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60 GHz Wireless Signal Transmitting Gate Driver for IGBT

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Abstract— This paper shows the very first demonstration result of wireless IGBT gate drive using with 60 GHz wireless module with sufficient “real-time” control with 100 ns-level time delay with small fluctuation of the delay.

Keywords—IGBT, Gate driver, Signal isolation, Wireless

I. INTRODUCTION

IGBTs have been driven by “wired” signal since they were used the first power electronics application. According to the spread of IGBT application to variety of systems, and to the innovative radio technologies and cost down of RF modules, wireless signal transmission become attractive for the IGBT gate drive. Wireless signal transmission can potentially replace optical-based insulated signal transfer by establishing special “real-time” signal transmission protocol for IGBT gate drive. The technique will be attractive for many power electronics applications since control PCB board and power circuit board can be completely separated (Fig. 1 (a)). Series connected IGBT such as high voltage DC power transmission is another potential application of wireless gate signal transmission technology with the high voltage signal isolation (Fig. 1 (b)).

This paper demonstrated, for the first time, wireless signal transmission for IGBT gate signal “real-time” transfer using 60 GHz RF modules.

II. WIRELESS GATE DRIVE CONFIGURATION

Different from high speed wireless transmission for digital data transmission, gate signal is required to be transferred in real-time. Figure 2 (a) illustrates typical module configuration with seven layers. Wireless transmission for digital data transfer has long delay time with compression and the re-transmission control of transfer data. In addition, there is time fluctuation (Jitter) due to the data process time difference in each layer in wireless modules. The delay time and jitter are around several milliseconds so that the digital data transmission protocol cannot be used for the IGBT gate signal transfer.

Assuring the signal simultaneity for IGBT gate triggering with high reliability, following points are required.

- (1) Wide frequency band for rectangular wave transmitting
- (2) Short range wireless for smaller cross talk

- (3) Multi-channel configuration for signal transmitting reliability

- (4) Possibility of single chip module with antenna [1], [2] for future cost and size reduction

Figure 2 (b) shows an example of wireless gate drive protocol and configuration. The real-time application layer directory accesses the multiple physical layers.

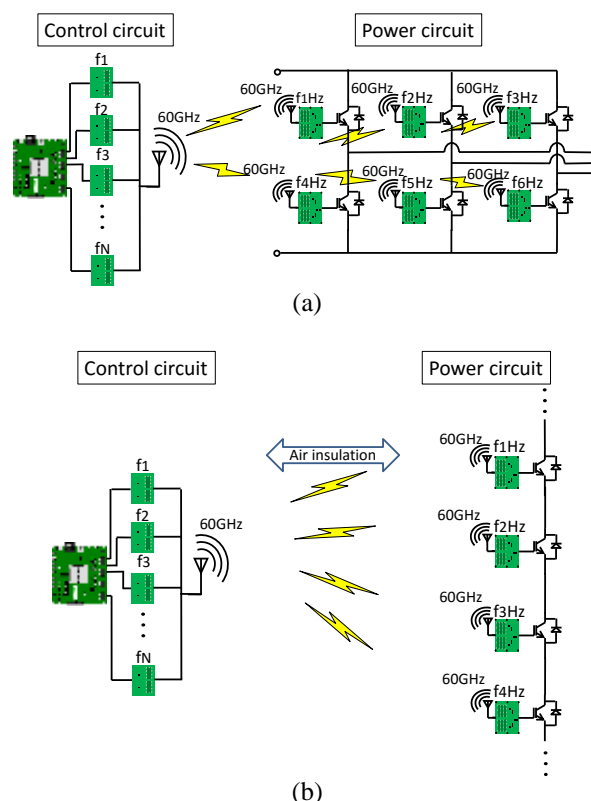


Fig. 1. Potential applications of wireless transmission for IGBT gate drive.

In the demonstration, we selected 60 GHz technology with wide frequency band width of 9 GHz from 57 GHz to 66 GHz. 60 GHz has the feature of short distance of signal transfer with absorption by oxygen in the air so that it has advantage for smaller cross talk.

