Silicon Carbide: A Brief Overview

March 14, 2019
ROHM Semiconductor, USA
Applications Engineering

SiC: A Brief Overview (this is what we will cover)

- Where we are
  - SiC Schottky Barrier Diodes
  - SiC MOSFETs (Discrete)
  - SiC Power Modules
- Where we are Headed
  - Packages with Kelvin connection
  - 4^{th} Generation SiC MOSFETs
- Tips for Successful Use
  - Gate Driver Criteria
  - Consider the Isolated DC/DC Converter
  - Check the Gate Drive signal
  - Check the overshoot voltage on the Drain
  - Look for current shoot-through

SiC: A Brief Overview

- SiC Diodes
  - The #1 choice as the "catch" diode for PFC Boost applications
  - Your choice of 80 diodes from 2A – 40A, from 650V – 1200V (20 are AECQ qualified)
  - Choice of 2nd Gen or 3rd Gen devices (as of now only 2nd Gen are AECQ qualified)
  - 3rd Gen offers the following improvements:
    - Improved Surge current rating (I_{FSM})
    - Lower Forward Voltage Drop (V_F)
    - Lower leakage current (I_R)

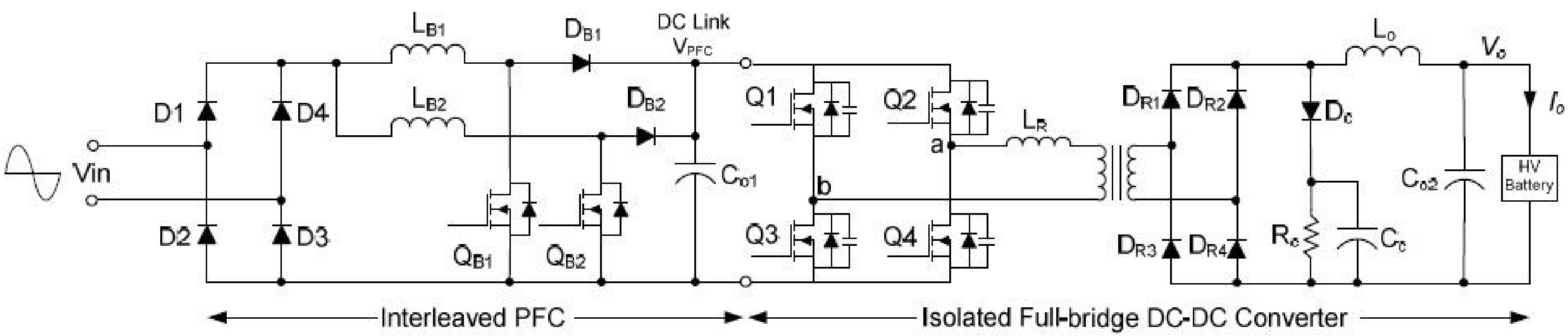
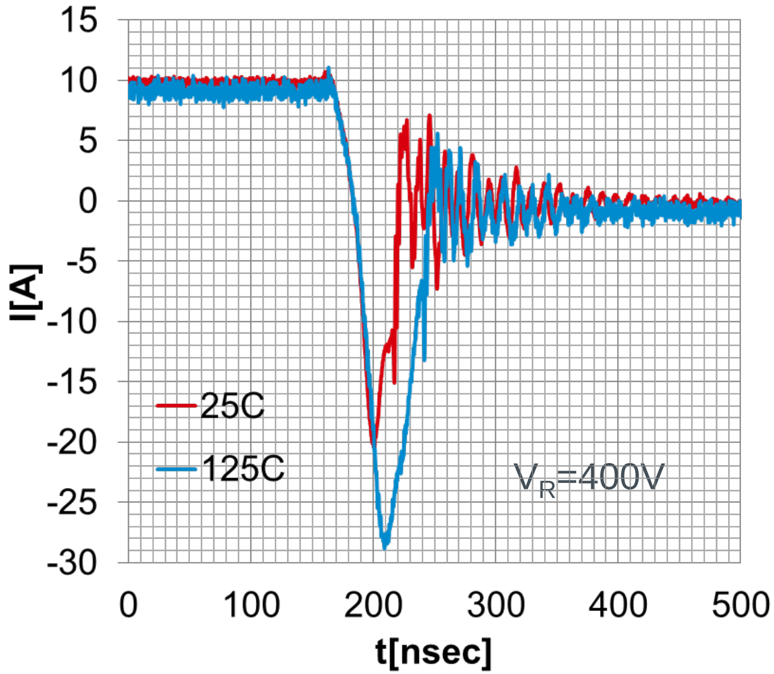


Figure 1. 3.3 kW Battery Charger

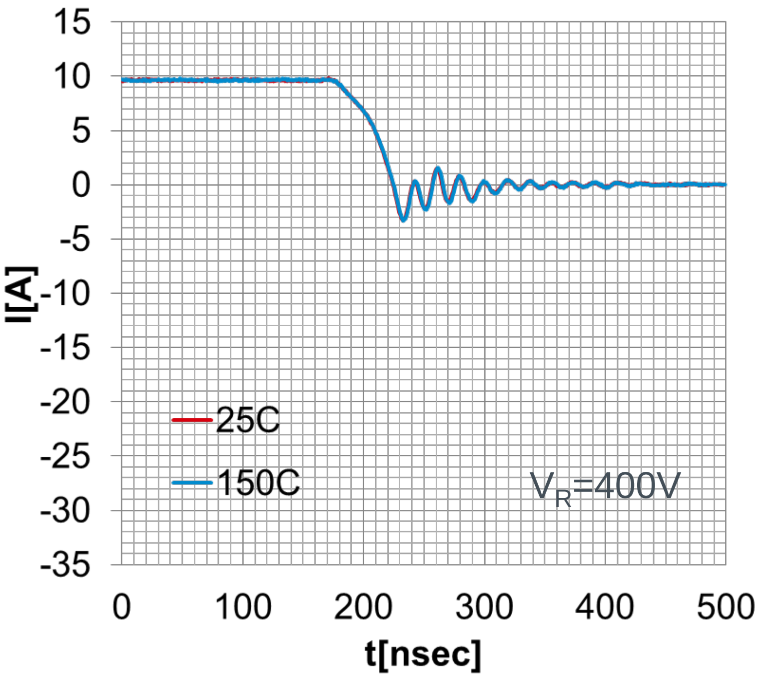
Reverse recovery characteristics

Si-FRD



Minority carrier device
→much depends on temperature

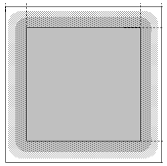
3G SiC-SBD



Majority carrier device
→no reverse recovery current

※These data are provided to show a result of evaluation done by ROHM for your reference. ROHM does not guarantee any of the characteristics shown here.

