$f_1(t)$ is applied to the diode D_1 through the printed circuit strip coupling. The RF path to D_2 is blocked by the RF choke. Thus, at the output of D_1 (or point A), the positive portion of the discriminator curve is produced. The negative portion of the discriminator output is produced by the action of D_2. Since the output of D_2 is at ground potential, point A is now negative with respect to ground as indicated in the circuit of Figure 2(b). The resultant of these two outputs is, therefore, a familiar S curve of a discriminator (see Fig. 3).

Two or more such discriminators can be formed to serve as a multidiscriminator unit. Fig. 4 is a cross-sectional view of a typical multidiscriminator unit. RF frequencies are fed to the cavities through the resistor-power-dividing network. The unit requires 14 cavities to form a 7-discriminator unit. This unit operates in the frequency range of 600 Mc through 1150 Mc. A photograph of an experimental unit is shown in Fig. 5.

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Q Measurement of Strongly Coupled Cavities*

INTRODUCTION

The long-line method herein described provides a rapid, simple, and fairly accurate measurement of resonant frequency and loaded bandwidth of a one-port cavity which is tightly coupled to its transmission line.

Such tightly coupled cavities are often used as signal couplers in beam-type electron tubes. The cavity itself has a very high unloaded Q, and the beam loads the cavity to give a loaded Q approximately equal to the external Q (*i.e.*, the beam is matched to the coupler's transmission line).

Because no transmitted signal is available from a one-port cavity, and because, with a tightly coupled cavity, the input VSWR is always too high to be of value, the only useful information is the phase of the reflected signal. A straightforward phase measurement, as for a Q circle, is at best laborious and involves the determination of a detuned-short position or similar phase reference at each frequency used. If the cavity is not accessible for detuning, the detuned-short positions must be obtained by extrapolation or calculation. A bridge or more elaborate arrangement alleviates this difficulty, but it involves considerable setup labor.

The long-line method uses for a phase reference the resonances of a long, nearly lossless transmission line between the detector and the cavity under test. The resonances of the long line are modified by the resonance of the test cavity, and from the modified resonant frequencies, the test cavity resonant frequency and loaded bandwidth are calculated.

MEASUREMENT OF RESONANT FREQUENCY

In the long-line method, a long, high-Q cavity is formed between the test cavity and the slide-screw tuner (planes 1 and 2 in Fig. 1). If this cavity is made long enough, the system passes through resonance repeatedly as the frequency is varied. At frequencies near f_0, the resonant frequency of the test cavity, the phase at plane 1 changes rapidly according to the relation

$$\phi = \arctan \frac{2G}{BW} \tag{1}$$

where $G=f-f_0$, and BW is the half-power bandwidth of the loaded test cavity. Thus the "long line" resonates at regular intervals in frequency except near f_0, where the pattern is modified by the resonance of the test cavity. By observing the system resonant frequencies (indicated by absorption pips in the reflected power) near f_0, we may calculate f_0 and the loaded bandwidth of the test cavity.

Let us set the slide-screw tuner to some arbitrary position. The system resonates at those frequencies at which the phase at plane 2 assumes integral multiples of π radians. Fig. 2(a) shows the irregular crowding of the resonances in the vicinity of f_0.

Moving the slide-screw tuner axially is

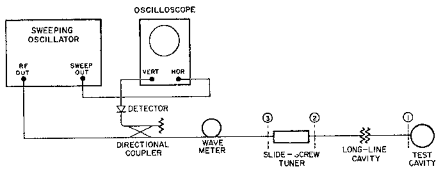

Fig. 1—Long-line method of measuring resonant frequency and bandwidth. The "long-line" cavity resonant frequencies are modified by the resonance of the test cavity.

