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MODE SUPPRESSION IN RESONANT CAVITIES

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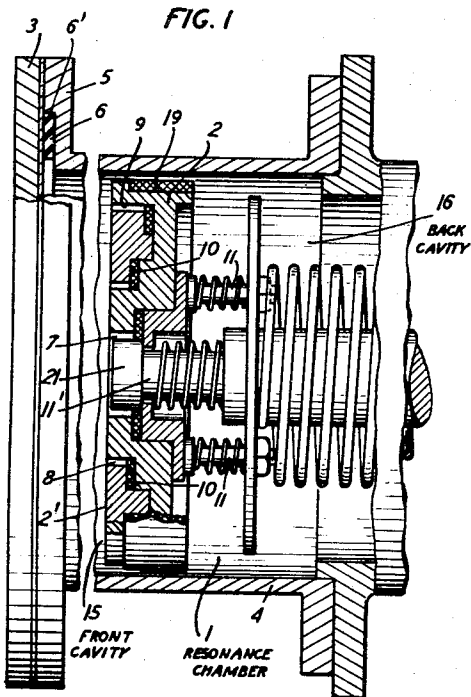


FIG. 2A

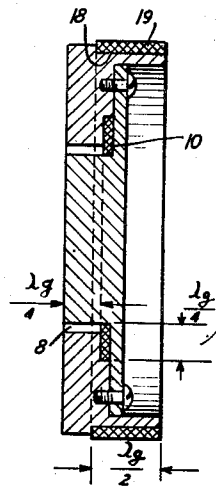


FIG. 2B

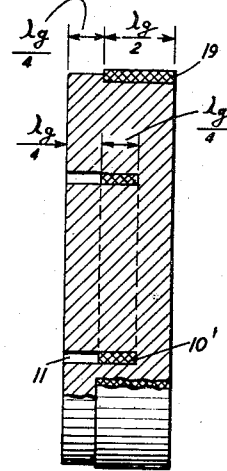
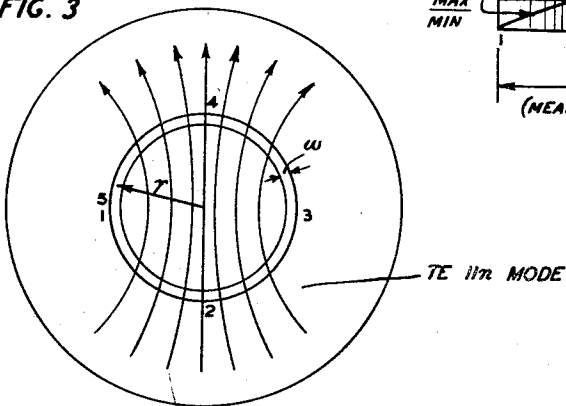
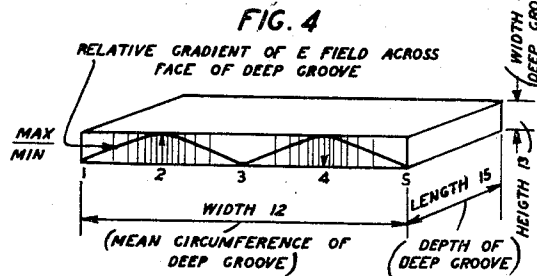


FIG. 3



PISTON FACE WITH A DEEP GROOVE



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2,710,945

MODE SUPPRESSION IN RESONANT CAVITIES

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9 Claims. (Cl. 333-83)

This invention relates to resonance chambers for microwaves and more particularly to the suppression of extraneous modes of oscillation in such chambers.

An object of the invention is to trap and absorb extraneous modes having a radial field component by means of terminated, impedance transforming deep grooves.

Another object of the invention is to prevent interaction between the front and back cavity of an echo box or tunable resonance chamber by means of absorption loading in the form of a sealing ring on the periphery of the tuning piston.

A feature of the invention is a mode suppressor for a resonance chamber, characterized by terminated deep grooves located therein, the grooves being concentrically arranged and having a depth related to

$$\frac{\lambda_g}{4}$$

where λ_g is the guide wavelength therein appropriate to an undesired mode, whereby numerous modes of initial intensity comparable to the main mode, may be effectively degraded.

