DRV2624 ERM, LRA haptic driver evaluation kit

The DRV2624 is a haptic driver designed for Linear Resonant Actuators (LRA) and Eccentric Rotating Mass (ERM) motors. It provides many features which help eliminate the design complexities of haptic motor control including reduced solution size, high efficiency output drive, closed-loop motor control, quick device startup, memory for waveform storage, and auto-resonance frequency tracking.

The DRV2624EVM-CT Evaluation Module (EVM) is a complete demo and evaluation platform for the DRV2624. The kit includes a microcontroller, linear actuator, eccentric rotating mass motor, and capacitive touch buttons which can be used to completely demonstrate and evaluate the DRV2624.

This document contains instructions to setup and operate the DRV2624EVM-CT in demo and evaluation mode.

Figure 1. DRV2624EVM-CT Board

Evaluation Kit Contents:

- DRV2624EVM-CT demo and evaluation board
- Micro-USB cable
- Demonstration Firmware

Required for programming and advanced **configuration**:

- Code Composer Studio™ (CCS) or IAR Embedded Workbench IDE for MSP430
- MSP430 LaunchPad (MSP-EXP430G2), or MSP430-FET430UIF hardware programming tool
- DRV2624EVM-CT firmware available on ti.com

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1 Getting Started

The DRV2624 can be used as a demonstration or evaluation tool. When the DRV2624EVM-CT evaluation module is powered on for the first time, a demo application automatically starts. To power the board, connect the DRV2624EVM-CT to an available USB port on your computer using the included micro-USB cable. The demo begins with a board power-up sequence and then enters the demo effects mode. The four larger buttons on the wheel (1–4) can be used to sample haptic effects using both the ERM and LRA motor in the top right corner.

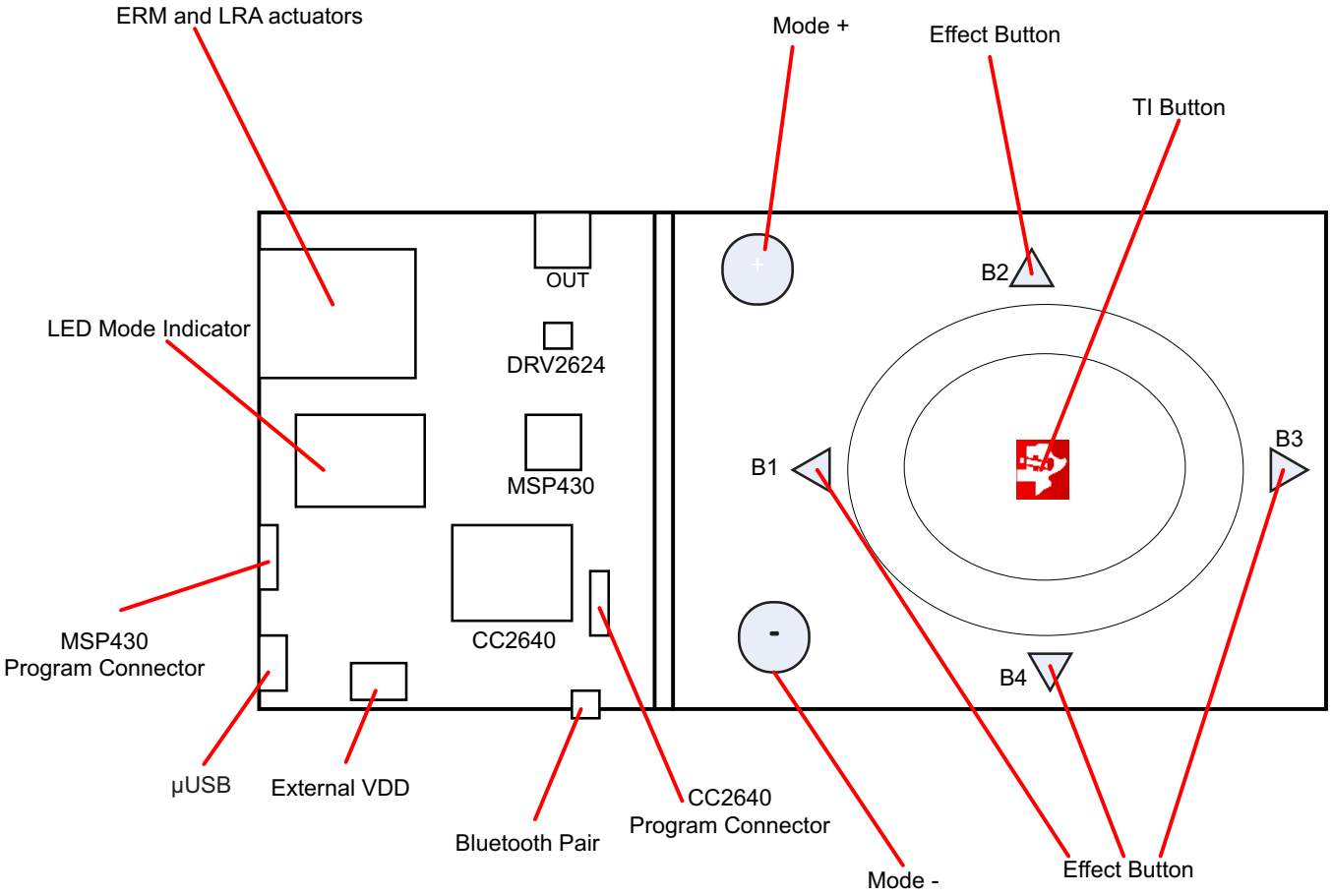

Figure 2. Board Diagram

1.1 Evaluation Module Operating Parameters

The following table lists the operating conditions for the DRV2624 on the evaluation module.

Parameter	Specification
Supply voltage range	2.7 V to 5.5 V
Power-supply current rating	400 mA

1.2 Quick Start Board Setup

The DRV2624EVM-CT firmware contains haptic waveforms which showcase the features and benefits of the DRV2624. Follow the instructions below to begin the demo:

1. Out of the box, the jumpers are set to begin demo mode using USB power. The default jumper settings are found in the table below.

Jumper	Default Position	Description
J3	Short pin 2-3	Powers using USB
J2	Short pin 2-3	USB power to DVDD
J5	Shorted	Level translator
J17	Open	Trigger/NRST for DRV2624
J7	Shorted	Bypass the I-Sense
J8	Shorted	Motor+ terminal
J9	Shorted	Motor- terminal
J4	Open	SDA/SCL connections to debug/Monitor advanced operations

2. Connect the included micro-USB cable to the USB connector on the DRV2624EVM-CT board.
3. Connect the other end of the USB cable to an available USB port on a computer, USB charger, or USB battery pack.
4. If the board is powered correctly, the LEDs will blink and the LRA and the ERM actuator will spin and stop at the start up.

2 DRV2624 Demonstration Program

The sections below provide a detailed description of the demo modes and effects.

2.1 Modes and Effects Table

The effects preloaded on the DRV2624EVM-CT are listed in Table 1. The modes are selected using the **+** and **–** mode buttons in the center of the board. The current mode is identified by the white LEDs directly above the mode buttons. Buttons B1–B4 trigger the effects listed in the description column and change based on the selected mode.

Table 1. Mode and Effects Table

Mode	Button	Description	Actuator	Waveform Location	Interface
Mode 0 LEDs Off	B1	Sharp Click	ERM	RAM	Internal Trigger (I^2C)
	B2	Sharp Click	LRA		
	B3	PulsingSharp	ERM		
	B4	PulsingSharp	LRA		
Mode 1 LED M1 On	B1	Soft Bump	ERM	RAM	Internal Trigger (I^2C)
	B2	Soft Bump	LRA		
	B3	Double Click	ERM		
	B4	Double Click	LRA		
Mode 2 LED M2 On	B1	Heartbeat x 3	ERM	RAM	Internal Trigger (I^2C)
	B2	Heartbeat x 3	LRA		
	B3	Buzz Alert 750mS	LRM		
	B4	Buzz Alert 750mS	ERA		
Mode 3 LED M3 On	B1	Closed Loop RTP 7F Buzz	LRA	RAM	RTP (I^2C)
	B2	Open Loop Pulsing with Auto Brake	LRA		RTP (I^2C)
	B3	Sine Wave Buzz RTP 7F	LRA		RTP (I^2C)
	B4	Open Loop Pulsing with no Auto Brake	LRA		RTP (I^2C)
Mode 4 LED M1 On	B1	RTP Strength change on position of the wheel	ERM and LRA	RAM	RTP (I^2C)
	B2				
	B3				
	B4				
	TI Button	Toggle ERM/LRA			Trigger One wire

2.2 Description of the Demo Modes

The following section highlights different features and benefits of using the DRV2624.

2.2.1 Mode Off – Haptics Effect Sequences

Below are a set of ERM and LRA Sharp Click waveforms. The four effects below show the difference between closed and open loop operation for both ERM and LRA.

In closed-loop operation for ERM's, the driver automatically overdrives and brakes the actuator. In open-loop, the waveform must be predefined with overdrive and braking.

For LRA's in closed-loop, the driver automatically tracks the resonant frequency, and overdrives and brakes the actuator. In open-loop, the waveform must be predefined with a static drive frequency, and overdrive and braking times.

