LB-849

A METHOD OF IMPROVING THE ELECTRICAL AND MECHANICAL STABILITY OF POINT-CONTACT TRANSISTORS

RADIO CORPORATION OF AMERICA
RCA LABORATORIES DIVISION
INDUSTRY SERVICE LABORATORY

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Approved

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Introduction

The use of thermosetting resins for embedding of point-contact transistors has resulted in a marked improvement in transistor mechanical and electrical stability. Developmental resin-embedded transistors have been subjected to severe impact and centrifuge tests with practically no change in electrical characteristics. Transistors utilizing this construction are highly resistant to the attack of water vapor and are able to withstand extended storage periods at elevated temperatures. Operation at low temperatures is satisfactory, but some changes in electrical characteristics occur at high ambient temperatures. The improvements described in this bulletin have extended the life of developmental transistors and indicate that their use may be feasible in applications having rigorous specifications with regard to mechanical ruggedness, high humidity, and extreme storage temperatures.

General Discussion

The extensive use of point-contact transistors as commercial devices greatly depends upon their reliability in operation. Up to the present, transistors have proven less reliable than electron tubes in many circuit applications both because of numerous early failures during operation and because of appreciable changes in operating characteristics and gain over short periods of time. Some of the sources of this instability may be traced to the germanium crystal material and to treatment of the crystal surface. Other transistor failures are directly related to the physical construction of the device. Four of the most important causes of instability are (1) high equivalent base resistance[1], (2) the attack of moisture and other chemical agents of the atmosphere on the emitter and collector contact area, (3) mechanical shifting of the point contacts, and (4) excessive changes in ambient temperature.

[1] A committee of the IRE is presently considering the use of the term "equivalent block resistance" to replace the term "equivalent base resistance".

The purpose of this bulletin is to describe a method of improving the electrical and mechanical stability of point-contact transistors.

Equivalent Base Resistance

Because operational stability of the transistor requires a low value of equivalent base resistance, several methods of obtaining these low values have been proposed. One of these methods is the use of germanium crystals of low resistivity. Another method, careful surface processing of the germanium crystals, frequently will reduce surface leakage between the emitter and collector contacts, thus reducing the value of equivalent base resistance. It has been previously reported that the equivalent base resistance may be reduced considerably by spacing the emitter and collector contacts widely[2]; no sacrifice in gain results from the

[2] B. N. Slade, "A High-Performance Transistor with Wide Spacing Between Contacts", *RCA Review*, vol. XI, No. 4, p. 517, December, 1950. (or see *LB-804*).

use of wide spacings although the frequency response of the device isdecreased. It appears, therefore, that improvement of operational stability by decreasing the value of equivalent base resistance relates directly to the germanium crystal, the crystal surface, and the distance between the point contacts.

The Embedded Transistor

Instability caused by moisture attack, mechanical shifting of the points, and excessive ambient temperatures are functions of the physical construction of the transistor. The need for a transistor which is stable electrically and mechanically has led to the development of a unit in which all of the parts are completely embedded in a thermosetting resin. A photograph of a developmental embedded transistor is given in Fig. 1. The transistor leads, crystal, crystal support, and rectifying contacts are all solidly embedded in the resin. Such a transistor is extremely rugged mechanically and is highly resistant to the attack of water vapor and other atmospheric chemical agents. The embedding process has extended the ambient temperature range over which transistors will satisfactorily operate, and has enabled transistors to withstand a wide range of storage temperatures.

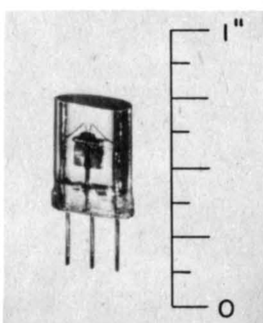

Fig. – Photograph of developmental embedded point-contact transistor.

