SF System:

Transistors, Diodes and Components

By A. J. WAHL, W. McMAHON, N. G. LESH and W. J. THOMPSON

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In this paper we describe the active and passive components used in the underwater portion of the SF Cable System. We present reasons for choosing certain types and, where appropriate, outline methods of manufacture, screening, aging and selection. Measures taken to safeguard the components before, during, and after assembly in repeaters are discussed briefly.

I. INTRODUCTION

The choice of passive components and active devices for use in a submarine cable system must often try to satisfy two conflicting demands. On the one hand, high system performance objectives may call for the use of the most advanced device technology and components. Reliability requirements, however, demand the use of those components and devices which have a proven record of dependable operation in conventional applications, and whose failure modes are understood. Where such conflicts arise, the choice is of necessity weighted in favor of reliability considerations.

In this section on components, both active and passive, for the SF System, we cover: (*i*) the basic types and their functions, with some of the reasons for their choice; (*ii*) procedures for providing them; (*iii*) screening, aging, and selection; (*iv*) results from experience in providing them; and (*v*) precautions for assembly into circuits.

II. BASIC TYPES AND FUNCTIONS

2.1 *Semiconductor Devices*

The evolution of transistor technology was especially timely for the development of a submarine cable system of substantially greater bandwidth than that of the SD System which had very successfully used vacuum tubes. At the time when final development of devices for the

SF System began, the frequency capability of germanium (but not of silicon) transistors had advanced to the stage where they could, with reasonable design configuration, provide the required bandwidth. Redesigned vacuum tubes, however, would entail mechanical configurations which would be unacceptable for submarine cable use. Furthermore, with the decreased repeater spacing necessitated by the higher operating frequencies, the supply of power to vacuum tubes would involve prohibitively high voltages at the ends of a long cable system; whereas, transistors could be powered with manageable voltages under similar circumstances. Considerations such as these made the use of transistors almost mandatory for the SF System. In an accompanying role, the semiconductor diodes could easily perform the limiter and secondary surge protective functions for the transistor circuits.

In a system which can accept the mechanical fragility of vacuum or gas tubes, the mechanical requirements in terms of shock and vibration presented no problems for semiconductor devices.

The failure rate objectives had been estimated to be 0.0001 and 0.0005 percent per thousand hours of operation for diodes and transistors respectively. Past experience with germanium diffused base transistors of similar design had indicated that the reliability objectives could probably be met. This experience, however, had been in the realm of far less stringent operational requirements and conditions, particularly in regard to power dissipation. Past experience with the reliability of high quality silicon diodes had also given favorable indications for submarine cable use. Feasibility for manufacture had been demonstrated for all necessary processes with the exception that the processing for the protective oxide and the Ni-Pt-Rh-Au contacting surfaces for the diode elements was new at the time the choice had to be made. To compensate for the missing experience, the diode elements were handled, mounted, and encapsulated as if they had no protective oxide over the junctions.

In order to simplify the manufacture, all semiconductor devices were encapsulated in containers of one design and configuration.

2.1.1 *Transistors*

Two basic codes of transistors are used. Both are diffused base germanium with alloyed emitters, differing only in size of the active element to accommodate appropriate power handling capability. One basic code (the L2287) is split into three acutal codes for operation in three places in the SF Repeater: (*i*) first stage amplifier as 38A, (*ii*) second stage amplifier as 38B, (*iii*) supervisory oscillator as 38D. Table I shows the primary electrical characteristics.

TABLE I—SOME MAJOR ELECTRICAL CHARACTERISTICS OF LOWER POWER TRANSISTOR (L-2287)

Parameter	Bias Condition	Typical Value
Collector-base breakdown voltage	100 μA	40 V
Collector-base leakage current	15 V	0.4 μA
Low frequency common base current gain	5 V, 15 mA	0.985
Frequency of unity common emitter current gain	5 V, 15 mA	950 MHz
Base resistance		60 ohms
Collector-base capacitance	5 V	3.5 pF
Noise figure at 5 MHz	5 V, 5 mA	3.0 dB

The other basic transistor code (the L-2288) is used only in the amplifier output stage of the SF Repeater as code 38C. Table II shows the primary electrical characteristics.