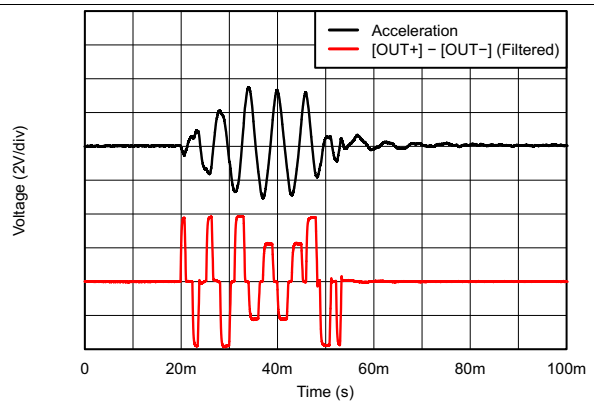

Figure 3. LRA Sharp Click Closed Loop Waveform

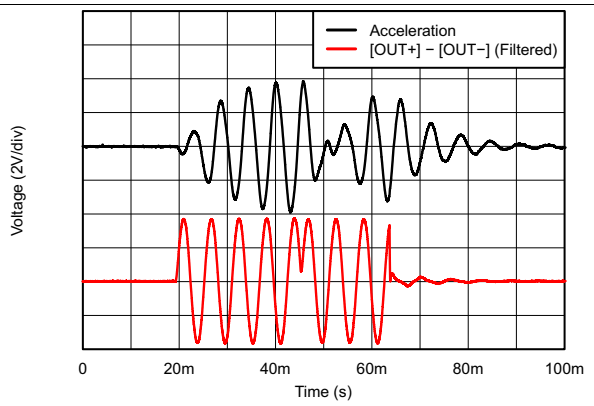

Figure 4. LRA Sharp Click Open Loop Waveform

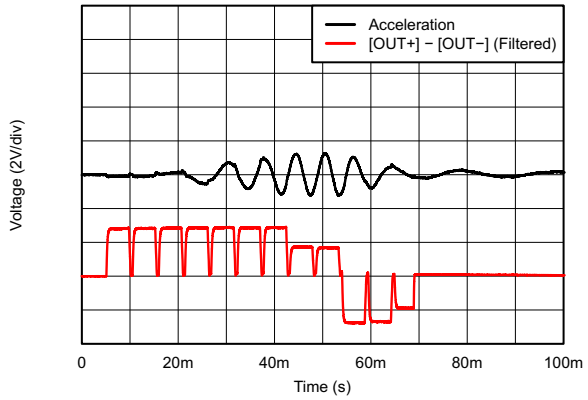

Figure 5. ERM Sharp Click Closed Loop Waveform

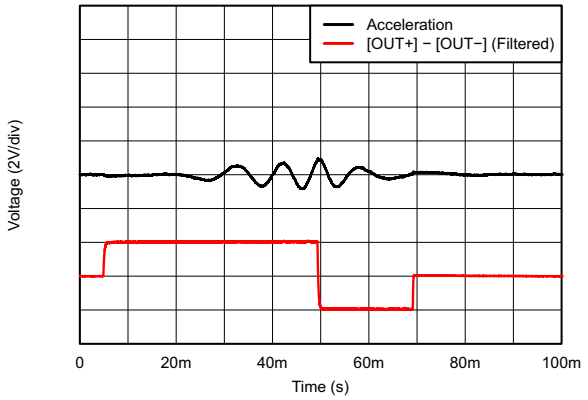

Figure 6. ERM Sharp Click Open Loop Waveform

2.2.2 Automatic Braking in Open Loop

The DRV2624 offers automatic braking in open-loop operation for both ERM and LRA. See Figure 7 and Figure 8 below for two separate LRA waveforms that show the advantage of using closed-loop breaking out of open loop operation. Notice that the settling time of the waveform with automatic braking is 15 ms, significantly faster than the 40-ms time achieved without automatic braking enabled.

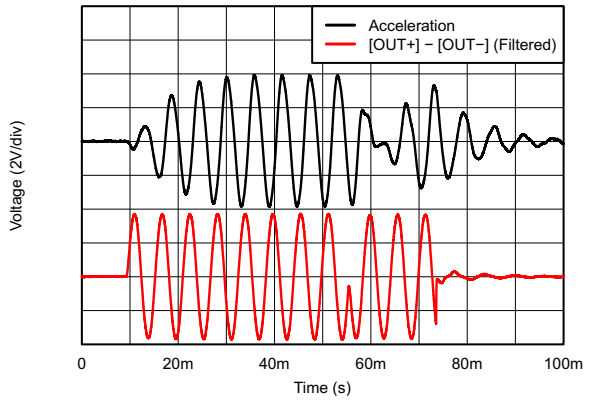

Figure 7. LRA Closed-Loop Click Waveform

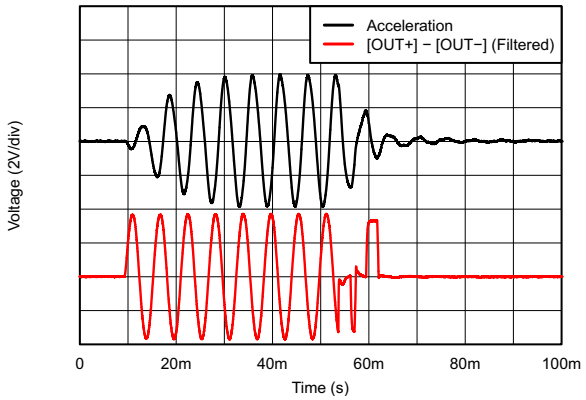

Figure 8. LRA Open-Loop Click Waveform

2.2.3 Auto-Resonance Tracking

Figure 9 and Figure 10 below showcase the advantages of the Smart Loop Architecture which includes auto-resonance tracking, automatic overdrive, and automatic braking. The two images below show the difference in acceleration between LRA auto-resonance ON and LRA auto-resonance OFF. Notice that the acceleration is higher when driven at the resonant frequency. The auto-resonance ON waveform has 1.32 G of acceleration and the auto-resonance OFF waveform has 0.92 G of acceleration. The auto-resonance ON waveform has 43% more acceleration.

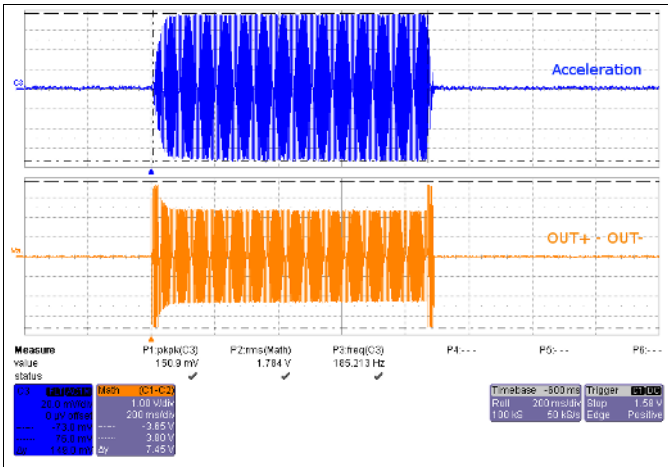

Figure 9. LRA Auto-Resonance ON Waveform (Button 1)

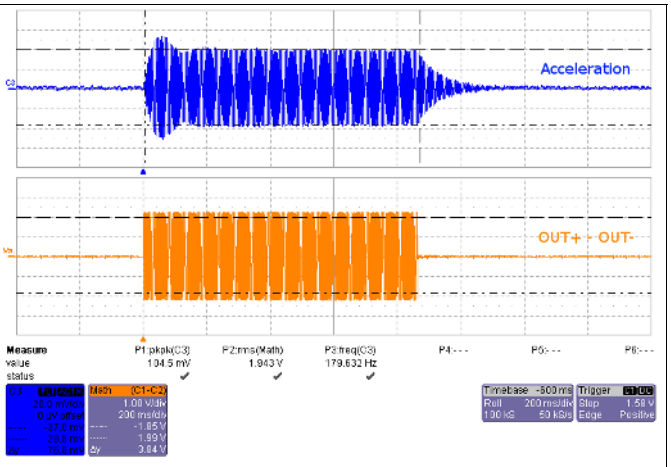

Figure 10. LRA Auto-Resonance OFF Waveform (Button 2)

The reason for higher acceleration can be seen in the acceleration versus frequency graph below. The LRA has a very narrow operating frequency range due to the properties of a spring-mass system. Furthermore, the resonance frequency drifts over various conditions such as temperature and drive voltage. With the Smart Loop auto-resonance feature, the DRV2624 dynamically tracks the exact resonant frequency to maximize the vibration force.

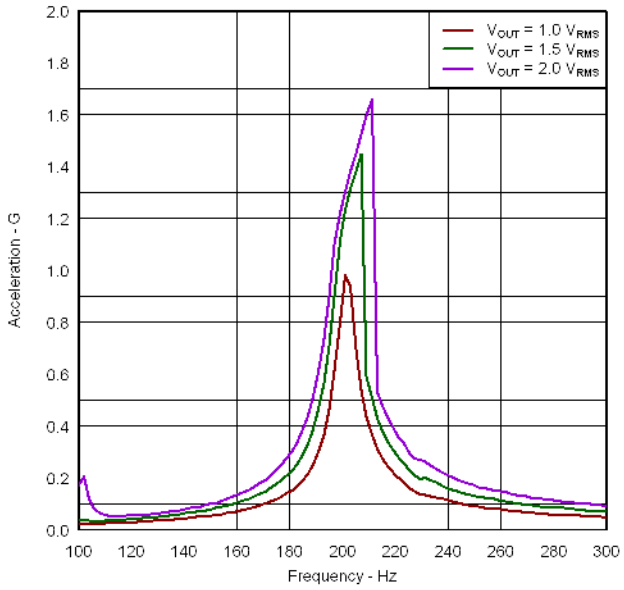

Figure 11. Acceleration Versus Frequency

3 Additional Hardware Modes

Additional modes are available on the DRV2624EVM-CT providing increased board control and functionality.

3.1 Accessing GUI Mode

The DRV2624EVM-CT has the ability to be controlled via Haptics Control Console. In order to place the EVM into 'GUI Mode', hold down the (+) for approximately 3 seconds. The LED indicators blink, and the right half of the LEDs remain on, indicating that the EVM is in GUI Mode.

3.2 Haptics Control Console GUI

Haptics Control Console (HCC) allows the user to have control over the DRV2624 driver through a number of controls and features.

