TI Designs
Touch Screen With Haptic Feedback

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Design Resources

TIDA-00408	Tool Folder Containing Design Files
DRV2667	Product Folder
DM3730	Product Folder

TI E2E™ Community

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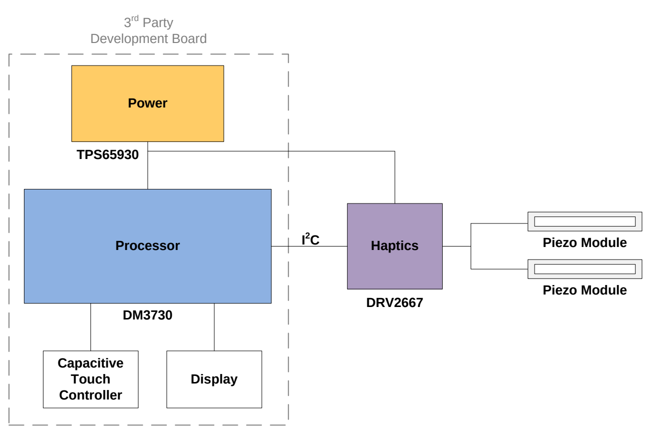
Design Features

- Provides Haptic Feedback for On-Screen Touch Controls
- Uses the DRV2667 Integrated High-Voltage Piezo Driver to Control Piezo Actuators that Produce Tactile Feedback
- Includes the Complete Haptic Subsystem Including Touch Screen, Processor, Software, and Haptic Driver
- Detailed Mechanical Design and Assembly Included
- Operating System (OS) for Android™ With Linux Software Drivers Available for Integration

Featured Applications

- Touch Screens
- Thermostats
- Building and Home Automation
- Medical Equipment
- Industrial Human-Machine Interface (HMI)



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1 System Description

This reference design serves as a guide for designing touch screen systems with haptic feedback. This document is not intended to be a comprehensive design guide, but one possible implementation for a touch screen haptics solution. This haptic human-machine interface (HMI) reference design contains a number of user interfaces with buttons and touch controls that respond with haptic feedback when pressed. The haptic HMI reference design contains the TI DRV2667 piezo haptic driver, TI DM3730 digital media processor, a power management integrated circuit (IC), Ethernet, Wi-Fi, universal serial bus (USB), inter-integrated circuit (I^2C), serial peripheral interface (SPI), general purpose input and output (GPIO), COM, and battery charger and supervisor.

Figure 1. Haptic Feedback Touch Screen

2 Block Diagram

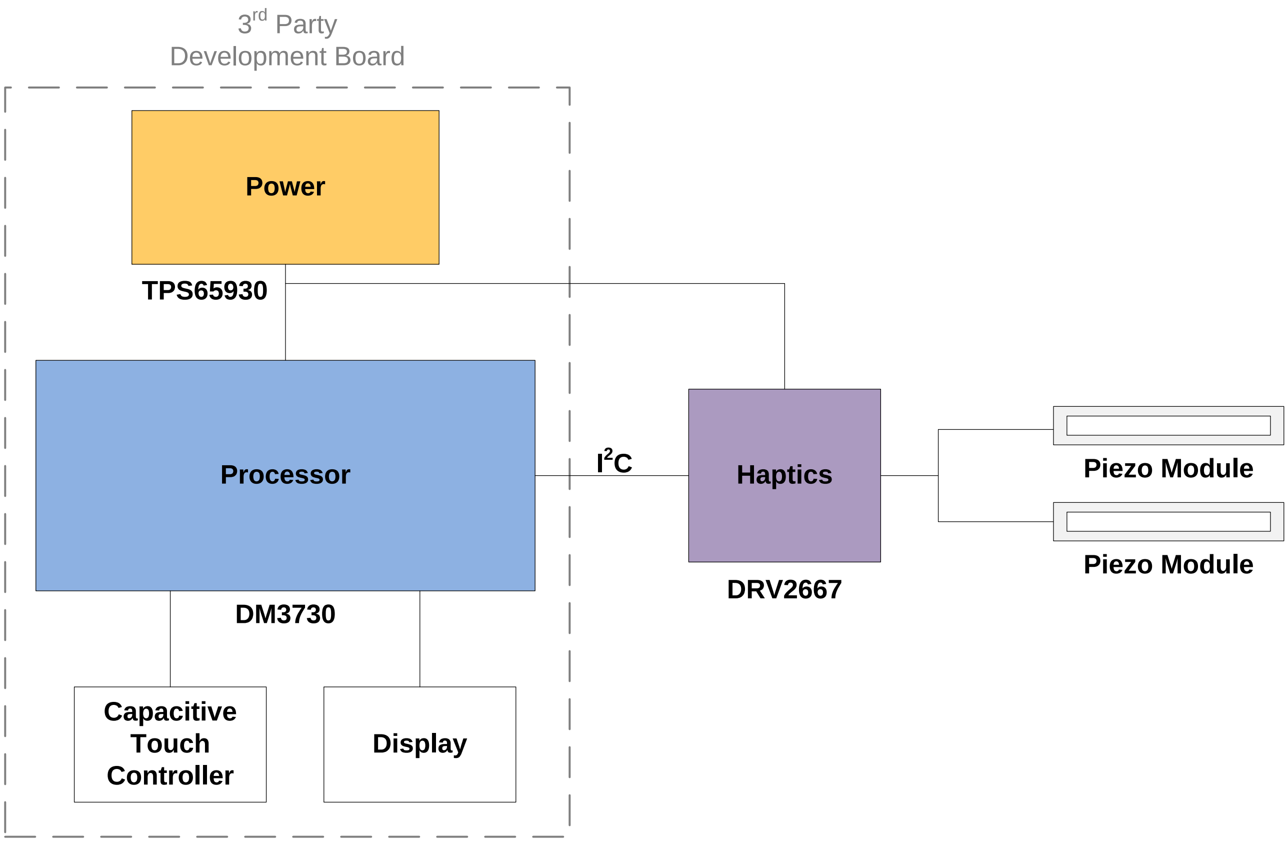

Figure 2. TIDA-00408 Block Diagram

3 Overview

The TIDA-00408 reference design showcases haptics in touch screen applications such as thermostats, building automation, factory automation, point-of-sale, and automotive. The reference design includes a 7-inch capacitive touch display, one DRV2667 piezo haptic driver, and two piezo actuators.

Figure 3. Thermostat Display

The *Touch Screen With Haptic Feedback* reference design is a reference design for applications that require touch screens, panels or human-machine interfaces. Table 1 lists example applications that can benefit from the addition of haptic feedback.

Table 1. HMI Applications

APPLICATION	DESCRIPTION
Building automation	Dynamic directories, dynamic elevator panels, control buttons, and lighting control
Factory automation	HMI control panels and mechanical button replacements
Home automation	Home control displays, thermostats, and light switches
Medical devices	Monitoring equipment, fluid impermeable displays, and mechanical button replacement
Retail	Kiosks, automatic teller machines (ATM), and vending machines
Automotive	Infotainment and rear-seat entertainment

Touch screens and dynamic displays are useful in applications that require custom or dynamic user interfaces. Imagine a factory automation control panel that must display dynamic content about the status of a machine or a self-checkout terminal at a grocery store that provides a menu with different options for payment.

The problem with these automated control panels is that there is no tactile feedback when the user presses or moves his or her finger across the screen. In contrast, a user types on a physical computer keyboard, he or she feels a click or bump when pressing a key.

This reference design shows how haptics can restore tactile feedback to touch screens and improve the user interaction with machines. The applications in Table 1 benefit from haptic technology because it restores tactile feedback and allows the user to feel again.

Other interfaces like touch pads, button panels, sliders, and wheels can also benefit from this design because they represent a similar style of interface.

3.1 Haptic System Overview

Figure 4 shows the basic haptic block diagram. The following three-step list describes the operation of the haptic system.

1. First the user touches the screen, which triggers an event.
2. The position of the touch is determined by the processor and a corresponding haptic effect is chosen.
3. The haptic driver receives a command to play a specific effect and drives the actuator with the appropriate waveform to produce vibration.

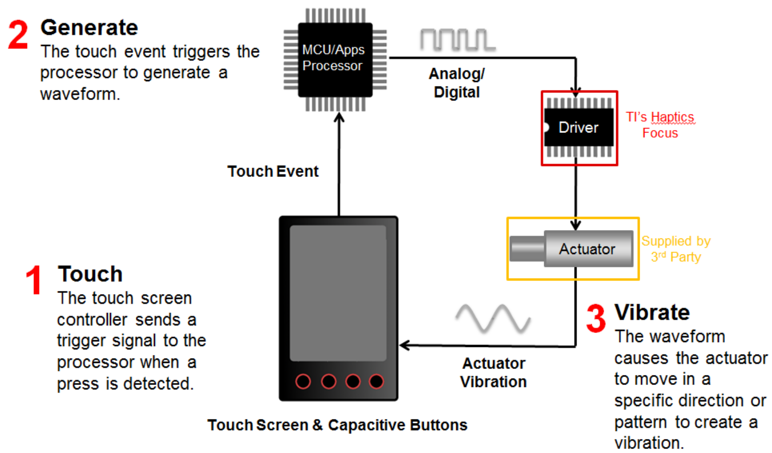

Figure 4. Haptics Block Diagram

3.2 Reference Design Overview

The *Touch Screen With Haptic Feedback* reference design contains three main components to create the haptic feedback system. This document primarily focuses on the haptic feedback and mechanical mounting portion of the design; however, there is basic information on the touch screen and TI processor used.

Figure 5. Input: Touch Input and Display

The touch input and display provide the input interface to the system. This design uses a capacitive touch panel, but resistive, inductive, or other touch technologies can be used.

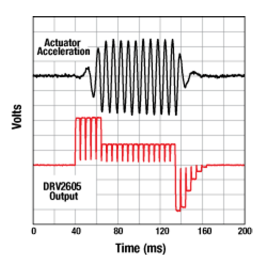

Figure 6. Haptic Feedback: Haptic Driver and Actuator

The haptic driver and actuator create the feedback to the user. The actuators are mounted to the display and connected to the driver on the PCB to create vibration.