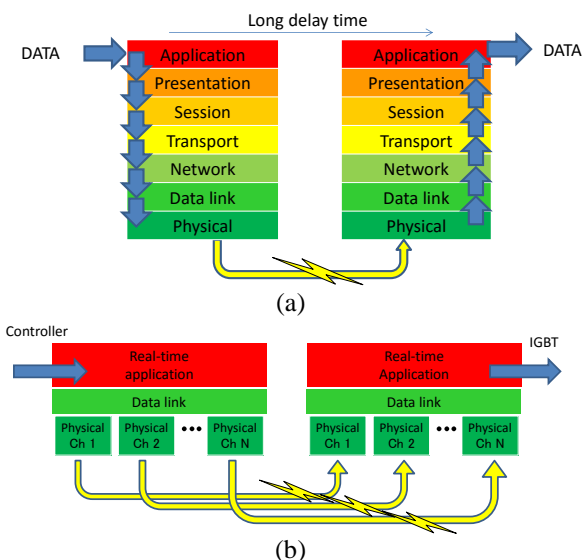


Fig. 2. Typical wireless module configuration (a) and wireless gate drive configuration.

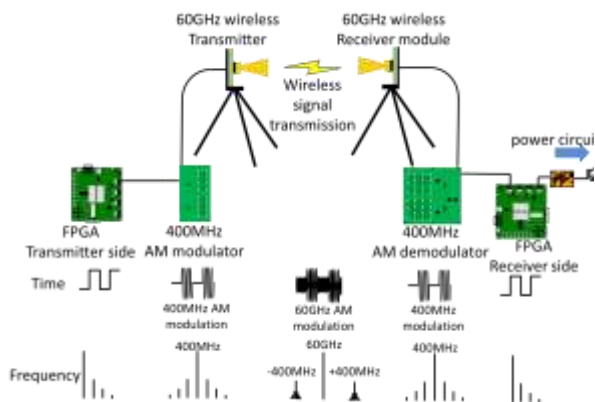


Fig. 3. Demonstrated wireless signal transmission gate driver for IGBT using 60 GHz modules

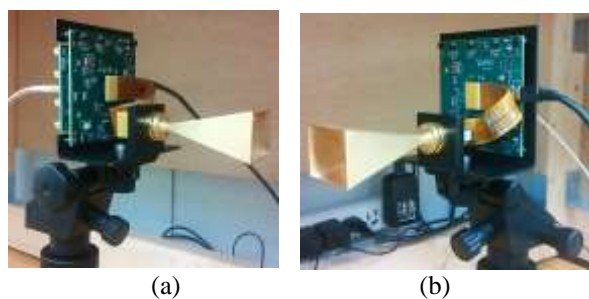


Fig. 4. 60 GHz radio frequency modules (a) Transmitter module (b) Receiver module

III. WIRELESS GATE DRIVE DEMONSTRATION WITH 60 GHz RF MODULE

The demonstrated wireless signal transmitting gate drive system for IGBT is shown in Fig. 3. We introduce a two-step modulation with 400 MHz AM modulator and demodulator. The PWM signal is transferred to 400 MHz modulator and the modulated signal is transferred to 60 GHz module. We directly access the physical layer of the wireless module to establish “real-time” signal transmitting. Assigning each IGBT gate signal channel to different frequencies (e.g., 400 MHz and 380 MHz etc.), multi-channel signal can be transferred with the 60 GHz technology. The wireless modules used in the demonstration are shown in Fig. 4. Table.1 shows detail of wireless modules, digital circuits and other components used in the demonstration. IGBT power circuit (buck converter) including the wireless gate-drive system with a 600 V 15 A IGBT is shown in Fig. 5. High side IGBT in the converter is controlled through the wireless gate signal transmission. We successfully demonstrated 60 GHz insulated IGBT gate drive with “real-time” wireless signal transmitting. Figure 6 shows experimental waveforms of the back converter.