To control the DRV2624EVM-CT via HCC, connect the EVM to an available port on a computer using the included micro USB cable. Once the EVM is powered on, access GUI Mode by holding down the (+) for approximately 3 seconds as described in *Section 3.1*.

Open up the latest version of Haptics Control Console, and on the tool bar the USB tab will read out '2.Haptics DRV2624 EVM [version]'. Once the GUI has recognized the DRV2624EVM-CT, press 'Connect' to access the device Console.

Once connected the HCC provides the user flexibility to control the EVM functions through a GUI 'Console', and the ability to read and write to and from the DRV2624 through the 'Register Map' window as seen below inFigure 12 below.

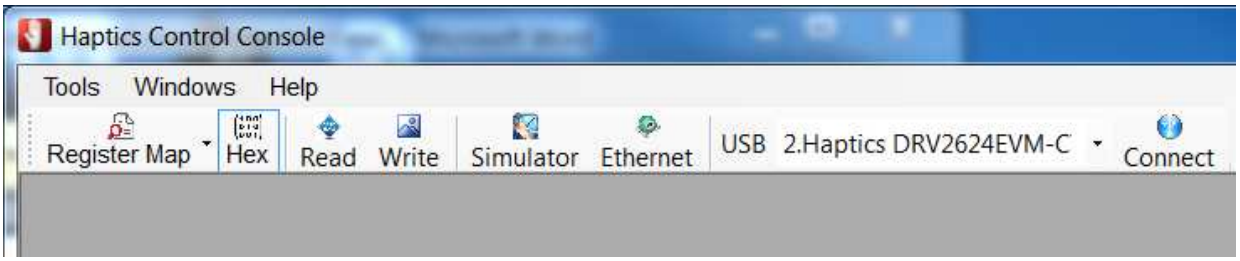

Figure 12. Haptics Control Console

3.2.1 DRV2624 Console

The DRV2624 Console is divided into three sections Initialization, Work Mode, and Board Status, as seen below in Figure 13. Each section allows the user to control the device on the EVM through I2C writes and communication.

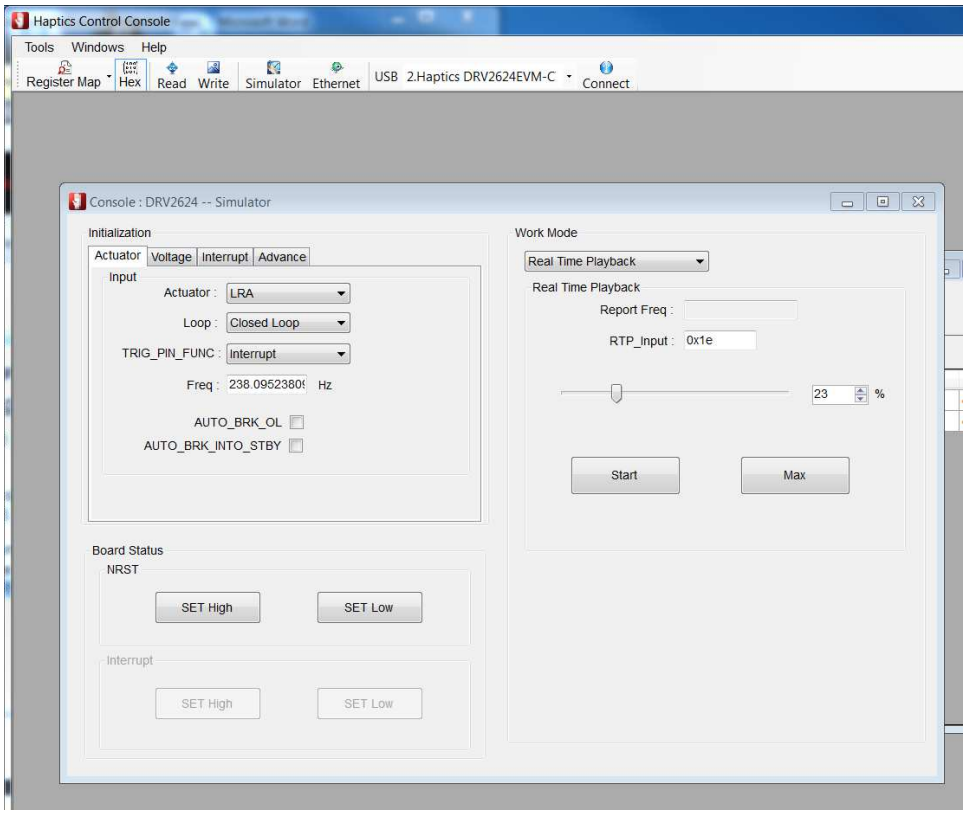

Figure 13. HCC DRV2624 Console

Please refer to the Haptics Control Console Users Guide for more detailed information on the device management features accessible through Haptics Control Console. The user's guide can be found on www.ti.com.

4 Hardware Configuration

The DRV2624EVM-CT is very flexible and can be used to completely evaluate the DRV2624. The following sections list the various hardware configurations.

4.1 Input and Output Overview

The DRV2624EVM-CT allows complete evaluation of the DRV2624 though test points, jacks, and connectors. Table 2 gives a brief description of the hardware.

Table 2. Hardware Overview

Signal	Description	I/O
DRV TRIG	External input or monitor to DRV2624 IN/TRIG pin	Input/Output
NRST	External DRV2624 shutdown control	Input
OUT+/OUT–	Filtered output test points for observation, connect to oscilloscope or measurement equipment	Output
USB	USB power (5 V)	Input
VBAT	External Supply Power (2.5 V – 5.5 V)	Input
SBW	MSP430 programming header	Input/Output
I^2C	DRV2624 and MSP430 I^2C bus	Input/Output

Hardware configuration details can be found in the following sections.

4.2 Power Supply Selection

The DRV2624EVM-CT can be powered by USB and an external power supply (VBAT). Jumpers J3 is used to select USB or VBAT for the DRV2624 and MSP430G2553, respectively. See Table 3 for possible configurations.

Table 3. Power Supply Configurations

Supply Configuration	DRV	MSP	DRV2624 Supply Voltage[(1)]
USB – Both	USB	USB	5 V
DRV2624 external supply, MSP430 USB	VBAT	USB	VBAT

(1) The DRV2624 supply must be on before operating the MSP430.

4.3 Using an External Actuator

The DRV2624EVM-CT can be used with an external actuator. Follow the instructions below to attach an actuator to the *OUT* terminal block.

1. Remove jumpers J8 and J9 to disconnect the on-board actuators from the DRV2624.
2. Attach the positive and negative leads of the actuator to the green *OUT* terminal block keeping in mind polarity.
3. Screw down the terminal block to secure the actuator leads.

Use the green terminal block when connecting an external actuator. The *OUT+* and *OUT–* test points have low-pass filters and should only be used for oscilloscope and bench measurements.

5 Measurement and Analysis

The DRV2624 uses PWM modulation to create the output signal for both ERM and LRA actuators. To measure and observe the DRV2624 output waveform, connect an oscilloscope or other measurement equipment to the filtered output test points, *OUT+* and *OUT–*.

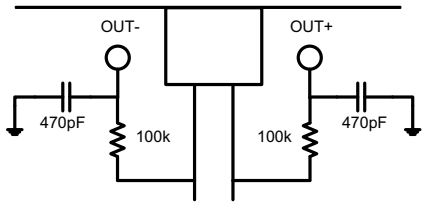

Figure 14. Terminal Block and Test Points

The DRV2624 drives LRA and ERM actuators using a 20-kHz PWM modulated waveform, but only the frequencies around the LRA resonant frequency or the ERM DC drive voltage are relevant to the haptic actuator vibration. The higher frequency switching content does not contribute to the vibration strength of the actuator and can make it difficult to interpret the modulated output waveform on an oscilloscope. The oscilloscope image on the left shows the DRV2624 unfiltered waveform and the image on the right shows a filtered version used for observation and measurement.

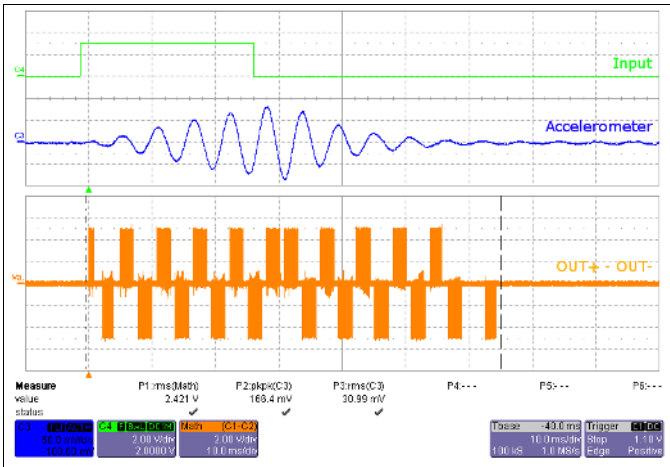

Figure 15. DRV2624 Unfiltered Waveform

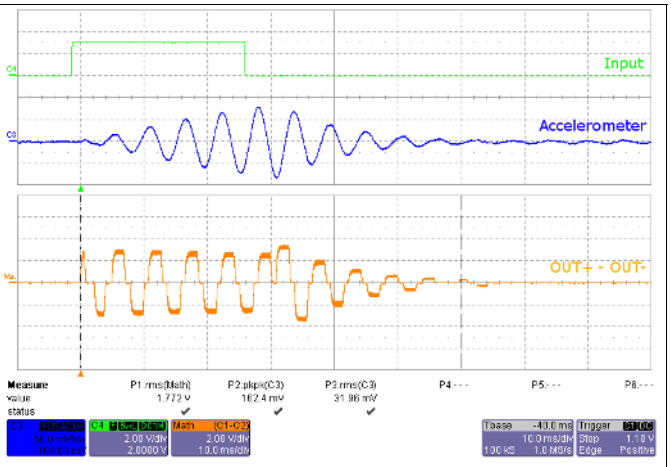

Figure 16. DRV2624 Filtered Waveform

6 Modifying or Reprogramming the Firmware

The MSP430 firmware on the DRV2624EVM-CT can be modified or reprogrammed to create new haptic effects or behaviors. Find the latest firmware source code and binaries on ti.com. Follow the instructions below to modify or reprogram the DRV2624EVM-CT.

