An integrated servo motor drive with self-cooling design using SiC-MOSFET

Wang Heng, Infineon China

speaker

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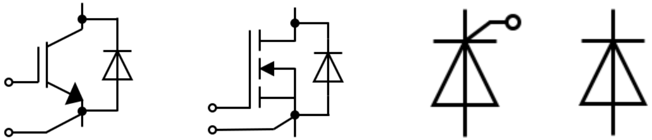
- **Background**
  - Bachelor / Master degree in Electrical Engineering
  - R&D engineer in Emerson
  - FAE in Infineon since 2010



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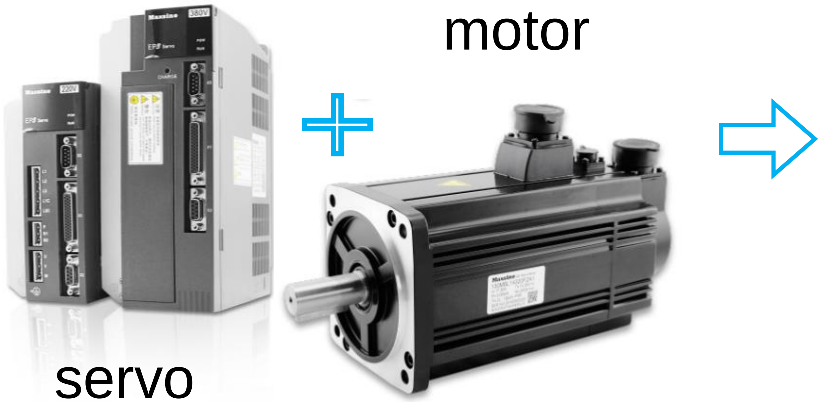
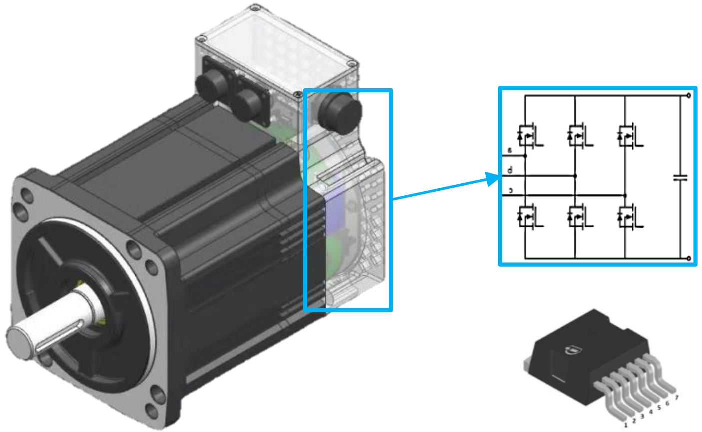


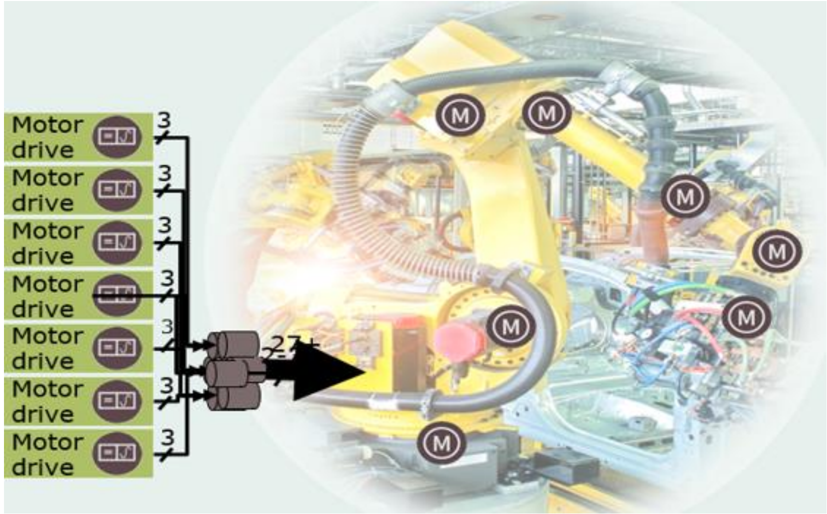
servo

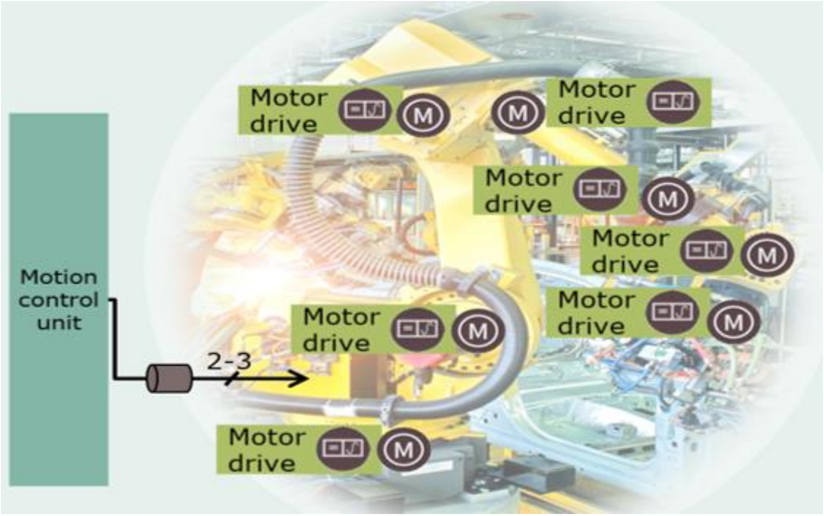


integrated servo motor drive

Application example:

