Evaluation of the TI TPS16412 eFuse for Use in the Rev. I ARX
Whitham D. Reeve

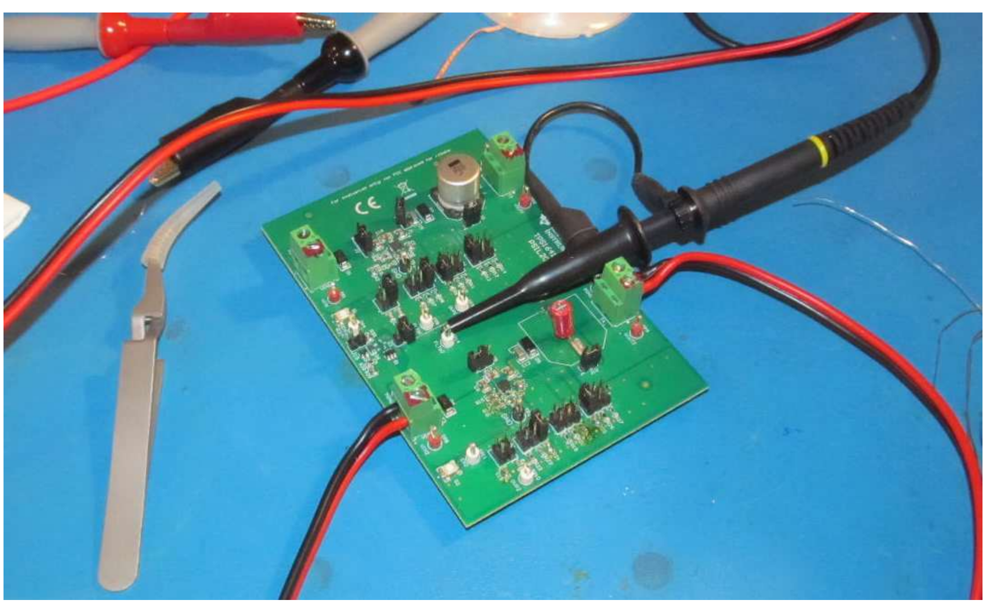
This document describes the evaluation of the TPS16412 eFuse as it applies to the Rev. I ARX design. In this application, the eFuse is used to connect and disconnect power from the Front End Electronics (FEE) while limiting the current to protect the bias-tee components from overcurrent. The eFuse also provides fault indication and load current monitoring.

The evaluation included the following functions and associated device pins:

- ✓ Enable and shutdown control (EN/SHDN)
- ✓ Overvoltage protection (OVP)
- ✓ Voltage slew rate (dV/dt)
- ✓ Current limiting (ILIM)
- ✓ Blanking time delay (IDLY)
- ✓ Overcurrent protection (IOCP/IMON)
- ✓ Fault (FLT)

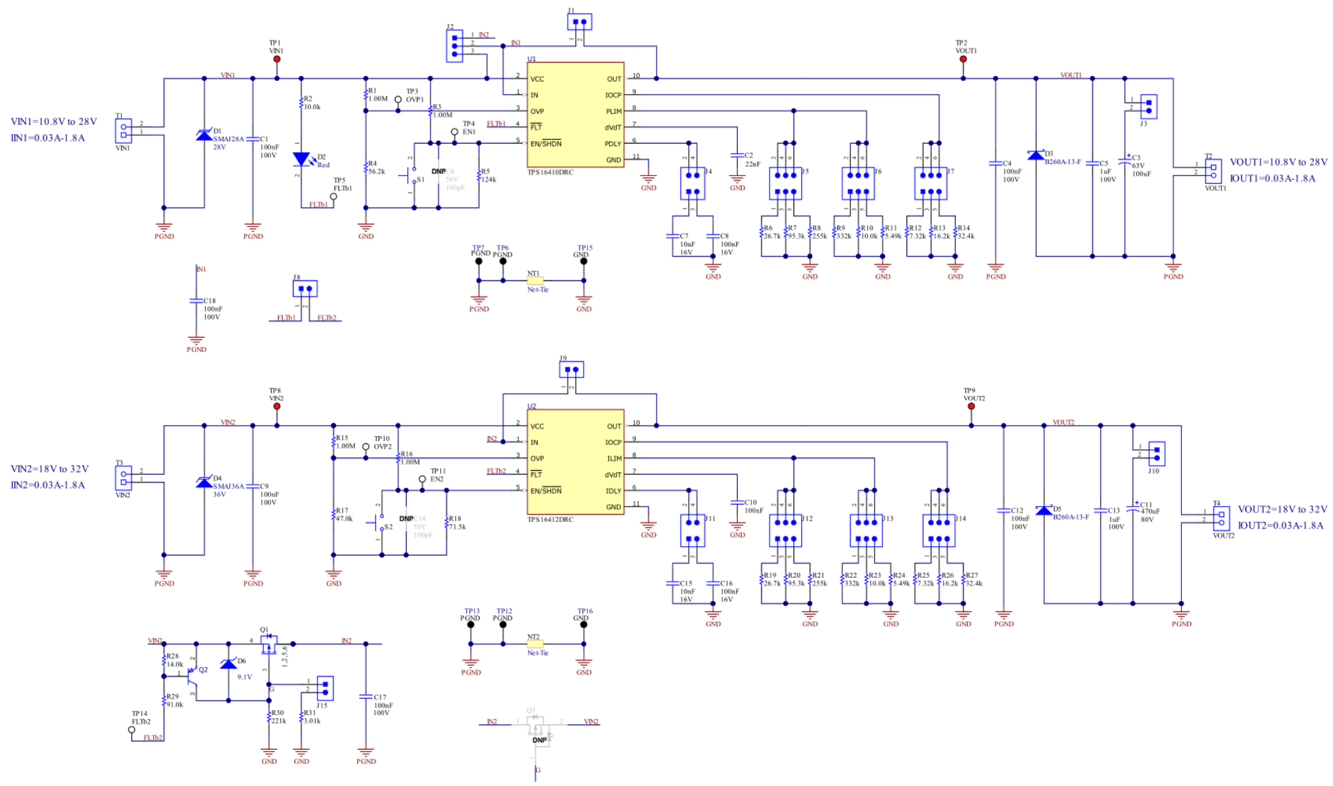
The evaluation was primarily designed to determine if the output voltage slew rate could be reduced to provide a ramp from 0 to 15 V in 100 ms to protect the output stage of the V1.8 Front End Electronics from transients. The TPS16412 datasheet does not directly address the possible internal heating effects of such a long voltage ramp, but the device design clearly supports a large range of slew rates. The concern was that the eFuse inherent overtemperature protection may trip the device before it reached full operating voltage. All functions, including the voltage slew rate, were found to work as designed.

