# Molded Insulated-Gate Bipolar Transistors

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## 1. Introduction

In 1988 Fuji Electric introduced to the market a molded IGBT (Insulated-Gate Bipolar Transistor) for the voltage resonant inverters circuit in microwave ovens. Since that time efforts have been improved the high speed switching and high performance characteristics of transistor chips, to commercialize them, and to expand the product series into such areas as CRT horizontal deflection and switching power supply. This paper introduces recent technical developments of IGBTs for voltage resonant inverter supplies and CRT horizontal deflection circuits.

## 2. IGBT for Voltage Resonant Inverter Supply

### 2.1 Outline

Power supplies of cooking equipment such as microwave ovens, rice cookers, and induction heating cookers have changed from commercial power supplies to high frequency-inverter power supplies aiming at attaining a high added value. Recently those power supplies have been made smaller and lighter. Additionally, semiconductor devices have been developed to reduce the number of their part and cost. Fuji Electric has introduced to the market a high performance IGBT for voltage resonant inverter supplies and IGBT with FWD connected in parallel in one package.

### 2.2 Technical development

#### 2.2.1 Reduction of power loss

In the voltage resonant inverter, power loss generated by IGBT switching is estimated, and the inverter is designed to prevent the temperature from exceeding allowable limits through the use of cooling fins or a cooling fan. The greater the IGBT's power loss, however, the larger the size of cooling fins or a cooling fan, increasing the size of the inverter equipment itself. Therefore the reduction of power loss is an important topic for inverter-circuit designers. In this IGBT product series, efforts have been made to reduce the power loss by 20% compared to conventional products while maintaining the same current density.

Fig. 1 Inverter power supply circuit and IGBT waveform during operation

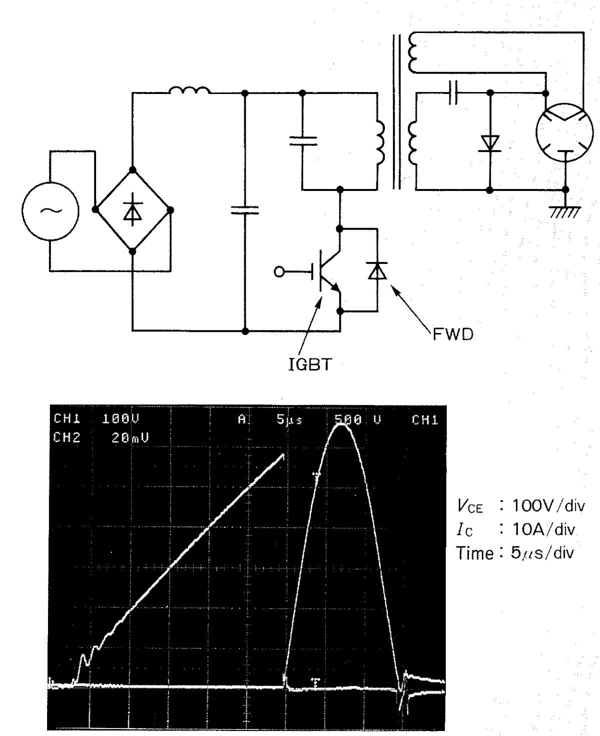



**Figure 1** shows a typical voltage resonant inverter power supply circuit and an IGBT waveform during operation. **Figure 2** shows an analysis of the IGBT's power loss. On-state loss is 70% of the total power loss with the remainder due to switching loss. There is a trade-off relationship between on-state loss and switching loss; the smaller the on-state loss the larger the switching loss. Therefore to improve the trade-off relationship, it is necessary to optimize silicon crystal specifications, chip patterns and wafer processes simultaneously. Three major points for improvement are as follows.