Multi-axis industrial robotic





Structure and Diagram of an integrated servo motor

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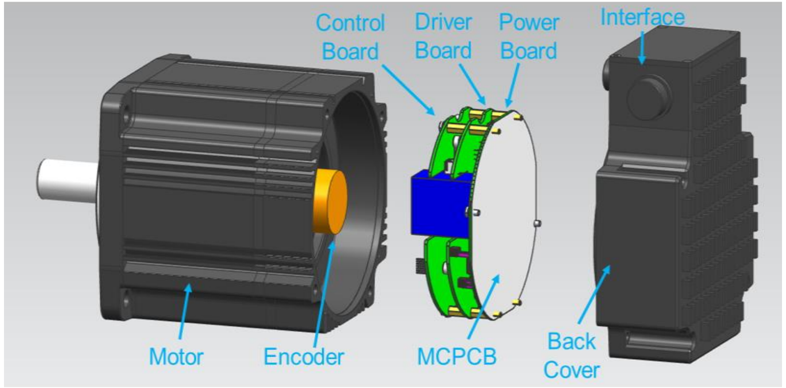
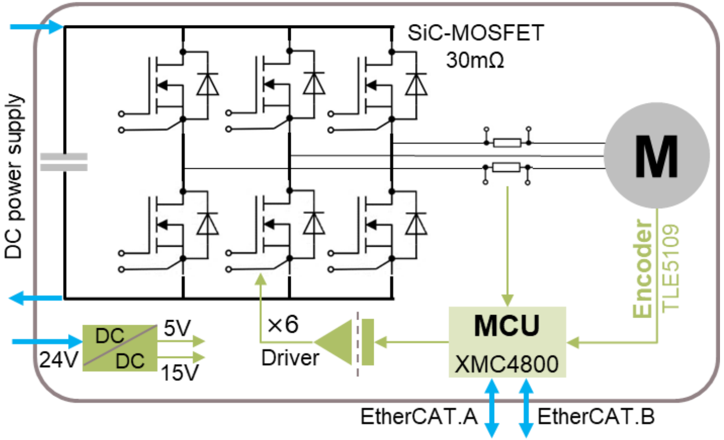
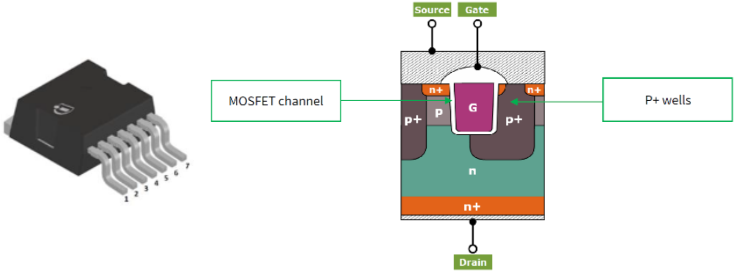




1) Motor: PMSM, 130mm*130mm
2) Encoder: Magnetic coding
3) Control Board: Motor control and communication
4) Driver Board: Driver circuit and power supply
5) Power Board: SiC-MOSFET for inverter
6) MCPCB: Aluminum base copper clad laminate
7) Back cover: incl. dissipation fins

CoolSiC™ MOSFEET technology:



SiC-MOSFET characteristics Vs IGBT

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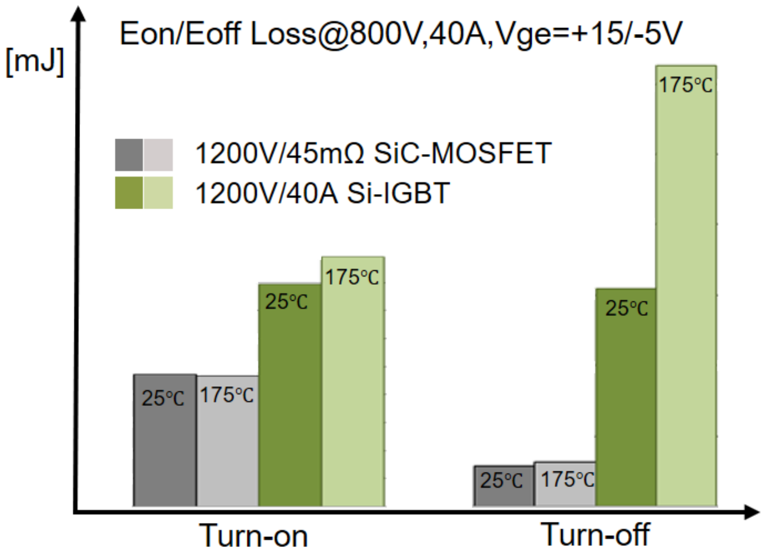
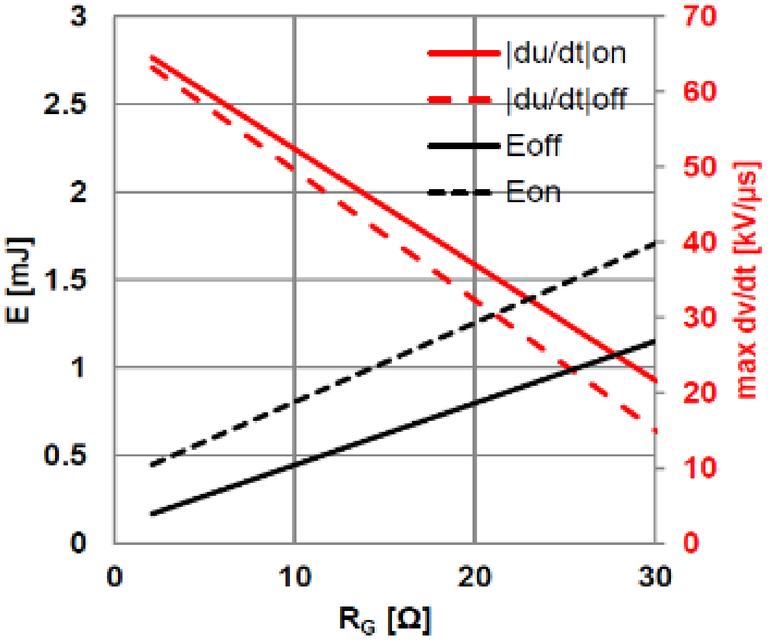
› Switching behavior



SiC MOSFET's switching losses

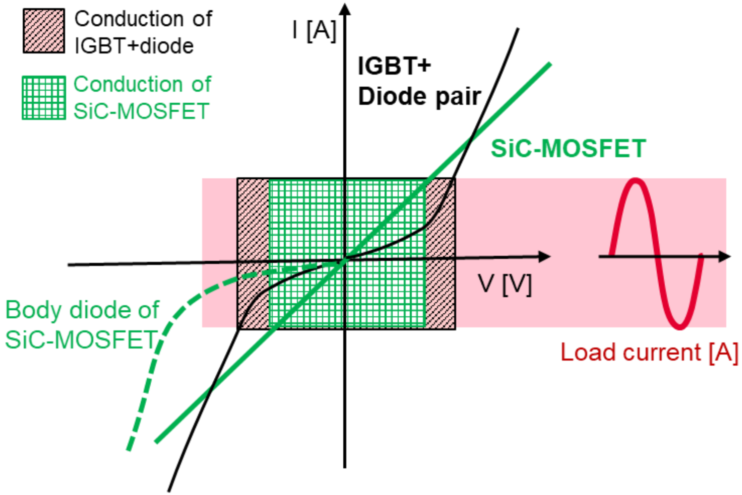
› dv/dt controllability



dv/dt controllability by Rg

SiC-MOSFET characteristics Vs IGBT

- On-state voltage



*for AC motor drive application

- SiC-MOSFET Power Losses:

- **Conduction loss**
  - V_{ds} = I_d*R_{dson} --------V_{gs} =15V----channel
  - V_{sd} = -I_d*R_{dson} --------V_{gs} =15V----channel
  - V_{sd} = $V_F(-I_d)$ ----------V_{gs} = -5V----body diode

- $$P_{con} = \frac{1}{T} \times [\int (V_{ds} * Id)dt + \int (V_{sd} * -Id)dt]$$

- **Switching loss**
  - $E_{on}=E(T_{vj},V_{dc},I_d,R_{gon})$
  - $E_{off}=E(T_{vj},V_{dc},I_d,R_{goff})$
  - $E_{rec}=E(T_{vj},V_{dc},I_d,R_{gon})$