2nd generation SiC-Schottky Barrier Diodes (SBD)

Package / Rated voltage	TO-220  K A	TO-220FM  K A	TO-247  A K A	D2pack (LPTL) K  N/C A	Bare dies 
650V	6A~20A	6A~20A	20A~40A	2A~20A	6A~20A(MP) 30A~100A(DS)
1200V	5A~20A		10A~40A		5A~20A 30A, 50A
1700V					10A~50A

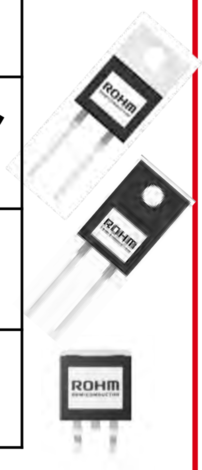
Automotive grade AEC-Q101 qualified

650V	6A~20A		20A~40A	6A~20A
1200V	5A~20A		10A~40A	

3rd Gen SiC-SBD portfolio

Line up

650V	P/N	2A	4A	6A	8A	10A	12A	15A	20A
TO-220ACP-2L	SCS3xxAH (halogen free)	✓	✓	✓	✓	✓	✓	✓	✓
TO-220FM-2L	SCS3xxAM New		✓	✓	✓	✓	✓	✓	✓
TO-263AB-3L (D2PAK/LPTL)	SCS3xxAJ New	✓	✓	✓	✓	✓	✓	✓	✓



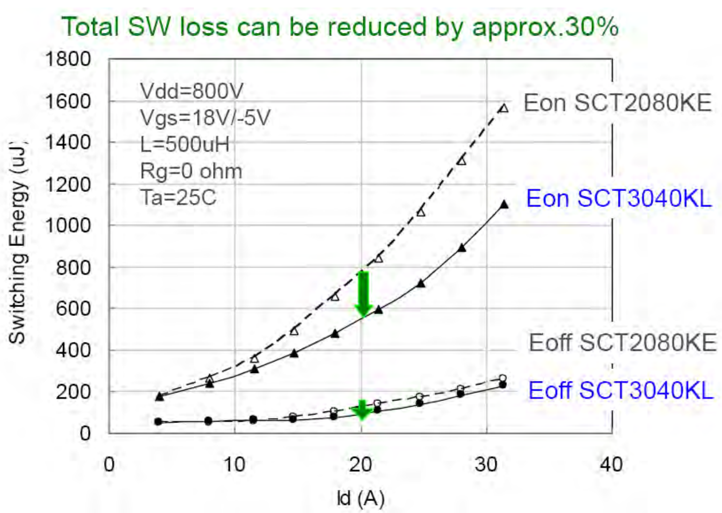
✓ Mass Production

✓ New Device

Note: Automotive (AECQ) Grade is in process.

SiC Discrete MOSFETs

- 2nd Generation devices utilizing **Planar** technology
  - Largest die size for a given ON resistance ($R_{DS(on)}$)
  - Longest Short-Circuit Withstand time (SCWT is about 10 microseconds)
- 3rd Generation devices utilizing **Trench** technology
  - About half the ON resistance ($R_{DS(on)}$) for a given die size
  - Short-Circuit Withstand time is lower (SCWT is about 5 microseconds)
  - Reduced Input capacitance (C_{iss}) makes it easier to drive
  - Less switching energy losses for both Turn-On and Turn-Off



2nd Generation DMOS Portfolio

650V	P/N	120mΩ
TO-220AB	SCT2120AF	✓

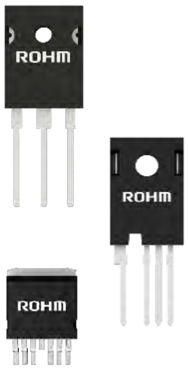
1200V	P/N	80mΩ	160mΩ	280mΩ	450mΩ
TO-247	SCT2xxxKE	✓	✓	✓	✓
	SCH2080KE **SBD co-pack**	✓			

1700V	P/N	750mΩ	1150mΩ
TO-3PFM	SCT2H12NZ		✓
TO-268-2L	SCT2xxxNY	✓	✓

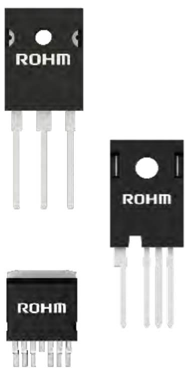
✓ Mass Production

3G SiC MOSFET Discrete development plan

650V	Part No. / Status	17mΩ	22mΩ	30mΩ	60mΩ	80mΩ	120mΩ
TO-247N	SCT3xxxAL on MP	✓	✓	✓	✓	✓	✓
TO-247-4L	SCT3xxxAR MP: Q2/19			✔	✔	✔	
TO-263-7L	SCT3xxxAW MP: Q2/19			✔	✔	✔	✔



1200V	Part No. / Status	22mΩ	30mΩ	40mΩ	80mΩ	105mΩ	160mΩ
TO-247N	SCT3xxxKL on MP	✓	✓	✓	✓	✓	✓
TO-247-4L	SCT3xxxKR MP: Q2/19			✔	✔	✔	
TO-263-7L	SCT3xxxKW MP: Q2/19			✔	✔	✔	✔



* as of Oct 2018

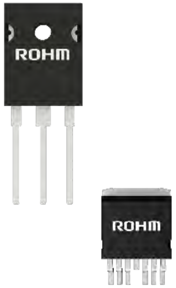
MP: Mass production

✓ Mass Production ✔ Under development

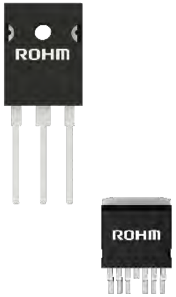
3G SiC MOSFET Discrete development plan

Automotive grade *(AEC-Q101 qualified)*

650V	Part No. / Status	17mΩ	22mΩ	30mΩ	60mΩ	80mΩ	120mΩ
TO-247N	SCT3xxxALHR New	✓	✓	✓	✓	✓	✓
TO-263-7L	SCT3xxxAWHR MP: Q2/19			✓	✓	✓	✓



1200V	Part No. / Status	22mΩ	30mΩ	40mΩ	80mΩ	105mΩ	160mΩ
TO-247N	SCT3xxxKLHR New	✓	✓	✓	✓	✓	✓
TO-263-7L	SCT3xxxKWHR MP: Q2/19			✓	✓	✓	✓



* as of Dec 2018

MP: Mass production

✓ Mass Production ✓ Under development

Full SiC module outline

C type

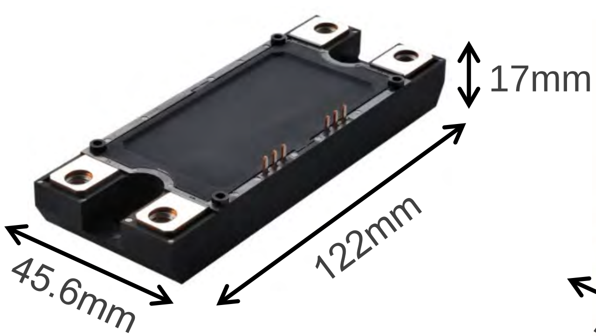
- ✓ 1200V
- ✓ 80, 120, 180A

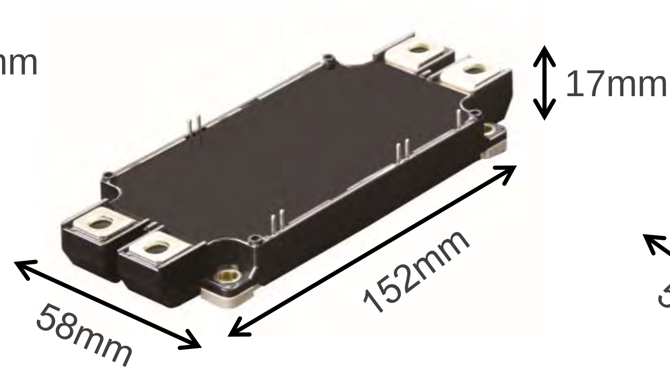
E type

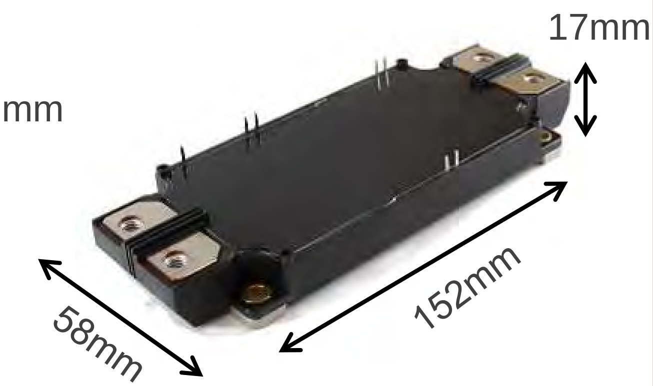
- ✓ 1200, 1700V
- ✓ 180, 250, 300A
- ✓ Higher voltage