Fig. 2 IGBT power loss analysis

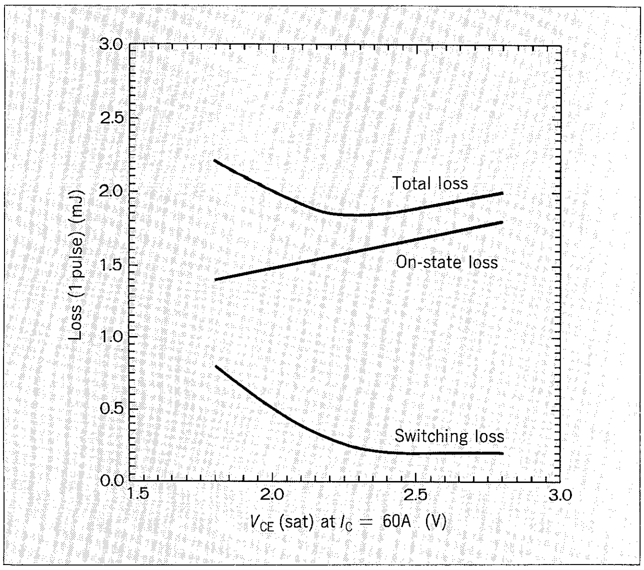



Fig. 3 IGBT structure and equivalent circuit

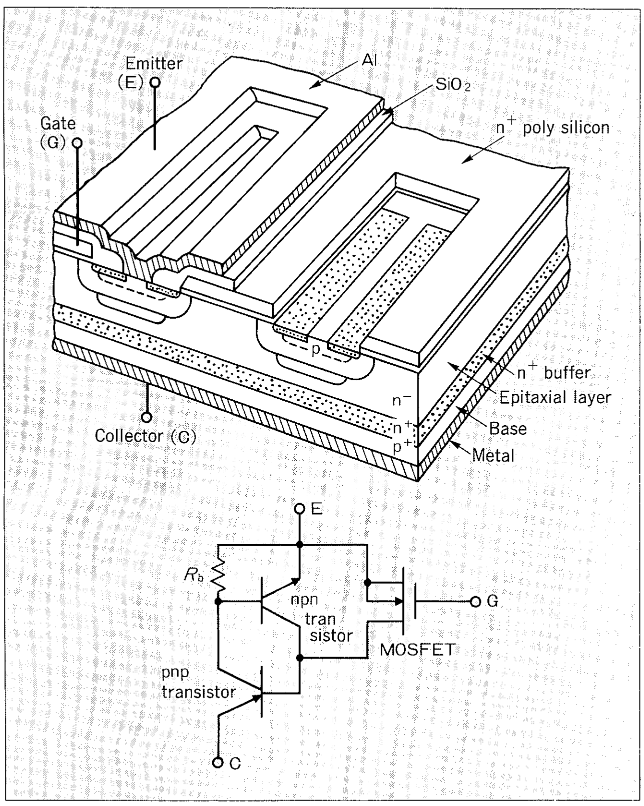



Fig. 4 IGBT cross section

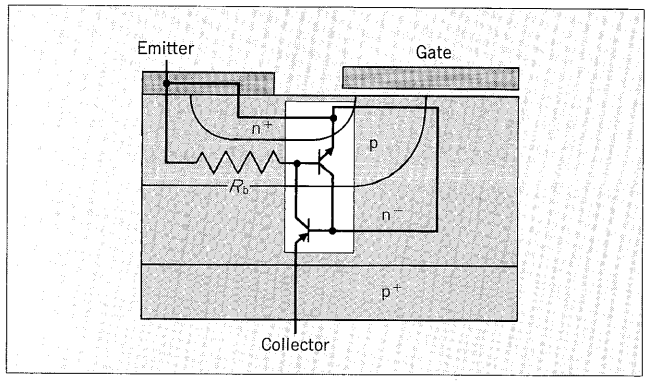



Fig. 5 Comparison of breakdown current

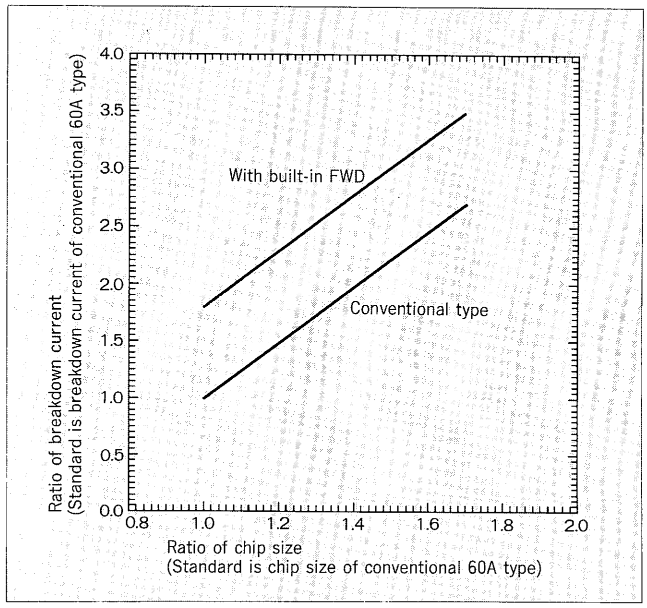
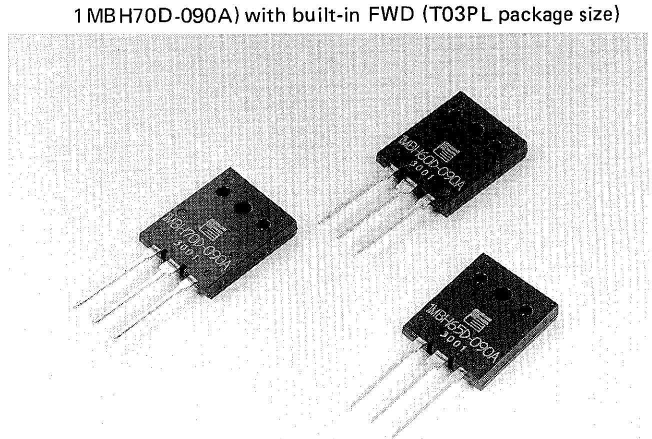



Fig. 6 Exterior view of IGBT (1MBH60D-090A, 1MBH65D-090A, 1MBH70D-090A) with built-in FWD (T03PL package size)




(1) Optimization of the injection efficiency of pnp transistors from crystal specifications
(2) Minimization with finer cell
(3) Optimization of life time $\tau$ control (life time killer)

**Figure 3** shows the IGBT's structure and its equivalent circuit. The circuit is represented by a MOSFET (Metal-Oxide-Semiconductor Field-Effect Transistor), a pnp and a parasitic-npn transistors. The on-state characteristics of the IGBT vary with transistor injection efficiency ($h_{FE}$) and MOSFET characteristics. Fuji Electric successfully reduced the on-state loss by optimizing both transistors with the above mentioned procedures.