- $$P_{sw} = \frac{1}{T} \times \int (E_{on} + E_{off} + E_{rec})dt$$

Simulation on servo system

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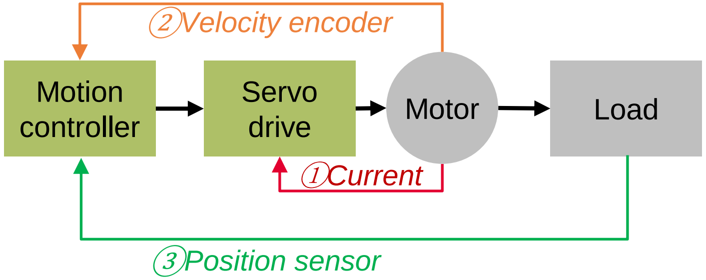
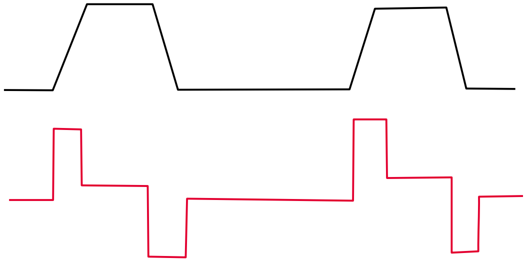
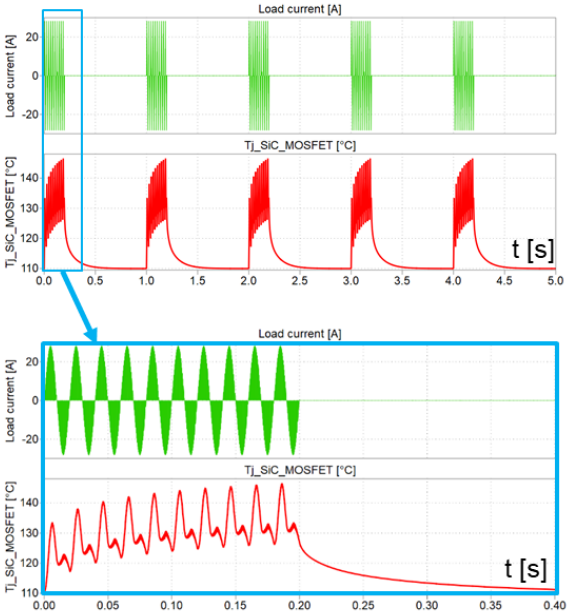
› Typical servo control set up



› Typical motion profile



› Power losses and Tvj



Pavg=4.4W
Per device

Vdc=800V, Uout=400V, Iout=20Arms, cosφ=0.8, fout=50Hz, fsw=20 kHz, Th=110℃. 20% operating duty per second.

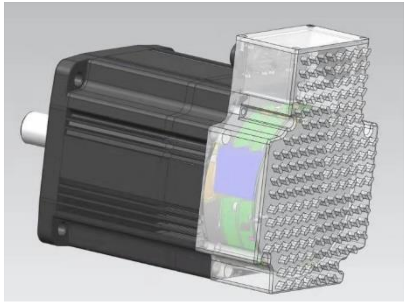
Simulation

› Natural convection cooling

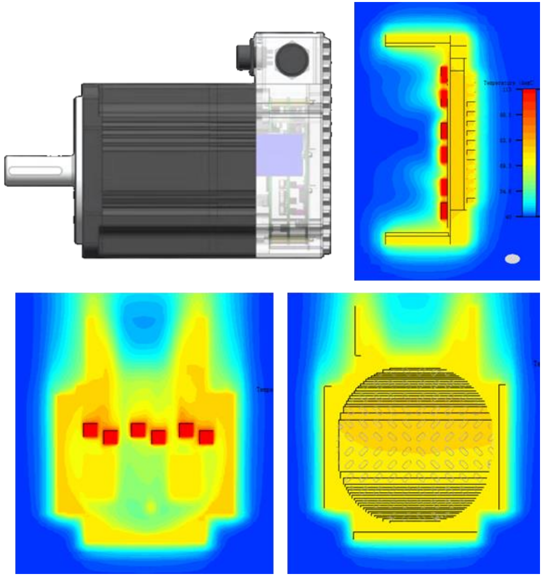
$$S = \frac{P_{avg}}{h \times \Delta T}$$

S is the required surface area
P_{avg} is the average value of power loss
h is the connective heat transfer coefficient
ΔT is the temperature gradient

Based on the simulation results, the design values are selected as P_{avg}=30 W, ΔT=25 ℃, h= 4 W/(m2*K) – it is an empirical value for natural convection cooling. Thus, the minimum value of the surface area '*S*' is calculated as 300 cm^2.
This value is used for designing the dissipation fins to increase the surface area of back cover.

