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POWER TRANSISTOR MODULES FOR POWER CONVERTER

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I. FORWORD

While the demand for large power transistors as the main semiconductor elements in power converters is increasing, attention is being focused on the total advantages of modules which house multiple elements in one package to make the equipment smaller, simplify design, easier handling and maintenance, and improved installation efficiency. Fuji Electric has obtained good market results with its existing series of large power transistors and recently completed a new series of 500 V and 1200 V power transistor modules for use in 200 VAC and 480 VAC input equipment based on the know-how accumulated with the existing series. This report introduces these power transistor modules.

II. POWER TRANSISTOR MODULE SERIES

Fig. 1 is a photograph of the power transistor modules in the new series. *Table 1* shows the line-up of the 500 V transistors. *Table 2* shows the line-up of the 1200 V transistors. The basic unit of the power transistor modules consists of a power transistor chip, high-speed free-wheeling diode chip, and a speed-up diode chip. A module is made up of one to six of these basic units housed in the same case. The single unit module is available with the semiconductor chip insulated from the case (insulated type) or not insulated from the case (noninsulated type). All double unit modules are the insulated type.

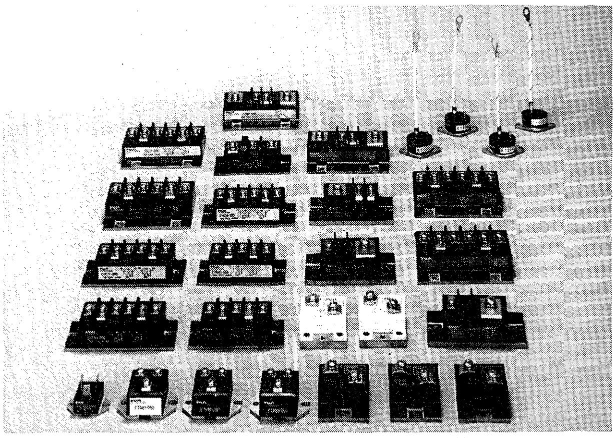

Fig. 1 Fuji power transistor modules

Table 1 Line-up of 500 V transistors

Current capacity	Insulated type		Uninsulated type
	Double unit	Single unit	
15A	*EVF31T-050A	FTF81-050A (1D1 15A-50)	
30A	EVG31-050A (2D1 30A-50)	ETG81-050A (1D1 30A-50)	
50A	EVK31-050A (2D1 50A-50)	ETK81-050A (1D1 50A-50)	
75A	EVK71-050A (2D1 75A-50)	ETK85-050A (1D1 75A-50)	
100A	EVL31-050 (2D1 100A-50)		2SC2770 (1S 100A-50)
	EVL31-055 (2D1 100B-55)		ET127 (1D 100C-50)
150A	EVM31-050 (2S1 150A-50)		
200A		ETN81-055 (1D1 200A-55)	ETN01-055 (1S 200A-55)
			ETN31-055 (1D 200A-55)
300A		ETN85-050 (1D1 300A-50)	

Table 2 Line-up of 1200V transistors

Current Capacity	Insulated Type	
	Double unit	Single unit
50A	2D1 50A-120	
75A	2D1 75A-120	
100A	2D1 100A-120	
150A	2D1 150A-120	
300A		1D1 300A-120

III. POWER TRANSISTOR ELEMENT DESIGN

The outside of the power transistor module was specially designed for easy installation and has three to six terminals arranged in one row on the same plane to simplify connection with one driver. (However, this does not apply to modules having a capacity under 30 A.) The outside case is made of the same material as our widely used BBT (Building Block Transistor). Ample consideration was also given to mechanical and thermal strength and moisture-resistance.

Fig. 2 is a typical example of the interior structure of the power transistor module. A large triple diffused planar chip with well-balanced static and dynamic characteristics is brazed to a copper substrate insulated by a ceramic plate through a molybdenum plate. The ceramic plate is, of course, not used with noninsulated chips. All connections between the outside terminals and the semiconductor chip are made with aluminum wire. The connections are protected by incombustible resin packing.

