USER GUIDE

Classification | PRIVATE

Combo-FET SSCB Evaluation Board

User Guide

General Information

This document provides descriptions and instructions for the Qorvo® Solid State Circuit Breaker (SSCB) application with Silicon Carbide (SiC) Combo-FET device in TOLL package and QPG6105 micro-controller. Included is schematics, PCB layout, interface definition, test procedure and bill of material.

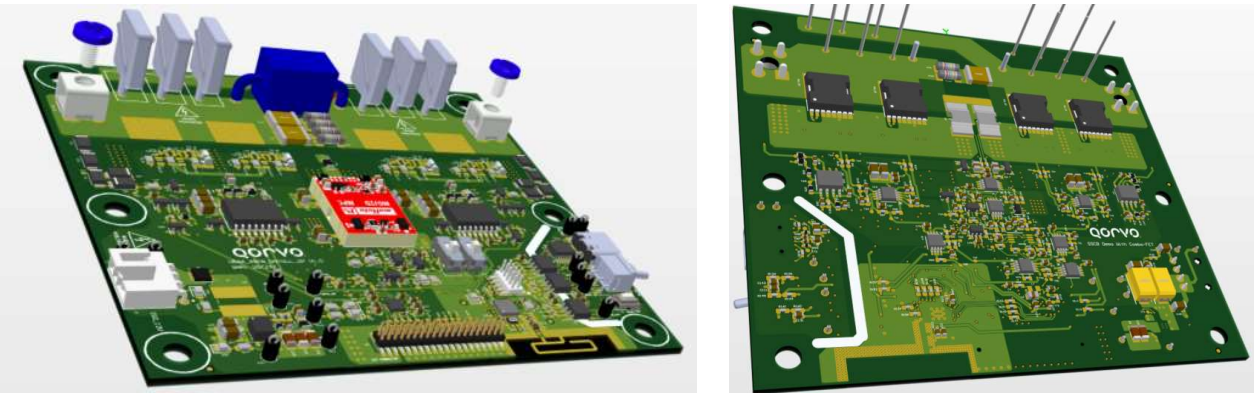


Figure 1 Picture of the evaluation board design

Referenced Documents

The reference documents below take precedence over the contents of this application note and should always be consulted for the latest information.

[1] Website page: UG4SC075005L8S - Qorvo

[2] Website page: QPG6105 - Qorvo

[3] Combo-FET Technical Overview: https://www.qorvo.com/products/d/da009537

[4] JFET Primer: https://www.qorvo.com/products/d/da009284.

[5] JFET User Guide: https://www.qorvo.com/products/d/da009285

Introduction

SiC Combo-FETs are composite devices consisting of a low-voltage Si MOSFET and a high-voltage SiC normally on JFET. Figure 2 shows the circuit schematic of the Combo-FET. The source of SiC JFET connects with drain of low voltage silicon MOSFET, both gates of SiC JFET and silicone MOSFET are accessible. Compared with standard cascode structure, the SiC Combo-FET has advantages of lower RDSon by over-drive, full switching speed control and junction temperature sensing, thanks to the accessibility of the gate of JFET. At the same time, with simple external configuration, the Combo-FET has normally off feature same as the standard cascode.

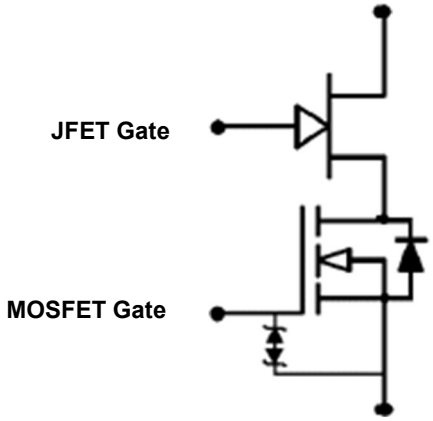


Figure 2. Circuit schematic of the Combo-FET

This evaluation board demonstrates the design of solid state circuit breaker with Qorvo Combo-FET device UG4SC075005L8S and Qorvo smart communication controller QPG6105.

Figure 3 UG4SC075005L8S (Left) and QPG6105 (Right), not scaled

Functional Blocks

There are seven functional blocks on this evaluation board:

- Power channel: includes power cells, snubbers and gate drivers.

- Current sensing: current sensing conditioning and over current protection
- JFET junction temperature sensing: measure the JFET gate to source voltage drop
- Vds sensing: measure the drain to source voltage drop of power FET
- ADC: analog to digital conversion
- MCU: micro-computer unit and interfaces
- Auxiliary power supply: auxiliary power input and control power converter

