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FUJI SWITCHING POWER TRANSISTOR

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1 FOREWORD

It has been ten years since Fuji Power Transistors had come to be manufactured in mass. The products had registered a rapid growth matching with the needs of time, thanks to our efforts in commercializing the products as forerunners of this sector of industries in adopting entirely the recent developed triple diffused planar structure, focus-the application into high voltage switching.

Fuji Power Transistors started with Power Darlington transistors of 6-8A, 400V for engine ignition of automobiles and developed into commercializing of large-scale mold transistor by utilizing the technology acquired in the power transistor for switching power supply high-speed transistor, then, in-to BBT (Building Block Transistor). BBT is a direct ancestor of later power module, the first in this sector of industries, so that the industrialization of the product is highly significant. And now, the time is ripe for complexification of the products whose first fruits indeed are the power modules. This coincides with other innovations in manufacture, for example, the ignition system has changed from contact system to contactless one, the general power supplies from dropper system to switching system, and the motor control from thyristor and triac systems to transistor system.

This report outlines the progress of the development, designing policies of Fuji Power Transistor together with its features and particularities of the products in order to promote better understanding on them.

2 DEVELOPMENT PROGRESS OF FUJI POWER TRANSISTOR

2.1 Power transistor for engine ignition

In order to generate a high voltage in tens of thousand volts in the secondary side of ignition coils, the function of opening and closing of the switch on the primary side has long been that of contact system. Together with fortifying of exhaust control law, high voltage and high resistance to mechanical breakdown power Darlington transistors have become everyday more necessary for coping with the demand for higher current, which has been solutioned by using power transistors in lieu of contacts, the practice starting from about the middle of 70's in the United States, at the same time, research has been made for making the products maintenance-free.

Fig. 1 shows the fundamental circuit of the ignition system with its operational waveform, as well as transistor operation locus. The operational characteristics of the transistors used therein are that, in the practical operations, their loci are applied to the sustained voltage of the transistor. Before the transistor for ignition had made debut, the practical use applying to transistor's sustained voltage did not exist, and as the means of measuring the transistor sustained voltage, there existed only a method of application called "latching" method.

It is obvious that in the ignition system, such operation mode is, for defining the resistance to puncture of the transistor, not suitable with conventional "forward bias safety operation area" (FBSOA). In general, the area of safe operation (ASO), when other designing parameters are kept inviariable and specific resistance (ρ) of high-resistance layer of the collector and thickness (W_i) are changed, will be the larger when $W_i \times \rho$ is made larger. However, in this

