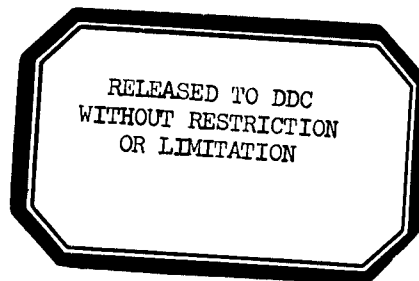


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Final Report

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PRECISION RF SENSITIVITY STUDIES
(Evaluations of MARK 1 MOD 0 Squib and
MARK 2 MOD 0 Ignition Element)

by

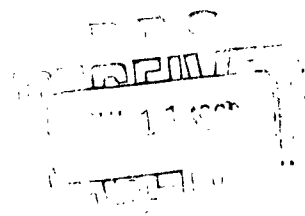
Paul F. Mohrbach
Robert F. Wood
Norman P. Faunce

January 23, 1961 to August 15, 1962

Prepared for

U.S. NAVAL WEAPONS LABORATORY
Dahlgren, Virginia
Code WHR

Contract No. N178-8730



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ABSTRACT

Developments leading to the establishment of precision RF firing evaluation techniques are set forth in this final summary report. The RF sensitivity of the MARK 1 MOD 0 squib and MARK 2 MOD 0 ignition element has been determined by these newly developed precision firing techniques. Data from 5 to 1000 Mc CW are obtained, differing little from the dc power sensitivity determined from 10-second constant current pulse data.

Many developments preceded the actual tests. Studies of system losses indicated that special matching devices would be desirable, for limiting to reasonable values the power lost in the RF plumbing. As a consequence, a novel shorted stub was developed for use at the higher frequencies. Low-loss lumped-parameter tuning networks were fabricated for the lower frequencies. Toward this same end, the design and construction of the fixture for mounting the initiator under test was given special attention.

Results with precision never before duplicated were obtained by use of a special calibration procedure that was developed. A photoconductive cell is focused onto the exposed bridgewire of the device to be tested and its response is calibrated against a steady-state dc power input. Following this, RF is fed to the same device and the ratio of the RF to dc level for the same bridgewire illumination is taken as the system calibration factor. In so doing, all losses between the point at which we measure input RF power and the bridge element are lumped. Because of this it is important first to evaluate the losses in the plug or base of the initiator, and, then with this to correct the system calibration factor. For the two items evaluated no detectable base loss was evident up to 1000 Mc.

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1. INTRODUCTION

The purpose of this program was to determine the RF sensitivity over a wide range of frequencies of the MARK 1 Squib and the MARK 2 MOD 0 Ignition Element with an error of less than 5%. The plan required the development and careful calibration of suitable systems of instrumentation. The test procedure was to use the Bruceton routine wherein power is the variable and each initiator is tested at one of several predetermined power levels; the particular level for each being one step higher or lower depending upon whether the preceding result was a non-fire or fire respectively. By following this procedure, testing randomly sampled groups of 40-100 initiators at each of several frequencies we can derive a curve of RF power versus frequency.

In the early days of the program, exhaustive tests were performed to evaluate losses in various matching devices, over a frequency range of 250 to 500 megacycles: Experimental tests were supplemented with theoretical studies of impedance matching, which led to the conclusion that large system losses are inevitable when matching into loads having a small resistive component or large reactive components. Acknowledging that system losses of 50 per cent or more were unavoidable, we proceeded to assemble and test practical systems for firing the two items being studied.

Calibrated RF thermocouples were used in the first attempts to evaluate system losses. These thermocouples were useful for comparing the relative losses of different matching systems. It was soon realized, however, that a better way to determine absolute system loss would involve determination of the RF power actually reaching the bridgewire of the ignition element or squib under test. This was done by means of photo-conductive cells mounted above the bridgewire of an inert device.

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The system loss evaluation technique above has one inherent source of error, in that the losses in the base of the ignition element are included in the loss factor obtained. Base losses, if present, should not be included in the loss factor.

Several experiments were made to determine the loss in the base of the MARK 2 MOD 0 ignition element at 250 megacycles. No numerical values were obtained since the losses were too small to measure. For frequencies below 1000 Mc, therefore, it is sufficiently accurate to ignore the base loss. A Bruceton test is conducted and a figure for system input power for 50% functioning obtained. Multiplication of the system input power by the system efficiency factor gives a calculated value for the power at the bridgewire. The value for calculated power to the bridgewire should remain essentially the same for all frequencies provided no factor other than bridgewire temperature causes initiation.

A valuable consequence of these studies was the evidence accumulated to show that stock radio frequency components (shorted stubs in particular) were not ideally suited to precision firing systems. This discovery resulted in extensive development of components, not originally contemplated in the scope of this project.

2. INVESTIGATIONS OF FIRING SYSTEM LOSSES

The accuracy of EED RF functioning sensitivity evaluation depends upon the degree to which it is possible to resolve the power delivered to the items being tested. Firing systems which feed known amounts of power into a matched termination will yield accurate results only if the hardware between the load (EED) and the point at which the power is introduced can be considered lossless. As these elements become lossy -- that is, as their dissipation of power becomes significant in relation to the power dissipated by the load -- the accuracy of resulting data is correspondingly reduced. However, if the amount of

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power lost in these parts can be determined with certainty equal to that associated with the measurement of input power, we can deduce the power delivered to the EED with comparable accuracy.

A two-prong program was initiated early in the study to select the most effective matching system and to specify its loss with reasonable accuracy. Since the loss would probably be related to the magnitude of the terminating impedance, we planned tests using UHF vacuum thermocouples of varying resistance as loads to investigate low frequency losses. For tests at higher frequency, above the limit for the thermocouples, we employed thermal radiation detectors whose response was calibrated to be proportional to the power dissipated in the bridgewire of the EED to be evaluated.

2.1 Losses Determined by Use of Thermocouple Loads

Loss measurements on impedance matching devices were initially restricted to the frequency range of 250 to 500 megacycles. The results were to serve as a guide for an intelligent approach to the more difficult range extending up to 1000 Mc, and beyond.

Stub stretchers, double stub tuners and triple stub tuners are made up from various combinations of adjustable stubs and line sections, and are almost universally employed for impedance matching at frequencies above 200 megacycles. A line stretcher, which is an adjustable length of coaxial line, is ordinarily inserted as a series component. An adjustable stub is a variable length of coaxial line which is shorted at one end and must of necessity be employed as a shunt. Open circuit stubs are seldom used because of radiation problems at the open end. These devices utilize the principle of combining series and shunt coaxial impedance elements to produce a match between the load and source impedance.

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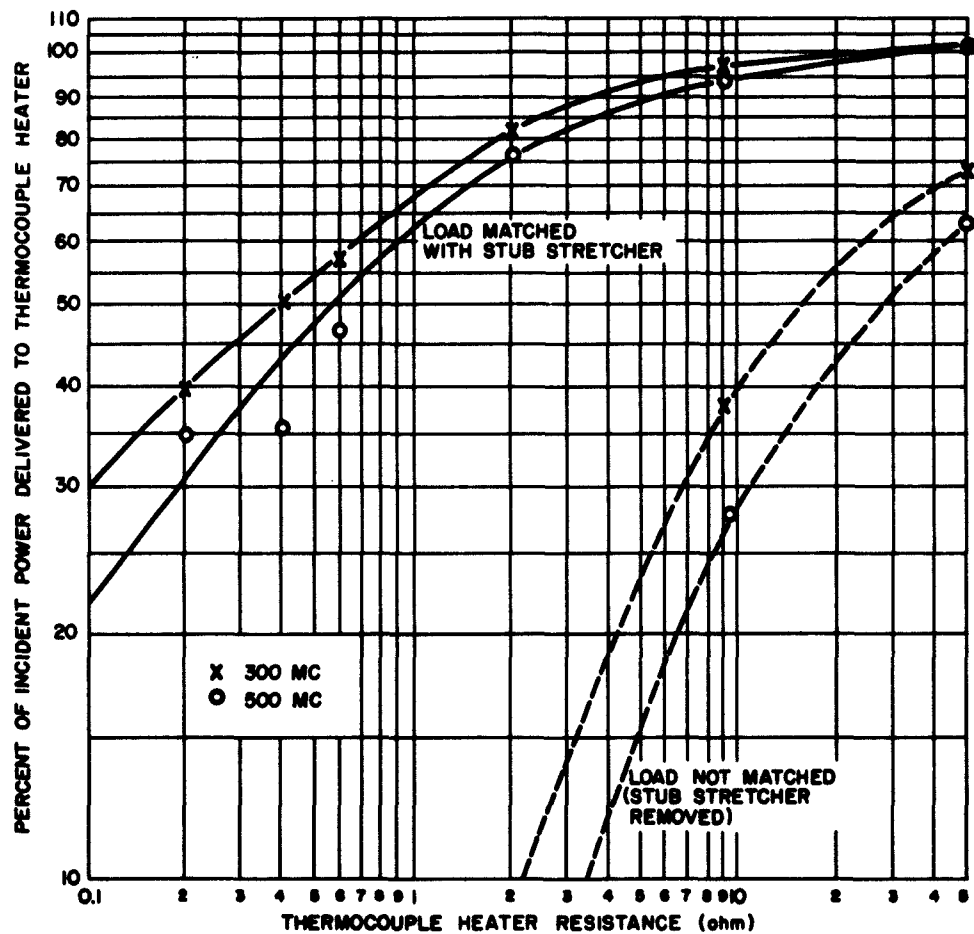
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An experiment was designed to determine the relative losses of several types of coaxial matching devices. A double stub tuner, a stub stretcher and an assortment of line stretchers and shorted stubs were available for tests. Six coaxially mounted UHF vacuum thermocouples were employed as load terminations. The nominal values of dc heater resistance for these thermocouples are 50, 9, 2, 0.6, 0.4 and 0.2 ohms.

An additional experiment was designed to determine the amount of power delivered to each of the thermocouples without matching. Data from this experiment were used to calculate an unmatched voltage standing wave ratio (VSWR) for each thermocouple. The aim was to determine the correlation between the unmatched VSWR and the power delivered to the thermocouples when matched.

Details of this evaluation may be found in report Q-B1805-2. Figure 2-1 is included here to show the nature of the results. Of the several matching systems examined, the stub stretcher showed the least loss in these tests. The figure suggests that we may expect about 35% system losses for loads comparable to the MARK 1 MOD 0 (1.0 ohm) and 70 to 80% for the MARK 2 MOD 0 (0.1 ohm), in the 300 to 500 Mc frequency range.

The dotted curves included in Figure 2-1 indicate the nature of losses that would result if we failed to match these loads. From these data we determined an estimate of VSWR which was to be compared to that value computed on the basis of impedance measurements. However, when the impedance measurements were made it became apparent that the thermocouples' impedances at these higher frequencies were in no way similar to the impedances expected of the EED terminations. Accordingly it was presumed that the system loss data acquired in this manner could not be relied upon to give the needed accuracy. Emphasis was therefore shifted to examination of photodetector techniques.



**FIG. 2-1. PERCENT OF INCIDENT POWER INTO THERMOCOUPLE VERSUS
HEATER RESISTANCE (LOAD)**

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2.2 Infrared Detector Above a Bridgewire for Loss Determination

It appeared reasonable that an infrared detector mounted above and close to a heated bridgewire should have a response related to heat energy from the wire. It should make no difference whether the wire is energized by dc or RF power, if the wire has a small diameter and a length which is short compared with the wavelength of the applied RF energy. These assumptions were experimentally validated before this technique was accepted for use.

We know from the experience gained with thermocouple loads that matching losses could be made negligible at 250 megacycles for a load of approximately 50 ohms. On the other hand, we had been unable to prevent excessive losses when matching a 0.2-ohm load. Therefore, we could be reasonably certain that the method was sound if the detector above a 50-ohm wire provided equal indications for equal powers of dc and RF excitation.

The instrumentation was designed around a pair of Kodak Ektron infrared detectors, type N-1, mounted on a common heat sink to provide temperature compensation. One cell is exposed directly to a radiating source while the other is shielded.

The photo-conductive cells were connected as opposing arms of an ac resistance bridge with a 1000-cps excitation voltage. Relative output of the infrared detector is indicated by balancing the bridge and reading a calibrated dial.

The infrared detector mount provides a means for placing the cell in the best position relative to the bridgewire. One end of the device under test is installed in an adapter fitting for RF input. The other end, with the bridgewire exposed, is put into an opening in the detector mount.

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As was previously mentioned, this measuring technique would be valid if equal amount of RF and dc power in a 50-ohm bridgewire would give equal output from the detector. A value of exactly 50-ohms could not be obtained; instead, a wire measuring $79 + j 16.5$ ohms at 250 Mc was employed.

Several tests with the 79-ohm wire indicated an efficiency of 95 per cent at 250 megacycles. This efficiency was derived from the ratio of the dc power to the RF power required for unity output of the detector. Since some loss was expected when matching 79-ohms instead of 50-ohms, the figure of 95 per cent efficiency was considered to indicate a confirmation of the infrared method.

Additional tests were made with bridgewires having dc resistances of 0.28 and 0.40 ohms. The efficiency, using a stub stretcher, varied between 60 and 65 per cent. These tests were conducted with RF power of 300 milliwatts.

The system used in these preliminary experiments of photoconductor techniques was not ideally adaptable to RF firing system requirements. However, indications were that the technique was feasible. While considering the needs for modifying the IR system to this new use it was decided to investigate other photoconductors such as the Clairex photoconductive cell. This cell was found to be more suited to the task of systems loss evaluation than were the cells tried first.

2.3 A Photo-Conductive Cell For Loss Determination

From a number of photoconductors a Clairex Type 404 photoconductive cell whose spectral response peaks at 6900 angstroms, and is down 30 per cent at 6300 and 9000 angstroms, was selected. The cell was mounted in a light-tight aluminum cover, which was designed to be easily slipped on and off the firing mount.

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We planned to operate the heated bridgewire at a temperature just below the visible glow point. Because of the high output obtained from the cell at this temperature, an ordinary ohmmeter, such as a Triplet Model 630 multimeter, was adequate for initial output indication. The resistance of this Clairex cell decreases from more than 20 megohms when dark down to about 500 kilohms for the bridgewire temperatures involved in our tests.

We exposed the detector above a 50-ohm heater in a matched RF system to prove again that the method was valid. A length of high resistance wire was installed on a MARK 2 ignition element plug assembly (not on the 50-ohm line as was done in the previous experiment) in place of the low resistance bridgewire. The effective series RF impedance of this wire was 31-j 10.5 ohms at 250 megacycles.

The ignition element, with the 31-ohm bridgewire, was installed in the firing mount and matched with a stub stretcher at 250 megacycles. The ratio of the dc power to the RF power required for equivalent output of the photo-detector was 96.5 per cent. This was assumed to be near enough to 100 per cent to prove the technique was valid. We should expect a loss of at least 3.5 per cent with a load of 31-j 10.5 ohms.

This Clairex photo-cell and housing was used for all of the system calibrations performed in this study.

2.4 Evaluations of Losses Attributable to the Squib or Ignition Element

The calibration procedure to be described in the following section assumes that the items to be tested have no inherent loss at the test frequencies. The total power entering the base of the items is, therefore, propagated to the bridgewire.

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This assumption appeared to be valid since attempts to determine the loss associated with both the MARK 1 squib plug or the MARK 2 ignition element base gave indication of small power loss.

Attenuation measurements through the base of the MARK 1 MOD 0 squib were made at 250, 500 and 1000 megacycles and values between zero and 0.2 db were obtained. In some cases the 0.2 db value was for 250 megacycles, and the zero db figure was at 1000 megacycles. This indicates that the attenuation is too low to be determined by the measuring equipment.

Similar results were obtained for MARK 2 MOD 0 ignition elements. These were measured at 500 and 1000 megacycles only. No values higher than 0.1 db were recorded for the attenuation through the base of the ignition element.

In section 2.3, an efficiency of 96.5% at 250 megacycles was cited for an element with a 31-ohm bridgewire; this indicates that attenuation through the plug cannot be very great at that frequency. However, we wished to be certain that the greater part of the 3.5% power loss was not expended in the plug.

Reference to Figure 2-2 (a) will give some idea of the complexity of the various thin sections of dielectric materials in the base of the MARK 2 ignition element. A simulated element was constructed to have the same outside physical dimensions and bridgewire resistance as a standard MARK 2. Its losses were expected to be less than those of the standard because of the use of a polystyrene insulator in place of the thin nylon insulators and the mica washer. The dimensions were such that the characteristic impedance of the base is 50-ohms up to the point of bridgewire attachment. A drawing of this simulant is given in Figure 2-2 (b).

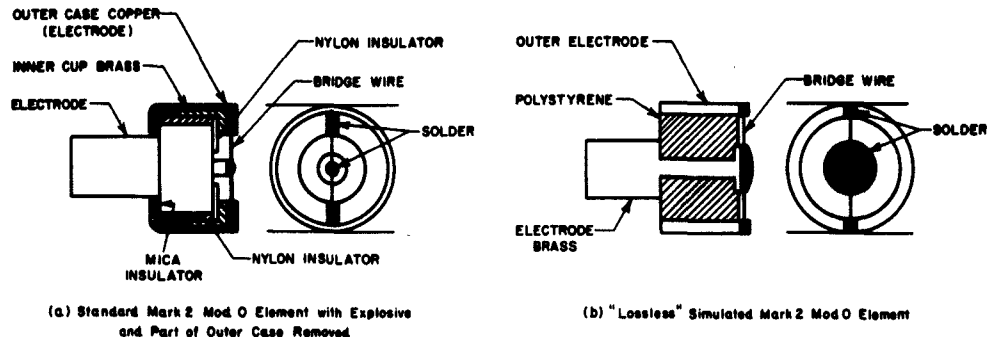


FIG. 2-2. COMPARISON OF STANDARD AND "LOSSLESS" MARK 2 MOD 0 IGNITION ELEMENT

The purpose of the unit was to serve as a reference for comparison with a group of standard MARK 2 ignition elements. Losses exhibited by the standard item could then be attributed to the base. At 250 Mc there was no significant difference between the two systems.