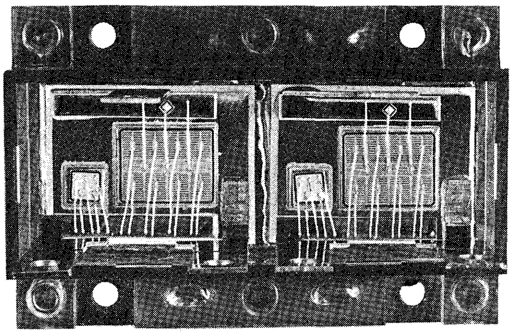

Fig. 2 Interior structure of power transistor module

IV. RATINGS AND CHARACTERISTICS OF POWER TRANSISTOR MODULE

Table 3 shows the absolute maximum ratings of the EVG31-050A (uses the same chip as the EVG33-050 and ETG81-050A), EVK31-050A (EVK33-050, ETK-81-050A), EVK-71-050A, and EVL31-050 as typical examples of the 500 V transistors. *Table 4* shows their electrical characteristics.

The specifications common to these elements are V_{CBO} = 600 V, $V_{CEO(SUS)}$ = 450 V, $V_{CEX(SUS)}$ = 500 V, a pulse current rating of double the DC ratings, minimum $h_{FE} \geqq 100$, etc.

Their characteristics will be described in detail by using the 75 A current capacity EVK71-050A as an example. *Fig. 3* shows the collector current dependency of the h_{FE} with the case temperature as a parameter. *Figs. 4, 5,* and *6* shows its switching characteristics.

Fig. 4 shows the current dependency, *Fig. 5* shows the base reverse bias current dependency, and *Fig. 6* shows the temperature dependency. As the base reverse bias current increases, the turn-off time becomes shorter, but its limit is restricted by the V_{EBO} and reverse bias SOA (abbreviated RBSOA. SOA: Safe Operation Area) the RBSOA becomes narrower the reverse bias current becomes larger. *Figs. 7* and *8* show the forward bias SOA (abbreviated FBSOA). *Fig. 7* is the FBSOA for repetitive operation and *Fig. 8* is the FBSOA for nonrepetitive operation. *Fig. 9* shows the RBSOA with $-I_B$ as a parameter. The RBSOA temperature dependency of this series is a positive coefficient as shown

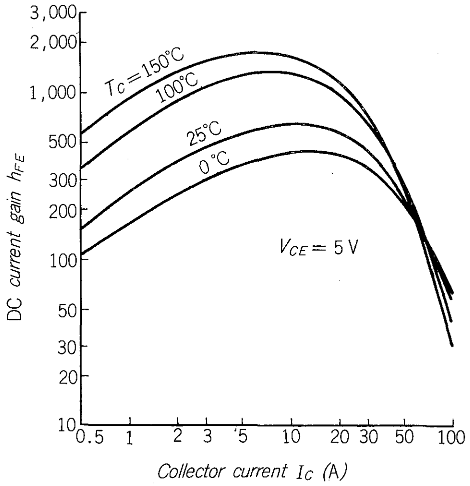

Fig. 3 $h_{FE}-I_C$ characteristics of EVK71-050A

Table 3 Absolute maximum ratings of 500 V

Item	Symbol	Condition	EVG31-050A	EVK31-050A	EVK71-050A	EVL31-050	Units
Collector-base voltage	V_{CBO}		600	600	600	600	V
Collector-emitter voltage	$V_{CEO(SUS)}$		450	450	450	450	V
Emitter-base voltage	V_{EBO}		6	6	6	6	V
Collector current	I_C	DC	30	50	75	100	A
Base current	I_B	DC	2	3	4.5	6	A
Collector loss	P_C	T_C = 25°C	200 x 2	300 x 2	350 x 2	500 x 2	W
Junction temperature	T_j		150	150	150	150	°C
Storage temperature	T_{stg}		–40 ~ +125	–40 ~ +125	–40 ~ +125	–40 ~ +125	°C

