

# 1-A Single-Input, Single-Cell Li-Ion Battery Charger

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This user's guide describes the bq2404x evaluation module (EVM), how to perform a stand-alone evaluation or interface with a host or system. The charger is designed to deliver up to 1000 mA of continuous current to the battery output when programmed with a resistor on the ISET pin and is programmed at the factory for ~540 mA. The USB current limit modes are selected by the ISET2 pin and limits current to a maximum of 500 mA (logic high) or 100 mA (float or high impedance). A low on the ISET2 pin programs the charge current using the ISET resistor.

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## 1 Introduction

The bq2404x series of devices are highly integrated Li-ion linear charger devices targeted at space-limited portable applications. The devices operate from either a USB port or AC adapter.

The bq2404x has a single power output that charges the battery. A system load can be placed in parallel with the battery as long as the average system load does not keep the battery from charging fully during the 10 hour safety timer.

The battery is charged in three phases: conditioning, constant current, and constant voltage. In all charge phases, an internal control loop monitors the IC junction temperature and reduces the charge current if an internal temperature threshold is exceeded.

The charger power stage and charge current sense functions are fully integrated. The charger function has high-accuracy current and voltage regulation loops, charge status display, and charge termination. The pre-charge current and termination current threshold are programmed via an external resistor on the bq24040 and bq24045. The fast charge current value is also programmable via an external resistor.

## 2 Considerations With Evaluating the bq2404x

Refer to the data sheet for specific details on the charger ICs. The main differences between the bq24040 and the bq24041 are that the Pre-Term pin is replaced with an Auto Start (I/O) (ASI/ASO) feature, a different Over-Voltage Protection Threshold, and a Temperature Sense Pin (TS) versus a BAT\_EN pin. The main difference between the bq24040 and bq24045 is in the regulation voltage. The bq24040 is 4.2-V and bq24045 is 4.35-V regulation voltage.

The ISET current control loop sets the maximum charge current. This maximum programmed current level can be further reduced by entering a USB mode, selected by the ISET2 pin.

The ASO output is dependent on the OUT pin to power the internal OR gate along with at least one high signal on the input (bq24041).

A system load may be connected to the OUT pin, which takes away some of the charge current. Normally it is not recommended to operate the device in pre-charge since the system load keeps the battery from recovering; but, since the PRE\_TERM pin can program a higher pre-charge current this restriction is not necessary.

## 3 Performance Specification Summary

Specification	Test Conditions	MIN	TYP	MAX	UNIT
Input DC voltage, $V_{IN}$	Recommended input voltage range	4.45		6.45	V
Reduced Performance, $I_{IN}^{(1)}$	Will not charge with Over Voltage input condition. Limited charging with under voltage input.	3.5		28	V
Power Dissipation <sup>(2)</sup>	$P_{DISS} = (V_{IN} - V_{OUT}) \times I_{OUT}$			1.5	W
$I_{OUT}^{(3)}$	RISET = 1 k $\Omega$		0.54	0.8	A

<sup>(1)</sup> Input voltage range is specified for normal operation. Input voltage between UVLO and 4.75 V has limited functionality, but does not damage the IC nor present any safety issue with the battery. Input voltage above OVP and less than 30 Vdc has no operation and will not damage the IC. Lower input voltage (closer to dropout operation) produces less heat dissipation and potentially better performance.

<sup>(2)</sup> The junction temperature rise above ambient is proportional to the power dissipation. Once the junction temperature reaches ~125°C, thermal regulations reduces the programmed charge current.

<sup>(3)</sup> The EVM is set for 800 mA, by changing R1 to lower values, it can support up to 1000 mA.

