MILLIMETRE-WAVE VECTOR MEASUREMENTS USING MULTISTATE REFLECTOMETERS WITH DIODE DETECTORS

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ABSTRACT

The use of diode power detection with millimetre-wave multistate reflectometers is described. The nonlinear behaviour of the diodes has been linearised and comparisons with thermistor-based systems show that high quality vector measurements are produced at Q-band and 94.9 GHz with a significant improvement in measurement speed.

INTRODUCTION

Heterodyne techniques are commonly used to make vector measurements at microwave and millimetre-wave frequencies. In the field of electrical standards it is more common to use direct detection systems such as six-port networks [1] and multistate reflectometers [2]. These systems have the advantages of being simple to construct, without the requirements of equalised path lengths or high input powers which are often necessary for heterodyne systems, hence they are suitable for use at millimetre-wave frequencies.

Generally, direct detection systems make use of thermistors as the power detectors because they are intrinsically linear and provide adequate sensitivity. Their main disadvantages are the speed of response and limited dynamic range, however in a multistate reflectometer the dynamic range requirement is traded for a need for good linearity.

This paper discusses the use of diodes as power detectors for multistate reflectometers. Their nonlinear behaviour is characterised and linearised. Measurements are described over the frequency range 30.0 to 40.0 GHz for a reflectometer with both thermistor and diode power detection. A novel multistate reflectometer employing a scalar network analyser with diode detectors is described and measurements are compared with a thermistor-based system at 94.9 GHz.

DIODE DETECTOR LINEARISATION

The method of Hoer, Roe and Allred was employed in the characterisation of the nonlinear behaviour of the detectors as a function of incident power [3]. The circuit layout is shown in Figure 1, its main component being a two-position switched attenuator. It is not necessary to have an accurate knowledge of the value of attenuation provided it is repeatable with switching. Readings of the diode response as a function of the input power are taken for the two switch positions.

A mathematical model is used in conjunction with the data. The

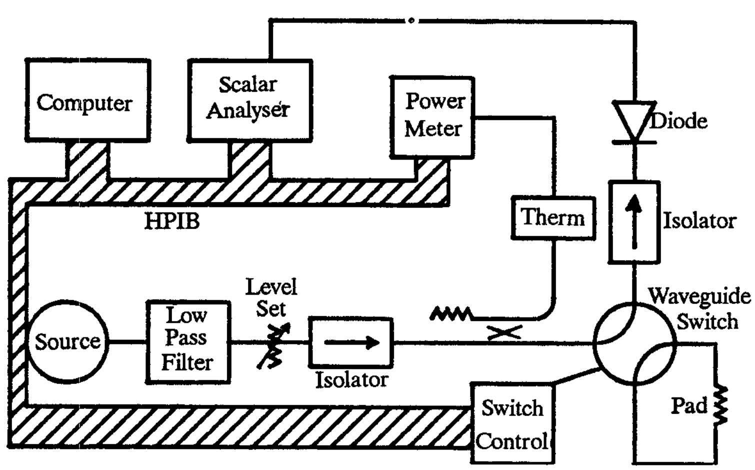

Figure 1 - Data Collection System for the Diode Linearisation Process

model of Chen and Xu [4] was chosen because it does not suffer from the limitations of the model of Hoer *et al* and is given as

$$P = K\,V\,(\,10^{\frac{1}{10}\sum_{i=1}^{N} a_i x^i}\,) \qquad (1)$$

where P is the incident power, V is the output voltage, K and a_i are constants and x is a function of V, for example

$$x = \log_{10}\left(\frac{V}{q} + 1\right) \qquad (2)$$

where q is a scale factor to maintain $0 < x < 0.5$. Combining this equation with the readings produces a system of equations which may be solved simultaneously to obtain the coefficients of the polynomial. A Chebychev polynomial model was also used, to determine the optimum number of coefficients required in the polynomial representations. The equation is the same as (1) except the variable x^i is replaced by the function $T_i(x)$ which is defined by

$$\begin{aligned} T_0(x) &= 1 \\ T_1(x) &= x \\ T_{n+1}(x) &= 2x\,T_n(x) - T_{n-1}(x) \end{aligned} \qquad (3)$$

It was found that a third order polynomial provided the best fit to the measurements, but it was necessary to make use of an over-determined set of equations to obtain consistent results.

