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ADAPTER EVALUATION BY AUTOMATED MEASUREMENTS

R. L. Jesch
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Final Report
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ABSTRACT

A problem of long standing interest in the UHF and microwave field is that of adapter evaluation. For many purposes, the adapter property of major interest has been its efficiency. However, a more complete description in terms of scattering parameters was required for the present adapter evaluation project. The approach to the problem was to automate the manual measurement technique for adapter efficiency. In achieving this goal, it was found that the entire set of scattering parameters could be obtained with little further effort. As a further by-product, an alternative procedure for determining correction factor for automated network analyzers was obtained.

Key Words: Adapter, power meters, test set, Automated Network Analyzer (ANA), reflection coefficient, scattering parameters.

CONTENTS

LIST OF FIGURES

1. INTRODUCTION

This is the final report on CCG project 72-72A. This project was the primary interest of the CCG R.F. Measurements Working Group (D.H. Caldwell, E.A. Fitzgerald, J.H. McAdams and R.D. Moyer). The objective of this project was to reduce to practice a proposed theoretical method for characterization of adapters. The approach to this problem was to provide a complete characterization of the adapter with emphasis on the efficiency. In particular, the ability to measure efficiency is enhanced by utilizing recently developed theories for non-ideal short-circuit performance and exploiting recent additions to the automated system which were made in conjunction with the development of a power calibration capability.

The theoretical approach was reduced to a computer program for adaptation on the NBS automatic network analyzer. This final report gives a brief description of the basic equations used in the computer program, in addition to the instrumentation and procedure required to make adapter measurements. A more complete description of the mathematical theory and its reduction to measurement practice is now being prepared in a paper by one of the authors (Engen).

2. INSTRUMENTATION

Existing, commercially available automated measurement systems are generally designed around the reflectometer concept and include a complex ratio detector as shown in figure 1. Although this suffices, in principle, for the desired efficiency measurement, the performance of the complex ratio detector generally falls substantially short of what is required to achieve the stated accuracy goals.

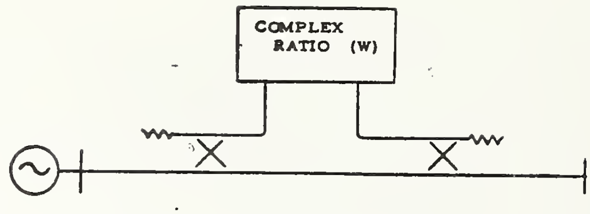

Figure 1. Test set.

At the National Bureau of Standards, the test set of figure 1 has been replaced by that shown in figure 2. The key feature is the addition of two power meters of high accuracy which permit a measurement of the absolute levels at the sidearms in addition to the existing complex ratio detector. Historically,

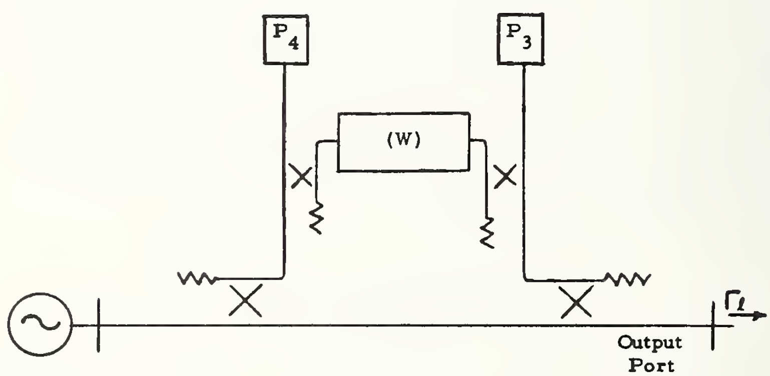

Figure 2. Test set for adapter evaluation.

the test set of figure 2 was developed for power meter calibration. Here, the net power at the output port is approximately proportional to P_4. The complex ratio detector provides a correction factor, which is typically no more than a few percent. Thus the error in its determination has only a small effect on the total accuracy. In this application the second power meter, P_3, is not required. The test set of figure 2 thus represents an extension of one initially developed for another application.

Although the power meters P_3, P_4 provide an absolute level indication, it is only their ratio which is of interest in adapter evaluation. In short, the power meters permit an order of magnitude, or more, improvement in the accuracy with which the magnitude of the complex ratio is measured. Although the dynamic range over which this improvement is realized is only 20 dB or so, this is more than adequate for the immediate application.