2.1.2 *Diodes*

The four basic diode codes are all of diffused silicon with junctions protected by a hard oxide grown in high pressure steam and with mounting surfaces of Ni-Pt-Rh-Au applied in that order outward from the silicon. The basic code L2317 is an n-p junction diode (zener) used as a surge protection device in the power path circuit of the SF Repeaters, and is designated as a 467A. Its primary electrical characteristics are shown in Table III.

The basic code L2318 actually consists of two pn junction diode elements in parallel and oppositely poled so that only forward characteristics are presented at the terminals. It is used in two places in the SF Repeater. As code 468A, it serves as a surge protection device for the amplifier input; as code 468B it serves as a limiter in the supervisory oscillator circuit. Table IV shows the primary electrical characteristics.

TABLE II—SOME MAJOR ELECTRICAL CHARACTERISTICS OF POWER OUTPUT TRANSISTOR (L-2288)

Parameter	Bias Condition	Typical Value
Collector-base breakdown voltage	100 μA	50 V
Collector-base leakage current	15 V	2.5 μA
Low frequency common base current gain	11 V, 90 mA	0.982
Frequency of unity common emitter current gain	11 V, 90 mA	750 MHz
Base resistance		40 ohms
Collector-base capacitance	11 V	9 pF

TABLE III—SOME MAJOR ELECTRICAL CHARACTERISTICS OF THE POWER PATH PROTECTION DIODE (L-2317)

Parameter	Bias Condition	Typical Value
Reverse breakdown voltage	120 mA	16 V
Reverse leakage current	13 V	30 nA
Forward voltage	500 mA	0.808 V

The basic code L2319 also consists of two elements in parallel and oppositely poled, but each element is a four-layer pnpn diode. The characteristics seen at the terminals are, therefore, the typical pnpn forward characteristics in either direction of polarity. This device, as code 469A, serves as a surge protector at the output of the amplifier. The pnpn forward characteristic was required in order to have a very high impedance across the amplifier output over the maximum signal voltage swing while still having the capability of breaking into a low impedance shunt path if this voltage swing is significantly exceeded. The primary electrical characteristics are shown in Table V.

The basic code L2320 is a pn junction (zener) diode used as code 467B to bias the third stage of the amplifier in the repeater. Primary electrical characteristics are shown in Table VI.

2.1.3 *Gas Tubes*

Primary signal path surge protection is accomplished by the WE 458A-gas tubes type used in the SD Submarine Cable System.[1]

2.2 *Resistors*

Prior submarine cable systems employed wire wound resistors.[2] Because the top frequency of the SF System is 5884 kHz[3] compared to 1052 kHz for the SD System, use of wire wound resistors would have required very special winding techniques to meet the out-of-band as well as in-band impedance characteristics. It, therefore, seemed prudent to

TABLE IV—SOME MAJOR ELECTRICAL CHARACTERISTICS OF INPUT PROTECTION AND OSCILLATOR DIODE (L-2318)

Parameter	Bias Condition	Typical Value
Forward voltage	1 mA	0.518 V
Forward voltage	200 mA	0.794 V
Capacitance	0 V	40 pF

TABLE V—SOME MAJOR ELECTRICAL CHARACTERISTICS OF OUTPUT PROTECTION DIODE (L-2319)

Parameter	Bias Condition	Typical Value
Forward breakover voltage		22 V
Forward leakage current	12 V	22 nA
Capacitance	0 V	45 pF

select film type resistors with their inherently lower parasitic effects.[4] As the number of channels which can be provided depends, not only on the gain-bandwidth product, but also on the stability of this product, the contribution of the resistance elements to the gain is critical and stability must be at least as good as the best wire wound types. Extensive laboratory tests led to the conclusion that tantalum nitride resistors could provide the desired characteristics.[5]

To achieve the reliability objectives for the cable system,[3] the average failure rate for the passive components must be of the order of 0.00001 percent per thousand hours. It is not practical to confirm this level by life tests. Therefore, exhaustive screening tests to weed out early failures and derating to insure long life are required to meet this goal.