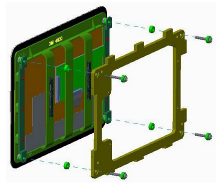

Figure 7. Mechanical and Mounting

The enclosure for the touch screen or panel must be specially designed to transfer the highest level of vibration to the finger of the user.

3.2.1 Haptic Feedback

The haptic feedback is the key component in this design. The DRV2667EVM-MINI breakout board and two Samsung Electro-Mechanics piezo modules were used to generate the haptic feedback on the touch screen.

3.2.2 DRV2667 Piezo Haptic Driver

The DRV2667 is a high-voltage piezo haptic driver with an integrated boost, high-voltage amplifier, and digital waveform engine. Waveforms can be created and stored inside the device RAM to create various haptic effects.

Figure 8 shows the typical application circuit for the DRV2667 device.

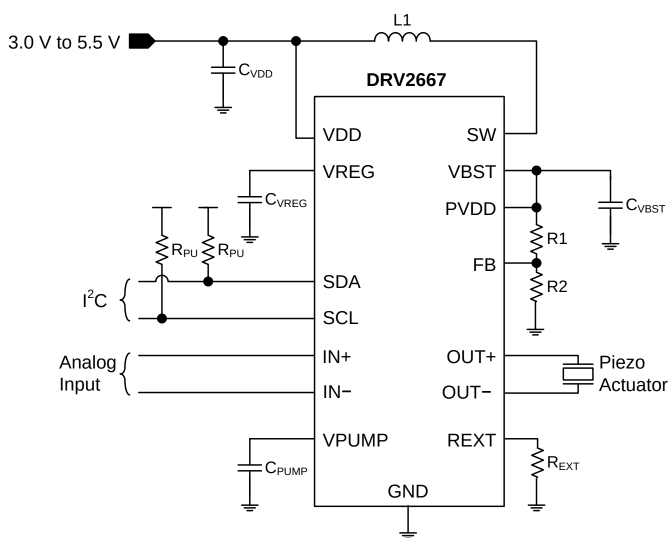

Figure 8. DRV2667 Application Diagram

In this reference design, the I^2C is used to create the haptic waveforms; however, a digital-to-analog converter (DAC) can also be used to generate waveforms by connecting to the IN+ and IN− analog input pins. Figure 9 shows the input to output signal path.

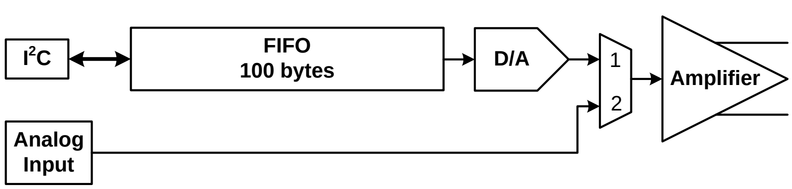

Figure 9. DRV2667 Control Options

3.2.3 DRV2667EVM-MINI Board

The DRV2667EVM-MINI breakout board contains the DRV2667, inductor, and passives for an easy connection to the DM3730 board. Figure 10 shows the schematic for the board.

In this case, the DRV2667 is configured for a 150-V_{PP} output with a boost converter voltage set to 80 V.

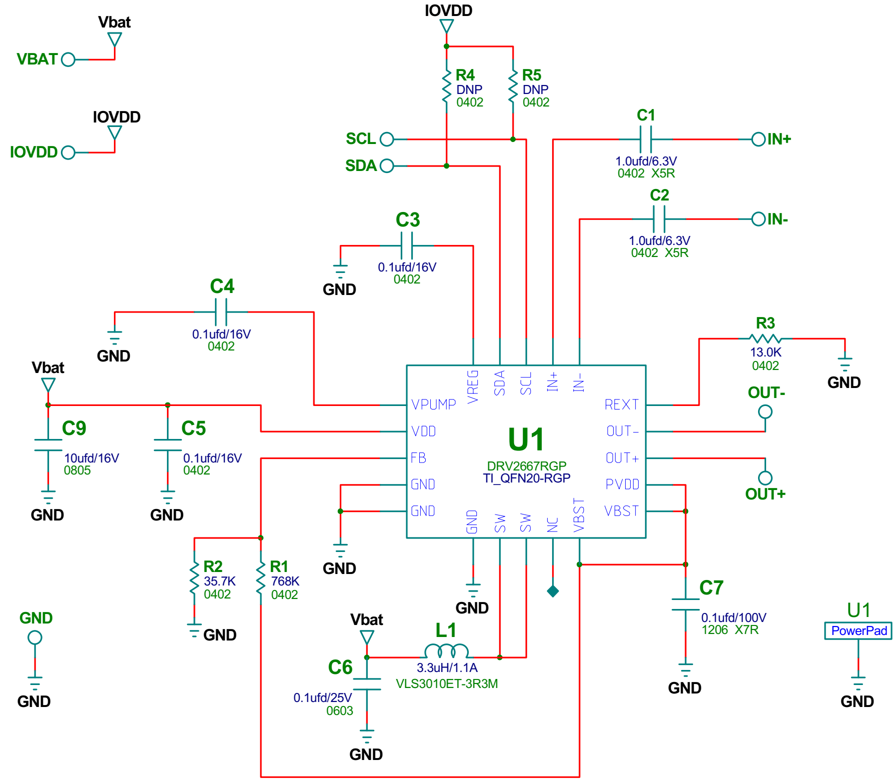

Figure 10. DRV2667EVM-MINI Breakout Board Schematic

3.2.4 Samsung Piezo Module

The Samsung Electro-Mechanics (SEMCO) piezo module is selected for this reference design because it has a very quick response time, which is ideal for creating button clicks. The module is mounted to the back of the touch panel so that vibration from the piezo module transfers to the glass whenever the user touches the screen. Table 2 shows the parameters for the piezo load.

Figure 11. Piezo Module

Table 2. Piezo Module Specifications

PARAMETER	VALUE	UNIT
Manufacturer	Samsung Electro-Mechanics	–
Manufacturer part number	PHAT423535XX	–
Rated voltage	± 75	V
Capacitance	25	nF
Resonant frequency	200	Hz

The SEMCO piezo is rated for 150 V and has a resonant frequency between 200 Hz to 210 Hz. Considering the resonance of the system is important when designing waveforms for piezo actuators. For maximum vibration strength, use 210-Hz waveforms for this reference design.

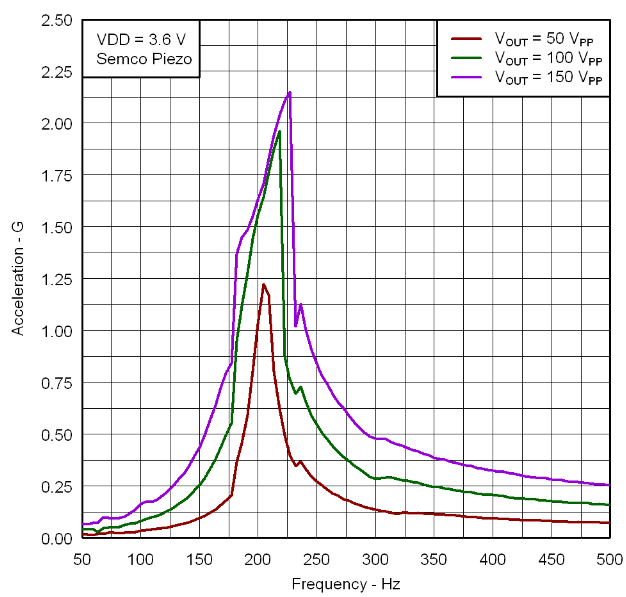

Figure 12. SEMCO Piezo Module—Acceleration Versus Frequency

Alternatively, other types of actuators can be used, such as linear resonant actuators (LRA) or eccentric rotating mass motors (ERM) depending on the required feel and price point.

3.2.5 Connecting DRV2667

As Figure 13 shows, the DRV2667EVM-MINI breakout board connects directly to the processor I²C port of the DM3730 digital media processor. In this design the processor runs on the open-source software for Android™ and has a specific driver for the DRV2667 device.

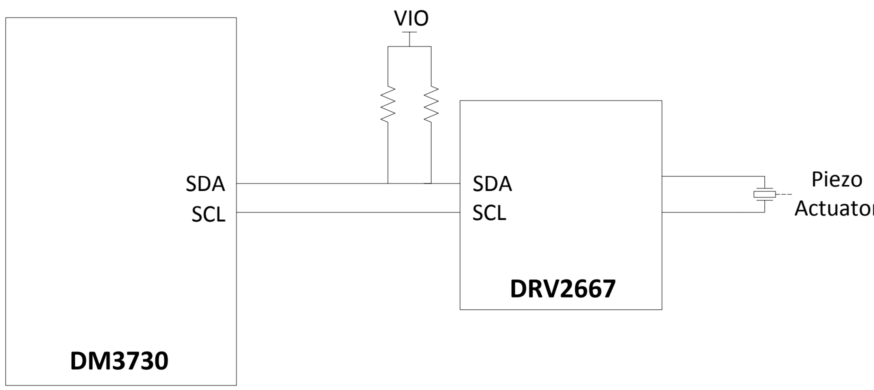

Figure 13. DM3730 Connections to DRV2667

The processor sends a signal using I²C to the DRV2667 device when a button is pressed to trigger a waveform effect. Depending on the button function a different effect can be triggered.

3.2.5.1 Configuring DRV2667 Output Voltage

The output voltage of the DRV2667 requires the GAIN settings of the high-voltage amplifier and the feedback resistors of the boost converter to be set appropriately.

The DRV2667 GAIN register sets the peak voltage level of the high-voltage amplifier and is controlled using I²C. Table 3 shows the different gain options and the associated peak voltages.

Table 3. DRV2667 Gain Settings

GAIN[1]	GAIN[0]	FULL SCALE PEAK VOLTAGE (V)	GAIN (dB)
0	0	25	28.8
0	1	50	34.8
1	0	75	38.4
1	1	100	40.7

The boost converter output voltage is set by resistors R1 and R2. The boost converter output voltage must be set to the full-scale peak voltage with an additional 5 V for the headroom. Find the equations for configuring the boost converter in the DRV2667 datasheet.