<u>Evaluation module</u>: Evaluation of the device was simplified by the Texas Instruments TPS1641EVM evaluation module shown in the image below. The EVM has two channels. Channel 1 uses the TPS16410 eFuse for power limited evaluation; and Channel 2 uses the TPS16412 eFuse for current limited evaluation; only the TPS16412 is evaluated here.



Modified TPS1641EVM evaluation module. See text for modifications. The channel evaluated is on the lower-right. An oscilloscope probe is connected to a test point. Power supply and load connections are through terminal blocks. Component values for different operating conditions are selected by jumper blocks along the lower-right side.

The evaluation module provides terminal blocks for input power and output load connections and uses headers and jumpers to set the evaluation parameters through on-board capacitors and resistors. Several of the component values on the stock evaluation board were not compatible with the Rev. I ARX receiver application so they were replaced. The EVM also includes input and output transient voltage protection components, which were left in-place. See schematic below.



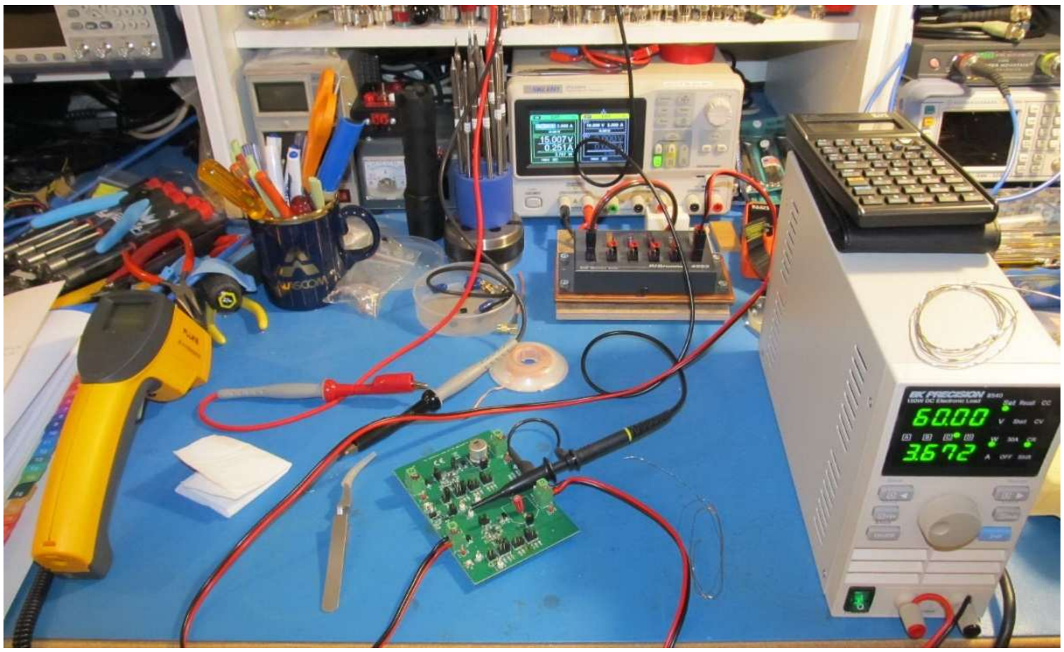
TPS1641EVM schematic. The lower channel has the TPS16412 and is the only one evaluated. Some components and connections are shared between the two channels, so both are shown.