3. FIRING SYSTEMS AND INSTRUMENTATION DEVELOPMENTS

Results of our investigation into system losses led to consideration of means for their reduction, if not their total elimination. Accordingly a number of development efforts were initiated.

Though we had performed firing tests prior to the inception of this program, using stock RF components, we did so without the full realization of the magnitude of the losses thereby introduced. We had suspected that our systems were far from ideal, but not so far as the evidence accumulated in this program indicated to us. To effect an improvement, we designed a special adjustable shorted stub, and took every precaution to keep the length as short as possible, so that losses would be minimized.

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Similarly we took especial care in designing mounts, to eliminate probable causes for loss. Selection and calibration of instrumentation, likewise, was made with an awareness of the rigorous demands of this totally new concept of precision firing. As a consequence, valuable knowledge was acquired, but more importantly, reliable systems became available and were used to perform RF firing evaluations with precision not previously obtainable.

3.1 Matching Systems

Our initial system loss evaluations (see Section 2) indicated that commercially available matching sections were responsible for unduly high system losses. Their chief drawback may be attributed to one or both of two shortcomings* in design: (1) The use of sliding contacts which either become dirty or lose their tension and thus give "high resistance" contact, or (2) because of the need for spring or finger contacts, the minimum stub length is unreasonably long. To offset these effects, we designed a unique shorted stub, which was the outgrowth of an arrangement assembled to fire one test at 250 Mc.

For the lower frequencies stub tuners become unwieldy, and it is necessary to resort to lumped parameter networks to perform the matching task.

3.1.1 A Novel Adjustable Shorted Stub

The novelty of our shorted stub lies first in the fact that it may be adjusted from 60 cm down to a length approaching zero and second in the unusual arrangement of collets which provide the actual short circuiting conductance across the line. A third feature is the provision of an external knob which allows the collets to be positively locked in any desired position. A micrometer adjustment for fine positioning is also included.

*For our purpose they are shortcomings; for their ordinary intended use, the consequences may be not serious, and this may be an unjust accusation.

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Figure 3-1 is a view of the adjustable shorted stub, partially disassembled to expose some of the inner constructional details. It consists basically of a 70-cm length of coaxial air line (outer and inner conductor) and an assembly containing the shorting slug which is inserted within the coaxial line. The 70-cm line is so constructed that it may be attached to the junction port of a coaxial tee fitting in such a way as to form a smooth continuation of the outer and inner conductors of the tee.

The shorting slug consists of two concentric silver plated collets. The outer collet has an internal taper which is a mating fit with the external taper of the inner collet. When the inner collet is drawn up into and flush with the outer collet, the locking action forces the contacting fingers against both the inner and outer conductor. The intimate contact between the tapered surfaces of the collets combines with finger-spreading collet action to create a plane of high conductance across the line at the junction of the coaxial tee. Figure 3-2 is a close-up view of the collets in the condition just described.

Figure 3-3 is a view of the completely assembled shorted stub with a section of adjustable air line attached for matching the MARK 1 MOD 0 squib at 250 megacycles. A longer adjustable line is shown just below the main assembly, and a short adjustable line at the bottom of the figure. These components can be interchanged as required.

3.1.2 An Expedient Shorted-Stub Adjustable Line Matching System

One attempt to solve an immediate matching problem was to assemble an adjustable line and a type "N" tee junction with a shorting cap screwed on one of the ports. This formed a simple stub stretcher with a fixed stub and an adjustable line. A trial showed that this "tuner" could almost match a MARK 2 ignition element inserted in the firing mount. A slight modification, to bring the shorting cap a little closer to the line junction, produced a match with a ratio of incident to reflected power of better than 200 to 1.

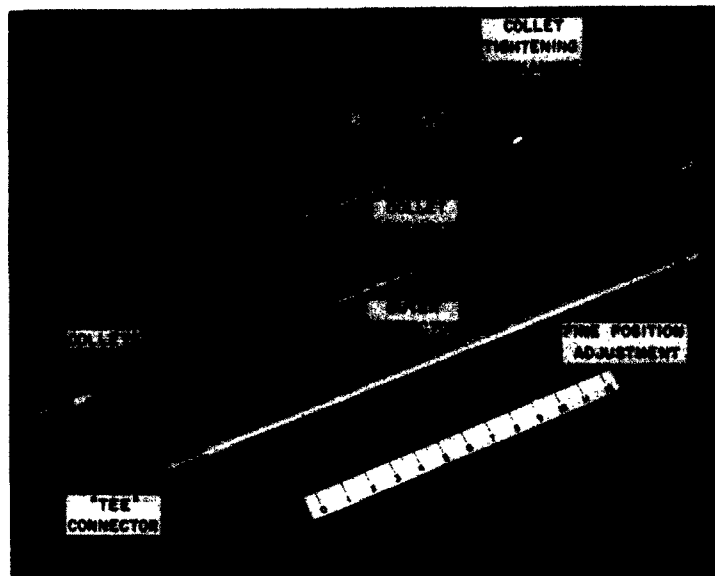


FIG. 3-1. ADJUSTABLE SHORTED STUB - DISASSEMBLED

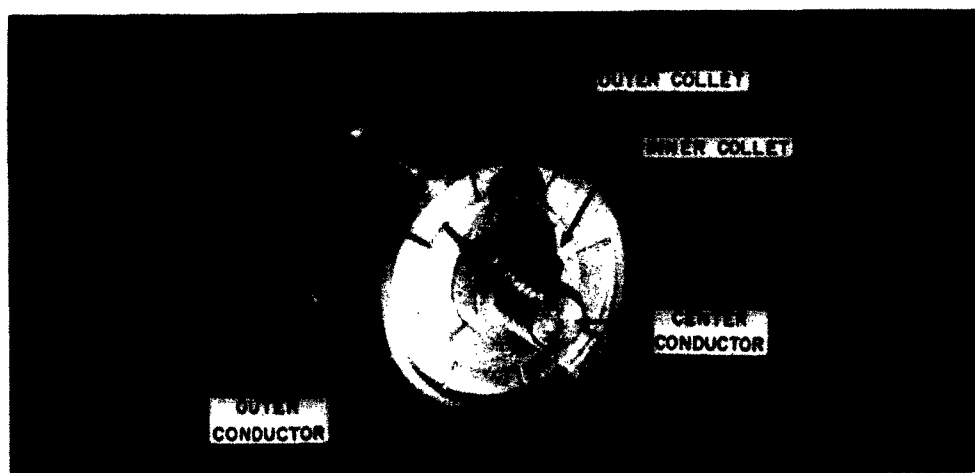


FIG. 3-2. CLOSE-UP OF COLLETS FOR ADJUSTABLE SHORT

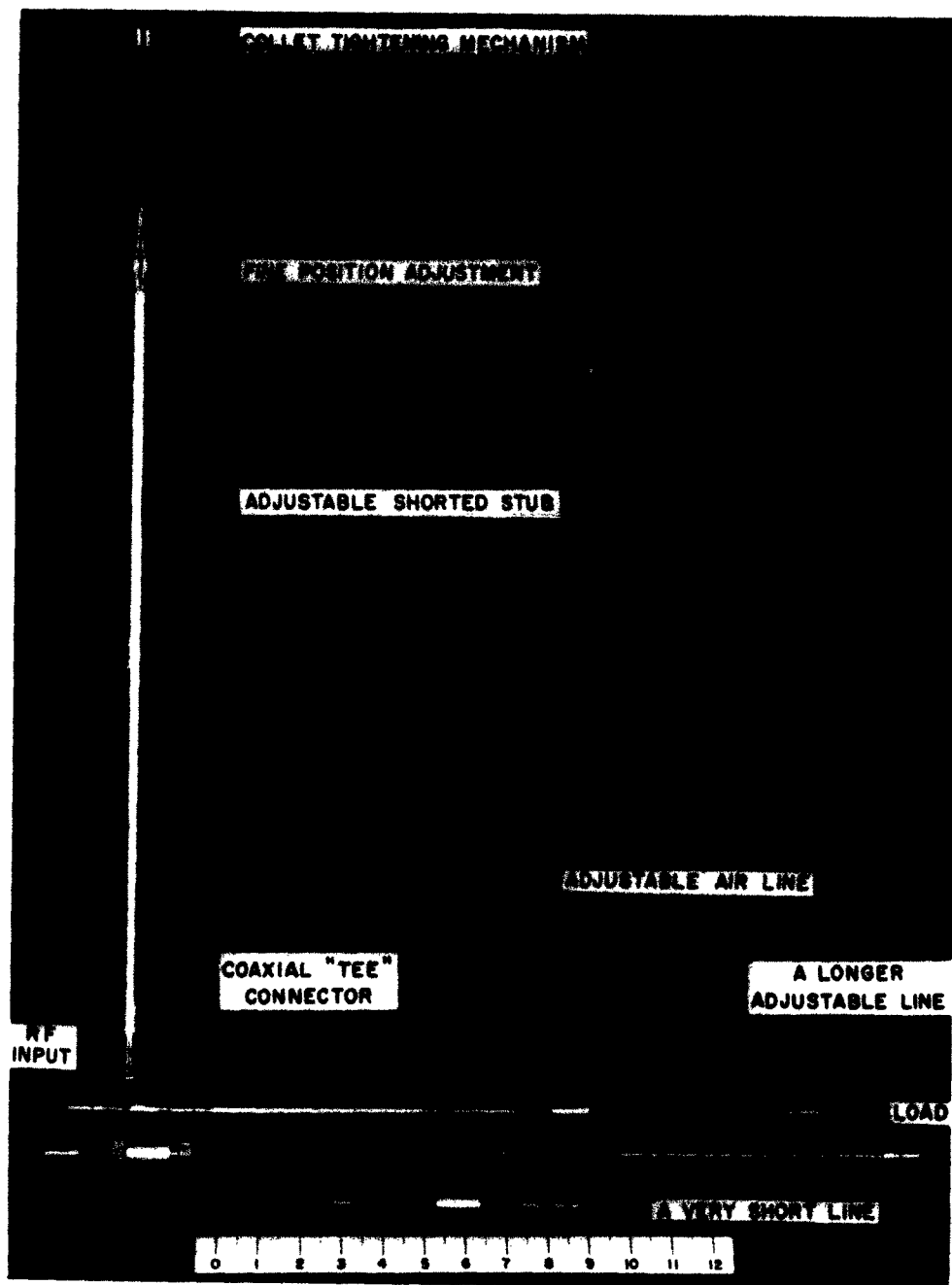


FIG. 3-3. MATCHING SYSTEM EMPLOYING THE SHORTED STUB AND SECTIONS OF ADJUSTABLE AIR LINE

Tests with a number of ignition elements suggested that a fixed shorted stub and an adjustable line stretcher would produce an acceptable match for any of the MARK 2 ignition elements at 250 megacycles. Furthermore, the system appeared to be exceptionally stable compared with previous systems. Consequently this arrangement was used to fire the 250 Mc test of the MARK 2 MOD 0 ignition elements while the adjustable stub was being developed.

3.1.3 Low Frequency Matching Systems

At frequencies of 5 and 30 megacycles, impedance measurements show that we may assume that the real part of the impedance of the MARK 2 ignition element corresponds to the dc resistance of the bridgewire. The bridgewire, normally 0.1 ohms when cold, is about 0.14 ohms when heated to a dull red.

Figure 3-4 is a theoretical circuit for matching a MARK 2 ignition element to a 50-ohm line. The values of reactance required for matching were obtained by substitution in equations (3-1) and (3-2).

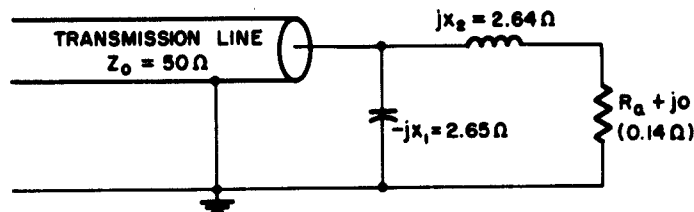


FIG. 3-4. THEORETICAL CIRCUIT FOR MATCHING MARK 2 IGNITION ELEMENT AT LOW FREQUENCIES

$$X_2 = \sqrt{Z_0 R_a - R_a^2} \quad (3-1)$$

$$X_1 = \frac{Z_0 R_a}{X_2} \quad (3-2)$$

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These equations yield almost equal values of 2.65 and 2.64 ohms for X_1 and X_2 . At 5 megacycles, a capacitor of 0.012 microfarads and an inductor of 0.082 microhenries are required for the calculated reactances of 2.65 ohms. At 30 megacycles, the component values are 0.002 microfarads and 0.0136 microhenries.

The equations from which we calculated X_1 and X_2 assume that the load has no reactance. The load in Figure 2-2 is therefore denoted as $R_a \pm j0$ which in the case of the MARK 2 element is approximately 0.14 ohms. The net reactance of the load will modify the calculated value of X_2 , however, this will not be considered here since the exact value of X_2 will be obtained empirically in actual practice.

Similar calculations were made to determine the theoretical values of components required for matching the MARK 1 MOD 0 squib at 5 and 30 megacycles. The nominal dc resistance of the squib bridgewire is 1 ohm (cold) and about 1.4 ohms when heated to a dull red. The calculated values for X_1 and X_2 are 8.49 and 8.24 ohms respectively. At 5 megacycles, these reactances may be obtained with a capacitor of 0.00375 microfarads and an inductor of 0.262 microhenries. At 30 megacycles, these values become 0.000625 microfarads and 0.0436 microhenries.

The matching networks used in the firing of the squib and ignition elements were simple combinations of inductive and capacitive elements mounted in an aluminum box as shown in Figure 3-5. Here can be seen a variable 1000-picofarad tuning capacitor, a fixed shunt capacitor, and a series tuning inductor. The fixed capacitor and the series inductor are removable so that other values may be substituted according to the frequency and the impedance of the item under test.

It would ordinarily be assumed that both the series inductor and the shunt capacitor would have to be variable in order to allow for the normal variation in resistance and reactance of the EED being tested. However, it was found that the MARK 1 MOD 0 squibs and the MARK 2 MOD 0

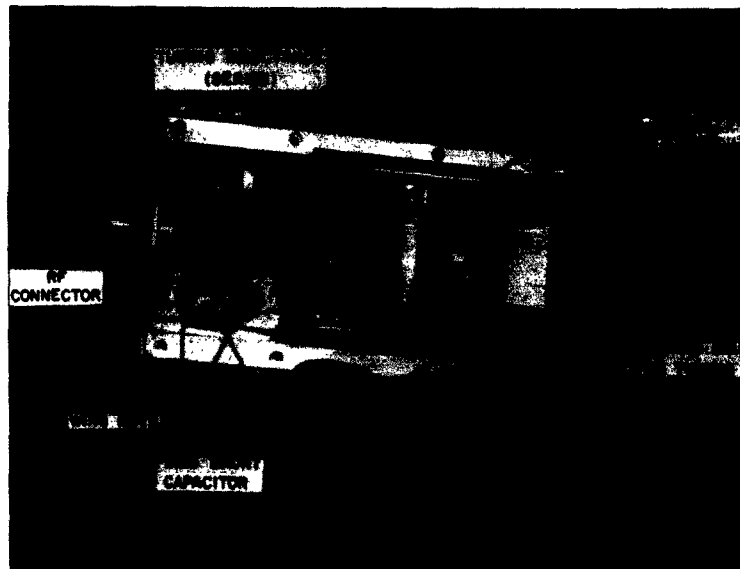


FIG. 3-5. A TYPICAL LUMPED ELEMENT MATCHING NETWORK

ignition elements were so uniform in their electrical characteristics that a fixed inductance and capacitance in combination with a single variable capacitor was enough to produce an acceptable match for any individual in a group under test.

3.2 Firing Mounts

The mount which adapts the EED to the RF line is not the least important part of the system. Mount designs must insure repeatability of mounting EED's so that no variation in results can be attributed to deficiencies at this point. Reliable contact between leads and line conductors must also be assured. It is for this latter reason as well as to make provision for insertion of a voltage probe, that a redesign of the mount initially constructed for this test schedule was required.

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Figure 3-6 shows a cross section of the mount finally used to perform the tests reported herein. Unique features of this mount include a collet arrangement to insure a positive electrical contact between the outer case of the ignition element and the body of the mount. Figure 3-7 shows this feature more clearly. The MARK 2 ignition element with the bridgewire exposed can be seen held by the collet.

A voltage probe can be inserted to make contact with the center conductor, at a point close to the base of the element. The probe is removable, and a plug closes the opening during actual firing. The probe was used for trials to measure power at the input to the EED, by a voltage-impedance method.

A series of adaptor parts permit this mount to accept the MARK 1 MOD 0 squib. These are shown in Figure 3-8. The leads of the squib must be cut to exact length and shaped before installation in the mount. This is done with a special holding and stripping device, not shown. A cut and dressed squib is in the foreground of the picture, which also shows another squib mounted in the center conductor. A socket-head screw is turned to fasten one of the leads in the center conductor. A slot is provided in the collet to force the ground lead against the bottom edge of the outer case of the squib. The collet-closer brings the collet into intimate contact with the bottom circumference of the squib case. The screw that tightens the center conductor is reached by a special wrench inserted through a hole in the main body of the mount. The complete assembly with squib in place is shown in Figure 3-9.