## 4 Test Procedure Summary

### 4.1 Equipment

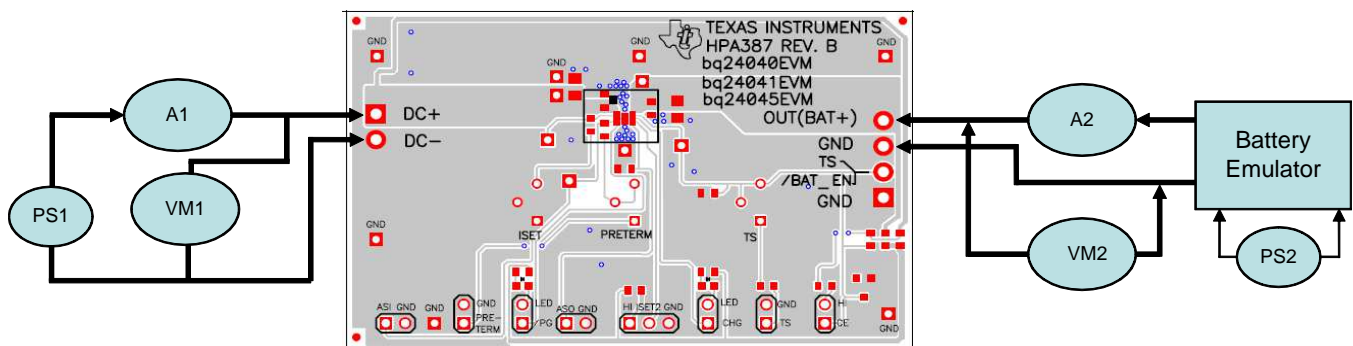
The following sections outline the equipment necessary to perform all tests in the test procedure.

- Power supply #1 (PS #1) capable of supplying 12 V at 3 A is required
- Power supply #2 (PS #2) capable of supplying up to 5 V at 5 A is required to power battery emulator.
- PR1010-002 (Battery emulator)
- Flat-head screwdriver
- Three voltage meters (VM) and two equivalent current meters (A) are required. The current meters must be able to measure 3-A current.

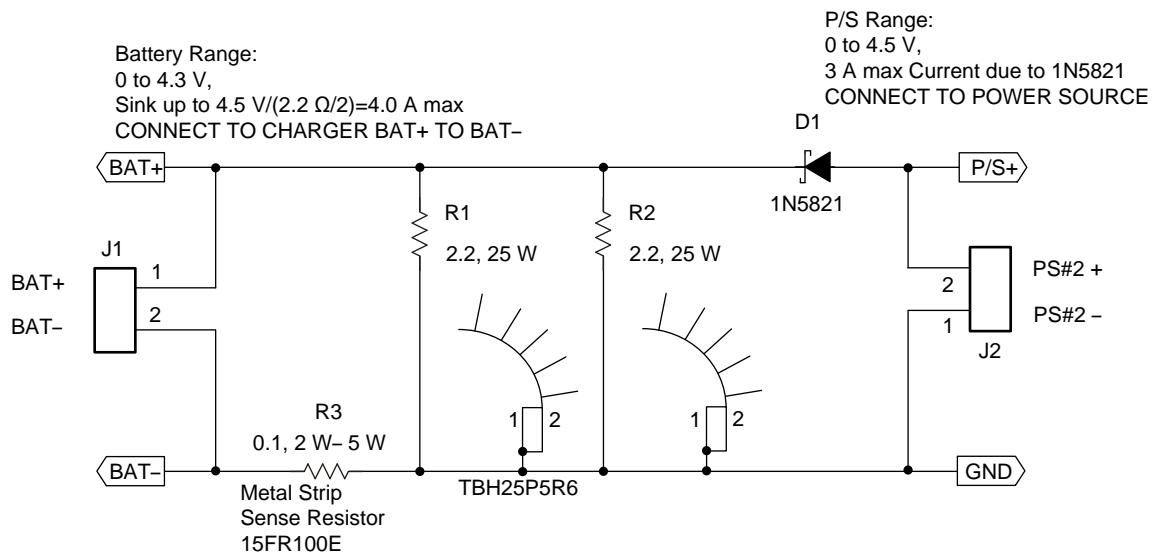
### 4.2 Equipment Setup

1. For all power connections, use short, twisted-pair wires of appropriate gauge wire for the amount of the current (can handle 3 A).
2. Set PS1 for 5-V, 2-A current limit and then turn off supply
3. Connect the PS1 in series with current meter (A1) to J1 (DC+ and DC-).
4. Connect a Voltmeter (VM1) across DC1 and DC2.
5. Adjust PS2 set to approximately 3.6 V with current limit of 4 A to the input side of battery emulator, then turn off PS2.
6. Connect VM2 across J2 (OUT, GND)
7. Connect the output side of the battery emulator in series with current meter (A2) to J2 (OUT and GND).

See [Figure 1](#) and [Figure 2](#) as Reference.



