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# NEW HIGH-SPEED 1,200V BIPOLAR TRANSISTOR MODULES "Z-SERIES"

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## 1. FOREWORD

Recently, power electronic applied products have grown tremendously with the advance of digital control technology and the appearance of power semiconductor devices, including power transistors.

In this movement, Fuji Electric was the first in the world to develop a 500V, 100A building block transistor (BBT). This BBT has made a large contribution to transistorization of inverter equipment. Furthermore, to meet the needs of overseas markets for simplification of equipment and high voltage, power transistor modules with withstand voltages up to 1,200V were developed. Many of these modules are being used in the static power converter field and are highly evaluated.

Recently, in this field, to miniaturize the circuitry and increase performance, the need to improve switching performance and for elements with a high withstand voltage and high short-circuit capability has increased. However, with existing bipolar transistor technology, the above needs could not be satisfied simultaneously by trading off among the various characteristics.

Fuji Electric has been researching this problem for many years. The new 1,200V power transistor modules "Z-series" with a switching time 50% shorter than that of existing power transistors and an RBSOA (Reverse Biased Safety Operation Area) which allows direct connection to 480V input voltage and a short-circuit withstand capability that allows short-circuit protection with a DC750V power supply is outlined below.

## 2. SERIES AND CHARACTERISTICS

### 2.1 Z-series models and rated characteristics

Exterior views of the Z-series are shown in *Fig. 1*. The main rated characteristics of the entire 30 to 300A series are shown in *Table 1*.

### 2.2 Typical characteristics

The $h_{FE}$-$I_C$ characteristics, saturation voltage characteristics, switching time characteristics, and RBSOA of the 2DI75Z-120 1,200V, 75A 2 pack module are shown in *Figs. 2, 3, 4,* and *5* as typical of the Z-series. The equivalent circuit (internal circuit diagram) is shown in *Fig. 6*.

*Fig. 1* Exterior views of 1,200V power transistor modules "Z-series"

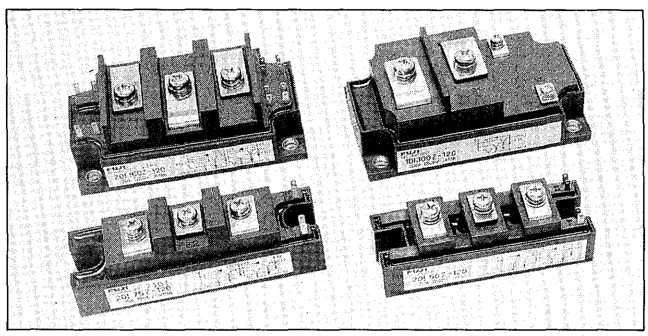


*Table 1* 1,200V power transistor modules Z-series models and rated characteristics (Unless otherwise specified, $T_j$=25°C)

| Model | $V_{CBO}$ (V) | $V_{CEO}$ (V) | $V_{CEX(SUS)}$ (V) | $I_C$ (A) | $P_C$ ($T_C$=25°C) (W) | $h_{FE}$ min | ($T_j$=125°C) $I_C$ (A) | $V_{CE}$ (V) | Switching time $t_{on}$ (μs) | $t_{stg}$ (μs) | $t_f$ (μs) | Short-circuit withstand capability (V) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2DI30Z-120 | 1,200 | 1,200 | 1,200 | 30 | 300 | 75 | 30 | 2.8 | 3 | 15 | 2 | 750 |
| 2DI50Z-120 | 1,200 | 1,200 | 1,200 | 50 | 400 | 75 | 50 | 2.8 | 3 | 15 | 2 | 750 |
| 2DI75Z-120 | 1,200 | 1,200 | 1,200 | 75 | 500 | 75 | 75 | 2.8 | 3 | 15 | 2 | 750 |
| 2DI100Z-120 | 1,200 | 1,200 | 1,200 | 100 | 800 | 75 | 100 | 2.8 | 3 | 15 | 2 | 750 |
| 2DI150Z-120 | 1,200 | 1,200 | 1,200 | 150 | 1,000 | 75 | 150 | 2.8 | 3 | 15 | 2 | 750 |
| 1DI200Z-120 | 1,200 | 1,200 | 1,200 | 200 | 1,400 | 75 | 200 | 2.8 | 3 | 15 | 2 | 750 |
| 1DI300Z-120 | 1,200 | 1,200 | 1,200 | 300 | 2,000 | 75 | 300 | 2.8 | 3 | 15 | 2 | 750 |