Fig. 1 Fundamental circuit of the ignition system and its functioning

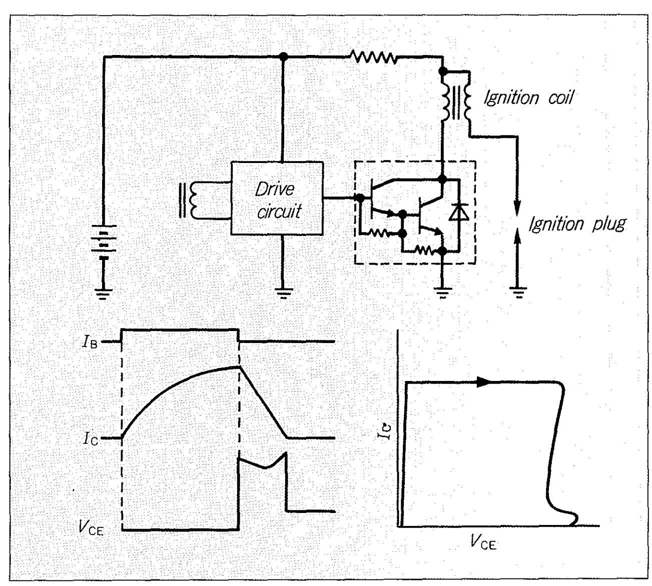


Fig. 2 Relation between $\rho \times W_i$ value and puncture resistance

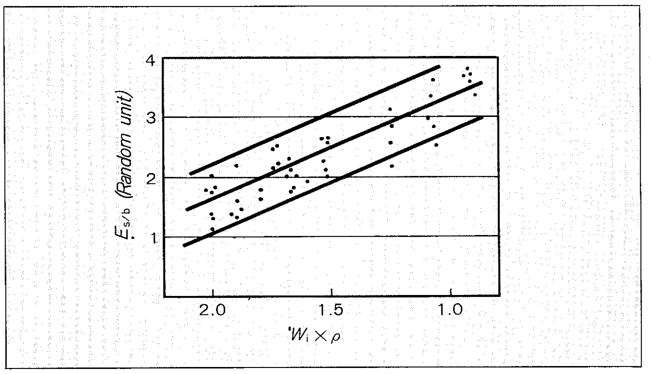
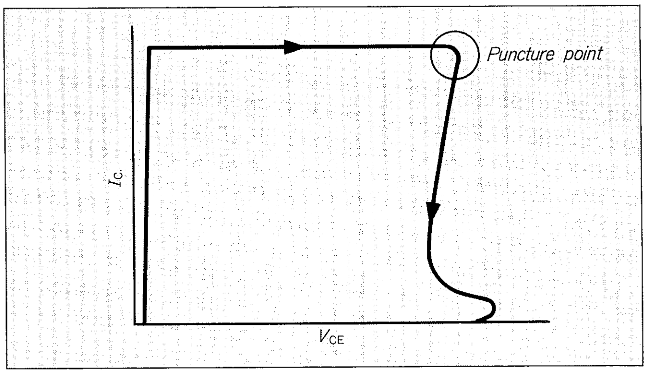


Fig. 3 Peak point puncture of the ignition transistor



particular application, as seen from *Fig. 2*, the result obtained was different from the above-mentioned inference. The puncture resistance is expressed, thus,

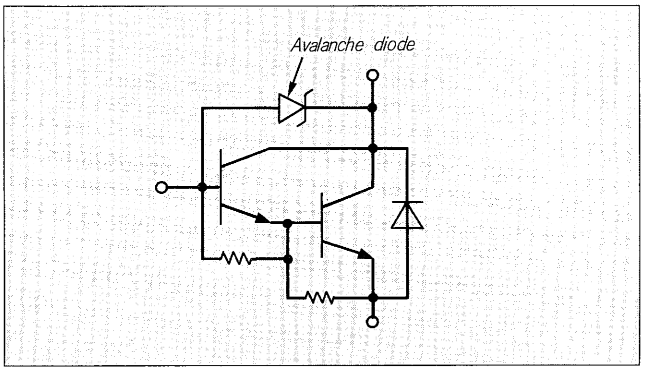
$$E_{s/b} = \frac{1}{2} LI^2 \text{ (mJ)}$$

whereas, L (mH): Coil inductance, being a load
I (A) : Collector current

This is the puncture resistance by Latching method. By analysis of the operation locus, it is made clear that the puncture takes place at an operational point shown in *Fig. 3*, and supposing that we call the point, "peak point puncture", its resistance will be the smaller when the $\rho \times W_i$ value is made larger, that is, withstand voltage is made larger. This can be explained as, by the rise of sustained voltage, the power (voltage × current) at the peak point becomes larger and this makes $W_i \times \rho$ value larger, surpassing the general effect of making ASO larger.

The measures that have to be taken for fortifying $E_{s/b}$ causing the peak-point puncture, are to make W_i larger without making ρ any larger. However, when taking into consideration of capability of processing at the time of manufacture, the measures to be taken will be, as shown in *Fig. 4* to insert avalanche diodes in between collector and base. Fuji Electric has introduced for the first time in this sector of industries, one-package transistor ETD32 with avalanche diodes, then 2SD1071 monolithic mold type transistors and these determined the trends of later ignition

Fig. 4 Power transistor with avalanche diodes



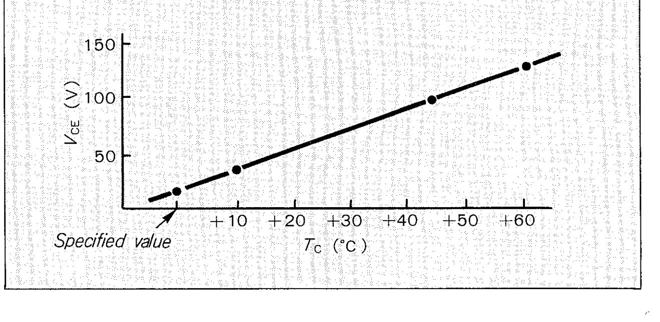
transistor and they are still used in an enormous quantity in both two-wheeled and four-wheeled vehicles.