**Figure 1. Original Test Setup**


**Figure 2. Battery Emulator**

### 4.3 Jumper Setup

- JMP1→Installed
- JMP2→ Installed
- JMP3→ISET2 and GND shorted
- JMP4→ Installed
- JMP5→ Installed

### 4.4 ISET, PRETERM, and TS Setup

#### 4.4.1 TS

- Use the VM3 to measure the Resistance across GND and TP9
- Adjust R11 until VM3 reads  $10\text{ k}\Omega \pm 500\ \Omega$

#### 4.4.2 ISET

- Use the VM3 to measure the Resistance across GND and TP2
- Adjust R2 until VM3 reads  $1\text{ k}\Omega \pm 50\ \Omega$

#### 4.4.3 PRETERM

- Use the VM3 to measure the Resistance across GND and TP4
- Adjust R4 until VM3 reads  $2\text{ k}\Omega \pm 100\ \Omega$

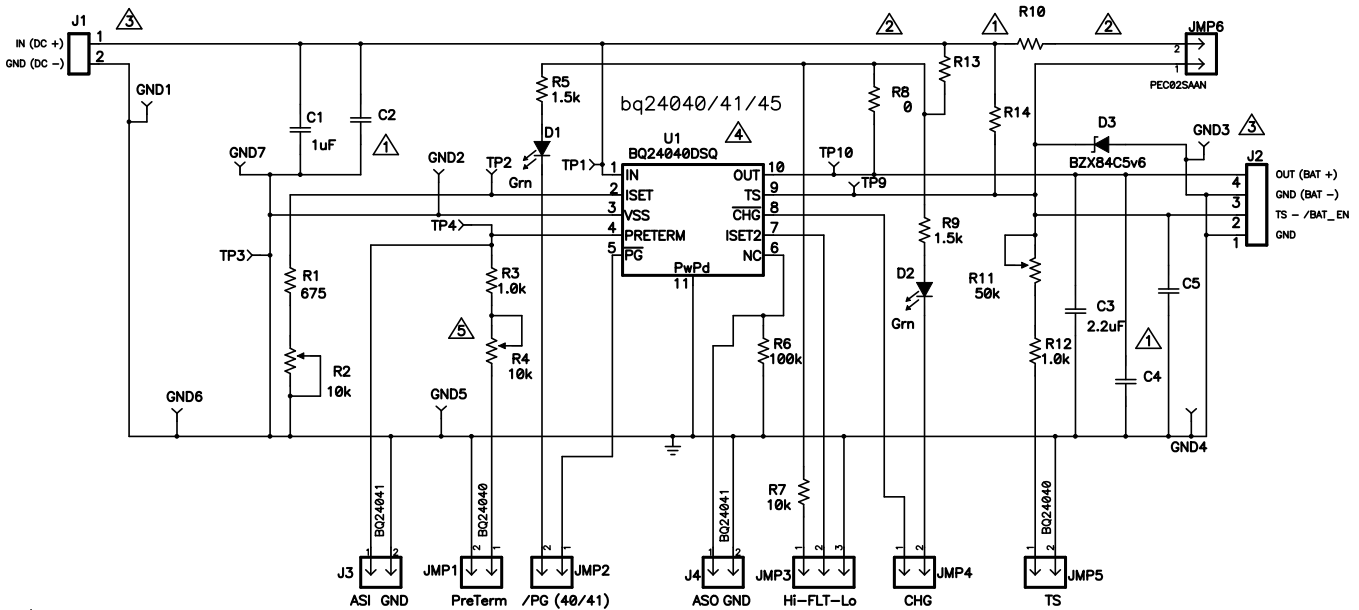
## 4.5 Procedure

### 4.5.1 Operational Testing

1. Ensure that the recommended test setup is followed
2. Turn ON PS1 and PS2
3. Adjust PS2 such that VM2 reads 3.6 V  $\pm$ 50mV
4. Adjust PS1 such that VM1 reads 5 V  $\pm$ 50mV
5. Measure on A#2  $\rightarrow I_{\text{CHRG}} = 540 \text{ mA} \pm 50 \text{ mA}$
6. Make sure D1 and D2 are ON
7. Remove the shorting jumper on JMP3
8. Measure on A#2  $\rightarrow I_{\text{CHRG}} = 100 \text{ mA} \pm 50 \text{ mA}$
9. Make sure D1 and D2 are ON
10. Short ISET2 to HI on JMP3
11. Measure on A#2  $\rightarrow I_{\text{CHRG}} = 500 \text{ mA} \pm 60 \text{ mA}$
12. Make sure D1 and D2 are ON
13. Put shorting jumper back on JMP3 between ISET2 and GND
14. Using VM3, measure the voltage between TP9 (TS pin) and GND
15. Adjust R11 until VM3 reads 0.9 V  $\pm$ 50 mV
16. Measure on A#2  $\rightarrow I_{\text{CHRG}} = 270 \text{ mA} \pm 50 \text{ mA}$
17. Adjust R11 until VM3 reads 1.3 V  $\pm$ 50 mV
18. Measure on A#2  $\rightarrow I_{\text{CHRG}} = 0 \text{ mA} \pm 20 \text{ mA}$