3. THEORETICAL BACKGROUND

The well known relationship between the complex ratio, w, and the reflection coefficient, Γ_ℓ, at the output port is given by,

$$w = \frac{a\Gamma_\ell + b}{c\Gamma_\ell + 1} \tag{1}$$

where a, b, c are complex constants. The relationship between P_3, P_4 and w may be written,

$$|w|^2 = K \frac{P_3}{P_4} \tag{2}$$

where K is a real constant. The evaluation of a, b, c is generally referred to as a calibration of the system and is basic to automated measurements. This problem will be considered in greater detail below. The parameter, K, can be easily evaluated by comparing the values $|w|^2$ and P_3/P_4 for several values of w and averaging. Provided that Γ_ℓ is such that P_3 and P_4 are within the dynamic range of power meter operation, $|w|$ is determined from (2), and the only role of the complex ratio detector is to provide the argument. As $|\Gamma_\ell|$ becomes small, however, P_3 also becomes small and it is necessary to obtain both magnitude and phase from the complex ratio detector.

The measurment of efficiency calls for observing P_3, P_4, and w in response to certain terminations, which are connected to the output port in figure 2, and a (usually) different set connected to the "output" port in figure 3. If one of these terminations is an ideal moving short, the locus of w in the complex plane is a circle, which may be characterized by its radius, R, and the position of its center, R_c. It is possible to express the efficiency in terms of the values of R and R_c obtained with an ideal sliding short connected to the output ports in figures 2 and 3. To a good approximation, the efficiency is merely the ratio of the two radii. Because $|R_c|$ is usually small in relation to R the accuracy with which R is measured depends primarily upon the accuracy in measuring $|w|$. The dependence upon the argument of w is small, and vanishes as R_c goes to zero. Moreover, the total expected range of variation in the value of $|w|$, in response to the short motion or adapter insertion, is perhaps no more than 10-20%. On the basis of these considerations it should be apparent that the modified test set is ideally suited to this particular application. As was the case in power calibration, the procedure has only a small sensitivity to errors in the complex ratio detector.

If an ideal (lossless) sliding short were available, no other terminations would be required. In reality, of course, no such device exists. Moreover, if the performance of the traditional manual method is to be equaled, some means of accounting for the non-ideal short performance must be devised. In order to accomplish this, it is convenient also to observe the system response to an impedance standard (typically a quarter-wavelength short) and a low reflection sliding termination.

Returning to (1), a, b, c are complex constants which characterize the measurement system of figure 2. Moreover,

$$R = \frac{|a - bc|}{1 - |c|^2} \qquad (3)$$

and

$$R_c = \frac{b - ac^*}{1 - |c|^2} \ . \qquad (4)$$

In figure 3 the relationship between w and Γ_ℓ may be written

$$w = \frac{a'\Gamma_\ell + b'}{c'\Gamma_\ell + 1} \qquad (5)$$

where a', b', c' are a new set of constants, which in turn determine R', R_c' as in (3) and (4).

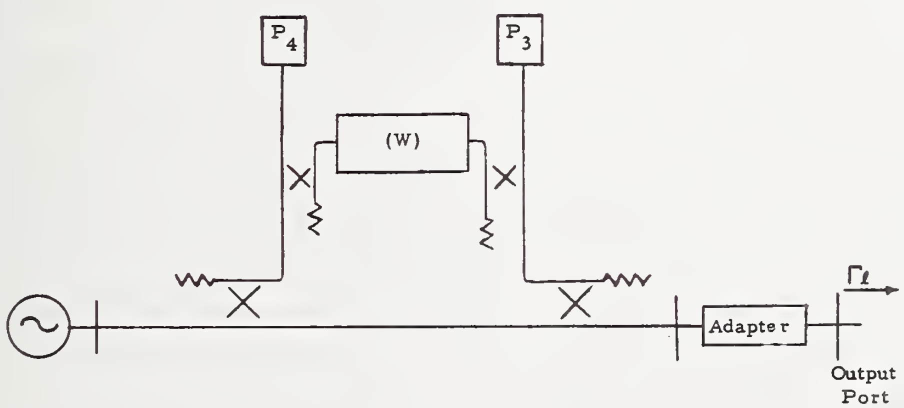

Figure 3. Test set with adapter inserted.

An alternative way of viewing the problem is that of using the impedance standard, non-ideal sliding short, and sliding load to determine the calibration constants a, b, c and a', b', c'. Quite apart from the immediate application, this procedure is of considerable general interest as an alternative calibration technique for automated network analyzers in which only one impedance standard is required. (Existing calibration routines often require two or more standards and include approximations which are inconsistent with the accuracy goals in this problem.)

The model to be assumed for the non-ideal short is that of a lossy uniform waveguide, of unknown attenuation, containing a moving piston of large but unknown reflection. The moving load is assumed to be contained in either the same waveguide, or at least one of the same attenuation constant, and possesses a small but unknown reflection.