2.2 High-speed switching power transistor

Power transistors for switch mode power supply are also produced on the same principle as that of the abovementioned ignition transistor, that is, load ON/OFF operation. The object searched for in the development of this series was a good equioibrium between high speed and high puncture resistance. For puncture resistance of the switching transistor, the reverse bias safety operation area (RBSOA) at the time of turn-off is more important, and we have proposed its estimation method and, at the same time, presented the reverse bias dependability. And as for a new fact, temperature dependability of RBSOA was different from that of FBSOA, and we have found out that it has a positive coefficient.

The puncture resistance, that is seen from other point, since it defines the level that transistor's junction temperature surpasses the critical value, so that, as a matter of course, it was expected that the temperature coefficient should be in negative value, but as it turned out from the result of experiment, as shown in *Fig. 5*, it has a positive value. This, we could infer that in the turn-off process of the transistor, a carrier is emitted from the part near to the base electrode, and it has to do with the size of the area of the last conductive area remaining in the central part of the emitter, and higher the temperature, larger its area would be, and it was due to the fact that the current density becomes smaller. On the

Fig. 5 Temperature dependability of RBSOA



basis of this conclusion obtained from our experiments, we have serialized high-speed switching power transistors corresponding to 400V, 5-15A, from 20 to 50 kHz.

2.3 Larger capacity

The designing techniques accumulated by our experience in manufacturing the ignition transistor, high-speed switching transistor, regarding $E_{s/b}$' RBSOA and switching characteristics are utilized for developing large-capacity transistors for electric motor control and this led us to industrialize Darlington transistors of 500V 30-50A class.

The features of this series of products represented by 2SD1067 and 2SD1056, are besides the realization of planar type large-area transistor chips, the incorporating of speed-up diode (SUD) for improving the switching characteristics simultaneously with incorporating of high-speed diode as free-wheeling diode (FWD) into large-sized TO-3 (MO-18) packages.

2.4 Birth of BBT

Based on the records of multiple application up to 50A by large-sized TO-3 packages, still larger capacity was expected to be developed, and from the point of view of ease in use, a development of new package in lieu of conventional plane pressure-contact type (also called flat-pack or hockey pack) was expected. In answer to this expectation, as a result of thorough technological studies, the newly manufactured products were the BBTs, and their representative models are 2SD1066, 2SC2770 and ET127.

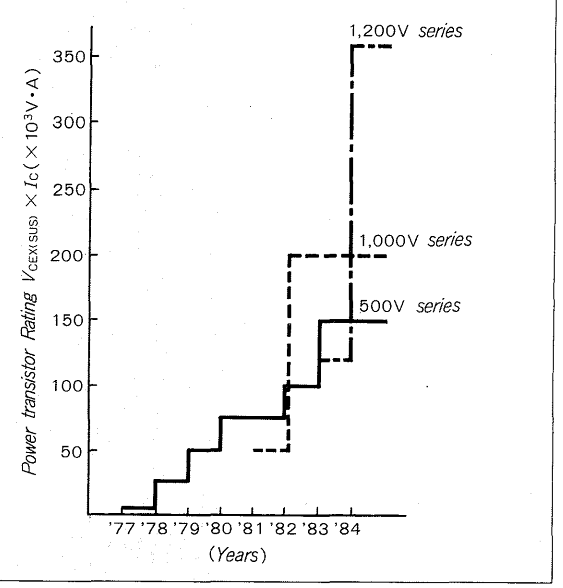
BBTs are the first large-capacity mold transistor of its type, having a capacity of 500V and 100A. But as they have FWD and SUD incorporated therein, they are more non-insulated type modules than transistor monobody. Through development of BBT, we could improve our soldering techniques and molding techniques and we could obtain high degree of reliability in resistance against humidity and resistance to power cycling.

We have further studied thoroughly the performance in parallel operations, which has been one of the objects in BBT development, and we have solutioned the concrete problems of improving the transistor characteristics themselves and, at the same time, problems derived from parallel operations by making positive communications with applications engineers. In particular, we have endeavored for direct parallel system and now it has become the standard practice in later parallel operation system.