While tantalum thin film resistors had not been widely used heretofore,[4] they have been under extensive laboratory study since 1957. A moderately large-scale study program comprising approximately 2500 resistors grouped in seventeen combinations of variables was initiated in 1964.[5,6,7] The resistors were subjected to a series of tests that included oven heating, temperature cycling, and operation at various power overload conditions. Measurements of resistance and current noise were made at appropriate intervals during the test after which samples of each group were subjected to a long-term intermittent rated load test, long-term continuous load tests, and humidity tests with and without intermittent loads. Other samples were subjected to long-term overload tests.

TABLE VI—SOME MAJOR ELECTRICAL CHARACTERISTICS OF BIAS REGULATOR DIODE (L-2320)

Parameter	Bias Condition	Typical Value
Reverse breakdown voltage	2 mA	11 V
Reverse leakage current	8 V	10 nA
Forward voltage	200 mA	0.850 V

The superiority of sapphire over glass or glazed high alumina as a substrate material became evident early in the program. Other variables had less effect on resistor performance, but the tests did indicate that films having a sheet resistance between five and ten ohms per square were somewhat less stable than films having a higher sheet resistance. The final design consisted of films with resistivities between 5 and 50 ohms per square deposited on sapphire substrates and with line widths not less than 0.008 inch as shown on Fig. 1.

Resistors above 5 ohms in the SF cable system are of one type: tantalum thin film. Four wire wound codes (246 type) complete the requirements except for one power wire wound resistor in the Ocean Block Equalizer. Selection of a single resistor style for essentially all repeater and equalizer functions greatly simplifies the reliability prediction problem and aging considerations. Sapphire provides the support or substrate on which the tantalum nitride film is deposited by reactive sputtering. After evaporating nichrome-gold terminations, the tantalum film is patterned using photolithographic techniques, anodized*[4] to 95 percent of the final desired value and heat stabilized. After attachment of clip leads, the resistors are trim anodized to the final value and placed in a protective Kel-F sleeve and secured with O-rings. These resistors serve all resistance functions including biasing of the transistors and diodes, current limiting, use in feedback networks, wave shaping networks and equalizers, impedance and load matching and level adjustment.

2.3 *Capacitors*

Repeaters in the SF Cable System contain there general types of capacitors: castor oil impregnated paper, silvered mica and solid tantalum. The first two were used in previous transoceanic cable systems with very satisfactory results, but solid tantalum capacitors were new to this application. They were introduced because of the need in the SF design for comparatively large value coupling capacitors having small physical volume.[3] Experience with this type of capacitor, both in actual service and in laboratory studies, established that it is fundamentally very reliable but that, because of the complexity of its manufacture, any given population was apt to contain a number of potential early failures. It was imperative, therefore, to devise and apply very exacting screening procedures to eliminate these.

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* Anodizing consists of passing a direct current from an external cathode through an electrolyte in contact with the tantalum film connected as the anode, thereby converting a portion of the tantalum to its oxide.

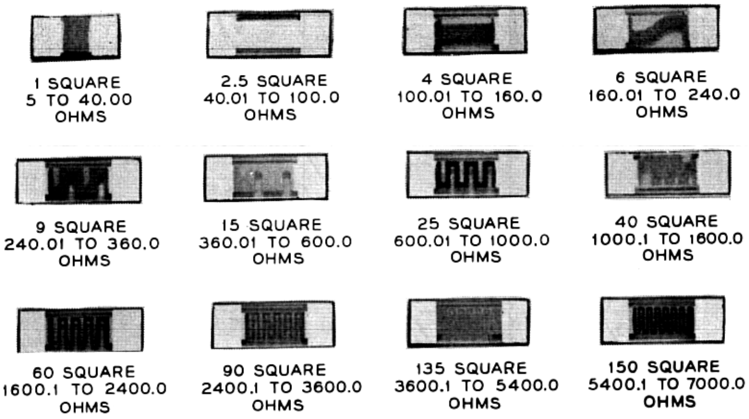


Fig. 1—Resistor patterns.