3.3 Output Indicator And Power Supply for Clairex Cell

A Triplet multimeter, Model 630, may be used for indication of the resistance of the Clairex 404 photocell. When set on the X100,000 ohms scale, this meter indicates 500,000 ohms mid-scale. With the Clairex cell about 1/16-inch above a squib or ignition element bridgewire

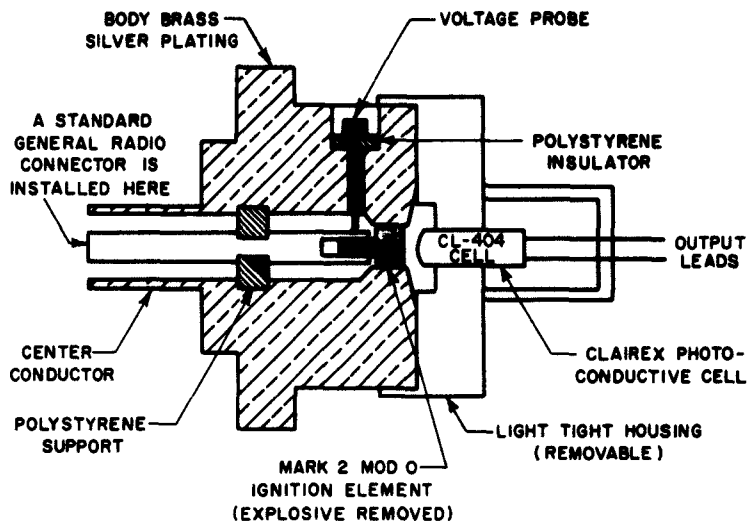


FIG. 3-6. CROSS-SECTION OF MARK 2 MOD 0 FIRING MOUNT
(Photocell Housing Attached)

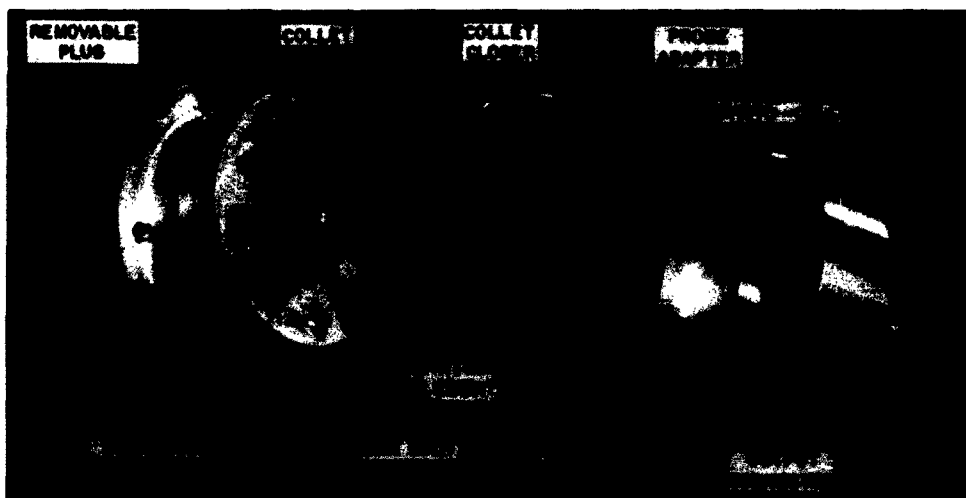


FIG. 3-7. FIRING MOUNT AND PHOTOCELL HOUSING

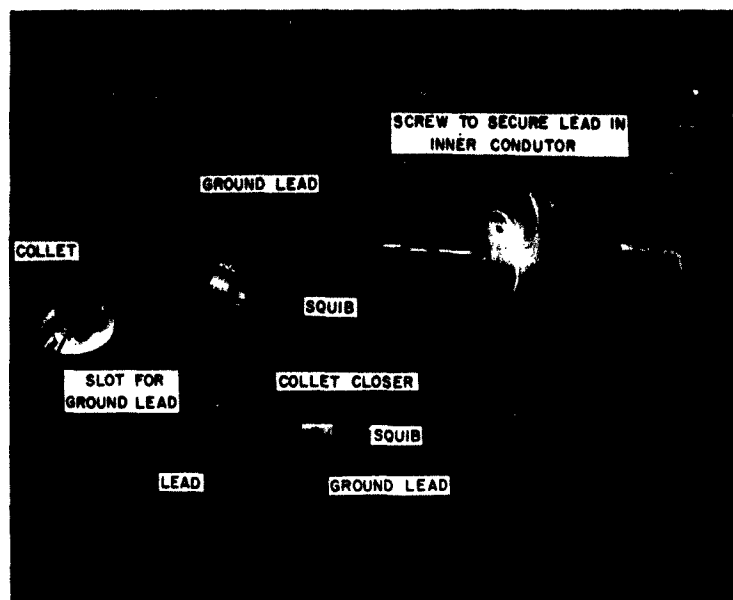


FIG. 3-8. ADAPTER PARTS FOR ACCOMMODATING MARK I MOD O SQUIB

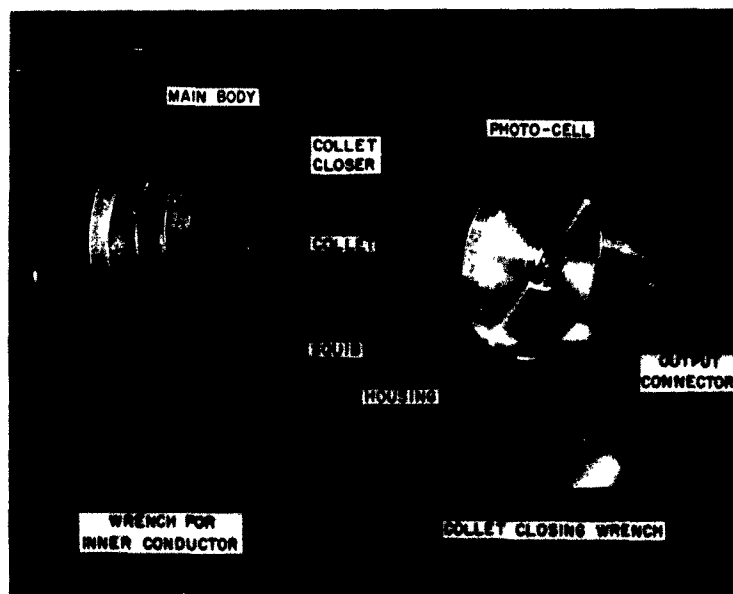


FIG. 3-9. FIRING MOUNT AND PHOTOCCELL HOUSING
(Adapted for Mark I Mod O Squib)

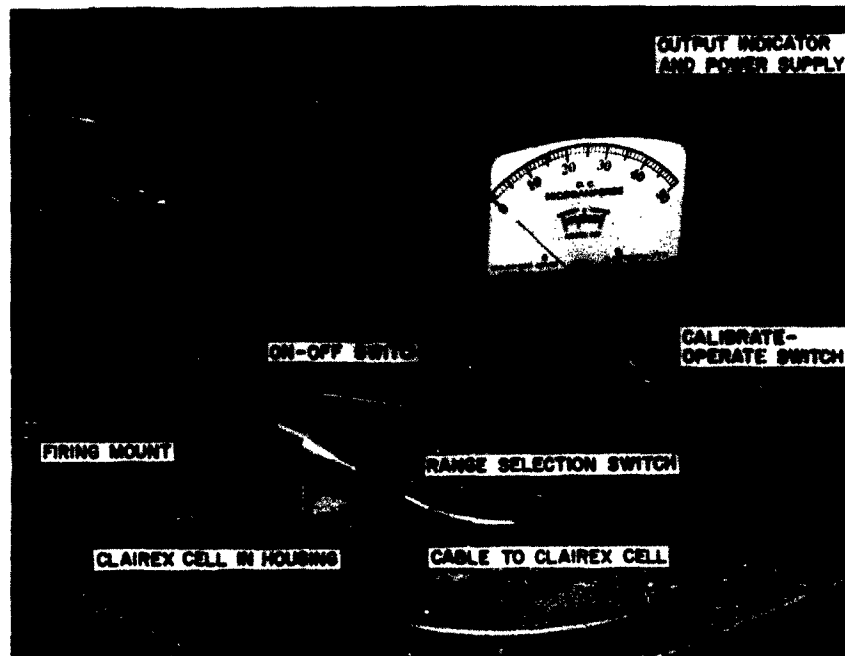


FIG.3-10. CLAIREX CELL OUTPUT INDICATOR AND POWER SUPPLY

this would correspond to a dull red glow of the bridgewire. Anticipating the need for greater sensitivity, we developed an improved meter system.

Initial firings indicated that the 50% fire level could be considerably below a dull red glow of the bridgewire. To facilitate tests at these lower power levels, we designed a combined photocell power supply and output indicator, specifically for use with the Clairex cell. Figure 3-10 is a view of this instrument. A photocell in a housing attached to the firing mount can be seen connected to the instrument by a shielded cable. A seven-inch 50-microampere meter is used as an indicator. Although the instrument functions as a high resistance ohmmeter, there is no necessity for calibrating the scale in ohms. The original calibration of the scale combined with observation of the range dial setting (1 to 10) is all that we need. Description of the electronic circuit follows.



The instrument we designed to replace the multimeter is essentially a regulated power supply and an ohmmeter circuit. Details of the circuit are shown in the schematic diagram Figure 3-11. The regulated power supply is a conventional supply with an OB2 gas-tube voltage regulator. The output across this tube is approximately 107 volts. R_3 is a series rheostat, which is adjusted to give a voltage drop of exactly 100 volts across the precision voltage divider R_4 to R_{13} .

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The voltage divider, consisting of ten precision wirewound resistors of 500 ohms each, draws a constant 20 milliamperes current from the 100 volt supply. Voltages from 10 to 100 volts, in steps of 10 volts, are selected by the range switch S_2 . Series resistors R_{14} to R_{23} are so chosen as to cause the "calibration" current to be 50 microamperes at each range. When the switch S_3 is thrown to "Calibration Check" position, the Clairex cell is shorted out and the meter will read 50 microamperes $\pm 1\%$ on all ranges. The first range position, S_2 set to R_{23} , is considered to be the reference position. R_3 is adjusted so that the meter reads exactly 50 microamperes or full scale when S_3 is on CAL. check and the range switch is on range 1. All other ranges will then be automatically adjusted to within 1%, which is the tolerance of the resistors used.

The value of 20 milliamperes for the current through the voltage divider was chosen to provide a maximum loading effect of 0.4% when the meter is indicating over the range of zero to 50 microamperes.

Voltage ranges of 10 to 100 volts in steps of 10 were chosen in place of normal scales 1X, 10X, 100X, etc., because steps of 10 volts are more practical for our special application. When used on the highest range, the meter is capable of indicating bridgewire heat about 40% below a dull red glow. The meter will then indicate at about mid-scale or 25 microamperes. This unit is a considerable improvement over an ordinary multimeter for indication of photocell resistance.

3.4 Calorimetric Power Reference Source

A Hewlett-Packard Model 434A calorimetric power meter was obtained as an RF reference standard for this program. This meter was selected for several reasons. First, it has several ranges, from 10 mw full scale to 10 watts full scale. The power levels at which the MARK 1 MOD 0 squib and the MARK 2 MOD 0 ignition element are expected to fire should fall within these ranges.

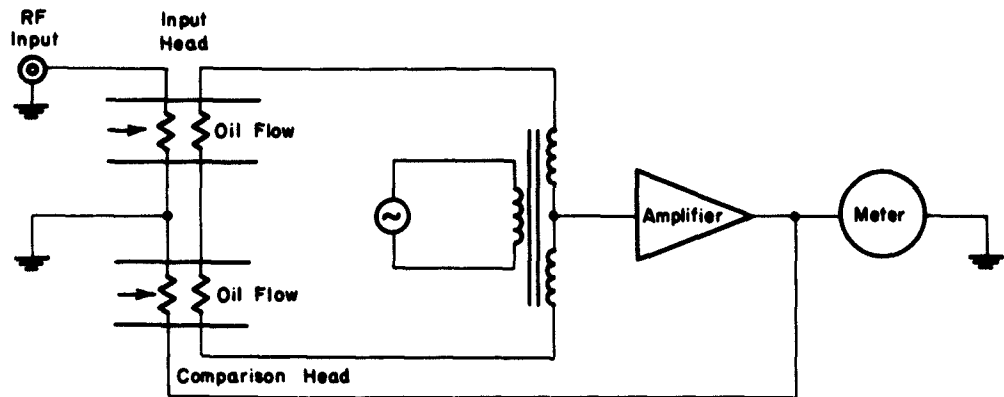


FIG. 3-12. SIMPLIFIED CIRCUIT OF HP MODEL 434A CALORIMETRIC POWER SUPPLY

Second, the calorimetric power meter can be calibrated simply by substituting an equivalent dc power for the RF power. This dc power can be accurately measured with instruments whose calibration is certified by the Bureau of Standards. The overall accuracy of the calorimeter can be held within $\pm 2\%$ of the full scale reading when special calibration techniques are employed.

Basically, the 434A power meter consists of a balanced bridge circuit which becomes unbalanced when applied RF power heats one branch. An error voltage produced by this unbalance is amplified and fed back to the bridge, bringing it back into balance. Figure 3-12 shows a simplified diagram of the power meter's circuit. The input head consists of a 50-ohm resistive termination for the RF input and a thermistor, which is a temperature sensitive resistor in close proximity. A flow of oil over these elements maintains them at the same temperature. The comparison head is constructed in the same way. The temperature sensitive resistors are in adjacent legs of an audio frequency bridge circuit. RF power, when dissipated in the terminating resistor, will raise the

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temperature of the thermistor, causing the bridge to become unbalanced. An error voltage, produced by this unbalance, is amplified and fed back into the comparison head load resistor. The power dissipated in this resistor causes the bridge to become balanced. A meter movement is connected to this feedback circuit and is deflected by an amount proportional to the power required to rebalance the bridge. To eliminate zero drift and maintain stability, the oil flowing in the input and comparison heads is passed through a heat exchanger prior to entering the heads. This maintains both heads at the same temperature initially. A series flow system is used so that the flow rates in the heads are identical.

A $100 \text{ mv} \pm 1\%$ dc power supply is provided with the calorimeter. When the instrument is calibrated with this supply the overall accuracy of the instrument is within $\pm 5\%$ of full scale. This error includes RF and calibration losses but does not include mismatch losses which might occur between the system being evaluated and the RF input head. The accuracy of the power meter can be greatly improved by calibrating at the same level as the RF power to be measured. In this way the power meter serves only as a transfer instrument and errors due to differences in range settings and meter tracking errors are eliminated. To do this a variable dc power supply of high stability is necessary. The power produced by this supply may be accurately measured by the following technique.

The RF input termination resistor, with a nominal value of 50 ohms, may differ from this by as much as ± 5 ohms. A calculation of power based on the input voltage and the load resistor would, therefore, be in considerable error unless the value of this resistor were accurately measured at each input power level. The error produced by changes in this resistor may be reduced greatly by the following method. A precision 50 ohm resistor (R_g) is placed in series with the load resistor (R_L) as

shown in Figure 3-13. The voltage is now measured across the series combination of the two resistors. Power dissipated in the load (R_L) may now be computed as follows:

$$P_L = \frac{E_L^2}{R_L} \quad (3-1)$$

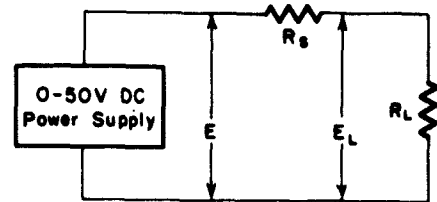


FIG. 3-13. DIAGRAM OF CALORIMETER
CALIBRATOR CIRCUIT

and

$$E_L = E \frac{R_L}{R_s + R_L} \quad (3-2)$$

therefore

$$P_L = E^2 \frac{R_L}{(R_s + R_L)^2} \quad (3-3)$$

The change in load power (P_L) as R_L changes from 40 to 60 ohms is plotted in Figure 3-14. As indicated in the plot, a change in R_L of ± 5 ohms from the nominal value of 50 ohms changes the power dissipated in R_L by less than 0.3%. Therefore, to measure P_L , accurately, all we need do is measure the voltage across the series combination and compute the power from equation 3-3, using the nominal value of R_L , since changes in this resistance produce negligible error. However, since the power is a function of the voltage squared, this voltage must be measured to an accuracy twice that of the accuracy required for P_L . By employing a precision potentiometer calibrated against a standard cell we should be able to compute the dc calibration power to within $\pm 1\%$.

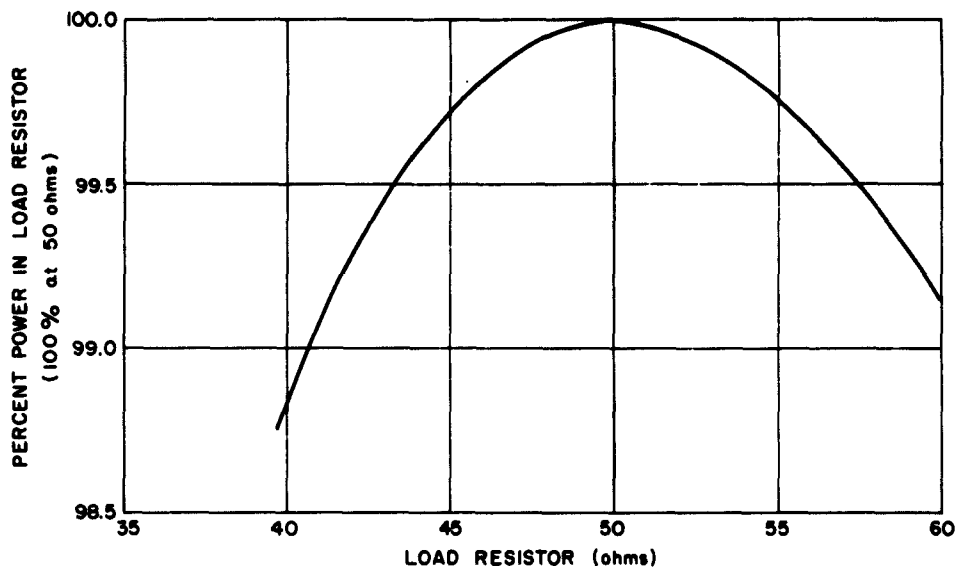


FIG. 3-14. CHANGE IN LOAD POWER FOR CHANGE IN LOAD RESISTANCE

4. DETERMINATION OF SYSTEM LOSS FACTOR; SYSTEM CALIBRATION

The total power entering a completely matched RF system can be accurately measured by conventional means. The RF power arriving at the exposed bridgewire of an EED can be detected as explained in Section 2.3. If there is no significant attenuation caused by the base of the element, we may reasonably assume that the system loss is equal to the total power entering the system minus the power absorbed in the bridgewire.