2.5 Insulation type power transistor module

The above-mentioned BBT is power transistor module and though it is advantageous for making it larger in capacity thanks to its good heat radiating properties and through parallel operation, it has certain restriction in function when various active chips were to be housed in one package for complexification. The emergence of power modules insulating the collector from heat sink brought a possibility for designers of equipment and devices, to realize more compact designing and to lower the assembling cost. *Fig. 6* shows the progress of industrialization of power transistor

Fig. 6 Progress of power transistor module development



module. The commonest form we encounter is what we call "Pair group" construction, composed of 2 transistors and 2 diodes. But the mainstream is 6-piece group (also called six-in-one) construction if it is concerned with those using comparatively low current and light load as inverters for air conditioners. Fuji Electric has adopted designation as 1DI, 2DI and 6DI, corresponding 1-piece group, 2-piece group and 6-piece group constructions, respectively. And these are adopted as model names, that is, D stands for Darlington structure and I, insulated type.

The power transistor module is growing without ever stopping, and its use is vaste, to cite only a few, there are electric motor control for machine tools, universal type transistor inverter, inverter of exclusive use for air conditioners, uninterrupted power supply (UPS), chopper, welding machine and power source for vehicles, etc.

3 DESIGNING OF FUJI POWER TRANSISTOR

The outline of electrical characteristics of Fuji power transistor and designing policies common to all equipment in chip designing, is the following.

3.1 Electrical characteristics

Since it is a transistor, it is only natural that it has pattern (mask) designing and diffusion profiles, but $E_{s/b}$ is guaranteed to have $1/2LI^2$ (mJ) value matched to applied phasizes particularly the importance of puncture resistance, reduction in turn-off loss, withstand voltage between emitter and base (V_{EBO}) and performance in parllel operation, as defined by $E_{s/b}$ and RBSOA.

The puncture resistance depends much on the chip pattern (mask) designing and diffusion profiles, but $E_{s/b}$ is guaranteed to have $\frac{1}{2}LI^2$ (mJ) value matched to applied circuits, and RBSOA is guaranteed, as shown in *Fig. 7*, with

Fig. 7 RBSOA of switching transistor

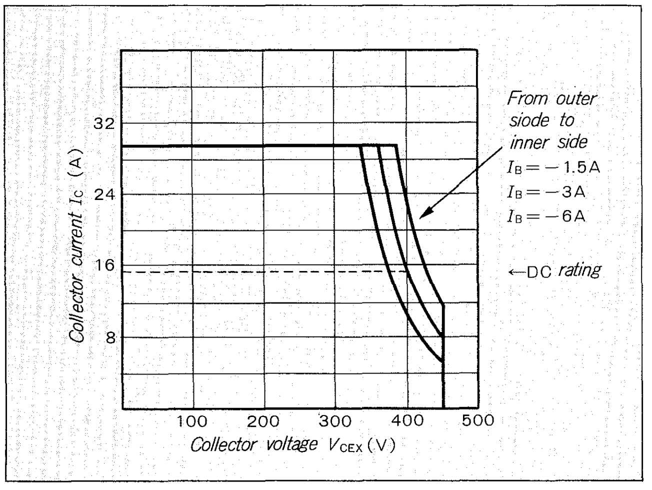
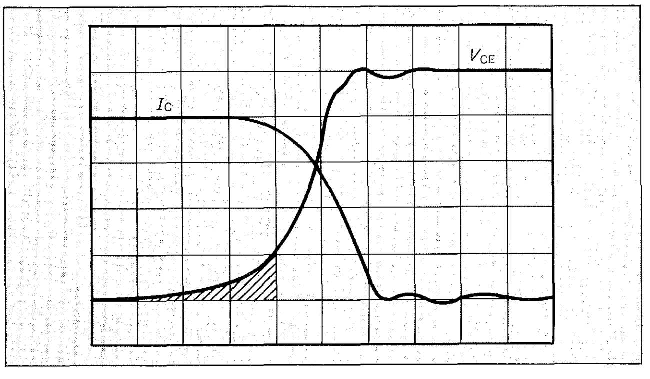


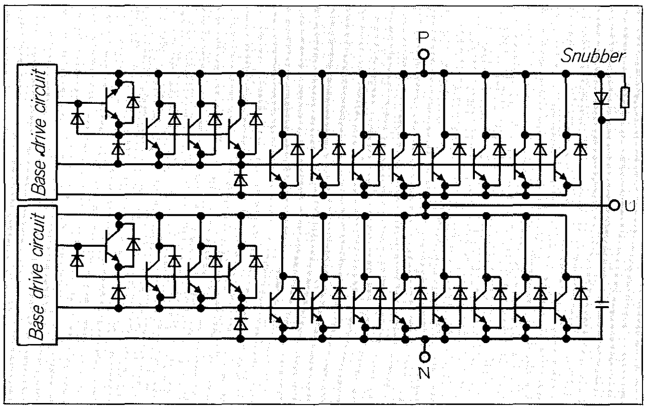
Fig. 8 Voltage rising up at the time of turn-off (□)



reverse bias withstand voltage (V_{CEX}) at 2 times more of DC rating ($2\,I_c$). This represents the spike voltage generated at the time of turn-off (V_{CEP}) or tolerance value for over-current. The presentation of short-circuit ASO is useful for designing the protective circuit.

