Low EMI Techniques for New Generation IGBT Modules

Fuji Electric's 6th generation IGBT modules have drastically improved the trade-off of radiated EMI noise and power dissipation loss. By applying new packaging technology, a reduction in radiated noise of about -5dB by reducing the noise loop area has been achieved. Additionally, new trench gate IGBTs reduce the radiated noise without significantly increasing switching losses. As a result, the total radiated noise is reduced by -15dB with the same dissipation losses compared to the conventional IGBT module.

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Electric motor drives have evolved rapidly in recent years with advances in power electronics. New IGBT modules exhibit superior electrical characteristics, such as low on-state voltage drop, and fast switching with high withstand capability for device destructive failure. A great improvement in IGBT properties has been achieved by the combination of the Field-Stop (FS) IGBT concepts [1] and the trench-gate structure [2]. In order to reduce the switching losses of IGBT modules, di/dt and/or dv/dt values have been increased to higher levels, and the corresponding EMI noise from the module has also increased. Therefore, various kinds of regulations related with EMI, EMS and EMC have been investigated all over the world.

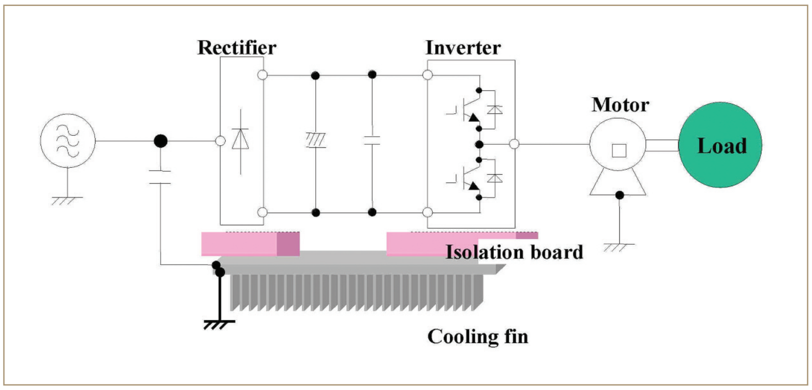


Figure 1: Typical AC motor drive system consisting of a diode rectifier and an IGBT inverter

Mechanism of radiated noise

Figure 1 shows a typical AC motor drive system consisting of a diode rectifier and an IGBT inverter. The IGBT module and rectifier diode module are mounted on a cooling fin. The cooling fin is commonly grounded for safety reasons, and the electric circuit elements in the module such as IGBT chips are electrically isolated from the fin with a high thermal conductivity insulating substrate. Snubber capacitors are also generally connected across the inverter to suppress spike voltages. The stray inductances and stray capacitances in the circuit elements of the motor drive have the greatest impact on radiated noise with frequencies of 30MHz or more.

Figure 2 shows the equivalent circuit of an inverter system in the frequency range from 30kHz to 1GHz. There is 10 to 100nH of stray inductance in the wiring around IGBT modules (L1, L2, L3), 100 to 1000pF of stray capacitance in the insulation substrate (C2, C3) and junction capacitance of IGBT chips (C4, C5). High frequency radiation noise is caused by inverter switching, when currents are induced in the high frequency resonant stray loops. The resonant currents flowing through these loops during IGBT switching generates peaks of radiated noise [3].

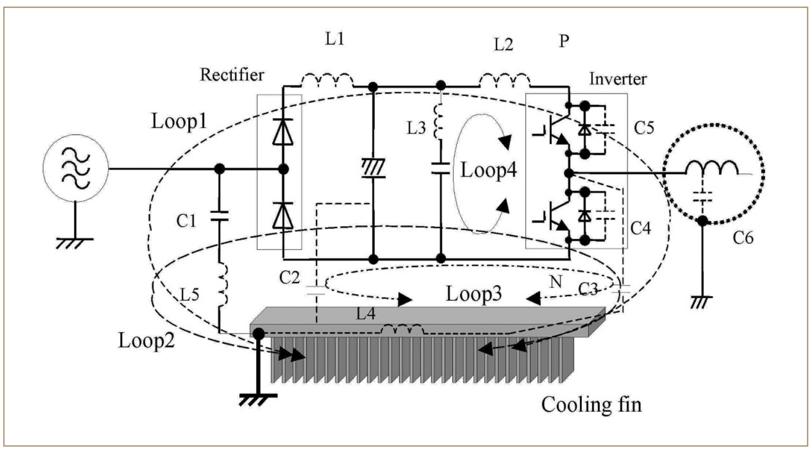


Figure 2: Equivalent circuit of the inverter system in the frequency range 30kHz to 1GHz