Table 4 Electrical characteristics of 500 V transistors

Item	Symbol	Condition				EVG31 -050A	EVK31 -050A	EVK71 -505	EVL31 -050	Unit
Collector-base voltage	$V_{CEO(SUS)}$	$I_C = 1A, R_{BE} = \infty$				$\geqq 450$	$\geqq 450$	$\geqq 450$	$\geqq 450$	V
Collector-emitter voltage	$V_{CEX(SUS)}$	$I_C = 60A$ $V_{EB} = 6V$ V_{CE}=500V peak $I_B = \pm 0.6A$	$I_C = 100A$ $V_{EB} = 6V$ V_{CE}=500V peak $I_B = \pm 1A$	$I_C = 150A$ $V_{EB} = 6V$ V_{CE}=500V peak $I_B = \pm 2A$	$I_C = 200A$ $V_{EB} = 6V$ V_{CE}=500V peak $I_B = \pm 2A$	$\geqq 500$	$\geqq 500$	$\geqq 500$	$\geqq 500$	V
Emitter-base voltage	I_{CBO}	$V_{CBO} = 600V$				$\leqq 1.0$	$\leqq 1.0$	$\leqq 1.0$	$\leqq 1.0$	mA
Collector current	I_{EBO}	$I_{EBO} = 6V$				$\leqq 150$	$\leqq 100$	$\leqq 100$	$\leqq 100$	mA
Base current	h_{FE}	$I_C = 30A$ $V_{CE} = 5V$	$I_C = 50A$ $V_{CE} = 5V$	$I_C = 75A$ $V_{CE} = 5V$	$I_C = 100A$ $V_{CE} = 5V$	$\geqq 100$	$\geqq 100$	$\geqq 100$	$\geqq 100$	
Collector loss	$V_{CE(sat)}$	$I_C = 30A$ $I_B = 0.6A$	$I_C = 50A$ $I_B = 1A$	$I_C = 75A$ $I_B = 2A$	$I_C = 100A$ $I_B = 2A$	$\leqq 2.0$	$\leqq 2.0$	$\leqq 2.0$	$\leqq 2.0$	V
Junction temperature	$V_{BE(sat)}$					$\leqq 2.5$	$\leqq 2.5$	$\leqq 2.5$	$\leqq 2.5$	V
Storage temperature	t_{on}	$I_C = 30A$ $I_B = \pm 0.6A$ $R_L = 10\Omega$ $P_W = 50\mu s$	$I_C = 50A$ $I_B = \pm 1A$ $R_L = 6\Omega$ $P_W = 50\mu s$	$I_C = 75A$ $I_B = \pm 2A$ $R_L = 5\Omega$ $P_W = 50\mu s$	$I_C = 100A$ $I_B = \pm 2A$ $R_L = 3\Omega$ $P_W = 50\mu s$	$\leqq 3.0$	$\leqq 3.0$	$\leqq 2.0$	$\leqq 2.0$	V
	t_{stg}					$\leqq 12.0$	$\leqq 12.0$	$\leqq 10.0$	$\leqq 10.0$	μs
	t_f					$\leqq 4.0$	$\leqq 4.0$	$\leqq 2.5$	$\leqq 3.0$	
		EVG31-050A	EVK31-050A	EVK71-050A	EVL31-050					