G type

- ✓ 1200V
- ✓ 400, 600A
- ✓ High current
- ✓ Low inductance







Low Inductance

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Package evolution of full SiC power modules

L_S=25nH
~120A

C type
45.6mm x 122mm x 17mm

L_S=13nH
~300A

E type
58mm x 152mm x 17mm

L_S=10nH
~600A

G type
58mm x 152mm x 17mm

Under development

> Low stray inductance L_S=10nH
> High current rating ~600A
> Compatible outline with market available IGBT modules

Line up

	Voltage Rating (V)	Current Rating (A)	Case Type	MOS device generation	Circuit	Ls (nH)	Thermistor
BSM400D12P2G003	1200	**400**	G	2G(planer)	Half bridge	**10**	○
BSM400D12P3G002	1200	**400**	G	3G(Trench)	Half bridge	**10**	○
BSM600D12P3G001	1200	**600**	G	3G(Trench)	Half bridge	**10**	○
BSM400C12P3G202	1200	**400**	G	3G(Trench)	Chopper	**10**	○
BSM600C12P3G201	1200	**600**	G	3G(Trench)	Chopper	**10**	○

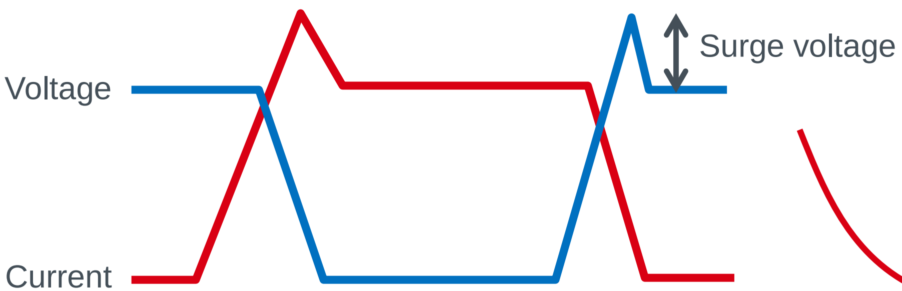
Low Inductance

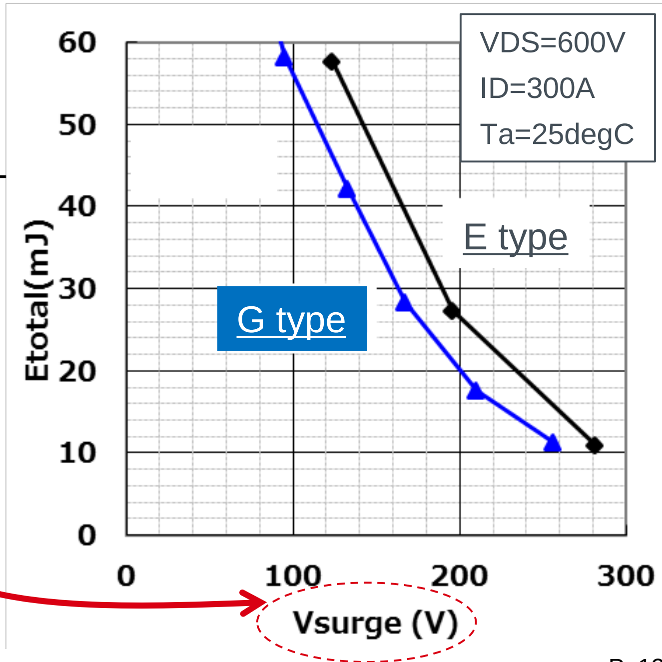
Patented

Feature

> Lower stray inductance by original main terminal structure

	E type	G type	Effort
Main terminal			> Reduction of stray inductance E type:13nH → G type:10nH > Reduction of surge voltage by 27% on same switching loss condition





Full SiC power modules lineup

Module type	Vdss	Io(Tc=60℃)	Part No.	MOS		Topology	Status	
C type  122 x 45.6 mm	1200V	80A	BSM080D12P2C008	2G	Planar	Half bridge	on MP	
		120A	BSM120D12P2C005			Half bridge	on MP	
			BSM120C12P2C201			Chopper (boost)	on MP	
		180A	BSM180D12P3C007	3G	Trench	Half bridge	on MP	
			BSM180C12P3C202			Chopper (boost)	on MP	
E type  152 x 62 mm	1200V	180A	BSM180D12P2E002	2G	Planar	Half bridge	on MP	
			BSM180C12P2E202			Chopper (boost)	on MP	
		300A	BSM300D12P2E001			Half bridge	on MP	
			BSM300D12P3E005 *	3G	Trench	Half bridge	2019	
			BSM300C12P3E201			Chopper (boost)	on MP	
			BSM300C12P3E301 *			Chopper (buck)	2019	
	1700V	250A	BSM250D17P2E004	2G	Planar	Half bridge	on MP	NEW
G type  152 x 62 mm Low Ls 10nH	1200V	400A	BSM400D12P2G003	2G	Planar	Half bridge	on MP	
			BSM400D12P3G002	3G	Trench	Half bridge	on MP	
			BSM400C12P3G202			Chopper (boost)	on MP	
		600A	BSM600D12P3G001			Half bridge	on MP	
			BSM600C12P3G201			Chopper (boost)	on MP	

* Under Development

Where we are headed - Package roadmap

SiC SBD

THD

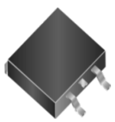
◆TO-247 (650/1200V)
◆TO-220AC (650/1200V)
◆TO-220FM (650V)

◆TO-220AC
Halogen free (650V)

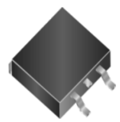
◆TO-220FM
3G SBD (650V)

◆TO-247 2L
(1700V)

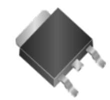
SMD



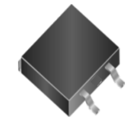
◆TO-263-3L
(2G SBD)



◆TO-263-3L
(3G SBD)



◆TO-252



◆TO-263-2L
(1200V)

SiC MOSFET

THD

◆TO-247 (650/1200V)
◆TO-3PFM (1700V)

◆TO-247N
(Automotive)

Kelvin source

◆TO-247-4L (650/1200V)

◆TO-247-4L (1700V)

SMD

◆TO-268-2L (1700V)

Kelvin source

◆TO-263-7L
(650/1200V)

◆TO-263-7L (650/1200V)
(Automotive)

・Leadless PKG ?
・Embedded ?

Low Ls technology

～2017 → 2018 → 2019 → 2020～

The trend is subject to change without notice.
PKG images are for illustrative purpose only.