The Mechanical Stability

The mechanical stability of an embedded transistor is demonstrated by the high resistance of the device to shock and to centrifugal force. In Table I the amplifier characteristics of four developmental transistors are tabulated before and after receiving impacts of 1000 times the acceleration due to gravity. Each transistor was subjected to five blows in each of four different directions. The directions of the impacts are indicated in Fig. 2. The data in Table I show that the impact test had practically no effect on the transistor characteristics.

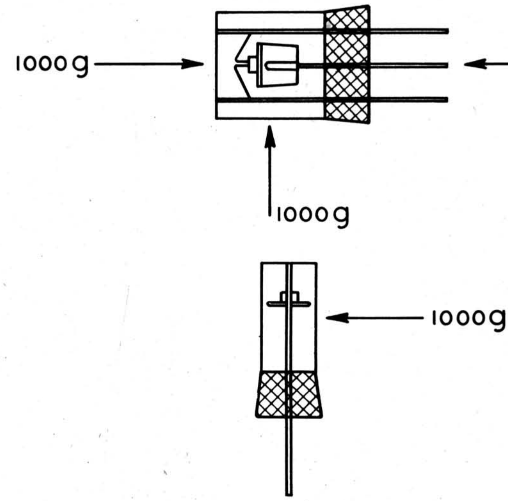

Fig. 2 – Magnitude and directions of impacts applied to embedded transistors.

Table I — Impact Test

	EMBEDDED TRANSISTOR							
	1		2		3		4	
	a	b	a	b	a	b	a	b
EMITTER VOLTS	.25	.3	.1	.12	.26	.31	.32	.33
EMITTER MA.	.67	.72	.34	.34	.62	.68	.89	.92
COLLECTOR VOLTS	20	20	20	20	15	15	20	20
COLLECTOR MA.	3.0	3.0	3.4	3.4	4.1	4.1	3.5	3.5
POWER GAIN (DB)	18.0	17.8	18.6	18.2	18.6	18.5	18.7	19.0

a. Before test. b. After 1000-g impact test.

Additional indication of the mechanical stability of such transistors may be seen in Table II which shows the operating characteristics of four transistors which were tested in a centrifuge. The directions and magnitudes of the centrifugal forces applied to the transistors are indicated in Fig. 3. The data in Table II indicate that practically no change in gain or operating characteristics occurred as a result of the test. Visual inspection of the transistors after the impact and centrifuge tests showed no evidence of any physical damage.

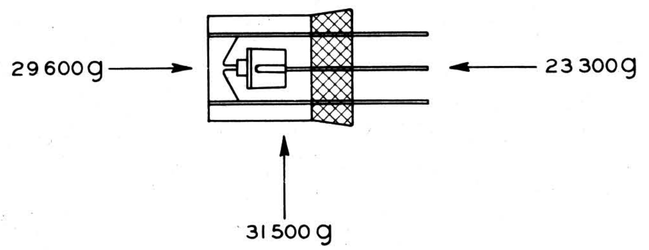

Fig. 3 – Magnitude and directions of centrifugal forces applied to embedded transistors.

Table II—Centrifuge Test

	EMBEDDED TRANSISTOR							
	1		2		3		4	
	a	b	a	b	a	b	a	b
EMITTER VOLTS	.16	.16	.21	.26	.11	.14	.29	.29
EMITTER MA.	.42	.42	.88	.88	.38	.34	.78	.78
COLLECTOR VOLTS	20	20	10	10	20	20	22.5	22.5
COLLECTOR MA.	2.8	2.8	2.5	2.5	2.2	2.2	2.7	2.7
POWER GAIN (DB)	18.0	18.0	18.8	18.8	17.2	17.2	16.2	15.8

a. Before centrifuge test. b. After centrifuge test.

The Effect of Moisture

The attack of moisture and other chemical agents of the atmosphere upon the point-contact area of the transistor contributes greatly to transistor instability. The presence of water vapor in the area of the emitter and collector contacts may cause large changes in the dc operating conditions and a considerable slump in gain, if not a complete failure of operation. The embedded transistor demonstrates a high degree of resistance to moisture, provided, of course, that the resin used has low moisture-absorption properties.

