Using an Arbitrary Six-Port Junction to Measure Complex Voltage Ratios*

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Abstract

An arbitrary six-port junction is analyzed as a microwave vector voltmeter, measuring the amplitudes and phase difference of two input signals in terms of power readings taken at the remaining four ports. The junction may be calibrated for measuring complex voltage ratios using a self-calibration procedure which requires no standards.

Introduction

This paper shows how the complex voltage ratio of two signals can be measured using an arbitrary six-port junction where four of the ports are terminated with power meters. If two coherent signals of the same frequency are applied to the remaining two ports, the junction gives the phase angle between the two signals as well as the amplitude of both in terms of the four power meter readings. The six-port junction thus becomes a vector voltmeter in which phase and amplitude information are calculated from power measurements. The analysis of a six-port junction for measuring complex voltage ratios is similar to that used for six-port power measurements.[1]

Theory

Consider the arbitrary six-port junction shown in figure 1, where four ports are terminated with power meters. The complex voltage ratio of two incident waves a_1 and a_2 is given by

$$\frac{a_2}{a_1} = K \frac{\sum z_i P_i}{\sum w_i P_i} \quad , \; i=3,\ 4,\ 5,\ 6 \qquad (1)$$

where each sum is over the four sidearm output power readings P_i. The complex constants z_i and the real constants w_i and K must be determined by some calibration process.

Calibration

A technique for calibrating the junction to obtain the z_i and w_i has been devised and tested. This technique is self-calibrating in the sense that no reference standards are needed in the calibration process. A signal is divided into two channels which are connected to the inputs of the six-port, as shown in figure 1. The signal a_1 in one channel is held constant while the signal in the other channel is passed through a level set attenuator, α_0, phase shifter, ϕ_0, and a two-position insertion device. Data for calculating the z_i and w_i are obtained by noting the values of all P_i for the two positions of the insertion device at different settings of α_0 and ϕ_0.

The constant K is not determined by this calibration procedure, but for many applications K does not have to be known. For example, attenuation and phase measurements can be made without knowing K. If a_1 is held constant, the ratio of a_2 at one time to a_2 (call it a_2') after inserting or changing a test item in the test channel is

$$L = \frac{a_2}{a_2'} = \frac{\sum z_i P_i}{\sum z_i P_i'} \quad , \; i=3,\ 4,\ 5,\ 6 \qquad (2)$$

where L is the complex insertion ratio (attenuation and phase) of the item inserted or changed in the test channel. The P_i are the sidearm power readings before the test item has been inserted, and the P_i' are the readings after inserting the test item. Note that K does not appear in (2). This means that the junction can be completely calibrated for making complex insertion ratio measurements without using any reference standards.

Experimental Setup

A six-port junction has been constructed using commercially available miniature coaxial X-band components with SMA connectors. A photograph of the junction is shown in figure 2. The components in the photograph are identified in figure 3, which also shows how the signals are combined to get the four desired outputs. Criteria for design of the junction will be discussed in the paper.

Since the six-port calibration and measurement process requires taking many sidearm power measurements, it is most desirable to have the data read directly into a computer which can then process the data. A programmable calculator is capable of taking the necessary sidearm power readings under program control, and then processing the data to give the calibration constants and measurement results.

Calculator programs have been written for calibrating the junction as a microwave vector voltmeter, and also for using it to measure complex insertion ratio. After calibrating the six-port, the setup in figure 1 is used to measure complex insertion ratios by either changing or inserting something in the test (lower) channel, and using equation (2) to calculate the ratio.

Results

Preliminary measurements have been made on this setup at 8, 9, 10, 11, and 12 GHz. The complex insertion ratio of a two-position step attenuator, L, was measured with the six-port and then measured by the NBS Automatic Network Analyzer. The results are shown in table 1. The six-port results were obtained using diode-type power detectors as can be seen in figure 2. Better power detectors should give greater accuracy. The comparison is, nevertheless, quite significant. It shows that the theory of using an arbitrary six-port junction as a vector voltmeter is correct. It also shows that the self-calibration procedure works; the six-port was calibrated without using any standards. The only precision component in the setup is the two-position step attenuator whose change in insertion ratio must be very repeatable, but need not be known. The complex value of L is one of the unknown constants which is determined by the calibration process.

References

1. G. F. Engen and C. A. Hoer, "Application of an arbitrary six-port junction to power measurement problems," IEEE Trans. Instrum. Meas., Vol. IM-21, pp. 470-474, Nov. 1972.

