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SQUIB DEVELOPMENT PROGRAM

REPORT

to

U.S. NAVAL WEAPONS LABORATORY

DAHLGREN, VIRGINIA

CONTRACT NO. N178-7770

FINAL REPORT

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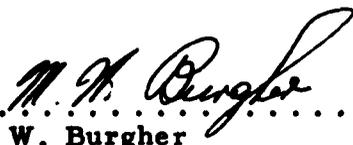
SCINTILLA DIVISION

SIDNEY, NEW YORK

Final Report
on
Squib Development Program
U.S. Naval Weapons Laboratory
Dahlgren, Virginia

Contract No. N178-7770

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THE BENDIX CORPORATION
SIDNEY, N. Y.

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SQUIB DEVELOPMENT PROGRAM

Contract No. N178-7770

FINAL REPORT

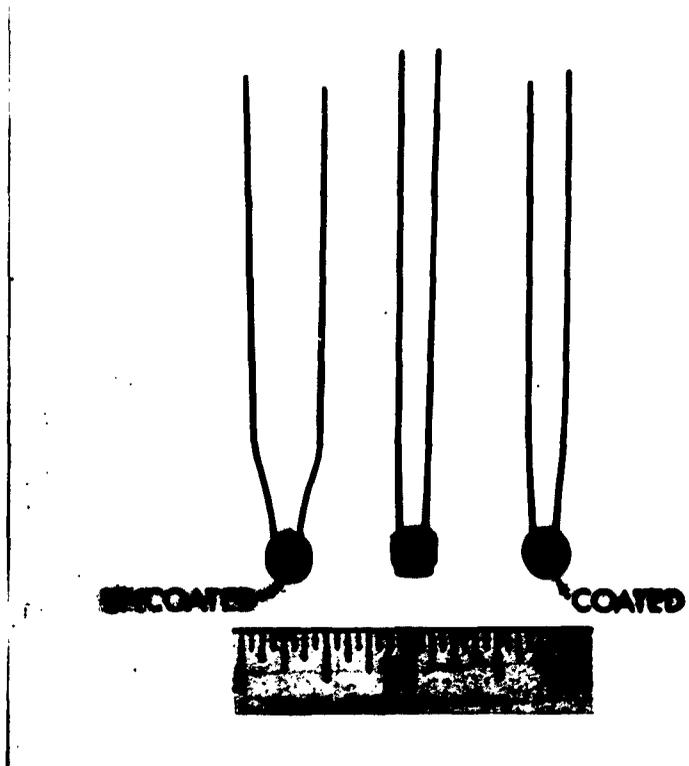


Figure 1

1. Summary

The object of this contract was to determine the feasibility of using a spark gap shunted by a semi-conducting material in an electro-explosive device to render it immune to stray RF. This objective has been accomplished. The feasibility has been demonstrated. Examples of the squibs made are shown actual size in figure 1.

Squibs were made utilizing a .030" spark gap, the electrodes of which were embedded in a graphite-epoxy molding compound. A two-fold function of the squib body was thus achieved; i. e., (1) a heat sink, and (2) a shunt.

An additional shunt consisting of a thin antimony film was applied across the face of the spark gap. It was shown that such a device having a total resistance across the gap of .4 ohms requires 28 - 30 watts of RF to fire. A similar value of DC is also required to fire the squib. A single charge of barium nitrate-zirconium was used as an explosive mix.

A power pack for firing the squibs was built. This provides a 1000 volt condenser discharge theoretically of 2 joules of energy and actually some 150,000 peak watts across the spark gap. Data concerning the construction and operation of the unit is included in this report.

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2. Introduction

The purpose of the work carried out under contract N178-7770 has been to determine whether or not it is feasible to use a shunted spark gap in the design of a squib to prevent premature ignition caused by induced RF currents.

The proposal to use a shunted gap in this application was based on the idea that RF at the frequencies involved might behave within a squib as DC. If this hypothesis proved to be sound then induced RF voltages and currents entering the squib could be divided and controlled in simple DC fashion.

This report is a summary of the effort, results, and conclusions regarding this investigation.

3. Initial Concept

There are five variables involved in the functioning of this type of squib; i. e., (1) spark gap width (2) shunt resistance (3) voltage (4) energy level and (5) explosive mixture. The first four of these govern the spark discharge across the gap. Combinations of the values of three of these parameters determine the value of the fourth.

Our basic approach involves the inclusion of electrical shunt characteristics in the molded squib body itself. In theory, therefore, the input energy must be the sum of that required to jump the gap plus that dissipated or shunted thru the molded body. With a fixed or constant voltage a combination of gap and shunt can be so designed as to establish the input energy at any pre-selected value. The size of the power supply required to fire the squib would be the limiting factor in determining this value.

With a sparking energy established, an explosive mixture sensitive to this energy may then be developed.

4. Present Concept

Investigation and testing proved the initial concept valid. It also disclosed the fact that a combination of the previously mentioned parameters which produced a satisfactory energy level also produced an unsatisfactorily low DC current - carrying ability. Likewise a combination having the ability to pass DC currents of a satisfactory value required what was considered excessively high firing energies.

A method of overcoming this phenomenon is the addition of a second parallel shunt resistance. This might be in the form of a thin conductive film across the spark gap. In theory this arrangement will produce a two-fold result:

1. By reducing the total shunt resistance, the amount of conducted DC current is increased.
2. Given two parallel resistors of equal value the current will be divided equally. The current density in the large mass of the conductive body will be low with little heating. With the same current, however, in the thin film the current density will be high and of such high value as to cause ionization of the gap and a resulting spark discharge. Lower firing energies can thus be attained regardless of the lowered shunt resistance.

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The two shunt resistances need not be of the same value, in which case the the currents will be divided in inverse ratio to the resistance values.

5. Development Program

The contract requires an investigation and correlation of different combinations of shunt resistance values, and explosive mixes with four different spark gaps - namely .015", .022", .030" and .050". To accomplish this a program embodying the following sequence of events was established:

1. Molding of squib bodies.
2. Spark testing to determine energy.
3. Loading with various explosive mixes and testing to determine firing energy. This work was done at and by National Northern Division of Atlantic Research Corporation in West Hanover, Massachusetts.
4. Radio frequency testing to determine susceptibility to induced RF. This work was done at the Franklin Institute Laboratories for Research and Development in Philadelphia, Pennsylvania.

This program was started by arbitrarily selecting a firing value of 1000 volts and an energy level of 1 to 2 joules. Shunt resistances of 1, 10, 100 and 1000 ohms would be provided. During the course of this investigation certain facts presented themselves.

1. It became evident almost immediately that the shunt resistance must be kept low in order to maintain the desired firing energy. The 10, 100 and 1000 ohm resistances reduced this firing energy to the low levels of .116, .017 and .004 joules respectively.
2. As the molding of the partially conductive squib bodies progressed, the .015" spark gaps proved themselves impractical. Molding material of the consistency used did not flow readily in such narrow confines and considerable difficulty was experienced in filling the mold properly. This, together with the fact that the short gap requires extremely low shunt resistance to produce the established energy level, led to the abandonment of both the .015" and the .022" gaps.
3. The .030" and .050" gaps could be molded with no difficulty and spark testing disclosed that either size gap could be made to fire at the same energy value if the proper shunt resistance were used.
4. A technique was developed for controlling the shunt resistance to virtually any desired value. This resistance in turn was found to control or establish the firing energy. It also controls the DC carrying ability of the squib. For instance energy levels as high as 10 joules for an "all fire" value produced a tolerance for DC of 8 amperes for an indefinite length of time.
5. In order to reduce the energy to fire, the shunt resistance must be increased. In order to raise the DC conductivity, the shunt resistance, of course, has to be lowered. The effort to lower energy and at the same time increase DC conductivity posed a problem solved by a second parallel shunt across the spark gap. The concept of using a thin, vacuum deposited metal film as a parallel shunt to reduce energy and at the same time increase DC conductivity proved most effective.

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As the work neared completion one combination of values emerged. The squib finally tested and submitted to the Naval Weapons Laboratory has a parallel shunt in the presence of a thin antimony coating across the surface of the gap. The total resistance of the squib is .4 ohms. The spark gap is .030" and the 50% firing energy is .38 joules. The following report concerns itself with the development of this particular squib.

6. Description of Squib

The squib developed on this feasibility study is shown in cross-section in Figure 2. It consists of a molded body "A" in which are embedded electrodes "B". Since the molding material is partially conductive a leakage path of .4 ohms exists between the two electrodes, or across electrode gap "F". This gap width can be held very accurately since it is machined in a single assembly and molded in place. Subsequent machining removes the electrode bridge and exposes two individual electrodes. Surface "G" is coated with an antimony film. Spacer "C" is assembled, explosive mix "D" "battered in", and cap "E" crimped into place.

In operation a 1000 volt condenser discharge of 2 joules is admitted to the squib thru leads "H". The energy follows two resistance paths - the conductive body, and the metallic film. The current density in the latter is of such a magnitude as to melt the film, ionize the gap and cause a spark discharge, which in turn ignites the explosive charge. Induced RF entering the squib via the leads is conducted thru the two resistances and does not ignite the powder until it reaches the order of 28 - 30 watts of power.

7. Materials and Molding Processes

7.1. Discussions of Molding Method

All shunted gap squib bodies which have been produced for this program have been molded by the "Transfer Molding" method. This method is characterized by the injection or "transfer" of the thermo-setting molding compound from a "Transfer Pot" into a closed, heated mold cavity. The transfer is accomplished by heating the molding compound to its softening point (achieved by maintaining the transfer pot and plunger at this temperature) and forcing it through an opening (the sprue) in the bottom of the pot by high pressure on the plunger. The pot is so positioned that the softened molding compound flows into the mold runners and thence to the mold cavities where it is formed and cured.

7.2. Eight Cavity Mold

The molding work made at the beginning of this program was done using a four cavity mold and transfer pot as shown in Figures 3A and 4A. There were several disadvantages in this mold design, one of which was that the runners were of unequal lengths. The compound must travel under high pressure thru these runners. The further the compound travels through the runners, the greater is the pressure loss to the runner system. Consequently, the compound arrived at the mold cavities at various pressures thus causing high and low resistance patterns.

The transfer pot (Figure 3B) for the eight cavity mold was designed with a small chamber and plunger. The amount of molding compound required per

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mold cycle was reduced by 50% as previously used by the four cavity mold, and more effective use of molding press pressure capacity was realized. The molding powder is pressed at room temperature to form a preform "pill" which can be quickly dropped into the small pot chamber. Under heat and pressure, the pill softens and flows the same as un-preformed powder.

7.3. Factors Affecting Resistance

The shunt resistance obtained in the squib body, as made by the transfer molding process employed here, is dependent upon several, inter-related factors. The dominant factors are:

- a. The amount of conducting material (graphite) in the molding compound,
- b. The pressure applied to effect transfer to the mold cavity, and
- c. The flow characteristics of the molding compound, this latter one being the most difficult to adjust and control. The compound should be of such a composition that the material will flow quickly and easily to the mold cavity with minimum loss of pressure at the proper temperature. Too high a molding temperature cures the resin binder, i. e., hardens it before reaching the mold cavities. Too low a molding temperature will not adequately soften the resin, and again, no compound reaches the mold cavities.

A new eight cavity mold and transfer pot (Figure 3B and 4B) was designed and built to eliminate this problem.

Eight cavities were arranged in a circle around the mold sprue. The cavities were then connected, in pairs, to a large central "reservoir" by means of a short "T" runner. All runners are therefore, of equal length and offer equal resistances to flow of molding compound. This gives resistances of practically the same value in every cavity. The values shown in Tables #1 and #2 are the resistances of .030" gaps taken from the cavities indicated by number and are from three consecutive molding cycles.

TABLE I (Four Cavity Mold)

Resistance in ohms - tabulated by cavity number.

| <u>Mold Cycle</u> | <u>Cavity Number</u> | | | |
|-------------------|----------------------|----------|----------|----------|
| | <u>1</u> | <u>2</u> | <u>3</u> | <u>4</u> |
| 1 | 8.6 | 3.85 | 3.74 | 5.90 |
| 2 | 5.2 | 3.9 | 3.87 | 4.40 |
| 3 | 3.80 | 3.20 | 3.20 | 3.60 |

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TABLE II (Eight Cavity Mold)

Resistance in ohms - tabulated by cavity number.

| <u>Mold Cycle</u> | <u>Cavity Number</u> | | | | | | | |
|-------------------|----------------------|----------|----------|----------|----------|----------|----------|----------|
| | <u>1</u> | <u>2</u> | <u>3</u> | <u>4</u> | <u>5</u> | <u>6</u> | <u>7</u> | <u>8</u> |
| 1 | 1.05 | 1.24 | 1.13 | 1.23 | 1.08 | 1.14 | 1.15 | 1.06 |
| 2 | 1.31 | 1.24 | 1.41 | 1.04 | 1.38 | 1.11 | 1.37 | 1.12 |
| 3 | 1.19 | 1.20 | 1.46 | 1.30 | 1.48 | 1.32 | 1.16 | 1.31 |

For the molding of the squib under consideration, the percent of each material in the molding compound is 36% resin binder, 33% graphite and 31% alumina. This ratio of the materials in conjunction with a molding temperature of $350 \pm 10^{\circ}\text{F}$ and a molding pressure of 5 tons per square inch gives a squib molded to a resistance value of between 1.0 and 1.9 ohms.

7.4. Effect of Molding Ingredients on Resistance

Three materials are used in the composition of the molding compound for this effort. The molding materials are:

1. graphite
2. alumina
3. binder (epoxy resin)

The evolution of a formula to produce a specific resistance value in the molded body involves combinations of all three ingredients of the molding compound along with various transfer pressures and temperatures. The design of the mold is an important factor in this consideration.

All three of the ingredients mentioned have some effect on the resistance of the squib, but the graphite exerts the predominant influence. The alumina has a slight effect on resistance, but its chief purpose is to act as a "filler". The resin binder also has a slight effect on resistance, but its purpose is to join or make possible a homogeneous mixture of the graphite and alumina materials. It is desired here to have a binder with good heat characteristics. Several epoxy resins were selected that were reputed to be stable over wide temperature ranges. These were used to mold squib bodies to a resistance of approximately .13 ohms. Tests were conducted on each body to determine the effect of temperature on resistance. As can be seen on the graph, (Figure 5) the molded body containing the XM-1592 resin as a binder possesses superior resistance stability at high temperatures. Other resins show a sharp rise in resistance above 450°F .

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7.5. Vacuum Metallizing Process

7.5.1. Vacuum Equipment

Mechanical vacuum pump - Cenco Megavac

Oil diffusion pump - Consolidated Electrodynamics MCF60

Vacuum gauge - Consolidated Electrodynamics PHG-T-01

Bell jar 9" diameter by 16" high

Pump plate 11" diameter

Power transformer - high current, low voltage:

Core - .012" Hipersil, 1.250" build up, 1.875" strip width,
5.500" window length, 2.000" window width.

Primary - 200 turns #16 Formvar

Secondary - 8 turns of 4 #4 stranded copper in parallel, insulated
with polyethelene jacket.

Variac 5 amp

Variac 20 amp

A. C. voltmeter 0 - 2.5 volts

Resistance bridge - (see figure 6 A & B)

7.5.2. Materials

Molybdenum strip .003" x 1.5"

Antimony metal, granular, analytical

Reagent, Mallenckrodt Chemical Works

7.5.3. Vacuum Metallizing Procedure

Following is a description of the process used in applying a thin antimony film to the firing surfaces of squibs developed on this contract. The block diagram (figure 7) and photographs (figures 8 and 9) show the arrangement of the vacuum system and metallizing equipment.

Figure 10 shows the squibs positioned in a fixture above a molybdenum "boat" containing granular antimony. All of these parts are located on a pump plate over which a bell jar is placed. Electrical leads are connected to the electrodes of one of the squibs and to a resistance measurement bridge.

With the squibs in place, the bell jar is positioned over the pump plate and the vacuum pumps are started. In about 45 minutes the pressure within the bell jar is reduced to one (1) micron or less. At this time, the power transformer is switched on, sending a heavy current through the molybdenum boat and the antimony. The transformer output voltage is adjusted to 1.5 volts, by means of the 20 amp. Variac. In approximately 45 seconds, the resis-

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tance bridge will indicate that antimony is being deposited on the squib. When the resistance across the squib electrodes indicates the desired value (for our purpose - .40 ohms), the transformer is shut off. After the diffusion pump has cooled sufficiently, air is admitted into the bell jar.

The squibs are then removed from the fixture and resistances measured on a Wheatstone bridge. The resistance range should be .35 ohms to .45 ohms.