<u>Test equipment</u>: Siglent SPD3303X 3-channel variable power supply, Keithley 2110 bench DMM, BK Precision 8540 Electronic Load, Siglent SDS2302X 2-channel oscilloscope, Fluke 63 IR Thermometer, Hakko FR-830 PCB Preheater.

<u>Initial tests</u>: The EVM was first checked for general operation with its default components and settings for 18-32 Vdc input and 1 A current limit (30 mA, and 1 and 1.8 A current limit settings are available). Overcurrent protection was set to 1.01 A (0.5, 1.01 and 2.23 A overcurrent settings are available).

The electronic load was set to the Constant Resistance mode and the resistance adjusted to provide the desired load current. For the initial tests, the resistance was set to 36 ohms to provide a load of 0.5 A at 18 V. The resistance was then reduced in 1 ohm increments to 18 ohms to increase the current to the current limit of 1 A at 18 V. The load resistance was further decreased to 17.8 ohms to trip the overcurrent protection. The voltage slew rate was checked with the default capacitor CdVdt (C10 = 100 nF) and blanking time based on default capacitors (C15 or C16).

ARX application tests: For all application tests specific to the ARX described below, the EVM was connected to the variable power supply and electronic load through 18 AWG cables. The power supply output voltage was set to 15.0 V except for the overvoltage protection tests. The power supply output current limit was set to 2.0 A for all tests. The electronic load was set to constant resistance mode and varied as needed. Device temperature was monitored with a Fluke 63 IR Thermometer held about 25 mm from the device package on the PCB. The basic setup is shown in the image below. Refer to ***TPS16412 eFuse Application*** for specific design methodologies and details for the ARX application [See References at the end].



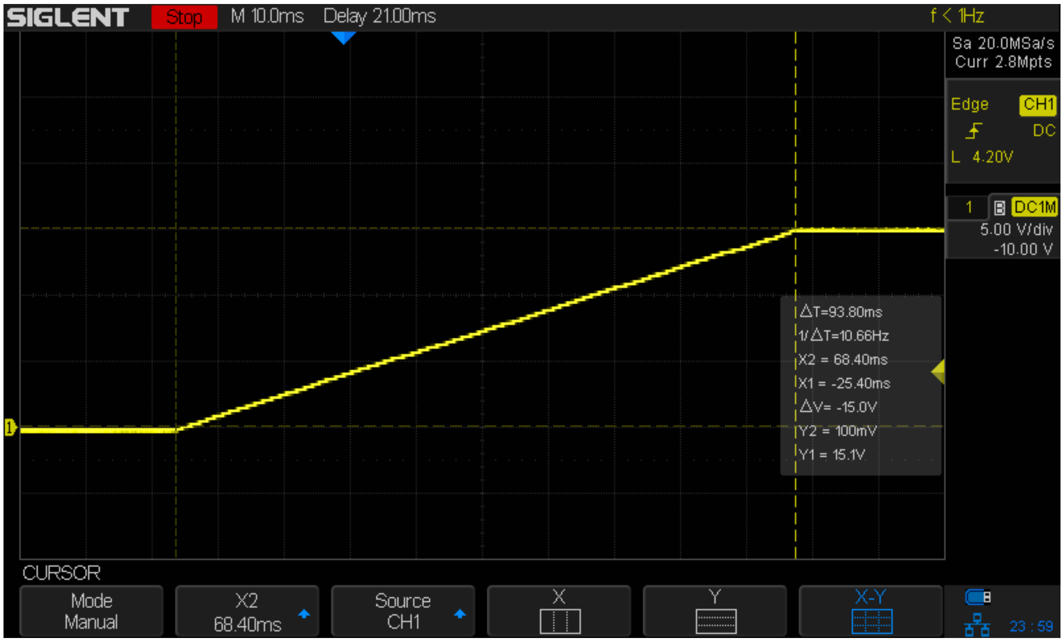
EVM test setup showing the variable power supply in the background, electronic load in the right-foreground and EVM in the middle-foreground. The electronic load is set to the constant resistance mode. The oscilloscope and DMM are outside the view. The IR thermometer is on the left.

Enable and shutdown control (EN/SHDN): The TPS16412 on the EVM is enabled by a 1 Mohm pullup resistor connected to the device operating voltage pin Vcc. The EVM has a pushbutton that shorts the pin to ground to shutdown the device. This function worked as expected.

Overvoltage protection (OVP): The OVP function on the EVM was originally set to 33 V through a resistive voltage divider R15 (1 Mohm) and R17 (47.0 kohm). Resistor R15 was left as original and R17 was replaced with a 68.1 kohm resistor to lower the voltage to about 23.5 V. With the new resistor, the input voltage was raised from 15.0 V until the unit tripped at the new voltage. When tripped, the internal FET is disabled, which removes voltage from the device output, and the fault pin is pulled low.