Fig. 7 Exterior view of T03PL frame

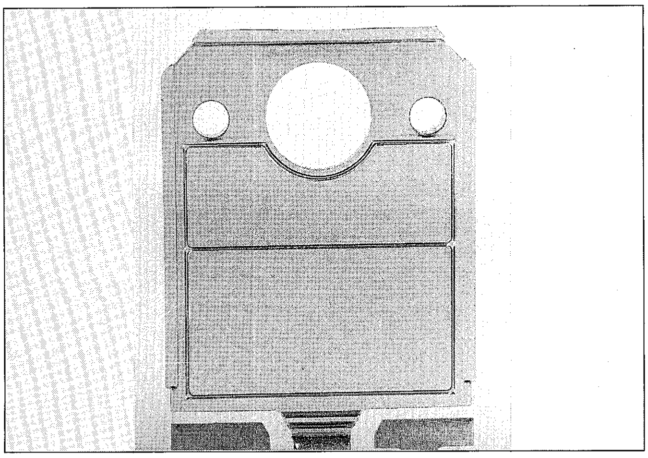


Table 1 Main ratings of IGBT with built-in FWD

| Characteristics / Model | Collector current $I_C$ | Collector-emitter voltage $V_{CES}$ | Max. Power dissipation $P_C$ | Saturation voltage $V_{CE(sat)}$ (Norm) | Turn-off time $t_f$ (Norm) |
|---|---|---|---|---|---|
| 1MBH60D -090A | 60A | 900V | 260W | 2.5V | 0.4 μs |
| 1MBH65D -090A | 65A | 900V | 300W | 2.3V | 0.4 μs |
| 1MBH70D -090A | 70A | 900V | 340W | 2.0V | 0.3 μs |

### 2.2.2 Improvement of breakdown strength

High reliability in an inverter power supply requires non latch up characteristics for IGBT. Latch up occurs when the voltage drop caused by a hole current crossing a diffused resistance region $R_b$ directly beneath the $n^+$ source layer, as shown in **Fig. 4**, exceeds the built-in voltage of the $n^+$-p junction, causing the parastic-npn-transistor to turn on and the IGBT to operate as a pnpn thyristor. Fuji Electric has achieved an increase of 30 to 80% in breakdown strength as compared with former products by reducing the size of the many cells connected in parallel within the IGBT and by lowering the resistance $R_b$ through improved channel layers (**Fig. 5**).

### 2.2.3 Built-in FWD

**Figure 6** shows a photograph of IGBTs with a built-in FWD and **Fig. 7** shows a photograph of the frame. Compared to former products, chip mounting area has increased by 20% due to the improvement of molding die for resin molding and through the adoption of coining with consideration for the stability of the positioning of two chips during die bonding. The technical development of two chip die bonding has raised productivity in the assembly process.

### 2.3 IGBT product series for voltage resonant inverter supplies

**Table 1** shows the main ratings and characteristics of IGBTs with bult-in FWD. Fuji Electric has applied the recent low power loss technology and high breakdown strength technology to this series of products and is determined to expand the series.

Table 2 Ratings and characteristics of 1MB12-140 for CRT horizontal deflection circuit

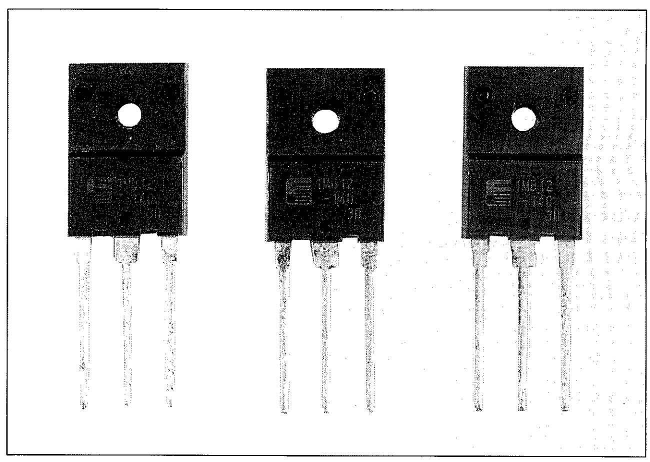
(a) Absolute maximum ratings ($T_C$=25°C)

| Item | | Symbol | Rating | Unit |
|---|---|---|---|---|
| Collector-emitter voltage | | $V_{CE}$ | 1,400 | V |
| Gate-emitter voltage | | $V_{GE}$ | ±20 | V |
| Collector current | DC | $I_C$ | 12 | A |
| | Pulse 50 μs | $I_{CP}$ | 60 | A |
| Max. power dissipation | | $P_C$ | 100 | W |
| Junction temperature | | $T_j$ | +150 | °C |
| Storage temperature | | $T_{stg}$ | –40 to +150 | °C |