19. Measure on A#1  $\rightarrow I_{\text{IN}} = 0 \text{ mA} \pm 50 \text{ mA}$
20. Adjust back R11 until VM3 reads 0.5 V  $\pm$ 50 mV
21. Measure on A#2  $\rightarrow I_{\text{CHRG}} = 540 \text{ mA} \pm 50 \text{ mA}$
22. Measure on A#1  $\rightarrow I_{\text{IN}} = 580 \text{ mA} \pm 70 \text{ mA}$
23. Increase PS2 until VM2 reads 4.30 V (4.2 V for bq24040)
24. Then slowly increase PS2 until D2 turns OFF
25. Measure on A#2  $\rightarrow I_{\text{CHRG}} = 0 \text{ mA} \pm 20 \text{ mA}$
26. Measure on A#1  $\rightarrow I_{\text{IN}} = 0 \text{ mA} \pm 50 \text{ mA}$
27. Decrease PS2 until VM2 reads 3.6 V  $\pm$ 10 mV
28. Measure on A#2  $\rightarrow I_{\text{CHRG}} = 540 \text{ mA} \pm 50 \text{ mA}$
29. Measure on A#1  $\rightarrow I_{\text{IN}} = 580 \text{ mA} \pm 70 \text{ mA}$
30. Turn PS1 and PS2 off
31. Remove all test equipment from the UUT

## 5 Schematic, Physical Layouts and Bill of Materials

### 5.1 Schematic



- ⚠ See BOM for component configurations for -001, -002, -003.  
R8 connects OUTpull-up for the LEDs and ISET2.
- ⚠ Can move R8 to R13 if Vin is desired as the pull-up source (note Vin should be <7V for this configuration).  
R14, R10 and JMP6 may be used in a future development.
- ⚠ Input Voltage: 4.5V to 5.5VDC Typical, Consider Thermal Issues for > 5.5V to OVP; No charging above OVP.  
OUT is a 4.2V regulated output with a programmable output current of 1A maximum.
- ⚠ TP1→TP10 are associated with U1 pin out. TP5,6,7 & 8 are omitted.  
See Table for differences in bq24040/45 and bq24041 ICs.

Part	bq24040/45	bq24041
Pin 4	PreTerm	AS
Pin 5	/PG	/PG
Pin 6	NC	ASO
Pin 9	TS	/CS-ID
OVP	6.6V	7.1V

