July 12, 1949. A. G. FOX 2,476,034

CONFORMAL GRATING RESONANT CAVITY

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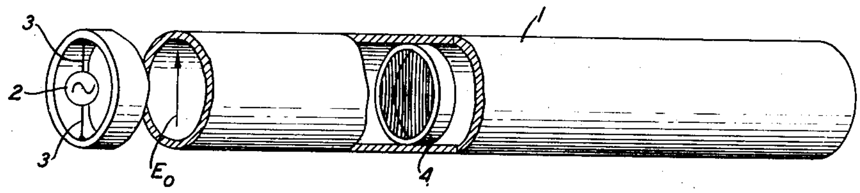
FIG. 1



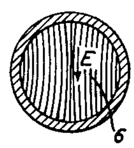


FIG. 1A

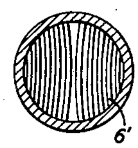


FIG. 1B

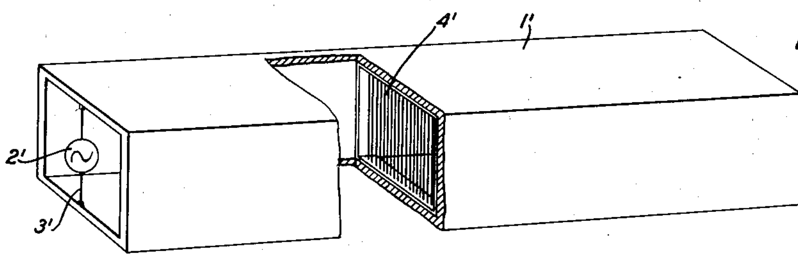


FIG. 2

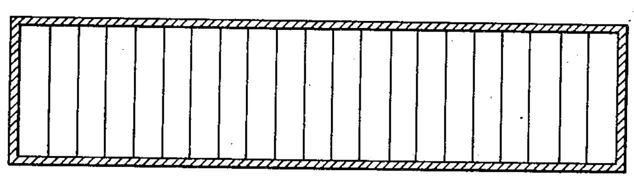


FIG 2A

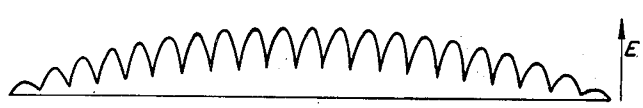


FIG. 2B

INVENTOR
A. G. FOX
BY
N. D. Ewing
ATTORNEY

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FIG. 3

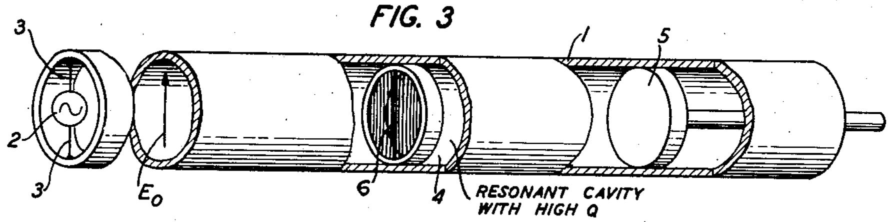


FIG. 4

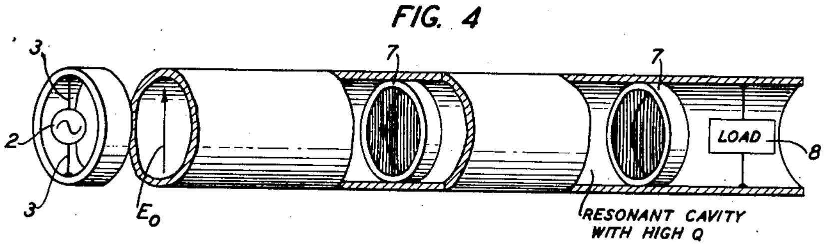
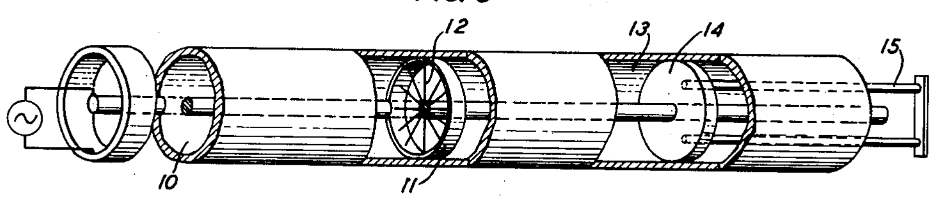


FIG. 5



INVENTOR
A. G. FOX
BY
N. D. Ewing
ATTORNEY

Patented July 12, 1949

2,476,034

UNITED STATES PATENT OFFICE

2,476,034

CONFORMAL GRATING RESONANT CAVITY

Arthur Gardner Fox, Red Bank, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application July 16, 1945, Serial No. 605,408

2 Claims. (Cl. 178—44)

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This invention relates to microwave transmission.

A principal object of the invention is to suppress predetermined higher order waves in wave guides and cavity resonators.

A further object of the invention is to increase the effective Q of a resonant cavity, by accentuating waves of a predetermined low order and suppressing waves of higher order.

Another object of the invention is to provide reactances with high Q, which will not generate higher order waves up to a predetermined order, particularly in wave guides of a size, capable of supporting such higher order waves.

Further objects will become apparent from a consideration of the specification, and the detailed drawings wherein:

Fig. 1 shows a wave guide containing a high Q resonant cavity in accordance with the invention.

