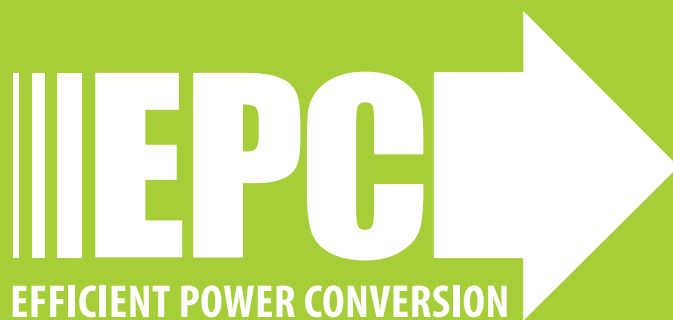


EPC91106

High Power Density, Low Profile, Synchronous Buck and Boost Converter Quick Start Guide

*Featuring the EPC23104 ePower™ Stage, Optimized for
Computing Power Supplies and USB-PD*

Revision 2.1



DESCRIPTION

The EPC91106 evaluation board is a digitally controlled, compact synchronous buck/boost converter evaluation board: it features the 100 V rated, 11 mΩ $R_{DS(on)}$ EPC23104 eGaN® IC that operates at 720 kHz with an input voltage range from 24 V through 64 V and can deliver up to 13 A load current. The default output voltage is set to 12 V. A block diagram overview of the functional blocks of the EPC91106, including details of the EPC23104 eGaN IC, is shown in figure 1.

REGULATORY INFORMATION

This evaluation board is for evaluation purposes only. It is not a full-featured unit and cannot be used in final products. No EMI test was conducted. It is not FCC approved.

KEY FEATURES OF THE EPC91106 EVALUATION BOARD

- Employs the latest eGaN IC technology with fully integrated half-bridge ePower™ Stage.
- Complete power converter solution fits within 21 x 13 mm.
- Optimized at 720 kHz for 48 V to 12 V conversion.
- Configured with a low-profile inductor of just 3 mm height.
- Pre-installed heat-spreader and heatsink for thermal management.
- Digital control enables implementation of advanced control techniques.

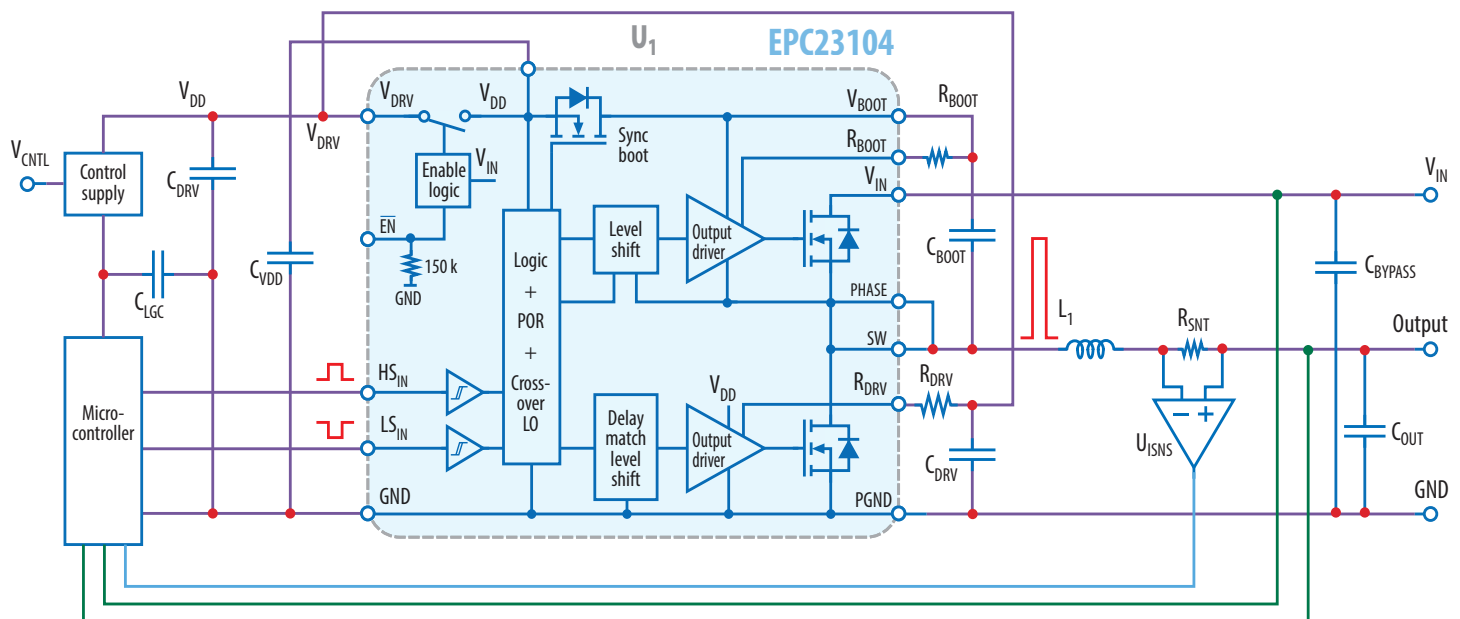
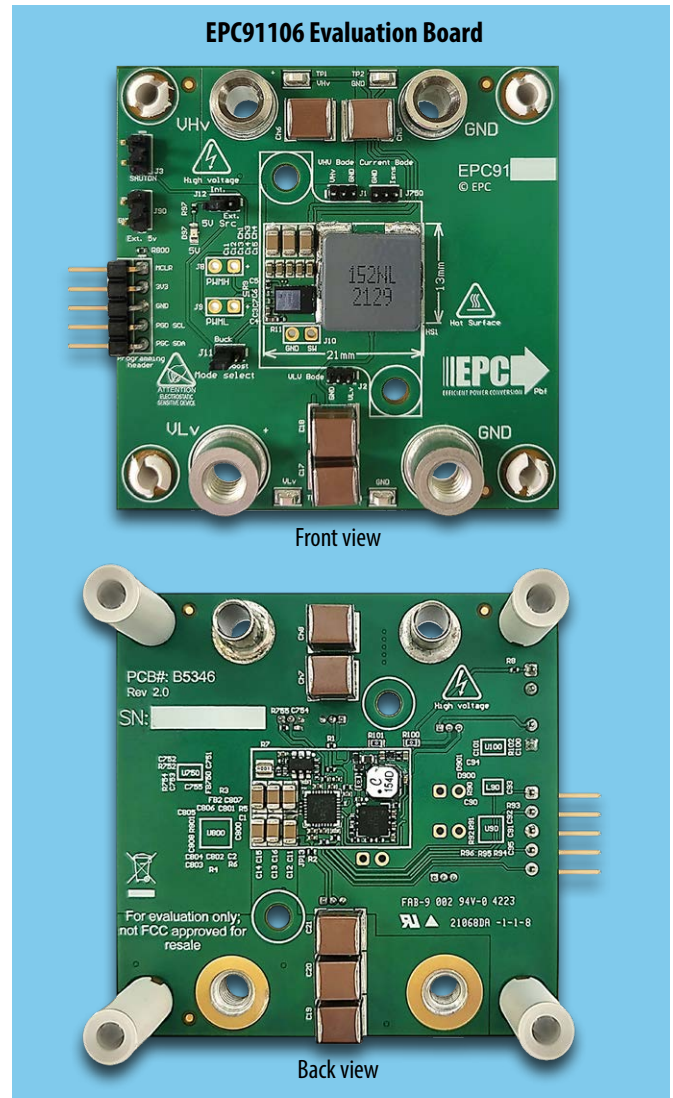


Figure 1: Block diagram overview of the EPC91106 evaluation board

FEATURED eGaN IC

The EPC91106 evaluation board features the 100 V rated, 11 mΩ $R_{DS(on)}$ EPC23104 eGaN IC. The detailed block diagram IC symbol and photo with pin assignment is shown in figure 2.

