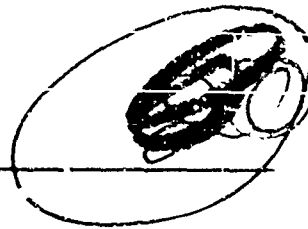


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Final Report



NON-DESTRUCTIVE RELIABILITY SCREENING OF
ELECTRONIC PARTS, USING RF NOISE MEASUREMENTS

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H. Avil
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FOREWORD

This final report, covering the work period from 19 December 1963 to 19 December 1964, was prepared under Contract No. AF30(602)-3258, Project No. 5519 and Task No. 551902 by Honeywell Inc., Aeronautical Division, Minneapolis, Minnesota.

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ABSTRACT

This is the final report for the Rome Air Development Center Contract AF30(602)-3258, entitled, "Non-destructive Reliability Screening of Electronic Parts, Using RF Noise Measurements." The report describes an investigation and evaluation of radio frequency (RF) noise in IN645 silicon diodes and solid tantalum capacitors. The specific intent of this effort was to establish and validate RF noise measurements as a technique for selecting and rejecting from a production lot of electronic parts those parts with lifetimes less than the average lifetime of the production lot, thereby increasing average lifetime and time to first failure.

Large quantities of diodes and capacitors were screened; results are categorized and tabulated in this report. In addition to the screening effort, rejected components were life-tested with a control sample of good components, and efforts were made to optimize the screening technique. Also failure mechanisms that cause generation of RF noise were investigated both theoretically and experimentally. Findings of these investigations, as well as results of life test and screening optimization, are also presented in this final report.

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Evaluation Memorandum

This effort has shown that the RF noise generated by individual diodes and capacitors in a production lot can be used to identify mechanically faulty units which are undetected by conventional test methods. In this study, gross defects such as poor bonds, large fractures and voids were discovered in noisy diodes while quiet diodes showed none. As a result of the selection and rejection of high RF noise devices from the production lot, the over-all lot failure rate was significantly reduced.

Since this technique detects failure modes which are likely to occur in all electronic parts, it appears feasible to include the technique in the specifications for all parts. However, before this test method can be included as a spec requirement, it will be necessary to determine its effectiveness on part types other than those studied and its over-all cost per part.

To evaluate the over-all screening efficiency of this technique, tests on large samples of active and passive devices of both conventional and microelectronic design from various sources should be conducted. These tests, which should be contractually supported, will also provide a means for estimating the per-part cost of the technique and will enable us to make trade-offs between the cost of the technique and its screening ability. For example, it may be more economical to apply the technique on a 100% basis only when production processes or materials are changed and then continue screening on a sampling plan basis.

Our program for the development of generally applicable accelerated and screening tests will include rf noise as a basis. The future studies will include microelectronic circuits and elements and more recently developed discrete semiconductor devices that have projected high use.

1.0 INTRODUCTION

The work discussed in this report represents a portion of the "Non-Destructive Reliability Screening Program" sponsored by the Rome Air Development Center. The specific investigation reported was done under Rome Air Development Center Contract AF 30(602)-3258, entitled, "Non-Destructive Reliability Screening of Electronic Parts, Using RF Noise Measurements". The work period of this contract was from 19 December 1963 to 19 December 1964. The specific intent of this effort was to establish and validate RF noise measurements as a technique for selecting and rejecting from a production lot of electronic parts those parts with lifetimes less than the average lifetime of the production lot, thereby increasing average lifetime and time to first failure.

The term RF noise, used in this study, denotes the generation of broad-band noise by electrical impulse signals or breakdown phenomena at frequencies between 2 MC and 30 MC. In particular, the term noisy denotes the presence of excessive or an abnormal amplitude of broad-band noise at these frequencies. All operating electrical circuits exhibit normal thermal and conductive noise levels which establish a background noise level or signature for each particular part or circuit.

The generation of transient impulse signals caused by short duration faults within a part raises this background noise level. It is possible to segregate such parts from a population of parts by monitoring the over-all noise level with a radio receiver.

Honeywell began investigating RF noise detection as a method of fault isolation several years ago. This technique was examined as a result of high noise spikes occasionally observed during the course of RF interference tests required for military equipment. Further study revealed that the noise spikes resulted from intermittent faults within the equipment.

Experimentation was conducted for two years on gyro sensors, temperature and guidance control amplifiers, and timers, to confirm that the noise spikes result from an intermittent type fault or a defect in the unit under test. During this period, it was discovered that the subassembly occasionally required mechanical shock to aggravate the incipient failure, thus making it detectable by RF noise measurements. When a defective subassembly was detected, the faulty component was located by tapping each component on the board with a phenolic rod to determine which one produced the highest amplitude of noise.

The parts used for this study were the IN645 silicon diode and two values of solid tantalum capacitors. These parts were selected because of their high volume of useage in military applications.

The study was divided into four phases, some of which were performed concurrently. The first phase was the screening of the diodes and capacitors. The screening technique used is the one developed over the past four years at Honeywell's radio frequency interference test facilities.

The second phase of the study was an effort to optimize the technique for measuring RF noise generated by these components. The major effort here was with the stabilization networks needed for RF noise isolation of the power source from the components being measured, and the transfer of maximum detectable RF noise energy to the measuring device.

The third phase of the study consisted of theoretical and experimental investigations into the failure mechanisms that cause the generation of RF noise in the electrical components studied. A literature search was conducted prior to and during this phase of the study.

Many experiments were performed on both quiet and noisy components. One of the more revealing experiments involved the dissection of a random sample

of noisy diodes. This dissection revealed that one of the more prominent sources of RF noise is microplasma breakdown in the semiconductor crystals.

The final phase of the study was the life-testing of the components. Those components that exhibited high RF noise along with a control sample of low noise components were placed on life test. The diode life test was run for 3000 hours and the capacitors for 2000 hours. Maximum benefit was derived from the test by subjecting components to their maximum allowable temperature ratings. Since these ratings did not exceed print specifications, the life test contained no acceleration factor. The failure rates encountered were, therefore, much higher than normal, but yet within the expected rates for the conditions of the life test.

2.0 CONCLUSION

2.1 LIFE TEST

The final data of the study confirms the original hypothesis. In both the diode and capacitor tests, components that exhibited high RF noise did fail at a higher percentage than the quiet components. In the case of the diodes, this higher percentage was approximately two to one. For the capacitors, the difference was approximately three to one. These differences in failures are computed from 3000 hours of test time for the diodes and 2000 hours for the capacitors. Even more significant is the greater difference in percentage failing during the initial 250 hours of life test. In this period, noisy diode failures were 2.6 times higher than quiet diode failures, and noisy capacitor failures were 6.2 times higher than the quiet capacitor failures.

In conclusion, results substantiate the higher incidence of failure of components containing high RF noise over components that do not exhibit such noise.

2.2 SCREEN TEST

There were 20,200 diodes screened. Of this total 146 (or 0.7 percent) exhibited excessive noise. However, only 86 of the noisy diodes passed all other specifications for this component. Similarly for the capacitors, 67 (or 0.7 percent) of the 9,808 screened passed all specifications, but were excessively noisy. These percentages are within the range anticipated for this type of test.

2.3 MEASUREMENT TECHNIQUE OPTIMIZATION

An extensive effort in this area for both the diode and capacitor yielded positive and negative results. On the positive side it was found that transformer coupling the diode output allowed the use of a less sensitive and less expensive receiver. However with the NF105 receiver that was used in the screening, the direct coupling method proved best. Work on the capacitor circuit yielded no real advantages.

2.4 THEORETICAL INVESTIGATIONS

Along with the normal noise sources in semiconductors, microplasma noise generation was shown to be a significant contributor to the detected RF noise. A darkroom photograph of a sectioned diode verifies the existence of these microplasmas.

When four noisy and one quiet diodes were dissected and photographed, all four noisy diodes showed physical abnormalities while the quiet diode showed none. This would indicate that RF measurement techniques are useful in revealing components that are physically faulty.

Appendix A shows the results of additional diode dissection.

2.5 GENERAL

The general conclusion that is drawn from the work reported here is that the results do substantiate the higher incidence of failure of components containing high RF noise over components that do not exhibit such noise.

3.0 RECOMMENDATION

In light of the results of this investigation it is recommended that work in the area of RF measurements be continued. Further correlations between the type of RF noise found and physical abnormalities should be investigated. The effects of RF noise upon failure rates of other components and integrated circuits should be pursued.

It is believed that RF noise detection is one of the more promising nondestructive type tests, and will find extensive future use.

4.0 DETAILS OF STUDY

4.1 LITERATURE SEARCH

A detailed literature search was conducted. It was geared primarily at noise generation source in semiconductors and tantalum capacitors and failure mechanisms of these types of devices. Some of the more pertinent references used are listed in Section 5 of this report.

4.2 THEORETICAL DISCUSSION OF FAILURE MECHANISMS

4.2.1 . Diodes

A number of tests were run on the noisy diodes, and also on a number of quiet diodes. Quiet diodes are those which exhibited normal RF noise and were within specifications. In particular, the following was obtained:

- Capacitance and Q measurements
- Forward and reverse characteristics
- 1/f noise at 10 and 1000 cps with d-c excitation
- The noise level from 22 mc to 29 mc with d-c excitation

An attempt to use the diodes as a capacitive element in a tuned circuit of an oscillator (where waveshape of oscillation would be indicative of anomalies in the diode) was not particularly effective.

The reasoning behind the experiment of measuring capacitance and Q was that faulty diodes might have a lower Q or different capacitance from quiet diodes. However, no significant difference between the noisy and quiet samples was detected in either capacitance or Q measurements.

An average of reverse characteristics (leakage current as a function of reverse voltage) of the diodes indicates that the noisy diodes tend to have a higher leakage current than the quiet ones. One would not, however, be able to decide into which group a diode would belong by its reverse characteristic alone, as can be seen in Figure 1. Reverse characteristics were taken with a one-megohm limiting resistor. The average forward characteristic of each group did not display a difference between the two groups.

1/f noise measurements were made on a Quan-Tech diode tester, model 327, at 10 and 1000 cps. The instrument reads in microvolts per root cycle. In the reverse biased position (225 volts), the average noise level of the IN 645 is 1.7 μ v at 10 cps, and 0.64 μ v at 1000 cps. The spectrum of a diode that

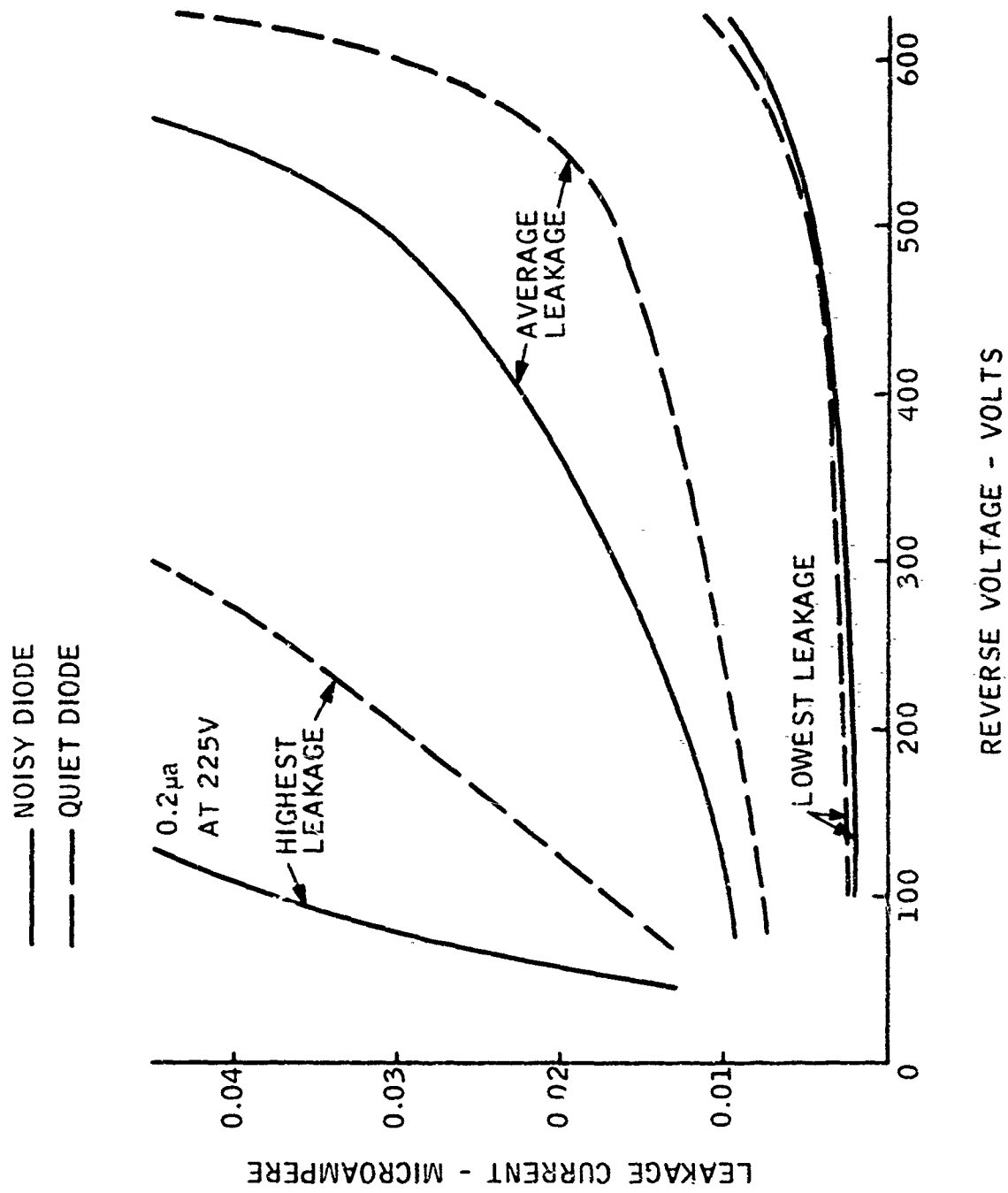


Figure 1. Comparison of the Reverse Characteristics of Noisy and Quiet Diodes

exhibits high $1/f$ noise, is shown in Figure 2. Its $1/f$ noise at 10 cps is $7.8\mu v$, and at 1000 cps is $0.95\mu v$. Of special interest is the fact that the $1/f$ noise extends into the megacycle region. Of the 86 diodes which exhibited high RF noise at 25 mc, 21 also had high $1/f$ noise, whereas only one out of an equal number of RF quiet diodes had an unusual amount of $1/f$ noise.

Four noisy diodes and one quiet diode were sectioned to display the junction region with the following results:

Low frequency or $1/f$ noise has been attributed to several causes; notable among these are localized hot spots at the junction². The cross-section of the first noisy diode which exhibited high $1/f$ noise, perhaps best displays the causes for hot spots, due to voids in the alloy uniting the silicon wafer to the molybdenum heat sink (see Figure 3).

Most of the noisy diodes displayed an excessive amount of noise independent of mechanical shock. A few (9 out of the 86) became noisy only after mechanical stress. The second noisy diode, whose cross-section is shown in Figure 4, was one of the diodes which became noisy after several blows of 100-g magnitude. The silicon wafer had a fracture which was apparently aggravated by the mechanical excitation.

The third noisy diode also had a fracture in the silicon wafer (see Figure 5). This diode, however, was noisy with a-c excitation without mechanical shock. It had a normal $1/f$ noise level and a normal RF noise level when excited with dc in the reverse direction. AC excitation appears to be a better method for detecting excessive noise levels, since a large percentage of diodes which had a normal noise level when excited with dc exhibited excessive noise with a-c excitation.

The fourth noisy diode (Figure 6), shows an imperfection through the junction region in the form of a void. It had a normal $1/f$ and RF noise level with d-c excitation. However, it displayed excessive RF noise with a-c excitation.

The fifth diode sectioned was a quiet diode with exceptionally good forward and reverse characteristics. Its cross-section is shown in Figure 7. The diode

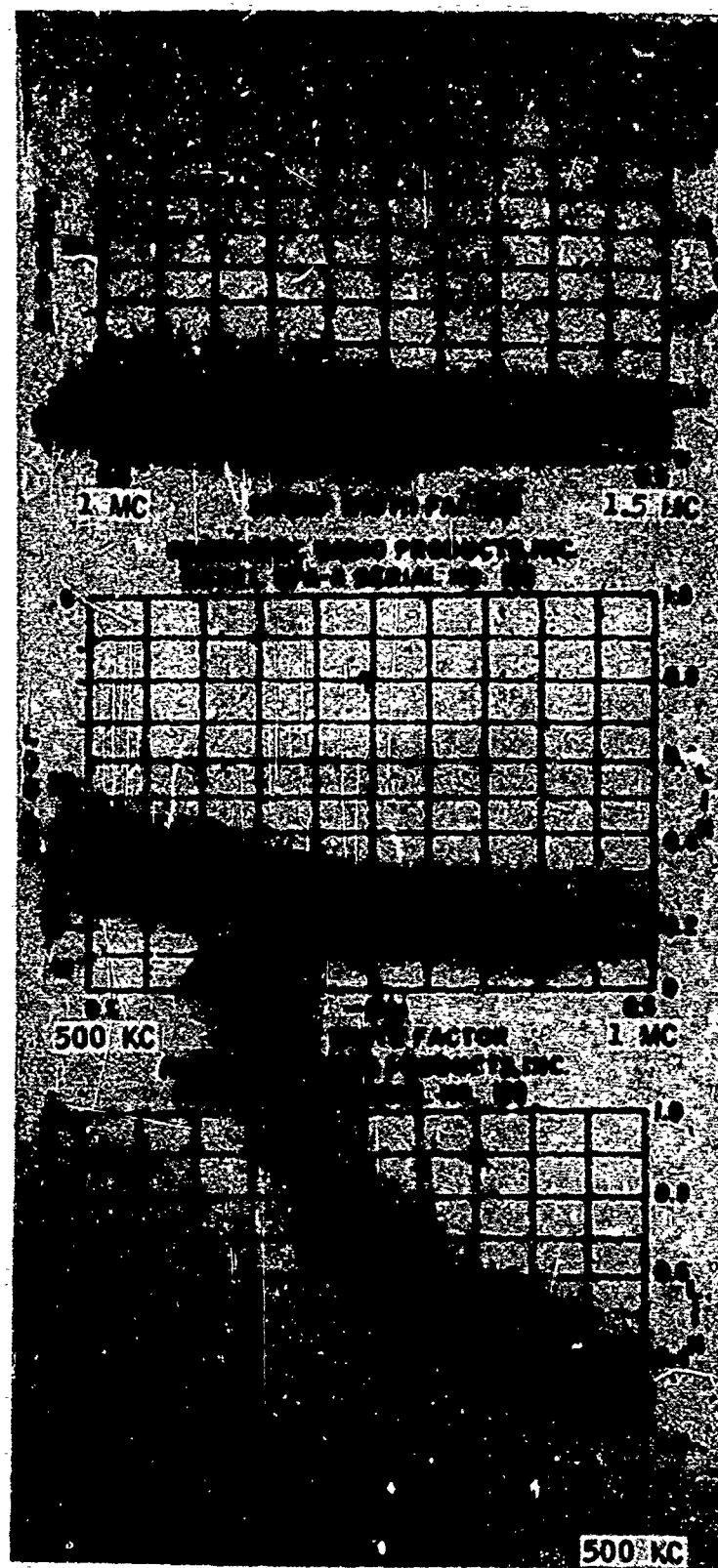


Figure 2. Power Spectral Density From 100 kc to 1.5 mc of a Noisy Diode



Figure 3. Noisy Diode Showing Voids in the Bonding Alloy Between the Silicon Crystal and Molybdenum Heat Sink

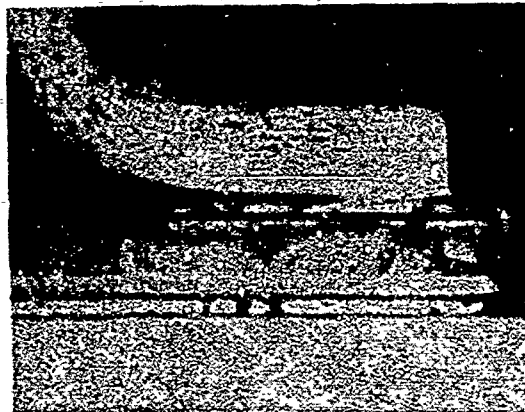


Figure 4. Fractured Silicon Wafer; Diode Became Noisy After Shock

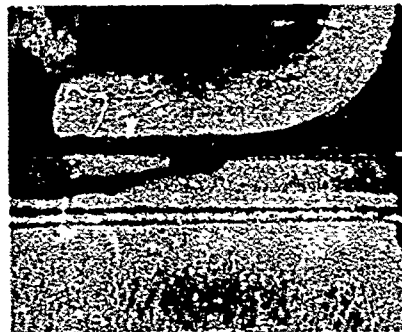


Figure 5. Fractured Silicon Wafer; Diode Emitted Noise on Excitation

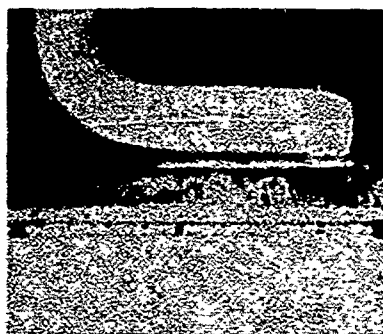


Figure 6. Noisy Diode Showing a Void in the Junction

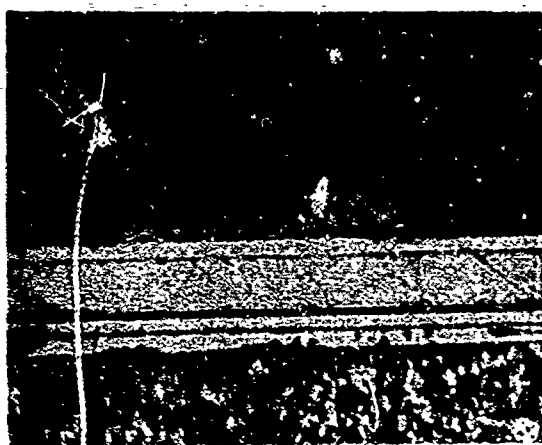


Figure 7. Etched Cross-Section of a Normal Diode Showing the Junction Regions

was etched with a hydrofluoric-nitric acid mixture (40 percent nitric, 20 percent water). The p-n junction of this diode occurs at the upper surface of the wide dark band. The junction region can occur near either surface of the silicon wafer. During manufacture, no attempt is made to orient the silicon crystal. Therefore, the polarity of the diode is randomly oriented with respect to the whisker and molybdenum heat sink. The wafers, after being diffused, are placed on the heat sink, and the polarity color bands are placed on either end, depending on the measured impedance of the diode. The results of additional diode dissection work is reported in Appendix A.

- 4.2.1.1 Surface State Noise -- Because of their mesa construction, which does not have the protective coating of silicon oxide over the edge of the junction region, the IN 645 diodes used in this study are subject to surface contamination.

Contaminants on the surface of a semiconductor tend to degrade its performance. In the p-n junction, softening of the reverse characteristic and current hysteresis is often caused by surface contamination.¹ This type of unstable reverse characteristic and high leakage can cause failure by excessive power dissipation in the junction.

The ideal diode would have a metal-semiconductor contact in which there is intimate contact between the metal and pure semiconductor, with no foreign materials intervening.² The plated contact in the manufacture of the IN 645 very closely approximates an idealized contact. However, the mesa construction of the diode allows a certain amount of contamination to appear at the exposed junction region. A silicon varnish coating is placed over the wafer, but this is not as effective as a layer of silicon oxide in providing resistance to the penetration of foreign contaminants.

The incidence of high $1/f$ noise has been attributed to surface contamination.³ A number of studies have been made with germanium junctions exposed to various environments^{4, 5, 6} and efforts have been made to measure contamination by modulation with an external electric field. Detection of surface contaminants on diodes exhibiting high $1/f$ noise was attempted by placing a metallic band outside of the diode case near the junction region, as shown in Figure 8. An alternating electric field was applied between the metallic

band and the silicon wafer; however, the modulation effect expected from foreign surface ions^{7, 8} could not be detected. This could be due to the small surface area of the exposed junction, and the relatively minute amount of current introduced because of surface ions.

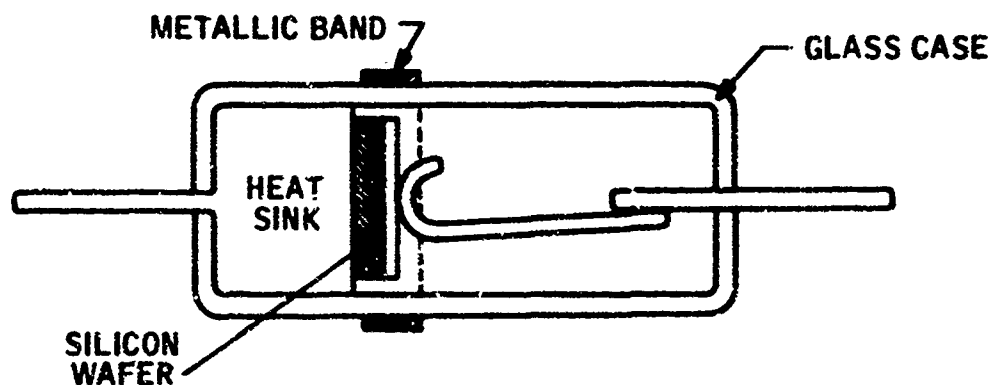


Figure 8. Semiconductor Diode

2.1.2 Noise Due to Microplasma Discharges -- Another cause of early failure in a semiconductor is dislocations in the crystal, where microplasma discharges tend to take place.⁶ The microplasma discharge in a p-n junction occurs at a lower voltage than the avalanche breakdown voltage of a diode with a uniform junction. The discharge can be detected by the RF noise generated in a p-n junction, as a bias voltage is applied.⁷ The microplasma discharges occur with either forward or reverse bias. Their light intensity increases with an increasing reverse bias voltage, until reaching a maximum, and then decreases as reverse voltage is increased further.

Light emitted in the recombination process appears white in color, with a tendency toward red. This is attributed to the absorption of the shorter wavelengths in the silicon. Figure 9a is a 15-minute exposure, 30X enlargement of a IN645 junction (shown in Figure 9b) with a reverse bias. In order to see the microplasma light sources, it is necessary to cut away the silicon varnish covering the junction and observe with a microscope.



(a)



(b)

Figure 9. Enlargement of a Diode Exhibiting Microplasma Discharges

If one considers the current flowing through the p-n junction to consist of simply two states, the power spectrum would be

$$G_n(\omega) = \frac{1}{\pi} \cdot \frac{4NA^2}{(4N^2 + \omega^2)}$$

where N is the average switching rate between states, in times per second, and A is the amplitude of the current pulses. Experimentation has shown that the power spectrum generated by the random binary wave (see Figure 10) closely approximates the actual signal⁹ observed.

A number of observed phenomena tend to indicate that the microplasma discharges generate the detected r-f noise. For example, when the semiconductor junction temperature is lowered, both light intensity of the discharges¹⁰ and noise intensity increase. Likewise, the behavior of the r-f noise and the microplasma light intensity is very similar when the applied voltage is varied. As the reverse voltage on the p-n junction is increased, both the r-f noise and emitted light increase until a maximum is reached and then both tend to decrease. (see Figure 11). This is due to the increase in current pulse amplitude as the reverse voltage is increased. The current pulses have longer duration and occur more frequently¹¹ until a voltage is reached at which current flows continuously. As a step function in voltage is applied to the junction, the r-f noise level and microplasma discharge light intensity respond in a similar manner, both are most intense at the instance of the step function and then decay with time. The presence of microplasma discharges and r-f noise at a voltage level below the avalanche breakdown of the junction should be indicative of crystal imperfections which tend to cause early failure.

Light intensity of the microplasma region was measured with a RCA 1P121 photomultiplier tube having an S-4 response. Figure 12 shows the light intensity versus time as various reverse bias voltages were applied to the junction. As reverse voltage is first applied, light reaches maximum intensity and then decays with time to an ambient level.

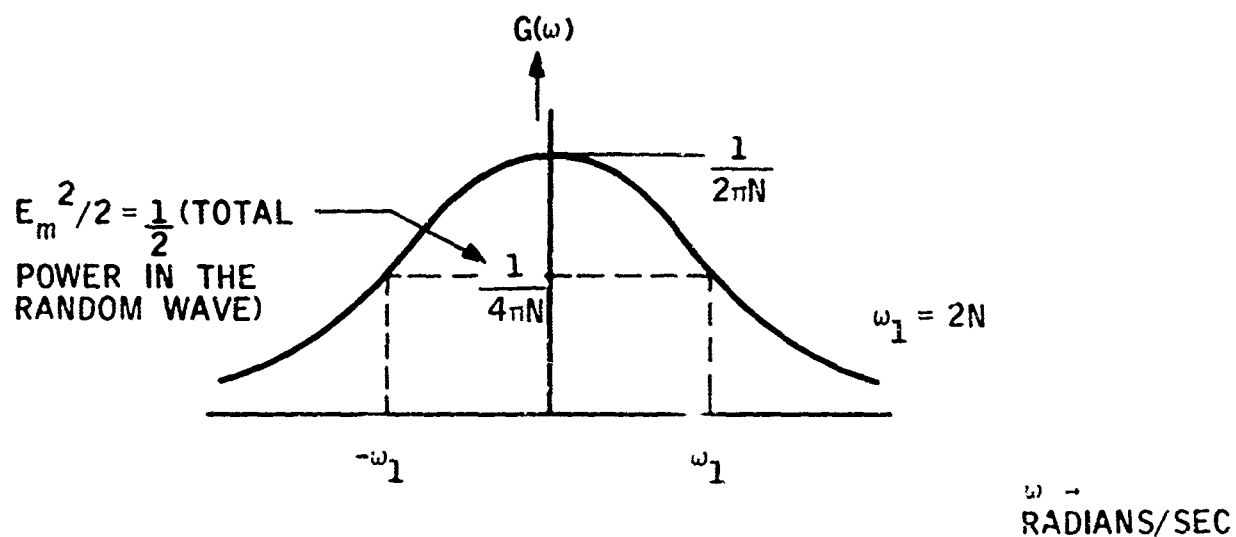


Figure 10. Power Spectrum for Random Binary Wave

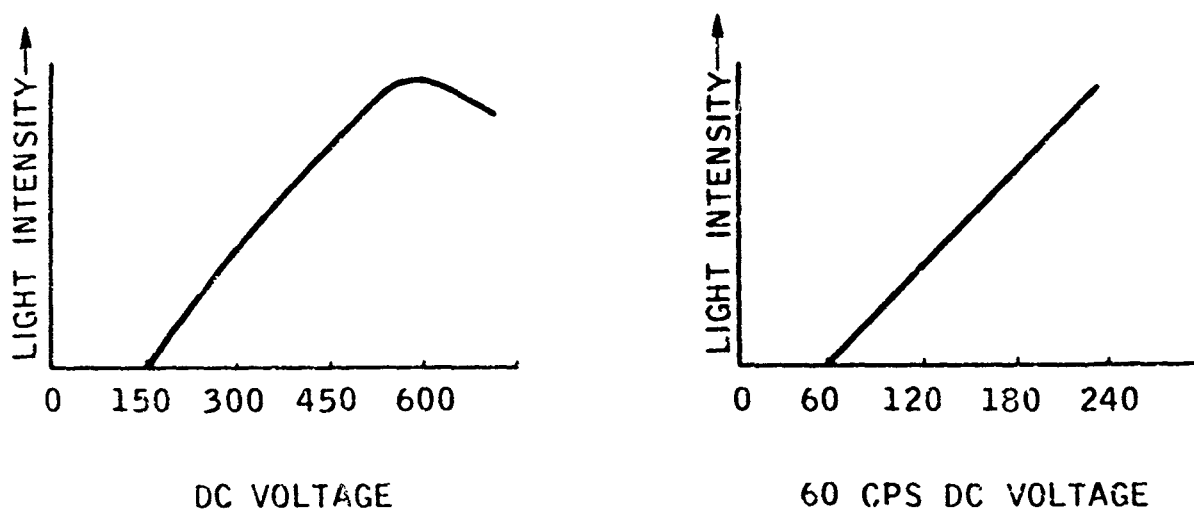


Figure 11. Light Intensity as a Function of Reverse Voltage

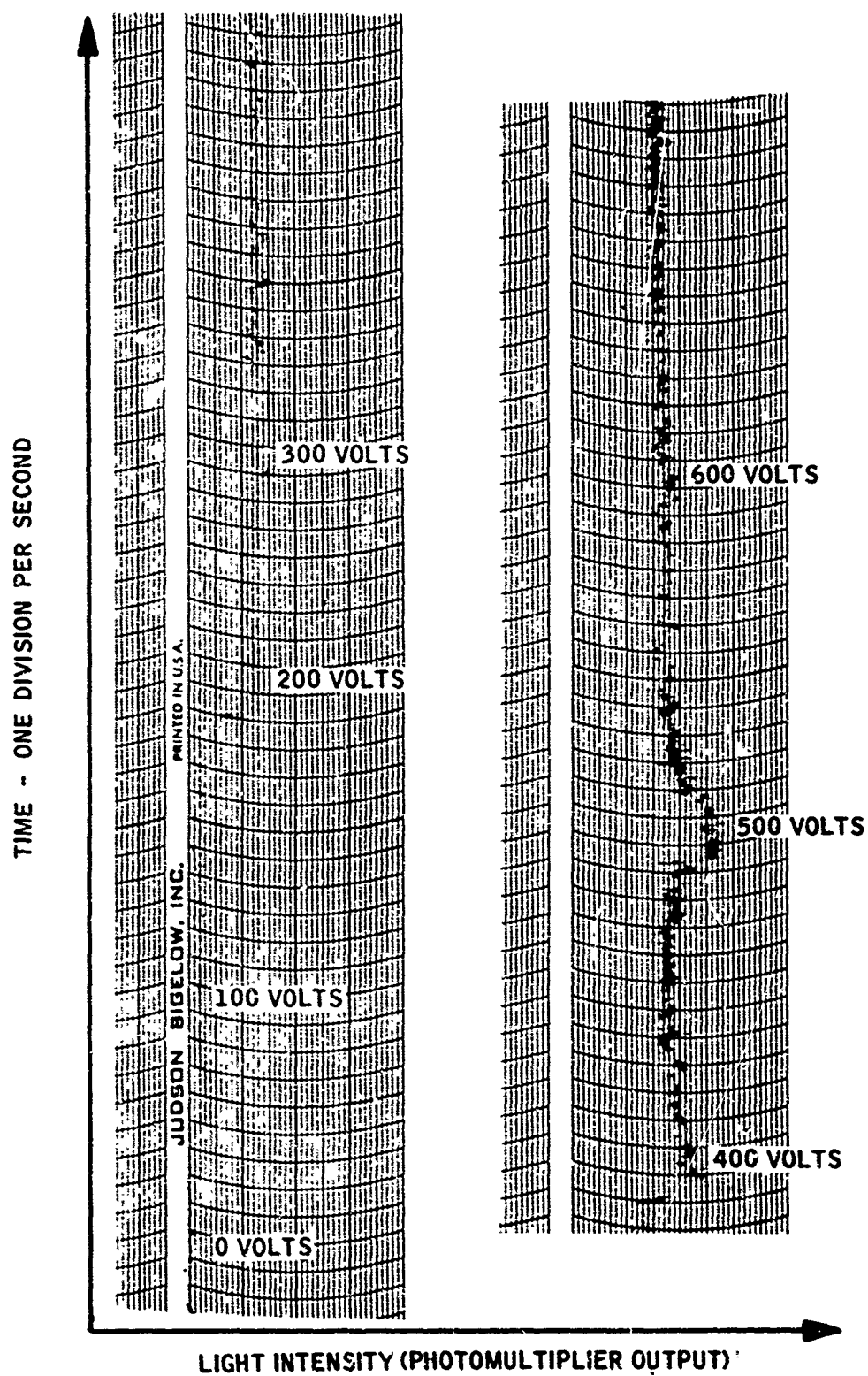


Figure 12. Light Response to a Voltage Step Function of Microplasma Regions

Microplasmas occur either in the forward or reverse biased conditions. The pulse rate is increased by light irradiation.¹² Microplasmas tend to occur at junctions having hard characteristics. By observing the reverse characteristics on a diode curve tracer, discontinuities can be detected as discharges occur. The breakdown voltage for these discharges is less than that of a uniform junction.

