A HIGH-POWER DUAL SIX-PORT AUTOMATIC NETWORK ANALYZER FOR DETERMINING BIOLOGICAL EFFECTS OF RF AND MICROWAVE RADIATION

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ABSTRACT

The design, calibration and performance of a high-power (1 to 1000W) automatic network analyzer based on the six-port concept are described for the 10 to 100 MHz range. Imprecision in measuring reflection coefficient Γ is 0.0001 in magnitude and $0.005/|\Gamma|$ degrees in phase. Corresponding estimated systematic errors are 0.001 and $0.1/|\Gamma|$ degrees. Imprecision in measuring power is 0.01% of range (20W, 200W, or 1000W) with an estimated systematic error of 1.25% of reading.

I. Introduction

In spite of the existence of so-called "safe tolerance limits" to microwave radiation, there is a continuing interest in obtaining a more complete understanding of this subject. At the National Institute for Occupational Safety and Health (NIOSH), a program exists for evaluating the response of selected biological specimens to carefully controlled electromagnetic fields with the objective of determining safe levels of rf and microwave radiation. The associated test chamber is designed in such a way as to provide fields which are predominantly either electric, magnetic, or selected combinations of both. This test chamber, shown schematically in figure 1, is a near-field synthesizer [1] consisting of a balanced, parallel-plate strip line to generate the electric field, and a rotatable single-turn inductor placed parallel to and midway between the plates to generate the magnetic field.

The purpose of this paper is to describe the design, calibration, and performance of a high-power automatic network analyzer (ANA) designed for NIOSH by NBS to measure the power and reflection coefficient at the E-field and H-field input ports of this test chamber at power levels of 1 to 1000 watts and frequencies of 10 to 100 MHz. Measurements at the inputs to the near-field synthesizer are made with two six-port reflectometers as shown in figure 1. The design of the reflectometers is based on the new six-port concept of measurement [2]. Basically, for one six-port the concept states that the power and reflection coefficient at one port of any linear network having six-ports can be obtained from measurements of the power at four other ports when a signal is applied to the remaining port.

Six-port reflectometers were chosen as the measuring instruments in this application because of the following significant features which are not found in other automated measurement systems.

1. Simplicity of the construction, operation, and calibration.
2. Superior accuracy and precision.
3. No lossy standards are required in the calibration, eliminating problems due to self-heating.
4. Stability of the calibration with time.

II. System Description

As shown in figure 1, the signal from the source is amplified and passed to the phase shift network where it is divided into two channels by the power divider. Each output from the phase shift network is passed through a six-port reflectometer to the near-field synthesizer. Six-port #1 measures the power and reflection coefficient at the input to the E-field plates of the synthesizer, and six-port #2 measures the power and reflection coefficient at the input to the H-field loop of the synthesizer. The power detectors are read and the switches are controlled by a programmable calculator.

A. Phase Shift Network

The purpose of the phase shift network is to change the phase angle of the two output signals a_1 and a_2 at the six-port measurement planes shown in figure 1. It is necessary to change the phase of a_2 relative to a_1 during calibration of the two six-port reflectometers and also during the measurement of two-port devices inserted between measurement planes 1 and 2.

