PROCEEDINGS

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AND

SCHOOL OF ELECTRICAL ENGINEERING

Co-sponsors

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Stillwater, Oklahoma

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NATIONAL ASSOCIATION OF RELAY MANUFACTURERS

RELAY CONFERENCE PAPERS

PREFACE

This publication is a compilation of papers presented at the Twelfth Annual National Relay Conference at Stillwater, Oklahoma on April 28, 29, 30, 1964. This conference is co-sponsored by the National Association of Relay Manufacturers and Oklahoma State University, and is conducted in order that various manufacturers and users of relays may exchange and discuss advances within the industry and may offer solutions to mutual problems.

We express our thanks to all those whose efforts have made this symposium successful, with particular mention to the authors without whom this publication would not be possible. We also express our appreciation to Assoc. Professor D. D. Lingelbach and the faculty of the School of Electrical Engineering of the Oklahoma State University, who have continually devoted untiring efforts toward conducting increasingly beneficial conferences each year.

The National Association of Relay Manufacturers in recognition of outstanding work in preparation and presentation of papers, awarded an honorary degree of "Fellow In the College of Relay Engineers," at the 1963 Conference to the following authors:

THOMAS N. LOCKYER, *Supervisor*
Components Section, Reliability Assurance Dept.
Philco Western Development Laboratory

Subject: Non-Destructive Testing for Parasitic Arc Susceptibility in Relays.

WHEELER D. MAYNARD, *Electrical Engineer*
General Railway Signal Co.

Subject: Design of a Non-Adjusted Relay.

HIDEO KUBOKOYA, *Assistant Manager*
Telephone Engineering Division
Nippon Electric Co., Ltd.

Subject: Dynamic Analysis of the Relay and its Application to the Improvement of the Impulse Relay.

A. R. LUCAS, *Senior Engineer*
DR. WEICHIEN CHOW, *Principal Engineer*
ITT Kellogg Telecommunications

Subject: Economical Magnetic Memory Device.

FRED C. EBERT, *Development Engineer*
Micro Switch Co.

Subject: Permanent Magnet Biasing and Operation of Dry Reed Switches.

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NATIONAL ASSOCIATION OF RELAY MANUFACTURERS

Mr. James V. Roughan

Executive Director

P. O. Box 7765

Phoenix, Arizona 85011

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IS THE RELAY GOING THE WAY OF THE DODO BIRD?

W. A. MURRAY

The Boeing Company
Aero-Space Division
Seattle, Washington

INTRODUCTION

The possibility of extinction for the relay exists. Traditional relay functions are being usurped daily by semi-conductors. Semi-conductors are reliable, fast operating, small and have no known wear-out modes. However, there are applications where the relay offers the designer characteristics not obtainable in a semi-conductor device.

If relays are to complete effectively for these applications, significant steps must be taken to improve relay reliability. The semi-conductor industry in response to the missile program requirements, developed techniques to improve the design, production and application data of their devices. The relay manufacturer can learn important lessons from these techniques in the solution of relay problems.

WHAT ADVANTAGES DO RELAYS OFFER?

The cost of a system using relays is generally much lower than for a semi-conductor circuit. This is due to the number of parts required to replace one relay and the design complexity.[1] Developments in micro-circuitry may reduce the cost of non-relay circuits where usage is large.

Current and voltage switching capabilities of relays exceed those of semi-conductors. Semi-conductors are being improved with Silicon Controlled Rectifiers available which can switch 250 amperes.

Relays are capable of isolating the input from the output circuit and are capable of switching between two mutually isolated circuits. In relays, circuits are isolated by resistances greater than 1000 megohms. Semi-conductor leakage currents of less than a micro-ampere reduce this advantage for many applications. Relays can control several circuits with one input signal and can provide current gain of a million. Current gain of several thousand is available with Silicon Controlled Rectifiers.