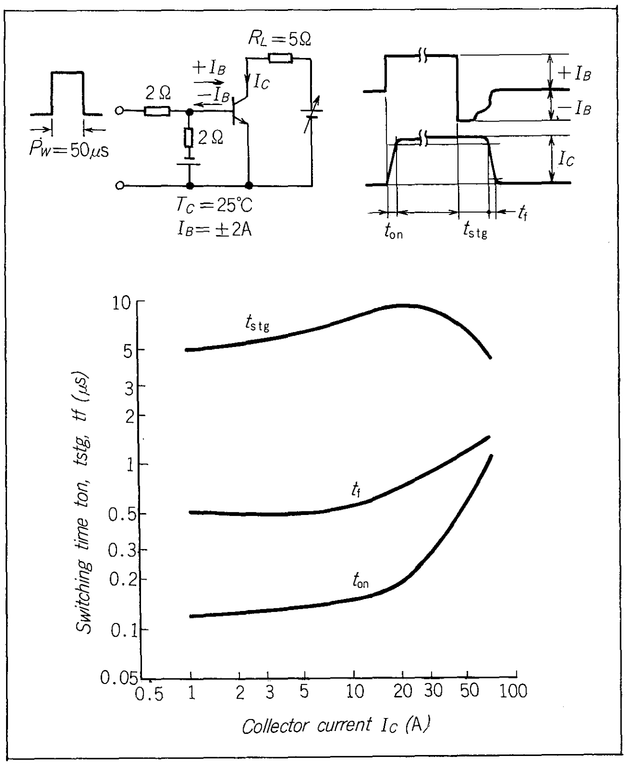

Fig. 4 Switching time $-I_C$ characteristics of EVK71-050A

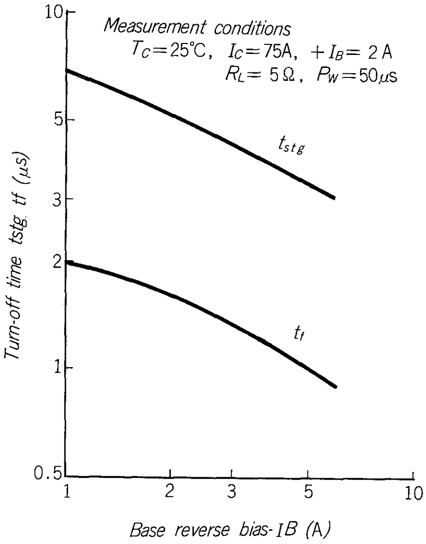

Fig. 5 Switching time $-(-I_B)$ characteristics of EVK71-050A

in *Fig. 10*. Therefore, the snubber circuit must be designed by using the RBSOA at the lowest operating temperature of the power transistor.

The noninsulated type new BBT series, ETN01-055 (single transistor and ETN31-055 (Darlington transistor), are special feature products. They are the old 100 A BBT with an improved substrate. The current capacity of both i 200 A.

The main improvements were a reduction in size b housing a unit having a current capacity of double that o the existing ET127 in a package of about 1.5 its size further consideration given to installation, including th arrangement of the terminals, increasing the size of th chip, improvement of the operating characteristics whe modules are connected in parallel at the outside, etc. A hig capacity system can be built by using these modules.