The turn-off time that is important in the switching characteristics, has portions that can be expressed fairly clearly by t_{sig} and t_f in quantative form, and other portions, as shown in *Fig. 8*, difficult to quantify as "rising up" of the collector voltage. Since the collector current in this area maintains more or less the maximum value, the generating loss will be large. And when the withstand voltage gets higher, this "rising up" will become more evident, and in the extreme cases, this induces thermal runaways. This phenemenon is qualitatively explainable that it is due to the increase of collector resistance due to the attenuation of conductivity modulation in the turn-off process, and the extinction of carrier progresses from the peripherial parts of the emitter (part nearer to the base electrode) leading to lessening of the emitter electrode surface in practive. This is a transient characteristic more or less inherent to this type of device. Regarding this point also, Fuji Power Transistor takes heed by pattern designing and diffusion profile designing near to the optimum designing.

Fig. 9 Parallel operations by direct parallel system



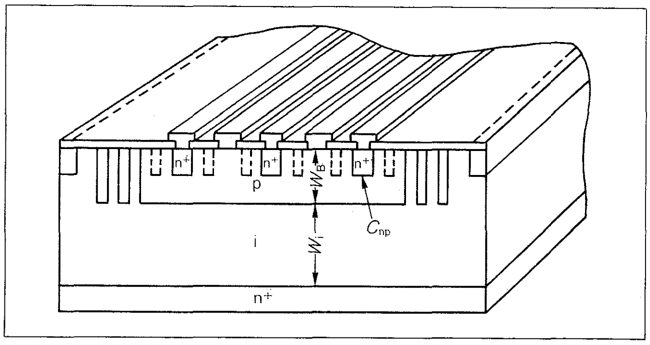
In order to shorten the turn-off time, the device is operated by applying a reverse bias between base and emitter. It is necessary that the emitter-base withstand voltage (V_{EBO}) should have a value larger than the pre-determined value. Also, when the reverse bias is the deeper, the shorter will the turn-off time will be. In general, 5-6V is applied, but depending on the case, about 10V will be necessary, and sometimes avalanche breakdown capability between emitter and base is required. In either case, a stable emitter base characteristic is required, and if it is unstable, it will cause directly a deterioration in V_{EB} characteristics, and as the secondary effect, a deterioration of h_{FE} characteristic also will be caused. Fuji Power Transistor copes with the problem by improving the transformation precision of junction between emitter and base, and by stabilizing the surface of the junction through planar technology.

The parallel operations of large-capacity transistors starting from BBT are carried out in view of applying them to larger-capacity equipment. In parallel operations of transistors, it is necessary to take heed of static balance and dynamic balance. The conventional countermeasures in this case have been to insert saturable reactors in series, and to insert an emitter resistance into the emitter side, as well as to in sert a base resistance to the base side. But as the result of our extensive resereach on the performance of parallel operations through switching power supply transistors and BBT, we have found out that it is the input characteristic between base and emitter ($V_{BE\ (SAT)}$) that determines the performance of parallel operation and the most effective way to obtain the good performance is to minimize its fluctuation. As the result, as shwon in *Fig. 9*, we have come to propose the simple and clear-cut so-called direct parallel system as the best solution. With this system, if we contain the fluctuation of $V_{BE(SAT)}$ to certain limit, we can contain also the dynamic balance not to mention the static ones. Fuji Power Transistors permit the parallel operations with comparative ease.

3.2 Chip designing

The means to realize the above-mentioned electrical characteristics consist mainly in designing of transistor chips. *Fig. 10* shows the model figure of Fuji power tran-

Fig. 10 Power transistor chip (□)



sistor chip. The thickness (W_I) of high-resistance i layer and specific resistance are determined by the withstand voltage class, and p+ guardrings are manufactured in twice or thrice fold construction for obtaining higher resistance and formed in the same process as that of base diffusion. In the emitter diffusion, the doping concentration itself is important, and this constitutes one of the factors determined the current denpendency of h_{FE}. The concentration (C_{np}) of the emitter-base junction after emitter diffusion is controlled by the diffusion time, and it determines the h_{FE} level.

