length ratio to about 0.5 (optimum Q for a closed cavity) and by changing the exterior design to eliminate the usual counterbores through which the coupling irises were drilled, by grinding off the parallel flats till the iris lips at their thinnest points were only 0.60 inch thick. The final gross dimensions selected were:

Outside diameter	2.410 inches
Length	1.650 inches
Inside diameter	1.635 inches.

The conductivity of this cavity was improved with a rubbed-on silver solution, and a set of open end plates was fabricated for it, similar in design to the series used on the second barrel described above, but with the pertinent dimensions so changed as to locate the central ring in the same region of the fields of the new cavity as was used to obtain the highest Q in cavity number 2. The length of each ring was 0.448 inch, and they left the cavity end 92.6 per cent open to air flow. Tested on the new cavity barrel, the resonant frequency was about 9400 mc and the Q about 7700.

To summarize, the series of experiments outlined above show that right cylindrical resonant cavities may be constructed having values of Q of about 8000 when more than 92 per cent of the area of the parallel boundaries has been removed.

The conducting surfaces of these open end plates must be located with some accuracy if the best results are to be achieved. For those consisting of a central ring which is offset into the cavity barrel, the optimum Q is obtained when the ring is slightly larger than the locus (in a closed cavity) of maximum intensity of the E_θ component of the electromagnetic field; for those consisting of a central ring extending outward from the cavity, the location of the ring at the zero intensity locus (in a closed cavity) of the H_z component of the field yields the maximum Q. These results are summarized graphically in Fig. 3 and Table II.

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Design of Open-Ended Microwave Resonant Cavities*

This paper summarizes a Ph.D. dissertation[1] on the design and analysis of open-ended microwave cavities. The study was motivated by the need for a cavity with a high measure of quality, Q, through which an unobstructed flow of gases or particulate matter could be obtained. Used in connection with the Crain refractometer, instantaneous measurements of the refractive index of the material in the cavity can be made. Measurements utilizing his technique but with other types of cavities have previously been made in order to study the dielectric properties of smoke and other aerosols.[2]

In the atmospheric refractometers developed by Crain[3,4] and Birnbaum,[5] provisions were made for permitting the flow of air and other gases through the sampling cavities by means of holes drilled in the end plates. The holes were located in regions of small current flow. Adey[6] and Thompson and Freethey[7] have extended this study and have obtained a considerable increase in the size of openings in the end walls of cylindrical cavities.

In the research described in this paper, cavities are terminated in short sections partitioned so that each subdivision is a waveguide operating at a frequency below cut-off. Although this technique may in some cases result in field configurations somewhat similar to those existing with the perforations located on the basis of current minima, it offers a fresh approach to the design of the cavities.

Two cavities have been considered. One is made from a rectangular waveguide with a thin dividing strip across the narrow dimension of the guide. The other is a cylinder terminated with sections which have thin dividing strips both concentric to the cylinder and radially outward.

The purpose of this research was to examine the basic principles involved and not to produce a finished cavity. For this reason, the prototypes were made from the most readily available materials. Improvement in the temperature characteristics could be obtained by other choices of materials.

To eliminate the end plates of a cavity as a physical barrier to free passage of material, it is required that they be replaced by some other type of termination which will satisfactorily perform the same function. Initial experiments used tuned stubs that were intended to cause a totally reflecting termination. This scheme was abandoned, however, because the problems of tuning the stubs, and at the same time having them correctly separated, were such as to make proper operation very difficult. Instead, terminations were used which involved very thin sheets of conducting material placed parallel to the axis of the cavity. These terminations present very little interruption to the smooth flow of material through the cavity.

The terminations used are so designed that they divide the waveguide which forms the body of the cavity into two or more smaller waveguides such that these smaller waveguides are "beyond cutoff" for the frequency of operation of the cavity. Two such terminations, placed approximately an integral number of half-wavelengths apart, serve the same function as the shorting end plates normally used. Actually, since the terminations are not short circuits but rather are reactive devices, they must be placed slightly closer together than would solid end plates for operation at the same frequency.

Two types of cavities using the general type of termination described in the previous section have been fabricated and tested. The first of these, rectangular in cross section, is shown in Fig. 1. It consists of a short piece of standard size brass waveguide (WR90) approximately one-half wavelength long between terminations. The terminations are made of 0.015 inch brass sheet material. The second, cylindrical in cross section, is shown in Fig. 2. It consists of commercial size brass tubing and, like the rectangular, is approximately one-half wavelength between terminations. The terminations are fabricated from a combination of 0.015 inch brass sheet material and approximately 1 inch tubing with 0.032 inch wall thickness. It is believed that the thickness of all of these terminations could be reduced without seriously affecting the electrical characteristics of the cavities if fabrication could be conveniently accomplished. However, since all parts are silver plated, all

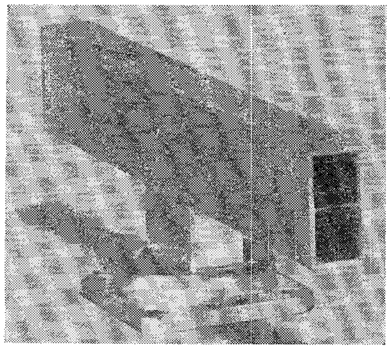

Fig. 1—Photograph of rectangular cavity.

