing ground very close to the sensor will reduce sensitivity by increasing C_p, parasitic capacitance. Generally, it is desirable to keep ground away from sensors and traces leading to the sensors. Doing so will reduce C_p, which will allow the oscillator to run faster, create larger changes relative to a finger press (easier detection) and allow a faster scan rate.

Sometimes placement of ground can have a positive effect to reduce sensitivity between adjacent buttons or shield traces. While not normally required, protecting traces or adjacent buttons from a finger press can be implemented by placing ground traces between the finger and the trace or pad. In the protected trace situation, the grounded copper below the covering plate will draw all of a finger's field lines to it and little or none will go to the traces. For reducing adjacent button interference, given sufficient spacing, a layer of ground between the buttons will reduce the sensitivity of Button 2 to a press on Button 1 (see Figure 2). A minimum distance of 1/16” (1.59 mm) between a button pad and ground is recommended to keep parasitic capacitance small.

FIGURE 2: PROTECTIVE GROUND



For applications with a lot of electromagnetic interference, shielding the traces leading to the pads will improve immunity. Obviously, the button interface may not be completely surrounded by ground, but if the inside of the panel can be shielded, it will help protect against EMI related problems.

TRACES AND PART PLACEMENT

Whenever possible, traces connected to the sensing plates should be kept small and away from ground and other traces to reduce parasitic capacitance and coupling of sensors to each other. It is also good to keep the area beneath a pad clear of traces if possible; instead, route traces around the outside of a pad and the gaps between pads. When using a 2-layer PCB, it is best to keep the traces on the bottom side of the PCB with all the devices, while the pads will be alone on the top of the PCB.

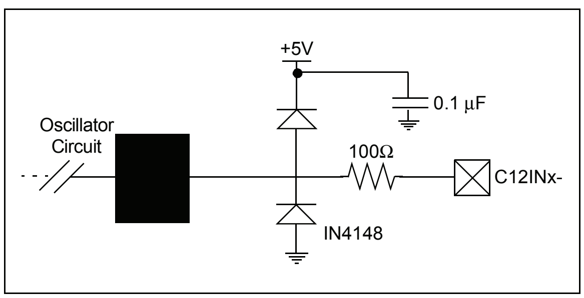
The PIC microcontroller and any additional sensitive parts should be laid out in a position on the PCB without button pads above them preferably. Placing parts in a centralized location can make all the traces coming to the PIC MCU easier to route. Again, this goes along the guideline of keeping the area beneath a pad clear. Infractions are permissible, but should be kept to a minimum.

Traces which are low frequency have little effect on the sensing process. For example, a trace leading to an LED is a non-critical, low-frequency trace. It may be routed wherever possible to make routing easier or plausible. An I^2C communications line will have high-frequency traces and it is desirable to keep high-frequency traces away from sensing traces. When such traces must cross, it is preferable to keep the noisy, high-frequency traces perpendicular to the sensing traces for minimal RF interference.

ELECTROSTATIC DISCHARGE

Microchip PIC microcontrollers include some ESD protection naturally. Microchip PIC MCUs are subjected to machine model and human body model tests. This has been sufficient for capacitive sensing systems, which have a copper pad directly tied to an input of the microcontroller. If additional security for ESD protection is required, an external circuit may be used (see Figure 3). The capacitor may be a standard, 0.1 µF capacitor from power to ground used for filtering near the microcontroller.

FIGURE 3: ESD PROTECTION CIRCUIT



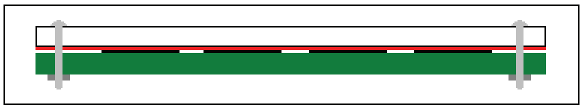
If the voltage rises above VDD + 0.7 volts, the top diode turns on and current flows into the capacitor. If the voltage goes below GND – 0.7 volts, the bottom diode turns on and current flows from the capacitor into the circuit. A nearly identical system is inside the microcontroller's I/O pin. The 100 ohm resistor ensures that the external diodes trigger first. This circuit has been tested to have minimal interference with capacitive sensing operations.

MOUNTING

The intent of this section is not to specify how a system must be created. There are many existing creative ways to build a system with capacitive sensors. Rather the purpose of this section is to describe a simple, easy and elegant method to make a sharp looking interface.