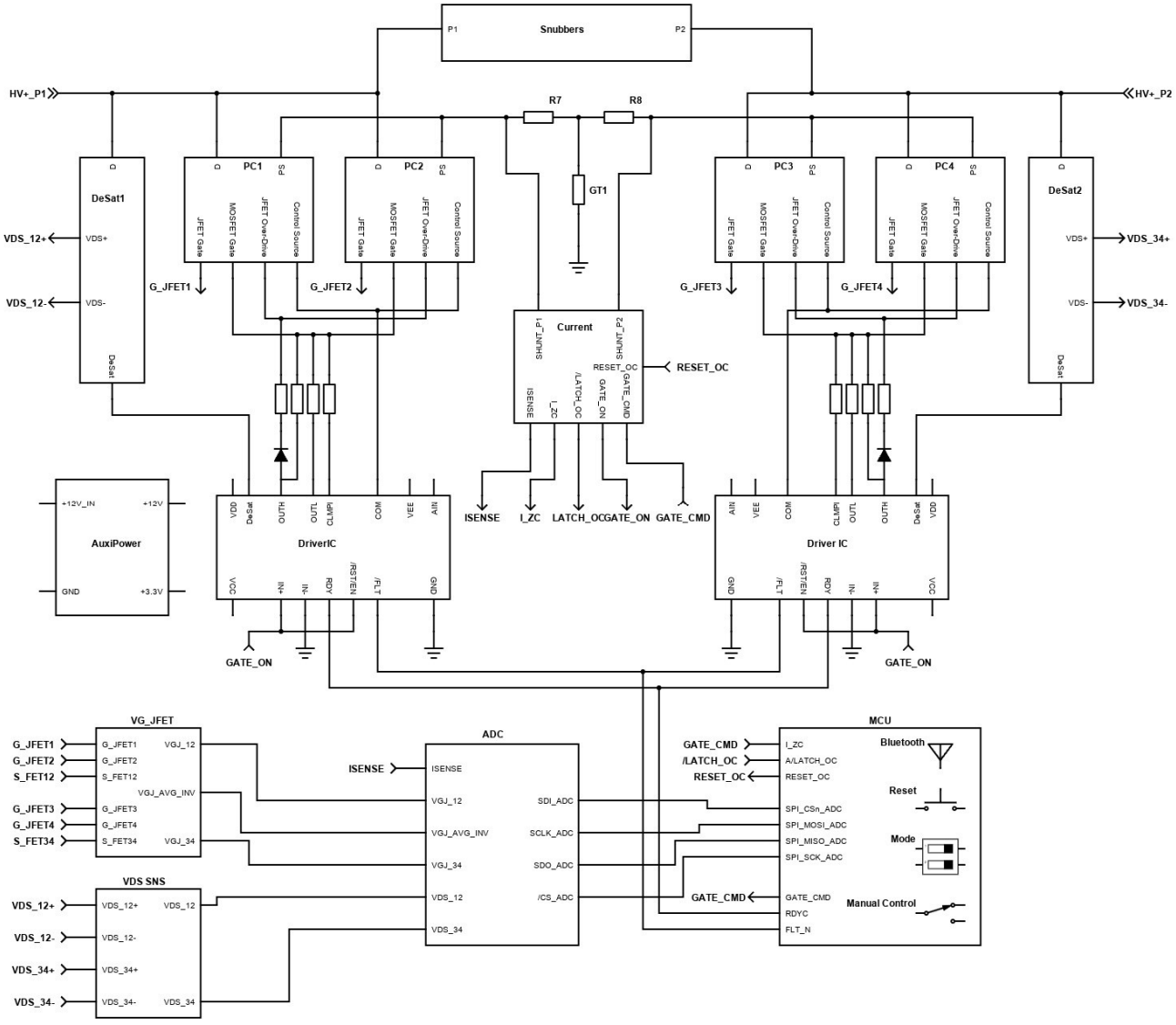


Figure 4 Evaluation board functional diagram

Power Channel

The power stage of this solid-state circuit breaker evaluation board is bidirectional blocking and constructed by the Combo-FET with two in parallel and common source series configuration. Two shunt resistors are inserted into common source for current sensing. RC snubber, TVS and MOVs are for absorbing the energy stored in parasitic inductors to clamp the voltage during Combo-FET switching off.

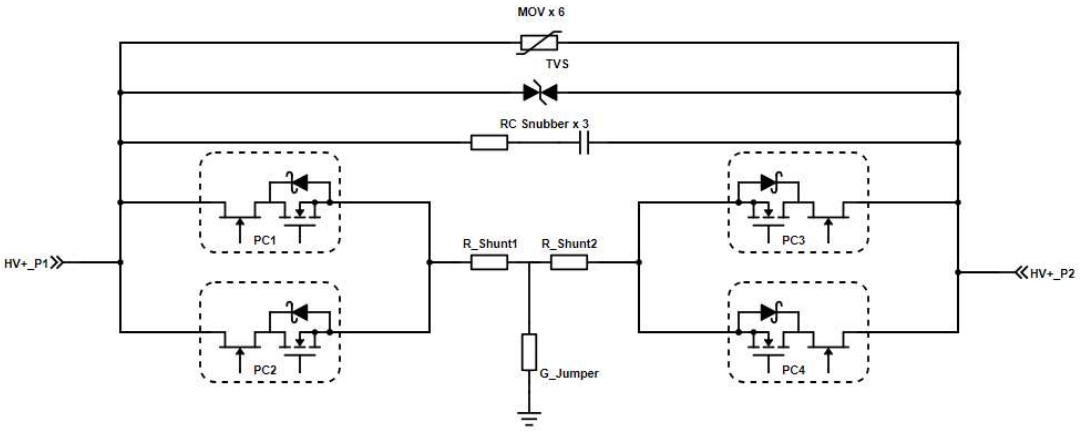


Figure 5 Power channel diagram

There are four identical power cells (PC1-PC4), the gate circuit configuration for each power cell is shown below. R1 and R2 are pull down resistors for the MOSFET and JFET respectively. R3 is JFET gate resistor to tune the switching speed. D1 is to block the over-drive voltage of JFET gate, R4 and R6 are the gate and control source resistors to isolate the loop current between two Combo-FETs in parallel.