7.6. Effect of Antimony Coating

In order to attain the desired firing energy of .1 to 1 joule a shunt resistance of 1.5 to 2.0 ohms was required. This resistance range produced a DC carrying capability thru the squib of 1.5 amperes for approximately 1.5 minutes. This was considered unsatisfactorily low. To carry this current for an indefinite time the shunt resistance had to be reduced to approximately .4 ohms. This increased the firing energy to some 2 joules which was considered too high.

The problem of reducing the firing energy level and, at the same time, maintaining the 1.5 amperes DC indefinitely was solved by the addition of a second shunt. Squib bodies were molded therefore to 1.5 ohms electrode-to-electrode resistance and the metallic film applied across the electrodes until the total resistance was reduced to .4 ohms. Since the film surface shunt is of extremely small mass, current density becomes extremely high. This localized high current density has the effect of producing an arc at a relatively low energy level.

Figure 11 is a graph showing time versus temperature curves of coated vs. uncoated squibs. It should be noted that the current is but 1.5 amperes.

8. Spark Testing at Scintilla

As each group of squibs was molded, 25 pieces were selected at random for spark tests. This was a Bruceton staircase type of test in which the energy level required to discharge a visible spark across the surface of the gap was determined. This information (Table III and IV) was sent to National Northern for use in selecting, or formulating, a powder mix.

Figure 12 shows the probability curve and confidence envelope of the squib described in this report. These curves were plotted from a 25 piece Bruceton sparking test.

Based on these curves National Northern was instructed to load with a mixture sensitive to approximately .4 joules of energy.

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TABLE III

Bruceton Type Spark Test at Scintilla

| GAP - .030 | | No.'s - 3366 - 3399 | | | |
|--------------------------|--------------------|---------------------|----|----|----|
| ELECTRODE LENGTH - .097" | | DATE: 1/25/62 | | | |
| No. | Resistance Ohms | Energy - Joules | | | |
| | | .1 | .2 | .3 | .4 |
| 3391 | .42 | | X | | |
| 3393 | .42 | 0 | | | |
| 3390 | .43 | | X | | |
| 3389 | .43 | 0 | | | |
| 3395 | .42 | | X | | |
| 3387 | .44 | 0 | | | |
| 3394 | .42 | | X | | |
| 3396 | .41 | 0 | | | |
| 3399 | .40 | | 0 | | |
| 3397 | .41 | | | X | |
| 3388 | .43 | | X | | |
| 3392 | .41 | 0 | | | |
| 3398 | .44 | | X | | |
| 3382 | .40 | 0 | | | |
| 3380 | .38 | | 0 | | |
| 3371 | .38 | | | X | |
| 3374 | .41 | | X | | |
| 3377 | .44 | 0 | | | |
| 3379 | .39 | | 0 | | |
| 3381 | .38 | | | X | |
| 3383 | .42 | | X | | |
| 3386 | .41 | 0 | | | |
| 3375 | .43 | | X | | |
| 3370 | .42 | 0 | | | |
| 3366 | .41 | | X | | |



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TABLE IV

Calculations for Bruceton Type Test at Scintilla

| H | ADJUSTED E | NO FIRING = N | ADJ. E x N = A | ADJ. ENERGY ² | ADJ. E ² x N = B |
|----|------------|---------------|-------------------|-----------------------------|--------------------------------|
| .1 | 0 | 0 | 0 | 0 | 0 |
| .2 | 1 | 9 | 9 | 1 | 9 |
| .3 | 2 | 3 | 6 | 4 | 12 |
| | | 12 | 15 | | 21 |

$$\bar{X} = H_1 + D \left(\frac{A}{N} - .5 \right)$$

$$\bar{X} = .1 + .1 \left(\frac{15}{12} - .5 \right)$$

$$\bar{X} = .1 + .1 (1.25 - .5)$$

$$\bar{X} = .1 + .075$$

$$\bar{X} = .175 \text{ Joules}$$

$$S = D \left[.06 + 1.6 \left(\frac{BE - A^2}{N^2} \right) \right]$$

$$S = .1 \left[.06 + 1.6 \left(\frac{12 \times 21 - 15^2}{12^2} \right) \right]$$

$$S = .1 \left[.06 + 1.6 (.187) \right]$$

$$S = .036 \text{ Joules}$$

$$PE\bar{X} = \frac{KS}{\sqrt{N}} = \frac{(4) (.036)}{\sqrt{12}} = \frac{.144}{3.46} = .041 \text{ Joules}$$

$$PEs = \frac{KS}{\sqrt{2N}} = \frac{(4) (.036)}{\sqrt{24}} = \frac{.144}{4.9} = .029 \text{ Joules}$$

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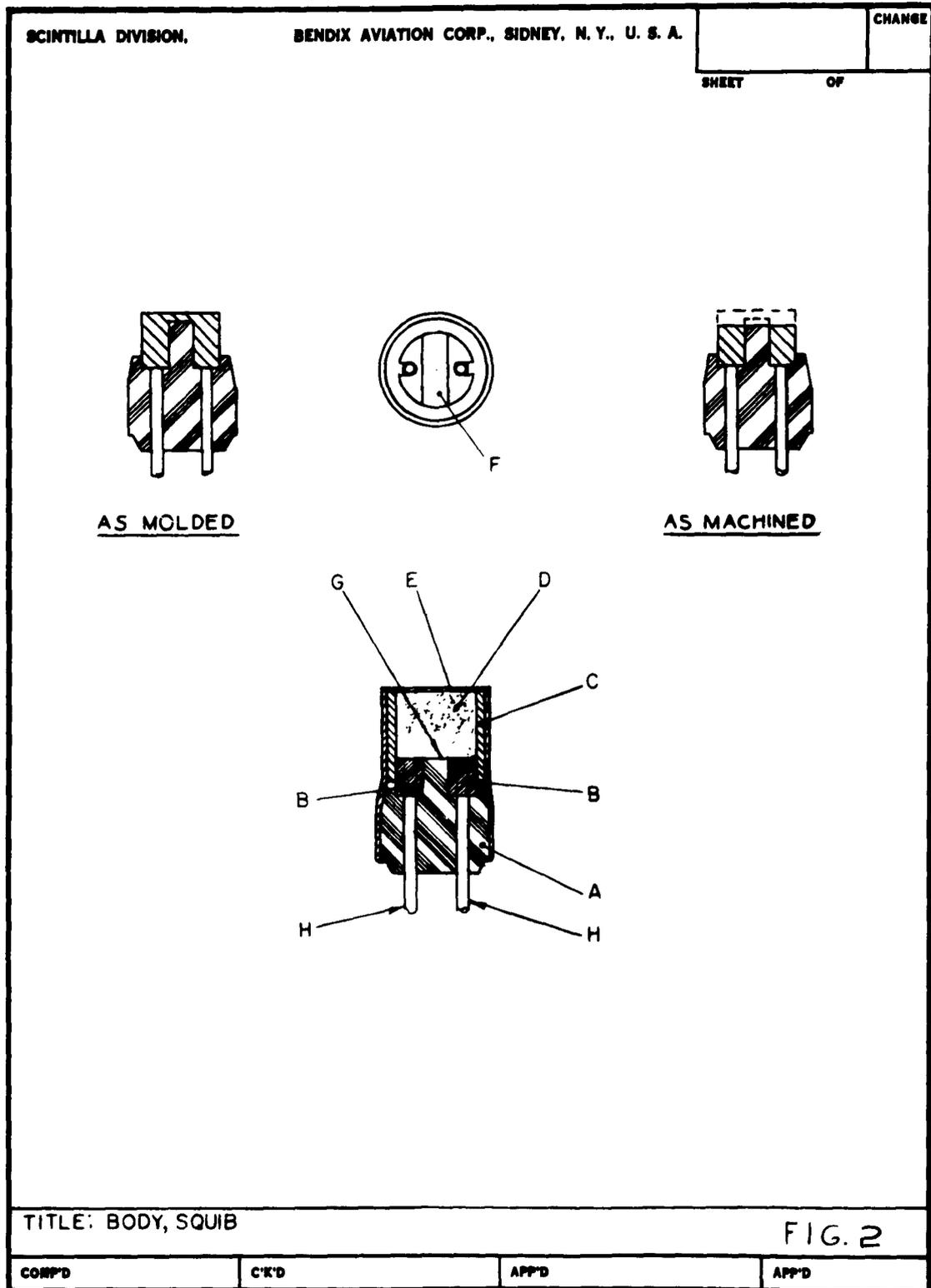


Figure 2

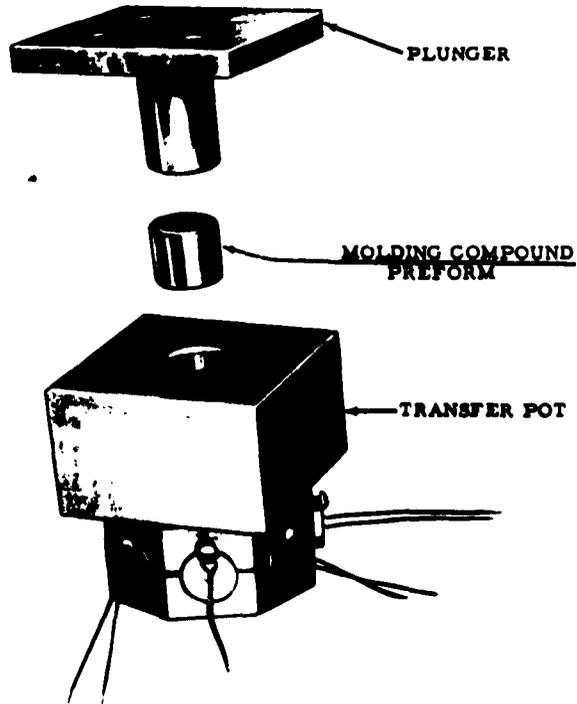
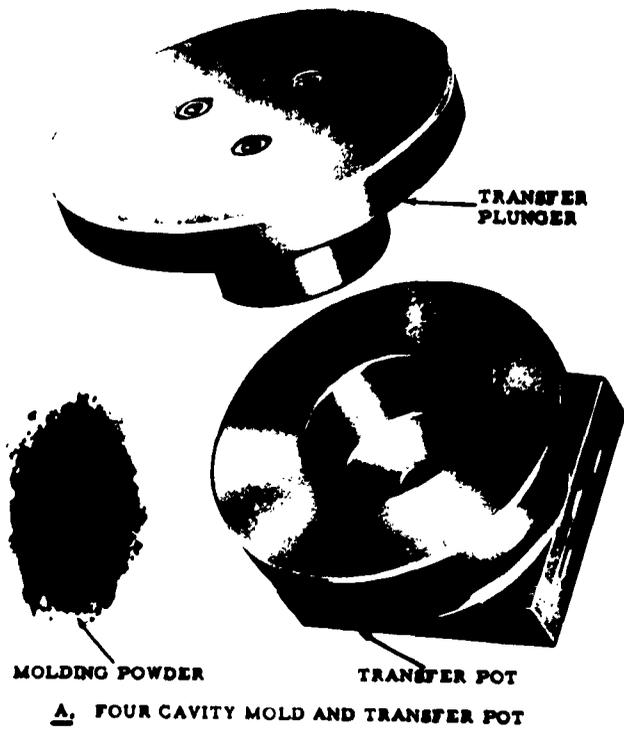


Figure 3

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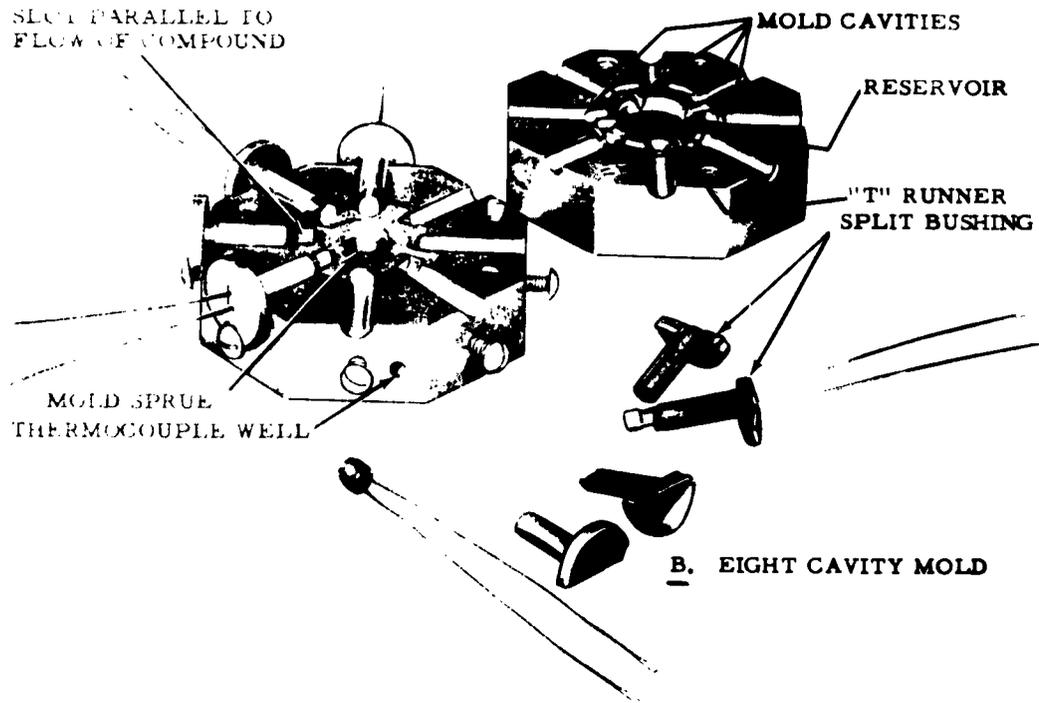
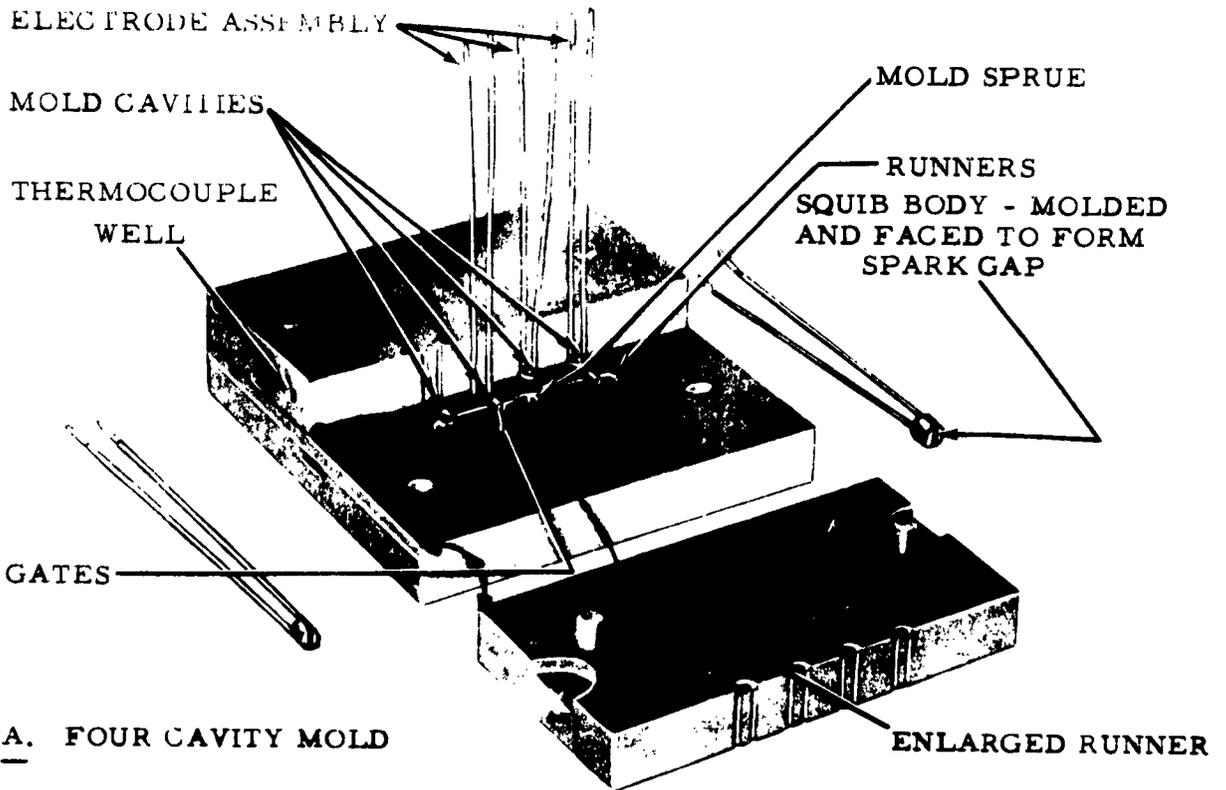