Fundamentally, by changing the mask and crystal, the particularities of each type are realized, and though the type numbers are different, the manufacturing process is the same. The width of emitter lattice determined by the mask designing, is that when it is made narrower, the longer the circumference in the same chip size will be, and it will be determined taking a good balance with the length of the emitter lattice. Instead of emitter lattice, so called mesh emitter construction in which emitter region is formed in a form of an isalnd, has also an effect of making the circumference longer. After forming the passivation film, en electrode will be formed by aluminum evaporation.

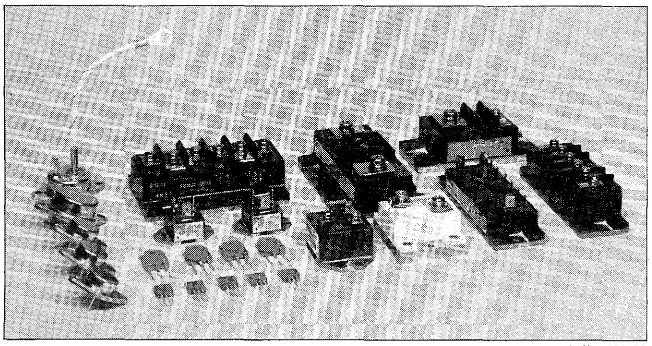
Table 2 Main series of Fuji power transistor modules

	Type	V_{CBO} (V)	V_{CEO} (V)	$V_{CE(SUS)}$ (V)	I_c (A)	P_c (W)	h_{FE}	I_c (A)	V_{CE} (V)
BBT	2SC2770	600	600	450	100	770	8	60	5
	ET127	600	600	450	100	770	100	100	5
500V Module	EVG31-050	600	600	450	30	200	100	30	5
	EVK31-050	600	600	450	50	300	100	50	5
	EVK71-050	600	600	450	75	350	70	75	5
	EVL31-050	600	600	450	100	500	100	100	5
	EVM31-050A	600	600	450	150	600	70	150	5
	ETN85-050	600	600	450	300	1,200	70	300	5
1,000V Module	2DI30D-100	1,000	1,000	1,000	30	200	100	30	5
	2DI50D-100	1,000	1,000	1,000	50	300	100	50	5
	2DI75D-100	1,000	1,000	1,000	75	400	100	75	5
	2DI100D-100	1,000	1,000	1,000	100	500	100	100	5
	2DI150D-100	1,000	1,000	1,000	150	800	100	150	5
	2DI200D-100	1,000	1,000	1,000	200	1,000	100	200	5
	1DI300D-100	1,000	1,000	1,000	300	1,600	100	300	5
	1DI400D-100	1,000	1,000	1,000	400	2,000	70	400	5
1,200V Module	2DI30A-120	1,200	1,220	1,200	30	200	70	30	5
	2DI50A-120	1,200	1,220	1,200	50	400	70	50	5
	2DI75A-120	1,200	1,220	1,200	75	500	70	75	5
	2DI100A-120	1,200	1,220	1,200	100	800	70	100	5
	2DI150A-120	1,200	1,220	1,200	150	1,000	70	150	5
	1DI200A-120	1,200	1,220	1,200	200	1,600	70	200	5
	1DI300A-120	1,200	1,220	1,200	300	2,000	70	300	5
6-Piece Group Module	EVF33T-040	450	450	400	15	80	100	15	5
	EVF34T-040	450	450	400	20	80	100	20	5
	6DI30A-050	600	600	450	30	150	100	30	5
	6DI50A-050	600	600	450	50	230	100	50	5