4.2.2 Capacitor Failure Mechanism

The 6.8 μ f and 0.015 μ f capacitors were both subjected to some of the same measurements and investigations as the diodes. RF noise in the capacitors was primarily in the form of spikes, rather than of a sustaining nature. Because of this, detailed investigation has been difficult.

There appear to be at least three main causes for capacitor failure. One failure mechanism is due to variations in thickness of the oxide film, due to irregularities in the tantalum metal surface. Breakdown at these stress areas would result in current in pulses and noise. Unfortunately, the MnO₂ film over the tantalum oxide tends to heal breakdowns of this type and noise generated becomes intermittent.

A second failure mode is the diffusion of Ta atoms through the oxide film. This diffusion is accelerated by thermal and electrical stress. This second phenomenon is not particularly amenable to RF noise detection schemes.

A final failure is of the catastrophic type where shorts and mechanical discontinuities are present. This seems to be the most common type of failure picked up in the screening procedure. Most of the 29 capacitors isolated display shorts or opens as they are mechanically shocked, but appear normal when not shocked.

Probably the most common failure mechanism in tantalum capacitors is caused by irregularities in the tantalum surface. Breakdown through the imperfections of the oxide layer or microfissures at these stress areas results in current impulses and noise. A number of mechanism have been proposed^{13, 14, 15, 16} for the formation of microfissures. Among them are surface impurities in the metal, contamination during fabrication, moisture, variation in the growth rate of amorphous and crystalline oxide, and hydrogen gas evolution¹⁷ at the metal dielectric surface (where rectification occurs). Microfissures are essentially breaks in the oxide in which the counterelectrode penetrates. In this manner, a small gap is formed between electrodes through which arcing takes place.

Arcing across microfissure breaks generates noise impulses, however the manganese dioxide film placed over the Ta_2O_5 tends to heal breakdowns of this type. For this reason, many of the noisy capacitors, especially of the sintered type exhibited only a few noise spikes and then became quiet. Ideally, the tantalum oxide would be amorphous in structure; however, the sintered slug has a crystalline structure. It is easy to visualize imperfections at the union of the two different type of structures or in the transition¹⁸ between the two. An interesting observation was the consistent increase in capacity of the sintered type, after they were intentionally broken down by excessive voltage, limiting the current to prevent burnout. An increase in capacity after voltage breakdown is probably due to the arcing and resultant heating at the imperfections in the oxide film, where contact, in all the crevices of the sintered slug, was not made between the Ta_2O_5 and the tantalum metal. When additional Ta_2O_5 is formed at the discharge points, the net result is an increase in area of the capacitor.

The solid wire type, having a smoother tantalum surface, consistently decreased in capacity after breakdown. One would postulate that here breakdown occurred at the thinnest layer of Ta_2O_5 ; however, the oxide coating over the tantalum was complete. During breakdown, a thicker layer of oxide is formed, thus reducing the total capacity of the unit.

An attempt was made to determine the nature of the tantalum oxide film by means of the change in capacity¹⁹ or the dissipation factor²⁰ of the capacitor at two frequencies (i.e., 100 cps and 5k cps). The crystalline oxide is expected to have a greater variation in capacity as the frequency is varied, than is expected from an amorphous oxide. The factors which produce a high dissipation factor also produce a high change in capacity as a function of frequency. A plot of the frequency independent part of the dissipation factor ($\tan \delta'$) versus the change in capacity, for the $6.8\mu\text{f}$ sintered tantalum capacitors, is shown in Figure 13. The two curves obtained by a least squares fit can be expressed by the following lines.

$$\tan \delta' = 0.01632 + 0.0228 \Delta c \text{ for the quiet sample}$$

$$\tan \delta' = 0.005338 + 0.03345 \Delta c \text{ for the noisy sample}$$

The average $\tan \delta'$ for the noisy capacitors was 0.0302 and the average $\tan \delta'$ of the quiet sample was 0.0255. Since $\tan \delta'$ is a measure of the Ta_2O_5 quality, one does get an indication that the noisy sample is of lower quality. In a similar manner, the equivalent series resistance (R_2) of the capacitor decreases with the number of coats of MnO_2 . For the noisy sample, the average R_2 was 0.015Ω in comparison to 0.999Ω for the quiet sample.

Since shock was more important in introducing noise in the solid wire type, one would conclude that mechanical faults were the major contributing factor. Most of these capacitors display opens or shorts when they are mechanically shocked, but appear normal otherwise. Random discontinuities of this type are readily detectable by the r-f noise generated.

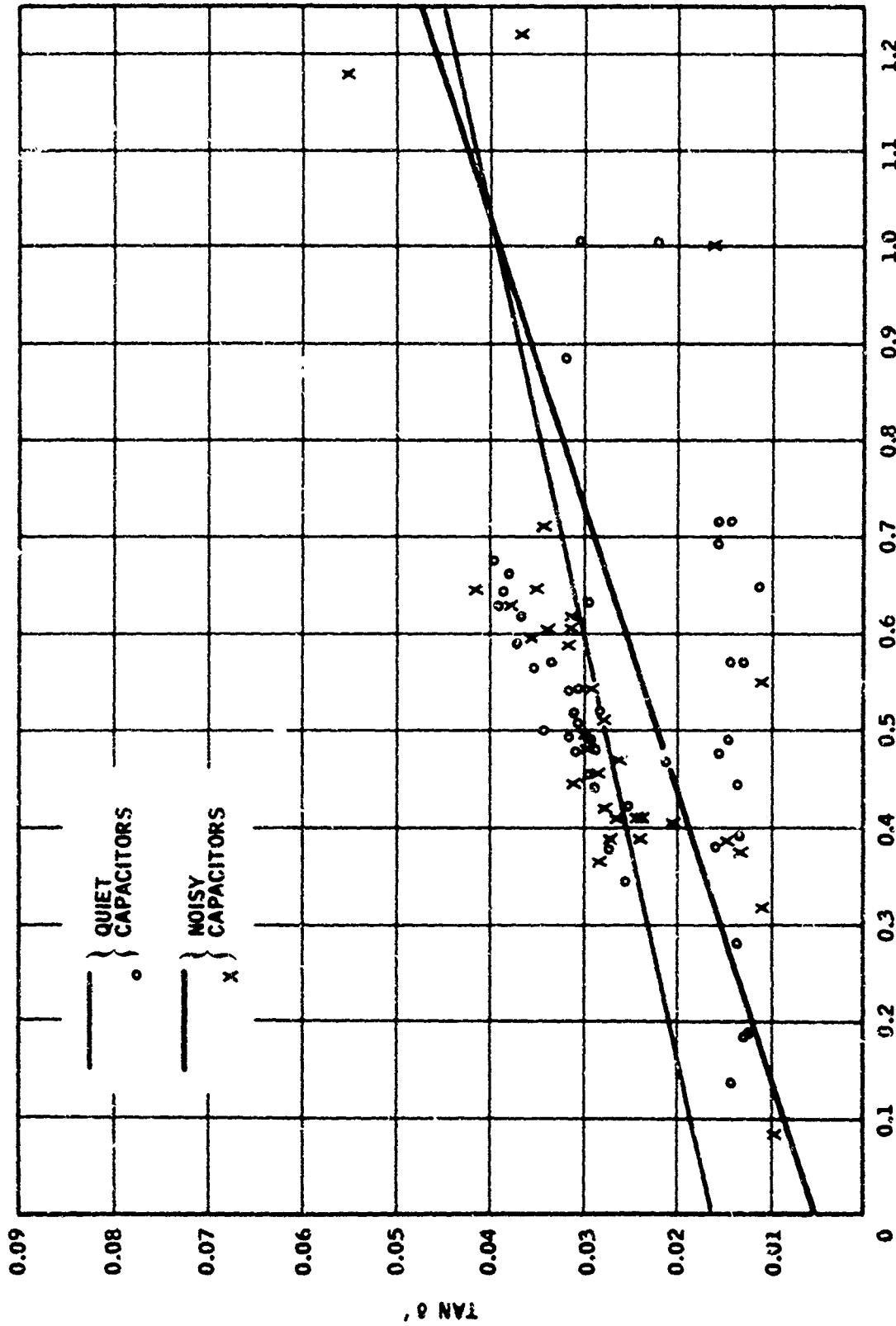


Figure 13. Frequency Independent Part of the Dissipation Factor ($\tan \delta'$) versus Change in Capacity, for the 6.8 μf Sintered Tantalum Capacitors

4.3 TESTING

4.3.1 Diodes

- 4.3.1.1 Test Specimen -- The IN645 diode is a double diffused silicon junction diode of a mesa construction. It is a 600-milliwatt diode with a peak inverse voltage rating of 225 volts. Forward voltage drop at the rated forward current of 400 ma is 1 volt at 25°C; maximum leakage current at 225 volts reverse bias is 200 nanoamps at 25°C; and typical capacitance at 12 volts reverse bias is 9 pF.

The IN645 diodes were obtained for this study from existing Honeywell stock. These diodes had been inspected under a one percent AQL plan, per MIL-STD-105. The diodes were screened for excessive RF noise, using equipment and techniques already employed at Honeywell for measuring RF noise generated by defective components.

- 4.3.1.2 Test Procedures -- A block diagram of the test circuit is shown in Figure 14. The diode tested was clamped in a holding fixture as shown in Figure 15. The fixture supported the diode by its leads, at a distance of 1/4 inch from the body, and also provided electrical contact to the diode. The holding fixture was shocked by a spring-loaded hammer, which was activated by cranking the handle. The hammer was designed to provide a shock of 100 g's for 1/2 millisecond.

The low noise Empire NF 105 receiver had a relatively flat response over a broad frequency range (± 1 db from 2 mc to 30 mc). It could detect signals having an amplitude of 0.1 μ V to 1 μ V, depending on ambient noise conditions. The IF amplifier was tuned at 1.6 mc with a 10-kc bandwidth. The receiver, together with the diode fixture, is shown in Figure 16.

The component under test was energized, and input of the receiver was impedance-matched to the diode power lead by means of a line stabilization unit. Additional work at optimizing this unit is reported in Appendix B. Voltage or current supplied to the diode was varied to determine the optimum value at which tests should be conducted. Power spectral density was measured on an rms meter monitoring the output of the receiver. By tuning the receiver

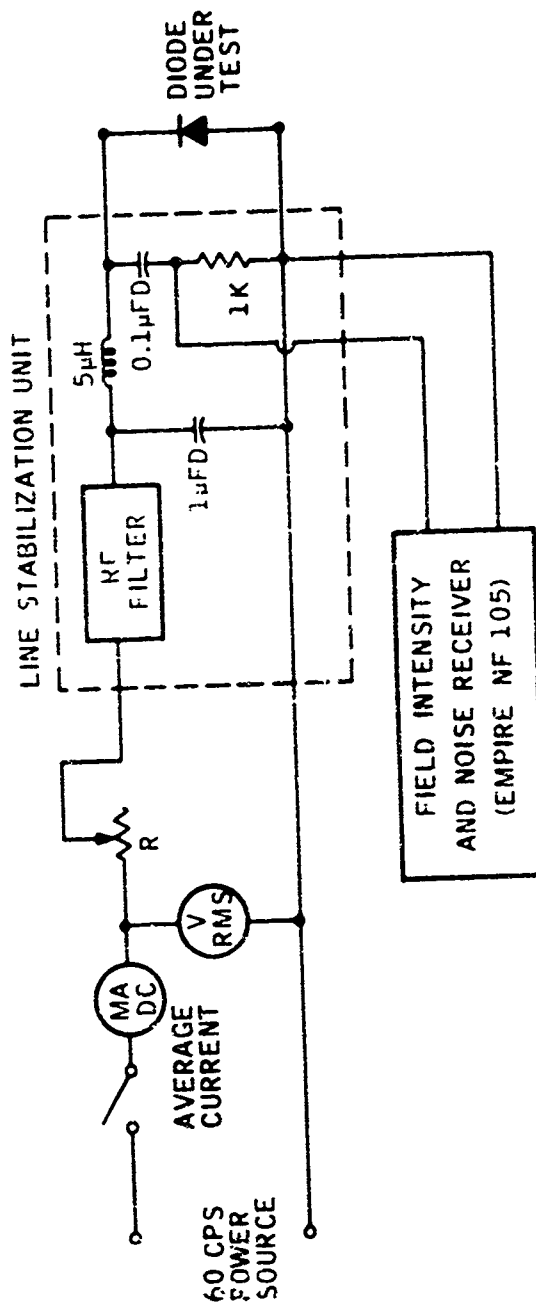


Figure 14. Block Diagram of the Diode Test Circuit

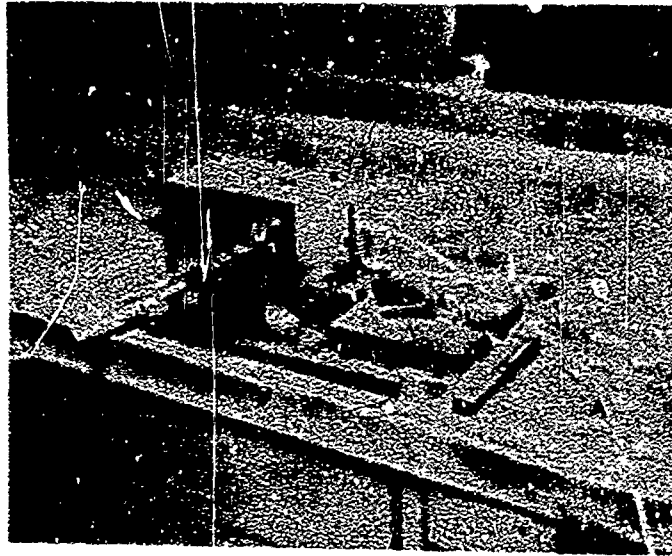


Figure 15. Holding Fixture and Shocking Device

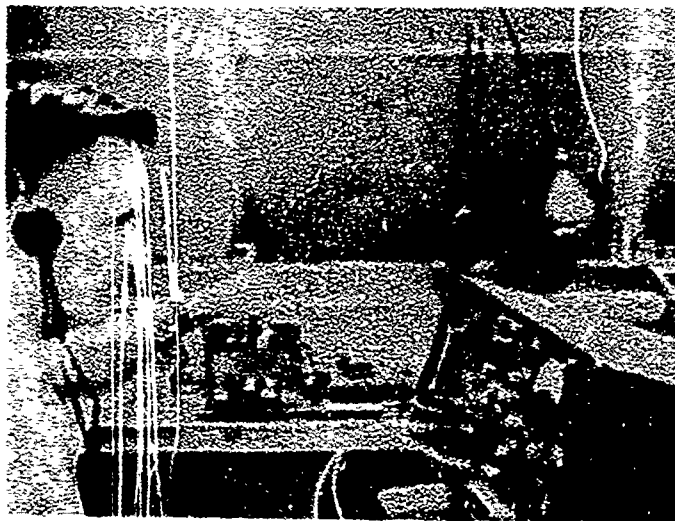


Figure 16. Radio Noise Test Station

over the frequency band of 2 mc to 25 mc and measuring the noise level of a number of diodes, a normal background noise level was determined for the standard, "normal" diode. Noise level of the normal unit was approximately at the threshold of the receiver (see Figure 17) and noise was white in nature over the frequency range.

After screening 1500 diodes it was decided to conduct the screening test on future diodes at 25 mc only. This was done because less background interference was encountered at this frequency and because abnormal noise when encountered was always present at all frequencies between 2 mc and 25 mc. The test specimen signature or normal background noise was used to detect abnormal diodes as their noise appeared with greater intensity above this background. This is apparent in Diodes 1, 2, and 3 in Figure 17. With the norm established, mechanical shock stress was applied to aggravate potential breakdowns if the diode did not already display abnormally high noise. Abnormal noise could be seen on the rms meter and was also audible on earphones. For maximum sensitivity to abnormal noise, normal component background noise was masked out of the audible signal by a slide-back control, which was a bias applied to the audio-amplifier.

Diodes were energized with ac to subject them to both forward and reverse stresses. An excitation level of 100 ma average current and 124 volts rms at 60 cps was used. These are typical levels to which the diodes are exposed in most applications. It was found at this level that the diodes generate very little noise, and because of receiver threshold, only 23 excessively noisy units were detected out of a sample of 10,250. Diode current was increased to 300 ma at the same voltage. Little change in noise level was detected until voltage was also increased to its maximum allowable value of 225 volts or 159 volts rms. It was found that many diodes previously screened at 124 volts rms now exhibited abnormal noise when rescreened at 159 volts rms. Therefore, back voltage appears to be more critical than current in causing noise in a p-n junction. This tends to indicate that noise arises from a breakdown phenomenon rather than a thermal effect.

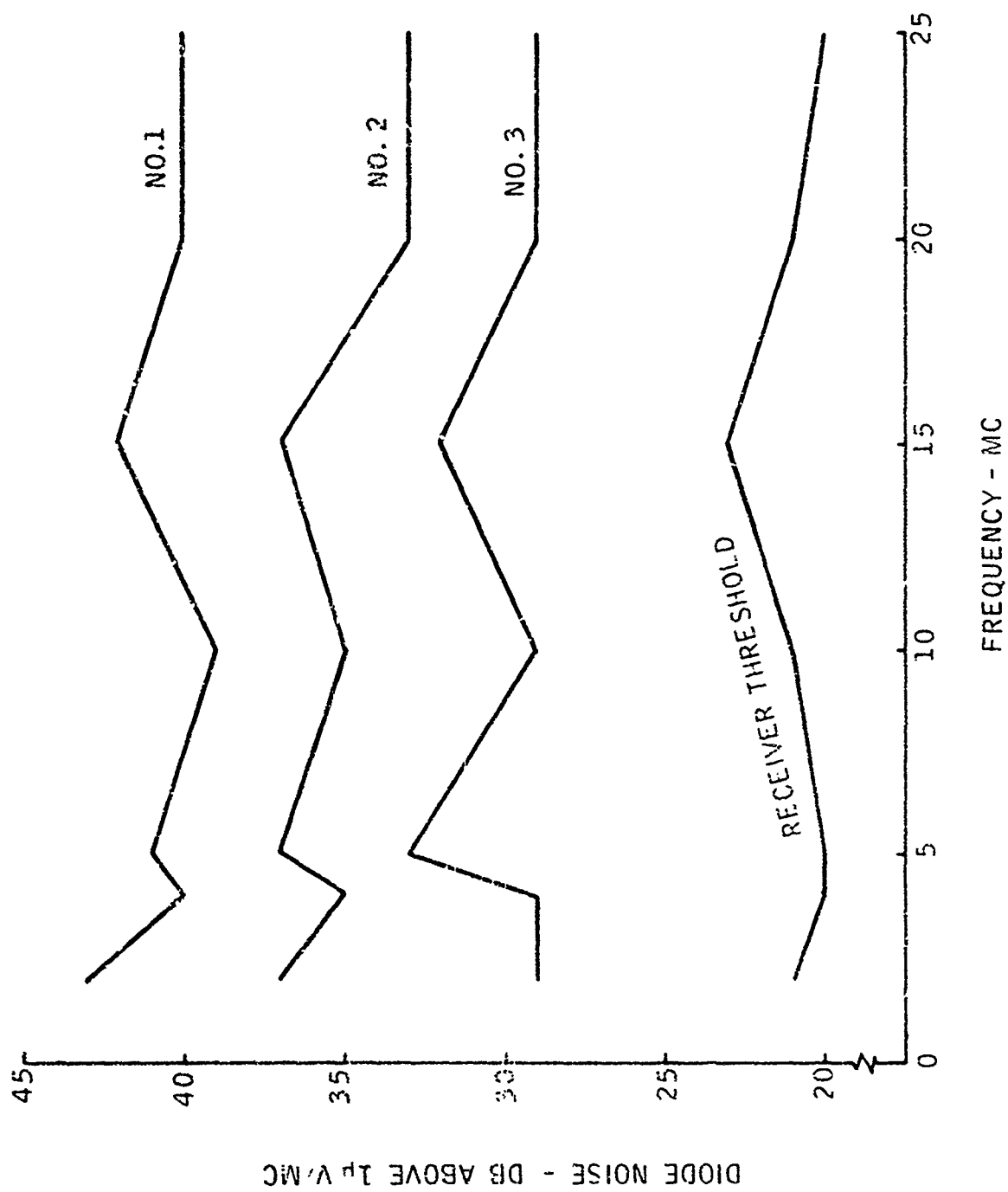


Figure 17. Power Spectral Density of Some Noisy Diodes

While monitoring for noise, diodes were subjected to a maximum of 12 impact shocks of 100 g's in each of three planes²¹. It became apparent during the program that breakdown of a diode under shock was independent of orientation of the diode to direction of shock. Therefore, to reduce handling time, diodes were mounted at 45 degrees to the direction of the shock. This mounting subjected them to shock in both axial and normal directions simultaneously, thus requiring only one series of shocks.

- 4.3.1.3 Screen Test Results -- Having determined the optimum excitation level of 300 ma and 159 volts rms, a total of 20,200 diodes were screened. Shock was applied to all of them, unless they exhibited noise upon electrical excitation alone. Only 15 of the 20,200 diodes screened became noisy as a result of the shocks. Of these, six had abnormal forward or reverse characteristics.

Table 1 is a breakdown of the different lot sizes of diodes that were screened and the quantity of noisy diodes found in each lot. Also shown are the different component excitation conditions that were employed.

Of the 20,200 diodes screened, 146 (or 0.7 percent) exhibited excessive noise. However, only 86 of the 146 (or 0.4 percent of the total screened) passed the reverse leakage current, forward voltage drop, and reverse voltage breakdown specifications. The 60 diodes which did not meet specifications are within expectations of a one percent AQL sampling plan. The 86 appeared normal in all respects except for a high RF noise level, and are referred to as the "noisy diodes". Type of noise displayed by the noisy diodes is shown in Figure 18. This Figure also includes the quantities and types of failures resulting from the subsequent life tests.

- 4.3.1.4 Life Test -- To determine whether excessive RF noise is correlated with early failure, a life test was run on both noisy and quiet diodes. This life test was conducted under maximum allowable conditions, with the diodes carrying 150 ma dc at 159 volts rms and temperature of 150°C. The diodes conducted for 50 minutes and were off for 10 minutes to subject them to normal switching transients. The forward voltage drop at 400 ma dc, and

Table 1. Summary of Diodes Screened

Screen Test Conditions	No. of Diodes in Group Tested	Total No. of Diodes Screened	No. of Noisy Diodes in the Group Tested	
			Meet Prints	Did Not Meet Prints
100 MA At 124 VAC	1000	1000	1	7
	500	1500	0	3
	500	2000	0	0
	550	2550	0	0
	500	3050	1	2
	1000	4050	0	1
	1000	5050	0	1
	2000	7050	0	0
	2000	9050	0	6
	1200	10,250	0	1
300 MA At 159 VAC	1900	12,150	6	3
	1200	13,350	4	8
	1000	14,350	1	1
	850	15,200	2	1
	350		4	2
	200		5	3
400 MA At 159 VAC	800		12	7
	50		1	0
300 MA At 159 VAC	700		3	1
400 MA At 159 VAC	100		1	0
300 MA At 159 VAC	350		4	2
	5000	20,200	41	11
			86	60

NOTE: These diodes had been previously screened at 124 VAC and were rescreened at 159 VAC. They therefore do not add to the overall total.

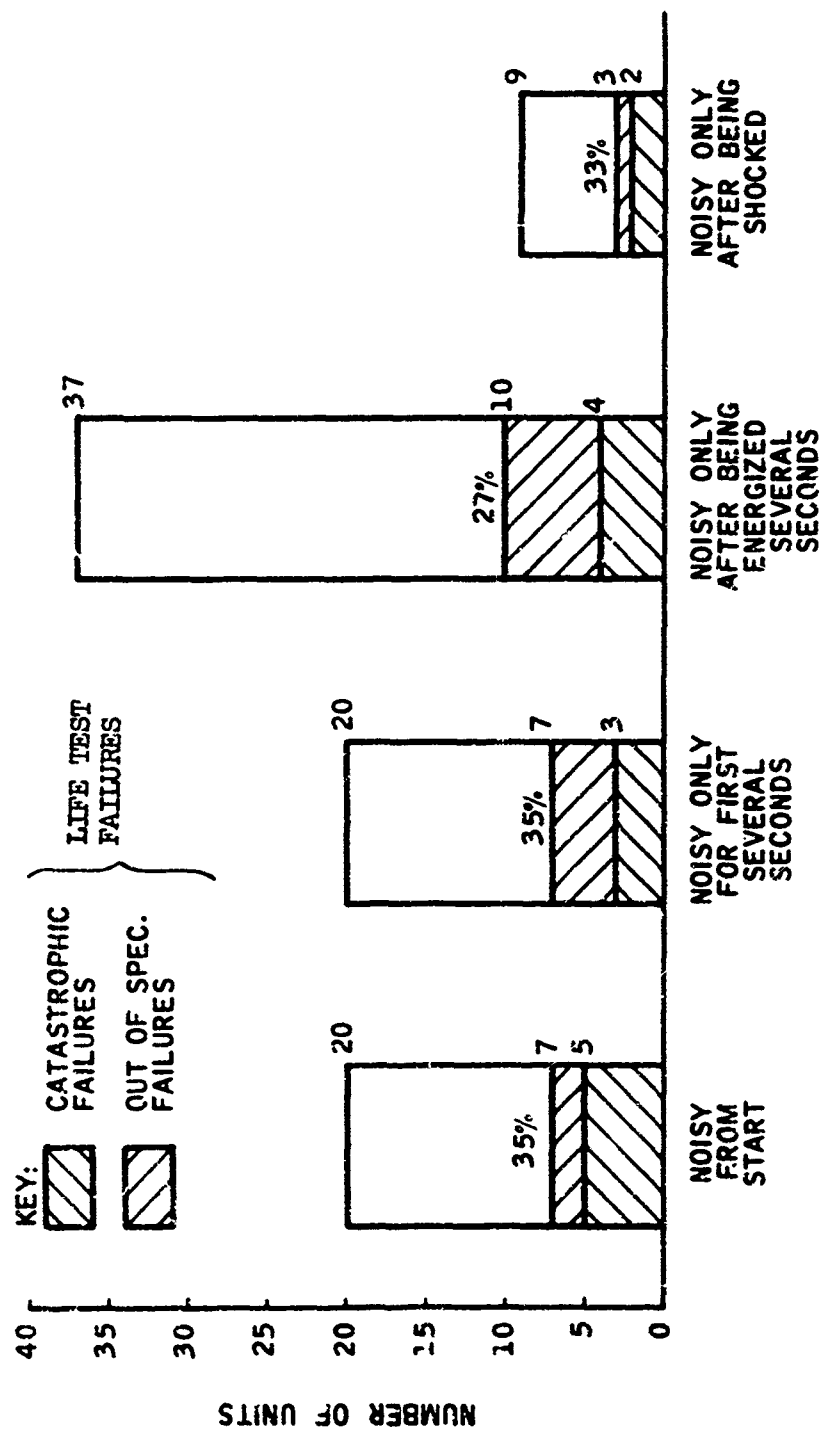


Figure 18. Distribution of Diodes and Life Test Failures in Several Noise Categories

leakage current at a reverse voltage of 225 volts dc, were measured at 250-hour intervals at 25°C.

Seventy-eight noisy diodes and thirty-eight quiet diodes were life tested for 3000 hours. Detailed life test data is included in exhibits I through IV in Appendix. Figure 19 shows the results of the life test. Here the percent of the test sample failures are plotted against hours on test. At the end of 3000 hours, 34.6 percent of the noisy diodes and 21.1 percent of the quiet diodes had failed under the life test conditions. Table 2 shows the breakdown of life test failures into catastrophic failures and units no longer meeting all specifications. The percent of noisy diode failures after 1000 hours is 78 percent greater than the percent of quiet diode failures, 58 percent greater after 2000 hours, and 64.4 percent greater after 3000 hours. At this point an attempt was made to determine if a relationship existed between the noisy diodes that failed life test and the type of noise they displayed during screening. Figure 18 shows a breakdown of the noise displayed by the 86 noisy diodes into four categories and the number of diodes in each group that failed life test. Here, as shown, approximately one-third of the diodes in each group failed during life test. The type of noise displayed by a noisy diode can not therefore be used to predict ultimate failure. Of special interest in Figure 18 is, as mentioned previously, the small number of diodes that required shock to set up a noise condition.

To obtain a more accurate figure for the quiet diode failure rate, the sample of quiet diodes was increased. Fifty-eight additional quiet diodes were placed on life test at the 1500 hour point, putting a total of 96 quiet diodes on life test. At the end of 3000 hours, the added quiet diodes had accumulated 1500 hours on test. The test results of these added diodes were combined with the test results of the original 38 quiet diodes at the 1500 point. This gives a more accurate picture of the quiet diode performance.

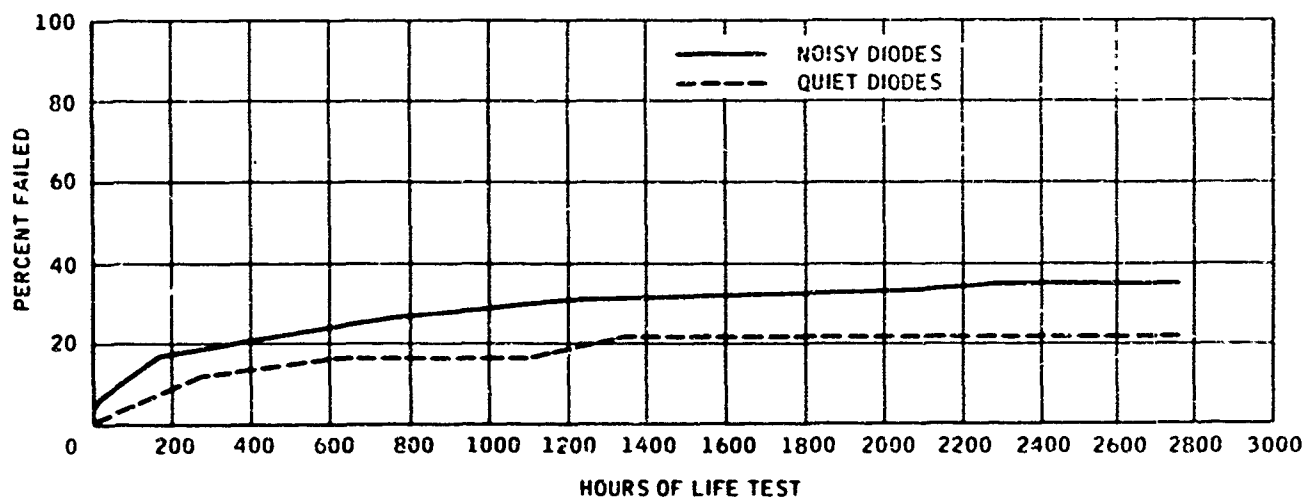


Figure 19. Percentage of Noisy and Quiet Diodes that Failed with Time on Life Tests

Table 2. Diode Life Test Failures

	78 Noisy						38 Quiet						96 Total Quiet					
	Catastro- phic			Out of Spec.			Catastro- phic & Out of Spec.			Catastro- phic			Out of Spec.			Catastro- phic & Out of Spec.		
	Total	%	Total	Total	%	Total	Total	%	Time Hrs.	Total	%	Total	Total	%	Time Hrs.	Total	%	Time Hrs.
50	4	5.1	11	14.1	15	19.2	20	25.7	750	1	2.6	5	13.2	6	15.8	1	1.0	500
60	7	9.0	10	12.8	17	21.8	17	21.8	500	1	2.6	5	13.2	6	15.8	1	1.0	500
70	7	9.0	13	16.7	20	25.7	20	25.7	750	1	2.6	5	13.2	6	15.8	1	1.0	750
80	7	9.0	15	19.2	22	28.2	22	28.2	1000	1	2.6	5	13.2	6	15.8	1	1.0	1000
90	11	14.1	13	16.7	24	30.8	24	30.8	1250	3	7.9	5	13.2	8	21.1	5	5.0	1250
100	11	14.1	13	16.7	24	30.8	24	30.8	1500	4	10.5	4	10.5	8	21.1	6	6.2	1500
110	12	15.4	13	16.7	25	32.0	25	32.0	1750	4	10.5	4	10.5	8	21.1			
120	12	15.4	14	17.9	26	33.3	26	33.3	2000	4	10.5	4	10.5	8	21.1			
130	12	15.4	15	19.2	27	34.6	27	34.6	2250	4	10.5	4	10.5	8	21.1			
140	14	17.9	13	16.7	27	34.6	27	34.6	2750	4	10.5	4	10.5	8	21.1			
150									3000	4	10.5	4	10.5	8	21.1			

Life test performance data was plotted against the performance data of the 78 noisy diodes during the first 1500 hour period and is shown in Figure 20. In the larger, quiet sample, 18.7 percent of the quiet diodes, and 30.8 percent of the noisy diodes failed at the 1500 hour point. The percent of noisy diode failures after 1500 hours became 65 percent greater than the percent of quiet diode failures.

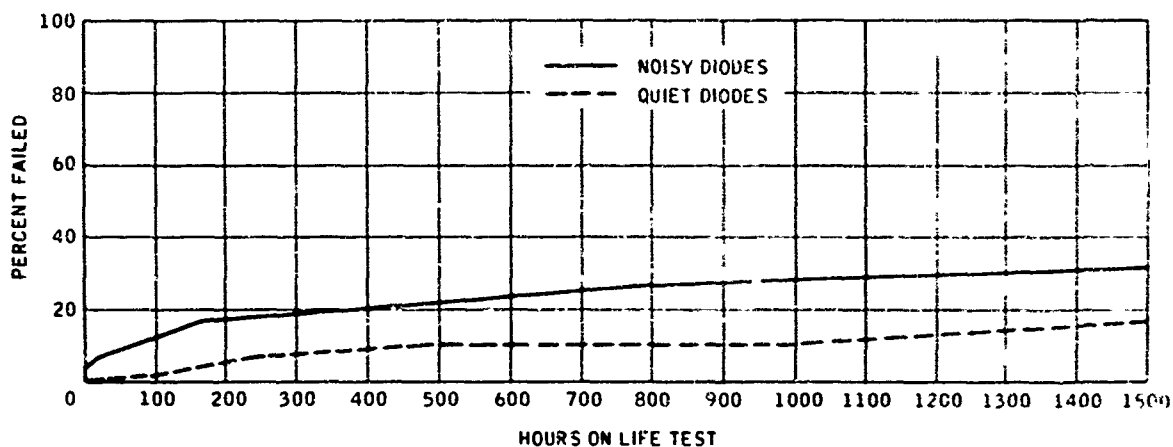


Figure 20. Percentage of Noisy and Quiet* Diodes that failed with Time on Life Test

Results of life testing show that diodes exhibiting excessive RF noise are considerably more failure prone than diodes exhibiting low RF noise, and good correlation is established between excessive RF noise and higher failure rate.