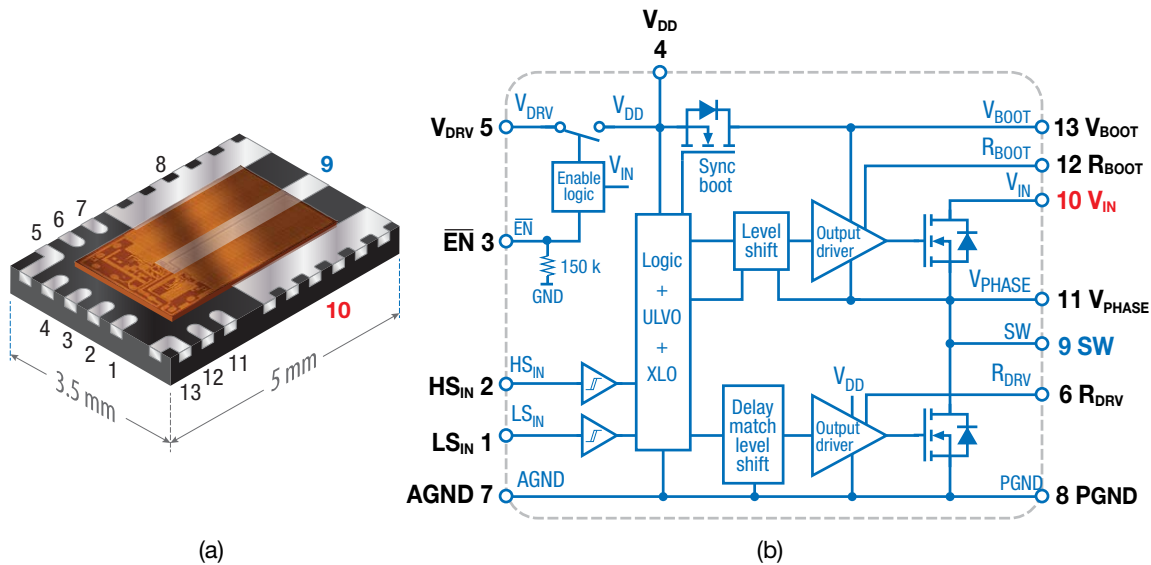


Figure 2: Detailed block diagram symbol and photo with pin assignment of the EPC23104

Refer to the [EPC23104 datasheet](#) for additional details.

OVERVIEW OF THE EPC91106 EVALUATION BOARD

Figure 3 shows an image of both sides of the EPC91106 evaluation board with the location of the various functional circuits highlighted.

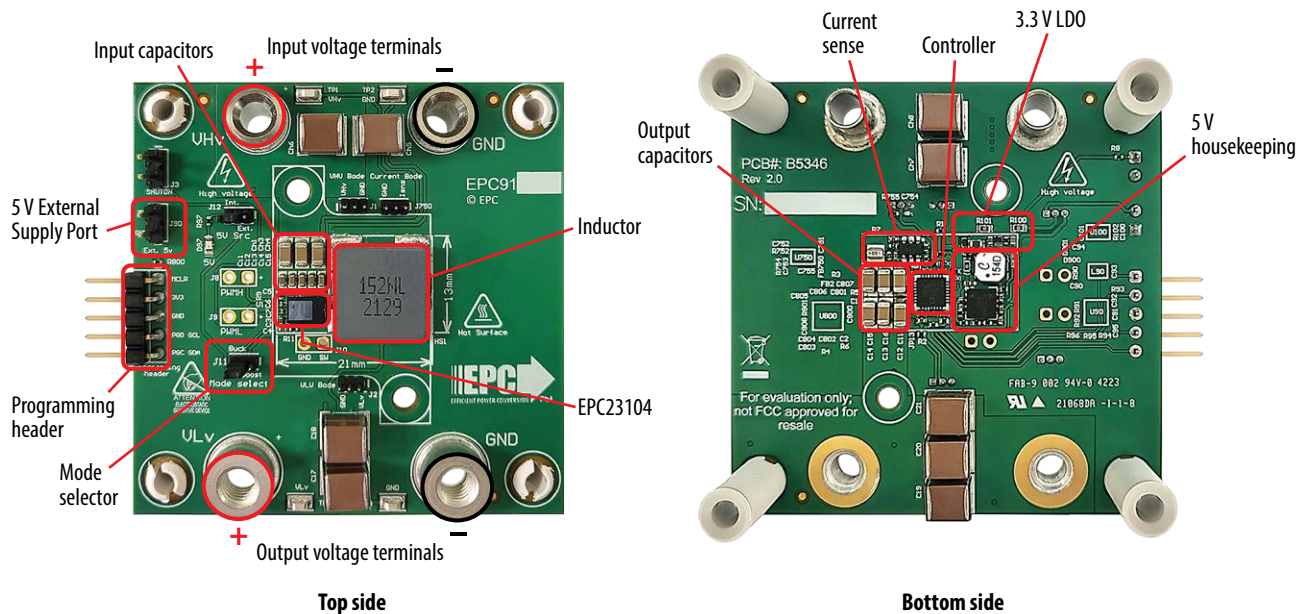


Figure 3: Photo overview of the EPC91106 evaluation board with various functional blocks highlighted

Figure 4 shows a photo of the zoomed-in area of both sides of the application circuit.

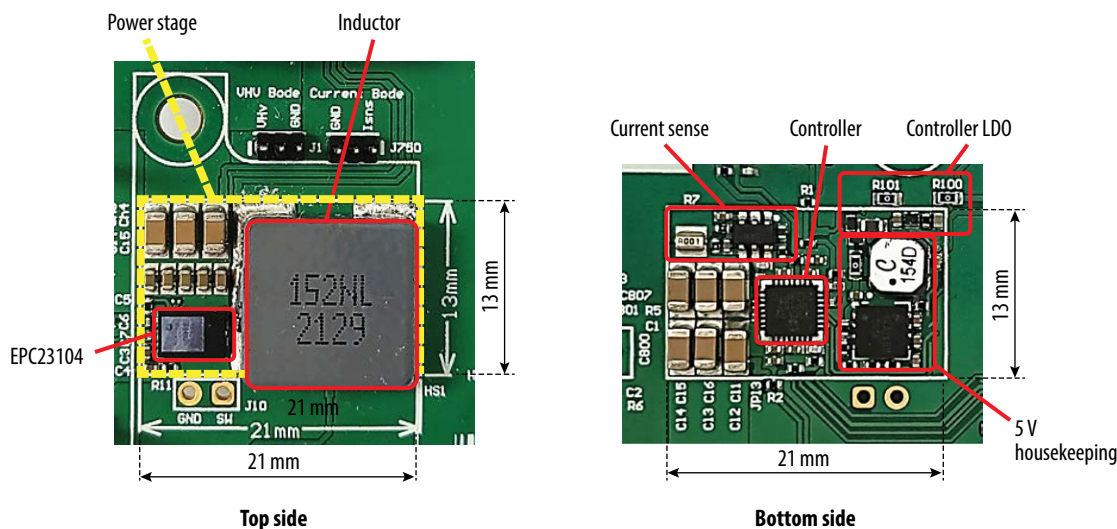


Figure 4: Zoomed-in photo details of the EPC91106 evaluation board with power circuit highlighted

It can be seen from figure 4 that the circuit is compact and can fit in a small area of approximately 21 x 13 mm excluding the input capacitors and output capacitors.

RECOMMENDED OPERATING CONDITIONS

Table 1: Performance Summary ($T_A = 25^\circ\text{C}$) EPC91106

Symbol	Parameter	Conditions	Min	Nominal	Max	Units
V_{HV}	Input Voltage		12	48	64 ¹	V
V_{LV}	Output Voltage		4	12	40 ²	
I_L	Output Current	With heatsink & 400 LFM airflow			13 ³	A
f_{sw}	Nominal Switching frequency			720	1000 ⁴	kHz
V_{5V}	5 V External Supply	Max $I_{OUT} = 500\text{ mA}$	4.75	5	5.5	V

¹ Maximum voltage limited by the current sense amplifier, and not the the 100 V rated EPC23104. Refer to the [MCP6C02T-050E datasheet](#) for specifications.

² Must have the V_{HV} port at a higher voltage than V_{LV} . Output voltage is set in controller and can be programmed to a new value.