Relays are more tolerant of transient voltage conditions than semi-conductors. The switching of inductive loads with semi-conductors is hazardous because of the induced transient voltage.

Semi-conductors are more susceptible to damage by nuclear radiation than relays. Permanent damage to semi-conductors occurs at lower radiation doses than with relays and parameter change is greater at low dosages. Reports indicate that the maximum tolerable radiation exposure for semi-conductors is 10^{13} neutrons/cm^2 as compared with 10^{15} neutrons/cm^2 for relays.[2]

WHY MINUTEMAN MINIMIZED RELAY USE

The capabilities of relays were recognized by the designers of the Minuteman system. However, it was decided that semi-conductors should be used wherever possible rather than vacuum tubes or relays. The decision was based on the need for high reliability in a system operated continuously for long periods under moderate environmental conditions. Semi-conductors reportedly offered superior reliability under these conditions.

BOEING RELAY EXPERIENCE.

Recent years have shown progress in the relay industry as well as in the semi-conductor industry. Many of the procedures used to improve semi-conductors are also in use by relay manufacturers. However, Boeing's experience with relays in various programs has shown the need for additional application data and for further improvement in reliability.

Application Data Needed

Minuteman relay use was curtailed by lack of data showing relay behavior under conditions appearing to be ideal for relays. Also, misapplications could have been prevented by adequate data.

Applications existed requiring power relays to be infrequently actuated, perhaps once a month for only a few minutes. All environmental conditions were ideal and contact current within ratings. Available relay failure rate data was unfavorable to relays as compared with failure rates published for Minuteman semi-conductors.[3] Relays were frequently used under these conditions because current requirements exceeded semi-conductors ratings.

Some applications required the coil to be continuously energized for prolonged periods. Coil life data were not always available from relay manufacturers. Contact behavior under these conditions was not known. It was feared that contacts held open for long periods would develop high contact resistance due to outgassing.

Relay use with semi-conductor circuitry has necessitated knowledge of relay parameter limits throughout life. Relay drop-out voltage, and release time have frequently been critical in circuits using semi-conductors. Data on pick-up voltage and coil resistance variations with temperature have been sought by designers. Operate time has not been critical. Realistic knowledge of contact resistance to be expected over the contact current range was needed.

Contact bounce limits throughout life have been important in logic applications. Coil inductance values were needed to determine radio frequency noise suppression requirements. Maximum contact to contact and contact to case capacitance values were needed for high frequency applications. Contact ratings have not been adequately defined. The following ratings have frequently been required:

(a) Minimum contact current rating

(b) A rating correlating contact current with open circuit voltage

(c) Inductive load rating in terms of inductive load energy levels

(d) Current-Time rating curves relating maximum permissible contact current to time.[4]

Contact ratings at voltages over 30 volts dc are not defined nor are minimum current values related to the open circuit voltage. Often no minimum current rating is given. Inductive load ratings are usually not defined in terms meaningful to designers. The recently revised MIL R6106D becomes meaningful by defining inductive load in terms of load energy.[5] Figures 1 through 5 illustrate a method of presenting the required data.

Inability to Predict Relay Reliability

Military system manufacturers are required to provide an analysis of system reliability. This analysis requires knowledge of part hourly failure rate or the probability of successful operation for a specified number of cycles in a given time. Minuteman required both types of failure rate analysis.

Scant reliability data was available for specific relays. Available data was generic. Lacking definitive data conservative failure rates were used.

As relays are improved it is necessary that a measure of this improvement be provided. If this is not provided failure rates for improved relays will be obtained from generic data.

Lack of Process and Quality Control

Suppliers of relays for the various projects have been manufacturers showing above average performance in our previous experience. Yet many failures have occured which were indicative of inadequate process of quality control. Examples follow of problems encountered with relays from several different manufacturers. These examples are representative of relay problems, not an indictment of a few manufacturers.

