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Monthly Progress Report

P-B1980-2

HERO SUPPORTING STUDIES

by

Norman P. Faunce
Paul F. Mohrbach

August 1 to August 31, 1962

Prepared for

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

Contract No. N178-8102

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THE FRANKLIN INSTITUTE
LABORATORIES FOR RESEARCH AND DEVELOPMENT
PHILADELPHIA PENNSYLVANIA

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ABSTRACT

A program of evaluation tests intended to extensively characterize hot wire-bridged EEDS ~~has~~ ^{have} been outlined. This ~~schedule~~ includes tests for both dc and RF functioning sensitivity. Tests to determine the rate of change of resistance with temperature, the RF cook-off power, and the effect of low level dc or RF excitation on normal functioning responses round out the program. The modified ~~MS-F-111-0~~ ignition element is to be the first component to be tested by this plan.

Analyses are being made of errors to be expected in RF power measuring systems. The directivity errors associated with use of directional couplers to measure incident and reflected power are developed. These errors, both of which approach a common value of 2% for couplers with 40 db of directivity combine to give a possible maximum error approaching infinity.

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SUMMARY

The component testing phase of the HERO Supporting Studies has been critically reviewed and a test schedule for hot-wire-bridged EED's has at last emerged. Reworking a die compression pin has been done on the component development phase. Major emphasis has centered on evaluating sources of error in power measuring systems, notably that from use of directional couplers. Continued effort to fabricate the stub tuner precision guides accounts for most of the physical labor during this period.

At a meeting with NWL representatives on the last working day of this period, we agreed upon a test outline for hot-wire-bridged EED's. This schedule was prepared by NWL using as a guide our proposed plans of the previous month. A few minor amendments were made at this meeting; the final draft is acceptable to all concerned. In addition a schedule was outlined for tests to be performed upon the MK 7 MOD 0 protected ignition element. This evaluation schedule is brief, because a number of the "General Test Program" tests have already been performed. Receipt of the lot of 800 MK 7 MOD 0 elements are expected early in the coming month, and we will begin to schedule them for tests soon thereafter.

A differential method for measuring RF power has been studied. In concept it appears to be ideally suited to measuring input to an EED. Examination of the probable sources of error has shown the need to be suspicious of the result when the power measured even by highly accurate directional couplers is combined to determine net power. For example, measurement of the power to a 2-ohm resistive load terminating a 50-ohm line may be in error by as much as 35%, even though the incident and reflected power errors are each only about 2%. This error may increase for loads having a higher reflection coefficient. These values represent possible error brought about by a unique phase relationship between measured voltages. Means for limiting actual error to a value considerably less than this should be possible. This will be our objective during the coming weeks, when we will continue our investigation of this method both theoretically and empirically.

The tuning assemblies for the new attenuation measuring system should be completely assembled and checked out during the coming month. This will conclude work in this direction except, possibly, extending the new technique to measurements at lower frequencies. Some thought has been given to such an extension, and should results obtained with the system warrant it, we may proceed accordingly.

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1. COMPONENT TESTING

At the conclusion of the previous reporting period The Franklin Institute had submitted their recommended procedure for evaluating wire-bridge electro-explosive devices. This took the form of three test schedules differing in the detail of the data that would be produced by each. Correspondingly they each differed in the degree to which they would allow the items under test to be classified according to their RF (and dc) characteristics.

During the present period, we have done little more on this phase of study except to review our proposal, thereby confirming our belief that it represents a sound approach. Personnel at the Naval Weapons Laboratory have been similarly engaged, in the expectation of preparing a single unified test schedule. Agreement on a general program was reached near the end of the month, and a detailed schedule of tests was prepared for evaluation of the MK 7 MOD 0 RF attenuated ignition element in this manner.

1.1 Outline of HERO Testing Program for All Hot-Wire Bridged EED's

The general test program for conventional wire-bridged EEDS is given in Table 1-1. A rather extensive evaluation is suggested by this schedule which calls for the expenditure of nearly one thousand ignition elements. If it were necessary to reduce this number, it would be readily possible to modify the general outline with a corresponding loss in detail of evaluation results.