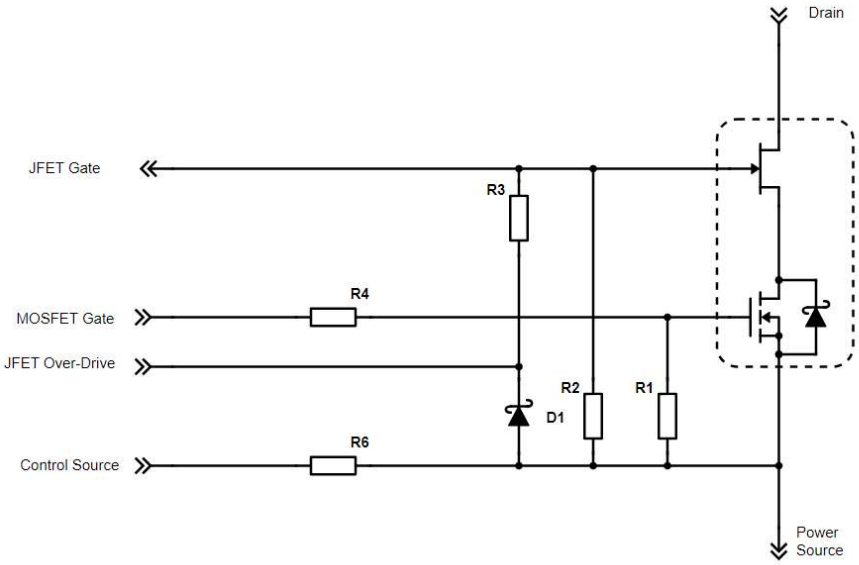


Figure 6 Power cell diagram

Current Sensing

The current is measured by shunt resistors and analog conditioning circuits, the hardware over current threshold can be changed by resistor value and over current state is latched until it is reset manually or by software through GUI.

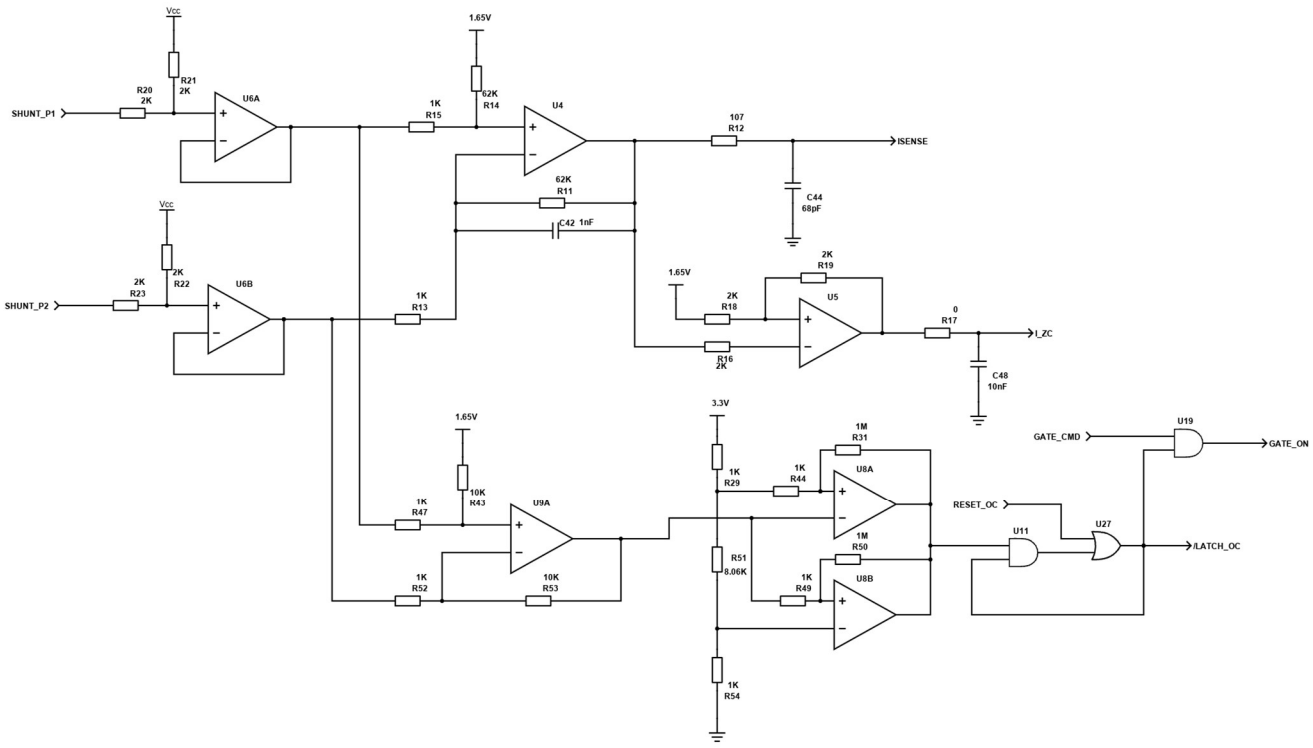
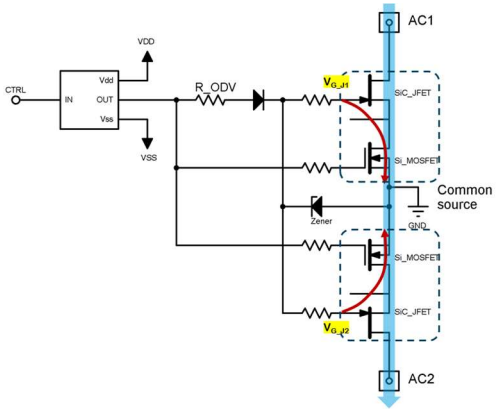


Figure 7 Current sensing and over current protection

JFET Junction Temperature Sensing

The JFET junction temperature is detected by measuring of JFET gate to source voltage. For Combo-FET, there is no access to the source of JFET, so the measurement of JFET gate voltage includes drain to source voltage drop of low voltage MOSFET cascoded with JFET. To get rid of voltage offset of low voltage MOSFET drain to source, a hardware sum circuit be developed.