(b) Electrical characteristics

| Item | Symbol | Condition | Min. | Norm | Max. | Unit |
|---|---|---|---|---|---|---|
| Gate-emitter leakage current | $I_{GES}$ | $V_{GE}$=±20V $V_{CE}$=0V | | | 100 | nA |
| Zero gate voltage collector current | $I_{CES}$ | $V_{CE}$=1,400V $V_{GE}$=0V | | | 1 | mA |
| Gate-emitter threshold voltage | $V_{GE(th)}$ | $V_{CE}$=$V_{GE}$ $I_C$=10mA | 2 | | 5 | V |
| Collector-emitter saturation voltage | $V_{CE(sat)}$ | $I_C$=12A $V_{GE}$=15V | | 6.0 | 7.0 | V |
| | | $I_C$=6A $V_{GE}$=15V | | 4.0 | 4.5 | |
| Input capacitance | $C_{ies}$ | $V_{GE}$=0V $V_{CE}$=25V $f$=1 MHz | | 2,000 | | pF |
| Switching characteristics | $t_{f1}$ | $I_C$=6A $V_{GE}$=15V | | | 0.2 | μs |
| | $t_{f2}$ | | | | 1.0 | μs |
| | $t_{off}$ | | | | 1.2 | μs |
| | $I_{off}$ | | | | 1.0 | A |
| Thermal resistance | $R_{th(j-c)}$ | | | | 1.25 | °C/W |

Fig. 8 Exterior view of 1MB12-140 for CRT horizontal deflection circuit (T03PF package size)



## 3. IGBT for CRT Horizontal Deflection Circuit

### 3.1 Outline

Fuji Electric has succeeded in mass-production of IGBT for CRT horizontal deflection circuit of the color television and display equipment (**Table 2, Fig. 8**). Recently, it could have characteristics necessary for CRT horizontal deflection circuit, high blocking voltage of 1,400V and high frequency operation up to 80 kHz.

Fig. 9 Blocking voltage waveform of 1MB12-140 for CRT horizontal deflection circuit

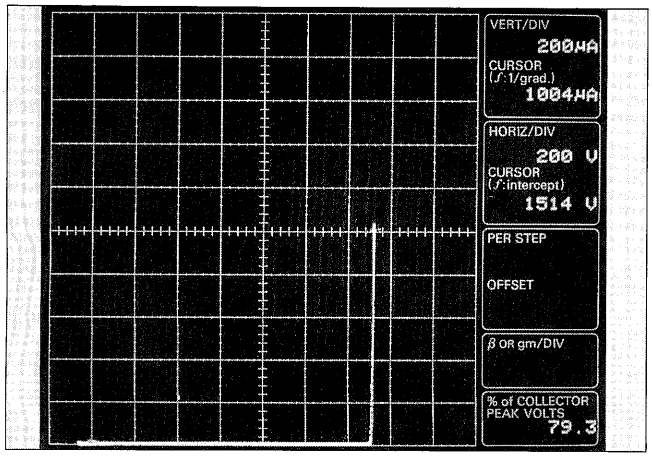
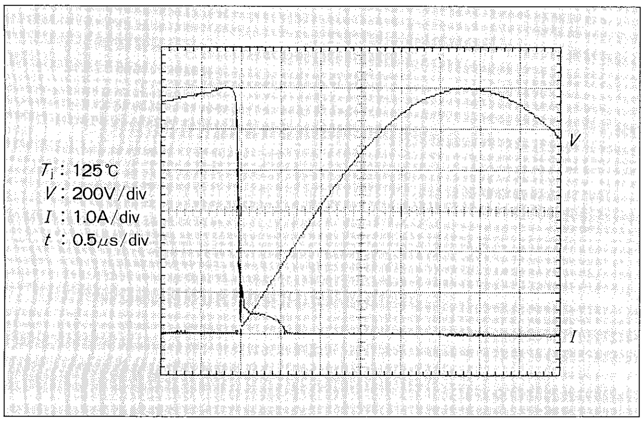