Figure 4



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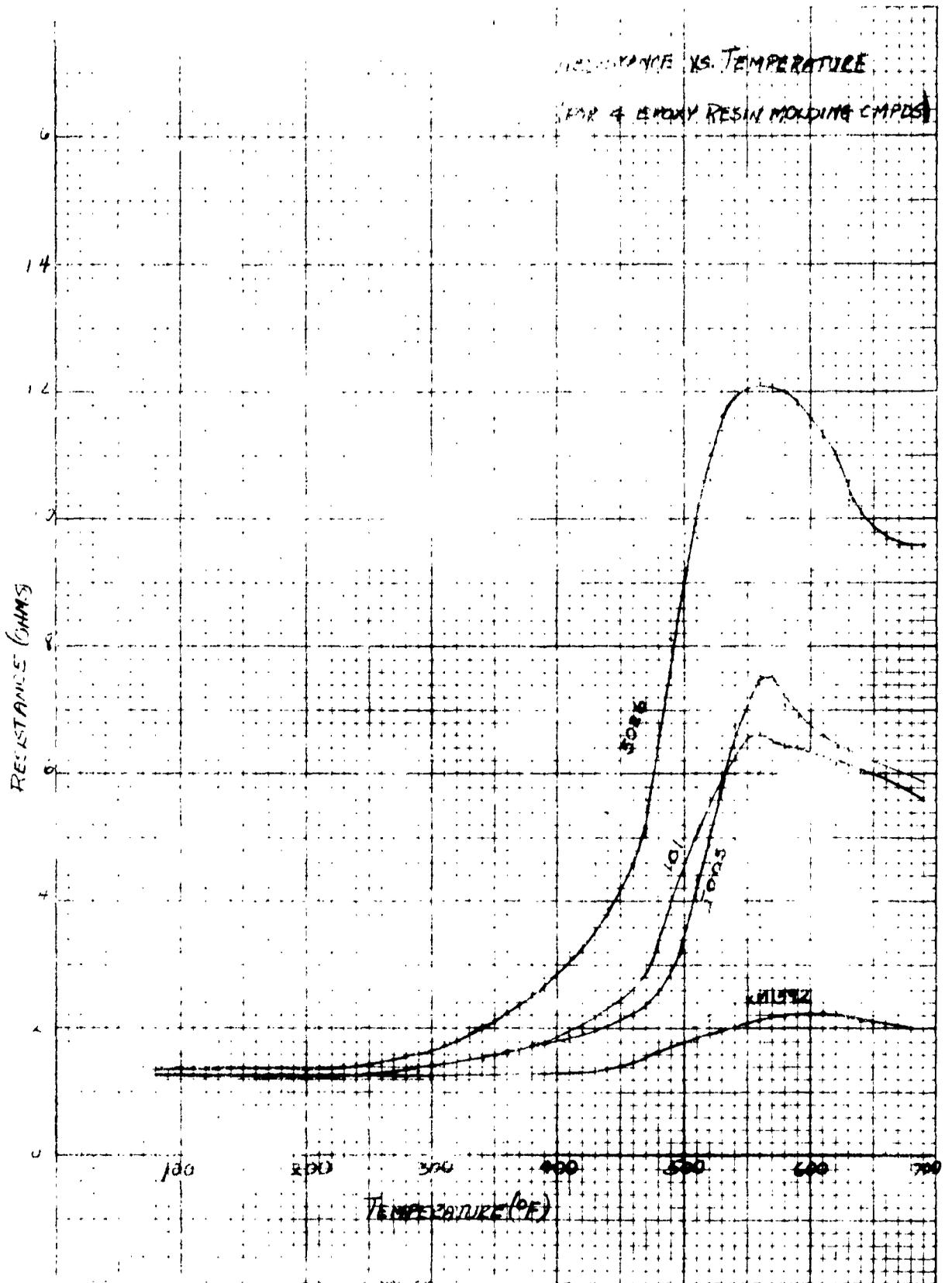


Figure 1



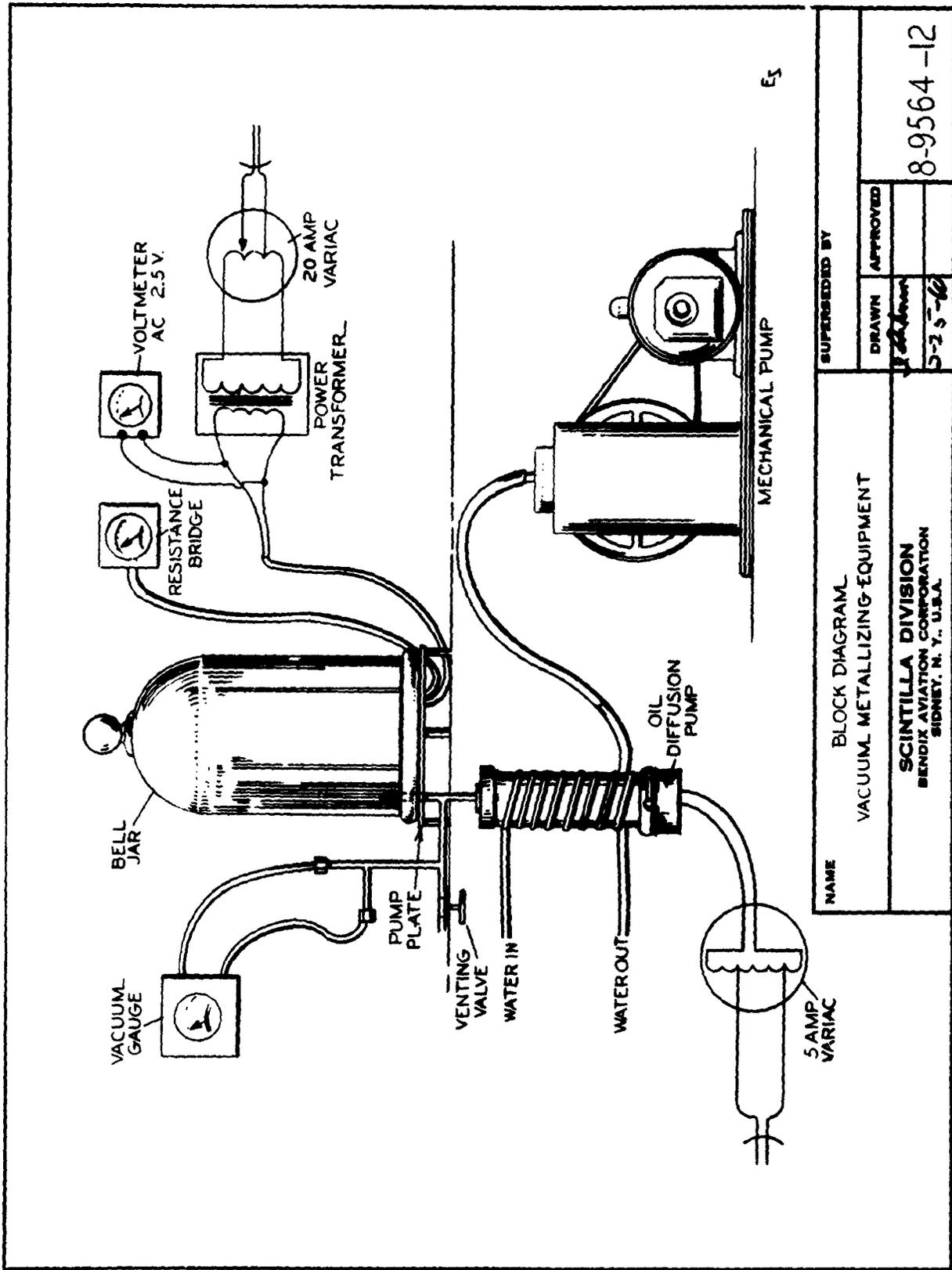
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| | | | |
|-----------------------------|--|--|--------|
| SCINTILLA DIVISION. | BENDIX AVIATION CORP., SIDNEY, N. Y., U. S. A. | 8-9564-11 | CHANGE |
| | | SHEET | OF |
| <u>LEGEND FOR 8-9564-10</u> | | | |
| T1 | - | Transformer, Stancoor P3062 | |
| C1 | - | Capacitor, electrolytic 100 Mfd. 50 volt | |
| R1 | - | Resistor, 0.5 ohm, 10 watt wire wound | |
| R2 | - | Resistor, 10 ohm, 10 watt wire wound | |
| R3 | - | Resistor, 1500 ohm, 2 watt | |
| R4 | - | Resistor, 150 ohm, 2 watt | |
| R5 | - | Resistor, 15 ohm, 2 watt | |
| R6 | - | Potentiometer, 2 ohm, 5 watt | |
| R7, R8 | - | Resistors, 1 ohm, 10 watt | |
| D1, D2 | - | Silicon diodes Westinghouse 303A | |
| D3, D4 | - | Stabistor, Transitron SQ22 | |
| S1 | - | Toggle switch, S.P.S.T. | |
| S2 | - | Wafer switch, 6 position | |
| G | - | Microammeter, 0-100 microamperes, Weston 301 | |
| COMP'D | <i>Andrew</i> 2-28-60 | CK'D | APP'D |
| | | | APP'D |

Figure 6 B



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E5

| | | | |
|------------------------------|--|----------------|--|
| NAME | | BLOCK DIAGRAM | |
| VACUUM METALLIZING-EQUIPMENT | | DRAWN APPROVED | |
| SCINTILLA DIVISION | | 5-25-66 | |
| BENDIX AVIATION CORPORATION | | 8-9564-12 | |
| SIDNEY, N. Y., U.S.A. | | | |

