11kW HVAC Motor Drive

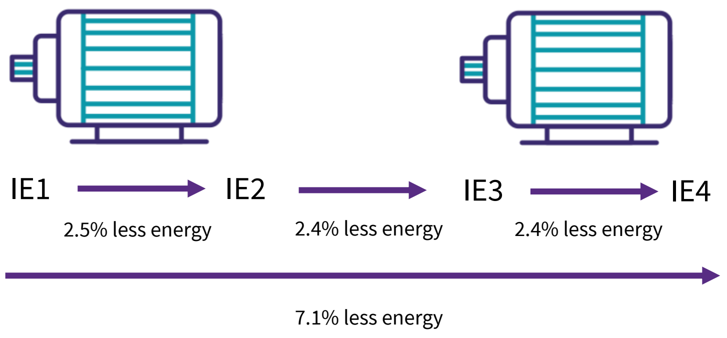
CONTENTS

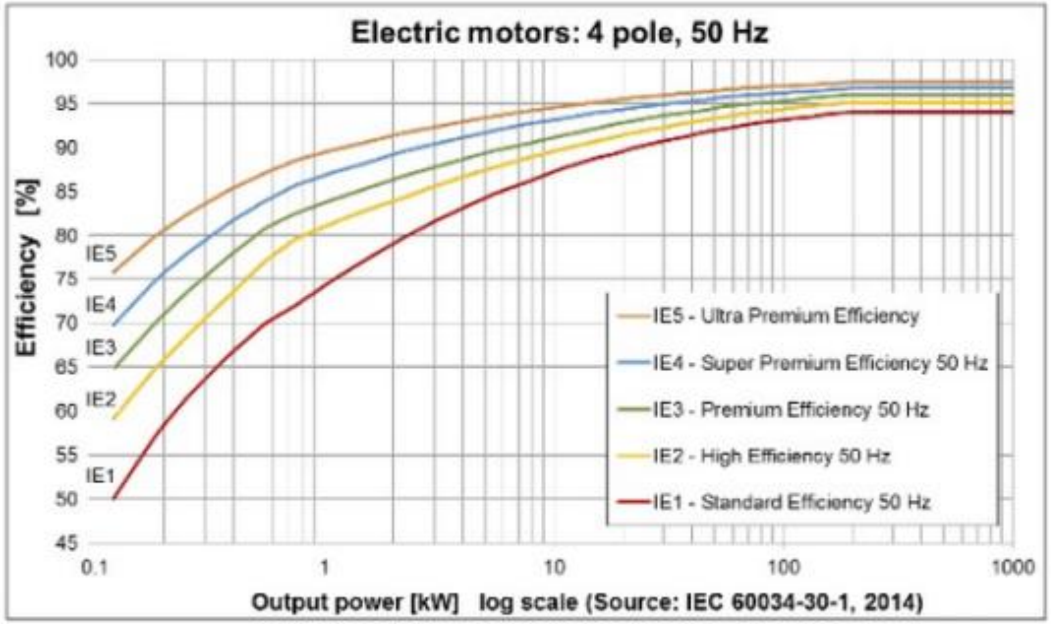
TECHNICAL TREND

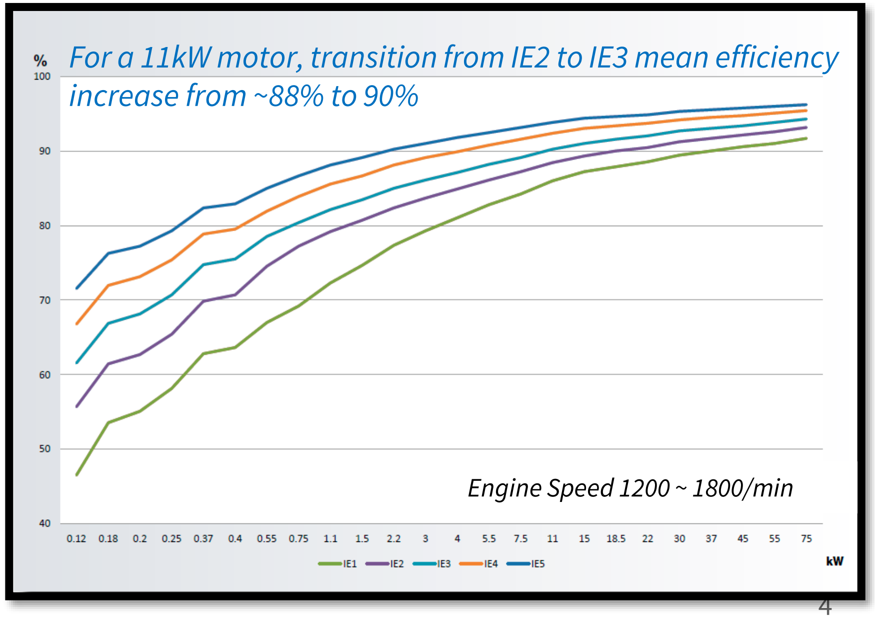
INDUSTRIAL MOTOR DRIVE EFFICIENCY STANDARDS DRIVE DESIGN CRITERIA

- Global standard IEC 60034-1-30 (Published in June 2014)
  - Standard includes levels IE1 through IE4
  - Adoption varies geographically
  - Majority of countries require or soon will require a **minimum standard of IE3**
  - EU mandated timeline for implementing regulations:
    - › July 2021: all 0.75kW – 1000kW motors (2-4-6-8 pole) to meet IE3 regulation
    - › July 2023: all 75kW – 1000kW motors (2-4-6-8 pole) to meet IE4 regulation

For a 55kW Motor

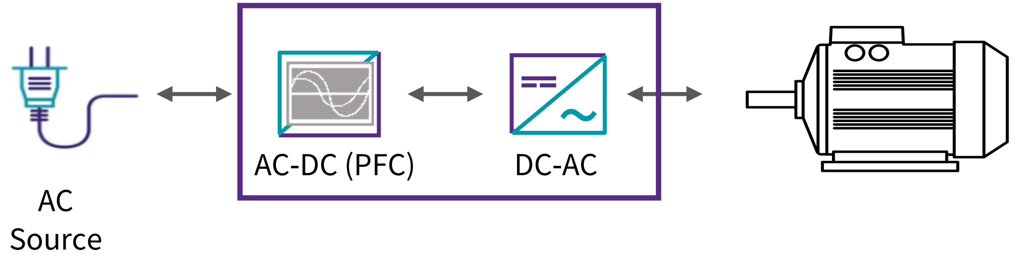






Efficiency classes according to IEC 60034-30-2:2016

ACHIEVING IE4 EFFICIENCY WITH DROP-IN SILICON CARBIDE DEVICES

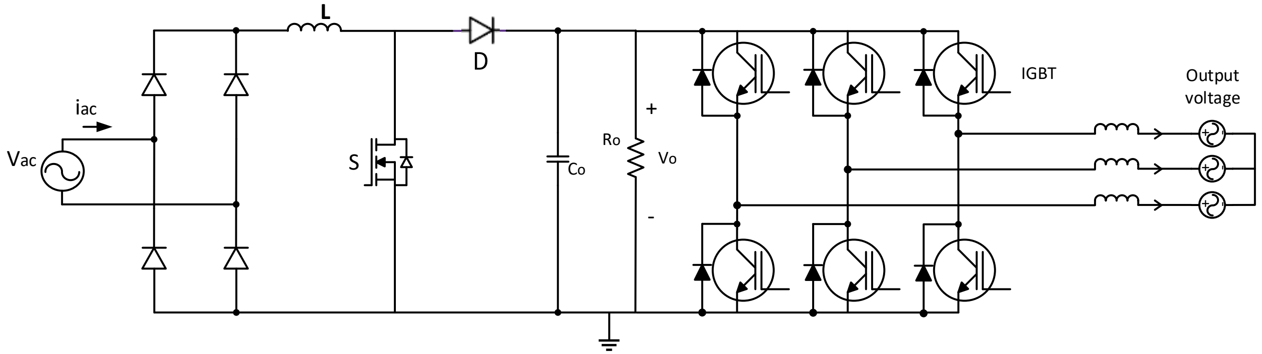


How can you move from IE3 to IE4 for a single phase 11 kW system?

- Solution requires a 209 W reduction in losses

- Modeled 11 kW compressor
  - AFE/PFC:
    - No re-design approach: Silicon Carbide in active boost PFC
    - Re-design approach: bridgeless and semi-bridgeless TP-PFC
  - Motor drive
    - Modeled using 5 kHz inverter frequency
    - Expected improvements using 16 kHz inverter frequency

Existing silicon approach:



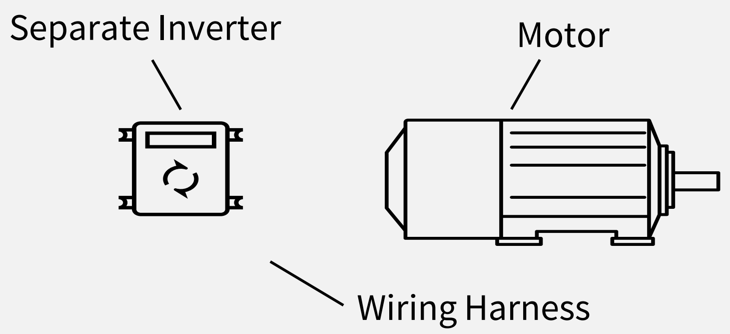
WOLFSPEED SILICON CARBIDE ENABLES EMBEDDED MOTOR DRIVES

Embedded drives integrate motors and drives into one unit

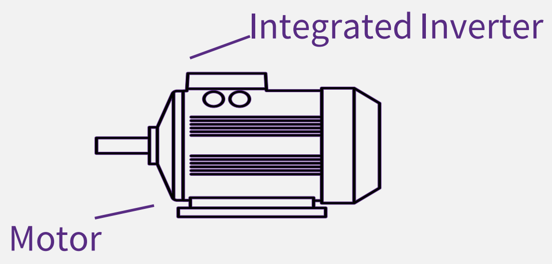
- **Traditionally, the two were separated and connected by long wires**
  - These “Merchant Drives” resulted in wastage of power
- **Silicon Carbide allows for higher operating temperatures and has led to improvements and further adoption of embedded drives**
- **Embedded drive advantages:**
  - Combining motors and drives into one package helps reduces costs by 20 to 40%
  - Improves system efficiency and reliability
  - Reduces the cost of ownership
  - Enhances electromagnetic capability
  - Controller can be specifically designed for the motor
- **Embedded Drives can be categorized into:**
  - General Motion Control
  - Computer Numerical Control

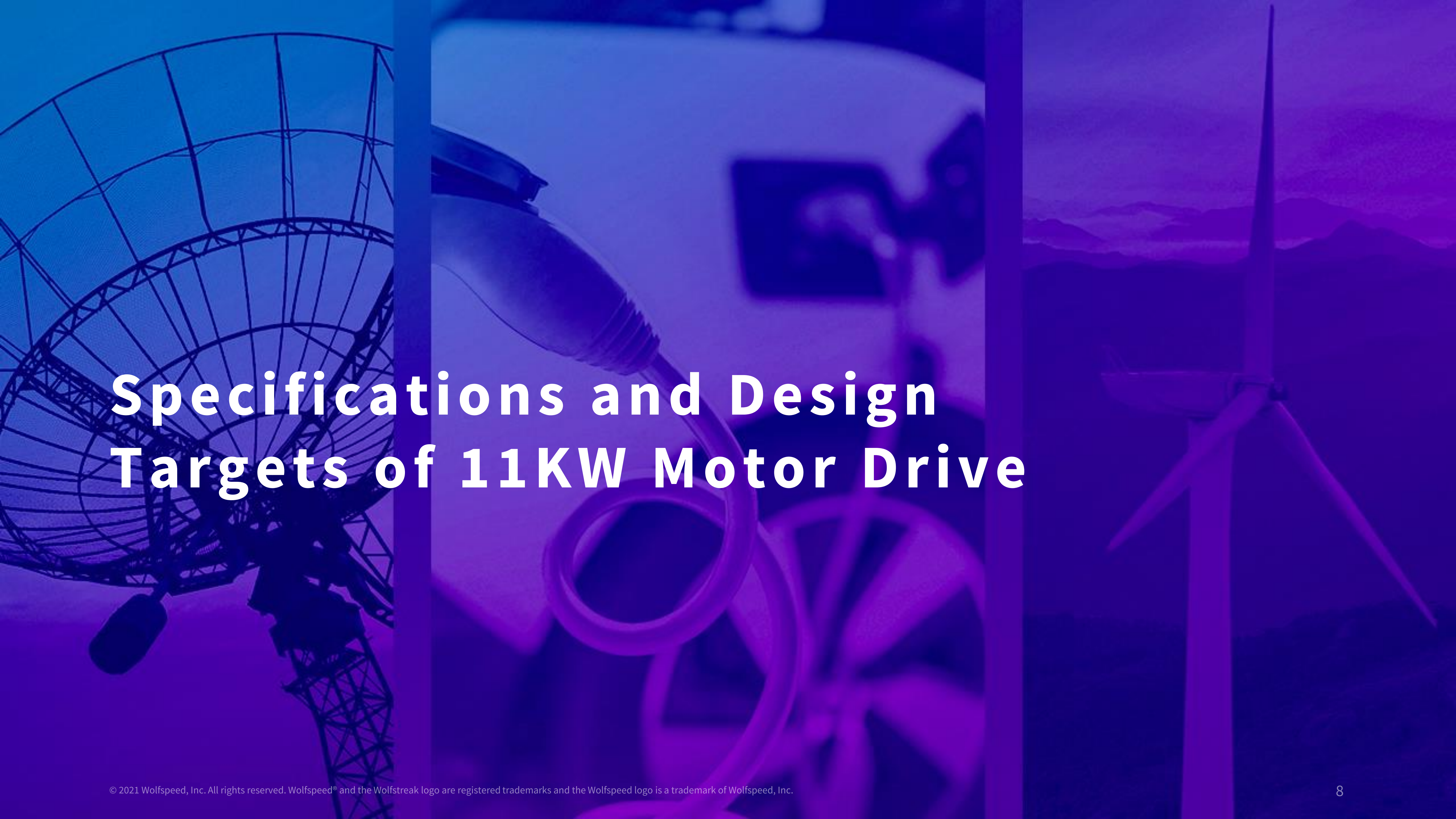
Replacing the IGBT or IPM(IGBT based), SiC can provide higher COP for CRHC and other Industrial motor drive.

