The Lenkurt Demodulator

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Basic Concepts of

ENGINEERING RELIABILITY

There are many basic factors which must be considered in the design and development of communications and electronics equipment. Among them is the subject of reliability which has, in recent years, acquired a very distinct meaning. Indeed, reliability has grown into a full-fledged engineering discipline, complete with mathematics and its own special jargon. Its aim is to assure the success of a product through a scientific program of performance evaluation, statistical analysis and prediction. This article discusses some of the fundamental aspects of reliability, including such related subjects as quality control and human engineering.

The demand for high quality and reliable products has always been an important consideration in the development of communications systems. To meet this demand, most commercial manufacturers have, over the years, developed very stringent engineering standards and quality control procedures to assure reliable products. Shortly after 1950, however, the subject of reliability began to receive separate attention, especially in the aerospace industry. Since that time, the word *reliability* has acquired a very specialized meaning in respect to the quality of manufactured products.

The rapid development of highly sophisticated missile systems and manned space vehicles created some special problems for the design engineer. The failure of one essential electronic component in a manned space vehicle, for example, could result in a catastrophic failure of its mission and the loss of life and millions of dollars. Consequently, an unusually high degree of reliability had to be achieved, generally within a very short development period. The need arose, therefore, for a means of *measuring* the reliability achieved in the *design* of these vital aerospace systems and *predicting* the mathematical odds of their success.

It became evident, with the growing use of computers and data processing equipment, that such a need could be partly fulfilled through statistical analysis. Emphasis was placed on compiling data relating to the causes of electronic component and system failures. Such data can be used to determine the *mean life* of components, to reveal the most prevalent causes and modes of failure, and to expose substandard parts and circuits.

This new technology, therefore, has added a statistical approach to the time-proven methods of achieving reliability, and has also given rise to a highly useful reliability rating system.

Evaluation and Prediction

What is considered satisfactory reliability? The reliability of a product is measured in relation to the mission that it is designed to accomplish. It would be ideal, of course, to accomplish this mission 100 percent of the time. Unfortunately, from a practical standpoint, the ideal is rarely possible to achieve. This can be attributed to many factors, such as design errors, material deficiencies, or cost limitations. In any event, the most important reason for considering reliability is to assure, with a *measurable* degree of confidence, that a product can accomplish its mission. Therefore, it is absolutely necessary to describe the mission clearly so that there is no doubt as to what must be achieved in the design of a product. Such a description must also include the tolerances which are to be allowed before the mission is considered a failure. When this is done, the design engineer can specify the degree of reliability in terms of the operational conditions involved.

It is significant to note the difference between *evaluating* the reliability of equipment and systems that have already been developed, and *predicting* the inherent reliability of a proposed new design. Evaluating reliability involves measuring the past performance of a product or component to determine what degree of reliability has been achieved. This is accomplished by subjecting the product to a variety of tests and by acquiring accurate reports of failures occurring during actual field use. Such information is of considerable value in evaluating the product's performance under typical operating conditions. The ultimate reason for accumulating failure reports from the field, of course, is to effect product improvement. This is usually done by analyzing the failure reports to determine the nature of the failures, and then taking steps to prevent them from occurring in the future. It is important, therefore, that these field reports be accurate so that a high degree of confidence may be placed on any conclusions derived from them.

Reliability prediction, on the other hand, involves the extrapolation and interpolation of statistical data to estimate the *inherent* reliability of a product *design,* before the product is approved for manufacture. This is done by carefully examining all pertinent engineering data and documentation, espe-

Figure 1. Quality assurance engineers perform complete system performance test on Type 46A carrier equipment, before shipment to customer.

cially the reliability ratings of all recommended components and parts, and then calculating the overall reliability of the proposed design using the mathematics of probability. By using such statistical techniques, designers are able to disclose design deficiencies or potential problems such as marginal circuits and misapplication of parts.

Measuring Reliability

How is reliability measured? Presently, there are a number of ways to measure reliability, many involving complex statistical analyses which are beyond the scope of this article. If not properly understood, however, mathematical expressions that purport to measure reliability can be easily misleading. It is helpful, therefore, to understand some of the more prevalent mathematical expressions linked with reliability.