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Table 1-1
GENERAL TEST PROGRAM

<u>Description of Test</u>	<u>Maximum Number of Items</u>
I. DC Sensitivity	
1. Establish current vs. time-sensitivity curve if unknown by firing 0.1 msec. or less, 1.0 msec, 10 sec.	200
2. Determine the alteration in sensitivity resulting from exposure to (say) .1% firing current for five minutes.	100
3. Determine the change of resistance with respect to time (dr/dt) for three dc pulse widths (0.1 msec or less, 1.0 msec, 10 sec).	<u>30</u>
	330
II. RF Sensitivity	
1. Establish RF sensitivity under CW conditions at five frequencies (suggest 5, 30, 250, 1000, 5000 Mc).	250
2. Calculate RF sensitivity under pulsed conditions from dc data and check by firing at 2 pulse lengths and repetition rates.	100
3. Check RF sensitivity as in II.1 above with instrumented units.	10
4. Lead-to-case RF test where applicable.	50
5. Expose 50 items each to 0.1% level CW and 0.1% level pulsed RF, 1 μ sec pulse length, for 5 minutes each at selected frequency. Fire subsequently in dc Bruceton to check dudding and alteration of sensitivity.	<u>100</u>
	510

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III. Cookoff Sensitivity (For attenuated items use
3 kMc Frequency), CW Modulation

1. Lead-to-Case, air environment

- | | |
|---|----|
| a. EED only - no heat sink. | 25 |
| b. EED in heat sink (heat sink to be
agreed upon later). | 25 |

2. Lead-to-Lead

- | | |
|---|----|
| a. EED only - no heat sink | 25 |
| b. EED in heat sink (heat sink to be
agreed upon later). | 25 |

100
940 Total

On the other hand, this program contains tests which may be found unnecessary provided some correlation is shown between similar phenomena. For example, Tests I-2 and II-5 are intended to show the same effect; if low level dc alters the item's sensitivity, we would expect a comparable low level RF to have the same effect. When this has been demonstrated with reasonable clarity we shall omit test II-5.

A few comments regarding the tests outlined in the table seem to be in order.

The first test (I-1) is a standard constant current evaluation. From this we learn the magnitude of current necessary to be delivered to the item undergoing test for various time intervals so as to result in a 50% probability of fire. Current pulse durations from micro-seconds to minutes may be used depending upon the nature of the item. In any event the pulse durations used for tests should include one specified by design or ordinary use, a time interval relatively short by comparison, and one correspondingly longer.

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In some cases if the EED is normally fired from a charged capacitor it may prove desirable to perform a capacitor discharge sensitivity test at several capacitances.

Test I-2 has been discussed previously; this test shows degradation wrought by low level excitations.

The final dc test (dr/dt evaluation) provides the link between RF and dc firing test results. Since power is used for describing RF response we must convert dc firing current to dc firing power. Knowledge of dr/dt is necessary for this conversion.

RF sensitivity is determined both for CW and pulsed excitation (Tests II-1&2). We believe that CW RF functioning levels are readily determined from dc long pulse time functioning levels; the difference being attributable to a frequency-dependent loss. Similarly, short time dc pulse firing response should be indicative of pulsed RF response. Prediction of pulsed RF levels from comparable dc levels has been made a part of this program to verify this conjecture.

For many components submitted for evaluation, the available quantity may be limited. In Test II-3, therefore, we have to learn, by expending only 10 units, as much as possible to indicate the results that would be derived from expending 930 units. A number of non-destructive tests will be evaluated to provide clues to a reasonable estimate of the results that might be obtained from a more extensive testing program. We will be fortunate in having results of the extension evaluation on hand to verify or refute our predictions based on this exceedingly small sample.

Test II-4 is included to investigate the possibility of leakage currents from bridge posts to case being responsible for initiations.

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An additional RF test is included to study the probability of low level RF excitation altering the normal functioning response. This test, (II-5) and the comparable dc test (I-2) are similarly directed. We expect the results of these tests also to be similar, and hopefully to be so much so that one or the other may be deleted from the schedule.