Many failures resulted from human failings preventable by application of rigid controls. One discrepancy showing lack of configuration control involved a

Rated Coil Duty Cycle : Continuous

Maximum Intermittent Coil Voltage (30 second duration) : 40 Vdc

Maximum Continuous Coil Voltage
- Absolute Maximum : 32 Vdc
- Recommended Maximum: : 30 Vdc

Coil Resistance	Minimum at -70°C	Minimum at 25°C	Maximum at 25°C	Maximum at 120°C
When coil previously de-energized	100 ohms	162 ohms	198 ohms	270 ohms
When coil current stabilized	139 ohms	173 ohms	290 ohms	370 ohms

Nominal Coil Inductance
- 25°C Ambient, 1000 cps : 300 millihenries maximum

Contact Terminal Capacitance : 10 PF Maximum

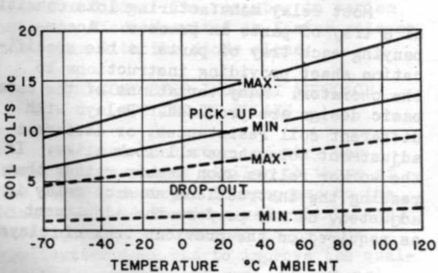
Contact Operation (at 25°C Ambient)

Coil Voltage (Vdc) :	18		28		32	
	Min.	Max.	Min.	Max.	Min.	Max.
Operate Time (Seconds) :	.020	.040	.010	.020	.009	.015
Release Time (Seconds) :	.005	.010	.005	.016	.005	.020
Bounce Duration (Seconds) :	0	.003	.	.003	0	.003

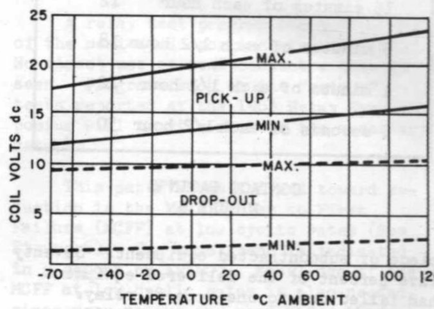
Contact Load Ratings

Load Type	Current (Amps)	Cyclic Life (Cycles)	Open Circuit System Voltage
Resistive	Max. 5	50,000	32 Vdc or 120 Vac Max.
	Min. .010	50,000	5 Vdc or 5 Vac Min.
Inductive	Max. 3	10,000	32 Vdc or 120 Vac Max.
Lamp	Max. 0.8	50,000	32 Vdc or 120 Vac Max.

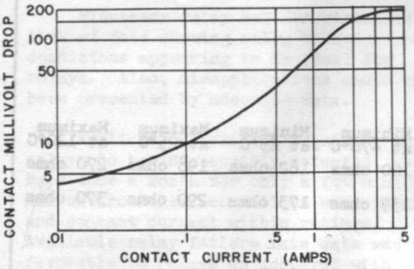
DESIGN DATA SHEET
FIGURE 1



PICK-UP AND DROP-OUT VOLTAGE
COIL PREVIOUSLY DE-ENERGIZED
FIGURE 2



PICK-UP AND DROP-OUT VOLTAGE
AFTER COIL CURRENT STABILIZED
FIGURE 3



MAXIMUM CONTACT MILLIVOLT
DROP VS CONTACT CURRENT
FIGURE 4

Current Making Capacity	
Maximum inrush duration Max. Occurrence Once per 1/2 hour	Current (amps)
.015 second	75
.070 second	30
.2 second	7
Current Carrying Capacity (No Make or Break)	
continuous	10
15 minutes of each hour	12
5 minutes of each 1/2 hour	18
1 minute of each 1/2 hour	22
5 seconds of each 1/2 hour	50

CONTACT RATINGS
FIGURE 5

piece of subcontracted equipment. Seventy five percent of the delivered equipment had failed due to one type of relay. Investigation revealed that this AC operated relay was produced either with a full wave or a half wave rectifier. The failed parts had been supplied with a full wave rectifier but with the lower resistance coil intended for use with the half wave rectifier. Coil burn-out resulted.