The radiated noise generated by the resonant loop current can be calculated according to equation 1

$$E_f = \frac{1.32\times10^{-14}}{r} \cdot S \cdot I_f \cdot f^2 \cdot \sin\theta \qquad (1)$$

with S loop area, I_f loop current, r distance from loop to noise measurement point, θ angle with loop side, f frequency.

Equation 1 expresses, that radiated noise is a square function of the the frequency. The noise generated by loop1 and loop2 is not high because their resonant frequency is low (1 to 8MHz). The greatest noise is generated by loop4 (>30MHz resonant frequency) and loop3 (>10MHz resonant frequency). Thus, loop4 generates the

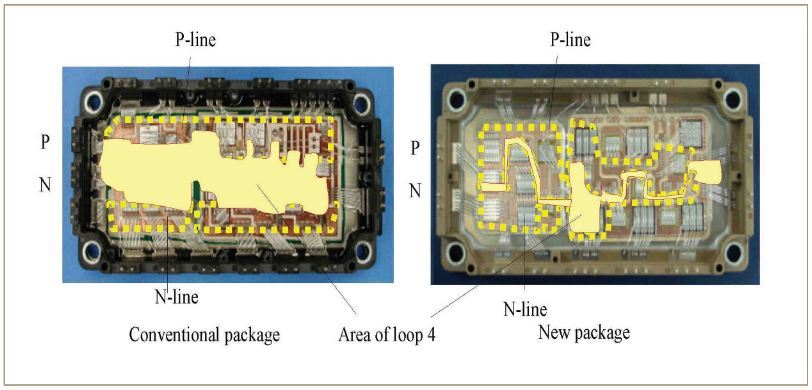


Figure 3: Internal layout of the conventional package (left) and the new package

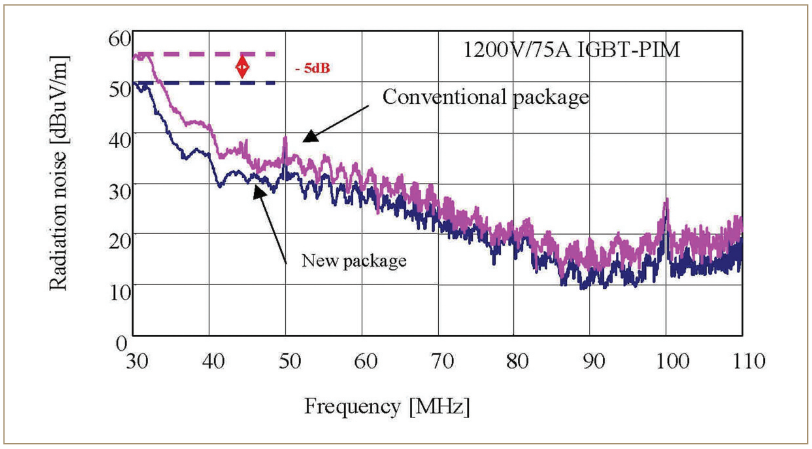


Figure 4: Experimental results on the example of a 15kW induction motor (no load, f_c = 4kHz)e

largest high frequency noise and therefore noise reduction techniques for this loop should be applied.

Reduction of loop area

To reduce radiated noise, it is effective to decrease the current I_f or to decrease the loop area. We approached the problem by making improvements in the package structure and the switching characteristics of the IGBTs.

First, we designed a new package with the smallest loop4 area. Loop4 area can be reduced by close P and N lines on the insulation substrate patterns. The comparison of internal layouts between the conventional package and the new package is shown in Figure 3. Inductance values did not change so much (60 and 55nH), but by reducing the loop4 area by 59% (to 336mm² from 571mm²) a corresponding reduction in radiated noise of slightly greater than the value predicted by equation 1 of -5dB (to 50dB µV/m from 55dB µV/m) was obtained. Figure 4 shows the experimental results on the example of a 15kW induction motor in an anechoic chamber (3m). A series regulator for the control power supply was used to eliminate the introduction of radiated noise from the control power supply. The noise was generated by the IGBT inverter only. Through these experiments, it was clear that we would be able to decrease the radiated noise by decreasing the loop4 area. We applied this technology to the Fuji 6th generation IGBT modules rated 1200V/75A~150A [6].