As of Feb. 2018

Where we are headed – Gen 4 SiC MOSFET

1200V target spec (compared with Gen 3)

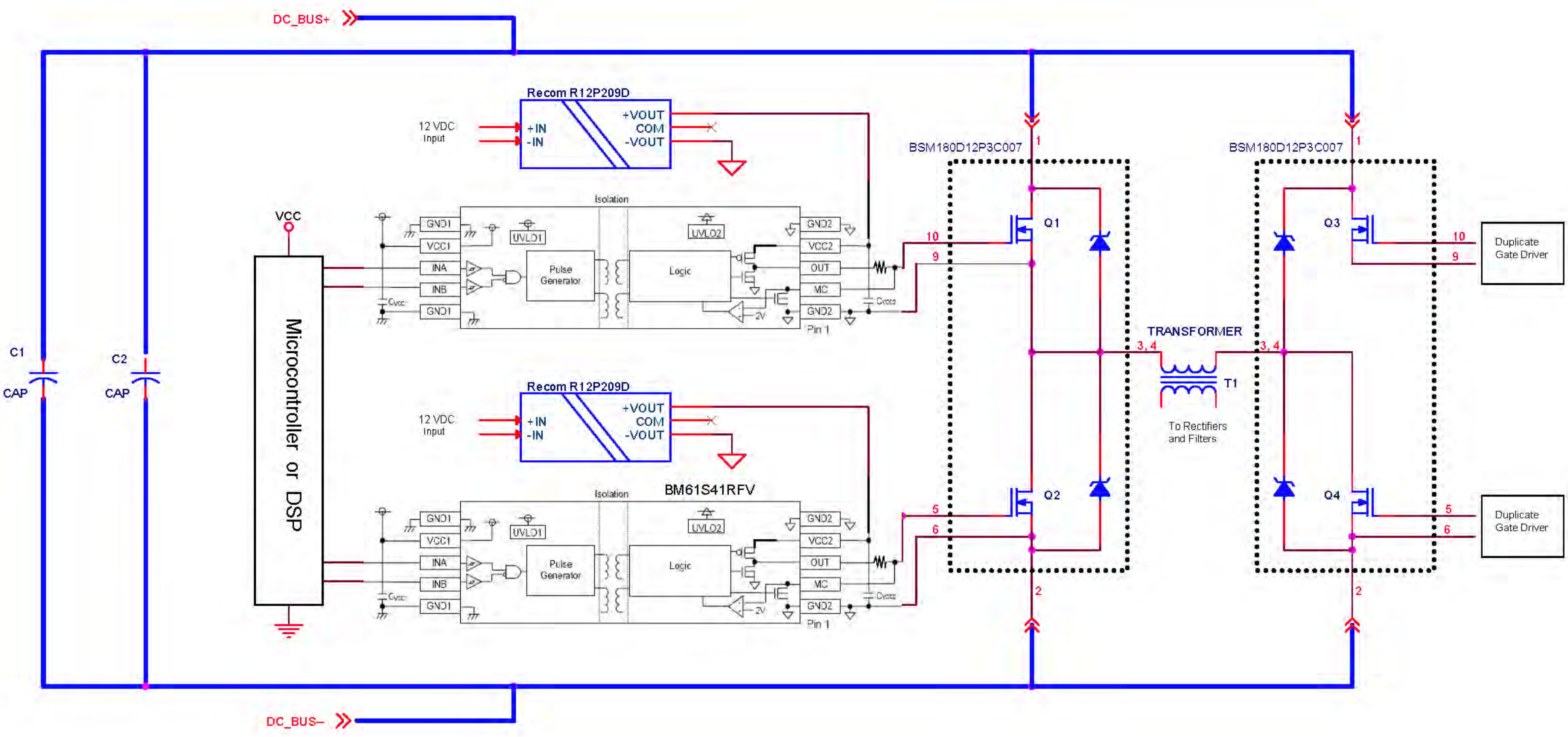
1) Ron*A : reduced by 50%
2) SCWT : > 5 μsec
3) Vgs rating : -10 to 20V (Vgs op is 15V)
4) Int R_g : <50%
5) C_{gd} : reduced
6) C_{gd}/C_{gs} : reduced

Target design sample : 2019 Q3 (Chip sample)

	Gen 2 2012~	Gen 3 2016~	Gen4 2019~
Structure	Planar	Trench	Trench
Vdsmax	1200V		
RonA	8.2mΩcm2	4.1mΩcm2	2.3mΩcm2
SCWT	11usec	5usec	>5usec
Vgs	-6 to 22V (surge -10V to 26V)	-4 to 22V	-6 to 20V
Vgs op	18V	18V	15V
Internal Rg (same size)	6.3Ω	7Ω	<3Ω
Cgd (same size)	16nF	27nF	<<16nF

SiC: A Brief Overview (Tips for Successful Use)

Consider the typical half-bridge topology:



Gate Driver Selection Criteria:

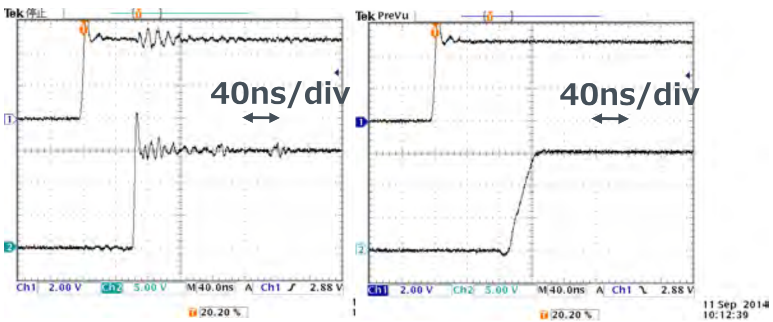
- Isolation Voltage Requirements (V_{IORM} and V_{IOWM} voltages)?
- Required Regulatory agency approvals in place?
- Automotive (AECQ) requirements?
- Creepage and clearance adequate?
- Appropriate temperature range?
- Input side supply current?
- Output drive current?
- Suitable CMR rating?
- Appropriate safety features?
- Cost and availability?

Propagation Delay Comparison example

Conditions: BM6105FW, ROHM Eval Board, VCC1=5.0V, VCC2=15V, VEE2=0V, INA=10kHz, OUT1_H/L=No Load

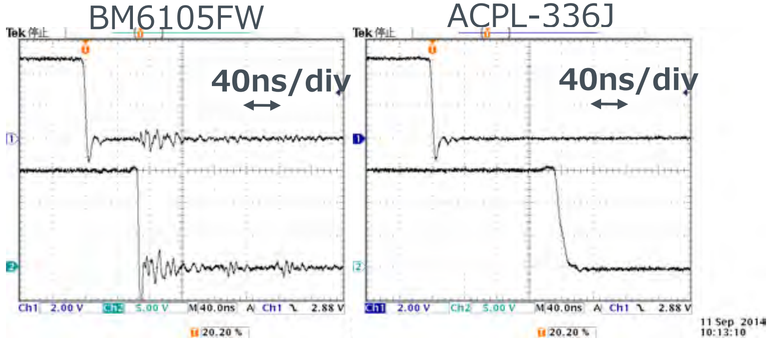
Turn ON time (Ta = 25℃)