Relays have been found with diodes soldered to the wrong terminal, electrically not in the circuit. Others were found with strands from wire insulation imbedded in the contacts.

Another discrepancy occuring in a critical circuit was clearly due to misapplication. But, failure analysis revealed that of seven failed parts, five contained irregularities showing lack of process controls. Solder flux and loose particles were found within the relay enclosure.

Visits to several relay manufacturing facilities have revealed conditions which permit the occurrence of discrepancies. In one plant adjustments were made in a poorly cleaned room. A worker was seen to pick up a relay, examine it, blow something away and adjust it.

Another manufacturer did not mark calibration date on equipment and records were not adequate to assure periodic inspection. No record could be found of any inspection of one piece of production line equipment. Materials for commercial and military relays were stored together by another manufacturer, reducing the control over the military relays. Rejected materials were placed near accepted materials and were not plainly marked allowing the possibility of use. Rejected relays were unmarked and identified only by being placed in different trays.

Most relay manufacturing lots consist of a tray of parts in process. Accompanying each tray of parts is the specification sheet providing instructions to the operator. Many variations of the same basic design are produced. Relays with different coil resistances, or different adjustment tolerances all look alike. If the worker relies upon memory rather than reading the instructions as each relay is adjusted, he may perform the adjustment as required on the previous tray of relays.

Unusual Practices

Unusual practices such as modifying proven designs to meet unusual circuit requirements created relay problems. The combination of high and low current contacts within the same relay is an example. This was necessary to switch power and to provide a logic signal indicating contact position. The application required switching of at least ten amperes and a few milliamperes on adjacent contacts.

Shunting of coils with diodes was required for some relays to suppress the coil transient. Because diodes were mounted internally, determination of diode condition or quality was difficult due to the masking effect of the shunting coil resistance. Elaborate techniques were needed to prevent diode damage during test and to determine that the coil transient was adequately suppressed. It was necessary to protect the diode from damage due to application of the wrong coil polarity in test. Coil transient suppression was required to protect transistor relay drivers and to reduce radio frequency interference. It was found that transient suppressors external to the relays performed equally well if placed in close proximity to the relay. Diodes, if used to suppress coil transients, should be external to the relay.

An undesireable side effect of transient suppression was slowing of the relay release time. Release time with a diode shunting the coil was three to five times as great as with no diode. This was tolerable, but the contact transfer time was also found to increase. Increased transfer time resulted in a longer arc duration and reduced cycle life. It was necessary to halve the rated cyclic life of one relay even with a resistor in series with the diode. The resistor in series with the diode resulted in faster release time than with the diode alone.

SEMI-CONDUCTOR INDUSTRY APPROACH APPLIED TO RELAYS

The semi-conductor industry was faced with problems similar to those of the relay industry. In response to the Minuteman need for improved reliability, techniques were developed to provide application data and to improve the quality and uniformity of semi-conductors. These same techniques have been used by resistor and capacitor manufacturers, and can be adapted to relay manufacture.

Semi-Conductor Test Program

Early in the program, test parts were produced using the best designs, materials and processes available. Large scale tests were conducted with groups of samples under various load conditions. Sample size was adequate to provide a statistically-valid indication of part behavior.

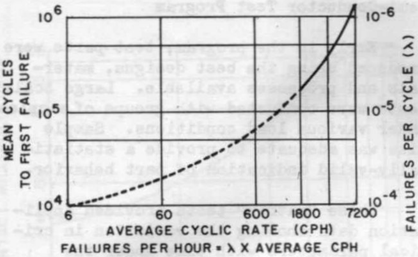
These "matrix" tests provided application data showing the variation in critical parameters with time under the different test conditions. A measure of part failure rate and the factors which accelerate failure rate were also obtained. These tests with analysis of failed parts showed that the principle failure modes of semi-conductors are due to chemical change. The rate of these chemical changes could be related to temperature and time, using the Arrehenius equation that rate of chemical reaction doubles for each 10°C increment in temperature.

