# Envelop Tracking Based Embedded Current Measurement for Monitoring of IGBT and Power Converter System

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## Abstract

Health monitoring of the power conversion system is very important. Therefore, we developed a new method for measuring IGBT currents and reproducing average load current to monitor IGBTs. This method was successfully tested on an experimental setup which showed that the tiny PCB sensors can be integrated into intelligent power modules. We proposed an inexpensive analogue circuit which is suitable for capturing current information from a tiny PCB Rogowski coil. The sensors and corresponding circuit can be embedded into an Intelligent Power Module. The method was named "Envelop tracking" as it simultaneously measures the currents of the high and low side switches of a power converter and reproduces the upper and lower edges of the load current which can be averaged by further digital processing.

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## 1. Introduction

The high reliability of power modules is significant issue as they play main roles in economics due to their energy-saving and cost efficiency properties [1-5]. The condition monitoring (CM) of power conversion systems is also important because protection occurs before breakdown of the system [6].

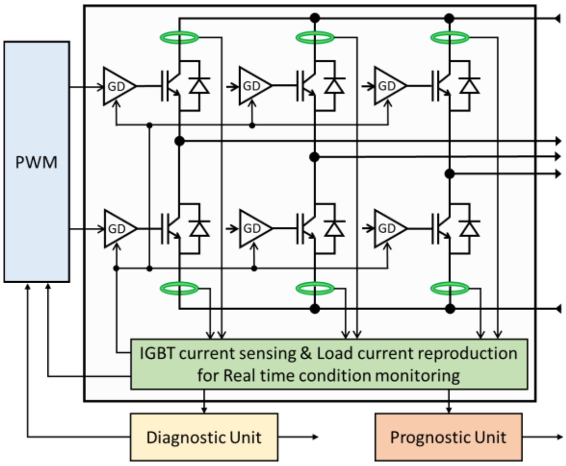

Fig. 1. Intelligent Power Module with the health monitoring system.

In other words, a health monitoring system is essential to create a reliable power conversion system. (Fig.1). For health monitoring systems, the fully integrated Intelligent Power Modules (IPMs) must be produced. Our study is focused on the integration of Real time condition monitoring for IPMs, and introduces Envelop tracking, a new method of measuring the insulated-gate bipolar transistor (IGBT) currents and reproduction of the load currents. Envelop tracking can determine the peak current, the output current, and the ripple current all in a single measurement which will be done inside an IPM. This way the new method economizes large external sensors and reduces the size and cost of a power system. Since every switching device in the IPM must be monitored, six sensors are used in three-phase power conversion system to detect power devices currents separately (Fig.1).

Fig. 2. Miniature (green) PCB coil and conventional current sensor.

While the miniaturization of conventional current sensors, such as current transformers, is limited by the principles of operation physics, Rogowski coil type sensors can be successfully miniaturized and integrated into IPMs [7, 8]. Several studies show that the Rogowski coil is suitable for measuring very high-speed pulses, up to nanosecond rise-time [8, 9], but is not suitable for low frequency regions, such as the load current measurement of power inverters.

In this study, we develop a new method of capturing current information from a current sensor called “PCB sensor”, which has a novel design [10] based on a tiny printed circuit board (PCB) Rogowski coils (Fig.2). Current sensors in the power inverters are mostly situated on the low frequency region and measure load currents. However, module integrated current sensors in an IPM can be placed on the high-speed transient switching current side of the module and can monitor the power semiconductor device much faster. This way, tiny PCB Rogowski coils can replace conventional current sensors, even if their measuring ratings are different. The frequency characteristic of a tiny PCB Rogowski coil is linear in the region from 10 kHz up to 10 MHz [11].

## 2. Envelop tracking method

### 2.1. Basic concept

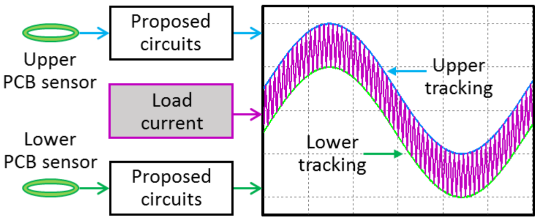

Fig. 3. Envelop tracking method. Additional current sensor is used for proofing.

In previous research, a switching device’s on/off currents both measured by a single PCB sensor. Therefore integrator circuit of the PCB sensor will produce positive and negative polarity pulses which require rectification for further digital processing [7]. Our study proposes to measure IGBT currents by using two coils on both the high and low side switches simultaneously to bypass the rectification requirement, which was the main idea to detect the average current with a single PCB sensor (Fig.3). In our new concept, the “envelop tracking method”, two sensors will detect the upper and lower edges of the output current, and then the average value of the load current can be calculated by software. Since a full bridge IGBT module is used in our setup, two sensors can be positioned in the high and low side of one leg, or in both low sides of two legs only, or in both high sides of two legs only. Therefore, conventional current sensor is inessential in our setup as it is used only for proofing.