The reasons for choosing oil impreganted paper capacitors and unencased silvered mica capacitors are given in an earlier article by M. C. Wooley.[2] Little more need be said here about this except to point out that time has borne out the wisdom of these decisions. During the thousands of component years of operation, no capacitor failures have occurred. The addition of the solid tantalum capacitor necessitated obtaining some measure of its intrinsic durability. Accordingly, a large number of capacitors were tested under accelerating conditions of elevated temperatures and voltages. These tests have been in progress for about six years and have provided much information on the dependence of failure rate on voltage and the failure rate at sea-bottom temperature at elevated voltage. Life tests at 85°C indicate a failure rate dependency on voltage to the eighth or ninth power as shown in Fig. 2. The failure rate at 5°C (sea bottom temperature) and 62.5 volts is 3×10^{-6} failures per hour. Extrapolating to 17 volts which is somewhat above the use voltage with the aid of the expression:

$$\frac{FR_u}{FR_t} = \left(\frac{V_u}{V_t}\right)^8$$

the computed failure rate at 5°C − 17 volts is 0.00001 percent per thousand hours which meets the general reliability objective for components in the system.

2.4 *Inductors and Transformers*

The broader frequency range and the large number of repeaters in the SF System requires that the inductors and transformers that affect

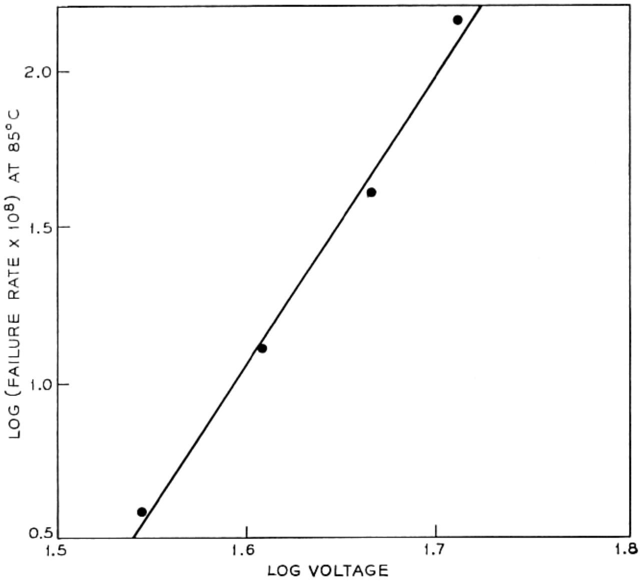


Fig. 2—Dependence of solid tantalum capacitor failure rate on voltage.

the frequency characteristic be more accurate and stable than those of earlier systems. Most of the frequency shaping inductors have solenoidal windings on forms of molded glass bonded mica. The winding surface of this dimensionally stable material is manufactured to a fraction of a mil tolerance so that, with precise control of the winding pitch, the inductor can be manufactured to high accuracy. This makes unnecessary even slight shifting of turns that could affect the stability. By the additional control of the winding tension, the long-time stability is further assured and by closer than normal control of wire and insulation, the effects of dissipation and parasitic capacitance are made very reproducible.

The winding form has a temperature coefficient of expansion that permits the use of molded-in metal terminals. This makes it possible to solder the fine wire of the winding directly to the terminal to avoid subsequent flexing. As an added feature, the form provides thermal isolation between the winding connection and the circuit wiring connection so that soldering the second cannot disturb the first.

The inductors in the directional filters have a small range of adjustment to tune precisely the sharply resonant circuits. This adjustment is accomplished by positioning a small slug of low loss magnetic material more or less in the field of the winding. The threaded carrier for this slug has an interference fit with a parallel thin wall tube of low-friction plastic so that the adjustment is smooth and sufficiently stable that there is no perceptible change when the carrier is later cemented in place.

In the ocean block equalizer, a somewhat lower accuracy of inductance can be tolerated. Advantage is taken of this by increasing the range of adjustment to minimize the number of inductor designs that must be manufactured to cover a wide range of inductance values.