Finally, a series of tests are proposed to evaluate the necessity for a reliable heat sink to insure protection against the hazard of cook-off.

1.2 Outline of HERO Tests for the Modified MK 7 Ignition Element

The modification of the MK 7 ignition element was designed by Franklin Institute and produced by Atlas Chemical Industries. As part of this development program a number of acceptance tests, including RF sensitivity, were performed. This development and evaluation of this item are documented in a final report*. Since most of these tests are included in the general HERO Test Program just described, there is no need for their being repeated. Consequently the test schedule shown in Table 1-2 will be used for this item.

There are approximately 800 elements remaining in the lot first made by Atlas. The test schedule calls for expending 640. Because of the changes in RF firing equipment and procedures that may have occurred in the interim it may be necessary to repeat a few earlier tests, which would use up the other 160 items.

*Franklin Institute Lab. Final Technical Report F-B1836, "RF Protection of MARK 2 MOD 0 and MARK 7 MOD 0 Ignition Elements" by David W. Mayer and Paul F. Mohrbach, April 25, 1961 to February 23, 1962, Contract No. DA-36-034-501-ORD-3431RD.

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Table 1-2

TEST PROGRAM FOR THE MODIFIED MK 7 IGNITION ELEMENT

<u>Test</u>	<u>No. of Items</u>
I. DC Sensitivity	
1. DC Sensitivity Curve (Two points already determined - 1 msec and 10 sec) Determine one point at 0.1 msec or less.	50
2. Determine the alteration in sensitivity resulting from exposure to (say) 0.1% firing current for 5 minutes.	100
3. Determine dr/dt for 0.1 msec or less, 1 msec and 10 sec pulses.	30
II. RF Sensitivity	
1. Determine RF sensitivity at 30 Mc, 200 Mc, and 5000 Mc with CW (10 Mc, 400 Mc and 900 Mc already determined).	150
2. Calculate RF sensitivity under pulsed conditions from dc data and check at 2 pulse lengths and repetition rates.	100
3. Determine RF sensitivity at 10 Mc, 30 Mc, 200 Mc, 400 Mc, 900 Mc, and 5000 Mc using instrumented units.	10
4. Expose 50 items each to 0.1% level CW and 0.1% level at 1 μ sec (pulsed RF) for 5 minutes, each at a selected frequency. Fire items subsequently in a dc Bruceton to check for dudding and alteration of sensitivity.	100
III. Cookoff Sensitivity	
1. Determine cookoff sensitivity for EED in an air environment with 3 kMc both lead-to-lead and lead-to-case-CW.	50

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2. Determine cookoff sensitivity for EED in a heat sink with 3 kMc both lead-to-lead and lead-to-case-CW (heat sink to be agreed upon later).

50
640 Total

2. COMPONENT DEVELOPMENT

Work on this phase of the program has been completely halted awaiting further instructions from the Naval Weapons Laboratory, except for correcting an error in the die parts for the MK 1 half-plug assembly. The compression pin designed to form the mating surface (flat surface with lead grooves) was originally made with the grooves separated by 0.060 inch center to center. For the MK 1 MOD 0 squib the lead separation is 0.060 inch clear space (approximately .086 center to center). A new compression pin to form the correct mating surface has been designed and constructed.

3. INSTRUMENTATION

3.1 Improved RF Attenuating Measuring Systems

The precision carriages, basic to the new system, are still in development, but final assembly is in process. Early during the next period these tuner adjusting assemblies should be in operation, and the complete system will be checked out. This development, therefore, should be concluded during the next period.

3.2 RF Power Measuring Techniques; Consideration of Errors Associated with Differential Power Detection

Methods for measuring by power differential depend upon comparing signals representing incident and reflected powers, whose difference should correspond to net power absorbed by the components terminating the power-sampling section of the system. A pair of directional couplers (or a dual directional coupler) is the heart of the differential power

detection system. Analysis of this unit has shown that results can be inordinately in error unless means are taken to reduce, if not eliminate, their cause. The following sections detail the error analysis; the first steps toward their circumvention will follow in the next period.