Environmental tests were conducted to establish the safe limits under stresses such as mechanical shock, acceleration, vibration and temperature shock. Analysis of failed parts from these tests established screening test criteria, that is stress levels which would make detectable discrepant parts but which would not damage normal parts. Failure analysis also revealed failure mechanisms which had resulted from design, process or material deficiencies.

Relay Tests to Provide Design and Reliability Data

A relay test program similar to that of the semi-conductor industry is needed. No direct use of semi-conductor data is seen. Programs such as the "matrix" tests reported at the 1963 Relay Symposium will provide much of the necessary data.[6]

This paper shows a trend toward reduction in the Mean Cycles to First Failure (MCFF) at low cyclic rates (See Figure 6). The same trend is indicated in a report by ARINC[7]. Knowledge of the MCFF at low cyclic rates is also needed since many relays are used under these conditions. In Figure 6 estimated MCFF at low cyclic rates is shown in dotted lines.



CYCLIC RATE VS MCFF
FIGURE 6

This data will form the basis for reliability prediction and establishing relay ratings. Figure 6 is presented in the form of a design data page useable to determine the relay hourly failure rate. It is assumed that data shown is obtained under worst case conditions.

It is not practical to consider all operating conditions. Predictions which are safe to use may be made if reliability is known under worst case conditions of resistive load current and voltage, coil voltage and temperature. Ratings for inductive motor, or lamp loads should be determined by the current level which produces the same life as the worst case resistive load.

Coil life data is often obtainable from wire manufacturers.[8] This data will be useful when predicting reliability of relays in continuous duty applications.

Process and Material Controls

Documented controls are enforced on materials and processes used in semiconductor manufacture to ensure product homogeneity. Great care is taken to use the same design, process and critical materials in the manufacture of each part in the lot. The essential features of the controls placed on materials and processes are shown in Table I.

The "people problem" is probably the biggest contributor to relay unreliability. The rigid controls shown in Table I will reduce the chance of human error.

TABLE I

Material Control

(a) Procurement by Specification

(b) Receiving inspection of material

(c) Surveillance of material sources Records kept of discrepancies.

(d) Storage Control. Cleanliness of critical materials, shelf life, temperature and humidity control. Commercial products raw materials stored separately.

(e) Traceability of finished product to material lot.

Process Control

(a) Each manufacturing step controlled by documentation.

(b) Critical stages of manufacturing process inspected by Quality Control.

(c) Test equipment calibration interual prescribed and labled on equipment. Automatic equipment used where feasible.

(d) Instructions to operators written and dated. Instructions for manual operations are illustrated.

(e) Manual operations minimized. Where used inspection by another individual follows:

(f) Cleanliness consistent with requirements. Clean room facilities used in critical manufacture.

(g) Rework permitted only where noncritical.

(h) Environmental controls provided as necessary, monitored by Quality Control.

(i) Rejected parts plainly marked, stored in locked area awaiting disposition.

(j) Most experienced operators employed on high reliability production line. Training programs provided.

(k) Same operators used to produce one lot whenever possible.

(l) Parts transported during and after manufacture in manner to protect from damage or contamination.

(m) Few manufacturing processes performed by outside sources. Outside processes controlled by specification with 100% inspection and surveillance of facilities.

Facilities

(a) Calibration Laboratory maintained with legal standards and master tools and gauges checked at periodic intervals.

(b) Painting facilities isolated to prevent contamination.

(c) Facilities and equipment available for analysis of failed parts.

Documentation and Drawings

(a) Documents and drawings numbered, dated and require project management approval.

(b) Drawing and document changes controlled.