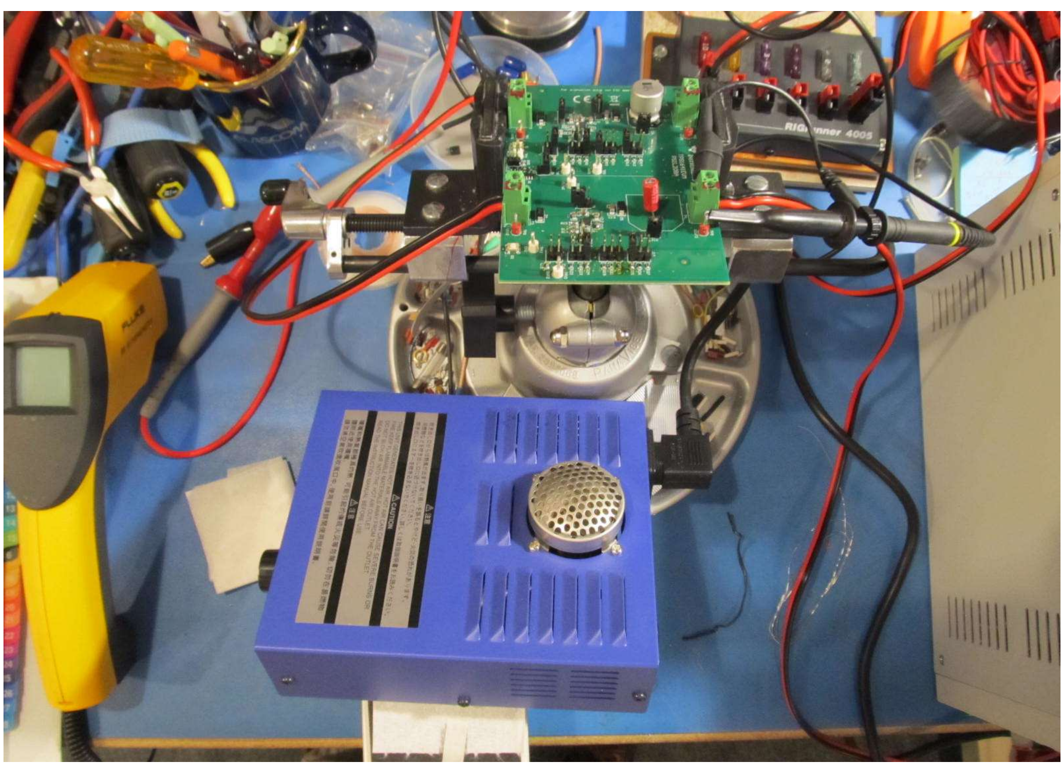
Voltage slew rate (dVdt): The output voltage slew rate and inrush current are related. The inrush current is controlled by the load capacitance on the device. The EVM originally was equipped with a fixed 1 µF capacitor (C13) and a jumper selectable 470 µF capacitor on its output (C11). Capacitor C11 was removed and replaced with a 10 µF capacitor to control the inrush current equivalent to the ARX design. A separate dVdt capacitor determines the slew rate. The original dVdt capacitor (C10) was 100 nF. It was replaced with a 0.68 µF (±10%) MLCC to provide a design slew rate of 150 V/s. The slew rate of the output voltage was measured with an oscilloscope by placing the X and Y cursors at the 0 and 100% voltage points. The measured time difference was

93.8 ms, giving a slew rate of 159.9 V/s. See the oscilloscope screenshot below. These tests were at room temperature.



Measured voltage ramp at room temperature. Timebase set to 10 ms/div and vertical scale set to 5 V/div with 0 V reference shown by the triangular icon on the left side. The table near the right shows the X and Y cursor settings (only one of the vertical cursors is visible in this image). The ΔT from 0 to 100% of the voltage ramp is 93.8 ms.

A Hakko FR-830 PCB Preheater was then placed to blow hot air on the bottom of the PCB to raise the device temperature; see image below. The minimum setting of the preheater is 150 °C but it was found for the experimental setup that a setting about 160 – 170 °C was adequate to raise the eFuse temperature to 48 °C. The temperature was measured with the IR thermometer by holding it about 25 mm from the device.



Test setup with the PCB preheater. The preheater is at the bottom of the image, and the EVM is held in a Panavise multipurpose vise above the preheater. Both were set at an angle with the preheater air output pointed at the bottom of the EVM. The IR thermometer is the on the far-left.

This test was designed to simulate the higher temperatures in the confined space of the ARX PCB card rack. The device temperature was raised over a period of several minutes while periodically connecting and disconnecting the input voltage to observe the voltage ramp on an oscilloscope. The load current for these measurements was 255 mA to simulate the V1.8 FEE. No failures to start were observed. See the oscilloscope screenshot below.