TABLE 1. List of radio modules, digital circuits and other components

400 MHz modulator	MAX1472	MAXIM
400 MHz demodulator	AD8307	ANALOG DEVICES
60 GHz transmitter	V60TXWG2	VubIQ
60 GHz receiver	V60RXWG2	VubIQ
FPGA	Spartan-6	Xilinx

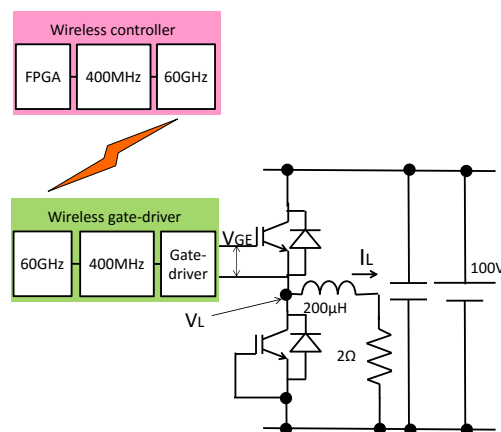


Fig. 5. Demonstrated power circuit and diagram for gate signal transmission.

Details of waveform for output signal from FPGA V_{PWM} , inductor voltage V_L and ripple current I_L are shown in Fig. 7. Sufficiently small time delay and fluctuation were observed in the power circuit waveforms.

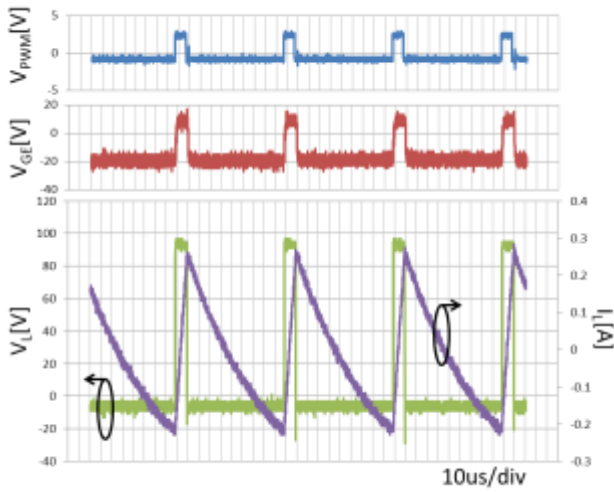


Fig. 6. Demonstrated waveforms of FPGA output signal (V_{PWM}), IGBT gate voltage (V_{GE}), load voltage (V_L) and inductor ripple current (I_L). Inductor DC current is ~ 5 A.

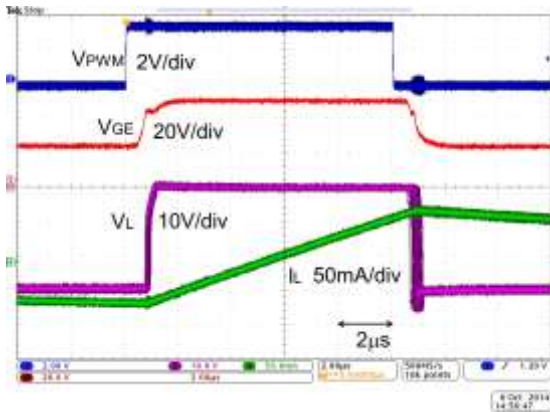
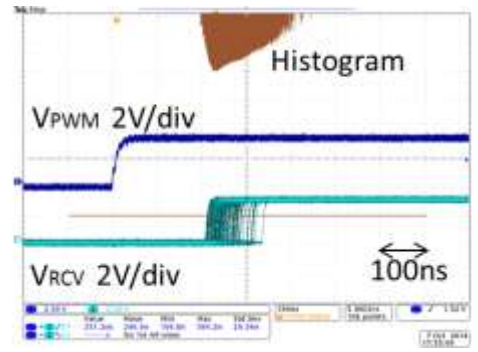


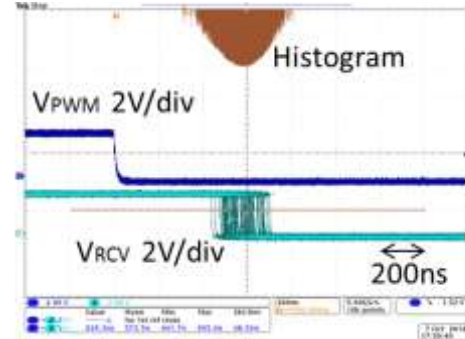
Fig. 7. Detailed waveforms. Time fluctuation was observed in inductor voltage (DC link voltage is 30 V).