1. Purchase one of the following MSP430F5510 compatible programmers:
   - MSP430 64-pin Target Development Board and MSP-FET(MSP-FETU64USB)
   - MSP-FET MCU Programmer and Debugger
2. Download and install Code Compose Studio (CCS) or IAR Embedded Workbench IDE.
3. Download the DRV2624EVM-CT source code and binaries from ti.com.
4. Connect the programmer to an available USB port.
5. Connect the programmer to the *J6* header on the DRV2624EVM-CT.
6. In CCS,
   a. Open the project file by selecting Project→Import Existing CCS Project.
   b. Select **Browse** and navigate to the DRV2624EVM-CT project folder, then press **OK**.
   c. Select the checkbox next to the DRV2624EVM-CT project in the *Discovered projects* window and then press **Finish**.
   d. Before compiling, navigate to Project→Properties→Build→MSP430 Compiler→Advanced Options→Language Options and make sure the checkbox for *Enable support for GCC extensions (–gcc)* is checked.
7. In IAR,
   a. Create a new MSP430 project in IAR,
   b. Select the MSP430F5510 device,
   c. Copy the files in the project folder downloaded from ti.com to the new project directory.

Figure 17 shows the connection between the MSP430 Programmer and Debugger (MSP-FET) and the DRV2624EVM-CT.