Fig. 10 IGBT turn-off waveform during voltage resonant operation




## 3.2 Technical development

### 3.2.1 High blocking voltage

To realize the high blocking voltage of 1,400V, this IGBT have used some guardrings and a field-plate structure for a part of a blocking voltage structure on horizontal deflection formed into edge of a chip surface. To realized reduction of power loss (improvement relationship turn-off swithing loss and on-state resistance) and a high blocking voltage of 1,400V, we have optimized $n^-$-layer thinning, silicon resistivity and life time killer conditions in the wafer construction. **Figure 9** shows the blocking voltage waveform of the IGBT.

### 3.2.2 High frequency

To comply with operation requirements of the CRT horizontal deflection circuit up to 80kHz, the voltage resonant circuit frequency, it is necessary to reduce turn-off switching loss. At the time of turn-off, the external voltage expands depletion layers inside the semiconductor and drives out residual carriers. To reduce turn-off loss, it is therefore necessary to rapidly expand the depletion layers and drive out the residual carriers. For this reason the layer is made as thin and highly resistive as possible. **Figure 10** shows the turn-off waveform for a collector cut-off current of 6A.

Fig. 11 Improvement in turn-off characteristics of 1MB12-140 for CRT horizontal deflection circuit

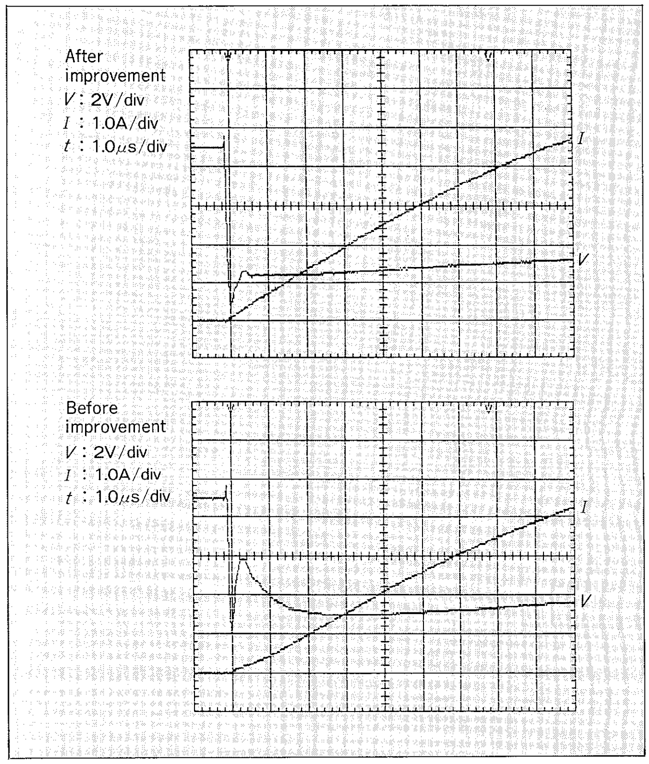
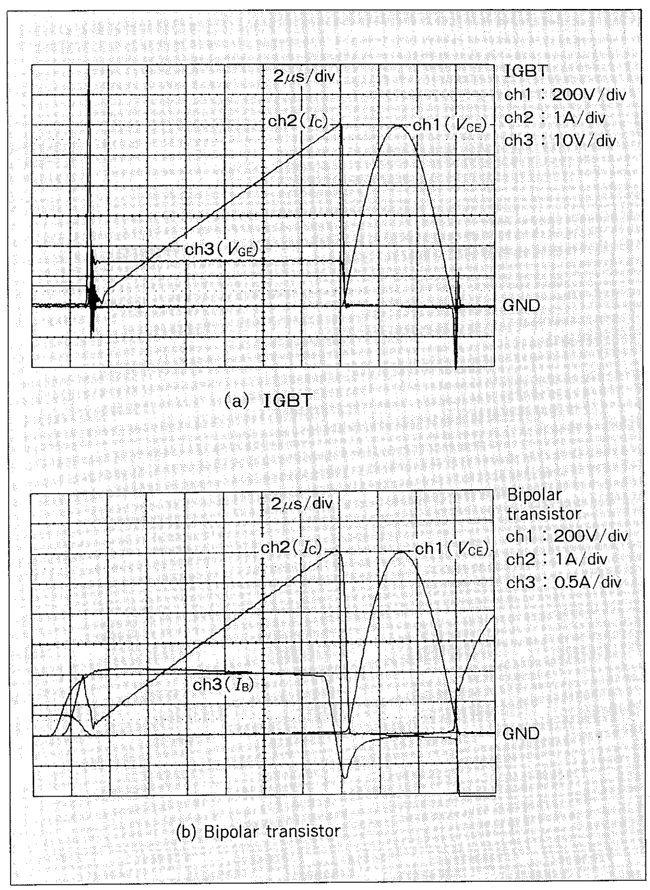