Figure 7



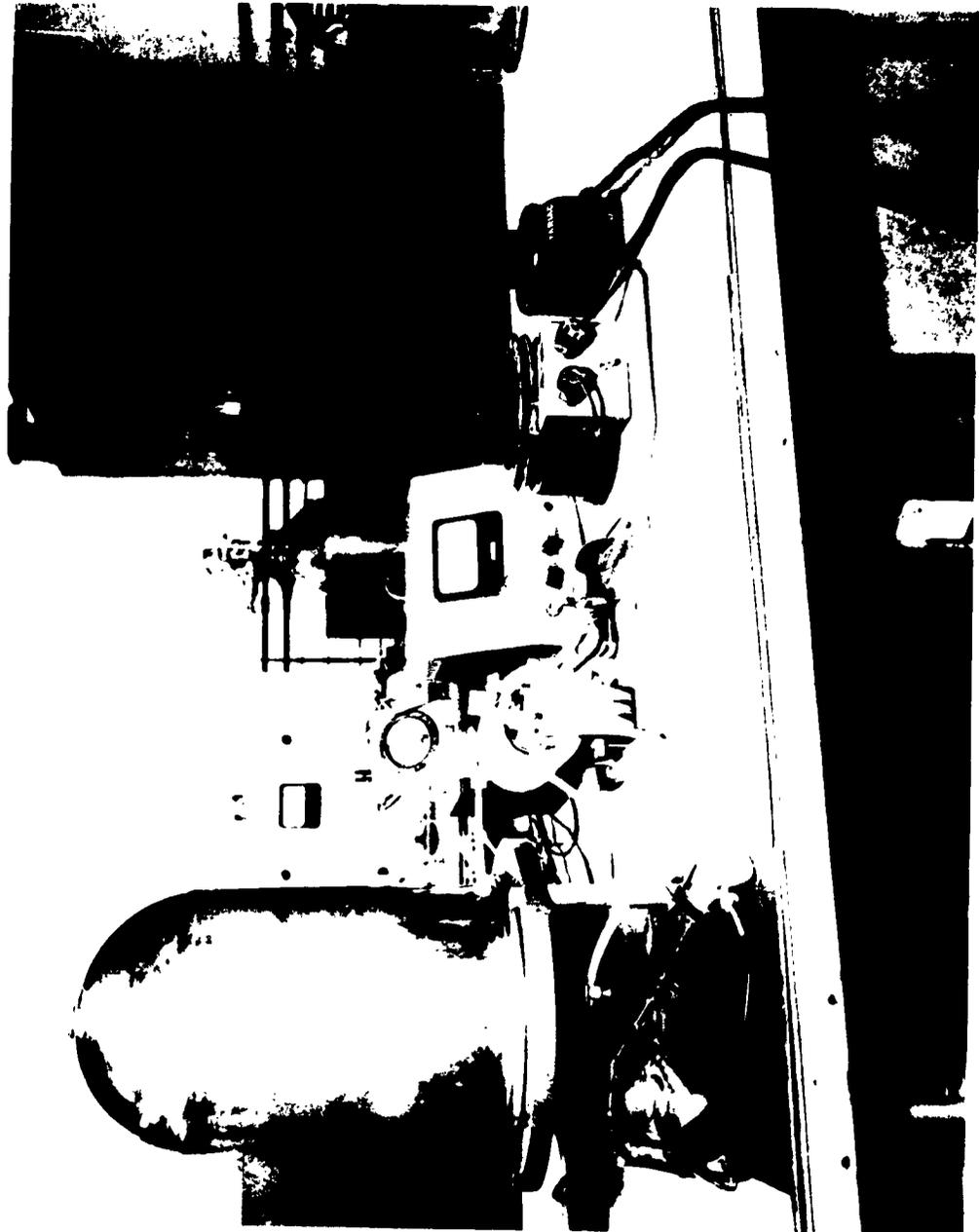


Figure 8

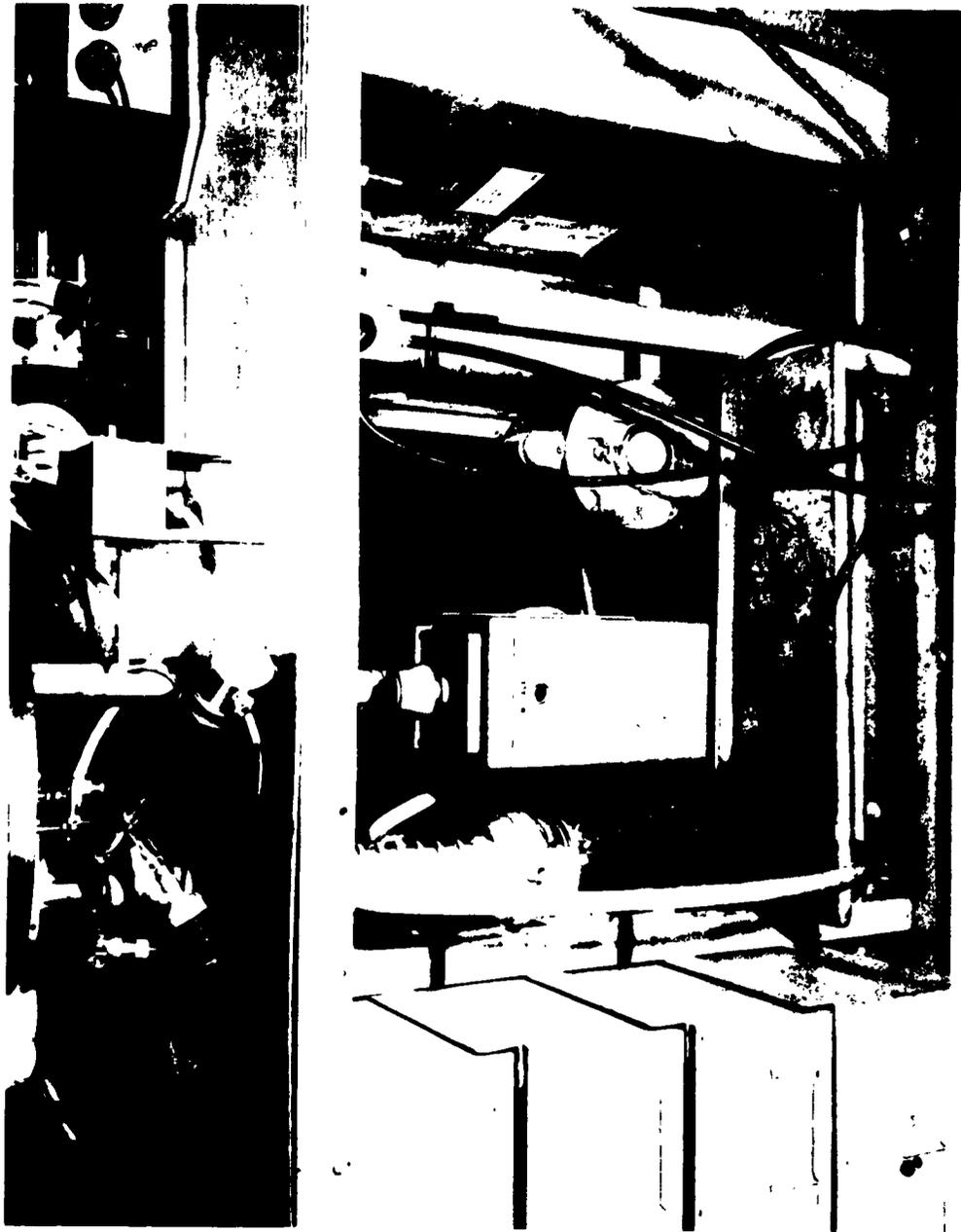


Figure 9

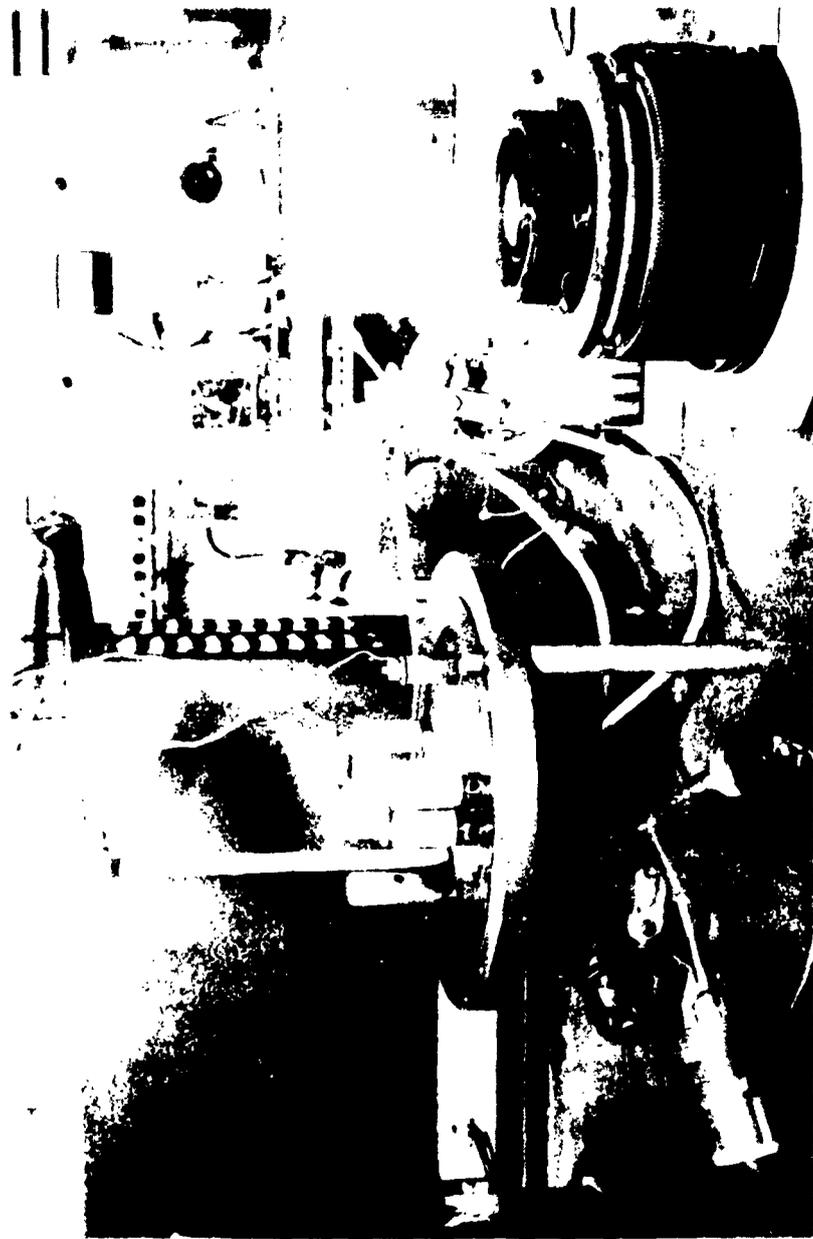


Figure 10

SCINTILLA DIVISION

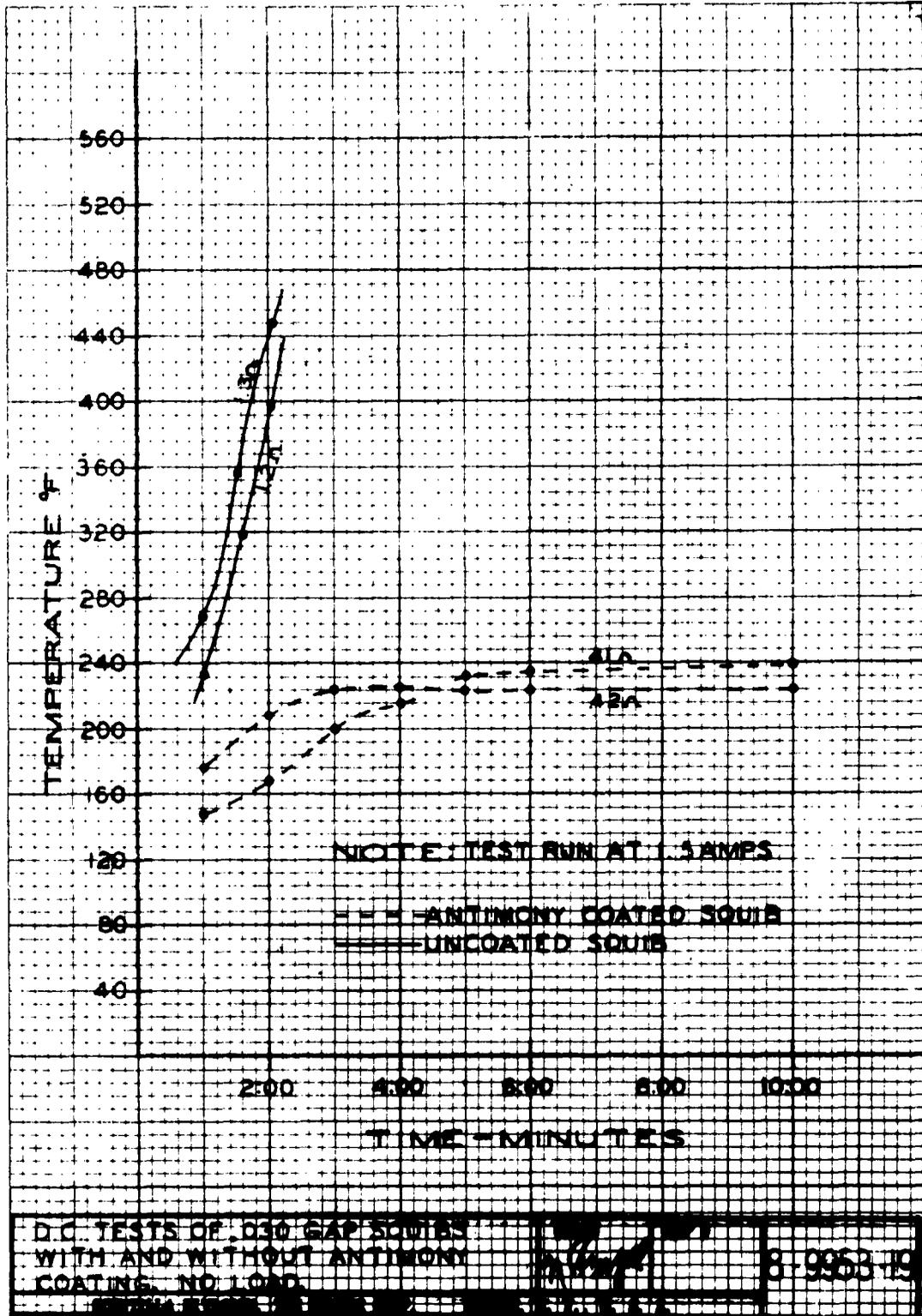


Figure 11



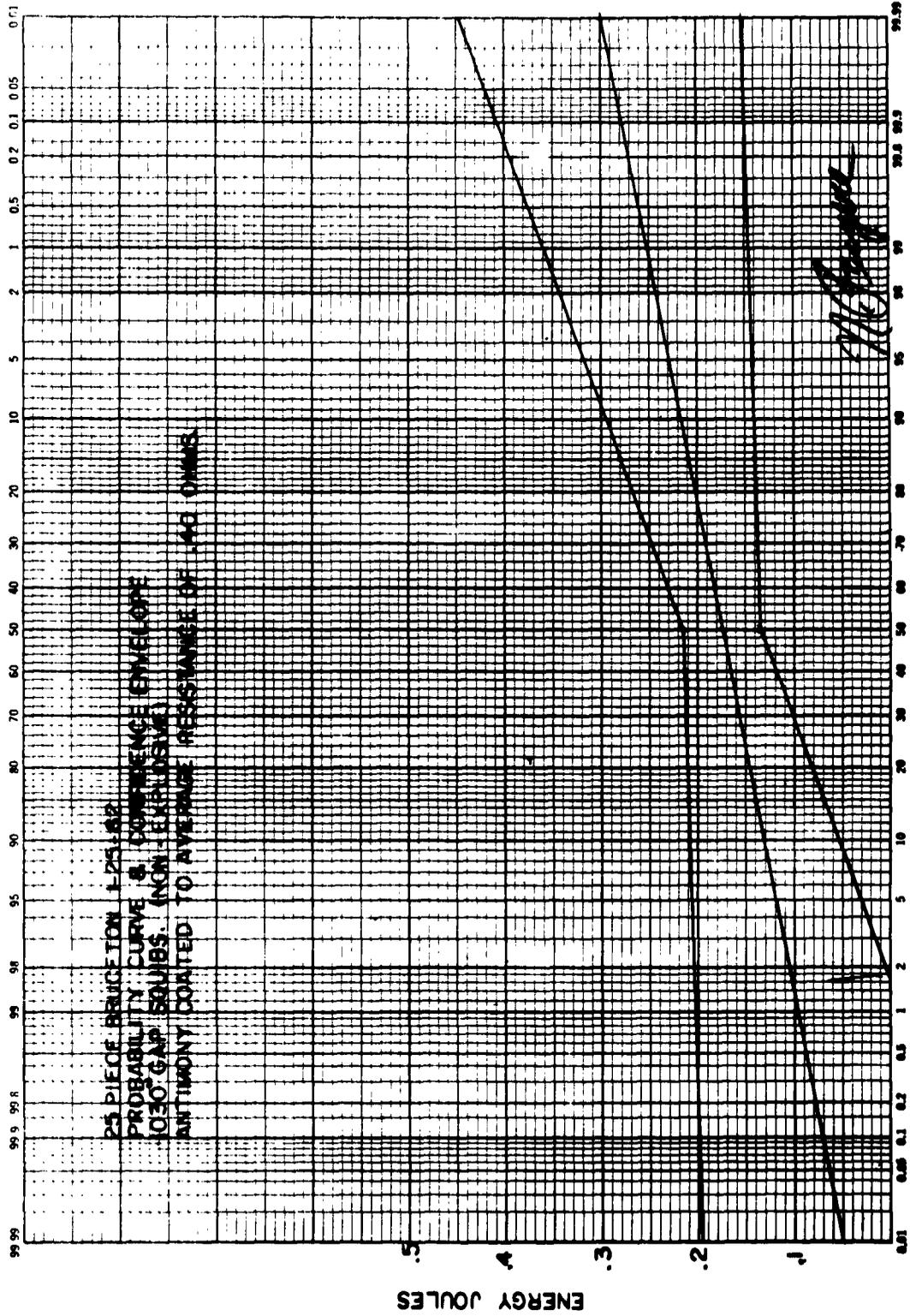


Figure 12

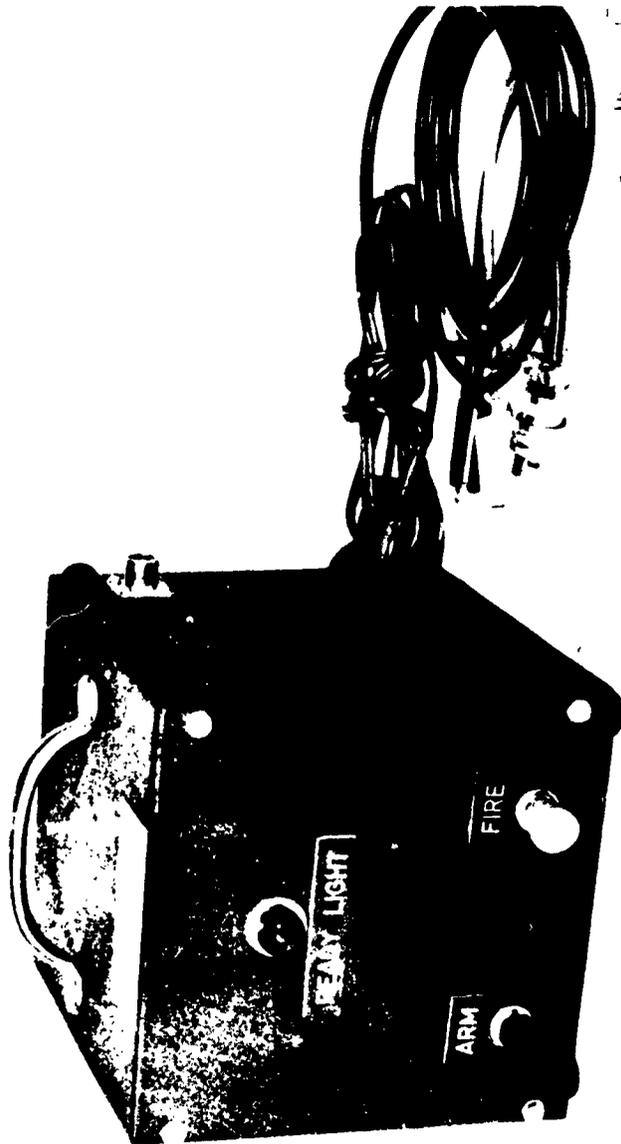


Figure 13

SCINTILLA DIVISION

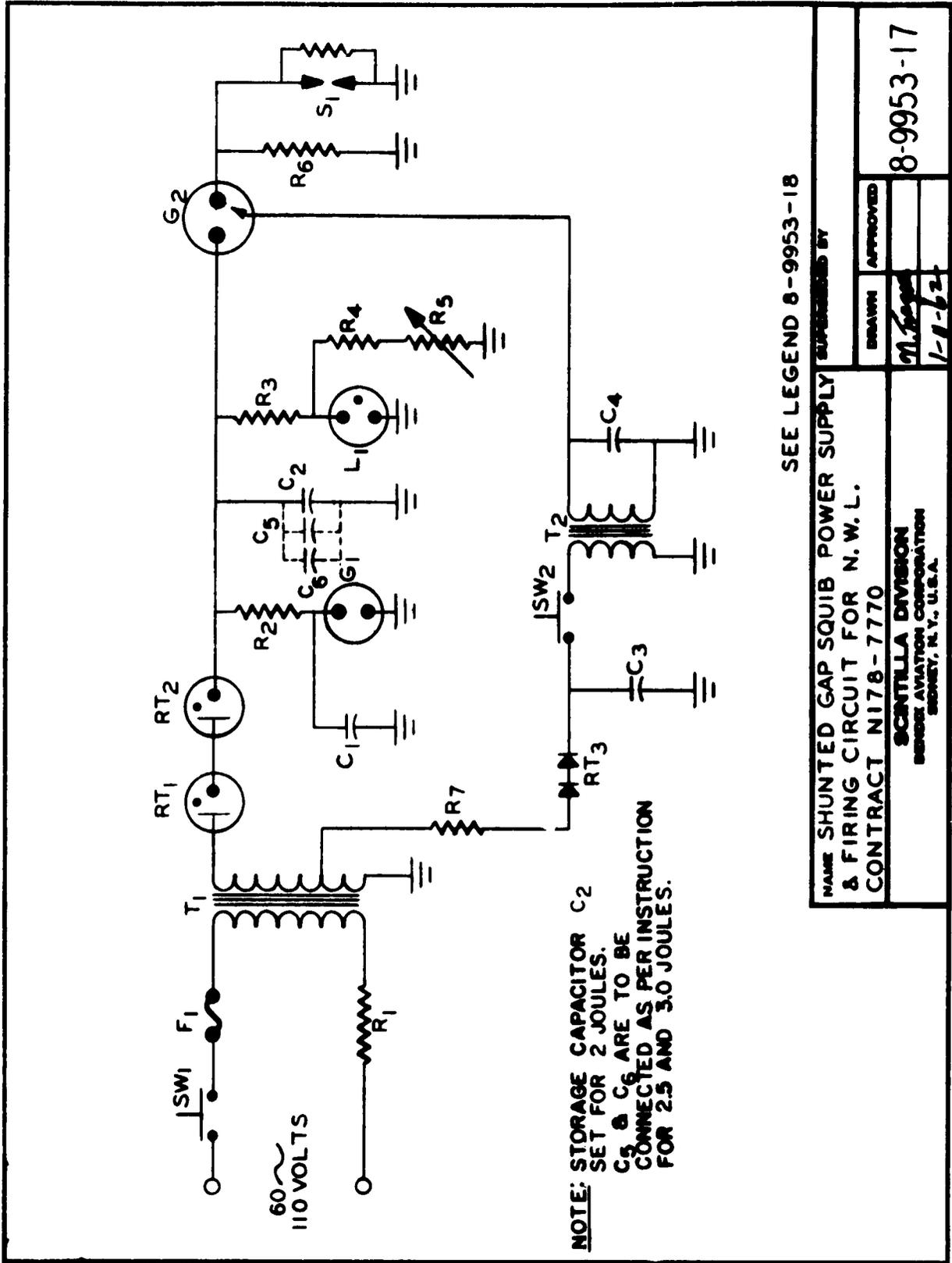


Figure 14A

SCINTILLA DIVISION

| | | | |
|--|---|--------------|--------|
| SCINTILLA DIVISION, | BENDIX AVIATION CORP., SIDNEY, N. Y., U. S. A. | 8-9953-18 | CHANGE |
| | | SHEET 1 OF 1 | |
| <u>L E G E N D for 8-9953-17</u> | | | |
| C1 | - .03 uf. capacitor, 1200 V. D.C. | | |
| C2 | - 4 uf. capacitor, 1000 V. D.C. | | |
| C3 | - 1 uf. capacitor, 200 V. D.C. | | |
| C4 | - .001 uf. capacitor, 1000 V. D.C. | | |
| C5, C6 | - 1 uf. capacitor, 1000 V. D.C. | | |
| | | | |
| G1 | - Spark gap tube L-15514-30 (1500 volts) 1050 volts breakdown | | |
| G2 | - 3 electrode triggered spark gap tube | | |
| | | | |
| L1 | - Neon bulb type NE-51 | | |
| | | | |
| R1 | - 450 Ohm, 50 watt resistor | | |
| R2 | - 220 K. Ohm, 2 watt resistor | | |
| R3 | - 1 Megohm, 2 watt resistor | | |
| R4 | - 47 K. Ohm, 2 watt resistor | | |
| R5 | - 50 K. Ohm, variable pot resistor - 2 watt | | |
| R6 | - 1 K. Ohm, 10 watt resistor, wire wound | | |
| R7 | - 1 Megohm, 2 watt resistor | | |
| | | | |
| RT1, RT2 | - Rectifier tubes 10-88383 | | |
| RT3 | - 2 - Silicone rectifier type F-6 Sarkes Tarzian | | |
| | | | |
| S1 | - Squib | | |
| | | | |
| SW1, SW2 | - SPST momentary contact switch | | |
| | | | |
| T1 | - Power Transformer | | |
| | | | |
| Primary - 1,700 Turns #32 wire | | | |
| Secondary - 25,000 Turns #40 wire with tap at 2500 turns | | | |
| | | | |
| Core - A-7 - no gap | | | |
| | | | |
| T2 | - Pulse Transformer | | |
| | | | |
| Primary - 45 Turns #30 wire | | | |
| Secondary - 750 Turns #22 wire | | | |
| | | | |
| Core - AL-7 - .016" gap | | | |
| | | | |
| COND | APP'D | APP'D | APP'D |

Figure 14B



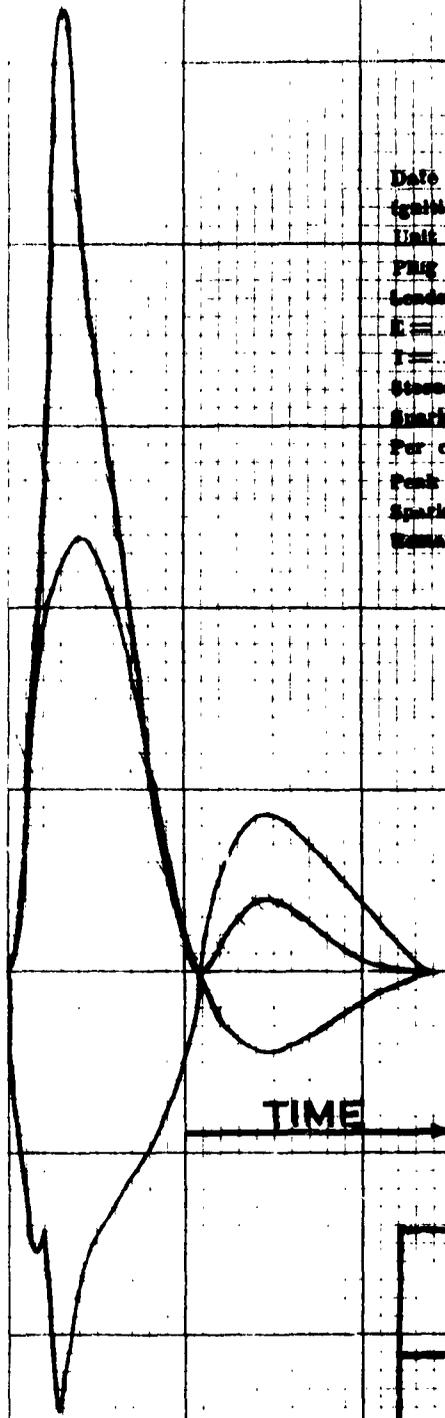
SCINTILLA DIVISION

| REL | CH'D | DATE | APP'D | SPECIFICATION | | 8-9953-20 | CHANGE |
|---|------|------|-------|--|-------|--------------|--------|
| | | | | | | SHEET 1 OF 1 | |
| | | | | | | ISSUED: | |
| SCINTILLA DIVISION | | | | BENDIX AVIATION CORP., SIDNEY, N. Y., U. S. A. | | | |
| SQUIB POWER SUPPLY OPERATING INSTRUCTIONS | | | | | | | |
| <ol style="list-style-type: none"> 1. Connect output line to squib. 2 Plug power supply into 60 cycle 110 volt outlet. 3. Press down "arm" button until "ready light" lights. This indicates that sufficient voltage is present on storage capacitor. 4. Press fire button. This will discharge 2 joules of stored energy into the squib. <p>NOTE: Power supply is set for 2 joules of stored energy. Provisions have been added to increase the stored energy to 2.5 or 3 joules. To accomplish this, simply remove the back of the power supply and connect a wire from the #2 position to the #2.5 position of the storage capacitor. This will give 2.5 joules stored energy. For 3 joules stored energy, simply connect position 3 of storage capacitor to position 2 and 2.5.</p> | | | | | | | |
| COMP'D <i>[Signature]</i> | | | CK'D | APP'D | APP'D | | |

Figure 14C



SCINTILLA DIVISION



Date 2-6-62
 Ignition System _____
 Volt 1000 Volt DC Supply B/N _____
 Plug Squirb B/N 3563
 Load Approx 4 ft
 E = 100 volts/ft P = 29,250 watts/ft
 I = 292.5 amps/ft P = 10 sec/ft
 Stored Energy 2 Joules
 Spark Energy 24 Joules/Spark
 Per cent Efficiency 37%
 Peak Watts 157,906
 Spark Duration 83.5 sec
 Remarks _____

THE BENDIX CORPORATION
 SCINTILLA DIVISION
 SIDNEY, N. Y.
 CURRENT, VOLTAGE
 AND
 POWER WAVEFORMS

Figure 14 D



SCINTILLA DIVISION

9. Tests at National Northern