³ Maximum current capability is lower than stated in EPC23104 datasheet as it is dependent on thermal conditions and die temperature, and on component choice and board design – actual maximum current is affected by switching frequency, bus voltage, inductor current and thermal limits, and thermal cooling. Refer to the thermal performance section in this guide and to EPC23104 datasheet for details.

⁴ Maximum frequency limited by controller computation time, current sense amplifier bandwidth, and other factors. Designers may use advanced techniques to allow high frequency operation in closed loop mode.

HIGHLIGHTED PARTS OF THE EPC91106 CIRCUIT

Refer to figures 1 and 4 for the main blocks and components that comprise the EPC91106 evaluation board.

Power Stage

The EPC91106 features a half-bridge converter using the EPC23104 eGaN IC. For more information on EPC23104, please refer to the datasheet available from EPC at www.epc-co.com. The datasheet should be read in conjunction with this quick start guide.

Internal Housekeeping Power Supply

The EPC23104 gate driver and the LDO circuit that regulates 3.3 V for the controller require a 5 V supply. This 5 V supply can be powered from either an external 5 V power supply or internal onboard 5 V housekeeping supply. The board includes a built-in switching buck converter (LM5018 from Texas Instruments) that steps down the input voltage to 5 V. This internal supply features an under-voltage lockout (UVLO) that prevents operation at low input voltages. The UVLO threshold is set at 8.8 V with a 2 V hysteresis. Refer to the board's jumper section for instructions for selecting either the external or internal 5 V supply.

Note: The LED will illuminate when the internal 5 V supply is on. The LED will not light up when the 5 V external supply is applied.

Current and Voltage Sense

The EPC91106 evaluation board is equipped with voltage and bi-directional current sense for feedback. Voltage is measured using simple resistor divider networks and bode measurement points are provided for closed loop tuning. For the high voltage port (J1), is used for signal injection and measurement for bode plots and J2 is used for the low voltage port. Inductor current is measured using a 1 mΩ shunt (R7) that is amplified using the bi-directional amplifier MCP6C02T-50E/CHY (U750) from Microchip. The high voltage amplifier provides a bi-directional analog voltage proportional to the measured current with a gain of 50 mV/A. The zero current offset of 1.65 V is provided by one of the Analog outputs of the controller (U800) buffered using one of the internal op-amps.

Controller

The power circuit of the EPC91106 evaluation board is controlled using a DSPIC33CK64MP102-I/M6 processor from Microchip. The controller can be programmed using the 100mil connector J800 that is compatible with Microchip programming hardware. For programming instructions from a HEX file, please see the section on programming.

For information on modifying the controller firmware please visit: <https://epc-co.com/epc/products/evaluation-boards/epc91106>

CONNECTIONS, MEASUREMENT TEST POINTS & JUMPERS

Power Connections

The EPC91106 can be configured to operate as a buck or boost converter. To operate the EPC91106 in buck mode (default), connect the input supply to the load as shown in figure 5.

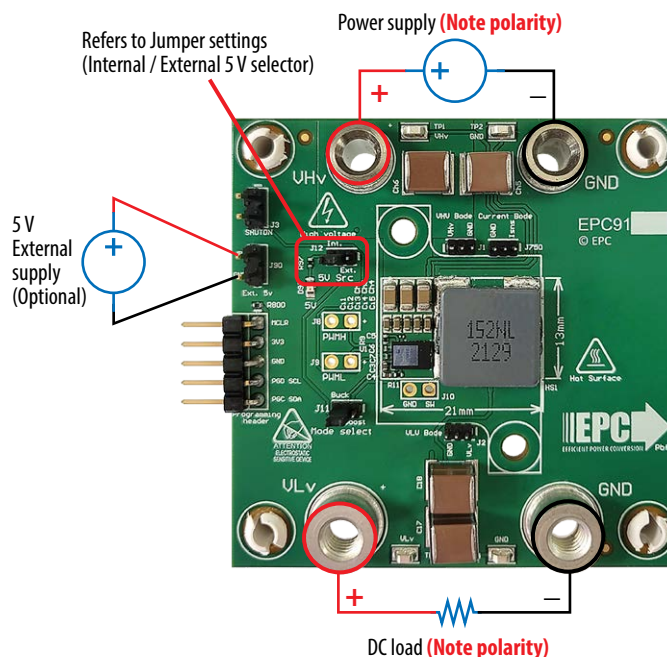


Figure 5: Power and load connections to the EPC91106 evaluation board, configured in Buck mode.

Test Points and Measurement Setup

Figures 6 and 7 show the various measurement connections of the EPC91106 evaluation board.

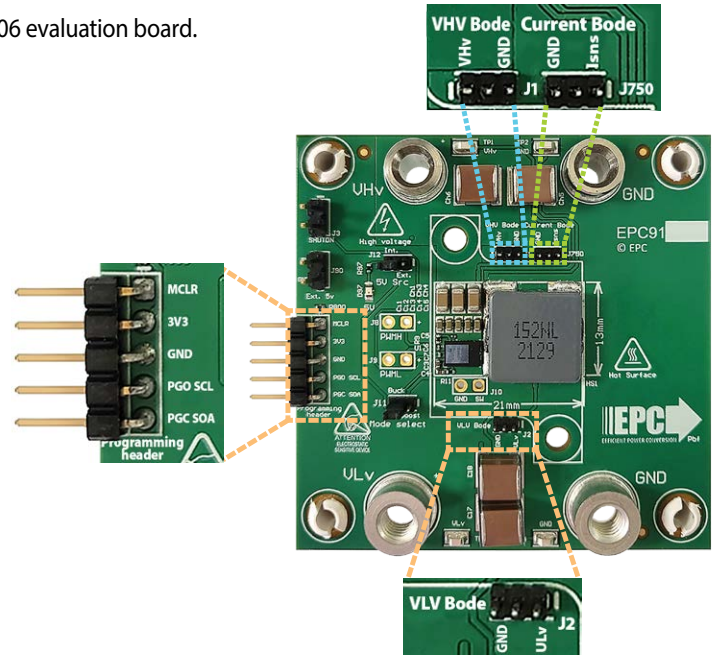
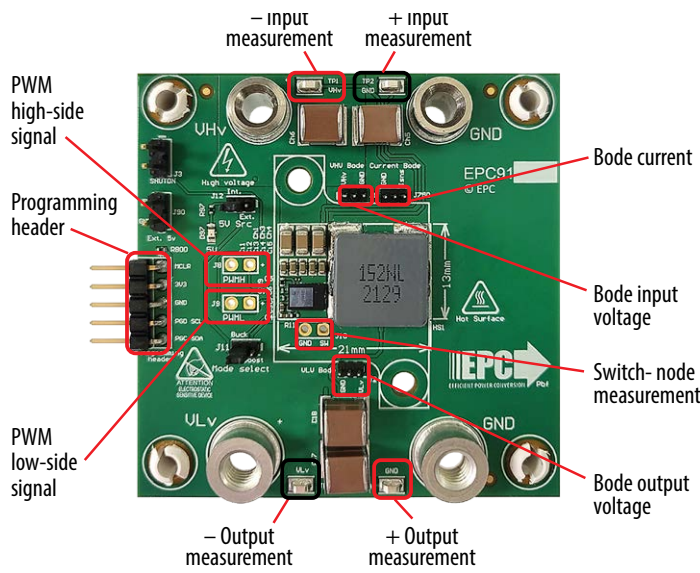


Figure 6: EPC91106 test point pad and hookup locations and designations.

Figure 7: Shows EPC91106's programming header and Bode test point details

The available measurement nodes with their respective reference are:

- **VIN-GND:** High voltage port voltage (**TP1 & TP2**)
- **VOUT-GND:** Output voltage (**TP3 & TP4**)
- **PWMH-GND:** High side PWM into the eGaN IC (**J8**)
- **PWML-GND:** Low side PWM into the eGaN IC (**J9**)
- **SW-GND:** Switch-node voltage measurement (**J10**).
- **VHV-GND:** High voltage port bode injection and measurement (**J1**)
- **VLV-GND:** Low voltage port bode injection and measurement (**J2**)
- **ISNS-GND:** Inductor current bode injection and measurement (**J750**)

See figure 7 for recommended method to measure the switch-node.