The linearity of the resulting models was investigated by measuring a fixed attenuator as a function of input power and the results for the two models are shown in Figure 2. The power series format produced the best response and was used in the following measurements.

30.0 TO 40.0 GHz MEASUREMENTS

A Q-band multistate reflectometer was used to determine the usefulness of the diode linearisation method in a measurement system. The layout of the measurement system is shown in Figure 3. The diodes were linearised at 30.0, 35.0 and 40.0 GHz and isolators were included to reduce any changes in detector input reflection coefficient as a function of input power.

Three sections of reduced-height waveguide were measured, terminated with either a short circuit or a matched load, producing a range of reflection coefficient values. The results are compared in Tables 1 to 3.

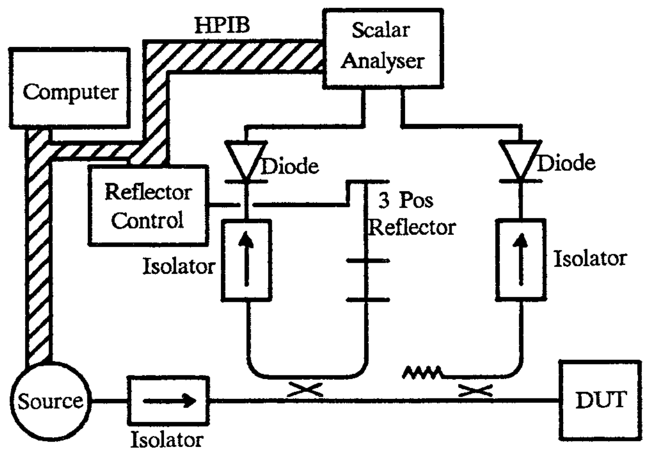

Figure 3 - Schematic Layout of the 26.5 to 40.0 GHz Multistate Reflectometer with Diode Detection

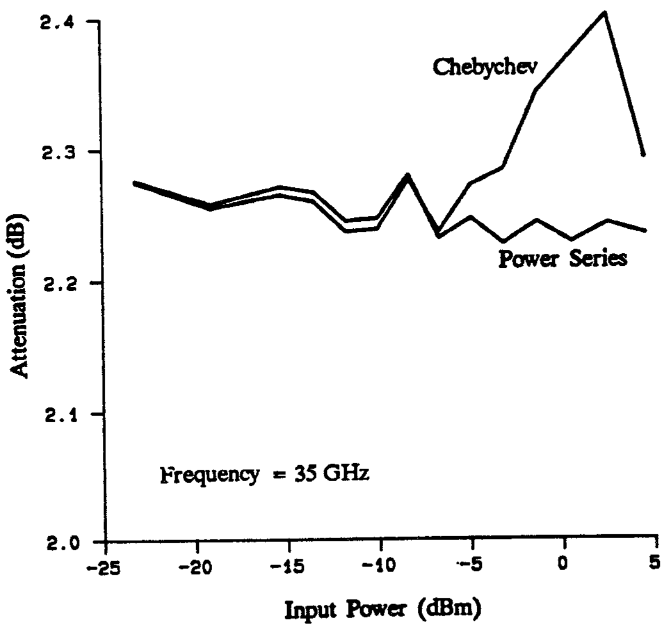

Figure 2 - Measured Value of Attenuation as a Function of Input Power for the Power Series and Chebychev Polynomial Models

Frequency (GHz)	Thermistor Detection		Diode Detection	
	Mag.	Phase	Mag.	Phase
30	0.9766	160.408	0.9704	160.129
35	0.9211	96.082	0.9175	95.384
40	0.8977	74.041	0.9155	75.140

Table 1 - Input Reflection Coefficient of a 1.20 mm Height Waveguide and Short Circuit

Frequency (GHz)	Thermistor Detection		Diode Detection	
	Mag.	Phase	Mag.	Phase
30	0.3939	230.692	0.3958	230.578
35	0.5525	197.746	0.5572	198.285
40	0.5696	193.098	0.5612	193.244

Table 2 - Input Reflection Coefficient of a 1.90 mm Height Waveguide and Matched Load

Frequency (GHz)	Thermistor Detection		Diode Detection	
	Mag.	Phase	Mag.	Phase
30	0.1062	243.313	0.1067	242.931
35	0.1914	207.818	0.1942	208.617
40	0.1959	201.745	0.1922	202.359

Table 3 - Input Reflection Coefficient of a 2.90 mm Height Waveguide and Matched Load

The agreement between the reflection coefficient magnitudes is very good for all the sections except at 40GHz in Table 1. In this case the difference is 0.0178 and is thought to be due to connection repeatability and the replacement of an alignment dowel. Other than this single value the differences are less than 0.01 in magnitude. The maximum difference between phase values is 1.1°, for the same measurement that gave the maximum magnitude error. The second largest error is 0.8° and so the results show good agreement.