The assumptions for this design are that a flat face is desired, all hardware will exist on a single PCB, the interface has graphics and may be mounted by small bolts. The PCB and circuitry are all mandated by what the application is to do and should all be placed on the back side of the PCB; the front side should be completely flush. The end result will be a sandwich with the PCB on the bottom, a piece of stylized paper in the middle, a piece of Plexiglas on top and it will all be held together by bolts as in Figure 4. The Plexiglas is assumed to be 2 mm Plexiglas, available at a local hardware store, and the bolts can be small 4-40 or similar bolts.

FIGURE 4: CONSTRUCTION SANDWICH



The thickness of the copper pads, the black layer, is grossly exaggerated on purpose in Figure 4. When looking from the top the viewer sees a very sharp image of the paper through the glass, and the paper can present any shapes or images desired. The paper can be printed in color, and it results in a very good image through the Plexiglas. This method provides good contact of the pad to the covering plate without any adhesives.

FIGURE 5: DEMO PICTURES

The demo boards shown in Figure 5 are more easily constructed compared to adhesively attaching the covering plate to the PCB, especially with the paper in between. Some interesting parts are used in the demo, such as backward facing surface mount LEDs to shine through holes cut in the PCB. The bill of materials is listed in **Appendix A: "Multibutton Capacitive Demo Board"** for reference.

Adhesives may also be used to affix a covering plate to a PCB and its display layer, but they can be more difficult to work with. Adhesives can provide a large aesthetic advantage because there are no bolts which stick through the front face, and a perfectly flat panel is formed. Often adhesives leave some sort of residue, and this can be distracting when using a clear covering plate like acrylics. If the covering plate is opaque, then adhesives leaving residue is not a problem. The PCB may be simply glued to the backside of the covering plate, and any imperfections will not show on the button interface side.

Also, the sensors may be separate from the PCB. Wires leading off-board may direct the sensors to the location where they are to be mounted and appropriately affixed. This can allow for very flexible designs and permits shapes which are not flat.

CONCLUSIONS

The layout and design of a capacitive sensing system can, and most likely will, have conflicting tradeoffs. The presented material should be used as a guideline, and good judgment should be exercised when tradeoff situations occur.

To recap, as a general rule, the layout of a capacitive sensing system should use minimal ground possible and route wires as short, clean and far away from other potential interference sources as possible. Other related application notes include *AN1101, "Introduction to Capacitive Sensing", AN1103, "Software Handling for Capacitive Sensing"* and *AN1104, "Capacitive Multibutton Configurations"*.

TABLE 1: GLOSSARY OF TERMS

Acronym	Description
ε_o	Permittivity of Free Space
ε_r	Relative Dielectric Constant
d	Distance Between Capacitor Plates
A	Area of Plates
C	Capacitance

APPENDIX A: MULTIBUTTON DEMO BILL OF MATERIALS

The bill of materials for the multibutton capacitive demo board is shown in Table A-1. Particularly noteworthy parts are the surface mount LEDs which fit in a hole in the PCB and shine through that hole.

Also, the 74HCT4351 MUX was selected at the design time of this board. A cheaper, similar version, the 74HCT4051, is also suitable, and it performs equivalently as desired. The 74HCT4051 does not have a latch while the 74HCT4351 does, but the latch is unnecessary for the purposes of multiplexing an analog signal.

TABLE A-1: BILL OF MATERIALS

Qty	Component Name	Value	Vendor	Vendor P/N:
1	BTH-9V-1294-SMT	9 Volt	Digi-Key	1294K-ND
7	CAP-CRCW0603	100 nF	Digi-Key	PCC1762CT-ND
2	CAP-CRCW0603	1000 pF	Digi-Key	PCC2151CT-ND
2	CAP-CRCW0805	10 µF	Digi-Key	587-1295-1-ND
1	DIO-1N4148WS-SOD-323	1N4148	Digi-Key	1N4148WXTPMSCT-ND
3	HDR-PICKIT2-SERIAL-1X6	PICKIT™ SERIAL	Digi-Key	929835-01-36-ND
2	IC7-74HC4351-MUX-20P-SOICL-300	74HCT4351	Digi-Key	568-2873-5-ND
1	ICP-PIC16F630/SN-SOIC-14PIN-150"	PIC16F610/SN	MCHP	Microchip
1	ICP-PIC16F887/PT-TQFP44	PIC16F887/PT	MCHP	Microchip
11	LED-1105W-1206-BOT-MNT-NO-HOLE	RED	Digi-Key	404-1033-1-ND
7	LED-1105W-1206-BOT-MOUNT-HOLE	GRN	Digi-Key	404-1037-1-ND
3	LED-1105W-1206-BOT-MOUNT-HOLE	YEL	Digi-Key	404-1031-1-ND
2	RES-CRCW0603	1.00K	Digi-Key	311-1.00KHRCT-ND
2	RES-CRCW0603	3.01K	Digi-Key	311-3.01KHRCT-ND
6	RES-CRCW0603	10K	Digi-Key	311-10.0KHRCT-ND
2	RES-CRCW0603	68.1K	Digi-Key	311-121KHRCT-ND
21	RES-CRCW0603	475	Digi-Key	311-475HRCT-ND
4	RES-CRCW0805	121K	Digi-Key	311-121KCRCT-ND
1	SWT-MOM-KSR-SERIES-SMT	MOM-NC	Digi-Key	401-1705-1-ND
1	VRG-LK112S-SOT23-5LEAD	LK112S	Digi-Key	497-4259-1-ND