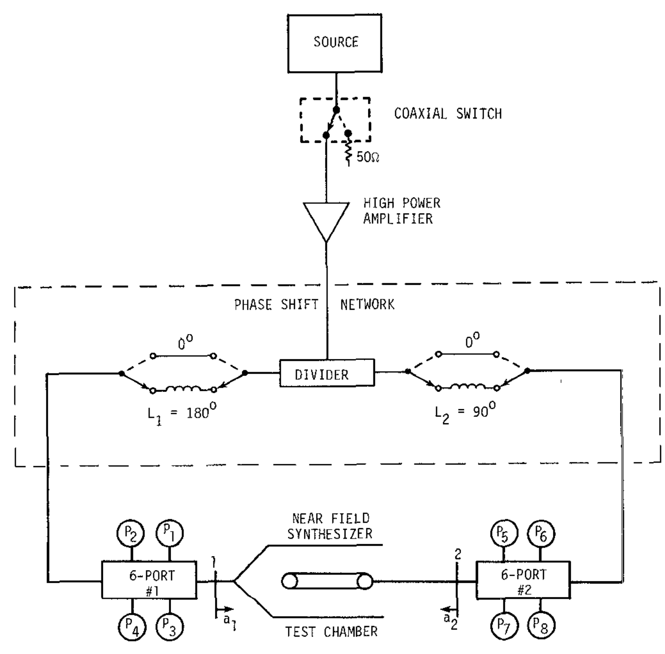

Fig. 1. Block diagram of the high power ANA and the near-field synthesizer test chamber.

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The phase shift network changes the phase difference between the two output waves a_1 and a_2 in four steps of roughly 90^o increments. The circuit accomplishes this phase shift with two lengths of coaxial transmission line L_2 and L_1 which have electrical lengths of approximately 90 and 180 degrees at the frequency of operation. To cover the 10-100 MHz range requires four different lengths of line for L_1 and for L_2.

B. Six-Port Design

The six-port reflectometer design is shown in figure 2. The high-power signal is passed through the main line of a dual directional coupler having 30 dB coupling to the two sidearms. These sidearm signals are further attenuated with two attenuators when the power in either direction in the main line exceeds about 20 watts. The level of attenuation is set by the calculator in 10 dB steps to keep the power level at the thermistor mounts within their optimum range of 1 to 10 mW.

The sidearm signals are then passed through two sets of low-pass filters to a number of hybrids and power dividers. The purpose of the hybrids and power dividers is to combine the two sidearm signals from the coupler in such a way as to give four output signals which are different (independent) combinations of the waves a and b at the measurement plane. The magnitudes of these four outputs are detected with thermistor-type power detectors. The power and reflection coefficient at the measurement plane are calculated from the readings of these four thermistor detectors.

III. Calibration

Before making measurements with the ANA, the six-port reflectometers must be calibrated at or near each frequency where measurements will be made. The steps in the calibration are displayed to the operator on the CRT of the calculator as outlined in figure 3. The input to each six-port is connected to the phase shift network as shown in figure 1 for all of these steps. All of the data taken during the steps shown in figure 3 are with each six-port on its low (20 watt) range.

The power readings taken in steps 4, 5, and 7 are used in the "thru-reflect-line" calibration technique [3] to determine the six-port parameters needed for making Γ and S-parameter measurements. These parameters are then used to determine the loss and phase shift of the line and the reflection coefficients of the shorts and opens. The consistency of these values from calibration to calibration and also with frequency is used as a check on the quality of the calibration. The six-port parameters are then used with the data from step 3 to determine the S-parameters of the 30 dB pad. The pad parameters plus the data from step 2 permit the six-port calibration to be completed so that both six-ports can now measure absolute power as well as reflection coefficient at their measurement planes on the low (20W) range. Other power ranges are calibrated after the last step while the "thru" connection is still made. The Mid (200 watt) ranges are calibrated by the opposite six-port Low range, and the High (1000W) ranges are calibrated by the opposite six-port Mid range.