Another feature of the invention is a reflecting tuning piston having an electromagnetic sealing ring on the periphery thereof to provide high loss for undesired modes and to prevent interaction between the front and back cavity in a tunable resonance chamber.

Extraneous mode suppression characterized by shallow, concentric cuts in a conductive end plate of a resonance chamber for discriminating against undesired modes having a radial field component, have heretofore been disclosed in the United States application Serial No. 570,192, filed December 28, 1944 by W. A. Edson, now patented as United States Patent 2,698,923, January 4, 1955.

More effective mode suppression than that obtainable by shallow cuts has become important particularly in the centimeter or millimeter wave range, where the number of extraneous modes present increases and the initial intensity thereof approaches that of the operating mode.

In accordance with the invention, deep grooves are provided in the reflecting face of a tuning piston, the grooves being concentrically arranged and having a depth related to

$$\frac{\lambda_g}{4}$$

A lossy termination is provided at the base of the deep grooves, where undesired modes having a radial component of field distribution may be fully absorbed. The tuning piston is also provided with peripheral loading, such as a ring of absorption material, for example neoprene. The piston loading may be viewed as a sealing ring, preventing electromagnetic leakage between the active front and the back cavity of the resonance cham-

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ber or echo box, thereby isolating said cavities from interaction effects.

In the drawings:

Fig. 1 represents a resonance chamber and the tuning piston end portion thereof;

Fig. 2A shows the folded deep groove construction in said piston;

Fig. 2B is a modified deep groove construction;

Fig. 3 shows a front view of a piston with a single deep groove for suppressing the TE_{11n} mode family; and

Fig. 4 shows the equivalent rectangular wave guide analogue of the deep groove shown in Fig. 3.

Referring to Fig. 1, a tunable resonance chamber 1 of cylindrical form, having a highly conductive interior coating of silver or the like, is provided with a movable tuning piston 2 adapted to be reciprocated by a mechanical drive which may be of a type such as disclosed in the United States application of W. F. Kannenberg et al., Serial No. 544,990, filed July 14, 1944, now Patent No. 2,537,139 issued Jan. 9, 1951, or the like, now patented as United States Patent 2,537,139, January 9, 1951.

The resonance chamber 1 comprises an end base plate 3 on which is accurately positioned the right circular cylinder 4 having transverse perpendicular supporting or aligning flange 5, so that the principal axis of the cylinder is ideally perpendicular to the base plate 3 at its center.

The end plate 3 may be provided with a pair of slits and a TE_{03} mode suppressor as more fully disclosed in the United States application of R. W. Lange, Serial No. 770,988 filed August 28, 1947, now patented as United States Patent 2,701,343, February 1, 1955. Between the base plate 3 and the flange 5 of cylinder 4, a loading ring 6 of neoprene absorber is seated in a deep groove 6', approximately

$$\frac{\lambda_g}{4}$$

in depth, where λ_g is the wavelength in the wave guide. The continuity of conductive surface between the end plate and the side wall of the chamber is thereby interrupted by the deep groove 6', which traps and absorbs the energy of extraneous modes propagating over said surfaces.

The tuning piston 2 is provided in its reflecting face 2' with a plurality of cylindrically shaped, deep grooves 7, 8, 9 therein, concentric to the principal axis of the resonance chamber 1. The grooves 7, 8, 9 are each

$$\frac{\lambda_g}{4}$$

in depth for the corresponding mode or modes, and are each terminated by a loading dielectric ring 10 made of conductive neoprene or the like, extending transversely to the principal axis of the resonance chamber 1.

To produce and maintain perfect parallelism between the piston 2 and base plate 3, pivoted centering bolts 11 as disclosed in the United States application of R. W. Marshall, Serial No. 714,621 filed December 6, 1946, which issued as United States Patent 2,587,055, February 26, 1952, are provided on the rear surface of the piston.

