Correspondence

End Plate Modification of X-Band TE_{011} Cavity Resonators*

In the application of microwave refractometers,[1,2] the sampling cavity consists of a right circular cylinder whose parallel faces are partially opened to permit air flow (See Fig. 1). The ambient air is aspirated through the cavity, and the instrument measures a weighted average of the index of the air contained at any time within the cavity.

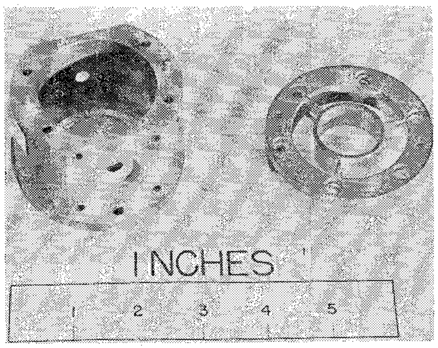

Fig. 1—Right cylindrical resonant cavity with open end plates.

In the interests of rapid response and simplification of turbulence considerations, attempts have been made to determine the effects of opening up the sampling cavity end plates. This has the immediate effect of reducing response time, but also impairs the electrical characteristics of the cavity by reducing its Q. This correspondence describes some experiments into the effects of different end plate configurations on the Q. Some earlier work on this problem has been reported by Adey.[3]

The general design of the end plates constructed is shown in Fig. 2, and they were used on a right cylindrical cavity barrel (number 1, Table I) of dimensions which gave it, with solid end plates, a resonant frequency of about 9,340 mc and a Q of 11,000. Five such sets of end plates of different ring radii and ring thickness were used, the total end plate area removed being about 90 per cent in each instance. All had the ring offset into the cavity barrel. With none of these end plate patterns was a Q greater than 5000 achieved.

To try to reduce the excessive fringing losses which seemed to be indicated by these very low Q values, another series of end plates was made having the ring flush with the inside surface of the end plate and extending *outward* from the barrel. It was believed that these protruding rings, acting as circular guides below cutoff, would diminish the losses due to external fields. To maintain

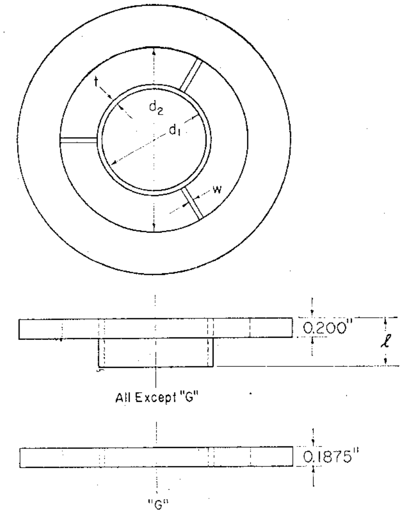

Fig. 2—General drawing of open end plates; end view at top, side views at bottom.

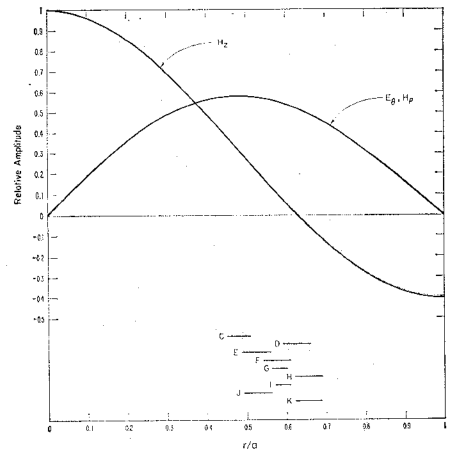

Fig. 3—Relative radial location of boundary surfaces of central ring of end plate in experimental open cavities.