Table 1 Fuji mold type switching transistors main series

	Type	V_{CBO} (V)	V_{CEO} (V)	$V_{CE(SUS)}$ (V)	I_c (A)	P_c (W)	h_{FE}			t_{on} (μs)	t_{stg} (μs)	t_f (μs)	Package
								I_c (A)	V_{CE}(V)				
Darlington	2SD1071	450	300	300	6	40	500	4	2	–	–	–	TO-220AB
	ETE41	450	300	300	8	80	500	7	2	–	–	–	TO-3P
Super high-speed switching	2SC3316	500	400	400	2	40	10	1	5	0.25	1.0	0.07	TO-220AB
	2SC3317	500	400	400	5	40	10	2	5	0.25	1.0	0.07	TO-220AB
	2SC3318	500	400	400	10	80	10	5	5	0.25	1.0	0.07	TO-3P
	2SC3319	500	400	400	10	100	10	5	5	0.25	1.0	0.07	TO-3
	2SC3320	500	400	400	15	80	10	6	5	0.25	1.0	0.07	TO-3P
	2SC3321	500	400	400	15	100	10	6	5	0.25	1.0	0.07	TO-3
High Resistance	2SC3549	900	800	800	3	40	10	1	5	1.0	4.0	0.8	TO-220AB
	2SC3550	900	800	800	3	80	10	1	5	1.0	4.0	0.8	TO-3P
	2SC3551	900	800	800	5	80	10	2	5	1.0	4.0	0.8	TO-3P
High-speed	2SC3723	450	400	400	5	40	10	2	5	1.0	2.5	0.5	TO-220AB
	2SC3724	450	400	400	10	80	10	4	5	1.0	2.5	0.5	TO-3P
	2SC3725	450	400	400	15	80	10	6	5	1.0	2.5	0.5	TO-3P

Fig. 11 Outer view of Fuji power transistor



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4 FUJI SWITCHING POWER TRANSISTOR SERIES

The *Table 2* shows the representative Fuji switching power transistor types and their characteristics. The transistor for engine ignition is of mold package product, and the chips contained therein are widely used for power hybrid ICs. For high-speed switching, there are, besides 2SC33□□ series the fastest corresponding to 100kHz, 2SC37□□ series and 2SC35□□ series withstanding 800V.

In modules, there are single-piece, 2-piece, and 6-piece group constructions and the series is completed with the ones of 1,200V and 300A. Fig. 11 shows the outer view of these components.

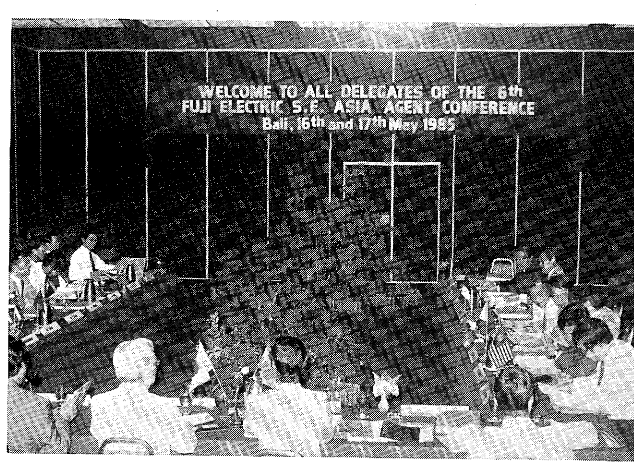
5 CONCLUSION

We have outlined in this report, the development progress, characteristics and actual situation of Fuji power transistor. The switching power transistor, as seen in the power transistor modules, shows a rapid growth. We believe that they will continue occupying an important position as one of actuators as the opposite of ICs. The key to their development lies in how to grasp effectively the users' needs even if we are to seek to explore the way to "intelligent power modules", one of the most promosing future for the products.

We are determined to seek the middle way by taking balance between differenciation and standardization to continue developing with order. What we aim is the development of our sector of industries, and we will be very glad if our users will give us their comments and suggestions.

TOPICS

THE 6TH SOUTHEAST ASIA AGENT CONFERENCE



The International Group, Distribution & Control Dept. I/SPD has opened the 6th Southeast Agent Conference in Indonesia for two days starting on May 16, 1985 to May 17, 1985. In this Conference, representatives of Agents from ASEAN countries, Hong Kong and Pakistan as well as members of associated trading firm in total of 24 persons have participated.

From Fuji Electric the general policies of our Company and its Overseas Divisions were explained in that occasion and Power Breakers, Color Mark Sensors, etc. were introduced as our new products and reports were made to the Conference from each Agent as for commercial activities in each country as well as the market report regarding the future forecast and others. All along the session, an active exchange of opinions in view of expanding our business in the territories of the Southeast Asia were made, and confirmation on the mutual policies was made also, being the Conference a very significant one. The next Conference, the seventh of the series is planned to be held in Hong Kong.