*Increased sample over that shown on Figure 19.

4.3.2 Capacitors

4.3.2.1 Test Specimen -- The type 150D685 x 0010B0Z4 (6.8 μ fd at 10 WVDC) is a polarized, direct current, solid-electrolyte, tantalum-fixed capacitor in a hermetically-sealed, tubular, metallic case. This capacitor has a maximum d-c voltage rating of 10 volts from -55°C to +85°C. Maximum leakage current at rated voltage is 1.4 μ amps, maximum dissipation factor is six percent, and maximum reverse voltage is 0.5 volts at 25°C. This capacitor is in a B style case.

The type 150D153 x 035A0Z4 (0.015 μ fd at 35 WVDC) is the same as the 6.8 μ fd capacitor, except for voltage rating and maximum leakage current. This capacitor has a maximum d-c voltage rating of 35 volts from -55°C to +85°C. Maximum leakage current at rated voltage is 1.0 μ amps at 25°C. This capacitor is in an A style case.

The capacitors meet requirements of MIL-C-26635, characteristic B. The capacitors were screened for excessive RF noise, using the same technique employed for the diodes.

4.3.2.2 Test Procedure -- The test procedure employed for the screening of the capacitors was almost identical to the diode screen test. The same test equipment and criteria were used to detect the presence of abnormal noise. Noise was monitored with both rated forward voltage and 0.5 volts of reverse voltage applied to the component under test. This was done by placing a diode across the line stabilization unit.

A-c was applied to the test circuit shown in Figure 21. The a-c voltage was of such a magnitude that the peak value of the positive half cycle was equal to the rated d-c voltage of the capacitor. The diode was so polarized that it conducted during the negative half cycle, shorting out the capacitor, and preventing reverse line voltage from appearing across the capacitor. However, conduction threshold of the diode is between 0.5 and 0.6 volts, so that

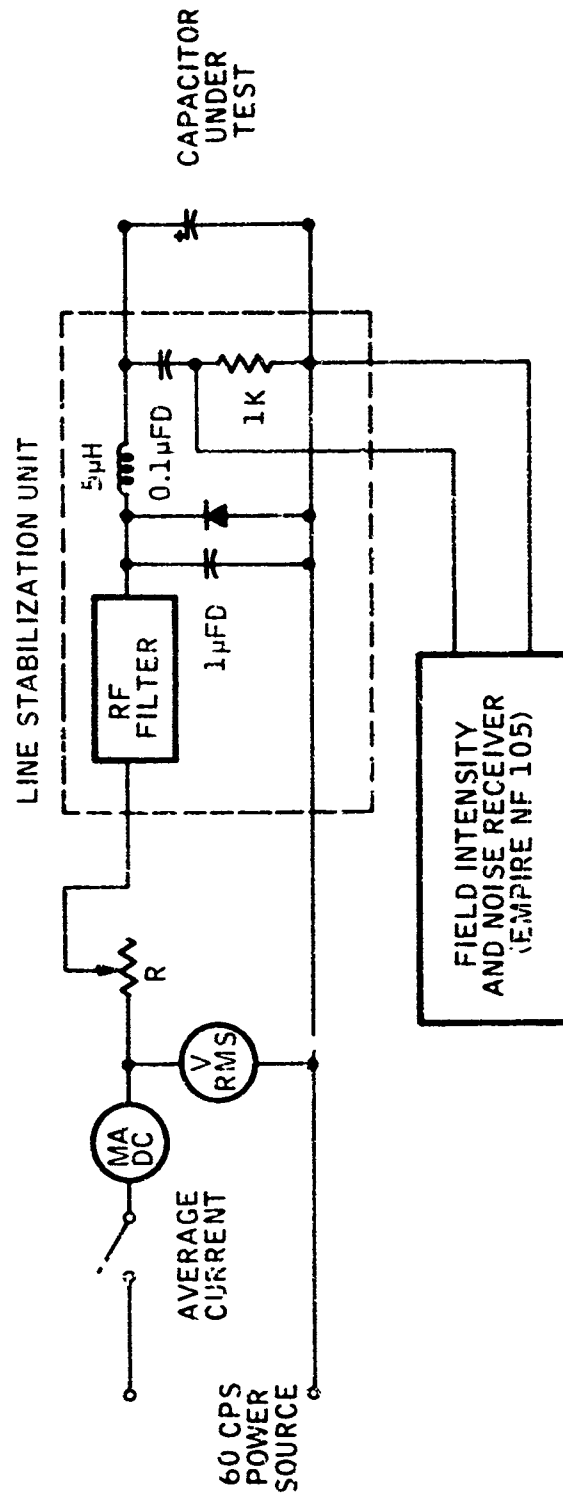


Figure 21. Block Diagram of the Capacitor Test Circuit

approximately 0.5 reverse volts appeared across the capacitor during the negative half cycle of the applied line voltage. The capacitors, therefore, were operating during the screening test under maximum allowable conditions. The resistance R shown in Figure 21 was adjusted to both limit diode current to a safe level, and to provide at least three Ω /volt of series impedance to the capacitor on test, as recommended by the manufacturer. This action prevented large surge currents during the charging time of the capacitors, and protected capacitors against surge damage. Appendix B contains the report of the efforts to devise a different capacitor noise detection circuit.

4.3.2.3 Screen Test Results -- A total of 4854,6.8 μ fd capacitors and 4954,0.015 μ fd capacitors were screened. Shock was applied to all of them, unless they exhibited noise upon electrical excitation alone. In the case of the capacitors, shock played an important role in the detection of noise.

Of the 4854,6.8 μ fd capacitors screened, 40 (or 0.8 percent) exhibited excessive noise and of the 4954,0.015 μ fd capacitors screened, 27 (or 0.5 percent) exhibited excessive noise. Therefore, of the total of 9,808 capacitors screened 67 (or 0.7 percent) exhibited excessive noise.

The noise displayed by the noisy capacitors in all cases occurred in the form of short duration spikes indicative of a breakdown phenomena. The type of noise displayed by the noisy capacitors is shown in Figure 22.

Figure 22 shows, as opposed to the diodes, that shock was a necessary parameter in the screening of capacitors. This was especially true for the 0.015 μ fd capacitors where nearly all of the abnormal noise occurred only during the application of shock. As was the case for the diodes, Figure 22 shows that no clear cut relationship exists between the type of noise displayed by the noisy capacitors and the units that ultimately failed life test.

In categorizing the capacitor noise content the numerous spike category refers to those that exhibited a train of spikes greater than four.

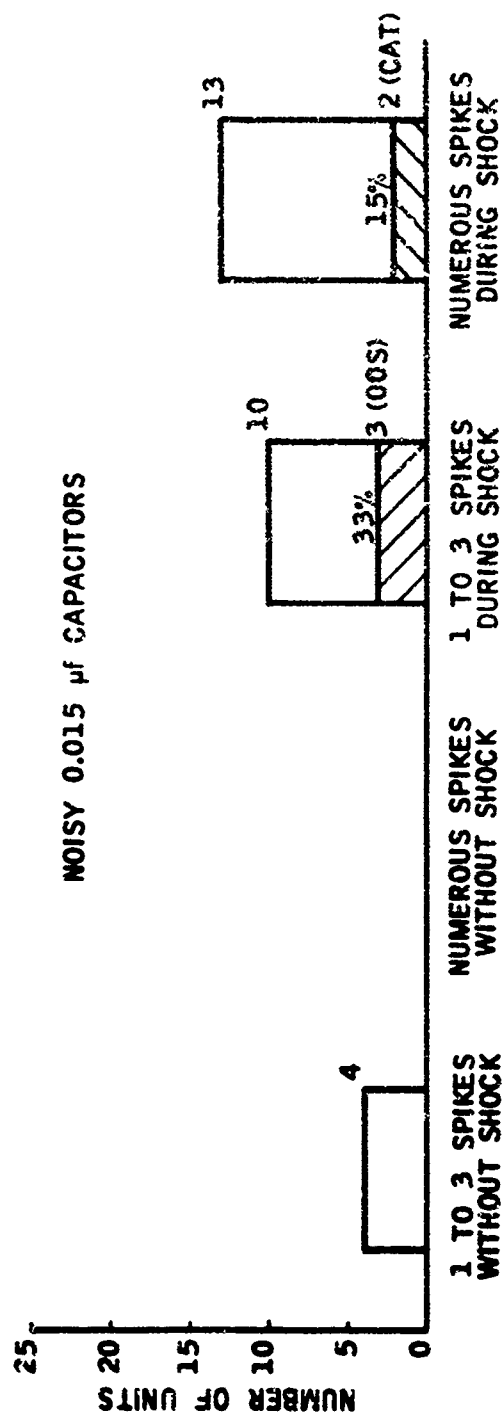
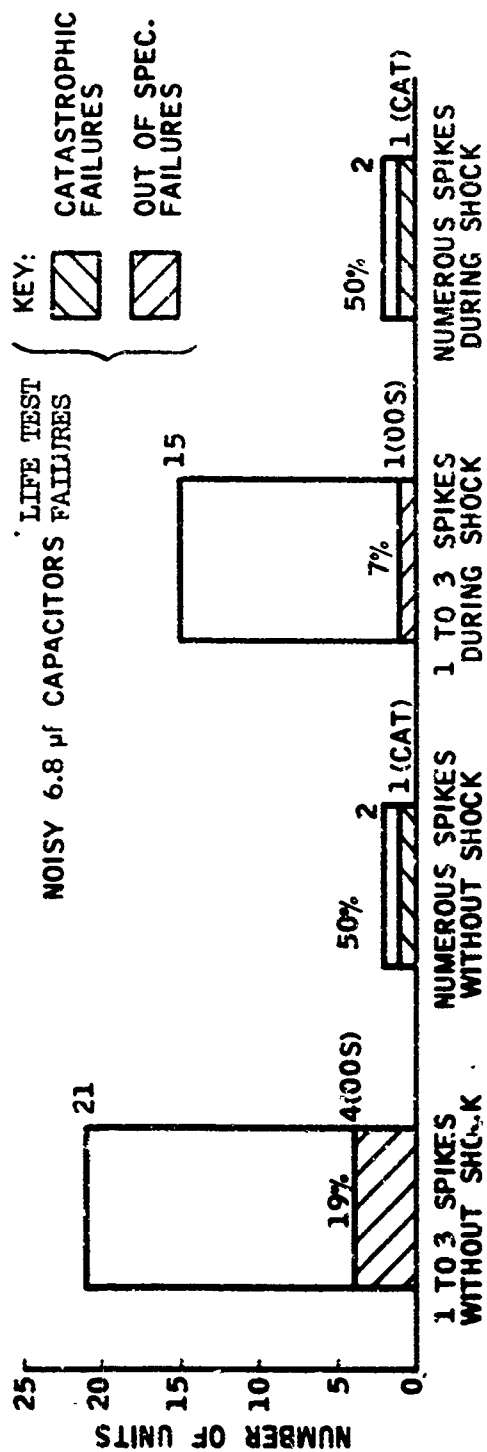


Figure 22. Type of Noise Encountered During Capacitor Screening and Life Test Failures Observed

Because of the random nature and short duration of these spikes it was not feasible to obtain photographs of the spikes.

The 40 noisy 6.8 μ fd capacitors and 24 of the 0.015 μ fd capacitors met all of the manufacturers specifications. The three remaining 0.015 μ fd capacitors were found to short intermittently during the pretest check and were not placed on the life test.

4.3.2.4 Life Test -Forty noisy 6.8 μ fd capacitors and 24 of the noisy 0.015 μ fd capacitors meeting all specifications were placed on life test, along with 40 quiet 6.8 μ fd capacitors and 27 quiet 0.015 μ fd capacitors. The life test was conducted under maximum allowable conditions, according to manufacturer's specifications. All capacitors were continuously subjected to two-thirds of their d-c working voltage at a constant temperature of 125°C. Twenty each of the noisy and quiet 6.8 μ fd capacitors, and all of the noisy and quiet 0.015 μ fd capacitors, operate in test circuits having a total of three ohms series resistance. This is standard procedure at Honeywell for life testing of this type of capacitor, and meets requirements of the manufacturer's specification. The remaining 20 noisy and 20 quiet 6.8 μ fd capacitors operated in test circuits having a total of 20 ohms series resistance. The 20 ohms resistance would better allow healing of small breakdowns should they occur at local weak points in the oxide coating. Object of the 20 ohms circuit testing was to see if the particular capacitors being tested had a different rate of failure than those in three-ohm circuits where even a small breakdown might result in a current avalanche and destroy the capacitors.

The capacitors were life tested for a total of 2000 hours. Results of this test are shown in Figure 23. Here, as in the case of the diodes, percent of the test sample failures are plotted against hours on test. Detailed life test data is shown in exhibits V through X in the appendix.

Tables 3, 4, and 5 show the breakdown between catastrophic failures and the number of units that no longer meet all specifications. Table 3 shows the

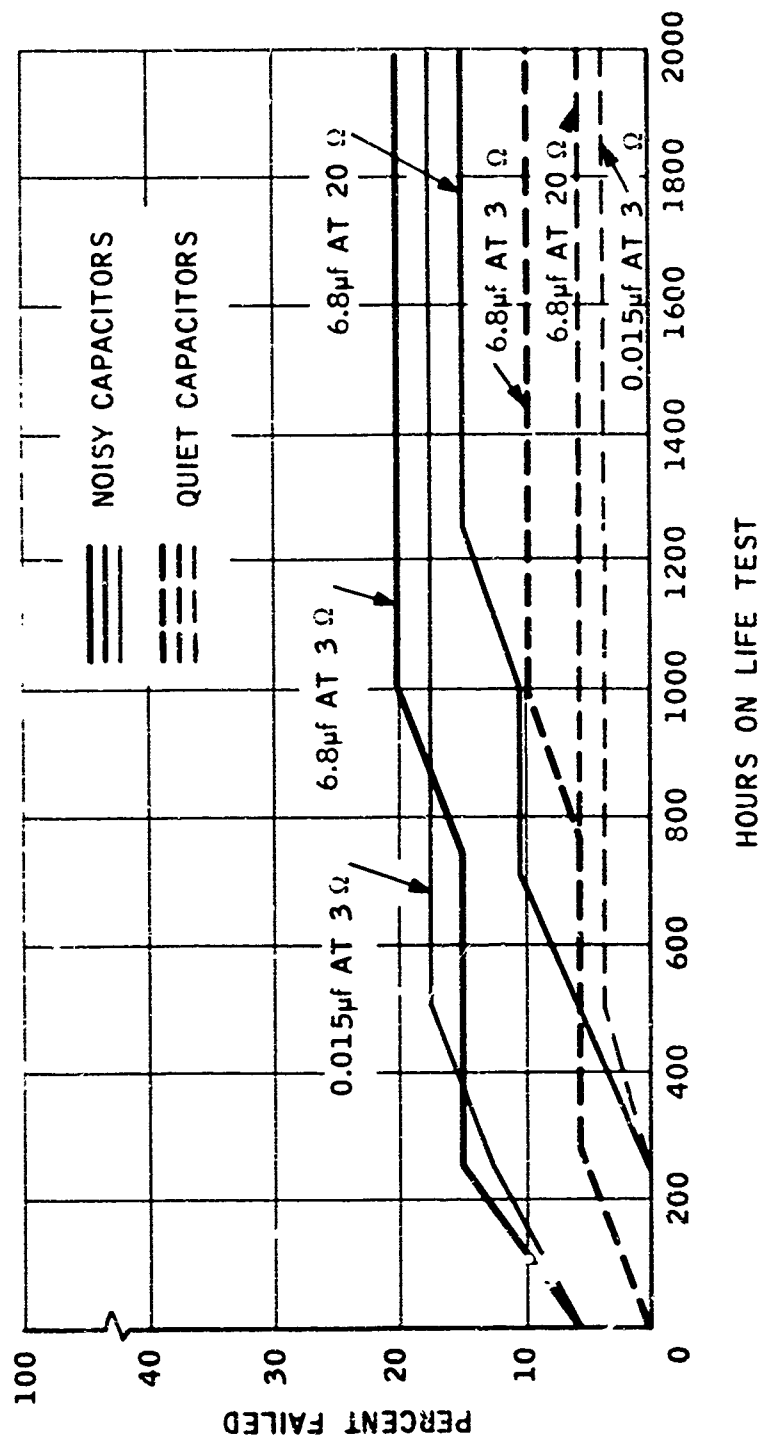


Figure 23. Percentage of Noisy and Quiet Capacitors that Failed with Time on Life Test

Table 3. Capacitor Life Test Failures

20 Noisy 6.8 μ Cap. With 3 Ω Series Res.						20 Noisy 6.8 μ Cap. With 20 Ω Series Res.							
Time Hrs.	Catastrophic		Out of Spec.		Total	%	Time Hrs.	Catastrophic		Out of Spec.		Total	%
	Total	%	Total	%				Total	%				
250	1	5.0	2	10.0	3	15.0	250	0	0	0	0	0	0
500	1	5.0	2	10.0	3	15.0	500	1	5.0	0	0	1	5.0
750	1	5.0	2	10.0	3	15.0	750	1	5.0	1	5.0	2	10.0
1000	1	5.0	3	15.0	4	20.0	1000	1	5.0	1	5.0	2	10.0
1250	1	5.0	3	15.0	4	20.0	1250	1	5.0	2	10.0	3	15.0
1500	1	5.0	3	15.0	4	20.0	1500	1	5.0	2	10.0	3	15.0
1750	1	5.0	3	15.0	4	20.0	1750	1	5.0	2	10.0	3	15.0
2000	1	5.0	3	15.0	4	20.0	2000	1	5.0	2	10.0	3	15.0

20 Quiet 6.8 μ Cap. With 3 Ω Series Res.						20 Quiet 6.8 μ Cap. With 20 Ω Series Res.							
Time Hrs.	Catastrophic		Out of Spec.		Total	%	Time Hrs.	Catastrophic		Out of Spec.		Total	%
	Total	%	Total	%				Total	%				
250	0	0	1	5.0	1	5.0	250	0	0	0	0	0	0
500	0	0	1	5.0	1	5.0	500	0	0	1	5.0	1	5.0
750	0	0	1	5.0	1	5.0	750	0	0	1	5.0	1	5.0
1000	1	5.0	1	5.0	2	10.0	1000	0	0	1	5.0	1	5.0
1250	1	5.0	1	5.0	2	10.0	1250	0	0	1	5.0	1	5.0
1500	1	5.0	1	5.0	2	10.0	1500	0	0	1	5.0	1	5.0
1750	1	5.0	1	5.0	2	10.0	1750	0	0	1	5.0	1	5.0
2000	1	5.0	1	5.0	2	10.0	2000	0	0	1	5.0	1	5.0

Table 4. Capacitor Life Test Failures

24 Noisy 0.015 μ Cap. With 3 Ω Series Res.					27 Quiet 0.015 μ Cap. With 3 Ω Series Res.						
Time Hrs.	Catastrophic		Out of Spec.	Catastrophic + Out of Spec.		Time Hrs.	Catastrophic		Out of Spec.	Catastrophic + Out of Spec.	
	Total	%		Total	%		Total	%		Total	%
250	1	4.2	2	3	8.3	250	0	0	0	0	0
500	2	8.3	2	4	8.3	500	0	0	1	3.7	1
750	2	8.3	2	4	8.3	750	0	0	1	3.7	1
1000	2	8.3	2	4	8.3	1000	0	0	1	3.7	1
1250	2	8.3	2	4	8.3	1250	0	0	1	3.7	1
1500	2	8.3	2	4	8.3	1500	0	0	1	3.7	1
1750	2	8.3	2	4	8.3	1750	0	0	1	3.7	1
2000	2	8.3	3	5	12.5	2000	0	0	1	3.7	1

Table 5. Capacitor Life Test Failures

64 Total Noisy Capacitors					67 Total Quiet Capacitors				
Time Hrs.	Catastrophic		Out of Spec. %	Catastrophic + Out of Spec. Total	Time Hrs.	Catastrophic		Out of Spec. %	Catastrophic + Out of Spec. Total
	Total	%				Total	%		
250	2	3.1	4	6	9.4	0	0	1	1.5
500	4	6.3	4	8	12.5	0	0	3	4.5
750	4	6.3	5	9	14.1	0	0	3	4.5
1000	4	6.3	6	10	15.6	1	1.5	3	4.5
1250	4	6.3	7	11	17.2	1	1.5	3	4.5
1500	4	6.3	7	11	17.2	1	1.5	3	4.5
1750	4	6.3	7	11	17.2	1	1.5	3	4.5
2000	4	6.3	8	12	18.7	1	1.5	3	4.5

6.8 μ f capacitor results, and Table 4 the 0.015 μ f capacitor results. Table 5 shows the total results.

After 2000 hours the noisy capacitors failed at a greater rate than the quiet capacitors. After 2000 hours, the ratio of noisy to quiet failures for the three test groups is two to one for the 6.8 μ fd capacitors with three ohms of resistance, three to one for the 6.8 μ fd capacitors with 20 ohms of resistance, and better than five to one for the 0.015 μ fd capacitors with three ohms of resistance.

Figure 24 shows an over-all comparison between the percents of noisy and quiet capacitor failures. Here, the failure data of noisy and quiet capacitors is combined and plotted against hours on test. After 2000 hours, 18.7 percent of the noisy capacitors, and 6.0 percent of the quiet capacitors had failed under life test conditions. Over-all percentage of noisy capacitor failures is 210 percent greater than the percentage of quiet capacitor failures. Even in the least case of 6.8 μ fd capacitors with three ohms series resistance, the percentage of noisy failures is 100 percent greater than the percentage of quiet failures.

The life test data indicates that capacitors exhibiting excessive RF noise are considerably more failure prone than capacitors exhibiting low RF noise. Results of this test, like the results of the diode test, establish a positive correlation between excessive RF noise and high failure rate.

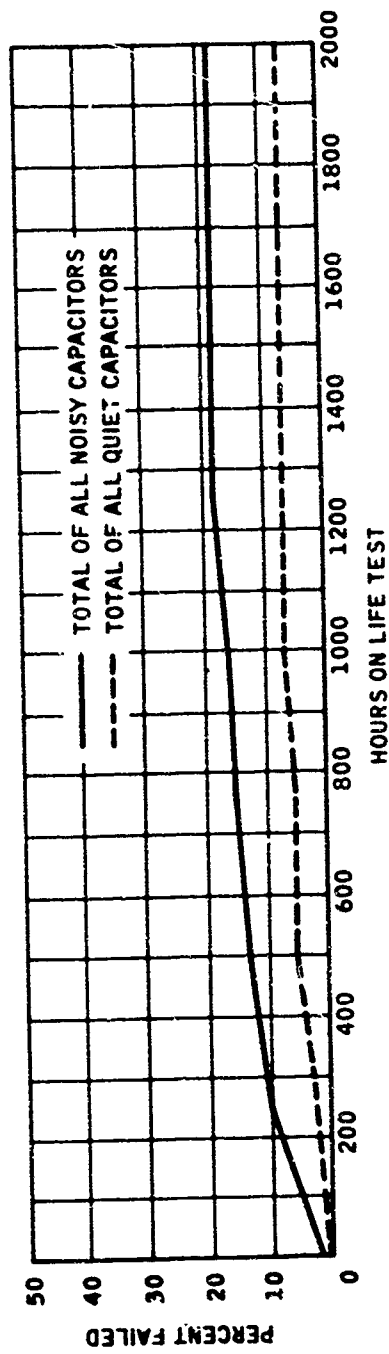


Figure 24. Percentage of Noisy and Quiet Capacitors that Failed with Time on Life Test, Failure Data of All Noisy and All Quiet Capacitors Being Combined

4.4 DATA ANALYSIS

An evaluation of the screening ability of RF noise measurements was conducted using the following criteria:

- a) Incremental Failure Rate - The failure rates of noisy versus quiet parts starting from time zero and processing in small time increments was determined.
- b) Cost of Performing Screening - The cost of screening the parts was established on a per serving part basis.
- c) Figure of Merit - The efficiency of the screening operation was established on a basis of the fraction of noisy parts that failed life test.

4.4.1 Incremental Failure Rates

Table 6. Diode Failure Rate %/1000 Hours

78 Noisy						38 Quiet						96 Quiet					
Time Hrs.	Total No. Failed	Δt Hrs.	ΔF	S	λ %/1000 hrs	Time Hrs.	Total No. Failed	Δt Hrs.	ΔF	S	λ %/1000 hrs	Time Hrs.	Total No. Failed	Δt Hrs.	ΔF	S	λ %/1000 hrs
250	15	250	15	78	77.0	250	4	250	4	38	42.1	250	7	250	7	96	29.2
500	17	250	2	63	12.5	500	6	250	2	34	23.5	500	11	250	4	89	18.0
750	20	250	3	61	19.7	750	6	250	0	32	0	750	12	250	1	95	4.7
1000	22	250	2	58	13.8	1000	6	250	0	32	0	1000	13	250	1	84	4.8
1250	24	250	2	56	14.3	1250	8	250	0	32	25.0	1250	17	250	4	83	19.3
1500	24	250	0	54	0	1500	3	250	0	30	0	1500	18	250	1	79	5.1
1750	25	250	1	54	14.8	1750	8	250	0	30	0					78	
2000	26	250	1	53	15.1	2000	8	250	0	30	0						
2250	27	250	1	52	0	2250	8	250	0	30	0						
2500	27	250	0	51	0	2500	8	250	0	30	0						
2750	27	250	0	51		2750	8	250	0	30	0						
3000				51		3000	8	250	0	30	0						

The incremental number of failures ΔF , which occur in an interval of time Δt , given that there were S devices operating at the beginning of the interval may be expressed.

F (failures) = S (devices) · λ (failures/device hour) · Δt (hours) where λ is a constant if the failures are random in time.

$$\text{Then } \lambda = \frac{1}{S} \frac{\Delta F}{\Delta t}$$

Where S = Number of devices operating at the start of the interval Δt

ΔF = Number of devices that failed during the interval Δt

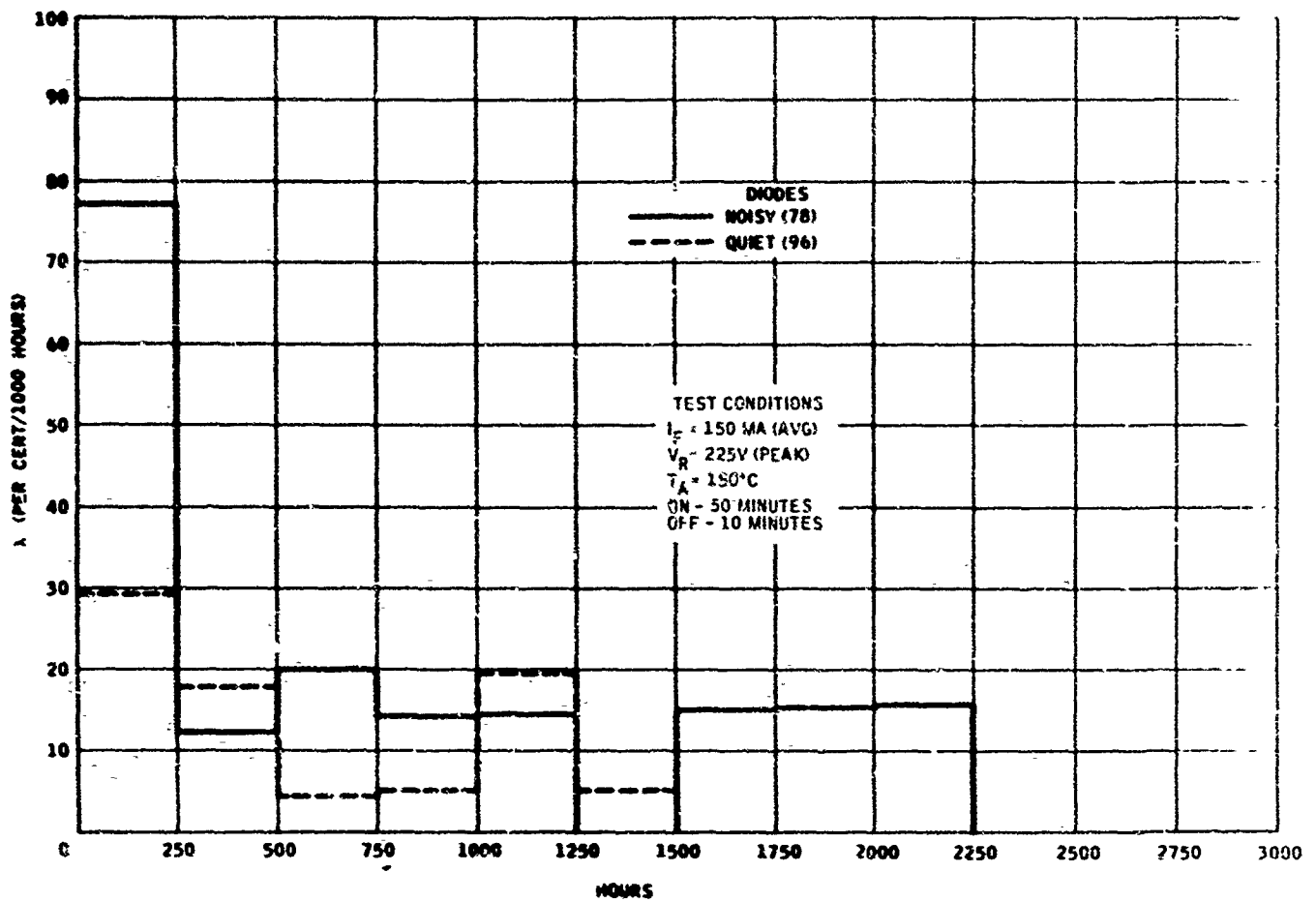


Figure 25. Diode Failure Rate λ /1000 hrs
from Data on Table 6

Table 7. Capacitor Failure Rate %/1000 Hrs.

64 Noisy						67 Quiet					
Time Hrs.	Total No. Failed	Δt Hrs.	ΔF	S	λ	Time Hrs.	Total No. Failed	Δt Hrs.	ΔF	S	λ
250	6	250	6	64	37.5	250	1	250	1	67	6.0
500	8	250	2	58	13.8	500	3	250	2	66	12.1
750	9	250	1	56	7.1	750	3	250	0	64	0
1000	10	250	1	55	7.3	1000	4	250	0	64	6.3
1250	11	250	1	54	7.4	1250	4	250	0	63	0
1500	11	250	0	53	0	1500	4	250	0	63	0
1750	11	250	0	53	0	1750	4	250	0	63	0
2000	12	250	1	53	7.6	2000	4	250	0	63	0
				52						63	

The incremental number of failures ΔF , which occur in an interval of time Δt , given that there were S devices operating at the beginning of the interval may be expressed.

F (failures) = S (devices) $\cdot \lambda$ (failures/device hour) $\cdot \Delta t$ (hours) where λ is a constant if the failures are random in time.

Then $\lambda = \frac{1}{S} \frac{\Delta F}{\Delta t}$

Where S = Number of devices operating at the start of the interval Δt

ΔF = Number of devices that failed during the interval Δt

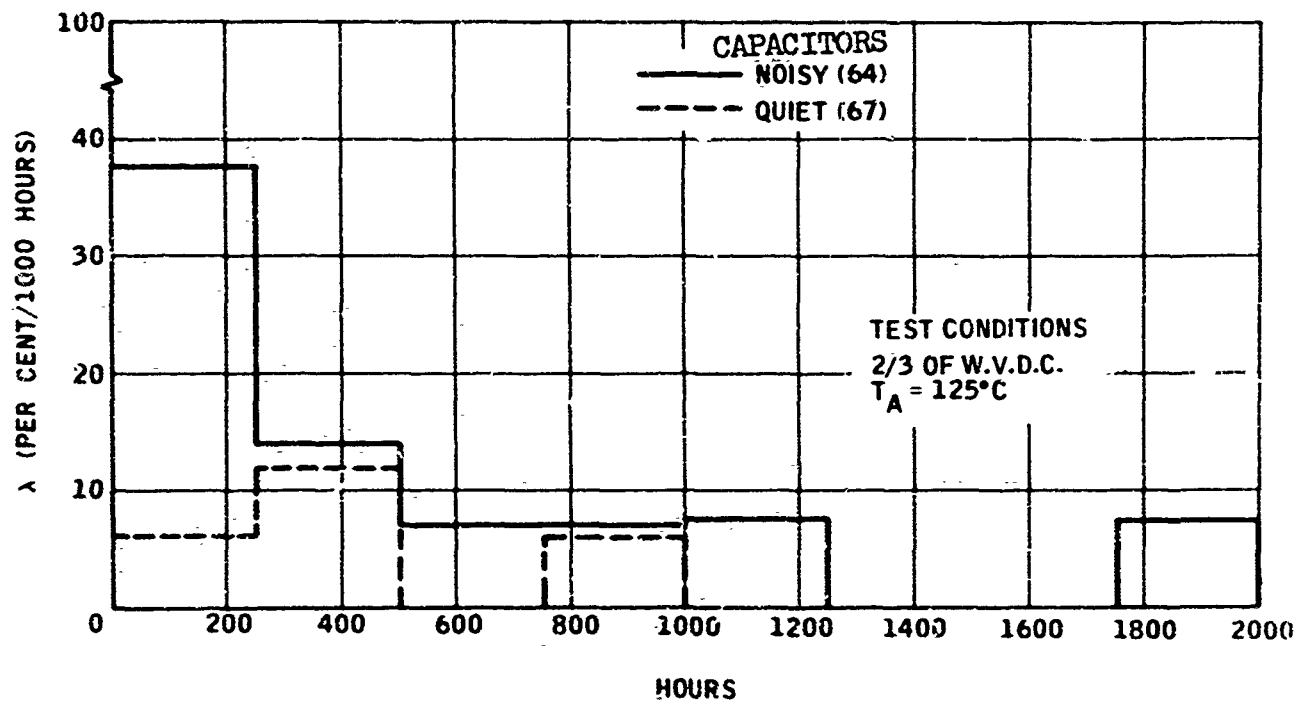


Figure 26. Capacitor Failure Rate %/1000 hrs
from Data on Table 7

4.2 Cost of Performing Screening

The cost of screening components is computed by dividing the total labor costs by the total number of components screened minus the number of components rejected by the test. This gives the cost based on a per surviving part basis.

The cost of the test equipment is not included because it is or would be shared by all component types. Therefore it would be unfair to include the cost against any one test run. The learning process is excluded from the figures used. This is done because anyone using this RF screening process would be screening large enough quantity that the initial learning process would be an insignificant part of the over-all program. The labor grade that performs the tests would really dictate the per unit cost. Therefore, an average figure for the hourly wage of the type of labor grade expected to perform the test is used.

Table 8. Cost of Screening - Per Surviving Part

<u>Diodes</u>	
Total quantity screened	20,200
Rejected units	147
Screening capacity	200 units/8 hour day
Labor cost	\$3.51/hour
Cost of Screening	$\frac{8 \text{ hours}}{200 \text{ units}} \times \frac{\$3.51}{\text{hour}} = \frac{\$.1404}{\text{diode}}$
Cost per Surviving Part	$\frac{20,200}{20,200 - 147} \times \frac{\$.1404}{\text{diode}} = \frac{\$.1410}{\text{surviving diode}}$
<u>Capacitors</u>	
Total quantity screened	9,808
Rejected units	64
Screening capacity	250 units/8 hour day
Labor cost	\$3.51/hour
Cost of Screening	$\frac{8 \text{ hours}}{250 \text{ units}} \times \frac{\$3.51}{\text{hour}} = \frac{\$.1123}{\text{capacitor}}$
Cost per Surviving Part	$\frac{9,808}{9,808 - 64} \times \frac{\$.1123}{\text{capacitor}} = \frac{\$.1130}{\text{surviving capacitor}}$

4.4.3 Figure of Merit

4.4.3.1 Diodes -- F_e = screening efficiency. Following are the calculations based on the life test data obtained after 1500 hours:

$$N_1 = 78$$

Number of parts exhibiting high RF noise and subsequently submitted to environmental life test.

$$N_2 = 24$$

Potential failures eliminated, i. e., the number of parts of N_1 that failed life test.

$$N_3 = 54$$

Good parts rejected by screening test ($N_1 - N_2$).