3.2.1 Incident Power Error

Consider a directional coupler oriented in a transmission line to sample the incident power as shown in Figure 3-1. The line is terminated in an arbitrary impedance so that both incident and reflected powers, P^+ and P^- respectively, are present. The magnitude* of the incident and reflected voltages are related to these powers by

$$\begin{aligned} V^+ &= \sqrt{P^+ R_0} && \text{(volt)} \\ V^- &= \sqrt{P^- R_0} && \text{(volt)} \end{aligned} \tag{1}$$

where R_0 is the characteristic impedance of the transmission line. The reflected voltage is a function of the magnitudes of the incident voltage and the reflection coefficient (ρ_l) of the arbitrary termination.

$$V^- = \rho_l V^+ \tag{2} \text{(volt)}$$

Each of the main line waves is coupled into the auxiliary line; but, because of the directional characteristics of the coupler, the coupled incident wave, V_i , flows toward the auxiliary port and the coupled reflected wave, V_r , flows toward the matched termination where it is absorbed. Since the coupling factor between primary and auxiliary lines is the same for both waves we shall for simplicity assume it to be unity.

*NOTE: In all of the equations of this development the symbols V & ρ represent magnitudes, normally written as $|V|$ & $|\rho|$. Since the magnitude and not the phasor quantity is used throughout we have eliminated magnitude signs.

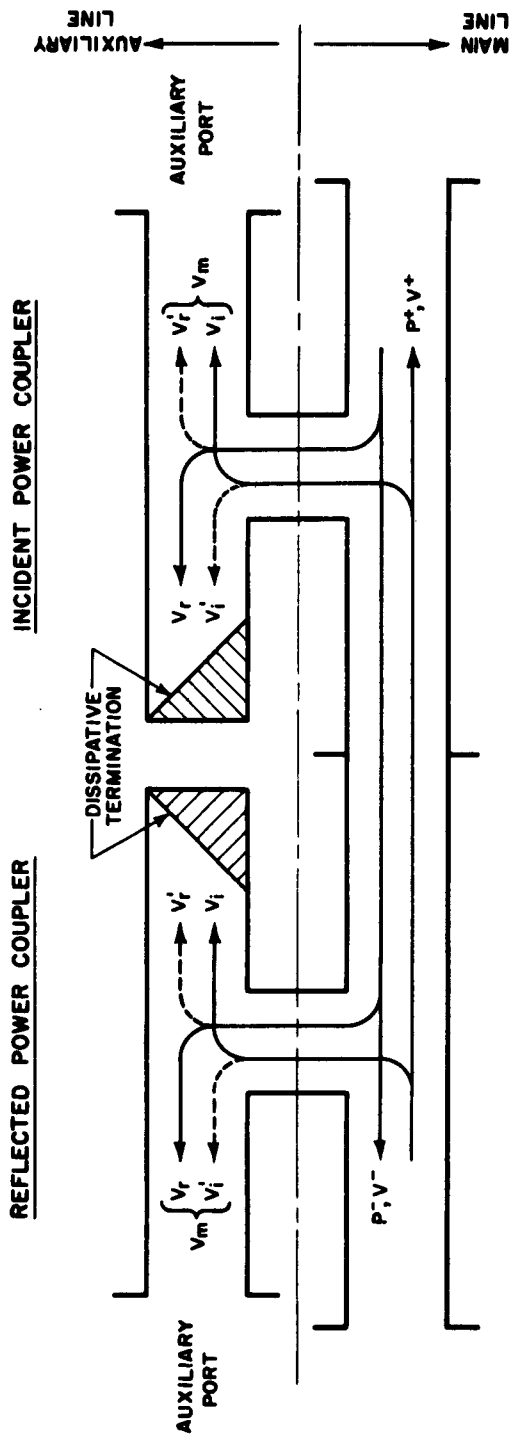


FIG. 3-1. POWER MEASUREMENTS WITH DIRECTIONAL COUPLERS

The incident and reflected waves in the auxiliary transmission line will be related as are the primary line waves as stated in equation (2).