$$V_{G\_J1} = V_{GS\_J1} + V_{DS\_MOSFET1}$$

$$V_{G\_J2} = V_{GS\_J2} + V_{DS\_MOSFET2}$$

$$\frac{V_{G\_J1} + V_{G\_J2}}{2} = \frac{(V_{GS\_J1} + V_{GS\_J2} + V_{DS\_MOSFET1} + V_{DS\_MOSFET2})}{2}$$

Any current direction: $V_{DS\_MOSFET1} = -V_{DS\_MOSFET2}$

$$\frac{V_{G\_J1} + V_{G\_J2}}{2} = \frac{V_{GS\_J1} + V_{GS\_J2}}{2}$$

Figure 8 Method of extracting JFET gate to source voltage for Combo-FET device

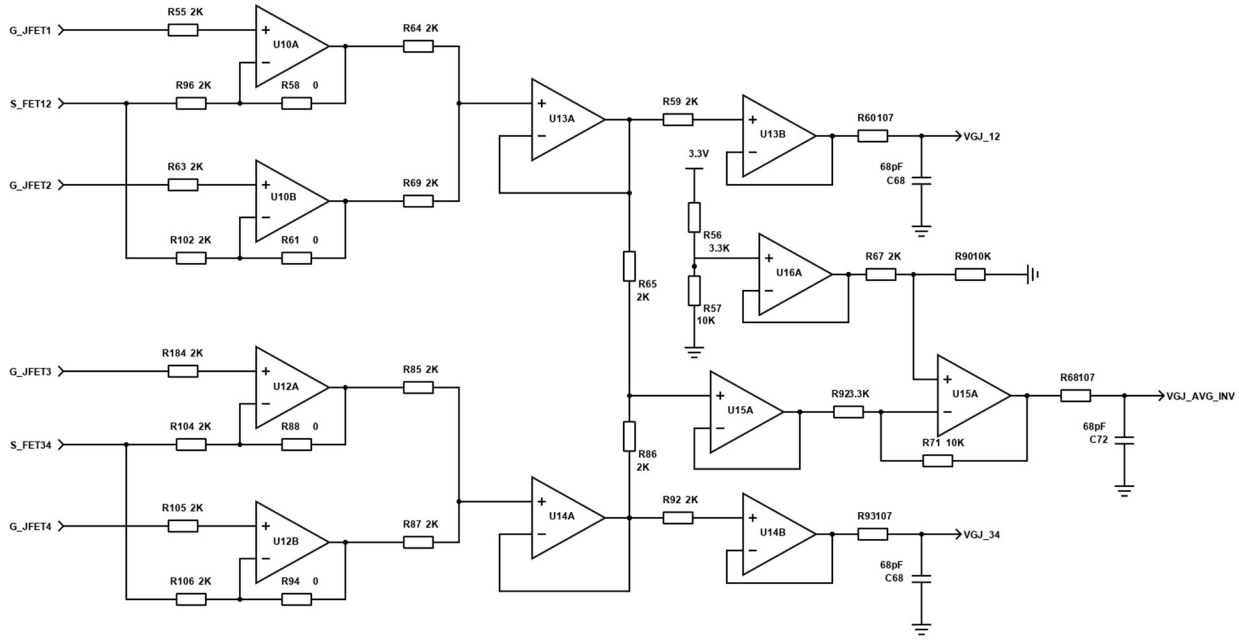


Figure 9 JFET Junction temperature sensing by JFET gate voltage measurement

VDS Sensing

Combo-FET drain to source voltage drop is measured by utilizing desaturation circuit. The D11 and D13 (D12 and D14) are for blocking high voltage when power devices are off to protect other circuits. D4 and D6 (D3 and D5) are series with D11 and D13 (D12 and D14) to mirror the voltage drop of D11 and D13 (D12 and D14), so the conditioning circuit can subtract the voltage drop of D11 and D13 (D12 and D14) from the measurement to have the drain to source voltage drop of the devices.

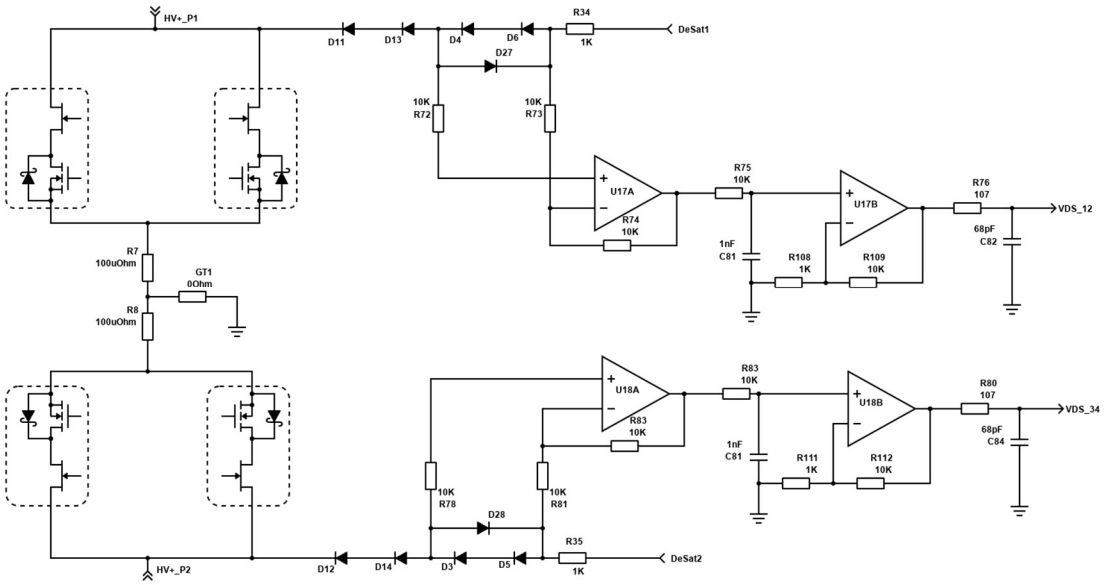


Figure 10 VDS sensing circuit

Analog to Digital Converter

This evaluation board uses 8-channel 16-bits analog to digital converter to read the analog signals, it can be controlled by MCU through SPI communication.