The central bolt 11' has its head 21 recessed in the piston, providing a flush surface with the piston face 2'. The deep groove 7 is formed by the hollow space, bounded by the cylindrical side surface of head 21 and the adjacent, recessed cylindrical surface, transverse to the piston face 2'. The rear end of the head 21 is in conductive contact with the rear of the piston.

The electric field of the TE_{01n} operating mode, being everywhere circular, fringes into the concentric groove and since the neoprene absorption rings 10 are recessed sufficiently deep, the loss to the wanted mode TE_{01n} is consequently very small. The depth of the concentric grooves for this purpose is

$$\frac{\lambda_g}{4}$$

for an undesired mode. The

$$\frac{\lambda_g}{4}$$

depth provides effectively a quarter wavelength transformer, whereby the impedance at the piston face 2 matches the impedance provided by the lossy terminations or rings 10 at the base of the grooves. When the proportions of air space and neoprene loading are proper in the deep grooves 7, 8, 9, unwanted modes having a radial component of the electric field, are severely degraded as the radial currents thereof flow across the circular zones of the deep grooves.

As the requirements of echo boxes advance to the higher frequency regions (such as the millimeter and the 1 to 10 centimeters wavelength region), and higher Q, the total number of modes possible in the working front cavity 15, the back cavity 16 and in between the two increases. These resonances can produce spurious ring and transmission and interaction effects comparable to those at a mode crossing. Therefore it becomes increasingly important in these frequency regions to eliminate all back cavity effects. For this purpose, a piston loading or sealing ring 19 operates in the peripheral gap space 20 to add loss, eliminate back cavity effects and furnish additional mode suppression in the active cavity, through the operation of a cylindrical deep groove having an open rather than a short-circuited end. The piston skirt 18, that portion of the piston adjacent and parallel to the side wall of the chamber 1 and measured back from the active piston face, supports a band 19

$$\frac{\lambda_g}{2}$$

in width of lossy dielectric, such as conductive neoprene. The width of the dielectric and its location

$$\frac{\lambda_g}{4}$$

distance back of the active piston face are important dimensions for its operation in an open end, deep groove mode suppressor. The gap space 20 has the function of suppressing extraneous modes with radial field components but the inclusion of the piston ring increases the suppression and effectively isolates the back cavity from the front cavity.

The deep grooves heretofore described and shown in Fig. 1 may be designated as the folded type.

A modified type of deep groove is shown in Fig. 2B. This may be designated the cylindrical deep groove, and is characterized by a groove

$$\frac{\lambda_g}{2}$$

in overall depth, having an air filling

$$\frac{\lambda_g}{4}$$

deep communicating with the front cavity and a dielectric filling 10' of conductive neoprene

$$\frac{\lambda_g}{4}$$

in depth, acting as an absorbing termination for unwanted modes.

Factors in design of a deep groove

Fig. 3 shows schematically the piston face with a single deep groove therein, located at radius r , and having a width w .

The factors which enter into the design of individual deep grooves for suppression of specific unwanted modes (all modes except $TE_{0,m,n}$) are the radius r , the depth and width w of the groove, and the properties of the dielectric loading material as illustrated in Figs. 2A, 2B, 3.

Inasmuch as the deep groove depends in part for its discrimination upon the direction of current flow of desired and undesired modes, it is best located in regions of maximum radial current of the undesired modes. The degradation of the unwanted mode is proportional to the dissipation in the lossy dielectric loading and this loss is proportional to the square of the radial current and to a resistance term. The resistance term is a minimum for a groove located at zero radius and a maximum at the chamber periphery and for this purpose is taken as varying with radius. In a simple case where the resistance varies linearly with the radius, the relative effectiveness of the deep groove is proportional to $I_p^2 r$ where I_p is the relative intensity of radial current and r is average relative radius.

For better visualization of its electrical characteristics, a deep groove may be considered as an imaginary rectangular wave guide folded around the axis of the piston until its opposite sides become adjacent and are removed, see Figs. 3 and 4. Analogously, the resonance chamber 1 for the purpose of this analysis, may be regarded as replaced by a rectangular guide, supporting the same operating mode and having the same width as the rectangular guide of Fig. 4. The height of the former equivalent guide will hereinafter be termed "the full height" to distinguish it from the height of the previous rectangular guide (Fig. 4).