System calibration is, therefore, performed on the equipment after it is assembled in preparation to fire the test. Figure 4-1 shows the general form of our firing systems; although the physical character of the separate components may vary with frequency, their function remains fixed. The procedure for calibration is as follows:

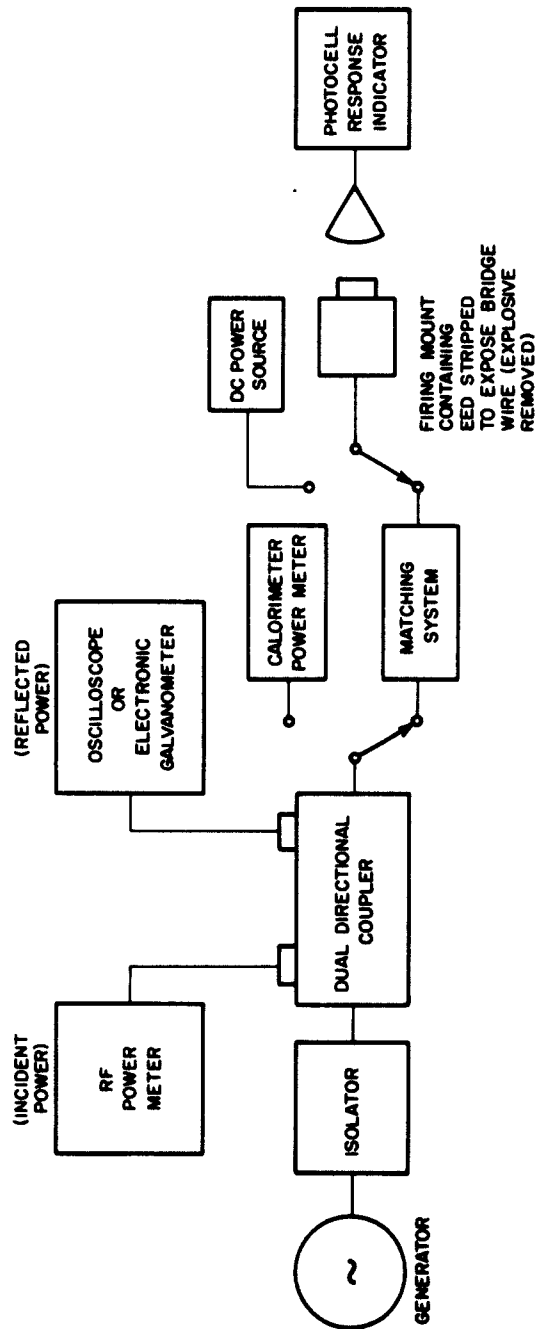


FIG. 4-1. BASIC ARRANGEMENT FOR FIRING SYSTEM CALIBRATION

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A number of EED's from the lot to be evaluated are stripped of their explosive charge to expose the bridgewire. One of these is mounted as a termination, with the photocell fixed to respond to the bridgewire illumination. The matching section is adjusted to give the best possible match, indicated by a minimum deflection of the galvanometer which responds to the reflected power out of the dual directional coupler. RF power is then adjusted to give a reasonable photocell indication (500 Kilohm, read by the multimeter, was standard for all calibrations made in this series). The magnitude of this RF power is determined by switching the generator output into the calorimeter power meter. The firing mount and photocell fixtures are then removed from the RF system and connected to a dc power source. DC power, measured by use of a Leeds and Northrop K-2 potentiometer, is adjusted to give the same photocell response as was noted for the RF input (500 Kilohms). The ratio of the RF to dc power magnitudes averaged for the number of EED's prepared for this purpose is taken as the system calibration (efficiency) factor.

Table 4-1 gives the results of system loss factors determined for ignition elements intended for use in this series of tests. The data from which these values are obtained are included in Appendix A.

Table 4-1

SYSTEM LOSS FACTORS

<u>Frequency (Mc)</u>	<u>System Loss Factor</u>	
	<u>MARK 1 Squib</u>	<u>MARK 2 MOD 0</u>
5	0.948	0.696
30	0.718	0.449
250	0.810	0.412
1000	0.514	0.560

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As stated earlier, the same basic system was used for each calibration. Why then are not the loss factors identical? First, because the matching system for 5 and 30 Mc is a lumped parameter network, whereas that for 200 and 1000 Mc is the stub and line-stretcher tuner. Second, for any system we would expect the loss to increase as frequency is increased, and as the load impedance departs from 50 ohms. Except for the MARK 2 MOD 0 loss factor at 1000 Mc, the data bear out these expectations.

5. RF SENSITIVITY TESTS OF MARK 1 SQUIB AND MARK 2 IGNITION ELEMENT

Both the squib and the ignition element have been evaluated for sensitivity at frequencies of 5, 30, 250, and 1000 Mc. Tests were run in accordance with the Bruceton Plan, ⁽¹⁾ and 100 of the devices were expended in each test to insure a reasonable confidence level. The sample group of each item was taken from a single production lot. Two large lots one of each item, were selected, so as to avoid the chance of a wide lot-to-lot deviation.

The firing systems were carefully calibrated for system efficiency as discussed in the previous section. Accordingly, data are given as input power to the bridgewire for various probabilities of functioning. On the assumption that power loss in the base of the element is negligible within the frequency span of the tests, we may construe the data to be equally representative of power input to the base of the element. Recognizing that the loss of the base plug will become more significant as frequency increases, we are led to be moderately suspicious of the data given for 1000 Mc.

Results of the firing evaluations are given in Table 5-1; raw data and calculations are appended. The appearance of two sets of data for MARK 2 MOD 0 elements evaluated at 30 Mc warrants some explanation. Those results tabulated at the bottom of the table were obtained first.

(1) For a description of the Bruceton Plan and the manner in which data are reduced therefrom see: AMP Report No. 101.12 "Statistical Analysis for a New Procedure in Sensitivity Experiment," July 1944.

Table 5-1
RF SENSITIVITY OF MARK 1 MOD 0 SQUIB AND MARK 2 MOD 0 IGNITION ELEMENT

Frequency (Mc)	System Input Power (watts) For Indicated (g)				System Calibration Factor	Calculated Input Power (watts) To Bridge Wire For Indicated (g) Probability of Functioning			
	0.1	1.0	50	92		0.1	1.0	50	92
MARK 1 MOD 0									
5	0.0652	0.0718	0.0966	0.1299	0.1431	0.06180	0.06806	0.09157	0.1231
30	.0812	.0903	.1250	.1732	.1925	.05828	.06481	.08971	.1243
250	.0714	.0798	.1134	.1584	.1771	.05783	.06464	.09185	.1283
1000	.1398	.1472	.2008	.2740	.3080	.07184	.07564	.1032	.1408
MARK 2 MOD 0									
5	1.024	1.070	1.226	1.404	1.467	.7129	.7449	.8535	.9775
30	1.504	1.599	1.937	2.345	2.495	.6754	.71833	.8699	1.053
250	1.451	1.599	2.165	2.930	3.231	.5979	.6589	.8922	1.207
1000	1.158	1.207	1.372	1.560	1.636	.6489	.6762	.7689	.8741
30 ⁽¹⁾	1.762	1.861	2.205	2.613	2.760	.7446	.7865	.9318	1.104

(1) Evaluation test using wrong lot of elements

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A comparison of the 50% level to other data which was available at the time indicated a difference much greater than had been anticipated. A study led to the discovery that the items used in this test were inadvertently taken from a second lot of elements in storage. Repeating the test with devices from the lot reserved for this program produced the data tabulated in its proper order. These two sets of data indicate the order of magnitude of the lot-to-lot variations that were eliminated from our results by working with a single lot.

Calculations made with dc firing data indicate that the mean firing (50%) level for the MARK 1 squib and the MARK 2 ignition element, expressed as power, should be 0.09 and 0.9 watts respectively. The results of calculated power to the bridgewire given in Table 5-1 confirms our long-held belief that the inherent (bridgewire mode of power application) sensitivity of a hot-wire bridged device is adequately defined by its dc sensitivity for frequencies below 1000 Mc. As frequency is increased beyond this point we can expect a significant difference between RF and dc power sensitivity. The data at 1000 Mc determined in this program, particularly that for the MARK 2 MOD 0 ignition element, indicate that differences between RF and dc sensitivity may, for some devices, show up at a lower frequency.

Evaluations at frequencies up to and including 10,000 Mc were initially planned to be a part of this program. However, technical problems had to be resolved to allow power at the input of the device to be measured with a precision comparable to that of the data already presented. It became apparent that these solutions could not be obtained under the limitations of the present program. Consequently no firings above 1000 Mc were performed. The data for the sensitivity of the MARK 2 MOD 0 ignition element must therefore be accepted at face value only. No plausible explanation can be given for its deviation until firings performed at higher frequencies are available to establish a trend.

6. CONCLUSIONS AND RECOMMENDATIONS

With the completion of Bruceton tests at 5, 30, 250 and 1000 megacycles, we are in a position to draw limited conclusions regarding the sensitivity of the MARK 2 ignition element. The loss in the base of this item is considered to be negligible at frequencies of 1000 megacycles and below. Therefore, the figure obtained for sensitivity at the bridgewire is the sensitivity at the base of the item. The average sensitivity of the MARK 2 element over the range of 5, 30, 250 and 1000 megacycles is, then, 0.893 watts. This figure corresponds very closely with the dc firing level, which for a 10 second pulse is 0.9 watts.

Bruceton tests have also been completed for the MARK 1 MOD 0 squib at these same frequencies. The loss in the base of the squib using negligible, we may give a tentative figure of 0.0910 watts for the sensitivity of this item. The equivalent dc sensitivity of this item, 0.09 watts, is as we would expect very close to the RF value.

While a considerable part of the original aims of the program were accomplished, several unforeseen complications arose during the study. It should be understood, that the attention given these complications has in nearly every case further extended the present state of knowledge in this field. These complications can be divided into two major categories; RF power detection at the base of the EED, and impedance matching.

With regard to power detection, it was indicated from the preliminary studies that vacuum thermocouples of varying resistances could be used to obtain a calibration of the system losses as a function of terminating resistance. However, while this still remains a possibility, it was found that the mounted thermocouples represented impedances that were so different from the actual EED's that it was decided to go to a different system. We now use for the lower frequencies

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a photo detector which detects the energy dissipated in the bridgewire. This system works very well at the lower frequencies, but is valid only as long as the RF energy is dissipated entirely in the bridgewire and there is no direct RF interaction with the detector. Both of these points are questionable at high frequencies.

The more direct and most useful approach to this problem is to determine the power directly at the base of the plug. However, this is more difficult to do, but additional study should lead to practical solutions.

With regard to matching techniques, great strides have been made. It was determined during this study that system losses are almost entirely functions of the degree of mismatch between the generating system and the termination, and the physical length of the system from the matching device to the EED. For the tremendous mismatches which normally occur between a typical 50 ohm system and an EED these losses can become quite large; so large in fact, that situations can occur which make it impossible or extremely difficult to obtain a match. A limited theoretical development indicated that present commercially available matching systems were not adequate and pointed out the necessary direction in which to go to develop more effective matching devices. These devices have subsequently been developed and proven in use. This then brings us to the final status of the contract. At this time the following items have been accomplished.

- a). Development of precision firing instrumentation for all four frequencies (5, 30, 250, 1,000 Mc) applicable to hot-wire bridged EED's having negligible loss in their base.
- b). Development of system loss calibration techniques for this same frequencies, and actual calibration of these firing systems.

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- c). Development of refined matching systems for the frequencies stated.
- d). Successful precision firing tests for both the MARK 1 MOD 0 squib and the MARK 2 MOD 0 ignition element at the frequencies stated.

Included in the scope of this contract, but not completed, were tests at 3 and 10 Gc. Because of the great number and complexity of problems that arose during the performance of the work documented herein, it was not possible to perform these tests within the limitations of this program. Additional problems requiring more intensive study than could be supported by this program were envisioned. It was concluded, therefore, that these would be deferred to a subsequent investigation.

On the other side of the balance, the solutions to the many unpredicted problems encountered in this investigation have yielded knowledge of considerable future value.

Though much has been learned during the performance of this work still more is to be learned. Means to provide this same sort of reliable test data at 3 and 10 Gc (or higher) must be developed. Likewise, in view of the evaluations of "RF protected" squibs and fixes, some thought must be given to the manner in which these will necessitate altering the technique proposed in this document.

Finally, many areas of potential hazard have been seemingly ignored in this study. Some thought should be given to "precision firings," to determine the sensitivity of EED's to: (1) pulsed RF signals, (2) lead-to-case functioning, and (3) plug heating leading to cook-off. More important than the mere evaluation of these functioning modes is the thought of investigating their interrelation one to another. Some evidence gained in years of RF testing suggests that pulsed signals of average power content much less than that required of a dc signal can induce a functioning of some EED's. To know why and how this is accomplished (if it is indeed so, and not merely an unwarranted conclusion) is to have knowledge of significant application to the HERO effort.

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Major portions of this report were prepared by these men cited in proportion to their contribution to the productive effort.



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APPENDIX A

SYSTEM CALIBRATION DATA

MARK 1 MOD 0 SQUIB. A1 - A4

MARK 2 MOD 0 IGNITION ELEMENT A5 - A9

Table A1

EFFICIENCY OF RF MATCHING SYSTEM AND FIRING MOUNT FOR MARK 1 MOD 0 SQUIB AT 5 MEGACYCLES

Squib Number	RF Power Input (Watts)	Load Resistance (ohms)	DC Calibration with 1. & 2. 100 Pot		Heater Current $I_H = \frac{E_H}{R_S}$ (amps)	Heater Power (dc) $P_{dc} = E_H \times I_H$ (Watts)	RF system Efficiency $= \frac{P_{dc}}{P_{rf}}$	RF Freq. (Mc)
			E_R (volts)	E_H (volts)				
7	0.182	500K	0.34586	0.49772	0.34586	0.172141	0.9458	5
6	0.178	500K	0.33797	0.49626	0.33797	0.167720	0.9422	5
5	0.181	500K	0.34061	0.50291	0.34061	0.171296	0.9464	5
4	0.181	500K	0.34511	0.50423	0.34511	0.174015	0.9614	5
3	0.178	500K	0.33649	0.50259	0.33649	0.169117	0.9501	5
7	0.180	500K	0.34405	0.49336	0.34406	0.169740	0.9430	5
6	0.180	500K	0.33852	0.49773	0.33852	0.168491	0.9361	5
5	0.180	500K	0.33992	0.50045	0.33992	0.170112	0.9451	5
4	0.182	500K	0.34431	0.50379	0.34431	0.173459	0.9531	5
3	0.181	500K	0.33875	0.51078	0.33875	0.173027	0.9559	5

Highest Efficiency = 0.9614
Average Efficiency = 0.94791
Lowest Efficiency = 0.9361

Table A2

EFFICIENCY OF RF MATCHING SYSTEM AND FIRING MOUNT FOR MARK 1 MOD 0 SQUIB AT 30 MEGACYCLES

Squib Number	RF Power Input P _{RF} (Watts)	Light Cell Resistance (ohms)	DC Calibration with L & N "K" Pot			Heater Current		Heater Power (dc) P _{dc} = E _H x I _H (Watts)	RF system Efficiency = P _{dc} P _{RF}	RF Freq. (Mc)
			E _R (volts)	E _H (volts)	R _S (ohms)	I _H = E _H R _S (amps)				
5	0.235	500K	0.34192	0.50351	1	0.34192		0.17216	0.7326	30
4	0.238	500K	0.34775	0.50446	1	0.34775		0.17542	0.7370	30
3	0.251	500K	0.34245	0.51479	1	0.34245		0.17629	0.7023	30
2	0.249	500K	0.33900	0.51527	1	0.33900		0.17158	0.6890	30
1	0.242	500K	0.33954	0.49101	1	0.33954		0.16669	0.6888	30
5	0.242	500K	0.34396	0.50726	1	0.34396		0.17448	0.7209	30
4	0.240	500K	0.34786	0.50611	1	0.34786		0.17605	0.7335	30
3	0.248	500K	0.34242	0.51466	1	0.34242		0.17623	0.7106	30
2	0.235	500K	0.33222	0.51539	1	0.33222		0.17122	0.7370	30
1	0.232	500K	0.34027	0.49559	1	0.34027		0.17216	0.7326	30

Highest Efficiency = 0.7370
Average Efficiency = 0.7177
Lowest Efficiency = 0.6888