Micro-Controller Unit

QPG6105 is a low power communications controller implementing Zigbee®, Thread, Matter, Bluetooth® Low Energy and Bluetooth Mesh protocols. It features the hardware based ConcurrentConnect™ technology enabling multiple protocols to operate simultaneously, delivering improved capacity and enhanced interoperability with the leading low power standards.

The QPG6105 SoC and its software is Zigbee and Bluetooth Low Energy certified and a candidate for Matter v1.0 certification. The QPG6105 development kit is a one-stop shop for boards, software and documentation for easy product development. Additionally, a connected lighting reference design is available to reduce time to market for customers.

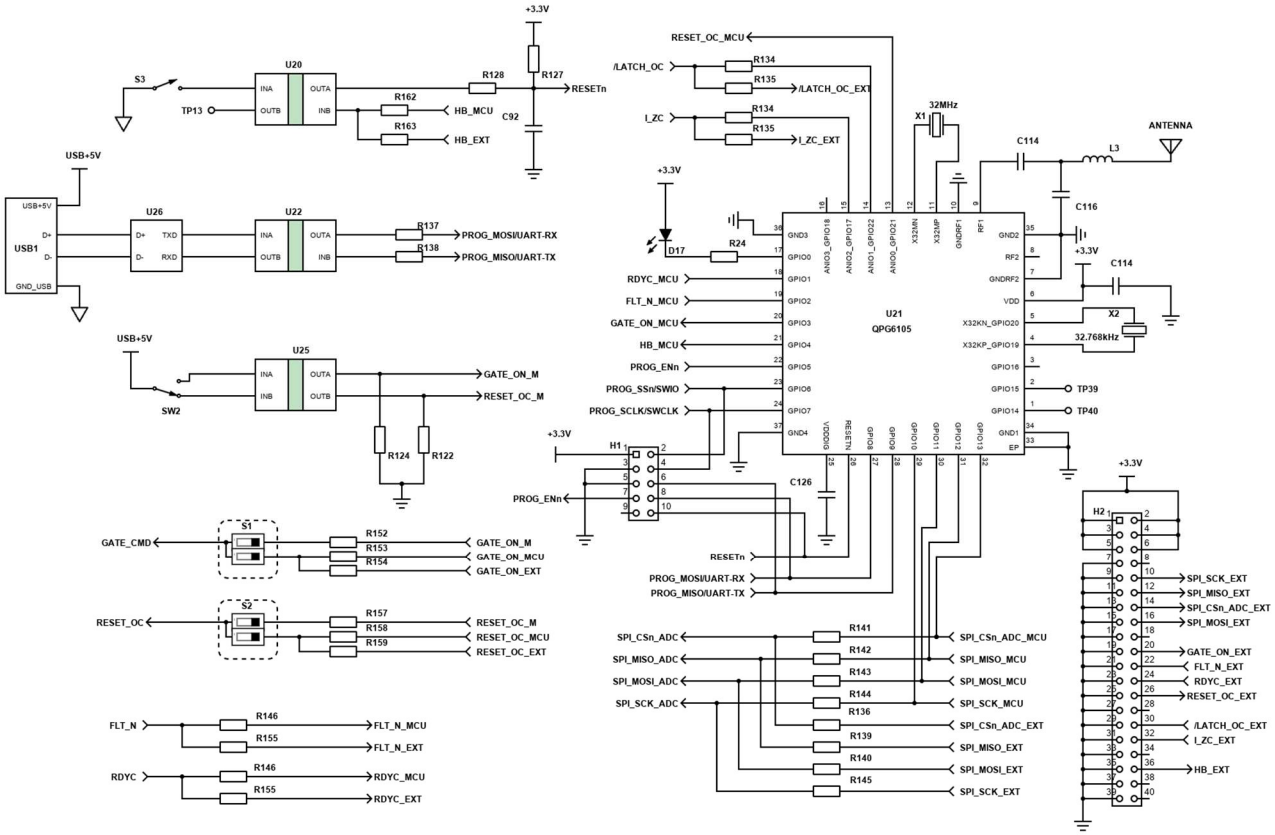


Figure 11 Control unit diagram

Auxiliary Power

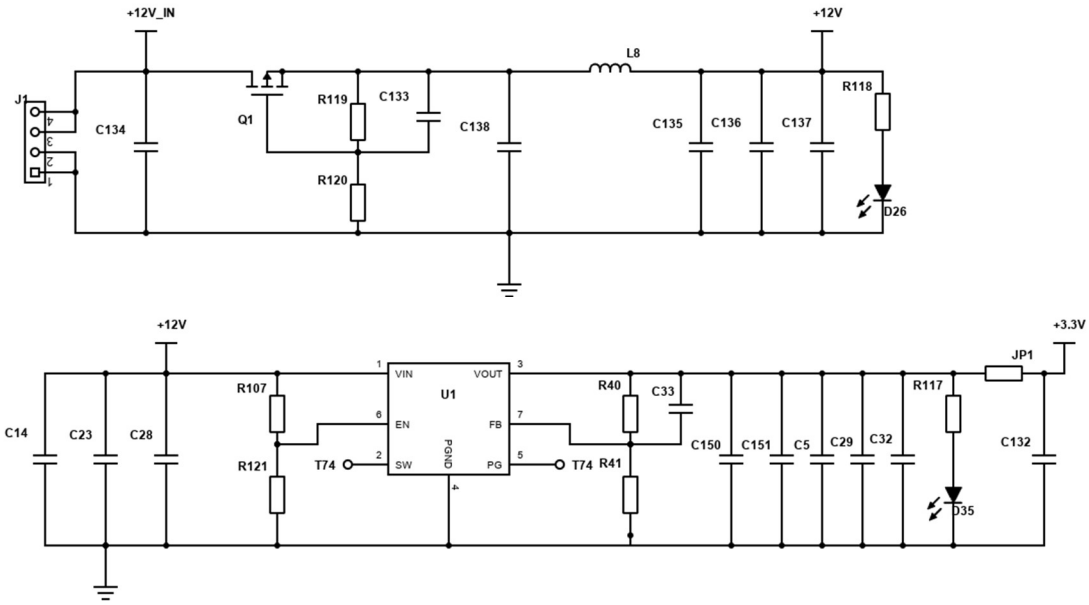


Figure 12 Auxiliary Power Diagram

Interfaces

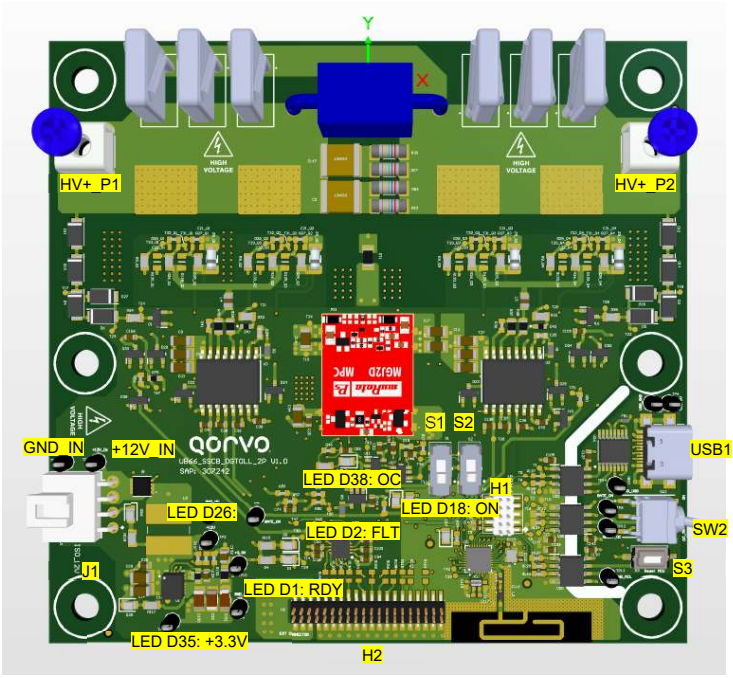


Figure 13 Interfaces

Table 1 Interface Definition

Interface	Function	Definition	Connector	Mating Part	Note
HV+_P1	Power Terminal 1	0-350V AC/DC	Screw Terminal	NA	10Arms
HV+_P2	Power Terminal 2	0-350V AC/DC			
J1	12V Power Supply	+12V, isolated power supply	105313-1204, Connector Header Through Hole, Right Angle 4 position 0.098" (2.50mm)	105307-1204, Rectangular Connectors - Housings Receptacle Black 0.098" (2.50mm) 1053002300, Non-Gendered Contact Gold 20-22 AWG Crimp Power	Cable connection