The use of diode detectors reduced the measurement time by approximately 50% (4 seconds) for a reflection coefficient measurement at a single frequency. The speed constraint of the system is now the time taken to change the position of the stepper-motor driven sliding short circuit.

94.9 GHz MEASUREMENTS

The layout of the W-band multistate reflectometer employing a scalar network analyser is shown in Figure 4. This system was developed at Leeds and it makes use of a three position waveguide switch as the repeatable reflector. This considerably reduces the time taken to make measurements. One of the switch positions is terminated with a load, allowing the system to revert to scalar measurement operation. The inclusion of the extra waveguide switch allows the diodes to be linearised *in situ*, reducing errors associated with connection or flange repeatability.

The major cause of error in this system was the source, an InP Gunn diode in a waveguide cavity which was neither phase-locked nor power levelled. The main problem with such a source is the generation of harmonics and drift as a function of time. It was necessary to provide 9 Volts of D.C. bias to stabilise the source causing harmonics of the 94.9 GHz signal to be generated to some extent.

A number of items were measured using this system and compared with measurements made on a thermistor-based reflectometer. A comparison of the results is shown in Table 4. The results show good agreement and it is thought that the variations are due to source drift in both frequency and power and the generation of harmonics in the system. The results do show that it is possible to get useful measurements for many applications from the system, with a large saving in time, since a single impedance measurement is made in 2-3 seconds by the diode detector reflectometer, compared to 9-10 seconds for the thermistor reflectometer.

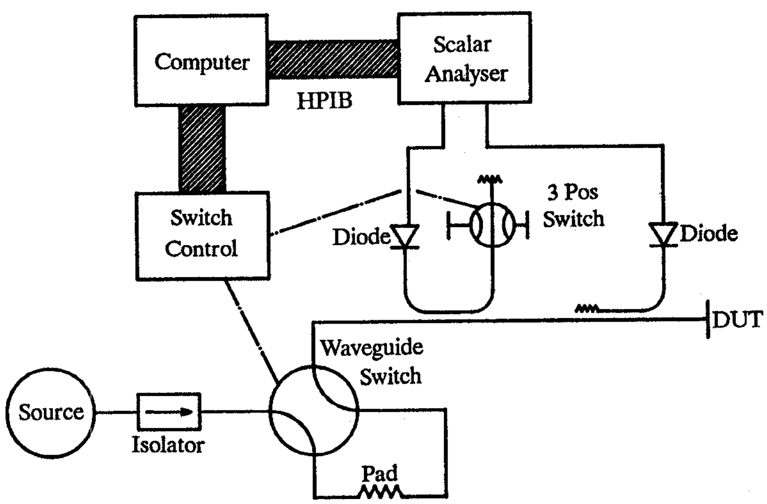

Figure 4 - Schematic Layout of the 94.9 GHz Multistate Reflectometer

Item	Thermistor Detection		Diode Detection	
	Magnitude	Phase	Magnitude	Phase
Matched Load	0.0127	211.39	0.0273	280.23
3.0 cm Line & Matched Load	0.0118	223.65	0.0205	284.88
3.0 cm Line & Short Circuit	0.9331	181.98	0.9123	182.82
Waveguide Iris & Matched Load	0.5626	211.08	0.5665	212.40
Attenuator & Short Circuit	0.5042	22.08	0.5016	20.36

Table 4 - Reflection Coefficients for a Diode-based and a Thermistor-based Multistate Reflectometer at 94.9 GHz

CONCLUSIONS

In conclusion, the use of diode detectors in a multistate reflectometer has been shown to produce high quality measurements at millimetre-wave frequencies. A significant reduction in the time taken to perform a measurement was obtained compared with a thermistor based system. The use of a scalar network analyser and diode detectors to make vector measurements has been demonstrated at W-band, requiring a controlling computer and some waveguide hardware. This would enable swept measurements to be made at a rate of one sweep every 2-3 seconds. The system will work in any waveguide band for which the necessary hardware is available.

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