Solid-State Radar (RASSR) array. The large number of measurements and limit comparisons required on each module to insure optimum system performance are made automatically in a minimum amount of time with standard laboratory accuracy. The test features of the system are summarized as follows.

1) Amplitude and phase is measured automatically on a pulsed basis and with frequency translation.

2) System errors are measured periodically, stored, and applied as corrections to the measured data.

3) Test parameters are automatically compared to unit specification limits, as well as reference standard (unit-to-unit) limits.

4) Input power is set automatically prior to each test.

5) Phase measurements can be made over any 100-ns portion of the output pulse.

6) Dual output coherent synthesizer.

7) Test figures incorporate precision adapters and temperature control.

8) Manual override.

Many of the test-system concepts developed and used on this program are being applied to other similar programs, and will be useful as well in future test systems. These include automatic power control, noise figure, and pulse measurements of phase and amplitude with different frequency translations.

Future solid-state phased arrays, each with hundreds of microwave modules which must perform reliably and near identically over wide ranges of operating conditions, will require similar automatic test systems to economically satisfy the measurement requirements and production rates.

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Automated Attenuation Test in Multimodal Waveguides by Resonance Return-Loss or Insertion-Loss Measurements

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***Abstract*—Two methods for testing short lengths of multimodal circular waveguides, working in the TE_{01} mode accompanied by many spurious modes are described. One method is based on the measurement of the return loss of a resonant one-port cavity; the second one measures the insertion loss of a cavity coupled to the rectangular main waveguide. Automatic data selection and manipulation are emphasized.**

I. Introduction

ATTENUATION constants of long-distance circular waveguides, working in the TE_{01} mode, are very low (typically, 2 to 3 dB/km for a 50 mm inner diameter in the 40 to 100 GHz range). Manufactured waveguide single pieces are short (about 4 m). The test of their losses must be performed with a resonant-cavity technique [1]. The resulting unloaded Q-factors are so high (typically, 10^6 or more) that an excellent frequency stabilization or some other kind of circuit complication is needed if a standard 3 dB bandwidth measurement is to be performed. This difficulty motivates the use of other setups.

Kazantsev and Meriakri [2] introduced a method based on comparing the cavity return losses at a resonance frequency and far away from the resonance condition. The setup is shown in Fig. 1, and it can be connected with previous work by King and Marcatili [3]. Another setup has been proposed by ourselves [4] and is shown in Fig. 2. Its principle of operation is closely related to a work by Young and Marcuse [5], but the microwave circuit is simpler. Some inconveniences, which are caused by this simplicity, are irrelevant if the measurements are automated, as the rest of the paper illustrates. The operating principle of this test set is

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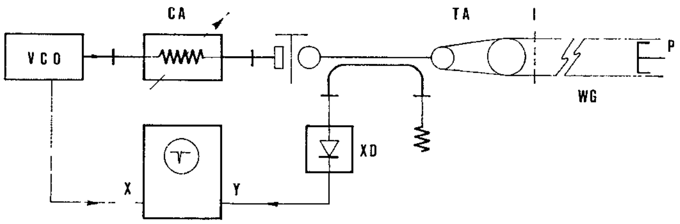

Fig. 1. Scheme of the return-loss setup. VCO is voltage-controlled oscillator; *CA* is calibrated attenuator; *T* is mode transducer; *TA* is taper; *I* is iris; *WG* is tested waveguide; *P* is sliding short-circuit piston; *XD* is crystal detector.

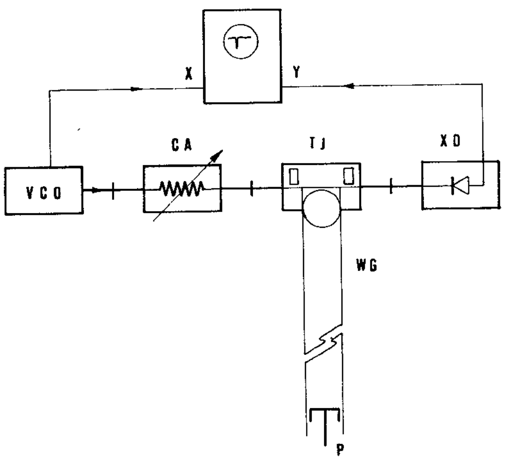

Fig. 2. Scheme of the insertion-loss setup. *TJ* is T-junction. Other symbols were illustrated in Fig. 1.

based on a comparison between the resonance and nonresonance insertion losses of a band-rejection filter consisting of the waveguide to be tested. In both methods, the quantity to be measured is the amplitude of a resonance dip; this leads to very simple equipment.