The broad band transformers are used primarily to reduce unwanted feedback around the amplifier. In one case, there are parallel feedback paths through the directional filters and around the amplifier, so that, by using a transformer in one path that differs by 180° of phase shift[3] from a transformer in the other path, the signals will cancel. This imposes relatively severe requirements for similarity of the two transformers particularly over the normal frequency range of the repeater. Again, this is attained by controls on winding and on the ferrite core properties.

A second unwanted feedback path exists around the repeater because of practical problems associated with separating the signal from the dc power. The result is a longitudinal mode of transmission both below and well above the normal signal band that would cause instabilities if uncorrected. A ferrite core transformer wound with turns of a coaxial conductor[4] effectively attenuates the longitudinal mode without loss to the signal in the transverse mode.

III. PROVISION OF DEVICES AND COMPONENTS

3.1 *Manufacture*

In order to assure that the best possible quality was built into the devices and components, the manufacturing operation was conducted under continuous and detailed scrutiny in an environment which minimized contamination.[4] Incoming material was certified before entering the production stream, and all operations were pedigreed by a system of records whereby the history of any completed individual device could be traced back to its beginning. Gaining the maximum benefit of this scrutiny required the continuous active participation by development engineers of Bell Laboratories and manufacturing engineers of Western Electric.

Due to the extensive technology and the complexity of equipment required to produce tantalum thin films, the basic tantalum resistor was produced at the Western Electric plant in Allentown, Pennsylvania, and shipped to the Kearny Works Clark Shop in New Jersey for finishing, screening, aging and final selection. To maintain identity the resistance element fabricated at Allentown was coded as the 247 type resistor.[4] It consists of the tantalum nitride element and terminations deposited on the sapphire substrate, patterned into the desired configuration, preanodized and heat treated to be between 95 and 100 percent of the final desired resistance value (see Fig. 3).

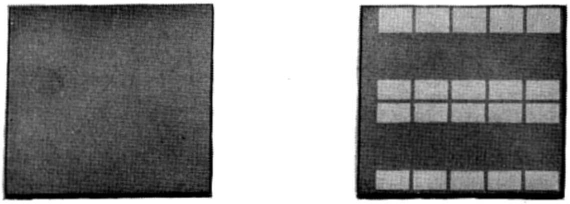
Upon receipt of 247 type resistors at Clark, terminals are attached, as shown in Fig. 4. The resistors are then trimmed to final values and given rigid visual inspection. Finally, the resistors journey through the screening, aging, and selection processes.[4] The completed resistors are designated 243-type resistors.

IV. SCREENING, AGING AND SELECTION

4.1 *Semiconductor Devices*

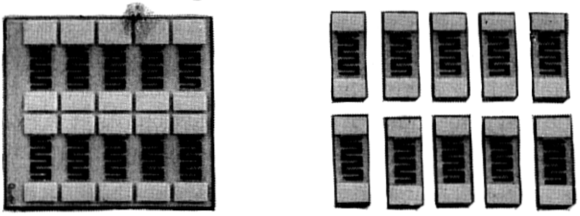
4.1.1 *Screening*

The screening operation first involved electrical testing to assure that operational specifications were met. It also involved subjecting the devices and components to a series of tests with the purpose of finding and identifying those individuals which did not conform to the behavior of the general population. Such tests include leak tests, mechanical



SAPPHIRE SUBSTRATE WITH SPUTTERED Ta_2N

EVAPORATE $NiCr$-Au AND DEFINE CONTACTS



DEFINE RESISTOR PATTERN, PREANODIZE, HEAT TREAT

SEPARATE INTO INDIVIDUAL 247 TYPE RESISTORS

Fig. 3—247 type resistor fabrication.