*Fig. 2* $h_{FE}$-$I_C$ characteristics of 2DI75Z-120

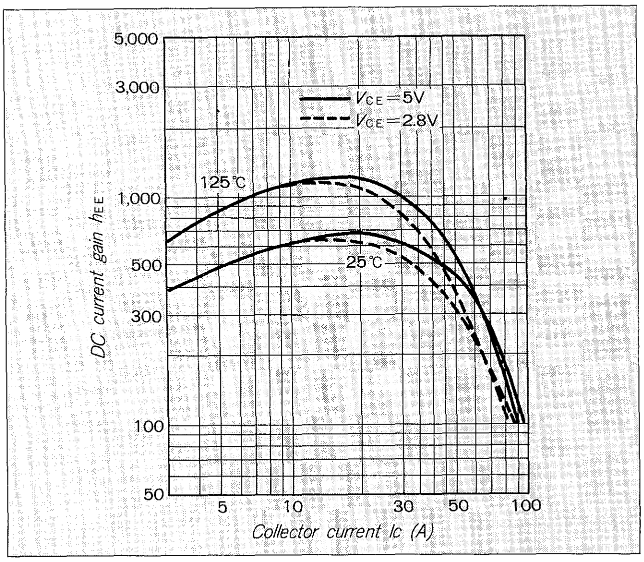



*Fig. 3* Saturation voltage characteristics of 2DI75Z-120

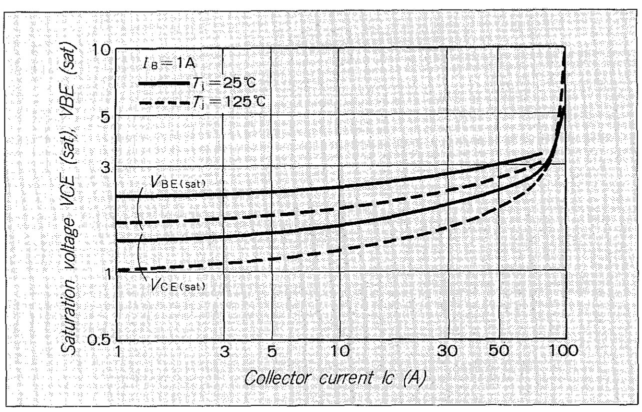



*Fig. 4* Switching time characteristics of 2DI75Z-120

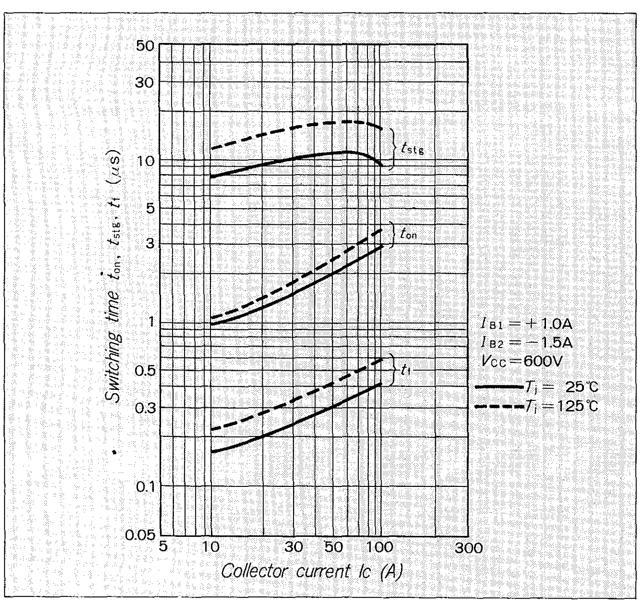



*Fig. 5* RBSOA of 2DI75Z-120

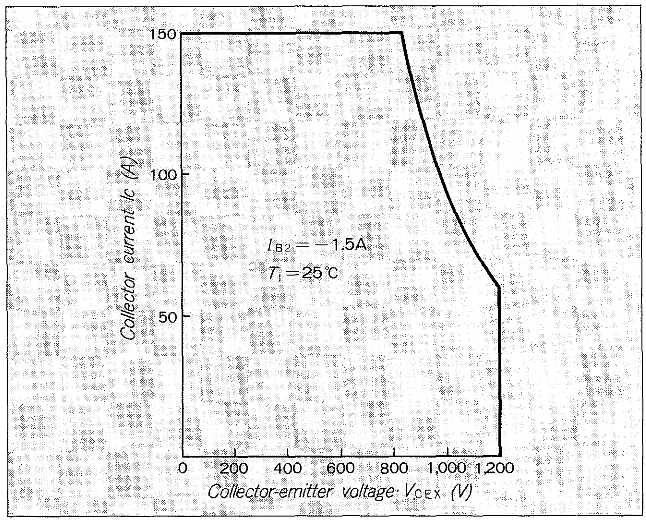
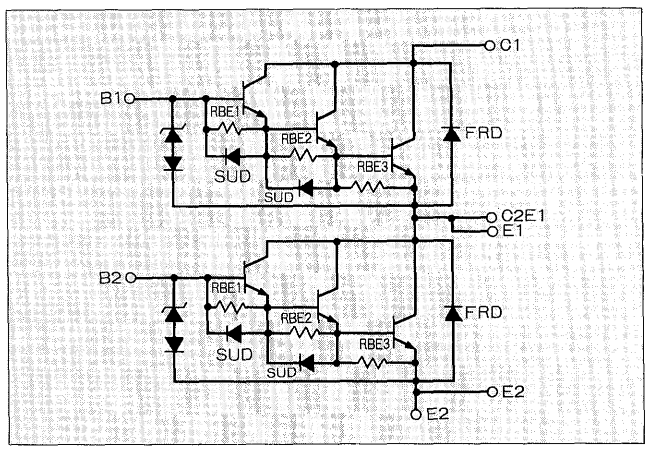



*Fig. 6* 2DI75Z-120 equivalent circuit




## 3. NEW DESIGN TECHNOLOGY FOR Z-SERIES DEVELOPMENT

### 3.1 Device characteristics demanded by high frequency inverter

The switching frequency of the power transistors used in inverters, the mainstream of pulse width modulation (PWM) control, is steadily increasing from the 1 kHz or less of the past to several kHz and faster switching performance is demanded. Furthermore, to make the equipment smaller, power transistors with a high $h_{FE}$ and wide RBSOA are needed. In addition, the appearance of devices having an ample short-circuit capability so that the power transistor is not destroyed by the overcurrent which flows when a short-circuit accident occurs in the equipment was desired.

On the other hand, with existing power transistors, if the RBSOA was emphasized, switching time was sacrificed and improving both at the same time was difficult. Further, since the overcurrent increases and the breakdown voltage decreases. As the $h_{FE}$ is made higher, an ample short-circuit withstand capability could not be obtained at a practical $h_{FE}$ level.

To solve these two problems, the new design technology described below was introduced to the Z-series.

### 3.2 Improvement of trade-off by emitter ballast resistance

*Fig. 7* is a cross-sectional diagram of the triple diffused planar transistor chip generally used with bipolar power transistors. The thickness $W_i$ of the n⁻layer and $h_{FE}$, $t_{stg}$, and RBSOA have the relationship shown in *Fig. 8*. As $W_i$ is made thinner, $h_{FE}$ and $t_{stg}$ improve, but the RBSOA decreases. Therefore, improving $h_{FE}$ and $t_{stg}$ by making $W_i$ thinner without reducing the RBSOA was a technological problem.