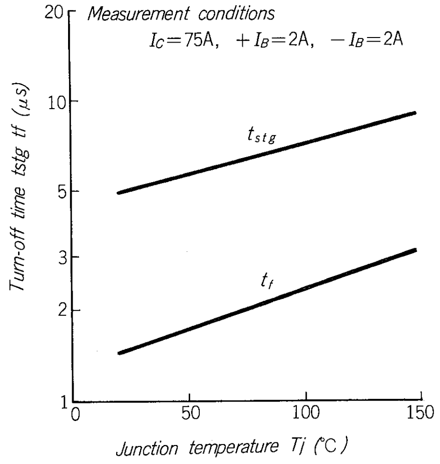

Fig. 6 Switching time $-T_j$ characteristics of EVK71-050A

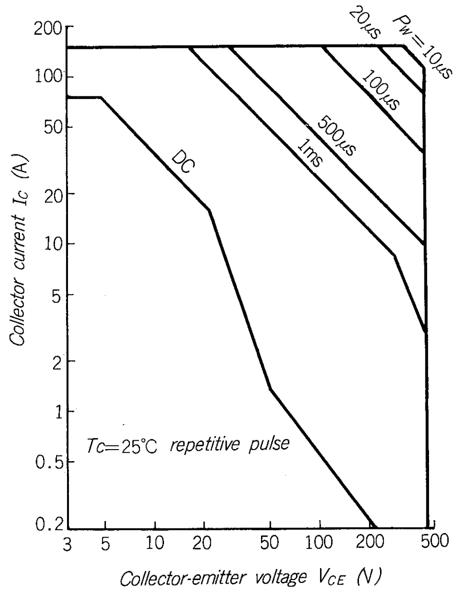

Fig. 7 Forward biased SOA (repetition) of EVK71-050A

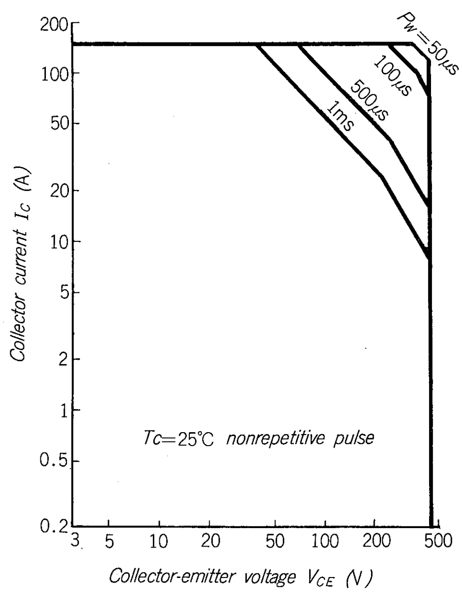

Fig. 8 Forward biased SOA (nonrepetition) of EVK71-050A

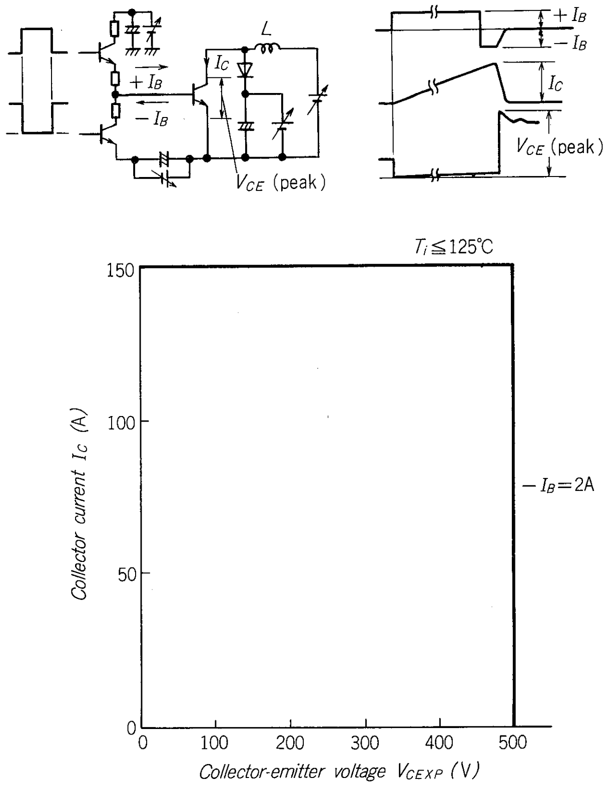

Fig. 9 Reverse biased SOA of EVK71-050A

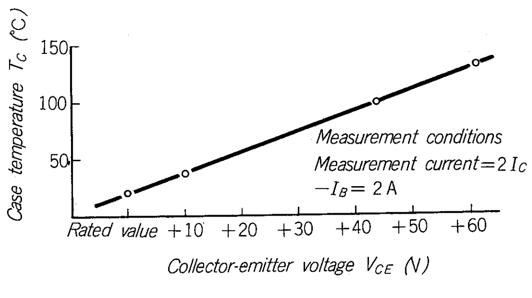

Fig. 10 RBSOA-T_j· characteristics of EVK71-050A

A large number of modules are also available in the 1200 V series. Except for their different shape and the chip is insulated the same design and manufacturing technology is used. The characteristics of this series will be outlined by using the two transistor 1DI300A-120 as an example. *Table 5* shows its absolute maximum ratings and electrical characteristics. *Fig. 11* shows its equivalent circuit. A high gain is obtained by a 3-stage Darlington construction. The breakdown voltage corresponds to the input voltage of 400 VAC to 480 VAC system, and the RBSOA at the reted current is specified at 1200 V, Balancing of the switching time, which becomes more severe as the breakdown voltage is increased, was taken into account by refinements in the chip design and internal structure. *Fig. 12* shows its h_{FE} dependency