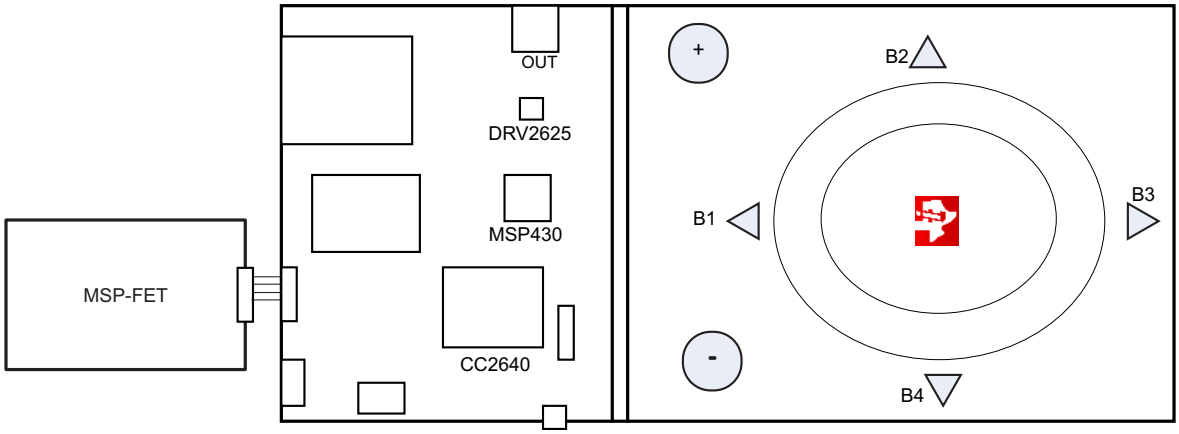

Figure 17. FET Programmer Connection

7 Schematic

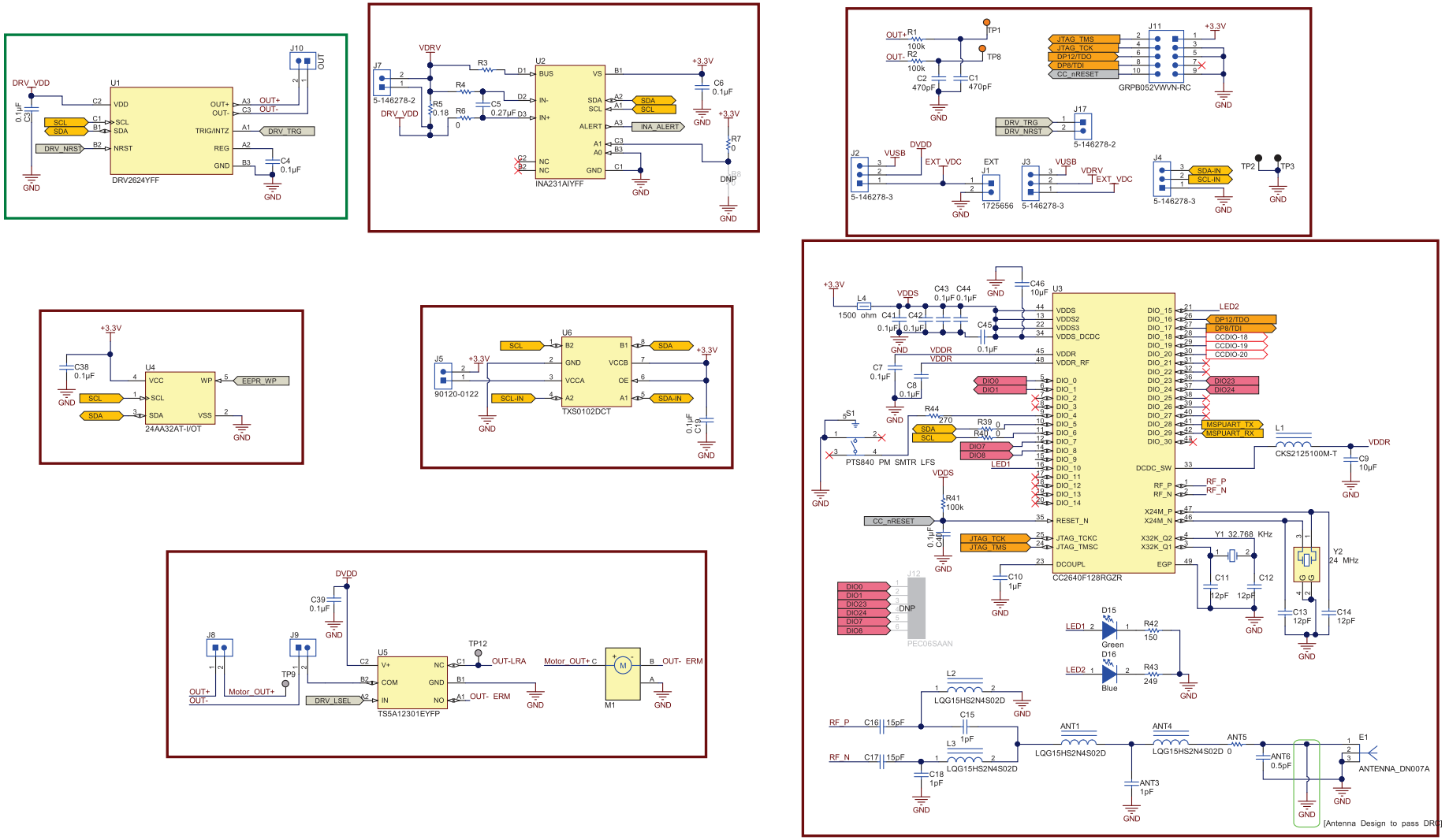

Figure 18. DRV2624EVM-CT Schematic Page 1

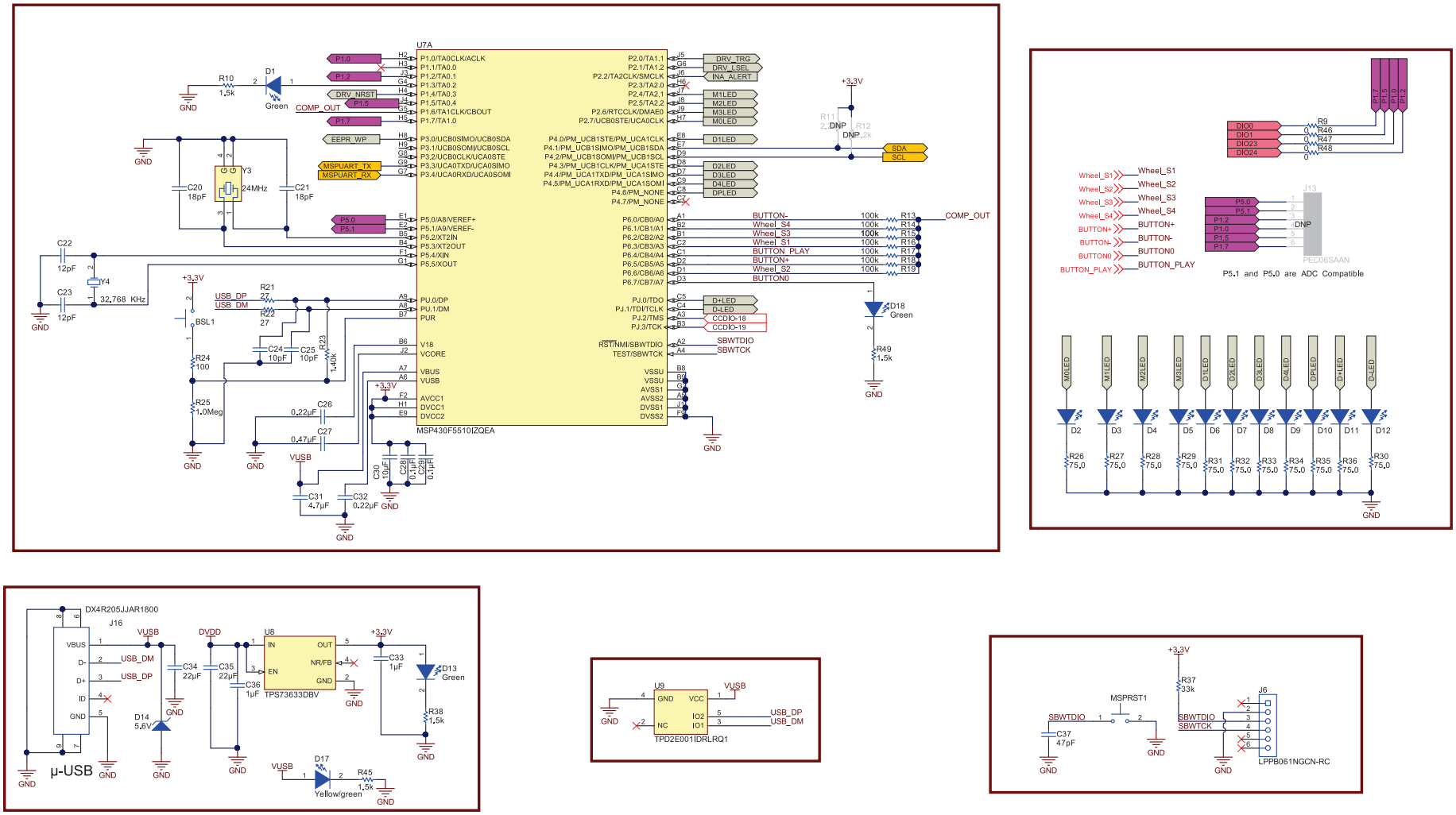

Figure 19. DRV2624EVM-CT Schematic Page 2

8 Layout

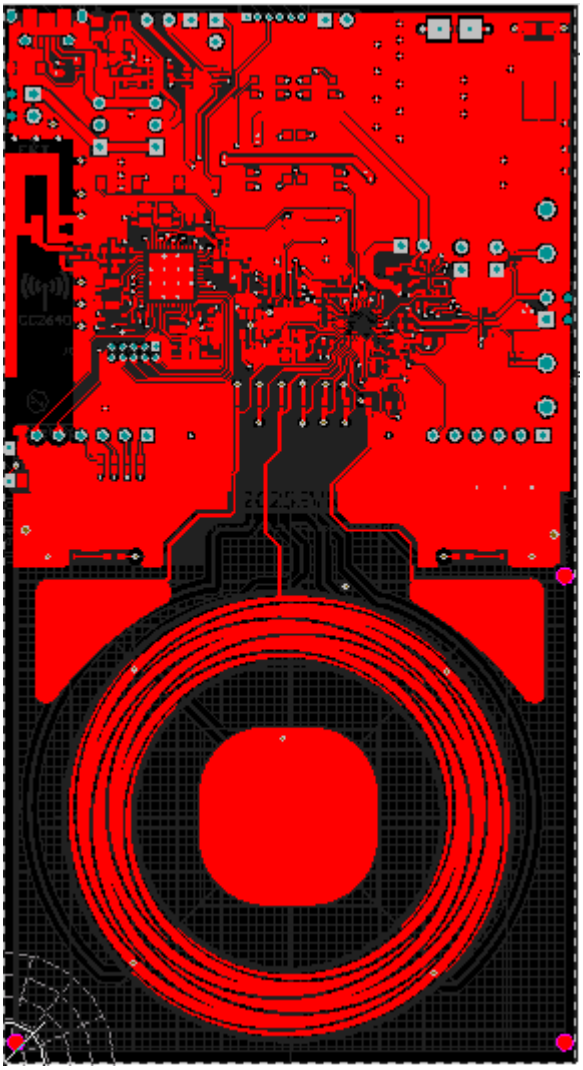

Figure 20. Top Layer

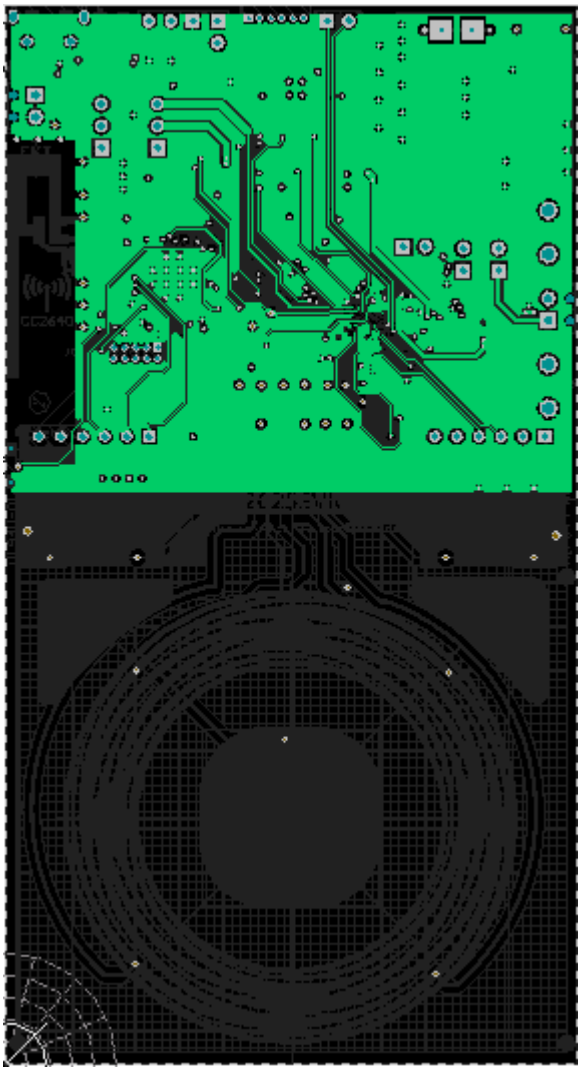

Figure 21. Layout Layer 2

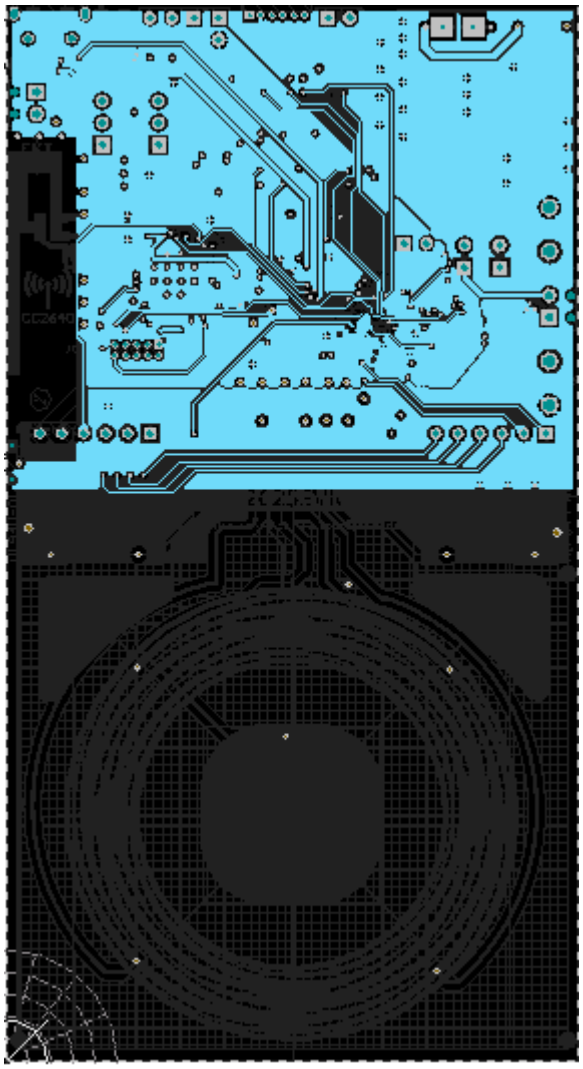

Figure 22. Layout Layer 3

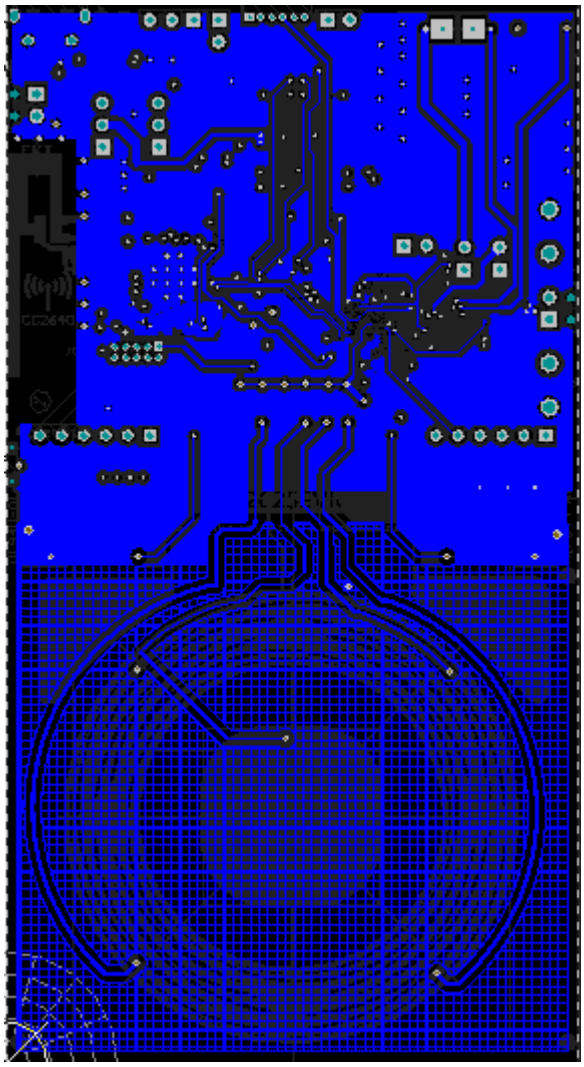

Figure 23. Layout Layer 4

9 Bill of Materials

Item #	Designator	Quantity	Value	Part Number	Manufacturer	Description	Package Reference
1	!PCB1	1		AIP044	Any	Printed Circuit Board	
2	ANT1, ANT4, L2, L3	4	2.4nH	LQG15HS2N4S02D	MuRata	Inductor, Multilayer, Air Core, 2.4 nH, 0.3 A, 0.15 ohm, SMD	0402 polarized
3	ANT3, C15, C18	3	1pF	GRM1555C1H1R0CA01D	MuRata	CAP, CERM, 1 pF, 50 V, +/- 5%, C0G/NP0, 0402	0402
4	ANT5, R3, R4, R6, R7, R9, R39, R40, R46, R47, R48	11	0	CRCW04020000Z0ED	Vishay-Dale	RES, 0, 5%, 0.063 W, 0402	0402
5	ANT6	1	0.5pF	GRM1555C1HR50BA01D	MuRata	CAP, CERM, 0.5 pF, 50 V, +/- 20%, C0G, 0402	0402
6	BSL1, MSPRST1	2		TL1015AF160QG	E-Switch	Switch, Tactile, SPST-NO, 0.05A, 12V, SMT	Switch, 4.4x2x2.9 mm
7	C1, C2	2	470pF	C1005C0G1H471J	TDK	CAP, CERM, 470 pF, 50 V, +/- 5%, C0G/NP0, 0402	0402
8	C3, C4, C19, C38, C39, C40, C41, C42, C43, C44, C45	11	0.1uF	GRM155R71C104KA88D	MuRata	CAP, CERM, 0.1 µF, 16 V, +/- 10%, X7R, 0402	0402
9	C5	1	0.27uF	GRM155R61A274KE15D	MuRata	CAP, CERM, 0.27 µF, 10 V, +/- 10%, X5R, 0402	0402
10	C6, C7, C8, C28, C29	5	0.1uF	GRM155R61C104KA88D	MuRata	CAP, CERM, 0.1uF, 16V, +/-10%, X5R, 0402	0402
11	C9, C30	2	10uF	GRM155R61A106ME44	MuRata	CAP, CERM, 10 µF, 10 V, +/- 20%, X5R, 0402	0402
12	C10, C33, C36	3	1uF	GRM155R61A105KE15D	MuRata	CAP, CERM, 1 µF, 10 V, +/- 10%, X5R, 0402, CAP, CERM, 1uF, 10V, +/-10%, X5R, 0402, CAP, CERM, 1 µF, 10 V, +/- 10%, X5R, 0402	0402
13	C11, C12, C13, C14, C22, C23	6	12pF	GRM1555C1H120JA01D	MuRata	CAP, CERM, 12 pF, 50 V, +/- 5%, C0G/NP0, 0402, CAP, CERM, 12 pF, 50 V, +/- 5%, C0G/NP0, 0402, CAP, CERM, 12 pF, 50 V, +/- 5%, C0G/NP0, 0402, CAP, CERM, 12 pF, 50 V, +/- 5%, C0G/NP0, 0402, CAP, CERM, 12pF, 50V, +/-5%, C0G/NP0, 0402, CAP, CERM, 12pF, 50V, +/-5%, C0G/NP0, 0402	0402
14	C16, C17	2	15pF	GRM1555C1H150JA01D	MuRata	CAP, CERM, 15 pF, 50 V, +/- 5%, C0G/NP0, 0402	0402
15	C20, C21	2	18pF	GRM1555C1H180JA01D	MuRata	CAP, CERM, 18pF, 50V, +/-5%, C0G/NP0, 0402	0402
16	C24, C25	2	10pF	GRM1555C1H100JA01D	MuRata	CAP, CERM, 10pF, 50V, +/-5%, C0G/NP0, 0402	0402
17	C26, C32	2	0.22uF	GRM155R71C224KA12D	MuRata	CAP, CERM, 0.22uF, 16V, +/-10%, X7R, 0402	0402
18	C27	1	0.47uF	GRM155R61C474KE01	MuRata	CAP, CERM, 0.47uF, 16V, +/-10%, X5R, 0402	0402
19	C31	1	4.7uF	GRM155R61A475M	MuRata	CAP, CERM, 4.7uF, 10V, +/-20%, X5R, 0402	0402
20	C34, C35	2	22uF	GRM21BR61C226ME44	MuRata	CAP, CERM, 22 µF, 16 V, +/- 20%, X5R, 0805	0805
21	C37	1	47pF	GRM1555C1E470JA01D	MuRata	CAP, CERM, 47pF, 25V, +/-5%, C0G/NP0, 0402	0402
22	C46	1	10uF	GRM155R61A106ME21D	MuRata	CAP, CERM, 10 µF, 10 V, +/- 20%, X5R, 0402	0402
23	D1, D13, D18	3	Green	LTST-C190GKT	Lite-On	LED, Green, SMD	1.6x0.8x0.8mm
24	D2, D3, D4, D5, D6, D7, D8, D9, D10, D11, D12	11		SML312WBCW1	Rohm	LED, White, SMD	LED, 0603
25	D14	1	5.6V	MMSZ5232B-7-F	Diodes Inc.	Diode, Zener, 5.6V, 500 mW, SOD-123	SOD-123
26	D15	1	Green	150060VS75000	Wurth Elektronik eiSos	LED, Green, SMD	LED_0603
27	D16	1	Blue	LB Q39G-L2N2-35-1	OSRAM	LED, Blue, SMD	BLUE 0603 LED
28	D17	1	Yellow/green	SML-P12MTT86	Rohm	LED, Yellow/green, SMD	0402 LED