Table 4 shows the settings used for the DRV2667EVM-MINI breakout board to drive the SEMCO piezo module in this design.

Table 4. DRV2667 Settings for HMI Design

PARAMETER	DESCRIPTION	VALUE	UNIT
GAIN	Internal gain setting (dB) - gain voltage (V_{PP})	38.4 – 150 V_{PP}	dB
Full scale peak voltage	Full scale peak voltage = gain voltage / 2	75	V_{PEAK}
Boost voltage	Integrated boost converter output voltage setting	80	V
R1	High-side boost feedback resistor	768	kΩ
R2	Low-side boost feedback resistor	35.7	kΩ

3.2.6 Haptic Waveforms

The reference design uses two waveforms to create effects for buttons and sliders. This effect was chosen because it has a short and sharp feel.

3.2.6.1 Short-Click Waveform

The first effect is a short click for small buttons and sliders. This effect is set to approximately 208 Hz at the full-scale amplitude. The duration of the effect is three periods or cycles. The short-click effect is intended to provide as much force feedback as possible in a very short period of time. The blue waveform represents the acceleration (57 mVp = 1 g) and the orange is the DRV2667 differential output voltage.

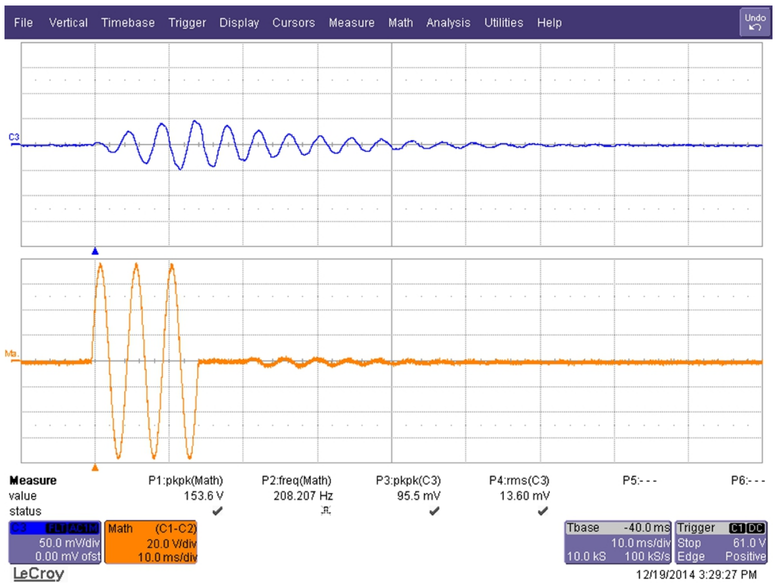

Figure 14. Short-Click Waveform

The following Table 5 shows the contents in the DRV2667 RAM to produce this waveform.

Table 5. Short-Click Waveform Parameters

		DESIRED OUTPUT		REGISTER VALUE		
BYTE	**PARAMETER**	**VALUE**	**UNIT**	**DEC**	**HEX**	**BIN**
1	Amplitude	75	V_{PEAK}	255	FF	11111111
2	Frequency	208	Hz	27	1B	00011011
3	Duration	3	Periods	3	3	00000011
4	Start time Stop time	0	ms	0	00	00000000

3.2.6.2 Bump Waveform

The bump waveform is used for the larger buttons to give a more substantial feel. This waveform allows users to feel the different buttons on screen rather than just see them. The blue waveform represents the acceleration (57 mVp = 1 g) and the orange is the DRV2667 differential output voltage.

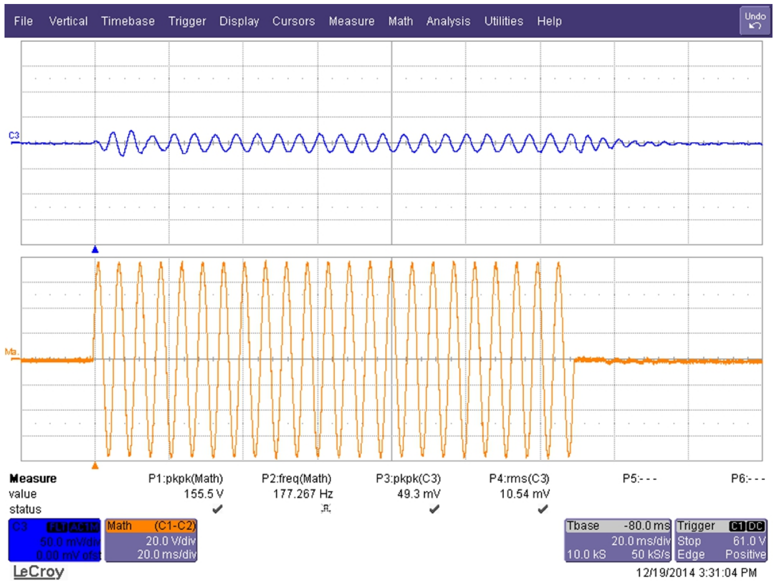

Figure 15. Bump Waveform

The following Table 6 shows the contents in the DRV2667 RAM to produce this waveform.

Table 6. Bump Waveform Parameters

		DESIRED OUTPUT		REGISTER VALUE		
BYTE	PARAMETER	VALUE	UNIT	DEC	HEX	BIN
1	Amplitude	75	V_{PEAK}	255	FF	11111111
2	Frequency	175	Hz	22	16	00010110
3	Duration	23	Periods	23	17	00010111
4	Start time	0	ms	0	00	00000000
	Stop time					

3.2.6.3 *Assigning Haptic Waveforms to Buttons*

Using haptics with a touch screen provides a physical, button-like feeling when using on-screen buttons, sliders, and wheels. Haptics can also enhance the user interface beyond what was possible with physical buttons; see the examples in the following Figure 16 and Figure 17.

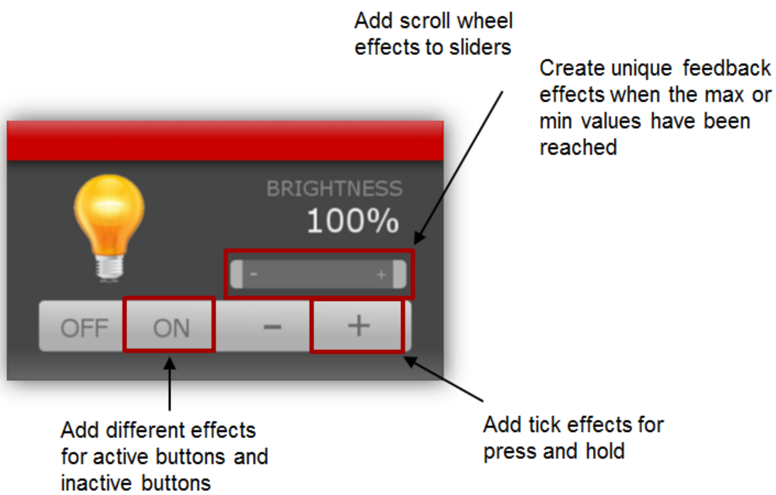

Figure 16. Home Automation Lighting Panel

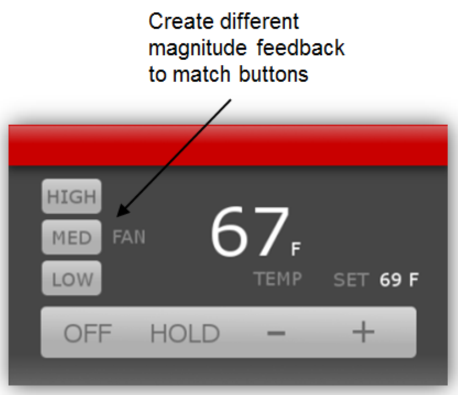

Figure 17. Thermostat Control Panel

4 Mechanical Design

The HMI reference design has a specially designed mechanical structure to help transfer more vibration to the glass touch screen so that users can feel the haptic feedback when touching the screen. Figure 18 shows the basic structure of the screen design.

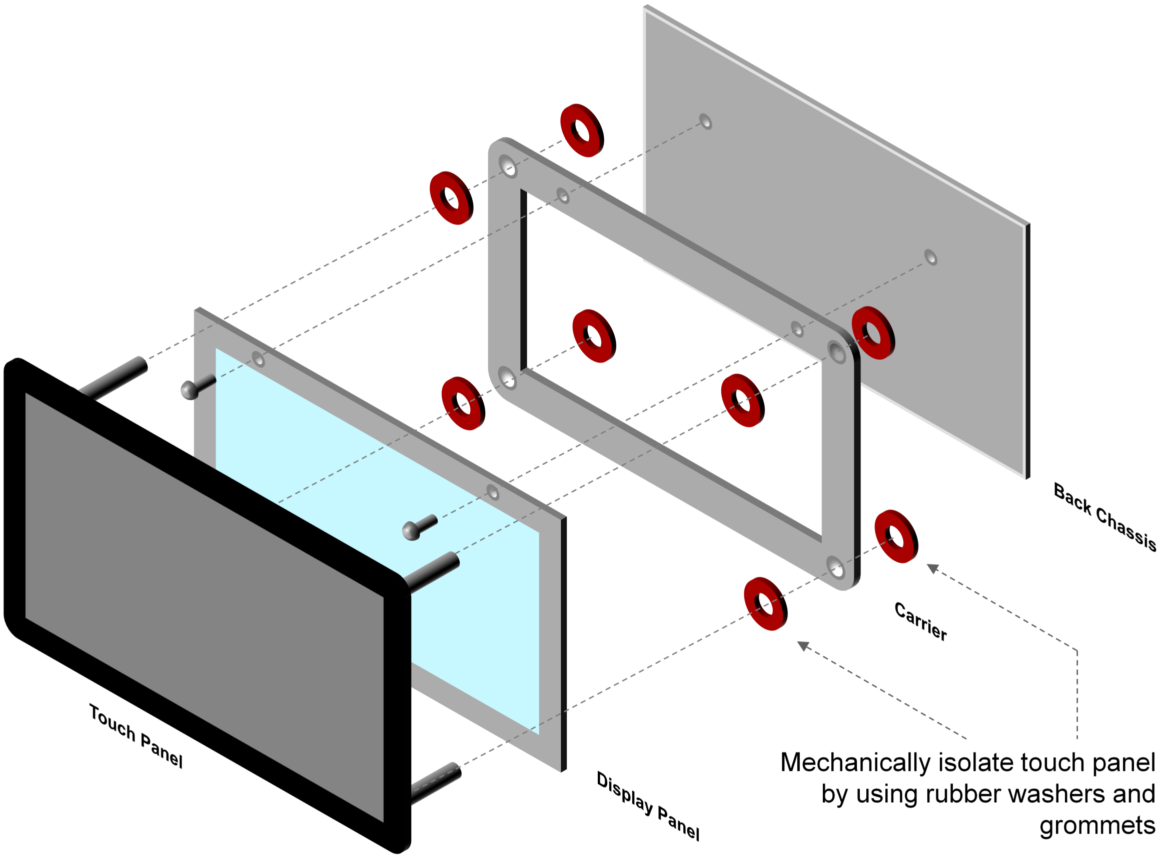

Figure 18. Haptic Touch Screen Mechanical Diagram

The basic principal of the structure is that the touch panel is mechanically isolated from the display panel, carrier, and back chassis by the red rubber grommets or washers. The actuators are then attached directly to the touch panel. When the actuators vibrate the installed grommets allow the touch panel to physically move.