Table 5 Ratings and characteristics of 1D1 300A-120

	Item	Symbol	Condition	Rated value, Characteristic value	Units
Absolute maximum rating	Collector-base valtage	V_{CBO}		1200	V
	Collector-emitter voltage	V_{CEO}		1200	V
	Emitter-base voltage	V_{EBO}		10	V
	Collector current	I_C	DC	300	A
		I_{CP}	1m	600	A
		$-I_C$	DC	300	A
	Base current	I_B	DC	8	A
		I_{BP}	1m	16	A
	Collector loss	P_C		1000+1000	W
	Junction temperature	T_j		+150	°C
	Storage temperature	T_{stg}		−40~+125	°C
	Insulation dielectric strength	–		AC2,500	V
Electrical and thermal characteristics	Collector-base voltage	V_{CBO}	I_{CBO} = 2mA	1,200	V
	Collector-emitter voltage	V_{CEO}	I_{CEO} = 2mA	1,200	V
		$V_{CEO(SUS)}$	I_C = 5A	1,000	V
		$V_{CEX(SUS)}$	I_C = 1,200A $-I_B$ = 24A	1,200	V
	Emitter-base voltage	V_{EBO}	I_{EBO} = 400mA	10	V
	Collector blocking	I_{CBO}	V_{CBO} = 1,200V	2	mA
	Emitter blocking	I_{EBO}	V_{EBO} = 10V	400	mA
	DC current gain	h_{FE}	I_C = 300A, V_{CE} = 5V	70	–
	Collector-emitter saturation voltage	$V_{CE(SAT)}$	I_C = 300A, I_B = 8A	2.5	V
	Base-emitter saturation voltage	$V_{BE(SAT)}$	I_C = 300A, I_B = 8A	3.5	V
	Switching time	t_{on}	I_C = 300A, I_B = 8A	3	μs
		t_s	$-I_B$ = 24A	15	μs
		t_f	P_w = 50μs	3	μs
	Collector-emitter reverse voltage	V_D	I_C = −300A	2.5	V
	Thermal resistance	$R_{th(t-c)}$	Transistor	0.062	°C/W
		$R_{th(t-c)}$	Diode	0.16	°C/W
	Contact thermal resistance	$R_{th(c-f)}$	Between case-fins	0.03	°C/W

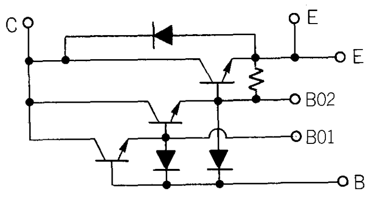

Fig. 11 Equivalent circuit of EV1234

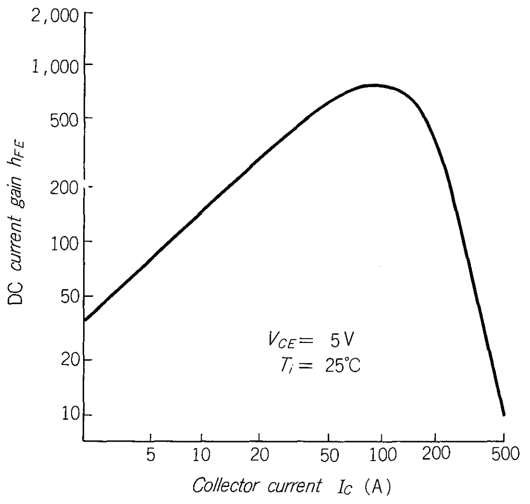

Fig. 12 DC collector current gain characteristics

and *Fig. 13* shows $V_{CE(sat)}$ characteristics, and *Fig. 14* shows its turn-off time current dependency and $-I_B$ dependency. *Fig. 15* shows RBSOA.