Note: Exercise caution when using the bode measurements to ensure proper connection to the instrument.

Switch-node

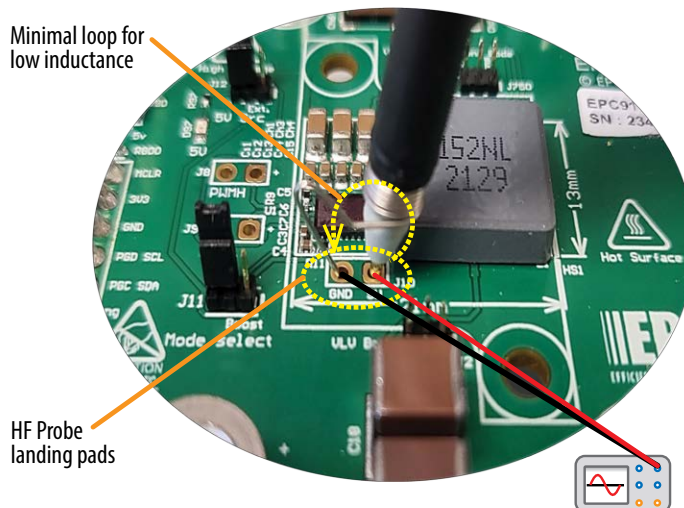


Figure 8: Recommended method to measure the switch-node measurement voltage waveform.

Jumper Settings

Note: A jumper must be inserted to select a mode at each jumper connector.

Enable/Disable Settings

The EPC91106 evaluation board offers an option to disable operation by inserting a 100-mil jumper into J3 (refer to Figure 9).

Buck/Boost Selector

The EPC91106 has two operating mode settings: 1) Buck, and 2) Boost. The desired operating mode can be selected by inserting a jumper into the appropriate position on J11 with position 1-2 for buck (default) and position 2-3 for boost. Details are shown in figure 10.

Internal or External 5 V Selector

The gate driver of the EPC23104 and LDO circuit on EPC91106 can be powered through two options: an external 5 V power or an internal onboard housekeeping 5 V power supply. By inserting a jumper on J12 with position 1-2 (default) to select onboard internal power supply, and position 2-3 to select 5 V external power supply. Details are shown in figure 10.

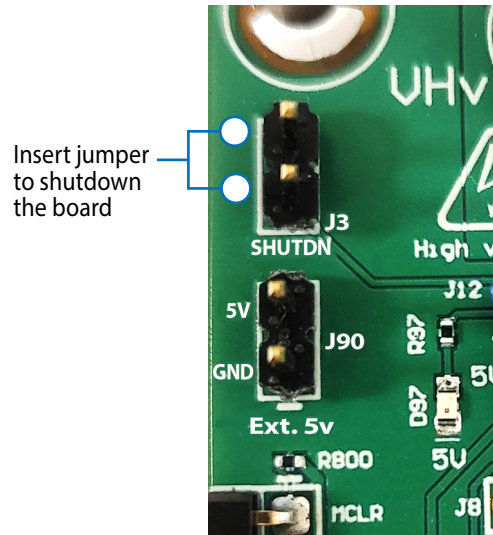


Figure 9: EPC91106 shut down pin

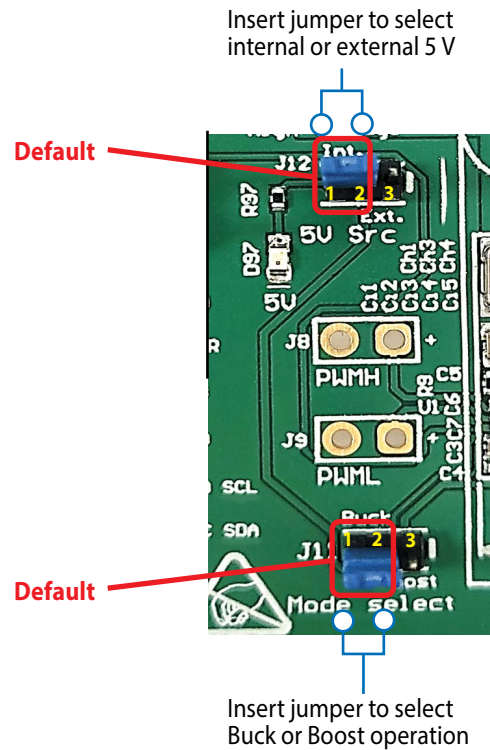


Figure 10: EPC91106 operating mode and control power source selectors details.

QUICK START PROCEDURE

The operating procedure is provided for **buck** mode only. The EPC91106 demonstration board is easy to set up to evaluate the performance of the EPC23104 eGaN IC. Refer to figures 5, 6, 7, 8, 9 and 10 for proper connection and measurement setup and follow the procedure below to operate the board:

1. Before proceeding, remove the shutdown jumper (J3). Ensure that both J11 and J12 are set to the correct setting (refer to jumper section).
2. With power off, connect the input power supply between VHV (J6) and GND (J4). Pay careful attention to the polarity as shown in figure 5. A shunt can be inserted in series with the positive supply to measure the input current. Note that shunt measurement must be floating with respect to GND.
3. With power off, connect a suitable load between VLV (J7) and GND (J5). Pay careful attention to the polarity as shown in figure 5.

If a 5 V external supply is used, follow step 4, else skip to step 5.

4. Ensure the jumper on J12 is in position 2-3 (Ext). With power off, connect a controller power supply set to 5 V to J90. Pay careful attention to the polarity as shown in figure 5. This power supply must be capable of supplying at least 200 mA of current.

5. To select 5V internal onboard housekeeping, ensure the jumper on J12 is in position 1-2 (Int).
6. With power off, connect the various measurement probes as shown in figure 6 and 7.
7. Turn on the 5V controller power supply if applicable.
8. **Keeping the load off**, turn on the main power supply. The converter will not start up until the input voltage is above 10 V per EPC23104 specification.
9. Engage the load and adjust the load current within the current capability of the EPC91106 per table 1 and observe the temperature of the eGaN IC and ensure it does not exceed the maximum value given in the EPC23104 datasheet.
10. Collect the various measurements while adjusting the supply voltage and load current while observing that all operating parameters remain within the specifications provided in table 1.
11. For shutdown, please follow steps in reverse. For custom configuration other than described please contact EPC.

The operating instructions in this document do not cover how to perform bode measurements. Please refer to the equipment manufacturer for those instructions.

THERMAL MANAGEMENT (Optional)

The EPC91106 is intended for bench evaluation at room ambient temperatures and under forced air convection cooling. The addition of heatsink along with forced air cooling is not required but can significantly improve the heat dissipation from the GaN IC by adding cooling from the top side of the device and thus increase the current capacity of the application. Figure 11 shows an exploded 3D view of the cooling system for the EPC91106 evaluation board.