The resistance of the embedded transistors to the attack of moisture is illustrated in Fig. 4, in which curves of average power gain vs number of days at a relative humidity of 95 per cent are shown for two groups of transistors. The power gain of these transistors was relatively unaffected by the high humidity. Only one of the transistors in the two groups represented by the curves showed a variation in gain greater than ±2.0 db during the test.

An additional indication of the resistance of the embedded transistors to the attack of moisture is given by Fig. 5 which shows a curve of power gain vs days of immersion in water at room temperature. The power gain of one of these units remained approximately the same throughout the 100 days of the test; the power gain of the second unit dropped approximately 2 db between the 50th and 100th day.

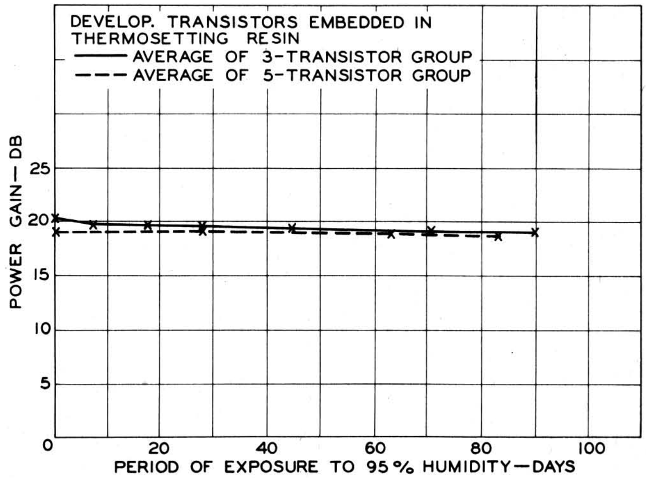

Fig. 4 – Effect of high humidity on power gain.

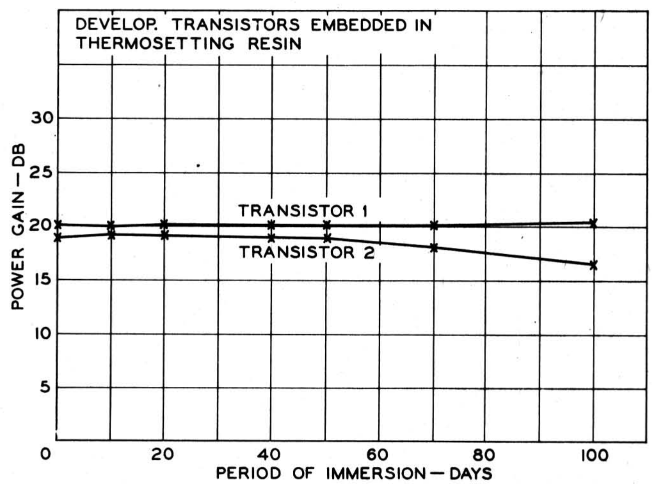

Fig. 5 – Effect of water immersion on power gain.

The Effect of Temperature

Ambient-temperature changes may also contribute to transistor instability. Large variations in ambient temperature may cause considerable changes in both transistor operating characteristics and gain. It is, of course, desirable that the operating temperature range of the transistor be extended as far as possible below and above normal room temperature but that the resultant variation in transistor characteristics be kept small. A number of measurements of the effects of varying ambient temperature on embedded transistors are given here.

Table III shows that only small changes in gain and operating characteristics occur in operation at ambient temperatures ranging from -70°C to 25°C. Readings for four transistors were taken at 25°C, at -70°C, and then, a final reading at 25°C to determine if any permanent change had occurred in transistor characteristics. It can be seen from the table that the low temperatures caused some change in dc characteristics during operation although there was no appreciable change in power gain. The final reading at 25°C indicates that no permanent damage to the transistor resulted from operation at low temperatures. These readings suggest that transistor operation may be feasible at temperatures well below 0°C.

