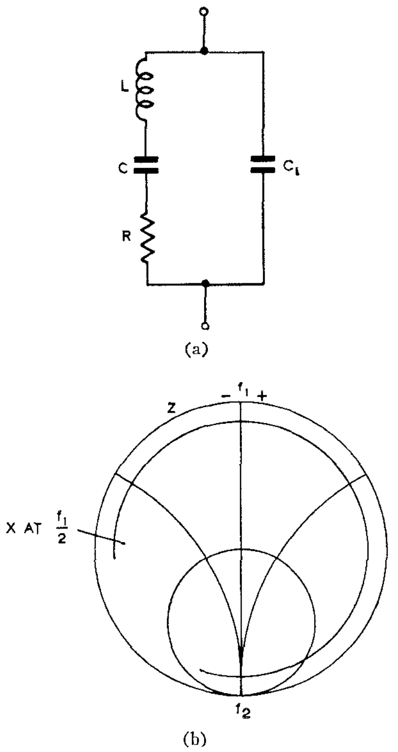

Fig. 5—(a) Equivalent circuit for varactor diode. (b) Schematic representation of impedance plot.

Now from (3) and (4)

$$C_1 = \frac{3B_0}{\pi f_1\left[4\left(\frac{f_2}{f_1}\right)^2 - 1\right]}, \qquad (5a)$$

or to a very good approximation as Y_0 is in practice almost entirely reactive,

$$C_1 = \frac{-3}{\pi f_1 X_0\left[4\left(\frac{f_2}{f_1}\right)^2 - 1\right]}, \qquad (5b)$$

where X_0 is the reactance at $f_0 = f_1/2$. Having determined C_1, (4) and (1) give

$$C = \left[\left(\frac{f_2}{f_1}\right)^2 - 1\right] C_1 \qquad (6)$$

$$L = \frac{1}{(2\pi f_1)^2 C}. \qquad (7)$$

Also, R may be determined from a direct measurement of VSWR at frequency f_1. If this is S_1,

$$R = \frac{Z_0}{S_1},$$

where Z_0 = characteristic impedance of the line.

Fig. 5(b) shows a schematic picture of the kind of Smith chart plot that would be expected from this type of equivalent circuit. f_1 and f_2 are the frequencies at which the resistive axis is crossed and $f_0 = f_1/2$.

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Microwave Insertion Loss Test Set

SUMMARY

A simple, accurate test set has been devised for measuring insertion losses at microwave frequencies. It is composed almost entirely of commercially available equipment and components. The short-term jitter is about 0.0004 db peak-to-peak, and long-term drift is typically 0.0015 db/hour. Accuracy of the measurements depends on the value of the insertion loss measured and is better than ±0.001 to ±3 per cent for insertion loss measurements in the 0 to 25 db range. These accuracies include the non repeatability of connecting and disconnecting the waveguide flanges used in the system.

The upper operating frequency is presently limited to 40 Gc by the thermistor mount characteristics of the Hewlett-Packard 431B power meter, although the test set has operated at frequencies as high as 90 Gc with transitions resulting in slight performance degradation.

INTRODUCTION

Accurate measurements of the parameters of passive microwave components are required in building and testing low-noise microwave receiving systems. At the Jet Propulsion Laboratory, Pasadena, Calif. there was a need for an instrument that could measure the insertion loss of low-loss coaxial and waveguide components beyond the normal precision capability of available equipment. Measurements of the required precision had previously been achieved[1] but at the cost of extreme care and extraordinary temperature stabilization.

A simple dual channel insertion loss test set (Fig. 1) has been constructed almost entirely from commercially available equipment and components. In this set, the signal level is sampled before application to the component under evaluation and then compared to the signal level after application. Potentiometer R1 (Fig. 1) is adjusted so that the null voltmeter indicates a null both before and after inserting the component to be measured at POINT A. The difference in the potentiometer ratio (converted to db) is a measure of the insertion loss of the component. Tables have been compiled to facilitate the conversion of the ratio reading to db.

Errors due to amplitude instability of the signal source are virtually eliminated by the test set. Modulation of the signal source is not required due to the excellent stability of the Hewlett-Packard HP 431B power meter, thus eliminating possible errors from klystron double moding, etc.

POWER METER MODIFICATIONS

The internal circuitry of the power meter has an output which is proportional to the square root of the applied power. In order to have a linear output with respect to power, a squaring circuit used on the output of the power meters gives straight line segments approximating square law nonlinearity. The output linearity of the power meters was greatly improved by monitoring the feedback current through one of the power meter range resistors[2] thereby bypassing the squaring circuit output.