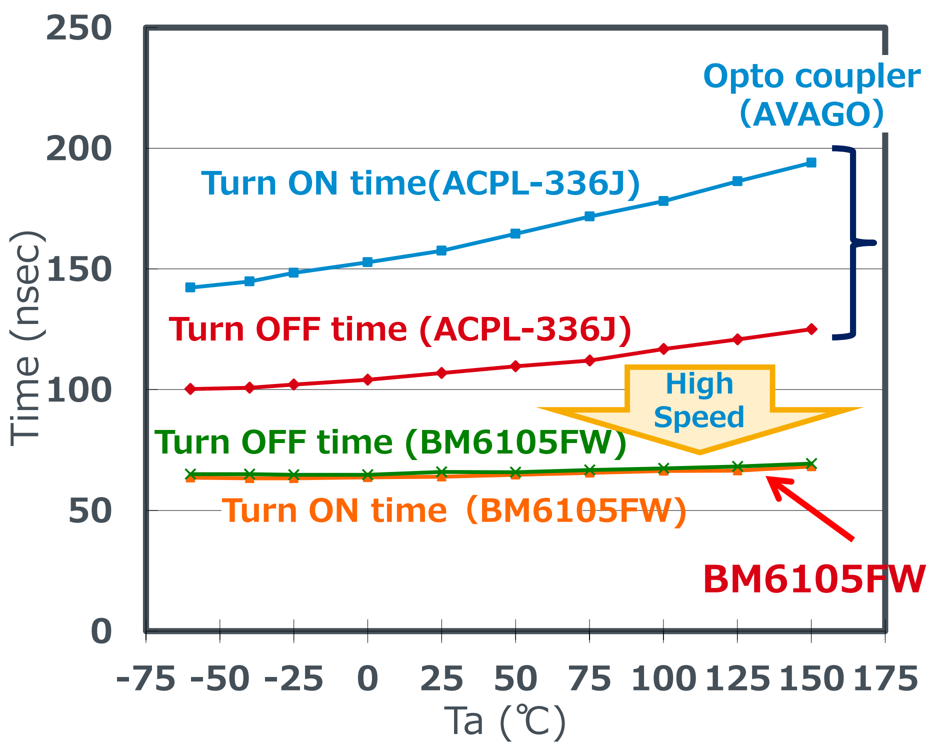
BM6105FW ACPL-336J



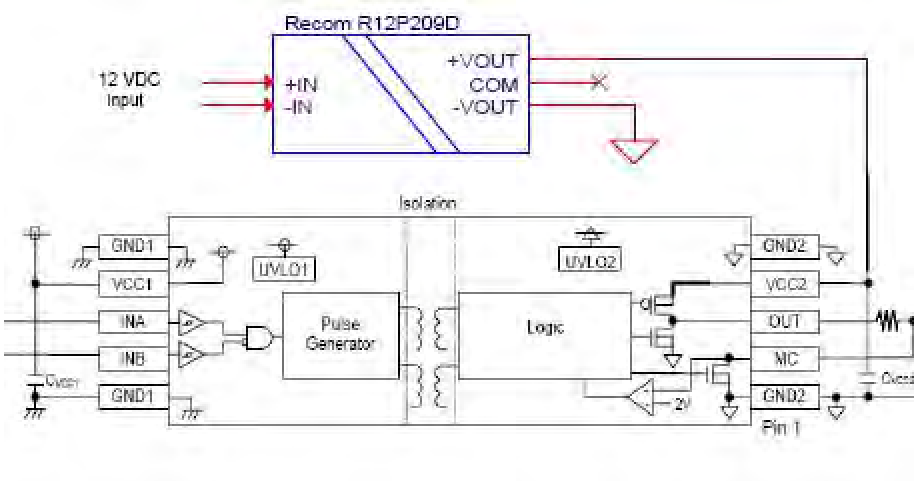
Turn OFF time (Ta = 25℃)

BM6105FW ACPL-336J





SiC: A Brief Overview (Tips for Successful Use)



- Use care when selecting your Isolated DC/DC Converter. Consider the following points:
  - Breakdown Voltage Rating
  - Capacitance from Primary to Secondary (<20pF)
  - Common-Mode Rejection. Is it specified?

Suppliers of Converters include MuRata, Recom, CUI, and Mornsun

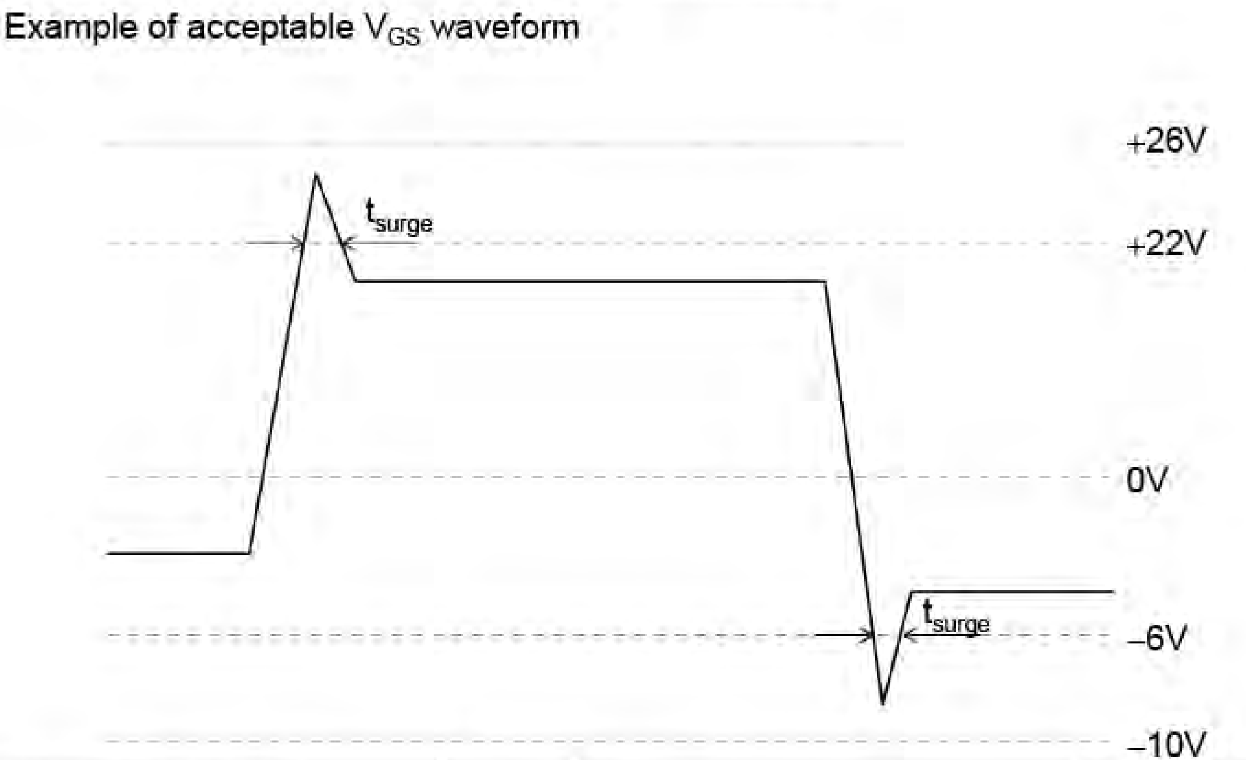
Estimated Power can be calculated from:

$$Pgate = Pdriver + (Qgate\, fsw\, \Delta Vgate) + (Cgs\, fsw\, \Delta Vgate^2)$$

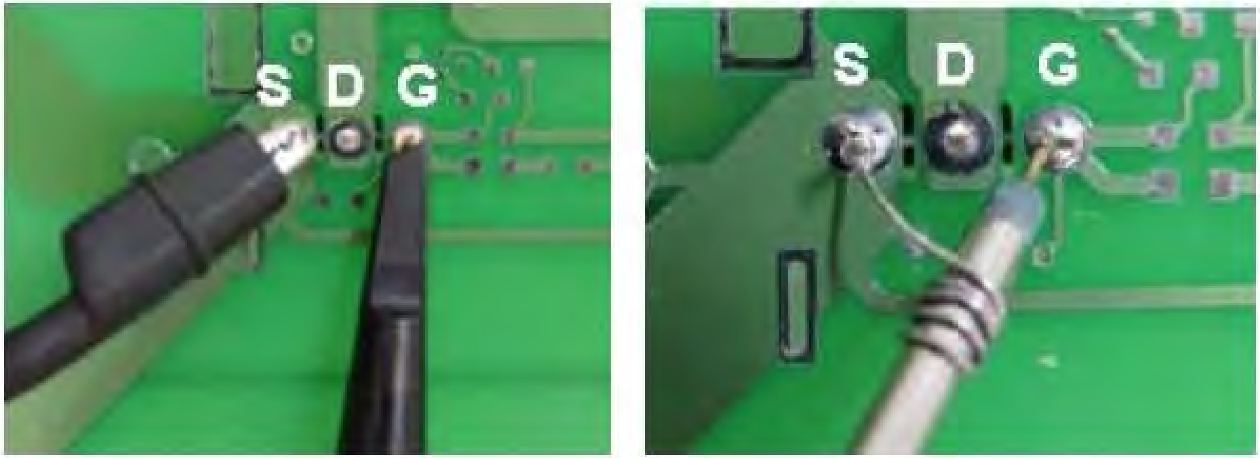
or approximated by $P_{DISS} \approx (C_{ISS} * 5) * (V_{CC2})^2 * fs$

