Accurate Six-Port Operation with Uncalibrated Nonlinear Diodes

P. I. SOMLO, SENIOR MEMBER, IEEE, J. D. HUNTER, SENIOR MEMBER, IEEE, AND D. C. ARTHUR

Abstract **—A new mode of six-port operation is described, in which uncalibrated semiconductor diodes operating at a constant level are used as power sensors. Each diode is used in turn as a leveling loop detector, and the resulting changes in source output power are measured by a single linear power meter.**

I. Introduction

It was shown by Engen [1] that six-port reflectometry requires the measurement of three power ratios, P_i/P_4, $i=1$, 2, and 3, where P_i is the power emergent at port i of a six-port junction. If linear (thermistor) power meters are used to measure the P_i, relatively high microwave power levels are required to drive the six-port. This requirement is avoided by using semiconductor diodes as power meters, but their inherent nonlinearity means that an assumption of square-law characteristics [2] should not be expected to yield highly accurate results.

Alternatively, the diodes may be calibrated [3], [4], but this is time-consuming for multifrequency measurements, particularly since it is necessary to perform periodic recalibrations in order to maintain high accuracy. The new operating mode introduced in this communication uses diodes whose detector laws need neither be assumed nor established.

II. Use of Uncalibrated Nonlinear Diodes

In the new mode of operation, diode detectors are connected to the four ports $i=1$, 2, 3, and 4 of a six-port reflectometer, as shown in Fig. 1. Each diode is used in turn as the sensor of a leveling loop which controls the power delivered from the source. This power is monitored by a single linear power meter which may be located at any point in the circuit at which the power level is adequate, but is most conveniently placed near the signal source. When the diode at port i operates as the leveling loop sensor, the power L_i indicated by the power meter is proportional to the inverse of the power which would have been emergent at port i in the absence of the leveling loop. Consequently, the required ratios P_i/P_4 are given by

$$P_i/P_4 = L_4/L_i, \qquad i=1,2,3.$$

Since L_i is always measured with the diode connected to port i operating at a constant level, the characteristics of the diode need not be known. In common with other six-port operating modes, the calibration factor of the linear power meter need not be known, because only power ratios are required.

Because leveling is achieved by reducing the microwave signal, the leveling point must be chosen below the minimum (unleveled) diode output encountered. If during the use of the six-port, changes occur in the sensitivities of the diodes (due, for example, to ambient temperature changes) they will, in general, lead to errors in the measured power ratios. This problem is readily overcome by reconnecting a reference termination to the measuring port, and comparing the L_i with those obtained previously. Subsequent power measurements can be scaled appropriately.

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The authors are with the Commonwealth Scientific and Industrial Research Organization (CSIRO) of Australia, Division of Applied Physics, National Measurement Laboratory, Bradfield Road, West Lindfield, Sydney, Australia.

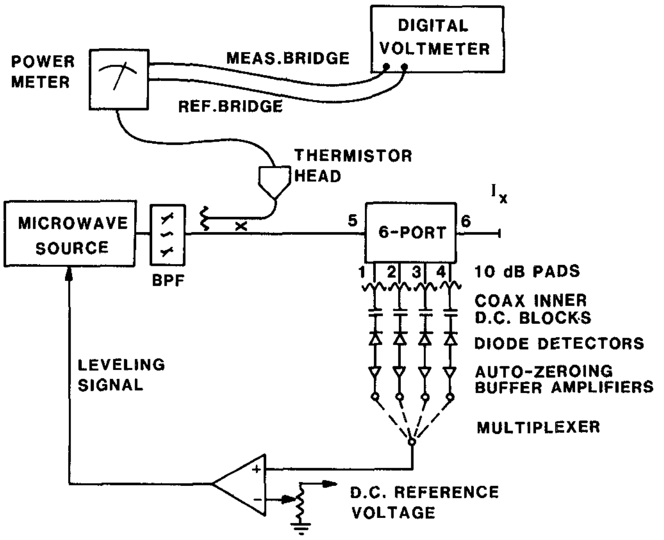

Fig. 1. Block diagram of six-port reflectometer operation with four nonlinear power detectors (semiconductor diodes) acting as leveling sensors The corresponding power changes are read from a linear (thermistor) power meter.

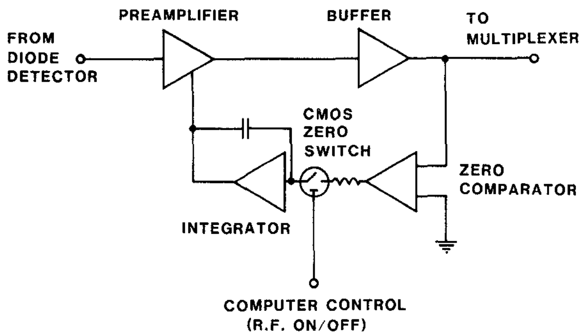

Fig. 2. Block diagram of the auto-zeroing detector amplifier. After the microwave signal is cut off, a charge is set on the integrating capacitor so as to cause a zero output to be presented to the multiplexer. This charge is maintained during the subsequent measurement, with the microwave signal on.