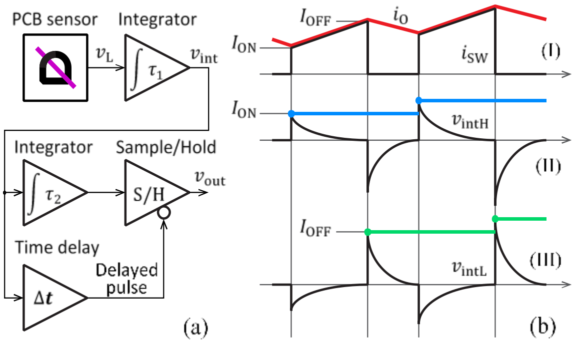

Fig. 4. Signal waveforms of the proposed circuit. (a) Block diagram of proposed circuit. (b) I. Switching current and load current, II. Upper PCB sensor pulse and sample/hold output, III. Lower PCB sensor pulse and sample/hold output.

When transistor switches off, the Rogowski coil (Lower or Upper PCB sensor in Fig. 3) will produce pulse with exact height which corresponds to the current value that is flowing through the load, the switch and the sensor coil. As shown in the previous implementation, this pulse is converted to voltage pulse by integration which is also used in our new method [7].

### 2.2. Circuit Implementation

Two identical analogue circuits based on inexpensive operational amplifiers are proposed in this study to capture upper and lower edges of the current signal simultaneously. A block diagram of the circuit is shown in Fig. 4(a). Each Rogowski coil will output $v_L$ pulses which are related to the switching current pulses. These pulses must be integrated to voltage signals with time constant $\tau_1$. The second integrator circuit with time constant $\tau_2$ is used for filtering out the reverse recovery oscillation of the current pulses. Then the proper height of the current pulses will be stored in the sample/hold amplifier. The sampling signal (delayed pulse) will occur after a short time delay ($\Delta t$) of the rising edge of the current signal $v_L$. The sample/hold amplifier output gives us a stable current signal for further digitizing process.

For lower edge tracking the same set of circuit will be used with another PCB sensor. The pulse polarity can be set the other way around by changing the direction of the coil which allows us to bypass the pulse rectification (Fig. 4(b. III)).

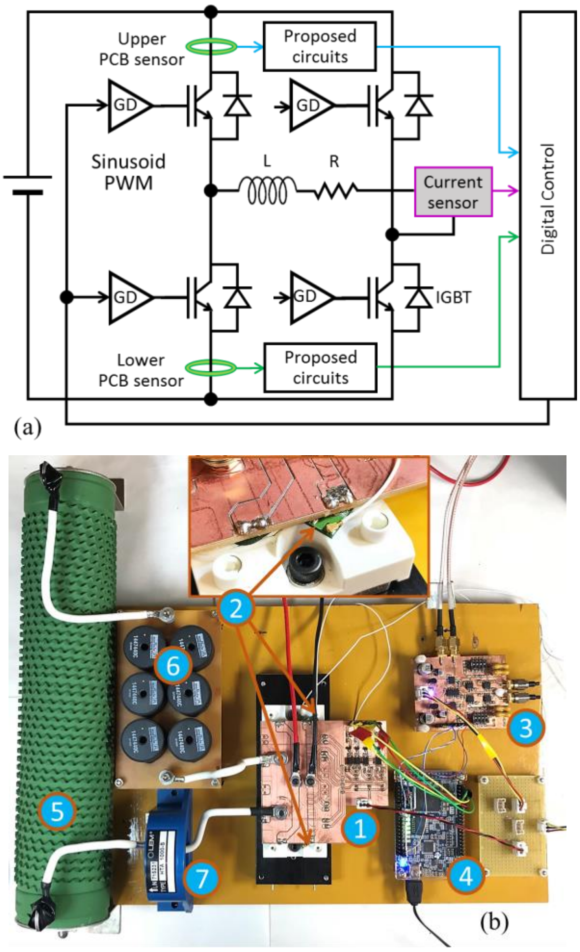

Fig. 5. Experimental setup. (a) Circuit configuration. (b) Photo of the experimental setup. 1. IGBT module with gate drivers, 2. Tiny PCB sensors (zoomed image is at the top), 3. Proposed circuits, 4. FPGA control board, 5. Load, 6. Inductor, 7. Conventional current sensor

