Components for the *Telstar* Project

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The Telstar project required a variety of components and structures of high reliability. The program for obtaining these components was essentially that originated for submarine cable devices, in which designs of proven integrity were manufactured under controlled conditions, screened and aged to remove defectives, and then life tested and certified using techniques for selecting the most stable components. This program summary illustrates in principle the techniques described in detail in the body of this components section of the issue.

I. INTRODUCTION

The papers comprising Part 3 of this issue describe the design, performance, and reliability considerations of the major components utilized in the Telstar spacecraft and certain of the unique electronic components of the earth station. Those papers pertaining to components of the spacecraft were presented orally at Bell Telephone Laboratories, Murray Hill, New Jersey, on November 14, 1962, to representatives of the National Aeronautics and Space Administration, Department of Defense, and many electronics and space companies. Particular emphasis was placed on the reliability requirements of spacecraft components and the means taken to ensure satisfactory life of the communications satellite. This issue highlights reliability by describing those steps taken to design, fabricate, test, and certify components to ensure reasonable certainty of operation for the communications satellite experiment. Companion papers presenting descriptions of the Telstar system are contained elsewhere.[1]

This paper is devoted to a broad description of component reliability as related to the design of the system. Consideration is given to the means for obtaining highly reliable components within a time schedule which precluded highly specialized manufacture and long term life testing.

II. COMPONENT RELIABILITY REQUIRED FOR PROJECT TELSTAR

The reliability requirements of components for communication satellites have been stated previously.[2] This earlier study described the three periods of satellite life, namely pre-launch, launch, and orbit, and showed how the orbit period dominates the reliability design. The Telstar experiment was undertaken with an objective of two years operating life in orbit. Because of the large launch cost penalty of increased weight and size, excessive component and circuit redundancy was considered prohibitive. The system therefore depended critically upon the use of highly reliable components which must survive a wide variety and range of thermal, electrical, mechanical, and radiation stresses. These stresses arise in particular during the launch and orbit phases when replacement of defectives is impossible. Certain of the components, such as the traveling-wave tube, are used singly or in small numbers, and thereby present a challenging design and reliability assurance problem. Other components are used in quantity and, to meet the objectives of the system, require maximum failure rates in the range of 1 to 20 failures per 10^9 component hours (0.0001 to 0.002 per cent per 1000 hours). This degree of reliability had been observed in the field and therefore gave confidence that the system objective could be met. When one considers that Project Telstar was accomplished in 15 months from start of the program to launch, and that design changes involving the addition of component types were made during a significant part of this period, the task of assuring this level of reliability became imposing indeed.

The decision was made at the onset that only components of proven integrity could be used. The environmental conditions during the launch phase, involving large mechanical stresses, and the orbit phase, involving Van Allen belt radiation and temperature cycles, were defined. Component designs were evaluated to ensure that they had the capability of meeting environmental conditions with margin. Where time allowed, devices were manufactured under engineering surveillance to ensure the highest possible integrity. All devices were carefully screened to expected environmental conditions and pre-aged to eliminate defectives. The survivors were then life tested under simulated system conditions and then the best were certified using statistical analysis and engineering judgment. Finally, the components were used in circuits of conservative design where they operated well within maximum ratings.

III. COMPONENT RELIABILITY ACHIEVEMENT

The program used to provide Telstar components was essentially that originated for submarine cable devices.[3] The major steps of this program are shown in Fig. 1.

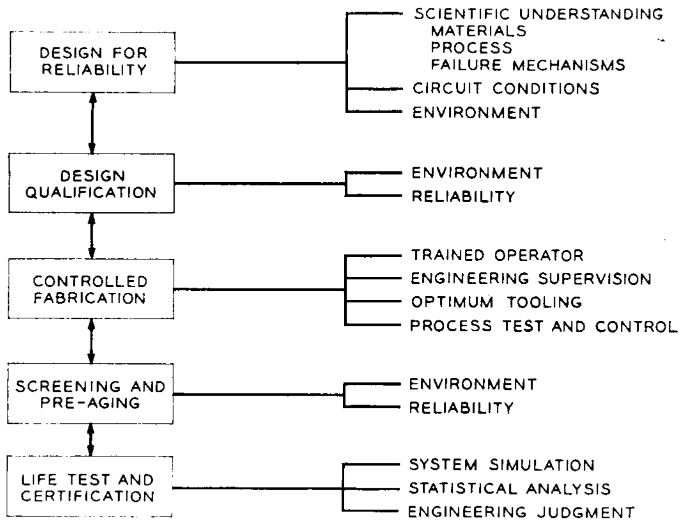

Fig. 1 — Major steps of component reliability program.

3.1 *Design for Reliability*

Satellite components must operate over a wide variety and range of mechanical, electrical, thermal, chemical, and radiation stresses. Device types intended for use were first examined for compatibility with these environments. In general only those which had demonstrated a consistent history of minimum manufacturing difficulty and outstanding field performance were considered. Specific details of design choices, such as diffused silicon semiconductor devices and nonadjustable passive components, are described in the companion papers of this part of issue.