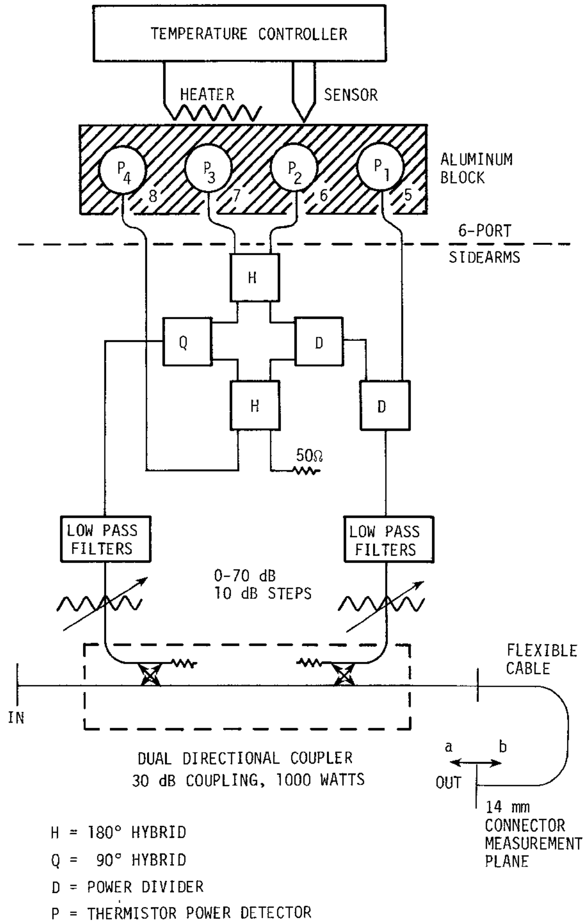

Figure 2. Design of each six-port reflectometer.

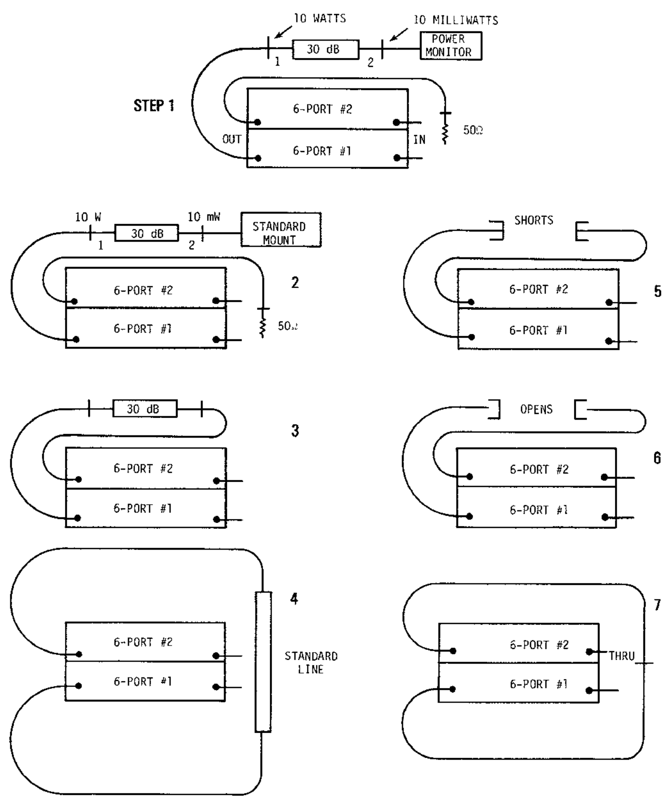

Figure 3. Connections that the operator must make during calibration of the two six-port reflectometers.

IV. Precision and Accuracy

The imprecision in measuring Γ is about 0.0001 in magnitude and $.005/|\Gamma|$ degrees in phase angle. The imprecision in measuring power is 0.01% of the power range. The sytematic error in measuring Γ is estimated to be less than 0.001 in magnitude and $0.1/|\Gamma|$ degrees in phase angle. The systematic error in measuring power is estimated to be less than 1.25%, primarily due to the 1% uncertainty with which NBS can determine the effective efficiency of the standard thermistor mount.

The imprecision and systematic error in measuring the scattering parameters S_{11} and S_{22} of a two-port are the same as those in measuring Γ of a one-port termination. The imprecision in measuring S_{12} or attenuation is less than 0.001 dB up to 15 dB, increasing to 0.15 dB at 60 dB. The systematic error in measuring attenuation was not determined because the instability in the high power pads due to changes with temperature and power level were greater than the errors we were trying to find in the six-port. A detailed investigation of the errors in another dual six-port ANA operating at 3 GHz concluded that the systematic errors were less than the imprecision [4]. That conclusion is probably valid for our high power dual six-port ANA also.

V. Acknowledgements

The author gratefully acknowledges the help of G. Engen who assisted in working out the calibration routines, R. Metzker who constructed the system, and W. Angevine, P. Fales, and R. Adair who assisted in the programming and checkout of the system.

VI. References

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