4.1 Mechanical Isolation Design

The following Figure 20 shows how mechanical isolation is achieved using a screw and rubber washers. Figure 19 shows the backside of the touch panel, the carrier frame, screws, and green rubber washers.

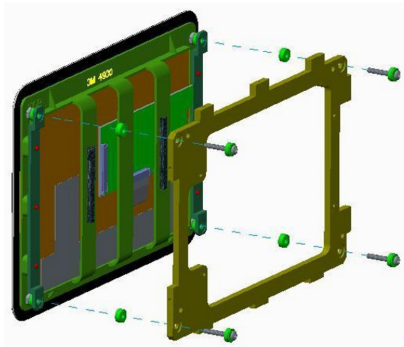

Figure 19. Mechanical Isolation Assembly

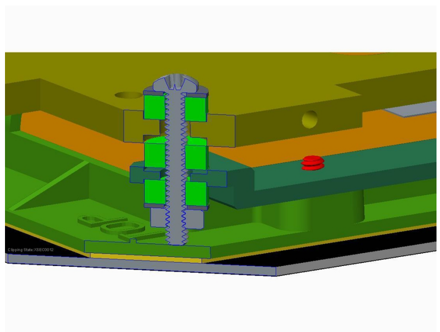

Figure 20. Mechanical Isolation Assembly (Zoomed-In)

4.2 Mechanical Ground

The back chassis functions as the mechanical ground in this system. Figure 21 shows how the carrier frame attaches to the back chassis using screws without any grommets or washers. This method of securing the frame means that the carrier frame is grounded as well.

Figure 21. Mechanical Ground

4.3 Piezo Placement Performance

Most vibrating systems require simulation or testing to understand where constructive and destructive interference occurs. This interference varies greatly from design to design. The information in the following subsections was generated using the mechanical design from Section 4.2 and two SEMCO piezo actuators. The acceleration plots were captured using off-the-shelf accelerometers.

4.3.1 Two Piezos—Top Placement

In the first test, two piezo modules were placed on the top of the touch panel and two accelerometers were placed vertically in the center of the touch panel, directly above one another.

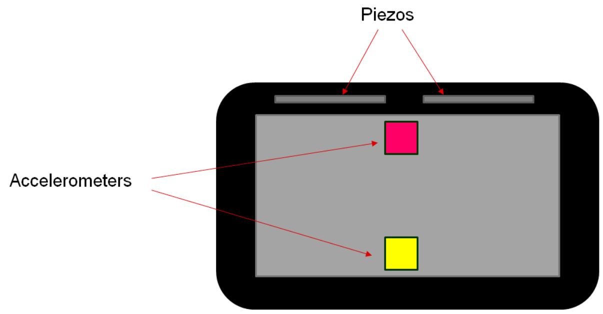

Figure 22. Diagram of Piezos—Top Placement

Figure 23 shows the measured acceleration. A short duration buzz effect was used to create vibration. The right side of the graph in Figure 23 shows the gravitational force of the acceleration (in Gs (9.81 m/s2)).

Figure 23. Acceleration Measurements for Piezos—Top Placement

4.3.2 Two Piezos—Side Placement

In this test, the actuators were placed on the sides of the touch screen.

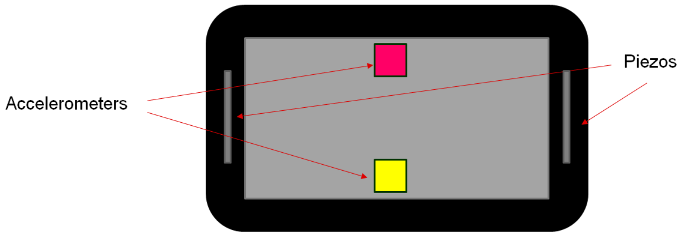

Figure 24. Diagram of Piezos—Side Placement

Figure 25 shows the measured acceleration for this test.

Figure 25. Measurement of Piezos—Side Placement

5 Touch Screen and Display: Anders DX4 Kit

The use of an off-the-shelf Anders DX DX4 kit provides the touch panel and control for the system. The kit includes the DM3730 digital media process, TPS65930 power management integrated circuit (PMIC), motherboard, display, touch panel, touch panel control board, and a number of different peripherals. To order the kit, please visit the AndersDX website.

The operating system for Android and Linux kernel were modified to support the DRV2667 using I^2C.

Figure 26. Anders DX4 Kit

Table 7. Anders DX4 Kit Contents

QUANTITY	DESCRIPTION
1	Assembled DX4 (core module, carrier board, capacitive touch thin-film transistor (TFT), display driving board, and 8-GB micro-SD card)
1	5-V power supply kit
1	Serial cable (DB9-F to ultra-mini plug)
1	USB cable (type A to mini A/B)
1	USB on-the-go adapter cable (mini USB type A/B to USB male type A)
1	USB-A to 4-pin header
1	40 ways flat flexible cable (FFC) for GPIOs
1	Ethernet cable (RJ-45 straight)
1	Wi-Fi antenna with cable adapter
1	Keypad and its cable
1	Lithium polymer battery (10 Wh)

5.1 SBC-T3730 Motherboard

The motherboard contains the electronics and connections for controlling the display, touch screen, and haptics. Figure 27 shows the motherboard, which is developed by CompuLab. For more information on this board please visit the product specification for the SBC-T3730 on the CompuLab website.

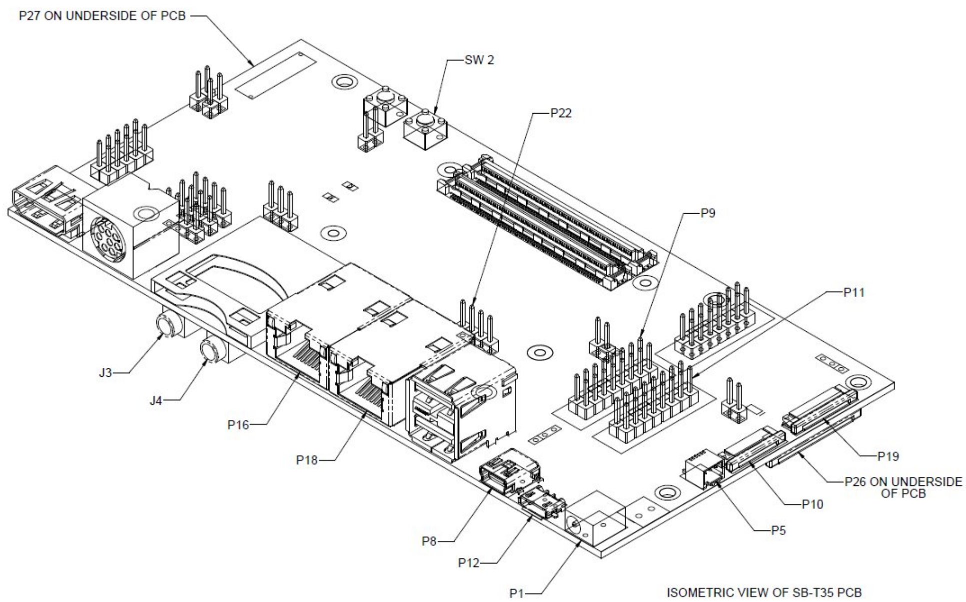

Figure 27. SBC-T3730 Board Isometric View (1)

The header P11 is used to connect the DRV2667EVM-MINI breakout board I^{2}C to the I^{2}C of the DM3730 processor.

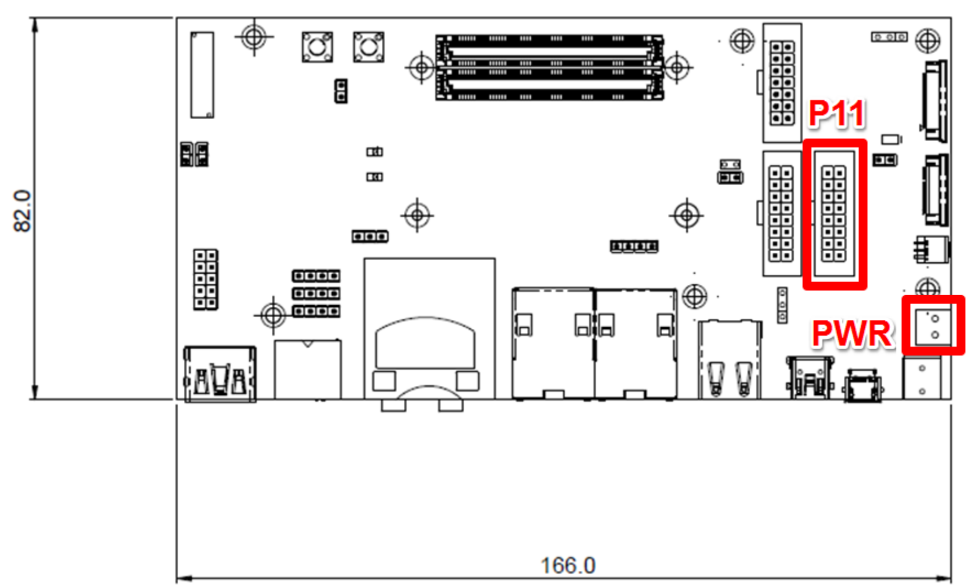

Figure 28. Board Connection Labels

Figure 29 shows the pin-out of P11. Connect the DRV2667 SDA and SCL pins to pin 2 and pin 4 on the P11 header. Connect the VDD and GND of the DRV2667 device to the PWR terminal.

