Oct. 11, 1955 W. A. EDSON ET AL 2,720,629

ORIFICE COUPLING TO RESONANT CAVITIES

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FIG. 7

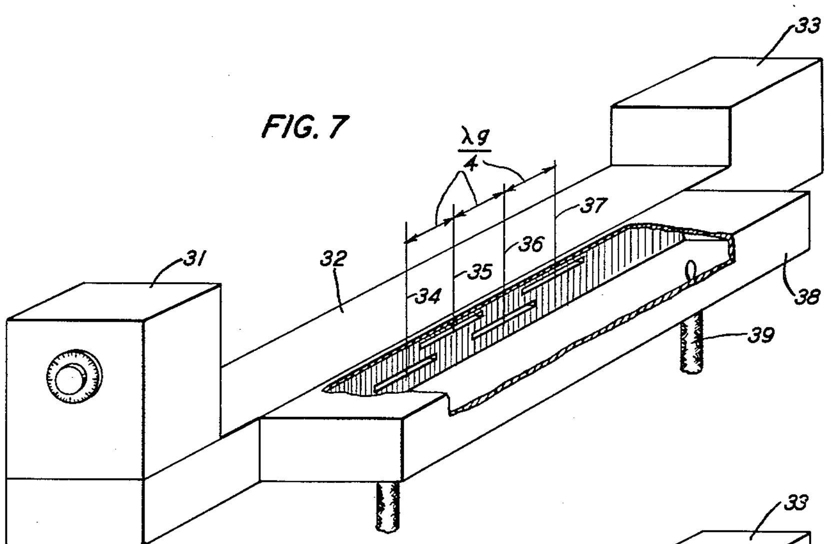
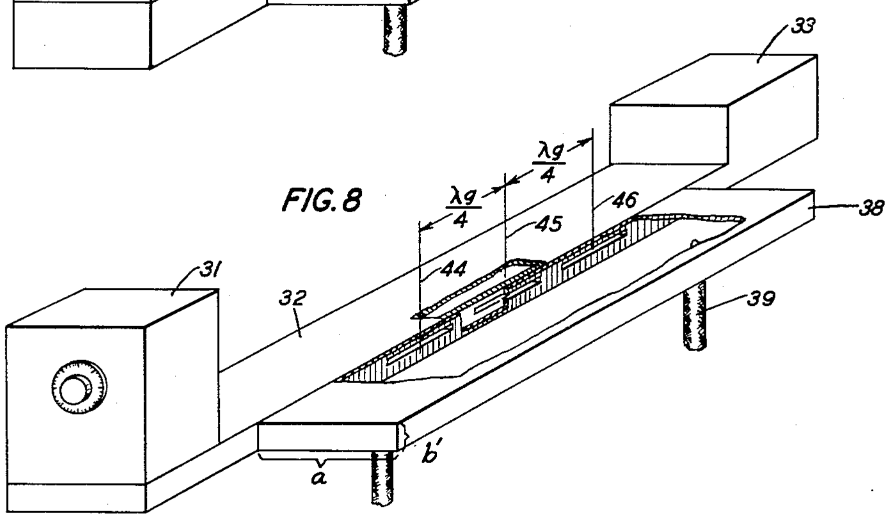


FIG. 8



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ORIFICE COUPLING TO RESONANT CAVITIES