Automation is very useful for measurements of this type. In a highly overmoded waveguide for long-distance transmission, launching of spurious modes and mode-conversion-reconversion effects can make the cavity response very complicated. When either the cavity length is varied or the frequency is swept, many absorption dips appear. Most of the dips are unsuitable for measurements. Even in the usual case, where all spurious modes are launched much less than the TE_{01} mode, only a few dips correspond to pure TE_{01} resonances and contain the desired information. Their selection is simple in principle, because the attenuation constant for the TE_{01} mode at the frequencies of interest is lower than that of any other mode [1], [3], and therefore the setups may be designed so that the TE_{01} dips are the deepest ones. However, the large amount of spurious dips makes the selection very tedious if operated manually.

A suitable automatic selection of the TE_{01} mode dips may relax the great importance of launching a pure TE_{01} mode, and the microwave setups can then become simpler.

If a 3-dB bandwidth technique is used, the dip selection is just a preliminary operation and must be followed by the measurements. In the return-loss and insertion-loss methods, the selection is operated directly on the quantity to be measured, and this yields a great advantage in the automation of the entire testing procedure.

II. Principle of Operation

The theoretical analysis of the two setups shown in Figs. 1 and 2 is very similar. In both cases, the dip amplitude is simply related to the coupling between the resonant cavity and the rest of the setup, and to the product αL, where α is the attenuation constant to be tested and L is the cavity length. Thus, in both methods calibrating the coupling junction and varying the length L are required.

Referring to Fig. 1, an analysis was performed by Kazantsev [6] in terms of electromagnetic (EM) field. It is easy to paraphrase in terms of scattering parameters [4]. Then the simplest way to express the results appears to be by the following relationship:

$$Y = \frac{1}{2}\,\frac{\epsilon_t + \epsilon_c}{\tau^2} + \frac{2\alpha L}{\tau^2} \tag{1}$$

where τ is the modulus of the iris transmission coefficient.

ϵ_c, representing losses in the sliding short-circuit piston, is defined by its relationship to the reflection coefficient as follows:

$$\rho_c = -(1 - \epsilon_c). \tag{2}$$

ϵ_t, representing losses in the iris, is defined by its relationship to the reflection coefficient ρ and to τ, as follows:

$$\rho = 1 - \frac{\tau^2}{2} - \epsilon_t. \tag{3}$$

The left-hand side quantity Y is a function of the ratio M of the reflected powers far from resonance and at resonance; precisely, we have:

$$Y = \frac{M}{M-1} \quad \text{if } \tau^2 < 2(\epsilon_t + \epsilon_c + 2\alpha L) \tag{4a}$$

$$Y = \frac{M}{M+1} \quad \text{if } \tau^2 > 2(\epsilon_t + \epsilon_c + 2\alpha L). \tag{4b}$$

In the (L, Y) plane, (1) describes a straight line (Fig. 3) intercepting the Y axis at $Y_0 = (1/2)(\epsilon_t + \epsilon_c)/(\tau^2)$, and having an angular coefficient $m = 2\alpha/\tau^2$. The purpose of the measurement is to find the slope of this line. Measurements of M are performed for various values of the cavity length L. Once the iris transmission τ has been measured, then α is known. The relationship (1) and its graphical presentation in Fig. 3 are convenient because the best fit of a straight line amid experimental points is a simple operation.