Therefore:

$$\begin{aligned} F_e &= \text{screening efficiency} \\ &= \frac{\text{potential failures eliminated}}{\text{potential failures eliminated} + \text{rejected good parts}} \\ &= \frac{N_2}{N_2 + N_3} = \frac{24}{24 + 54} = \frac{24}{78} = 0.31 \end{aligned}$$

Here, a scale of 1.00 would indicate a perfect test where all of the noisy parts failed life test.

4.4.3.2 Capacitors - F_e = screening efficiency. Following are the calculations based on the life test data obtained after 2000 hours.

$$N_1 = 64$$

Number of parts exhibiting high RF noise and subsequently submitted to environmental life test.

$$N_2 = 12$$

Potential failures eliminated, i. e., the number of parts of N_1 that failed life test.

$$N_3 = 52$$

Good parts rejected by screening test
($N_1 - N_2$)

Therefore:

F_e = screening efficiency

$$= \frac{\text{potential failures eliminated}}{\text{potential failures eliminated} + \text{rejected good parts}}$$

$$= \frac{N_2}{N_2 + N_3} = \frac{12}{12 + 52} = \frac{12}{64} = 0.19$$

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EXHIBITS I THROUGH X
DIODE AND CAPACITOR LIFE TEST DATA

**EXHIBIT I
NOISY DIODES**

The following critical parameter was measured during the life test, at approximately 250-hour intervals, at room temperature (25°C):

1. Leakage current (I_R) in nano-amps. (NA) at a reverse voltage (V_R) of 225 volts.

The vendor specifications for this diode (IN645) allow a maximum leakage current of 200 nano-amps, at the maximum allowable reverse voltage of 225 volts at room temperature (25°C).

All measurements of leakage current are in nano-amps unless otherwise noted.

When a unit exceeds the maximum allowable leakage current it is noted and considered to have failed life test.

NOISY DIODES

 I_R in (NA) at $V_R = 225$ V at 25°C I_R (max) = 200 NA at 25°C

Exhibit I

Time Diode No.	Initial Reading	165 hrs.	323 hrs.	509 hrs.	740 hrs.	981 hrs.	1241 hrs.	1489 hrs.	1771 hrs.	2101 hrs.	2313 hrs.	2572 hrs.	2829 hrs.
1	5.0	7.0	7.4	11.0	8.2	7.9	11.0	27.0	29.0	21.5	25.5	14.0	49.0
2	15.0	1.0	0.8	1.9	0.8	0.6	2.0	2.5	4.2	5.0	3.4	6.5	3.5
3	9.0	11.0	12.5	Shorted	-	-	-	-	-	-	-	-	-
4	20.0	8.0	6.8	8.0	6.0	5.4	7.7	22.1	26.0	30.0	36.0	16.2	120
5	60.0	23.0	23.0	28.0	26.0	20.1	*	-	-	-	-	-	-
6	10.0	7.0	8.8	11.0	11.0	9.7	12.0	14.1	16.0	14.8	19.0	20.8	20.5
7	14.0	2.0	1.8	3.2	2.0	1.4	1.9	2.0	3.0	2.0	2.5	4.0	10.0
8	9.0	4.0	4.2	6.3	4.9	4.2	5.2	6.1	6.2	8.6	9.8	7.7	17.5
9	1.8	2.5	4.4	150.0	150.0	$\Delta 1.0$ μa	$\Delta 2.4$ μa	$\Delta 2.5$ μa	$\Delta 3.9$ μa	$\Delta 4.0$ μa	$\Delta 4.4$ μa	$\Delta 3.7$ μa	$\Delta 3.0$ μa
10	19.0	20.0	20.0	26.0	24.0	20.0	22.0	28.0	22.5	21.0	23.8	21.9	24.1
11	17.0	16.0	16.0	21.0	14.9	13.0	*	-	-	-	-	-	-
12	13.0	12.0	14.0	17.0	14.0	11.9	*	-	-	-	-	-	-

* Iradventently destroyed when subjected to a temperature overrun (not included in failure data).

 Δ Units out of specification.

- Units removed from life test.

Exhibit I (Cont.)

Time Diode No.	Initial Reading	165 hrs. μ a	323 hrs. μ a	509 hrs.	740 hrs.	981 hrs.	1241 hrs.	1489 hrs.	1771 hrs.	2101 hrs.	2313 hrs.	2572 hrs.	2829 hrs.
13	36.0	Δ 120 μ a	Δ 3.6 μ a	Δ 380.0	Δ 450.0	Δ 590.0	Shorted	-	-	-	-	-	-
14	13.0	Δ 15 μ a	Δ 360.0	Δ 640.0	Δ 740.0	Δ 740.0	Δ 0.11 ma	Δ 0.01 ma	Δ 0.014 ma	Δ 0.011 ma	Δ 0.012 ma	Δ 0.013 ma	Δ 0.014 ma
15	14.0	Δ 10 μ a	Δ 400.0	Δ 420.0	Δ 300.0	Δ 350.0	Δ 150.0	Δ 500.0	Δ 230.0	Δ 300.0	Δ 210.0	Δ 250.0	Δ 250.0
16	34.0	Δ 3 μ a	Δ 40 μ a	Δ 105 μ a	Δ 130 μ a	Δ 17 μ a	Shorted	-	-	-	-	-	-
17	7.0	Δ 8.0	Δ 8.0	10.5	7.5	6.5	8.9	9.8	8.8	9.0	11.0	11.4	14.0
18	9.0	10.0	11.0	13.0	12.0	7.2	10.5	11.8	11.0	11.5	13.5	13.0	13.0
19	10.0	11.0	15.0	17.0	15.0	15.0	*	-	-	-	-	-	-
20	23.0	27.0	30.0	34.0	30.0	23.0	*	-	-	-	-	-	-
21	14.0	6.0	8.0	13.0	16.0	57.0	Δ 30 μ a	Δ 88 μ a	Shorted	-	-	-	-
22	7.0	Δ 300	Δ 1.7 μ a	Δ 1.7 μ a	Δ 2.1 μ a	Δ 1.2 μ a	Shorted	-	-	-	-	-	-
23	17.0	23.0	32.0	31.0	26.0	21.0	*	-	-	-	-	-	-

*Inadvertently destroyed when subjected to a temperature overrun (not included in failure data).

 Δ Units out of specification.

-Units removed from life test.

Exhibit I (Cont.)

Time Diode No.	Initial Reading	165 hrs.	323 hrs.	509 hrs.	740 hrs.	981 hrs.	1241 hrs.	1489 hrs.	1771 hrs.	2101 hrs.	2313 hrs.	2572 hrs.	2829 hrs.
24	18.0	180	40.0	26.0	35.0	20.5	*	-	-	-	-	-	-
25	10.0	18.0	12.0	14.0	14.0	12.0	14.5	17.6	27.8	48.0	38.0	27.4	59
26	8.0	18.0	14.5	17.0	16.0	14.1	*	-	-	-	-	-	-
27	27.0	100.0	33.0	Shorted	-	-	-	-	-	-	-	-	-
28	3.0	7.0	8.4	11.0	10.0	10.0	18.8	52.0	62.0	58.0	52.0	19.0	74.0
29	2.0	3.0	3.2	5.0	3.5	3.3	3.8	4.4	5.9	4.4	6.2	6.2	5.1
30	2.0	7.0	6.0	7.0	5.5	4.3	6.0	7.0	7.5	7.7	9.0	9.4	16.1
31	9.0	15.0	15.2	18.0	16.0		11.0	14.4	12.8	11.2	13.1	14.8	12.2
32	9.5	16.0	15.3	16.0	15.5	11.1	13.0	16.8	39.0	95.0	95.0	87.0	Δ 235.0
33	1.1	2.0	2.85	5.0	4.0	3.9	*	-	-	-	-	-	-
34	18.5	18.0	19.5	25.0	20.0	17.7	*	-	-	-	-	-	-
35	9.1	9.0	9.8	12.0	10.0	8.2	11.6	13.0	16.2	18.3	Δ 219.0	Δ 1.8 μ a	Δ 8.0 μ a

*Inadvertently destroyed when subjected to a temperature overrun (not included in failure data).

 Δ Units out of specification.

-Units removed from life test.

Exhibit I (Cont.)

Time Diode No.	Initial Read- ing	165 hrs.	323 hrs.	509 hrs.	740 hrs.	981 hrs.	1241 hrs.	1489 hrs.	1771 hrs.	2101 hrs.	2313 hrs.	2572 hrs.	2829 hrs.
36	7.0	4.0	5.0	6.0	4.5	4.4	4.8	5.5	5.2	5.9	220.0	1.2 μ a	2.0 μ a
37	7.0	Δ 22 μ a	Δ 44 μ a	Δ 180 μ a	Δ 300 μ a	Δ 250 μ a	Shorted	-	-	-	-	-	-
38	8.5	7.0	7.0	9.0	6.4	5.4	5.9	7.0	7.0	6.3	7.7	7.7	19.0
39	6.0	25.0	6.3	8.0	5.6	4.7	5.8	6.6	7.1	6.1	6.9	6.4	7.2
40	11.0	12.0	45.0	16.0	12.0	11.0	20.0	75.5	23.0	26.1	25.5	26.5	34.0
41	2.4	3.0	5.0	20.0	Δ 500.0	Δ 210.0	4.2	5.1	6.0	5.0	5.7	6.6	9.0
42	120.0	15.0	15.0	13.0	12.0	10.5	14.0	16.1	15.9	39.0	36.0	25.0	49.9
43	3.0	7.0	8.0	7.5	9.0	9.6	12.0	14.0	14.8	13.0	14.0	14.9	14.9
44	3.0	4.0	4.0	6.0	5.0	4.7	9.3	25.0	12.8	21.0	19.6	9.0	50.0
45	15.0	5.0	5.0	7.0	5.7	3.5	4.0	4.3	5.5	4.2	5.5	6.2	9.0
46	1.3	1.2	2.0	27.0	Δ 2.2 μ a	Δ 3.8 μ a	Δ 1.5 μ a	Δ 6.8 μ a	Δ 6.9 μ a	Δ 1.6 μ a	Δ 1.0 μ a	Δ 36 μ a	Δ 58 μ a

 Δ Units out of specification.

- Units removed from life test.

Exhibit I (Cont.)

Time Diode No.	Initial Reading	165 hrs.	323 hrs.	509 hrs.	740 hrs.	981 hrs.	1241 hrs.	1489 hrs.	1771 hrs.	2101 hrs.	2313 hrs.	2572 hrs.	2829 hrs.
47	9.0	10.0	10.0	13.0	$\Delta 1.5$ μa	$\Delta 6.0$ μa	$\Delta 23\mu a$	$\Delta 23\mu a$	$\Delta 34\mu a$	$\Delta 62\mu a$	$\Delta 120\mu a$	Shorted	-
48	3.5	$\Delta 16$ μa	$\Delta 1.5$ μa	120.0	72.0	$\Delta 12.0$ μa	$\Delta 400.0$	$\Delta 500.0$	$\Delta 450.0$	$\Delta 760.0$	$\Delta 640.0$	$\Delta 700.0$	$\Delta 1.2$ μa
49	2.7	3.0	3.0	4.1	3.3	3.1	3.8	5.2	4.7	4.7	4.6	4.6	4.9
50	1.8	1.4	1.0	1.7	1.2	1.1	1.6	2.4	2.1	5.2	4.4	5.6	32.0
51	2.5	26.0	3.0	3.4	2.7	3.0	3.2	5.1	4.2	3.7	4.1	3.6	3.9
52	4.0	Shorted	-	-	-	-	-	-	-	-	-	-	-
53	1.0	1.5	2.0	2.1	1.5	$\Delta 2.5$ μa	$\Delta 750.0$	$\Delta 2.7$ μa	$\Delta 3.8$ μa	$\Delta 1.9$ μa	$\Delta 7.7$ μa	Shorted	-
54	3.0	$\Delta 320$ μa	$\Delta 800$ μa	$\Delta 750$ μa	$\Delta 1.1$ ma	$\Delta 3.0$ ma	$\Delta 1.1$ ma	$\Delta 1.1$ ma	$\Delta 0.80$ ma	$\Delta 1.1$ ma	$\Delta 1.1$ ma	$\Delta 1.0$ ma	$\Delta 0.54$ ma
55	9.0	4.0	4.0	5.4	5.0	4.8	5.1	6.8	5.9	6.9	8.2	6.8	9.5
56	3.0	5.0	5.0	6.4	5.2	4.2	4.9	5.5	14.5	43.9	48.0	14.0	50.0
57	4	5	5	6.0	5.5	5.2	5.6	6.4	6.0	5.7	6.0	6.7	6.6

 Δ Units out of specification.

-Units removed from life test.

Exhibit I (Cont.)

Time Diode No.	Initial Reading	165 hrs.	323 hrs.	509 hrs.	740 hrs.	981 hrs.	1241 hrs.	1489 hrs.	1771 hrs.	2191 hrs.	2313 hrs.	2572 hrs.	2829 hrs.
58	3.0	3.0	4.0	4.8	3.7	7.6	2.8	3.0	3.1	3.0	3.2	3.6	4.4
59	9.0	36.0	110	72.0	100.0	60.0	62.0	43.0	85.0	110.0	46.0	14.1	15.0
60	4.0	Shor- ted	-	-	-	-	-	-	-	-	-	-	-
61	5.0	5.0	5.0	6.3	6.0	7.4	*-	-	-	-	-	-	-
62	2.0	3.0	2.0	2.9	2.6	2.7	3.1	3.4	3.6	3.6	3.9	4.2	5.9
63	18.0	20.0	32.0	36.0	32.0	33.0	*-	-	-	-	-	-	-
64	4.0	20.0	22.0	16.5	6.6	6.2	4.9	85.0	170.0	210.0	280.0	220.0	310.0
65	3.0	6.0	6.0	Open	-	-	-	-	-	-	-	-	-
66	1.0	2.0	2.0	2.9	2.1	2.3	2.4	2.5	2.8	3.7	3.4	3.7	3.6
67	3.0	4.0	4.0	4.1	3.0	3.5	60.0	50.0	5.5	7.3	7.7	7.3	12.0
68	3.0	Shor- ted	-	-	-	-	-	-	-	-	-	-	-
69	3.0	4.0	5.0	5.5	5.2	5.5	5.2	6.1	5.9	6.9	7.4	7.9	10.0

*Inadvertently destroyed when subjected to a temperature overrun (not included in failure data).

Δ Units out of specification.

- Units removed from life test.

Exhibit I (Cont.)

Time Diode No.	Initial Reading	165 hrs.	323 hrs.	509 hrs.	740 hrs.	981 hrs.	1241 hrs.	1489 hrs.	1771 hrs.	2101 hrs.	2313 hrs.	2572 hrs.	2829 hrs.
70	5	Shor- ted	-	-	-	-	-	-	-	-	-	-	-
71	3	3	4	4.4	3.7	4.0	3.9	4.7	4.6	4.8	4.8	4.8	44
72	4	5	7	9.1	9.6	11.5	*	-	-	-	-	-	-
73	4	Δ 100 μ a	Δ 170 μ a	Δ 230 μ a	Δ 600 μ a	Δ 850 μ a	Δ 1.5 ma	Δ 1.6 ma	Δ 1.5 ma	Δ 1.7 ma	Δ 1.5 ma	Δ 1.2 ma	Δ 2.7 ma
74	3	6	6.6	9.0	8.5	8.7	12.2	12.0	14.2	13.0	15.0	12.5	19.0
75	3	3	3.2	4.5	5.4	7.0	9.5	10.2	11.0	12.1	11.4	11.0	13.5
76	6	9	13.3	59.0	13.2	18.4	15.1	24.0	45.0	30.0	43.0	35.0	84.0
77	160.0	110.0	33	20	13.5	13.2	*	-	-	-	-	-	-
78	4	4.5	4.6	5.1	4.4	4.7	*	-	-	-	-	-	-

*Inadvertently destroyed when subjected to a temperature overrun (not included in failure data).

 Δ Units out of specification.

-Units removed from life test.

II-1

EXHIBIT II NOISY DIODES

The following critical parameter was measured during the life test, at approximately 250-hour intervals, at room temperature (25°C):

1. Forward voltage drop (V_F) in volts at an average forward current (I_F) of 400 milli-amps.

The vendor specifications for this diode (IN645) allow a maximum forward voltage drop of 1.0 volts at the maximum allowable average forward current of 400 milli-amps at room temperature (25°C).

All measurements of forward voltage drop are in volts.

When a unit exceeds the maximum allowable forward voltage drop it is noted and considered to have failed life test.

NOISY DIODES

V_F (Volts) at $I_F = 400$ ma at 25°C

V_F (MAX) = 1.0 Volts at 25°C

Exhibit II

Time Diode No.	Initial Read- ing	165 hrs.	323 hrs.	509 hrs.	740 hrs.	981 hrs.	1241 hrs.	1489 hrs.	1771 hrs.	2101 hrs.	2313 hrs.	2572 hrs.	2829 hrs.
1	0.75	0.73	0.75	0.76	0.76	0.75	0.82	0.75	0.75	0.75	0.75	0.81	0.83
2	0.75	0.76	0.80	0.78	0.76	0.75	0.85	0.79	0.84	0.80	0.78	0.86	0.91
3	0.90	0.91	0.91	Shorted	-	-	-	-	-	-	-	-	-
4	0.78	0.76	0.77	0.98	0.77	0.77	0.92	0.84	0.80	0.78	0.79	0.82	0.81
5	0.75	0.74	0.75	0.76	0.78	0.77	*	-	-	-	-	-	-
6	0.78	0.76	0.77	0.79	0.78	0.77	0.85	0.84	0.79	0.80	0.90	0.82	0.83
7	0.77	0.76	0.78	0.78	0.79	0.77	0.85	0.79	0.79	0.79	0.78	0.80	0.84
8	0.77	0.76	0.77	0.78	0.76	0.78	0.84	0.79	0.79	0.79	0.80	0.84	0.83
9	0.76	0.74	0.74	0.76	0.73	0.75	0.81	0.78	0.77	0.77	0.79	0.77	0.90
10	0.78	0.73	0.74	0.76	0.73	0.74	0.83	0.76	0.77	0.78	0.81	0.83	0.78
11	0.81	0.79	0.79	0.80	0.79	0.79	*	-	-	-	-	-	-
12	0.77	0.75	0.76	0.78	0.83	0.87	*	-	-	-	-	-	-
13	0.77	0.75	0.80	0.78	0.77	0.77	Shorted	-	-	-	-	-	-
14	0.78	0.75	0.77	0.76	0.76	0.84	0.80	0.80	0.80	0.80	0.80	0.81	-
15	0.82	0.78	0.78	0.80	0.79	0.79	0.85	0.84	0.85	0.79	0.84	0.83	-
16	0.80	0.75	0.76	0.77	0.80	0.76	Shorted	-	-	-	-	-	-
17	0.81	0.76	0.76	0.78	0.76	0.77	0.84	0.82	0.79	0.79	0.83	0.80	0.80
18	0.80	0.77	0.78	0.80	0.78	0.82	0.86	0.82	0.80	0.84	0.80	0.84	0.86

*Inadvertently destroyed when subjected to a temperature overrun (not included in failure data).

- Units removed from life test.

Exhibit II (Cont.)

Time Diode No.	Initial Reading	165 hrs.	323 hrs.	509 hrs.	740 hrs.	981 hrs.	1241 hrs.	1489 hrs.	1771 hrs.	2101 hrs.	2313 hrs.	2572 hrs.	2829 hrs.
19	0.84	0.79	0.80	0.81	0.80	0.82	*	-	-	-	-	-	-
20	0.80	0.76	0.77	0.78	0.75	0.77	*	-	-	-	-	-	-
21	1.00	1.00	0.80	0.79	0.76	0.78	0.84	0.83	Shorted	-	-	-	-
22	0.81	0.79	0.80	0.81	0.77	0.80	Shorted	-	-	-	-	-	-
23	0.82	0.77	0.79	0.80	0.77	0.78	*	-	-	-	-	-	-
24	0.81	0.79	0.79	0.82	0.77	0.80	*	-	-	-	-	-	-
25	0.86	0.84	0.86	0.86	0.84	0.85	0.95	0.90	0.91	0.87	0.85	0.87	0.91
26	0.79	0.76	0.78	0.79	0.76	0.79	*	-	-	-	-	-	-
27	0.89	0.91	Δ 1.15	Shorted	-	-	-	-	-	-	-	-	-
28	0.92	0.90	0.92	0.92	0.89	0.95	Δ 1.07	Δ 1.02	Δ 1.04	Δ 1.03	Δ 1.02	Δ 1.01	Δ 1.10
29	0.78	0.77	0.76	0.78	0.75	0.77	0.83	0.90	0.80	0.81	0.83	0.82	0.83
30	0.76	0.73	0.75	0.76	0.76	0.74	0.82	0.84	0.76	0.74	0.78	0.80	0.85
31	0.77	0.75	0.75	0.77	0.74	0.76	0.82	0.84	0.78	0.76	0.77	0.77	0.83
32	0.85	0.78	0.78	0.80	0.78	0.85	Δ 1.02	Δ 1.07	Δ 1.08	Δ 1.35	Δ 1.40	Δ 1.42	Δ 1.50
33	0.88	0.82	0.83	0.85	0.78	0.83	*	-	-	-	-	-	-
34	0.82	0.77	0.78	0.81	0.87	0.78	*	-	-	-	-	-	-
35	0.82	0.78	0.79	0.82	0.80	0.85	1.00	0.98	Δ 1.05	Δ 1.04	Δ 1.07	Δ 1.01	Δ 1.10
36	0.78	0.76	0.76	0.79	0.75	0.76	0.87	0.80	0.78	0.80	0.82	0.80	0.81

*Inadvertently destroyed when subjected to a temperature overrun (not included in failure data).

Δ Units out of specification.

- Units removed from life test.

Exhibit II (Cont.)

Time Diode No.	Initial Read- ing	165 hrs.	323 hrs.	509 hrs.	740 hrs.	981 hrs.	1241 hrs.	1489 hrs.	1771 hrs.	2101 hrs.	2313 hrs.	2572 hrs.	2829 hrs.
37	0.78	0.76	0.76	0.78	0.75	0.76	Shorted	-	-	-	-	-	-
38	0.81	0.77	0.78	0.79	0.76	0.78	0.83	0.83	0.80	0.78	0.81	0.80	0.84
39	0.80	0.76	0.78	0.80	0.76	0.76	0.83	0.82	0.81	0.80	0.81	0.78	0.81
40	0.95	0.78	0.80	0.83	0.79	0.80	0.85	0.86	0.81	0.82	0.84	0.82	0.90
41	0.75	0.75	0.75	0.75	0.74	0.75	0.80	0.79	0.77	0.78	0.75	0.81	0.74
42	0.79	0.75	0.78	0.79	0.88	0.78	0.84	0.83	0.80	0.92	0.80	0.86	0.77
43	0.78	0.76	0.77	0.78	0.75	0.77	0.83	0.80	0.78	0.83	0.78	0.82	0.78
44	0.76	0.73	0.74	0.75	0.75	0.74	0.81	0.77	0.77	0.80	0.75	0.80	0.75
45	0.78	0.76	0.76	0.77	0.80	0.78	0.82	0.80	0.80	0.79	0.81	0.88	0.77
46	0.78	0.76	0.76	0.77	0.75	0.76	0.82	0.80	0.80	0.80	0.79	0.87	0.74
47	0.77	0.77	0.76	0.77	0.76	0.76	0.87	0.77	0.78	0.78	0.85	Shorted	-
48	0.77	0.75	0.76	0.77	0.75	0.76	0.84	0.80	0.79	0.78	0.82	0.77	0.77
49	0.78	0.75	0.76	0.79	0.77	0.76	0.90	0.77	0.83	0.86	0.81	0.79	0.76
50	0.77	0.76	0.76	0.77	0.75	0.76	0.83	0.80	0.82	0.77	0.85	0.80	0.76
51	0.80	0.79	0.79	0.80	0.77	0.78	0.86	0.84	0.91	0.86	0.90	0.84	0.88
52	0.76	Shorted	-	-	-	-	-	-	-	-	-	-	-
53	0.81	0.79	0.79	0.80	0.77	0.79	0.85	0.82	0.88	0.83	0.83	Shorted	-

-Units removed from life test.

Exhibit II (Cont.)

Time Diode No.	Initial Read- ing	165 hrs.	323 hrs.	509 hrs.	740 hrs.	981 hrs.	1241 hrs.	1489 hrs.	1771 hrs.	2101 hrs.	2313 hrs.	2572 hrs.	2820 hrs.
54	0.77	0.75	0.76	0.76	0.74	0.75	0.82	0.78	0.88	0.77	0.77	0.80	0.76
55	0.76	0.74	0.75	0.76	0.73	0.76	0.82	0.82	0.80	0.85	0.85	0.85	0.82
56	0.79	0.78	0.78	0.79	0.76	0.79	0.85	0.83	0.85	0.81	0.82	0.80	0.83
57	0.78	0.78	0.78	0.79	0.76	0.78	0.85	0.84	0.82	0.81	0.80	0.81	0.77
58	0.76	0.75	0.76	0.77	0.73	0.75	0.82	0.78	0.78	0.78	0.82	0.81	0.77
59	0.80	0.78	0.78	0.79	0.76	0.78	0.85	0.82	0.88	0.79	0.92	0.83	0.82
60	0.76	Shor- ted	-	-	-	-	-	-	-	-	-	-	-
61	0.78	0.76	0.98	0.78	0.74	0.75	*-	-	-	-	-	-	-
62	0.80	0.79	0.78	0.79	0.77	0.78	0.85	0.83	0.81	0.81	0.81	0.84	0.81
63	0.81	0.80	0.80	0.82	0.78	0.81	*-	-	-	-	-	-	-
64	0.78	0.77	0.76	0.78	0.74	0.76	0.86	0.81	0.83	0.80	0.81	0.86	0.82
65	0.80	0.78	0.94	Open	-	-	-	-	-	-	-	-	-
66	0.79	0.78	0.77	0.79	0.75	0.79	0.84	0.80	0.81	0.81	0.80	0.83	0.84
67	0.81	0.78	0.79	0.81	0.78	0.80	0.87	0.83	0.85	0.83	0.88	0.84	0.81
68	0.81	Shor- ted	-	-	-	-	-	-	-	-	-	-	-
69	0.81	0.80	0.80	0.82	0.80	0.81	0.87	0.86	0.87	0.87	0.88	0.86	0.80

*Inadvertently destroyed when subjected to a temperature overrun (not included in failure data).

-Units removed from life test.

Exhibit II (Cont.)

Time Diode No.	Initial Read- ing	165 hrs.	323 hrs.	509 hrs.	740 hrs.	981 hrs.	1241 hrs.	1489 hrs.	1771 hrs.	2101 hrs.	2313 hrs.	2572 hrs.	2829 hrs.
70	0.78	Shor- ted	-	-	-	-	-	-	-	-	-	-	-
71	0.76	0.75	0.75	0.76	0.74	0.75	*-	-	-	-	-	-	-
72	0.77	0.75	0.78	0.75	0.77	*-	-	-	-	-	-	-	-
73	0.78	0.77	0.77	0.78	0.76	0.77	0.84	0.81	0.83	0.81	0.81	0.82	0.78
74	0.76	0.75	0.75	0.77	0.74	0.75	0.82	0.80	0.77	0.76	0.82	0.88	0.73
75	0.76	0.75	0.75	0.77	0.74	0.76	0.82	0.79	0.78	0.77	0.80	0.80	0.80
76	0.76	0.75	0.75	0.76	0.75	0.76	0.82	0.78	0.77	0.79	0.90	0.78	0.76
77	0.77	0.77	0.78	0.79	0.76	0.77	*-	-	-	-	-	-	-
78	0.82	0.80	0.80	0.82	0.80	0.76	*-	-	-	-	-	-	-

*Inadvertently destroyed when subjected to a temperature overrun (not included in failure data).

-Units removed from life test.

III-1

EXHIBIT III QUIET DIODES

The following critical parameter was measured during the life test, at approximately 250-hour intervals, at room temperature (25°C):

1. Leakage current (I_R) in nano-amps (NA) at a reverse voltage (V_R) of 225 volts.

The vendor specifications for this diode (IN645) allow a maximum leakage current of 200 nano-amps at the maximum allowable reverse voltage of 225 volts at room temperature (25°C).

All measurements of leakage current are in nano-amps unless otherwise noted.

When a unit exceeds the maximum allowable leakage current it is noted and considered to have failed life test.

QUIET DIODES

 I_R (NA) at $V_R = 225$ V at 25°C I_R (MAX) = 200 NA at 25°C

Exhibit III

Time Diode No.	Initial Reading	111 hrs.	275 hrs.	620 hrs.	851 hrs.	1082 hrs.	1342 hrs.	1590 hrs.	1872 hrs.	2202 hrs.	2414 hrs.	2673 hrs.	2930 hrs.
1	14.0	30.0	22.0	29.0	22.1	20.0	*	-	-	-	-	-	-
2	13.0	**	-	-	-	-	-	-	-	-	-	-	-
3	6.0	**	-	-	-	-	-	-	-	-	-	-	-
4	19.0	21.0	20.0	26.0	20.0	21.0	*	-	-	-	-	-	-
5	12.0	15.0	13.0	17.0	14.4	18.0	15.0	15.0	15.5	15.5	23.0	23.1	25.0
6	8.0	14.0	13.0	19.0	14.2	16.2	*	-	-	-	-	-	-
7	3.0	5.0	5.0	8.0	5.1	4.9	4.9	6.0	6.4	5.9	6.3	6.3	4.8
8	7.0	7.0	10.0	shorted	-	-	-	-	-	-	-	-	-
9	16.0	20.0	20.0	24.0	18.0	22.2	*	-	-	-	-	-	-
10	29.0	25.0	23.0	32.0	23.8	25.9	23.4	27.6	26.2	25.5	36.0	40.0	31.0
11	10.0	15.0	16.0	21.0	16.1	16.9	15.8	17.0	16.5	28.7	23.5	24.8	22.0
12	27.0	8.5 μa	1.2 μa	270.0 Δ	14.0 μa	15.0 Δ μa	shorted	-	-	-	-	-	-
13	3.0	8.0	7.0	12.0	9.4	14.0	28.8	36.0	33.0	33.0	40.0	24.1	39.0

*Inadvertently destroyed when subjected to a temperature overrun (not included in failure data).

**Destroyed by a short in the testing fixture (not included in failure data).

 Δ Units out of specification.

-Units removed from life test.

Exhibit III (Contd)

Time Diode No.	Initial Reading	111 hrs.	275 hrs.	620 hrs.	851 hrs.	1082 hrs.	1342 hrs.	1590 hrs.	1872 hrs.	2202 hrs.	2414 hrs.	2673 hrs.	2930 hrs.
14	2.0	3.5	3.0	5.0	4.4	5.1	4.6	4.8	5.0	6.5	18.5	8.6	15
15	4.0	9.0	10.0	12.0	9.5	11.0	9.5	9.8	10.5	10.2	17.0	19.7	54
16	17.0	16.0	155.0	Δ_{29} μa	Δ_{120} μa	Δ_{77} μa	Δ_{39} μa	Δ_{28} μa	Δ_{34} μa	Δ_{34} μa	Δ_{22} μa	Δ_{24} μa	Δ_{30} μa
17	7.0	8.0	7.0	9.0	7.4	9.0	8.0	8.8	8.1	13.0	11.5	11.4	9.2
18	13.0	23.0	24.0	$\Delta_{1.05}$ μa	$\Delta_{7.5}$ μa	$\Delta_{5.2}$ μa	shorted	-	-	-	-	-	-
19	8.0	44.0	11.0	20.0	13.4	16.5	13.9	15.0	26.0	15.0	32.2	16.4	14.0
20	2.0	2.1	3.5	6.0	5.1	6.4	*	-	-	-	-	-	-
21	8.0	10.0	10.0	12.0	10.0	11.2	*	-	-	-	-	-	-
22	6.0	22.0	13.0	13.0	10.5	12.1	9.2	12.0	12.9	12.7	46.5	22.1	37.0
23	25.0	22.0	20.0	22.0	21.0	22.6	*	-	-	-	-	-	-
24	8.0	16.0	13.0	19.0	19.2	18.0	16.0	16.2	15.2	12.9	29.6	24.0	29
25	2.0	3.0	3.0	5.0	3.8	4.2	4.6	4.9	4.9	13.0	8.3	8.4	10.5

* Destroyed by a short in the testing fixture (not included in failure data).

 Δ Units out of specification.

- Units removed from life test.

Exhibit III (Contd)

Time Diode No.	Initial Read- ing	111 hrs.	275 hrs.	620 hrs.	851 hrs.	1082 hrs.	1342 hrs.	1590 hrs.	1872 hrs.	2202 hrs.	2414 hrs.	2673 hrs.	2930 hrs.
26	1.0	3.4	Δ 2.2 μ a	Δ 56 μ a	Δ 31 μ a	Δ 31 μ a	Δ 0.14 ma	Δ 0.110 ma	Δ 0.26 ma	Δ 0.22 ma	Δ 0.14 ma	Δ 0.12 ma	Δ 0.12 ma
27	2.0	3.8	5.0	8.0	5.6	7.9	*	-	-	-	-	-	-
28	12.0	12.0	15.0	19.0	20.5	20.0	18.8	20.4	19.8	20.4	28.8	32.0	30.0
29	12.0	11.0	11.0	15.0	13.0	14.2	14.0	15.0	16.7	14.4	19.8	21.0	16.0
30	16.0	20.0	19.0	22.0	18.7	20.0	20.0	20.2	17.5	19.0	25.0	25.0	21.0
31	3.0	3.2	3.0	5.0	4.8	5.1	4.8	5.2	5.0	5.3	7.2	6.8	5.9
32	2.0	2.9	3.0	5.0	4.7	11.0	Δ 49 μ a	Δ 72 μ a	Δ 11.5 μ a	Δ 13 μ a	Δ 15.4 μ a	Δ 52 μ a	Δ 50 μ a
33	11.0	15.0	14.0	19.0	16.5	18.0	16.0	17.0	16.1	16.1	22.8	22.1	17.1
34	13.0	25.0	15.0	18.0	15.5	16.0	17.6	21.5	36.0	44.0	49.0	28.0	42.0
35	5.0	Δ 55 μ a	Δ 27 μ a	Δ 8.8 μ a	Δ 18 μ a	Δ 17 μ a	Δ 33 μ a	Δ 21 μ a	Δ 19.5 μ a	Δ 15.5 μ a	Δ 13.5 μ a	Δ 10.3 μ a	Δ 10.0 μ a
36	8.0	10.0	10.0	13.0	12.5	13.2	15.0	14.2	14.6	20.8	25.5	17.6	16.2

* Destroyed by a short in the testing fixture (not included in failure data).

 Δ Units out of specification.

- Units removed from life test.