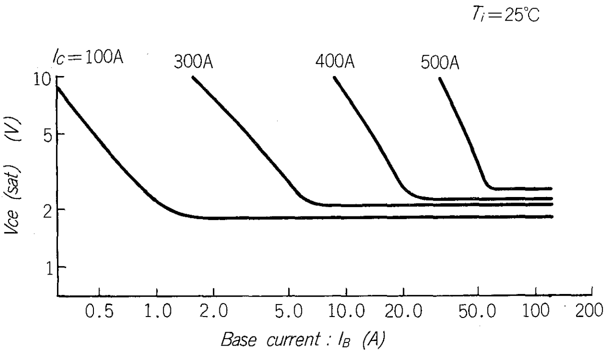

Fig. 13 Collector-emitter saturation voltage characteristics

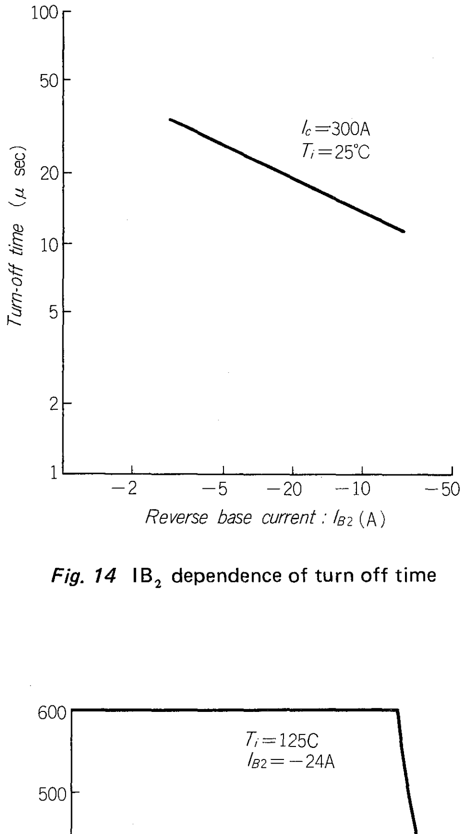

Fig. 14 IB_2 dependence of turn off time

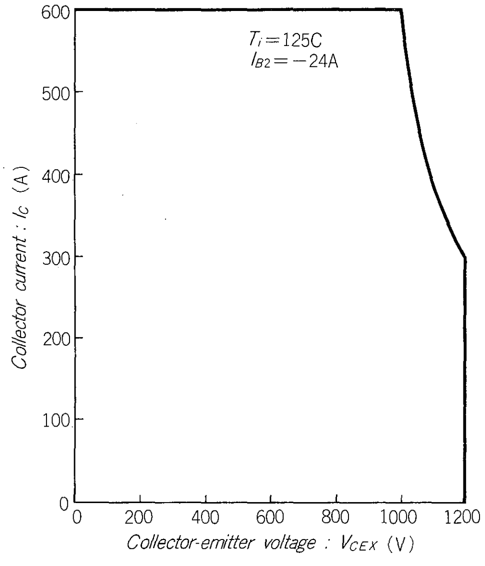

Fig. 15 Reverse bias safe operating area

V. POWER TRNAISTOR MODULE OVERCURRENT CAPACITY

Considering the overcurrent capability of the device not only with the power transistor module, but also with the high capacity power transistors is very important. Recently the depend for clarification of the overcurrent capability has become very strong. Its approach is described next. The most severe over current condition is arm short-circuit that the both upper and lower transistor of one-arm in a inverter circuit turn on at the same time without any impedance from DC bus. This phenominon is generally caused by malfunction of drive circuit or breakdown of a transistor.

Fig. 16 is a model of the current and voltage waveforms when the arm is short-circuited. V_{CES} is the voltage applied between the collector and emitter when the short-circuit occurs. It is almost equal to the DC power supply voltage. I_{CS} is the collector current that flows when the short-circuit occurs, the transistor h_{FE} and base current I_B determine its value.

Only the FBSOA shown as FBSOA in the figure was usually considered as the overcurrent capacity at a short-circuit. However, considering two characteristics is actually more accurate. One of these characteristics is the FBSOA up to the time $I_B = 0$ by operation of the protection circuit after the arm is short-circuited and an overcurrent beings to flow. The other characteristic is the RBSOA until the collector current drops and the collector voltage reaches V_{CEP}. *Fig. 17* shows how the collector current of the DC rated current 75 A VK71-050A changes with the transistor h_{FE} and power supply voltage at an arm short-circuit. *Fig. 18* shows how the collector current changes with the base current I_B at an arm short-circuit. The current pulse width is set to 50 μs in both cases. The element does not breakdown under these conditions. The actual breakdown point is a pulse width of about 100 μs for DC power supply voltage = 300 V, T_C = 125°C. Arm short-circuits of 50 μs or less under the same conditions are amply allowable. Besides, since the collector current at an arm short-circuit substantially exceeds the FBSOA shown in *Figs. 7* and *8*, an