The bridge circuit and the necessary modifications to the power meters are shown in Fig. 2. The added resistance of the helipots assures full-scale operation of the power meters, providing the highest linearity possible. The capacitors provide noise filtering. Since the feedback current varies as the square root of the applied power, the insertion loss (in decibels) measured by the potentiometer bridge is given by 20 log (ratio).

TEST-SET PERFORMANCE

Fig. 3 is a photograph of the 8448-Mc microwave insertion loss test set. The VSWR, looking in either direction from POINT A, is under 1.02 to obtain the necessary absolute accuracy.[1]

To give an example of typical test-set performance, a right-angle waveguide section was measured 8 consecutive times.

1) Average insertion loss was 0.0282 db.
2) Maximum difference from this average was 0.0017 db.
3) Average difference of all measurements from 0.0282 db was 0.0008 db, which includes the nonrepeatability of connecting and disconnecting waveguide flanges.

The measurement of linearity of an insertion loss test set is very difficult. The most successful technique used an S-band precision rotary vane attenuator[3] as a standard. Table I lists the rotary vane theoretical attenuation, measured attenuation and per cent difference between the two. The per cent difference between theoretical and measured attenuation (db) is shown graphically in Fig. 4. The insertion loss test-set accuracy (derived from repeatability and linearity measurements) is somewhat better than that shown in Table II.

A selection of insertion loss measurements of H-band components is listed in Table III. Each value represents an average of ten consecutive measurements. The last column in Table III is the average value of the difference of each measurement from the average insertion loss value.

A stability test was made of the test set by recording the output of the null voltmeter, a typical sample of which is shown in Fig. 5. Short-term jitter is about 0.0004 db peak-to-peak, and long-term drift is typically 0.0015 db/hr.

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[1] C. F. Engen and R. W. Beatty, "Microwave attenuation measurements with accuracy from 0.0001 to 0.06 db over a range of 0.01 to 50 db," *J. Res. Nat. Bur. Standards*, Section C, Engineering and Instrumentation, vol. 64C; April-June, 1960.

[2] Suggested by Mr. F. Praman of Hewlett-Packard, Palo Alto, Calif. These are resistors R160-R166 shown in Fig. 5-3 of HP Instruction Manual for the HP 431B power meter.

[3] T. Otoshi, "*S* Rotary Vane Attenuator," "Space Programs Summary," vol. IV, California Institute of Technology, Jet Propulsion Lab., Pasadena, Rept. No. 37-25, February 29, 1964.

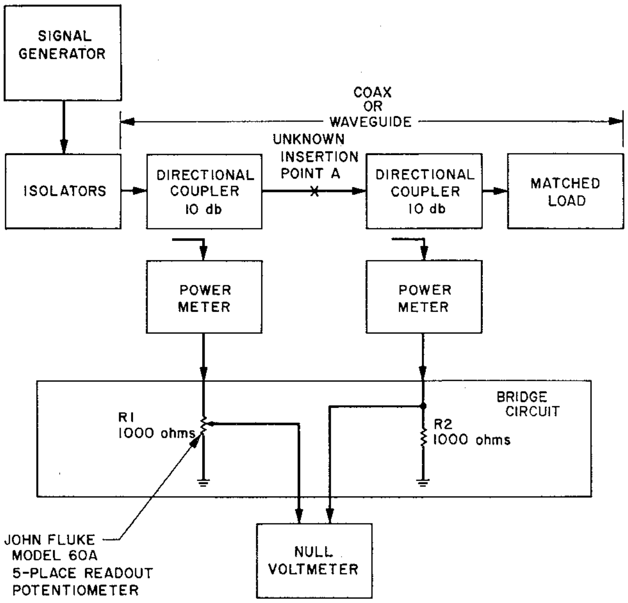

Fig. 1—Block diagram of microwave insertion loss test set.

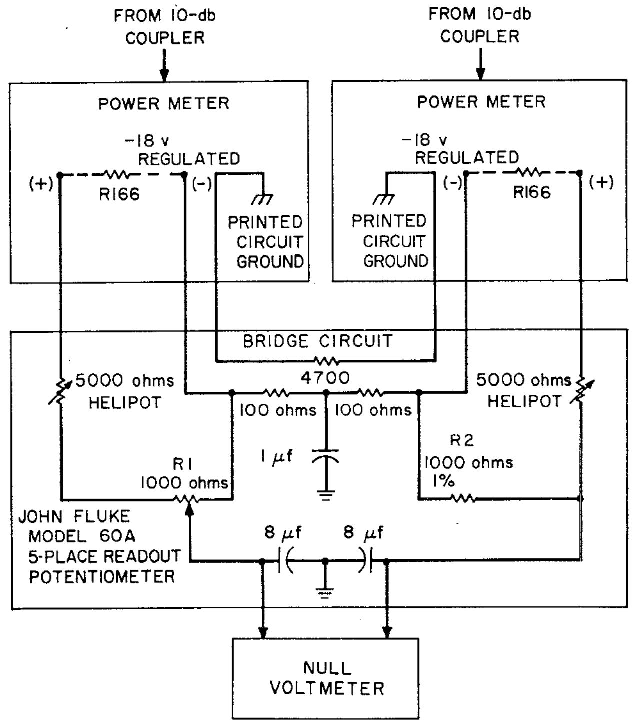

Fig. 2—Modifications made to improve linearity of microwave insertion loss test set.