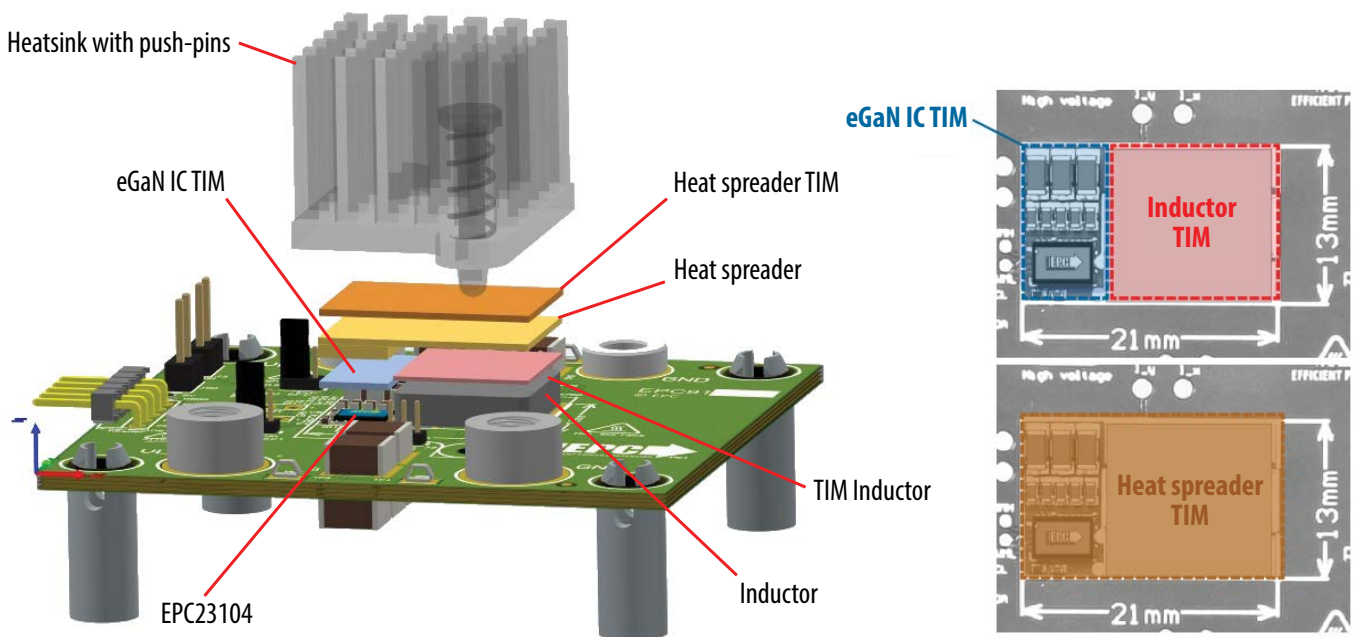


Figure 11: Exploded view of the cooling system assembly with location of the various TIM's

The available measurement nodes with their respective reference are:

- A thermal interface for the eGaN IC, see figure 12
- A thermal interface for the Inductor, see figure 12
- A thermal interface for the heat-spreader, see figure 12
- A custom profile copper heat-spreader, see figure 13
- A pop-in heatsink from Wakefield; Part Number: 960-21F

To assemble the cooling system, eGaN IC and inductor TIM sheets should be located as shown in figure 11. It is important that the TIM for the eGaN IC properly cover the exposed pads of the bus capacitors as it also serves to electrically insulate those connections from the heat-spreader. Carefully place the custom designed heat-spreader over the TIM sheets observing not to puncture the TIM sheets beneath. The heat-spreader TIM is then placed over the heat-spreader and the heatsink is then carefully placed on top with the pop-in pins located into their respected holes in the EPC91106 PCB. The pins are then carefully popped into place to secure the heatsink.

A detailed drawing of the heat-spreader is given in figure 13.

The choice of TIM for the eGaN IC needs to consider the following characteristics:

- **Mechanical compliance** – During the attachment of the heat spreader, the TIM underneath is compressed from its original thickness to the vertical gap distance between the spacers and the FETs. This volume compression exerts a force on the eGaN FET/IC. A maximum compression of 2:1 is recommended for maximum thermal performance and to constrain the mechanical force which maximizes thermal mechanical reliability.
- **Electrical insulation** – The backside of the eGaN FET/IC is a silicon substrate that is connected to ground. Electrical insulation is not required but is still recommended to isolate the GaN IC from the thermal solution.
- **Thermal performance** – The choice of thermal interface material will affect the thermal performance of the thermal solution. Higher thermal conductivity materials are preferred to provide higher thermal conductance at the interface.

The thermal requirements for the choice of TIM for the inductor and heat-spreader can be relaxed due to the larger areas which allows the use of lower thermal conductivity materials with negligible impact on thermal performance. To help make up for the lower thermal conductivity, a thinner sheet may be used.

EPC recommends the t-Global Part Number: TG-A1780 for the eGaN IC TIM as it has a high thermal conductivity of 17.8 W/m-K. For the inductor and heat-spreader TIM's, the t-Global Part Number: TG-A620 with a moderate thermal conductivity of 6.2 W/m-K can be used.

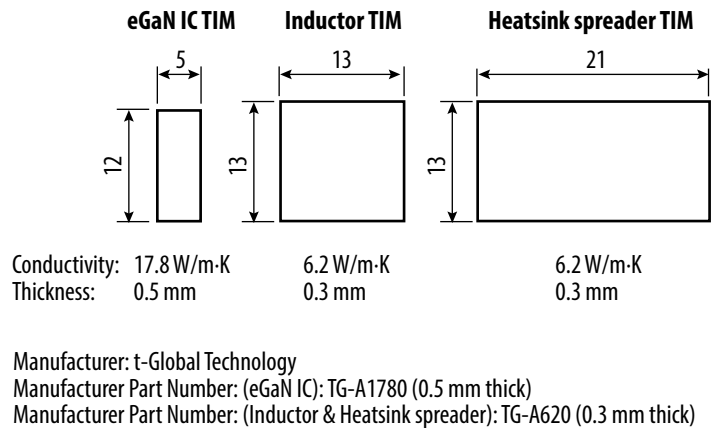


Figure 12: Details of the TIM's used on the EPC91106 evaluation board.

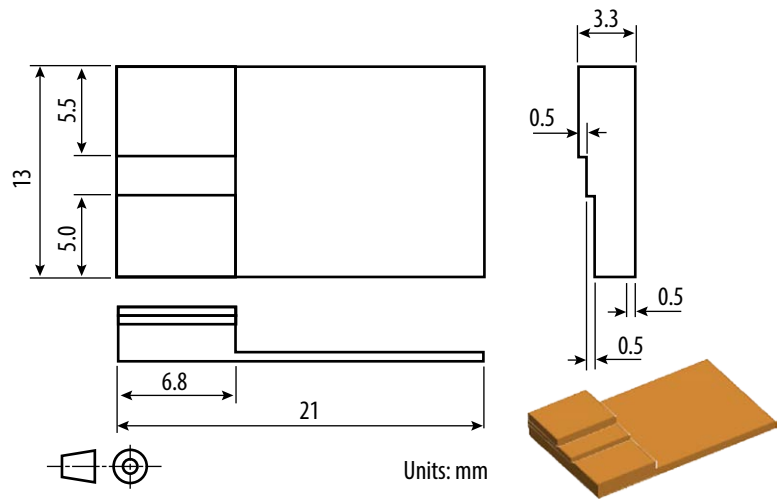


Figure 13: Detailed drawing of the copper heat-spreader used for the EPC91106 evaluation board cooling system.

EXPERIMENTAL VALIDATION

The EPC91106 evaluation converter was programmed with an average mode buck controller, set to 12 V output, 720 kHz switching frequency, 10 ns dead-time, and operated with various input voltages. The tests and measurements were taken with forced air cooling limited to 400 LFM airflow.

Efficiency and Power Loss Results

Figures 14 illustrates the measured efficiency of EPC91106 across different supply voltages. The solid line represents the test conducted without airflow, while the dashed line represents the test with 400 LFM airflow.

The efficiency calculations include the power consumption of the controller, switching and gate drive losses of the EPC23104 eGaN IC, and the 5 V housekeeping power supply.

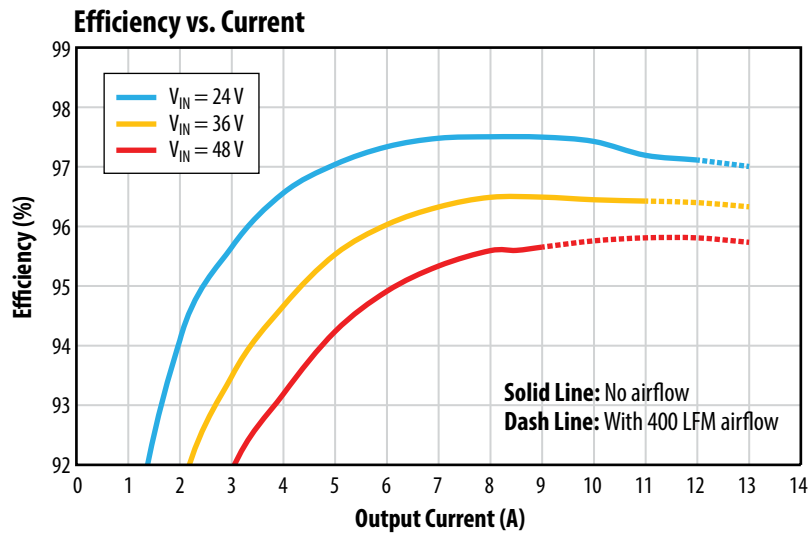


Figure 14: Measured the overall efficiency of the EPC91106 board operating in buck mode for multiple input voltages with $V_{OUT} = 12\text{ V}$. Two conditions are presented: one without airflow (solid line) and another with 400 LFM airflow (dash line) Both conditions were tested without a heatsink.

