16-channnel micro magnetic flux sensor array
for IGBT current distribution measurement

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Abstract

Current crowding of IGBT and power diode in a chip or among chips is a barrier to the realization of highly-reliable power module and power electronics system. Current crowding occurs because of the parasitic inductance, difference of chip characteristics or temperature imbalance among chips. Although current crowding among IGBT or power diode chips has been analysed on numerical simulations, no sensor with sufficiently high special resolution and fast measurement time has yet been demonstrated. Therefore, the author developed and demonstrated 16-channel flat sensitivity sensor array for IGBT current distribution measurement. The sensor array consists of tiny-scale film sensors with analog amps and shield case against noise. The array and digital calibration method will be applied for reliability analysis, designing and screening of IGBT modules.

1. Introduction

Current crowding of IGBT and power diode in a chip or among chips is a barrier to the realization of highly-reliable power electronics system. Current crowding occurs because of the parasitic inductance [1], difference of chip characteristics or temperature imbalance among chips [2, 3]. Although current crowding among IGBT or power diode chips has been analysed on numerical simulations [4, 5], no sensor with sufficiently high special resolution and fast measurement time has yet been demonstrated. For example, commercialized current transformer and Rogowski coil is too large to realize the high special resolution around bonding wires [6-8]. Therefore film sensor is suitable [9]. However, it's difficult to maintain fast measurement time and flat sensitivity because array sensor needs amps for each sensor and single sensor takes long scanning time.
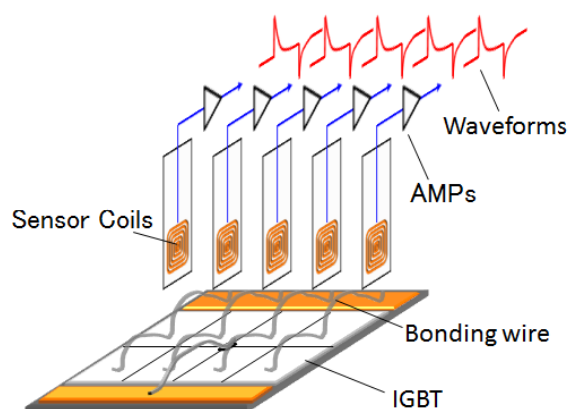

Fig. 1. Schematic view of proposed measurement method.

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Furthermore, conventional methods using a film sensor or film sensors require insertion between bonding wires [10, 11], which cannot apply high voltage measurement because the measurement needs insulating gel removal.

The 16-channel sensor array and digital calibration method proposed in this paper makes it possible to imagine the current distribution in IGBT chips by acquiring the local magnetic flux over bonding wires without the insertion (see Fig. 1). Therefore, fast measurement time and flat sensitivity is realised without making any change to the chip wiring. The 16-channel sensor array is able to apply reliability analysis, designing and screening of IGBT modules [12].

2. Current distribution imaging

2.1. Current distribution imaging method

To cancel the effect of noise from other current pass, differential signal of low position to high position from target bonding wires is employed for current distribution imaging. It's because the magnetic flux from distant current is considered
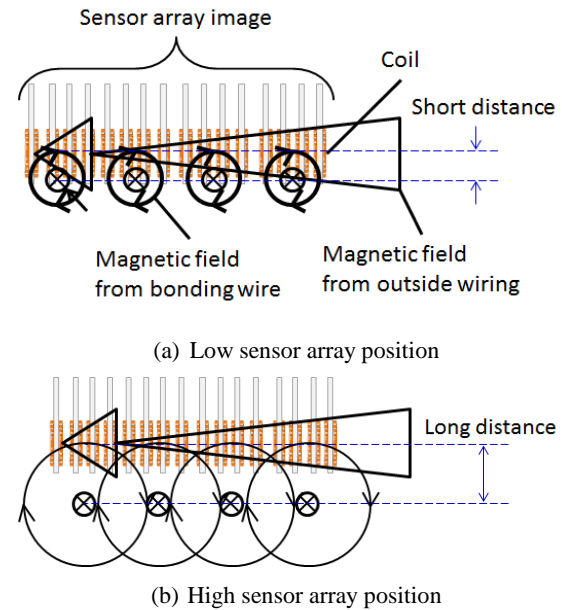