S1	Slide switch	GATE_ON signal switch between manual control and MCU control	NA	NA	
S2	Slide switch	RESET_OC signal switch between manual control and MCU control	NA	NA	
S3	Push button	MCU reset signal	NA	NA	
SW2	Manual control	GATE_ON and RESET_OC manual control singal	NA	NA	
H1	MCU Program connector	0/+3.3V	FTSH-105-01-L-DV-K-TR, CONN, HDR, 10 POS, 0.050", SMD	1.27mm, dual row, 10 position, receptacle	
H2	External access signals	0/+3.3V	M50-3612042, Connector Header Surface Mount 40 position 0.050" (1.27mm)	1.27mm, dual row, 40 position, receptacle	

Test Setup – Manual Control

Precaution: this test has high voltage involved and can potentially be explored if failure happens. The lab safety instructions must be followed, and users of this board shall take their own responsibility for safety.

1. For manual control mode, S1 and S2 need to be switched to the position towards MCU/Antenna side, see Figure 14
2. Power the board with 12V power supply (isolated to main power lines) through connector J1, or test point (+12V_IN and GND_IN).
3. Power the safe area (USB powered) by plugging in USB cable.
4. On/Off control: switch SW2 to turn the power switch on (towards antenna) or off (towards USB port), see Figure 14.

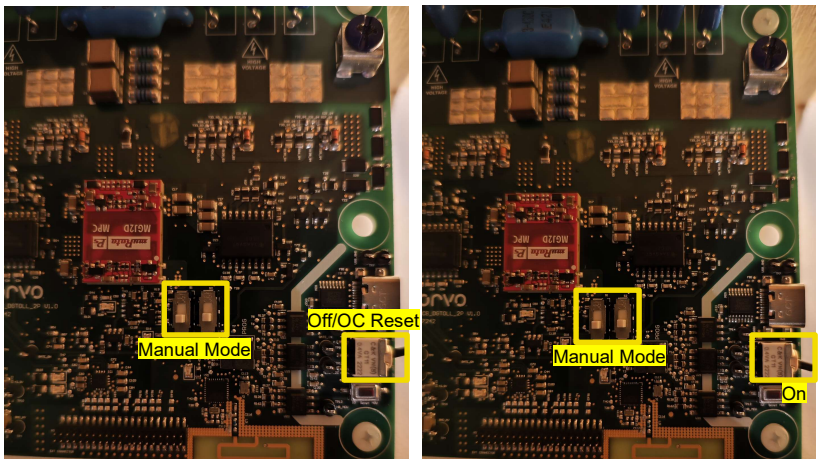


Figure 14 Manual/MCU mode (S1 and S2), ON/OFF Switch

The test setup for over current protection is shown as Figure 15, the length of L1 and L2 is 2 feet for test results in this user guide.