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FIG. 1B

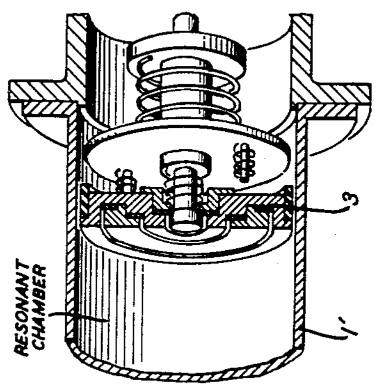

FIG. 1A

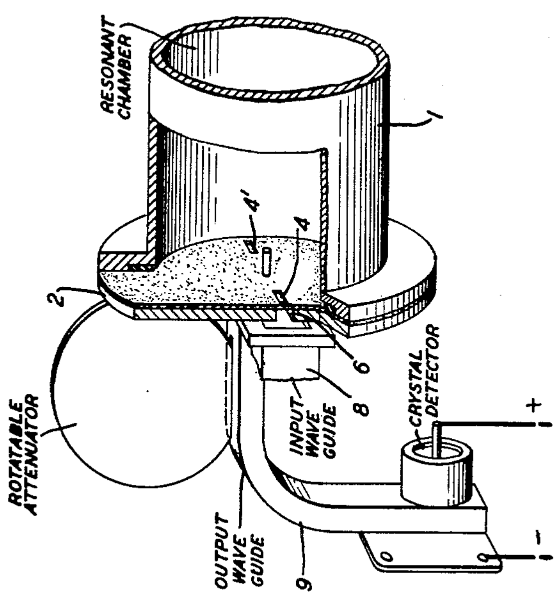

FIG. 1C

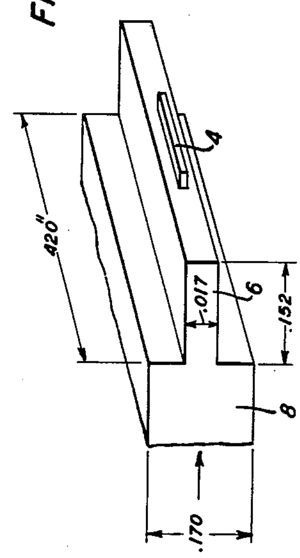

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FIG. 2A

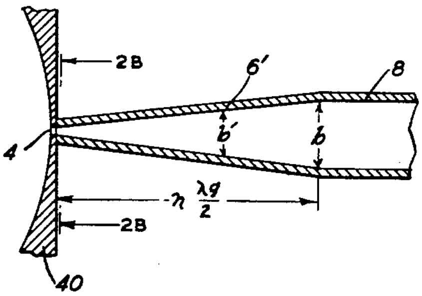


FIG. 2B

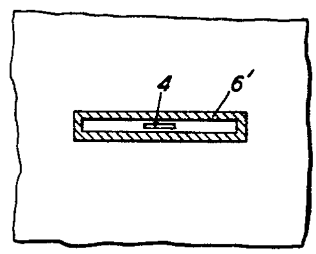


FIG. 3

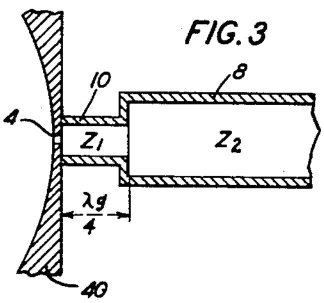


FIG. 4

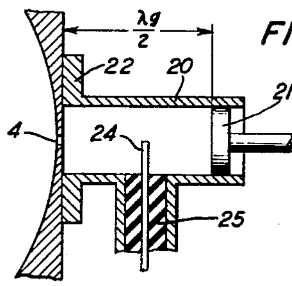


FIG. 5

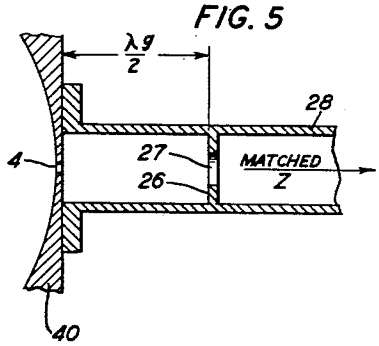
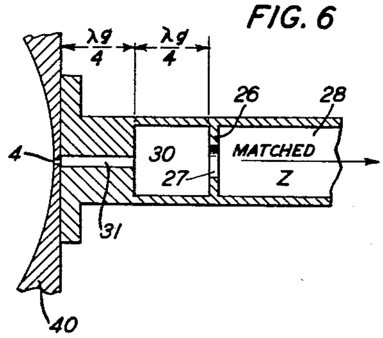


FIG. 6



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ORIFICE COUPLING TO RESONANT CAVITIES

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Application September 9, 1947, Serial No. 772,936

8 Claims. (Cl. 333—83)

This invention relates to cavity resonators and more particularly to improvements in feeding wave energy thereto.