## 3. Experimental results

### 3.1. Experimental setup

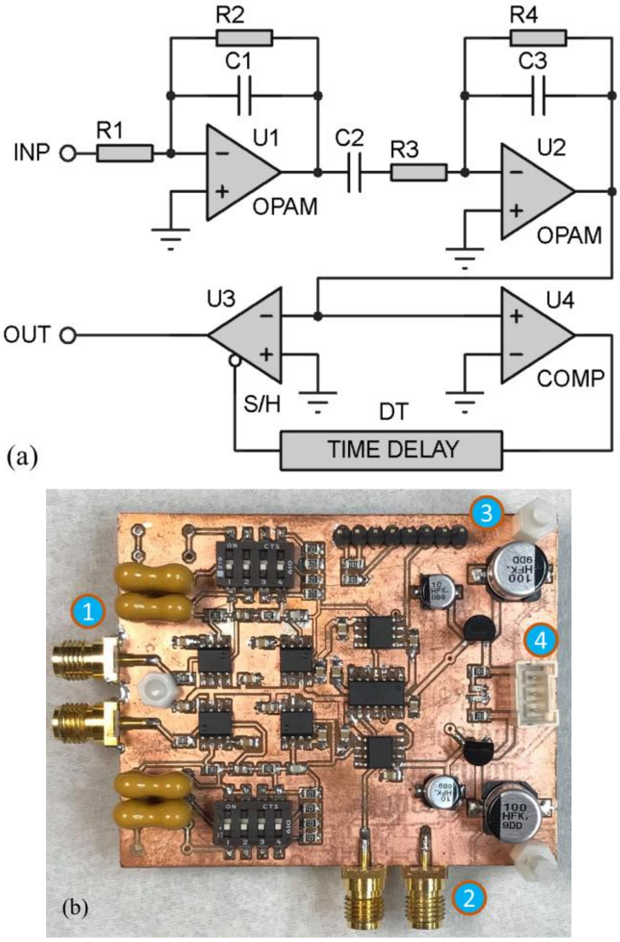

Fig. 6. Proposed circuit. (a) Circuit configuration. (b) Photo of the assembled circuit. 1. Sensor inputs, 2. Signal outputs, 3. Digital control connector,

To test our new method we have assembled the experimental setup with full bridge sine wave (50Hz) inverter circuit which is controlled by digital PWM with 5 kHz carrier frequency (Fig. 5). Two pieces of tiny PCB sensors (2) are placed on the IGBT module (1) as shown in Fig. 5b.

In this study we successfully developed our proposed circuit (Fig. 6) for converting tiny PCB sensor signals by using linear opamps and a sample-hold amplifier chip. To produce a delayed pulse for the sample-hold signal a linear comparator IC is used.

For experimental purpose time constant and gain of the integrators are changed by DIP switches to select different capacitances on U1 and different resistances on U2 to match range of the load current. Comparator (U4) output triggers the delayed Sample-hold signal when positive current pulse occurs on the output of the integrator. Proper time delay is adjusted by digital control module programmed in FPGA board. High speed, voltage feedback operational amplifier LM7171B from National semiconductor is used for integrators and sample-hold amplifier AD783 from Analog devices is used as the output amplifier.

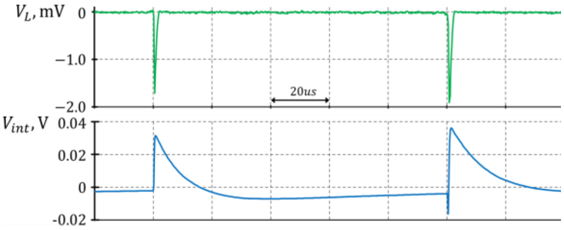

Fig. 7. Tiny PCB sensor output signal ($v_L$) and integrator output signal ($v_{int}$).

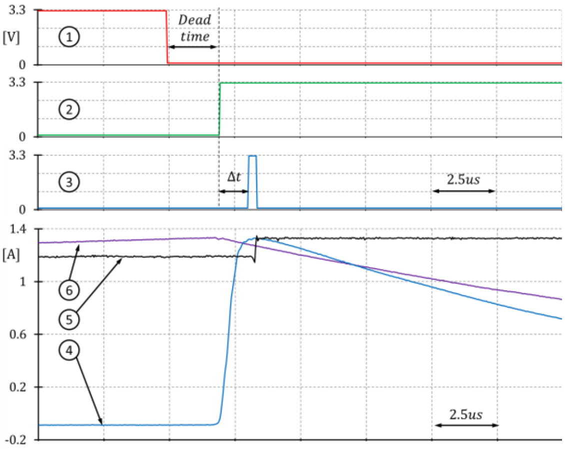

Fig. 8. Measured signal waveforms. 1. High side gate signal, 2. Low side gate signal, 3. Delayed Sample-hold signal, 4. Sensor integrator output ($v_{int}$), 5. Sample-hold amplifier output, 6. Conventional sensor output.