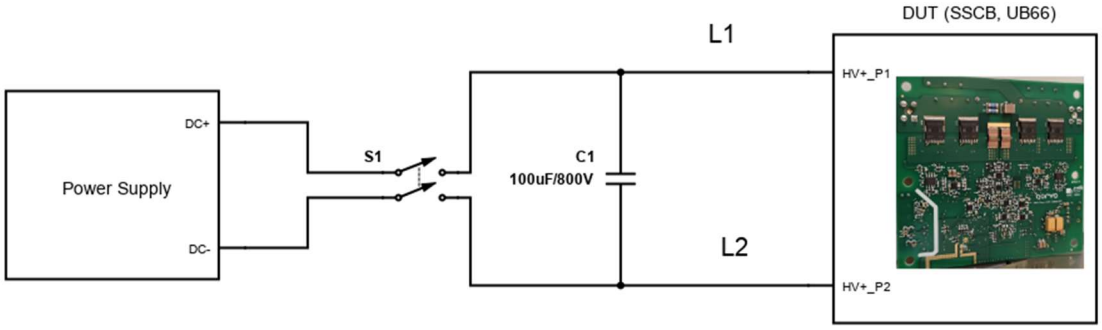


Figure 15 Over-current protection test setup

Test Results

The junction temperature can be sensed by measuring the gate to source volage of JFET when over-drive it. Details see JFET Primer: https://www.qorvo.com/products/d/da009284. [4] and ref [5]. This method was modified for the Combo-FET because there is no access to JFET source for the Combo-FET package. This modified method can cancel the offset caused by the volage drop of low voltage MOSFET. The test result verified this method works.

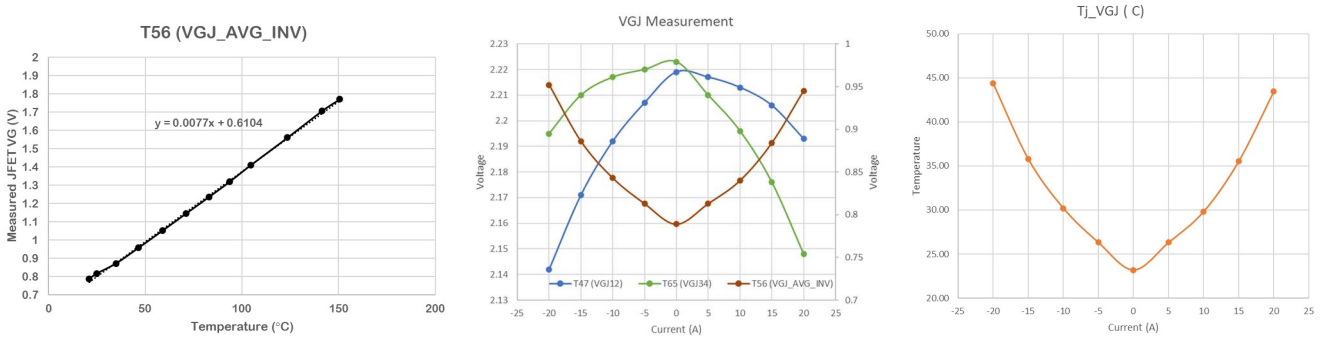


Figure 16 Junction temperature sensing test results, left: calibration, middle: comparsion of with and without low voltage MOSFET voltage drop cancellation, right: junction temperature sensing result under different DC current.

Figure 16 shows the results of calibration and junction temperature sensing results.

The conduction current is sensed by shunt resistors or derived from measuring of drain to source voltage drop (V_{DS}) and estimated conduction resistance ($I=V_{DS}/R_{DSon}$), the conduction resistance (R_{DSon}) is estimated by plugging in sensed junction temperature into the curve of Normalized on-resistance vs. temperature.