IGBT Solution



Wolfspeed Silicon Carbide Solution

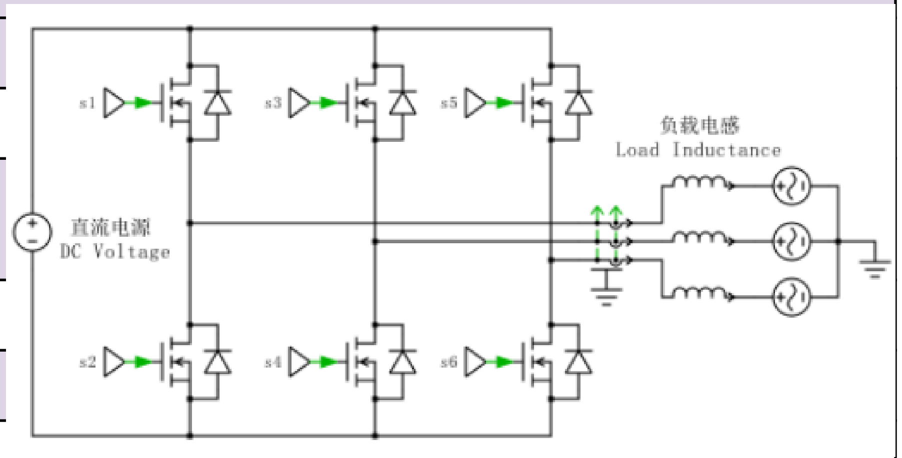




Specifications and Design Targets of 11KW Motor Drive

SPECIFICATIONS OF INDUSTRIAL MOTOR DRIVE

Parameters	Value	Comments
Input voltage	550V-850V universal rectified	
Output current	25 A RMS Maximum 380Vac rated	
Rated power	11 kW Maximum	
Topology	2 level, 3 phase	
SiC MOSFET	C3M0075120K for 11 kW C3M0040120K for 20 kW	
Switching frequency	16-32 kHz	
Efficiency	>98.5% at dv/dt < 15 V/ns	
DSP	F280049CPZS	
Control algorithm	Sensorless FOC	
Motor type	IPMSM	https://www.tecowestinghouse.com/wp-content/uploads/2020/02/pm-motor-brochure-low-res.pdf



Simulation results

System Overview

Input Voltage	Output Voltage	Actual Output Power	AC Frequency	Switching Frequency	Deadtime
850.0 V	380.0 V	11.00 kW	50.0 Hz	16.0 kHz	100.0 ns

Temperatures

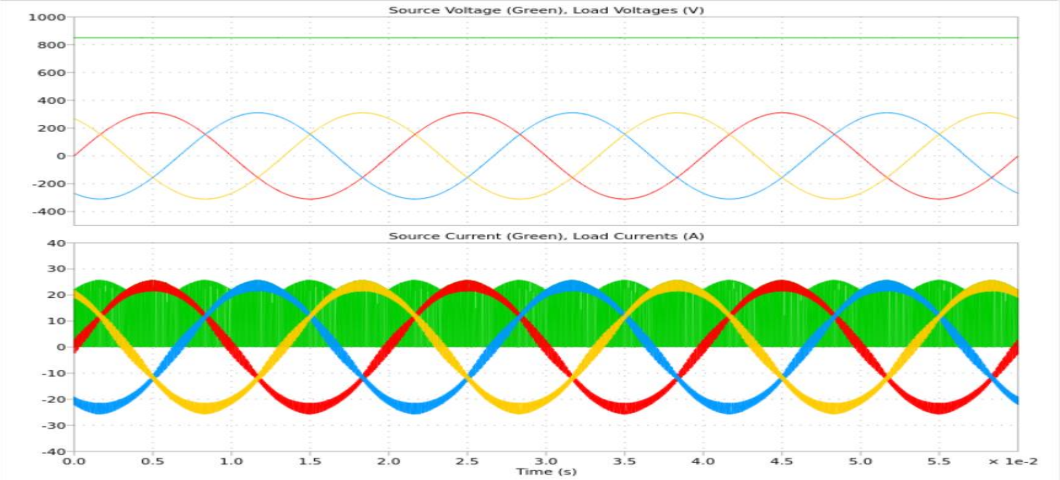
MOSFET	Module	Number of Parallel	Max Tj	Heatsink Max Temp.	Ambient Temp.
C3M0075120K		1	116.2 °C	65.0 °C	65.0 °C

Losses Overview

Switching Losses	Per Switch Position	Conduction Losses	Per Switch Position	Combined Losses *	Efficiency
36.33 W	6.05 W	89.36 W	14.89 W	125.69 W	98.87 %

Losses Breakdown

Turn-on Losses Eon	Turn-off Losses Eoff	Forward Conduction	Reverse Conduction	Body Diode Conduction (Deadtime)
26.14 W	10.19 W	73.06 W	15.53 W	0.78 W



System Overview

Input Voltage	Output Voltage	Actual Output Power	AC Frequency	Switching Frequency	Deadtime
850.0 V	380.0 V	20.00 kW	50.0 Hz	16.0 kHz	100.0 ns

Temperatures

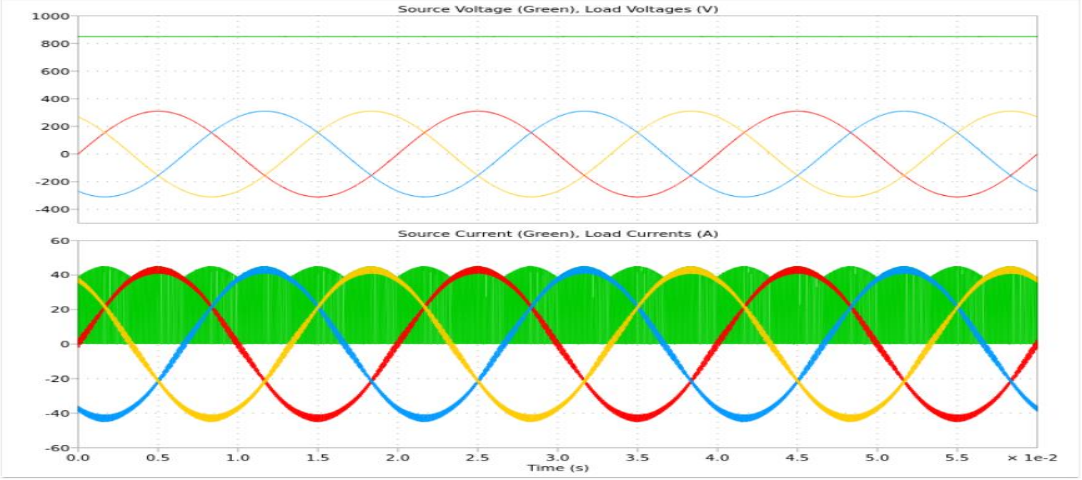
MOSFET	Module	Number of Parallel	Max Tj	Heatsink Max Temp.	Ambient Temp.
C3M0040120K		1	125.8 °C	65.0 °C	65.0 °C

Losses Overview

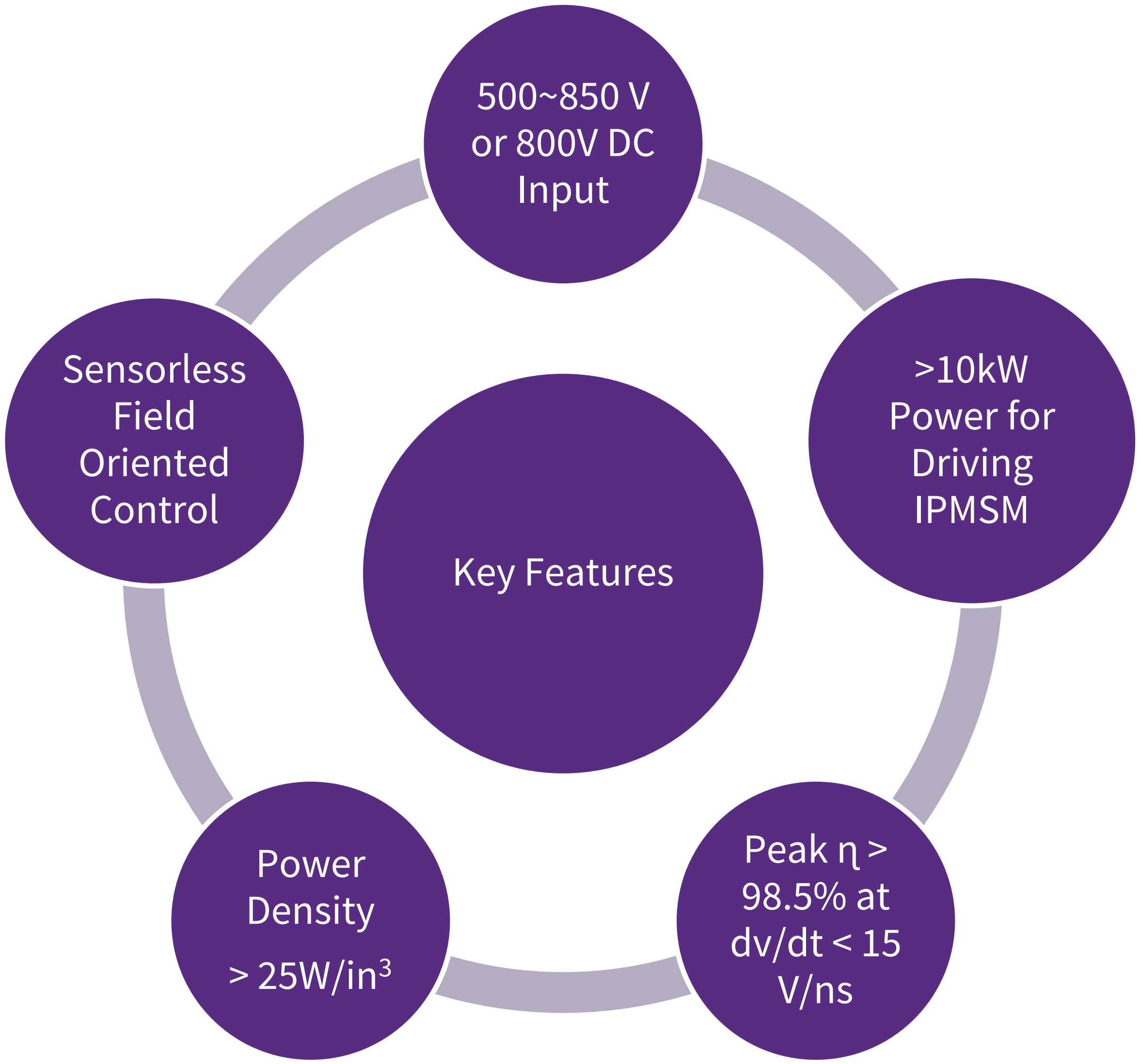
Switching Losses	Per Switch Position	Conduction Losses	Per Switch Position	Combined Losses *	Efficiency
95.01 W	15.84 W	162.05 W	27.01 W	257.06 W	98.72 %

Losses Breakdown

Turn-on Losses Eon	Turn-off Losses Eoff	Forward Conduction	Reverse Conduction	Body Diode Conduction (Deadtime)
66.22 W	28.79 W	132.79 W	27.70 W	1.56 W

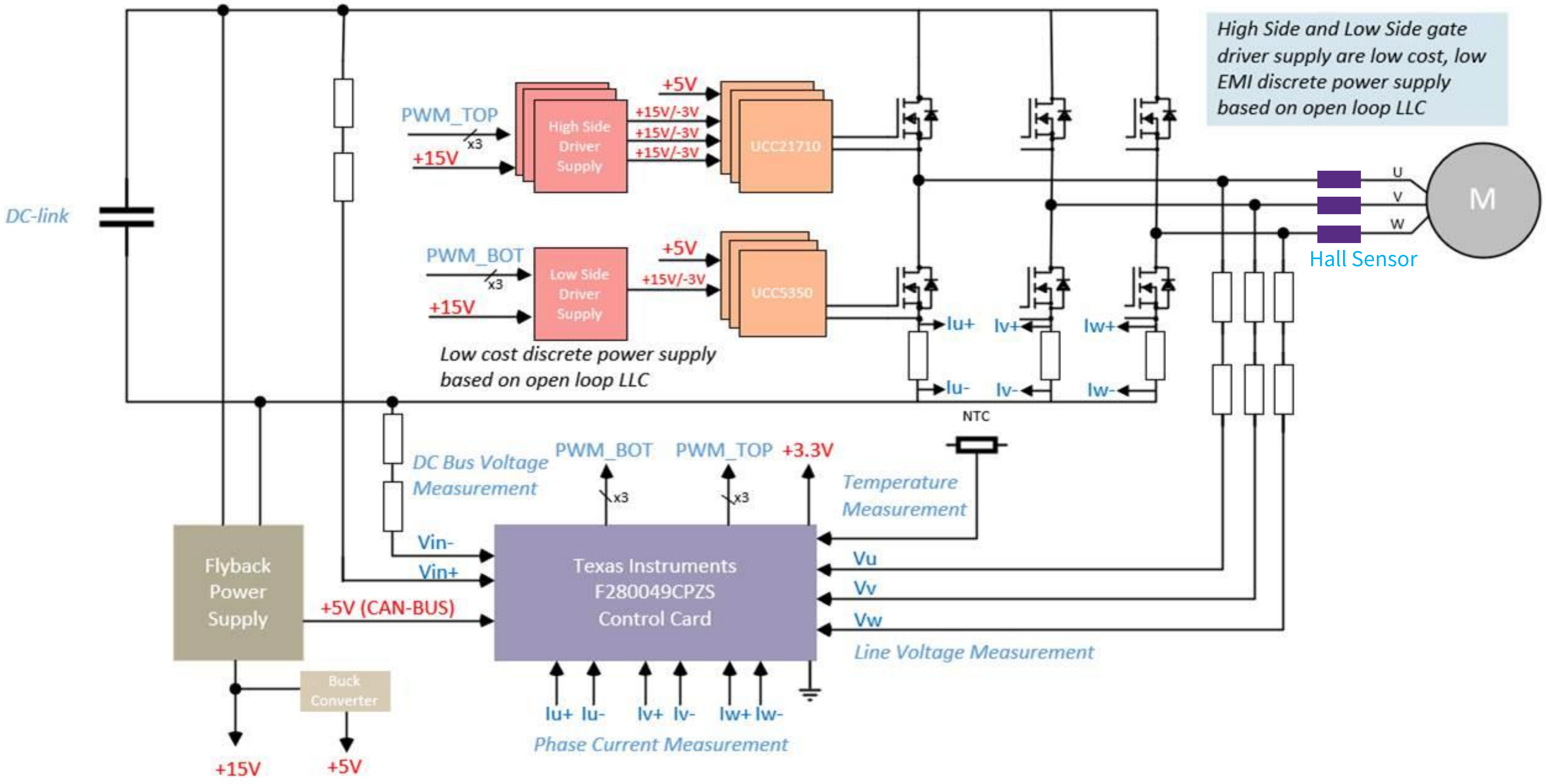


WHAT WILL THIS REFERENCE DESIGN ACHIEVE?



- We can show the most important advantage of SiC in the inverter applications → the efficiency improvement comparing to IGBT.
- We can showcase the operation and performance of the inverter in our lab.
- We will try to show advanced control of the motor. But that is not our priority. We may not able to let the inverter and control match all the motors at customers side.

11KW MOTOR DRIVE DESIGN



UCC21710QDWQ1 for high side MOS, **UCC5350MCDR** for low side MOS



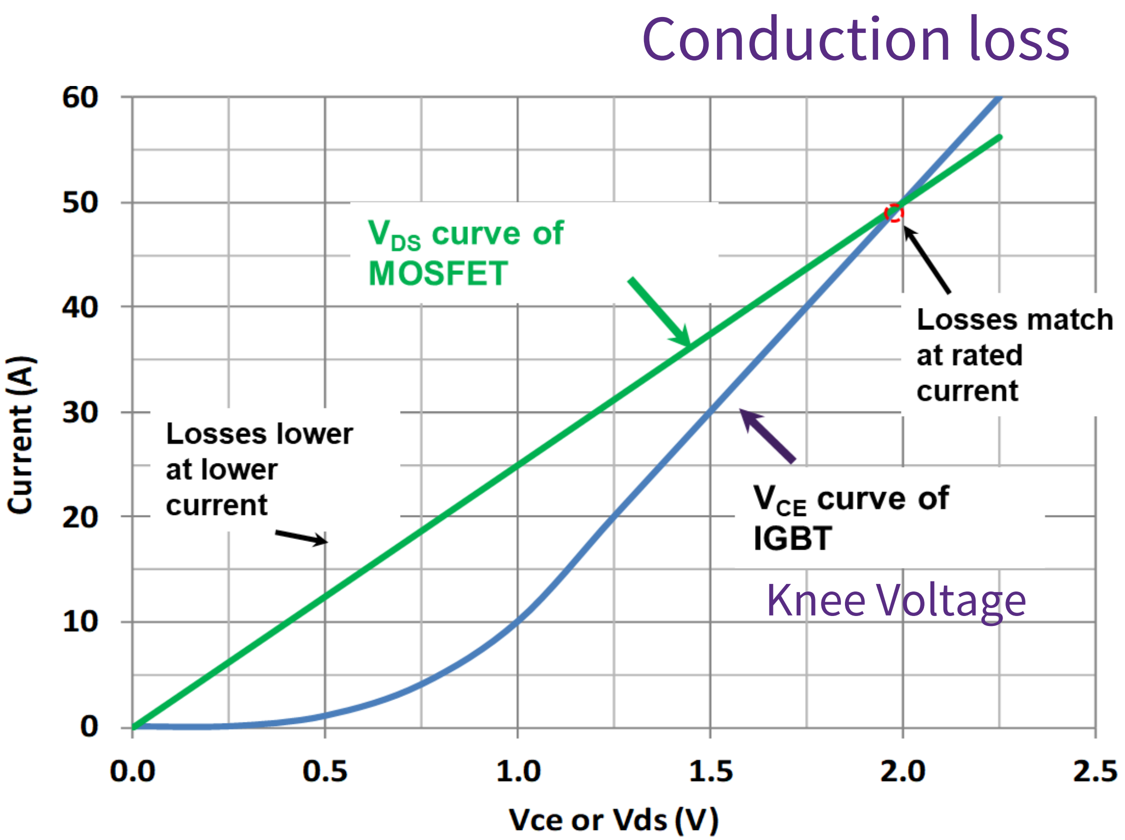
Power Components Selection

WHY SIC?