Referring to Fig. 4, the length dimension 15 of the equivalent rectangular wave guide would correspond to the depth of the deep groove, measured along the principal axis from the piston face 2' to the bottom of the respective groove. The rectangle's width 12, which determines the frequency of cut-off, corresponds to the mean circumference of the deep groove, and its height 13 corresponds to the radial measure of the groove's width. For the mode family $TE_{1,m,n}$ in the resonant chamber 4, the field distribution in the deep groove considered in terms of an equivalent rectangular guide, will be that of the $TE_{2,0}$ mode, i. e. the equivalent rectangular guide 4 supports a mode having two half wavelengths measured along its width dimension 12 (Fig. 4). For the $TE_{2,m,n}$ family in the resonant chamber, there would be four half wavelengths measured along the width in the equivalent rectangular guide of the deep groove.

The cut-off frequency f_c of this rectangular guide is

$$f_c = \frac{cl}{2\pi r}$$

and the guide wavelength (in the absence of a loading dielectric) is:

$$\lambda_g = \frac{c}{f \sqrt{1 - \left[\frac{cl}{2\pi r f} \right]^2}}$$

where

c is the velocity of light $= 3 \times 10^{10}$ cms./sec.

f is the operating frequency in cycles/sec.

l is the l index of a particular unwanted mode in the echo box

r is the mean radius of the deep groove in cms.

It is to be noted that the equivalent guide wavelength is a function of the radius r of the groove and the l index of the mode.

The effective electrical length of the air and lossy

neoprene sections of a deep groove are each slightly less than

$$\frac{\lambda_g}{4}$$

as determined in experiments at 1 to 3 centimeters wavelength. The deep groove was found to provide the best termination to the wave guide chamber 1 when the shortest air section, somewhat less than

$$\frac{\lambda_g}{4}$$

and a conductive neoprene section of approximately the same length were used. Sections longer by integral numbers of half guide wavelength were more critical in dimensions and more frequency sensitive.

The impedance seen at the junction of the wave guide chamber and groove, looking into the groove, is the admittance of the loaded groove in parallel with a capacitive susceptance produced by the change in their respective heights. The best termination to the full height guide is obtained when the conductance offered by the groove matches that of the main guide and when the susceptance offered by the groove cancels that produced by the aforementioned change in height. It appears that the heavily loaded section slightly less than

$$\frac{\lambda_g}{4}$$

long presents a low resistive termination to the unloaded section and this impedance transformed by less than a

$$\frac{\lambda_g}{4}$$

section presents high resistive and inductive components to match the large guide and neutralize the reactance due to the change in height. The impedance looking into the loaded grooves depends on the mode being suppressed, the dimensions of the groove, the conductivity and dielectric constant of the loading material.

The width w of the deep groove measured along a radius of the cavity corresponding to the height 13 of the equivalent rectangular guide is important in two respects. First, the capacitive susceptance produced by the change in height is dependent upon the width of the groove, which in turn reflects in the depth dimension as stated above. Second, the degradation of the desired mode depends on the reflecting surface of the piston that is removed, so the width of the groove should be held to a minimum. A width approximately 1% of the cavity diameter has been successfully used in several designs of echo boxes.

Folded grooves

In general the treatment of cylindrical (Fig. 2B) and folded grooves (Fig. 2A) is similar. The fold is made in the unloaded section or at the junction of the loaded and unloaded section principally to permit constructing the loading in the form of flat washers. The washers can be made easily and can be retained in place so that the construction will withstand shake and shock tests.

The computation of λ_g is further complicated by the fold; however, the folded grooves used in 3 centimeters and 1.25 centimeters wavelength bands were computed the same as cylindrical grooves. The depth of each section measured along the center line of the groove is slightly less than

$$\frac{\lambda_g}{4}$$

The width, measured along the radius in the cylindrical part and along the bore axis in the folded part, is approximately 1% of the cavity diameter as in the cylindrical groove.