Figure 3. bq2404x EVM Board Schematic

## 5.2 Physical Layouts

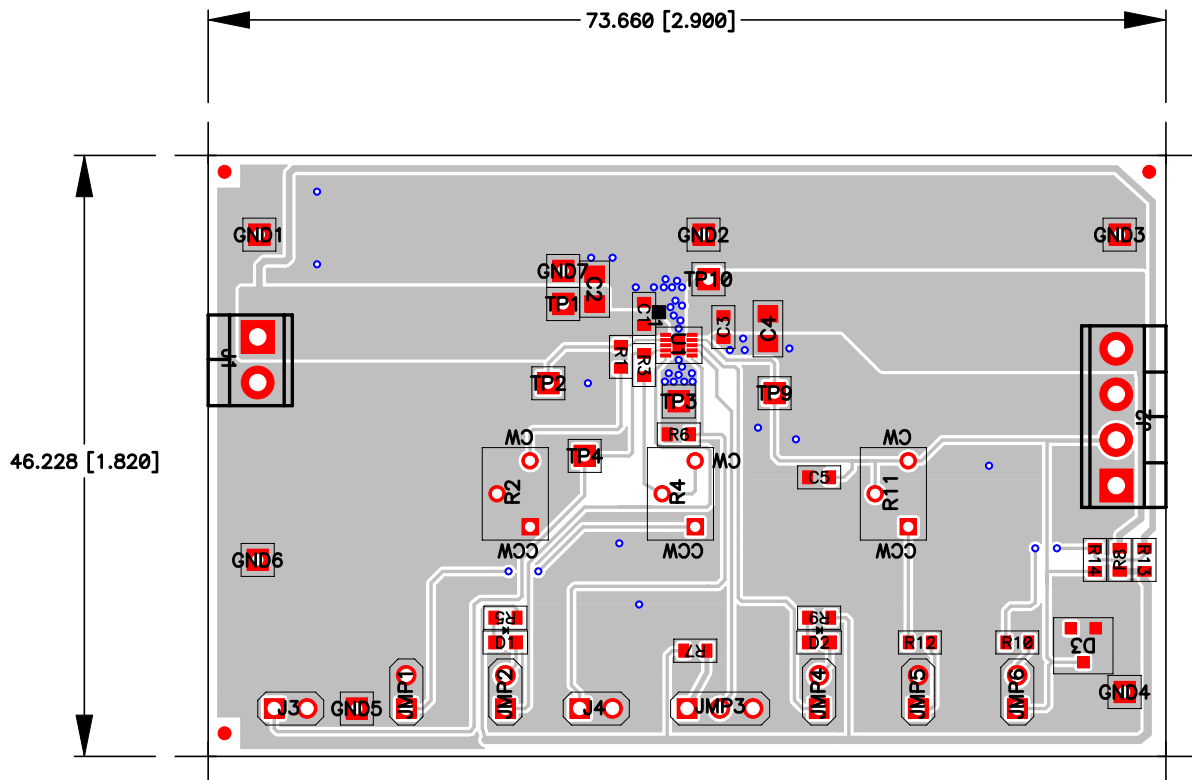


Figure 4. bq2404x EVM Assembly Layer

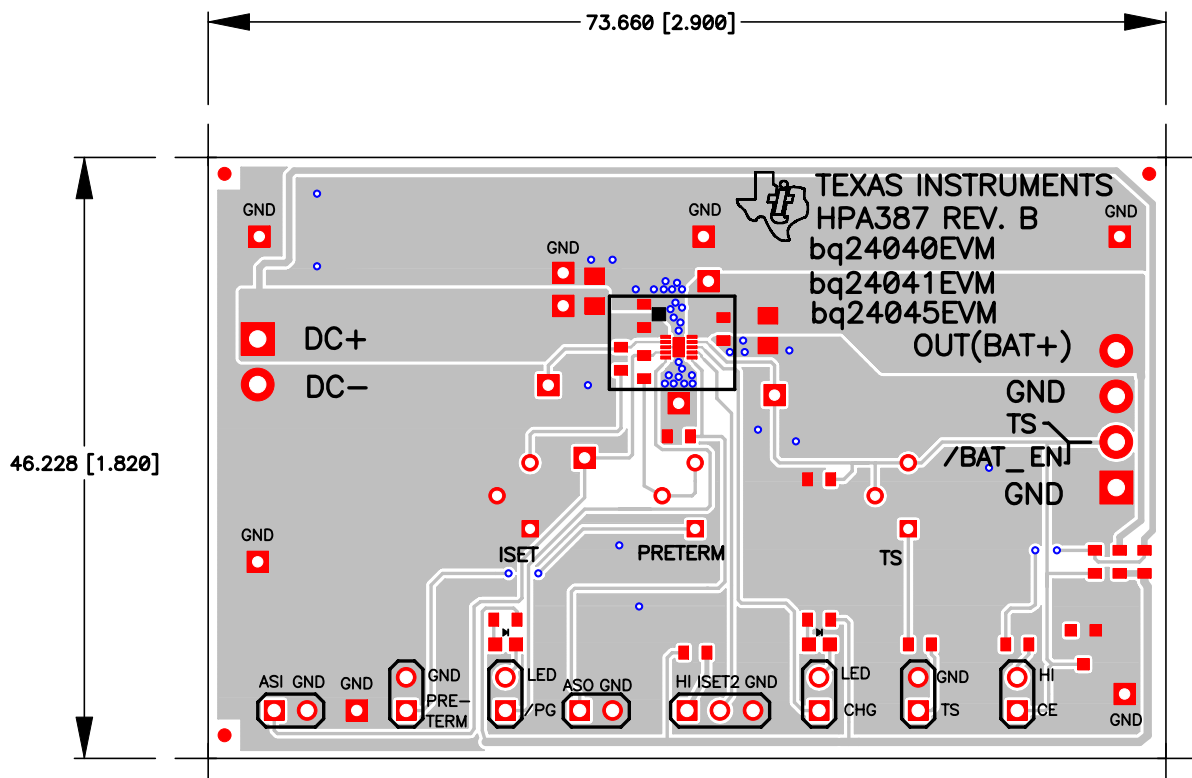


Figure 5. bq2404x EVM Top Layer

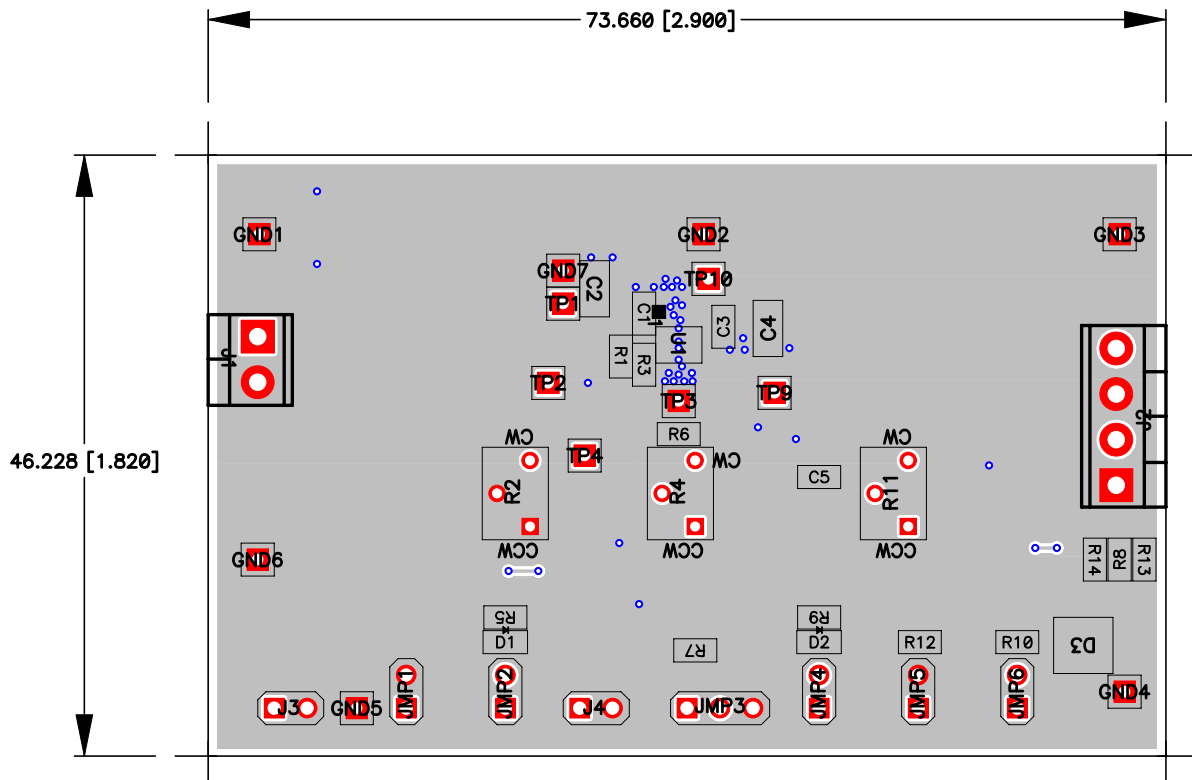


Figure 6. bq2404x EVM Bottom Layer



### 5.3 Bill of Materials

-001	-002	-003	Ref Des	Value	Description	SIZE	Part Number	MFR
1	1	1	C1	1uF	Capacitor, Ceramic, 25V, X5R, 10%	0603	C1608X5R1E105K	TDK
0	0	0	C2		Capacitor, Ceramic, 25V, X5R, 10%	0805		
1	1	1	C3	2.2uF	Capacitor, Ceramic, 10V, X5R, 10%	0603	C1608X5R1A225K/0.8	TDK
0	0	0	C4		Capacitor, Ceramic, 10V, X5R, 10%	0805		
0	0	0	C5		Capacitor, Ceramic, 25V, X5R, 10%	0603		
2	2	2	D1, D2	LTST-C190GKT	Diode, LED, Green, 2.1-V, 20-mA, 6-mcd	0603	LTST-C190GKT	Lite On
0	1	0	D3	BZX84C5v6-7-F	Diode, Zener, 5.6-V, 350-mW	SOT-23	BZX84C5v6-7-F	Diodes
1	1	1	J1**	ED555/2DS	Terminal Block, 2-pin, 6-A, 3.5mm	0.27 x 0.25 inch	ED555/2DS	OST
1	1	1	J2**	ED555/4DS	Terminal Block, 4-pin, 6-A, 3.5mm	0.55 x 0.25 inch	ED555/4DS	OST
0	2	0	J3, J4	PEC02SAAN	Header, Male 2-pin, 100mil spacing, (2-pin strip)	0.100 inch x 2	PEC02SAAN	Sullins
3	3	3	JMP2, JMP4, JMP5	PEC02SAAN	Header, Male 2-pin, 100mil spacing, (2-pin strip)	0.100 inch x 2	PEC02SAAN	Sullins
0	0	0	JMP6	PEC02SAAN	Header, Male 2-pin, 100mil spacing, (2-pin strip)	0.100 inch x 2	PEC02SAAN	Sullins
1	0	1	JMP1	PEC02SAAN	Header, Male 2-pin, 100mil spacing, (2-pin strip)	0.100 inch x 2	PEC02SAAN	Sullins