*Fig. 7* Triple diffused planar transistor chip

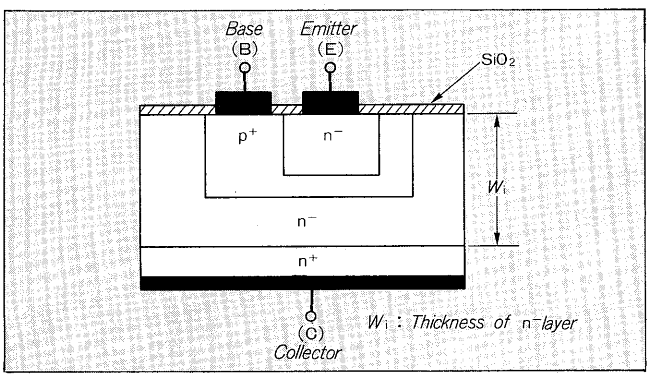



*Fig. 8* Relationship between $W_i$ and various characteristics of existing bipolar transistor

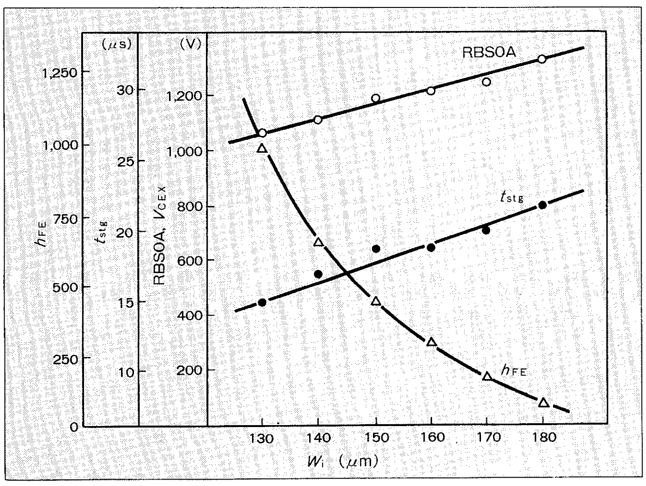
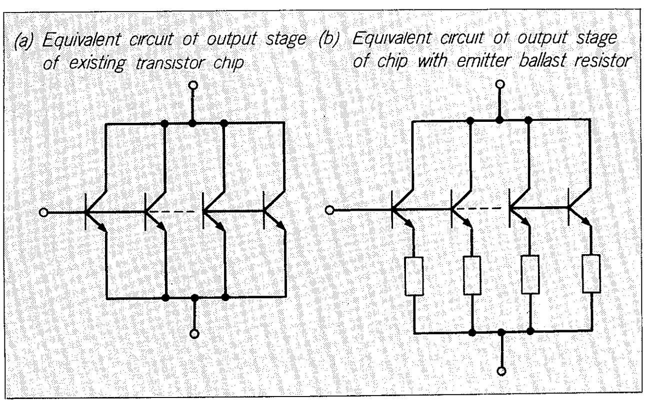



*Fig. 9* Equivalent circuit of output stage of Darlington transistor




Transistor chips consists of over several hundred transistor cells connected in parallel as shown in *Fig. 9*. With such a construction, when the current flowing in the cells is unbalanced, the cells through which a large current flows are destroyed by a voltage lower than the breakdown voltage when the current is balanced. Therefore, it was deduced that the same RBSOA as in the past could be obtained even with a thin $W_i$ by improving this current balance.

The method of a ballast resistor to the emitter of each cell as shown in *Fig. 9* was reported for low capacity power transistors for low output power supplies, but since the manufacturing of uniform resistors in a large chip is difficult, it could not be applied to high capacity power transistors. However, recent improvement of IC, power MOSFET, etc. process technology has made this possible. An example of a pattern with an emitter ballast resistor added to each cell is shown in *Fig. 10*. The same RBSOA as in the past was obtained even with a thin $W_i$ by means of this. As a result, the high current region $h_{FE}$ was improved as shown in *Fig. 11* and operation with a base drive current of 1/2 of that of the past was possible and a $t_{stg}$ of approximately 1/2 of that of the past as shown in *Fig. 12* was realized.