$$V_r = \rho_l V_i \quad (3)$$

When a directional coupler is constructed it is impossible to make it totally perfect so that the incident wave (V_i) flows only toward the auxiliary port and the reflected wave (V_r) only toward the dissipative load. Some part of the incident wave (V_i) will flow toward the matched load, where it too will be dissipated. Likewise part of the reflected wave (V_r) will flow toward the auxiliary port where it will combine with (V_i). A quantity expressing relationship between the undesired and the desired wave is called the directivity (D) and is given by the following expression.

$$D = 10 \log \left(\frac{P_i}{P_r} \right) = 10 \log \left(\frac{P_r}{P_i} \right) \quad (\text{db}) \quad (4)$$

In terms of voltage this can be stated as

$$D = 20 \log \left(\frac{V_i}{V_r} \right) = 20 \log \left(\frac{V_r}{V_i} \right) \quad (\text{db}) \quad (5)$$

For this discussion, it is convenient to define a quantity ρ_d which is related to the directivity by

$$\rho_d = \frac{V_i'}{V_i} = \frac{V_r'}{V_r} = \frac{1}{\log^{-1} \left(\frac{D}{20} \right)} \quad (6)$$

The voltage measured at the auxiliary port is the sum of the desired voltage, V_i and the undesired voltage V_r' . A maximum error occurs when these voltages add either in or out of phase.

$$V_m = V_i \pm V_r' \quad (\text{volt}) \quad (7)$$

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(V_r') can be expressed in terms of (V_r) using equation (6).

$$V_r' = \rho_d V_r \quad (\text{volt}) \quad (8)$$

Combining with equation (3) we have

$$V_r' = \rho_d \rho_l V_i \quad (9)$$

and equation (7) becomes

$$V_m = V_i (1 \pm \rho_d \rho_l) \quad (\text{volt}) \quad (10)$$

The error associated with the power measured at the auxiliary port can be written as

$$\% \text{ error} = \frac{P_m - P_i}{P_i} = \frac{V_m^2 - V_i^2}{V_i^2} \quad (11)$$

where P_m is the quantity actually measured and P_i is the true value.

Combining equations (10) and (11) we have

$$\% \text{ error} = 100 \cdot \frac{V_i^2 (\pm \rho_d \rho_l)^2 - V_i^2}{V_i^2} \quad (12)$$

which reduces to

$$\% \text{ error} = 100 \cdot \rho_d \rho_l (\rho_d \rho_l \pm 2) \quad (13)$$

Plots of this equation for several values of directivity are shown in Figure 3-2. The voltage standing wave ratio, S , is related to the magnitude of ρ_l by