III. Implementation and Results

In our implementation, the diode detectors are connected sequentially, under computer control, to the leveling amplifier, as shown in Fig. 1, while the computer operated digital voltmeter monitors the thermistor power meter. Each diode is operated into a low-drift operational preamplifier followed by a conventional buffer amplifier, with an overall gain of 40 dB, as shown in Fig. 2. Before measuring a reflection coefficient, the outputs of the buffer amplifiers are zeroed in order to eliminate amplifier offsets and the effects of thermal EMF's at the preamplifier input. Our method of zeroing under computer control is to cut off the microwave signal by switching the leveler input to a high dc voltage, and then close the CMOS switch. This causes the zero comparator to drive the integrator until the buffer amplifier output is zero. (The outputs of the power meter are also measured with the microwave signal off, to allow for the correction of power meter offset errors.) After the CMOS switch is released, the integrator maintains the correction signal while measurements are taking place.

Because semiconductor diodes generate harmonics which will be detected by other diodes, each is preceeded by a 10-dB pad,

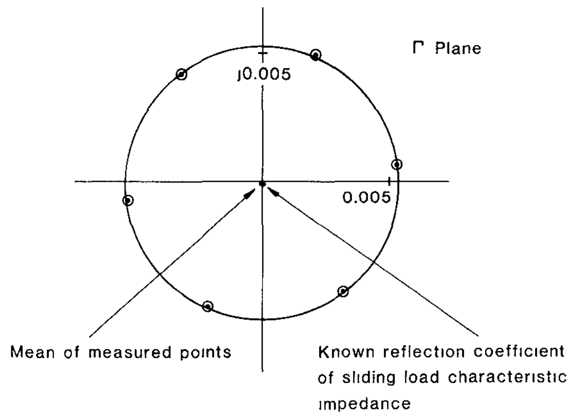

Fig. 3. Measured reflection coefficients of a sliding load at 6 equispaced positions The center of the best-fit circle is within 0.00007 of the known reflection coefficient of the characteristic impedance of the sliding load

which not only ensures at least 20-dB additional isolation between diodes, but also stabilizes their impedances as seen from the six-port junction. Some diode types produce at their microwave port a fraction of the detected dc voltage, and therefore each is also preceeded by a dc block on the inner coaxial conductor to eliminate dc cross-talk.

To illustrate the viability of the operating mode, a six-port [3] was calibrated using five standard terminations [6], and Fig. 3 shows the results of measurements made at 5 GHz on a sliding load (with a residual VSWR of approximately 1.01) moved in equal increments. The standard deviation of the measured values of $|\Gamma|$ from the best-fit circle was less than 0.00003, and the magnitude of the difference between the mean of the measurements and the known value of the reflection coefficient of the characteristic impedance of the sliding load was less than 0.00007. The standard deviation of the difference between the measured arguments of Γ was less than 0.85 degrees, which is noteworthy considering that angular definition is indeterminate at the origin.

A test at 5 GHz was made on a sliding short-circuit moved in equal increments. The standard deviation of the differences between the measured arguments of Γ was less than 0.08 degrees, corresponding to a physical displacement of 0.0066 mm.

These results show that six-port operation using uncalibrated nonlinear diodes is no less accurate than methods using calibrated diodes [3], [5], [6].

A variation of the operating mode described above is to replace one of the diodes (say diode 4) with a linear power meter, and use the remaining three diodes in turn as leveling loop detectors, thus providing three values of L_i, $i = 1$, 2, and 3. The value of L_4 is a constant, K, as can be seen by imagining a fourth diode to be in parallel with the power meter, and used as a leveling detector. Thus

$$P_i / P_4 = K / L_i, \qquad i = 1,2,3.$$

with K assigned an arbitrary positive value. Since only three diodes are used, there is a 25-percent reduction in measurement time, but the method is sensitive to changes in the leveling reference voltage (effectively, changes in K), whereas the four-diode mode is largely immune to leveling reference changes, with any sensitivity being solely due to differences in diode characteristics. Such differences are small at the low diode operating level.

IV. Conclusions

Multiplexing four diodes to act in turn as sensors for a closed loop leveling circuit, and recording the corresponding power readings of a single linear power meter, eliminates the need for either a) four linear power meters, and therefore in practice, the use of relatively high powers, or b) the calibration of semiconductor diodes to be used as low-level power meters.

By operating all the diodes at a fixed level, sensitivity changes (with temperature of time) may be easily accomodated by the use of scaling factors.

The operating mode also offers flexibility in the choice of diodes, since their linearity is not a consideration. Instead, low $1/f$ noise may be a selection criterion, suggesting, for instance, the use of tunnel diodes.

The only disadvantage of the mode of operation is that nonlinear (level dependent) impedances cannot be measured, since the level at the measuring port is not held constant during the measurement.

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Scalar Variational Analysis of Single-Mode Waveguides with Rectangular Cross Section

PRASANNA K. MISHRA, ANURAG SHARMA, S. LABROO, AND A. K. GHATAK

Abstract —**We use the variational method to analyze single-mode optical waveguides with rectangular cross section. In particular, we propose a new trial field and show that it gives much better results and involves less computational effort as compared to other trial functions.**

I. Introduction

Single-mode optical waveguides with rectangular cross sections are the building blocks of most of the devices in integrated optics, and, hence, a knowledge of their propagation characteristics is important for the design of such devices. However, it is not possible to solve the electromagnetic boundary value problem analytically to obtain the propagation characteristics of such

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The authors are with the Department of Physics, Indian Institute of Technology, New Delhi-110016, India. P K. Mishra is currently on study leave from G. M. College, Sambalpur-768004, Orissa, India

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