The three most popular expressions of reliability are the *probability function*, the *failure rate*, and the *mean-time-between-failure* or *MTBF*. (For products that are not repairable, the latter expression is referred to as the *mean-time-to-failure)*. Each of these expressions can be applied to a part, component, assembly, or to an entire system, depending on the particular needs. The probability function is expressed as a decimal or a percentage and is an estimate of what the chances are that a particular device will perform its mission. The failure rate is ordinarily expressed in terms of the number of failures per unit of time, usually 1 hour, 100 hours, or 1000 hours, or as a percentage of failures per 1000 hours. The MTBF is expressed in hours and

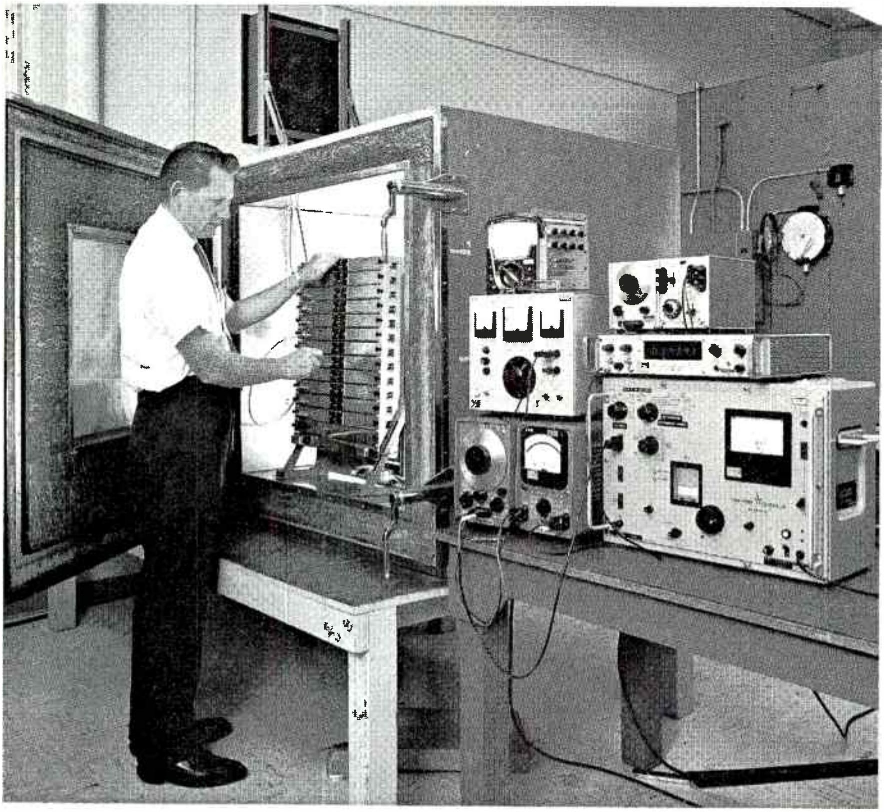


Figure 2. Type LN2 cable carrier equipment undergoes extensive temperature testing to assure reliable operation under a variety of environmental conditions.

is the ratio of the total test time (or operating time) of a device to the total number of failures that occur during the test period.

The probability function P can be expressed mathematically as:

$$P = \frac{a}{a + b}$$

where

a = *number of successes*
b = *number of failures*

To illustrate how this expression is applied, consider the following example. If 100 components were tested for 1000 hours and there were no failures during the test period, the probability function would be 1.0 or 100 percent.

$$P = \frac{100}{100 + 0} = 1.0$$

If, however, 10 components failed during the test, the probability function would be 0.9 or 90 percent.

$$P = \frac{90}{90 + 10} = 0.9$$

Thus, stating that a product is 90 percent reliable does not mean that it will probably operate only 90 percent of the time, but that there is a 90 percent chance that it will successfully complete its mission. It is important to note that the probability function must be *qualified* in order to be meaningful. Expressing reliability in terms of an abstract number is meaningless unless the physical conditions that prevailed when the reliability was assessed are included. It is also important to know the size of the sampling used to determine the probability function. In the previous example, it can be seen that 10 failures represented a 10 percent decrease in reliability. If the 100 components were taken from a production run of 5000, then the sampling may not be large enough to accurately predict the performance of the entire run.