Exhibit III (Contd)

Time Diode No.	Initial Read- ing	111 hrs.	275 hrs.	620 hrs.	851 hrs.	1082 hrs.	1342 hrs.	1590 hrs.	1872 hrs.	2202 hrs.	2414 hrs.	2673 hrs.	2930 hrs.
37	22.0	38.0	36.0	58.0	43.0	35.0	53.0	55.0	79.0	75.0	56.5	33.0	52.0
38	8.0	14.0	13.0	16.0	14.0	15.8	$\Delta 3.0$ μa	shorted	-	-	-	-	-
39	2.0	2.0	1.6	2.0	2.2	2.2	2.2	2.5	3.9	2.9	3.3	3.5	4.0
40	7.0	9.5	9.0	10.0	9.0	8.8	8.2	9.1	8.5	10.5	17.8	11.4	16.2

 Δ Units out of specification.

- Units removed from life test.

Exhibit III (Contd)

Time Diode No.	Initial Read- ing	111 hrs.	275 hrs.	620 hrs.	851 hrs.	1082 hrs.	1342 hrs.	1590 hrs.	1872 hrs.	2202 hrs.	2414 hrs.	2673 hrs.	2930 hrs.
37	22.0	38.0	36.0	58.0	43.0	35.0	53.0	55.0	79.0	75.0	56.5	33.0	52.0
38	8.0	14.0	13.0	16.0	14.0	15.8	$\Delta 3.0$ μa	shorted	-	-	-	-	-
39	2.0	2.0	1.6	2.0	2.2	2.2	2.2	2.5	3.9	2.9	3.3	3.5	4.0
40	7.0	9.5	9.0	10.0	9.0	8.8	8.2	9.1	8.5	10.5	17.8	11.4	16.2

 Δ Units out of specification.

- Units removed from life test.

IIIa-1

EXHIBIT IIIa
ADDITIONAL QUIET DIODES

The following critical parameter was measured during the life test, at approximately 250-hour intervals, at room temperature (25°C):

1. Leakage current (I_R) in nano-amps (NA) at a reverse voltage (V_R) of 225 volts.

The vendor specifications for this diode (IN645) allow a maximum leakage current of 200 nano-amps at the maximum allowable reverse voltage of 225 volts at room temperature (25°C).

All measurements of leakage current are in nano-amps unless otherwise noted.

When a unit exceeds the maximum allowable leakage current it is noted and considered to have failed life test.

IIIa-2
Additional Quiet Diodes

I_R in (NA) at $V_R = 225V$ at $25^\circ C$

I_R (MAX) = 200NA at $25^\circ C$

Exhibit IIIa

Time Diode No.	Initial Read- ing	248 hrs.	530 hrs.	860 hrs.	1072 hrs.	1331 hrs.	1588 hrs.
1	7.6	9.1	8.0	40.0	22.0	76.0	60.0
2	4.0	7.1	6.7	6.0	6.6	5.6	8.4
3	17.2	32.0	28.0	25.5	27.6	25.0	26.0
4	5.4	7.8	6.1	5.5	5.8	5.3	5.5
5	12.5	13.8	11.8	11.0	11.8	10.8	14.0
6	16.8	24.0	20.2	19.0	20.4	18.2	21.0
7	3.8	3.6	3.3	3.1	3.2	3.1	5.0
8	17.4	19.7	18.2	17.4	19.0	16.8	17.1
9	10.0	11.0	8.4	9.0	8.6	7.8	7.9
10	13.5	11.0	9.4	10.0	9.6	8.5	10.1
11	7.4	17.0	15.8	15.0	16.0	14.5	14.7
12	22.0	18.0	18.0	17.0	18.0	16.8	16.8
13	20.5	21.0	21.0	20.1	21.3	19.8	20.0

IIIa-3

Exhibit IIIa (Cont.)

Time Diode No.	Initial Reading	248 hrs.	530 hrs.	860 hrs.	1072 hrs.	1331 hrs.	1588 hrs.
14	10.0	15.0	15.9	15.0	19.0	21.5	50.0
15	11.0	11.5	11.6	11.2	11.2	10.6	11.2
16	13.0	12.4	12.2	12.8	14.5	13.0	17.1
17	9.6	9.6	9.0	9.0	11.3	8.3	9.5
18	16.0	17.0	15.5	18.9	23.6	26.5	21.5
19	4.4	10.1	10.4	9.4	13.9	13.0	9.0
20	6.2	10.6	6.7 μa	$\Delta 51 \mu a$	$\Delta 44 \mu a$	$\Delta 39 \mu a$	$\Delta 40 \mu a$
21	21.0	36.0	42.0	48.0	78.0	72.0	63.0
22	16.5	$\Delta 2.4$ μa	$\Delta 63 \mu a$	$\Delta 34 \mu a$	$\Delta 32 \mu a$	$\Delta 25 \mu a$	$\Delta 30 \mu a$
23	7.6	10.0	13.6	13.2	16.5	18.0	18.5
24	13.0	21.7	21.0	19.2	24.7	25.0	22.5
25	16.0	15.0	14.5	13.6	15.0	14.0	15.0

Δ Units out of specification.

Exhibit IIa (Cont.)

Time Diode No.	Initial Read- ing	248 hrs.	530 hrs.	860 hrs.	1072 hrs.	1331 hrs.	1588 hrs.
26	14.0	17.0	17.0	16.0	17.5	16.0	20.0
27	3.8	7.6	8.7	11.3	16.0	19.9	82.0
28	7.6	10.0	10.0	10.5	12.6	15.4	13.5
29	10.0	9.8	9.5	15.5	13.5	27.2	11.5
30	18.0	21.0	19.5	22.0	26.5	26.5	20.5
31	5.8	3.5	4.0	3.5	4.7	5.2	7.9
32	11.0	9.4	8.6	9.4	10.2	10.0	11.5
33	23.0	^Δ 220.0	^Δ 270.0	84.0	98.0	77.0	27.9
34	1.5	2.0	4.0	4.4	5.2	6.2	9.0
35	15.0	20.2	17.0	18.0	20.0	19.9	27.5
36	4.0	^Δ 750.0	^Δ 23.0 μa	^Δ 5.9 μa	^Δ 1.1 μa	^Δ 510.0	^Δ 580.0 μa
37	6.9	13.8	12.7	11.5	15.0	14.0	25.4

^Δ Units out of specification.

IIIa-5

Exhibit III.a (Cont.)

Time Diode No.	Initial Read- ing	248 hrs.	530 hrs.	860 hrs.	1072 hrs.	1331 hrs.	1588 hrs.
38	7.7	11.4	11.8	14.2	21.4	24.0	.32 μ a
39	11.0	9.5	9.5	10.2	12.0	Shorted	-
40	7.6	9.0	10.0	11.9	13.5	14.0	16.5
41	11.0	11.0	10.2	11.5	13.1	13.5	14.0
42	13.0	22.8	17.5	17.0	18.3	17.1	17.8
43	1.7	1.6	1.64	2.1	3.4	3.5	5.5
44	5.0	7.1	12.6	18.0	23.0	Shorted	-
45	9.1	12.0	12.0	13.5	15.7	15.2	14.1
46	13.0	17.0	Δ 1.9 μ a	42.0	Δ 450.0	Δ 12.5 μ a	Δ 170.0 μ a
47	5.6	5.8	6.5	7.3	6.7	6.6	9.5
48	4.4	11.8	14.8	9.1	11.5	9.0	12.0
49	13.0	17.0	18.5	18.9	20.5	20.0	22.0

Δ - Units out of specification.
 - Units removed from life test.

IIIa-6

Exhibit IIIa (Cont.)

Time Diode No.	Initial Read- ing	248 hrs.	530 hrs.	860 hrs.	1072 hrs.	1331 hrs.	1588 hrs.
50	7.2	10.0	10.5	10.9	11.8	10.2	14.0
51	9.5	12.0	13.0	13.4	15.4	13.6	14.5
52	3.0	5.3	5.0	5.6	5.6	5.1	5.1
53	15.0	17.7	19.6	18.2	19.5	16.2	20.0
54	15.0	15.0	16.0	Δ 720.0	Δ 280.0	Δ 17.0 μ a	Δ 17.0 μ a
55	2.6	2.3	2.0	1.8	75.0	28.0	36.0
56	17.0	25.0	37.0	88.0	Δ 10 μ a	Δ 19 μ a	Δ 32 μ a
57	18.0	14.0	13.8	12.2	14.0	13.0	13.0
58	15.0	12.9	12.0	11.0	12.1	11.2	11.9

Δ - Units out of specification.

IV-1

EXHIBIT IV QUIET DIODES

The following critical parameter was measured during the life test, at approximately 250-hour intervals, at room temperature (25° C):

1. Forward voltage drop (V_F) in volts at an average forward current (I_F) of 400 milli-amps.

The vendor specifications for this diode (IN 645) allow a maximum forward voltage drop of 1.0 volt at the maximum allowable average forward current of 400 milli-amps at room temperature (25° C).

All measurements of forward voltage drop are in volts.

When a unit exceeds the maximum allowable forward voltage drop it is noted and considered to have failed life test.

QUIET DIODES

 V_F (volts) at $I_F = 400$ MA at 25°C V_F (max) = 1.0 volts at 25°C

Exhibit IV

Time Diode No.	Initial Reading	111 hrs.	275 hrs.	620 hrs.	851 hrs.	1082 hrs.	1342 hrs.	1590 hrs.	1872 hrs.	2202 hrs.	2414 hrs.	2672 hrs.	2930 hrs.
1	0.75	0.79	0.81	0.79	0.75	0.76	*-	-	-	-	-	-	-
2	0.76	**	-	-	-	-	-	-	-	-	-	-	-
3	0.75	**	-	-	-	-	-	-	-	-	-	-	-
4	0.76	0.77	0.77	0.78	0.75	0.82	*-	-	-	-	-	-	-
5	0.76	0.78	0.76	0.81	0.76	0.82	0.83	0.80	0.81	0.80	0.83	0.82	open
6	0.77	0.78	0.77	0.79	0.77	0.84	*-	-	-	-	-	-	-
7	0.78	0.78	0.76	0.78	0.77	0.85	0.82	0.83	0.93	0.80	0.80	0.90	0.96
8	0.79	0.79	0.78	Shorted	-	-	-	-	-	-	-	-	-
9	0.76	0.78	0.78	0.79	0.77	0.83	*-	-	-	-	-	-	-
10	0.76	0.76	0.76	0.78	0.76	0.76	0.83	0.79	0.88	0.86	0.80	0.80	0.90
11	0.77	0.78	0.76	0.79	0.76	0.77	0.84	0.79	0.92	0.80	0.84	0.84	0.87
12	0.76	0.78	0.76	0.80	0.76	0.77	Shorted	-	-	-	-	-	-
13	0.76	0.78	0.76	0.78	0.76	0.82	0.83	0.79	0.79	0.79	0.88	0.82	0.87

* Inadvertently destroyed when subjected to a temperature overrun (not included in failure data).

** Destroyed by a short in the testing fixture (not included in the failure data).

- Units removed from life test.

Exhibit IV (Cont.)

Time Diode No.	Initial Read- ing	111 hrs.	275 hrs.	620 hrs.	851 hrs.	1082 hrs.	1342 hrs.	1590 hrs.	1872 hrs.	2202 hrs.	2414 hrs.	2672 hrs.	2930 hrs.
14	0.78	0.78	0.78	0.80	0.78	0.78	0.85	0.80	0.85	0.79	0.85	0.85	0.80
15	0.80	0.80	0.79	0.86	0.79	0.87	0.85	0.85	0.92	0.84	0.82	0.85	0.95
16	0.76	0.78	0.77	0.75	0.75	0.82	0.83	0.82	0.78	0.89	0.83	0.83	1.00
17	0.75	0.76	0.75	0.77	0.75	0.82	0.82	0.80	0.77	0.76	0.81	0.78	0.83
18	0.78	0.78	0.78	0.80	0.77	0.82	Shorted	-	-	-	-	-	-
19	0.78	0.79	0.78	0.80	0.86	0.92	0.84	0.81	0.90	0.91	0.83	0.83	0.96
20	0.81	0.81	0.81	0.85	0.80	0.80	*-	-	-	-	-	-	-
21	0.79	0.80	0.79	0.81	0.78	0.80	*-	-	-	-	-	-	-
22	0.75	0.76	0.78	0.80	0.83	0.75	0.82	0.77	0.82	0.87	0.78	0.80	0.87
23	0.76	0.76	0.76	0.76	0.74	0.76	*-	-	-	-	-	-	-
24	0.76	0.77	0.76	0.78	0.80	0.78	0.82	0.78	0.88	0.84	0.89	0.79	0.87
25	0.75	0.75	0.75	0.91	0.74	0.76	0.81	0.78	0.77	0.76	0.76	0.79	0.90
26	0.76	0.77	0.76	0.77	0.78	0.76	0.82	0.81	0.89	0.87	0.88	0.81	0.92

* Inadvertently destroyed when subjected to a temperature overrun (not included in failure data).

- Units removed from life test.

Exhibit IV (Cont.)

Time Diode No.	Initial Reading	111 hrs.	275 hrs.	620 hrs.	851 hrs.	1082 hrs.	1342 hrs.	1590 hrs.	1872 hrs.	2202 hrs.	2414 hrs.	2672 hrs.	2830 hrs.
27	0.77	0.78	0.77	0.79	0.78	0.77	*	-	-	-	-	-	-
28	0.77	0.77	0.76	0.77	0.75	0.76	0.85	0.78	0.85	0.82	0.78	0.79	0.95
29	0.76	0.77	0.76	0.79	0.75	0.77	0.82	0.79	0.79	0.79	0.79	0.79	0.81
30	0.75	0.75	0.76	0.77	0.74	0.76	0.82	0.77	0.79	0.78	0.76	0.80	0.81
31	0.74	0.75	0.74	0.75	0.74	0.75	0.81	0.77	0.82	0.79	0.75	0.79	0.74
32	0.77	0.78	0.77	0.78	0.76	0.78	0.83	0.80	0.85	0.79	0.78	0.83	0.96
33	0.76	0.77	0.77	0.78	0.79	0.78	0.82	0.78	0.78	0.77	0.76	0.82	0.95
34	0.77	0.78	0.77	0.79	0.77	0.77	0.33	0.82	0.82	0.80	0.79	0.83	0.87
35	0.76	0.77	0.85	0.79	0.84	0.85	0.82	0.78	0.77	0.78	0.75	0.81	0.82
36	0.75	0.75	0.75	0.77	0.77	0.76	0.81	0.77	0.77	0.78	0.78	0.79	0.80
37	0.79	0.79	0.79	0.81	0.92	0.80	0.84	0.80	0.81	0.79	0.78	0.80	0.93
38	0.78	0.79	0.78	0.80	0.80	0.79	0.67	Shorted	-	-	-	-	-
39	0.75	0.75	0.75	0.77	0.76	0.75	0.81	0.77	0.77	0.78	0.79	0.80	0.78
40	0.78	0.80	0.79	0.81	0.79	0.80	0.85	0.81	0.81	0.79	0.79	0.85	0.85

* Inadvertently destroyed when subjected to a temperature overrun (not included in failure data).

- Units removed from life test.

IVa-1

EXHIBIT IVa
ADDITIONAL QUIET DIODES

The following critical parameter was measured during the life test, at approximately 250-hour intervals, at room temperature (25° C):

1. Forward voltage drop (V_F) in volts at an average forward current (I_F) of 400 milli-amps.

The vendor specifications for this diode (IN 645) allow a maximum forward voltage drop of 1.0 volts at the maximum allowable average forward current of 400 milli-amps at room temperature (25° C).

All measurements of forward voltage drop are in volts.

When a unit exceeds the maximum allowable forward voltage drop it is noted and considered to have failed life test.

IVa-2

Exhibit IVa

ADDITIONAL QUIET DIODES

V_F (volts) at $I_F = 400$ MA at 25°C

$V_F(\text{max}) = 1.0$

Time Diode No.	Initial Read- ing	248 hrs.	530 hrs.	860 hrs.	1072 hrs.	1331 hrs.	1588 hrs.
1	0.86	0.82	0.83	0.82	0.83	0.83	0.84
2	0.85	0.81	0.80	0.79	0.82	0.80	0.86
3	0.84	0.78	0.78	0.79	0.86	0.78	0.84
4	0.87	0.83	0.83	0.83	0.85	0.86	0.87
5	0.84	0.83	0.82	0.80	0.80	0.79	0.81
6	0.90	0.87	0.83	0.88	0.92	0.89	0.88
7	0.86	0.84	0.80	0.78	0.86	0.80	0.82
8	0.83	0.79	0.82	0.79	0.91	0.79	0.94
9	0.84	0.82	0.82	0.80	0.81	0.79	0.77
10	0.85	0.81	0.80	0.81	0.85	0.80	0.81
11	0.84	0.80	0.79	0.79	0.82	0.78	0.94
12	0.86	0.83	0.82	0.82	0.86	0.85	0.83
13	0.86	0.84	0.82	0.82	0.88	0.83	0.87

IVa-3

Exhibit IVa

Time Diode No.	Initial Read- ing	248 hrs.	530 hrs.	860 hrs.	1072 hrs.	1331 hrs.	1588 hrs.
14	0.87	0.85	0.83	0.82	0.83	0.81	0.98
15	0.88	0.85	0.85	0.88	0.86	0.85	0.82
16	0.89	0.84	0.84	0.84	0.88	0.85	0.84
17	0.84	0.80	0.80	0.78	0.81	0.80	0.80
18	0.86	0.84	0.82	0.84	0.79	0.82	0.85
19	0.85	0.80	0.79	0.81	0.79	0.81	0.79
20	0.90	0.85	0.85	0.83	0.85	0.84	0.85
21	0.87	0.82	0.84	0.87	0.86	0.82	0.80
22	0.86	0.82	0.82	0.79	0.80	0.81	0.78
23	0.87	0.85	0.82	0.81	0.88	0.83	0.84
24	0.89	0.84	0.94	0.88	0.82	0.83	0.81
25	0.81	0.80	0.80	0.79	0.78	0.78	0.79
26	0.84	0.81	0.82	0.83	0.84	0.81	0.84

Exhibit IVa

Time Diode No.	Initial Read- ing	248 hrs.	530 hrs.	860 hrs.	1072 hrs.	1331 hrs.	1588 hrs.
27	0.90	0.87	0.89	0.89	0.90	0.88	0.94
28	0.84	0.82	0.80	0.80	0.81	0.82	0.82
29	0.83	0.91	0.83	0.81	0.92	0.80	0.81
30	0.81	0.77	0.76	0.79	0.75	0.77	0.76
31	0.84	0.81	0.80	0.80	0.80	0.79	0.80
32	0.83	0.83	0.84	0.84	0.79	0.80	0.82
33	0.80	0.81	0.77	0.82	0.75	0.77	0.81
34	0.84	0.85	0.85	0.81	0.80	0.86	0.88
35	0.82	0.83	0.77	0.78	0.77	0.78	0.85
36	0.81	0.83	0.82	0.83	0.81	0.80	0.86
37	0.76	0.78	0.79	0.79	0.80	0.77	0.82
38	0.81	0.80	0.83	0.78	0.77	0.89	0.84
39	0.79	0.84	0.86	0.82	0.84	Shorted	-

- Units removed from life test.

IVa-5

Exhibit IVa

Time Diode No.	Initial Read- ing	248 hrs.	530 hrs.	860 hrs.	1072 hrs.	1331 hrs.	1588 hrs.
40	0.78	0.83	0.82	0.82	0.78	0.79	0.77
41	0.73	0.80	0.78	0.75	0.75	0.77	0.79
42	0.77	0.82	0.82	0.81	0.80	0.82	0.83
43	0.74	0.80	0.76	0.82	0.78	0.78	0.91
44	0.80	0.83	0.88	0.85	0.85	Shorted	-
45	0.79	0.83	0.83	0.85	0.80	0.80	0.84
46	0.77	0.80	0.78	0.79	0.82	0.78	0.82
47	0.76	0.79	0.77	0.77	0.76	0.79	0.79
48	0.75	0.79	0.79	0.77	0.77	0.78	0.77
49	0.75	0.79	0.80	0.77	0.79	0.78	0.75
50	0.78	0.82	0.84	0.83	0.80	0.82	0.86
51	0.79	0.80	0.79	0.81	0.79	0.82	0.77
52	0.78	0.80	0.81	0.83	0.80	0.81	0.77

- Units removed from life test.

Exhibit IVa

Time Diode No.	Initial Read- ing	248 hrs.	530 hrs.	860 hrs.	1072 hrs.	1331 hrs.	1588 hrs.
53	0.79	0.83	0.83	0.84	0.80	0.82	0.78
54	0.76	0.84	0.77	0.77	0.79	0.77	0.79
55	0.79	0.78	0.84	0.83	0.84	0.85	0.83
56	0.77	0.80	0.79	0.95	0.85	0.80	0.79
57	0.76	0.79	0.81	0.80	0.82	0.80	0.80
58	0.75	0.79	0.80	0.79	0.81	0.79	0.83

EXHIBIT V
NOISY 6.8 μ fd CAPACITORS
WITH 3 OHMS SERIES RESISTANCE

EXHIBIT VI
QUIET 6.8 μ fd CAPACITORS
WITH 3 OHMS SERIES RESISTANCE

The following critical parameters were measured during the life test, at approximately 250-hour intervals, at room temperature (25°C):

1. Dissipation factor (D) at a frequency of 60 cycles per second with the rated direct current working voltage (DCWV) impressed across the capacitor.
2. Leakage current (I_R) in micro-amps with the rated direct current working voltage (DCWV) impressed across the capacitor.

The vendor specifications for this type of capacitor (150 D) at room temperature (25°C) allow:

1. A maximum dissipation factor of 6.0 percent at the rated DCWV and 60 cps.
2. A maximum leakage current of 1.4 micro-amps at the rated DCWV.

All measurements of dissipation factor are in percent and all measurements of leakage current are in micro-amps.

When a unit exceeds the maximum allowable dissipation factor or leakage current it is noted and considered to have failed life test.

6.8 μ fd Capacitors
Initial Measurement

Exhibit V Noisy Quiet Exhibit VI

With 3 Ohms Series Resistance			With 3 Ohms Series Resistance		
Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.4 μ A	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.4 μ A
1	5.74	0.30	1	2.88	0.28
2	3.23	0.96	2	1.63	0.19
3	2.27	0.15	3	2.47	0.50
4	3.09	0.28	4	2.86	0.06
5	1.98	0.17	5	1.87	0.26
6	2.12	0.51	6	2.26	0.05
7	2.56	0.20	7	2.99	0.16
8	2.58	0.37	8	3.32	0.51
9	2.47	0.36	9	1.63	0.12
10	2.30	0.10	10	2.85	0.05
11	2.16	0.26	11	1.10	0.79
12	1.61	0.03	12	2.75	0.09
13	1.69	0.15	13	1.58	0.08
14	3.05	0.46	14	3.31	0.18
15	1.39	0.05	15	1.19	0.06
16	2.14	0.55	16	2.75	0.11
17	2.40	0.39	17	1.70	0.07
18	2.18	0.44	18	2.78	0.15
19	3.24	0.27	19	3.14	0.14
20	3.29	0.26	20	2.97	0.16

6.8 ufd Capacitors

250 Hours

Exhibit V

Exhibit VI

Noisy

Quiet

With 3 Ohms Series Resistance			With 3 Ohms Series Resistance		
Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μA) I_R (MAX) = 1.4 μA	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μA) I_R (MAX) = 1.4 μA
1	7.76	0.03	1	2.60	0.08
2	2.70	0.14	2	2.99	0.04
3	2.04	0.003	3	2.16	0.03
4	2.70	0.015	4*	-	-
5	2.02	0.09	5	1.80	0.03
6	1.82	0.29	6	1.79	0.18
7*	-	-	7*	-	Δ
8	2.27	0.10	8	2.83	2.25
9*	-	-	9	2.14	0.01
10	2.30	0.02	10*	-	-
11	2.08	0.06	11	1.05	0.02
12	1.94	0.02	12	2.36	0.01
13	1.55	0.03	13	1.72	0.34
14*	-	-	14*	-	-
15	2.23	0.01	15	1.22	0.03
16	2.42	0.02	16	2.36	0.14
17	2.62	0.28	17	1.84	0.02
18	2.17	0.22	18	2.60	0.02
19	3.14	0.08	19	3.69	0.03
20	2.81	Δ 1.64	20*	-	-

* Inadvertently destroyed during bench test.

Δ Units out of specification.

- Units removed from life test.

6.8 μ fd Capacitors
500 Hours

Exhibit V Noisy Quiet Exhibit VI

With 3 Ohms Series Resistance			With 3 Ohms Series Resistance		
Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.4 μ A	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.4 μ A
1	8.14	0.03	1	2.78	0.061
2	2.86	0.1	2	2.89	0.031
3	2.10	0.001	3	1.83	0.015
4	2.75	0.004	4*	-	-
5	2.06	0.30	5	1.82	0.017
6	2.00	0.07	6	1.91	0.275
7*	-	-	7*	-	-
8	2.35	0.064	8	2.76	0.12
9*	-	-	9	2.21	0.007
10	2.45	0.018	10*	-	-
11	2.22	0.054	11	1.04	0.017
12	1.90	0.018	12	2.45	0.036
13	1.53	0.024	13	1.78	0.032
14*	-	-	14*	-	-
15	2.29	0.007	15	1.25	0.215
16	2.56	0.013	16	2.56	0.185
17	2.68	0.12	17	1.92	0.02
18	2.29	0.255	18	2.74	0.02
19	3.35	0.06	19	4.10	0.04
20	2.92	0.96	20*	-	-

Δ Units out of specification.
* Inadvertently destroyed during bench test.
- Units removed from life test.

1000 Hours

Exhibit V Noisy Quiet Exhibit VI

With 3 Ohms Series Resistance			With 3 Ohms Series Resistance		
Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μA) I _R (MAX) = 1.4μA	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μA) I _R (MAX) = 1.4μA
1	Δ 7.96	0.20	1	2.63	0.11
2	2.59	0.13	2	5.02	0.03
3	1.99	0.008	3	2.15	0.017
4	2.60	0.010	4*	-	-
5	2.00	0.125	5	1.83	0.016
6	1.81	1.42	6	1.95	0.285
7*	-	-	7*	-	-
8	2.24	0.082	8	2.63	0.165
9*	-	-	9	2.65	0.008
10	2.40	0.024	10*	-	-
11	2.03	0.056	11	0.97	0.021
12	1.80	0.022	12	2.41	0.034
13	1.51	0.02	13	2.02	0.062
14*	-	-	14*	-	-
15	2.77	0.01	15	1.15	0.036
16	2.65	0.018	16	2.51	0.076
17	2.78	0.70	17	2.36	0.015
18*	-	-	18	Shorted	-
19	2.95	0.068	19	4.68	0.066
20	2.86	1.0	20*	-	-

- Δ Units out of specification.
- * Inadvertently destroyed during bench test.
- Units removed from life test.

- Units removed from life test.

V-7

6.8 μ fd Capacitors
1250 Hours

Exhibit V Noisy Quiet Exhibit VI

With 3 Ohms Series Resistance			With 3 Ohms Series Resistance		
Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.4 μ A	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.4 μ A
1	Δ 7.60	0.150	1	2.54	0.255
2	2.54	0.130	2	5.20	0.022
3	2.06	0.002	3	2.24	0.016
4	2.71	0.005	4*	-	-
5	2.06	0.16	5	1.88	0.018
6	1.91	Δ 1.60	6	1.87	0.30
7*	-	-	7*	-	-
8	2.24	0.09	8	2.46	0.17
9*	-	-	9	2.68	0.006
10	2.42	0.21	10*	-	-
11	2.14	0.056	11	1.04	0.017
12	1.87	0.021	12	2.49	0.031
13	1.62	0.023	13	1.92	0.061
14*	-	-	14*	-	-
15	2.71	0.009	15	1.21	0.037
16	2.58	0.017	16	2.65	0.023
17	2.85	0.27	17	2.18	0.014
18*	-	-	18	-	-
19	3.32	0.060	19	5.05	0.14
20	2.98	0.91	20*	-	-

Δ Units out of specification.
* Inadvertently destroyed during bench test.
- Units removed from life test.

6.8 μ fd Capacitors
1750 Hours

V-9

Exhibit V Noisy Quiet Exhibit VI

With 3 Ohms Series Resistance			With 3 Ohms Series Resistance		
Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.4 μ A	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.4 μ A
1	1.82	0.066	1	2.64	0.15
2	2.54	0.13	2	5.90	0.018
3	2.05	0.002	3	2.30	0.014
4	2.64	0.006	4*	-	-
5	2.24	0.18	5	0.837	0.015
6	1.80	Δ 1.8	6	1.920	0.34
7*	-	-	7*	-	-
8	2.23	0.25	8	2.46	0.29
9*	-	-	9	2.82	0.010
10	2.44	0.042	10*	-	-
11	2.26	0.046	11	0.985	0.022
12	2.04	0.022	12	2.435	0.024
13	1.58	0.022	13	2.03	0.052
14*	-	-	14*	-	-
15	3.00	0.008	15	1.20	1.15
16	2.51	0.010	16	2.76	0.50
17	2.99	0.38	17	2.26	0.011
18*	-	-	18	-	-
19	3.26	0.056	19	5.25	0.17
20	2.42	0.88	20*	-	-

- Δ Units out of specification.
- * Inadvertently destroyed during bench test.
- Units removed from life test.

6.8 μ fd Capacitors
2000 Hours

Exhibit V Noisy Quiet Exhibit VI

With 3 Ohms Series Resistance			With 3 Ohms Series Resistance		
Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.4 μ A	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.4 μ A
1	Δ 6.82	0.06	1	2.64	0.01
2	2.56	0.14	2	5.95	0.024
3	2.15	0.005	3	2.39	.016
4	2.83	0.002	4*	-	-
5	2.38	0.14	5	1.92	0.020
6	2.21	Δ 1.45	6	1.82	0.33
7*	-	-	7*	-	-
8	2.14	0.60	8	2.50	0.22
9*	-	-	9	2.86	0.014
10	2.47	0.12	10*	-	-
11	2.17	0.052	11	1.28	0.026
12	2.06	0.03	12	2.39	0.033
13	1.79	0.022	13	2.09	0.048
14*	-	-	14*	-	-
15	3.18	0.006	15	1.21	0.14
16	2.63	0.014	16	2.76	0.76
17	2.45	0.27	17	2.44	0.013
18*	-	-	18	-	-
19	3.12	0.06	19	5.42	0.21
20	2.90	0.88	20*	-	-

Δ Units out of specification

* Inadvertently destroyed during bench test.

- Units removed from life test.

EXHIBIT VII
NOISY 6.8 μ f CAPACITORS
WITH 20 OHMS SERIES RESISTANCE

EXHIBIT VIII
QUIET 6.8 μ f CAPACITORS
WITH 20 OHMS SERIES RESISTANCE

The following critical parameters were measured during the life test, at approximately 250-hour intervals, at room temperature (25°C):

1. Dissipation factor (D) at a frequency of 60 cycles per second with the rated direct current working voltage (DCWV) impressed across the capacitor.
2. Leakage current (I_R) in micro-amps with the rated direct current working voltage (DCWV) impressed across the capacitor.

The vendor specifications for this type of capacitor (150 D) at room temperature (25°C) allow:

1. A maximum dissipation factor of 6.0 percent at the rated DCWV and 60 cps.
2. A maximum leakage current of 1.4 micro-amps at the rated DCWV.

All measurements of dissipation factor are in percent and all measurements of leakage current are in micro-amps.

When a unit exceeds the maximum allowable dissipation factor or leakage current it is noted and considered to have failed life test.

6.7 μ fd Capacitors
Initial Measurements

Exhibit VII Noisy Quiet Exhibit VIII

With 20 Ohms Series Resistance			With 20 Ohms Series Resistance		
Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.4 μ A	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.4 μ A
1	3.02	0.08	1	2.79	0.34
2	1.34	0.05	2	2.79	0.42
3	2.26	0.22	3	2.97	0.10
4	3.40	0.29	4	3.05	0.13
5	3.01	0.20	5	2.57	0.06
6	2.54	0.50	6	2.23	0.09
7	2.86	0.05	7	2.88	0.36
8	2.54	0.54	8	1.35	0.08
9	2.38	0.41	9	2.07	0.26
10	2.32	0.16	10	2.50	0.36
11	2.60	0.32	11	1.26	0.04
12	2.74	0.80	12	1.36	0.05
13	1.40	0.05	13	1.36	0.04
14	2.51	0.42	14	3.00	0.18
15	2.38	0.07	15	2.41	0.30
16	2.42	-.37	16	2.161	0.42
17	1.51	0.90	17	2.58	0.11
18	3.60	0.08	18	2.73	0.42
19	0.96	0.38	19	2.40	0.40
20	2.06	0.04	20	2.27	0.16

6.8 μ fd Capacitors
250 Hours

Exhibit VII Noisy Quiet Exhibit VIII

With 20 Ohms Series Resistance			With 20 Ohms Series Resistance		
Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.4 μ A	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.4 μ A
1	2.80	0.07	1	2.42	0.13
2	1.72	0.02	2	2.51	0.05
3	1.90	0.05	3	2.59	0.03
4	3.79	0.17	4	3.11	0.5
5	2.76	0.07	5	2.30	0.03
6	2.14	1.10	6	2.12	0.03
7	2.43	0.02	7	2.42	0.03
8	2.40	0.04	8	1.75	0.04
9	2.11	0.03	9	2.02	0.03
10*	Shorted	-	10	2.39	1.20
11	2.27	0.16	11	1.08	0.01
12	2.23	0.07	12	1.71	0.02
13	1.45	0.01	13	1.39	0.02
14	2.14	0.18	14	1.88	0.06
15	2.15	0.02	15	2.22	0.10
16	2.23	0.38	16	1.99	0.06
17	1.55	0.04	17	2.51	0.03
18	4.07	0.74	18	2.50	0.07
19	0.96	0.26	19	1.96	0.04
20	1.90	0.33	20	5.94	0.07

* This capacitor had a series resistance of 3 ohms and was charged to the test group having 3 ohms series resistance.

- Units out of specification.

6.8 μ fd Capacitors

500 Hours

Exhibit VIII

Exhibit VII

Noisy

Quiet

With 20 Ohms Series Resistance			With 20 Ohms Series Resistance		
Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.4 μ A	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.4 μ A
1	3.05	0.054	1	2.47	0.13
2	1.45	0.014	2	2.66	0.047
3	2.00	0.040	3	2.80	0.020
4	3.95	0.14	4	3.38	0.015
5	2.78	0.056	5	2.51	0.010
6	2.12	0.21	6	2.18	0.010
7	2.57	0.013	7	2.40	0.010
8	2.44	0.032	8	1.84	0.038
9	2.18	0.020	9	2.08	0.25
10	-	-	10	2.40	0.42
11	2.44	0.29	11	1.11	0.013
12	2.35	0.056	12	1.77	0.015
13	1.45	0.012	13	1.45	0.015
14	2.28	0.155	14	2.94	0.054
15	2.15	0.024	15	2.42	0.32
16	2.21	0.46	16	2.03	0.048
17	1.60	0.023	17	2.64	0.032
18	4.38	1.25	18	2.52	0.068
19	0.95	0.072	19	4.05	0.029
20	-	-	20	Δ 7.16	0.061

 Δ Units out of specification.

- Units removed from life test.