During the course of this program some 1600 squibs have been sent to National Northern Division of Atlantic Research Corporation for loading and testing. Thirteen different explosive mixes were developed and tested. These were described in the third quarterly report. Sparking energy data was forwarded to National with each group of squibs shipped. A total of 16 such task assignments were processed at National, each in the following sequence:

- a. Preliminary scanning of 4-5 explosive mixes. The purpose of this was to determine a mixture which would be responsive in the squib to energy levels determined by spark tests at Scintilla.
- b. Bruceton testing using a mix selected from preliminary scanning.
- c. Tests to determine DC carrying ability.

The following curves and tables pertain to the particular squib about which this report is concerned:

SCINTILLA DIVISION

8-9953

BRUCETON TEST

| GAP - .030 | | POWDER MIX - A | | No. 's 3089 - 3330 | | | | |
|-------------------------|------------------------|-----------------|------|--------------------|------|------|-------|------|
| ELECTRODE LENGTH - .097 | | Date: 11/27/61 | | | | | | |
| No. | Time Mil. Sec.'s | Energy - Joules | | | | | | |
| | | .244 | .292 | .345 | .395 | .445 | .4975 | .545 |
| 3098 | 2.2 | | | x | | | | |
| 3254 | 5.19 | | x | x | | | | |
| 3237 | | 0 | | | | | | |
| 3272 | | | 0 | | | | | |
| 3238 | | | | 0 | | | | |
| 3139 | 2.2 | | | | x | | | |
| 3104 | NS | | | x | | | | |
| 3318 | 8.07 | | x | | | | | |
| 3199 | | 0 | | | | | | |
| 3118 | | | 0 | | | | | |
| 3178 | | | | 0 | | | | |
| 3089 | | | | | 0 | | | |
| 3195 | | | | | | 0 | | |
| 3287 | NS | | | | | | x | |
| 3253 | NS | | | | | x | | |
| 3166 | NS | | | | x | | | |
| 3105 | | | | 0 | | | | |
| 3330 | | | | | 0 | | | |
| 3171 | | | | | | 0 | | |
| 3246 | | | | | | | 0 | |
| 3192 | | | | | | | | x |
| 3232 | | | | | | | 0 | |
| 3198 | | | | | | | | x |
| 3107 | | | | | | | x | |
| 3154 | | | | | | 0 | | |
| 3327 | | | | | | | x | |
| 3240 | | | | | | x | | |
| 3134 | | | | | x | | | |
| 3227 | | | | 0 | | | | |
| 3194 | | | | | x | | | |



SCINTILLA DIVISION

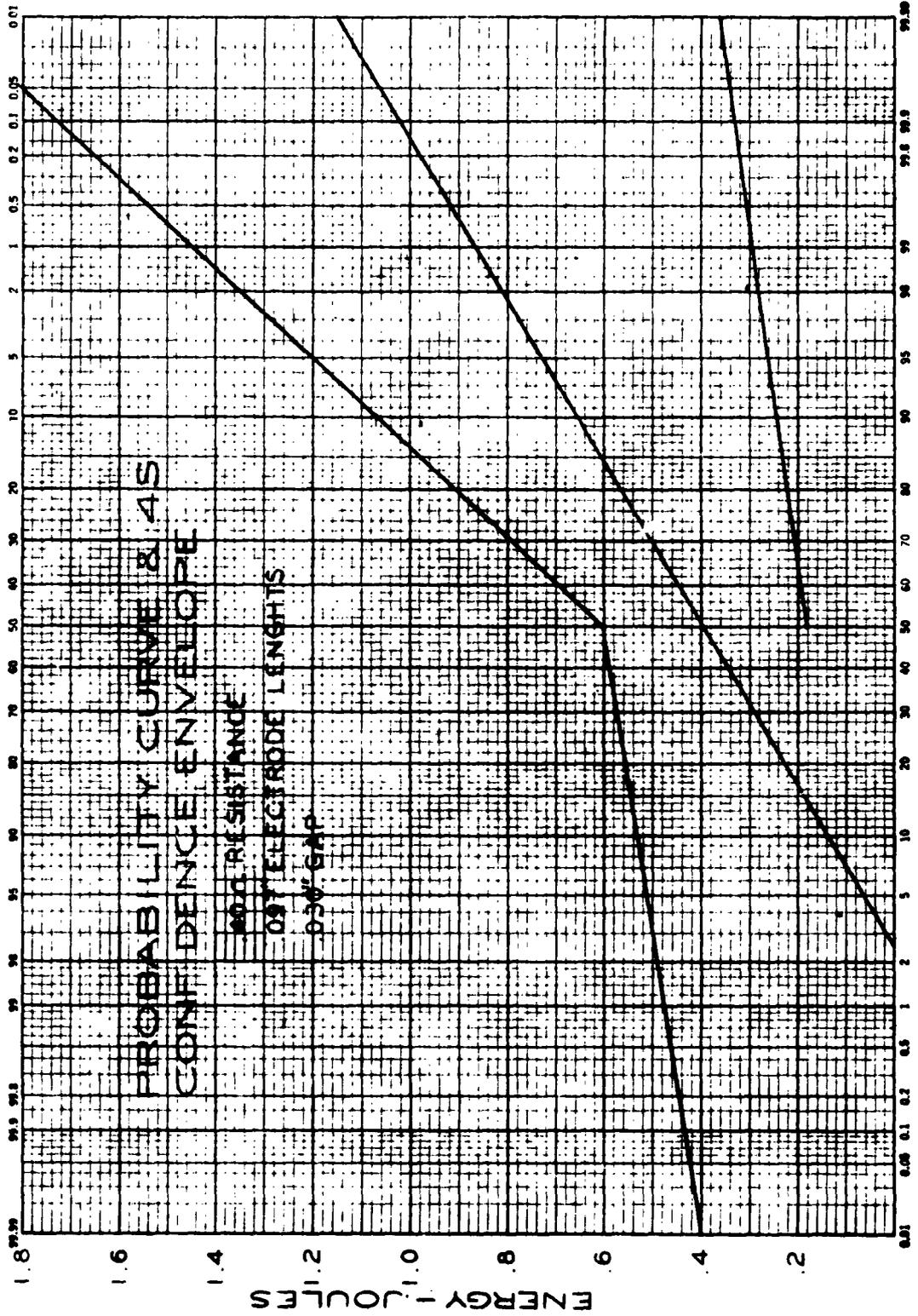
8-9953

| GAP - .030 | | POWDER MIX - A | | | No.'s 3089 - 3330 | |
|-------------------------|-----------------|----------------|-----------------|----------------------|--------------------|------------------|
| ELECTRODE LENGTH - .097 | | | | Date: 11/27/61 | | |
| No. | OHM BEFORE LOAD | OHM AFTER LOAD | OHM AFTER CRIMP | FIRING ENERGY JOULES | FUNCTION TIME M.S. | OHM AFTER FIRING |
| 3098 | .35 | .50 | .48 | .345 | 2.2 | 1.31 |
| 3254 | .35 | .54 | .50 | .292 | 5.19 | .97 |
| 3237 | .41 | .72 | .69 | .244 | NP | .80 |
| 3272 | .40 | .69 | .60 | .292 | NP | .85 |
| 3238 | .42 | .64 | .60 | .345 | NP | .70 |
| 3139 | .40 | .56 | .51 | .395 | 2.2 | 1.35 |
| 3104 | .44 | .66 | .59 | .345 | NS | 1.16 |
| 3318 | .38 | .58 | .52 | .292 | 8.07 | 1.09 |
| 3199 | .35 | .74 | .69 | .244 | NP | .60 |
| 3118 | .41 | .69 | .68 | .292 | NP | .96 |
| 3178 | .44 | .68 | .63 | .345 | NP | 1.25 |
| 3089 | .35 | .52 | .50 | .395 | NP | .62 |
| 3195 | .43 | .70 | .67 | .445 | NP | .69 |
| 3287 | .45 | .68 | .61 | .4975 | NS | .91 |
| 3253 | .39 | .58 | .52 | .445 | NS | .90 |
| 3166 | .41 | .66 | .60 | .395 | NS | 1.32 |
| 3105 | .45 | .70 | .60 | .345 | NP | .76 |
| 3330 | .37 | .52 | .50 | .395 | NP | .84 |
| 3171 | .45 | .66 | .63 | .445 | NP | .92 |
| 3246 | .41 | .63 | .60 | .4975 | NP | .73 |
| 3192 | .44 | .76 | .69 | .545 | NS | .97 |
| 3232 | .43 | .62 | .58 | .4975 | NP | 1.08 |
| 3198 | .38 | .62 | .56 | .545 | NS | 1.11 |
| 3107 | .37 | .60 | .59 | .4975 | NS | .73 |
| 3154 | .38 | .58 | .52 | .445 | NP | .62 |
| 3327 | .45 | .62 | .60 | .4975 | NS | 1.17 |
| 3240 | .40 | .59 | .55 | .445 | NS | .91 |
| 3134 | .39 | .67 | .63 | .395 | NS | 1.11 |
| 3227 | .42 | .60 | .58 | .345 | NP | .69 |
| 3194 | .45 | .98 | .69 | .395 | NS | 1.15 |