(a) Low sensor array position

(b) High sensor array position

Fig. 2. Noise cancel method by differential signal form high/low sensor array position
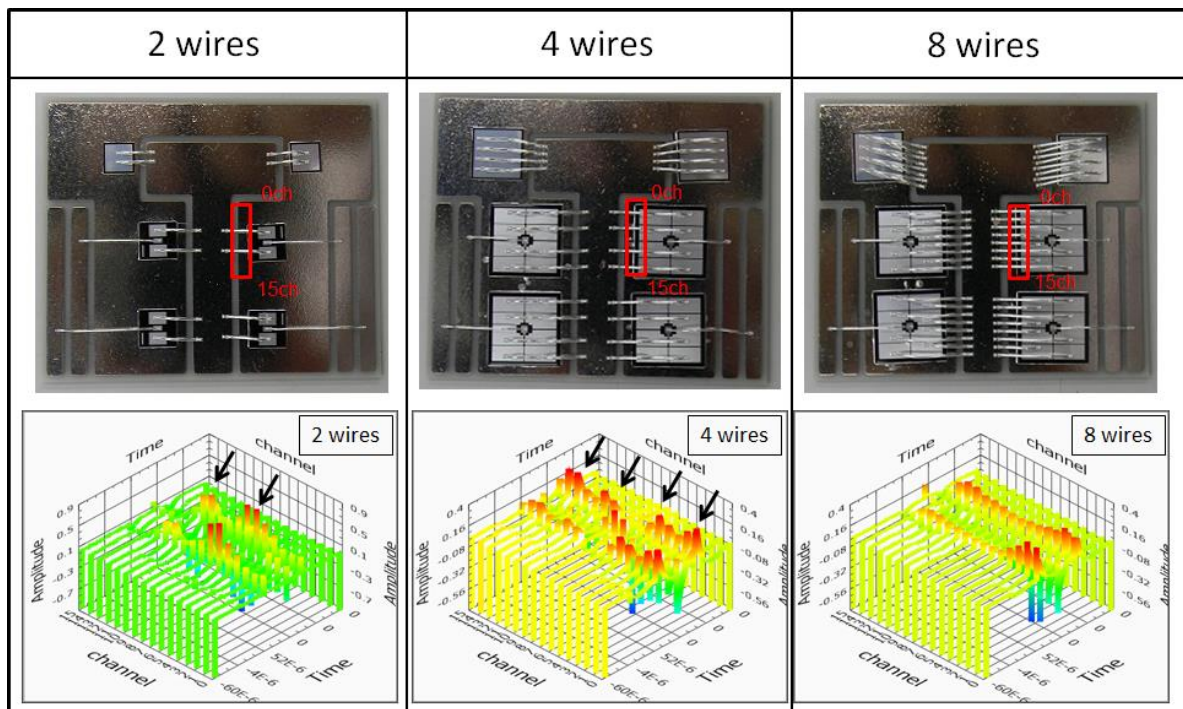

Fig. 3. Demonstration of current distribution imaging with 2, 4 and 8 bonding wires
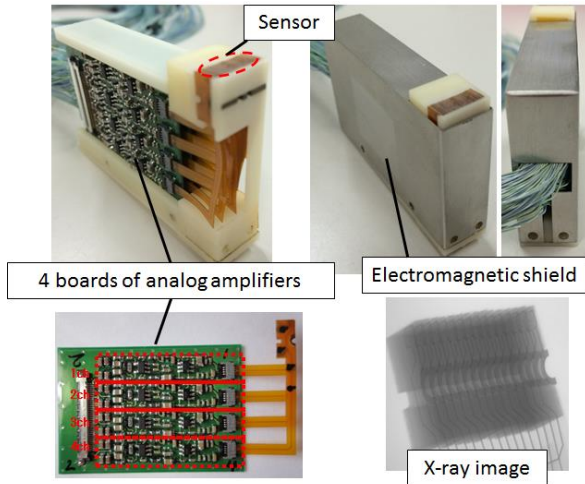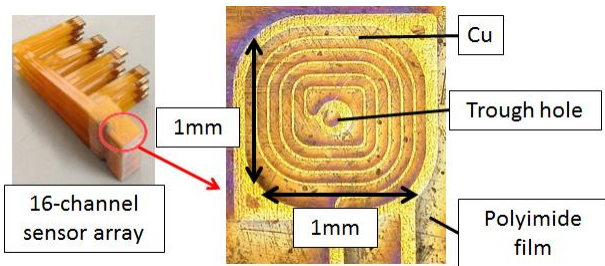
Fig. 4. 16-channel sensor array configuration.

Fig. 5. Sensor coil structure.

almost the same regardless of height. On the other hand, the magnetic flux from nearby bonding wires is different corresponding to the height (see Fig. 2).

## 2.2. Demonstration of current distribution imaging

The current distribution imaging is demonstrated by the differential signal for IGBT chip with 2, 4 and 8 bonding wires with the 16-channnel micro magnetic flux sensor array. The switching condition is inductive load and double pulses. DC voltage and turn-off current are 100 V and 100 A respectively. The signal distribution of 2 and 4 bonding wires successfully reflects current path (see Fig. 3). For the 8 bonding wires, the signals are continuous because the space between each wiring is very close.