$$S = \frac{1 + \rho_l}{1 - \rho_l} \quad (14)$$

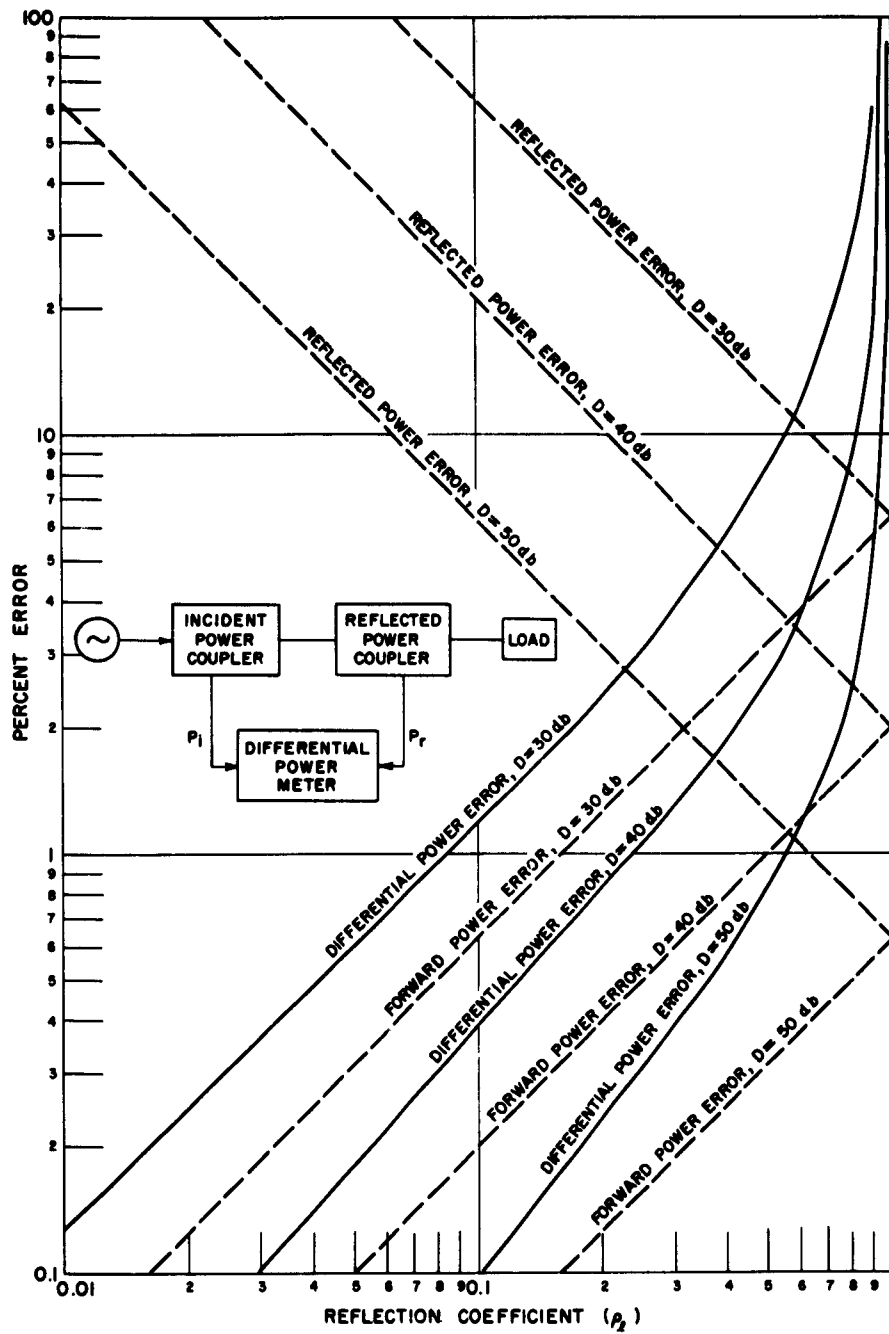


FIG. 3-2. MAXIMUM MEASUREMENT ERROR DUE TO DIRECTIONAL COUPLER DIRECTIVITY

The curves show that the error produced by the finite directivity of a coupler increases to a maximum value as the reflection coefficient approaches unity. For 40 db of directivity the maximum error for large reflection coefficients approaches 2%.

3.2.2 Reflected Power Error

Consider another coupler connected to the same transmission line but oriented to measure the reflected power as shown in Figure 3-1. In respect to the primary line waves, the auxiliary line incident wave is directed to the auxiliary termination and the reflected wave is directed to the auxiliary port. We will assume both couplers to have the same coupling factor (unity) and directivity. Equations (3) and (6) then, also apply for the reflected power coupler.

The measured voltage at the auxiliary port is again the sum of the desired and undesired voltages, and for maximum error they are added either in or out of phase.

$$V_m = V_r \pm V_i' \quad (\text{volt}) \quad (15)$$

From Equation (6) V_i' can be expressed in terms of V_i .

$$V_i' = \rho_d V_i \quad (\text{volt}) \quad (16)$$

Substituting from Equation (3) gives us

$$V_i' = \frac{\rho_d}{\rho_1} V_r \quad (\text{volt}) \quad (17)$$

Combining equation (15) and (17)

$$V_m = V_r \left[1 \pm \frac{\rho_d}{\rho_1} \right] \quad (\text{volt}) \quad (18)$$

The error associated with the power measured at the auxiliary port is

$$\% \text{ error} = 100 \cdot \frac{V_r^2 \left(1 \pm \frac{\rho_d}{\rho_l}\right)^2 - V_r^2}{V_r^2} \quad (19)$$

which reduces to

$$\% \text{ error} = 100 \cdot \frac{\rho_d}{\rho_l} \left(\frac{\rho_d}{\rho_l} \pm 2\right) \quad (20)$$

This equation is plotted as a family of curves for various directivities in Figure 3-2. Here the error approaches infinity for small reflection coefficients but decreases to the same value as the incident power error for large reflection coefficients (both couplers having the same directivity).

