

#### Exploration of the Electric Current Flow inside Power Modules and Chips with Tiny Sensors Ichiro Omura Kyushu Institute of Technology





### Agenda

- Introduction: Why?
- Chip current distribution measurement for DBC/Chip level screening
- PCB Rogowski coil for current measurement in power module and chip
- Integration possibility of output current sensor in IPM with PCB Rogowski coil
- Conclusions



#### Measured current imbalance in DBC-module



T. Domon et al., IEEJ 2004

Clearly, Current imbalance exists among parallel IGBT chips, especially at turn-off and turn-on





Why electric current flow measurement inside power modules and chips?

- Feedback to power module design for balanced current flow
- <u>Gate drive circuit optimization / feedback</u>
- DBC/chip level <u>screening method</u> in mass production lines
- Integration of current sensing function in the power module



• Others, such as short-circuit protection









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By Y. Kasho, M. Tsukuda, H. Hirai, H. Tomonaga



### Basic idea for screening in DBC/chip level



#### Inductance matrix calculation with "Sonnet-2D"→SPICE simulation

2D simulation is more than X10 faster than 3D simulation.



# Configuration of 16ch sensor array module



The 16ch sensor array module consists of spiral coils on the both side of the films, analog amps



#### **Demonstration setup**

Test head



Kyushu Institute of Technology

#### Screening tester

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# Magnetic flux distribution example (Double pulse test)





# Method of normal/abnormal classification (two IGBTs on a DBC)

#### Normal/abnormal classification method with statistical approach







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By M. Koga, M. Tsukuda, K. Nakashima, H. Yamaguchi





- Use of tiny core-less coil on PCB
  - Reproducibility, mass-productivity(Low cost), less flexibility
  - Improvement with advancement of PCB technology
  - Integration in gate circuit board etc.
- <u>Analog + digital processing</u>
  - Automatic calibration, Signal equalizing
- In-house high speed design tool

- Application specific design



Consists of printed-circuit board (PCB)

![](_page_12_Picture_12.jpeg)

![](_page_12_Picture_13.jpeg)

Installation on DBC for chip current measurement

![](_page_13_Picture_0.jpeg)

#### **Fishbone coil pattern**

![](_page_13_Figure_2.jpeg)

![](_page_13_Picture_3.jpeg)

# Analog + digital processing

- 2-stage signal processing
  - Analog incomplete integration circuit (Shorter RC-constant)
  - Digital compensation of low frequency region

![](_page_14_Figure_4.jpeg)

 $I(t) \propto V(t) + \frac{1}{CR} \int V(t) dt$ 

![](_page_14_Figure_6.jpeg)

## In-house high speed design tool

#### Distribution of the mutual inductance by in-house highspeed simulator (MATLAB)

![](_page_15_Figure_2.jpeg)

# Coil pattern design

in-house high-speed simulation and experimental results for mutual inductance error ratio

![](_page_16_Figure_2.jpeg)

![](_page_16_Picture_3.jpeg)

![](_page_17_Picture_0.jpeg)

# Demonstration

- Two IGBTs are parallel connection on DBC
- Gate signal delay to IGBT B

![](_page_17_Figure_4.jpeg)

- Current imbalance during turn-off is measured
- Total current is coincided to CT result

![](_page_17_Picture_7.jpeg)

## Demonstration

![](_page_18_Figure_1.jpeg)

#### It is possible to current measurement even in a limited space

![](_page_18_Picture_3.jpeg)

# 16 channel system

![](_page_19_Picture_1.jpeg)

![](_page_19_Figure_2.jpeg)

#### Labview (NI digitizer setting)

![](_page_19_Picture_4.jpeg)

#### Labview (calibration)

![](_page_20_Picture_0.jpeg)

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#### By K. Takahara, K. Hasegawa, S. Tabata

![](_page_20_Picture_8.jpeg)

# Inverter output current measurement function integration in IPM

![](_page_21_Figure_1.jpeg)

Output Current

![](_page_21_Picture_2.jpeg)

New Method
PCB coils are placed on
negative/positive bus
→Reproduction of output current
from switching current

K. Hasegawa, S. Takahara, S. Tabata, M. Tsukuda, and I. Omura, "A New Output Current Measurement Method with Tiny PCB Sensors Capable of Being Embedded in an IGBT Module," *IEEE Trans. Power Electron*, vol. 32. no. 3, pp. 1707-1712, Mar. 2017.

![](_page_21_Picture_5.jpeg)

![](_page_22_Picture_0.jpeg)

#### **Current Reproducing Procedure**

![](_page_22_Figure_2.jpeg)

# Experimental setup with IGBT Module

![](_page_23_Figure_1.jpeg)

FPGA eliminates influence by reverse recovery or turn-off tail current

![](_page_23_Picture_3.jpeg)

![](_page_24_Picture_0.jpeg)

#### **Transient response**

![](_page_24_Figure_2.jpeg)

Note: Delay of half of PWM cycle will appear in practical implementation

![](_page_24_Picture_4.jpeg)

![](_page_25_Picture_0.jpeg)

### Conclusions

- Why: package design, gate drive optimization, new screening method, sensor for protection and possibility of output current sensor integration in IPM, etc.
- Practical examples
  - DBC/Chip level screening method
  - PCB Rogowski coil for power module
  - Integration of output current sensor in IPM
- PCB coils advantage and requirement
  - PCB coil has advantage of reproduction of the performance, cost, size (thickness), physical strength (<u>but less flexibility</u>)
  - Design tool is required for application specific design
  - Digital system will help the measurement for automatic calibration, waveform processing

![](_page_25_Picture_11.jpeg)

### **Related papers**

- M. Koga et al. CIPS2016
- M. Tsukuda et al. ESREF2016
- M. Tsukuda et al. CIPS2016
- H. Tomonaga et a;. ESREF2015
- M. Tsukuda et al. ESREF2015
- S. Tabata / K. Hasegawa et al. ISPSD2017
- H. Hasegawa et al. IEEE Trans on PE, 2017-03
- K. Nakashima(中島), IEEJ Workshop, 2015 in Japanese
- K. Takahara(高原), IEEJ Workshop, 2015, in Japanese
- H. Yamaguchi(山口), IEEJ Workshop, 2014, in Japanese
- H. Hirai, ISPSD 2012
- Y. Kasho, ESREF 2011
- Find at Kyushu Institute of Technology Academic Repository
  - http://power.kyutech.ac.jp/en/publications.html

![](_page_26_Picture_15.jpeg)

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÷	Publications	Satellite Electrical Power System		D	2017	
		Current Measurement Function	I.Omura	Proc. of ISPSD2017	2017	
	Event	Current Distribution Based Power Module Screening by New	Masanori Tsukuda, Daisuke Yuki, Hiroki Tomonaga, Hyoungseop Kim,	Proc. of ISPSD2017	2017	
•	Document	Normal/Abnormal Classification Method with Image Processing	Ichiro Omura			
	Access	An Evaluation Circuit for DC-Link Capacitors used in a Single-Phase PWM Inverter	Kazunori Hasegawa, Ichiro Omura, Shin-ichi Nishizawa,	PCIM Europe2017	2017	