(c) Drawings and documents accessible to personnel needing them.

(d) All processes, materials, procedures, dimensions or inspections are covered by a drawing or document.

Part Acceptance Tests

After semi-conductors are produced screening tests are conducted to further ensure uniformity of all parts in the lot. These tests eliminate discrepant parts which would otherwise not be detectable. Appendix I shows examples of screening tests used by semi-conductor manufacturers. Following the screening tests critical parameters of all parts are measured. The parameter limits are set by circuit requirements and capabilities of parts as demonstrated by test.

Measurement of certain less critical parameters or time consuming measurements may be made on a sampling basis. Failure of any samples generally necessitates measurement of the entire lot.

Additional relay screening techniques are needed. The miss test has proven effective in detecting many contact irregularities. Other failure modes may go undetected. Poor hermetic seals may pass the leak test. Contact adjustment may be marginal causing early failure. Loose contaminants are very difficult to detect unless present on the contacts during test.

Lot Quality Assurance Test

To assure that the entire semiconductor lot complies with specification requirements, groups of samples are subjected to further tests. One group of samples is subjected to environmental tests such as humidity, shock, vibration, lead strength and lead solderability.

A second test group is subjected to accelerated life test at elevated temperature. This test generally of 1000 hour duration provides a measure of the failure rate of parts in the lot. The cumulative data is indicative of the effectiveness of changes in design, processes and materials and provides a better measure of part reliability.

In some cases sample groups are subjected to nonaccelerated long term life tests. These tests are conducted at room ambient temperatures with maximum rated load applied. Test results verify failure rates obtained under accelerated conditions and verify predicted parameter drift.

A relatively inexpensive measure of relay lot quality level has been provided by NARM [9] and the military [10]. Quality level is expressed as percent failures per 10,000 cycles of operation. These tests should be conducted under worst case conditions within ratings. Under these conditions cumulative lot test data will permit determination of MCFF, at the tested cyclic rate, more accurately than has been shown by the matrix tests.

Cumulative lot test data is more accurate than "matrix" test data due to the increased number of samples tested. Test samples are more representative of all parts produced since they have been obtained from many lots.

MCFF may be determined from percent failures per 10,000 cycles of operation as follows:

$$MCFF = \frac{10{,}000}{p}$$

Where: MCFF = Mean Cycles to First Failure

p = percent failures per 10,000 cycles of operation expressed as a decimal.

Design, Process, and Material Improvements

Deficiencies in design, materials and processes used in semi-conductor manufacture are evidenced by recurring failures. Careful analysis of failed parts determines the failure mechanisms. Corrective action is determined and placed in effect. Controls are present to assure that changes are not incorporated into production until their value is demonstrated. Appendix I gives examples [11] of deficiencies in semi-conductors discovered through failure analysis.

Relay Design

Relay design contributes to unreliability by necessitating manual manufacturing processes. Manufacturing processes using the repeatability of machines should be sought.

The entrance of the reed relay into the field is an encouraging sign of progress toward mechanized manufacturing. Also encouraging is the increased use of welding, which eliminates solder flux contamination and the skill required to solder well.

Relay designs should be standardized rather than being modified to fit each particular application. System reliability will usually be better served by modifying the circuits to fit relays of proven design rather than by modifying the relay to fit the circuit. Obtaining sufficient data and experience to firmly establish the reliability of a relay precludes relay modification.

FUTURE NEEDS

It appears that most future Aerospace programs will require delivery of few systems, but that reliability requirements will be severe. Few space probes are required to perform a mission, but they must operate for months without repair.

This type of program requires the use of relay standards of proven reliability. It will be difficult to justify the cost of adding new standards for any single program.

Improvement of hermetic seals will be necessary to permit prolonged operation in the near vacuum of space. Loss of atmosphere within the relay is likely to result in dielectric failures. More knowledge of radiation effects is needed. Reduction in size and weight will be important. Vibration resistance will be critical in relays operating during powered flight.