An object of the invention is to enhance the concentration of the exicting electromagnetic field at the entrance to a resonant cavity.

Another object of the invention is to concentrate the electromagnetic field at the entrance to a resonant cavity in such a manner as to reduce intermode couplings.

A feature of the invention is a resonant cavity with a lineal feed slit in a wall thereof, at which the exciting electromagnetic field is concentrated by a tapered, impedance matching transformer.

Another feature of the invention is a wave energy "supercharger" feed device comprising a stepped quarter-wavelength impedance matching transformer connected to a lineal slit in a resonant chamber.

Another feature of the invention is a wave energy "supercharger" feed device comprising a combination of a resonant wave guide transducer and/or a quarter wavelength step transformer for concentrating the exciting electromagnetic field at a lineal slit of a resonant chamber.

Referring to the figures of the drawing:

Fig. 1A shows the energy feed for a resonant chamber in accordance with the invention;

Fig. 1B shows the tuning piston end of the same resonant chamber;

Fig. 1C shows a schematic view of the passageway through the impedance step transformer;

Fig. 2A shows a side elevation of the tapered impedance matching transformer connected to a lineal slit in the wall of said chamber;

Fig. 2B is an end view thereof;

Fig. 3 shows a quarter wavelength step with the lineal slit impedance transformer associated therewith;

Figs. 4 and 5 show resonance transducers connected to the lineal slit;

Fig. 6 shows a combined resonance transducer and a quarter wavelength transformer feeding a lineal slit; and

Figs. 7 and 8 show directional couplers with concentrated energy feeds in accordance with the invention.

Intermode coupling exists in a wave guide cavity or the like when there is energy transfer from one mode of oscillation to another. In high Q resonant cavities, such as echo boxes, intermode coupling results in a degradation of the desired performance characteristics of the operating mode.

Resonant chambers have heretofore been fed and excited at a circular or rectangular orifice located in the side or end wall thereof. The two types of orifice may give equal intermode coupling when adjusted for equal couplings to the main or operating mode, or the couplings may materially change in shifting the orifice from the side to end wall or vice versa. Experimental work indicates that the two also give equal performance as to polarization and that the rectangular slot produces less intermode coupling than does the equivalent round orifice. The intermode coupling is primarily a property of the orifice and is apparently independent of the apparatus external to the resonant chamber echo box or the like.

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Moreover, since the intermode coupling decreases with the size of the orifice, it becomes desirable to reduce the size and dimensions thereof to the smallest value consistent with existing mechanical limitations and tolerances of manufacture. Experimental work by applicants verifies the theoretical prediction that the loading on a cavity through a given slit orifice is substantially increased, when the characteristic impedance of the feeding guide is reduced by reducing its height.

Resonant chambers having a narrow feed slit in a wall thereof, to which a tapered section of wave guide is connected for improving the ringtime are disclosed in the United States application, Serial No. 772,987, filed concurrently herewith by W. F. Kannenberg. The present invention represents an improvement and extension of the invention disclosed in said application, particularly in narrowing the slit to achieve an appresiable reduction in intermode couplings and in concentrating the exciting field at the slit by means of impedance matching transformers and/or resonant transducers.

In accordance with the invention, resonant chambers, echo boxes or the like, are fed wave energy and excited by means of a "supercharger," which may be defined as a narrowed slit in the wall thereof associated with an impedance matching transformer, resonant transducer or the like for increasing the concentration of the field thereat and reducing the intermode couplings in the chamber. The transformer may be a tapered impedance matching section, a

$$\frac{\lambda g}{4}$$

stepped wave guide section, or a resonant transducer, and suitable combinations thereof to further enhance the field concentration and correspondingly reduce the intermode couplings.