The second expression is the failure rate f, which can be expressed mathematically as:

$$f = \frac{a}{b}$$

Where

a = *number of failures*
b = *duration of test, in hours*

As an example, if 100 components are tested for 1000 hours, and ten of them fail during the test, then the failure rate is:

$$f = \frac{10}{1000} = 0.01 \text{ per hour}$$

When calculating the failure rate, it is important to consider the age of the product. Failure rates of new electronic products are apt to be high because of such factors as production errors, defective parts, faulty installation, and improper alignment. After a normal *break-in* period, however, failures become less frequent and failure rates tend to remain relatively constant during the useful life of the equipment. When the product begins to wear out, the failure rate may begin to increase steadily. A typical curve of electronic equipment failure rate versus age is shown in Figure 3.

Closely associated with the failure rate is the mean-time-between-failure (MTBF). This expression is merely the average time between failures and is the reciprocal of the failure rate. Using the previous example, the MTBF would be expressed as:

$$MTBF = \frac{1}{0.01} = 100 \text{ hours}$$

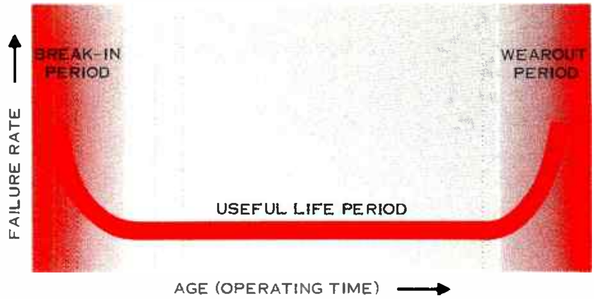


Figure 3. Curve showing typical failure pattern of electronic equipment.

Therefore, the larger the value of MTBF the greater the reliability and, inversely, the smaller the value of the failure rate, the greater the reliability.

Users of communications equipment are more concerned generally with system or equipment reliability. However, the reliability of parts, components, and circuit design provide the basis for measuring the overall reliability of communications equipment or systems. Perhaps the most important factor affecting overall reliability is the increasing number of components required in single systems. Since most system failures are actually caused by the failure of a single component, the reliability of such components must be considerably better than the required overall system reliability. This fact becomes quite evident when considering how the overall system reliability is measured.

If all the components of a system are considered to be functionally in series, and if the failure of any component results in a system failure, then the overall system reliability R is:

$$R = r^n$$

Where

r = *mean reliability (probability function) of each component*

n = *number of components in series*

The formula for calculating the overall system reliability produces some rather interesting results as seen in the following table.

n	r	R
10	0.99	0.90
100	0.99	0.40
200	0.99	0.19
500	0.999	0.60
1000	0.999	0.37

One means of improving reliability when designing a product is through simple redundancy — that is by providing an alternate means of accomplishing a given function. The probability function for redundant electronic circuits, arranged in parallel, is expressed as:

$$R = r_1 + r_2 - r_1 \times r_2$$

where

R = *Overall reliability*

r_1 = *Reliability of circuit 1*

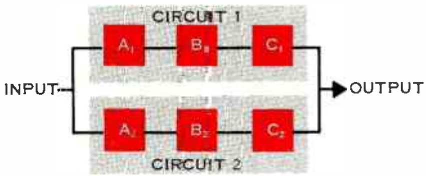
r_2 = *Reliability of circuit 2*

As an example of how redundancy works, consider the following circuit containing three components, A, B, and C, each connected in series.

If the reliability of each component is 0.95, then the overall reliability for the series circuit is:

$$R = 0.95 \times 0.95 \times 0.95$$
$$R = 0.86$$

When a redundant circuit is added in parallel, as shown in the following diagram, the overall reliability increases.



Using the formula for computing the probability function of a parallel (redundant) circuit, the overall reliability becomes:

$$R = 0.86 + 0.86 - 0.86 \times 0.86$$
$$R = 0.98$$

Thus, there was a 14 percent gain in the overall reliability as a result of adding the redundant circuit. However, redundancy often requires the use of additional components, such as a switching circuit, which may lower the overall system reliability.