29	H1	1		ELV1036A	AAC	AAC1036 LRA Actuator	Used in PnP output
30	H2	1		TI-EVACASE-BLACK	Royal Case	TI Black EVA Case	Used in PnP output
31	H3	1		3-5-468MP	3M	TAPE TRANSFER ADHESIVE 3" X 5YD	Used in PnP output
32	H4	1		2-5-4466W	3M	TAPE POLY FOAM 2" x 5YD	Used in PnP output

Item #	Designator	Quantity	Value	Part Number	Manufacturer	Description	Package Reference
33	H5	1			Heavy Metal	Metal Block (Custom Block, Heavy Metal, See metal block spec)	Used in PnP output
34	J1, J10	2		1725656	Phoenix Contact	Terminal Block, 100mil, 2x1, 6A, 63V, TH	6.2x8.5x5.54 mm
35	J2, J3, J4	3		5-146278-3	TE Connectivity	Header, 100mil, 3x1, Tin, TH	Header, 3x1, 100mil, TH
36	J5	1		90120-0122	Molex	Header, 100mil, 2x1, Tin, TH	Header 2x1
37	J6	1		LPPB061NGCN-RC	Sullins Connector Solutions	Receptacle, 50mil, 6x1, Gold, R/A, TH	6x1 Receptacle
38	J7, J8, J9, J17	4		5-146278-2	TE Connectivity	Header, 100mil, 2x1, Tin, TH	Header, 2x1, 100mil, TH
39	J11	1		GRPB052VWVN-RC	Sullins Connector Solutions	Header, 50mil, 5x2, Gold, TH	Header, 5x2, 50mil
40	J16	1		DX4R205JJAR1800	JAE Electronics	Connector, Receptacle, Micro-USB Type AB, R/A, Bottom Mount SMT	Connector, USB Micro AB
41	L1	1	10uH	CKS2125100M-T	Taiyo Yuden	Inductor, Multilayer, Ferrite, 10 µH, 0.11 A, 0.52 ohm, SMD	0805
42	L4	1	1500 ohm	BLM18HE152SN1D	MuRata	Ferrite Bead, 1500 ohm @ 100 MHz, 0.5 A, 0603_950	0603_950
43	M1	1		BAL-3611	NIDEC SEIMITSU	Motor, SMT	15.1x4.55mm
44	R1, R2, R13, R14, R15, R16, R17, R18, R19	9	100k	CRCW0402100KJNED	Vishay-Dale	RES, 100 k, 5%, 0.063 W, 0402, RES, 100 k, 5%, 0.063 W, 0402, RES, 100k ohm, 5%, 0.063W, 0402, RES, 100k ohm, 5%, 0.063W, 0402, RES, 100k ohm, 5%, 0.063W, 0402, RES, 100k ohm, 5%, 0.063W, 0402, RES, 100k ohm, 5%, 0.063W, 0402, RES, 100k ohm, 5%, 0.063W, 0402, RES, 100k ohm, 5%, 0.063W, 0402	0402
45	R5	1	0.18	ERJ-3RSFR18V	Panasonic	RES, 0.18, 1%, 0.1 W, 0603	0603
46	R10, R38, R45, R49	4	1.5k	CRCW04021K50JNED	Vishay-Dale	RES, 1.5k ohm, 5%, 0.063W, 0402	0402
48	R23	1	1.40k	CRCW04021K40FKED	Vishay-Dale	RES, 1.40k ohm, 1%, 0.063W, 0402	0402
49	R24	1	100	CRCW0402100RJNED	Vishay-Dale	RES, 100 ohm, 5%, 0.063W, 0402	0402
50	R25	1	1.0Meg	CRCW04021M00JNED	Vishay-Dale	RES, 1.0Meg ohm, 5%, 0.063W, 0402	0402
51	R26, R27, R28, R29, R30, R31, R32, R33, R34, R35, R36	11	75.0	CRCW040275R0FKED	Vishay-Dale	RES, 75.0 ohm, 1%, 0.063W, 0402	0402
52	R37	1	33k	CRCW040233K0JNED	Vishay-Dale	RES, 33k ohm, 5%, 0.063W, 0402	0402
53	R41	1	100k	RG1005P-104-B-T5	Susumu Co Ltd	RES, 100 k, 0.1%, 0.063 W, 0402	0402
54	R42	1	150	CRCW0402150RJNED	Vishay-Dale	RES, 150, 5%, 0.063 W, 0402	0402
55	R43	1	249	CRCW0402249RFKED	Vishay-Dale	RES, 249 ohm, 1%, 0.063W, 0402	0402
56	R44	1	270	CRCW0402270RJNED	Vishay-Dale	RES, 270, 5%, 0.063 W, 0402	0402
57	S1	1		PTS840 PM SMTR LFS	C&K Components	SWITCH TACTILE SPST-NO 0.05A 12V, SMT	3.5x1.35x3.55mm
58	SH-J1, SH-J2, SH-J3, SH-J4, SH-J5, SH-J6	6	1x2	969102-0000-DA	3M	Shunt, 100mil, Gold plated, Black	Shunt
59	TP1, TP8	2	Orange	5013	Keystone	Test Point, Multipurpose, Orange, TH	Orange Multipurpose Testpoint
60	TP2, TP3	2	Black	5011	Keystone	Test Point, Multipurpose, Black, TH	Black Multipurpose Testpoint
61	U1	1		DRV2624YFF	Texas Instruments	DRV2624YFF, YFF0009AHAN	YFF0009AHAN
62	U2	1		NA231AIYFF	Texas Instruments	High- or Low-Side Measurement, Bidirectional CURRENT/POWER MONITOR with 1.8-V I2C Interface, YFF0012AKAD	YFF0012AKAD
63	U3	1		CC2640F128RGZR	Texas Instruments	Ultra low-power ARM Cortex M3 2.4 GHz Radio MCU, Bluetooth Low Energy, RGZ0048A	RGZ0048A
64	U4	1		24AA32AT-I/OT	Microchip	32K I2C™ Serial EEPROM, SOT-23-5	SOT-23-5