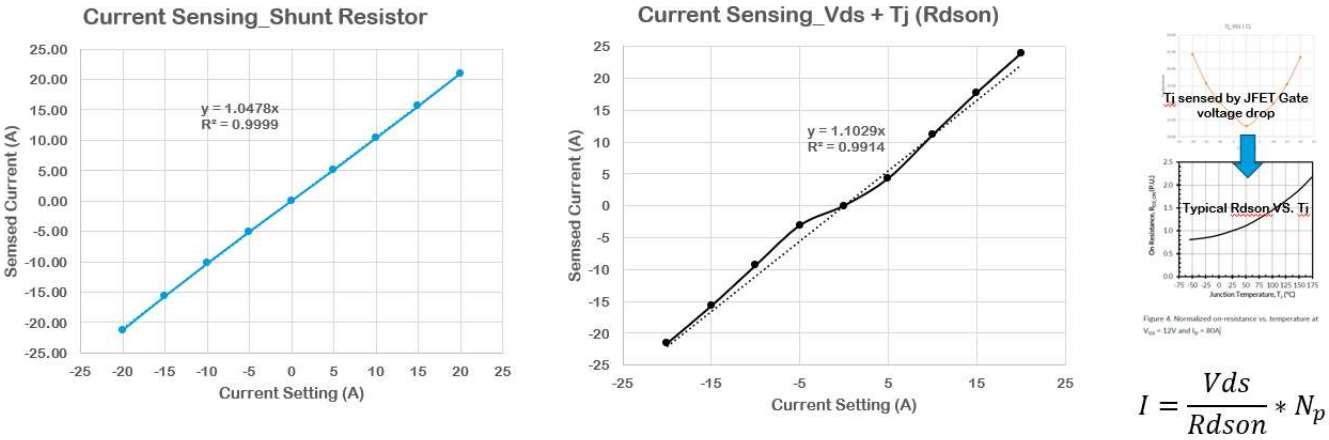


Figure 17 Current sensing test results, left: shunt resistors, middle: V_{DS} and T_J, right: method of current sensing by V_{DS} measurement

Figure 15 shows how the over-current protection is tested, the test results (Figure 18) show the effectiveness of turning off speed control by JFET gate resistance. The gate resistance of JFET shall be selected based on the application, the limits are the switching off energy and FET over-shoot voltage must be within its safety operation area (SOA).

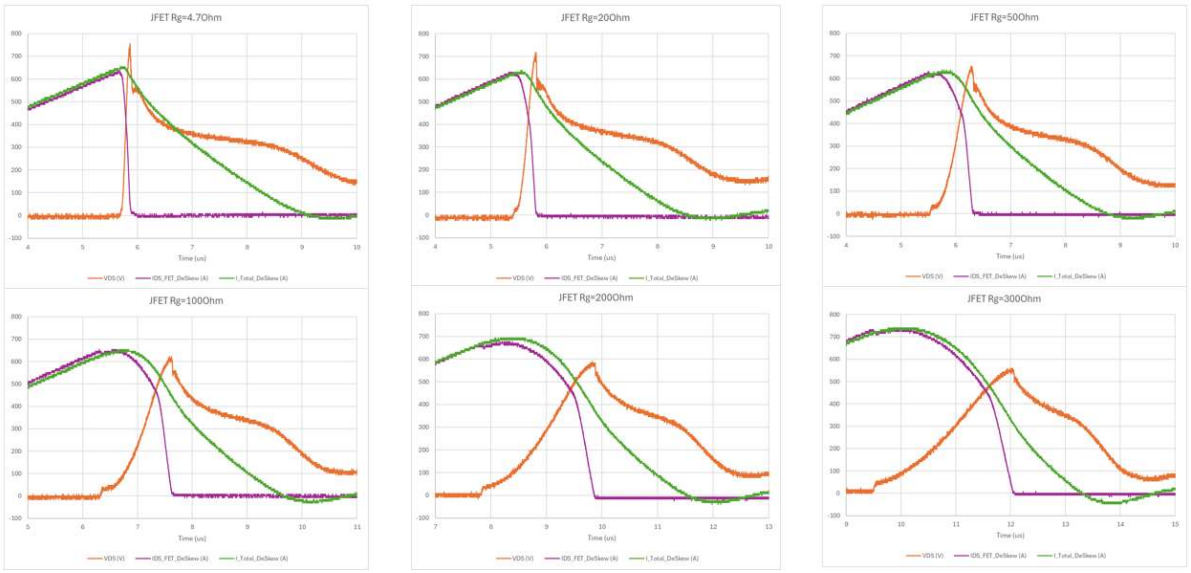
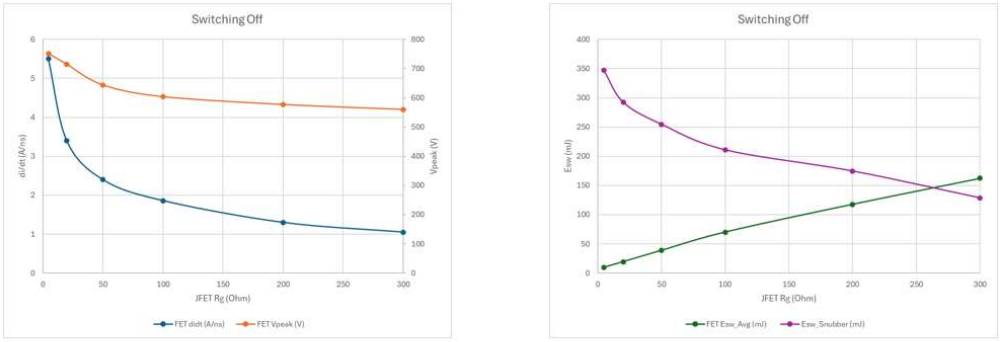


Figure 18 Over-current protection test results



JFET Rg (Ohm)	FET didt (A/ns)	FET Vpeak (V)	FET Esw_Avg (mJ)	Esw_Total (mJ)	Esw_Snubber (mJ)
4.7	5.5	752	9.6	366.5	347.3
20	3.4	715	19.35	331	292.3
50	2.4	644	38.725	332	254.55
100	1.86	604	70.1	351	210.8
200	1.3	577	117.75	410	174.5
300	1.05	560	162.15	452.8	128.5

Figure 19 Over-shoot voltage and switching energy with different JFET gate resistance

Evaluation Board with JFET

Qorvo has developed another Solid-State Circuit Breaker (SSCB) demo board with JFET (UJ4N075004L8S) and external low voltage MOSFET. Details refer to device website: UJ4N075004L8S - Qorvo.

Design Document and BoM

Download design Document and BoM from Qorvo website: UG4SC075005L8S - Qorvo.

Contact Information

For the latest specifications, additional product information, worldwide sales and distribution locations:

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