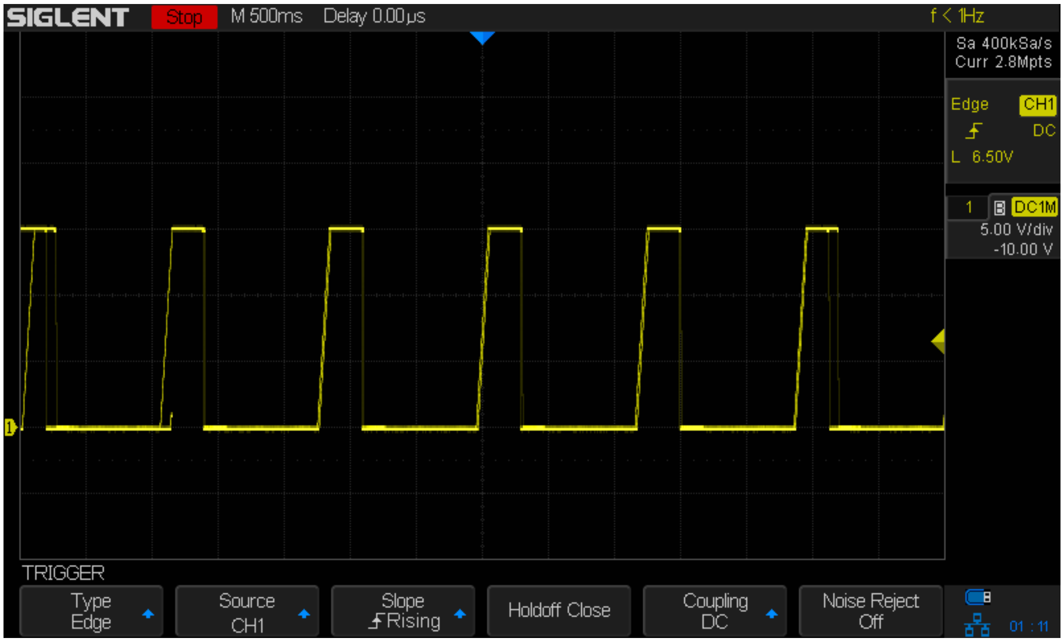
Voltage ramp with device temperature at 48 °C. There was no change in the ramp time and no failures to start over dozens of power cycles. Timebase set to 20 ms/div and vertical scale set to 5 V/div with 0 V reference shown by the triangular icon on the left side.

Current limiting (ILIM): Current limiting is set by a resistor connected between the ILIM pin and ground. The factory EVM has jumper selectable resistors (J12 and J13) but none of them were near the desired value. The calculated RILIM value for the ARX was 32.8 kohms, but the nearest value available from stock was 35.7 kohms. This resistor was installed and provided a 276 mA current limit. It was noted that both the current limit and overcurrent protection (described below) lead to device tripping caused by high power dissipation in the internal FET junction.

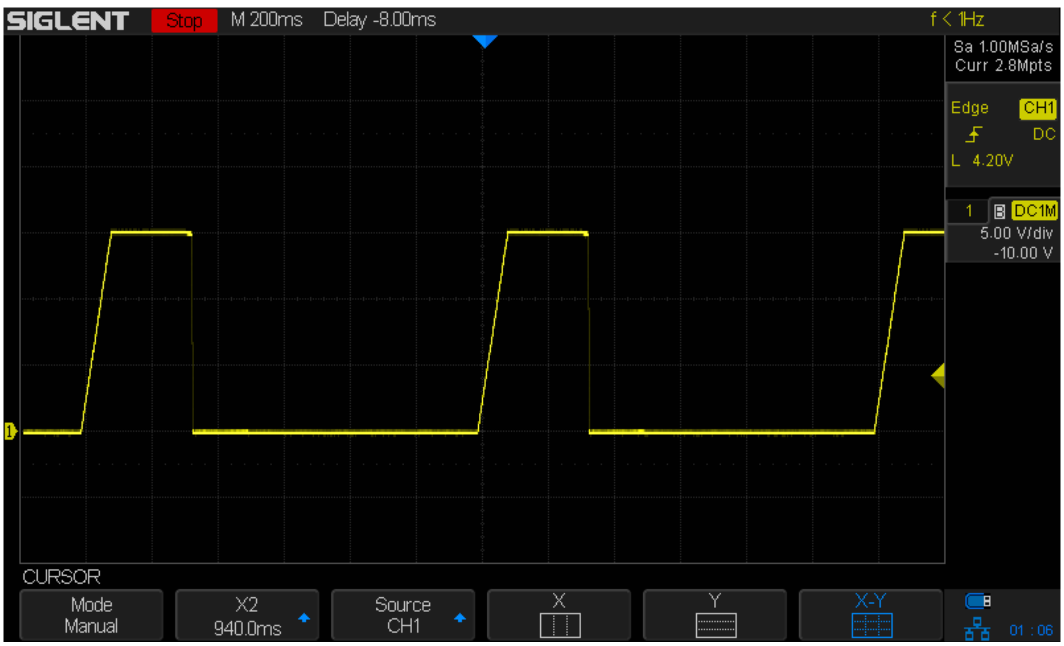
Blanking time (IDLY): The blanking time was disabled by removing the jumper block on J11 so that the IDLY pin was open-circuited.

Overcurrent protection (IOCP/IMON): In conjunction with the current limit described above, the device has jumper selectable overcurrent protection resistors (J14) but none were usable. The desired value was 47.0 kohms but a 43.2 kohms resistor was available from stock and installed in place of one of the factory resistors. On rising load current (falling load resistance to 46.5 ohms), the IOCP tripped at 323 mA. There was some hysteresis so the ICOP tripped condition automatically reset when the load current was decreased to 321 mA (increasing the load resistance to 46.8 ohms).