If a pure TE_{01} mode is launched, then it can be shown that pure TE_{01} resonances yield values of Y which are

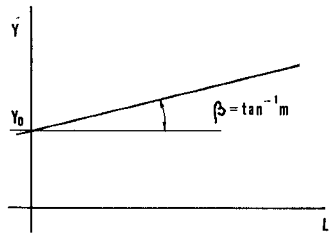

Fig. 3. Plot of the theoretical behavior of Y (a function of the waveguide attenuation constant, defined by (4) for the setup of Fig. 1 and by (6) for the setup of Fig. 2) versus the cavity length, L.

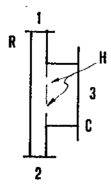

Fig. 4. Scheme of the T-junction connecting rectangular and circular waveguides in the insertion-loss setup. R is rectangular waveguide; C is circular waveguide; H is coupling holes.

smaller than those affected by spurious modes. Hence the highest values of M have to be selected when (4a) holds, while the lowest ones have to be kept when (4b) holds.

The analysis of the setup shown in Fig. 2 is that of a band-rejection filter [7]. It may be performed [4] in such a way that the results are very similar to those given before. Indeed, (1) is replaced by the relationship:

$$Y = \frac{\epsilon\delta}{\tau^2} + \frac{2\delta\alpha}{\tau^2} L \tag{5}$$

where

$$Y = M/(M - 1) \tag{6}$$

and where

$$S = \begin{vmatrix} \xi & -\delta & \tau \\ -\delta & \xi & -\tau \\ \tau & -\tau & -\psi \end{vmatrix} \tag{7}$$

is the scattering matrix of the symmetrical E-plane T-junction shown in Fig. 4[1]. Once more we have a straight line on the (L, Y) plane (Fig. 3), and the former considerations apply. Again the measurement consists of finding the slope of the line and calibrating the coupling T-junction.

As we shall see in the next section, the differences between the two setups with respect to automation are minor. Presently, we are performing measurements with both setups and taking advantage of the comparison of results, which show good agreement. However, the branch resonator setup looks preferable under certain viewpoints, especially because the transitions from rectangular to circular waveguide are simple to design and to build. Furthermore, the whole setup is easily adapted to various waveguide sizes and/or types.

[1] If attention is paid to the coupling between the rectangular waveguide TE_{10} mode and many of the propagating modes in the circular waveguide, the junction shown in Fig. 4 is an n-port with a large n. However, if one assumes the coupling to the spurious modes is small enough, and if all the "good" measurements are performed when the spurious modes are far from resonance, then we may say that n-3-ports are terminated on constant resistors, so that we remain with a lossy frequency-independent 3-port whose scattering matrix is (7).

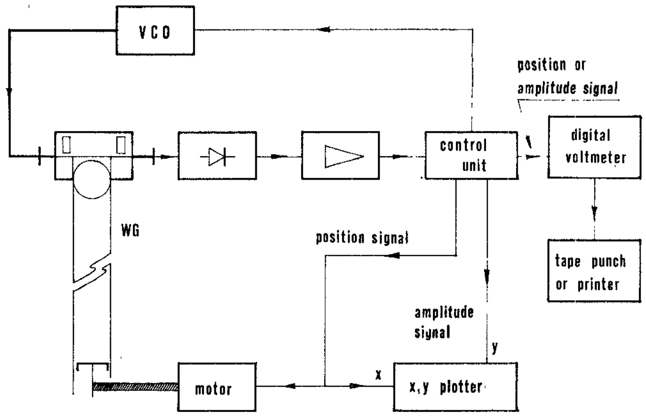

Fig. 5. Block diagram of the setup for automated measurements. The insertion-loss scheme is drawn, but the essential features are unchanged in the return-loss setup.

III. Automatic Measurements

The cavity length L is varied by moving a short-circuit piston. The selection of the suitable dips is operated by controlling the motion of the piston according to the following principle.

For the insertion-loss setup, the dips corresponding to the pure TE_{01} mode become deeper as the cavity becomes shorter [e.g., Fig. 3 and (6), yielding $dY/dM<0$]. However, as we said before, dips caused by pure TE_{01} resonances are deeper than those belonging to any other mode or mode mixture, provided this comparison is drawn for almost equal cavity lengths. If the piston moves inwards, we should let it stop whenever the detector output exhibits a dip that is larger than the one which corresponded to the previous stop.