1	1	1	JMP3	PEC03SAAN	Header, Male 3-pin, 100mil spacing, (3-pin strip)	0.100 inch x 3	PEC03SAAN	Sullins
1	1	1	R1 (Note 6)	675	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	1	1	R11	50k	Potentiometer, 1/4 in. Cermet, 12-Turn, Top-Adjust	0.25x0.17	3266W-1-503LF	Bourns
0	0	0	R13, R14		Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	1	1	R2	10k	Potentiometer, 1/4 in. Cermet, 12-Turn, Top-Adjust	0.25x0.17	3266W-1-103LF	Bourns
1	0	1	R4	10k	Potentiometer, 1/4 in. Cermet, 12-Turn, Top-Adjust	0.25x0.17	3266W-1-103LF	Bourns
2	2	2	R3, R12	1.0k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
2	2	2	R5, R9	1.5k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
0	2	0	R6, R10	100k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	1	1	R7	10k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	1	1	R8	0	Resistor, Chip, 1/16W, 1%	0603	Std	Std
0	0	0	TP1-TP10	5000	Test Point, Red, Thru Hole Color Keyed	0.100 x 0.100 inch	5000	Keystone
0	0	0	GND1-GND7	5001	Test Point, Black, Thru Hole Color Keyed	0.100 x 0.100 inch	5001	Keystone
1	0	0	U1	BQ24040DSQ	IC, 1000mA, Single-Input, Single Cell Li-Ion BATTERY CHARGER w/wo Auto Start (ASI/ASO)	SON-10	BQ24040DSQ	TI
0	1	0	U1	BQ24041DSQ		SON-10	BQ24041DSQ	TI
0	0	1	U1	BQ24045DSQ		SON-10	BQ24045DSQ	TI
5	5	5	Shunt (Note 5)		Shunt, 100-mil, Black	0.1	929950-00	3M
1	1	1	—		PCB, 2.9 In x 1.8 In x 0.031 In		HPA387	Any

- Notes: 1. These assemblies are ESD sensitive, observe ESD precautions.  