After the device trips due to current limit or overcurrent, it tries to automatically reset (auto-retry). If the overcurrent condition still exists, the TPS16412 will trip again. The TPS16412 does not latch in the tripped state. As long as the overcurrent condition exists, the device will periodically trip and reset as shown in the oscilloscope screenshots below. Note that a similar device, the TPS16413, will latch off rather than auto-retry.



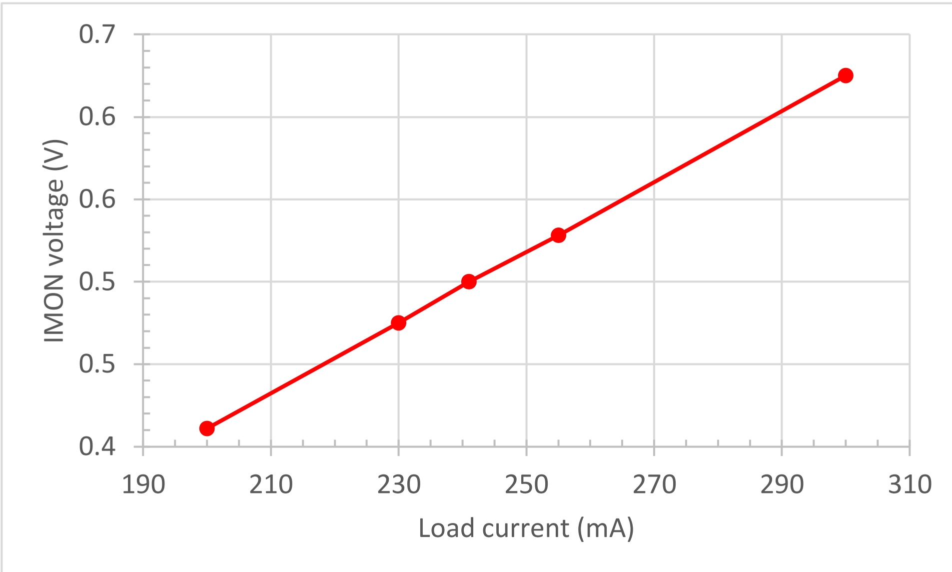
Output voltage with 0.1 ohm short circuit on the output. Note the period is approximately 1.2 s. Timebase set to 500 ms/div and vertical scale set to 5 V/div with 0 V reference shown by the triangular icon on the left side.



Output voltage with 1.67 A current (9.0 ohm load). Note the period is approximately 1.2 s. Timebase is set to 200 ms/div and vertical scale is 5 V/div with 0 V reference shown by the triangular icon on the left side.

Load current monitoring: The voltage at the IOCP/IMON pin can be used to derive the load current. Therefore, the pin was monitored during normal operation with various load currents from 200 to 300 mA. The voltages measured from the IOCP/IMON pin to ground are listed and plotted below. Note the high linearity of the plot.

- 200 mA: 0.411 V
- 230 mA: 0.475 V
- 241 mA: 0.500 V
- 255 mA: 0.528 V
- 300 mA: 0.625 V

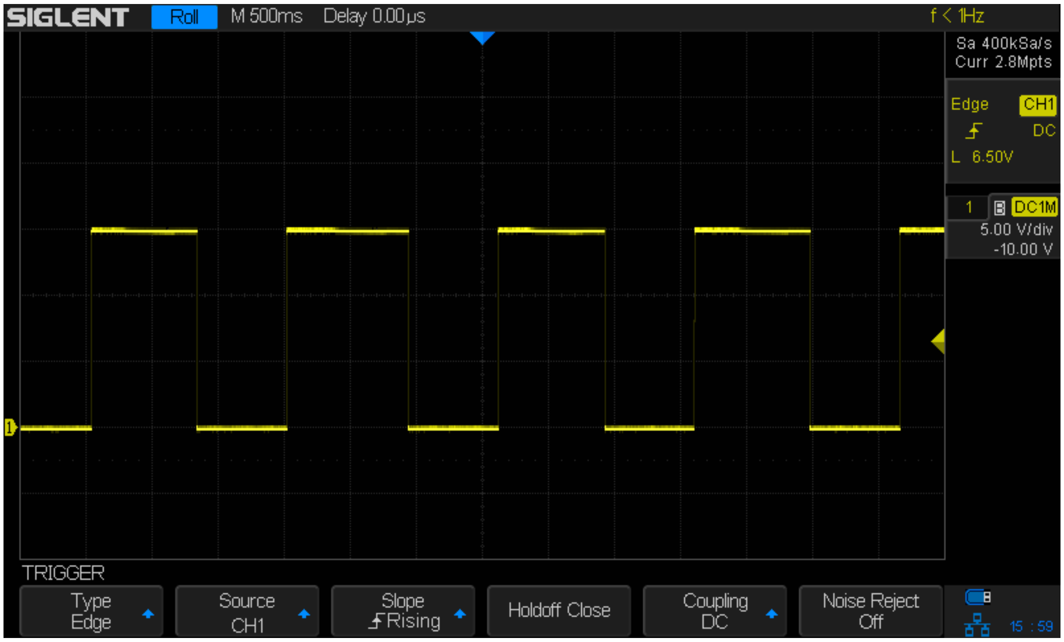


IMON pin voltage for load currents from 200 to 300 mA. The dots indicate the measured values.