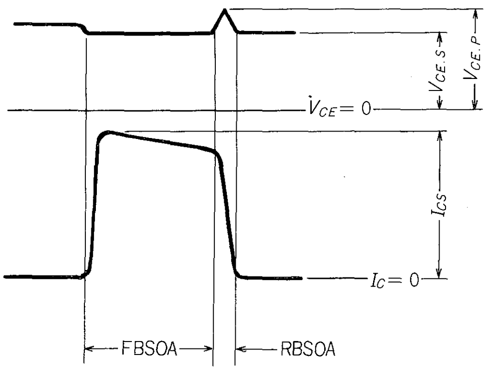

Fig. 16 Voltage and current waveforms at overcurrent

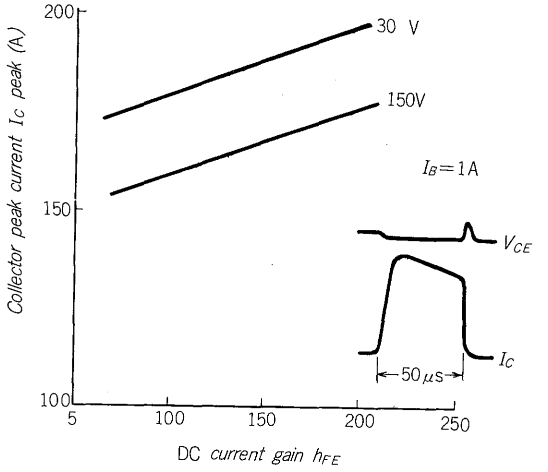

Fig. 17 Overcurrent-h_{FE}, DC power supply voltage characteristics of EVK71-050A

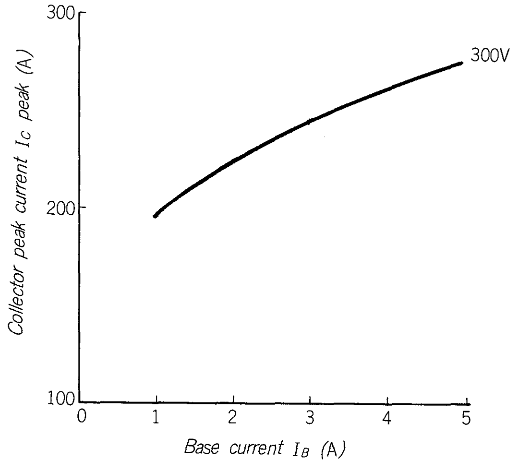

Fig. 18 Overcurrent –I_{BA} characteristics of EVK71-050A

RBSOA (RBSOA at arm short-circuit) in the region which exceeds the pulse current exceeds the normally specified is necessary. *Fig. 19* shows the RBSOA of the EVK71-050A at an arm short-circuit.

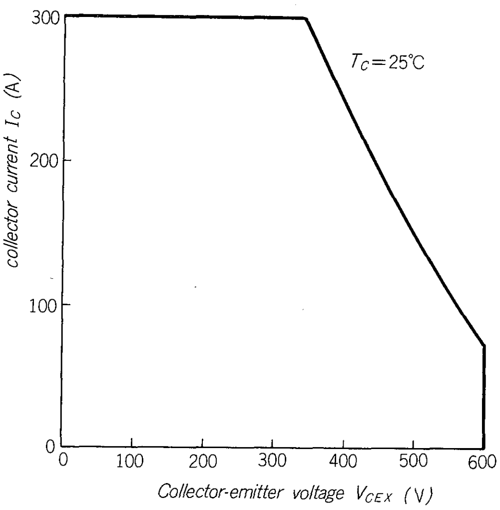

Fig. 19 RBSOA of EVK71-050A at overcurrent

The EVK71-050A can be protected against arm short-circuits by suppressing the D_C power supply voltage during a short-circuit to 300 V or less and tripping the circuit so that the RBSOA is not exceeded when an arm short-circuit within 50 μs after the short circuit occurs. Arm short-circuit protection harmonization should also be designed in accordance with the approach to breakdown resistance described here for other transistors also.

VI. CONCLUSION

The newly completed series of power transistor modules was introduced and their element construction and electrical characteristics were described. The method of providing positive protection of the power transistors against overcurrents was also described. Fuji Electric is now developing a still higher capacity power transistor module. Needless to say, the design concepts described here are amply reflected in these elements and this is the time for more effort toward the development of easier to use power transistor and more complete application data.