6.8 ufd Capacitors
750 Hours

Exhibit VIII

Quiet

With 20 Ohms Series Resistance			With 20 Ohms Series Resistance		
Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μA) I_R (MAX) = 1.4 μA	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μA) I_R (MAX) = 1.4 μA
1	2.96	0.063	1	2.44	0.37
2	1.44	0.016	2	2.50	0.048
3	1.90	0.049	3	2.63	0.046
4	3.95	0.75	4	3.50	0.051
5	2.78	0.068	5	2.45	0.150
6	2.13	0.275	6	2.19	0.030
7	2.60	0.017	7	2.21	0.034
8	2.40	0.039	8	1.95	0.040
9	2.16	0.026	9	2.15	0.030
10	-	-	10	2.49	0.60
11	2.40	0.31	11	1.15	0.012
12	2.26	0.074	12	1.93	0.011
13	1.45	0.015	13	1.47	0.017
14	2.22	0.19	14	2.83	0.059
15	2.15	0.022	15	2.08	0.115
16	2.18	1.35	16	2.04	0.050
17	1.58	0.032	17	2.56	0.034
18	4.49	Δ 2.25	18	2.42	0.076
19	0.96	0.259	19	2.03	0.024
20	-	-	20	Δ 9.17	0.058

Δ Units out of specification.

- Units removed from life test.

6.8 μ fd Capacitors

Exhibit VII Noisy Quiet Exhibit VIII

1000 Hours

With 20 Ohms Series Resistance			With 20 Ohms Series Resistance		
Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.4 μ A	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.4 μ A
1	2.74	0.054	1	2.44	0.190
2	1.55	0.017	2	2.63	0.040
3	1.88	0.044	3	2.24	0.021
4	4.25	0.15	4	3.58	0.041
5	2.65	0.056	5	2.16	0.052
6	2.10	0.21	6	2.18	0.030
7	2.72	0.007	7	2.25	0.029
8	2.30	0.03	8	2.27	0.029
9	2.10	0.016	9	2.09	0.024
10	-	-	10	2.35	0.34
11	2.34	0.16	11	1.22	0.014
12	2.28	0.064	12	2.15	0.007
13	1.74	0.014	13	1.73	0.011
14	2.10	0.165	14	2.88	0.044
15	2.20	0.021	15	2.12	0.090
16	2.07	1.20	16	1.92	0.048
17	1.62	0.015	17	2.65	0.028
18	4.68	0.14	18	2.44	0.028
19	0.94	0.23	19	2.03	0.021
20	-	-	20	^{Δ} 9.86	0.051

 ^{Δ} Units out of specification.

- Units removed from life test.

6.8 μ fd Capacitors

250 Hours

Exhibit VII Noisy Quiet Exhibit VIII

With 20 Ohms Series Resistance			With 20 Ohms Series Resistance		
Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.4 μ A	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.4 μ A
1	3.98	0.048	1	2.39	0.37
2	1.58	0.012	2	2.50	0.04
3	1.92	0.041	3	2.51	0.05
4	4.14	0.135	4	3.66	0.040
5	2.82	0.054	5	2.39	0.049
6	2.15	0.28	6	2.14	0.023
7	2.86	0.008	7	2.15	0.026
8	2.41	0.029	8	2.15	0.026
9	2.05	0.019	9	2.27	0.022
10	-	-	10	2.41	0.36
11	2.29	0.155	11	1.06	0.013
12	2.18	0.061	12	2.06	0.0064
13	1.56	0.017	13	1.51	0.011
14	2.17	0.17	14	2.82	0.042
15	2.06	0.018	15	2.12	0.083
16	2.14	Δ 1.5	16	1.95	0.046
17	1.67	0.019	17	2.44	0.024
18	4.97	0.44	18	2.39	0.061
19	0.94	0.22	19	2.05	0.014
20	-	-	20	Δ 10.7	0.048

Δ Units out of specification.
- Units removed from life test.

6.3 μ fd Capacitors
1500 Hours

Exhibit VII Noisy Quiet Exhibit VIII

With 20 Ohms Series Resistance			With 20 Ohms Series Resistance		
Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.4 μ A	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.4 μ A
1	2.82	0.054	1	2.41	0.26
2	1.47	0.013	2	2.42	0.042
3	1.88	0.041	3	2.54	0.052
4	4.22	0.140	4	3.65	0.044
5	2.73	0.050	5	2.40	0.066
6	2.08	0.24	6	2.13	0.031
7	2.76	0.012	7	2.12	0.025
8	2.39	0.030	8	2.14	0.032
9	2.05	0.019	9	2.28	0.026
10	-	-	10	2.42	0.31
11	2.31	0.16	11	1.07	0.007
12	2.26	0.061	12	2.18	0.008
13	1.52	0.013	13	1.57	0.0094
14	2.21	0.22	14	2.75	0.048
15	2.03	0.017	15	2.20	0.096
16	2.15	0.80	16	1.99	0.042
17	4.76	0.016	17	2.46	0.026
18	5.00	0.72	18	2.40	0.067
19	0.85	0.22	19	2.05	0.022
20	-	-	20	Δ 10.9	0.054

Δ Units out of specification.

- Units removed from life test.

6.8 μ fd Capacitors
1750 Hours

Exhibit VII
Noisy

Exhibit VIII
Quiet

With 20 Ohms Series Resistance			With 20 Ohms Series Resistance		
Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.4 μ A	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.4 μ A
1	2.94	0.058	1	2.40	0.36
2	1.56	0.011	2	2.46	0.042
3	1.895	0.038	3	2.58	0.14
4	4.32	0.93	4	3.9	0.04
5	2.32	0.048	5	2.4	0.043
6	2.122	0.35	6	2.20	0.105
7	2.92	0.011	7	2.16	0.18
8	2.40	0.024	8	2.22	0.030
9	2.184	0.014	9	2.23	0.019
10	-	-	10	2.52	0.68
11	2.27	0.22	11	1.08	0.007
12	2.21	0.061	12	2.26	0.008
13	1.585	0.027	13	1.59	0.010
14	2.22	0.25	14	2.71	0.04
15	2.04	0.015	15	2.18	0.11
16	2.10	1.05	16	1.98	0.041
17	1.703	0.009	17	2.50	0.026
18	5.28	0.48	18	2.41	0.060
19	0.948	0.21	19	2.04	0.016
20	-	-	20	Δ 11.4	0.046

Δ Units out of specification.

- Units removed from life test.

6.8 μ fd Capacitors2000 Hours

Exhibit VII Noisy Quiet Exhibit VIII

With 20 Ohms Series Resistance			With 20 Ohms Series Resistance		
Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.4 μ A	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.4 μ A
1	3.04	0.056	1	2.45	0.19
2	1.66	0.014	2	2.41	0.038
3	1.89	0.04	3	2.54	0.44
4	4.32	1.15	4	4.15	0.04
5	2.79	0.05	5	2.40	0.038
6	2.07	0.22	6	2.14	0.048
7	3.12	0.012	7	2.11	0.13
8	2.40	0.032	8	2.38	0.027
9	2.16	0.014	9	2.39	0.023
10	-	-	10	2.50	0.64
11	2.39	0.20	11	1.10	0.01
12	2.27	0.06	12	2.40	0.006
13	1.58	0.02	13	1.54	0.009
14	2.29	0.30	14	2.87	0.046
15	2.08	0.018	15	1.90	0.12
16	2.09	0.42	16	1.98	0.042
17	1.57	0.013	17	2.62	0.028
18	5.60	0.25	18	2.54	0.068
19	1.04	0.22	19	2.03	0.026
20	-	-	20	Δ 11.6	0.054

 Δ Units out of specification.

- Units removed from life test.

VII-1

EXHIBIT IX
NOISY 0.015 μ fd CAPACITORS
WITH 3 OHMS SERIES RESISTANCE

The following critical parameters were measured during the life test, at approximately 250-hour intervals, at room temperature (25°C).

1. Dissipation factor (D) at a frequency of 60 cycles per second with the rated direct current working voltage (DCWV) impressed across the capacitor.
2. Leakage current (I_R) in micro-amps with the rated direct current working voltage (DCWV) impressed across the capacitor.

The vendor specifications for this type of capacitor (150 D) at room temperature (25°C) allow:

1. A maximum dissipation factor of 6.0 percent at the rated DCWV and 60 cps.
2. A maximum leakage current of 1.0 micro-amps at the rated DCWV.

All measurements of dissipation factor are in percent and all measurements of leakage current are in micro-amps.

When a unit exceeds the maximum allowable dissipation factor or leakage current it is noted and considered to have failed life test.

Noisy 0.015 μ d Capacitors
(With 3 Ohms Series Resistance)
INITIAL MEASUREMENTS

Exhibit IX

Cap. No.	Dissipation Factor δ D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A	Cap. No.	Dissipation Factor δ D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A
1	2.59	0.0016	15	0.38	0.024
2	2.74	0.0001	16	2.95	0.0029
3	Shorted }	Not included in the Life Test sample	17	0.54	0.023
4	Shorted }		18	2.46	0.0001
5	Shorted }		19	2.29	0.00038
6	4.09		20	0.45	0.0076
7	2.15		21	3.30	0.0026
8	4.20		22	1.62	0.0002
9	2.68	0.00048	23	3.30	0.002
10	3.02	0.017	24	0.34	0.0092
11	2.32	0.050	25	4.10	0.00033
12	2.14	0.0013	26	6.63	0.0011
13	2.57	0.00059	27	2.49	0.00022
14	3.47	0.060			

Noisy 0.015 μ fd Capacitors
(with 3 ohms series resistance)

250 Hours

Exhibit IX

Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A
1	Δ 3E.0	Δ 1.30	15	0.55	0.019
2	2.42	0.0001	16	2.57	0.10
3	-	-	17	0.71	0.023
4	-	-	18	2.15	0.214
5	-	-	19	2.42	0.00001
6	3.91	0.003	20	0.58	0.001
7	1.85	0.15	21	1.28	0.0002
8	-	-	22	1.51	0.00018
9	2.15	0.021	23	3.37	0.00094
10	2.65	0.008	24	0.46	0.00014
11	2.21	Δ 1.20	25	3.74	0.0062
12	1.65	0.015	26	2.48	0.0004
13	2.29	0.215	27	2.39	0.00046
14	3.02	0.11			

Δ Units out of specification.

- Units removed from life test.

Noisy 0.015 μ fd Capacitors
(with 3 ohms series resistance)

500 Hours

Exhibit IX

Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A
1	Δ 109.0	Δ 2.0	15	0.53	0.015
2	2.87	0.0001	16	2.81	0.084
3	-	-	17	0.56	0.017
4	-	-	18	1.93	0.145
5	-	-	19	2.62	0.00001
6	4.35	0.003	20	0.39	0.232
7	1.81	0.20	21	Open	-
8	-	-	22	1.44	0.00016
9	2.15	0.02	23	3.32	0.001
10	2.80	0.006	24	0.30	0.0094
11	2.38	0.57	25	4.05	0.00015
12	1.36	0.027	26	2.83	0.195
13	2.45	0.017	27	2.64	0.0006
14	2.28	0.020			

Δ Units out of specification.

- Units removed from life test.

Noisy 0.015 μ fd Capacitors
(with 3 ohms series resistance)

750 Hours

Exhibit IX

Cap. No.	Dissipation Factor % D(MAX) = 5%	Leakage (μ A) I_R (MAX) = 1.0 μ A	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A
1	Δ 117.0	0.00028	15	0.31	0.009
2	2.74	0.0001	16	2.87	0.096
3	-	-	17	0.48	0.013
4	-	-	18	2.02	0.028
5	-	-	19	2.47	0.0001
6	3.38	0.0024	20	0.50	0.075
7	1.81	0.015	21	-	-
8	-	-	22	1.63	0.0002
9	2.18	0.040	23	3.41	0.0012
10	2.86	0.0049	24	0.58	0.031
11	2.14	0.68	25	4.05	0.0002
12	1.35	0.017	26	2.57	0.032
13	1.45	0.015	27	2.57	0.00042
14	3.26	0.0059			

Δ Units out of specification.

- Units removed from life test.

Noisy 0.015 μ fd Capacitors
(with 3 ohms series resistance)

1000 Hours

Exhibit IX

Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A
1	Δ 49.7	0.00066	15	0.684	0.0076
2	2.30	0.0005	16	2.81	0.130
3	-	-	17	0.637	0.105
4	-	-	18	2.05	0.105
5	-	-	19	2.42	0.0001
6	3.09	0.0024	20	0.685	0.014
7	1.86	0.41	21	-	-
8	-	-	22	1.37	0.0003
9	1.92	0.0054	23	3.35	0.0013
10	2.54	0.105	24	0.408	0.002
11	2.12	0.90	25	3.45	0.0002
12	1.39	0.0083	26	2.49	0.0098
13	1.87	0.0185	27	2.34	0.00018
14	2.94	0.0175			

Δ Units out of specification.

- Units removed from life test.

Noisy 0.015 μ fd Capacitors
(with 3 ohms series resistance)

1250 Hours

Exhibit IX

Cap. No.	Dissipation Factor % D(MAX) = 6d	Leakage (μ A) I_R (MAX) = 1.0 μ A	Cap. No.	Dissipation Factor % D(MAX) = 6d	Leakage (μ A) I_R (MAX) = 1.0 μ A
1	Δ 39.0	2 μ A	15	0.48	0.0047
2	2.23	10 μ A	16	2.51	0.140
3	-	-	17	0.74	0.0061
4	-	-	18	1.90	0.135
5	-	-	19	2.49	0.0001
6	2.89	0.0019	20	0.51	0.012
7	1.69	0.42	21	-	-
8	-	-	22	1.43	0.00024
9	1.90	0.0072	23	3.37	0.0013
10	2.47	0.175	24	0.52	0.0073
11	2.03	0.91	25	3.60	0.00029
12	1.21	0.0026	26	2.53	0.0235
13	1.91	0.00085	27	2.42	0.00016
14	2.91	0.014			

Δ Units out of specification.

- Units removed from life test.

Noisy 0.015 μ fd Capacitors
(with 3 ohms series resistance)

1500 Hours

Exhibit IX

Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A
1	Δ 58.0	0.0095	15	0.47	0.004
2	2.18	0.00027	16	2.46	0.14
3	-	-	17	0.74	0.0044
4	-	-	18	1.80	0.225
5	-	-	19	2.40	0.0004
6	4.68	0.00019	20	0.58	0.0026
7	1.78	0.44	21	-	-
8	-	-	22	1.28	0.00073
9	1.68	0.15	23	3.30	0.0016
10	2.21	0.011	24	0.60	0.0008
11	1.95	0.87	25	3.38	0.0069
12	1.28	0.004	26	2.42	0.24
13	1.78	0.0012	27	2.20	0.00044
14	2.73	0.022			

Δ Units out of specification.

- Units removed from life test.

Noisy 0.015 μ fd Capacitors
(with 3 ohms series resistance)

1750 Hours

Exhibit IX

Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A
1	Δ 71.0	0.0068	15	0.42	0.0023
2	2.14	0.0002	16	2.49	0.040
3	-	-	17	0.83	0.004
4	-	-	18	1.69	0.073
5	-	-	19	2.36	0.0005
6	4.58	0.0015	20	0.72	0.22
7	1.58	0.12	21	-	-
8	-	-	22	1.35	0.0008
9	1.57	0.055	23	3.35	0.0015
10	2.28	0.0062	24	0.48	0.0008
11	2.02	0.48	25	3.58	0.0008
12	1.20	0.0032	26	2.44	0.19
13	1.78	0.0009	27	2.35	0.0005
14	2.65	0.017			

Δ Units out of specification.

- Units removed from life test.

Noisy 0.015 μ fd Capacitors
(with 3 ohms series resistance)

2000 Hours

Exhibit IX

Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A
1	Δ 78.0	0.018	15	0.65	0.0028
2	2.14	0.00026	16	1.98	0.077
3	-	-	17	0.73	0.003
4	-	-	18	1.68	0.021
5	-	-	19	2.18	0.0006
6	3.60	0.19	20	2.39	6.15
7	1.92	0.23	21	-	-
8	-	-	22	0.27	0.0007
9	1.69	0.14	23	3.24	0.0018
10	1.82	0.012	24	0.38	0.0009
11	1.92	0.83	25	3.31	0.001
12	1.13	0.015	26	2.42	0.14
13	1.76	0.004	27	2.28	0.0005
14	1.54	0.006			

Δ Units out of specification.

- Units removed from life test.

EXHIBIT X
QUIET 0.015 μ fd CAPACITORS
WITH 3 OHMS SERIES RESISTANCE

The following critical parameters were measured during the life test, at approximately 250-hour intervals, at room temperature (25°C):

1. Dissipation factor (D) at a frequency of 60 cycles per second with the rated direct current working voltage (DCWV) impressed across the capacitor.
2. Leakage current (I_R) in micro-amps with the rated direct current working voltage (DCWV) impressed across the capacitor.

The vendor specifications for this type of capacitor (150 D) at room temperature (25°C) allow:

1. A maximum dissipation factor of 6.0 percent at the rated DCWV and 60 cps.
2. A maximum leakage current of 1.0 micro-amps at the rated DCWV.

All measurements of dissipation factor are in percent and all measurements of leakage current are in micro-amps.

When a unit exceeds the maximum allowable dissipation factor or leakage current it is noted and considered to have failed life test.

**Quiet 0.015 μ fd Capacitors
(With 3 Ohms Series Resistance)**

INITIAL MEASUREMENTS

Exhibit X

Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A
1	2.98	0.00016	15	2.29	0.0016
2	0.53	0.014	16	2.39	0.0016
3	3.00	0.001	17	4.30	0.0037
4	0.51	0.015		2.54	0.094
5	2.28	0.026	19	0.60	0.0125
6	3.32	0.0002	20	0.43	0.010
7	2.37	0.0021	21	2.17	0.008
8	1.94	0.028	22	2.52	0.0034
9	2.73	0.013	23	0.56	0.033
10	0.44	0.0088	24	2.10	0.00054
11	3.42	0.0084	25	2.23	0.00012
12	2.29	0.005	26	1.85	0.00015
13	3.80	0.0024	27	0.57	0.0072
14	3.42	0.0003			

Quiet 0.015 μ fd Capacitors
(with 3 ohms series resistance)

250 Hours

Exhibit X

Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A
1	2.81	0.0001	15	1.94	0.0004
2	0.067	0.0081	16	2.30	0.0003
3	2.78	0.105	17	4.18	0.030
4	0.59	0.10	18	2.26	0.0009
5	2.04	0.28	19	0.61	0.0056
6	3.14	0.0003	20	0.48	0.0062
7	2.24	0.0016	21	1.87	0.012
8	1.82	0.29	22	2.44	0.012
9	2.46	0.16	23	0.62	0.028
10	0.57	0.0062	24	1.87	0.0036
11	3.54	0.0012	25	2.01	0.0003
12	1.80	0.0056	26	1.89	0.0001
13	3.70	0.0026	27	0.50	0.0072
14	2.18	0.00016			

**Quiet 0.015 μ fd Capacitors
(with 3 ohms series resistance)**

500 Hours

Exhibit X

Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A
1	2.92	0.00032	15	2.05	0.0005
2	0.48	0.004	16	2.24	0.0002
3	3.01	0.155	17	4.55	0.0013
4	0.41	0.0042	18	2.41	0.017
5	1.18	Δ 40.0	19	0.43	0.0025
6	3.50	0.00024	20	0.43	0.013
7	2.29	0.0021	21	1.92	0.009
8	1.79	0.056	22	2.74	0.028
9	1.78	0.020	23	0.53	0.014
10	0.46	0.0032	24	2.03	0.00072
11	3.74	0.0015	25	2.15	0.00052
12	1.76	0.0047	26	1.85	0.00031
13	3.99	0.0003	27	3.36	0.0054
14	2.15	0.0002			

Δ Units out of specification.

Quiet 0.015 μ fd Capacitors
(with 3 ohms series resistance)

750 Hours

Exhibit X

Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A	Cap. No.	Dissipation Factor % D(MAX) = 3%	Leakage (μ A) I_R (MAX) = 1.0 μ A
1	2.87	0.00038	15	2.03	0.00042
2	0.46	0.0033	16	2.09	0.00015
3	3.10	0.072	17	4.44	0.00089
4	0.67	0.0019	18	2.41	0.013
5	Δ 6.96	Δ 3.50	19	0.54	0.0024
6	3.58	0.0004	20	0.54	0.0064
7	2.39	0.0025	21	1.71	0.0083
8	1.79	0.076	22	2.42	0.035
9	1.53	0.025	23	0.82	0.0105
10	0.47	0.0021	24	2.17	0.001
11	3.64	0.0020	25	2.17	0.00074
12	1.74	0.0042	26	1.92	0.0006
13	4.07	0.00043	27	0.23	0.0045
14	2.41	0.0002			

Δ Units out of specification.

Quiet 0.015 μ fd Capacitors
(with 3 ohms series resistance)

1000 Hours

Exhibit X

Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A
1	2.42	0.0005	15	1.78	0.00056
2	0.64	0.0033	16	1.88	0.00020
3	1.66	0.105	17	4.12	0.0016
4	0.516	0.0021	18	2.23	0.0175
5	5.56	Δ 35.0	19	0.60	0.0042
6	3.00	0.00052	20	0.55	0.0069
7	1.33	0.00245	21	1.48	0.011
8	1.41	0.063	22	2.15	0.055
9	2.18	0.035	23	0.66	0.0072
10	0.60	0.0017	24	1.90	0.001
11	3.42	0.0029	25	1.92	0.0225
12	1.66	0.0053	26	1.84	0.00086
13	3.60	0.0004	27	0.46	0.0040
14	1.85	0.0002			

Δ Units out of specification.

Quiet 0.015 μ fd Capacitors
(with 3 ohms series resistance)

1250 Hours

Exhibit X

Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A
1	2.32	0.0003	15	1.67	0.00060
2	0.74	0.0028	16	2.01	0.00016
3	2.42	0.056	17	4.02	0.0018
4	0.58	0.0014	18	2.03	0.010
5	4.44	Δ 27.0	19	0.61	0.0038
6	3.02	0.00054	20	0.62	0.0039
7	1.81	0.00155	21	1.55	0.012
8	1.70	0.045	22	2.05	0.062
9	2.16	0.040	23	0.71	0.004
10	0.61	0.0011	24	1.82	0.0011
11	3.61	0.0033	25	1.85	0.084
12	1.65	0.0041	26	1.82	0.00077
13	3.49	0.00043	27	0	0.0014
14	2.14	0.00021			

Δ Units out of specification.

Quiet 0.015 μ fd Capacitors
(with 3 ohms series resistance)

1500 Hours

Exhibit X

Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A
1	2.33	0.00049	15	1.66	0.00073
2	0.63	0.0029	16	1.82	0.00038
3	2.44	0.031	17	3.82	0.0019
4	0.48	0.0015	18	2.03	0.009
5	5.95	Δ 28.0	19	0.71	0.0047
6	3.09	0.001	20	0.53	0.0031
7	1.79	0.0014	21	1.43	0.014
8	1.55	0.032	22	2.02	0.060
9	2.18	0.040	23	0.66	0.004
10	0.59	0.0014	24	1.71	0.0013
11	3.52	0.0043	25	1.93	0.019
12	1.55	0.0048	26	1.79	0.0012
13	3.31	0.00025	27	0.34	0.0014
14	1.97	0.0008			

Δ Units out of specification.

Quiet 0.015 μ fd Capacitors
(with 3 ohms series resistance)

1750 Hours

Exhibit X

Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A
1	2.29	0.0005	15	1.62	0.0008
2	0.50	0.003	16	1.84	0.0004
3	2.57	0.032	17	3.82	0.002
4	0.44	0.0013	18	2.06	0.010
5	5.02	Δ 26.0	19	0.69	0.005
6	3.00	0.0011	20	0.69	0.0033
7	1.78	0.0016	21	1.54	0.019
8	1.56	0.039	22	2.06	0.070
9	2.08	0.044	23	0.51	0.0042
10	0.59	0.0013	24	1.70	0.0015
11	3.47	0.0043	25	1.78	0.0093
12	1.45	0.0056	26	1.50	0.0014
13	3.58	0.00084	27	0.43	0.0013
14	1.92	0.00046			

Δ Units out of specification.

**Quiet 0.015 μ fd Capacitors
(with 3 ohms series resistance)**

2000 Hours

Exhibit X

Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A	Cap. No.	Dissipation Factor % D(MAX) = 6%	Leakage (μ A) I_R (MAX) = 1.0 μ A
1	2.20	0.0006	15	1.70	0.0008
2	0.76	0.0028	16	1.62	0.0014
3	2.45	0.043	17	3.70	0.0016
4	0.49	0.0012	18	1.94	0.0089
5	5.38	Δ 26.0	19	0.72	0.0081
6	3.02	0.0012	20	0.51	0.0165
7	1.80	0.0017	21	1.43	0.0275
8	1.66	0.042	22	2.03	0.069
9	2.11	0.047	23	0.71	0.0039
10	0.48	0.0012	24	1.71	0.0013
11	3.58	0.0049	25	1.82	0.005
12	1.50	0.0053	26	1.58	0.0015
13	3.47	0.0008	27	0.59	0.0011
14	1.91	0.0005			

Δ Units out of specification.

APPENDIX A
RESULTS OF DIODE DISSECTION
POST LIFE TEST DIODE ANALYSIS

INTRODUCTION

At completion of the life test all diodes still operating were re-screened for abnormal R.F. noise. Table A1 describes these noise level changes and explains how they relate to the manufacturer's maximum specifications.

This table shows that almost all diodes still operating are now quiet, which may explain why the curves (Figures 19 and 20) of units failed versus time on test became almost flat after 1000 hours. The noise sources possibly emanated from conditions which corrected themselves without destroying the diodes. It is interesting to note that three of the 80 quiet diodes still operating are now noisy. It is possible that the quiet diodes that failed catastrophically during life test became noisy prior to failure.

An effort was made to determine cause of the noise level changes and the reasons why some units drifted out of specification. Twenty of the diodes still operating were sectioned to display their junction regions. All of the diodes exhibiting noise at the end of the life test were included, plus noisy diodes which became quiet, and quiet diodes which stayed quiet. The diodes were numbered 1 through 20 for purposes of identification. Table A2 shows the categories the diodes fall into and the number assigned each in those categories. (See Figure 18 for reference to noise categories and quantities within each category.)

Table A1. Results of Re-Screening Life-Tested Diodes

Noise Category at the Start of the Life Test:	Number of Units Placed On Life Test	Hours on Life Test	Number Still Operating at the end of the Life Test	Noise Category at the End of the Life Test					
				Number Noisy			Number Quiet		
				Meet Specs.	Do Not Meet Specs.	Total	Meet Specs.	Do Not Meet Specs.	Total
Noisy	73	3000	49	2	3	5	34	10	44
Quiet	38	3000	25	0	2	2	20	3	23
Quiet	58	1750	55	0	1	1	45	9	54

Table A2. Quantity and Identification Number of Diodes Sectioned from Each Category

	Diodes Sectioned				
	No Longer Meet Max. Specifications			Still Meet Specifications	
	Type of Noise Displayed	Still Noisy	Now Quiet	Still Noisy	Now Quiet
	Noisy from start	1, 2		9, 10	11, 12
Noisy at start of life test	Noisy only for first several seconds	3	4		
	Noisy only after being energized for several seconds		5, 6 7		
	Noisy only after being shocked		8		
Quiet at start of life test		Now Noisy	Still Quiet	Now Noisy	Still Quiet
		13, 14 15	16		17, 18 19, 20

Figures A1 through A20 are photos of the sectioned diodes enlarged 75 times. Unlike the five diodes (Figures 3 through 7), sectioned prior to the life tests, great difficulty was encountered in sectioning these diodes. The silicon chips had become quiet brittle, resulting in some chipping and flaking of the silicon, which shows up on the photos. Diode 19 was shattered during the grinding operation.

SECTIONING RESULTS

Results of sectioning the 20 diodes went as follows:

Diode 1

The source of noise cannot be determined. Physically, the diode appears normal; if a defect exists it has either been cut away during sectioning or has not yet been reached. This diode has a very high leakage current.

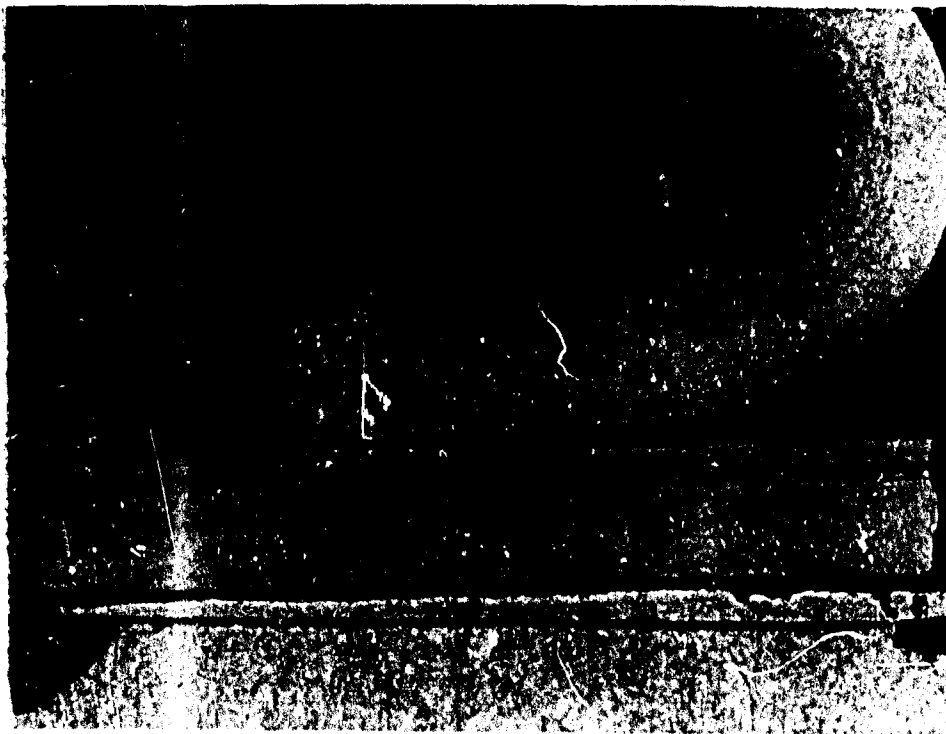


Figure A1. Diode 1

Diode 2

This diode, like diode 1 does not indicate why it is noisy or why it has a large leakage current.

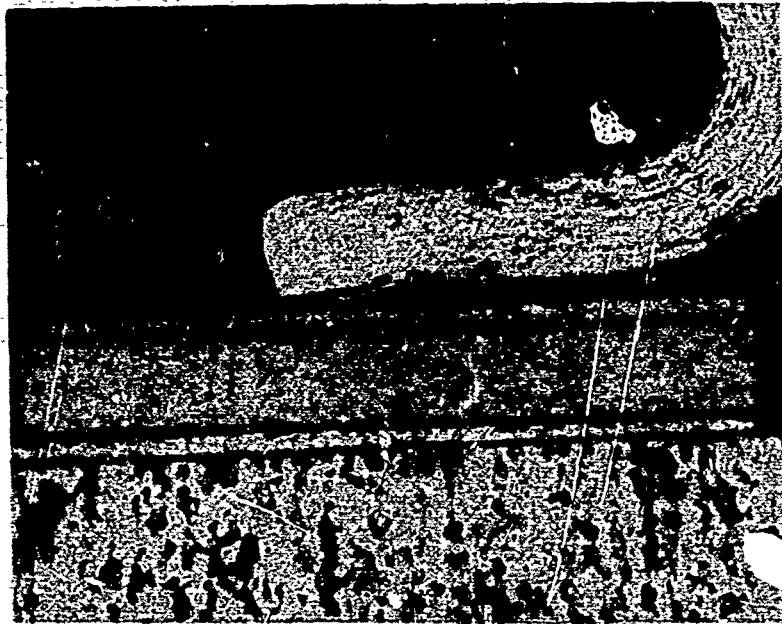


Figure A2. Diode 2

Diode 3

This diode, which was noisy for only a few seconds and then became quiet during the screening test, is again noisy. Bonding between the pedestal and chip is poor. The chips near the whisker occurred during sectioning.

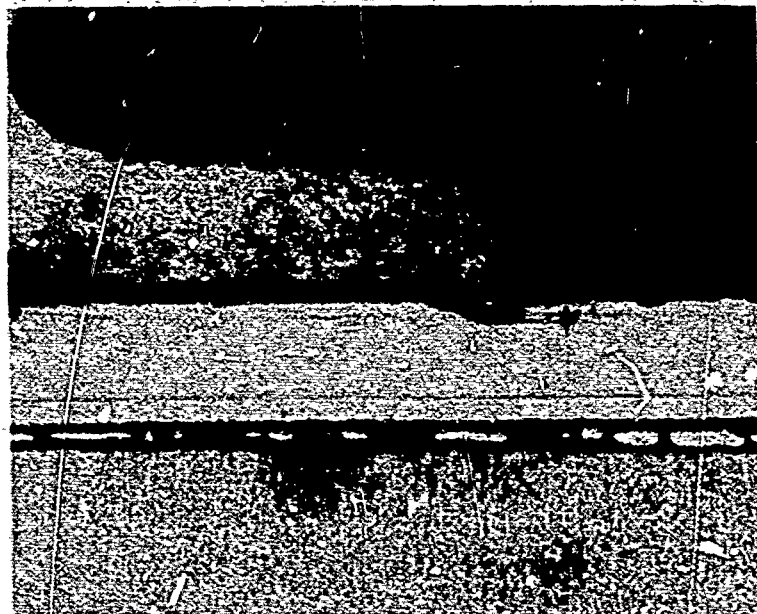


Figure A3. Diode 3

Diode 4

This diode, from the same category as 3 has stayed quiet. However, it does not indicate why it was at first noisy or why it developed a high leakage current which is now normal. The small fractures near the whisker were caused by the sectioning.

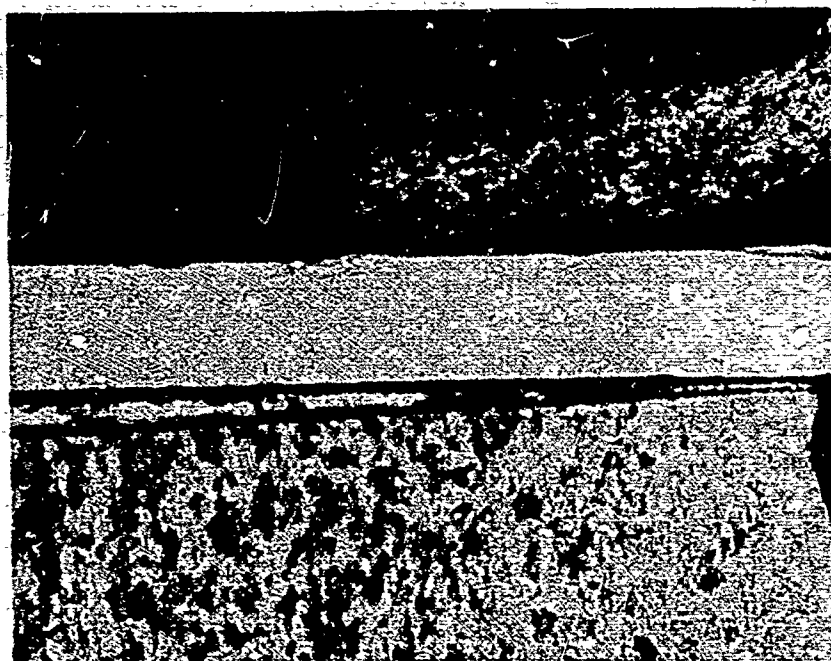


Figure A4. Diode 4

Diode 5

This diode, now quiet, appears normal. It developed a high leakage current only after more than 2000 hours of operation. The chipping and flaking occurred during the sectioning.