1		I2C2_SCL	2
		I2C2_SDA	4
5	GND		
9	GND		
13	GND		

Figure 29. P11 Header Pin-Out

5.2 DM3730

The DM3730 is selected for this reference design because of features that support HMI devices like home automation, thermostats, and industrial control. The graphics capabilities and peripheral set are perfect for expanding this design to other applications. Figure 30 shows the block diagram of the DM3730 device.

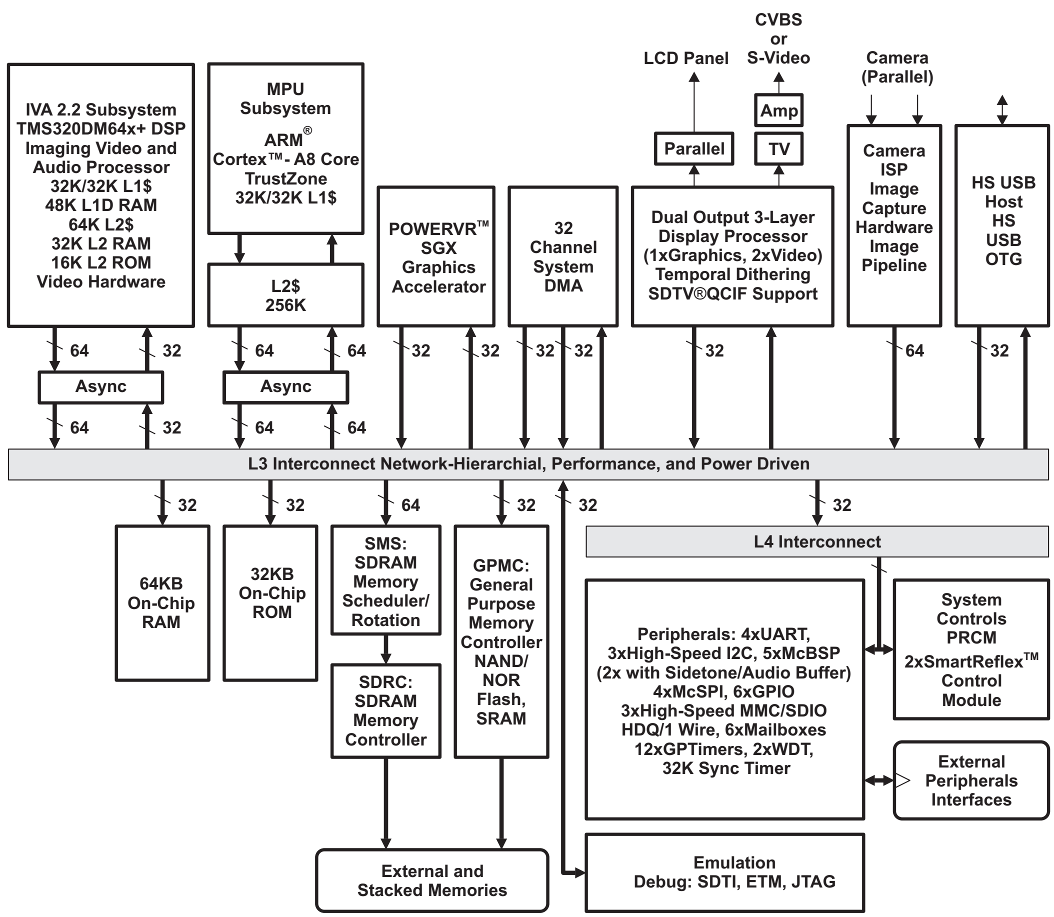

Figure 30. DM3730 Block Diagram

5.3 TPS65930 Power Management Device

The DM3730 processor is powered by the TPS65930, which is an integration power management device with peripherals. Figure 31 shows the block diagram for the TPS65930 power management IC.

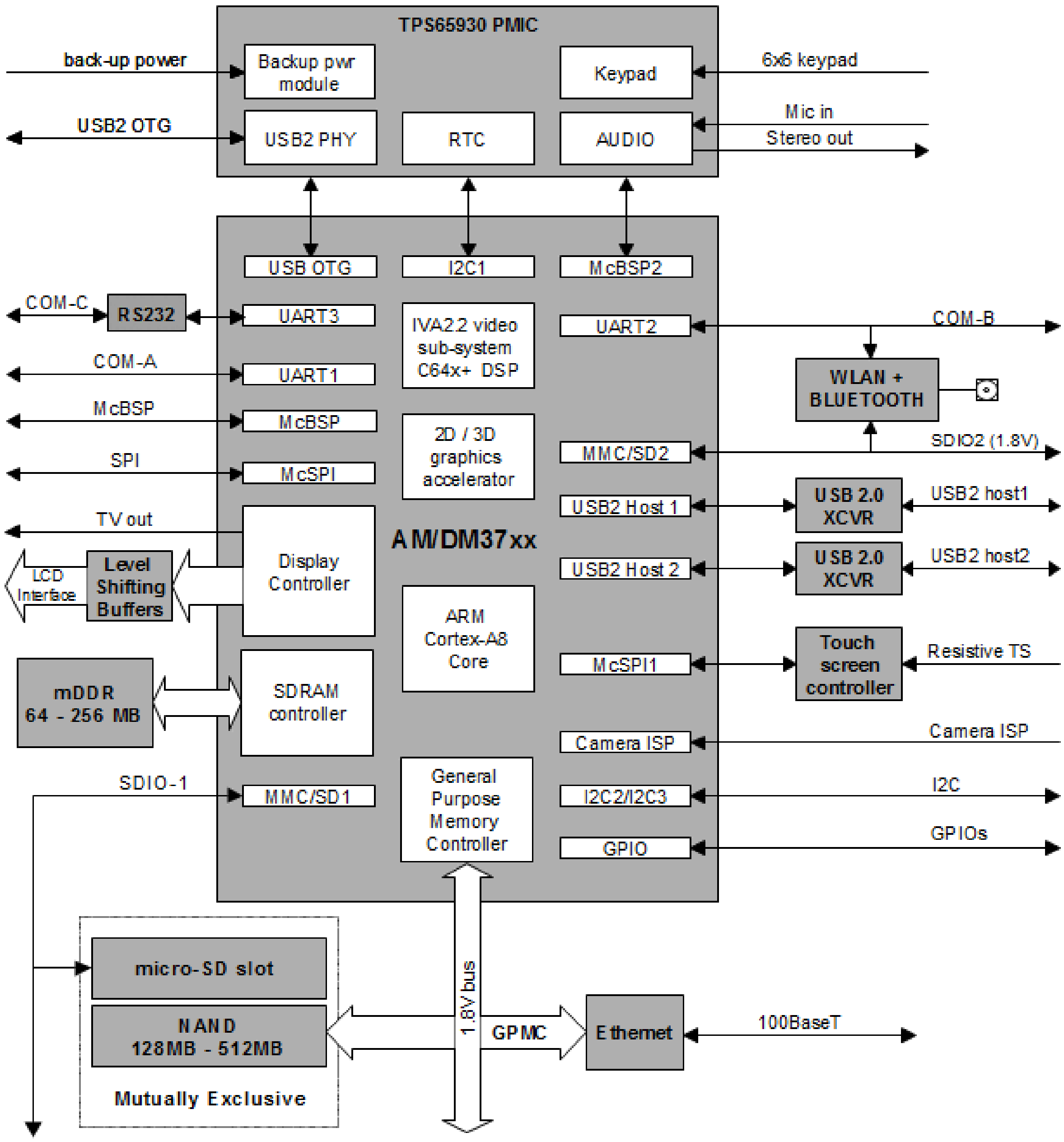

Figure 31. TPS65930 Block Diagram

6 Design Files

6.1 Schematics

To download the schematics, see the design files at TIDA-00408.