Table A3

EFFICIENCY OF RF MATCHING SYSTEM AND FIRING MOUNT FOR MARK 1 MOD 0 SQUIB AT 250 MEGACYCLES

Squib Number	RF Power Input (Watts)	Light Cell Resistance (ohms)	DC-Calibration with L & N type Pot			Heater Current $I_H = \frac{E_H}{R_S}$ (amps)	Heater Power (dc) $P_{dc} = E_H \times I_H$ (Watts)	RF system Efficiency $= \frac{P_{dc}}{P_{rf}}$	RF Freq. (Mc)
			E_R (volts)	E_H (volts)	R_S (ohms)				
7	0.212	500K	0.34564	0.49647	1.0	0.34564	0.17159	0.8094	250
6	0.208	500K	0.34066	0.50206	1.0	0.34066	0.17103	0.8222	250
5	0.207	500K	0.34195	0.50477	1.0	0.34195	0.17261	0.8338	250
4	0.217	500K	0.34483	0.50424	1.0	0.34483	0.17387	0.8013	250
3	0.217	500K	0.33812	0.50806	1.0	0.33812	0.17178	0.7916	250
7	0.214	500K	0.34457	0.49326	1.0	0.34457	0.16996	0.7942	250
6	0.208	500K	0.33822	0.49642	1.0	0.33822	0.16789	0.8072	250
5	0.209	500K	0.34085	0.50125	1.0	0.34085	0.17085	0.8175	250
4	0.214	500K	0.34346	0.50045	1.0	0.34346	0.17188	0.8032	250
3	0.212	500K	0.33963	0.51138	1.0	0.33963	0.17368	0.8192	250

Highest Efficiency = 0.8338
 Average Efficiency = 0.80997
 Lowest Efficiency = 0.7916

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Table A-4.
EFFICIENCY OF RF MATCHING SYSTEM AND FIRING MOUNT FOR
MARK 1 MOD 0 SQUIB AT 1000 MEGACYCLES

Squib Number	RF Power Input P_i (watts)	Light Cell Resistance (ohms)	DC Calibration with L & N "K" Pot			$I_H = \frac{E}{R_S}$ (Amps)		Heater Power (dc) $P_{dc} = E_H \times I_H$ (Watts)	RF System Efficiency $= \frac{P_{dc}}{P_{rf}}$	RF Freq. (Mc)
			E_R (Volts)	E_H (Volts)	R_S (Ohms)	I_H	R_S			
A	0.231	500 K	0.14313	0.42534	0.5	0.28626	0.5	0.12176	0.52709	1000
3	0.224	500 K	0.14398	0.39367	0.5	0.28796	0.5	0.11336	0.50607	1000
4	0.229	500 K	0.14664	0.39122	0.5	0.29328	0.5	0.11474	0.50108	1000
5	0.222	500 K	0.14592	0.39052	0.5	0.29184	0.5	0.11397	0.51338	1000
6	0.221	500 K	0.14457	0.38409	0.5	0.28914	0.5	0.11104	0.50244	1000
A	0.230	500 K	0.14301	0.42526	0.5	0.28602	0.5	0.12163	0.52882	1000
3	0.219	500 K	0.14769	0.41203	0.5	0.29538	0.5	0.12170	0.55570	1000
4	0.231	500 K	0.14699	0.39195	0.5	0.29398	0.5	0.11523	0.49883	1000
5	0.228	500 K	0.14647	0.39136	0.5	0.29294	0.5	0.11464	0.50280	1000
6	0.225	500 K	0.14548	0.38859	0.5	0.29096	0.5	0.11303	0.50248	1000

Highest Efficiency = 0.55570

Average Efficiency = 0.51387

Lowest Efficiency = 0.49883

Table A5

EFFICIENCY OF RF MATCHING SYSTEM AND FIRING MOUNT FOR MARK 2 MOD 0 IGNITION ELEMENT AT 5 MEGACYCLES

Element Number	RF Power Input (Watts)	Light Cell Resistance (ohms)	DC Calibration with I. & N. "K" Pot		$I_H = \frac{E_R}{R_S}$ (amps)	Heater Power (dc) $P_{dc} = E_H \times I_H$ (Watts)	RF system Efficiency = $\frac{P_{dc}}{P_{rf}}$	RF Freq. (Mc)
1	1.54	500K	E_R (volts)	E_H (volts)	R_S (ohms)			5
3	1.63	500K	1.39632	0.38024	0.5	1.06187	0.6895	5
4	1.59	500K	1.44192	0.38514	0.5	1.11068	0.6814	5
8	1.45	500K	1.37102	0.41072	0.5	1.12621	0.7083	5
1	1.54	500K	1.28854	0.39794	0.5	1.02553	0.7072	5
4	1.55	500K	1.39651	0.37918	0.5	1.05905	0.6876	5
8	1.45	500K	1.36494	0.39238	0.5	1.07115	0.6910	5
			1.29371	0.39704	0.5	1.02730	0.7084	5

Highest Efficiency = 0.7084
 Average Efficiency = 0.6962
 Lowest Efficiency = 0.6814

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Table A-6
EFFICIENCY OF RF MATCHING SYSTEM AND FIRING MOUNT FOR MARK 2 MOD 0 AT 30 Mc

Element Number	RF Power Input P_{rf} (watts)	Light Cell Resistance (ohms)	DC Calibration with L & N "K" Pot		$I_H = \frac{E_R}{R_S}$ (Amperes)	Heater Power (dc) $P_{dc} = E_H \times I_H$ (Watts)	RF System Efficiency $\frac{P_{dc}}{P_{rf}}$	RF Freq. (Mc)
			E_R (Volts)	E_H (Volts)	R_S (Ohms)			
9	2.48	500 K	1.43208	0.36212	0.5	1.03716	0.41816	30
8	2.05	500 K	1.22884	0.38386	0.5	0.94340	0.46019	30
1	2.20	500 K	1.33466	0.36908	0.5	0.98519	0.44781	30
10	2.19	500 K	1.32468	0.37984	0.5	1.00633	0.45951	30
11	2.19	500 K	1.32099	0.38386	0.5	1.01415	0.46308	30
9	2.47	500 K	1.43209	0.36222	0.5	1.03746	0.42002	30
8	2.00	500 K	1.22792	0.37945	0.5	0.93186	0.46593	30
1	2.27	500 K	1.34239	0.37066	0.5	0.88514	0.43838	30
10	2.21	500 K	1.32596	0.38306	0.5	1.01584	0.43965	30
11	2.20	500 K	1.31329	0.38535	0.5	1.01215	0.45798	30

Highest Efficiency = 0.46595

Average Efficiency = 0.449071

Lowest Efficiency = 0.42002

Table A7

EFFICIENCY OF RF MATCHING SYSTEM AND FIRING MOUNT FOR MARK 2 MOD 0 IGNITION ELEMENT AT 30 MEGACYCLES

Element Number	RF Power Input (Watts)	Light Cell Resistance (Ohms)	DC Calibration with L & N "K" Pot		$I_H = \frac{E_R}{R_S}$ (amps)	Heater Power (dc) $P_{dc} = E_H \times I_H$ (Watts)	RF system Efficiency $= \frac{P_{dc}}{P_{rf}}$	RF Freq. (Mc)
1	2.54	500K	E_R (volts)	E_H (volts)	R_S (ohms)			30
4	2.62	500K	1.35830	0.38121	0.5	1.03559	0.40771	30
8	2.33	500K	1.35239	0.42303	0.5	1.14416	0.43670	30
1	2.62	500K	1.27418	0.41029	0.5	1.04554	0.44872	30
4	2.60	500K	1.38182	0.38424	0.5	1.06188	0.40529	30
8	2.32	500K	1.34920	0.40837	0.5	1.10195	0.42383	30
Low Loss			1.27218	0.40854	0.5	1.03945	0.44804	30
Simulant	2.63	500K	1.37928	0.39253	0.5	1.08279	0.41171	30
Low Loss								
Simulant	2.68	500K	1.37284	0.38913	0.5	1.06842	0.39866	30

Highest Efficiency = 0.44872
 Average Efficiency = 0.42258
 Lowest Efficiency = 0.39866

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Table A-8
EFFICIENCY OF RF MATCHING SYSTEM AND FIRING MOUNT FOR MARK 2 MOD 0 IGNITION ELEMENT AT 250 Mc

MARK 2 Element Number	RF Input P (watts)	Light Cell Resistance (ohms)	DC Calibration with L & N "K" Pot.		Heater Current $I = \frac{E_R}{R_S}$ (amps)	Heater Power (dc) $P_{dc} = E_H \times I_H$ (Watts)	RF System Efficiency $\eta = \frac{P_{dc}}{P_{rf}}$		RF Freq. (Mc)
			E_R (volts)	E_H (volts)			η	η	
2	2.63	500 K	1.4036	0.37739	0.5	1.0594	0.4028		2.50
1	2.48	500 K	1.3634	0.38103	0.5	1.0390	0.4189		2.50
3	2.75	500 K	1.4419	0.38055	0.5	1.0974	0.3990		2.50
4	2.60	500 K	1.3693	0.38514	0.5	1.0547	0.4056		2.50
8	2.32	500 K	1.2878	0.39081	0.5	1.0065	0.4338		2.50
1	2.60	500 K	1.3971	0.37564	0.5	1.0496	0.4037		2.50
2	2.51	500 K	1.3603	0.38143	0.5	1.0377	0.4134		2.50
3	2.75	500 K	1.4432	0.38094	0.5	1.0995	0.3998		2.50
4	2.55	500 K	1.3648	0.38796	0.5	1.0590	0.4153		2.50
8	2.28	500 K	1.2900	0.39241	0.5	1.0124	0.4440		2.50
Low-Loss Simulant	2.65	500 K	1.3872	0.38282	0.5	1.0621	0.4010		2.50
Low-Loss Simulant	2.67	500 K	1.3836	0.38348	0.5	1.0612	.3974		—

Highest Efficiency = .4189

Average Efficiency = .4112

Lowest Efficiency = .3974

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Table A-9
EFFICIENCY OF RF MATCHING SYSTEM AND FIRING MOUNT FOR
MARK 2 MOD 0 IGNITION ELEMENT AT 1000 MEGACYCLES

Element Number	RF Power P _r (watts)	Ignit Cell Resistance (ohms)	DC Calibration with L & N "K" Pot		$I_H = \frac{E_R}{R_S}$ (Amps)	Heater Power (dc) $P_{dc} = E_H \times I_H$ (Watts)	RF System Efficiency $\frac{P_{rf}}{P_{dc}}$	RF Freq. (Mc)
			E_R (Volts)	E_H (Volts)	R_S (Ohms)			
1	1.98	500 K	1.35256	0.38607	0.5	1.04438	0.52746	1000
4	2.05	500 K	1.34124	0.40649	0.5	1.09040	0.53190	1000
8	1.78	500 K	1.25446	1.25446	0.5	1.070409	0.60135	1000
9	2.03	500 K	1.46547	0.37069	0.5	1.06470	0.53206	1000
10	1.81	500 K	1.34136	0.39035	0.5	1.047191	0.57856	1000
1	1.99	500 K	1.37284	0.39565	0.5	1.086328	0.54589	1000
4	2.02	500 K	1.34936	0.43139	0.5	1.164200	0.57633	1000
8	1.72	500 K	1.26784	0.40453	0.5	1.025758	0.59637	1000
9	2.04	500 K	1.46316	0.37166	0.5	1.087596	0.53312	1000
10	1.80	500 K	1.33982	0.38992	0.5	1.044845	0.58046	1000

Highest Efficiency = 0.60135

Average Efficiency = 0.56036

Lowest Efficiency = 0.52746

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APPENDIX B

BRUCETON DATA

MARK 1 MOD O SQUIB. B1 - B8
MARK 2 MOD O IGNITION ELEMENT B9 - B18

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B-1 BRUCETON TEST MK 1 MOD 0 SQUIB 5 MC

Functioning Levels (%)								FUNCT. TIME	RESISTANCE	ITEM NO.	Functioning Levels (%)								FUNCT. TIME	RESISTANCE	ITEM NO.
.0721	.0773	.0828	.0887	.0950	.102	.109	.117				.0721	.0773	.0828	.0887	.0950	.102	.109	.117			
								secs	Ω										secs	Ω	
				0				-	0.97	1					X				1.4508	1.00	81
				X				0.9561	1.05	2				0					-	0.98	82
				0				-	1.00	3					0				-	1.03	83
				X				1.3051	0.98	4					X				1.2299	1.04	84
				0				-	-	5					X				0.4939	0.86	85
				X				1.6824	1.07	6				0					-	1.02	86
				0				-	1.11	7					0				-	0.99	87
				X				1.4058	1.20	8					X				0.7450	1.01	88
				0				-	1.02	9					0				-	0.94	89
				X				0.9210	1.04	10					X				0.9335	0.86	90
				0				-	0.89	11					X				0.9523	1.06	91
				0				-	1.05	12					0				-	1.00	92
				X				0.9581	0.92	13					X				0.2586	0.89	93
				X				0.6939	0.93	14					X				0.9780	0.85	94
				0				-	1.07	15					X				2.2287	0.97	95
				0				-	1.10	16				0					-	1.08	96
				X				0.8630	0.91	17				0					-	0.96	97
				X				0.5868	1.05	18					0				-	1.07	98
				X				1.6867	1.02	19					0				-	0.96	99
				0				-	0.95	20					X				0.8392	0.93	100
				X				1.8088	-	21					0				-	0.98	101
				0				-	1.00	22					X				0.6616	0.97	102
				0				-	0.82	23					0				-	1.00	103
				X				0.9376	0.96	24					X				1.9130	1.00	104
				X				1.2630	0.95	25					X				0.8979	1.01	105
				0				-	1.04	26					0				-	1.01	106
				X				2.7396	1.04	27					X				-	1.00	107
				0				-	1.06	28					0				-	0.98	108
				0				-	0.96	29					0				-	1.00	109
				X				0.6590	0.98	30					0				-	1.06	110
				0				-	1.04	31						X			-	1.02	111
				X				1.1086	1.08	32					X				0.9062	0.98	112
				0				-	0.92	33					0				-	1.05	113
				X				0.8547	1.04	34					X				0.9181	0.94	114
				X				1.2789	1.01	35					0				-	0.97	115
				X				1.4277	1.01	36					X				1.1642	0.95	116
				0				2.2124	1.03	37					X				0.7915	1.01	117
				0				-	1.08	38					0				-	0.97	118
				0				-	0.98	39					0				-	1.12	119
				0				-	1.00	40					0				-	1.03	120
				0				-	1.02	41						X			-	1.04	121
				X				0.7459	1.05	42					X				0.6993	1.01	122
				0				-	1.07	43					0				-	1.06	123
				0				-	0.97	44					0				-	1.00	124
				X				0.9475	0.98	45					0		X		1.0313	1.00	125
				0				-	1.00	46					X				1.1060	1.04	126
				X				0.7641	0.98	47					0				-	1.05	127
				X				0.6914	0.97	48					0				-	1.00	128
				0				-	0.94	49						X			0.8341	1.06	129
				X				0.5641	1.04	50					X				1.0134	1.10	130
	0	1	1	5	14	4		n ₁ =		X		0	1	1	7	12	4		n ₁ =		X
	1	1	5	14	4	0		n ₀ =		0		1	1	7	12	4	0		n ₀ =		0

i	i ²	n _i	n _i	i = MW
0	0	2	0	77.9
1	1	2	2	82.8
2	4	12	2	88.7
3	9	26	12	95.0
4	16	8	26	102.0
5	25	0	8	109.0
6	36			

Totals: N₀ = 50 N₁ = 50

Special Parameters
 $c = (\log \zeta)_{1, \infty} = 1.88818$
 $d = (\log \zeta)_{1, 1} - (\log \zeta)_1 = 0.08$

Primary Statistics
 $A = \sum i n$
 $B = \sum i^2 n$
 $M = (NB - A^2)/N^2$
 $m = c + d (A/N \pm K)^2$
 $\sigma = 1.62 d (M + 0.029) \sqrt{\frac{N}{N-1}}$
 *Use + for "s's", - for "x's"
 **Valid for M > 0.3 only, otherwise consult "Brunston Report" (AMP Report No. 101.1R, "Statistical Analysis for A New Procedure in Sensitivity Experiments" July, 1944) File No. M-1

For "s's"	For "x's"
A = 136	186
B = 412	734
M = .84160	.84160
m = 1.98478	1.98478
$\sigma = .04274$	.04274

Secondary Statistics
 $n = \frac{N_0 n_0 + N_1 n_1}{N_0 + N_1} = 1.98478$
 $\sigma = \sqrt{\frac{N_0 \sigma_0^2 + N_1 \sigma_1^2}{N_0 + N_1}} = .04274$
 $\zeta = \text{Antilog } m = .096562 \text{ WATTS}$

Probability Levels	Confidence Level	Probability Levels	Confidence Level
P% = 99.9	X% = 90	P% = 99	X% = 90
100-P% = .1		100-P% = 1	
m = 1.98478	k _p ^② = 3.020	m = 1.98478	k _p ^② = 3.326
$\sigma = .04274$	k ₂ ^② = 1.282	$\sigma = .04274$	k ₂ ^② = 1.282
d = .03	G ^③ = .965	d = .03	G ^③ = .965
S = $\frac{G}{d} = 1.425$	G ² = .93122	S = $\frac{G}{d} = 1.425$	G ² = .93122
N = 100	H ^③ = 1.54	N = 100	H ^③ = 1.54
n ^① = 50	H ² = 2.37160	n ^① = 50	H ² = 2.37160

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 ≥ .5, and Graph V
 When S < .5

Confidence Interval (Y)
 $Y = k_x \left(\frac{N+1}{n} \right) \left(\frac{G^2 + H^2 k_p^2}{n} \right)^{1/2}$
 $= .03853$

Final Calculations
 (99%) (90% Conf) = $m + k_p \sigma + Y$
 $= 2.15537 \text{ log units}$
 $= .443099 \text{ WATTS}$
 (.1%) (90% Conf) = $m - k_p \sigma - Y$
 $= 1.81449 \text{ log units}$
 $= .06519 \text{ WATTS}$

Confidence Interval (Y)
 $Y = k_x \left(\frac{N+1}{n} \right) \left(\frac{G^2 + H^2 k_p^2}{n} \right)^{1/2}$
 $= .029433$

Final Calculations
 (99%) (90% Conf) = $m + k_p \sigma + Y$
 $= 2.11362 \text{ log units}$
 $= .04299 \text{ WATT}$
 (.1%) (90% Conf) = $m - k_p \sigma - Y$
 $= 1.85594 \text{ log units}$
 $= .00777 \text{ WATT}$