The measured system power loss of the EPC91106 operating from various supply voltages is shown in figure 15. The tests were conducted with 400 LFM airflow.

The efficiency calculations include the power consumption of the controller, switching and gate drive losses of the EPC23104 eGaN IC, and the 5 V housekeeping power supply.

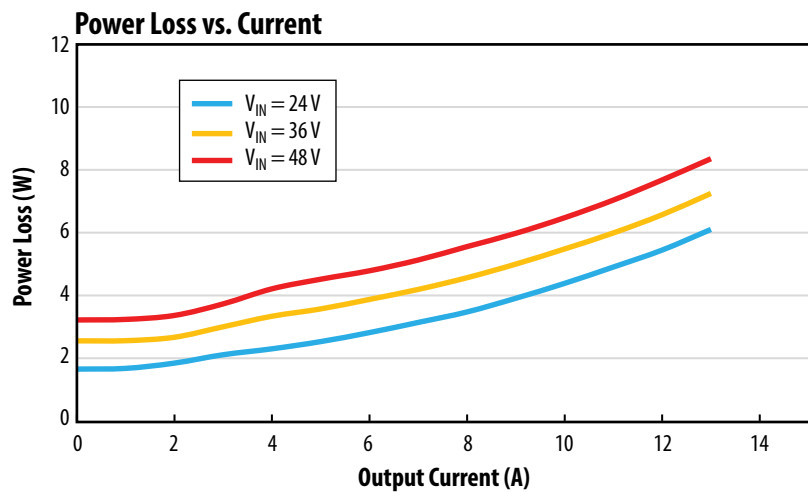


Figure 15: Measured power loss of the EPC91106 board operating in buck mode for multiple input voltages with $V_{OUT} = 12\text{ V}$ (with 400 LFM airflow.)

Waveforms

Figure 16 shows the measured switch-node waveform taken with the EPC91106 operating in buck mode with 48 V input, 12 V output and delivering 10 A into the load.

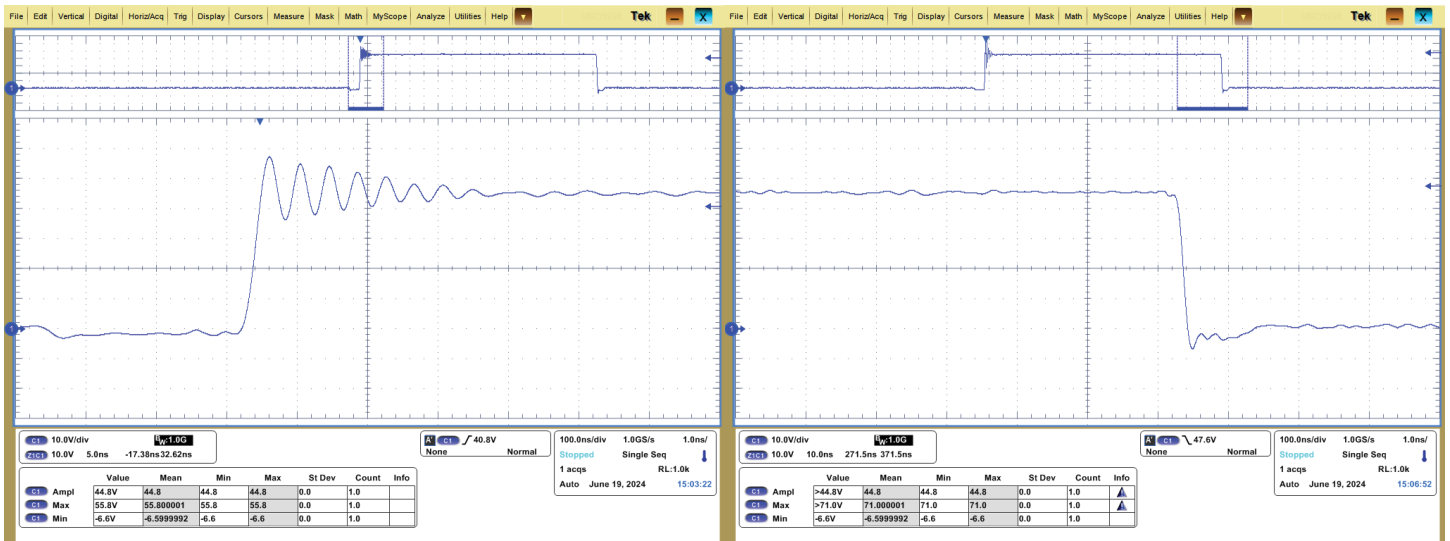


Figure 16: Measured switch-node voltage waveform of the EPC91106 operating in buck mode with 48 V input, 12 V output and delivering 10 A into the load.

Figure 17 shows the measured output ripple voltage taken with the EPC91106 operating in buck mode with 48 V input, 12 V output and delivering 1 A into the load. Figure 17 only shows the load at 1 A load current given that the conversion ratio and operating the converter in continuous conduction mode has negligible impact on ripple voltage.

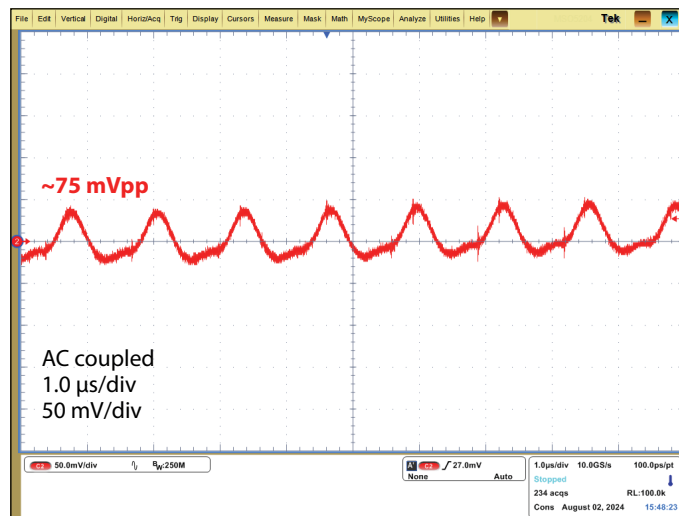


Figure 17: Measured output ripple voltage of the EPC91106 operating in buck mode with 48 V input, 12 V output and delivering 1 A into the load.

Transient Response

Figure 18 shows the measured transient response taken with the EPC91106 operating in buck mode with 48 V input, 12 V output with a load step change of 10% to 90% and 90% to 10% of 13 A.

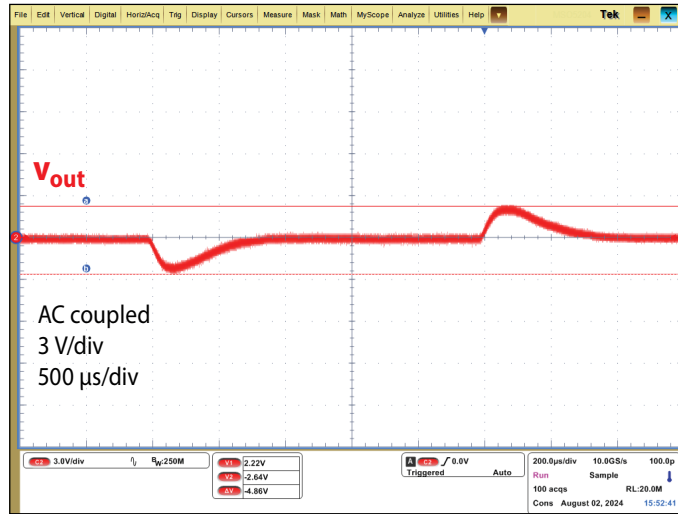


Figure 18: measured transient waveform of the EPC91106 operating in buck mode with 48 V input, 12 V output and with a load step change of 10% to 90% and 90% to 10% of 13 A.