Fig. 12 Comparison between IGBT and BJT during turn-off operation



### 3.2.3 Low noise

Noise from the IGBT must be suppressed as much as possible for it causes disturbances in the picture on a CRT screen. In particular, transient on-state voltage is likely to result in video noise. To cope with this problem it is necessary to suppress transient on-state voltage and create a rapid conductivity modulation inside the IGBT. In this transistor the $n^+$ buffer layer was designed to significantly improve injection efficiency and turn-off characteristics, thereby reducing the noise to a practically insignificant level. **Figure 11** shows turn-off characteristics before and after the improvement and the reduction in transient jump-up voltage.

### 3.3 Advantage of IGBT application for horizontal deflection circuit

### 3.3.1 Comparison with bipolar transistor

In the past, the BJT (Bipolar Junction Transistor) has been used in the horizontal deflection circuit as a switching device. For mono-frequency the BJT functions satisfactorily, but for a multi-frequency scanning CRT which is now widely used, its circuit becomes overly complicated. This is because after the BJT's base current is cut off, its collector current still takes some time, delay time, until it is cut off. This phenomenon is shown in **Fig. 12**. In an IGBT the collector current is instantaneously cut off when the gate voltage cut off. It is not necessary for storage time to consider, regardless of the horizontal deflection frequency. Because IGBT is a voltage drive type device, the gate drive circuit was simplifed to reduce costs. The IGBT can be operated simply the same parallel drive as MOSFET (Metal-Oxide Semiconductor Field Effect Transistor).

### 3.2.2 Comparison with power MOSFET

The high voltage MOSFET has a considerably high on-state resistance. Since MOSFETs are intrinsically unipolar devices, on-state resistance can hardly be improved because it is determined by the n-layer resistivity. A MOSFET has about 20 times greater on-state resistance than an IGBT. This on-state resistance increases further at higher temperatures. The MOSFET has extremely low switching loss, but because of its high on-state resistance, the IGBT is preferred.

## 4. Conclusion

This paper has presented a summary of commercialized IGBTs for voltage resonant inverter supplies and CRT horizontal deflection circuits.

With regard to the IGBTs for voltage resonant inverter supplies improvement and integration of an FWD into the unit package have provided products that meet circuit designer's requirements for higher efficiency, work simplification, and smaller size. These IGBTs are expected to come into wide use in the expanding voltage resonant inverter supply market.

The IGBTs for CRT horizontal deflection circuits are a unique Fuji product for high voltage (1,400V) and high speed operation (80Hz) use, special consideration was given to noise reduction measures. The product is already being used in the monitor display market and is expected to be even more widely used in the near future.


**Reference**

(1) Seki, Y. et al.: High Switching Speed 1,500V IGBT for CRT Deflection Circuit, Proceedings of ISPSD '91, p. 237-241 (1991)