Referring to Figs. 1A and 1B, a cylindrical resonant chamber cut into two sections, the feed section **1** and tuning section **1'**, respectively, is shown, designed to operate in the TE_{01n} mode. The metallic end feed plate **2** is provided with a pair of mode suppressing slits **4, 4'** spaced 180 degrees apart and at a distance approximately equal to ½R from the center C thereof to the slit midpoint, where R is the radius of the resonant chamber. The slits **4, 4'** in the end plate **2** (diameter 2.04 inches) are 10 mils high, 120 mils wide, when operating at 1.25 centimeter wavelength, and effectively coupled to the TE_{01n} mode without exciting the TE_{02n} mode, the slit **4** being the energy input feed for the resonant chamber. Impedance matching transformers **6** of the

$$\frac{\lambda g}{4}$$

type, more fully disclosed subsequently, are connected to the chamber in such a manner as to match the impedance of the slits **4, 4'** respectively at one end to wave guide feeds **8, 9** respectively, of rectangular cross-section at the other end. As shown in Fig. 1C, the input transformer **6** has a width of 420 mils, a height of 17 mils, and a length measured along the path of transmission of 152 mils. The output transformer (not shown) has a width of 420 mils, a height of 50 mils and a length of 152 mils, and is more loosely coupled to the cavity than is the input transformer. The output slit **4'** is connected to a rectangular wave guide **9** for measuring the output energy from the chamber **1** by means of the crystal detector shown. The wave guides **8, 9** in an exemplary embodiment were each .42 inch wide x .170 inch high, the wave guide **8** serving as the input and the wave guide **9** as the output of the chamber **1**.

The narrowed slits **4**, **4'** are preferably lineally dimensioned, i. e., reduced substantially to a single dimension to give less intermode coupling than round orifices or ordinary rectangular slots. The size of the slits may be reduced to an extreme limit and still provide an improved ring-time in the resonant chamber by using therewith either a tapered impedance matching section, or a quarter wavelength stepped transformer or a resonance transducer as shown in Figs. 2A, 3, 4.

The mode suppressing slits **4**, **4'** are also disclosed in the United States application of R. W. Lange, Serial No. 770,988, filed August 28, 1947, which issued as United States Patent 2,701,343, February 1, 1955.

The tuning piston end **1'** of the resonant chamber is described in the United States application of W. A. Edson, Serial No. 776,194, filed September 26, 1947, which issued as United States Patent 2,710,945, June 14, 1955.

Fig. 1C shows schematically the passageway construction and dimensioning of the quarter-wave form of "supercharger" represented in Fig. 1A. In Fig. 1C, the input rectangular wave guide **8** is connected to the quarter wavelength step transformer **6**, hollowed out of plate **2** in the form of a rectangular channel, and communicating with a lineal slit **4** cut into the silver facing **2'** of the end plate.

Referring to Figs. 2A, 2B, an impedance transformer **6'** is shown as a tapered section of rectangular wave guide connected to side wall **40** of a resonant chamber at slit **4**. The rectangular feed pipe **8** is connected integrally to one end of the transformer **6'**, the latter tapering down therefrom in its height dimension b to the dimensions of the narrow slit **4**, over a length approximately equal to

$$n\frac{\lambda g}{2}$$

where n is an integer and λg is the wavelength in the guide.

Referring to Fig. 3, a quarter wavelength step transformer **10** corresponding to the transformer **6** in Fig. 1A, is shown for matching the impedance of the rectangular feed pipe **8** to the impedance of the lineal slit **4**. The length of the transformer **10** is

$$\frac{\lambda g}{4}$$

where λg is the wavelength in the guide and its characteristic impedance $Z_1=\sqrt{Z_2 \cdot Z_3}$ where Z_2 represents the impedance of the rectangular guide **8** and Z_3 the impedance at the slit **4**. For a rectangular guide .42" x .170" for example, Z_2 may have a typical value of 500 ohms. In practice, the quarter wavelength step transformer **10** is found to be more compact than the tapered transformer section **6**.