It is impossible to anticipate data requirements for all ap plications to come. Relay users will have to consult the manufacturer whenever existing data is not clearly applicable. Manufacturers must disseminate updated application and reliability data as it is generated or modified by experience.

Semi-conductor use is expected to increase with improved capabilities and their incorporation into micro-circuitry. Relays with proven reliability may find use as output switches for micro-circuitry or for power switching.

Relay use will be attractive, if reliability is improved without excessive cost increase. This will be especially true of ground equipment where cost is important and environment not severe. It may also be true in space where semi-conductors are more affected by radiation than are relays.

Is the relay going the way of the Dodo bird? The answer depends upon the action taken by the relay manufacturers.

CONCLUSIONS

In order to effectively compete with the semi-conductor industry the following action should be taken by relay manufacturers:

1. Provide adequate application data to

enable the user to properly apply the relay

2. Provide data that enables realistic prediction of relay failure rate.

3. Institute rigid process and quality control procedures to provide relays of uniform quality.

4. Improve designs and manufacturing processes to minimize human errors in relay manufacture.

5. By means of tests and failure analysis, obtain a better understanding of failure mechanisms which will be used to provide application data and to improve designs and processes.

APPENDIX I

1. Examples of Screening Tests used by the Semi-conductor Industry

(a) Temperature Age: Migration of contaminatants into the junction region results in high leakage current and other parameter changes. This migration has been demonstrated to be accelerated by temperature. Parts are stored at elevated temperature for a specified time period to stabilize noncontaminated parts and to make contaminated parts detectable in later measurements.

(b) Centrifuge: A 20,000 g acceleration is applied to all parts by means of a centrifuge to rupture any weak compressive bonds.

(c) Temperature Cycle: Parts are subjected to a series of temperature cycles to detect defective welds or deformation which may result in cracked crystals.

(d) Parameter Drift Screening: Parts are aged under load at elevated temperature for a specified time. Parameter measurements are made before, during and after aging. Parts with parameters drifting more than a specified amount from the initial value are rejected. This is done to eliminate parts differing from the lot.

2. Examples of Semi-conductor deficiencies discovered through failure analysis.

"Purple Plague" is a deficiency discovered through failure analysis. "Purple Plague" is an aluminum-gold intermetallic reaction which results in a bond weakness when bonding gold to aluminum. Microscopic examination reveals a purple area at the junction of the two materials. A process change was necessary to correct this problem.

Investigation of diode weld failures resulted in an automated welding process. A specific range of the weld time-temperature ratio was found to give consistently strong welds. The process uses sensors to detect the weld temperature and automatically controls the voltage pulse amplitude and duration. A great deal of testing to assure uniformity of results preceded incorporation of this process into part production.

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FUNDAMENTALS OF DYNAMIC NOISE GENERATION IN REED SWITCH CONTACTS

JACK J. VITOLA
JOHN P. BREICKNER
Wheelock Signals, Inc.
Long Branch, N. J.

INTRODUCTION

Operation of the contacts in reed relays generates a dynamic contact noise which is peculiar to this type of switch. With the growing use of reed relays in low level applications, any form of dynamic contact noise becomes extremely significant.

The purpose of this paper is to illustrate noise characteristics of miniature reed switches and to present an introduction to the theoretical considerations of the mechanisms present so that they may be better understood by the designer and user of reed switching devices.

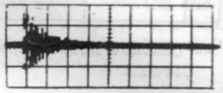
GENERAL CONSIDERATIONS OF CONTACT NOISE

In general, noise is any spurious signal introduced into a circuit either from components within the circuit or from some outside source. Noise from outside the switching device will vary with individual applications and can usually be eliminated by some type of shielding. Therefore, the noise of interest here is any spurious signal produced by the relay contact mechanism itself. Shielding would be ineffective with such noise.