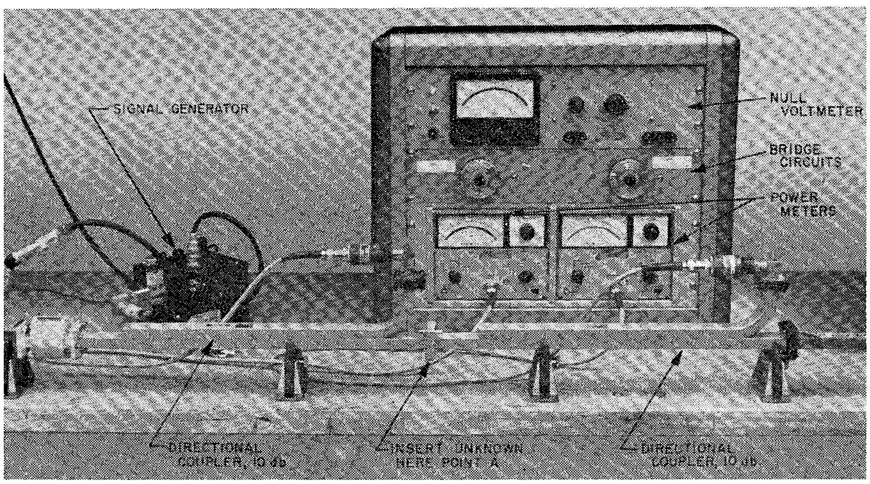

Fig. 3—Microwave insertion loss test set.

TABLE I

Rotary Vane Measured Attenuation Compared to Theoretical Attenuation at 2388 Mc

Theoretical attenuation Av, db	Measured attenuation Am, db	Average measured difference from corrected attenuation (Av-Am) db	Per cent difference of db reading $\left(\frac{Av-AM}{Av}\right)$ ×100 per cent
0.0000	—	—	—
0.0201	0.0201	0.0000	—
0.0400	0.0400	0.0000	—
0.0601	0.0599	+0.0002	—
0.0801	0.0800	+0.0001	—
0.1001	0.0999	+0.0002	—
1.0018	1.0007	+0.0011	0.11
3.0043	3.003	+0.0013	0.04
6.0097	6.013	−0.003	0.05
9.0147	9.031	−0.016	0.18
12.0178	12.060	−0.042	0.35
18.0312	18.188	−0.157	0.87
20.0382	20.27	−0.230	1.1
25.0597	25.61	−0.550	2.2

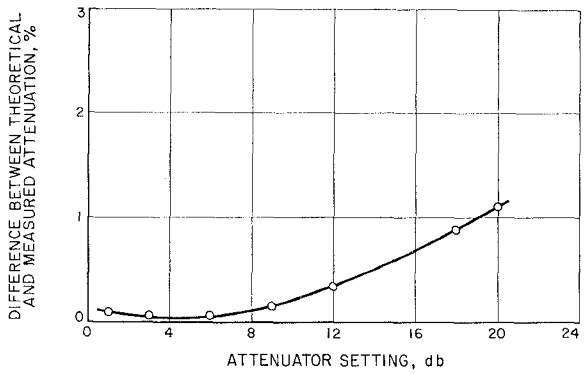

Fig. 4—Linearity test of the insertion loss test set.

TABLE II
ACCURACY TOLERANCES OF INSERTION LOSS MEASUREMENTS

Insertion loss measurement range, db	Accuracy of measured value, db
0 to 6	±0.001 ±0.1 per cent
6 to 18	1 per cent
18 to 25	±3 per cent

TABLE III
INSERTION LOSS OF VARIOUS *H*-BAND WAVEGUIDE COMPONENTS

Description of test item	Date	VSWR	Insertion loss db	Average difference db
6-in straight waveguide (Narda type 341)	7-11-63	1.005	0.014	0.0006
Mica window (RG-51/U) (Microwave Associates)	7-12-63	1.01	0.012	0.0007
20 db directional coupler-matched loads on two unused faces (Hewlett-Packard H 750D)	—	—	0.0640	0.0010
3.4-inch straight stainless steel waveguide (RG-51/U) plated inside with 0.00015 inch Cu, 0.00001 inch Au	8- 6-63	—	0.0120	0.0004
24-inch straight stainless steel waveguide (no plating)	8- 9-63	—	0.389	0.0005