- **Smaller capacitance, Fast switching and low switching losses**
- **Less temperature dependence of Rdson and low conduction loss at high temperature**
- **Low reverse recovery body diode enables reliability in case of hard-commutation**

  - ✓ **Enabling higher switching frequency**
  - ✓ **Increasing power density and reducing weight**
  - ✓ **High efficiency**
  - ✓ **Bi-directional operation**

1200V SIC MOSFET VS IGBT – CONDUCTION LOSSES



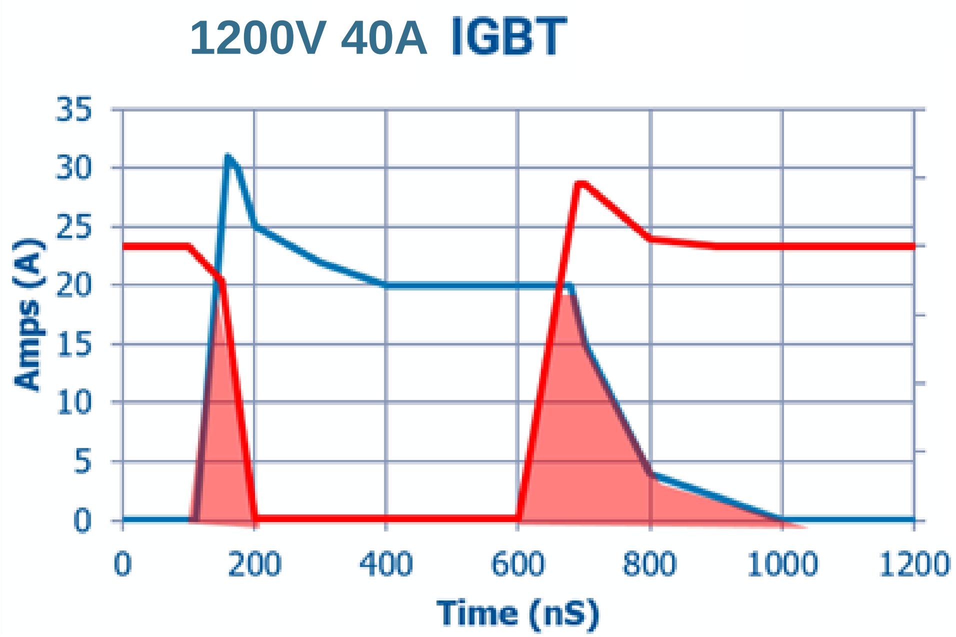
COMPARISON OF 40A IGBT TO 40A SIC MOSFET

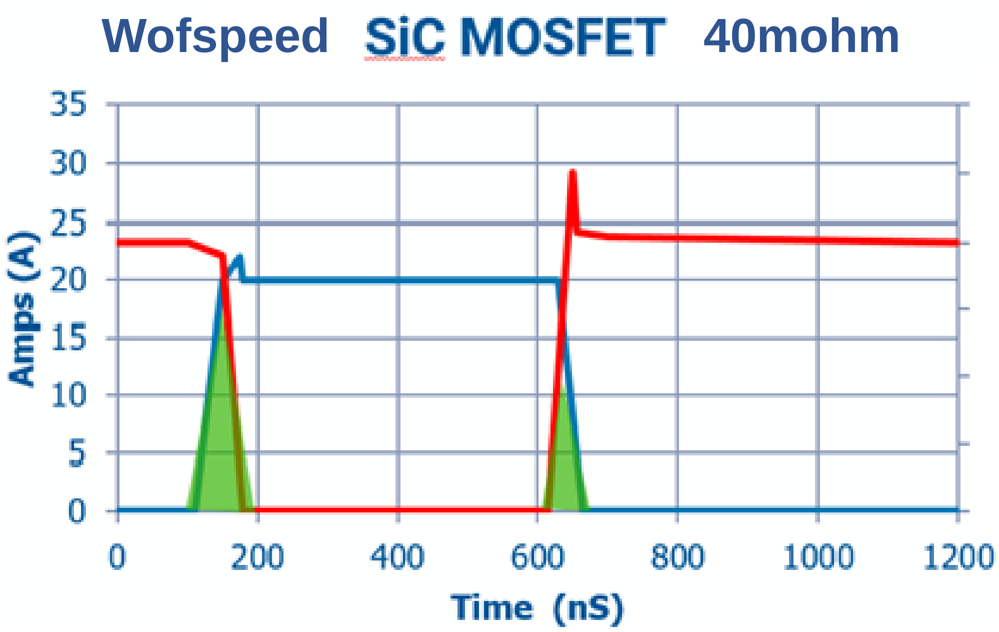
SIC MOSFETS HAVE LOWER CONDUCTION LOSSES THAN IGBT FROM 99% RATED CURRENT AND BELOW

PARALLEL DEVICES AND SIC VALUE IS CLEAR.

- **SiC MOSFET conduction loss is 30% lower and 50% lower than Si IGBT at half load and 30% load. No matter *for soft switching or hard switching***

1200V SIC MOSFET VS IGBT – SWITCHING LOSSES





- IGBT tailing current impacts the turn-off loss
- Eoff=2.66mJ
- Etotal=Eon+Eoff=4.86 mJ

- IGBT tailing current eliminated with SiC
- Eoff=0.1mJ
- Etotal=Eon+Eoff=0.71mJ

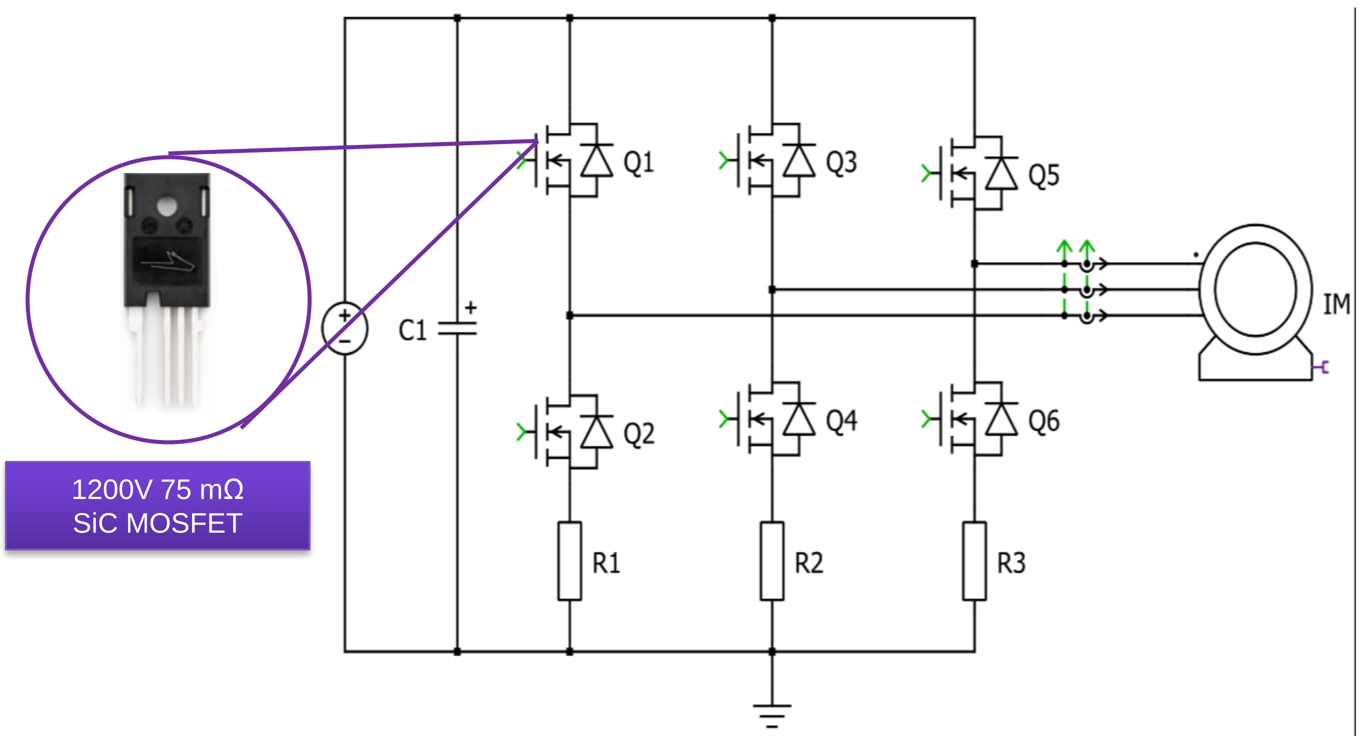
➢ ***~95% lower turn-off switching losses! – applicable for soft switching***

➢ ***~85% lower total switching losses! – applicable for hard switching***

POWER COMPONENTS SELECTION

The DC link voltage is up to 850V. 25A max rms current.

C3M0075120K 1200V 75mohm SiC MOSFET is selected for DC/AC converter based on electrical stress and thermal design. 6 devices provide 11kW output.



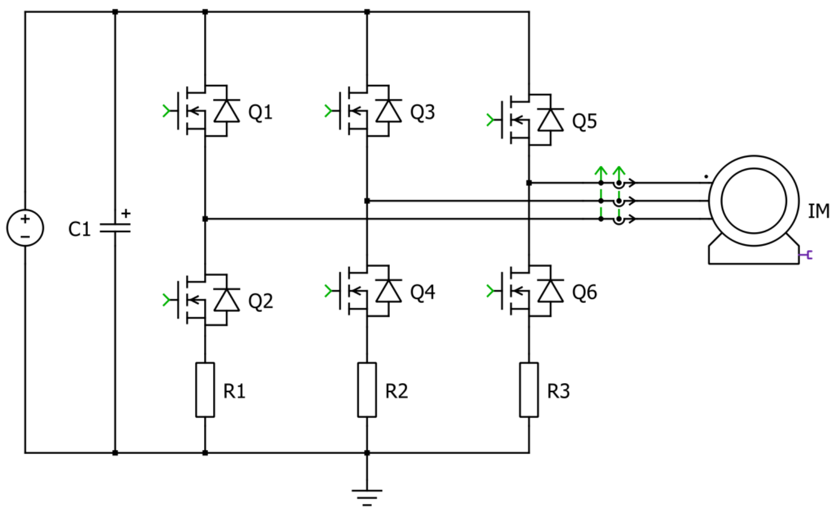
❑Best figure of merit (FOM)
❑K-Source package reduces switching loss and reduce cross talk
❑Easy to drive (V_{gs} = +15V)

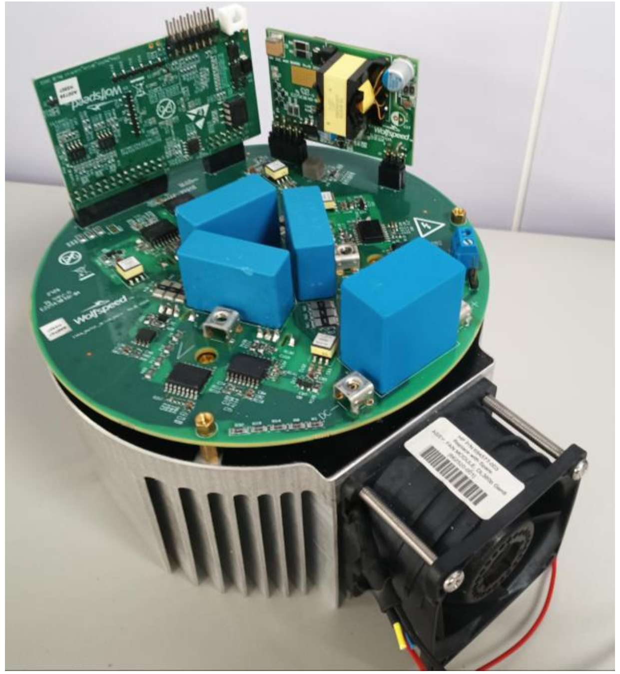


PCB Layout Considerations

PCB LAYOUT AND DIMENSION

	Dimension(mm)	Power density(kW/L)
PCBA(including Aux and control board)	145X133X60	13.68
PCBA(without Aux and control board)	145X133X30	27.37
Aux board	67X40	NC
Control board	76X47	NC





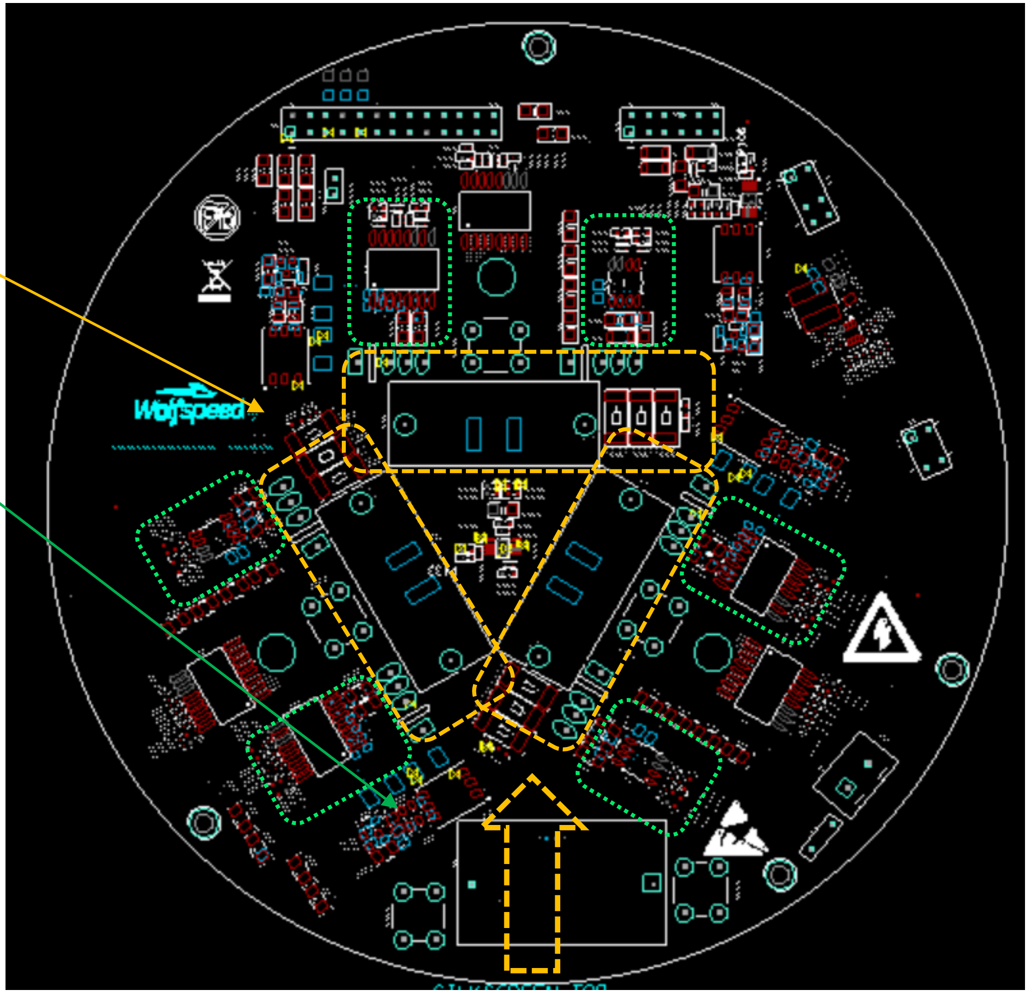
Prototype

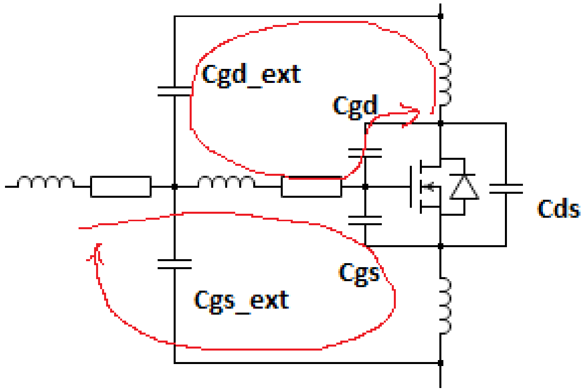
COMPONENTS PLACEMENT

- Avoid overlap between Gate, Gate drive circuit, bias power supply for Gate drive and the drain of the MOSFET.