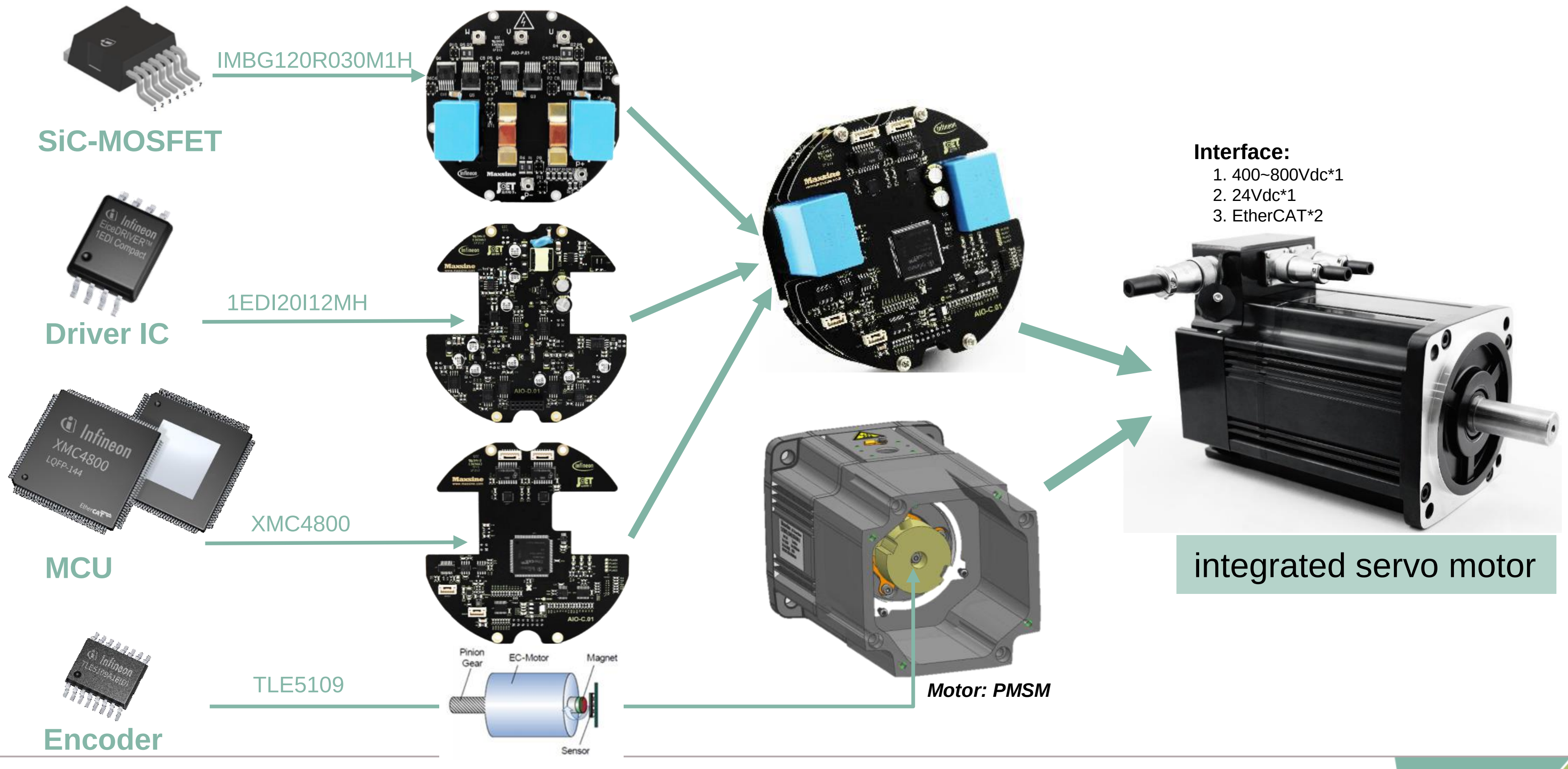


› Thermal simulation

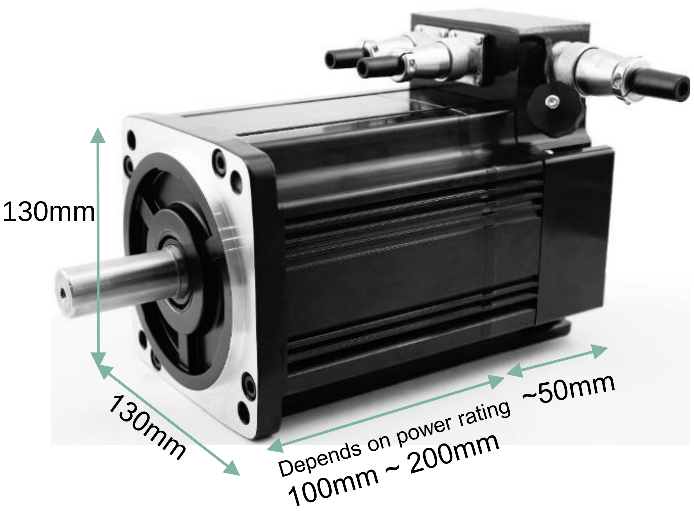


Natural convection cooling:
Pavg=5W per switch (+10% margin), Ta=40℃
- Surface temperature of the back cover is 70~80℃.
- Maximum temperature is 113℃ at the top of the MCPCB