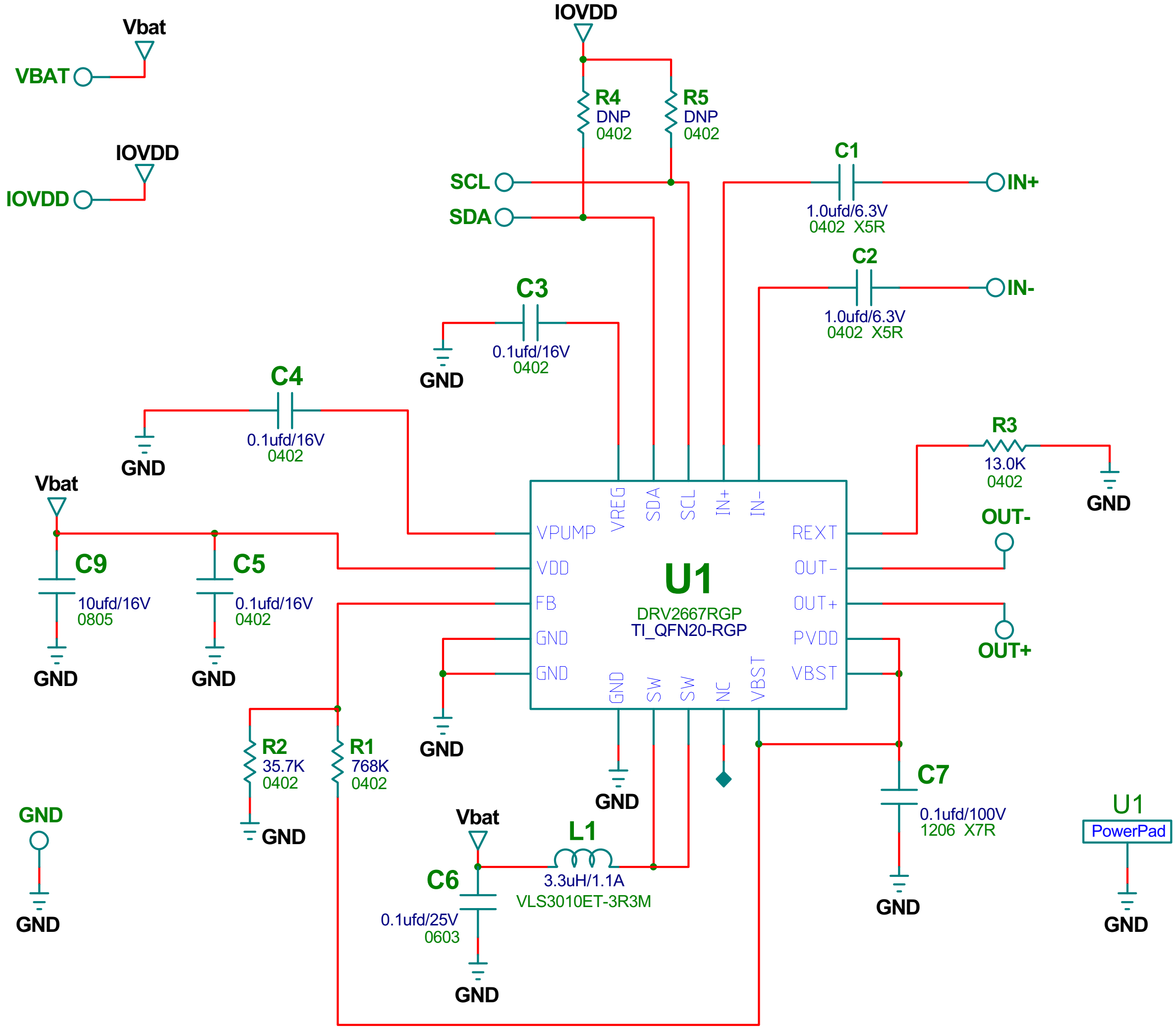

Figure 32. DRV2667EVM-MINI Schematic

6.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-00408.

Table 8. BOM

ITEM	QTY	REFERENCE	VALUE	PART DESCRIPTION	MANUFACTURER	MANUFACTURER PART NO.
1	1	U1	–	PIEZO HAPTIC DRIVER WITH DIG FRONT END QFN2	TEXAS INSTRUMENTS	DRV2667RGP
2	1	C9	10µF	CAP SMD0805 CERM 10UFD 16V X5R 10% ROHS	AVX	0805YD106KAT2A
3	1	C6	0.1µF	CAP SMD0603 CERM 0.1UFD 25V 10% X5R ROHS	AVX	06033D104KAT2A
4	3	C3, C4, C5	0.1µF	CAP SMD0402 CERM 0.1UFD 16V X7R 10% ROHS	MURATA	GRM155R71C104KA88D
5	2	C1, C2	1.0µF	CAP SMD0402 CERM 1.0UFD 6.3V X5R 10% ROHS	MURATA	GRM155R60J105KE19D
6	1	R1	768k	RESISTOR SMD0402 THICK FILM 768K OHM 1% 1/16	YAGEO	RC0402FR-07768K
7	1	R2	35.7k	RESISTOR SMD0402 35.7K OHMS 1% 1/16W ROHS	VISHAY/DALE	CRCW040235K7FKED
8	1	C7	0.1µF	CAP SMD1206 CERM 0.1UFD 100V 10% X7R ROHS	KEMET	C1206F104K1RACTU
9	1	R3	13k	RESISTOR SMD0402 13.0K OHMS 1% 1/16W ROHS	VISHAY	CRCW040213K0FKED
10	1	L1	1µH	POWER INDUCTOR SMD 1.0uH 2.5A ROHS	TDK CORP.	VLS3012T-1R0N2R2
11	2	R4, R5	10k	R0402_DNP	YAGEO	R0402_DNP
12	2	–	–	Samsung Electro-Mechanics Piezo Module	SEMCO	PHAH353832XX

Table 9. Mechanical BOM

ITEM	QTY	PART DESCRIPTION	MANUFACTURER	MANUFACTURER PART NO.
1	1	Touch Screen, LCD, Motherboard Module	AndersDX	DX4K3730-70A-LS
2	1	Skeleton_Plate	Machine Shop	
3	16	Grommet Silicone 40A Black	General Rubber Company	3328-704-BLK
4	1	LCD Holder	Arrk	lcd_holder
5	1	Tape Transfer Adhesive 3" x 5 yds.	3M	3-5-468MP
6	1	Front Case	Arrk	front_case
7	1	Back Case	Arrk	back_case_slim
8	2	Aluminum Braket	Machine Shop	
9	18	"18-8 Stainless Steel Type A SAE Flat Washer, No. 4 Screw Size, 5/16"" OD, .02""-.04"" Thick"	McMaster-Carr	96659A101
10	4	"Nylon Unthreaded Spacer, 3/16"" OD, 3/16"" Length, #4 Screw Size"	McMaster-Carr	94639A704
11	4	"Type 316 Stainless Steel Pan Head Phillips Machine Screw, 8-32 Thread, 1"" Length"	McMaster-Carr	91735A199
12	4	Type 316 Stainless Steel Pan Head Phillips Machine Screw, 4-40 Thread, 3/4" Length	McMaster-Carr	91735A113
13	4	"Type 316 Stainless Steel Pan Head Phillips Machine Screw, 4-40 Thread, 7/16"" Length"	McMaster-Carr	91735A105
14	10	Type 316 Stainless Steel Pan Head Phillips Machine Screw, 4-40 Thread, 5/16"	McMaster-Carr	91735A103
15	6	"Type 316 Stainless Steel Pan Head Phillips Machine Screw, 4-40 Thread, 3/16"" Length"	McMaster-Carr	91735A101
16	4	"Titanium Hex Nut, 4-40 Thread Size, 1/4"" Width, 3/32"" Height"	McMaster-Carr	90545A005
17	2	"316SS Pan Head Phillips Screw for Sheet Metal, No.10 Size, 1"" Length"	McMaster-Carr	90184A378

6.3 Layer Plots

To download the layer plots, see the design files at TIDA-00408.

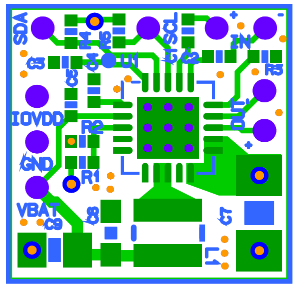

Figure 33. Top Silkscreen Layer

6.4 Altium Project

To download the Altium project files, see the design files at TIDA-00408.

6.5 Gerber Files

To download the Gerber files, see the design files at TIDA-00408.

6.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-00408.

7 References

1. CompuLab, *CM-T3730 computer-on-module (CoM) | system-on-module (SoM)*, Block Diagram (http://www.compulab.co.il/products/computer-on-modules/cm-t3730/#diagram)

8 About the Author

BRIAN BURK is an Applications Manager at Texas Instruments leading a team of engineers developing and supporting Haptic and Piezo products. Brian brings to this role experience developing reference designs and applications using processors, mixed-signal, and power management components. Brian earned his Bachelor of Science in Electrical and Computer Engineering from the University of Texas at Austin. He continues to enjoy developing new designs and finding new applications to aid the next generation of technology innovation.

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PETER LI is a Haptics and Piezo Applications Engineer at Texas Instruments who is responsible for developing applications, EVM and reference designs to support worldwide customers. Peter brings his previous knowledge of cell phone system engineering across a diverse range of platforms including: TTP-Com, Windows Mobile, Android, and many more. Peter earned his MSEE in Electronics Measuring Technology and Instruments and his BSEE from Shanghai Jiao Tong University at Shanghai, China.

IMPORTANT NOTICE FOR TI REFERENCE DESIGNS

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265

Appendix A Mechanical Assembly Instructions

A.1 Assembling Carrier Frame

Begin by securing two metal brackets to the metal carrier frame. Be sure to align the carrier frame as the following Figure 34 shows.

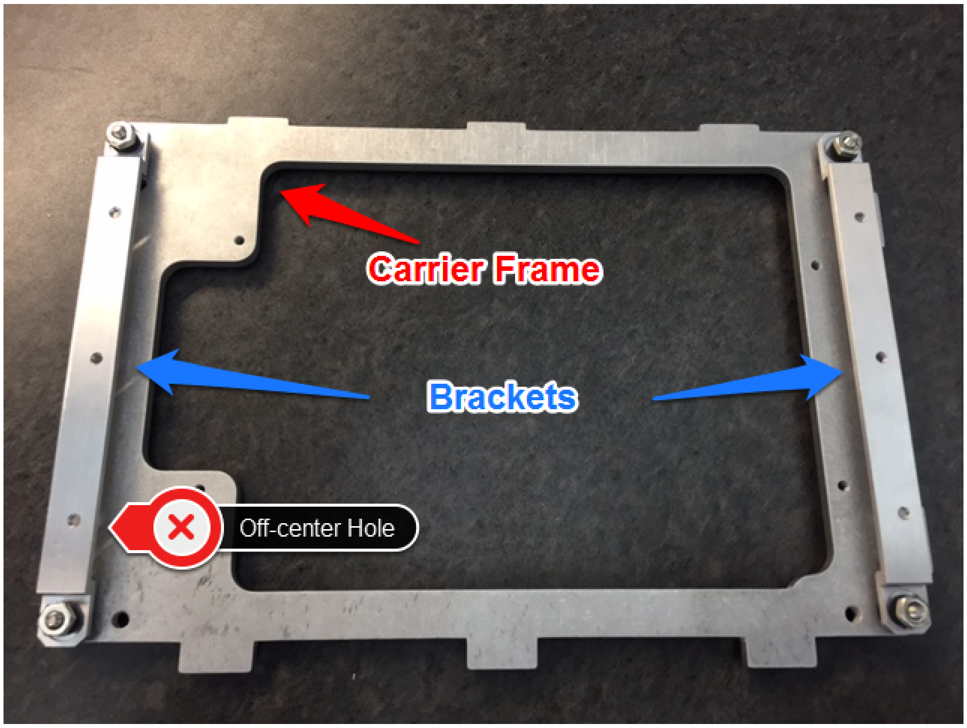

Figure 34. Attaching Brackets to Carrier Frame

- The metal brackets have three off-center holes along the middle of the bracket. Align these holes so that they are closer to the interior of the metal carrier frame.
- Place the metal brackets so that there is a space between the center of the metal brackets and carrier frame.