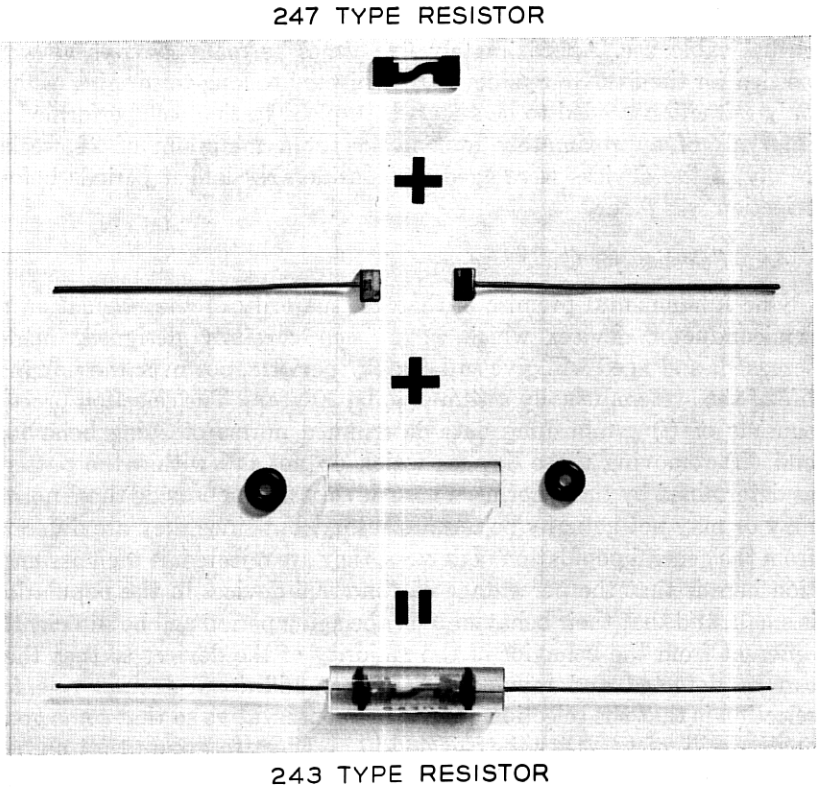


Fig. 4—243 type resistor assembly.

tests, temperature cycling and storage, surge tests, and short-term aging under electrical conditions which exceed normal operating levels by as wide a margin as possible without causing damage to the normal devices. Interspersed among the screening tests were the appropriate number of electrical tests and visual inspections with records maintained on individual devices.

In order to be effective in locating the nonconforming devices, the screening operations must be done on all individual devices instead of just on a sample.

4.1.2 *Aging*

All candidate semiconductor devices were subjected to long-term aging under simulated worst-case use conditions of power and temperature. This operation provides information on how the devices might be expected to behave under the conditions of power and temperature of actual cable use. Approximately five times as many devices as were needed for the first SF System were subjected to long-term aging so that only a fraction needed to be selected. In-place testing was performed at intervals of approximately four weeks for a minimum of 24 weeks. Many of the devices were aged for considerably longer periods before selection was made.

4.1.3 *Selection for Cable Use*

One fundamental premise is that the majority of the population of semiconductor devices which have been carefully designed, made, screened, and aged will give satisfactory performance over the nominal life of the system, usually assumed to be 20 years. The selection process consists of (*i*) establishing data-determined norms of aging behavior, and (*ii*) removing those devices which do not fall within the pattern as determined by these norms. Those devices falling outside these norms may or may not actually be unsatisfactory, but since they are different from the general population of devices, they are rejected. A tacit assumption here is that the percentage of abnormal devices in the population is small, and that their behavior over the aging period will be sufficiently different from the behavior of the majority of the devices so that they can be detected and removed. A further additional ground rule for selection is that the selection criteria are conservative so that some good devices will, of necessity, be rejected in an effort to ensure that no bad devices are accepted. A basic challenge then is to develop the statistical methods and criteria which will minimize the rejection of good devices.

The data upon which selection is based contains variations due both to the devices and to the data collection system. Systematic data analysis is necessary to assess and separate these sources of variation, and then the development of special statistical techniques is required to adjust for or reduce these effects. Since these techniques could not be developed prior to shipment of devices for the first SF System, extremely conservative selection procedures were used in an effort to ensure the exclusion of abnormal devices. More sophisticated selection procedures are now being developed.