TABLE I

Cavity Barrel Dimensions (inches)

Barrel number	a Inside diameter	b Length	c Outside diameter	d Iris thickness (At thinnest point)	e Depth of counter bores	f Iris diameter
1	1.905	1.653	2.750	0.030	round 0.135 rectangular 0.142	0.25
2	1.670	1.625	2.750	0.030	0.242 0.244	0.25
3	1.635	1.650	2.410	0.060	0	0.25

TABLE II

Dimensions, Frequency and Q of Various Experimental End Plate Patterns

Code Designation	Dimensions (inches) See Figure 2					Cavity barrel number	f_0 mc	Q	Per cent end area open
	t width central ring	d_1 I.D. central ring	w width of struts	d_2 I.D. sup ring	l length central ring				
C	1/16	0.852	1/16	1.90	0.5	1	8,951	3,000	90.6
D	1/16	1.125	1/16	1.90	0.5	1	8,953	4,080	89.6
E	1/16	0.935	1/16	1.90	0.5	1	9,021	4,920	90.3
F	1/16	1.030	1/16	1.90	0.5	1	8,977	4,688	90.0
G	1/32	0.935	1/16	1.67	0.188	2	9,237	2,340	92.6
H	1/16	1.031	1/16	1.67	0.5	2	9,233	8,817	88
I	1/32	1.094	1/16	1.90	0.5	1	8,961	3,815	93.6
J	1/16	0.814	1/16	1.67	0.55	2	9,254	7,416	89
K	1/16	1.007	1/16	1.635	0.448	3	9,381	7,720	92.6
109 A and B	~0.5	0.500	~1/4	1.82	A =0.487 B =0.456	1	8,974	9,031	21.4
Solid	—	—	—	—	—	2	9,345	11,000	0

the resonant frequency at about the same level, a new barrel was constructed, (number 2, Table I) dimensionally changed to keep the frequency at 9,350 mc in spite of the effective lengthening which resulted from inversion of the ring position, and three new sets of end plates of differing ring radii and ring length were tried thereon. To investigate the effect of ring length, each ring of these sets was originally made 0.75 inch long. They were then shortened in 0.05 inch steps and the Q and frequency noted during the shortening process. The frequency varied only a few mc throughout, but the Q, after showing little variation during the reduction of ring length from 0.75 inch to 0.5 inch fell rapidly as the ring length was reduced below 0.5 inch. On this barrel, the open end plates with the longer rings gave Q values for the cavity ranging from 7000 to 9000.

The data obtained from the second cavity, described in the preceding paragraph, indicated that a loss of about 100 mc in the calculated frequency was inherent in the use of the open type of end plate. Consequently, a third barrel (number 3, Table I) was fabricated of brass, the dimensions of which, using this criterion, would give it a resonant frequency of about 9,400 mc. It was further altered by adjusting the value of radius to

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[1] G. Birnbaum, "A recording microwave refractometer," *Rev. Sci. Instr.*, vol. 6, pp. 169–171; February, 1950.

[2] C. M. Crain, "An airborne microwave refractometer," *Rev. Sci. Instr.*, vol. 23, pp. 143–151; April, 1952.

[3] A. W. Adey, "Microwave refractometer cavity design," *Can. J. Tech.*, vol. 34, pp. 519–521; March, 1957.

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

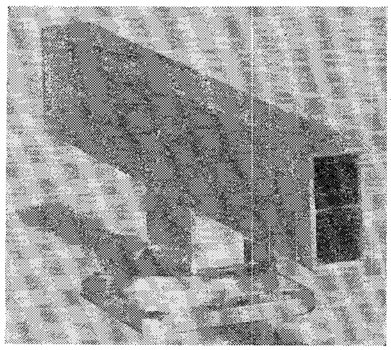

Fig. 1—Photograph of rectangular cavity.

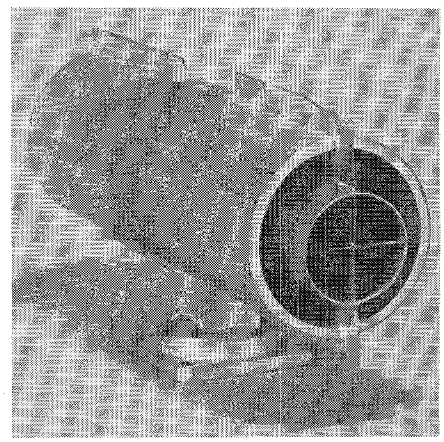

Fig. 2—Photograph of cylindrical cavity.

* 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.