Power loop

Gate drive loop

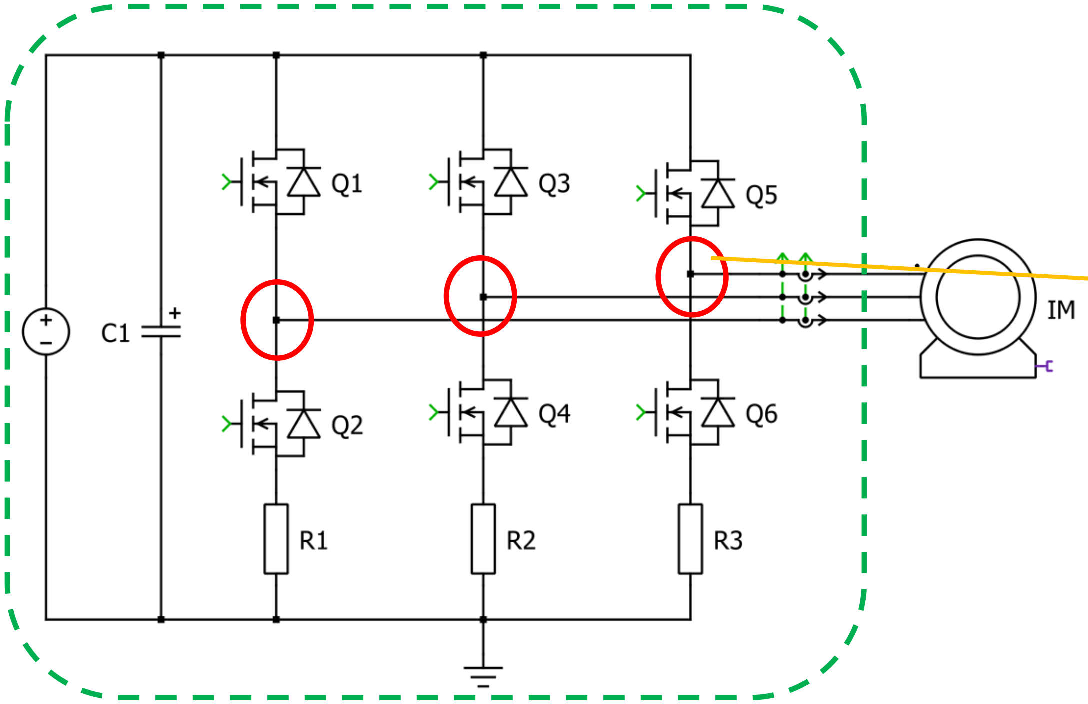


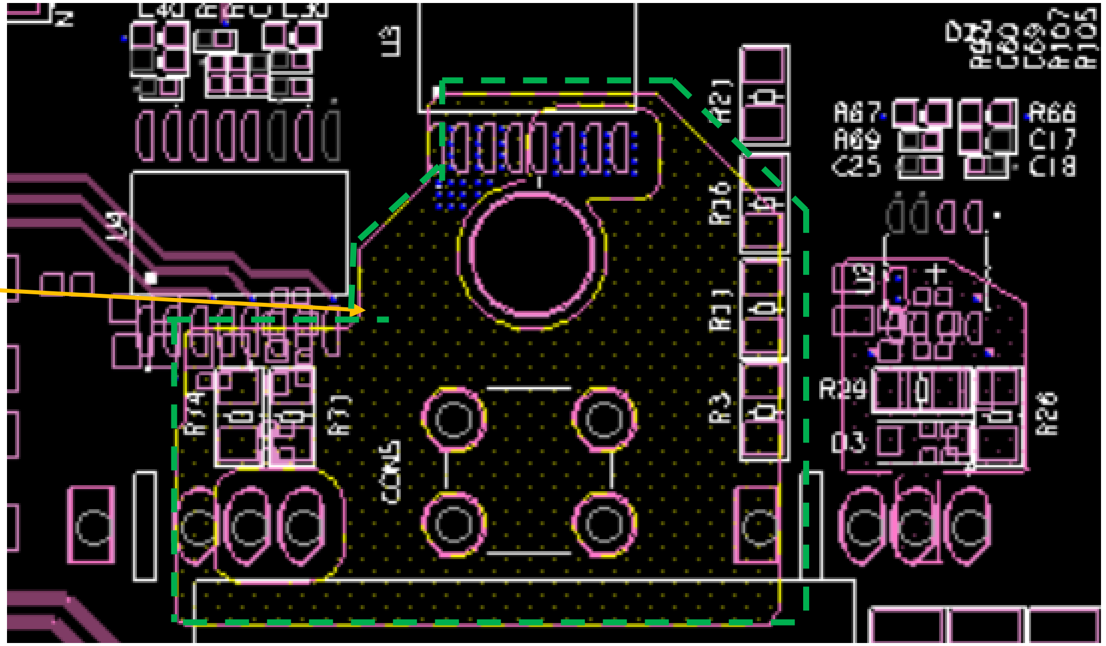


Consequences external Cgd:

- Not only higher switching loss
- Risk of gate oscillation
- EMI

HIGH DV/DT TRACE/NODE

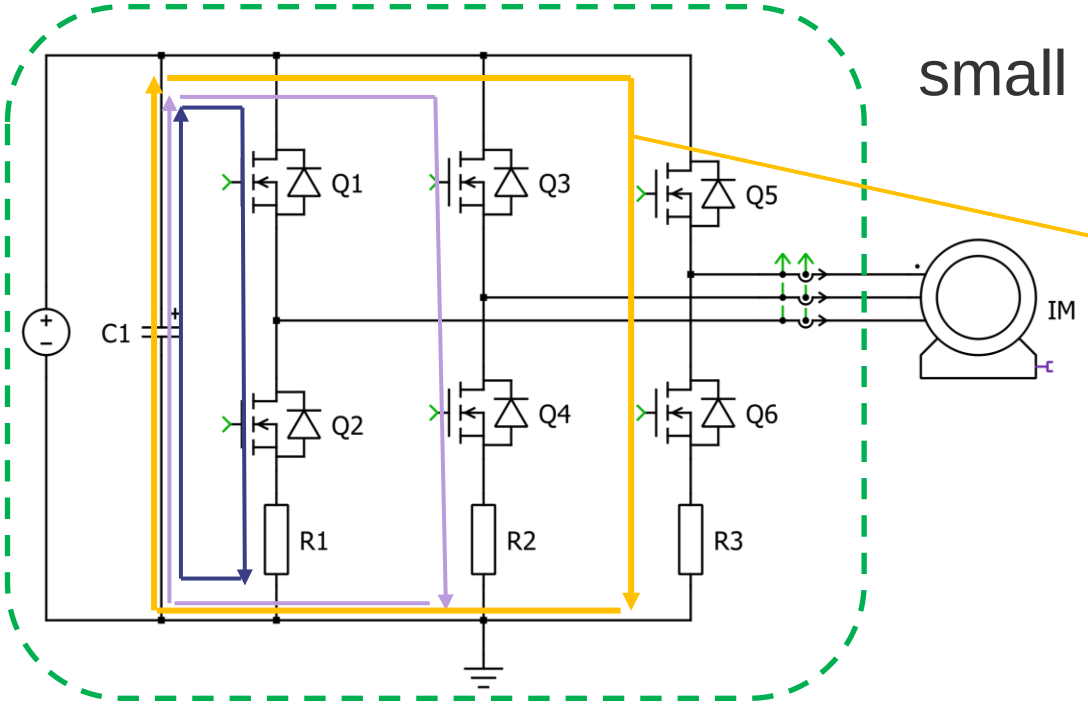




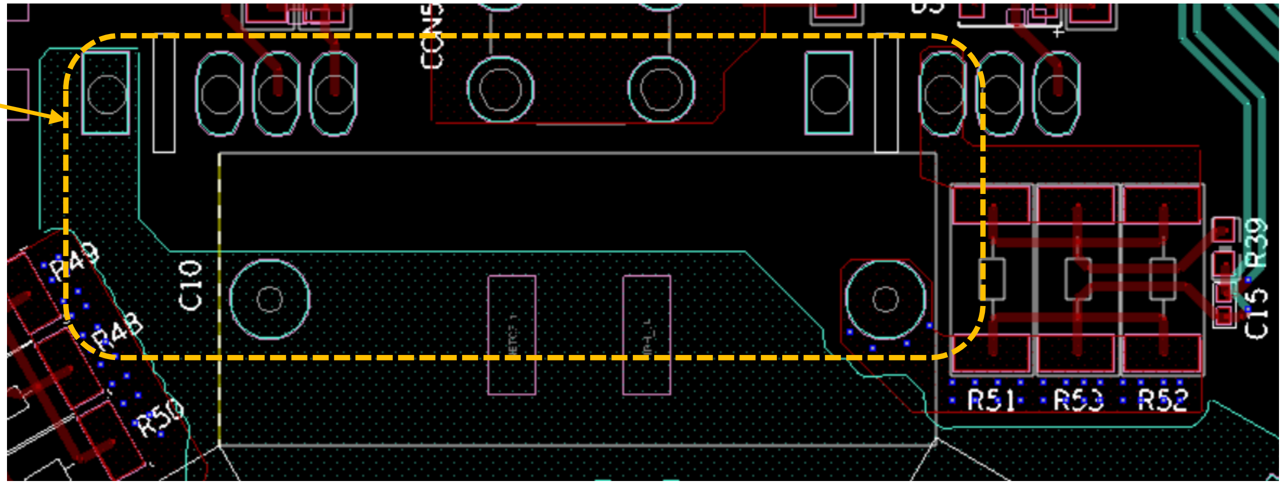
Keep the sensitive signals far away from the high dv/dt trace/nodes.

Small pad size of Drain nodes to reduce the coupling and parasitic capacitance

HIGH DI/DT LOOP



small di/dt loop

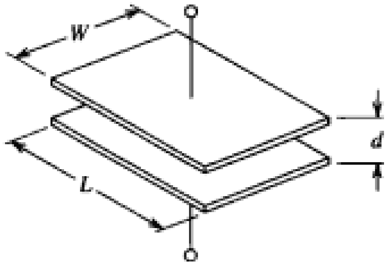


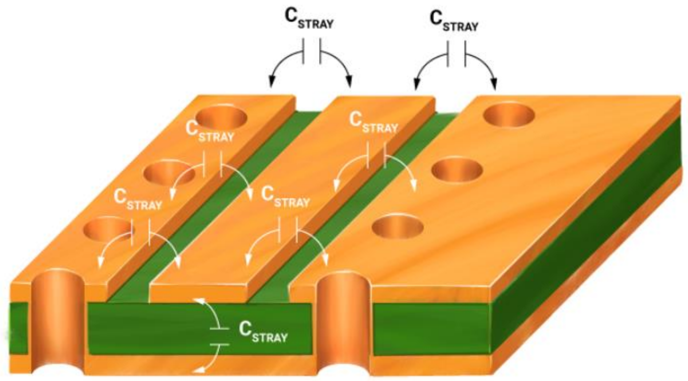
Place ceramic and film caps as close as possible to minimize the high frequency di/dt loop.

Proper PCB layout of the power components to minimize the high frequency di/dt loop.

PARASITIC CAPS OF PCB

$C = \varepsilon_r S/4\pi k d$





$1/4\pi k = 8.85\times10^{-12}$F/m

ε_r of FR4 → ~4.3

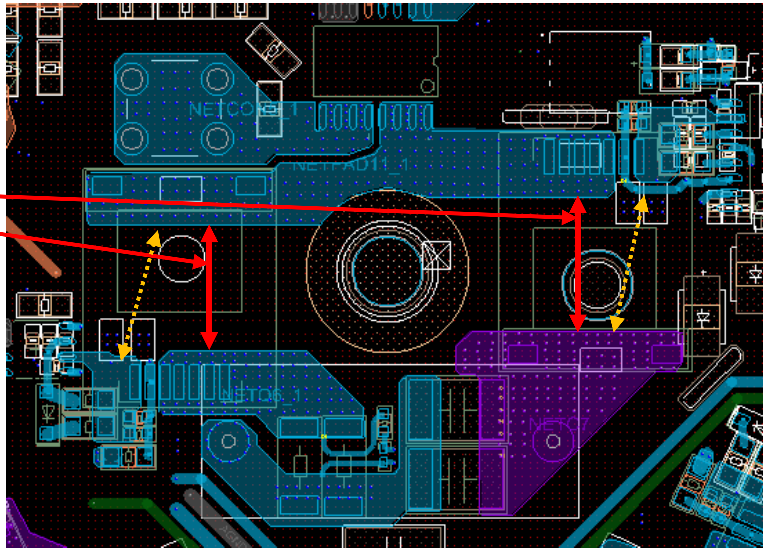
d = 0.0001m

For 1 cm^2 PCB trace overlap:

$C = 4.3*0.01*0.01*8.85\times10^{-12} / 0.0001 = 38$pF

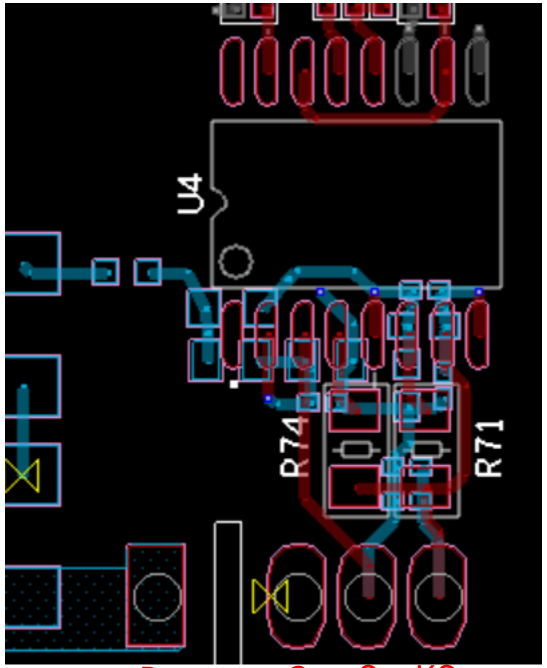
$P_c = 0.5*C*f*V^2 =$ 1.2W for 800Vbus hard switching @100kHz

- Avoid overlap to reduce the coupling and parasitic capacitance.