NP - No Fire
NS - No Stop



SCINTILLA DIVISION



SCINTILLA DIVISION

| H | ADJUSTED E | NO FIRING = N | ADJ. E x N = A | ADJ. ENERGY ² | ADJ. E ² x N = B |
|-------|------------|---------------|-------------------|-----------------------------|--------------------------------|
| .244 | 0 | 0 | 0 | 0 | 0 |
| .292 | 1 | 2 | 2 | 1 | 2 |
| .345 | 2 | 2 | 4 | 4 | 8 |
| .395 | 3 | 4 | 12 | 9 | 36 |
| .445 | 4 | 2 | 8 | 16 | 32 |
| .4875 | 5 | 3 | 15 | 25 | 74 |
| .545 | 6 | 2 | 12 | 36 | 72 |
| | | 15 | 53 | | 225 |

$$\bar{X} = H_1 + D \left(\frac{A}{N} - .5 \right)$$

$$S = D \left[.06 + 1.6 \left(\frac{NB - A^2}{N^2} \right) \right]$$

$$\bar{X} = .244 + .05 \left(\frac{53}{15} - .5 \right)$$

$$S = .05 \left[.06 + 1.6 \left(\frac{15 \times 225 - 53^2}{15^2} \right) \right]$$

$$\bar{X} = .244 + .05 (3.53 - .5)$$

$$S = .05 \left[.06 + 1.6 \left(\frac{3375 - 2809}{225} \right) \right]$$

$$\bar{X} = .244 + .05 (3.03)$$

$$S = .05 \left[.06 + 1.6 \left(\frac{566}{225} \right) \right]$$

$$\bar{X} = .244 + .152$$

$$S = .05 \left[.06 + 1.6 (2.52) \right]$$

$$\bar{X} = .396 \text{ Joules}$$

$$S = .05 \left[.06 + 4.032 \right]$$

$$S = .05 \left[4.092 \right]$$

$$S = .205 \text{ Joules}$$

$$PE_{\bar{X}} = \frac{KS}{\sqrt{N}} = \frac{4 \times .205}{\sqrt{15}} = \frac{.82}{3.872} = .212 \text{ Joules}$$

$$PE_S = \frac{KS}{\sqrt{2N}} = \frac{4 \times .205}{\sqrt{30}} = \frac{.82}{5.477} = .150 \text{ Joules}$$

$$K = 4$$

8-9953

DIRECT CURRENT TEST

| GAP - .030 | | POWDER MIX - A | | | No.'s 3090 - 3338 | | |
|-------------------------|------------------------|-----------------------|---------------------|----------------|-------------------|-------------------------|------------------------|
| ELECTRODE LENGTH - .097 | | | | Date: 11/29/61 | | | |
| No. | Current in Amps. | Drop in Current | Time | Function | Time | Ohm Before Firing | Ohm After Firing |
| NEW - UNUSED SQUIBS | | | | | | | |
| 3338 | 2.75 | 2.5 | 1 Min. | Fired | 1 Min. 15 Sec. | .69 | 4.7 |
| 3111 | 2.5 | 2.25 | 2 Min. | Fired | 2 Min. 8 Sec. | .56 | 2.8 |
| 3219 | 2.0 | NONE | 6 Hrs. | No Fire | 6 Hrs. | .53 | 1.59 |
| 3286 | 2.0 | NONE | 5 Min. | No Fire | | .62 | .92 |
| 3312 | 2.25 | 2.10 | 3.5 Min. | Fired | 3 Min. 55 Sec. | .59 | 2.5 |
| 3188 | 2.0 | 1.85 1.75 | 2.5 Min. 1/2 Hr. | No Fire | | .70 | 1.23 |
| 3306 | 2.0 | 1.85 1.75 | 2.5 Min. 1/2 Hr. | Fired | 36 Min. | .55 | 3.3 |
| 3297 | 2.0 | NONE | 1 Hr. | No Fire | 1 Hr. | .67 | 1.4 |
| 3283 | 2.0 | NONE | 1 Hr. | No Fire | 1 Hr. | .66 | 1.11 |
| 3102 | 2.0 | NONE | 6 Hr. | No Fire | 6 Hr. | .74 | 1.7 |
| SURVIVORS OF BRUXTON | | | | | | | |
| 3090 | 2.5 | 2.0 | 1.5 Min. | Fired | 1 Min. 54 Sec. | .66 | 10.0 |
| 3263 | 2.0 | NONE | 1 Hr. | No Fire | | .63 | 1.34 |
| 3288 | 2.0 | 1.85 1.75 | 2.5 Min. 1/2 Hr. | No Fire | | .53 | .82 |
| 3149 | 2.0 | 1.85 1.75 | 2.5 Min. 1/2 Hr. | No Fire | | .55 | .80 |
| 3289 | 2.0 | NONE | 1 Hr. | No Fire | 1 Hr. | .50 | .90 |
| 3200 | 2.0 | NONE | 1 Hr. | No Fire | 1 Hr. | .68 | 2.0 |

SCINTILLA DIVISION

10. Tests at Franklin Institute

Radio frequency tests to determine susceptibility of the squibs to induced RF were conducted at the Franklin Institute Laboratories for Research and Development in Philadelphia, Pa.

The report issued by Franklin Institute at the conclusion of their work is reproduced on the following pages.



Final Report

F-B1907-1

EVALUATION OF SPARK GAP SQUIBS

by

**PAUL F. Mohrbach
Raymond R. Raksnis**

January, 1962

Prepared for

**SCINTILLA DIVISION
Bendix Corporation
PO - 2435577**

THE FRANKLIN INSTITUTE
LABORATORIES FOR RESEARCH AND DEVELOPMENT
PHILADELPHIA PENNSYLVANIA

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SQUIBS

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ABSTRACT

Special squibs supplied by the Scintilla Division were evaluated at 10 Mc continuous wave RF energy and with constant current pulses of 10 second duration. As part of a complementary program, inert plugs were examined at 10 Mc RF, and input impedance measurements were determined over a frequency range of 10 to 500 Mc.

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I. INTRODUCTION

The protection of electrically initiated devices from stray RF energy can conceivably be accomplished by a variety of methods, singly or in combination. Some of these include incorporation of integral attenuators, or energy absorbers, in the base of the plug, shielding, lossy firing cables, and the use of inherently insensitive devices.

The present analysis included examining a squib which could be classified in the last category mentioned above: a device insensitive by virtue of its construction. This squib contains a low resistance shunt element which by passes currents from low voltage sources and a transducing element in the form of a thin layer of antimony located at the face of the plug which is in proximity to the explosive material. By virtue of the low resistances involved and the quantity of conductive mix material in the body of the plug, considerable power can be absorbed by the plug without initiating the device (if a good heat sink is supplied). For normal initiations, a high voltage source produces a spark or arc at the face of the plug.

The extent of the present program included determining the sensitivity of live squibs to RF power (CW) and to direct (constant) current, plus examinations of inert plugs subjected to various RF exposures, with the intent of defining the RF hazard.

2. ANALYSIS OF UNLOADED PLUGS

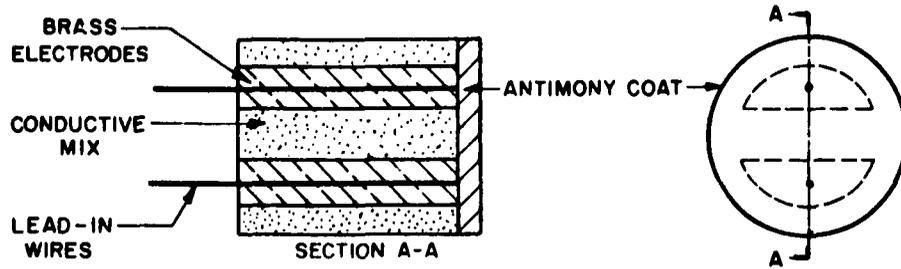
A group of unloaded squibs were supplied to be analysed in conjunction with the complete squibs. These were of three types; the complete plug including the conductive mix body with an antimony coating, plugs with a conductive mix body with no coating, and plugs containing a high dielectric material between the electrodes and the antimony

coating. To simplify the discussion that follows, we will refer to these groups as A, B, and C respectively. Diagrams of these plugs are shown in Figure 2-1. Work on these plugs included input impedance measurements over the frequency range of 10 to 500 Mc, and power injection tests at 10 Mc where visual observations were made during the application of RF power and dc resistance measurements were also made before and after power application.

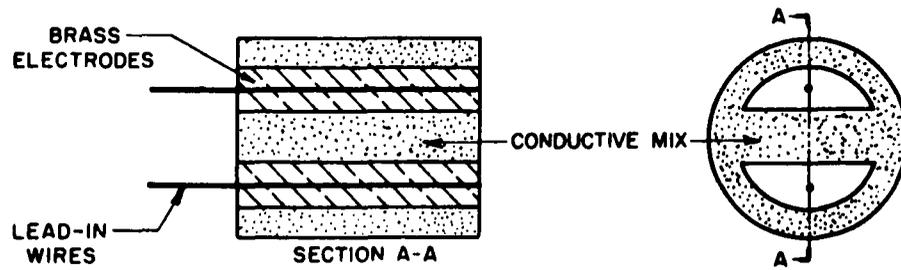
2.1 Impedance Measurements (10 to 500 Mc)

Groups A, B, and C (Figure 2-1) were subjected to a series of input impedance measurements at frequencies extending from 10 to 500 Mc. The indication of the measuring equipment, gave the input impedance as a resistance in series with a reactive component, that is in the form $R \pm jX$. At low frequencies (10 to 20 Mc) a General Radio Type 916A Impedance Bridge is employed. With this equipment, the unknown impedance is substituted in one leg of a bridge circuit and calibrated dials enable one to rebalance the bridge and determine the unknown impedance. Above 40 Mc a General Radio Type 1607A Transfer Function and Immittance Bridge is used. With this equipment a 50-ohm coaxial conductor is used up to the base of the plug. The plug being connected across the end of the line, becomes the load impedance. This equipment also gives measurements in the form of $R \pm jX$. Table 2-1 is a summary of the impedance measurement data. Figure 2-2 is a plot of the resistive component of the impedance measurement vs. frequency, and Figure 2-3 is a plot of the reactive component vs. frequency.

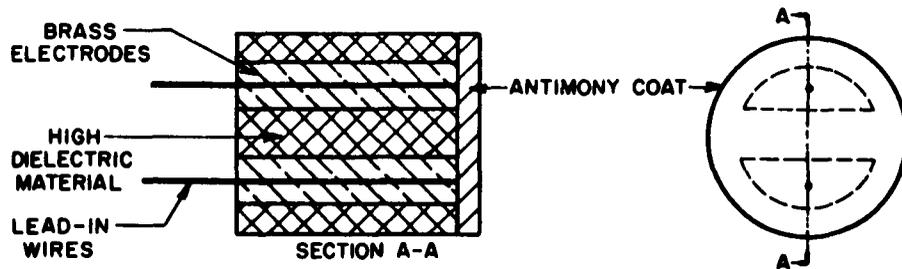
Discussing each component of the impedance measurement separately, we observe from Figure 2-2, that the complete plug (Group A) behaves like two resistors in parallel out to frequency of 80 Mc. That is, Group B is essentially 1.8 ohms, and Group C is 0.7 ohms, out to 80 Mc. The parallel equivalent of these is 0.5 ohms which is close to the measured value for Group A. Above 80 Mc, the simple parallel resistance



(Group A) Conductive Mix Plug Antimony Coat $R_{dc} = 0.41\Omega$



(Group B) Conductive Plug $R_{dc} = 1.7\Omega$



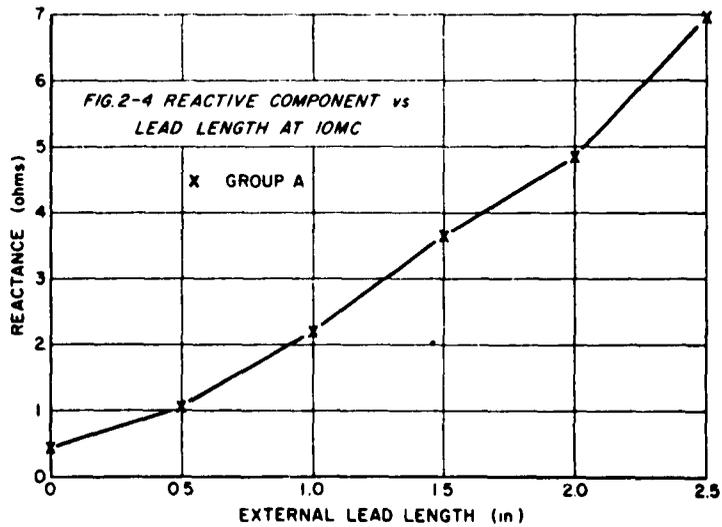
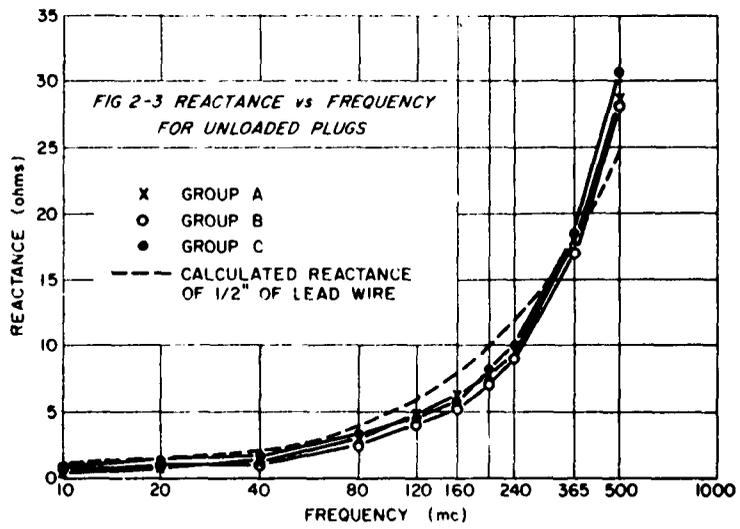
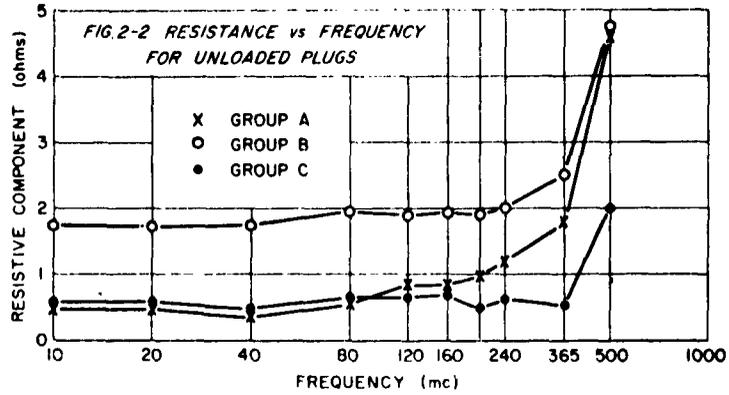
(Group C) Inert Plug Antimony Coat $R_{dc} = 0.45\Omega$

FIG. 2-1. DIAGRAMS OF UNLOADED SQUIBS

Table 2-1
INPUT IMPEDANCE VS FREQUENCY FOR UNLOADED SCINTILLA SQUIBS

| Plug No. | Freq. (Mc) | | | | | | | | | |
|----------------|------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|------------|
| | 10 | 20 | 40 | 80 | 120 | 160 | 200 | 240 | 365 | 500 |
| <u>Group A</u> | | | | | | | | | | |
| 3076 | .47+J.48 | .49+J.8 | .4+J1.3 | .6+J3.1 | 1.0+J.4.7 | .8+J6.1 | .9+J7.8 | 1.1+J9.4 | 1.7+J17.4 | 4.2+J27.1 |
| 3079 | .47+J.52 | .48+J.9 | .3+J1.6 | .5+J3.2 | .7+J4.7 | .9+J6.3 | 1.0+J7.9 | 1.3+J9.8 | 1.9+J18.8 | 5.0+J30.1 |
| Average | .47+J.50 | .485+J.85 | .35+J1.45 | .55+J3.15 | .85+J4.7 | .85+J6.2 | .95+J7.85 | 1.2+J9.6 | 1.8+J18.1 | 4.6+J28.6 |
| <u>Group B</u> | | | | | | | | | | |
| 3374 | 1.75+J.4 | 1.69+J1.2 | 1.7+J1.5 | 2.0+J2.4 | 1.9+J4.4 | 1.9+J5.6 | 1.9+J7.3 | 2.1+J9.9 | 2.5+J17.9 | 4.8+J29.6 |
| 3378 | 1.79+J0.7 | 1.73+J.9 | 1.8+J1.3 | 1.9+J2.6 | 1.9+J4.1 | 2.0+J5.2 | 1.9+J6.9 | 1.9+J8.5 | 2.5+J16.0 | 4.7+J26.6 |
| Average | 1.76+J.55 | 1.71+J1.1 | 1.75+J1.4 | 1.95+J2.5 | 1.9+J4.25 | 1.95+J5.4 | 1.9+J7.1 | 2.0+J9.2 | 2.5+J17.0 | 4.75+J28.1 |
| <u>Group C</u> | | | | | | | | | | |
| 3360 | .64+J.62 | .71+J1.15 | .6+J1.7 | .7+J3.2 | .9+J4.3 | .8+J6.3 | .7+J8.3 | .7+J10.2 | .61+J19.0 | 2.1+J31.3 |
| 3361 | .48+J.45 | .51+J1.1 | .4+J1.5 | .6+J3.2 | .4+J6.7 | .6+J6.3 | .7+J8.05 | .55+J10.0 | .45+J13.8 | 1.9+J31.0 |
| Average | .56+J.54 | .6+J1.13 | .5+J1.6 | .65+J3.2 | .65+J4.75 | .7+J6.3 | .5+J8.18 | .63+J10.1 | .53+J18.9 | 2.0+J31.15 |

A = complete plug
 B = conductive mix only
 C = antimony with no conductive mix



relationship no longer holds. The inference drawn is that as the frequency is increased above 80 Mc, the resistive component of the impedance of the complete plugs (Group A) approaches that of the conductive body plugs (Group B). This suggests that at high frequencies, the antimony film could be removed without altering the input impedance of the device, or stated in another way, as frequency is increased, the percentage of the total current passing through the conductive mix become higher compared with the current through the antimony. This behavior could be viewed as a form of attenuation. The validity of the above conclusions, however, is questionable when one considers that the impedance measurements using the immittance bridge were made with a short circuit reference at the base of the plug. Thus, while the conclusions are probably valid for frequencies up to 80 Mc, the behavior of the plug at high frequencies cannot be fully analyzed with impedance measurements made at the base of the plug, but we must consider the fact that the plug length, material and configuration become more and more important as frequency is increased.

