IV. Conclusions

This paper details a computer oriented technique for network optimization utilizing exact algebraic partial derivatives of the response function with respect to any circuit parameters of interest. The method is applicable to a broad class of active, nonlinear, and distributed circuits. The method of obtaining the partial derivatives eliminates the disadvantages inherent in the numerical estimation of the derivatives and requires no additional analytical effort. Several examples were presented to illustrate the efficacy of the technique.

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Letters

Group-Delay Smoothing by Noncentral Statistics

A. UHLIR, JR.

***Abstract*—Automatic network analyzer group-delay measurements are improved by simple hardware substitutions, more exact frequency calculations, and a discounting of group-delay variations that fail to persist through several settings of the reference path length.**

Introduction

Severe group-delay flatness requirements are sometimes imposed upon microwave relay components such as band-separation filters. Delay variations of 0.2 ns out of 75 ns must be resolved at frequency intervals of about 1 MHz.

The Hewlett-Packard 8542A general-purpose automatic network analyzer indicates spurious delay variations much larger than the desired tolerances, when used in its stock configuration with two-port measurement programs such as Hewlett-Packard's CGPS2 or Computer Metrics' GPM1. These programs compute group delay from successive CW transmission measurements in accordance with the approximate relation

$$\tau_g = -\frac{\Delta\phi}{360\Delta f} \tag{1}$$

where $\Delta\phi$ is the phase change in degrees corresponding to a frequency increment Δf. Sources of inaccuracy will be discussed along with techniques for combating them.

Frequency-Set Error

Some of the problems are peculiar to the limited resolution of digital systems. For example, the frequency can be set only to discrete values which are spaced 2–20 KHz apart, depending upon the operating frequency. When the program *calls* for a particular frequency, a phase-locked signal source is *set* to the nearest discrete frequency. A possible discrepancy of 2 KHz is 0.2 percent of a 1-MHz frequency increment, too large to ignore. Therefore, the difference between *set* frequencies must be used as the Δf in (1), whereas the stock software uses the difference between the *called* frequencies.

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Resolver Error

Another digital resolution problem arises in the measurement of phase. The analog-to-digital converter used to read the transmission coefficient in Cartesian form does not have enough bits to give accurate phase differences when the frequency steps are small in comparison to the electrical length of the component under test. In such a situation, some improvement can be expected from averaging results obtained by repeating the measurement with small variations in the size of the frequency steps.

This time-consuming approach was set aside in favor of the following procedure that also bypasses the quadrature imbalance errors inherent in a Cartesian coordinate measurement. The analog phase output of the 8413A phase-gain indicator is read by a precision digital voltmeter interfaced to the system computer. The analog phase detector output is smooth and linear except at the extremes of its range, where it becomes totally nonlinear and changes by an amount corresponding to 360°. One or more such crossovers usually occurs over the passband of a typical communication filter.

Since the results for some of the frequency intervals will be completely obliterated by the crossovers in a single pass over the frequency band, replicate measurements are required with the crossovers somehow shifted to other parts of the band. This shift can be done with the manual phase offset control on the 8413A or by altering the length of the reference signal path with the internally-provided calibrated trombone; the latter procedure was adopted. From the band-center frequency and the number of replications, the computer determines and requests trombone settings that vary the phase over a full cycle.

Information-Processing Rationale

Next, the replicate measurements are dealt with by a simple procedure for using *a priori* knowledge. We know that changing the setting of the trombone does not change the properties of the com-