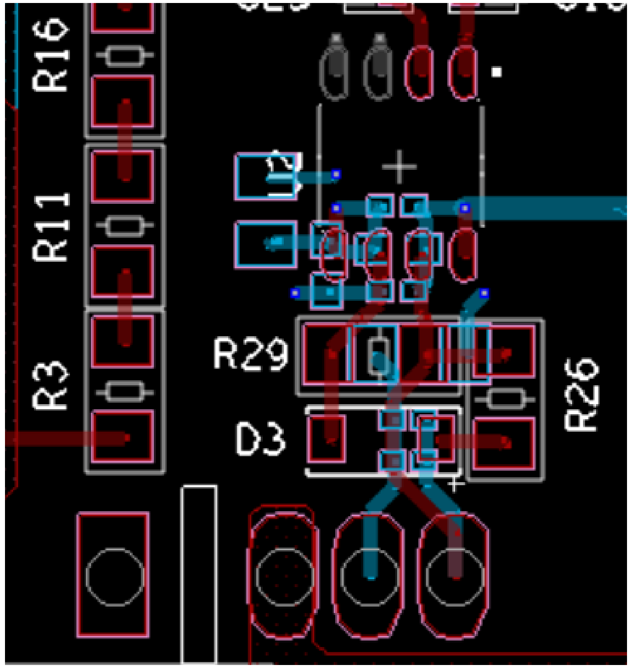
SIC MOSFET GATE DRIVER

- Minimized the loop of gate drive
- Minimized the loop of active miller clamp
- Separated gate source. Don’t introduce parasitic inductance from power source loop
- Place the external Gate to Source cap as close as possible to the MOSFET



D G S KS

High side Gate driver



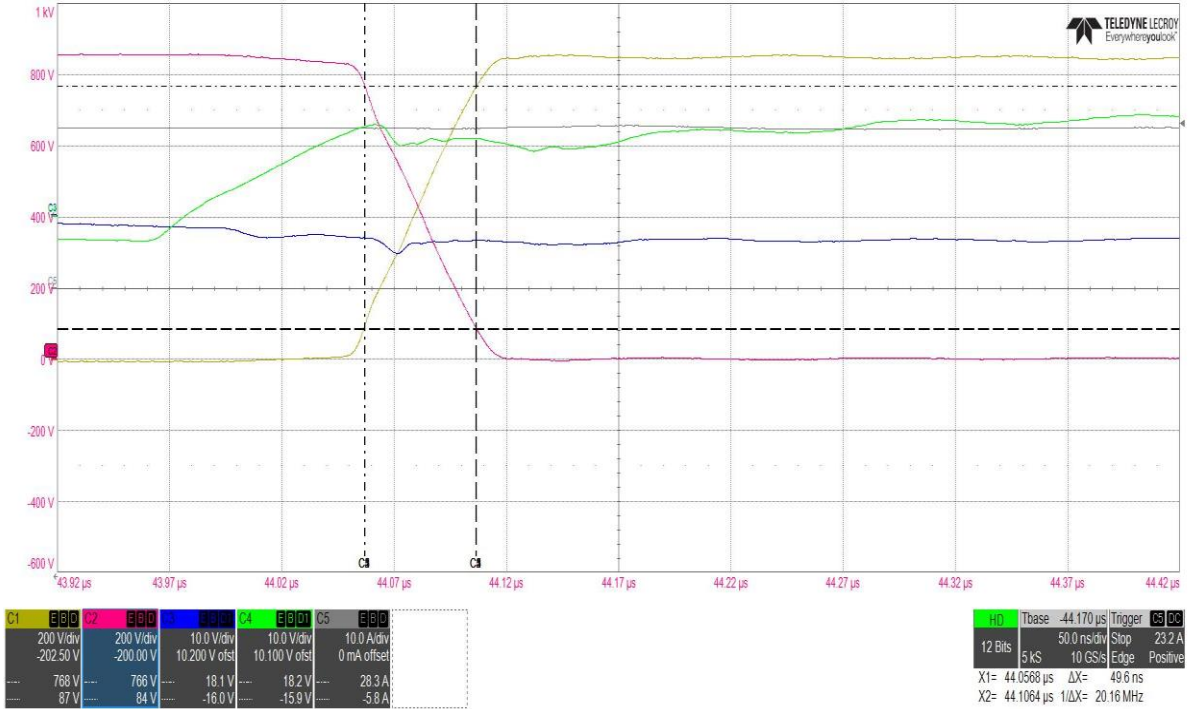
D G S KS

Low side Gate driver

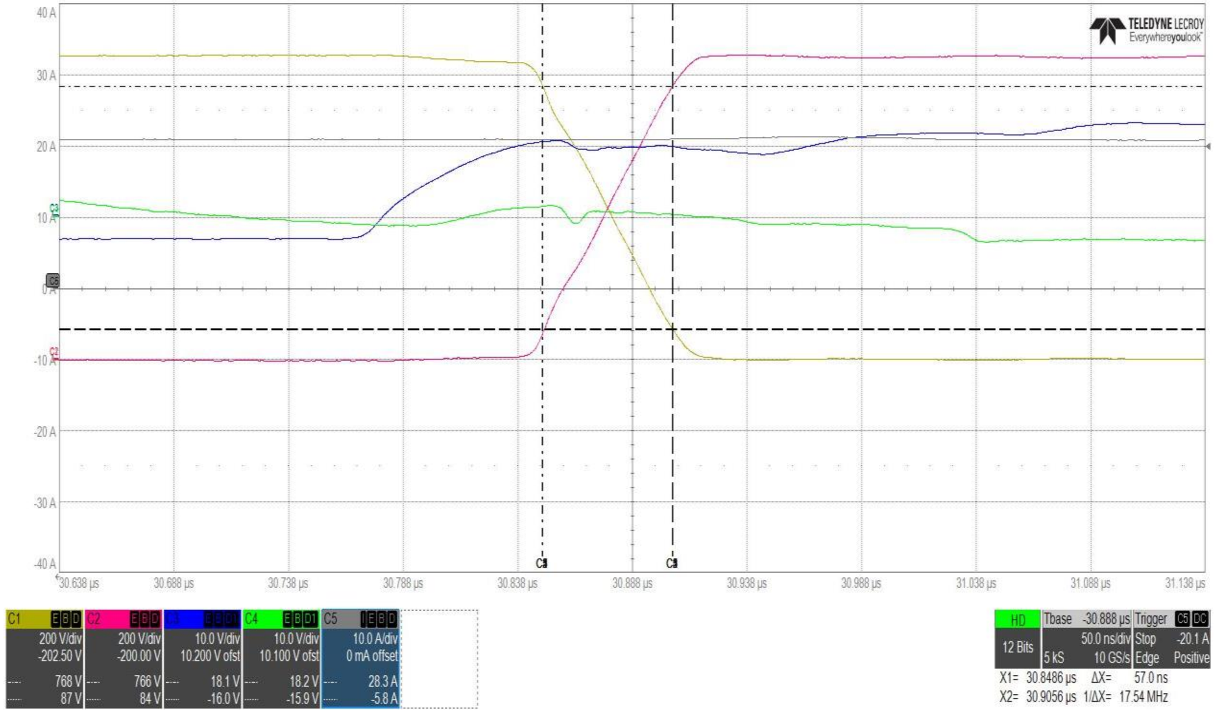
Test Results

WAVEFORM(OPEN LOOP)

	high side		low side	
	turn on	turm off	turn on	turm off
Rg(ohm)	22//56	56	22	56
dv/dt(V/ns)	**13.71**	**15.45**	**11.93**	**12.5**



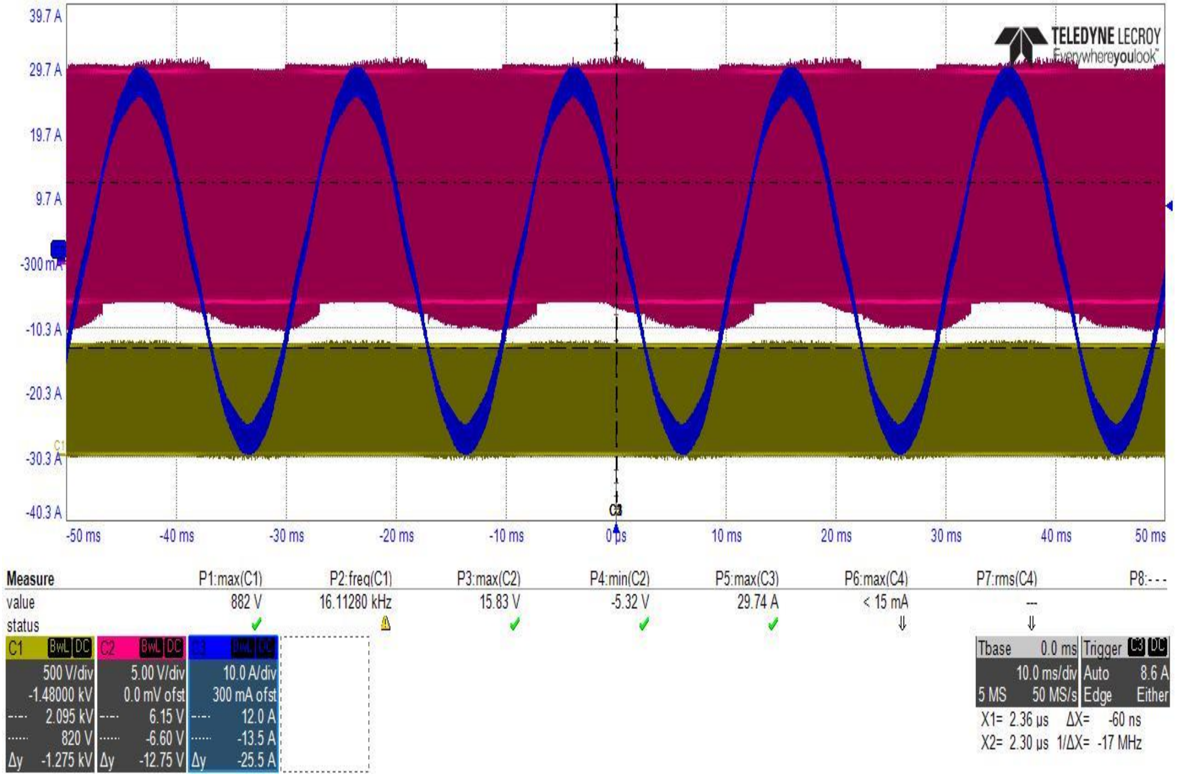
High side turn on and Low side turn off @ 850V 11kW

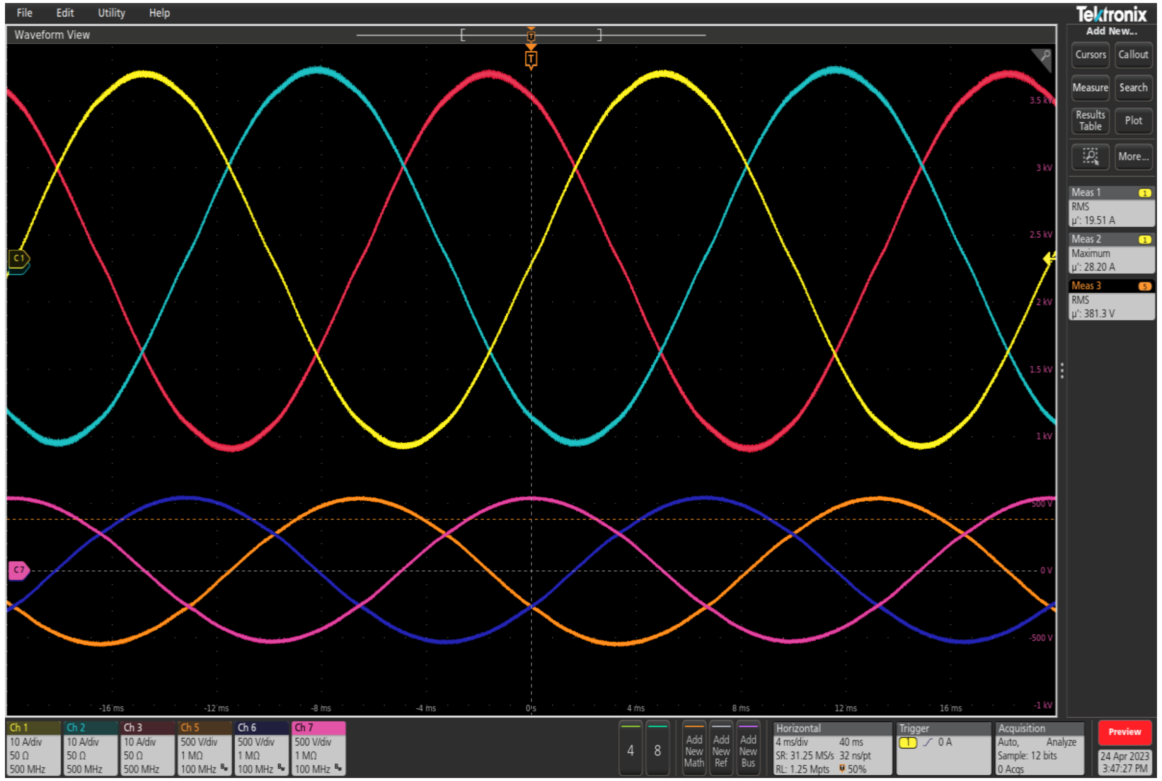


Low side turn on and High side turn off @ 850V 11kW

WAVEFORM (OPEN LOOP)

Test condition: Vin=850V Vo=380VL-L Po=11KW

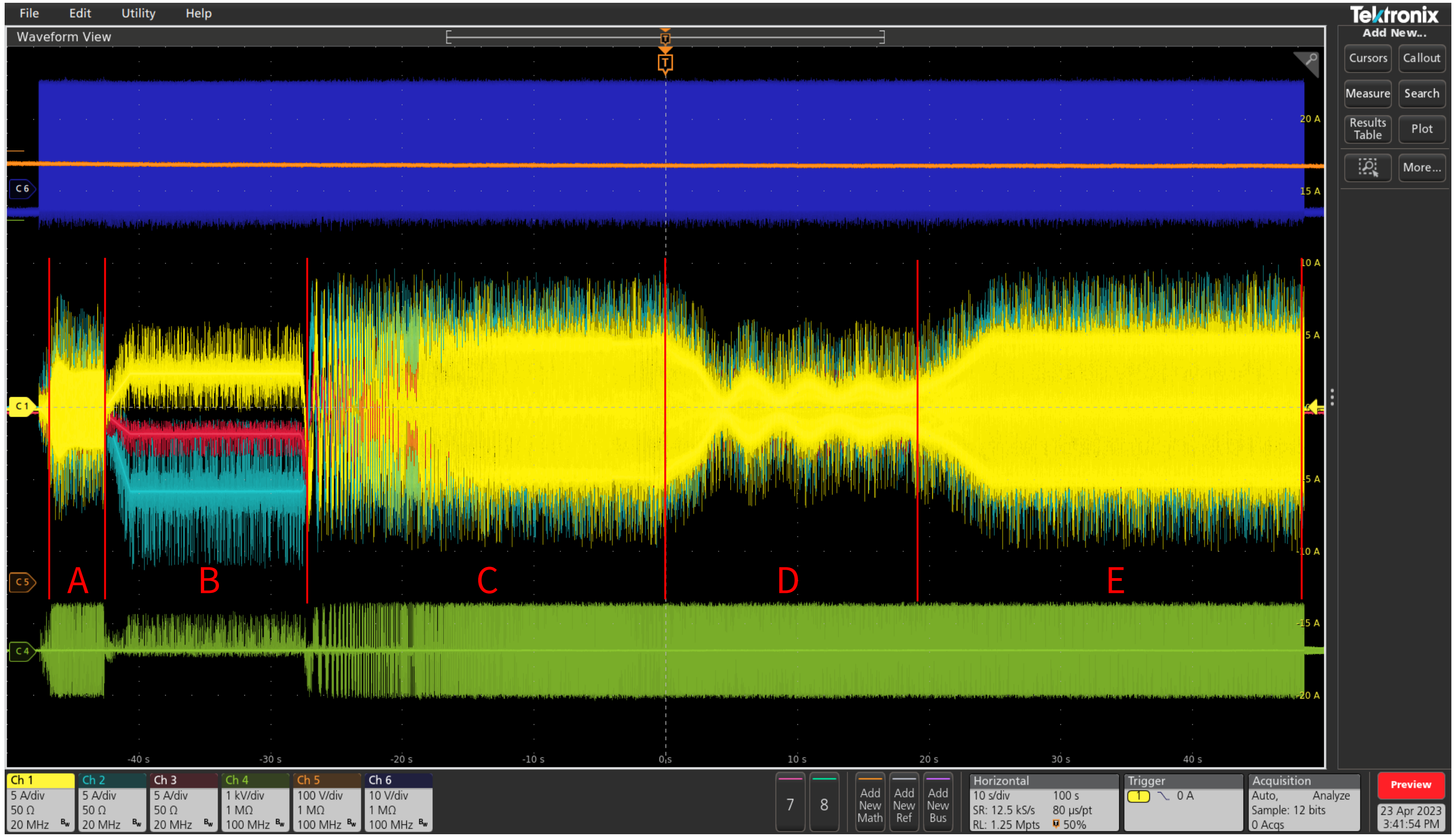




CH1: Vds
CH2: Vgs
CH3: Phase current

CH1/2/3: Phase current
CH5/6/7: Phase voltage

MOTOR PARAMETERS IDENTIFY



Identified Parameters:

Rr_Ohm	float	0.0
Rs_Ohm	float	0.016999241
RsOnLine_Ohm	float	0.016999241
Ls_d_H	float	0.000596260419
Ls_q_H	float	0.000596260419
RoverL_rps	float	464.52243
flux_VpHz	float	0.83773154
flux_Wb	float	0.133329108

Parameters from vender:

Motor P/N: TYB180M-2

Frequency：200Hz 20kw

Voltage：320V （Peak line voltage-Y type）

Rated Current：38A

Pole pairs：4

Ld：0.00069H = 6.9e-4H = 690uH

Lq：0.00164H = 1.64e-3H = 1.64mH

Rs（20℃）：0.026Ω

A: RoverL (5s)

B: Rs identify (3+12s)

C: Ramp up (26s)

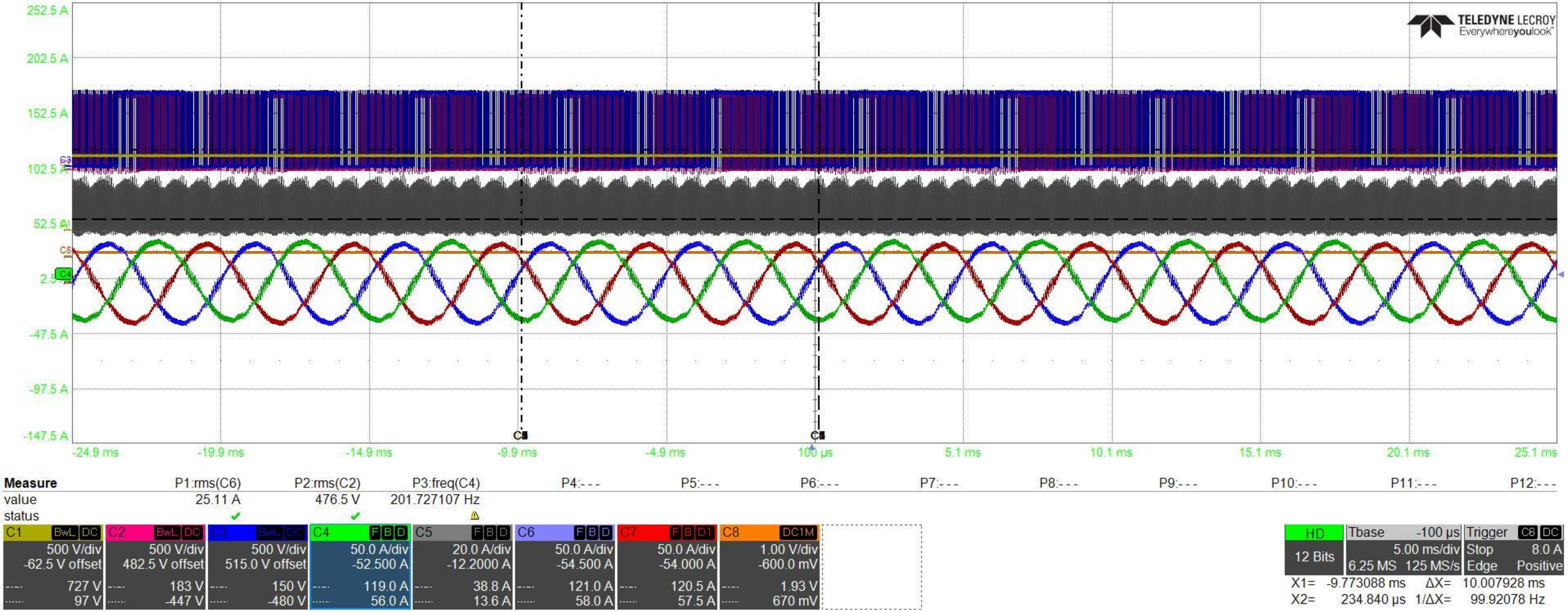
D:Rated Flux (20s)

E: Ls identify (30s)

Total time: 96s

Speed Closed Loop waveforms

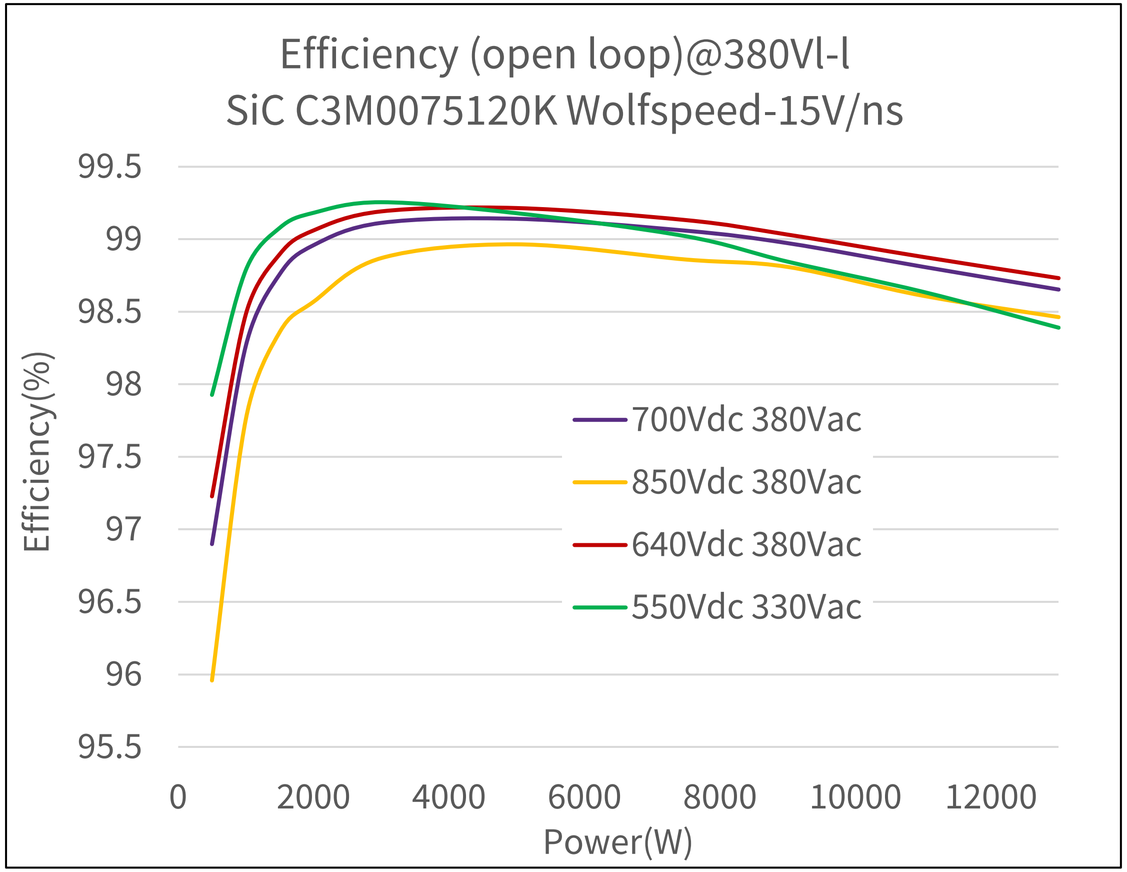
Test condition: 680Vdc, 3000rpm, 33NM, 13kW