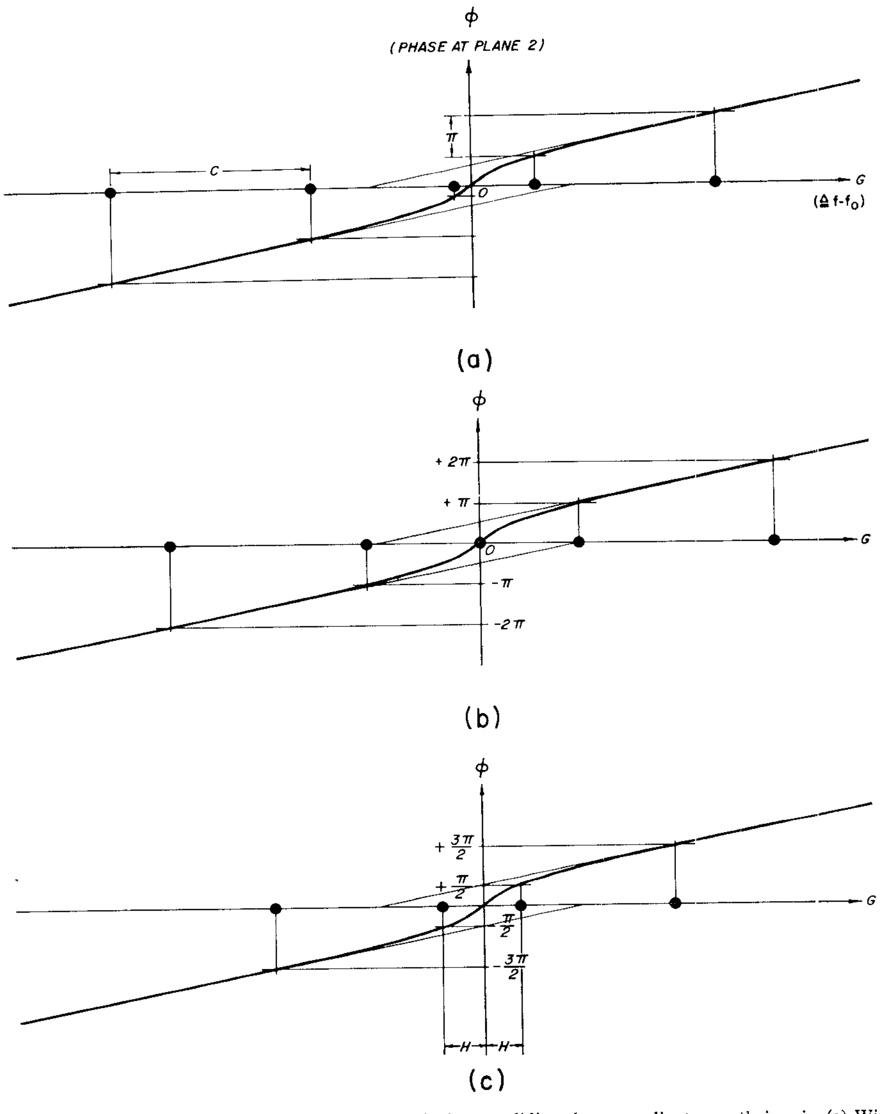

Fig. 2—Phase vs frequency. Sliding the tuner is equivalent to sliding the ϕ coordinates on their axis (a) With an arbitrary position of the tuner, the resonant frequencies are bunched in the vicinity of f_0. (b) f_0 is found by obtaining this symmetry pattern of resonant frequencies. (c) the tuner is then moved to obtain this symmetry pattern. H varies with the test cavity bandwidth.

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equivalent merely to sliding the phase coordinates along their axis. If the slide-screw tuner is adjusted so that the system resonates at f_0, the other resonant frequencies are symmetric about f_0, as indicated in Fig. 2(b). Conversely, when the resonant frequencies are symmetric about one resonance, the frequency of that resonance is f_0. Thus f_0 is found by adjusting the slide-screw tuner to produce a pattern symmetric about one resonant frequency. As the slide-screw tuner is moved, all resonant frequencies move in the same direction. As long as their separation is somewhat greater than the bandwidth of the test cavity, the resonance near f_0 moves less rapidly than the others, as is evident from the increased slope of the phase-vs-frequency curve in the vicinity of f_0. The condition of symmetry is thus found with some precision.

If the resonant frequencies are much more closely spaced than the bandwidth of the cavity, several resonances move almost together, and f_0 is difficult to determine.

If the test cavity can be physically detuned, the resonance at f_0 disappears, and those on each side move closer to f_0. This test, when it can be made, simplifies the approximate location of f_0.

We may adjust the line length by trial, or we may estimate the frequency-separation C of the resonances from the relation

$$C = \frac{v_g}{2L} \tag{2}$$

where v_g is the group velocity and L is the length, both of the long line between planes 1 and 2. (The line may be nonuniform; *e.g.*, it may include two types of line and a transition with a reasonably smooth phase function, since only an estimate of C is required.) But it is evident that if the group velocity varies appreciably with frequency, as in a waveguide near cutoff, C also varies with frequency, and the asymptotic lines of Fig. 2 are curved. In such cases, C must not be more than a few test cavity bandwidths, or the symmetry arguments are no longer valid.

Thus the long-line length should be chosen so that C is at least one test cavity bandwidth, but C should not be made so large that the system resonant frequencies are not symmetrical about f_0.

Measurement of Loaded Bandwidth

We could evaluate the test cavity loaded bandwidth BW from the system resonant frequencies in Fig. 2(b), but the results would be imprecise, especially if C were much greater than BW. Instead, we may use the other possible symmetric pattern, indicated in Fig. 2(c). Here a resonance does not occur at f_0, but two resonances occur close to it. Their frequency separation is a more sensitive function of BW than is the position of the resonances in Fig. 2(b).