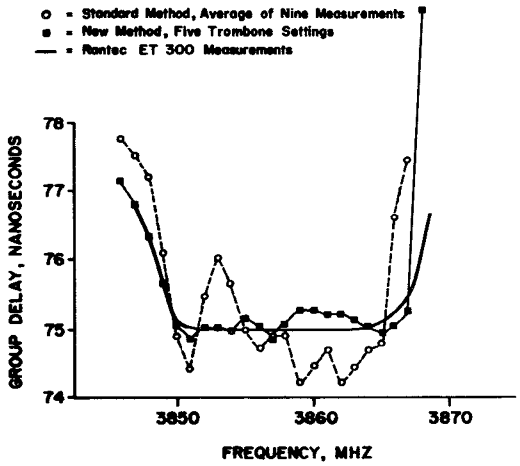

Fig. 1. Comparison of group-delay measurements of filter by two methods on H-P 8542A automatic network analyzer with Rantec ET-300 measurements.

ponent, which can be left connected throughout the measurements. All differences between measured results must be attributed to the system, not the component.

This concept is put into effect by first calculating the group delays for each set of measurements from the phase differences, using the true frequency differences. Then the differences between the successive group delays are calculated, again for each set of measurements. Next, the group-delay differences corresponding to a given frequency are compared and one is selected that is relatively small in absolute magnitude.

Specifically, if five replications are involved, the group-delay difference with the smallest absolute value is selected. If six to eight replications are available, the next-to-smallest-magnitude group-delay difference is selected. A single list of group-delay differences as a function of frequency is thus composed. Group delay as a function of frequency is calculated by summing along this list and adding a constant.

The constant may be chosen so that the average group delay over the passband is equal to that measured in the usual way over a large frequency interval corresponding to most of the passband. A still more accurate average value of group delay could be obtained by selecting the frequency interval so that the phase change is close to 360° or a multiple thereof. This refinement was not included since the main interest is in group-delay variations rather than absolute value of delay.

Well-matched pads for source and load make it unnecessary to correct for mismatches.

A measurement of a prototype linear-phase filter is shown in Fig. 1, along with the results obtained from a standard measurement on the same system and the presumably more accurate results from a Rantec ET-300 group-delay test set.

While the procedure that has been described is bound to give a smoothing effect, it preserves data that would be suppressed by a simple smoothing with respect to frequency of a single set of measurements. If a component truly has a defect, evidence of it will probably be present in all of the replicate measurements and the defect is not likely to be concealed (extremely unlikely if the next-to-smallest group-delay difference is used). On the other hand, when a component is designed to give a smooth response and the smoothness is confirmed by one or two measurements, one would be foolish to penalize the component for other measurements made on equipment known to be prone to frequent relatively large errors. Nor is an average of good and bad results a fair representation of the component's performance—hence, the term "noncentral statistics."

No claim is made that the method can compete in accuracy with special group-delay measuring equipment employing modulated signals. The objective has simply been to extend the usefulness of the point-by-point CW automatic network analyzer.

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MICTPT—A Minicomputer General-Purpose Microwave Two-Port Analysis Program

D. H. OLSON AND F. J. ROSENBAUM

General-purpose microwave network-analysis programs [1], [2] are typically organized on a time-shared basis using large-scale computers. As minicomputers become widely available, it is desirable to have a compatible general-purpose analysis program to assist the microwave engineer in his design efforts. The purpose of this letter is to describe the implementation of one such program for machines with 4K words of memory. Although MICTPT was designed for a Digital Equipment Corporation PDP-5 computer with 4K (4096) of 12-bit word core storage, the approaches used are applicable to any similar small computer.

The program is capable of the frequency analysis of networks which include interconnections of lumped elements, transmission lines, and waveguides, and any two-port which is described by the elements of a scattering matrix. The present implementation will not handle four-port elements or completely arbitrary network interconnections, such as bridged tees, etc. Other implementations are, of course, possible [3].

In order to meet the size objective, MICTPT is organized in three parts: the "source" describing the network is first created and edited using the operating system EDITOR which allows manipulation of the description statements. It is then stored on magnetic tape and a second program MICVER is run to compile the "source" description into an "object" description, which is also stored on tape. Finally, the analysis MICTPT is run with the "object" description as the input.

This technique, although requiring some effort to change the

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