*Fig. 10* Example of pattern with emitter ballast resistor

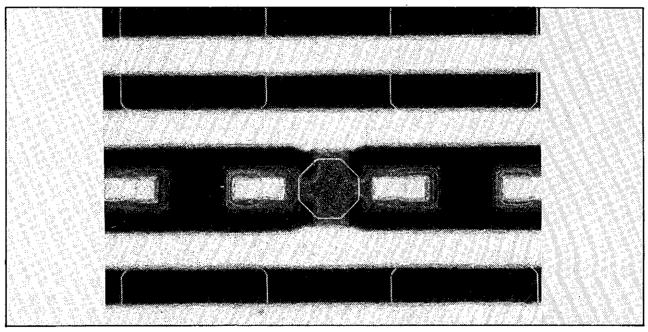


*Fig. 11* Comparison of $h_{FE}$-$I_C$ characteristic of 2D175Z-120 and existing type

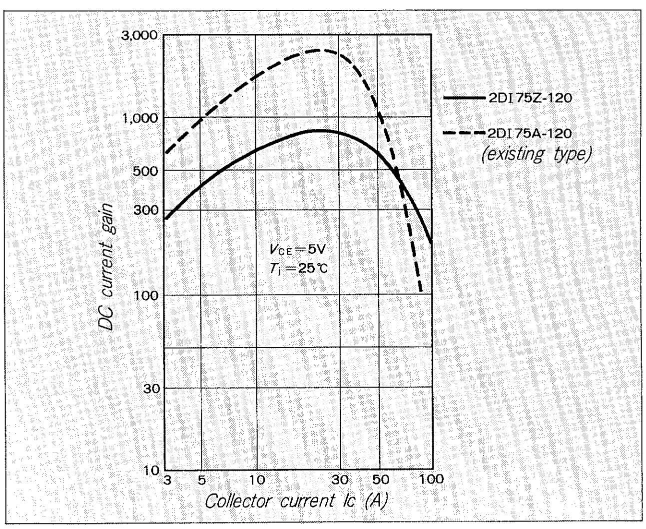


*Fig. 12* Comparison of switching characteristics of 2DI75Z-120 and existing type

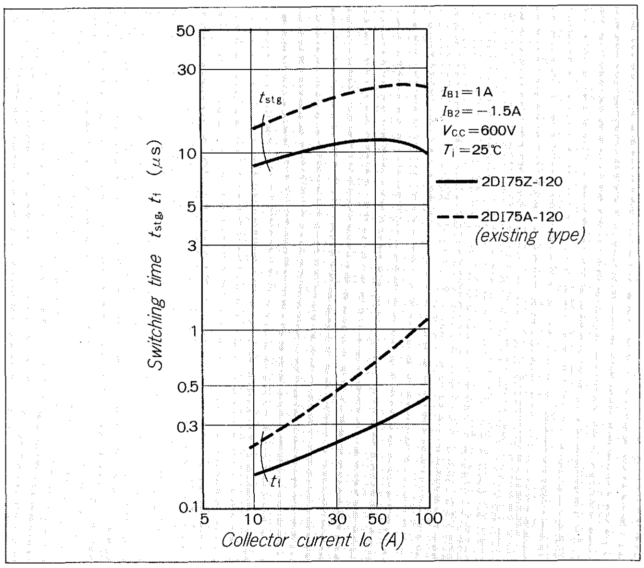
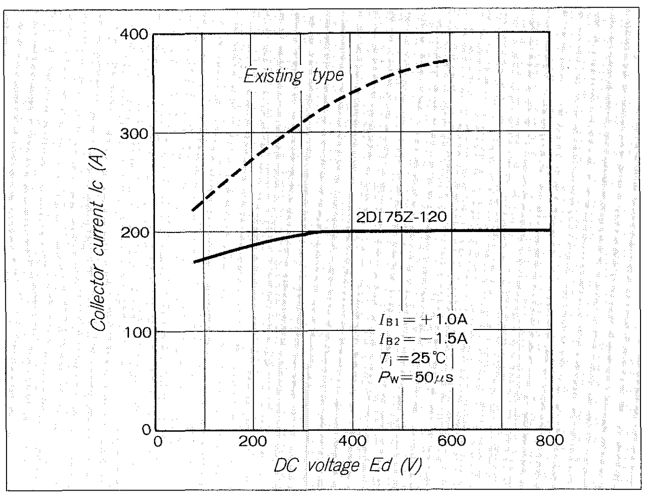