APPENDIX B: SCHEMATICS

FIGURE B-1: CAPACITIVE TOUCH SENSOR DEMO SCHEMATIC (PAGE 1 OF 3)

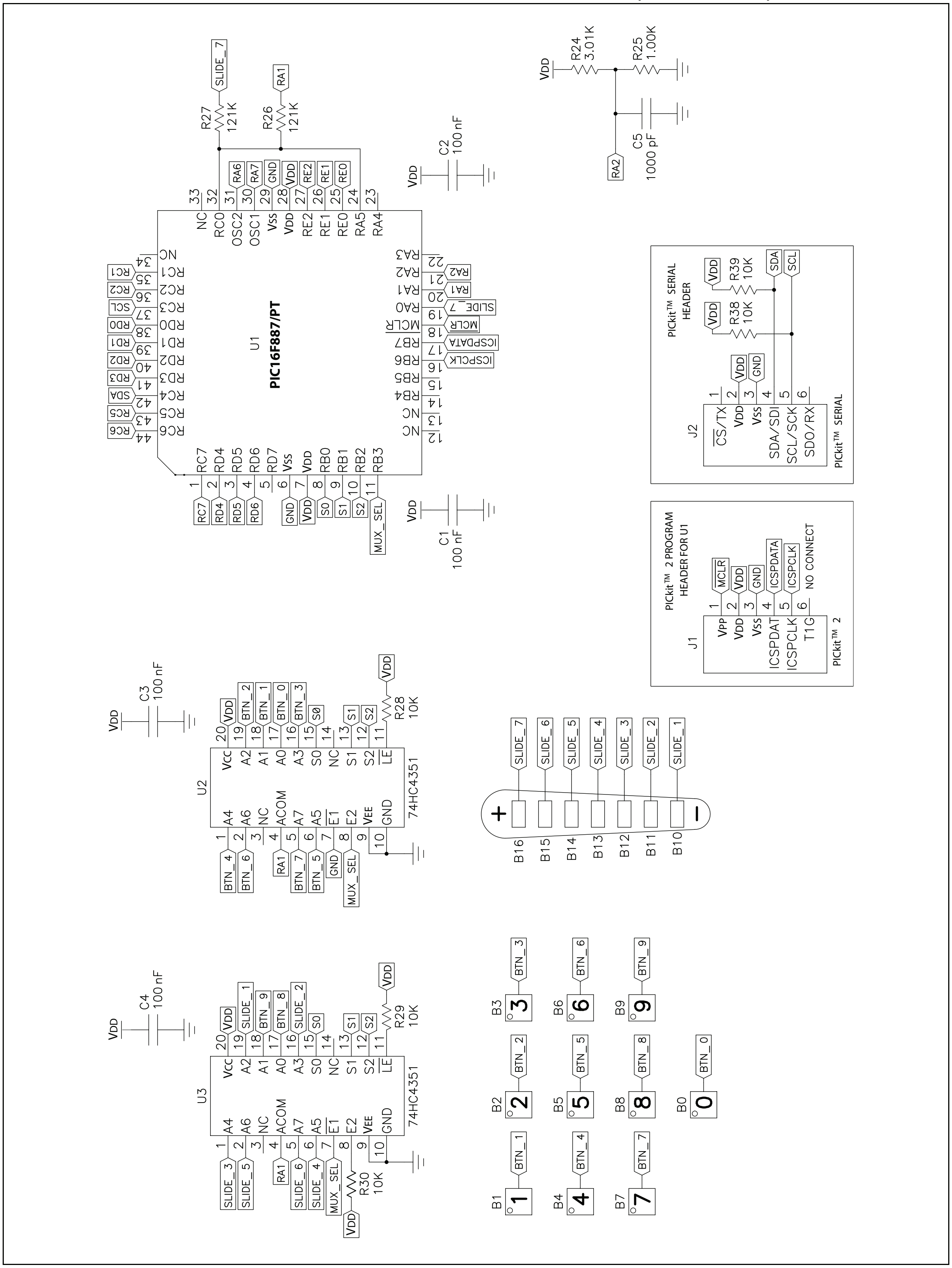


FIGURE B-2: CAPACITIVE TOUCH SENSOR DEMO SCHEMATIC (PAGE 2 OF 3)

