Effects of Thermal and X-ray Radiation upon Transistors[1]

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The object of this research was to determine the behavior of a transistor in environments similar to those that would be encountered in outer space. The environments dealt with were extremes in temperature and low-level X-ray radiation. Characteristic curves of the transistor were made at standard temperatures ranging from 70 C to —195 C in order to determine the relationship of amplification factor (or *beta)* to the temperature. Only three levels of X-ray radiation could be used because of the limiting factors of the monitoring equipment.

The compiled data were then analyzed and measures discussed for protecting the transistor from the adverse affects of thermal and X-ray radiation.

OBJECTIVE

The objective of this research was to determine how a transistor would operate in environments similar to those encountered in outer space. Results from this research can be used to guide the engineering of electronic equipment to be used in outer space or wherever similar environments might be encountered.

THEORY OF OPERATION

A PNP transistor consists of three sections, the emitter, base, and collector. The emitter and collector consist of a material which is deficient in electrons in the valence band, while the base is composed of a

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material with free electrons in the conduction band. The collector has a voltage which is negative in respect to the emitter. This causes a small flow of current in the emitter-to-collector circuit because of thermal agitation. When a signal is applied to the base region, the excess electrons will jump into the holes in the emitter region and the pair (hole and electron) appear to migrate toward the collector. The intensity of the signal on the base governs how much amplification will occur.

PROCEDURE

The first step was to find the room temperature characteristics of the 2N176 transistor. The collector current and collector voltage requirements were taken from *General Electric Transistor Manual.* The base current then ha dto be found by trial-and-error methods. When the proper approximate base current was found, a test panel was made so that the voltage and current requirements of the transistor could be monitored during tests.

The procedure used to determine the characteristics of this transistor were as follows:

(1) Set base current on 0.5 milliamperes.

(2) Set collector to emitter voltage at 0.5 volt.

(3) Record collector current.

(4) Advance voltage in 0.5 volt steps to 10 volts, noting collector current for each step.

(5) Reset base current to 1 milliampere and repeat procedure.

(6) Keep advancing base current in 0.5 milliampere steps. Repeat 3 and 4 until sufficient data have been compiled.

This procedure was repeated for each different environment. Room temperature data were used for a constant, and lower and higher temperatures were used to stimulate those encountered in space. Data were taken at 20 C, 0 C, —79 C, —195 C, and 70 C. Ice, dry ice, and liquid nitrogen were used for temperature standards for the cold experiments. A thermostatically controlled burner on a stove was used to create the higher temperature. The *Transistor Manual* indicated the breakdown temperature was 80 C, so 70 C was chosen for the high limit for experimentation.

It was originally planned to used a high radiation source to bombard the transistor to simulate the Van Allen Belts in space. The Atomic Energy Commission states that no one under the age of eighteen can receive more than 1/10 the maximum adult dosage. Because of this rule, it was impossible to use a radioactive material to irradiate the transistor, and an X-ray machine had to be used.

The procedure governing the intensity of the X-ray field was to start at a low intensity and double the voltage on the equipment until sufficient data were compiled to make a reasonable judgment. The range of the monitoring equipment was also a limiting factor in this situation.

TABULATION OF RESULTS

Variable	Intensity	Average Beta
Temperature	20.0C	71.0
Temperature	0.0C	46.5
Temperature	–78.5C	28.7
Temperature	–195.8C	5.2
Temperature	70.0C	1000.0
X-ray	30.0 kv, 8 ma	61.6
X-ray	60.0 kv, 8 ma	174.6
X-ray	120.0 kv, 8 ma	400.0

DISCUSSION OF DATA

It is noticed from the tabulated results that the beta of the transistor is decreased as the temperature is lowered. The converse is also true— as the temperature increases so does the beta. These facts can be explained by the fact that molecular motion slows as the temperature is increased, the level of excitement rises, and the transistor operates with greater gain for the same amount of input energy.

The beta becomes increasingly higher during bombardment with the X-ray radiation. The beta remained at this high level, then slowly returned to normal approximately one hour after the radiation was removed.

The reasons for this are not quite as simple as for the temperature experiment.

(1) Another element or isotope could have been created. The new substance could be more efficient than the original element, and the slow decline of the beta may have been due to the half-life of this substance.

(2) The X-rays may have simply acted as an external heat stimulus to the transistor. This is hardly valid because of the fact that the transistor took so long to return to normal.

CONCLUSION

By analyzing these data the characteristics this transistor would assume in outer space can be determined. These characteristics must be kept in mind when one designs equipment that is to be used in space. If the temperature becomes too high, the transistor will overdrive the rest of the equipment; whereas, if the temperature becomes too low, the transistor will not furnish sufficient drive to operate efficiently. Therefore, a standard operational temperature must be decided upon and the circuit designed for that temperature. A thermistor could be used to compensate for 20 - 30 C temperature variations by raising the voltage as the temperature decreases and lowering the voltage as the temperature rises.

The radiation on the transistor can cause it to overdrive its associated equipment in a form similar to an increase in temperature. Should the radiation be at an increased level for an extended period of time, the transistor will be destroyed. To prevent any damage or change in the transistor from occurring, it should be shielded from radiation as much as physically possible.

ADDITIONAL RESEARCH

All reference materials dealing with the effects of radiation on transistors were concerned only with the breakdown level of the transistor.

The breakdown level of the transistor is quite important, because when it is reached the transistor will cease to operate and the equipment will fail. Data concerning changes in amplification of the transistor before it reaches the breakdown point are quite important, but there is very little information of this type available. This field is one in which quite extensive research would be extremely valuable.

Bibliography

General Electric Semiconductor Products Department, *Transistor Manual,* Second Edition.

Second Conference on Nuclear Radiation Effects on Semiconductor Devices, Materials, and Circuits, New York, Cowan Publishing Company, 1960.