Testing and Quality Control

Two very important practices which affect the reliability of a product, after it is designed, are testing and quality control. The major function of quality control is to inspect the workmanship of a product to determine if it meets the level of quality proposed in the design. A good quality-control effort can detect design and manufacturing errors which otherwise might have shortened the life of a product and adversely affected its reliability. It is far better to correct errors during the manufacturing process than to make corrections later on the basis of failures that occur during actual field operation.

Electronic components must be capable of operating satisfactorily, not only under the conditions required of the equipment or system of which they are a part, but more importantly, in the *electrical environment* in which they

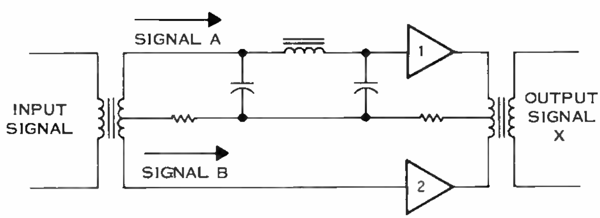
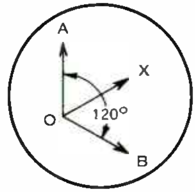


Figure 4. An example of redundancy without a switching circuit is exhibited by this amplifier circuit used in the AN/FCC-17 multiplexer set. In this circuit, there is a 120° phase difference between the output signals of the two amplifiers. Thus, the combined output level is equal to the output level of each amplifier. If one amplifier should fail, the final output level will remain constant because of the 120° phase difference. (In the vector diagram, line OX will shift toward the vector point, A or B, representing the output level of the amplifier with the higher gain.)



operate. To determine if any deleterious effects may occur during sustained operation of an electronic device, it must be subjected to many tests and field trials before being declared operationally suitable. The main purpose of such tests is to determine whether or not the device meets the acceptance criteria, and to provide concrete evidence of its performance capability. These tests range from environmental and temperature tests of individual components to burn-in tests and field trials of entire systems. In addition to testing the usual electrical characteristics of an electronic device, it should be subjected to a variety of physical or environmental tests. These may include such things as temperature tests, vibration tests, corrosion or salt spray tests, fungus-resistance tests, sand and dust tests, and shock tests. Failure data gathered from these tests are used to analyze component reliability as well as the overall reliability of the product or system.

Human-Factors Engineering

Any reliability effort would not be complete without considering the people who must operate and maintain the equipment. Because the performance of a communications system is determined by the human operator as well as by equipment reliability, it will certainly be improved if the mechanical component is designed to fit the human component. Such a design must consider the capabilities and limitations of the human operator and, where possible, relieve him of purely mechanical tasks. The art or science that deals with such problems is known as *human-factors engineering*.

A good example of human-factors engineering occurred in the development of the modern telephone. In earlier telephones, the letters and numbers were placed inside the dialing holes. This had the disadvantage of covering up the letter or number as the user placed his finger in the hole. This seemingly unimportant factor not only annoyed the user, but also contributed to dialing errors. To overcome this, the letters and numbers were placed outside the dialing holes. This appeared to be a fine idea, but it resulted in an increased number of dialing errors. A human-factors investigation showed that the letters and numbers, while inside the holes, had provided a natural *target* by which the user could aim his finger. By removing the letters and numbers from inside the holes, the so-called target had also been removed. By putting a mark inside each hole, however, the target was replaced, and dialing errors decreased.

Some Practical Considerations

The fact that aerospace companies have been more aggressive in developing formal reliability programs is not difficult to understand. Most aerospace contracts require that the contractor develop and build exotic and sophisticated missiles or space vehicles that have little or no precedent in their design and mission. The advanced electronic and communications equipment that supports these rather complex systems is equally as unprecedented. In addition, there is seldom enough time for these systems to mature, as they are being continually modified to take advantage of new techniques — and are soon replaced to make way for superior or more advanced systems. The relatively short life and the vital mission of these aerospace systems, therefore, does not permit reliability to be increased through a routine course of product improvement.