In the return-loss setup we have the same situation when (4a) holds, giving $dY/dM<0$, while (4b) would yield $dY/dM>0$. Careful iris design and measurement is needful.

The whole automated setup is described by the block diagram of Fig. 5. The position of the piston is very critical for getting a resonance dip. Hence it is driven by a dc motor equipped with a magnetic clutch, insuring prompt stop. Once the operator has started the motor, the control unit stops it automatically when a suitable dip is detected. Also, the control unit provides analog signals on the piston position and on the dip amplitude. They can be sent to an x, y plotter. In addition, the control unit provides sampled position and amplitude signals. A digital voltmeter translates this information for a printer or for a tape punch. In the latter case, the punched tape can be directly fed into an electronic computer. A program can perform the best fit of the straight

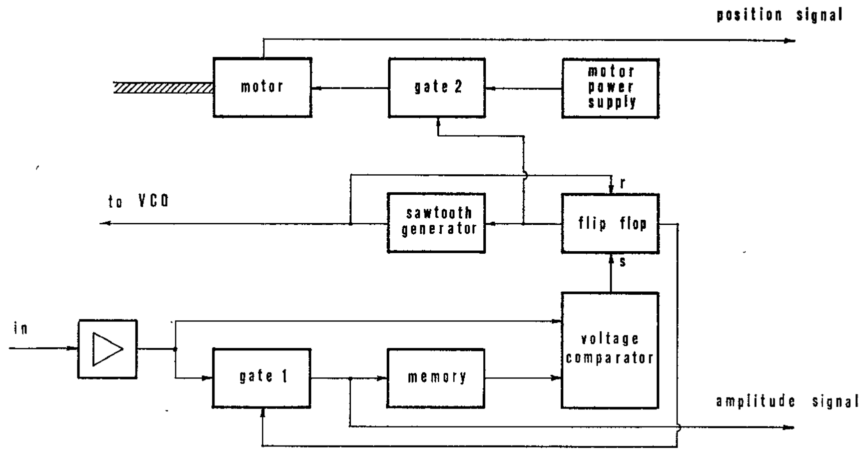

Fig. 6. Block diagram of the unit that controls the motion of the sliding short-circuit piston and feeds selected data into the plotter.