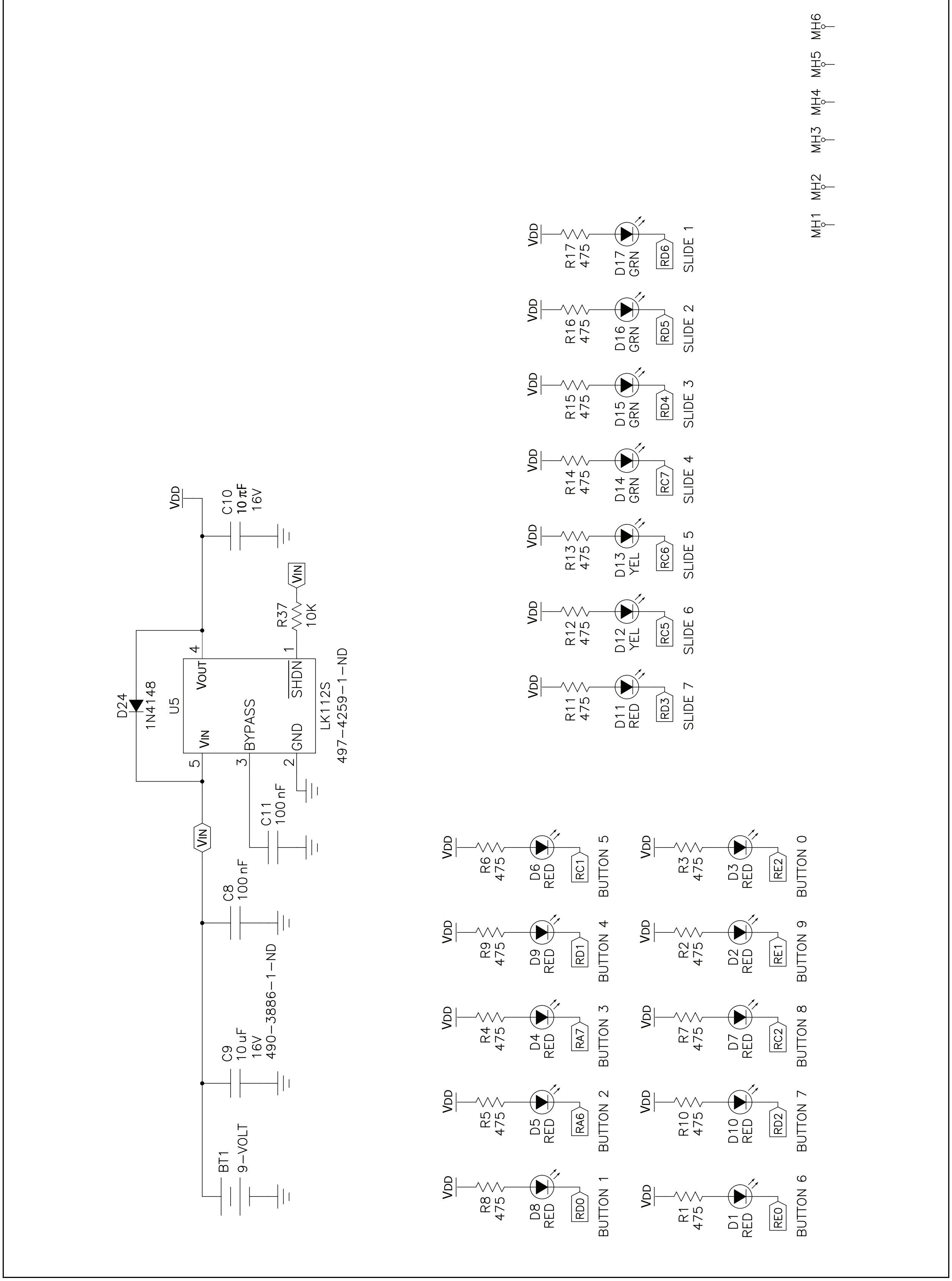
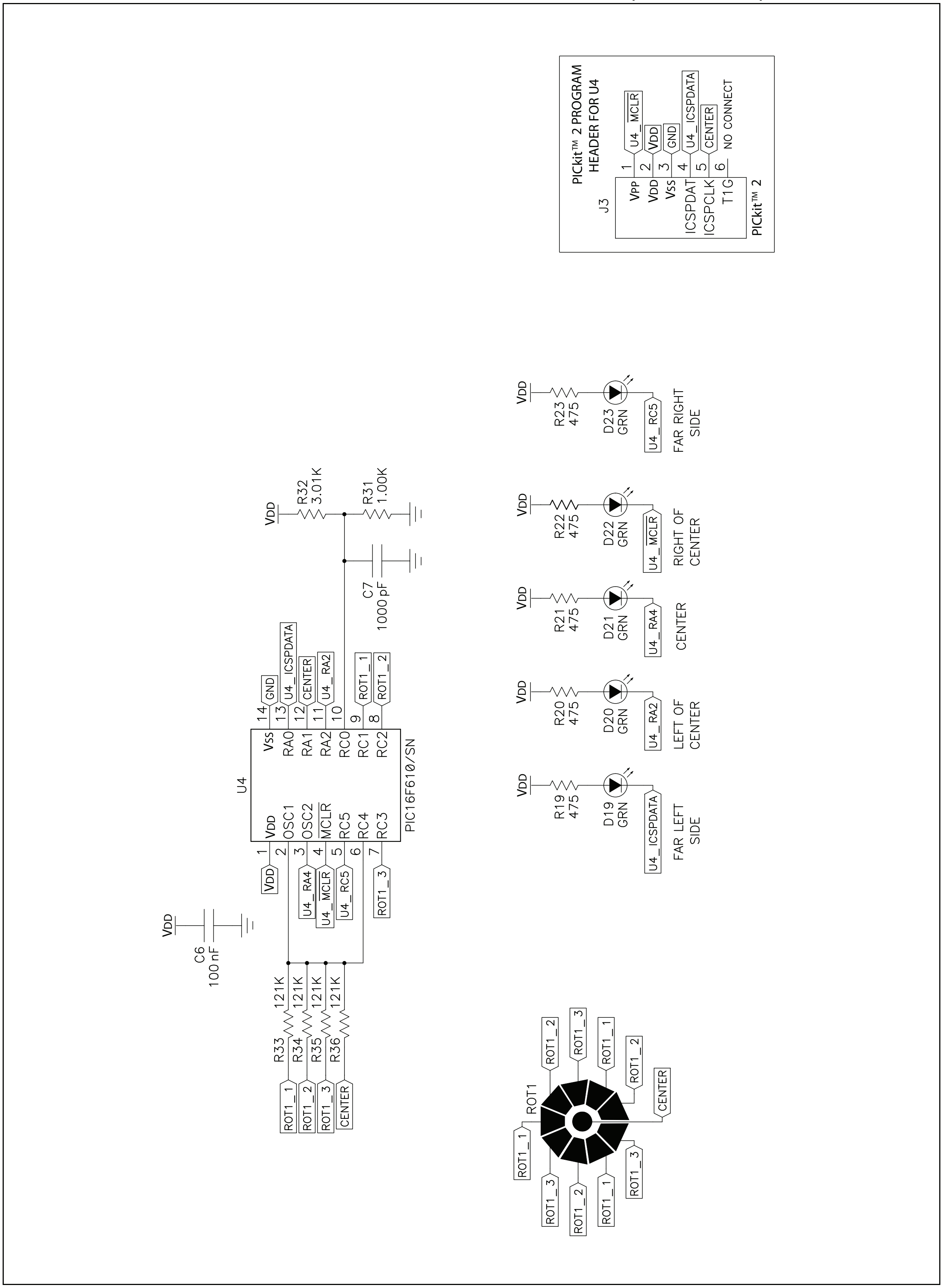


FIGURE B-3: CAPACITIVE TOUCH SENSOR DEMO SCHEMATIC (PAGE 3 OF 3)



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