Check the Gate Drive signal:

BSM180D12P2E002



Gate-source voltage(+)	V_{GSS}	D-S short	22	V
Gate-source voltage(–)			–6	
G - S Voltage (t_{surge}<300nsec)	V_{GSS_surge}	D-S short	–10 to 26	



(a) Measurement with standard setup (b) measurement with probe tip and ground lead removed.

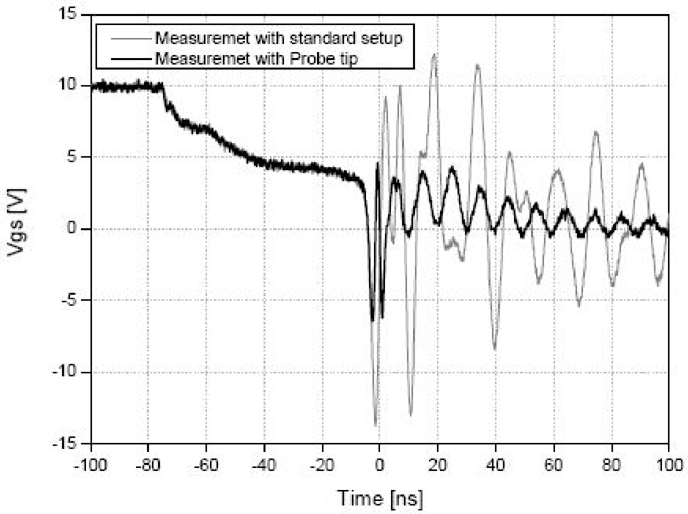


Fig. 27. Comparison measured oscillation according to probing methods.

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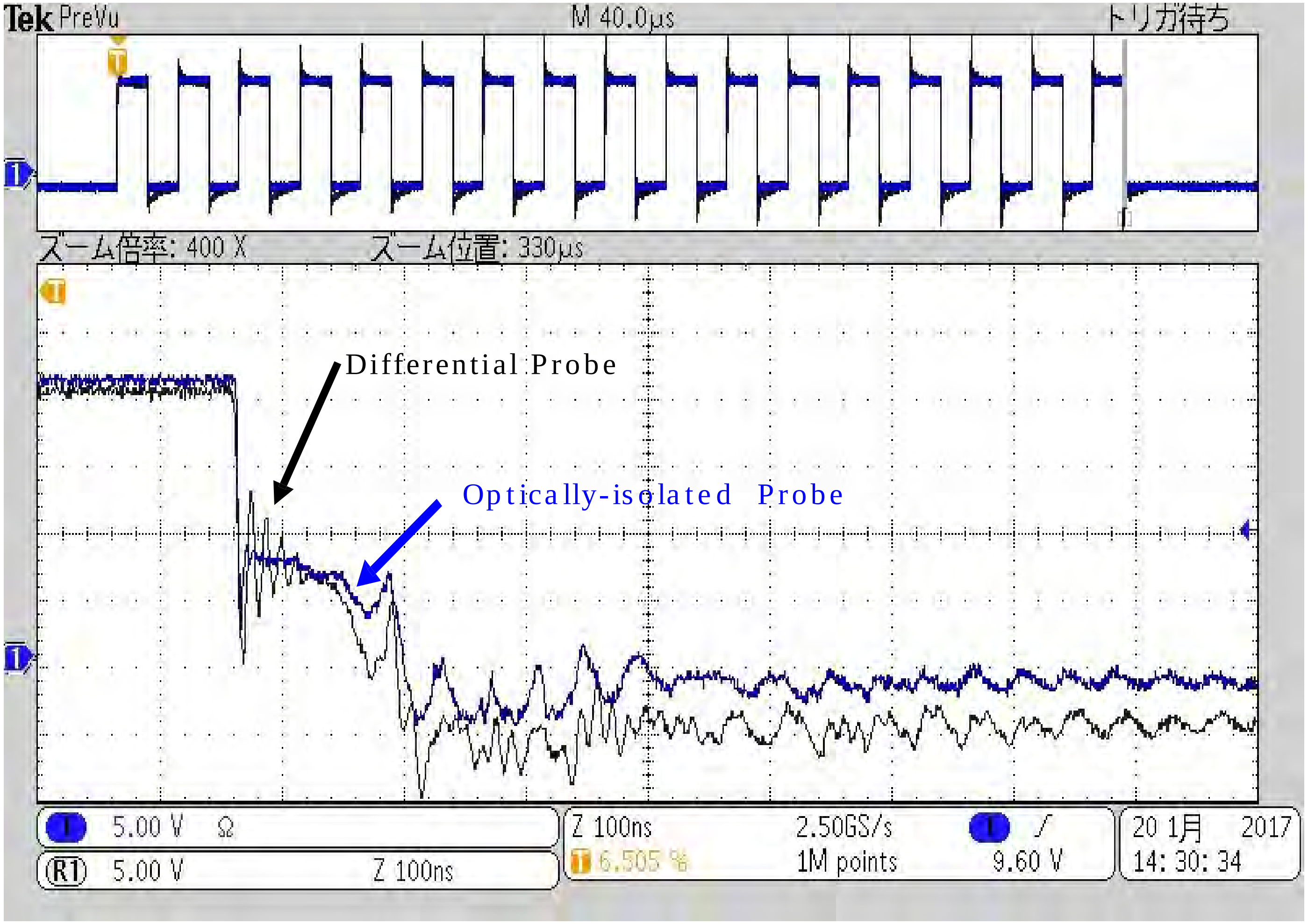
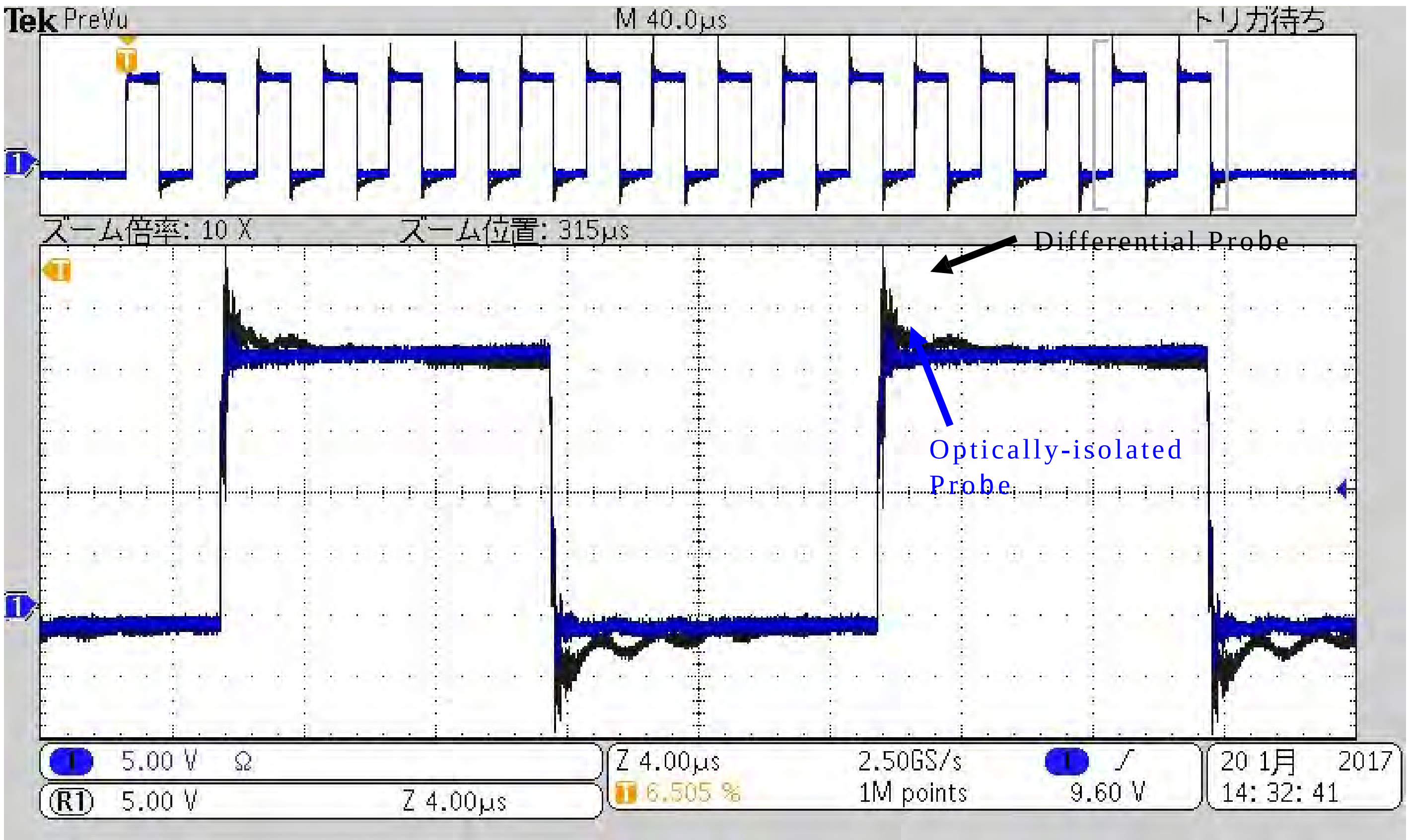
Tektronix IsoVu Probe is the best ($ 15k - $20k)