### *3.2. Measurements*

Tiny PCB sensor detects the current of IGBT as shown in Fig. 7. First integrator's output ($v_{int}$) is measured simultaneously with the sensor signal ($v_L$).

The digital sample-hold pulse (waveform 3 in Fig. 8) is produced in certain delay time ($\Delta t$) after switching the gate pulse (2). This will update the sampled current value (5) at the output by the exact height value of the integrator output (4).

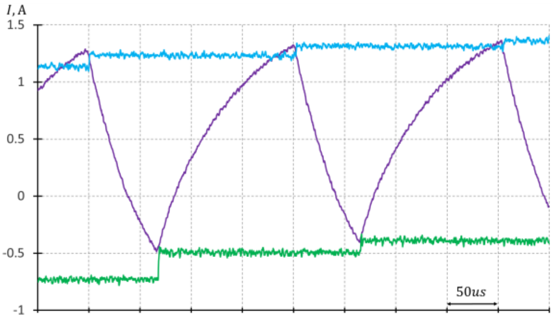

Fig. 9. Upper (cyan) and lower (green) sample-hold tracking signals catch exact points of output current.

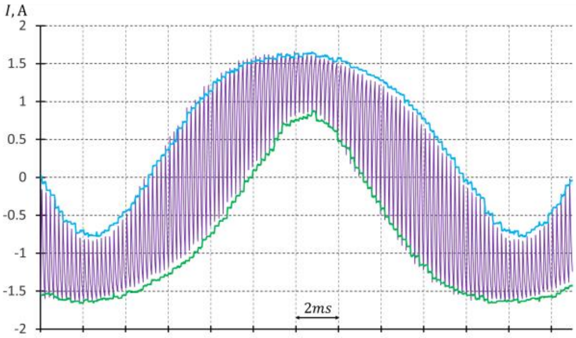

Fig. 10. The final result of new method.

By using both channels of the proposed circuit we acquired the successful result (Fig. 9, 10). Each channel output exactly follows upper or lower edges of the load current. Our experimental result shows that 98% of the measured data matches with conventional current sensor values (Fig. 10). These upper and lower edge signals will be digitized in the digital control system and average value can be calculated by software. Therefore we assume that our new method can be used for health monitoring and over current protection of the power conversion system.

## 4. Conclusion

This study successfully proposes the new "Envelop tracking" met determine the peak current, the output current and the ripple current all in single measurement which will be done inside an IPM. This way the new method is economizes external sensors and reduces the size and the cost of a power system. Therefore we conclude that this method is convenient for monitoring the health of a power system, and increasing the reliability.

## Acknowledgements

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## References

[1] R. Herzer, “Integrated gate drive circuit solutions,” *in Proc. Intl. Conf. on Integrated Power Electron. Sys. (CIPS)*, no. 1.2, Mar. 2010.

[2] B. Vogler et al., “Integration of 1200V SOI gate driver ICs into a medium power IGBT module package.” *in Proc. ISPSD,* pp. 97-100, 2010.

[3] M. März et al., “Power Electronics System Integration for Electric and Hybrid Vehicles,” *in Proc. CIPS,* no. 6.1, Mar. 2010.

[4] G. Majumdar et al., “Review of Integration Trends in Power Electronics Systems and Devices,” *in Proc. CIPS,* Mar. 2016.

[5] D. Cooper, “Power Module Integration: A new approach,” *IEEE Power Electron Mag.,* vol. 3, no. 3, pp. 31-36, Sep. 2016.

[6] Y. Avenas et al., “Condition monitoring: A decade of proposed techniques,” *IEEE Ind. Electronics Mag.,* vol. 9, no. 4, pp. 22-36, Dec. 2015.

[7] M. Tsukuda et al., “Micro PCB Rogowski coil for current monitoring and protection of high voltage power modules” *Microelectronics Reliability 64,* pp. 479-483, 2016.

[8] K. Hasegawa et al., “A New Output Current Measurement Method with Tiny PCB Sensors Capable of Being Embedded in an IGBT Module” *IEEE Transactions on Power Electronics,* PP (99):1-1, Sep. 2016.

[9] C. R. Hewson et al., “Verification of Rogowski current transducer’s ability to measure fast switching transients.” *in Proc. 21st Annual IEEE, Appl. Power Elec. Conf. and Expo*, 2006.

[10] Ruo-Yu Han et al., “Hybrid PCB Rogowski Coil for Measurement of Nanosecond-Risetime Pulsed Current” *IEEE Transactions on Plasma Science*, Vol. 43, pp. 3555-3561, Oct. 2015.

[11] M. Koga et al., “Application-specific micro Rogowski coil for power modules” *in Proc. CIPS*, Mar. 2016.