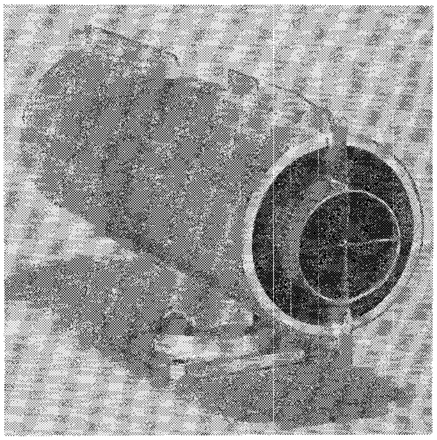

Fig. 2—Photograph of cylindrical cavity.

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* Received by the PGMTT, December 8, 1958; revised manuscript received February 9, 1959.

[1] Donald C. Thorn, "Design of open-ended resonant cavity," Ph.D. dissertation, The University of Texas, Austin; August, 1958 (available from University Microfilms, Inc., Ann Arbor, Mich.).

[2] C. M. Crain, J. E. Boggs, and D. C. Thorn, "Refractive index measurements of smokes and aerosols," IRE TRANS. ON INSTRUMENTATION, vol. I-6, pp. 246–251; December, 1957.

[3] C. M. Crain, "Dielectric constants at water vapor and atmospheric air at a frequency of 9,340 megacycles," *Phys. Rev.*, vol. 74, pp. 691–693, September, 1948.

[4] C. M. Crain, "Apparatus for recording fluctuations in the refraction index of the atmosphere," *Rev. Sci. Instr.*, vol. 24, pp. 456–457; May, 1950.

[5] G. Birnbaum, "A recording microwave refractometer," pp. 169–176; February, 1950.

[6] Albert W. Adey, "Microwave refractometer cavity design," pp. 519–521; 1957.

[7] M. C. Thompson and F. E. Freethey, "Effects of End-Plate Modification on Q at X-Band Cylindrical TE$_{011}$ Resonant Cavities," Natl. Bur. of Standards, Rep. No. 5049. Boulder, Colo.

junctions are made with silver solder. The temperature necessary for silver soldering limits the thinness of material to be worked. In both type cavities, the sections with the terminations were chosen long enough so that the fields in these sections of "beyond cutoff" waveguide will be attenuated adequately and hence will not radiate. Some radiation from the cylindrical cavity occurred because the number of cross-plates was insufficient to prevent the propagation of modes in the outer portion.

Each of the cavities of both types considered was originally fabricated with the terminations left unsoldered and held in place only by friction (increased by adding external clamps). This was done so that the cavities might be tuned to a reasonable frequency by sliding the terminations in and out. The frequency of each design was near 9435 mcps, the nominal frequency of Crain refractometer measuring cavities.

After the terminations were properly placed and soldered, measurements of the voltage standing wave ratio (VSWR) due to cavity input impedance were made as a function of frequency. Since there is no convenient means of calculating the size of feed hole which gives critical coupling, feed holes were cut small and gradually enlarged until the plot of VSWR vs frequency showed a minimum value near unity.

Following the technique given by Montgomery,[8] the unloaded Q of these cavities was calculated to be 3420 for the rectangular cavity and 2310 for the cylindrical cavity.

The next pertinent test was to determine the relation between cavity Q and the axial length of the terminations. When the length of termination sections on the rectangular cavities was decreased by increments, it was found that the Q was essentially constant for terminating section lengths greater than two inches but dropped rapidly as the length of the stub was decreased below two inches.

Since physical dimensions, as well as index of refraction, determine the resonant frequency of a cavity, the coefficient of thermal expansion of the material of the cavity will cause an erroneous indication of change in index unless the proper temperature correction is known. A possible means of temperature compensation involves the use of a material with a larger temperature coefficient for the divider in the terminating stub than for the material in the body of the cavity, but extensive efforts in this direction were not carried out.

The rectangular cavity must be considered a satisfactory, working piece of equipment with sufficiently good characteristics to make it acceptable for its designed function as a governing cavity for a Pound oscillator. The cross sectional obstruction due to the termination is only 1.66 per cent of the waveguide cross section area. With sufficient effort, it should be possible to temperature compensate such a cavity to any degree required.

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[8] C. G. Montgomery, ed., "Technique of Microwave Measurements," Mass. Inst. Tech., vol. 11, McGraw-Hill Book Co., Inc., New York, N. Y.

Transverse Electric Field Distributions in Ferrite Loaded Waveguides*

The transverse electric field distribution in dielectric and ferrite loaded waveguides has been measured by several investigators.[1,2] Knowledge of the actual field distribution within the waveguide is needed in the design of field displacement isolators, phase-shifters, and similar microwave devices. In making such measurements, care must be taken to choose lengths of samples of ferrites or dielectrics sufficiently long enough so that the distribution in one transverse plane will be the same (except for an attenuation effect) as in another transverse plane.