Suppression to a group of modes

The suppression of a group of modes follows the pattern described for the suppression of an individual mode. The best radius for a deep groove is selected for each mode and a compromise radius is chosen. In some cases a single radius may prove satisfactory for less than all of the modes of the group. This then requires a sorting of modes on the basis of optimum radius of grooves and the selection of two or more radii for the location of grooves. In making this selection, consideration must be given to the relative

$$\frac{Q\delta}{\lambda}$$

value of the unwanted modes and the relative suppression required. In general, greater suppression is required for those modes having the larger

$$\frac{Q\delta}{\lambda}$$

values.

The modes to be suppressed by each groove may be collected into families according to the l index and the depth of each groove computed for these families. A compromise in depth is made according to the relative suppression required. Modes requiring the greatest suppression are favored. If large values of l are encountered, as at the 1.25 centimeter wavelength band design, these modes must be treated by special grooves close to or at the piston edge.

A particular example is the choice of the deep groove to suppress the $TE_{1,3,n}$ mode in the 1.25 centimeter wavelength echo box. A groove at 40% radius chosen to suppress many other unwanted modes offered only a few per cent relative suppression to the $TE_{1,3,n}$ mode as the best location to suppress the $TE_{1,3,n}$ is at 15% radius. The echo box was again tested with a piston incorporating a deep groove with mean radius at about 18% (a slight compromise for mechanical considerations), and the $TE_{1,3,n}$ mode was completely suppressed for both ring and transmission. The ring was degraded from $6\frac{1}{2}\mu s$ at least to $2\frac{1}{2}\mu s$ (as observed by the transmitter pulse and receiver recovery) which with a decrement of about 9 db/ μs indicates a suppression exceeding 36 db. The suppression to transmission exceeds 25 U. H. F. db for the mode was tentatively identified by a slight trace (less than $\frac{1}{4}$ meter division) of rectified current with minimum U. H. F. attenuation in the transmission path.

In the measurements of a 1.25 centimeter wavelength echo box simulated in 3 centimeter band, absolute identification of modes was difficult particularly if various perturbations were introduced by mode suppression devices. The deep groove performance was judged by the reduction in extraneous transmitting and ringing modes both as to total quantity and value. At approximately 9420 megacycles a total of 15 extraneous modes were reduced to 3 (excluding $TE_{0,2}$ and 0, 3 modes) after installing a deep groove at 40% radius. At 9500 megacycles, 16 extraneous modes were reduced to 7 and at 9360 megacycles 13 reduced to 6. The greatest transmission reduction exceeded 40 db measured on a transmission oscilloscope at video frequencies. Extraneous rings, some as long as 3000 yards were reduced at least to 400 yards (the recovery time of the radar). The introduction of the groove reduced the average transmission and ring of the wanted mode about 3 to 5%.

Piston peripheral loading

There are two general factors in the design of suppression in the form of a lossy skirt at the piston gap, namely the depth of loading measured along the axis and the width measured radially.

The peripheral gap space can be considered an open end deep groove. The lengths of the loaded and unloaded

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portions are dependent on the l index of the modes to be suppressed. The depth of the unloaded section is slightly less than

$$\frac{\lambda_g}{4}$$

where λ_g is computed as in the piston deep groove and the depth of the loaded section is increased to approximately

$$\frac{\lambda_g}{2}$$

to compensate for removing the closed end of the groove.

Unless suppression is required for a specific mode these depths are sometimes reduced as a compromise on the physical size of the piston for shake and shock considerations.

The width of the peripheral gap is primarily selected to perturb the TM companion of the wanted mode, consistent with a small degradation of the TE mode. The width is about 3 to 5% of the diameter. The gap width applies at the piston face and may change along the piston skirt. As stated previously, changes in width affect the equivalent lengths of the unloaded and loaded sections of the gap.