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B-2 BRUCETON TEST MK 1 MOD 0 SQUIB 30 KC

Functioning Levels (%)										FUNCT. TIME	RESISTANCE	ITEM NO.	Functioning Levels (%)										FUNCT. TIME	RESISTANCE	ITEM NO.				
.111	.119	.127	.136	.144	.156	.168	.180	.192	.206				.111	.119	.127	.136	.144	.156	.168	.180	.192	.206							
DOCS										DOCS										DOCS									
				X								1.03	1											-	1.06	31			
												1.00	2											-	1.06	32			
				X						0.3522	1.07	3												-	1.01	33			
										-	0.94	4											1.1132	0.98	34				
				X						1.07312	0.98	5												-	1.07	35			
										-	0.96	6												-	1.02	36			
				X						0.3421	1.00	7												1.7666	1.10	37			
										1.3734	0.97	8												-	1.06	38			
				X						1.9152	1.01	9												0.4144	0.98	39			
										-	0.90	10												-	1.01	40			
				X						0.9912	1.02	11												1.1790	1.01	41			
										-	0.92	12												-	1.03	42			
				X						1.0786	0.97	13												-	1.00	43			
										-	0.85	14												0.7731	1.05	44			
				X						1.8906	1.06	15												-	1.01	45			
										1.0486	1.01	16												-	0.95	46			
										-	1.06	17												0.7144	0.98	47			
										-	0.90	18												0.4012	1.10	48			
				X						1.2598	0.98	19												-	0.98	49			
										-	0.98	20												-	0.95	50			
										-	1.02	21												0.7245	0.99	51			
				X						0.4957	1.03	22												0.5179	0.98	52			
										1.1313	1.05	23												1.5015	1.05	53			
										-	0.92	24												-	1.02	54			
										-	1.03	25												-	1.02	55			
				X						0.5286	0.97	26												-	1.07	56			
										0.8939	1.05	27												0.4001	1.02	57			
				X						0.6331	0.95	28												0.6754	1.05	58			
										-	0.97	29												0.9248	0.97	59			
										-	1.03	30												-	1.00	60			
										-	1.08	31												-	0.98	61			
				X						0.8389	1.00	32												-	1.02	62			
										-	0.99	33												0.4618	1.04	63			
				X						0.5346	1.00	34												3.5891	0.99	64			
										-	0.99	35												-	0.95	65			
										-	0.94	36												0.8810	0.98	66			
										0.5385	0.98	37												-	1.01	67			
				X						1.1909	1.05	38												1.4732	0.99	68			
										-	1.04	39												-	0.92	69			
				X						1.3588	1.03	40												-	0.98	70			
										-	0.94	41												0.5361	0.97	71			
				X						0.8192	0.97	42												-	0.98	72			
										-	0.99	43												0.4935	0.97	73			
										-	0.94	44												-	0.96	74			
										0.5691	0.98	45												0.6352	0.99	75			
				X						1.9441	0.94	46												1.1168	0.97	76			
										0.8049	1.03	47												-	0.93	77			
										0.4557	0.99	48												1.1209	1.01	78			
										-	0.97	49												-	0.93	79			
				X						1.3148	1.02	80												1.1099	0.97	100			
0	4	8	9	6						n ₁ =	X												n ₁ =	X					
3	7	8	5	0						n ₀ =	0												n ₀ =	0					
													3	6	10	7										0			

i	i ²	x _i	x _i ²	(i-MN)	Probability Levels	Confidence Level	Probability Levels	Confidence Level
0	0	6	0	111	P% = 99.9	X% = 90	P% = 99	X% = 90
1	1	13	6	119	100-P% = 0.1		100-P% = 1	
2	4	18	13	127				
3	9	12	19	136	n = 2.09706	k _p ^② = 3.09	n = 2.09706	k _p ^② = 2.326
4	16	0	13	146	σ = 0.046637	k _z ^② = 1.282	σ = 0.046637	k _z ^② = 1.282
5	25				d = 0.03	G ^③ = 0.957	d = 0.03	G ^③ = 0.957
6	36				S = $\frac{G}{d}$ = 1.56	G ² = 0.91589	S = $\frac{G}{d}$ = 1.56	G ² = 0.91589
Totals: N _o = 49 N _p = 51					N = 100	H ^③ = 1.59	N = 100	H ^③ = 1.59
					n ^① = 50	H ² = 2.5281	n ^① = 50	H ² = 2.5281

Special Parameters
 $c = (\log \zeta)_{i=0} = 2.04632$
 $d = (\log \zeta)_{i=1} - (\log \zeta)_i = .03$

Primary Statistics
 $A = \sum i x_i$
 $B = \sum i^2 x_i$
 $M = (NB - A^2)/N^2$
 $m = c + d (A/N \pm \frac{1}{2})^2$
 $\sigma = 1.62 d (M + 0.029) \sqrt{\frac{N}{N-1}}$
 *Use + for "o's"; - for "x's"
 **Valid for M ≥ 0.3 only, otherwise consult "Brunton Report" (AMP Report No. 101.1R, "Statistical Analysis for A New Procedure in Sensitivity Experiments" July, 1944) File No. M-1

For "o's"	For "x's"
A = 85	141
B = 193	437
M = .92961	.92503
m = 2.11236	2.08236
σ = .04512	.09805

Secondary Statistics
 $n = \frac{N_o N_x + N_o N_x}{N_o + N_x} = 2.09706$
 $\sigma = \sqrt{\frac{N_o \sigma_o^2 + N_x \sigma_x^2}{N_o + N_x}} = .046637$

$\zeta = \text{Antilog } m = 1.2604 \text{ Watts}$

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Confidence Interval (Y)
 $Y = k_x \left(\frac{N+1.2}{n} \right) \left(\frac{G^2 + H^2 k_p^2}{n} \right)^{1/2} \sigma$
 $= 0.043334$

Final Calculations
 (99%) (90% Conf) = $m + k_p \sigma + Y$
 $= 2.28450 \text{ log units}$
 $= 0.192530 \text{ watt}$
 (0.1%) (90% Conf) = $m - k_p \sigma - Y$
 $= 1.90961 \text{ log units}$
 $= 0.08121 \text{ Watt}$

Confidence Interval (Y)
 $Y = k_x \left(\frac{N+1.2}{n} \right) \left(\frac{G^2 + H^2 k_p^2}{n} \right)^{1/2} \sigma$
 $= 0.0330729$

Final Calculations
 (99%) (90% Conf) = $m + k_p \sigma + Y$
 $= 2.23855 \text{ log units}$
 $= 0.17320 \text{ watt}$
 (1%) (90% Conf) = $m - k_p \sigma - Y$
 $= 1.95551 \text{ log units}$
 $= 0.090262 \text{ watt}$

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[illegible]

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i	i ²	x _i	x _i ²	(x _i W)
0	0	10	0	103
1	1	16	10	110
2	4	16	16	118
3	9	8	16	126
4	16	0	8	135
5	25			
6	36			
Totals: N ₁ = 50 N ₂ = 50				

Special Parameters
 $c = (\log \zeta)_{i=0} = 2.01284$
 $d = (\log \zeta)_{i=1} - (\log \zeta)_i = .03$

Primary Statistics
 $A = \sum i x_i$
 $B = \sum i^2 x_i$
 $M = (NB - A^2)/N^2$
 $m = c + d (A/N \pm \frac{1}{2})^2$
 $\sigma = 1.62 d (M + 0.029) \sqrt{\frac{N}{N-1}}$
 *Use + for "o's", - for "x's"
 **Valid for N ≥ 0.3 only, otherwise consult "Bureau Report" (AMP Report No. 101.1B, "Statistical Analysis for A New Procedure in Sensitivity Experiments" July, 1964) File No. M-1

For "o's"	For "x's"
A = 72	129
B = 152	346
M = .96640	.96640
m = 2.05104	2.05104
σ = .048875	.048875

Secondary Statistics
 $n = \frac{N_1 m_1 + N_2 m_2}{N_1 + N_2} = 2.05104$
 $\sigma = \sqrt{\frac{N_1 \sigma_1^2 + N_2 \sigma_2^2}{N_1 + N_2}} = .048875$
 $\zeta = \text{Antilog } m = .11349 \text{ WATTS}$

Probability Levels	Confidence Level	Probability Levels	Confidence Level
P% = 99.9	X% = 90	P% = 99	X% = 90
100-P% = .1		100-P% = .1	
n = 2.05104	k _p ^② = 3.090	n = 2.05104	k _p ^② = 3.326
σ = .048875	k _x ^② = 1.282	σ = .048875	k _x ^② = 1.282
d = .03	G ^③ = .954	d = .03	G ^③ = .954
S = $\frac{G}{d} = 1.62916$	G ² = .9011	S = $\frac{G}{d} = 1.62916$	G ² = .9011
N = 100	H ^③ = 1.617	N = 100	H ^③ = 1.617
n ^① = 50	H ² = 2.6146	n ^① = 50	H ² = 2.6146

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 ≥ .5, and Graph V
 When S < .5

Confidence Interval (Y)
 $Y = k_x \left(\frac{N+1}{n} \right) \left(\frac{G^2 + H^2 k_p^2}{n} \right)^{1/2} \sigma$
 = 0.046144

Final Calculations
 (99%) (90% Conf) = $m + k_p \sigma + Y$
 = 2.24820 log units
 = 0.17702 WATT
 (.1%) (90% Conf) = $m - k_p \sigma - Y$
 = 1.85388 log units
 = 0.071426

Confidence Interval (Y)
 $Y = k_x \left(\frac{N+1}{n} \right) \left(\frac{G^2 + H^2 k_p^2}{n} \right)^{1/2} \sigma$
 = 0.03519255

Final Calculations
 (99%) (90% Conf) = $m + k_p \sigma + Y$
 = 2.19991 log units
 = 0.15885 WATTS
 (.1%) (90% Conf) = $m - k_p \sigma - Y$
 = 1.90212 log units
 = 0.07983 WATTS

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BRUCETON TEST MK 1 MOD 0 SQUIB 1000 Ms

Functioning Levels (Z)								FUNCT. TIME	RESISTANCE	ITEM NO.	Functioning Levels (Z)								FUNCT. TIME	RESISTANCE	ITEM NO.
.152	.163	.174	.187	.200	.214	.230	.246				.152	.163	.174	.187	.200	.214	.230	.246			
				X				2.61376	0.98	1					0					0.95	81
			0					-	0.92	2					0					0.93	82
			X					1.33786	0.94	3							X		0.58383	1.00	83
			0					-	0.97	4					Y				0.62154	0.95	84
			X					1.19542	0.92	5					X				1.02805	1.00	85
			0					-	1.00	6				0					-	1.01	86
			0					-	0.96	7					0				-	0.98	87
				X				.92022	0.92	8					X				1.13684	0.98	88
			0					-	0.92	9					0				-	0.97	89
				X				.78576	0.92	10					X				0.61744	0.98	90
			X					1.02220	1.02	11					0				-	0.95	91
			X					1.25096	0.90	12					0				-	0.91	92
	0							-	1.05	13							X		0.85747	0.90	93
		X						1.01453	.95	14					X				0.97428	0.91	94
	0							-	.96	15					0				-	1.04	95
	0							-	0.94	16					0				-	0.92	96
		0						-	1.00	17						X			0.85274	0.95	97
			X					0.45235	0.95	18					X				0.78870	0.97	98
			X					0.99686	0.92	19					0				-	0.92	99
		0						-	0.90	20					X				0.62307	0.93	100
			0					-	0.89	21					X				0.96742	0.91	101
				0				-	0.90	22				0					-	0.91	102
				X				0.51894	1.04	23					0				1.42388	1.01	103
				X				0.76499	0.95	24					X				0.58359	1.00	104
			0					-	1.00	25					X				1.00075	0.95	105
				X				.46380	0.94	26					0				-	1.01	106
			X					1.19620	0.95	27					0				-	1.00	107
		0						-	0.95	28					0				-	0.98	108
		X						1.08956	0.94	29						X			0.56778	0.89	109
		X						0.96433	1.01	30					0				-	0.92	110
	0		X					-	0.95	31						X			0.61289	0.95	111
		X						0.97222	0.95	32					0				-	1.01	112
								-	0.96	33						X			0.78368	1.00	113
	0							-	1.00	34						X			1.46647	0.96	114
		0						-	0.97	35					X				0.91489	0.92	115
		X						1.29637	0.97	36				0					-	0.98	116
		0						-	0.93	37					0				-	0.99	117
		0						-	0.96	38					X				0.66573	0.99	118
			X					1.10385	0.97	39					0				-	0.98	119
		0						-	0.96	40					X				1.41505	1.03	120
			0					-	0.96	41					0				-	0.95	121
				X				1.56338	1.01	42					X				0.45479	0.96	122
			0					-	0.96	43					X				0.89510	1.01	123
			X	X				-	0.95	44					0				-	0.94	124
			X					2.24720	0.96	45					X				0.71009	0.90	125
		X						1.30083	0.98	46					0				-	0.91	126
		0						-	0.76	47					0				-	0.90	127
			0					-	1.07	48					X				0.38367	0.96	128
				0				-	0.95	49					X				2.16910	0.98	129
				X				1.06542	0.95	50					0				-	0.99	130
0	1	6	9	8	1			$R_1 = 25$		X		0	7	12	6				$R_1 = 25$		X
1	6	9	8	1	0			$R_2 = 25$		0		7	12	6	0				$R_2 = 25$		0

i	i ²	x _i	x _i ²	Σ = M
0	0	1	0	163
1	1	6	1	176
2	4	16	6	187
3	9	20	16	200
4	16	7	20	214
5	25	0	7	230
6	36			
Totals: N ₁ = N ₂ =				

Special Parameters

$a = (\log \zeta)_{1,00} = 2.21219$

$d = (\log \zeta)_{1,01} - (\log \zeta)_1 = .03$

Primary Statistics

$A = \sum i x_i$

$B = \sum i^2 x_i$

$M = (NB - A^2)/N^2$

$m = c + d(A/N \pm k)^2$

$\sigma = 1.02 d (M + 0.089) \sqrt{\frac{N}{N-1}}$

*Use + for "a's" - for "r's"

**Valid for N ≥ 0.5 only, otherwise consult "Brunton Report" (NSF Report No. 101-12, "Statistical Analysis for A New Procedure in Sensitivity Experiments" July, 1964) File No. 10-1

For "a's"	For "r's"
A = 126	176
B = 362	664
M = .88260	.88260
m = 2.30279	2.30279
σ = .04510	.04510

Secondary Statistics

$m = \frac{N_1 \sigma_1^2 + N_2 \sigma_2^2}{N_1 + N_2} = 2.30279$

$\sigma = \sqrt{\frac{N_1 \sigma_1^2 + N_2 \sigma_2^2}{N_1 + N_2}} = .04510$

Σ = Analog = .20081 watts

DATE 1-3-62 INITIALS PMS

Probability Levels	Confidence Level	Probability Levels	Confidence Level
PK = 99.9	K _p = 90	PK = 99	K _p = 90
100-PK = .1		100-PK = 1	
m = 2.30279	k _p [Ⓢ] = 3.080	m = 2.30279	k _p [Ⓢ] = 2.326
σ = .04464	k _p [Ⓢ] = 1.282	σ = 0.04464	k _p [Ⓢ] = 1.282
d = .03	0 [Ⓢ] = .961	d = 0.03	0 [Ⓢ] = 0.961
S = $\frac{d}{d} = 1.488$	G ² = .9235	S = $\frac{d}{d} = 1.488$	G ² = 0.9235
N = 100	N [Ⓢ] = 1.56	N = 100	N [Ⓢ] = 1.56
n [Ⓢ] = 50	N ² = 2.434	n [Ⓢ] = 50	N ² = 2.434

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 ≥ .5, and Graph V When S < .5

Confidence Interval (Y)

$Y = k_x \left(\frac{N+1}{N} \right) \left(\frac{G^2 + N^2 k_p^2}{N} \right)^{1/2} \sigma$

= .04078436

Confidence Interval (Y)

$Y = k_x \left(\frac{N+1}{N} \right) \left(\frac{G^2 + N^2 k_p^2}{N} \right)^{1/2} \sigma$

= 0.0311061

Final Calculations

(99.9%) (90% Conf) = m + k_p σ + Y

= 2.48857 log watts

= .30802 watts

(99.9%) (90% Conf) = m - k_p σ - Y

= 2.11701 log watts

= .1398 watts

(99%) (90% Conf) = m + k_p σ + Y

= 2.43773 log watts

= 273.98 mWatts

(1%) (90% Conf) = m - k_p σ - Y

= 2.16785 log watts

= 147.18 mWatts

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B-4 BRUCETON TEST MK 2 MOD 0 ELEMENT 5 MC