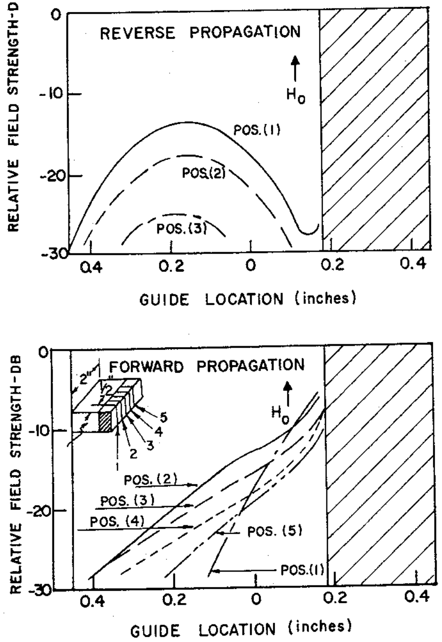

Fig. 1—Electric field distribution at 0.250 inch intervals along ferrite slab 0.259 inch thick with an external dc field of 2000 gauss.

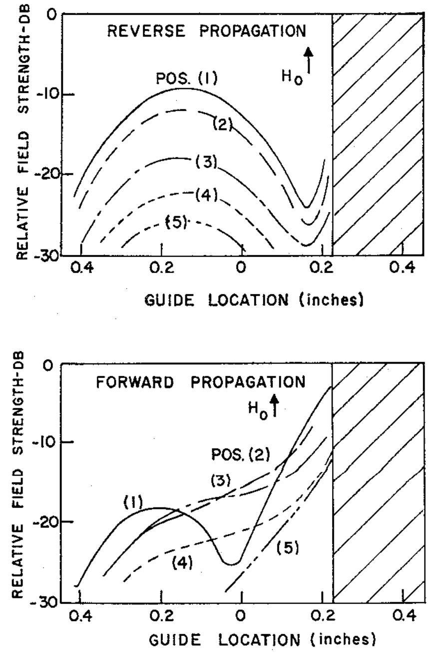

Fig. 2—Electric field distribution at 0.250 inch intervals along ferrite slab 0.227 inch thick with H_0 = 2000 gauss.

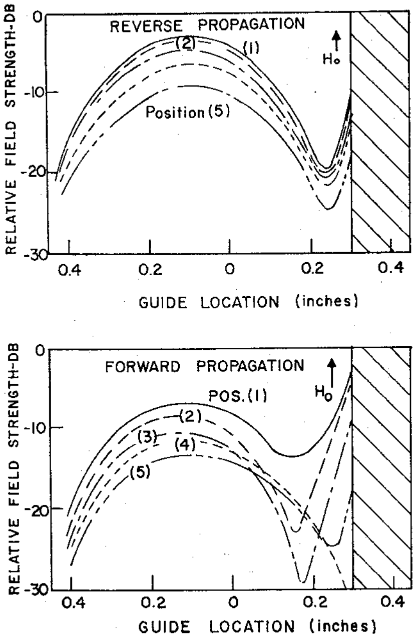

Fig. 3—Electric field distribution at 0.250 inch intervals along ferrite slab 0.145 inch thick with H_0 = 2000 gauss.

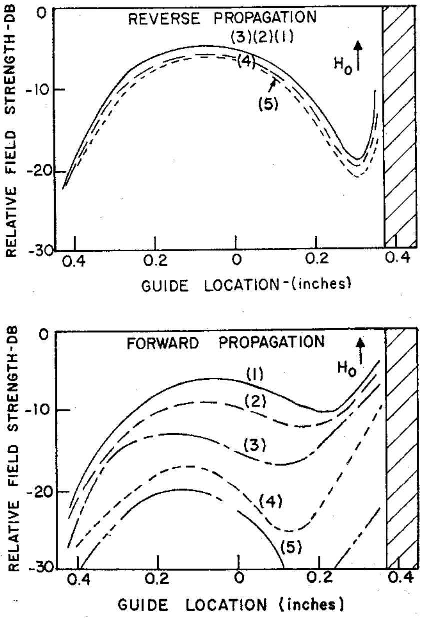

Fig. 4—Electric field distribution at 0.250 inch interval along ferrite slab 0.081 inch thick with H_0 = 2000 gauss.

To show that variations in distribution are indeed present, measurements were made with a transverse electric field detector[1,2] at various positions along a ferrite slab (see the sketch in the lower half of Fig. 1). As the incident wave penetrates from

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[1] R. L. Comstock, D. J. Angelakos and A. Johnson. "Determination of Fields in a Ferrite-Loaded Waveguide," Elec. Res. Lab., Univ. of California, Series 60, Issue 186; 1957.

[2] T. M. Straus, 1958 IRE Wescon Convention Record, pt. I.