There must be sufficient volume of lossy material on the skirt to suppress transmission to the back cavity adequately. This was achieved in the 1.25 centimeter echo box range in a reasonable length by increasing the gap beyond the unloaded section to accommodate a conductive neoprene band. From mechanical considerations this step in gap width provides a locating ridge for the band and is sufficient to prevent the loading material from touching the cavity wall. For a particular conductive neoprene used, the thickness of material is .040 inch for 1.25 centimeter wavelength and $\frac{1}{16}$ inch in the 3 centimeter region. The surface of the band extends slightly above the unloaded gap section.

It should be understood that the deep groove mode suppressors previously disclosed as located in the piston face of the echo box or resonant chamber, may be also situated in the fixed end plate thereof or in the side walls without departing from the spirit of the invention. Also it is possible and in some cases mechanically desirable, to locate some of the deep grooves in the piston face and some in the end plate without departing from the spirit of this invention.

What is claimed is:

1. In a substantially closed electromagnetic resonator tunable about a predetermined operating frequency and having substantially the shape of a right circular cylinder, a conductive piston movable axially of the said resonator and dividing the said resonator into an active resonating chamber adapted to support electromagnetic waves of the operating frequency in a TE₀₁ mode, said piston having two cylindrical peripheral surfaces each spaced from the cylindrical wall of the resonator, one of said surfaces having an axial length of approximately a quarter wavelength and the other of said surfaces carrying a band of lossy material having an axial length of approximately a half wavelength, said piston having, in the face thereof that bounds said active chamber, at least one annular recess concentric with said chamber, said recess having a low-loss impedance matching section that is substantially a quarter wavelength in depth terminated in another portion containing lossy material wherein the wavelength taken corresponds to that of an undesired mode.

2. In combination, a cylindrical hollow cavity resonator adapted to operate in TE_{0mn} mode and having a tuning piston, the active face of said piston being provided with a series of selective annular deep grooves located in regions of maximum radial current of unde-

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sired modes, said grooves adapted to provide an impedance match between the impedances at opposite ends thereof and the depth thereof being substantially equal to an integral multiple of a quarter wavelength corresponding to the l index of a family of undesired modes, and an absorber located at the base of each groove to attenuate the undesired modes without substantially affecting the operating mode.

3. In combination, a hollow cavity resonator, means for exciting said resonator with electromagnetic energy in a predetermined mode of oscillation, a tuning piston for said resonator having two cylindrical peripheral surfaces, one thereof having a groove and having an axial length of approximately a half wavelength of an undesired mode, the other surface having an axial length of approximately a quarter wavelength for impedance transformation, and a band of lossy dielectric filling said groove.

4. A hollow cavity resonator having conductive end walls, means for exciting said resonator with electromagnetic oscillations in a TE_{0mn} mode, one end wall being provided with spaced concentric deep grooves communicating with the cavity space, said grooves each having an extraneous mode absorber at the base thereof, the depth of said grooves being different and substantially equal to an integral multiple of a quarter wavelength corresponding to the extraneous modes for transforming the impedance of said resonator to the absorber impedance.

5. The structure of claim 4 wherein said grooves are filled in their basal portions to half their depth with said absorber.

6. The structure of claim 2 wherein each of said grooves has a transverse fold forming its closed end and said absorber is a flat ring

$$\frac{\lambda_g}{4}$$

in width filling the closed end of said groove, where λ_g is the wavelength corresponding to an extraneous mode.

7. A hollow cavity resonator comprising conductive walls, means for exciting said resonator electromagnetically in a predetermined operating mode and extraneous mode selective devices comprising concentric deep grooves of unequal depth corresponding to the l index of extraneous modes suppressed thereby, said grooves being located in a conductive wall, said grooves communicating with the cavity space at one end thereof and being loaded with dissipative material at the other end, said grooves being located radially at positions where $I_p^2 r$ is maximum where I_p is the relative intensity of radial current of undesired modes and r is the average relative radius.

8. The structure of claim 7, wherein said wall comprises a tuning piston having two cylindrical peripheral surfaces, one thereof being a groove substantially a half wavelength long corresponding to an undesired mode and a band of lossy dielectric filling said groove.

9. The structure of claim 2, wherein said resonator is provided with a recessed end plate, the recess being offset and having an absorber therein for trapping extraneous modes propagating between the end plate and cylindrical side wall thereof.

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