<u>Fault (FLT)</u>: The various fault conditions in the eFuse are:

- ✓ Overvoltage protection (tested)
- X IN-to-OUT Short detection (not tested)
- ✓ Thermal shutdown (tested)
- ✓ Current limiting timeout (tested)

The Fault pin is pulled low during a fault and pulled high through a pull-up resistor during normal operation. As previously described, the device attempts to automatically reset and does not latch. With a fault continuously applied to the output, the FLT pin pulses between a high and low condition in cadence with the attempts to reset. See the oscilloscope screenshots below for the faulted and normal conditions. The device temperature was measured to see if it would eventually rise due to the cyclic nature of the auto-retry function, but it remained at room temperature overnight, indicating the device protects itself regardless of the auto-retry duty cycle.



Fault pin is periodically pulled low from 15 V to 0 V with 323 mA load current (overcurrent condition). The period is approximately 1.2 s. Timebase is set to 500 ms/div and vertical scale is set to 5 V/div with 0 V reference shown by the triangular icon on the left side.

Fault pin at 250 mA load current (normal condition) is pulled high. The indication is a steady 15 V. Timebase and vertical scale as above with 0 V reference shown by the triangular icon on the left side.

Modifications to factory EVM components: The following components were replaced on the EVM.

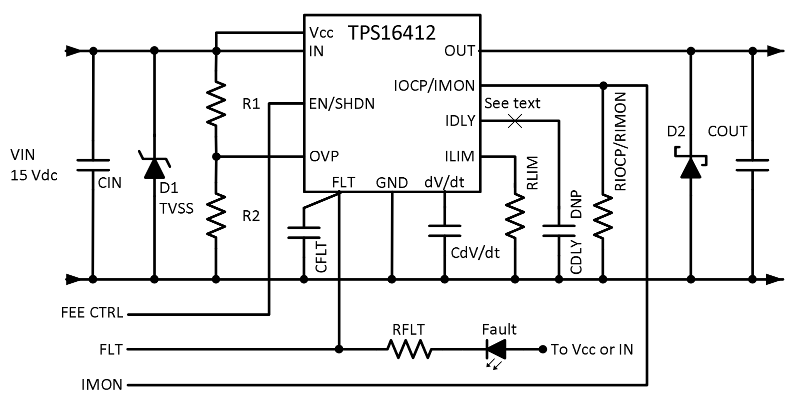
Function	**EVM component designation**	**Calculated modification**	**Size**
IDLY	C15 or C16	CDLY = GND or Open	N/A
dV/dt	C10	CdVdt = 0.68 µF	0603
ILIM	R19, R20, R21 or R22, R23, R24	RLIM = 32.4 kohm	0603
IOCP	R25, R26, R27	RIOCP = 47.5 kohm	0603
OVP	R15 & R17	R1 = 1 Mohm (ok), R2 = 68.1 kohm	0603
COUT	C11 or C13	COUT = 10 µF, 50 V	radial or 1206

EVM settings:

Jumper	Default setting	Default function	New setting	New function
J9	Open	No FET short	Open	No FET short
J10	Shorted	Connect bulk output capacitor COUT = 470 µF	Shorted	Bulk output capacitor COUT = 10 µF
J11	3-4	50 ms blanking time for current limit	Open	No blanking time for current limit
J12	Open	Not used	Open	Not used
J13	5-6	1.8 A current limit	3-4	276 mA current limit
J14	1-2	2.23 A overcurrent protection	3-4	323 mA overcurrent protection
J15	Open	No fast turn-on for Q1 input to channel 2	Open	No fast turn-on for Q1 input to channel 2

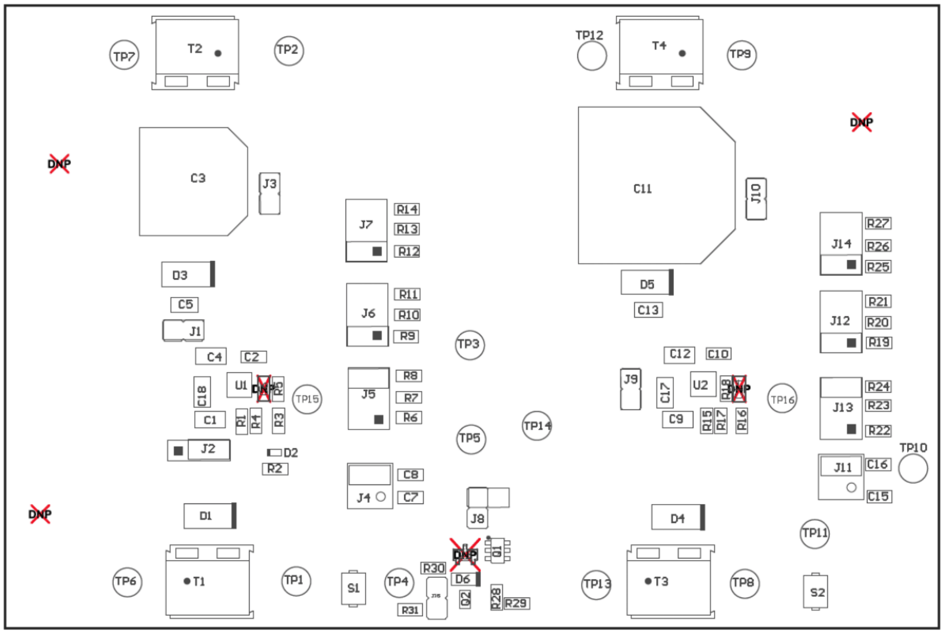
Summary of components in ARX application (see application schematic below):