Voltage Regulation Performance

Figure 19 shows the measured output voltage regulation taken with the EPC91106 operating in buck mode with various input voltages and delivering 12 V into the load as function of load current.

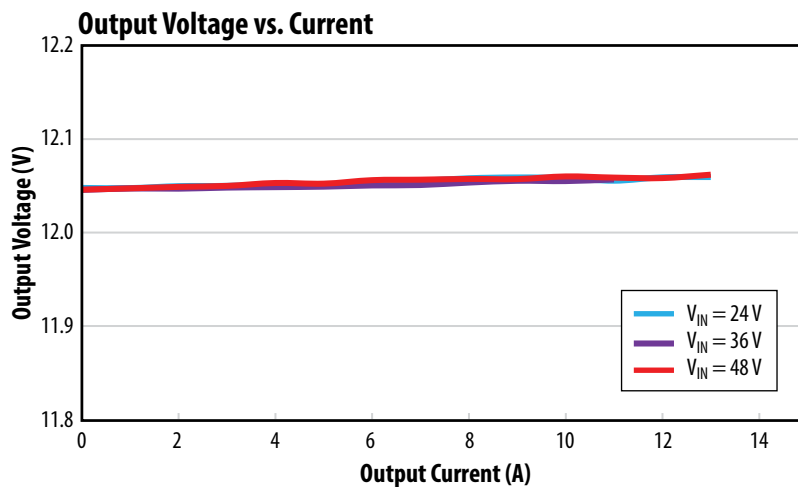


Figure 20: Measured output voltage regulation of the EPC91106 operating with various input voltages and delivering 12 V into the load as function of load current.

Thermal Performance

Figures 20 through 22 show the measured thermal performance of EPC91106 in buck mode. The tests were conducted at input voltages of 24 V, 36 V, and 48 V, with a constant output voltage of 12 V. The device delivered a load current of 13 A. All tests were conducted without a heatsink and with 400 LFM airflow.

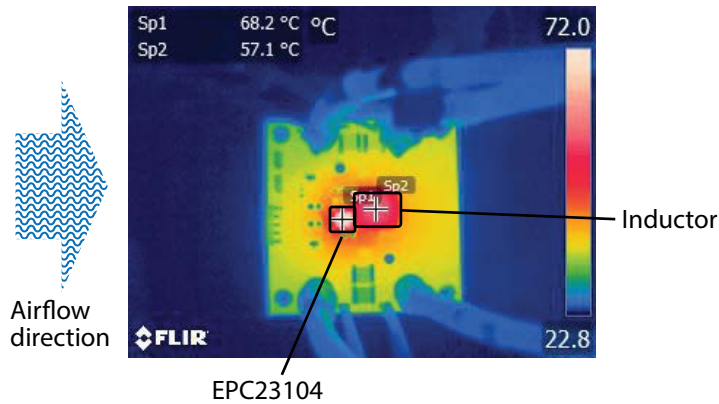


Figure 20: Steady state measured thermal image of the EPC91106 operating with 24 V input, 12 V output and delivering 13 A into the load, 400 LFM airflow and no heatsink attached.

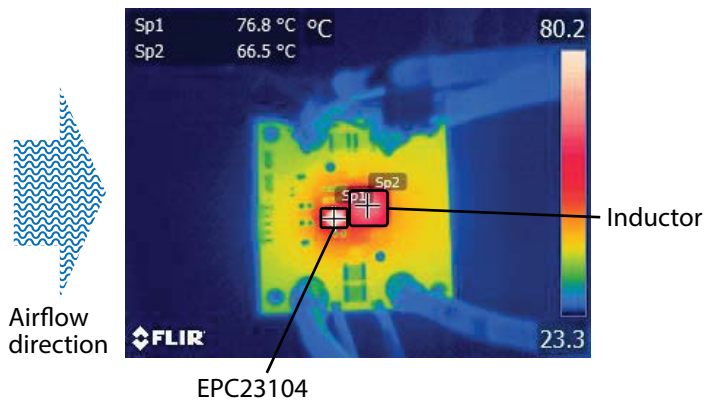


Figure 21: Steady state measured thermal image of the EPC91106 operating with 36 V input, 12 V output and delivering 13 A into the load, 400 LFM airflow and no heatsink attached.

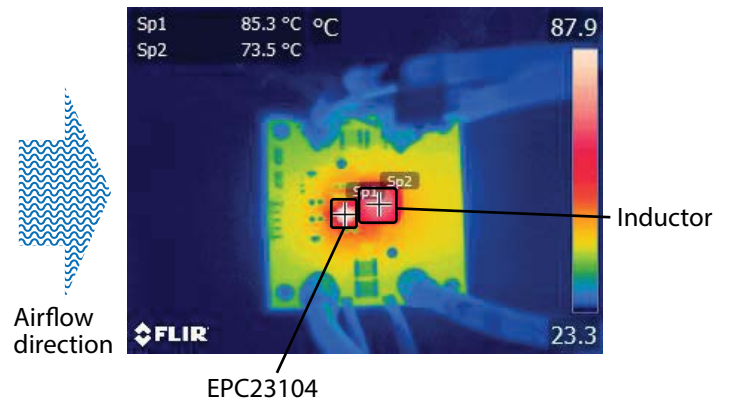


Figure 22: Steady state measured thermal image of the EPC91106 operating with 48 V input, 12 V output and delivering 13 A into the load, 400 LFM airflow and no heatsink attached.

For support files including schematic, Bill of Materials (BOM), and gerber files please visit the EPC91106 landing page at: <https://epc-co.com/epc/products/evaluation-boards/EPC91106>

PROGRAMMING

The EPC91106 evaluation board controller is a Microchip dSPIC33CK64MP102 that can be programmed using a HEX file through the 5-pin header J800 (compatible with standard Microchip programmer hardware). It supports all of Microchip’s in-circuit programmers/debuggers, such as MPLAB® ICD4, MPLAB® REAL ICE or MPLAB® PICKit4 and previous derivatives. Development tools can be found at <https://www.microchip.com/development-tools>.

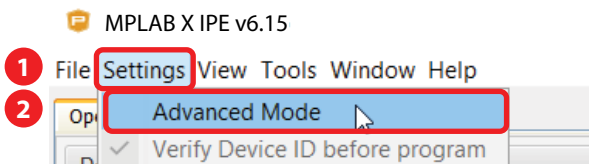
Compatible Microchip MPLAB: PICKIT3, PICKIT4

Steps for Programming with HEX File

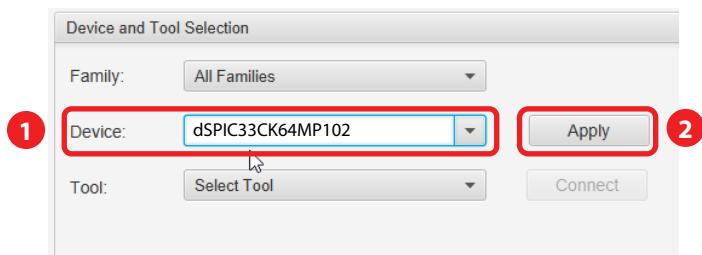
Prior to programming, disconnect ALL power connections to the EPC91106 board. Disabling power may not be sufficient as it can short the terminals and prevent programming. Programming with main power present can damage the controller and programmer. Follow the following steps from the EPC91106 evaluation board from a HEX file. For details on how to generate a HEX file or how to draft control firmware contact Microchip directly.