V_{PWM} and the input signal of the gate-drive circuit V_{RCV} is shown in Fig. 8. The maximum delay time for rising edge of received signal V_{RCV} was 400 ns and the falling edge 800 ns. Jitter was 250 ns at the rising and 500 ns at the falling.

Figure 9 shows 300 V DC bus voltage switching demonstration set up. Distance between 60 GHz modules are about 20 cm in this demonstration. It has been confirmed that the gate signal is transmitted more than 5 m with the same setup. Figure 10 shows 300 V demonstration waveforms.

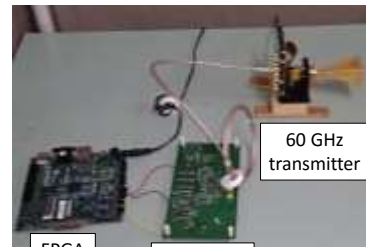


(a)

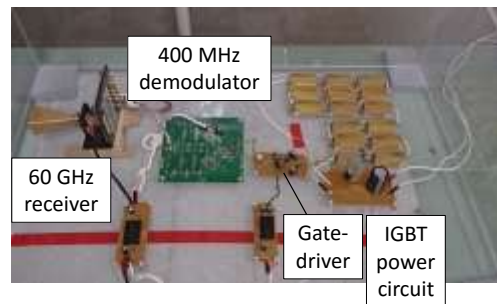


(b)

Fig. 8. Delay time and the jitter from FPGA(V_{PWM}) signal to the input signal of the gate-drive circuit(V_{RCV}) for (a) rising edge and (b) falling edge.



(a)



(b)

Fig. 9. Photograph of resistive load wireless gate drive demonstration. Transmitter side (a) and receiver and power circuit side (b).

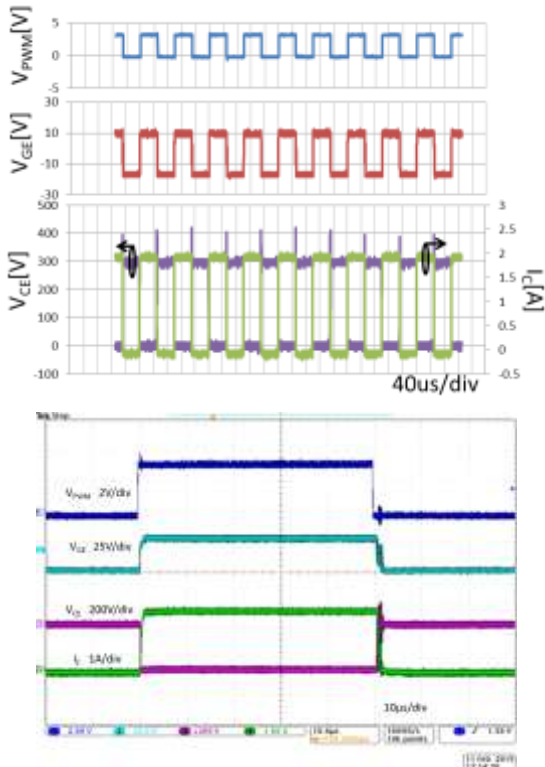


Fig. 10. Waveforms under resistive load (DC link voltage: 300 V)

IV. CONCLUSION

It was successfully demonstrated, for the first time, that wireless signal transmission with 60 GHz RF module is practically applicable for IGBT gate control by direct access to physical layer of RF transceiver.

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