 2. These assemblies must be clean and free from flux and all contaminants. Use of no-clean flux is not acceptable.  
 3. These assemblies must comply with workmanship standards IPC-A-610 Class 2.  
 4. Ref designators marked with an asterisk (\*\*\*) cannot be substituted. All other components can be substituted with equivalent MFG's components.  
 5. Apply shunt to JMP1/2/4/5 and JMP3:2/3. Note J3 and J4 are test pins and don't have shunts (jumpers).

-001	-002	-003	Ref Des	Value	Description	SIZE	Part Number	MFR								
6. To get more than 800 mA output current of this design, consider changing the value of R1 to lower values																
<table border="1"> <thead> <tr> <th colspan="2">Assembly Number</th> </tr> </thead> <tbody> <tr> <td>HPA387-001</td> <td>bq24040</td> </tr> <tr> <td>HPA387-002</td> <td>bq24041</td> </tr> <tr> <td>HPA387-003</td> <td>bq24045</td> </tr> </tbody> </table>									Assembly Number		HPA387-001	bq24040	HPA387-002	bq24041	HPA387-003	bq24045
Assembly Number																
HPA387-001	bq24040															
HPA387-002	bq24041															
HPA387-003	bq24045															

## EVALUATION BOARD/KIT/MODULE (EVM) ADDITIONAL TERMS

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The user assumes all responsibility and liability for proper and safe handling of the goods. Further, the user indemnifies TI from all claims arising from the handling or use of the goods.