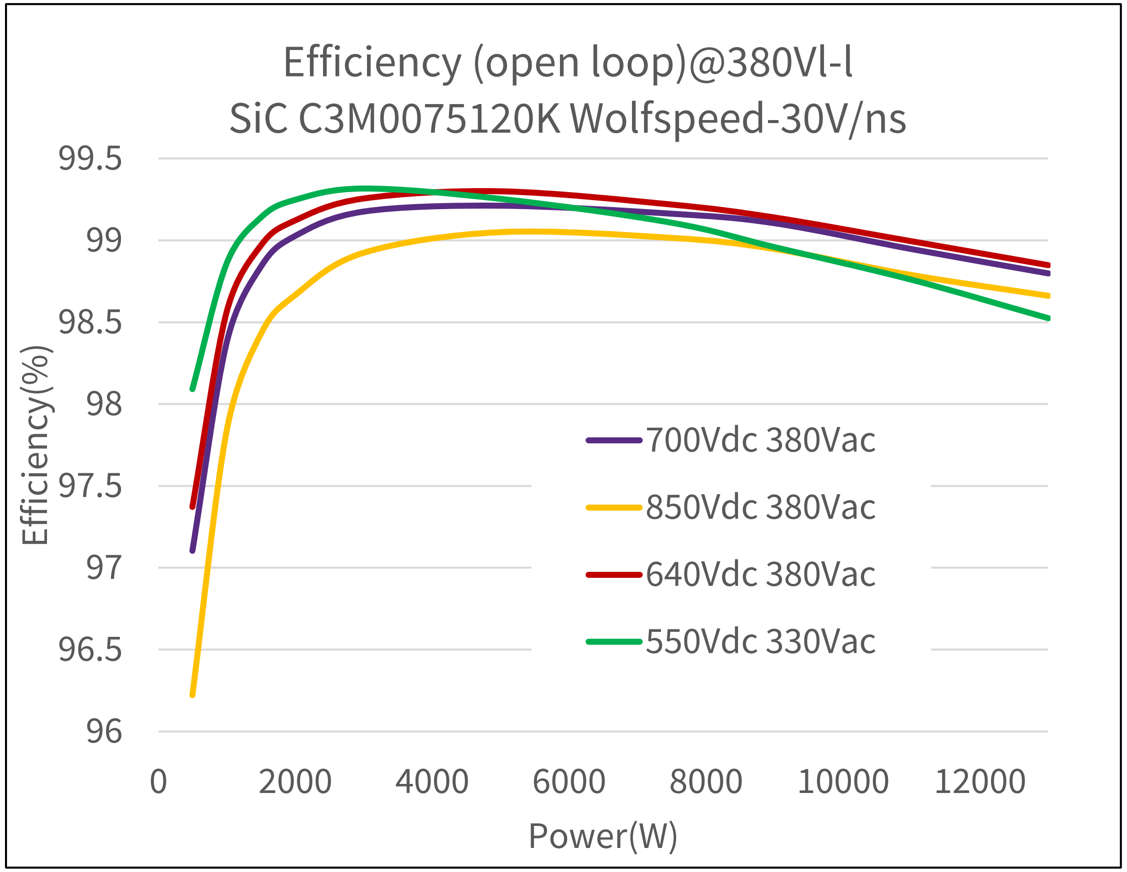


CH1: Vdc CH2/3: Vac CH4/6/7: AC current CH5: DC current

SIC EFFICIENCY CURVE (OPEN LOOP) – WITH FILTER

11/13kW with C3M0075120K



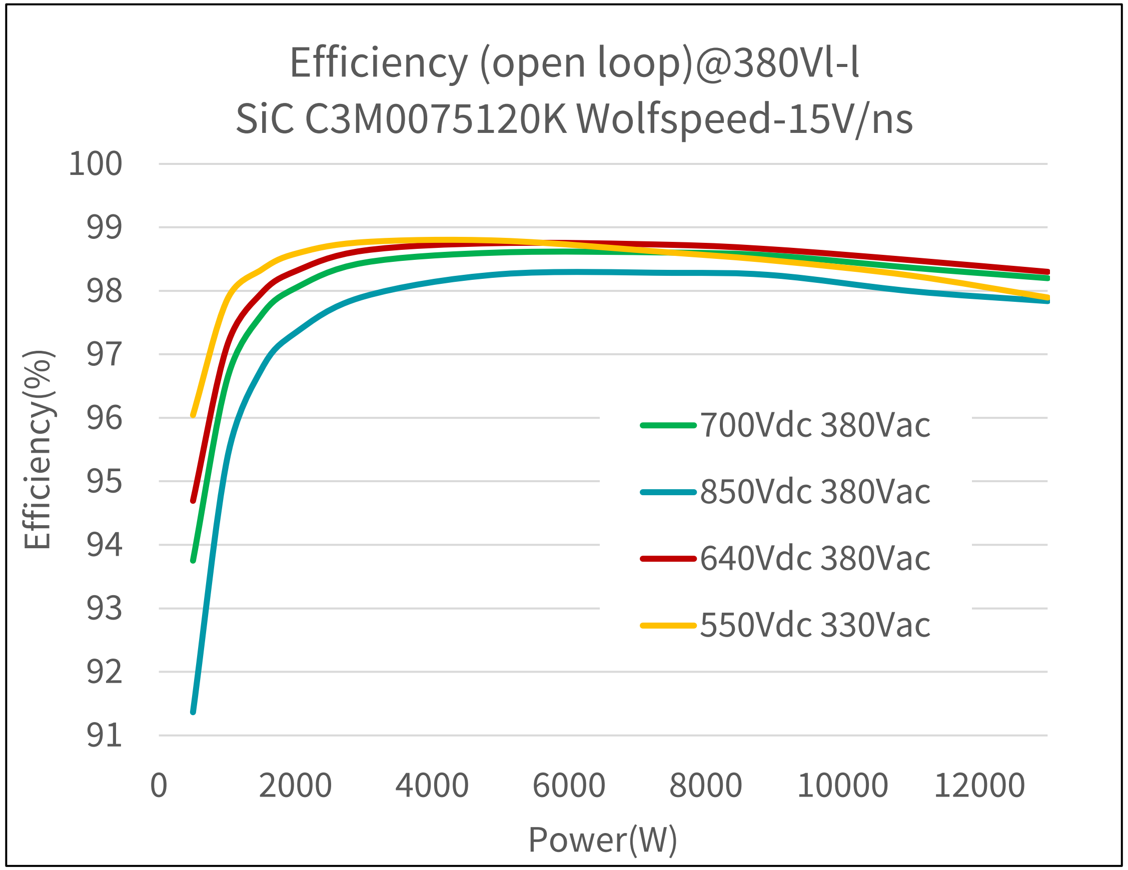


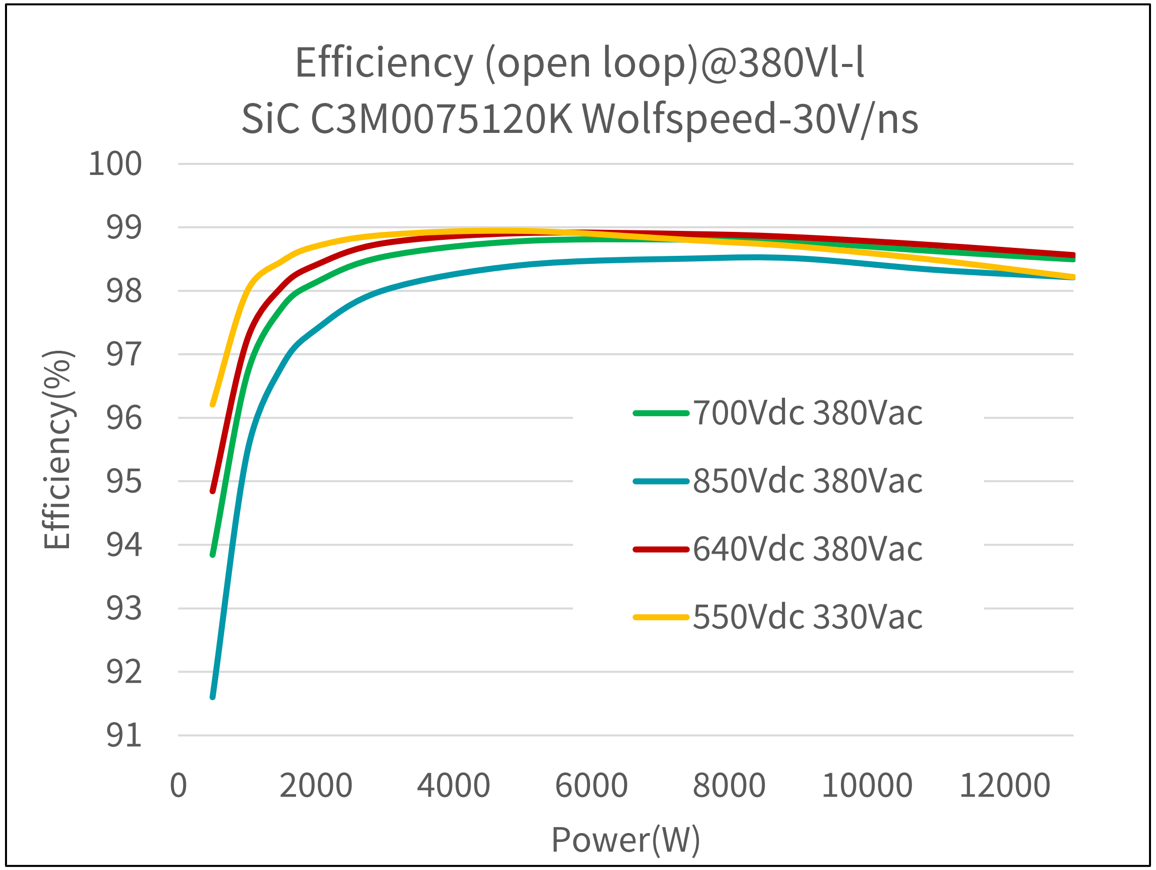
16kHz dv/dt: 15V/ns
Peak eff: 99.25%

16kHz dv/dt: 30V/ns
Peak eff: 99.3%

SIC EFFICIENCY CURVE (OPEN LOOP) – WITH FILTER

11/13kW with C3M0075120K





32kHz dv/dt: 15V/ns

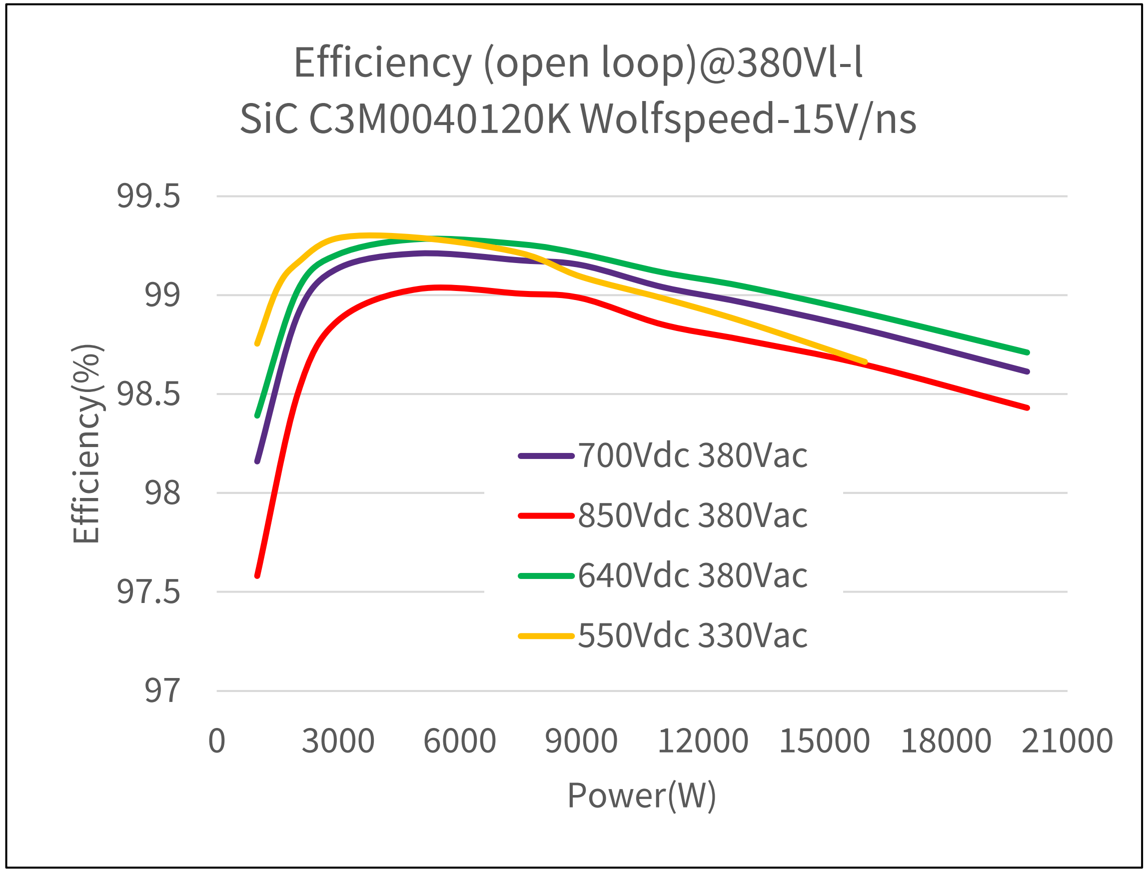
Peak eff: 98.8%

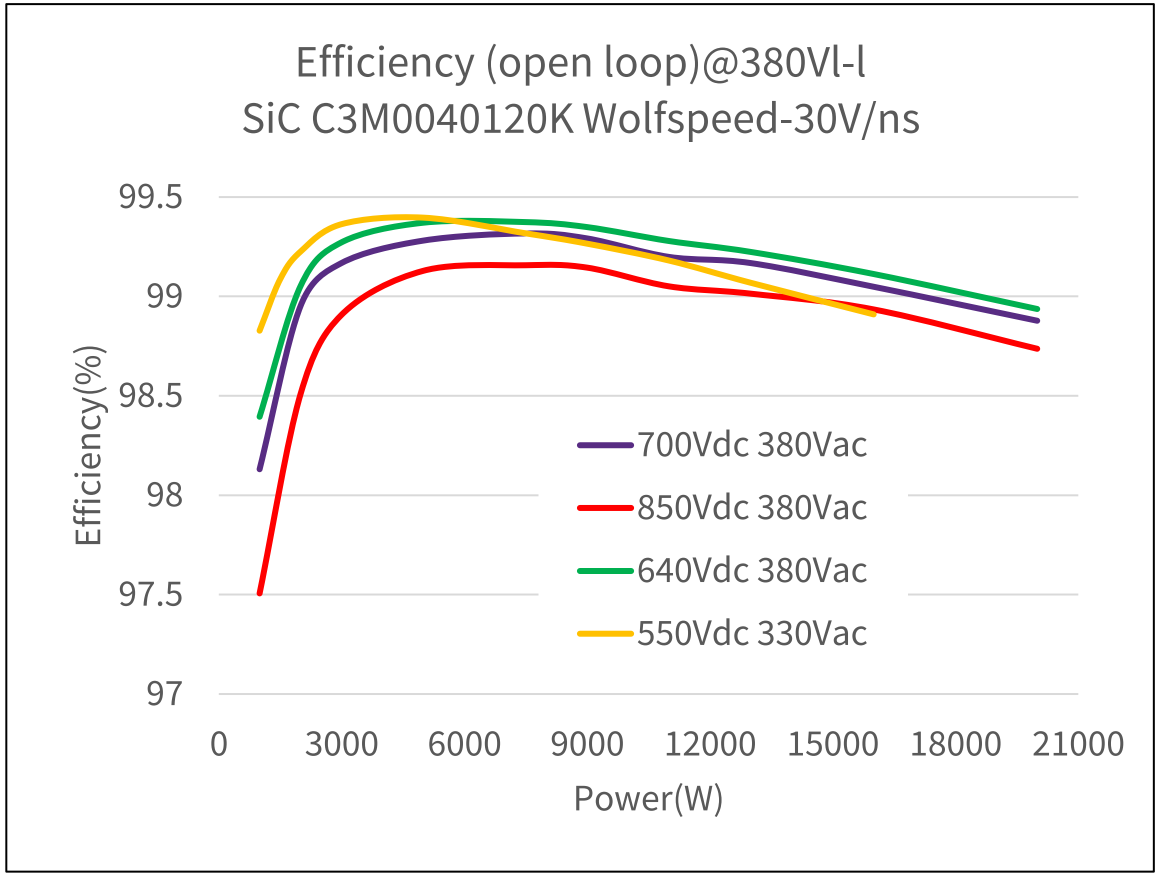
32kHz dv/dt: 30V/ns

Peak eff: 98.94%

EFFICIENCY CURVE

20kW with C3M0040120K



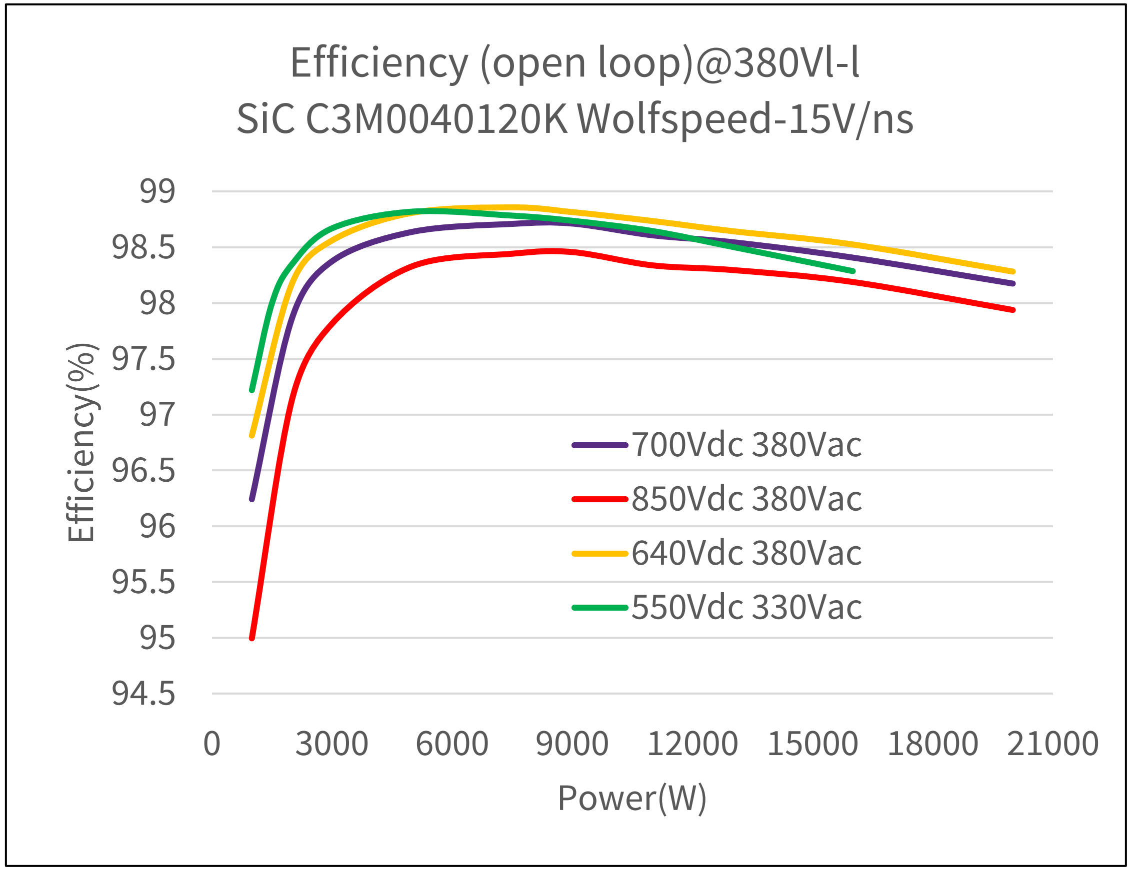


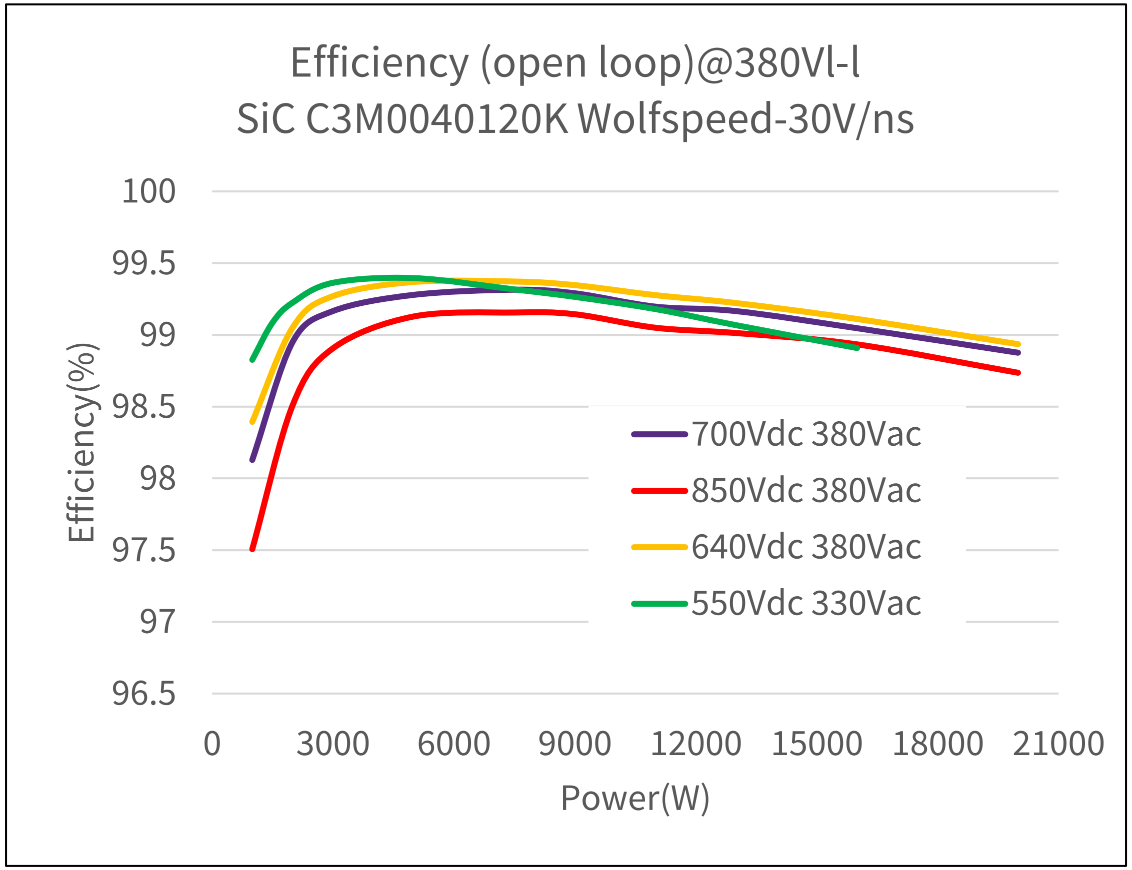
16kHz dv/dt: 15V/ns
Peak eff: 99.29%

16kHz dv/dt: 30V/ns
Peak eff: 99.39%

EFFICIENCY CURVE

20kW with C3M0040120K





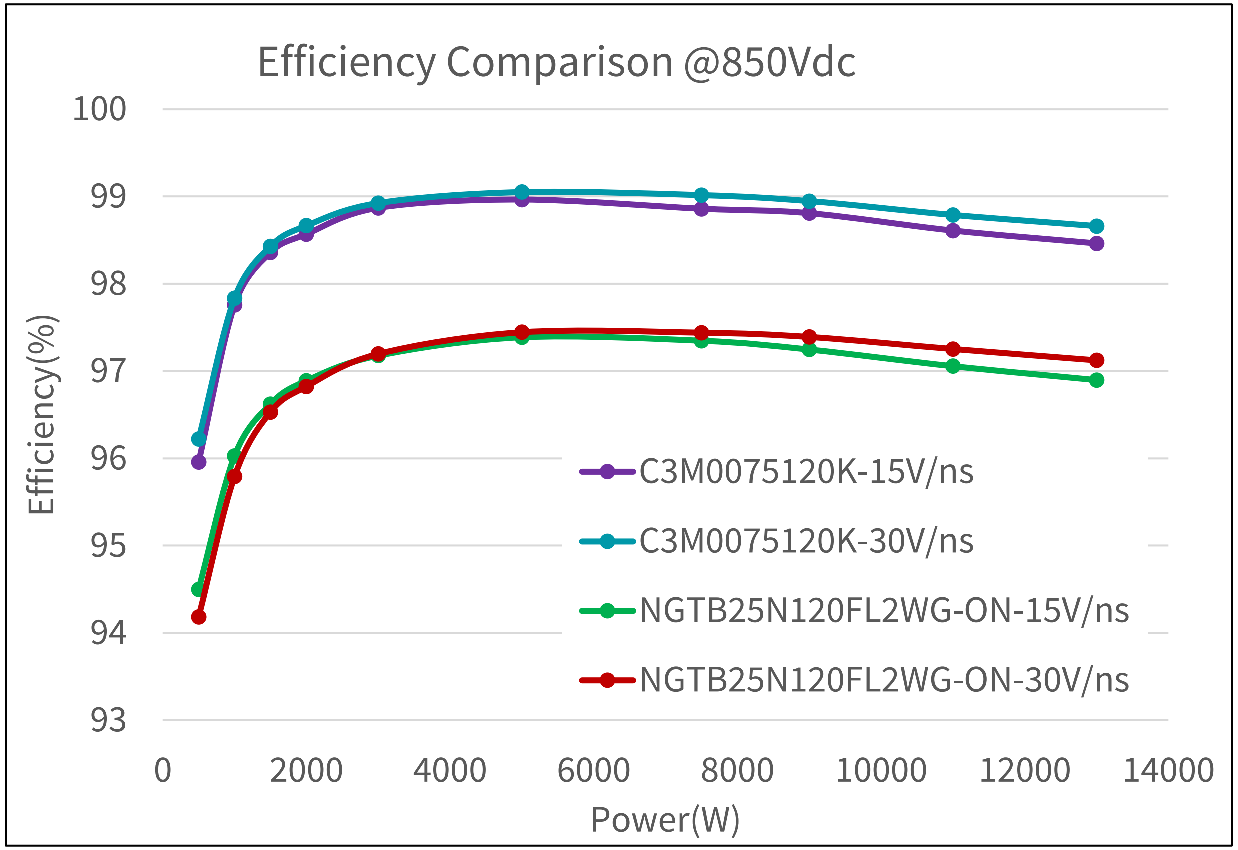
32kHz dv/dt: 15V/ns

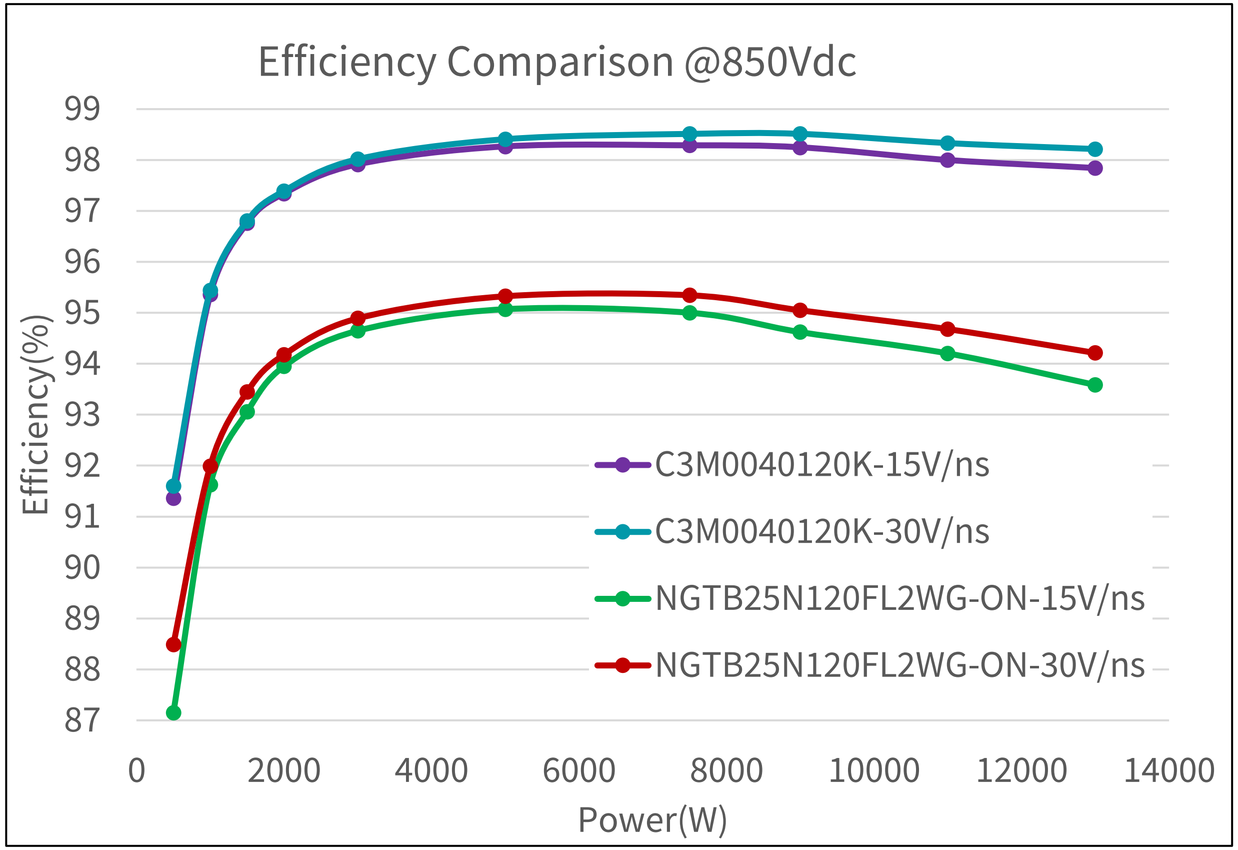
Peak eff: 98.82%

32kHz dv/dt: 30V/ns

Peak eff: 99.39%

SiC& IGBT Efficiency comparison with 75mohm