Table III — Low-Temperature Test

	EMBEDDED TRANSISTOR											
	1			2			3			4		
	a	b	c	a	b	c	a	b	c	a	b	c
EMITTER VOLTS	.42	.0	.42	.5	.68	.4	.01	.16	0	.23	.31	.23
EMITTER MA.	1.1	1.0	1.1	.55	.78	.5	.68	.64	.52	.9	.9	.7
COLLECTOR VOLTS	20	20	20	17.5	17.5	17.5	25	25	25	22.5	25.0	22.5
COLLECTOR MA.	4.6	4.6	4.6	3.6	3.6	3.6	3.3	3.3	3.3	2.6	2.6	2.6
POWER GAIN (DB)	17.9	18.9	18.8	26.5	24.0	26.5	19.8	19.8	19.8	18.5	18.1	17.8

a. Operation at 25°C before test. b. Test operation at -70°C.
c. Operation at 25°C after test.

Several embedded transistors were operated at liquid-air ambient temperatures, approximately -180°C. The results of this test are of little practical significance, but they do indicate that embedded transistors will withstand extreme cold. None of the transistors tested showed any appreciable change in power gain during operation for approximately 10 minutes at the liquid-air temperature. Some of the transistors, however, decreased a few db in gain after being returned to room temperature. This decrease may have been caused by slight mechanical changes in the resin due to the extremely large variations in temperature.

The characteristics of the point-contact transistor become more sensitive to changes in ambient temperature above 25°C. It has been reported previously that the current amplification factor, alpha, may increase slightly with increasing ambient temperature.[3] Despite this increase in current amplification at higher ambient temperatures, the over-all power gain of the transistor may either remain the same or even decrease due to a decrease in the collector resistance. Not only does the change in collector resistance cause a change in the power gain at high ambient temperatures, but it also causes considerable changes in the dc operating characteristics of the transistor. The greatest changes in all of these characteristics generally occur at temperatures of 45°C to 50°C or greater. If the heat generated at the collector contact is rapidly removed from the crystal, the temperature gradient which exists between the contact area and the outer portion of the transistor may be reduced. Consequently, less variation in transistor characteristics would occur with ambient temperature changes. In the embedded transistor, the resin is a good conductor of heat and thus expedites the heat transfer from the crystal. The good heat-conduction properties of the resin used in the embedded transistor were determined qualitatively by measuring the change in power gain and collector resistance resulting when the ambient temperature was changed from 25°C to 60°C. For purposes of comparison, several transistors of the same construction but utilizing a wax impregnant rather than the resin were measured under the same conditions. The resulting data showed no appreciable change in power gain and a maximum of 20 per cent decrease in collector resistance over the 25°C to 60°C range in the case of the embedded transistors. The wax-impregnated units showed a decrease in collector resistance ranging from 20 per cent to 45 per cent; the power gain decreased by as much as 90 per cent. Several Type-A transistors were also measured in the same manner. The results obtained with these units are comparable to the results obtained with the embedded transistors. In the case of the Type-A transistors, the heat transfer from the crystal is obtained by means of the large crystal support. The resin in the embedded transistor appears to accomplish the function of heat transfer from the crystal to about the same degree as the large-area crystal support. In point-contact transistors, however,

[3] See for example J. Bardeen and W.H. Brattain, "Physical Principles Involved in Transistor Action", *Phys. Rev.*, Vol. 75, pp. 1208-1225, April 15, 1949.

the change in electrical characteristics at high ambient temperatures still remains a limiting operating factor.

Although point-contact transistors cannot be operated at high ambient temperatures, it is often necessary to store them at temperatures considerably higher than 25°C. A group of five embedded transistors was stored at 75°C for 50 days and tested at frequent intervals. Only minor changes in operating conditions and power gain occurred during the test. Several embedded transistors have been heated for five hours at 150°C with no effect upon the electrical characteristics. It may thus be feasible to use embedded transistors in circuits which will be completely embedded in resins requiring high setting temperatures.