1. **If not already installed, download and install the latest MPLAB® X IPE from the Microchip website:** <https://www.microchip.com/en-us/tools-resources>

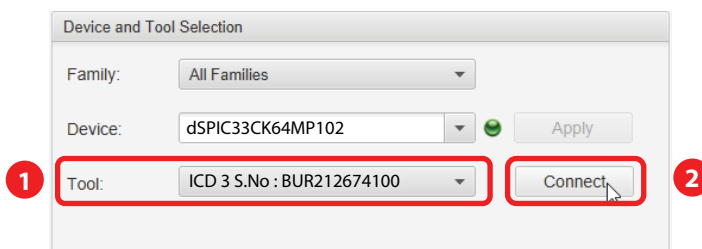
2. **Start MPLAB® X IPE and enable **Advanced Mode****
(Password: microchip)



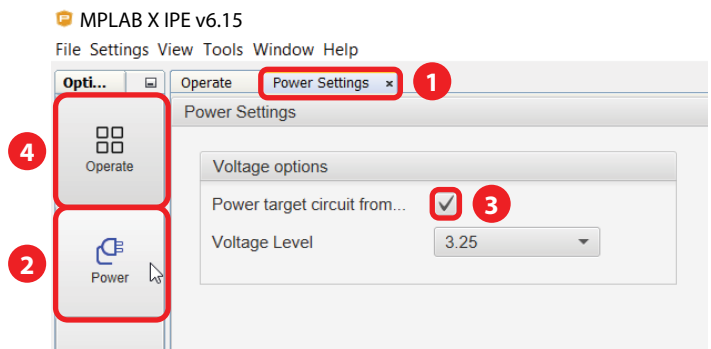
3. **Select Device** (or type it in): **dSPIC33CK64MP102** then click **apply**



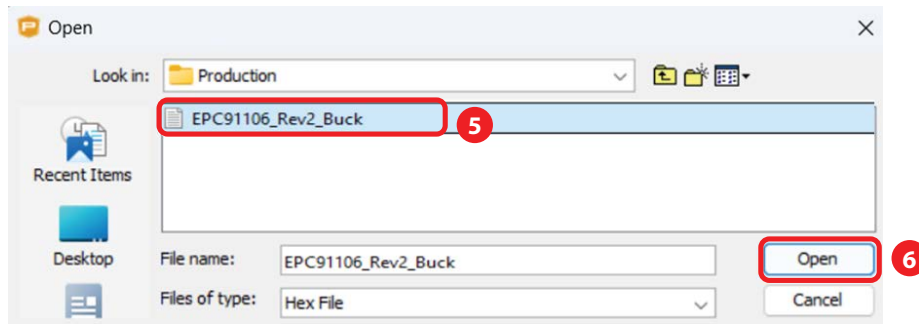
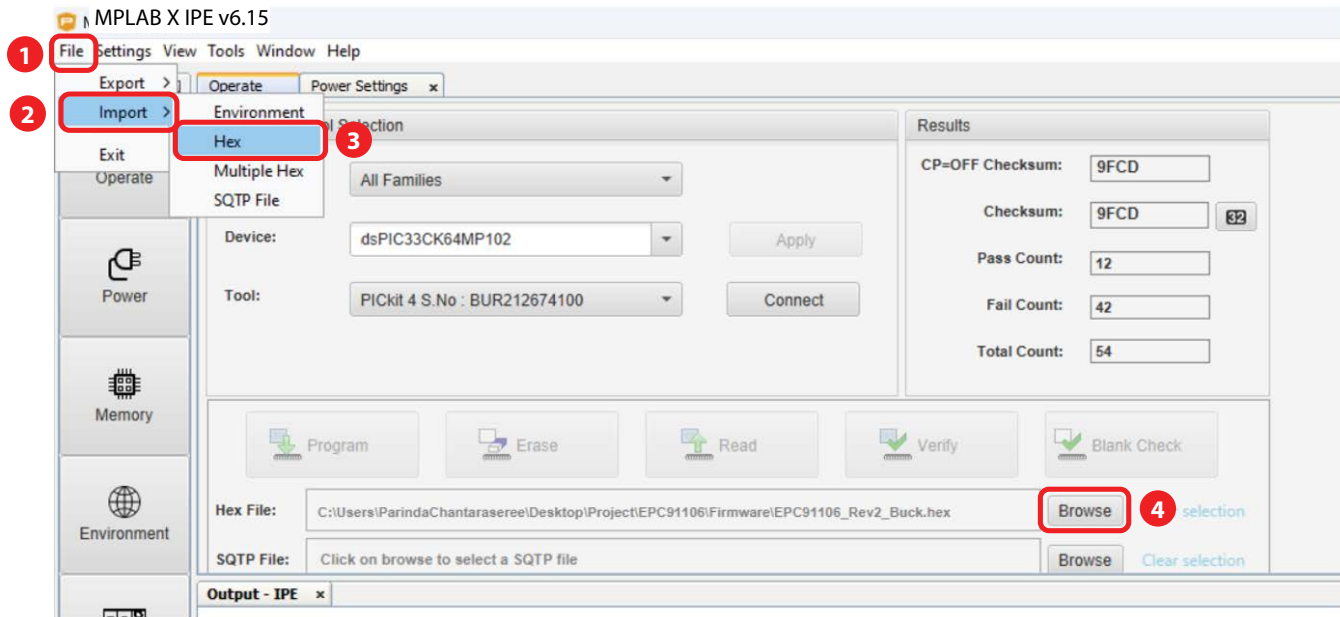
4. **Select programming tool** then click **connect**
(Note: each programmer will have a unique serial number)



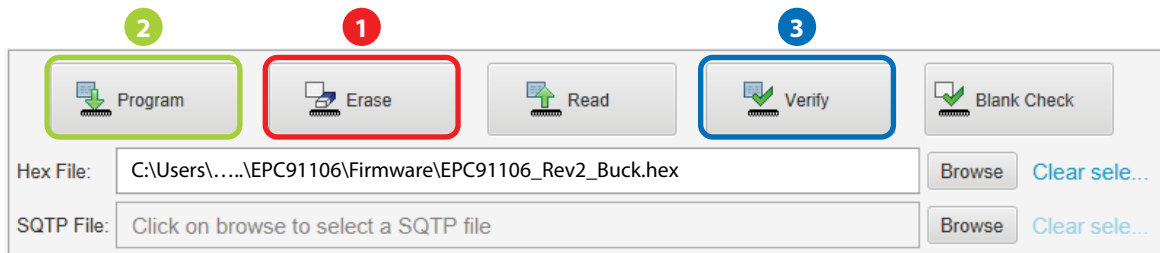
5. **Programmer power** (optional: Do this if no external power is provided to the EPC91106 board. This option will use the USB to power the controller during programming): Select **Power Settings**, then select **Power**, then **Enable Power target circuit from programming tool** by checking the box, return by selecting **Operate**.



5. Load HEX file. Click **Browse** to select the provided .hex file



7. **Erase, Program and Verify.** **Erase** first if required, **Program** the controller by selecting 'Program' and is complete when LEDs stop flashing, **Verify** is optional



8. Unplug the programmer upon completion of programming. **Never operate the evaluation board with the programmer still connected.**

ACKNOWLEDGEMENTS



EPC would like to acknowledge Microchip Technology Inc. (www.microchip.com) for their support of this project. Microchip Technology Incorporated is a leading provider of smart, connected and secure embedded control solutions. Its easy-to-use development tools and comprehensive product portfolio enable customers to create optimal designs, which reduce risk while lowering total system cost and time to market. The company's solutions serve customers across the industrial, automotive, consumer, aerospace and defense, communications and computing markets. The EPC91106 evaluation board features the dSPIC33CK64MP102 16-Bit Digital Signal Controller with High-Speed ADC, Op Amps, Comparators and High-Resolution PWM. Learn more at www.microchip.com.

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Evaluation Board Notification

The EPC91106 board is intended for product evaluation purposes only. It is not intended for commercial use nor is it FCC approved for resale. Replace components on the Evaluation Board only with those parts shown on the parts list (or Bill of Materials) in the Quick Start Guide. Contact an authorized EPC representative with any questions. This board is intended to be used by certified professionals, in a lab environment, following proper safety procedures. Use at your own risk.

As an evaluation tool, this board is not designed for compliance with the European Union directive on electromagnetic compatibility or any other such directives or regulations. As board builds are at times subject to product availability, it is possible that boards may contain components or assembly materials that are not RoHS compliant. Efficient Power Conversion Corporation (EPC) makes no guarantee that the purchased board is 100% RoHS compliant.

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