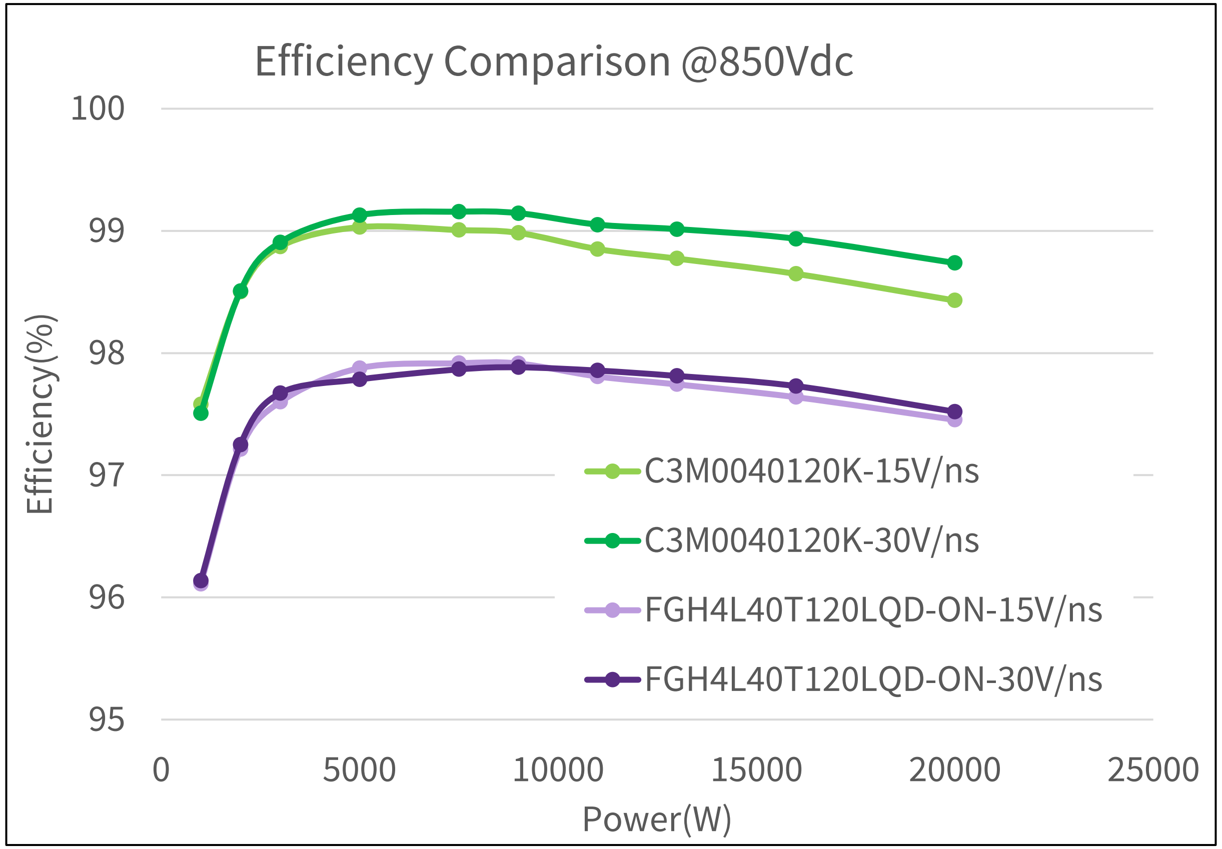




11kW efficiency comparison @ 16kHz
Up to 1.5% eff improvement

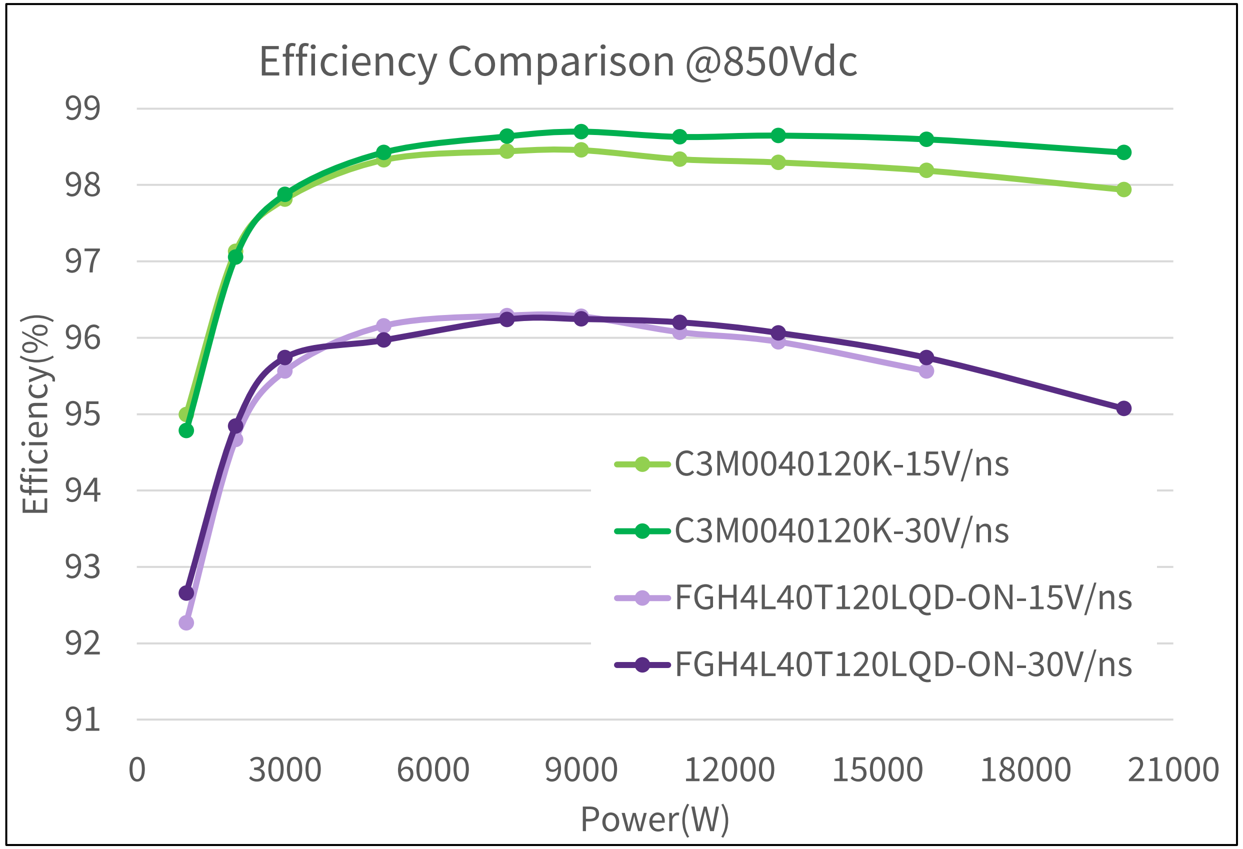
11kW efficiency comparison @ 32kHz
Up to 3% eff improvement

SiC& IGBT Efficiency comparison with 40mohm



20kW efficiency comparison @ 16kHz

Up to 2.2% eff improvement



20kW efficiency comparison @ 32kHz

Up to 3.5% eff improvement

EFFICIENCY CURVE (OPEN LOOP)

Part Number	Heatsink Temp.	Rth (j-c) (c/w)	Calculated Power Loss (watts)	Case Temp.	Calculated Junction Temp.	Max. Junction Temp.	Comments
Input = 850Vdc Output = 380Vl-l 16kW							
C3M0040120K Q3	64.4	0.46	27.7	73.4	86.14	175 °C	**PASS**
Input = 850Vdc Output = 380Vl-l 20kW							
C3M0040120K Q3	64.46	0.46	42.85	71.4	91.1	175 °C	**PASS**
Input = 850Vdc Output = 380Vl-l 11kW							
C3M0075120K Q1	64.72	1.1	21.7	69.67	93.54	175 °C	**PASS**
Input = 550Vdc Output = 320Vl-l 11kW							
C3M0075120K Q1	65.4	1.1	27.76	71.3	101.84	175 °C	**PASS**

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