The advantages derived from the "supercharger" feed construction may be illustrated by the following exemplary case. Thus, assuming a ten-to-one ratio of wave guide heights at opposite ends of the transformer section **10**, the equivalent coupling ratio is 100:1. This may be compensated for by a reduction of the slit length by

$$\sqrt{100:1} \text{ or } 2.16$$

An advantage in intermode couplings of ten-to-one and of Q dip at a crossing of one hundred-to-one should accompany the change.

Resonance transducers **20** in the supercharger feed as shown in Fig. 4 may be used as impedance matching transformers. The transducer may be a rectangular section of wave guide

$$\frac{\lambda g}{2}$$

in length, connected to a cylindrical echo box or resonant chamber side wall **40** for concentrating the electromagnetic field at the slit **4**. The flange **22** on the transducer **20** serves to fasten the latter to the wall **40** of the echo box. A matched probe **24** extends into the transducer **20** from the coaxial feed line **25** connected thereto as shown in Fig. 4. The echo box loading or cavity to feed line coupling factor is increased if the probe **24** is shortened or retracted from the transducer. Resonance is set up in the transducer **20** which operates as a TE_{101} resonator, and the resulting magnification of the fields increases the coupling through the slit **4**. The piston **21** may be used to adjust for best resonance about the

$$\frac{\lambda g}{2}$$

position shown in Fig. 4.

Fig. 5 shows a modified transducer arrangement for a resonance chamber or echo box. An inductive iris **26** having a round aperture **27** such as disclosed in the United States application Serial No. 452,851, filed July 30, 1942, by A. G. Fox, which issued as United States Patent 2,432,093, December 9, 1947, forms the end wall of transducer **20**. A wave guide feed line **28** is matched in impedance by the iris **26** to the impedance to the left thereof represented by the transducer and slit in combination.

Fig. 6 shows a resonance transducer **30** combined with a

$$\frac{\lambda g}{4}$$

type of impedance matching transformer **31** similar to that shown in Fig. 3 for enhancing the concentration of the exciting field at slit **4**. The combination of transducer **30** and

$$\frac{\lambda g}{4}$$

step transformer **31** in the "supercharger" feed provides a progressive reduction in impedance going from the echo box or cavity toward the wave guide line **28**, namely, the transformer **31** accomplishing the first reduction and the transducer **30** the second reduction. The iris **26** provides the effect of an inductance shunted across the wave guide feed line **28**.

Thus, by way of example, the value of iris **26** may be chosen so that the effective series resistance of this basically shunt combination is 50 ohms. The length of transducer section **30** between the iris **26** and the quarter wavelength step **31** is then so chosen that the impedance is a pure resistance closely equal to 5000 ohms. The step transformer **31**, which is a quarter wavelength long, again inverts this impedance about its own value of 50 ohms to the low value of 0.5 ohm. For optimum ringtime in this connection, the orifice size must be reduced so that the cavity has an equivalent resistance of 0.05 ohm.

It is seen that the impedance level of the cavity is lowered by a factor of ten with each elaboration of the feed device. Naturally this factor is arbitrary, but it is illustrative of the relatively large effects which may be obtained. It is worth noting that the length of slit in Fig. 4 must be

$$\sqrt[6]{1000}$$

or 3.16 times as great as that of Fig. 6 to achieve the same coupling into the cavity for the wanted mode. This corresponds to a factor of 31.6 in intermode coupling and 1000 in depth of Q dip at a crossing.

It should be understood that dielectric materials of low loss may be used in the coupling orifice **4** and in the feeding wave guide. It is known that the use of a dielectric lowers the cut-off frequency of a wave guide by the factor $\sqrt{\epsilon}$ is the dielectric constant. The characteristic impedance is likewise lowered but by a somewhat different factor. It is, therefore, possible to secure a reduction in the required size of both orifice and feeding guide by this expedient. The use of plastic dielectrics having relatively large values of dielectric constant may be desirable as a supplement to impedance transformers or resonant transducers, particularly in cavities where a relatively heavy loading is desired.