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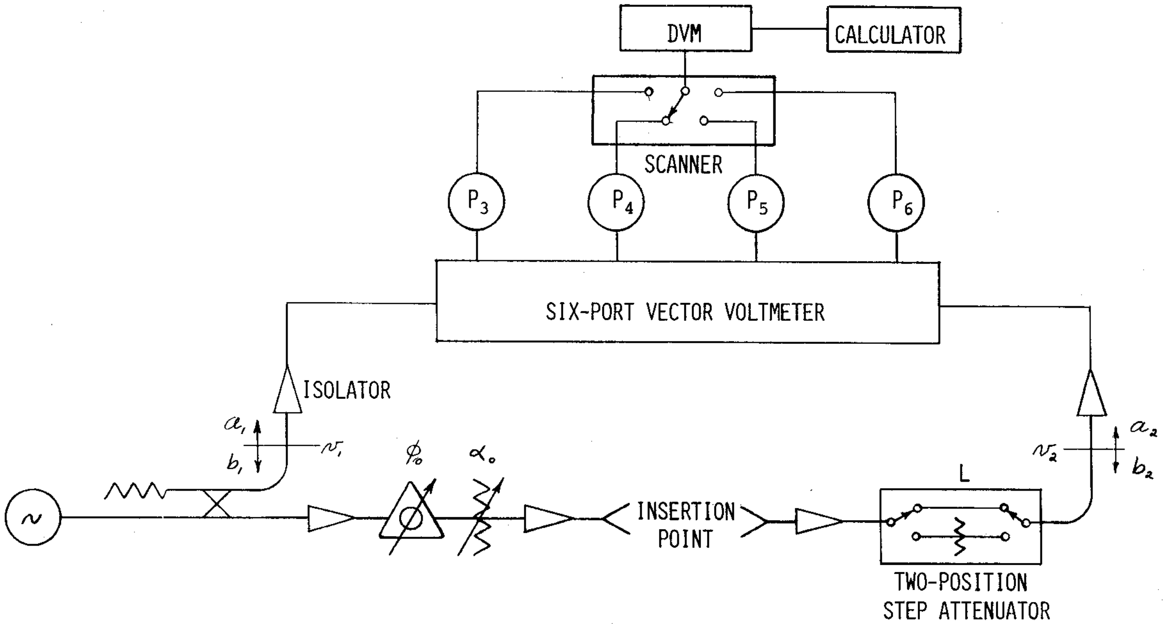

Figure 1.
Setup for calibrating and using a six-port junction to measure complex insertion ratios.

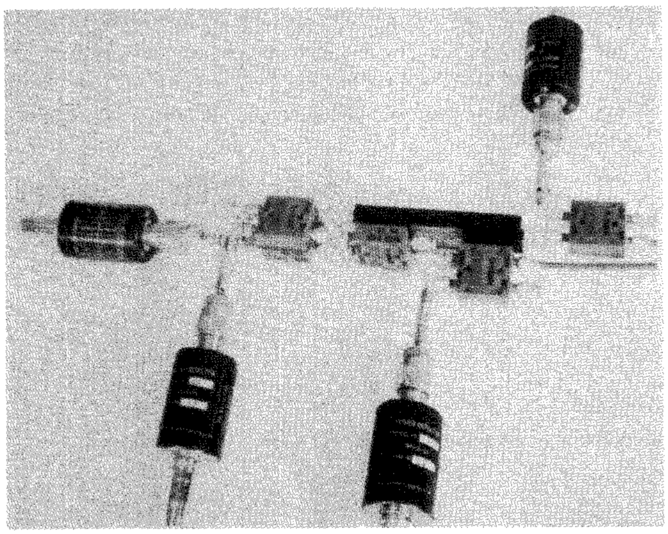

Figure 2. Experimental X-band six-port junction. The components are identified in figure 3.

TABLE 1. AMPLITUDE AND PHASE CHANGE IN THE TWO-POSITION STEP ATTENUATOR AS MEASURED BY THE SIX-PORT WITH DIODE POWER METERS AND BY THE NBS AUTOMATIC NETWORK ANALYZER.

SIX-PORT vs. ANA

FREQUENCY, GHz,		8	9	10	11	12
ATTENUATION DB	SIX-PORT	7.82	7.58	7.52	7.91	8.53
	ANA	7.75	7.57	7.48	7.92	8.36
	DIFFERENCE	.07	.01	.04	-.01	.17
PHASE DEG.	SIX-PORT	38.15	34.13	33.19	31.49	31.00
	ANA	38.09	34.81	32.45	31.73	30.91
	DIFFERENCE	.06	-.68	.74	-.24	.09

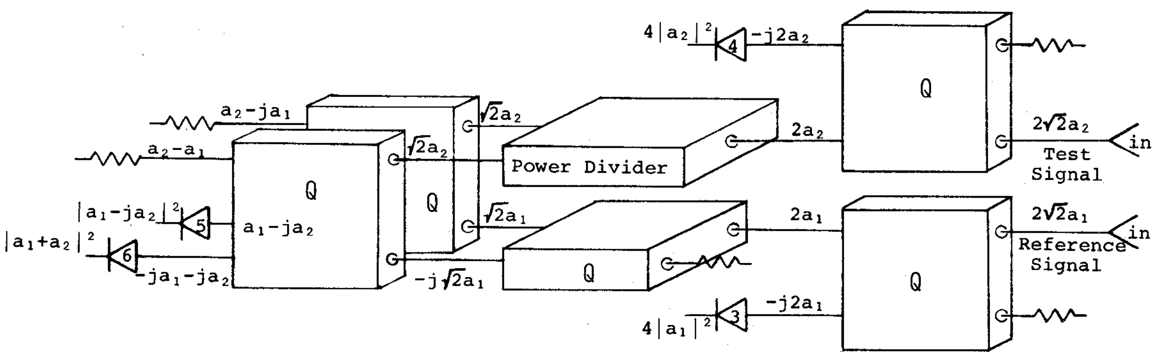

Figure 3. Combining Quadrature hybrids (Q) and a Power divider to make a six-port junction having two input ports and four output ports which are terminated with diode detectors. The signals labeled at different parts of the junction are those one would obtain from ideal components if the two input signals are $2\sqrt{2}a_1$ and $2\sqrt{2}a_2$.