4. ADAPTER MEASUREMENT SYSTEM

The adapter measurement system utilizes an automatic network analyzer which consists of a four-arm reflectometer, shown in figure 4, with the incident and reflected arms terminated with thermistor mounts. Provisions are made to allow the computer of the ANA to measure substituted dc powers in the thermistor mounts and test to reference channel complex ratios. NBS Type II bridges are used for measuring dc powers. With the standard termination and sliding short connected to the test port, ratios are measured using the thermistor mount power readings. The ANA provides phase information for both the high and low reflection terminations, and also the low reflection magnitude of reflected to incident signals at the test port.

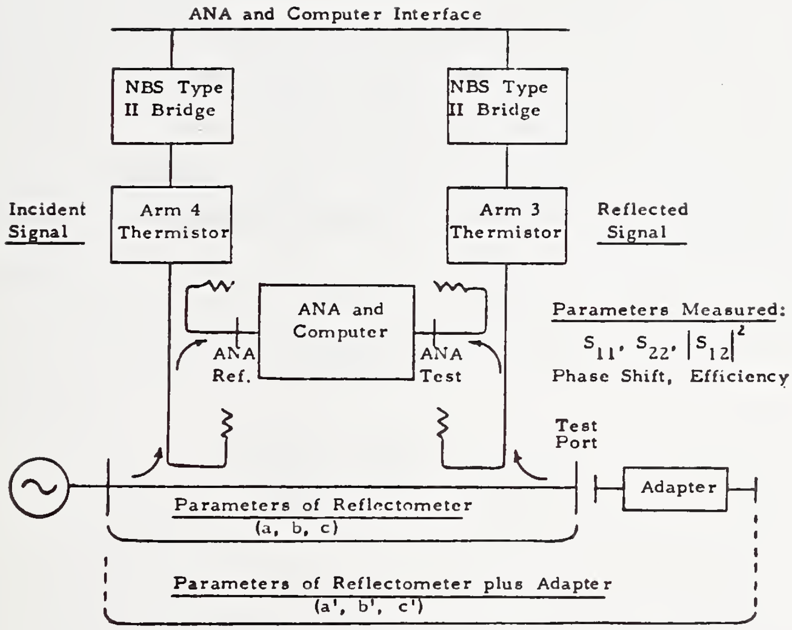

Figure 4. Adapter measurement system.

In order to use the adapter measurement system, sliding low reflection terminations, sliding short circuits, and one standard high reflection termination are required in each of the types of transmission lines or waveguides which terminate the adapter to be measured. In order to measure a coax-to-waveguide adapter, a coaxial sliding load, sliding short and fixed short along with a waveguide sliding load, sliding short and fixed short are required. Terminations for most waveguide sizes are presently available along with 7 mm and 14 mm coaxial terminations. In order to obtain phase information from this system, the phase of the fixed "standard" termination must be known. In general, a nominal quarter-wavelength short or open circuit will suffice for the "standard" (for multiple frequency measurements, the propagation constant and depth of the quarter-wavelength short must be accurately known and accounted for).

5. SCATTERING PARAMETER MEASUREMENTS

The design of the hardware and software for the adapter measurement system is arranged to measure the scattering parameters of any adapter or two-port device regardless of input and output connections. The system also provides for measuring S_{11} only, the magnitude and phase of reflection coefficient, for a termination.

The scattering parameters for the adaptor are obtained from the previous equations and are related by equations (6), (7) and (8).

$$S_{11} = \frac{b' - b}{a - b'c} \tag{6}$$

$$-S_{22} = \frac{ac' - a'c}{a - b'c} \tag{7}$$

and

$$S_{12}S_{21} - S_{11}S_{22} = \frac{a' - bc}{a - b'c}. \tag{8}$$

The assumption in the computer program is made that $S_{12} = S_{21}$. The software is designed to lead an operator through the measurement procedure without his having a knowledge of the basic theory.

6. CONCLUSIONS AND RECOMMENDATIONS

This report has described the basic theory, equations and instrumentation leading to the first step in adapter characterization. The principal accomplishment was the reduction of theoretical concepts into a computer program. A test set was successfully modified and adapted to the automatic network analyzer.

This effort is by no means complete. Additional funding is needed to perform a number of adapter measurements that are required to examine and verify the parameters of interest.

Many varieties of "non-precision" connectors and adapters are used with various types of equipment with losses in accuracy. One cannot forever refuse to measure the performance of such equipment just because its connectors don't mate with precision connectors. The advent of the automatic network analyzer make this problem even more acute, since one must necessarily know the transition from one connector system to another. The funding on the part of CCG for adapter evaluation prompted the Electromagnetics Division to initiate a formal program on connector and adapter evaluation. The EMD effort was designed primarily for modelling and measuring selected types of adapters and connectors, especially SMA type connectors.

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17. KEY WORDS (Alphabetical order, separated by semicolons)

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