Functioning Levels (%)					FUNCT. TIME	RESISTANCE	ITEM NO.	Functioning Levels (%)					FUNCT. TIME	RESISTANCE	ITEM NO.
	1.03	1.10	1.18	1.26					1.03	1.10	1.18	1.26			
					secs	Ω							secs	Ω	
					-	.105	1						.228372	.102	81
					-	.110	2						.686500	.096	82
					.1222	.105	3						-	.1012	83
					*	.101	4						-	.107	84
					-	.110	5						.218169	.098	85
					*	.100	6						.218044	.100	86
					-	.103	7						-	.097	87
					*	.113	8						-	.101	88
					-	.104	9						.173205	.108	89
					*	.106	10						.461746	.105	90
					-	.106	11						-	.091	91
					.1898	.112	12						-	.108	92
					*	.105	13						.054076	.098	93
					-	.102	14						.978690	.100	94
					*	.103	15						-	.098	95
					-	.107	16						.225844	.095	96
					-	.102	17						-	.112	97
					*	.100	18						-	.105	98
					-	.108	19						.061874	.097	99
					*	.106	20						.688470	.097	100
					-	.105	21						-	.098	101
					*	.098	22						-	.110	102
					-	.105	23						.456767	.111	103
					*	.102	24						-	.112	104
					-	.100	25						.077086	.107	105
					.17832	.095	26						.971377	.103	106
					*	.104	27						.352244	.107	107
					-	.108	28						-	.107	108
					-	.100	29						-	.101	109
					*	.110	30						-	.115	110
					-	.101	31						.115032	.100	111
					*	.095	32						.972218	.105	112
					.951730	.106	33						-	.100	113
					-	.095	34						.462057	.094	114
					-	.100	35						.645810	.106	115
					.339	.103	36						-	.098	116
					-	.100	37						-	.107	117
					.009705	.090	38						.562359	.094	118
					.667347	.102	39						-	.095	119
					-	.110	40						.203946	.107	120
					.442181	.100	41						-	.110	121
					-	.093	42						.402804	.102	122
					-	.091	43						-	.110	123
					-	.097	44						.288443	.094	124
					*	.095	45						-	.095	125
					*	.093	46						-	.115	126
					-	.108	47						.113653	.102	127
					.173841	.100	48						.053918	.113	128
					-	.096	49						-	.107	129
					-	.095	50						-	.100	130
					n ₁ = 24		X						n ₁ = 25		X
					n ₀ = 26		0						n ₀ = 25		0

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i	i ²	n _i	n _i	i ² n _i	Probability Levels	Confidence Level	Probability Levels	Confidence Level
0	0	8	0	0	P% = <u>99.9</u>	X% = <u>90</u>	P% = <u>99</u>	X% = <u>90</u>
1	1	9	8	9	100-P% = <u>0.1</u>		100-P% = <u>1</u>	
2	4	12	30	48	m = <u>0.08849</u>	k _p ^② = <u>3.09</u>	m = <u>0.08849</u>	k _p ^② = <u>2.326</u>
3	9	0	11	0	σ = <u>0.02033</u>	k _x ^② = <u>1.282</u>	σ = <u>0.02033</u>	k _x ^② = <u>1.282</u>
4	16				d = <u>0.03</u>	G ^③ = <u>1.066</u>	d = <u>0.03</u>	G ^③ = <u>1.066</u>
5	25				S = <u>0.677</u>	G ² = <u>1.136356</u>	S = <u>0.677</u>	G ² = <u>1.136356</u>
6	36				N = <u>100</u>	H ^③ = <u>1.26</u>	N = <u>100</u>	H ^③ = <u>1.26</u>
Totals: N ₀ = 57 N ₁ = 49					n ^① = <u>50</u>	H ² = <u>1.5876</u>	n ^① = <u>50</u>	H ² = <u>1.5876</u>

Special Parameters
c = (log L)_{i=1} = 0.04139
d = (log L)_{i=1} - (log L)_i = 0.3

Primary Statistics
A = Σ i n
B = Σ i² n
M = (NB - A²) / N²
m = c + d (A/N ± 1/4)²
σ = 1.62 d (M + 0.029) / √(N-1)
*Use + for "o's", - for "x's"
**Valid for M ≥ 0.3 only, otherwise consult "Brunton Report" (AMP Report No. 101.1R, "Statistical Analysis for A New Procedure in Sensitivity Experiments" July, 1944) File No. Mh-1

For "o's"	For "x's"
A = <u>55</u>	A = <u>101</u>
B = <u>79</u>	B = <u>227</u>
M = <u>0.38600</u>	M = <u>0.38401</u>
m = <u>0.08874</u>	m = <u>0.08823</u>
σ = <u>0.02037</u>	σ = <u>0.02028</u>

Secondary Statistics
m = 0.08849
σ = 0.02033
L = Antilog m = 1.226 watts

Probability Levels	Confidence Level	Probability Levels	Confidence Level
P% = <u>99.9</u>	X% = <u>90</u>	P% = <u>99</u>	X% = <u>90</u>
100-P% = <u>0.1</u>		100-P% = <u>1</u>	
m = <u>0.08849</u>	k _p ^② = <u>3.09</u>	m = <u>0.08849</u>	k _p ^② = <u>2.326</u>
σ = <u>0.02033</u>	k _x ^② = <u>1.282</u>	σ = <u>0.02033</u>	k _x ^② = <u>1.282</u>
d = <u>0.03</u>	G ^③ = <u>1.066</u>	d = <u>0.03</u>	G ^③ = <u>1.066</u>
S = <u>0.677</u>	G ² = <u>1.136356</u>	S = <u>0.677</u>	G ² = <u>1.136356</u>
N = <u>100</u>	H ^③ = <u>1.26</u>	N = <u>100</u>	H ^③ = <u>1.26</u>
n ^① = <u>50</u>	H ² = <u>1.5876</u>	n ^① = <u>50</u>	H ² = <u>1.5876</u>

Confidence Interval (Y)
Y = k_x (n^① / n) (G² + H² k_p²)^{1/2}
= 0.0152337

Final Calculations
(99.9%) (90% Conf) = m + k_p σ + Y
= 0.16654 log units
= 1.4673 Watts
(0.1%) (90% Conf) = m - k_p σ - Y
= 0.01045 log units
= 1.0243 Watts

Confidence Interval (Y)
Y = k_x (n^① / n) (G² + H² k_p²)^{1/2}
= 0.01177046

Final Calculations
(99.9%) (90% Conf) = m + k_p σ + Y
= 0.14755 log units
= 1.4045 Watts
(0.1%) (90% Conf) = m - k_p σ - Y
= 0.02943 log units
= 1.0701 Watts

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BRUCETON TEST MK 2 MOD 0 IGNITION ELEMENT
30 Mc (Repeat Test)

F-B1805

Functioning Levels (%)								FUNCT. TIME	RESISTANCE	ITEM NO.	Functioning Levels (%)								FUNCT. TIME	RESISTANCE	ITEM NO.
1.56	1.67	1.79	1.91	2.05	2.20	2.35	2.52				2.70	secs	Ω	1.56	1.67	1.79	1.91	2.05			
			X						---	.100	1				X				.151334	.105	81
			0						---	.095	2				0				-	.100	82
			X						0.48453	.100	3				X				.225657	.102	83
			X						Missed t.	.095	4				0				-	.101	84
			0						---	.100	5				0				-	.102	85
			X						missed	.101	6					X			.097223	.100	86
	X								1.78812	.105	7				X				.219763	.101	87
	0								---	.095	8				0				-	.098	88
	0								---	.106	9				X				.728974	.094	89
			0						---	.092	10				0				-	.098	90
				X					.343231	.105	11				X				.352954	.105	91
			X						.453110	.099	12				X				.637321	.102	92
			0						---	.090	13				0				-	.094	93
			0						---	.096	14				X				missed	.105	94
				X					.224473	.110	15				0				-	.095	95
			0						---	.100	16				0				-	.106	96
				X					.169449	.105	17					X			.494908	.105	97
			0						---	.104	18				0				-	.095	98
				X					.446556	.098	19					X			.358085	.100	99
			0						---	.101	20				X				missed	.107	70
				X					.379210	.100	21				0				-	.110	71
			0						---	.100	22				0				-	.103	72
				X					1.184453	.105	23				X				.323172	.110	73
			0						---	.095	24					0			-	.105	74
				X					.408014	.107	25					X			.138832	.105	75
			0						---	.105	26				0				-	.097	76
				X					.439036	.105	27					X			.425668	.099	77
			0						---	.106	28				X				.758932	.108	78
				X					.165355	.090	29				0				-	.106	79
			X						.564075	.105	30					0			-	.095	80
			0						---	.090	31					X			.607774	.102	81
			0						---	.100	32				0				-	.106	82
				X					.191785	.100	33					X			.736332	.106	83
			X						.558972	.094	34				X				.772614	.100	84
			X						.26328	.104	35				X				1.017622	.107	85
			0						---	.094	36				0				-	.098	86
			0						---	.090	37				0				-	.102	87
				0					---	.089	38					0			-	.105	88
				0					---	.090	39					0			-	.100	89
				X					.128199	.102	40						X		1.134676	.092	90
				X					.276661	.095	41					X			.507455	.100	91
			X						.723825	.090	42					X			1.333180	.106	92
			0						---	.100	43				0				-	.099	93
			0						---	.090	44				0				-	.095	94
				X					.244478	.097	45					X			.673662	.090	95
			0						---	.090	46				X				.938012	.103	96
			X						.928037	.095	47				0				-	.099	97
			0						---	.100	48				0				-	.105	98
			0						---	.098	49					0			-	.094	99
			0						---	.096	50					X			.182215	.104	100
0	3	6	4	1				n ₁ = 24		X		0	1	7	14	3			n ₁ = 25		X
3	7	5	1	0				n ₂ = 26		0		1	7	14	3	0			n ₂ = 25		0

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i	i ²	n _i	n _i	Σ n _i w _i
0	0	4	0	1.67
1	1	14	4	1.79
2	4	29	13	1.91
3	9	4	28	2.05
4	16	0	4	2.20
5	25			
6	36			
Totals: N ₀ = 51 N ₁ = 49				

Special Parameters
 $c = (\log \zeta)_{i=0} = .22272$
 $d = (\log \zeta)_{i=1} - (\log \zeta)_i = 0.3$

Primary Statistics
 $A = \Sigma i n_i$
 $B = \Sigma i^2 n_i$
 $M = (NB - A^2)/N^2$
 $m = c + d (A/N \pm \frac{1}{2})^2$
 $\sigma = 1.62 d (M + 0.089) \sqrt{\frac{N}{N-1}}$

*Use + for "o's" - for "x's"
 **Valid for N > 0.3 only, otherwise consult "Bureau Report" (NSF Report No. 101.12, "Statistical Analysis for A New Procedure in Sensitivity Experiments" July, 1964) File No. M-1

For "o's"	For "x's"
A = 84	130
B = 166	372
M = .542099	.55310
m = .28684	.28732
σ = .02791	.02858

Secondary Statistics
 $n = \frac{N_0 n_0 + N_1 n_1}{N_0 + N_1} = .28708$
 $\sigma = \sqrt{\frac{N_0 \sigma_0^2 + N_1 \sigma_1^2}{N_0 + N_1}} = .02824$

ζ = Amilog m = 1.9368 watts

Probability Levels	Confidence Level	Probability Levels	Confidence Level
P% = 99.9	X% = 90	P% = 99	X% = 90
100-P% = 0.1		100-P% = 1	
m = .28708	k _p ^② = 3.090	m = <u>0.28708</u>	k _p ^② = 2.326
σ = .02824	k _x ^② = 1.282	σ = <u>0.02824</u>	k _x ^② = 1.282
d = .03	G ^③ = 1.012	d = <u>0.03</u>	G ^③ = 1.012
S = $\frac{G}{d} = 0.9413$	G ² = 1.024144	S = $\frac{G}{d} = 0.9413$	G ² = 1.024144
N = 100	H ^③ = 1.36	N = 100	H ^③ = 1.36
n ^① = 50	H ² = 1.8496	n ^① = 50	H ² = 1.8496

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 ≥ .5, and Graph V
 When S < .5

Confidence Interval (Y)
 $Y = k_x \left(\frac{n+1.2}{n} \right) \left(\frac{G^2 + H^2 k_p^2}{n} \right)^{1/2} \sigma$
 = .02266

Final Calculations
 (99.9%) (90% Conf) = m + k_p σ + Y
 = .39700 log units
 = 2.4946 watts
 (0.1%) (90% Conf) = m - k_p σ - Y
 = .17716 log units
 = 1.5037 watts

Confidence Interval (Y)
 $Y = k_x \left(\frac{n+1.2}{n} \right) \left(\frac{G^2 + H^2 k_p^2}{n} \right)^{1/2} \sigma$
 = 0.01741298

Final Calculations
 (99%) (90% Conf) = m + k_p σ + Y
 = 0.370179 log units
 = 2.3452 watts
 (1%) (90% Conf) = m - k_p σ - Y
 = 0.20398 log units
 = 1.5995 watts

DATE 2-1-62	INITIALS	ROOM
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[illegible]

i	i ²	n _i	n _i	Σ i ² n _i
0	0	13	0	1.83
1	1	27	13	2.05
2	4	9	27	2.30
3	9	1	9	2.58
4	16	0	1	2.90
5	25			
6	36			

Totals: N = 50 N₁ = 50

Special Parameters

c = (log Z)₁₀₀ = 0.26245

d = (log Z)₁₀₁ - (log Z)_i = 0.05

Primary Statistics

A = Σ i n_i

B = Σ i² n_i

M = (NB - A²)/N²

m = c + d (A/N ± 1/2)

σ = 1.62 d (M + 0.029) $\sqrt{\frac{N}{N-1}}$

*Use + for "o's"; - for "x's"

**Valid for N ≥ 0.3 only, otherwise consult "Bracegirdle Report" (NSP Report No. 101.1R, "Statistical Analysis for A New Procedure in Sensitivity Experiments" July, 1946) File No. M-1

For "o's"	For "x's"
A = 48	
B = 72	
M = 0.51840	
m = 0.33545	
σ = 0.44790	

Secondary Statistics

n = $\frac{N_1 \sigma_o^2 + N_2 \sigma_x^2}{N_1 + N_2}$

σ = $\sqrt{\frac{N_1 \sigma_o^2 + N_2 \sigma_x^2}{N_1 + N_2}}$

ζ = Antilog m = 2.165 WATTS

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Probability Levels	Confidence Level	Probability Levels	Confidence Level
P% = 99.9	X% = 90	P% = 99	X% = 90
100-P% = 0.1		100-P% = 1	
m = 0.33545	k _p ^② = 3.09	m = 0.33545	k _p ^② = 2.326
σ = 0.44790	k _x ^② = 1.282	σ = 0.44790	k _x ^② = 1.282
d = 0.05	G ^③ = 1.020	d = 0.05	G ^③ = 1.020
S = $\frac{m}{d}$ = 6.896	G ² = 1.0404	S = $\frac{m}{d}$ = 6.896	G ² = 1.0404
N = 100	H ^③ = 1.34	N = 100	H ^③ = 1.34
n ^① = 50	H ² = 1.7956	n ^① = 50	H ² = 1.7956

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 ≥ .5, and Graph V
When S < .5

Confidence Interval (Y)

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

= 0.0354598

Final Calculations

(99.9%) (90% Conf) = m + k_p σ + Y

= 0.50931 log units

= 3.2308 watt

(0.1%) (90% Conf) = m - k_p σ - Y

= 0.16159 log units

= 1.4507

Confidence Interval (Y)

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

= 0.02727033

Final Calculations

(99.9%) (90% Conf) = m + k_p σ + Y

= 0.46690 log units

= 2.9302 watt

(1%) (90% Conf) = m - k_p σ - Y

= 0.20409 log units

= 1.5995

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BRUGETON TEST MK 2 MOD 0 IGNITION ELEMENT 1000 Mc

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Functioning Levels (%)						FUNCT. TIME	RESISTANCE	ITEM NO.	Functioning Levels (%)						FUNCT. TIME	RESISTANCE	ITEM NO.
1.19	1.27	1.39	1.49	1.60					1.19	1.27	1.39	1.49	1.60				
		X				0.35999		1		0					-	.100	81
	0					-		2			X				-	.104	82
		X				0.26222		3		0					-	.102	83
	0					0.57752		4			X				0.72364	.105	84
0						-		5		0					-	.100	85
	0					-		6			0				-	.106	86
		X				0.20892		7				X			0.22631	.110	87
	0					-		8			X				0.43095	.100	88
		X				0.04599		9		0					-	.105	89
	0					-		10			X				0.45608	.099	90
		X				0.07166		11		0					-	.100	91
	0					-		12			X				0.82424	.110	92
		X				0.30865		13		0					-	.090	93
		X				0.49039		14			0				-	.095	94
X						1.4784		15				X			0.33169	.095	95
0						-		16			X				0.33761	.096	96
	0					-		17		0					-	.092	97
	0					-		18			0				-	.098	98
		X				0.36572		19				X			0.47852	.095	99
	0					-		20			0				-	.100	100
		0				-		21				X			0.39156	.097	101
			X			0.05109		22			X				0.40023	.105	102
		X				0.11151		23		0					-	.095	103
	0					-		24			0				-	.100	104
		X				0.30358		25				X			0.19756	.097	105
	0					-		26			0				-	.105	106
		X				0.17837		27				X			0.63491	.095	107
	0					-		28			X				1.18029	.095	108
		X				0.11849		29		0					-	.100	109
	X					0.19561		30			0				-	.091	110
0						-		31				X			0.06355	.100	111
	0					-		32			X				0.41264	.095	112
		X				0.16234		33		0					-	.099	113
	X					0.64489		34			X				0.12832	.095	114
0						-		35		0					-	.090	115
	0					-		36			X				0.81469	.094	116
		X				0.44492		37		0					-	.095	117
	0					-		38			0				-	.100	118
		X				0.22438		39				0			-	.104	119
	0					-		40					X		0.11133	.110	120
		X				0.13074		41				X			0.17200	.101	121
	X					0.51588		42			X				0.27081	.104	122
0						-		43		0					-	.104	123
	X					0.34559		44			X				0.38859	.097	124
0						-		45		0					-	.100	125
	X					0.29197		46			0				-	.095	126
0						-		47				X			0.37996	.105	127
	X					0.59536		48			0				-	.100	128
0						-		49				X			0.40252	.105	129
	X					0.87958		50			X				-	.100	130
0 1 8 15 1						n ₁ = 25		X	0 0 14 10 1						n ₁ = 25		X
1 8 15 1 0						n ₂ = 25		0	0 14 11 1 0						n ₂ = 25		0

1	1 ²	a ₁	a ₂	Σ watts
0	0	1	0	1.19
1	1	22	1	1.27
2	4	25	22	1.39
3	9	2	25	1.49
4	16	0	2	1.60
5	25			
6	36			
Totals: N ₁ = 50 N ₂ = 50				