Should this evaluation board/kit not meet the specifications indicated in the User's Guide, the board/kit may be returned within 30 days from the date of delivery for a full refund. THE FOREGOING LIMITED WARRANTY IS THE EXCLUSIVE WARRANTY MADE BY SELLER TO BUYER AND IS IN LIEU OF ALL OTHER WARRANTIES, EXPRESSED, IMPLIED, OR STATUTORY, INCLUDING ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR ANY PARTICULAR PURPOSE. EXCEPT TO THE EXTENT OF THE INDEMNITY SET FORTH ABOVE, NEITHER PARTY SHALL BE LIABLE TO THE OTHER FOR ANY INDIRECT, SPECIAL, INCIDENTAL, OR CONSEQUENTIAL DAMAGES.

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## REGULATORY COMPLIANCE INFORMATION

As noted in the EVM User's Guide and/or EVM itself, this EVM and/or accompanying hardware may or may not be subject to the Federal Communications Commission (FCC) and Industry Canada (IC) rules.

For EVMs **not** subject to the above rules, this evaluation board/kit/module is intended for use for ENGINEERING DEVELOPMENT, DEMONSTRATION OR EVALUATION PURPOSES ONLY and is not considered by TI to be a finished end product fit for general consumer use. It generates, uses, and can radiate radio frequency energy and has not been tested for compliance with the limits of computing devices pursuant to part 15 of FCC or ICES-003 rules, which are designed to provide reasonable protection against radio frequency interference. Operation of the equipment may cause interference with radio communications, in which case the user at his own expense will be required to take whatever measures may be required to correct this interference.

### General Statement for EVMs including a radio

*User Power/Frequency Use Obligations:* This radio is intended for development/professional use only in legally allocated frequency and power limits. Any use of radio frequencies and/or power availability of this EVM and its development application(s) must comply with local laws governing radio spectrum allocation and power limits for this evaluation module. It is the user's sole responsibility to only operate this radio in legally acceptable frequency space and within legally mandated power limitations. Any exceptions to this are strictly prohibited and unauthorized by Texas Instruments unless user has obtained appropriate experimental/development licenses from local regulatory authorities, which is responsibility of user including its acceptable authorization.

### 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

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**

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.

### **For EVMs annotated as IC – INDUSTRY CANADA Compliant**

This Class A or B digital apparatus complies with Canadian ICES-003.

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

### **Concerning EVMs including radio transmitters**

This device complies with Industry Canada licence-exempt RSS standard(s). 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.

### **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.

Cet appareil numérique de la classe A ou B est conforme à la norme NMB-003 du Canada.

Les changements ou les modifications pas expressément approuvés par la partie responsable de la conformité ont pu vider l'autorité de l'utilisateur pour actionner l'équipement.

### **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.

### **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.

## **【Important Notice for Users of this Product in Japan】**

**This development kit is NOT certified as Confirming to Technical Regulations of Radio Law of Japan**

If you use this product in Japan, you are required by Radio Law of Japan to follow the instructions below with respect to this product:

1. Use this product 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 this product only after you obtained the license of Test Radio Station as provided in Radio Law of Japan with respect to this product, or
3. Use of this product only after you obtained the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to this product. Also, please do not transfer this product, unless you give the same notice above to the transferee. Please note that if you could not follow the instructions above, you will be subject to penalties of Radio Law of Japan.

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**(address) 24-1, Nishi-Shinjuku 6 chome, Shinjuku-ku, Tokyo, Japan**

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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。

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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。

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**For Feasibility Evaluation Only, in Laboratory/Development Environments.** Unless otherwise indicated, this EVM is not a finished electrical equipment and not intended for consumer use. It is intended solely for use for preliminary feasibility evaluation in laboratory/development environments by technically qualified electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems and subsystems. It should not be used as all or part of a finished end product.

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3. You will employ reasonable safeguards to ensure that your use of the EVM will not result in any property damage, injury or death, even if the EVM should fail to perform as described or expected.
4. You will take care of proper disposal and recycling of the EVM's electronic components and packing materials.

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Energy and Lighting	<a href="http://www.ti.com/energy">www.ti.com/energy</a>
Industrial	<a href="http://www.ti.com/industrial">www.ti.com/industrial</a>
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