Turning to an analysis of the series reactive component, which is plotted on Figure 2-3, it becomes immediately apparent that the reactance is inductive, and has approximately the same value for Groups A, B, or C. This inductive reactance is believed to be caused primarily by the lead-in wires which were approximately 1/2 inch long, this including the portion inside the plug. To support this belief, the impedance of a half inch of the wire used with these plugs was determined at 10 Mc. The measured value was $0 + j0.50$. From the relation $X_L = 2 \pi fL$, the lead-in wires are found to have an inductance of approximately .01 microhenries. If one were to assume that L is constant between 10 and 500 Mc the inductive reactance of this wire would vary with frequency as indicated on Figure 2-3. To confirm the conclusion that lead-wire reactance is a large portion of the total measured reactance, two plugs were measured at 10 Mc, with 2.5, 2.0, 1.5, 1.0, 0.5

and 0 inches of external lead. These measurements are shown in Table 2-2 and plotted in Figure 2-4. The figure shows how the inductive reactances changes rapidly with lead length. In conclusion it can be stated that the plugs considered without lead-in wires are essentially resistive from dc to approximately 100 Mc. Above this frequency the accuracy of the impedance measurements suffers because of the critical adjustments required for the measurements.

Table 2-2
IMPEDANCE VS LEAD LENGTH AT 10 Mc (Group A)

| Plug No. | External Lead Length (inches) | | | | | |
|----------|-------------------------------|-----------|-----------|----------|------------|----------|
| | 2-1/2 | 2 | 1-1/2 | 1 | 1/2 | 0 |
| 3068 | .44+J7.5 | .61+J5.2 | .37+J4.0 | .68+J2.3 | .49+J1.1 | .48+J.50 |
| 3074 | .48+J.64 | .42+J4.5 | .48+J3.3 | .42+J2.1 | .43+J1.05 | .37+J.35 |
| Average | .46+J6.95 | .51+J4.85 | .43+J3.65 | .55+J2.2 | .465+J1.08 | .43+J.43 |

2.2 Tests at 10 Mc

To facilitate later comparison, the three types of plug bodies (Groups A, B, and C of Figure 2-1) were subjected to RF radiation at 10 Mc with the same evaluation equipment and mounting fixture used for the 10Mc Bruceton test of loaded squibs, which will be discussed in Section 3-2. The present tests were primarily concerned with determining what power each type plug could withstand without being destroyed or seriously altered. For this purpose, items were subjected to a wide range of powers, for 10 second periods. The initial and final dc resistances were measured, and visual observations were made during the period of time when RF power was being applied. The results of each of these tests are shown in Table 2-3, 2-4, and 2-5 for Groups A, B, and C respectively.

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Table 2-3

10 MC TEST ON GROUP A

| Item No. | Dc Resistance | | Ave. Pwr. (watts) | Visual Observations |
|----------|---------------|-------|-------------------|--|
| | before | after | | |
| 3059 | .520 | .842 | 40 | Slight arcing at gap. smoking. Liquid solder discolored surface. |
| 3062 | .532 | 3.511 | 40 | Immediate smoking, and discoloration, then arcing & finally bubbling of solder. |
| 3058 | .464 | 1.300 | 50 | Immediate arcing at gap followed by discoloration, smoking and liquid solder. |
| 3065 | .499 | 4.750 | 50 | Immediate arcing at gap followed by discoloration, smoking and liquid solder. |
| 3063 | .530 | 1.06 | 60 | Immediate sparking at gap and smoke followed by discoloration, liquid solder, white & yellow smoke. |
| 3067 | .538 | 1.94 | 60 | Immediate sparking in gap area followed by sparking all over, discoloration, smoking from the sides of plug, yellow resin. |
| 3066 | .440 | .776 | 70 | Immediate sparking in gap area followed by sparking all over. Smoke and discoloration. Face of plug burst into flames liquid solder. |
| 3073 | .480 | 1.178 | 70 | Immediate arcing at gap followed by smoke discoloration. Indication of varying load, liquid solder. |
| 3072 | .520 | 2.21 | 80 | Immediate arcing at gap followed by smoke. VSWR went up. Item stopped heating. |
| 3069 | .567 | .484 | | Immediate arcing at gap followed by smoke discoloration and liquid solder, resin. VSWR fluctuated. |

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Table 2-4

10 MC TEST ON GROUP B

| Item No. | Dc Resistance | | Ave. Pwr. (Watts) | Visual Observations |
|----------|---------------|-------|-------------------|--|
| | before | after | | |
| 3379 | 1.82 | 2.04 | 20 | No change in plug. |
| 3377 | 1.83 | 2.29 | 30 | Smoke after 3 seconds. Liquid solder appeared at sides, arcing at gap. |
| 3376 | 1.74 | 2.80 | 40 | Smoke after 3 seconds. Liquid metal on face of brass. No arcing. |
| 3375 | 1.80 | 3.90 | 50 | Smoke after 1 second. Liquid solder at face. Arcing at gap. VSWR high after 3 seconds. Test stopped. |
| 3373 | 1.79 | 1.17 | 60 | Arcing at 1 second. Liquid solder at 2 seconds. Smoking. High VSWR after 4 seconds. |
| 3371 | 1.68 | 1.20 | 70 | Arcing, smoke and liquid solder after 2 seconds. VSWR high after 3 seconds. |
| 3370 | 1.54 | 3.70 | 80 | Arcing at gap, liquid metal and smoke after 2 seconds. VSWR high after 2 seconds. Test stopped. |

Table 2-5
10 MC TEST ON GROUP C

| Item No. | Dc Resistance | | Ave. Pwr. (Watts) | Visual Observations |
|----------|---------------|-------|-------------------|--|
| | before | after | | |
| 3358 | .540 | 86 | 5.0 | Immediate smoking, burned area, at gap, slight arcing. VSWR high. |
| 3360 | 1.03 | 1.20 | 1.0 | No change in plug. |
| | 1.20 | 1.71 | 2.0 | Slight discoloring of face only. |
| | 1.71 | 6.70 | 3.0 | Burning and discoloration at gap smoke. VSWR high after 5 seconds. |
| 3361 | .76 | 8.1 | 3.0 | Immediate discoloration at gap smoking. VSWR high after 3 seconds. |
| 3363 | .85 | 200 | 4.0 | Immediate discoloration at gap smoking. VSWR high after 4 seconds. |
| 3366 | .73 | 30 | 7.0 | Immediate discoloration and smoke at gap. VSWR high after 1 second. |
| 3364 | .67 | 7.0 | 10.0 | Immediate discoloration and smoke at gap. VSWR high immediately. Test stopped. |
| 3368 | .73 | open | 20.0 | Instant burning at gap. VSWR went up immediately. |

The data from the three tables are more or less self-explanatory. The results indicate that the antimony film (Table 2-5) is destroyed with approximately 5 watts* of RF power at 10 Mc. The conductive plug (Table 2-4) can absorb powers below 20 watts for relatively long periods of time. Above 30 watts the plug material can be altered by absorbing too much heat. As the power is increased, the data show that the insulating binder around the graphite is burned out so that the final resistance is lower. Arcing at the gap can occur with power as low as 30 watts. With very high power, the energy must be absorbed within the first 3 seconds; otherwise the voltage standing wave ratio (VSWR) becomes too high showing that the load is no longer matched to

*All powers quoted in this section must be considered in the light of the system efficiency discussed in Section 3.2.

the generator. This suggests that the plug is changing resistance rapidly. An indication of the plug temperature can be obtained by noting when liquid metal (believed to be the solder around the electrodes) is observed at the face of the plug. Solder of 40/60 composition has a melting point of 240°C. The table of data for the complete plug (Table 2-3) indicates why it was necessary to go to powers between 50 and 80 watts to perform a 10 second Bruceton Test (See section 3.2). The high power was needed if significant arcing was to occur. Arcing probably does not occur below 30 watts; and to have the loaded squibs fire in milliseconds (See Appendix A) the action must occur by arcing and not cook-off.

In summary, it appears that the plugs can absorb a great deal of RF energy, and whether a device will be initiated or not depends on the amounts of arcing, and of heat conduction, occurring in the plug. To have instantaneous initiation, (millisecond range) power in the 50 to 80 watt range is required. These firings are probably the consequence of arcing at the gap. Initiation could be produced by much lower power applied for longer time. The power to cause initiations will be a function of the heat sink, which controls the temperature attained by the plug within a given time.

3. EVALUATION OF LOADED SQUIBS

The extent of work with loaded squibs included one constant current and one RF 10 second Bruceton Test at 10 Mc. This work is discussed in the following sections.

3.1 Constant Current Test

A 10-second constant current Bruceton Test was made on the spark gap squibs. The equipment used to perform the evaluation is known as The Franklin Institute Laboratory Universal Pulser (FILUP).⁽¹⁾ This

⁽¹⁾ Paper #22 "Generating Rectangular Pulses for Electroexplosive Devices", Proceedings of Electric Initiator Symposium 1960, Report No. F-A2446, prepared for U.S. Naval Ordnance Laboratory, White Oak, under Contract Nonr-3220(OO). ASTIA Number AD-323 117.

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equipment, developed for Picatinny Arsenal under Contract No. DA-36-034-501-ORD-3115RD, can control the amplitude of the current pulse to within $\pm 1\%$ of the desired value. A GE C35C silicon controlled rectifier is used as a switching element for pulse times greater than 100 microsecond. The desired duration of the pulse is obtained to within 3%.

For a sample of 14 devices tested, a 50% firing probability of 6.79 amps with a standard deviation, in log units, of 0.0383 was established. The 99.9% and 0.1% firing probabilities with 90% confidence were calculated and are respectively 10.97 amps, and 4.21 amps. During this test the squibs were mounted in the same heat sink fixture that was used for the 10 Mc RF test.

3.2 10 Mc RF Test

A Bruceton test, using RF power, was performed on 32 loaded squibs. In the Bruceton method, the firing stimulus is either raised or lowered by a fixed increment depending upon whether the preceding observation was a non-fire or a fire. The fixed increment is a logarithmic difference between successive stimulus levels. On the data sheet (Appendix A) this difference is indicated by (d). By applying the statistical analysis described in the Bruceton Report⁽²⁾ the mean or 50% fire level and the standard deviation (σ) may be calculated. Further calculations can be performed to determine other probability-of-fire levels (such as the 99.9% and 0.1%). To any probability point, a confidence interval (usually 90%) may be included; this is in recognition of the fact that the test was conducted on a finite, and not an infinite, number of samples.

In conducting an RF evaluation, we are concerned with dissipating energy at a certain frequency and power level within the

(2) Bruceton Report (AMP Report No. 101.1R) "Statistical Analysis for a New Procedure in Sensitivity Experiments", July, 1944.

the explosive device. We are also concerned with determining the amount of power actually arriving at the load as compared to that put out by the generator. These requirements can be fulfilled by a system that is illustrated in block diagram form in Figure 3-1. The system has an RF generator and suitable attenuators which, in combination, constitute a variable source of RF power. The output is transmitted by a 50-ohm coaxial line through directional couplers to a switch which can allow energy to flow either into a dummy load or into a branch of transmission line that is terminated with the device being evaluated. The squib is contained within a special mounting fixture that prevents loss of power by radiation, and terminates the line with the impedance of the squib.

The directional couplers separate the forward and reflected power so that each may be measured independently, without affecting transmission in either direction. As shown in Figure 3-1, the forward power is measured by a bolometer-type RF power meter at A. The reflected

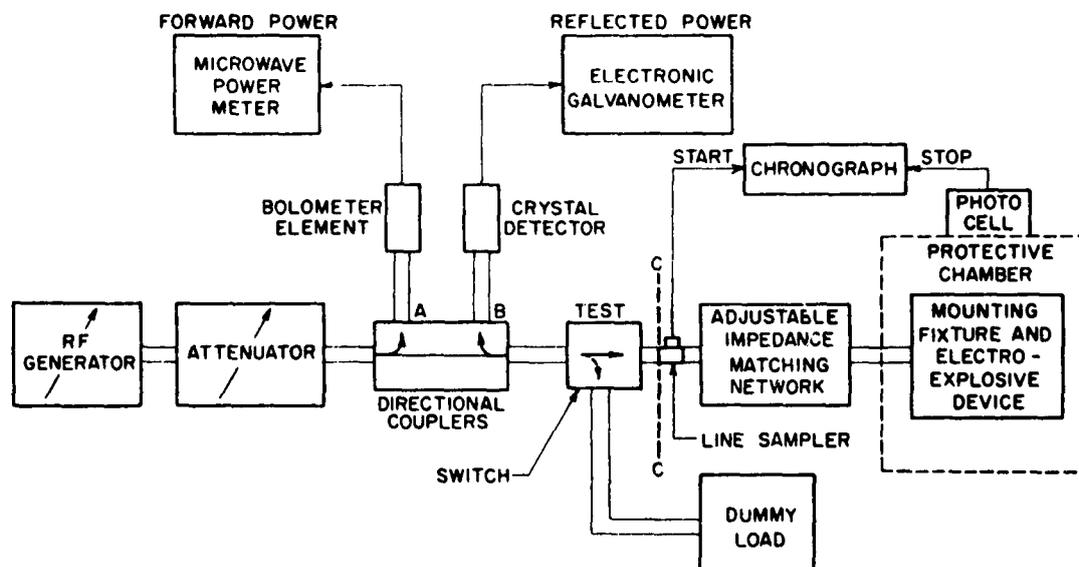


FIG. 3-1. BASIC RF EVALUATION SYSTEM

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power is rectified by a crystal at B, and the signal is applied to an electronic galvanometer. When power flows into the dummy load, there is no impedance mismatch. Under this condition the forward power measured at A will be the power dissipated in the load resistance, and there will be no reflected power to be detected by the galvanometer at B. If power is now permitted to flow into the device under test (which has a resistance of 1/2 ohm), an impedance mismatch of 100 to 1 will occur and 99% of the power will be reflected back to the generator.

To obtain the advantages of a matched system, an adjustable impedance-matching network is inserted between the switch and the load, and this network is varied until the reflected power is insignificant. Under these conditions, the power measured at A will enter and be dissipated by all of the resistive elements associated with the impedance matching network and the resistance of the device. Usually the matching network and associated hardware contain a loss factor that must be determined. The procedure for subjecting a device to microwave energy would be as follows (Refer to Figure 2-1).

1. The device is inserted in its mounting fixture, and enclosed within a protective chamber. This operation usually involves trimming the lead wires to a length of less than 1/2 inch. For coaxial systems, one wire is connected to the center conductor, and the other to the outside ground conductor. The metallic case of the device is also connected to ground, thereby forming a closed system which eliminates radiation.
2. The dc resistance of the device is measured with a Wheatstone bridge and recorded.
3. With the switch in the DUMMY LOAD position, the output of the generator is set for a small amount of power. (Usually about 5 to 10% of the full power desired for the test.)
4. The switch is then turned to the TEST position, and the impedance matching network is adjusted for a minimum of reflected power which must be no greater than 5% of the incident power for a valid test.

5. The switch is again turned to the DUMMY LOAD position, and the RF power is increased to the full level desired for the test.
6. The full power test then commences when the switch is returned to the TEST position and is terminated by switching to the DUMMY LOAD.