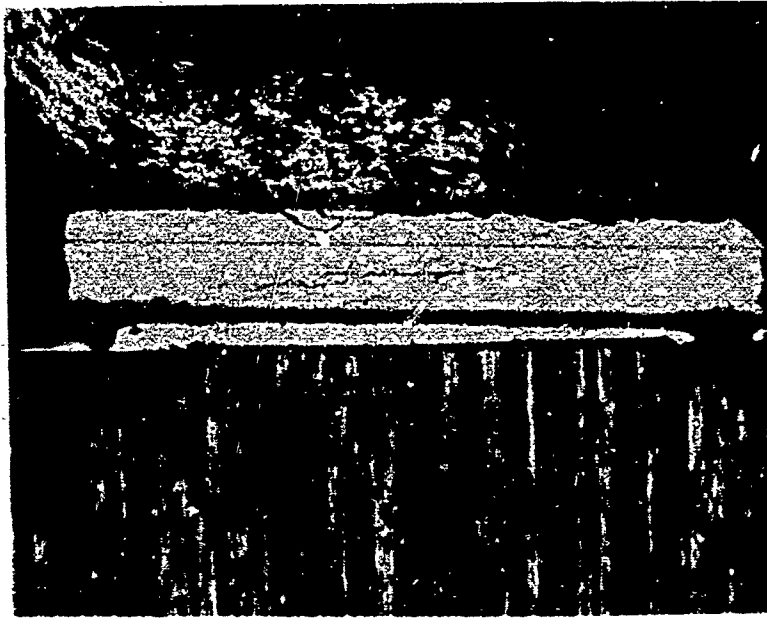


Figure A5. Diode 5

Diode 6

This diode, although now quiet, has a poor bond between the whisker and the silicon. The poor bond is easily visible when magnified 500 times. Here again, the voids on the top of the silicon chip were caused by the sectioning.

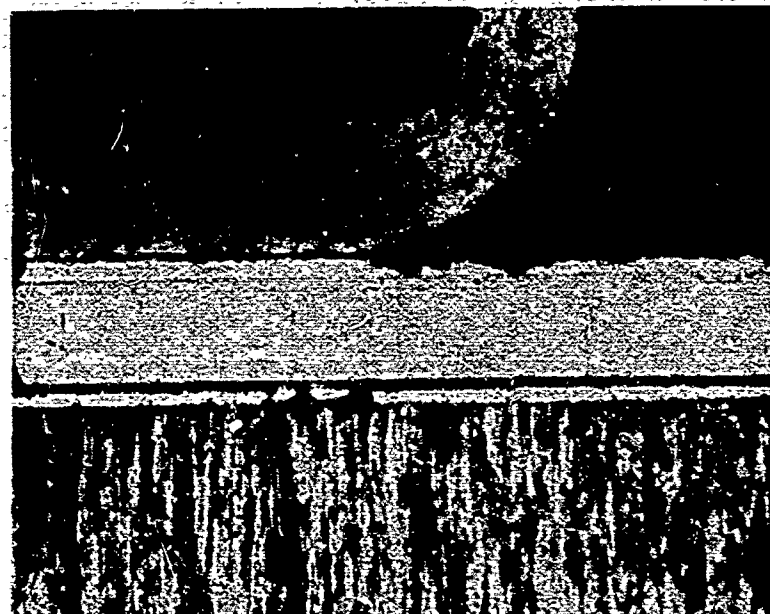


Figure A6. Diode 6

Diode 7

This diode, also now quiet, has a very poor bond between the silicon and the pedestal and has a high leakage current.

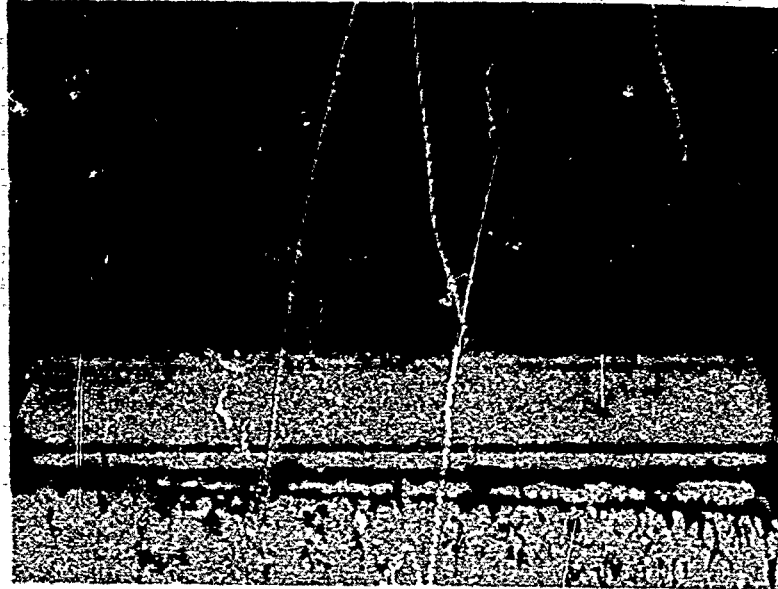


Figure A7. Diode 7

Diode 8

This diode first exhibited noise when subjected to mechanized shocks, but has now become quiet. The sectioned photo shows a very large void between the silicon and the pedestal. This diode has a high leakage current.

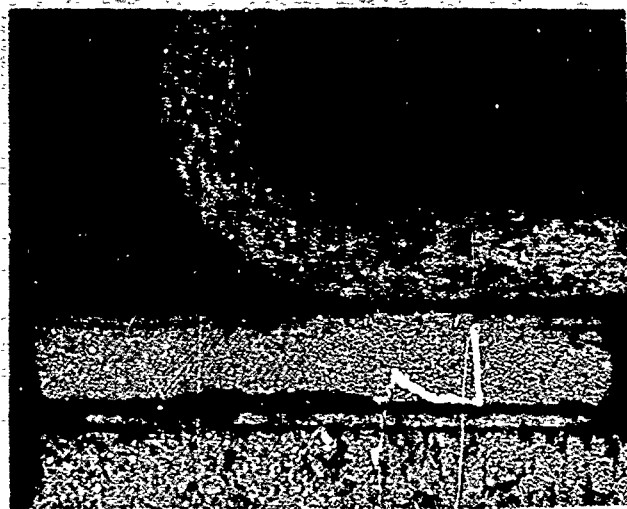


Figure A8. Diode 8

Diode 9

This diode is still operating within specifications and is still noisy. Like diode 6, it has a poor bond between the whisker and the silicon. This diode also had high $1/f$ noise.

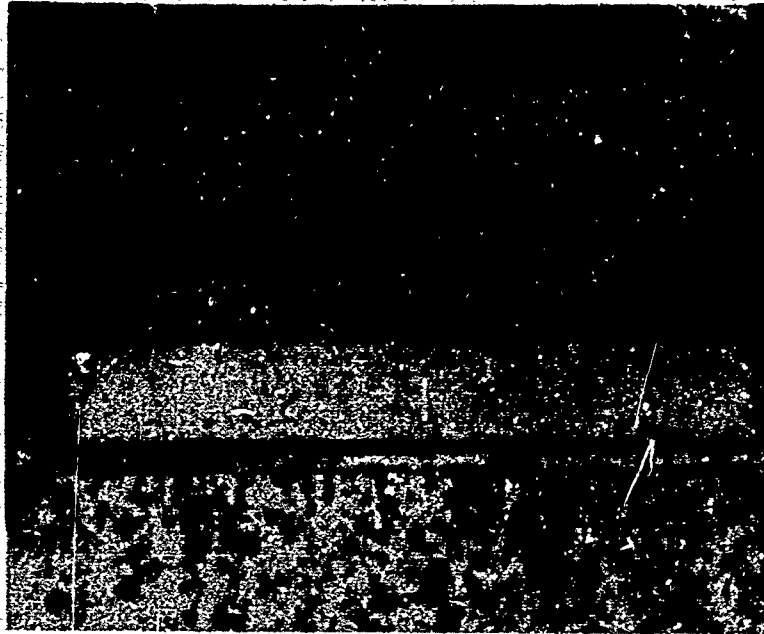


Figure A9. Diode 9

Diode 10

This diode is still noisy but operating within specifications. The cause of noise is not apparent from the sectioned view.

- A10 -

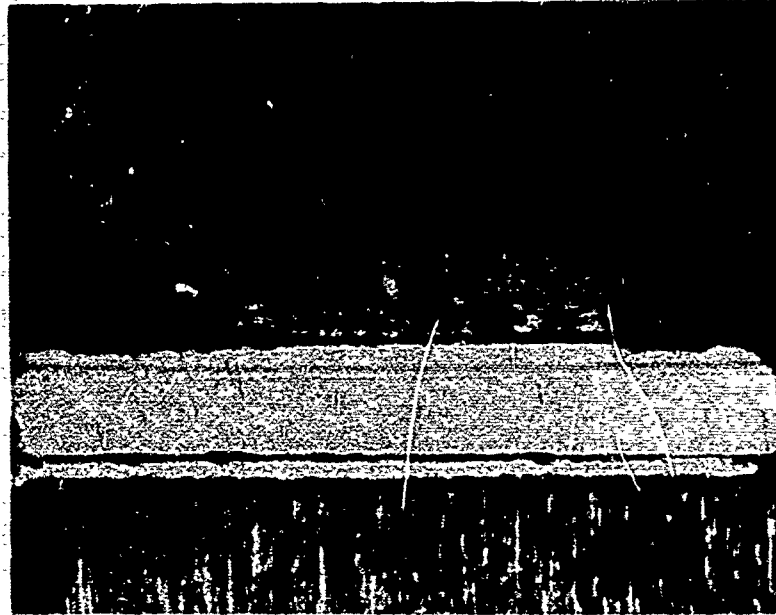


Figure A10. Diode 10

Diode 11

This diode is now quiet and operating within specifications. The large void and fractures in the silicon occurred during sectioning. Except for these, the diode appears normal. This diode also exhibited high $1/f$ noise prior to the life test.

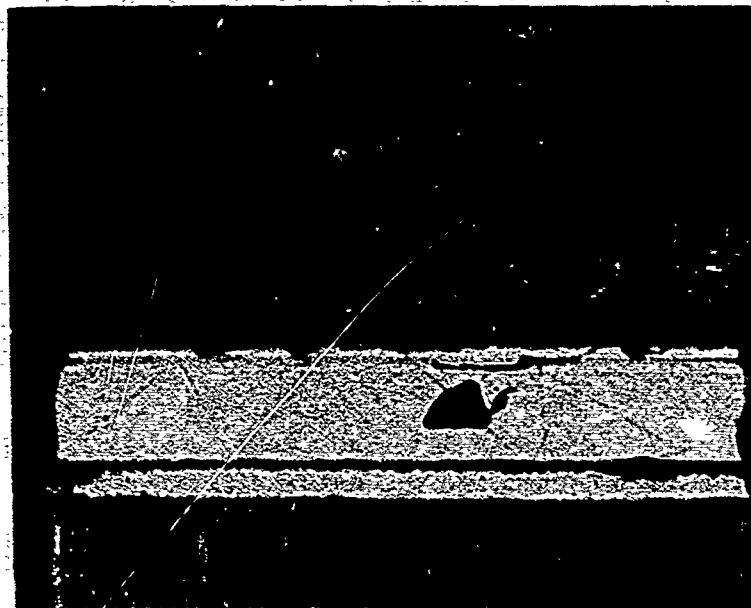


Figure A11. Diode 11

Diode 12

This diode also appears normal. The original cause of noise cannot be determined.

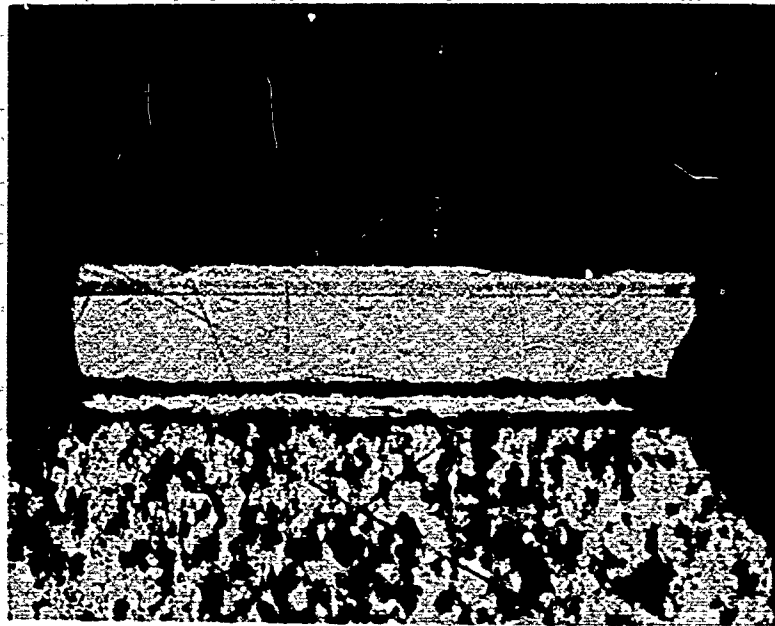


Figure A12. Diode 12

Diode 13

This diode, taken from the quiet group, suddenly developed a high leakage current after 3000 hours of operation and is now noisy. It has a poor bond between the whisker and the silicon which cannot be seen in the photo. The shortened view of the whisker is due to sectioning at a slight angle to the whisker, and is not a defect.

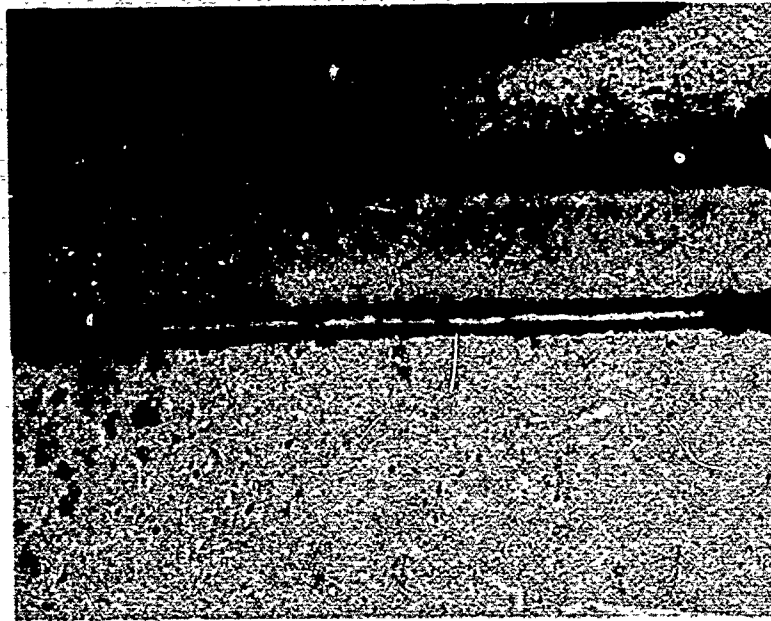


Figure A13. Diode 13

Diode 14

This diode is now noisy and has a high leakage current. It has a very poor bond between the whisker and the silicon which cannot be seen on the photo. Also, this diode has abnormally thick bonding between the silicon and the pedestal.

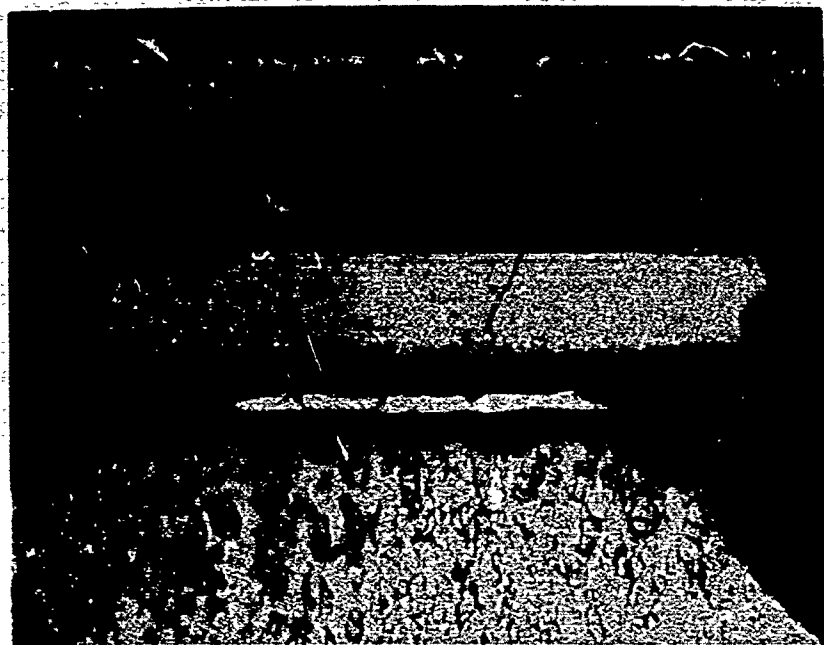


Figure A14. Diode 14

Diode 15

This diode is one of the quiet diodes added at midpoint in the life test. It is now noisy and has a high leakage current. The bonding between the silicon and the pedestal is poor and has several large voids.

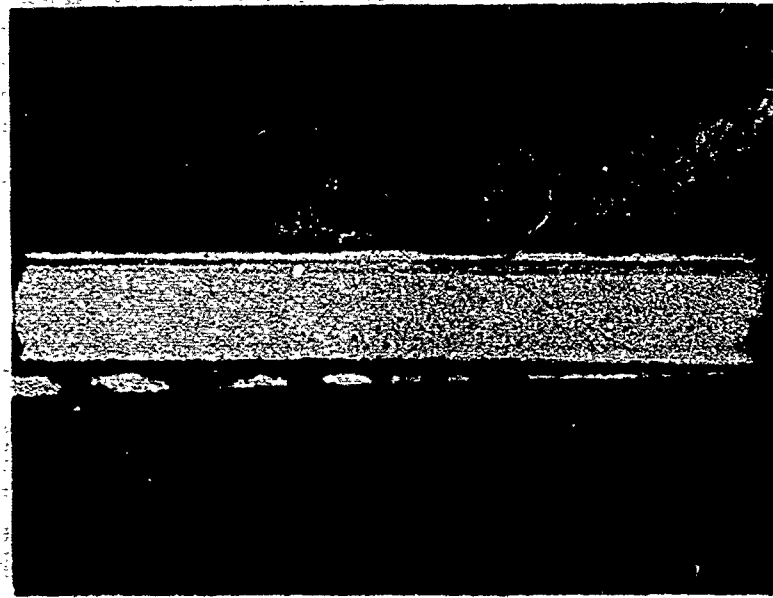


Figure A15. Diode 15

Diode 16

This diode has a very high leakage current but is still quiet and appears normal. The flaking and fracture in the silicon occurred during sectioning.

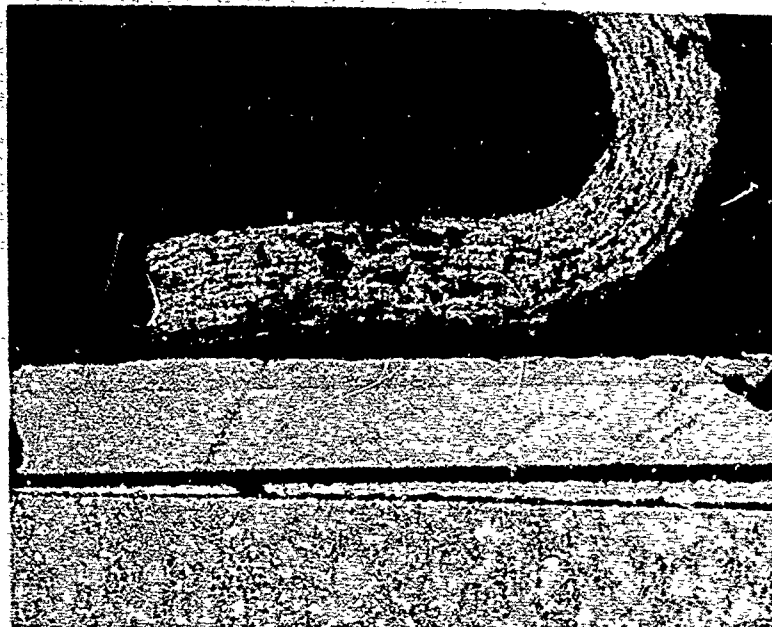


Figure A16. Diode 16

Diode 17

This diode is still quiet and meets all specifications.

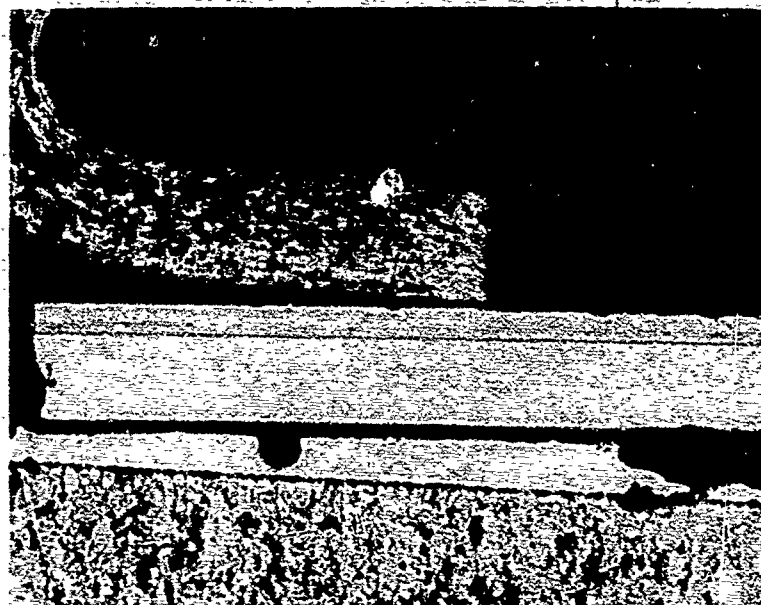


Figure A17. Diode 17

Diode 18

This diode is still quiet and meets all specifications.

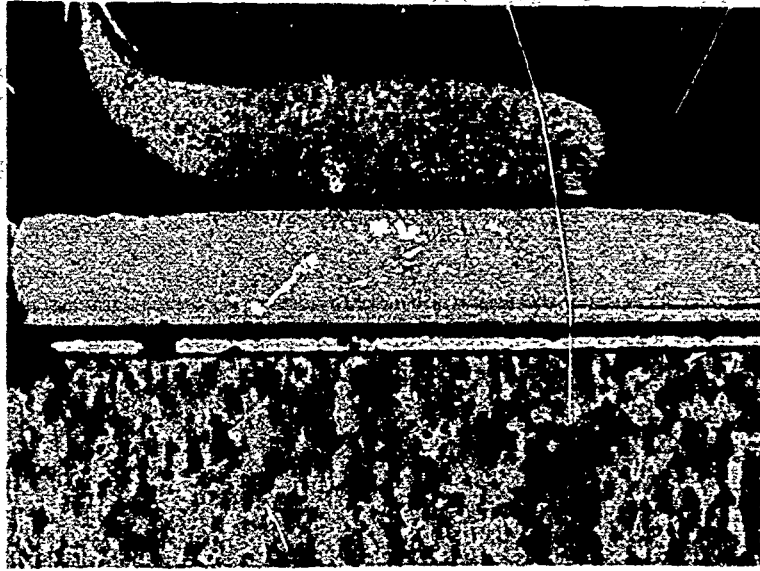


Figure A18. Diode 18

Diode 19

This diode was fractured during sectioning. It was quiet and met all specifications in spite of the large voids in the bonding between the silicon and the pedestal. It is not known why this seemingly poor bonding had no effect on the diode's operation and noise level. It is possible that the voids are not wide-spread and that an adequate total bond exists.

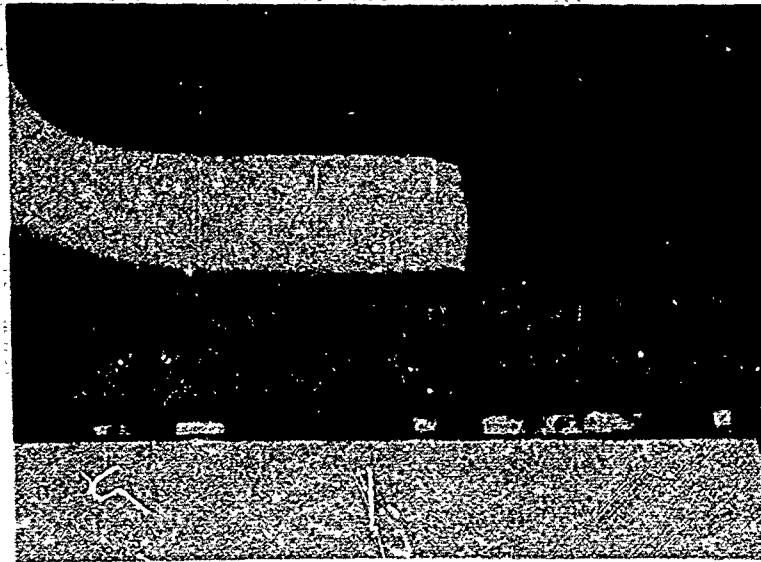


Figure A19. Diode 19

Diode 20

This diode, like 19, is a paradox. The sectioned view of the bonding between the silicon and the pedestal indicates a very poor bond. However, this diode is still quiet and meets all specifications.



Figure A20. Diode 20

CONCLUSIONS

In examining the sectioned views of all 20 diodes, it is difficult to make a definite conclusion regarding noise sources and causes of poor operation. Sectioning as a means of analysis did not provide all of the answers as physical defects may have been hidden or cut away. Conversely, defects shown may not be as gross as indicated and might disappear with less or deeper penetration of the sectioning.

Since only five of the remaining 49 noisy diodes are still noisy the noise sources in these cases were transient in nature and cleared up during operation without destroying the diodes. The noisy diodes that failed catastrophically obviously had noise-producing faults that eventually led to their destruction. Note the quiet diodes that are now noisy and the faults found in their sectioned views. It is entirely possible that the quiet diodes which failed catastrophically developed noise from incipient faults not detected during the screening test.

APPENDIX B OPTIMIZATION OF RF NOISE MEASURING TECHNIQUE

DIODES

Presented here is a report of the experimental procedures used to maximize the output of the test circuit shown below.

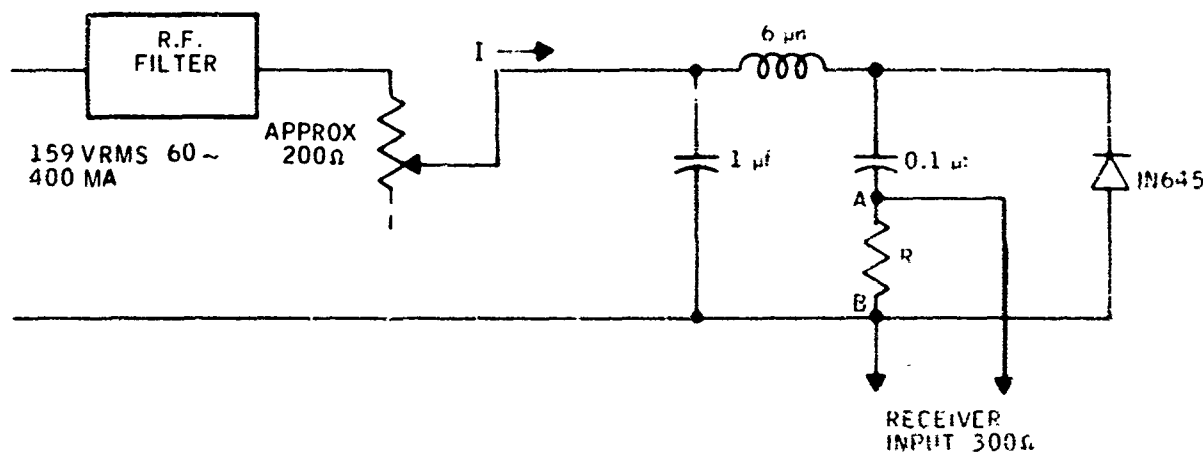


Figure B-1. Test Circuit

To optimize the output of this circuit, it is necessary to determine which impedance across terminals A-B draws maximum power from the circuit. Then, if a receiver with this input impedance is used, its output power is a maximum for any given gain.

To find the optimum impedance, a National HRO "60" receiver was connected across R and its output set to zero db with the 60-cycle excitation shut off. Then, the 60-cycle excitation was applied and the receiver output voltage measured as a function of R. This was done with the input current I set to a d-c value of 400 ma, and the Table B-1 results were obtained.

Table B-1. Receiver Output in Volts,
As a Function of R

<u>Resistance</u>	<u>1M</u>	<u>100K</u>	<u>10K</u>	<u>1K</u>	<u>100</u>	<u>15</u>	<u>0</u>
Diode #61	1.6	1.6	1.6	1.6	1.5	1.3	1.0
Diode #35	1.2	1.2	1.2	1.0	0.9	0.9	0

Voltages were measured at the output of the receiver and are related to v_{AB} by $v_o = K v_{AB}$, where K is the voltage gain of the receiver, and v_{AB} is the voltage across resistor R. Power delivered to terminals A-B was then calculated by

$$P = \frac{(v_o/K)^2}{\frac{R R_{in}}{R + R_{in}}} \quad \text{where } R_{in} \text{ is the receiver input resistance (300 } \Omega \text{).}$$

Power calculated by this method is plotted in Figure B-2 as a function of R for diodes #35 and 65. On this graph, $R_{eq} = R R_{in} / R + R_{in}$. This data did not lead to any useable conclusion.

The next approach used a transformer for impedance matching. Two available transformers were tried first. They were wound on a Q-3 ferrite, toroidal core, and had Faraday shielding. One had 15- and 30-turn windings, the other had 8- and 40-turn windings. It was found that a significant increase in output occurred when the transformers were connected so as to increase the impedance into which the test circuit was working. The largest increase of output occurred with a 40-turn primary and 8-turn secondary. With diode #61, this gave an output of 36v; whereas, with direct coupling (no transformer) output was 1.6-1.7 v (6-7 db). For each case, gain was set so that output was 0.85 v (0 db) when the diode was unexcited. This gain was higher with the transformer coupling, and unexcited noise was lower. Next,

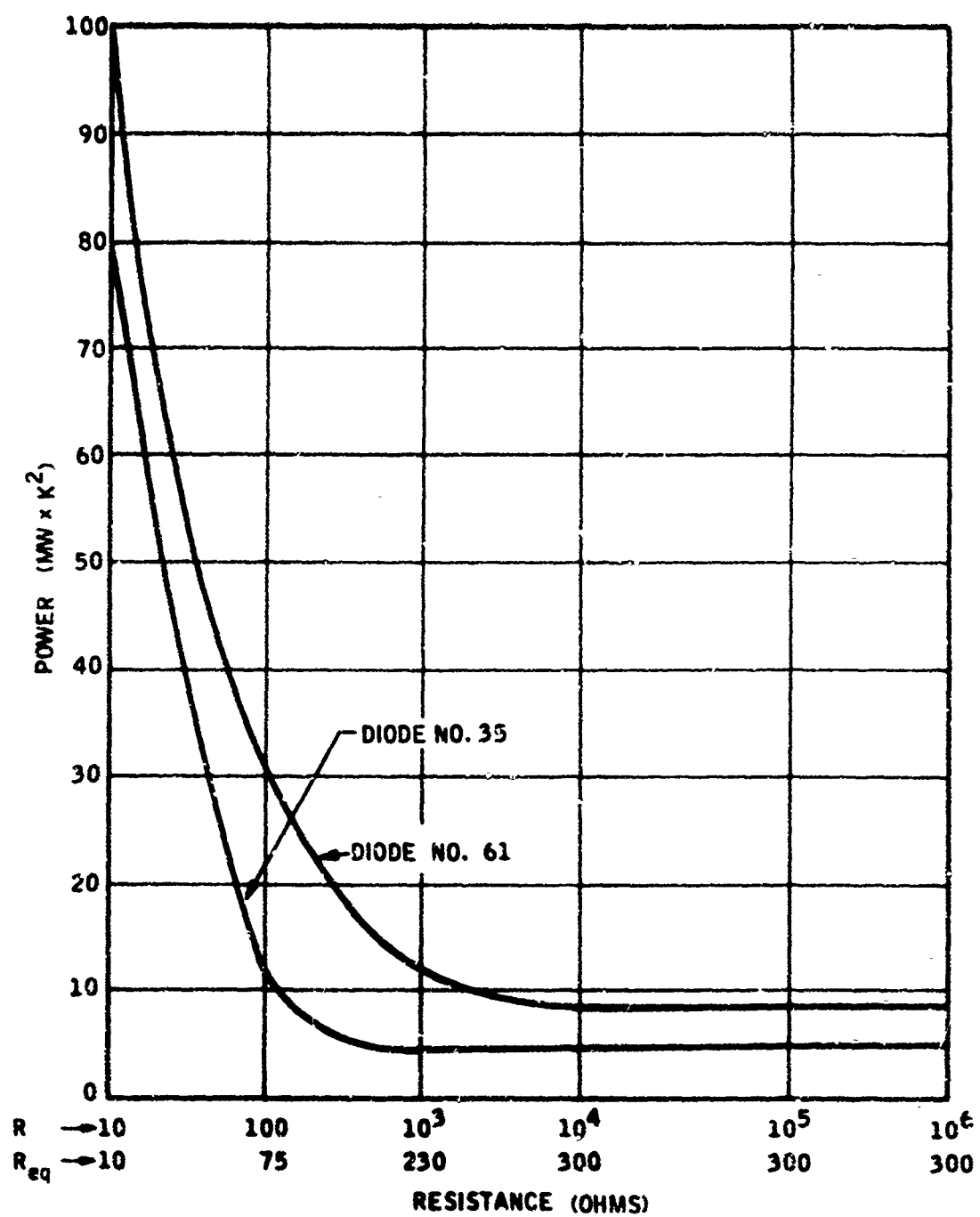


Figure B-2. Detected Power as a Function of Resistance

an attempt was made to determine the optimum turns ratio. Several toroids were wound with various turns on the primary. Then, secondary turns were varied. Results are plotted in Figure B-3.

Optimum turns ratio seems to be about 8:1, but none of the coils give as large an output as did the coil with the 40-turn primary and 8-turn secondary (33v). This, however, seems to be due to some characteristic of the coil other than its turns ratio -- probably its low leakage inductance. Figure B-3 shows that, as the number of primary turns, and hence, transformer inductance, decreased, maximum output increased. This seems to indicate that a transformer with a turns ratio of 8:1, and as low an inductance as possible, would give optimum results. Figure B-4 shows the final test circuit.

For comparison, transformer coupling techniques were tried with the Empire NF105 receiver at the screening test station. Using the same 8:1 transformer, the receiver output decreased by 6 db. Other ratios running from 1:1 to 18:1 resulted in an even greater loss of output. The direct coupling method employed for screening parts provides optimum power transfer with the NF105 receiver used.

The advantage that this transformer coupling provides is that it allows similar results to be obtained with a less expensive receiver.