SiC: A Brief Overview (Tips for Successful Use)

Vgs comparison with optically isolated probe



SiC: A Brief Overview (Tips for Successful Use)

Check to see that $V_{(BR)DSS}$ is not exceeded:

- What is the peak voltage from Source to Drain? Remember the *allowable voltage goes* DOWN as the *temperature goes* DOWN:

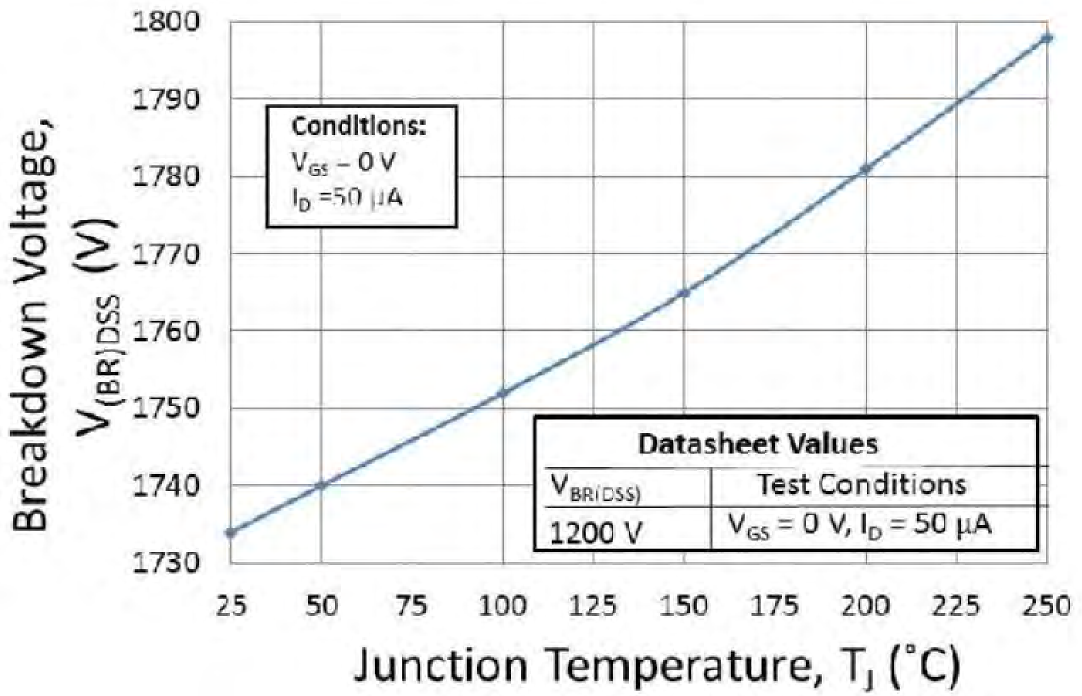
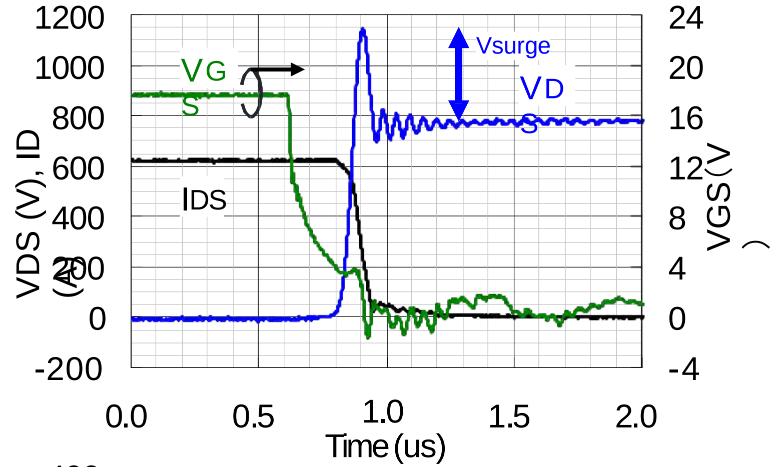


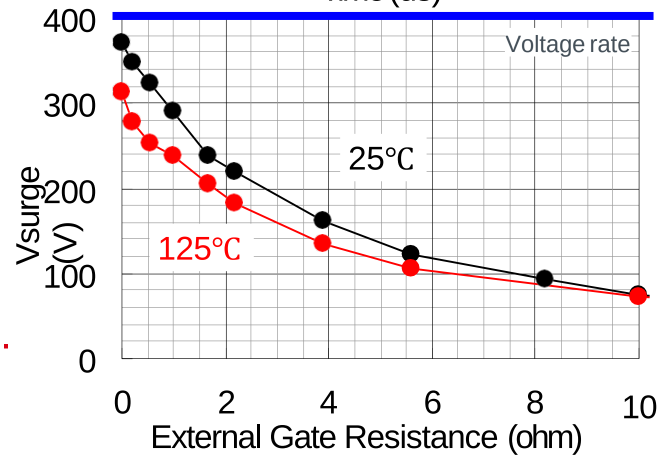
Fig. 5. Measured breakdown voltage VBR(DSS) versus junction temperature Tj (°C) for a 1200 V/50-A commercial SiC power MOSFET. For comparison, data sheet values are also shown along with measurement conditions.