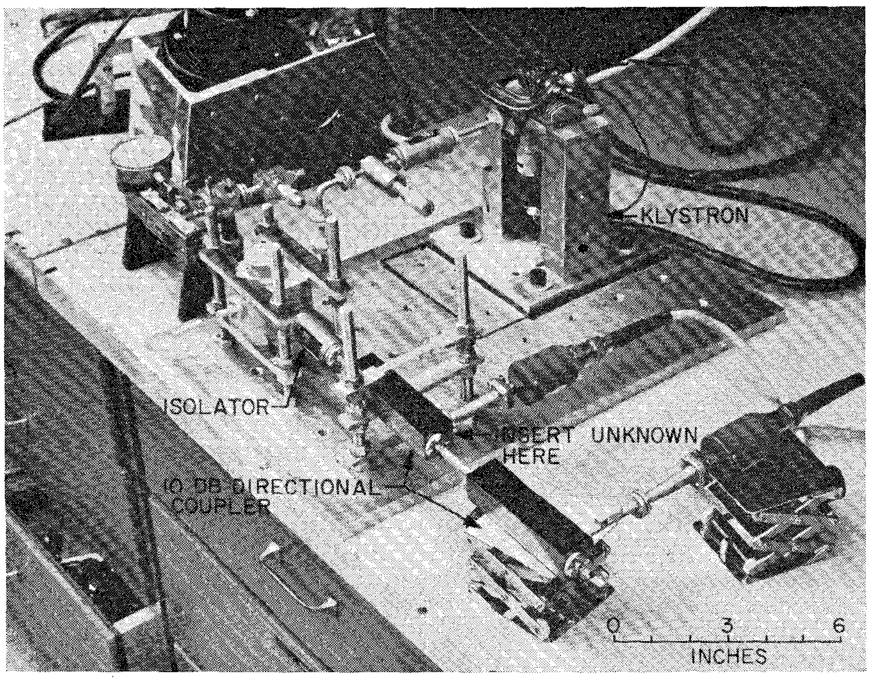

Fig. 5—Stability recording of insertion loss test-set instrumentation.

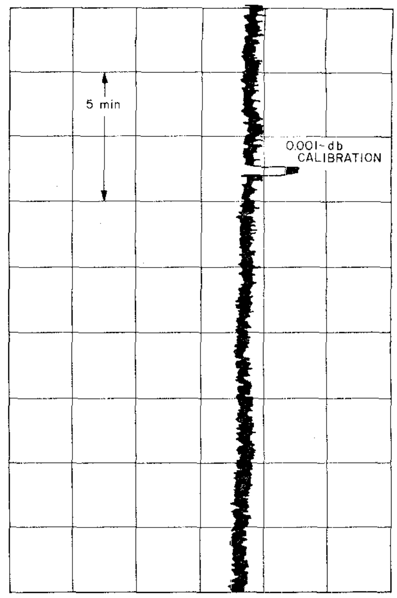

Fig. 6—Insertion loss test-set application at 90 Gc.

The test set has recently been used at 90 Gc (Fig. 6) for component evaluation of a millimeter radiometer. Commercially available power meter detectors rated to 40 Gc were used with transitions. The performance was somewhat degraded from that otherwise obtained at lower frequencies.

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Circular Polarization at Millimeter Waves by Total Internal Reflection

A plane wave traveling from a dielectric medium with dielectric constant ϵ_1 into a dielectric medium with dielectric constant ϵ_2, for which $\epsilon_1 > \epsilon_2$, is totally reflected at an angle of incidence θ_i greater than the critical angle of incidence θ_c, defined by

$$\sin^2 \theta_c = \frac{\epsilon_1}{\epsilon_2}.$$

When this phenomenon of total reflection occurs, a plane incident wave polarized in the plane of incidence is reflected[1,2] with a phase change δ_p, where

$$\delta_p = 2 \tan^{-1} \frac{\epsilon\sqrt{\epsilon \sin^2 \theta_i - 1}}{\cos \theta_i \sqrt{\epsilon}}.$$

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[1] J. A. Stratton, "Electromagnetic Theory," McGraw-Hill Book Company, Inc., New York, N. Y., pp. 497–500; 1941.

[2] F. A. Jenkins and H. E. White, "Fundamentals of Optics," McGraw-Hill Book Company, Inc., New York, N. Y., pp. 512–518; 1957.