Under such irregular and accelerated conditions, it has become absolutely essential to be able to measure the reliability of a product and to predict its probable success before placing it into an operational environment. Thus, in the aerospace industry, reliability is recognized as a design parameter.

Unlike aerospace or military equipment, commercial communications products do not undergo radical changes and are seldom replaced simply because a newer design is on the market. This is especially true in the telephone business where equipment is generally retained as long as it performs its job. Usually, new equipment introduced into the communications industry must be compatible with existing equipment to the extent that a complete departure from earlier designs seldom occurs. This allows commercial manufacturers, who have done business with the communications industry for many years, to develop mature products and to acquire a skilled and experienced organization in which to produce reliable systems.

Most manufacturers of commercial communications equipment take special care in selecting parts and designing circuits that provide optimum reliability

Figure 5. Transistors that fail during operation are examined and tested in Lenkurt's Material Evaluation Laboratory. If electrical tests do not reveal the cause and mode of failure, the transistor is cut open, potted, and then slowly abraded and polished until the physical defect can be seen under a microscope. Cause of failure can usually be determined by viewing the damaged area of the transistor.

for their equipment. Usually, this equipment is expected to operate for a useful life period of at least twenty years. Unfortunately, parts of a given type made by different manufacturers may have the same initial characteristics, but may change in different directions and degree with time and environment; usually as a result of different manufacturing processes. Because of this, only high quality parts should be selected, and used so that stress levels are safely below the manufacturer's recommended rating.

Lenkurt manufactures many of its own parts, such as quartz crystals, toroid coils, transformers, and capacitors, to assure a high degree of product and system reliability. In addition, all products are guaranteed for one year against faulty components and workmanship, which more than covers the *break-in* period shown in Figure 3. Records are maintained of all equipment and components that are returned to the factory for replacement during this warranty period. If any particular type exhibits an excessive number of failures, it then becomes the subject of a special investigation. The purpose of such an investigation is, of course, to determine the causes of the excessive failures so that steps can be taken to increase the overall reliability of the product. Accurate records are also kept of all costs incurred in support of this warranty. Such costs provide a good yardstick for measuring the quality achieved in the design and manufacture of each product.

Figure 6. Transistors used in Lenkurt products are life-tested to determine their quality and operating characteristics. At certain intervals the essential parameters of each transistor are measured and recorded. Photograph shows 20 transistors being checked automatically. Analog measurements are fed into analog-to-digital converter and then into a keypunch machine which punches the data into a card for future processing. Punched cards are used in computer programs to predict transistor failure rates or MTBF, and end-of-life.

Conclusions

Historical data and extrapolation form the basis for predicting the reliability of a product. The concept of predicting reliability by purely statistical means is new to engineering, and it has yet to gain the respect and understanding enjoyed by certain older engineering concepts. Many view it suspiciously as an abstract numbers game that is of value and interest only to the statistician. This lack of respect may be caused, in part, by its misuse in applications ill-suited to promote its real value. Unfortunately, until such a new discipline reaches maturity, its concepts, theories, and applied methods are apt to be disorderly and easily misunderstood. Consequently, a large amount of money spent for reliability programs has undoubtedly been wasted — because users have misinterpreted the statistical data, or have compiled such data without an effective plan for its use.

Most of the present statistical concepts of reliability have been developed and put into formal practice by the aerospace industry and related government agencies. These practices have proven to be effective in guiding the development and assuring the reliability of highly sophisticated systems, especially where precedent and other engineering guidelines are lacking. In commercial practice, however, it has not yet become necessary or economical to employ elaborate statistical methods to achieve reliability. This is due to the regular manner in which the needs of commercial industry evolve. Manufacturers of commercial communications equipment, for example, are able to concentrate on a particular line of long-life products and develop highly dependable equipment through tradition and experience.

The government has had to pay a high price to advance this new concept of reliability to assure the success of vital missile systems and manned space vehicles. Such costs, of course, are a real bargain if these advanced systems successfully perform their mission, especially where human lives are at stake. In time, the statistical approach to achieving reliability may also prove to be an effective tool in advancing the technical excellence of commercial products. •

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