To record functioning times, a portion of the input signal is used to start a chronograph. A photocell detects the light output when the item initiates and transmits a stop signal to the chronograph. The least count of the chronograph is 0.1 microsecond.

The RF Bruceton Test performed with the 32 loaded squibs placed the 50% point at 58.4 watts, with a standard deviation of .09142 log units. The 99.9% and 0.1% levels with 90% were calculated to be 164.5 and 20.7 watts respectively. The power levels quoted on the Bruceton sheets, (Appendix A), however, do not include system losses from point C (Figure 3-1) to the load. With initiators that contain a bridgewire as the energy transducer system losses can be determined by detecting the bridgewire heating with a calibrated photocell. This method cannot be used with devices such as the squib under evaluation, which do not glow. However, experience with determining system losses with bridgewire devices has shown that, for a device of approximately 1/2-ohm, with the measurements made at 10 Mc, only about 50 to 60% of the measured power reaches the load. This factor, therefore, should be applied to the power levels indicated on the Bruceton sheet to determine the approximate power at the load. It should be remembered that this figure is not a true measurement, but an estimate based on data obtained with bridgewire devices. With a 50% system loss correction, the data now becomes

| | |
|---------------------------|------------|
| 50% Fire | = 30 watts |
| All Fire (99.9% 90 conf.) | = 82 watts |
| No Fire (0.1% 90 conf.) | = 10 watts |

4. SUMMARY AND CONCLUSIONS

The present analysis of the spark gap squib has indicated that they are inherently rather insensitive to low voltages. Direct currents of approximately 7 amperes must be applied for 10 seconds to expect 50% of the items to initiate, and RF powers of 30 watts (at the device) for 10 seconds are required to initiate them. There is some evidence, derived from impedance measurements that as frequency is increased the power required to initiate these devices will also increase. The above constant current and RF tests indicated that the mechanism of initiation was probably caused by arcing or sparking at the gap. This inference becomes stronger when one notices that the functioning times (see data sheets, Appendix A) are down in the millisecond range. Heating of the plug and subsequent transfer of energy to the explosive cannot possibly occur within these time intervals. Therefore, the two Bruceton tests reflect the magnitude of power required for instantaneous initiations. One must, however, remain aware of the fact that these devices can be initiated by much lower power applied for longer periods of time.

As the duration of energy input becomes longer, the factor causing initiations tends to become the temperature attained by the plug and explosive material. The temperature of the plug and device is not only a function of the input power, but also of the medium or heat sink which is in close proximity to the device. The above factors must be known when conducting a long time evaluation, otherwise misleading data will result.

Finally, the sensitivity of these devices to pulsed RF power was not determined. From the fact that these devices are normally initiated from a 1000-volt source, it is reasonable to suppose that pulsed powers could initiate these squibs at lower power than was obtained with CW. A pulsed-power test could not be performed since the output power average of the transmitter at present is limited to 10 watts, which is insufficient to fire the device.

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We have observed during the RF evaluation of many low impedance devices (mainly wire bridge types) that the RF power sensitivity with CW is approximately the same as the dc level for frequencies below 500 Mc. This relationship also appears to hold true for the spark gap squibs when CW is compared with constant current dc sensitivity. However, the spark gap squibs are probably more voltage-sensitive than they are current-sensitive. It would therefore be of interest to evaluate them with RF pulses of high voltage.

As was pointed out above, a pulse test was attempted but no firings occurred. The average power used was ten watts which, from the CW data, would appear to be too low. However, the power in this case is contained in one microsecond pulses that are repeated every millisecond. This means that the peak power is one thousand times greater than for CW. The voltage will increase by $\sqrt{1000}$ as derived by

$$E = \sqrt{P} \cdot \sqrt{R}$$

where R is a constant

The highest peak voltage that can occur in the line is this value multiplied by the VSWR which, for this device, can approach one hundred.

Thus it could be reasoned that a large voltage should be available to initiate the item under test. This is true. The high voltage is present in the line; however, the use of it to initiate the low impedance spark gap squibs has not been accomplished.

Basically, the problem can be stated in this manner. In our firing system, we use impedance matching to achieve the maximum transfer of power. This means that an impedance transfer from fifty ohms to approximately 0.5 ohms is obtained. To accomplish this impedance transformation, the low impedance squib must appear at a low impedance point in the transfer curve (This is one of the definitions of matching). However, the voltage across the line is also a function of the impedance; i.e., the highest voltage will occur at the highest impedance point and

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the lowest voltage at the lowest impedance point. This is exactly what we don't want! Therefore, it can be seen that matching, though giving maximum transfer of power does not necessarily produce maximum voltage at the load.

This immediately brings forth the question, how can we obtain maximum voltage (or at least a large voltage) at the load? The answer has not been obtained as of this time. We have been considering the problem long before the inception of this contract. Several methods have been suggested and are being investigated. One such method is to analyze the transmission line mathematically to determine if a solution is possible whereby a low impedance can be located at a high voltage point.

It may well be that this cannot occur in reality. If this is so, then we have essentially proven that the item is insensitive to pulse power, not by its own basic sensitivity, but due to the external circuit arcing over. Therefore, a low impedance high voltage device should offer RF protection unless the entire system is low impedance. If a circuit could be made that was lower in impedance than the squib, then the squib could be placed at a high impedance point. In practice, this is easier said than done. The construction of a low impedance circuit of the type required here is impractical.

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APPENDIX A

FIRING DATA SHEETS

| dc Resistance after test | Functioning Levels (ζ) Watts | | | | FUNCT. TIME milli sec | RESISTANCE Ω | ITEM NO. |
|--------------------------|------------------------------|------|------|------|--------------------------|-----------------|----------|
| | 4.6 | 50.1 | 63.1 | 70.8 | | | |
| 1.10 | 3288 | 0 | | | 50 | 1 | |
| 1.30 | 3288 | 0 | | | 50 | 2 | |
| 3.74 | 3284 | | X | | 1252.810 | 3 | |
| 1.33 | 3184 | 0 | | | 45 | 4 | |
| 1.97 | 3287 | | X | | 1767.456 | 5 | |
| 1.77 | 3095 | 0 | | | 54 | 6 | |
| 9.35 | 3186 | | X | | 10,356.815 | 7 | |
| 2.05 | 3222 | 0 | | | 58 | 8 | |
| 2.15 | 3283 | 0 | | | 49 | 9 | |
| 1.21 | 3286 | | 0 | | 53 | 10 | |
| 1.15 | 3285 | | X | | 122.451 | 11 | |
| 5.14 | 3201 | 0 | | | 52 | 12 | |
| 1.20 | 3175 | | X | | 172.931 | 13 | |
| 1.00 | 3143 | | X | | 118.771 | 14 | |
| 1.14 | 3144 | | X | | 566.557 | 15 | |
| 1.32 | 3157 | 0 | | | 53 | 16 | |
| 1.61 | 3291 | 0 | | | 51 | 17 | |
| 2.05 | 3291 | 0 | | | 52 | 18 | |
| 12.06 | 3287 | | X | | 10,891.391 | 19 | |
| 1.07 | 3185 | | X | | 258.453 | 20 | |
| 1.41 | 3216 | 0 | | | 91 | 21 | |
| 2.39 | 3240 | 0 | | | 45 | 22 | |
| 9.85 | 3282 | | X | | 10,244.104 | 23 | |
| 1.23 | 3129 | 0 | | | 52 | 24 | |
| 9.8 | 3287 | | X | | 137.128 | 25 | |
| 2.27 | 3118 | 0 | | | 55 | 26 | |
| 2.90 | 3180 | | X | | 11,133.013 | 27 | |
| 1.85 | 3111 | | X | | 127.117 | 28 | |
| 1.25 | 3221 | | X | | 210.416 | 29 | |
| 9.5 | 3088 | | X | | 1252.437 | 30 | |
| 1.50 | 3409 | 0 | | | 53 | 31 | |
| 1.77 | 3222 | 0 | | | 61 | 32 | |
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| i | i ² | n _i | n _i ² | (i - Watts) |
|---|----------------|----------------|-----------------------------|-------------|
| 0 | 0 | 2 | 0 | 44.6 |
| 1 | 1 | 6 | 1 | 50.1 |
| 2 | 4 | 3 | 5 | 56.2 |
| 3 | 9 | 6 | 3 | 63.1 |
| 4 | 16 | 0 | 6 | 70.8 |
| 5 | 25 | | | |
| 6 | 36 | | | |
| Totals: N ₀ = 17 N ₁ = 15 | | | | |

Special Parameters
 $c = (\log \zeta)_{i=0} = 1.64933$
 $d = (\log \zeta)_{i+1} - (\log \zeta)_i = .05$

Primary Statistics
 $A = \sum i^n$
 $B = \sum i^2 n$
 $M = (NR - A^2)/N^2$
 $m = c + d(A/N \pm 1/2)^2$
 $\sigma = 1.62 d (M + 0.029) \sqrt{\frac{N}{N-1}}$

For "o's" For "x's"
 $A = 30$ 44
 $B = 72$ 144
 $M = 1.12111$ 0.17556
 $m = 1.76257$ 1.11159
 $\sigma = 0.7603$ 0.4593

Secondary Statistics
 $n = \frac{N_0 \sigma_0^2 + N_1 \sigma_1^2}{N_0 + N_1} = 1.76652$
 $\sigma = \sqrt{\frac{N_0 \sigma_0^2 + N_1 \sigma_1^2}{N_0 + N_1}} = .07142$

$\zeta = \text{Antilog } m = 58.414 \text{ Watts}$
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| Probability Levels | Confidence Level |
|----------------------------|---------------------|
| $P_X = 99.9$ | $X_S = 90$ |
| $100 - P_X = 0.1$ | |
| $m = 1.76652$ | $k_p^{(2)} = 3.090$ |
| $\sigma = .07142$ | $k_x^{(2)} = 1.282$ |
| $d = .05$ | $G^{(2)} = .946$ |
| $S = \frac{G}{d} = 1.8284$ | $G^2 = .89416$ |
| $N = 32$ | $H^{(2)} = 1.69$ |
| $n^{(1)} = 16$ | $H^2 = 2.8561$ |

① $n = \frac{N}{2}$ when N is even integer
 $n = \frac{N+1}{2}$ when N is odd integer
 ② From BR*, p. 19, at given P or X
 ③ From BR* for G & H versus S. Use Graphs III & IV. When $S \geq .5$, and Graph V. When $S < .5$

Confidence Interval (Y)
 $Y = k_x \left(\frac{n+1.2}{n} \right) \left(\frac{G^2 + H^2 k_p^2}{n} \right)^{1/2} \sigma$
 $= 0.16717$

Final Calculations
 (99.9%) (90% Conf) = $m + k_p \sigma + Y$
 $= 2.21617 \text{ log units}$
 $= 166.58 \text{ Watts}$
 (0.1%) (90% Conf) = $m - k_p \sigma - Y$
 $= 1.31687 \text{ log units}$
 $= 20.743 \text{ Watts}$

(1) These power levels do not include system losses. See text for correction factor.

*Bruceton Report (AMP Report No. 101.1R "Statistical Analysis for a New Procedure in Sensitivity Experiment", July 1944) File No. Ma-1.

| dc Resistance after Test | Item Number | Functioning Levels (I) amps | | | FUNCT. TIME | RESISTANCE | ITEM NO |
|--------------------------|-------------|-----------------------------|-------|-------|-------------|------------|---------|
| | | 5.705 | 6.310 | 7.995 | | | |
| 1.33 | 3179 | | X | | 229.6 | 521 | 1 |
| 1.61 | 3177 | | X | | 255.6 | 560 | 2 |
| .90 | 3213 | 0 | | | | 620 | 3 |
| 1.48 | 3161 | 0 | | | | 672 | 4 |
| 1.22 | 3176 | | X | | 236.1 | 660 | 5 |
| 1.39 | 3211 | 0 | | | | 597 | 6 |
| 1.65 | 3171 | | X | | 590.8 | 494 | 7 |
| 1.12 | 3269 | 0 | | | | 495 | 8 |
| 1.35 | 3153 | | X | | 126.8 | 511 | 9 |
| 1.62 | 3172 | 0 | | | | 544 | 10 |
| 1.21 | 3251 | 0 | | | | 561 | 11 |
| 1.67 | 3221 | | X | | 791.6 | 661 | 12 |
| 1.78 | 3171 | 0 | | | | 331 | 13 |
| .58 | 3108 | | X | | 41.8 | 459 | 14 |

| i | i ² | n _i | n _i ² | Σ = amps |
|--------|----------------|--------------------|-----------------------------|----------|
| 0 | 0 | 1 | 0 | 5.623 |
| 1 | 1 | 4 | 1 | 6.310 |
| 2 | 4 | 2 | 4 | 7.080 |
| 3 | 9 | 0 | 2 | 7.943 |
| 4 | 16 | | | |
| 5 | 25 | | | |
| 6 | 36 | | | |
| Totals | | N ₀ = 7 | N ₁ = 7 | |

Special Parameters
 $\bar{x} = (\log \bar{X})_{10} = 0.74997$
 $d = (\log \bar{X})_{10} - (\log \bar{X})_1 = .05$

Primary Statistics
 $A = \bar{X} \ln$
 $B = \bar{X}^2 n$
 $M = (\ln B - A^2) / N^2$
 $m = e^{-d} (A \bar{X} + 1)^*$
 $\sigma = 1.624 (M + 0.029) \sqrt{\frac{N}{N-1}}$
 *Use + for "n's" - for "x's"
 **Valid for M > 0.1 only, otherwise consult 'Bruceton Report' (AMP Report No. 101.1B "Statistical Analysis for A New Procedure in Sensitivity Experiments" July 1944) File No. Ma-1

| | For "n's" | For "x's" |
|---|-----------|-----------|
| A | 8 | 15 |
| B | 12 | 35 |
| M | 0.90816 | - |
| m | 0.83211 | - |
| σ | 0.3825 | - |

Secondary Statistics
 $m = \frac{N_0 m_0 + N_1 m_1}{N_0 + N_1} = 0.83211$
 $\sigma = \sqrt{\frac{N_0 \sigma_0^2 + N_1 \sigma_1^2}{N_0 + N_1}} = 0.3825$
 $\bar{X} = \text{Antilog } m = 6.7737 \text{ amps}$

Probability Levels
 $P\% = 99.9$
 $100 - P\% = 0.1$

Confidence Level
 $X\% = 90$

m = 0.83211
 $k_p = 3.090$
 $k_x = 1.282$
 $G = 1.045$
 $G^2 = 1.09225$
 $H = 1.30$
 $H^2 = 1.690$

① $n = \frac{N}{2}$ when N is even integer
 $n = \frac{N+1}{2}$ when N is odd integer

② From BR*, p. 19, at given P or X

③ From BR* for G & H versus S. Use Graphs III & IV.
 When $S \geq .5$, and Graph V
 When $S < .5$

Confidence Interval (Y)
 $Y = k_x \left(\frac{n+1.2}{n} \right) \left(\frac{G^2 + H^2 k_p^2}{n} \right)^{1/2} \sigma$
 = 0.9972

Final Calculations
 (99.9%) (90% Conf) = $m + k_p \sigma + Y$
 = 1.09022 log units
 = 13.970 amps
 (0.1%) (90% Conf) = $m - k_p \sigma - Y$
 = 0.62400 log units
 = 4.2073 amps

TYPE OF TEST: Instant Current
 FREQUENCY: 12.5
 PULSE WIDTH: 100
 REP RATE: 1000

DATE: 12/11/61 INITIALS: A.F. PAGE NO.:

*Bruceton Report (AMP Report No. 101.1B "Statistical Analysis for a New Procedure in Sensitivity Experiment", July 1944) File No. Ma-1.

SCINTILLA DIVISION

11. Conclusions:

The theory that RF might behave within the squib as if it were DC seems to have some justification. The input energy can be divided proportionally through parallel shunts. This energy, to discharge a spark across the gap and fire the squib, must be the sum of that dissipated through the shunts plus that required to initiate an arc. This seems to be true below 500 Mc. However, as the frequency increases above 500 Mc, the squib seems to become less sensitive and requires more power for initiation. It would appear that around 500 Mc the squib begins to act less like a simple DC device and discloses attenuation properties typical of AC or RF devices. Duration of exposure appears to be an important element which has not been investigated thoroughly. There is evidence that the squib will fire when exposed to relatively low magnitudes of power if applied for long periods of time. It is known, however, that 20 watts of power can be absorbed for relatively long periods of time.

The purpose of the contract was to determine the feasibility of a shunted gap for providing immunity to stray RF. It has been demonstrated that such a device is feasible. The degree of immunity achieved, however, is dependent on many factors which are sometimes either unknown or impossible to determine. Some of these are CW or pulsed RF, frequency, peak voltage, length of exposure, and heat sink properties of the squib mount.