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BANDWIDTH-SUBSTITUTION TECHNIQUE FOR ABSOLUTE MEASUREMENT OF PO--ETC(U)  
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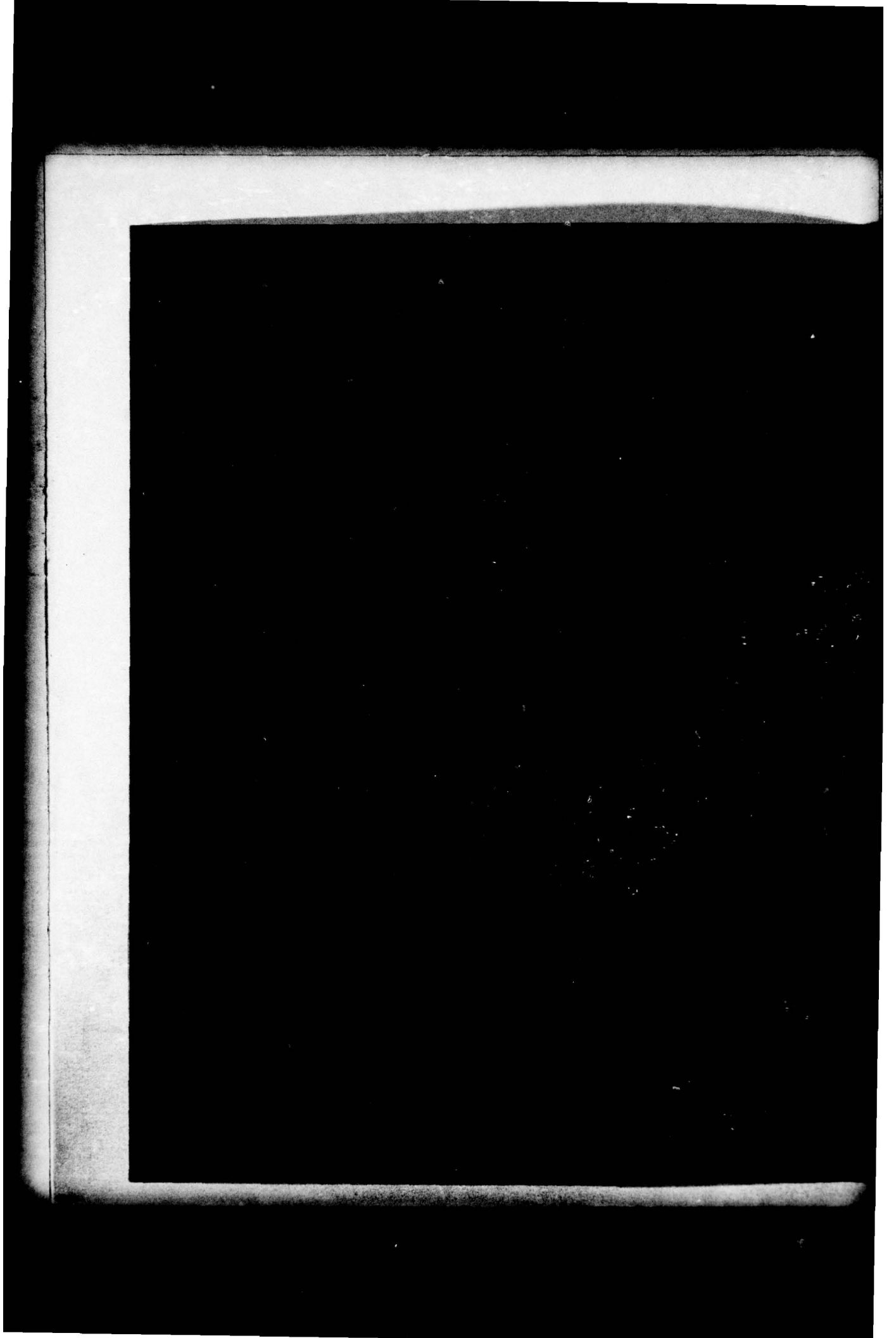


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of the unknown rf power with a primary standard, whereas the other techniques (except for the Incremental Method) require a conversion of the power to heat before the comparison can be made. The main advantage of this technique over the Incremental Method is that it has much higher sensitivity, permitting absolute measurement of rf power to be made down to about -100 dBm, compared with only about -10 dBm for the Incremental Method. An additional advantage of this technique is that it permits the measurement of noise as well as coherent rf power, whereas the Incremental Method is valid only for coherent rf.