Demonstrator design



Demonstrator design



integrated servo motor

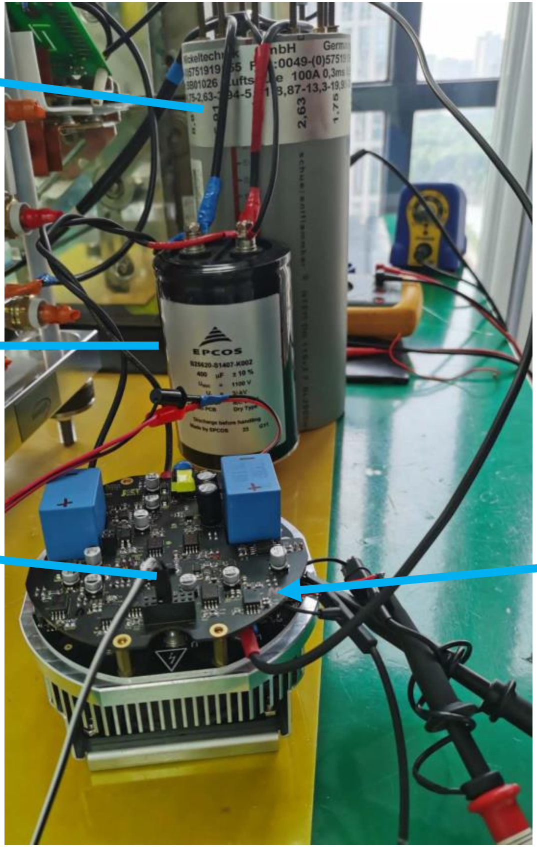
~15kW

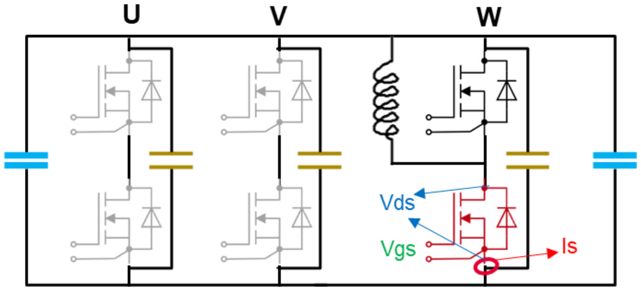
power per device

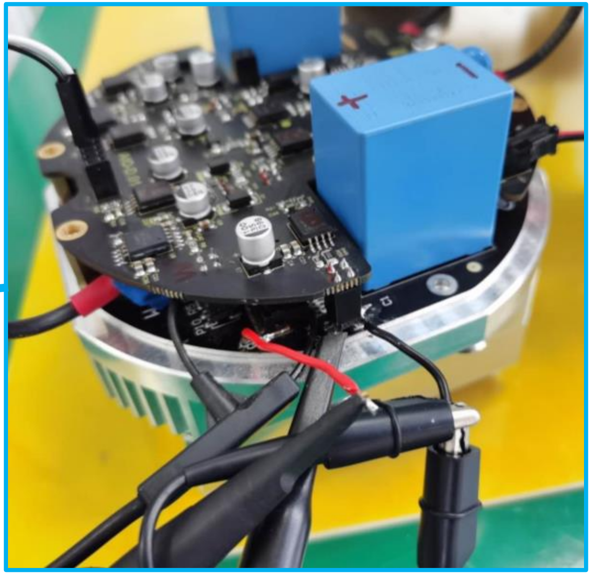
~1kW

	SMD	Natural convection cooling	Forced air cooling
Rdson [mΩ]	**1200 V D²PAK-7 Pin**	**Typical/Peak power rating**	**Typical/Peak power rating**
30	IMBG120R030M1H	3kW/9kW	9kW/15kW
45	IMBG120R045M1H	2.67kW/8kW	7.5kW/13kW
60	IMBG120R060M1H	2kW/6kW	6kW/10kW
90	IMBG120R090M1H	1.5kW/4.5kW	4kW/8kW
140	IMBG120R140M1H	1kW/3kW	3kW/6kW
220	IMBG120R220M1H	750W/2.2kW	2kW/4kW
350	IMBG120R350M1H	400W/1.2kW	1kW/2kW

Set-up for double pulse test







- SiC-MOSFET
  - IMBG120R030M1H
  - Phase W, low side
- Driver IC
  - 1EDI20I12MH
- Power supply
  - +15.8V/0V
- Gate resistor
  - 10Ω and 20Ω
- Junction Temperature
  - RT, ~25℃
- Commutation loop
  - ~17nH
- Current probe delay correction
  - -8ns

Switching Waveforms

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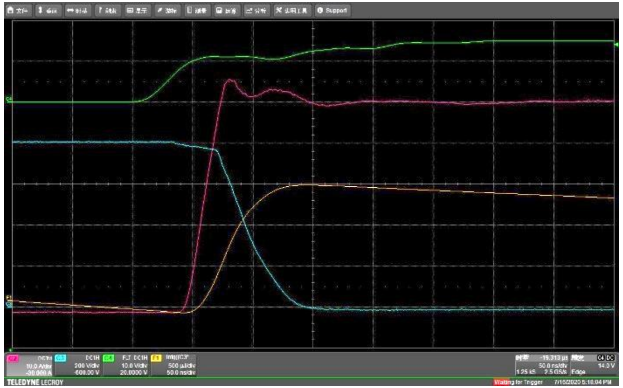
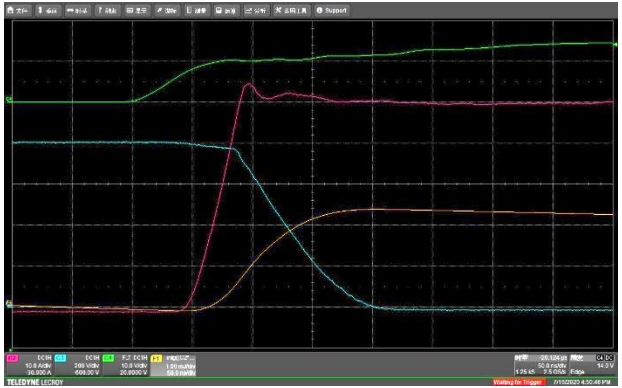
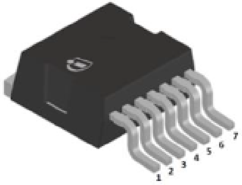
› Rg = 10Ω, 800V, 50A