Reduction of loop current

Our second challenge was to reduce the loop current I_f. We approached this problem by applying technologies that allowed for the reduction dv/dt without significantly increasing the switching losses. The voltage of the high frequency region decreases by reduction of dv/dt shown in Figure 5. As the result of reducing loop

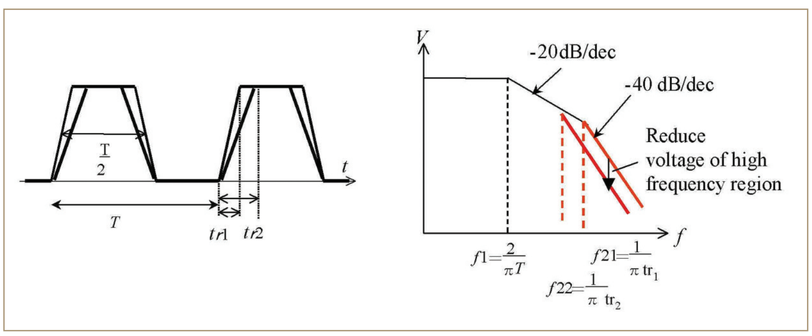


Figure 5: IGBT switching waveform and voltage spectrum

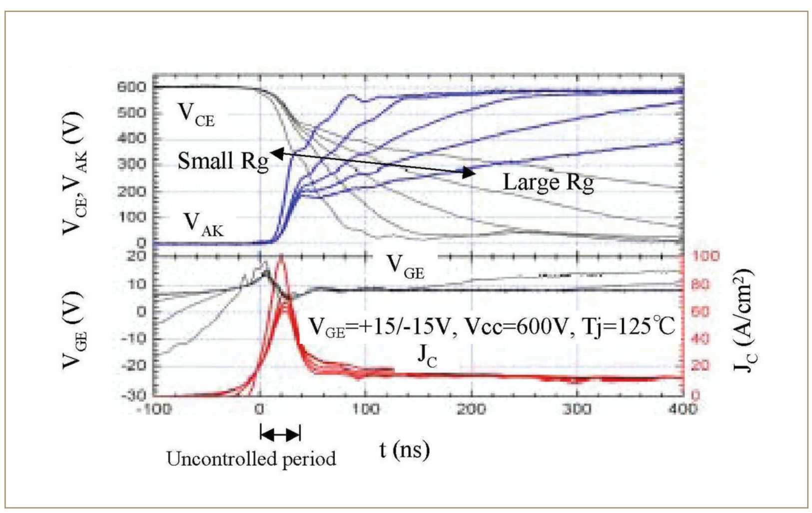


Figure 6: Turn on waveforms of conventional trench gate IGBT

Figure 7: Schematic cross-sectional view of the trench gate IGBT

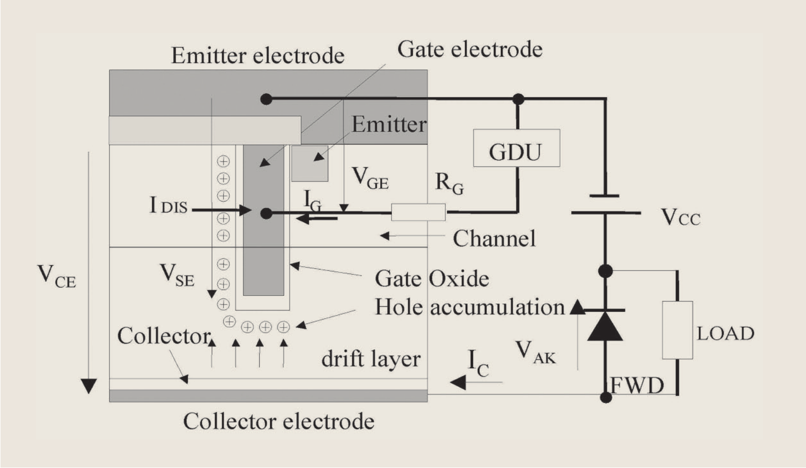
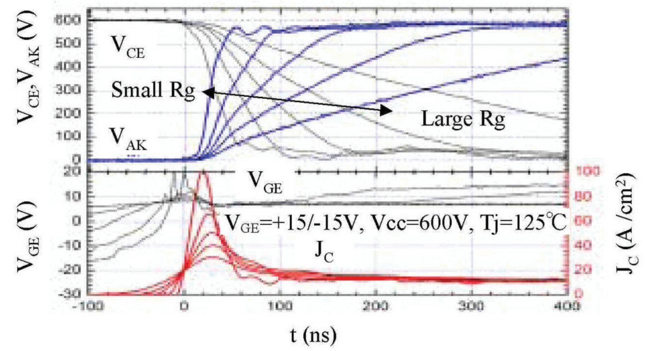