It should be understood that the resonant chamber or echo box may be drilled with a round orifice and be associated with an impedance transformer whose end constitutes a sort of slit orifice, which is set back from the inner surface of the chamber proper by a small circular recess. This recess tends to vanish as the thickness (measured along the direction of transmission) of the chamber wall approaches zero.

It should be understood that it is fully within the spirit of the invention to use dumbbell-shaped slits in conjunction with the impedance matching transformers and resonance transducers for further reducing intermode couplings in echo-boxes and the like.

Circular wave guide sections, elliptical or any other suitable wave guide shapes may be used for the impedance matching transformers and transducers heretofore described and illustrated as rectangular in cross-section.

It should be understood that although the impedance transformers and resonance transducers associated with a lineal slit to form a "supercharger" are frequently designed on the basis of single frequency operation, nevertheless their usefulness and operability has been extended over a band of frequencies approximately ± 6 per cent from the operating frequency.

Referring to Figs. 7 and 8, directional couplers are shown for wave guide transmission or the like, utilizing concentration of the electromagnetic field at the coupling slits for reducing the transmission loss therethrough. For details of general construction and mode of operation of directional couplers, reference is made to the United States application Serial No. 540,252, filed June 14, 1944, by W. W. Mumford, which issued as United States Patent 2,562,281, July 31, 1951.

The auxiliary wave guide **38**, which may be rectangular in cross-section as shown, is coupled to the main guide **32** by narrow slits **34**, **35**, **36**, **37** in staggered and overlapping relation as shown in Fig. 7. The centers of adjacent slits are spaced apart

$$\frac{\lambda g}{4}$$

where λg is the wavelength in the main guide **32**. The length of the slits may be suitably chosen in accordance with the couplings desired. For enhanced transmission, the length of the slits may be

$$\frac{\lambda g}{2}$$

In prior art construction of directional couplers, where the coupling apertures were collinear, the transmission therethrough could be increased by increasing the size of the apertures. A limit to further increase the transmission resulted when the apertures merged.

In the stagger and overlap of apertures **34**, **35**, **36**, **37** disclosed in Fig. 7, this physical limit to increase of transmission is obviated and directional couplers with low loss characteristics may thereby be produced.

The wave generator **31**, load circuit **33**, and coaxial lines **39** are as disclosed in the aforementioned application of W. W. Mumford.

Referring to Fig. 8, a modified low loss directional coupler is shown, wherein the heights of the auxiliary guide **38** and the coupling slits **44**, **45**, **46** are sufficiently reduced to provide an enhanced concentration of field thereat. The auxiliary wave guide section **38** and the corresponding portion of main guide **32** have a height b which is approximately $1/10$ of the standard wave guide height. The standard rectangular wave guide may be characterized by two dimensions

$$a = \tfrac{1}{2}\,\lambda g$$
$$b < \tfrac{1}{2}\,\lambda g$$

The transition from wave guide **32** to the dimensions of the main guide **33** may be effected by an impedance matching taper section as disclosed in the United States application of A. E. Bowen Serial No. 715,587, filed December 11, 1946, which issued as United States Patent 2,603,709, July 15, 1952.

What is claimed is:

1. In combination, a high Q cylindrical cavity resonator, a conductive circular end wall having a lineally dimensioned slit at

$$\frac{R}{2}$$

where R is the radius of said end wall adapted to couple principally into an operating TE_{01n} mode and being dimensioned to reduce the intermode coupling, said slit being located in a region of high field intensity for the operating mode and means for concentrating the electromagnetic field intensity at said slit, comprising an impedance matching transformer connected thereto, said transformer comprising a solid end plate whose thickness is comparable to a fraction of a wavelength, said plate and wall forming a seal against energy loss, a hollow channel in said end plate for transmitting electromagnetic waves above cut-off, the length of said channel in the direction of propagation being

$$\frac{\lambda g}{4}$$

where λg is the wavelength.