Voltage Surge Measurement Conditions

Measurement Circuit	Inductive Load Chopper
Current	600A
Drain Voltage	800V
Gate Voltage	On 18V / Off 0V
Gate Resistance	0.2ohm
Inductive Load	250uH
Junction Temperature	25ª, 125ª
Snubber Circuit	C-Snubber (1.2uF) Nippon Chemi-con HACD1C2V125JTLJ Z0
Gate Drive IC	ROHM BM6103
Oscilloscope	YOKOGAWA DL7480
Differential Voltage Prove	YOKOGAWA 700924, 701921

V_{DC} + Voltage surge is under 1150V in this condition.





※ These data are provided to show a result of evaluation done by ROHM for your reference. ROHM does not guarantee any of the characteristics shown here.

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Another example of cold vs. warm rating:

IXYS

Curves

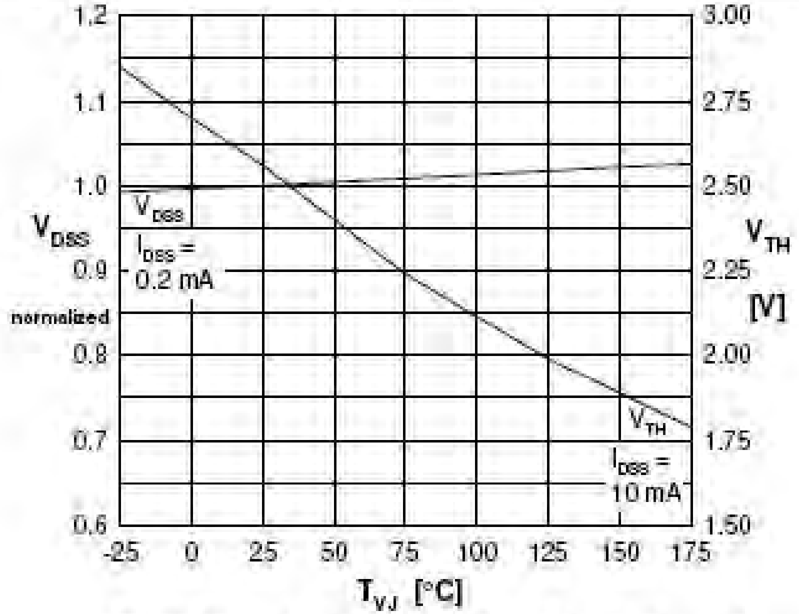


Fig. 7 Norm. breakdow V_{DSS} & treshhold voltage V_{TH} versus junction temperature T_{VJ}

SiC: A Brief Overview (Tips for Successful Use)

Remember to use enough dead-time! We recommend starting with 200 nanoseconds.

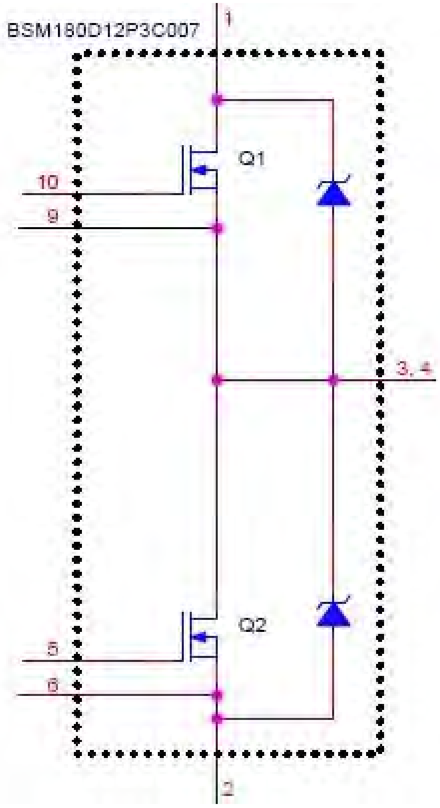
If you are using an optically isolated driver, check the datasheet for propagation delay vs. temperature.

Remember, MOSFETs take longer to turn-off at **minimum** load current, *not maximum load*!

Use a Rogowski Current Probe to check for shoot-through.

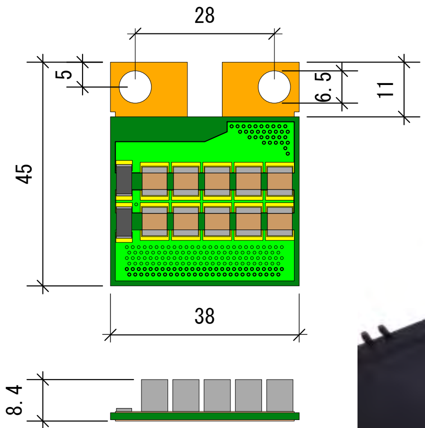
SiC MOSFETS tolerate only about 5 – 10 usec of overcurrent before shorting.

Use a snubber if needed



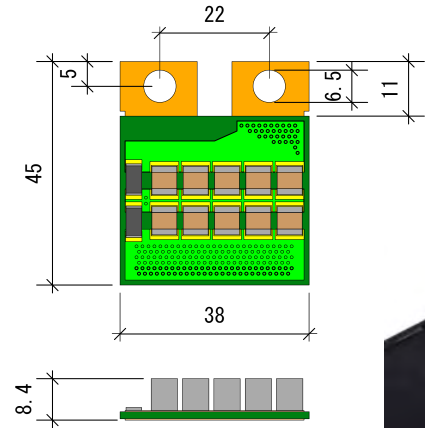
Snubber module

EVSM1D72J2-145MH26



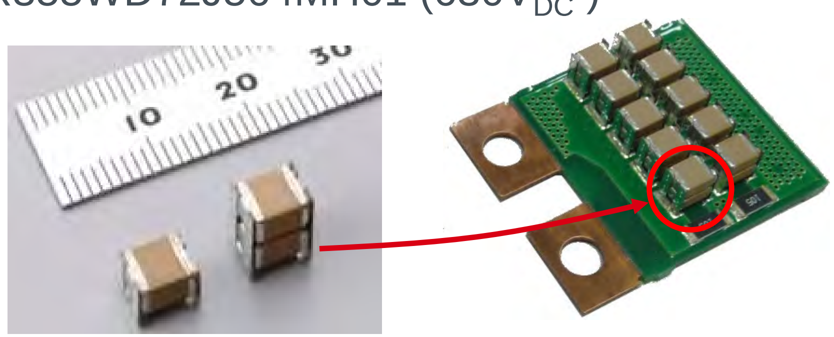
C type
1200V

EVSM1D72J2-145MH16



E type & G type
1200V

Capacitor (Murata)
KR355WD72J564MH01 (630V_{DC})



280nF　560nF
(2 parallel)

Note:
The capacitor has been mass produced.
The snubber module is only for evaluation use.

Bibliography

Figure 1: D. Gautam, F. Musavi, M. Edington, W. Eberle "An Automotive On-Board 3.3 kW Battery Charger for PHEV Application", Delta-Q Technologies Corp.

Figure 5: “Future Prospects of Widebandgap (WBG) Semiconductor Power Switching Devices” Krishna Shenai, 2015 IEEE Transactions on Electron Devices

Figure 7: IXYS SiC Power MOSFET Data Sheet IXFN50N120SiC 2018 P.6

Page 22 Pictures: “Driving and Layout Requirements for Fast Switching MOSFETs” Won-suk Choi, Dong-kook Son, Markus Hallenberger and Sungmo Young, Fairchild Semiconductor Power Seminar 2010-2011

Parts may be found at Mouser using these links:

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