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FOREWORD

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## 1. INTRODUCTION

Absolute measurements of microwave power generally employ some type of low-frequency substitution technique involving a transformation of the electromagnetic energy into heat. In the upper frequency range of the microwave region, however, the heating effects of the rf and low-frequency power are not identical. Yet, as the frequency increases, it becomes increasingly difficult to accurately estimate to what extent they differ. For this reason, the existing techniques for *absolute* measurement of rf power are inherently frequency limited, with the current upper limit effectively being about 75 GHz.

Exploitation of frequency bands above 75 GHz is of interest for both military and commercial reasons. The Department of Defense is pursuing the exploitation of these bands for such applications as Low Probability Intercept (LPI) radar, LPI communications, and secure fuzing. Commercially, the exploitation of these frequency bands is pursued primarily because of the enormous bandwidths they provide for communications. Absolute measurement of power is of fundamental importance in these radio-frequency bands because at these frequencies power is one of the two absolute measurements made upon a system.

A recent report<sup>1</sup> describes a new method, the Incremental Method, that represents a significant breakthrough in absolute measurement of rf power, in that it permits the measurements to be made at *all* radio frequencies. However, the Incremental Method has two major shortcomings: it is limited to coherent rf and to power levels at or above -10 dBm.

This report describes the Bandwidth-Substitution Technique, which, like the Incremental Method, permits absolute measurement of power at all radio frequencies. Although somewhat more complicated than the Incremental Method, it has two important advantages over that method. The major advantage is its enormously improved sensitivity: it permits measurements to be made down to about -100 dBm, yielding an improvement in sensitivity of about nine orders of magnitude. Another advantage is that it permits the measurement of noise as well as coherent rf power.

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<sup>1</sup>Abraham Singer and Jan M. Minkowski, *Incremental Technique for Absolute Measurement of Coherent Power at Millimeter and Submillimeter Wavelengths*, Harry Diamond Laboratories TR-1699 (February 1976).



## 2. GENERAL DESCRIPTION

The Bandwidth-Substitution Technique requires a broadband rf noise source of known temperature. Currently, the National Bureau of Standards is providing calibration services\* for noise sources in the frequency regions between 2.6 and 4, 8 and 18, and 55 and 65 GHz, using as a primary standard a "hot-body noise source," such as a silicon-carbide wedge in a gold waveguide or a zinc-titanate wedge in a platinum 13-percent rhodium waveguide hermetically sealed and maintained at about 1300 K. (By primary standard we mean a device whose parameters can be related to fundamental units by an accepted system of theoretical equations.) Outside these frequency regions, and particularly above 65 GHz, the noise source may be calibrated against a gas-driven shock tube, since it has recently been shown<sup>2,3</sup> that such a tube may be used as a primary standard of high temperature. Broadband rf noise sources are available<sup>4</sup> up to about 700 GHz; and a convenient excess noise level may be readily obtained by stacking such sources in tandem.

A basic feature of this technique is its use of an accurate bandwidth measurement at a convenient I.F. to achieve an absolute measurement of power at a desired rf. For this reason, this technique is referred to as the Bandwidth-Substitution Technique.

## 3. MEASUREMENT PROCEDURE

Figure 1 is a block diagram of the measuring system. An auxiliary rf source, of the same type as the one under test, is required to serve as a local oscillator (LO) in providing part of the bias of the diode mixer (the other part of the bias is provided by dc). The auxiliary source must have an output of about -20 dBm or higher, but its value need not be known.

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\*For example, *Calibration and Test Services of NBS, NBS Special Publication 250, 1970*; and *NBS Measurement Users' Bulletin No. 5*.