The large error which develops when measuring power reflected from a termination whose reflection coefficient is small can be explained as follows: The magnitude of the reflected power decreases with a decrease in the termination's reflection coefficient while the directivity error signal, which is proportional to the incident power, remains approximately constant. The percent error must, therefore, increase. When measuring the incident power, however, the directivity error signal is proportional to the reflected power, which decreases with decreasing reflection coefficient, the percent error likewise decreases.

3.2.3 New Power Error

The net power flow in a transmission line is the difference between the incident and reflected powers. The maximum error of the new power is, therefore,

$$\% \text{ error} = 100 \frac{(P_{mi} - P_{mr}) - (P_i - P_r)}{(P_i - P_r)} \quad (21)$$

Substituting square of the voltages measured at the auxiliary ports as given in Equations (10), and (18) we have

$$\% \text{ error} = 100 \frac{V_i^2 (1 \pm \rho_d \rho_\ell)^2 - V_r^2 \left(1 \pm \frac{\rho_d}{\rho_\ell}\right)^2 - V_i^2 + V_r^2}{V_i^2 - V_r^2} \quad (22)$$

substituting $V_r = \rho_\ell V_i$ as given in equation (3) and expanding we have

$$\% \text{ error} = 100 \left[\frac{\pm \rho_d \rho_\ell}{1 - \rho_\ell^2} - \rho_d^2 \right] \quad (23)$$

The final equation for the percent error associated with the differential power is also plotted as a family of curves for various values of directivity. This error is very small for small reflection coefficients but increases rapidly as the coefficient approaches unity.

In light of the fact that both incident and reflected power errors approach a common value (both in percent and in magnitude) when the reflection coefficient approached unity it may seem surprising that the net power error becomes increasingly larger. The problem here is that the net power error is the sum of the magnitudes of the incident and reflected errors, and it too approaches a fixed value as the reflection coefficient approaches unity, while the net power, on the other hand, becomes smaller and smaller, approaching zero. The magnitude of the error can in fact be several times greater than the magnitude of the net power for a reflection coefficient sufficiently close to unity. Unfortunately, most electroexplosive devices have rather high reflection coefficients when used as the termination of a transmission line. For example, a device with a nominal reflection coefficient of 0.82, which is equivalent to a purely resistive load of 5 ohms, will produce a possible error of $\pm 10\%$ when using two 40 db directivity directional couplers to measure net power. Further steps must be taken to reduce the net power error if this type of measurement is to be practical.

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One such step is a reduction in the directivity error through phase shifting techniques. We assumed in our development of the incident and reflected power errors that the greatest error will occur when the desired and undesired voltages add either in or out of phase at the coupler auxiliary ports. The actual phase relationship between these waves is dependent on the phase relationship of the incident and reflected waves in the primary transmission line. It may be possible, through shifting the relative phase of these waves to produce maximum and minimum measurements, whose average should be the actual value (for large reflection coefficients the positive and the negative errors are approximately equal). More investigation is needed, however, before we can apply this technique.

ACKNOWLEDGEMENTS

Significant contributions to Section 3 of this report were made by George McKay. The contributions of Peter Altman of NWL speaking for his associates and of Robert F. Wood to the substance of Section 1 are also acknowledged.



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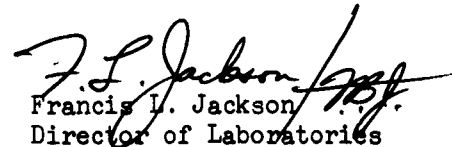


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