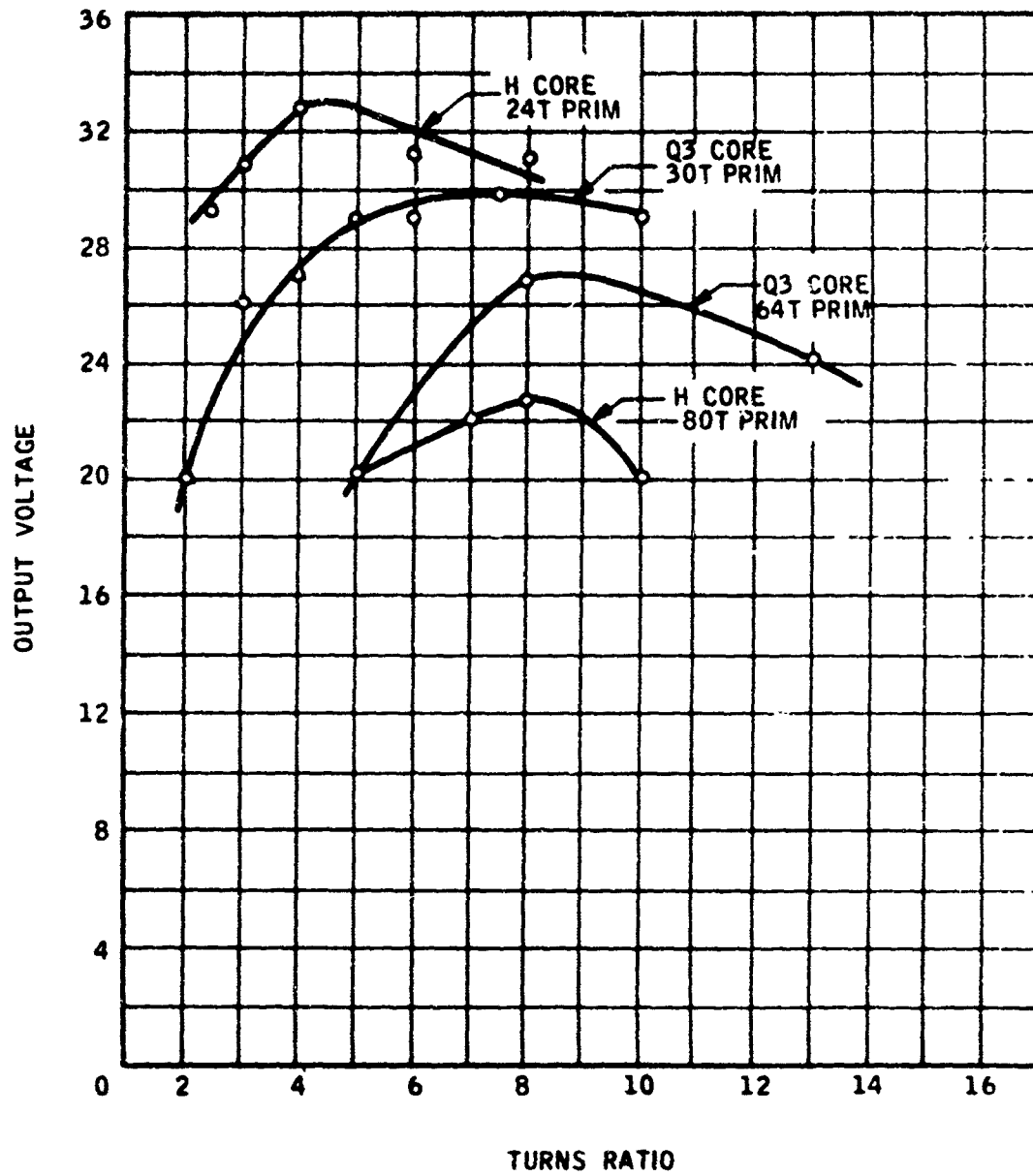


Figure B-3. Transformer Output Voltage as a Function of Turns Ratio and Core Material

- B6 -

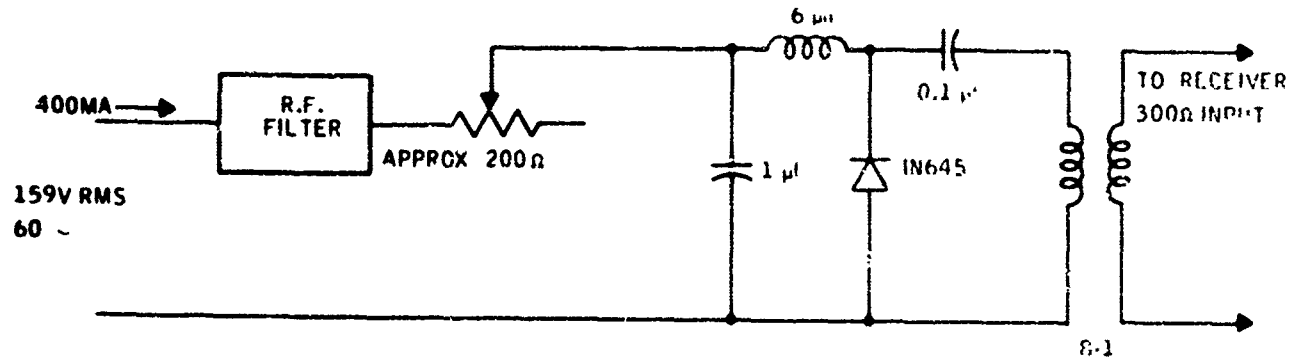


Figure B-4. Final Test Circuit

CAPACITORS

An attempt was made to optimize a test circuit for detecting capacitor noise. The following circuit, Figure B-5, was tried first.

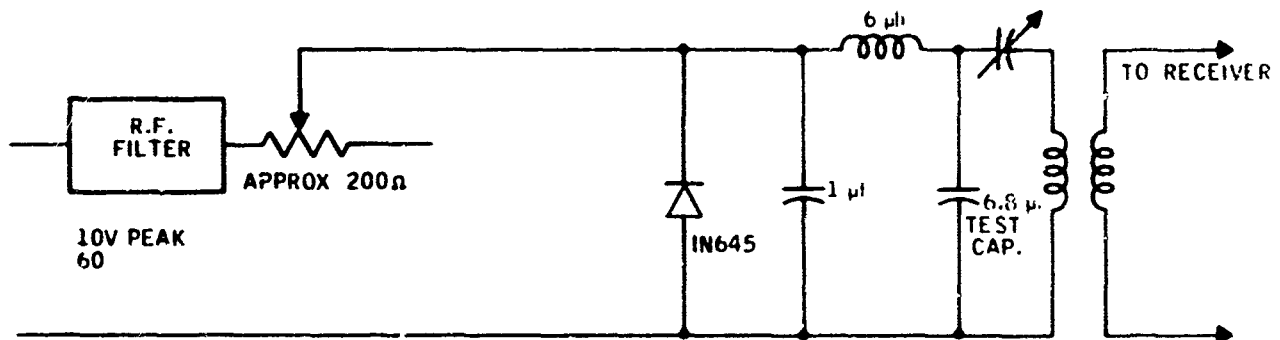


Figure B-5. Test Circuit

With this circuit, voltage across the test capacitor was as shown in Figure B-6.

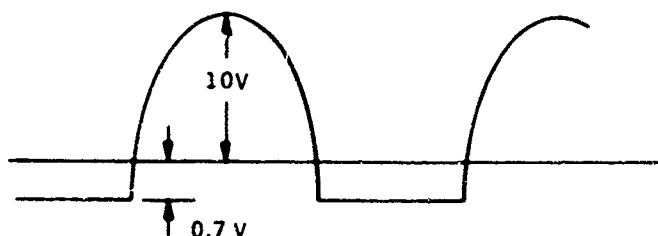


Figure B-6. Voltage Waveform Applied to Capacitor Under Test

No capacitor noise was detected with any of the transformers tried. However, when capacitors were driven to breakdown, noise was detected with direct coupling (no transformer). When transformers with ferrite cores were used as coupling, no noise was detected.

An air core transformer was tried with various turn ratios, the circuit tuned to 25 mc, using the variable capacitor in the primary circuit. The largest output observed with this type of coupling was approximately equal to that observed with direct coupling. This was with a turns ratio of 1:1. No readings were recorded, since the capacitor could be kept in breakdown only 2-3 seconds without overheating. Also, the readings were not consistent.

An attempt was made to simulate the noise source, thus avoiding the necessity of breaking down the capacitors. Since the 6.8 μ f capacitor has such low impedance at 25 mc (9.4×10^{-4} ohms), it was thought that a parallel signal generator would not disturb circuit impedance and would allow matching and tuning.

Using the circuit in Figure B-7, the signal generator was set so that the 330 Ω resistor had 2 mv across it. Then, various coupling schemes were tried in an attempt to improve this output.

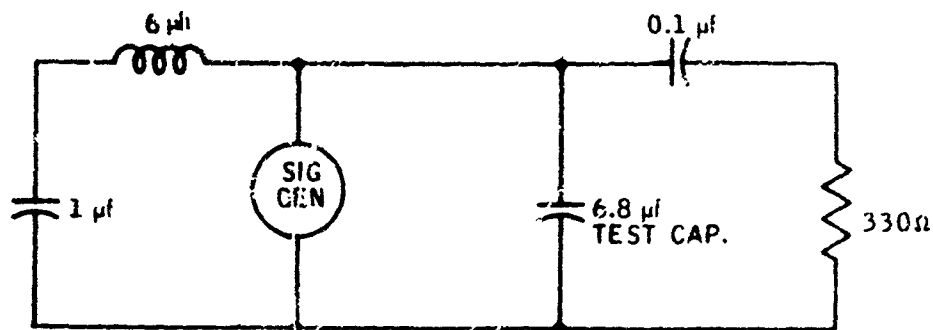


Figure B-7. Test Circuit

Signal generator output impedance is 37 ohms. To couple the load to the test circuit the following scheme was used (Figure B-8).

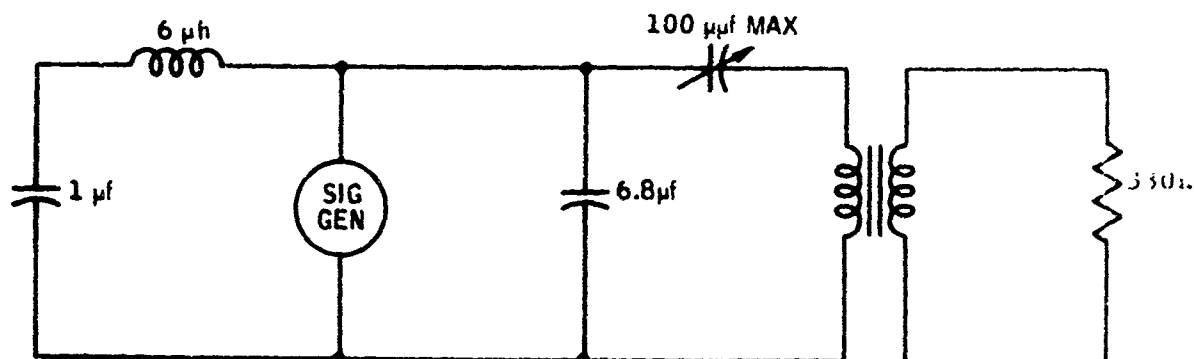


Figure B-8. Coupling Scheme

First, an air core transformer with an 8-turn primary and 40-turn secondary was tried. This gave an output of 2.3 mv when the primary circuit was tuned. With the turns ratio reversed, output was 1 mv. Next, a 20-turn primary and a 40-turn secondary was tried. Output was 2.1 mv with the circuit tuned. A

20-turn primary and 100-turn secondary gave an output of 5.6 mv with proper tuning. This last coupling arrangement was tried with the original excitation and receiver, but no noise was detected until the capacitor broke down. Noise output was not as great as that observed with direct coupling, and no improvement was observed when both the primary and secondary of the coupling transformer were tuned.

Finally a tuned circuit without a transformer was tried (Figure B-9).

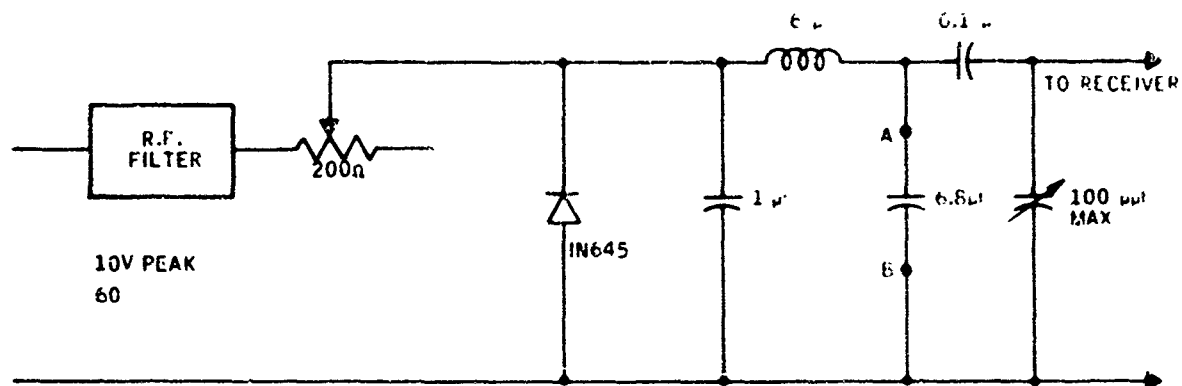


Figure B-9. Tuned Circuit Without Transformer

This circuit did not demonstrate any significant increase in noise level.

Alternate Capacitor Circuits -- To detect noise generated by a capacitor, it was thought that placing the capacitor in a marginally stable circuit might result in erratic behavior of the circuit, and would be an indication of noise in the capacitor. A monostable, multivibrator circuit was tried first. The circuit shown in Figure B-10 was found to be very sensitive to extraneous noise and by adjusting the potentiometer, it could be made to operate very near its switching point. The switching rate of the circuit was different for different capacitors; it was not affected by size of the test capacitor, but it was affected by leakage current of the capacitor.

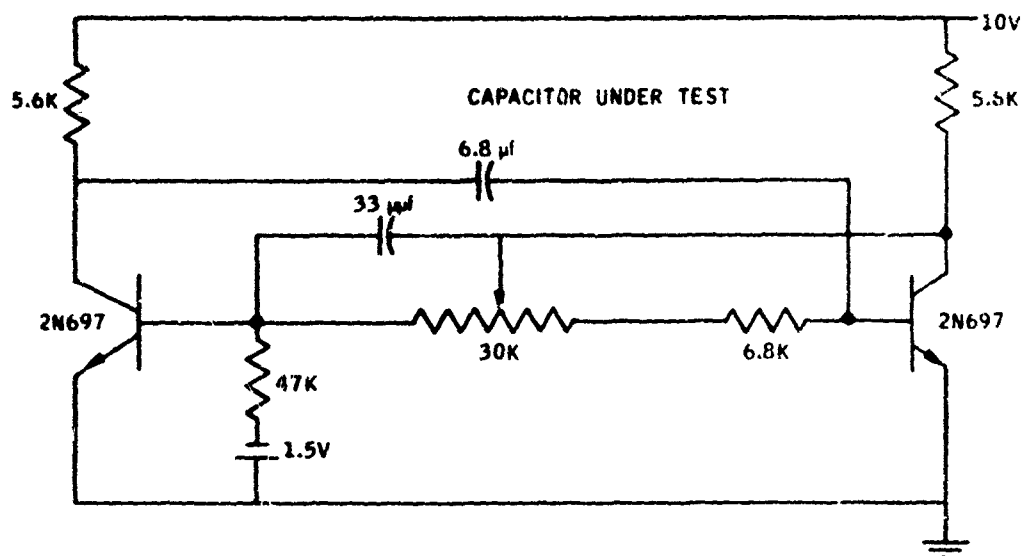


Figure B-10. Monostable Multivibrator Test Circuit

The operating point of this circuit tended to drift quite rapidly. In an attempt to overcome this difficulty, the circuit of Figure B-11 was tried. This circuit has a more stable operating point, but was less sensitive to differences between capacitors. The switching rate still seemed to be related to leakage current of the capacitor, however, there was not an exact correlation. Although it was not determined whether noise generated by the capacitors was the primary factor affecting switching rate, the circuit, in any case, was extremely sensitive to ambient noise.

The Schmitt trigger shown in Figure B-12 was also tried as a possible method of detecting capacitor noise, but it could not be made sensitive enough. Several of the circuit parameters shown were varied. in an attempt to increase sensitivity. However, the switching threshold of about one millivolt was too high to be excited by capacitor noise.

- B11 -

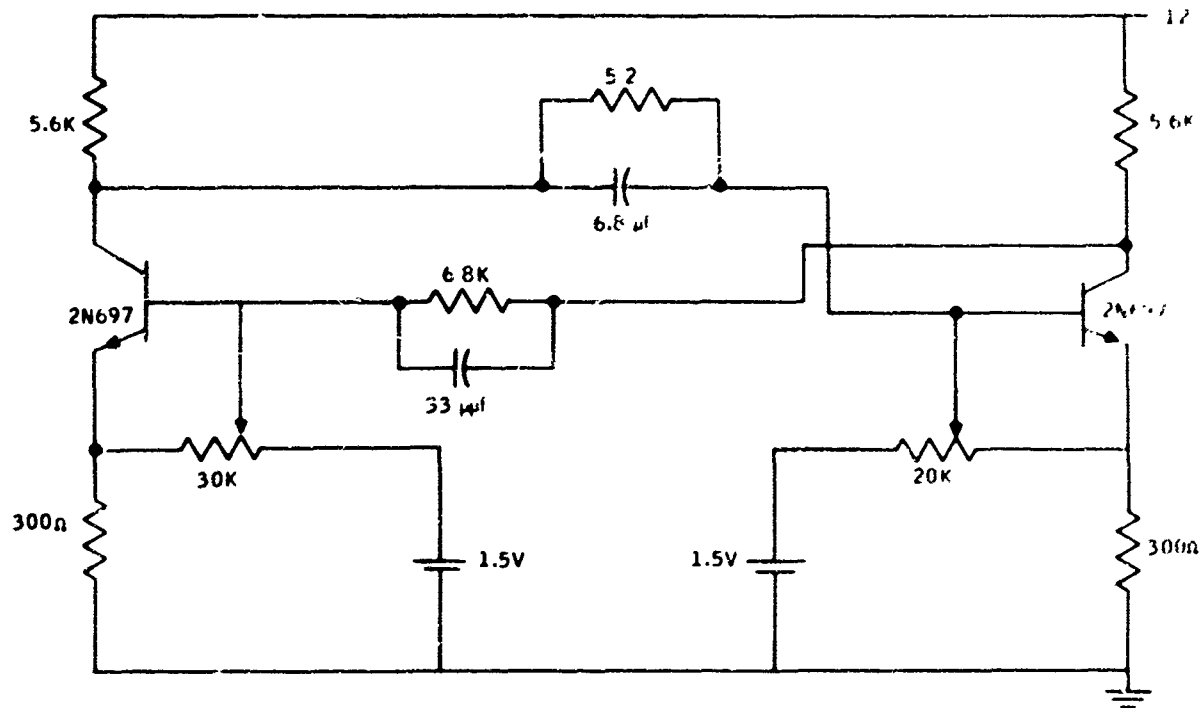


Figure B-11. Second Monostable Multivibrator Test Circuit

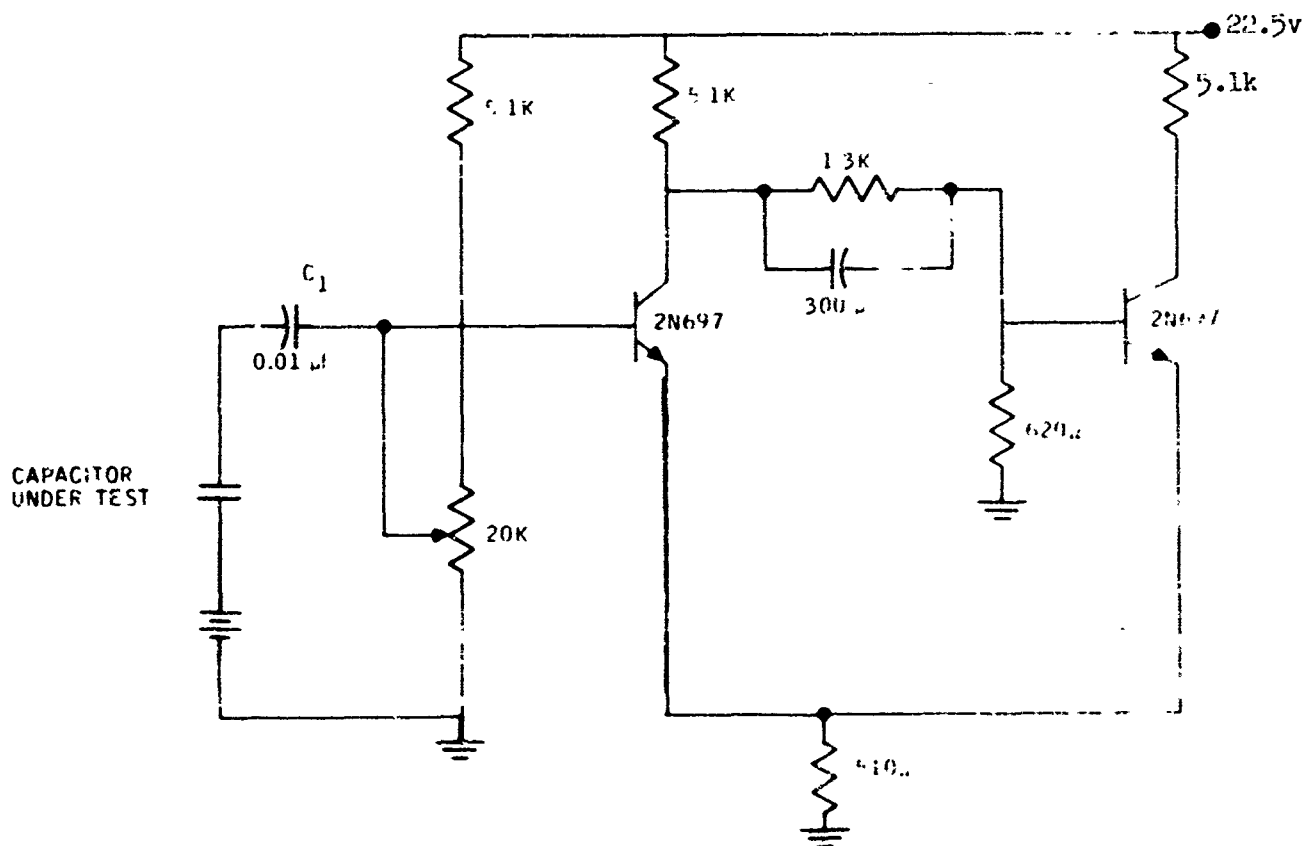


Figure B-12. Schmitt Trigger Test Circuit

The tunnel diode circuit of Figure B-13 was tried and was found to be very sensitive; but the switching point (see Figure B-14) of the diode drifted too much to make the circuit practical. The 1N2941 Germanium tunnel diode displayed about five millivolts of drift in the voltage at which the diode approached the negative resistance region.

Since the 0.015 μ f capacitors seemed to generate noise of greater intensity under mechanical stress, it was attempted to vibrate the capacitor and measure the resulting noise with the "HRO 60" receiver. The capacitors were vibrated at 20 KC in an ultrasonic cleaner. All but two of the capacitors checked gave about one volt, approximately 3 db, increase in noise output when voltage was applied during capacitor vibrations. The other two capacitors (3A and 4A) behaved more erratically and gave a larger increase in noise output.

It is known that tantalum capacitors have small breakdowns occurring in the oxide layer, even when operated within the rated voltage. These breakdowns should be a source of noise. However, attempts to detect this noise,

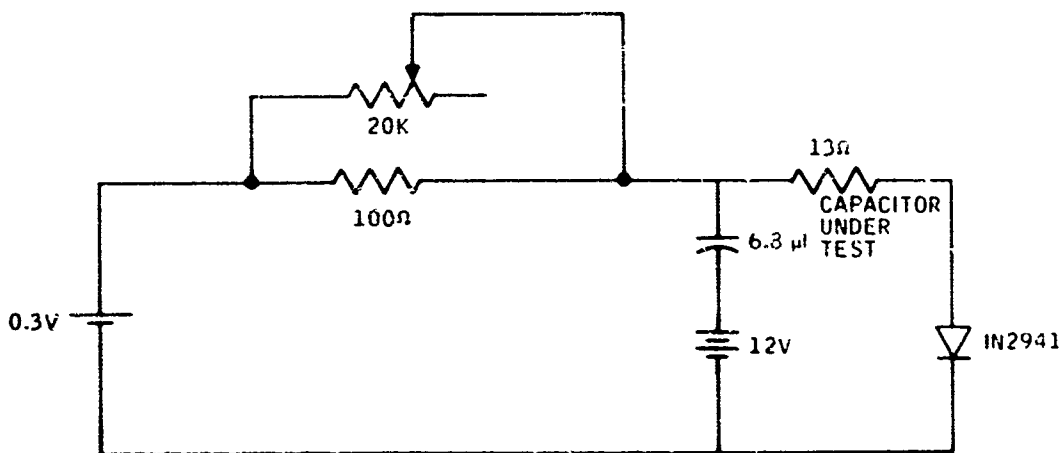


Figure B-13. Tunnel Diode Test Circuit

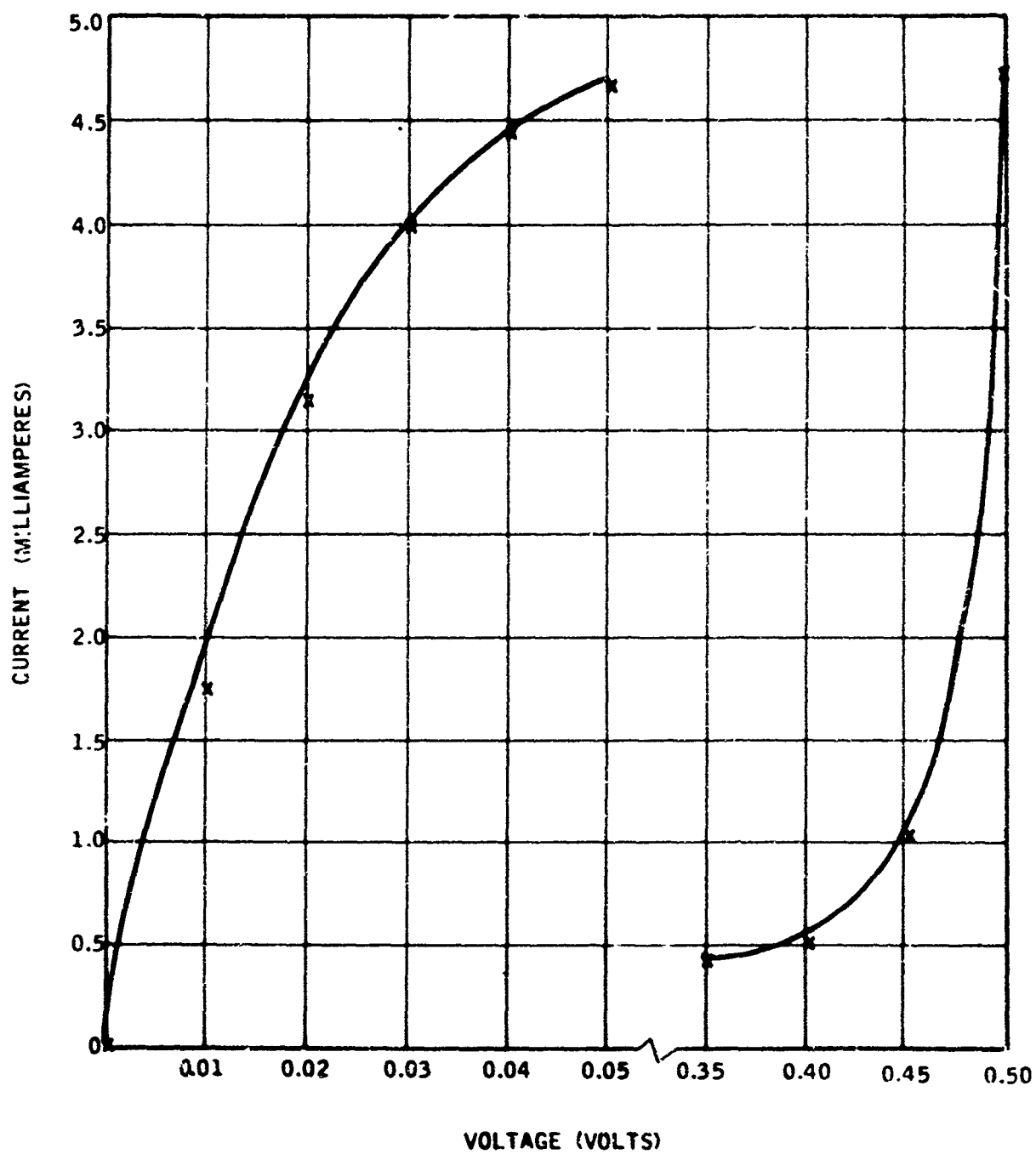


Figure B-14. Current-Voltage Characteristics of a IN2941 a-c Tunnel Diode

using the HRO 60 radio receiver, have not been successful unless components are subjected to mechanical stress. In an effort to increase the capacitor noise signal at the receiver input, a preamp was tried. This amplifier, shown in Figure B-15 has few components, and a current gain of about 5000. The voltage source in series with the test capacitor can be varied to put rated voltage on the capacitor. Any breakdowns occurring in the capacitor should cause current fluctuations in the base current of the first transistor and be amplified at the receiver input.

When the circuit shown in Figure B-15 was used in conjunction with the radio receiver, it was found that there was an increase in noise output when bias voltage on the capacitor was increased. Further investigation showed that leakage current through the capacitors changed the operating point of the transistors, and a portion of noise increase was due to transistor noise, which increased as transistor bias current increased. An attempt was made to determine how much noise was actually due to the capacitor, by placing an RF filter between the test capacitor and the amplifier input, as shown in Figure B-16. Data from this test (see Table B-2) seems to indicate that at least some noise was due to the test capacitor, since noise output usually increased when the RF filter was removed. Also, when the same transistor bias point was obtained by replacing the capacitor with a large resistor, noise level was lower. To show the effect of increasing bias voltage across the capacitor, noise outputs recorded for various 0.015 μ f tantalum capacitors and three large resistors with a 22-1/2 volt bias applied to the component are also shown in Table B-2.

Capacitance and conductance of several tantalum capacitors were measured on a Wayne Kerr bridge Model B 221 which applies a low level a-c signal (1592 cps, 80 mv) to the component under test. Conductance with this a-c signal was somewhat higher than conductance observed with a large d-c bias (10-20 volts).

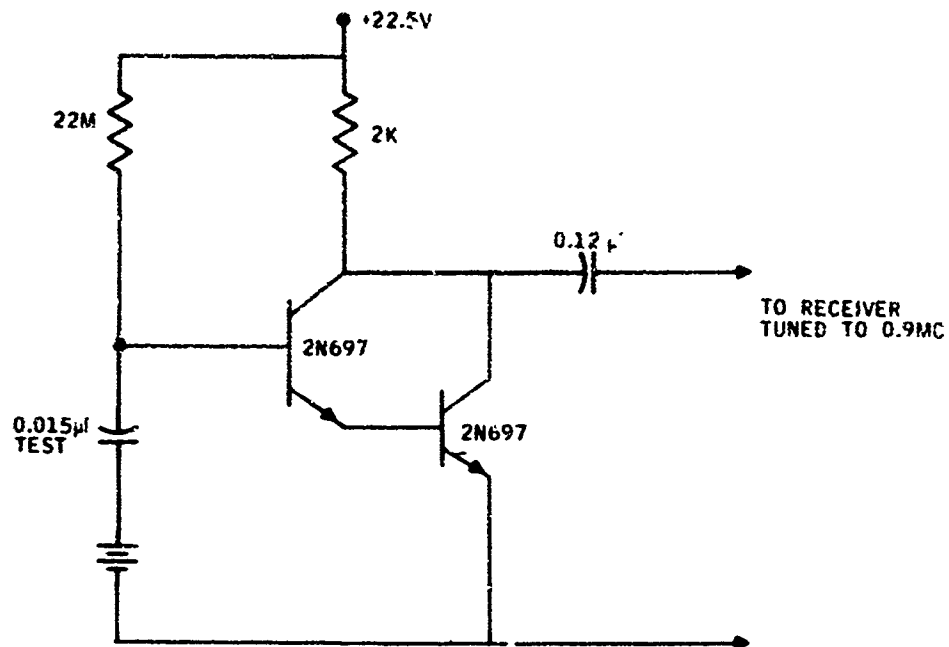


Figure B-15. Receiver Preamplifier Test Circuit

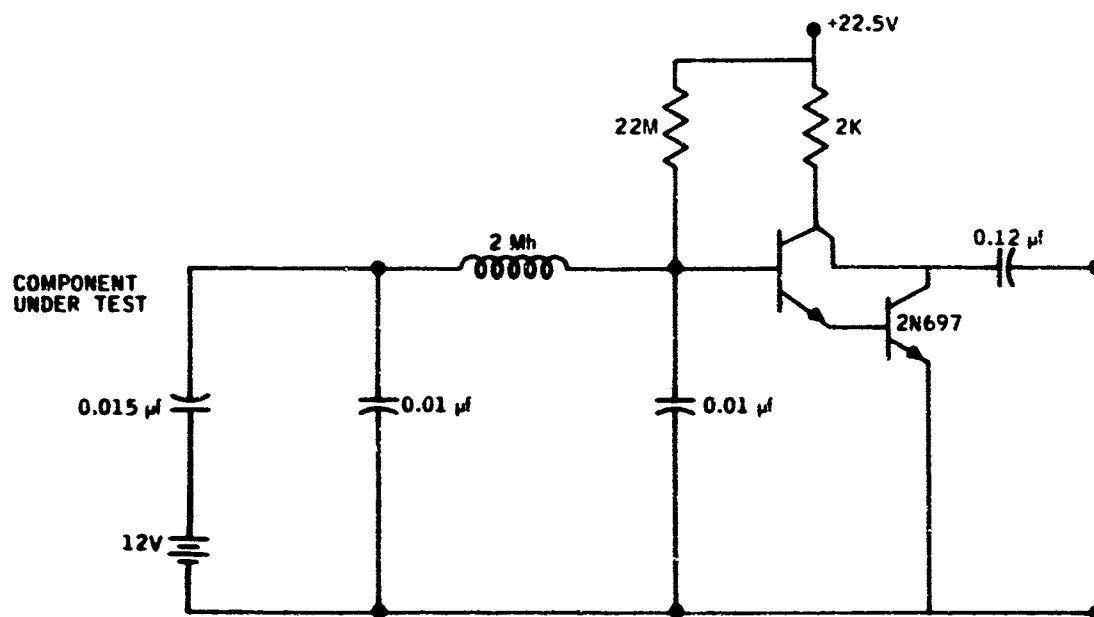


Figure B-16. Receiver Preamplifier Test Circuit with RF Filter

Table B-2. HRO Receiver Tuned at 900 KCPS

Component	12-1 1/2 Volts Bias on Test Component			22-1 1/2 Volts Bias on Test Component		Capacitance and Conductance at 1592 cps	
	Collector Volts	Noise Output with RF Filter	Noise Output minus RF Filter	Collector Volts	Noise Output minus RF Filter	Capacitance	Conductance
None	19 v	5 v	5 v				
5M wire wound resistor	6	10	6.5	1	2.5	Inductive	0.2004 μ mho
10M carbon composition	12	8.25	6.5	5	6.5	1.475 μ f	0.1090
22M carbon composition	16	6.5	6	12.5	7.0	1.30 μ f	0.10516
0.015 μ f Tantalum Wire Capacitors							
B I	17	6	7	11	11	0.01515 μ f	6.20
B G	17.5	5.5	6.5	10	10	0.01353	0.70
B D	13.5	8	9.5	2	12.5	0.01187	3.75
B F	10.5	8.75	10	1	8	0.01211	9.40
A E	14	7.25	9	7.5	12	0.00806	3.30
B C	17.5	5.75	6.5	16	7.5	0.01216	0.85
B A	18.5	5.5	6.5	16	7.5	0.01596	1.02
B H	19	5	5	18.5	5.5	0.01282	4.45
6.8 μ f Sintered Tantalum Capacitors							
C J	18	5.5	6				
C G	17	6	7				
C A	17	6	6.5				
C H	18	5.5	6				
C B	17	6	7				
0.0056 μ f Ceramic							
0.0056	19	5					