<sup>2</sup>A. Singer and J. M. Minkowski, *Determination of Electron Temperature of Shock-Heated Plasma from Microwave Measurements (An Improved Model for Relating the Measured Microwave Plasma Parameters to the Electron Temperature), The Physics of Fluids, 16 (July 1973), 1176*.

<sup>3</sup>A. Singer and J. M. Minkowski, *Technique for Absolute Measurement of Noise Power at All Radio Frequencies, Harry Diamond Laboratories TR-1671 (March 1975); and U. S. Patent No. 579644 (May 1975)*.

<sup>4</sup>K. H. Breeden, W. K. Rivers, and A. P. Sheppard, *A Submillimeter Interference Spectrometer: Characteristics, Performance and Measurement, NASA Contractor Report CR-495 (May 1966)*.

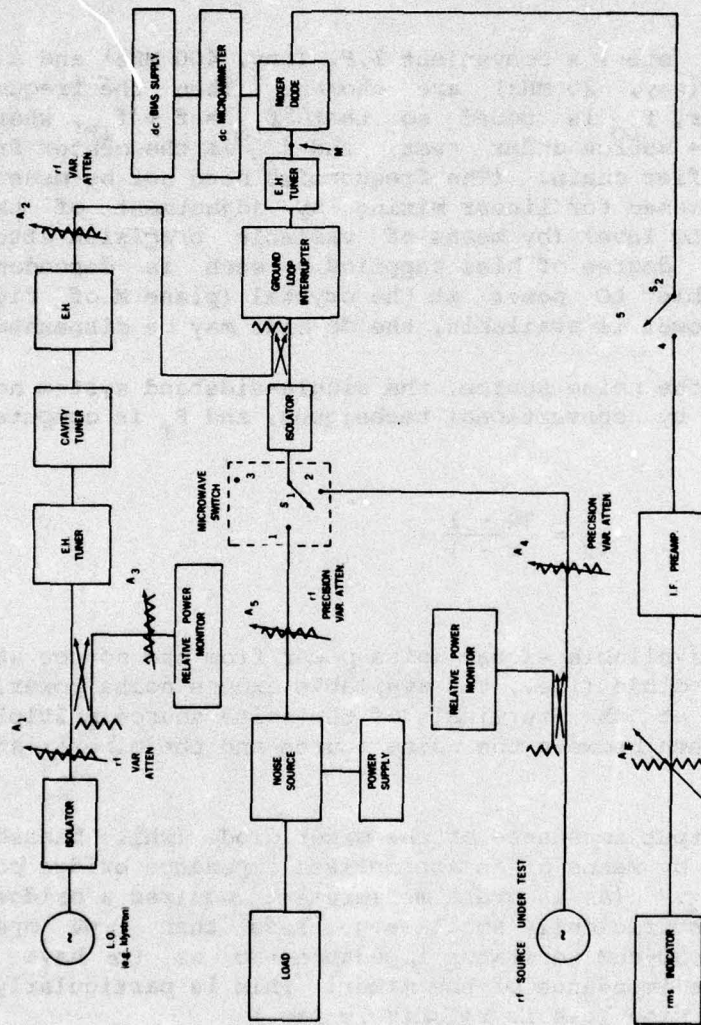


Figure 1. Block diagram of system for absolute measurement of rf power.

As in the Incremental Method,<sup>1</sup> the primary function of the tuned rf cavity in the LO arm is to suppress the AM noise in the vicinity of the output LO line so that its contribution in the I.F. window under consideration is negligible. The trade-offs involved in eliminating the need for the tuned rf filter are similar to those in the Incremental Method.

As a first step, a convenient I.F. (say, 400 MHz) and a convenient I.F. bandwidth (say, 20 MHz) are chosen. Then the frequency of the local oscillator,  $f_{LO}$  is tuned so that  $f_{LO} = f + f_{IF}$ , where  $f$  is the frequency of the source under test, and  $f_{IF}$  is the center frequency of the I.F. amplifier chain. (The frequencies need not be measured.) The diode is then biased for linear mixing by adjustment of the dc power supply and the LO level (by means of variable precision attenuators  $A_1$  and  $A_2$ ). The degree of bias supplied by each is dependent on the maximum available LO power at the crystal (plane M of fig. 1). If sufficient LO power is available, the dc bias may be dispensed with.