## 3. 16-channel micro magnetic flux sensor array

3.1. Sensor array configuration

The 16-channel sensor array consists of film sensors, analog amps and shield case (see Fig. 4). About the sensors, the side of the spiral coil on polyimide film is 1mm x 1mm and each 5 turns on both sides (see Fig. 5). And the 16 sensors are laminated in position error of plus or minus 20 μm. 16-channel sensor array is installed near IGBT chips and bonding wires. However, the sensor array detects noise from untargeted bonding wires. Therefore noise reduction is required with analog amps and shield case. The analog amps increase signal to noise ratio and shield case reduces the effect of direct noise to the amp boards.

3.2. Sensor sensitivity digital calibration with correction values by LabVIEW program
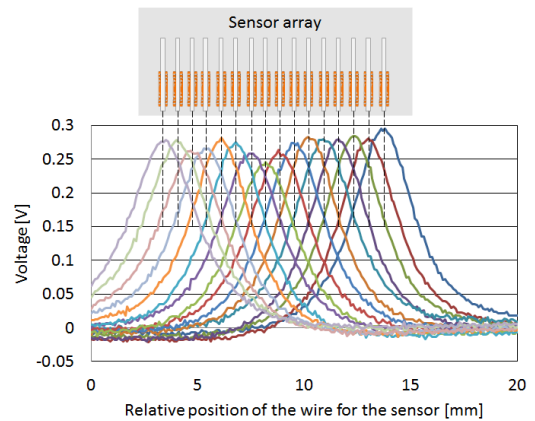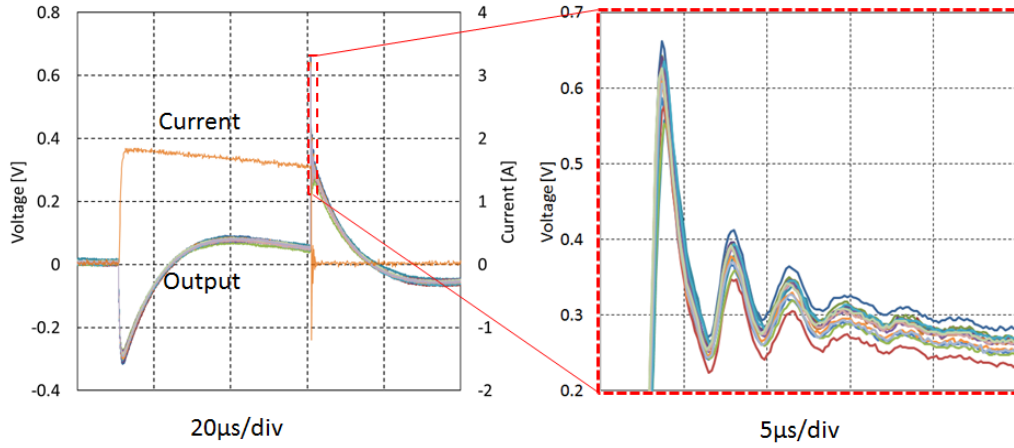

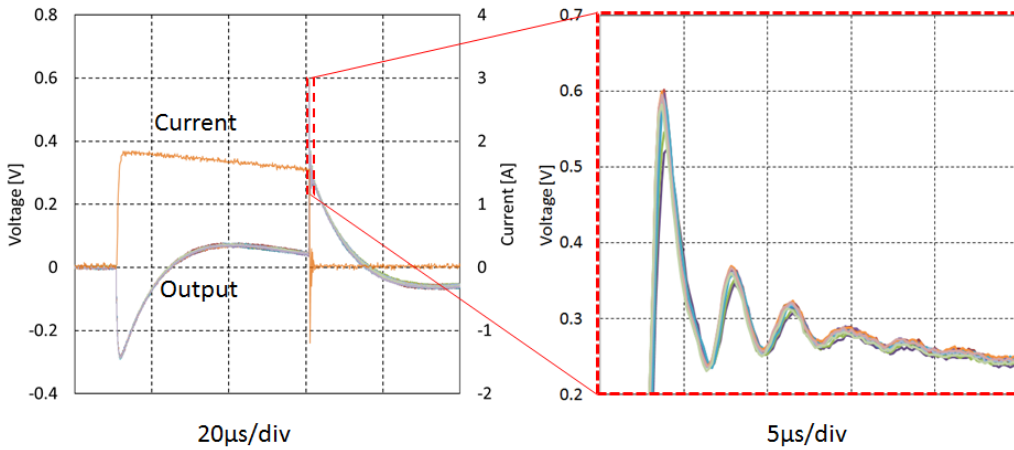(a) Original signals (before digital calibration)
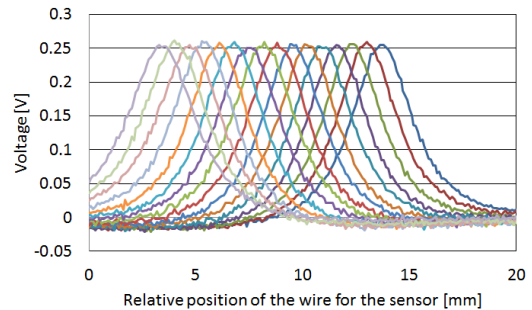
(b) Calibrated signals (After digital calibration)