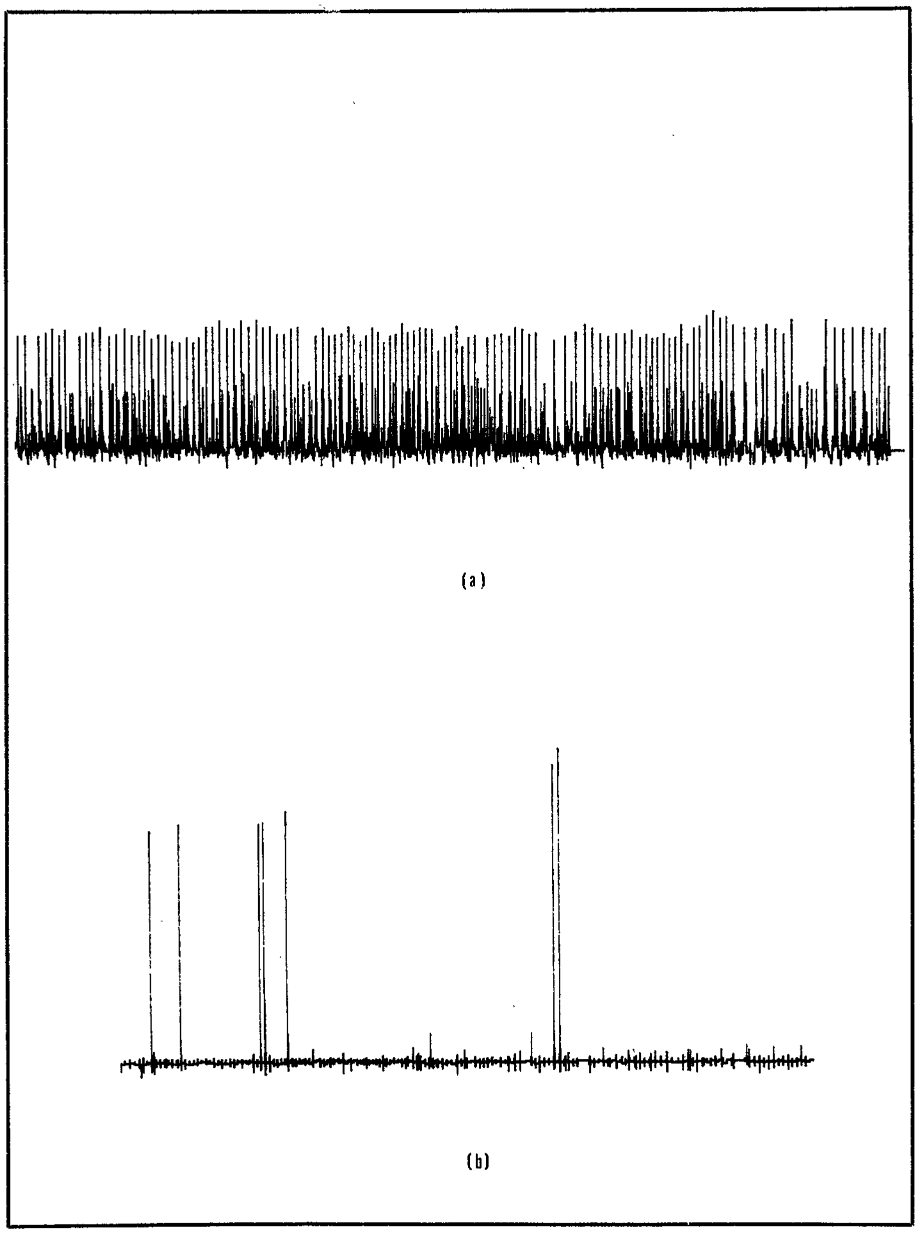

Fig. 7. Recording of resonance dip amplitudes versus cavity length. (a) All resonances of wanted and unwanted modes were recorded. (b) Shows the selected pure TE_{01} mode resonances only. The automatic selection was operated by the setup explained in Fig. 6.

line shown in Fig. 3 amid the experimental points and give the attenuation constant of the tested line.

Further details on the control unit are illustrated in a block diagram shown in Fig. 6. After one selected dip has been measured, and before getting to the next one, the measured amplitude is stored in the memory. Gate 1 is closed, gate 2 is open, and the voltage-controlled oscillator (VCO) works in the CW mode. When an input dip is larger than the stored one, then the flip-flop commutes. This causes the motor to stop, the VCO frequency to be swept and the new input dip to substitute the former one in the memory. The end of the frequency-sweeping sawtooth resets the flip-flop and then the gates, after which the piston moves again.

The importance of the automatic selection is clearly depicted by Fig. 7, where dip amplitudes are shown versus cavity length. Fig. 7(a) was recorded without blanking the spurious dips. The control unit had been modified so that it stopped the piston whenever a dip appeared at the detector output. Fig. 7(b) was recorded selecting only the pure TE_{01} mode resonances. All the spurious mode dips have been blanked, as well as many TE_{01} resonances, which were clearly affected by simultaneous resonances of other modes. These recordings were obtained with the insertion-loss setup (Fig. 2). The tested line was a section of helix waveguide, 4 m in length, manufactured by the Società Generale di Telefonia ed Elettronica, Milan, Italy.

The time required for testing one section is essentially limited by the speed of the motor. In our case, it has been of about 10 min. Additional time (about 100 s for each selected dip) is needful if analog recording is desired.

This shows that the test is rapid and comfortable. The whole method looks appropriate for industrial quality tests at the installations where waveguides are manufactured.

IV. Conclusion

Indirect measurements of very small attenuations have been described, and those aspects which are relevant to automated measurements have been emphasized.

Automatic selection of valuable information is very important when dealing with multimodal waveguides, as our Fig. 7 shows. A merit of the method discussed here is that the selection mechanism is controlled by the quantity to be measured. The use of a digital voltmeter, a tape punch, and a calculator yields directly the final results. The method is proposed for quality tests on an industrial scale.

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