By use of the noise source, the single-sideband system noise factor  $F_T$  is measured by conventional techniques, and  $F_T$  is computed from the expression

$$F_T = \frac{2N - 1}{Y - 1} \quad (1)$$

where  $N$  is the available excess noise power from the source at the plane M of the mixer diode (i.e., the available excess noise power, expressed as a numeric, at the terminals of the noise source multiplied by the loss in the path between the noise source and the mixer); and  $Y$  is the Y-factor.

The I.F. output impedance of the mixer diode (while biased by dc and LO) is measured by means of an appropriate impedance bridge connected to position 5 of  $S_2$ . (An accurate measurement requires a bridge having an output signal sufficiently small--e.g., less than 1-mV open circuit voltage from a 50-ohm generator impedance--so as to have negligible influence on the impedance of the mixer. This is particularly true when the mixer conversion loss is relatively low.)

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<sup>1</sup>Abraham Singer and Jan M. Minkowski, *Incremental Technique for Absolute Measurement of Coherent Power at Millimeter and Submillimeter Wavelengths*, Harry Diamond Laboratories TR-1699 (February 1976).

The I.F. noise bandwidth  $B$  is now determined by use of an I.F. generator whose output impedance approximately equals the I.F. output impedance of the mixer diode, and whose output level is kept constant with changes in its frequency. The noise bandwidth is not always equal to the 3-dB I.F. bandwidth. Therefore, to establish  $B$  accurately, we should sweep the I.F. amplifier chain with a signal generator over a much wider frequency range, e.g., until the relative amplitude of the output signal drops by, say, 20 dB below its center value. Now, assuming that the shape of the power output versus frequency curve is roughly that of a single bell, we compute the useful channel bandwidth by dividing the area under the curve by the amplitude at the center. For simplicity we are assuming that the superheterodyne system has a single principal response of bandwidth  $B$  and no spurious responses.

By use of the rf source under test, the system noise factor  $F_T$  is now measured by the signal generator method. It can be shown that here  $F_T$  may be expressed as

$$F_T = \frac{P_O}{kT_B} - 1 \quad , \quad (2)$$

where  $P_O$  is the unknown available rf power at plane M from the signal generator under test,  $k$  is Boltzmann's constant,  $T$  is the temperature of the system (usually room temperature), and  $B$  is the effective noise bandwidth.

Equating (1) and (2) and solving for  $P_O$ , we get

$$P_O = kT_B \left( \frac{2N - 1}{Y - 1} + 1 \right). \quad (3)$$

Since all quantities on the right-hand side of the equation are either known or have been measured, the output power level  $P_O$  of the rf source under test at the terminals of the mixer may be readily calculated.

#### 4. CONCLUSIONS

The major advantage of the Bandwidth-Substitution Technique over the Incremental Method is its enormously higher sensitivity: it permits absolute measurement of rf power to be made down to about -100 dBm, compared with only about -10 dBm for the Incremental Method--an improvement in sensitivity of about nine orders of magnitude. An

additional but less important advantage of this technique is that it permits measurement of noise as well as coherent rf power, whereas the Incremental Method is valid only for coherent rf.

The two techniques require about the same amount of work to execute the measurements, but their steps are not the same. Both methods require the measurement of the I.F. output impedance of the mixer. The Incremental Method requires a careful measurement of the mixer-conversion loss and noise-temperature ratio and of the noise factor of the I.F. amplifier chain; the Bandwidth-Substitution Technique does not require these measurements, but instead, requires a measurement of the effective I.F. noise bandwidth. On the other hand, the Incremental Method requires only one measurement of the system noise factor, whereas the Bandwidth-Substitution Technique requires two. Further, if one chooses not to include a tuned rf filter in the LO arm, in the Incremental Method one must provide sufficient I.F. bandwidth to accommodate the drift of one rf source; in the Bandwidth-Substitution Technique, the I.F. bandwidth must be sufficient to accommodate the drift of two rf sources.

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