*Fig. 13* Comparison of short-circuit current characteristic of 2DI75Z-120 and old type




### 3.3 Improvement of short-circuit withstand capability by overcurrent limiting circuit

When an inverter circuit is short-circuited by erroneous operation or trouble, a high voltage and high current are applied to the power transistor simultaneously. The overcurrent which flows at this time reaches 4 to 5 times of the rated current as shown in *Fig. 13*. The time required to protect the power transistor by detecting this overcurrent and turning off the power transistor is usually 50 $\mu$s or less, and the power transistor must withstand the high voltage and high current state during this period.

On the other hand, the maximum circuit voltage at normal operation of an inverter circuit with an AC460 to 480V input voltage is DC747V. If the device can withstand overcurrent which flows at this voltage for 50 $\mu$s, the power transistor can be protected. However, because the actual breakdown voltage of a existing 1,200V power transistor was only 650 to 700V, insertion of an overcurrent limiting

*Fig. 14* Overcurrent limiting circuit

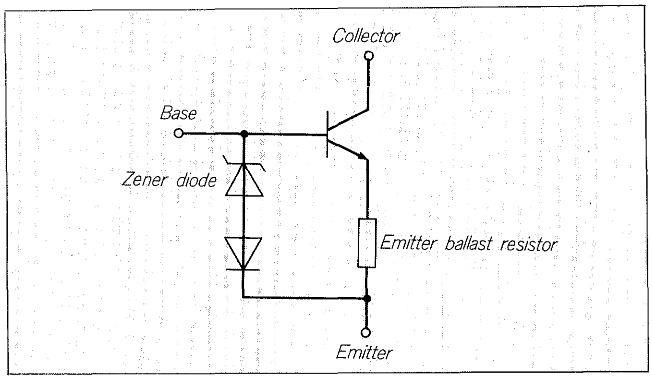
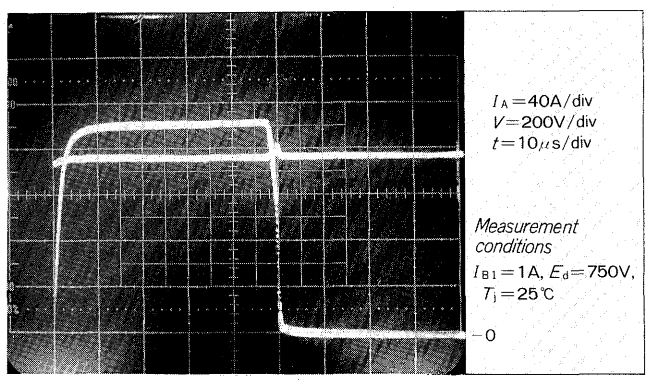



*Fig. 15* 2DI75Z-120 short-circuit current and voltage waveform




reactor into the circuit or other countermeasures were necessary.

The amplitude of the short-circuit overcurrent is determined by the base current supplied to the power transistor and the $h_{FE}$. If the base current when the overcurrent starts to flow is made small, the current is kept at a low value and a higher voltage can also be withstood. Therefore with the Z-series, the emitter ballast resistor is used as a current detection resistor and the overcurrent is limited by connecting a constant voltage circuit such as that shown in *Fig. 14* between the base and emitter. When an overcurrent begins to flow in the emitter ballast resistor, since the $V_{BE}$ of transistor rises suddenly and the base current is bypassed at the constant voltage circuit side, the overcurrent is limited to 60% or less of the conventional value as shown in *Fig. 13* and a short-circuit withstand capability of 750V or more as shown in *Fig. 15* is realized.

## 4. CONCLUSION

The characteristics and device design of the 1,200V power transistor modules "Z-series" were outlined above. We are confident that this product, with its unheard of features, will meet the expectations of the inverter field, which is demanding smaller size and higher performance. In the future, we will also put efforts into raising the level of the new technology developed this time still farther and developing products which satisfy the various demands of the market place.