4.2 *Resistors*

4.2.1 *Screening*

In the reliability assessment of any component, it is the control of the manufacturing process and uniformity of these processes that provides the greatest contribution to ultimate reliability. Screening and aging tests provide a measure of the effectiveness of process control and additionally locate nonconforming devices. To be effective, screening must be done on 100 percent of the product.

Of the 247 type resistors shipped to Clark from Allentown and made into 243 type resistors, approximately 75 percent passed the screening tests and were placed on long-term aging tests.

4.2.2 *Aging*

All screened 243 type resistors were subjected to a power of 0.25 watts at 25°C for 4000 hours. These conditions are not considered harmful to the resistors even though they represent accelerated aging over the use conditions of approximately 0.0625 watts maximum at an average temperature of 4°C An acceleration factor of 18.2 was calculated by taking the ratio of the change at aging conditions versus the change at use conditions.

In addition to the aging performed routinely on all resistors, representative samples have been aged at a power of $\frac{1}{8}$ watt and 25°C for periods up to 20,000 hours with an average change of approximately 0.008 percent.[6] This is in good agreement with changes calculated by using the formula for time and temperature dependence.[8]

A variety of initial resistance tolerances are used ranging from 0.04 percent to 2.5 percent.[3] In all but one case, the initial tolerance was set at one-half the end-of-life tolerance (EOL), that is, the tolerance at which circuit performance would be degraded to an unacceptable level. In this case the EOL tolerance was 0.1 percent permitting a change of 0.06 percent from an initial tolerance of 0.04 percent. To obtain an estimate of the average mean life, the mean life for each EOL tolerance was calculated and weighted by its usage in a repeater. Applying a 90 percent confidence interval, the lower limit of the estimate yields a failure rate of 0.0000024 percent per thousand hours.

Of special note was the additional screening provided on certain critical codes. These are resistance values on which dc voltage is impressed during service. By virtue of the dc application, they are the most susceptible to whisker growth emanating from the soldered termination area. All codes were desleeved at the end of the 4000 hours of aging and examined for whisker growth. The sleeves were reinstalled and the critical codes aged for an additional 250 hours at $\frac{1}{2}$ watt and 25°C. They were then re-examined for possible whisker growth and remeasured to ascertain whether they still met electrical requirements. Terminations having less than complete solder coverage are most susceptible to whisker growth. For this reason, all critical codes have now been changed to require complete solder coverage of the termination.

4.2.3 *Selection*

After aging, resistors are selected for use by utilizing both fixed and variable limits. Resistance readings at 1000, 2000 and 4000 hours of aging are compared to the initial readings and resistance changes, average and sigma calculated. Resistors may be rejected at any point if they fail to meet the following fixed limits:

	Percent Change	
Elapsed Aging	≦ 50 ohms	> 50 ohms
First 1000 hours	0.05	0.05
Second 1000 hours	0.05	0.04
Total 4000 hours	0.08	0.06

In addition to these fixed limits, they had to meet variable limits. For 0.1 percent EOL resistors (codes 243 AC, AD & AE) only those falling within ± two standard deviations were selected. For other tolerances, the variable limit was ± three standard deviations from the mean.

4.3 *Capacitors*

While there is good reason for confidence in the adequacy of the solid tantalum capacitor intrinsically, it is necessary to take elaborate measures to screen out potential "early failures." This is evidenced by the fact that at least one early failure occurred in each of the accelerated tests. To eliminate these among capacitors to be used in the system, all Ta solid capacitors are exposed to 35 volts at 85°C for six months. During this period parameters such as capacitance, dissipation factor and leakage current are carefully monitored. A significant deviation of any of these properties from the norm is cause for rejection.