In Fig. 2(c), the phase is given by

$$\phi = \frac{\pi G}{C} + \arctan \frac{2G}{BW} \cdot \tag{3}$$

At the new system resonant frequencies, where $\phi = \pm\pi/2$, let us set $G = \pm H$. At $G = +H$, (3) becomes

$$\frac{\pi}{2} = \frac{\pi H}{C} + \arctan \frac{2H}{BW} \cdot \tag{4}$$

We solve this for BW, the test cavity bandwidth, in terms of C and H as follows:

$$BW = 2H \tan \frac{\pi H}{C} \cdot \tag{5}$$

Since the line length (and therefore C) varies with the position of the slide-screw tuner, C should be measured at the same time as H is measured.

Summary of the Procedure

The long-line length and the slide-screw tuner are adjusted to produce a series of resonances separated by a very few test cavity bandwidths. The vicinity of f_0 is found as that region where the system resonant frequencies are grouped in an irregular pattern, and move in an irregular manner as the tuner is moved axially. The tuner is moved to produce the symmetric pattern of resonant frequencies shown in Fig. 2(b), and f_0 is read as the center frequency. The tuner is then moved to produce the symmetric pattern of Fig. 2(c), and the test cavity loaded bandwidth is determined from (5).

One must bear in mind that the test cavity is assumed to be tightly coupled to its transmission line (*i.e.*, the loaded Q is nearly equal to the external Q, and the unloaded Q is much greater than either the external or loaded Q). The long-line cavity is also assumed to have a Q much higher than Q_{ext} or Q_L.

Finally, the procedure herein described does not yield either the test cavity unloaded Q or coupling coefficient. The unloaded Q may be obtained by measuring the coupling coefficient (input VSWR at f_0) by the double-minimum method with a standing-wave detector. Then

$$Q_0 = Q_L(1 + B)$$

where B is the coupling coefficient, and

$$Q_L = \frac{f_0}{BW} \cdot$$

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A Microwave Quadruplexer*

In an earlier issue of these Transactions Brown and Clark brought an unpublished phenomenon into discussion with their correspondence, "A Unique Solid-State Diplexer:"[1] When a ferromagnetic oxide with small linewidth (yttrium-iron garnet substituted with aluminium in their experiments) is applied to a Y-junction circulator at a frequency lying just below the ferromagnetic resonance then circulation takes place in the opposite sense to that for a frequency just above the resonance.

In order to further this discussion, we will contribute some results of an investigation on a very similar effect which were found in our laboratory some time ago.

First of all a remark on why we call an element, based on that effect, a quadruplexer: A circulator can always be used as a duplexer, that is, a circuit element which makes possible the simultaneous transmission of two messages in opposite directions over the same line. A diplex system, on the other hand, permits the simultaneous transmission of two messages at different carrier frequencies in the same direction over a single line. The effect which we are talking about—and also that communicated by Brown and Clark—combines both. Therefore such an element can be called a quadruplexer according to the definition of a quadruplex telegraph system which permits the simultaneous sending of two messages in either direction over a single line.[2]

Fig. 1 depicts such a quadruplex system where Transmitter I and Receiver I are working on a carrier frequency f_1, while Transmitter II and Receiver II work on a carrier frequency f_2.

Fig. 2 gives a typical result of the experiments on a three-port junction quadruplexer in X band.

In the quadruplexer system of Fig. 1 it is necessary that the impedances of all networks connected to the three ports of the quadruplexer are matched to its impedance. Should a mismatch occur a received signal would partly be reflected and after circulating around leave the quadruplexer in the direction from which it had entered.

To avoid the necessity of exact matching of the receivers, the quadruplexer has to behave as a bridge so that signals reflected from a mismatched receiver will be absorbed in the "balancing arm." Fig. 3 indicates the principle for two incoming signals on two different carrier frequencies, circulating in opposite senses. The reflections from the receivers circulate further to the "balancing arm" where they will be absorbed in a matched load. There are only two elements to be matched on the quadruplexer for both frequencies: the transmission line and the absorbing load. Because of this advantage most of our experiments have been done on four-port junctions, and all the following results have been obtained with this structure.

Up to now there is not much exact knowledge published about the action of such a junction circulator but it is certain that the creation of an asymmetric phase pattern by the tensor permeability of the ferrite is the reason that a wave is deflected at a certain angle. If the dimensions of the ferrite and certain tuning elements are properly chosen, then the phase pattern depends so steeply on the frequency that for certain angles (*e.g.*, 90° for a four-port circulator, 60° for a three-port circulator) the nodes and antinodes of

* Received September 10, 1962.
[1] J. Brown and J. Clark, vol. MTT-10, p. 298; July, 1962.

[2] See, for example, F. D. Graham, Ed., "Audel's New Electric Science Dictionary," Theodore Audel and Co., New York, N. Y.; 1956.