Fig. 6. The spatial signal distribution just after turn-off.

(a) Original signals (before digital calibration)

(b) Calibrated signals (after digital calibration)

Fig. 7. Signal waveform before/after digital calibration.

It is difficult to realise flat sensitivity sensor array because of non-uniformity of resistor and capacitor for analog amps and error of sensor array levelness. However, it's not better to solve the problem by hardware architecture, because it takes long and costs much to maintain flat sensitivity. Therefore, we propose digital calibration with correction values by software (LabVIEW program).

The calibration is carried out according to the following procedures.

First, one wire flowing pulse current is scanned under the 16-channel sensor array and maximum signal existing just under each sensor is selected to calibrate the non-uniformity of the sensitivity. Next,

the correction values for agreement with the all signal waveforms are extracted with following equation.

$$S(t) \propto \Delta A \cdot \left(V(t) + \frac{1}{\Delta CR} \int V(t)dt \right) \qquad (1)$$

where S(t), V(t), t, ΔA and ΔCR are magnetic flux signal, output voltage (original signal), time, correction value of amplification and correction value of droop respectively. Finally, original signal waveform is calibrated with the correction values by LabVIEW program. The digital calibration is demonstrated. The sensitivity error in space is
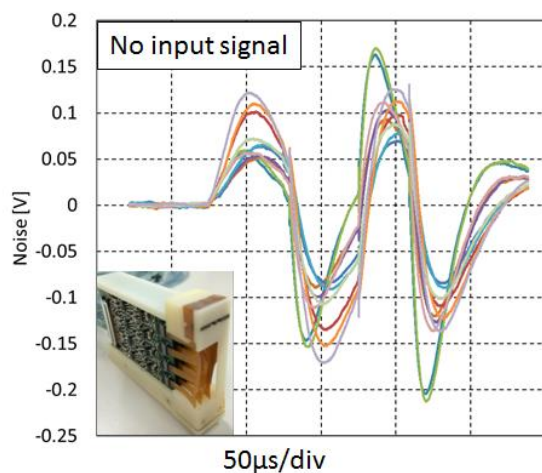
(a) Noise influence
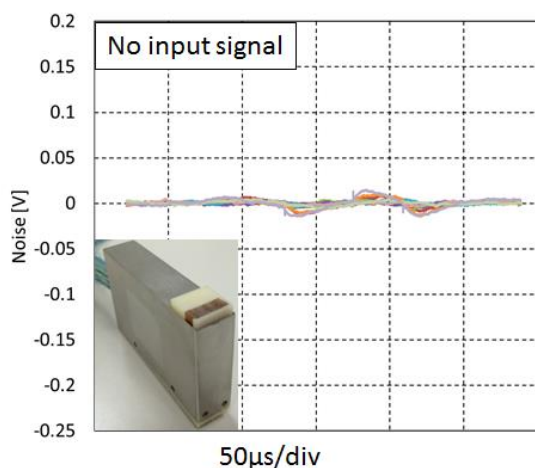
(b) Reduction of noise influence

Fig. 8. Noise reduction by shield case.

successfully reduced by the digital calibration and the sensitivity is to be flat (see Fig. 6). In addition, signal waveforms shown in Fig. 7 perfectly agree.

3.3. Noise shield

Noise shield effect is confirmed by signal waveform from amps with/without the shield case. The input terminals of the amps are shorted circuit in experiment. Thus, the signal waveforms directly show noise effect nearby wiring. It's confirmed that the noise effect is greatly reduced to 10 % with the shield case (see Fig. 8).

4. Conclusion

16-channel flat sensitivity sensor is developed and demonstrated for currant distribution measurement. The 16-channel sensor array consists of tiny-scale film sensors with analog amps and shield case against noise. The 16-channel sensor array and the digital calibration method will be applied for reliability analysis, designing and screening of IGBT modules.

Acknowledgements

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