2. In combination, a cylindrical cavity resonator including a conductive disc forming an end wall thereof, said disc having a coupling aperture therein located at a position of maximum field strength for a desired TE_{omn} mode, means for exciting an oscillating electromagnetic field therein having a desired mode of oscillation comprising a wave guide feed of uniform cross-section therefor and means for increasing the energy density at said aperture comprising an impedance matching transformer section connected between said feed and aperture, said transformer comprising a solid end plate whose thickness is comparable to a fraction of a wavelength, said plate and wall forming a seal against energy loss, a hollow channel in said end plate for transmitting electromagnetic waves above cut-off, the length of said channel in the direction of propagation being

$$\frac{\lambda g}{4}$$

where λg is the wavelength.

3. The structure of claim 2, wherein said impedance matching section comprises a solid end plate for said resonator having a lineal slit in one face thereof and a rectangular opening in the opposite face thereof connected together by a channel, the length of said channel being substantially a quarter wavelength and a thin silver facing for said end plate having a registering slit therein.

4. An echo box adapted for operation about a predetermined wavelength comprising a circular cylindrical cavity resonator having an internal diameter of several times said wavelength whereby said resonator is adapted to support electromagnetic waves of TE_{01} and higher order modes, said resonator having a laminated end plate comprising an outer self supporting metal wall portion and an inner facing of thin metal of relatively higher conductivity than said supporting wall, said facing being many times thinner than said outer wall portion, means to excite waves of TE_{01} mode in said resonator comprising a uniform hollow-pipe guide terminating at one end on said outer wall portion, said laminated end plate having an elongated aperture therein coupling the interiors of said resonator and guide, said aperture comprising a fine slit in said facing located at a point of maximum field intensity for said TE_{01} mode and a rectangular passage in

said outer wall portion of lesser size than guide, said passage having a length of substantially a quarter of the wavelength of the waves transmitted therethrough and a characteristic impedance that is the geometric mean of the impedance presented at said slit and the characteristic impedance of said guide, and a second balancing slit in said facing similarly coupled to the TE_{01} mode.

5. In combination, a rectangular wave guide, an echo box cavity resonator and a circular, flat end plate therebetween, said end plate having symmetrical lineal slits therein for exciting a TE_{01n} mode in said resonator, said slits being located at a position of maximum field strength for the TE_{01n} mode and reduced in lineal dimension to minimize intermode coupling, said end plate constituting an impedance step transformer between said resonator and guide, said plate having a hollow rectangular channel tapering toward a slit, the length of said channel being

$$\frac{\lambda g}{4}$$

where λg is the wave length in the guide, said channel having a characteristic impedance for matching the wave guide and slit.

6. In combination, a rectangular feed wave guide, a circular wave guide and an impedance step transformer in contact with said guides, said transformer comprising a flat conductive plate having a lineal slit in one face thereof and a rectangular slit in the opposite face adjoining said rectangular guide, and a rectangular channel cut in said plate

$$\frac{\lambda g}{4}$$

in length and having a characteristic impedance for matching the impedances of said feed guide and slit, said slit being located at a point of maximum field intensity for a desired TE_{01n} mode.

7. The device of claim 6, and a second symmetrically disposed slit located at a point of maximum field intensity for said desired mode.

8. In combination, a high Q cylindrical echo box resonator having a conductive end wall, said end wall being a circular plate having lineal slits at a position

$$\frac{R}{2}$$

from the center, where R is the radius of the end wall to couple into a TE_{01n} mode, said slits being dimensioned to reduce the intermode coupling, a wave guide feed for exciting said TE_{01n} mode abutting said end wall adjacent one slit, and an impedance step transformer formed in said end wall comprising a channel therein,

$$\frac{\lambda g}{4}$$

in length where λg is the wave length in the wave guide and having a characteristic impedance for matching the impedance of the wave guide to that of the slit.

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