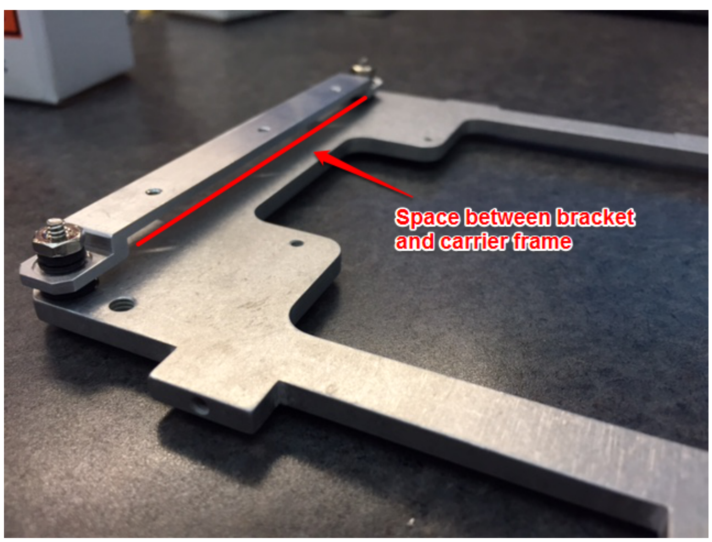

Figure 35. Side View—Bracket and Carrier Frame

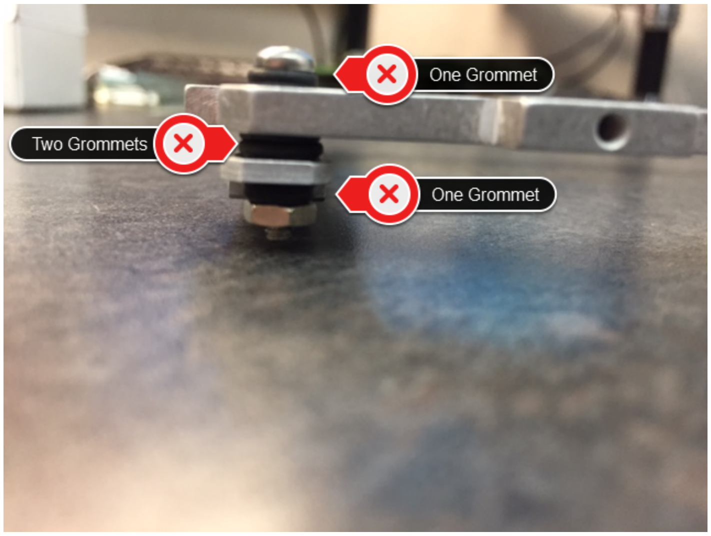

Figure 36. Bracket, Carrier Frame, and Grommet Stack

- Place a grommet on a 4-40 5/8-inch screw and push the grommet all the way to the head of the screw.
- Insert the screw through the carrier-frame hole until the attached grommet is resting against the carrier frame.
- Place two more grommets on the opposite side of the screw.
- Place the bracket on the screw.
- Place one more grommet on the opposite side of the screw.
- Secure the screw with a small 4-40 nut and tighten until the screw is snug. Do not overly tighten the screws, because the rubber grommets must be able to move when the actuator is vibrating.

Complete the same screw-grommet stack-up for each corner of the carrier frame. Tighten the screws so that the height between the carrier frame and the brackets are the same for each corner.

A.2 Attaching Plastic Frame

Align the holes in the metal brackets with the holes in the metal frame. The thicker side of the plastic frame should align with the thicker side of the carrier frame.

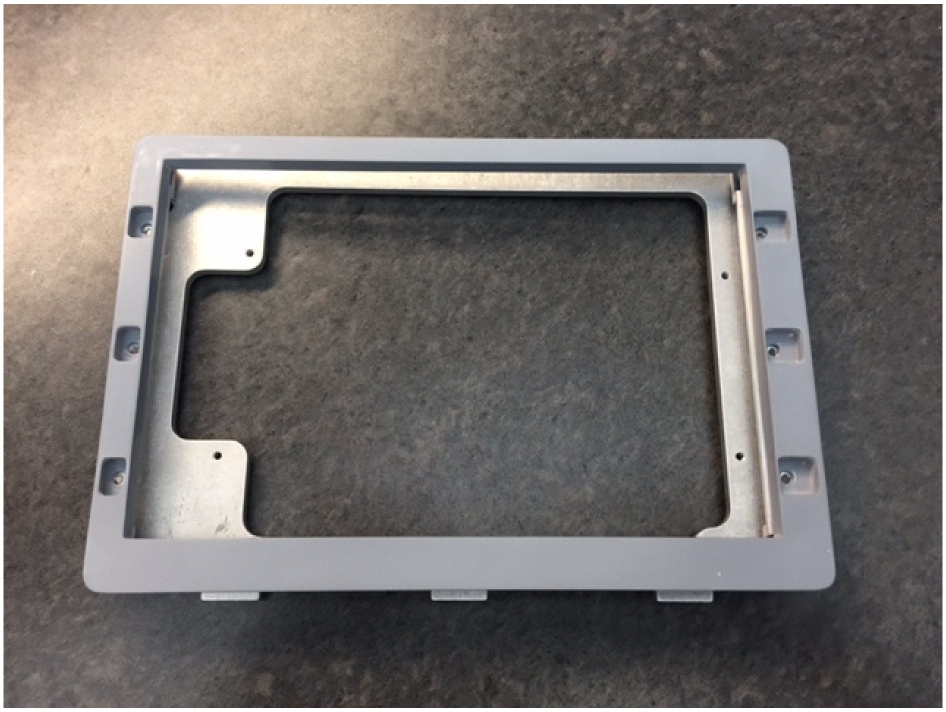

Figure 37. Bottom View—Plastic Touch Screen Frame

Figure 38. Securing Plastic Touch Screen Frame to Bracket

- Use the 4-40 3/16-inch screws to secure the plastic frame to the carrier frame using a total of six screws.

The following Figure 39 and Figure 40 show the final assembly.

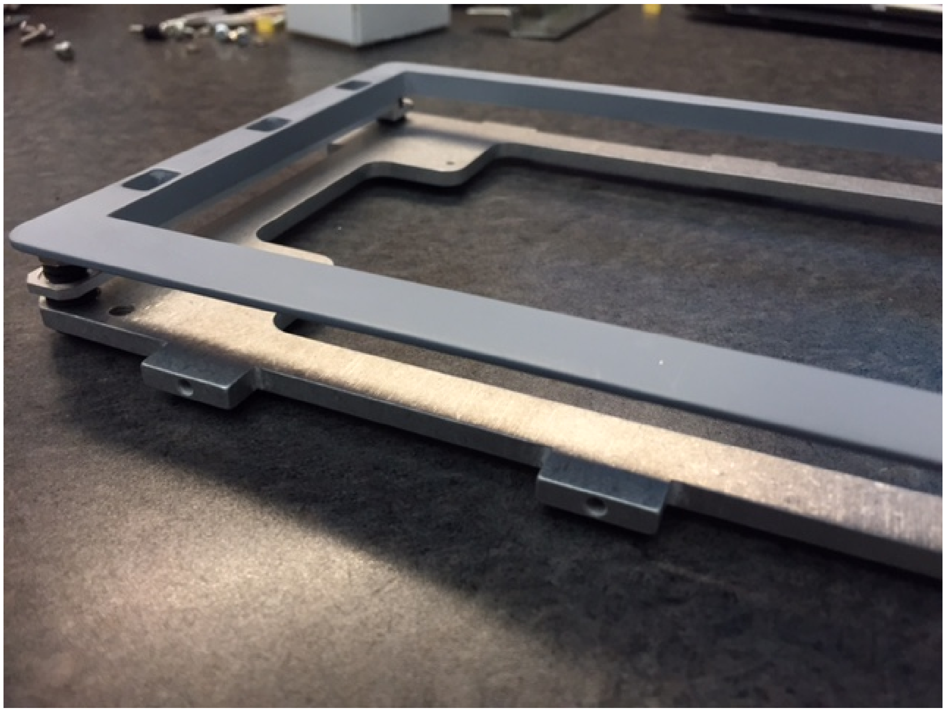

Figure 39. Side View—Attached Plastic Touch Screen Frame

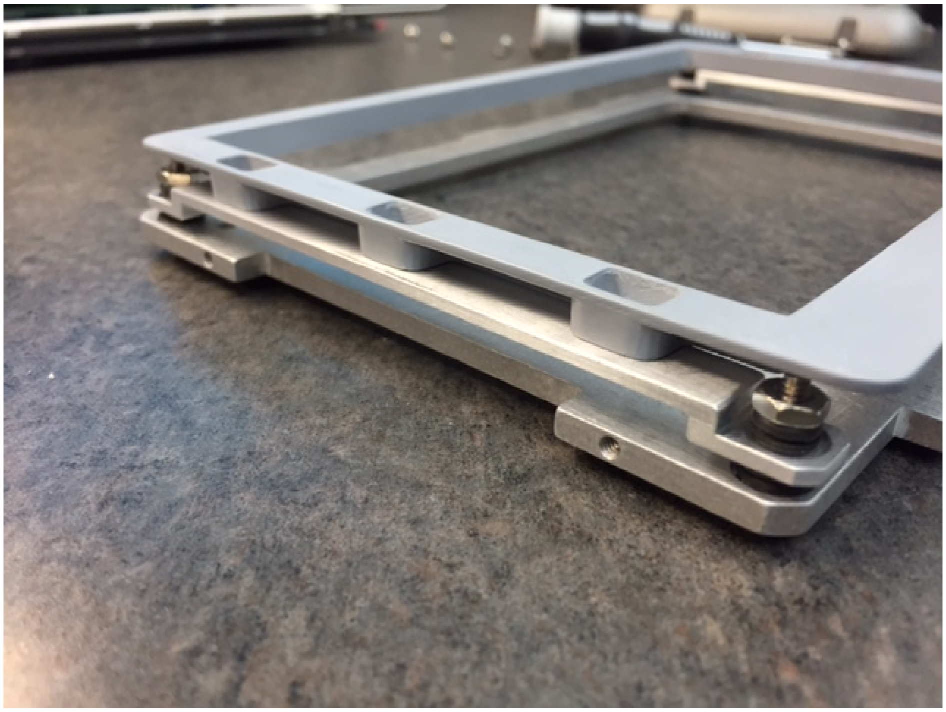

Figure 40. Side View—Attached Plastic Touch Screen Frame and Bracket

A.3 Securing Plastic Frame to Touch Panel

Once the carrier frame, brackets, and plastic frame are assembled, they can be attached to the back of the glass touch screen. Use 3M™ adhesive transfer tape (double-sided) to secure the plastic frame to the glass.