Probability Levels	Confidence Level	Probability Levels	Confidence Level
PK = <u>99.9</u>	XS = <u>90</u>	PK = <u>99</u>	XS = <u>90</u>
100-PK = <u>.1</u>		100-PK = <u>1</u>	
m = <u>.13735</u>	k _p ^② = <u>3.090</u>	m = <u>.13735</u>	k _p ^② = <u>2.326</u>
σ = <u>.01917</u>	k _x ^② = <u>1.282</u>	σ = <u>.01917</u>	k _x ^② = <u>1.282</u>
d = <u>.03</u>	G ^③ = <u>1.085</u>	d = <u>.03</u>	G ^③ = <u>1.085</u>
S = $\frac{G}{d}$ = <u>.6390</u>	G ² = <u>1.177</u>	S = $\frac{G}{d}$ = <u>.6390</u>	G ² = <u>1.177</u>
N = <u>100</u>	H ^③ = <u>1.262</u>	N = <u>100</u>	H ^③ = <u>1.262</u>
n ^① = <u>50</u>	H ² = <u>1.593</u>	n ^① = <u>50</u>	H ² = <u>1.593</u>

Special Parameters	Primary Statistics	Confidence Interval (Y)	Final Calculations
c = (log ζ) ₁₀₀ = <u>.07555</u>	A = Σ i ² = <u>78</u>	① n = $\frac{N}{2}$ when N is <u>even</u> integer	(99.9%) (90% Conf) = m+k _p σ + Y
d = (log ζ) ₁₀₁ - (log ζ) ₁₀₀ = <u>.03</u>	B = Σ i ² n = <u>140</u>	n = $\frac{N+1}{2}$ when N is <u>odd</u> integer	= <u>.21099</u> log units
	M = (NB-A ²)/N ² = <u>0.36640</u>	② From BR*, p. 19, at given P or X	= <u>1.6355</u> watts
	m = c + d (A/N ± M) ² = <u>0.13735</u>	③ From BR* for G & H versus S. Use Graphs III & IV.	(.1%) (90% Conf) = m-k _p σ - Y
	σ = 1.68 d (M + 0.009) $\sqrt{\frac{N}{N-1}}$ = <u>.01917</u>	When S ≥ .5, and Graph V	= <u>.06370</u> log units
	"Use + for 'a' or - for 'b' or"	When S < .5	= <u>1.1579</u> watts
	**Valid for N ≥ 0.5 only, otherwise consult "Bureau Report" (NSF Report No. 101.12, "Statistical Analysis for A New Procedure in Sensitivity Experiments" July, 1964) File No. 10-1		
	For "a" or "b" For "x" or "y"		
	A = <u>78</u> B = <u>140</u> M = <u>0.36640</u>		
	m = <u>0.13735</u> σ = <u>.01917</u>		
	Secondary Statistics		
	m = $\frac{A}{N} + \frac{B}{N^2}$ = <u>.13735</u>		
	σ = $\sqrt{\frac{A^2}{N^3} + \frac{B^2}{N^4}}$ = <u>.01917</u>		
	ζ = Antilog m = <u>1.372</u> watts		

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B-5 BRUCETON TEST MK 2 MOD 0 ELEMENT 30 MC

Functioning Levels (%)							FUNCT. TIME	RESISTANCE	ITEM NO.	Functioning Levels (%)							FUNCT. TIME	RESISTANCE	ITEM NO.
1.56	1.67	1.79	1.91	2.05	2.20	2.35				1.56	1.67	1.79	1.91	2.05	2.20	2.35			
							secs	Ω									secs	Ω	
				0			-	.106	1								.2097	.09	81
				X			.15180	.10	2					0			-	.109	82
				0			-	.08	3								.3970	.10	83
				X			.3432	.09	4					X			.17951	.09	84
				0			-	.08	5					0			-	.09	85
				X			.4813	.09	6					X			.8381	.10	86
				X			.1185	.10	7					0			-	.09	87
				0			-	.08	8					X			.16048	.09	88
				X			.10687	.08	9					0			-	.10	89
				0			-	.08	10					0			-	.08	90
				X			.6868	.09	11					X			.1461	.10	91
				0			-	.109	12					0			-	.09	92
				0			-	.08	13					X			.4824	.09	93
				X			.5971	.08	14					X			.7760	.10	94
				0			-	.67	15					0			-	.09	95
				X			.3478	.09	16					0			-	.10	96
				0			-	.08	17					X			.2886	.09	97
				0			-	.08	18					0			-	.11	98
				X			.0651	.08	19					X			.3854	.09	99
				0			.8519	.07	20					0			-	.08	100
				X			-	.08	21					X			.2105	.11	101
				0			.2390	.09	22					0			-	.09	102
				0			-	.08	23					0			-	.10	103
				0			-	.09	24					X			.1279	.10	104
				X			.2649	.08	25					X			.1882	.09	105
				0			-	.08	26					0			-	.09	106
				X			.4071	.09	27					X			.5520	.09	107
				0			.4025	.09	28					X			.5890	.09	108
				0			-	.08	29					0			-	.09	109
				0			-	.08	30					0			-	.10	110
				X			.1168	.08	31					X			.7287	.10	111
				0			-	.07	32					X			.7901	.12	112
				0			-	.08	33					0			-	.10	113
				X			-	.08	34					0			-	.09	114
				0			.6971	.08	35					X			.4037	.09	115
				0			-	.09	36					X			.5358	.10	116
				0			-	.11	37					0			-	.09	117
				X			.0805	.09	38					0			-	.11	118
				X			.15161	.08	39					X			.10656	.09	119
				0			-	.09	40					X			.16397	.11	120
				X			.3525	.10	41					0			-	.09	121
				0			-	.08	42					0			-	.09	122
				X			.3863	.09	43					X			.4705	.10	123
				0			-	.09	44					0			-	.08	124
				X			.5093	.09	45					X			.1520	.10	125
				X			.8791	.08	46					0			-	.10	126
				0			-	.09	47					0			.2862	.09	127
				0			-	.10	48					0			-	.08	128
				X			.4698	.09	49					X			.4268	.09	129
				0			-	.09	50					X			.4267	.09	130
				0			n ₁ = 24		X					0			n ₁ = 26		X
				0			n ₀ = 26		0					0			n ₀ = 24		0

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i	i ²	n _i	n _i	i ² n _i
0	0	3	0	1.91
1	1	18	3	2.05
2	4	26	18	2.20
3	9	3	26	2.35
4	16	0	3	2.52
5	25			
6	36			
Totals: N ₁ = 50 N ₂ = 50				

Special Parameters
 $c = (\log \zeta)_{i=0} = 0.28103$
 $d = (\log \zeta)_{i=1} - (\log \zeta)_i = 0.03$

Primary Statistics
 $A = \sum i n_i$
 $B = \sum i^2 n_i$
 $M = (NB - A^2)/N^2$
 $m = c + d (A/N \pm \frac{1}{2})^2$
 $\sigma = 1.62 d (M + 0.029) \sqrt{\frac{N}{N-1}}$
 *Use + for "o's"; - for "x's"
 **Valid for M ≥ 0.3 only, otherwise consult "Brunton Report" (AMP Report No. 101-1R, "Statistical Analysis for A New Procedure in Sensitivity Experiments" July, 1944) File No. Mh-1

For "o's"	For "x's"
A = 79	
B = 149	
M = 0.48360	
m = 0.34343	
σ = 0.02517	

Secondary Statistics
 $m = \frac{N_1 n_1 + N_2 n_2}{N_1 + N_2} = 0.34343$
 $\sigma = \sqrt{\frac{N_1 \sigma_1^2 + N_2 \sigma_2^2}{N_1 + N_2}} = 0.02517$

$\zeta = \text{Antilog } m = 2.2051 \text{ watts}$

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Probability Levels	Confidence Level	Probability Levels	Confidence Level
P% = 99.9	X% = 90	P% = 99	X% = 90
100-P% = 0.1		100-P% = 1	
m = 0.34343	k _p ^② = 3.09	m = 0.34343	k _p ^② = 2.326
σ = 0.02517	k _x ^② = 1.282	σ = 0.02517	k _x ^② = 1.282
d = 0.03	G ^③ = 1.030	d = 0.03	G ^③ = 1.030
S = $\frac{G}{d} = 0.08390$	G ² = 1.0609	S = $\frac{G}{d} = 0.08390$	G ² = 1.0609
N = 100	H ^③ = 1.32	N = 100	H ^③ = 1.32
n ^① = 50	H ² = 1.7424	n ^① = 50	H ² = 1.7424
① n = $\frac{N}{2}$ when N is even integer n = $\frac{N+1}{2}$ when N is odd integer		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		② From BR*, p. 19, at given P or X	
③ From BR* for G & H versus S. Use Graphs III & IV. When S ≥ .5, and Graph V When S < .5		③ From BR* for G & H versus S. Use Graphs III & IV. When S ≥ .5, and Graph V When S < .5	
Confidence Interval (Y) $Y = k_x \left(\frac{n+1}{n} \right) \left(\frac{G^2 + H^2 k_p^2}{n} \right)^{1/2} \sigma$ = 0.01965789		Confidence Interval (Y) $Y = k_x \left(\frac{n+1}{n} \right) \left(\frac{G^2 + H^2 k_p^2}{n} \right)^{1/2} \sigma$ = 0.0151327	
Final Calculations (99%) (90% Conf) = m + k _p σ + Y = 0.44086 log units = 2.7596 watt (01%) (90% Conf) = m - k _p σ - Y = 0.24600 log units = 1.76196 watt		Final Calculations (99%) (90% Conf) = m + k _p σ + Y = 0.41711 log units = 2.6128 watt (01%) (90% Conf) = m - k _p σ - Y = 0.26986 log units = 1.8614 watt	

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APPENDIX C

DRI SIMULATOR TESTS

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**C. RF TESTS ON SIMULATED MARK 2 MOD 0 IGNITION ELEMENTS
FROM DENVER RESEARCH INSTITUTE**

During the performance of this program the Denver Research Institute delivered to us 28 simulated MARK 2 MOD 0 ignition elements. These simulators consist of the standard MARK 2 MOD 0 assembly complete through the bridgewires, with a thermocouple substituted for the explosive. The elements were divided into four groups according to the spacing of the thermocouples above the bridgewires. The MARK 2 MOD 0 element has two paralleled bridgewires. The simulated elements have two thermocouples designated A and B - one for each of the parallel bridgewires. The spacings previously referred to are: very far (VF), far (F), medium (M), and close (C).

Tests were conducted at 5, 30, 250 and 1000 megacycles. These tests have shown that the simulated elements have an increase in thermocouple output as frequency is raised from 5 to 1000 megacycles. In some cases the output is considerably more than doubled, over this frequency range. At 5 megacycles, however, the output tends to level off to the dc value.

Data for millivolt output versus frequency are given in Table C-1. The simulators were all tested in the same RF systems used for the Bruceton tests of the complete MARK 2 MOD 0 ignition elements. Input power was set at the 50% mean fire level.

Curves showing output as a function of frequency for a limited number of simulators from the group of 28 are plotted in Figures C-1 and C-2.

A few of the DRI simulators were also tested with dc power applied to the bridgewires. The output was a linear function of dc input. Figure C-3 displays this relationship.

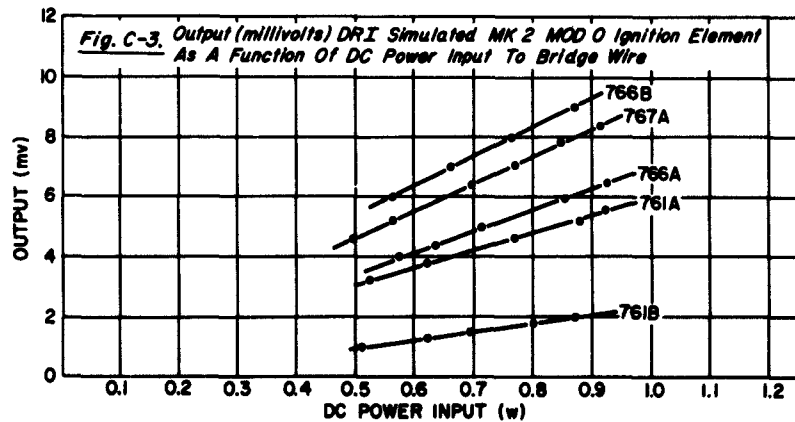
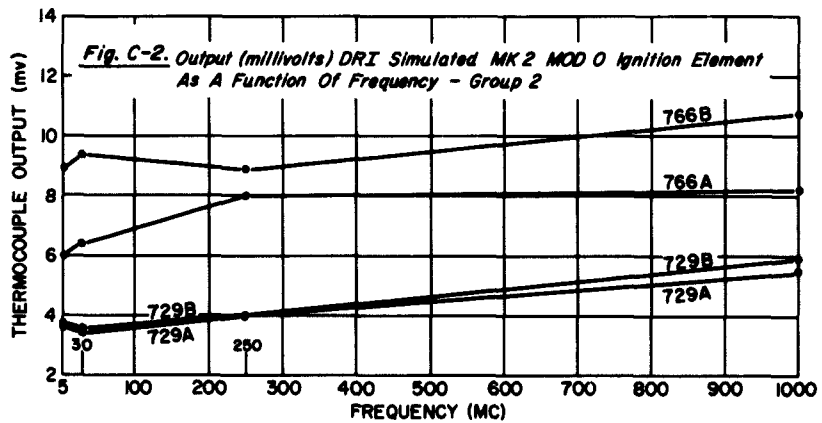
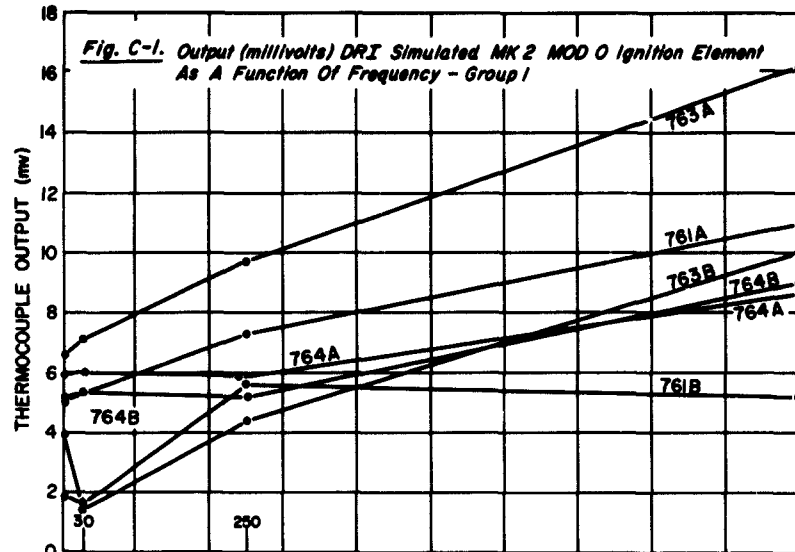
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Table C-1

RF TESTS AT FRANKLIN INSTITUTE ON DRI SIMULATED
MARK 2 MOD 0 IGNITION ELEMENTS

Element Number	Thermocouple - Millivolt				Output				Between Thermocouple and Bridgewire
	5 Mc		30 Mc		250 Mc		1000 Mc		
	Thermocouple A	Thermocouple B	Thermocouple A	Thermocouple B	Thermocouple A	Thermocouple B	Thermocouple A	Thermocouple B	
761	5.18	1.88	5.3	1.6	7.3	5.6	11.0	5.2	very far
763	6.55	3.90	7.1	1.4	9.7	4.4	16.2	10.0	very far
764	5.9	5.05	6.0	5.3	5.8	5.2	8.65	9.0	very far
766	6.0	8.9	6.4	9.4	8.0	8.9	8.2	10.8	very far
767	cut	open	7.8	6.6	9.5	9.2	12.0	13.1	very far
715	6.10	5.40	6.05	5.7	6.0	5.6	3.5	3.28	Far
724	0	9.6	0	9.6	7.9	10.0	0	13.7	Far
728	2.65	2.4	2.55	2.5	2.7	2.7	3.35	3.1	Far
729	3.6	3.7	3.4	3.45	4.0	4.0	5.5	5.9	Far
730	3.44	1.55	3.22	1.44	3.6	1.8	4.3	2.78	Far
733	6.00	3.2	5.81	3.1	11.0	4.5	11.4	9.0	Far
736	3.2	4.0	3.30	4.05	4.3	4.2	6.21	5.0	Far
740	5.58	3.3	5.70	3.35	6.4	4.1	7.66	8.1	Far
716	6.6	8.1	6.3	7.6	6.7	7.7	7.41	10.8	Medium
717	12.1	10.8	12.0	11.8	18.0	15.0	16.0	0	Medium
719	7.55	0	7.8	0	8.5	15.8	10.2	0	Medium
732	11.1	10.7	10.8	10.8	10.5	13.7	10.3	16.0	Medium
734	7.2	6.43	6.8	6.3	9.4	7.8	8.0	13.0	Medium
735	0	4.25	0	4.7	13.5	5.2	0	9.8	Medium
742	8.6	2.9	8.6	2.9	11.3	5.2	14.4	10.9	Medium
714	7.7	3.6	7.6	3.75	10.8	7.0	13.8	7.4	Close
718	4.7	5.45	4.8	5.10	5.0	5.2	5.9	6.0	Close
721	13.4	10.5	13.2	3.55	16.6	9.2	18.5	10.0	Close
727	Cut	open	0	0	0	4.0	0	11.0	Close
731	7.05	0	6.8	0	6.9	12.6	9.0	0	Close
737	3.15	6.2	3.15	5.9	6.0	8.5	Not Measured		Close
738	8.6	7.8	8.3	7.8	11.5	9.4	Not Measured		Close
741	9.1	7.9	8.8	8.2	11.5	11.5	Not Measured		Close



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