The reed relay is unique in that the contact arm and armature are one and the same unit. This presents a case of a conductor moving thru a magnetic field and, therefore, "generating" a current.

In addition to noise caused by the generator effect, most of the noise produced in the contact members is due to magnetostriction.

The contact noise consists of a damped oscillatory wave which occurs after the contacts have closed and stopped bouncing but are still vibrating. (See Figure 1)



0.5 ms/cm
.001 VOLTS/cm

0.1 ms/cm
.002 VOLTS/cm

Fig. 1 -- Typical Contact Noise

NOISE MEASUREMENT AND EVALUATION

The most important considerations in noise measurement are shielding from external noise and sensitivity of the recording apparatus. In the circuit shown in Figure 2, all vertical deflection connections were made thru a shielded conductor. Using this circuit gives the noise with respect to t = o at the application of coil voltage. The vertical sensitivity available must be at least .005 volts/cm. A decade amplifier can also be used for increased sensitivity. The resistance R_1 serves to load the vertical input of the oscilloscope when the reed is open and can be any convenient value from 100 to 10,000 ohms. Its value has negligible effect on reed noise. (See Figure 3)

Different types of commercially

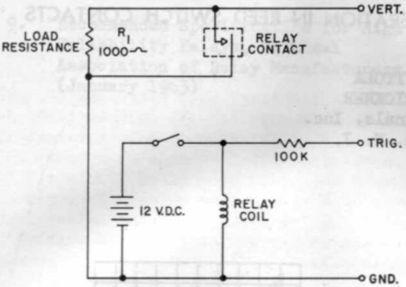


Fig. 2 -- Contact Noise Measurement Circuit

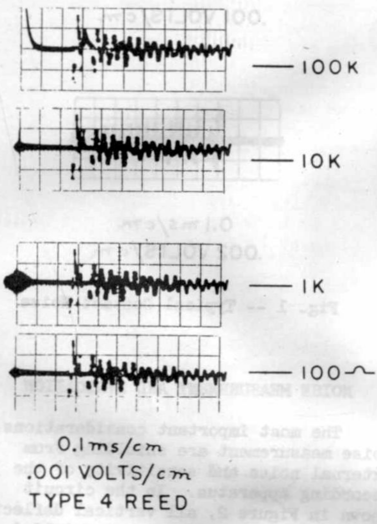


Fig. 3 -- Effect of Load Resistance, R_1, on Contact Noise

available reeds, designated Type 1,2,3 and 4 were chosen to determine the effects of various parameters on noise output.

Reed Type

Figure 4 shows a comparison of the noise output trace of the reed switch types used in this study. All traces are on the same time and voltage scales; the reeds shown are of approximately 50 ampere-turns.

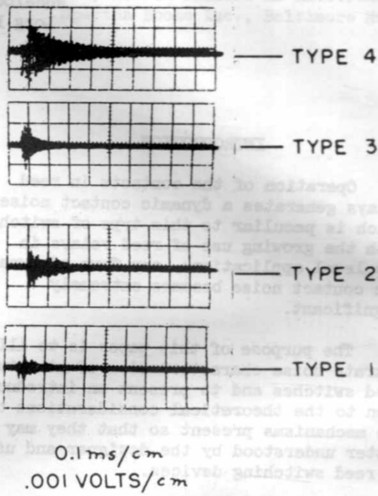


Fig. 4 -- Contact Noise vs Type of Reed Switch

From Table I, the maximum peak-to-peak noise level shown is approximately 3.5mv for Type 4 switch while the minimum noise level is approximately 1.5mv for Type 1. The duration of the noise is defined as the time from the beginning of

TABLE I
NOISE AMPLITUDE AND DURATION OF FOUR TYPES OF REED SWITCHES

Type	Max. Peak-to-Peak Noise Level (mv)	Duration (ms)
1	1.5	1.0
2	2.0	1.3
3	2.6	1.0
4	3.5	3.0