Life Considerations

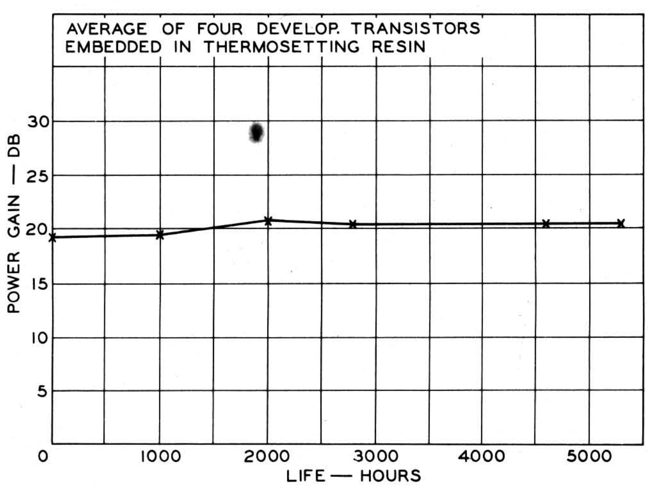

Fig. 6 - Variation of power gain with life.

A life test conducted on several developmental transistors has shown a high degree of stability under normal operating conditions. In this test, voltages of fixed dc values were applied to the emitter and collector. Fig. 6 shows a curve of average power gain vs hours of life testing for four transistors. At no time during this test did the measured power gain of any of the four transistors vary more than 2.5 db from its original gain reading. The gain of all four units increased during the 5300 hours of test. Fig. 7 shows curves of both average emitter and collector currents vs hours of life testing for the same units. None of the four

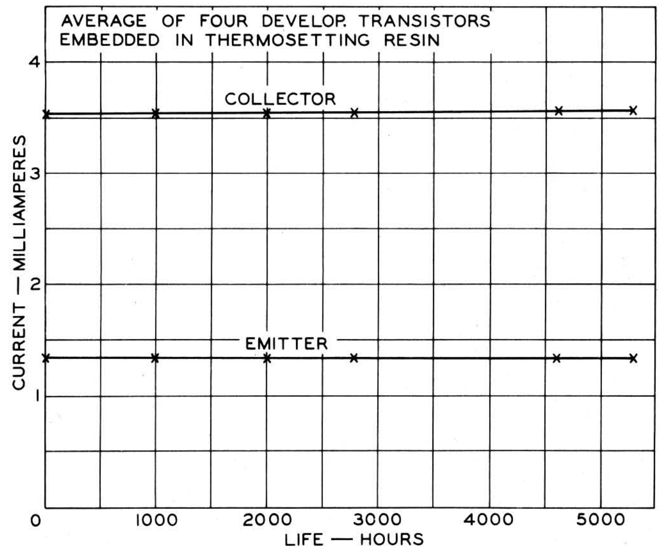

Fig. 7 - Variation of emitter and collector currents with life.

transistors varied more than 6 per cent in emitter current or collector current during a period of 5300 hours.

Properties of Casting Resins

The properties of the thermosetting casting resins used for embedding point-contact transistors must be beneficial to transistor performance and life. The resin should have a very low mechanical shrinkage during the setting process in order to prevent appreciable changes in contact spacings and contact pressures. During the polymerization process the resin should not give off volatile material which might contaminate the point-contact area and the crystal surface. The resin should have very low moisture-absorption properties in order to assure long transistor life. It should possess a high degree of mechanical strength and should closely adhere to all parts of the transistor. Finally, the resin should be a good conductor of heat so that the transistor will have good stability with variations in ambient temperature.

The thermosetting resin "Araldite", manufactured by CIBA Ltd., possesses these characteristics to a high degree; it has been used quite successfully in this application.

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