› Rg = 20Ω, 800V, 50A

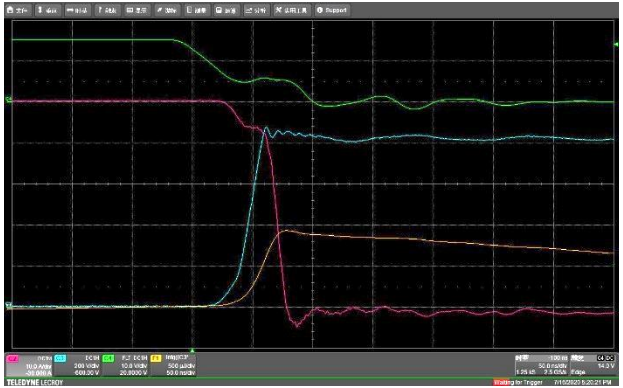
Turning on

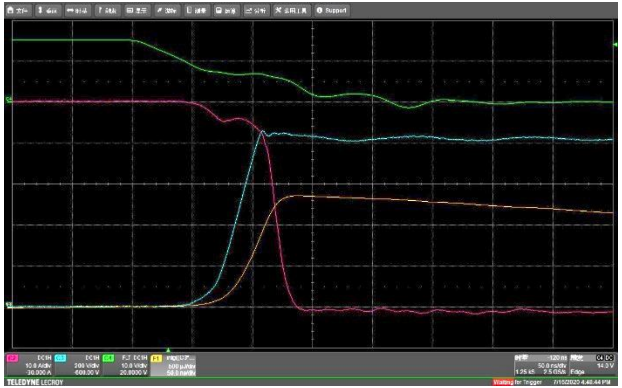




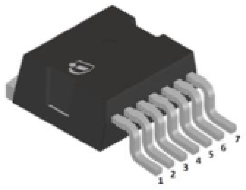


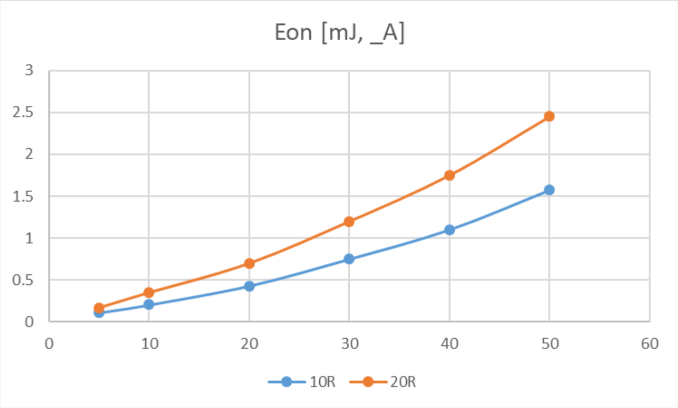
Turning off

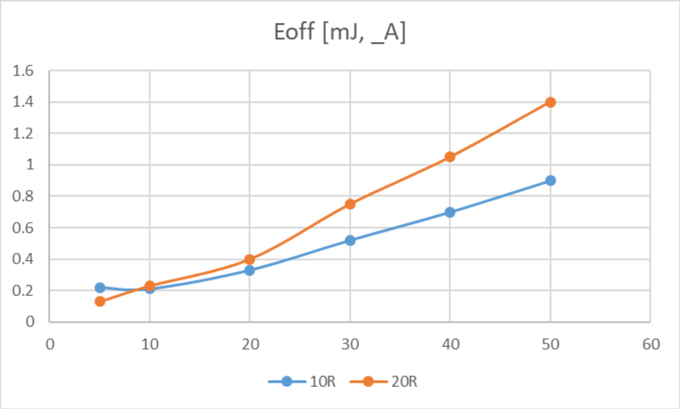




Overview

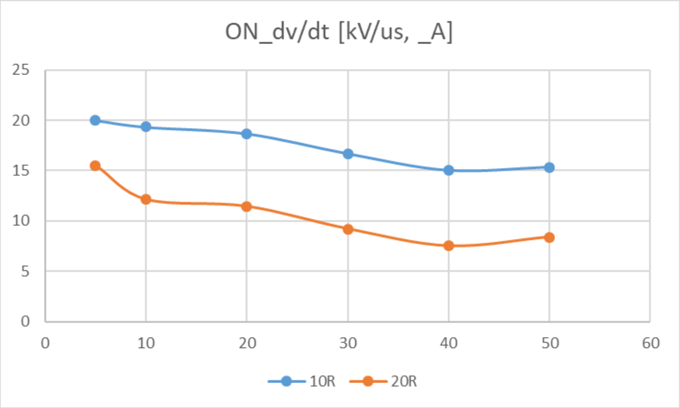


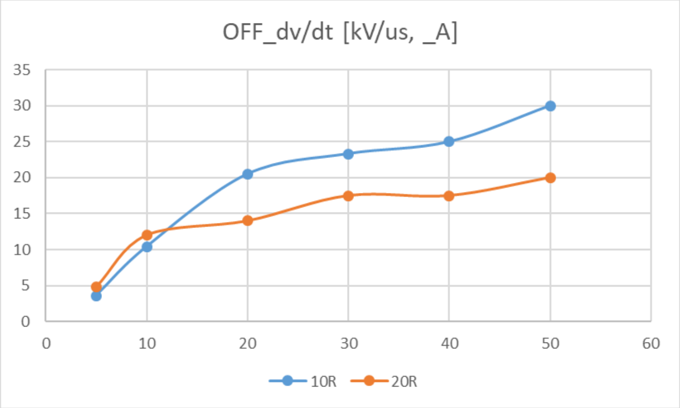




Note:

- The dv/dt is measured from Drain-Source pin of the SiC-MOSFET in double pulse test.
- In the real application with motor load, the dv/dt would be reduced by the parasitic capacitance of windings.





Experiments

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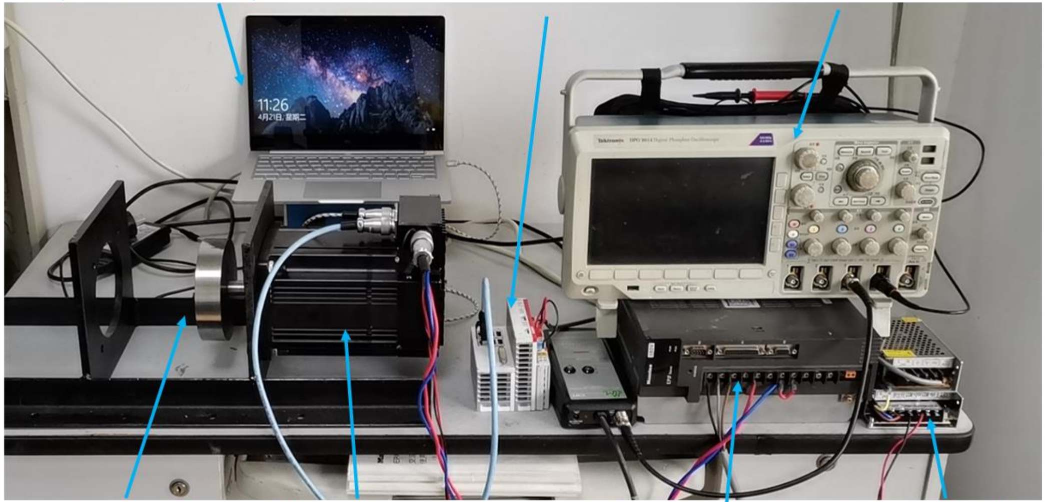
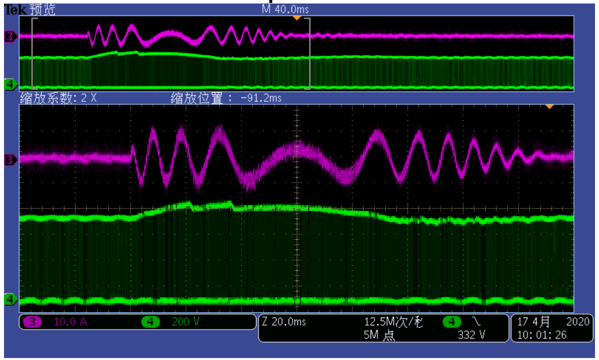
Acceleration and **Deceleration** (from +1500 rpm to -1500 rpm).

Computer software platform   Beckhoff controller   Oscillator

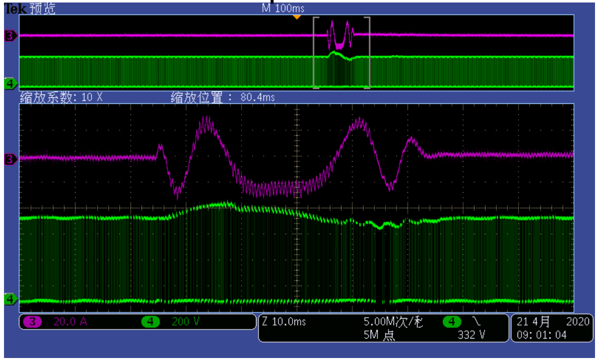


Inertia simulator   Servo Motor   DC power supply   Auxiliary 24V

Normal response in 150ms



Fast response in 50ms



CH3: AC line current, CH4: V_{DS} of SiC-MOSFET

Outlook and Conclusion

- **The benefits of SiC-MOSFET for servo motor**
  - Fewer losses both in Pcon and Psw
  - Higher power density
  - Embedded solution is available
  - Cooling design without fan(no maintenance issue)
  - Less voltage spike stress for motor(no traveling wave reflection due to short cable length)

- **The challenge of SiC-MOSFET for servo motor**
  - SiC device has to slow down the speed to meet the dv/dt limitation of the motor.
  - Servo motor can adopt the following measures to enhance the ability to resist dv/dt
    A. Change the frame material to strengthen the insulation
    B. Select professional class F laminated insulation paper
    C. Use a vacuum-dipping process with two-component epoxy resin

Acknowledgement

Thanks for great support from JingChuan and Maxsine

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