Figure 8: Turn-on waveforms of new trench gate IGBT



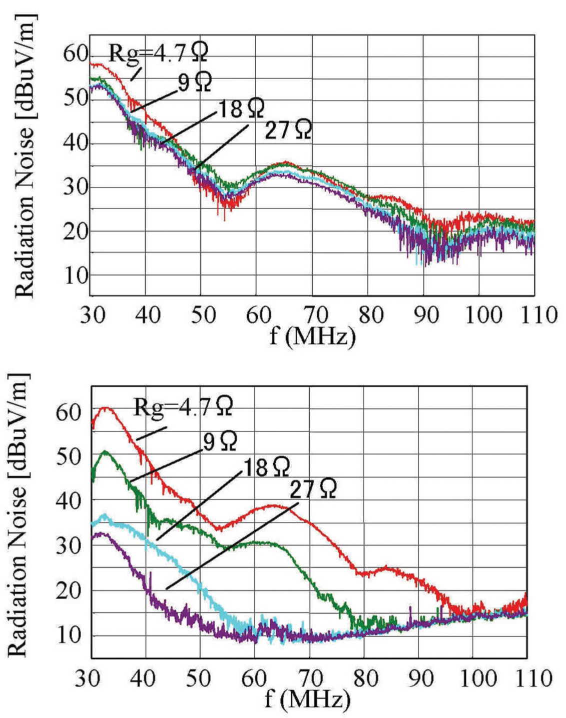


Figure 9: Comparison of radiated noise for conventional (upper) versus improved trench gate design

current I_f, the high frequency region decreases.

Trench-gate IGBTs have made dramatic improvements in the trade-off relationship between the on-state voltage drop and the turn-off loss. However, it has a large gate-collector (Miller) capacitance C_{GC}, which causes a long voltage-tail during the turn-on period, according to equation 2 [4],

$$\frac{dV_{CE}}{dt} = \frac{V_{GA} - \left(V_{TH} + \frac{1-\alpha}{g_{MOS}} I_L\right)}{R_G \cdot C_{GC}} \qquad (2)$$

where V_{GA}, R_g and I_L are the applied gate voltage, the gate resistance and the load current, respectively. But as a result, its turn-on power dissipation increases remarkably.

Figure 6 shows the turn-on waveforms of a conventional trench gate 1200V IGBT. It is apparent that the long voltage-tail region extends with increasing values of R_g.

The larger Miller capacitance causes not only higher turn-on loss but also smaller turn-on dIC/dt controllability by R_G shown in Figure 7. When the V_{GE} exceeds $V_{GE(th)}$, the IGBT is turned on, and holes are injected from the p-collector into the drift layer. Since the holes are accumulated beneath the gate oxide, the potential in this region, rises due to the positive charge of the holes. The gate-emitter capacitance C_{GE} is charged by the current from the positive charge V_{SE} region to emitter (displacement current I_{DIS}). There is an uncontrolled period, which is unable to be dv/dt controlled by R_g depending on the displacement current. Therefore, the turn-on dI_c/dt is increased by the uncontrolled V_{GE} increase [4, 5]. As a result, the turn-on dI_c/dt of IGBT will be fixed to a specific higher value even if the gate resistance R_g is set to a sufficiently large value.

We designed the trench gate structure to reduce to the positive charge of the holes and to reduce the C_{GE}. As a result, the displacement current I_{DIS} hardly flows and the gate-emitter capacitance C_{GE} is charged only by the current through the gate resistance. Figure 8 shows the turn-on waveforms of the new trench gate 1200V IGBT. It is shown that dv/dt decreases by enlarging the gate resistance. Moreover, the improved trench IGBT was able to eliminate the uncontrolled period. Therefore, the FWD reverse-recovery current also decreases by increasing R_g.