Component	Value	Remarks	Mfr
R1	1 Mohm, 1%		
R2	68.1 kohm, 1%		
CdVdt	0.68 µF, 50 V, 5%		
RLIM	32.4 kohm, 1%		
RIOCP	47.5 kohm, 1%		
CDLY	Not used (see text)	Connect pin to GND or open	
CFLT	1 nF, 50 V		
D1	18 to 36 V	SMAJ-series	Littelfuse TVS
D2	60 V	B260A or B360A	Diodes, Inc. Schottky
COUT	10 µF + 0.1 µF	Both MLCC, Low ESR	
CIN	1 µF + 0.1 µF	Both MLCC	

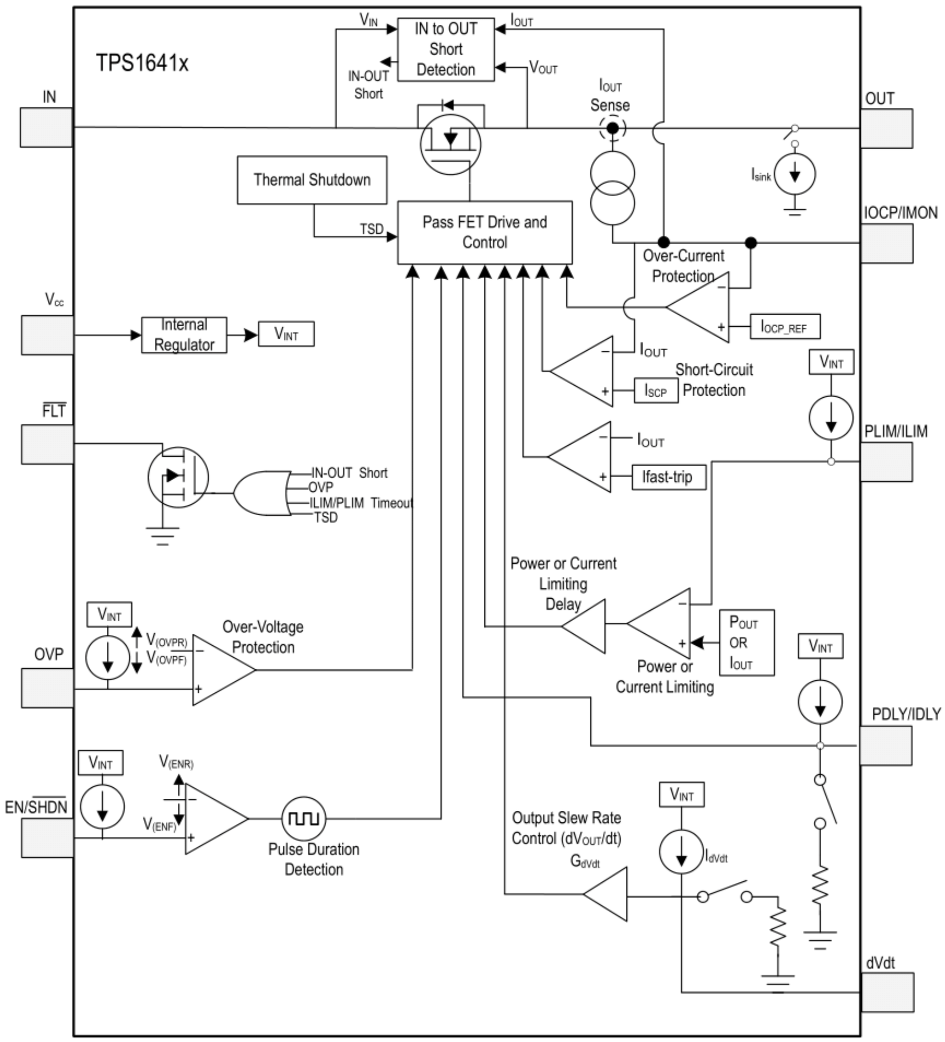


TPS16412 application schematic for the ARX.

TPS16412EVM PCB Layout:



TPS16412 block diagram:



References:

Reeve, W., ***TPS16412 eFuse Application***

Texas Instruments, TPS1641EVM evaluation module

Document Information

Author: Whitham D. Reeve

Revisions: 0.0 (Original draft started, 19 Apr 2023)
0.1 (Added measurements, 22 Apr 2023)
0.2 (Completed 1st draft, 23 Apr 2023)
0.3 (Improved formatting and removed Draft watermark, 28 Aug 2023)

Word count: 2411

File size (bytes): 1387574