Table 10. Adhesive Transfer Tape Product Information

PART NUMBER	MANUFACTURER	DESCRIPTION
3-5-468MP	3M	Adhesive transfer tape

The plastic frame goes around the display panel on the back of the glass, as Figure 41 shows. Place 3M tape around the display panel on all four sides.

Figure 41. Backside—Touch Screen

As Figure 42 shows, remove the tape backing and press the plastic frame and display panel together firmly.

Figure 42. Tape on Backside of Touch Screen

A.4 Connecting Motherboard to Carrier Frame

Use 4-40 7/16-inch screws to secure the board to the carrier frame. Place white plastic spacers between the board and the carrier frame.

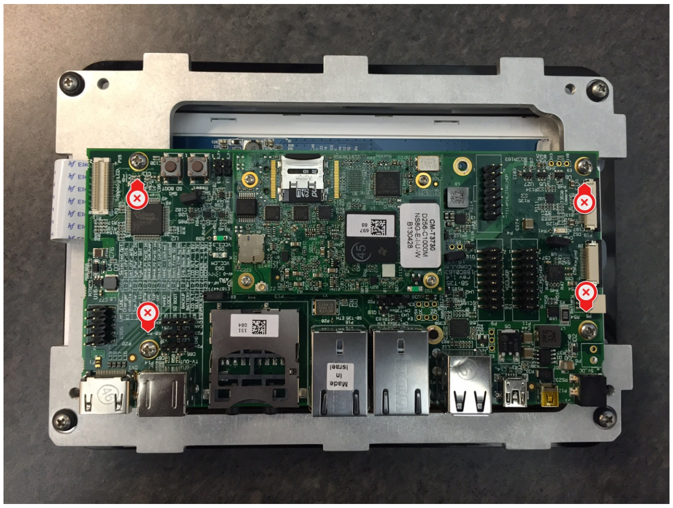

Figure 43. Motherboard and Carrier Frame Screw Locations

A.5 Attaching Chassis to Metal Frame

Place the plastic chassis frame around the touch panel. Make sure that the plastic frame aligns with the holes in the carrier frame (see Figure 44).

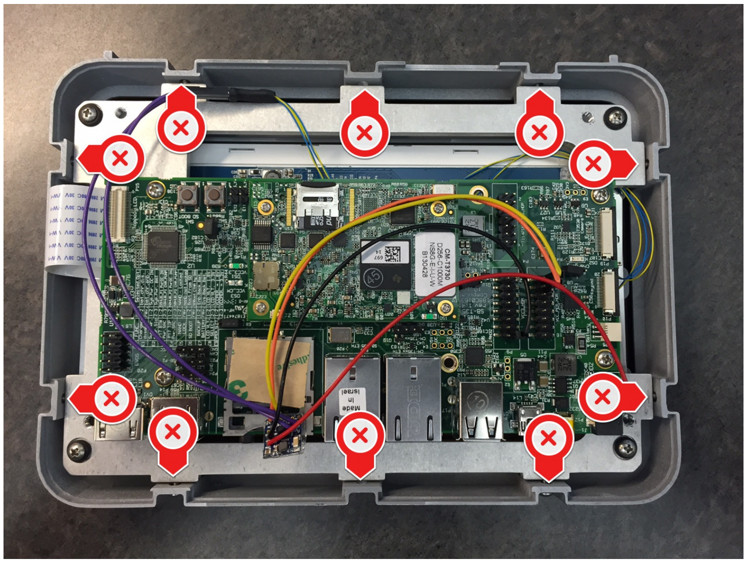

Figure 44. Screw Locations for Chassis and Carrier Frame

Insert 4-40 5/16-inch screws into the ten screw holes around the perimeter of the chassis (Figure 45).

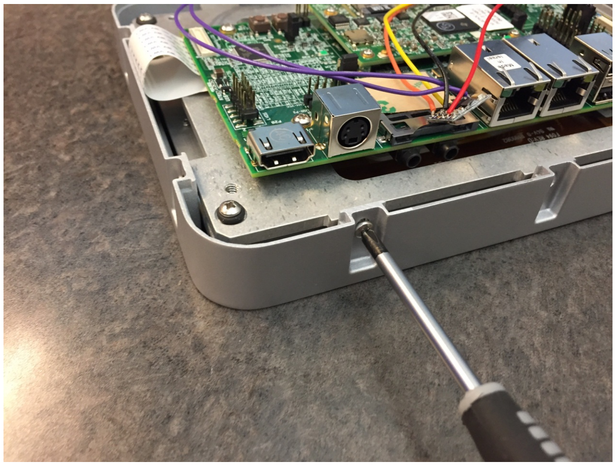

Figure 45. Secure Chassis to Carrier Frame

Finally, attach the back cover plate to the frame and secure with four 8-32 1-inch screws.

Figure 46. Enclosure with Back Cover Attached

Appendix B Electrical Connections

The DRV2667EVM-MINI and motherboard are connected using jumper wires. Figure 47 shows the overall solution.

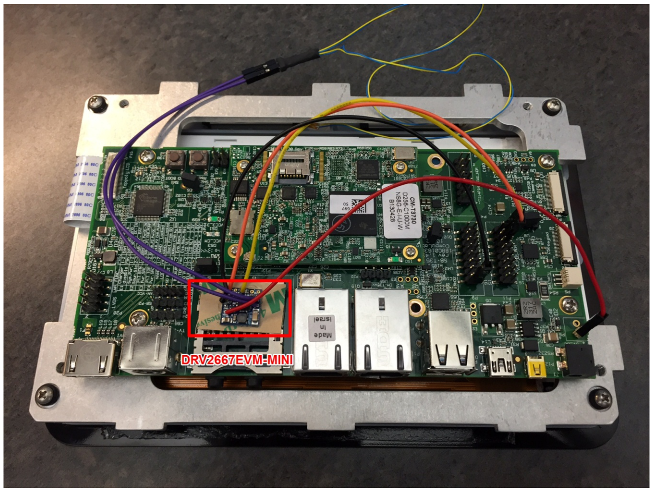

Figure 47. Haptic Electrical Connections Overview

The connections on the DRV2667EVM-MINI include VDD, GND, SDA, SCL, OUT+, and OUT−. Figure 48 shows a zoomed-in image of the board.

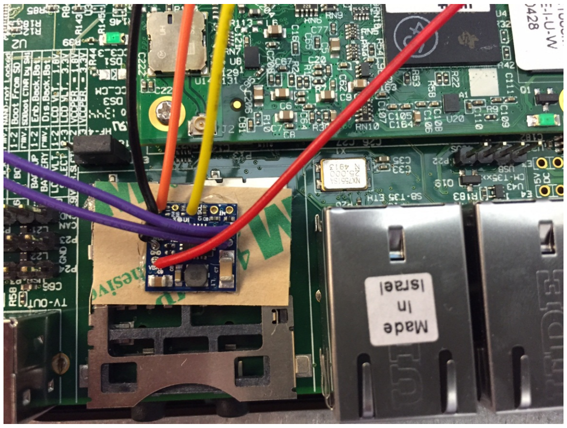

Figure 48. DRV2667EVM-MINI Board Connections

The wires are then connected to P9 and P11 of the mother board as Figure X shows. The orange wire is SDA, the yellow wire is SCL, and the black wire is GND.

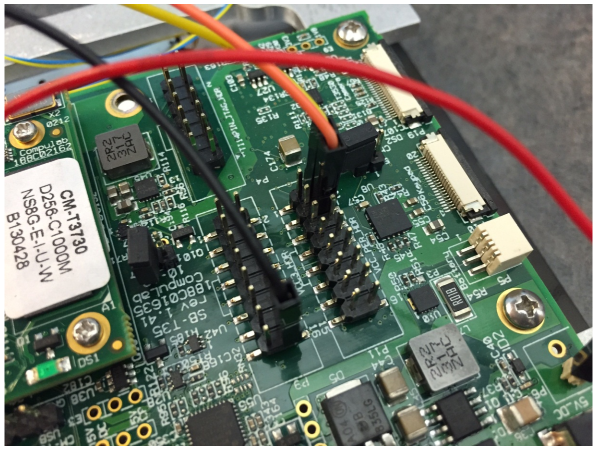

Figure 49. I²C and Ground Connections

Connect the red VDD wire to the 5-V rail near the power terminal of the mother board as Figure 50 shows.

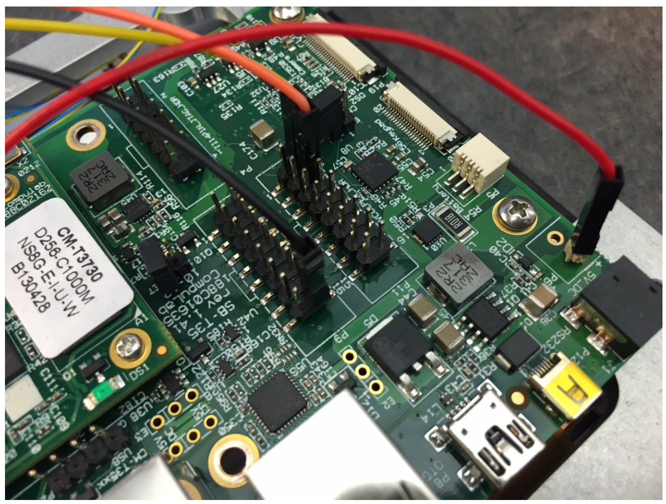

Figure 50. VDD Connection