A comparison of radiated noise for conventional versus improved trench gate designs is shown in Figure 9. The radiation noise of the conventional trench gate is hardly decreased when the gate resistance is increased, and is much higher than the improved IGBT because of the large loop current caused by large dv/dt at the uncontrolled period. However, the radiation noise of the new trench gate decreases greatly by enlarging the gate resistance. Turn-on dv/dt is decreased by enlarging the gate resistance and, as a result, the loop current also decreases. A small increase in gate resistance reduces the radiated noise. For example, the noise can be reduced 10dB by changing the gate resistance from

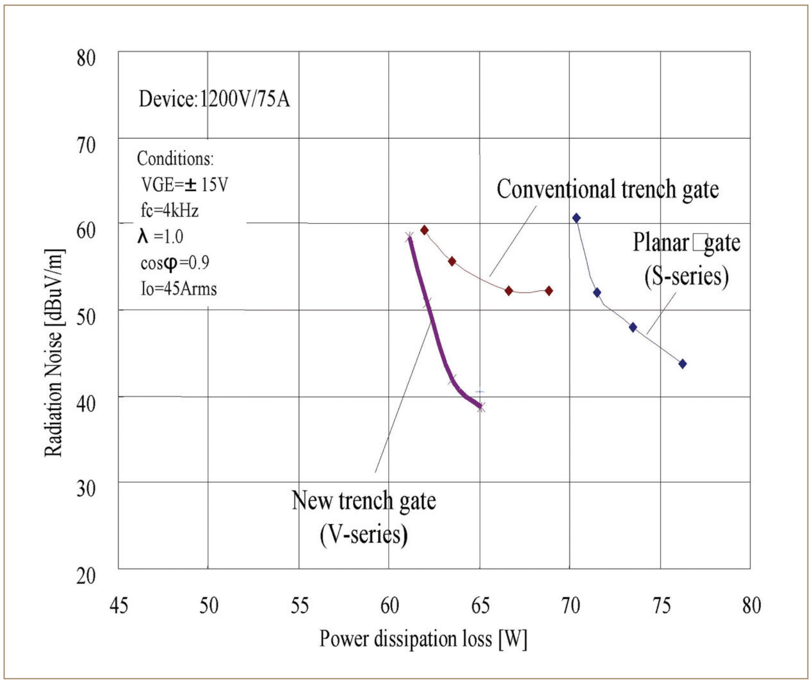


Figure 10: **Trade-off relationship between power dissipation losses and radiated noise**

4.7 to 9Ω. Therefore, the radiation noise standard can be satisfied without significantly increasing the switching losses than that of conventional IGBT.

The trade-off relationship between the power dissipation losses and the radiated noise is shown in Figure 10. The gate resistance was varied to control the IGBT switching speed in this measurement. The characteristic of planar gate NPT is shown for the comparison with the technology. The radiated noise of conventional trench gate does not decrease for uncontrolled period, even if the gate resistance enlarges and the power dissipation loss increases by enlarging the gate resistance, because the conventional trench gate IGBT has the larger Miller capacitance. However, the radiated noise of new trench gate decreases, and the increase in the dissipation losses is also caused a little by enlarging the gate resistance. The radiated noise of the new trench gate decreases -15dB than that of the conventional trench gate at the dissipation losses of 65W (to 49dB V/m from 54dB μV/m). And the dissipation losses of the new trench gate decreases -10% than that of the conventional trench gate at the radiation noise of 52dB (to 62W from 68W). The radiated noise of planar gate almost decreases at the same level as the new trench gate, but the dissipation loss is larger than that of the trench gate because of higher on-state loss. Fuji's 6th generation IGBTs have applied the new trench gate technology [7].

Conclusion

This article describes the mechanism of radiated noise coming from power electronics in a motor drive. The radiated noise is generated from the loop currents between the stray capacitance and inductance during IGBT switching. With the innovations described, we were able to reduce the radiation noise by -15dB, compared to that of the conventional trench gate with the same dissipation losses. Fuji's 6th generation IGBT modules apply these low EMI noise techniques; the first of the line-up is a 200V/75A~150A PIM.

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