Both paper and mica capacitors are subjected also to lengthy screening and aging. However, the incidence of early failures of paper capacitors in these tests is rare and among micas it is virtually absent. This is undoubtedly attributable to the great care exercised in the manufacture of these units from the selection of raw materials through each process step to the final product.[4]

V. RESULTS FROM EXPERIENCE IN PROVIDING THE COMPONENTS

5.1 *Semiconductor Devices*

Previous experience had shown that the only semiconductor device characteristic that would exhibit an aging effect was transistor gain, which would increase at a slowly decreasing rate. The repeater circuits were designed to accommodate an average common base current gain change of 0.002 per transistor over a 20-year period. Long-term aging results on some of the candidate transistor devices which have remained on aging for 3.5 years indicate that actual aging will be less than the 0.002 objective. Figure 5 illustrates this behavior, which is equivalent to a total excursion of only 0.0001 in the common base current gain. Note also that most of the change occurred during the first half of the aging period.

It is always desired to compare these long-term aging results with destructive step-stress results performed during manufacture of these devices. One possible method for making this comparison, although recognized as being inadequate or possibly misleading, is in terms of the exponential or constant failure-rate model. At the time when the first SF Submarine Cable was being laid, the total accumulated device hours of aging (transistors and diodes) was over 140 million without either a catastrophic failure or failure due to aging beyond initial specification limits. Under the assumptions of the constant failure rate model, a range of 0 to 0.0017 percent failures per thousand hours is consistent with a chance of more than 9 out of 10 of actually observing no failures in 140 million total device hours. This upper bound of 0.0017 percent per thousand hours is of the right magnitude and the best that can be obtained from 140 million device hours of aging.

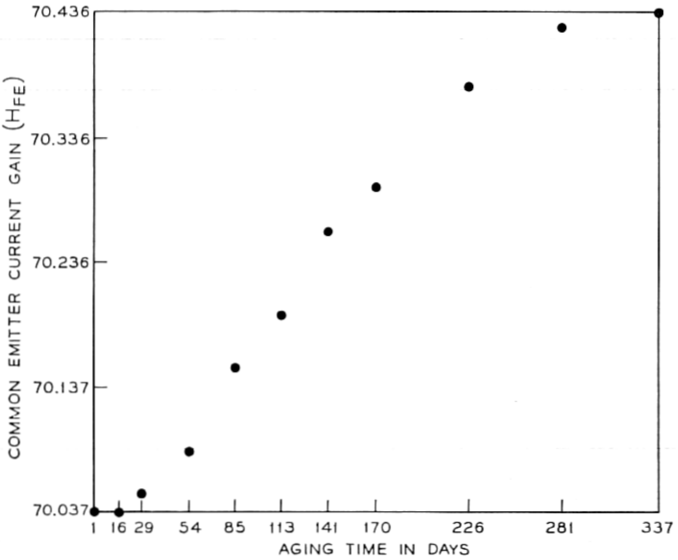


Fig. 5—Aging of transistor common emitter current gain.

VI. PRECAUTIONS FOR ASSEMBLY OF DEVICES AND COMPONENTS INTO CIRCUITS

6.1 *Semiconductor Devices*

In order to protect the semiconductor devices from the possibility of mechanical, electrical, and thermal damage from the time they leave the device manufacturing area until they are completely incorporated into the circuit, a fixture is attached at the base of each device. This fixture has floating tab conductors through which each lead of the device is threaded so that no force of any kind is exerted on the device leads. After the fixture is rigidly attached to the body of the device and each lead is rigidly attached to its floating tab, the tabs are rigidly cemented in place to the fixture. Later, in the SF Repeater Circuit, electrical connection is made only to the tabs. In this way the possibility of mechanical damage to the glass seals around each lead of the device is avoided. The possibility of thermal damage to the device due to soldering into the circuit is thus also much more remote. To protect against the possibility of electrical damage the external leads of each device have a short circuit, which is not removed until the device has been electrically and mechanically secured in its circuit.

6.2 *Passive Components*

To protect against corrosion during storage or handling, all metal cases and leads were gold plated. In the assembly, no component was mounted by its leads. Mounting fixtures were provided which minimized the possibility of damage to the component, its leads and connections due to shock or vibration. Components which were not in hermetically sealed containers were protected from moisture during manufacture and storage by maintaining a fairly low ambient humidity. The finished repeater was flushed with dry nitrogen gas and then sealed.

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