Item #	Designator	Quantity	Value	Part Number	Manufacturer	Description	Package Reference
65	U5	1		TS5A12301EYFP	Texas Instruments	IEC LEVEL 4 ESD-PROTECTED 0.75-O SPDT ANALOG SWITCH WITH 1.8-V COMPATIBLE INPUT LOGIC, YFP0006AAAA	YFP0006AAAA
66	U6	1		TXS0102DCT	Texas Instruments	2-BIT BIDIRECTIONAL VOLTAGE-LEVEL TRANSLATOR FOR OPEN-DRAIN AND PUSH-PULL APPLICATIONS, DCT0008A	DCT0008A
67	U7	1		MSP430F5510IZQEA	Texas Instruments	25 MHz Mixed Signal Microcontroller with 32 KB Flash, 4096 B SRAM and 47 GPIOs, -40 to 85 degC, 80-pin BGA (ZQE), Green (RoHS & no Sb/Br)	ZQE0080A
68	U8	1		TPS73633DBV	Texas Instruments	Cap-Free, NMOS, 400mA Low-Dropout Regulator with Reverse Current Protection, DBV0005A	DBV0005A
69	U9	1		TPD2E001IDRLRQ1	Texas Instruments	Automotive Catalog Low-Capacitance + / - 15 kV ESD-Protection Array for High-Speed Data Inter, 2 Channels, -40 to +85 degC, 5-pin SOT (DRL), Green (RoHS & no Sb/Br)	DRL0005A
70	Y1	1		FC-135 32.7680KA-A3	Epson	Crystal, 32.768 KHz, 12.5 pF, SMD	SMD, 2-Leads, Body 3.2x1.5mm
71	Y2	1		TSX-3225 24.0000MF20G-AC3	Epson	Crystal, 24 MHz, 9 pF, SMD	SMD, 4-Leads, Body 2.65x3.35mm, Height 0.6mm
72	Y3	1		ABM8-24.000MHZ-B2-T	Abracon Corportation	Crystal, 24.000MHz, 18pF, SMD	3.2x0.8x2.5mm
73	Y4	1		FC-12M 32.7680KD-A3	Epson	Crystal, 32.768kHz, 12.5pF, SMD	Crystal 2.05x.6x1.2mm
74	FID1, FID2, FID3	0		N/A	N/A	Fiducial mark. There is nothing to buy or mount.	Fiducial
75	J12, J13	0		PEC06SAAN	Sullins Connector Solutions	Header, 100mil, 6x1, Tin, TH	TH, 6-Leads, Body 608x100mil, Pitch 100mil
76	R8	0	0	CRCW04020000Z0ED	Vishay-Dale	RES, 0, 5%, 0.063 W, 0402	0402
77	R11, R12	0	2.2k	CRCW04022K20JNED	Vishay-Dale	RES, 2.2k ohm, 5%, 0.063W, 0402	0402

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (December 2016) to A Revision	Page
• Changed 'ROM' to 'RAM' in Waveform Location column in the Table 1 table	5
• Deleted 'ROM Library Mode' and 'Waveform Library Effects List' sections	8

Changes from A Revision (March 2017) to B Revision	Page
• Deleted section: *Accessing Bluetooth Mode*	8

1 Trademarks

Code Composer Studio is a trademark of Texas Instruments.

STANDARD TERMS FOR EVALUATION MODULES

1. *Delivery:* TI delivers TI evaluation boards, kits, or modules, including any accompanying demonstration software, components, and/or documentation which may be provided together or separately (collectively, an “EVM” or “EVMs”) to the User (“User”) in accordance with the terms set forth herein. User's acceptance of the EVM is expressly subject to the following terms.

   1.1 EVMs are intended solely for product or software developers for use in a research and development setting to facilitate feasibility evaluation, experimentation, or scientific analysis of TI semiconductors products. EVMs have no direct function and are not finished products. EVMs shall not be directly or indirectly assembled as a part or subassembly in any finished product. For clarification, any software or software tools provided with the EVM (“Software”) shall not be subject to the terms and conditions set forth herein but rather shall be subject to the applicable terms that accompany such Software

   1.2 EVMs are not intended for consumer or household use. EVMs may not be sold, sublicensed, leased, rented, loaned, assigned, or otherwise distributed for commercial purposes by Users, in whole or in part, or used in any finished product or production system.

2 *Limited Warranty and Related Remedies/Disclaimers*:

   2.1 These terms do not apply to Software. The warranty, if any, for Software is covered in the applicable Software License Agreement.

   2.2 TI warrants that the TI EVM will conform to TI's published specifications for ninety (90) days after the date TI delivers such EVM to User. Notwithstanding the foregoing, TI shall not be liable for a nonconforming EVM if (a) the nonconformity was caused by neglect, misuse or mistreatment by an entity other than TI, including improper installation or testing, or for any EVMs that have been altered or modified in any way by an entity other than TI, (b) the nonconformity resulted from User's design, specifications or instructions for such EVMs or improper system design, or (c) User has not paid on time. Testing and other quality control techniques are used to the extent TI deems necessary. TI does not test all parameters of each EVM. User's claims against TI under this Section 2 are void if User fails to notify TI of any apparent defects in the EVMs within ten (10) business days after delivery, or of any hidden defects with ten (10) business days after the defect has been detected.

   2.3 TI's sole liability shall be at its option to repair or replace EVMs that fail to conform to the warranty set forth above, or credit User's account for such EVM. TI's liability under this warranty shall be limited to EVMs that are returned during the warranty period to the address designated by TI and that are determined by TI not to conform to such warranty. If TI elects to repair or replace such EVM, TI shall have a reasonable time to repair such EVM or provide replacements. Repaired EVMs shall be warranted for the remainder of the original warranty period. Replaced EVMs shall be warranted for a new full ninety (90) day warranty period.

WARNING

Evaluation Kits are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems.

User shall operate the Evaluation Kit within TI’s recommended guidelines and any applicable legal or environmental requirements as well as reasonable and customary safeguards. Failure to set up and/or operate the Evaluation Kit within TI’s recommended guidelines may result in personal injury or death or property damage. Proper set up entails following TI’s instructions for electrical ratings of interface circuits such as input, output and electrical loads.

NOTE:

EXPOSURE TO ELECTROSTATIC DISCHARGE (ESD) MAY CAUSE DEGREDATION OR FAILURE OF THE EVALUATION KIT; TI RECOMMENDS STORAGE OF THE EVALUATION KIT IN A PROTECTIVE ESD BAG.

3 *Regulatory Notices:*

3.1 *United States*

3.1.1 *Notice applicable to EVMs not FCC-Approved:*

FCC NOTICE: This kit is designed to allow product developers to evaluate electronic components, circuitry, or software associated with the kit to determine whether to incorporate such items in a finished product and software developers to write software applications for use with the end product. This kit is not a finished product and when assembled may not be resold or otherwise marketed unless all required FCC equipment authorizations are first obtained. Operation is subject to the condition that this product not cause harmful interference to licensed radio stations and that this product accept harmful interference. Unless the assembled kit is designed to operate under part 15, part 18 or part 95 of this chapter, the operator of the kit must operate under the authority of an FCC license holder or must secure an experimental authorization under part 5 of this chapter.

3.1.2 *For EVMs annotated as FCC – FEDERAL COMMUNICATIONS COMMISSION Part 15 Compliant:*

CAUTION

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

FCC Interference Statement for Class A EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

FCC Interference Statement for Class B EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- *Reorient or relocate the receiving antenna.*
- *Increase the separation between the equipment and receiver.*
- *Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.*
- *Consult the dealer or an experienced radio/TV technician for help.*

3.2 *Canada*

3.2.1 *For EVMs issued with an Industry Canada Certificate of Conformance to RSS-210 or RSS-247*

Concerning EVMs Including Radio Transmitters:

This device complies with Industry Canada license-exempt RSSs. Operation is subject to the following two conditions:

(1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Concernant les EVMs avec appareils radio:

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes: (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

Concerning EVMs Including Detachable Antennas:

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication. This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

Concernant les EVMs avec antennes détachables

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante. Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d'usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur

3.3 *Japan*

3.3.1 *Notice for EVMs delivered in Japan:* Please see http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_01.page 日本国内に輸入される評価用キット、ボードについては、次のところをご覧ください。
http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_01.page

3.3.2 *Notice for Users of EVMs Considered "Radio Frequency Products" in Japan:* EVMs entering Japan may not be certified by TI as conforming to Technical Regulations of Radio Law of Japan.