Fig. 2 shows a failure distribution for a manufacturing lot of a component type in which failure rate is plotted as a function of time under expected system conditions. The distribution has two regions of relatively high failure rate, one early in life attributable to manufacturing "freaks," one later in life attributable to "wear-out," separated by a region of low failure rate. Device types were chosen in which the designer, through his knowledge of structure and mechanisms of change, could place the onset of wear-out well beyond the required useful life. Specific instances of wear-out were the deactivation of cathode life in the traveling-wave tube used in the satellite transmitter and the degradation of solar cells by energetic bombardment in the Van Allen belt. In cases like these, lengthening the onset of wear-out could only be achieved by understanding the mechanisms and then designing the devices to minimize or eliminate the effect.

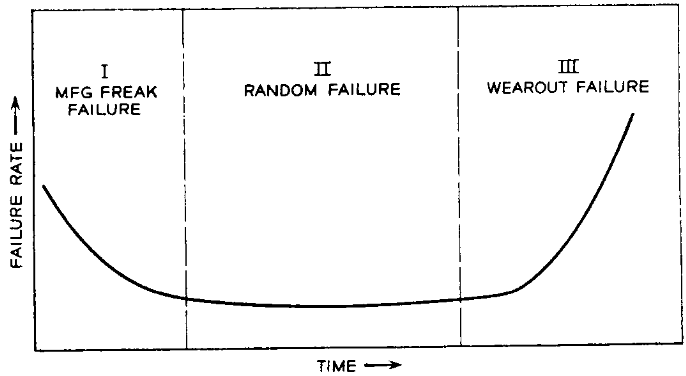

Fig. 2 — Failure distribution curve for components from one manufacturing lot.

3.2 *Design Qualification*

After the question of wear-out was settled, the next step was to ensure that the design was capable of meeting the variety of environmental conditions encountered during launch and orbit. Samples of each device type were subjected to qualification tests, many of which greatly exceeded the expected system conditions. Of particular note were gamma ray bombardment studies designed to simulate long periods of exposure expected in the Van Allen belt. Many tests were extended to destruction to obtain a measure of the design margins obtainable under actual operating conditions.

3.3 *Controlled Fabrication*

Because of the short Telstar program schedule, most of the devices were selected from manufacturing lines already producing standard products; only in a few cases were new lines established for special controlled production runs. In all cases, reliance was placed on the use of trained operators working on stable product lines in which quality control procedures were well established. These lines normally produce product in which the occurrence of manufacturing "freaks" (Fig. 2) is kept to a low level.

3.4 *Screening and Pre-Aging*

Remaining "freaks" were carefully removed from the manufactured product through the use of environmental screening and pre-aging tests. All devices were given environmental tests, many of which exceeded the expected system levels. For example, short-term aging at highly elevated temperatures was used to eliminate devices that normally would have exhibited early failure. Samples from each manufacturing lot were subjected to step-stress aging,[4] in which the median stress for failure and the failure distribution with stress were compared to previous lot history. This latter test is a rapid means to determine whether the lot is similar to preceding lots.

Controls applied during the manufacturing phase and the screening and pre-aging tests were designed to eliminate the "freaks." The remaining product should then exhibit the low and almost constant failure distribution of the "random failure" portion of Fig. 2.

3.5 *Life Test and Certification*

For this last step, a larger number of devices than needed for the system was put on life test under circuit and temperature conditions expected in service. Every effort was made to continue the life test for the longest possible time. Parameter data were taken periodically using automatic testing and recording techniques. Only those devices were chosen for satellite assembly which showed the minimum change and closest behavior to design predictions. Final certification was done after the use of statistical analysis and engineering knowledge and judgment by experienced personnel.

IV. CONCLUSIONS

The Telstar experiment required a large number and variety of components, the reliability of which, for satellite use, had to be in the range of 1 to 20 failures per 10^9 component hours for success of the mission. This need called for the same approach to component reliability that was first used for submarine cable devices, in which devices of proven integrity are used in a conservative design. Fig. 1 lists the major steps in the program. Devices with proven design were manufactured under controlled conditions, screened and aged to remove manufacturing "freaks," and then life tested and certified using statistical techniques and engineering judgment.

Detailed descriptions of each major class of device used in the Telstar project are given in the papers to follow. Each paper describing components used in the satellite illustrates the application of these reliability principles in detail. Although components used in the earth station did not require the same degree of reliability assurance as those in the satellite, they were also designed for reliable, high performance service.

REFERENCES

1. B.S.T.J., this issue, Parts 1 and 2.
2. Ross, I. M., Reliability of Components for Communication Satellites, B.S.T.J., **41,** March, 1962, p. 635.
3. McNally, J. O., Metson, G. H., Veazie, E. A., and Holmes, M. F., Electron Tubes for the Transatlantic Cable System, B.S.T.J., **36,** January, 1957, p. 163.
4. Dodson, G. A., and Howard, B. T., High Stress Aging to Failure of Semiconductor Devices, Proc. Seventh National Symposium on Reliability and Quality Control, Philadelphia, Pa., Jan., 1961.