If User uses EVMs in Japan, not certified to Technical Regulations of Radio Law of Japan, User is required to follow the instructions set forth by Radio Law of Japan, which includes, but is not limited to, the instructions below with respect to EVMs (which for the avoidance of doubt are stated strictly for convenience and should be verified by User):

1. Use EVMs in a shielded room or any other test facility as defined in the notification #173 issued by Ministry of Internal Affairs and Communications on March 28, 2006, based on Sub-section 1.1 of Article 6 of the Ministry's Rule for Enforcement of Radio Law of Japan,
2. Use EVMs only after User obtains the license of Test Radio Station as provided in Radio Law of Japan with respect to EVMs, or
3. Use of EVMs only after User obtains the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to EVMs. Also, do not transfer EVMs, unless User gives the same notice above to the transferee. Please note that if User does not follow the instructions above, User will be subject to penalties of Radio Law of Japan.

【無線電波を送信する製品の開発キットをお使いになる際の注意事項】 開発キットの中には技術基準適合証明を受けていないものがあります。 技術適合証明を受けていないもののご使用に際しては、電波法遵守のため、以下のいずれかの措置を取っていただく必要がありますのでご注意ください。

1. 電波法施行規則第6条第1項第1号に基づく平成18年3月28日総務省告示第173号で定められた電波暗室等の試験設備でご使用いただく。
2. 実験局の免許を取得後ご使用いただく。
3. 技術基準適合証明を取得後ご使用いただく。

なお、本製品は、上記の「ご使用にあたっての注意」を譲渡先、移転先に通知しない限り、譲渡、移転できないものとします。
上記を遵守頂けない場合は、電波法の罰則が適用される可能性があることをご留意ください。 日本テキサス・インスツルメンツ株式会社
東京都新宿区西新宿 6 丁目 2 4 番 1 号
西新宿三井ビル

3.3.3 *Notice for EVMs for Power Line Communication:* Please see http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_02.page
電力線搬送波通信についての開発キットをお使いになる際の注意事項については、次のところをご覧ください。http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_02.page

3.4 *European Union*

3.4.1 *For EVMs subject to EU Directive 2014/30/EU (Electromagnetic Compatibility Directive)*:

This is a class A product intended for use in environments other than domestic environments that are connected to a low-voltage power-supply network that supplies buildings used for domestic purposes. In a domestic environment this product may cause radio interference in which case the user may be required to take adequate measures.

4 *EVM Use Restrictions and Warnings:*

4.1 EVMS ARE NOT FOR USE IN FUNCTIONAL SAFETY AND/OR SAFETY CRITICAL EVALUATIONS, INCLUDING BUT NOT LIMITED TO EVALUATIONS OF LIFE SUPPORT APPLICATIONS.

4.2 User must read and apply the user guide and other available documentation provided by TI regarding the EVM prior to handling or using the EVM, including without limitation any warning or restriction notices. The notices contain important safety information related to, for example, temperatures and voltages.

4.3 *Safety-Related Warnings and Restrictions:*

4.3.1 User shall operate the EVM within TI's recommended specifications and environmental considerations stated in the user guide, other available documentation provided by TI, and any other applicable requirements and employ reasonable and customary safeguards. Exceeding the specified performance ratings and specifications (including but not limited to input and output voltage, current, power, and environmental ranges) for the EVM may cause personal injury or death, or property damage. If there are questions concerning performance ratings and specifications, User should contact a TI field representative prior to connecting interface electronics including input power and intended loads. Any loads applied outside of the specified output range may also result in unintended and/or inaccurate operation and/or possible permanent damage to the EVM and/or interface electronics. Please consult the EVM user guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative. During normal operation, even with the inputs and outputs kept within the specified allowable ranges, some circuit components may have elevated case temperatures. These components include but are not limited to linear regulators, switching transistors, pass transistors, current sense resistors, and heat sinks, which can be identified using the information in the associated documentation. When working with the EVM, please be aware that the EVM may become very warm.

4.3.2 EVMs are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems. User assumes all responsibility and liability for proper and safe handling and use of the EVM by User or its employees, affiliates, contractors or designees. User assumes all responsibility and liability to ensure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard. User assumes all responsibility and liability for any improper or unsafe handling or use of the EVM by User or its employees, affiliates, contractors or designees.

4.4 User assumes all responsibility and liability to determine whether the EVM is subject to any applicable international, federal, state, or local laws and regulations related to User's handling and use of the EVM and, if applicable, User assumes all responsibility and liability for compliance in all respects with such laws and regulations. User assumes all responsibility and liability for proper disposal and recycling of the EVM consistent with all applicable international, federal, state, and local requirements.

5. *Accuracy of Information:* To the extent TI provides information on the availability and function of EVMs, TI attempts to be as accurate as possible. However, TI does not warrant the accuracy of EVM descriptions, EVM availability or other information on its websites as accurate, complete, reliable, current, or error-free.

6. *Disclaimers:*

6.1 EXCEPT AS SET FORTH ABOVE, EVMS AND ANY MATERIALS PROVIDED WITH THE EVM (INCLUDING, BUT NOT LIMITED TO, REFERENCE DESIGNS AND THE DESIGN OF THE EVM ITSELF) ARE PROVIDED "AS IS" AND "WITH ALL FAULTS." TI DISCLAIMS ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, REGARDING SUCH ITEMS, INCLUDING BUT NOT LIMITED TO ANY EPIDEMIC FAILURE WARRANTY OR IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF ANY THIRD PARTY PATENTS, COPYRIGHTS, TRADE SECRETS OR OTHER INTELLECTUAL PROPERTY RIGHTS.

6.2 EXCEPT FOR THE LIMITED RIGHT TO USE THE EVM SET FORTH HEREIN, NOTHING IN THESE TERMS SHALL BE CONSTRUED AS GRANTING OR CONFERRING ANY RIGHTS BY LICENSE, PATENT, OR ANY OTHER INDUSTRIAL OR INTELLECTUAL PROPERTY RIGHT OF TI, ITS SUPPLIERS/LICENSORS OR ANY OTHER THIRD PARTY, TO USE THE EVM IN ANY FINISHED END-USER OR READY-TO-USE FINAL PRODUCT, OR FOR ANY INVENTION, DISCOVERY OR IMPROVEMENT, REGARDLESS OF WHEN MADE, CONCEIVED OR ACQUIRED.

7. *USER'S INDEMNITY OBLIGATIONS AND REPRESENTATIONS.* USER WILL DEFEND, INDEMNIFY AND HOLD TI, ITS LICENSORS AND THEIR REPRESENTATIVES HARMLESS FROM AND AGAINST ANY AND ALL CLAIMS, DAMAGES, LOSSES, EXPENSES, COSTS AND LIABILITIES (COLLECTIVELY, "CLAIMS") ARISING OUT OF OR IN CONNECTION WITH ANY HANDLING OR USE OF THE EVM THAT IS NOT IN ACCORDANCE WITH THESE TERMS. THIS OBLIGATION SHALL APPLY WHETHER CLAIMS ARISE UNDER STATUTE, REGULATION, OR THE LAW OF TORT, CONTRACT OR ANY OTHER LEGAL THEORY, AND EVEN IF THE EVM FAILS TO PERFORM AS DESCRIBED OR EXPECTED.

8. *Limitations on Damages and Liability:*

   8.1 *General Limitations*. IN NO EVENT SHALL TI BE LIABLE FOR ANY SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL, OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF THESE TERMS OR THE USE OF THE EVMS , REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES. EXCLUDED DAMAGES INCLUDE, BUT ARE NOT LIMITED TO, COST OF REMOVAL OR REINSTALLATION, ANCILLARY COSTS TO THE PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES, RETESTING, OUTSIDE COMPUTER TIME, LABOR COSTS, LOSS OF GOODWILL, LOSS OF PROFITS, LOSS OF SAVINGS, LOSS OF USE, LOSS OF DATA, OR BUSINESS INTERRUPTION. NO CLAIM, SUIT OR ACTION SHALL BE BROUGHT AGAINST TI MORE THAN TWELVE (12) MONTHS AFTER THE EVENT THAT GAVE RISE TO THE CAUSE OF ACTION HAS OCCURRED.

   8.2 *Specific Limitations.* IN NO EVENT SHALL TI'S AGGREGATE LIABILITY FROM ANY USE OF AN EVM PROVIDED HEREUNDER, INCLUDING FROM ANY WARRANTY, INDEMITY OR OTHER OBLIGATION ARISING OUT OF OR IN CONNECTION WITH THESE TERMS, , EXCEED THE TOTAL AMOUNT PAID TO TI BY USER FOR THE PARTICULAR EVM(S) AT ISSUE DURING THE PRIOR TWELVE (12) MONTHS WITH RESPECT TO WHICH LOSSES OR DAMAGES ARE CLAIMED. THE EXISTENCE OF MORE THAN ONE CLAIM SHALL NOT ENLARGE OR EXTEND THIS LIMIT.

9. *Return Policy.* Except as otherwise provided, TI does not offer any refunds, returns, or exchanges. Furthermore, no return of EVM(s) will be accepted if the package has been opened and no return of the EVM(s) will be accepted if they are damaged or otherwise not in a resalable condition. If User feels it has been incorrectly charged for the EVM(s) it ordered or that delivery violates the applicable order, User should contact TI. All refunds will be made in full within thirty (30) working days from the return of the components(s), excluding any postage or packaging costs.

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