Fig. 1A represents a sectional view of the grating shown in Fig. 1.

Fig. 1B represents a modified grating in section.

Fig. 2 represents a rectangular wave guide modification of Fig. 1.

Fig. 2A is a cross-section of Fig. 2.

Fig 2B shows an explanatory diagram.

Fig. 3 is a cut-away view of Fig. 1 showing the details of the resonant cavity.

Fig 4 shows a modification thereof.

Fig. 5 shows a coaxial transmission line with a high Q coaxial resonator contained therein.

A feature of the invention is the provision of a conformal grating in a wave guide, characterized by a definite relationship between the number of higher order waves which must be suppressed and the number of wires or corresponding elements of the grating.

A further feature of the invention is to provide a resonant cavity having high Q by terminating it with a conformal grating, designed to suppress higher order waves and spurious resonances.

A wave guide is capable of transmitting electromagnetic energy in one or more of an infinite number of ways or wave modes, distinguishable from each other by characteristic field patterns formed within the guide. In some instances, only one or a limited number of wave modes may be excited depending upon the frequency employed, the geometry of the device for applying the energy to the guide and the geometry of the guide itself.

All wave modes which can exist within a tubular conductor may be classified either as transverse electric TE or transverse magnetic TM. In

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the former case (TE), the electric field is at all points directed transverse to the axis of the wave guide and there are no components parallel to the axis, while in the latter case (TM) the same applies to the magnetic field.

For rectangular wave guides, a specific mode is designated as TE_{mn} or TM_{mn}, the indicia m and n representing the number of half-wave variations in field intensity developed in traversing the cross-section of the guide along the principal, orthogonal axes.

The term "dominant wave" refers to the dominant mode, characterized by the lowest possible frequency which the wave guide will support. In the case of a rectangular guide, TE_{10} is the dominant mode.

All other modes may be designated as higher order waves, their indicia m, n being higher than those of the dominant mode.

The term "conformal grating" as used in this specification refers to a grating of wires or the like, configurated to conform or be parallel to the electric lines of force of the desired wave mode at the location of the grating.

The term "effective Q," as used in this specification, refers to the percentage selectivity of a resonant cavity, namely

$$\frac{\Delta f}{f}$$

where Δf is the width of the selectivity curve between points 3 decibels down and f is the mid-band frequency.

Irises and conformal gratings in wave guides have heretofore been known and disclosed in the United States patents of G. C. Southworth 2,129,712 patented September 13, 1938, 2,129,713 patented September 13, 1938, and in the United States Patent 2,151,157 of S. A. Schelkunoff, patented March 21, 1939.

Resonant cavities or chambers (for use with ultra-high frequencies and microwaves) terminated by an apertured iris member or the like, have heretofore been disclosed in the United States patents of G. C. Southworth 2,106,768 patented February 1, 1938, and W. L. Barrow 2,281,550 patented May 5, 1942.

It is well known that iris plates or corresponding structures placed in a wave guide for the purpose of introducing the effect of a reactance have concomitantly acted as generators of waves of higher order than the one for which the reactive effect was desired. One way of suppressing such higher order waves in common practice has been by the employment of wave guides so dimensioned that only the dominant transverse electric wave could be propagated therein. Under these circumstances, any higher order waves generated by an iris element were effectively suppressed within a short distance therefrom.

However, in the case of wave guides of sufficiently large dimensions, capable of supporting and propagating higher order waves, special provision for the effective suppression thereof is essential, particularly in wave guide filters excited by a dominant, transverse electric wave. Such higher order waves tend to abstract power from the dominant mode, resulting in inefficiency and spurious resonance effects.

Thus, an iris plate with a circular or rectangular opening in the center, placed across a rectangular guide is particularly suitable for use in filter construction, because inherently it will not generate higher order waves up to the third order. Thus, it does not give rise to the following waves: $TE_{2,0}$, $TE_{1,1}$, $TM_{1,1}$, $TE_{2,1}$, $TM_{2,1}$. The first higher order wave, which such a centrally apertured iris generates, is the $TE_{3,0}$, and assuming that the wave guide is beyond cut-off for this wave, no power will be abstracted from the dominant mode, so that the iris will act as a pure shunt reactance.

However, in the case of a wave guide of still larger dimensions such that $TE_{3,0}$ can be propagated, the iris should be replaced by some other form of structure, which does not generate $TE_{3,0}$ or other higher order waves, capable of propagation in said guide.

In accordance with the invention, it has been found that higher order modes of oscillation within a wave guide may be eliminated or substantially reduced by introducing a conformal grating comprising a grid of wires, paralleling at all points thereof the lines of electric force of the desired or dominant wave mode associated with the wave guide or cavity. Equivalently, the number of wires employed in the grating, or the spacing between adjacent wires, may be predetermined to insure the virtual absence of any number of higher order wave modes. Besides retaining available power in the desired mode, the conformal grating makes available a shunt reactance element of higher Q than the apertured iris. Thus, it has been found experimentally, that a conformal grating capable of suppressing higher order waves can be used to construct more efficient wave guide structures in general and particularly when applied as a closure to a resonant cavity, than a corresponding apertured iris plate. With the conformal grating, less power is lost as dissipation for any given value of reactance provided by the grating, i. e., the Q of the conformal grating is higher than the Q of the apertured iris, where Q represents the ratio of the series reactance to the series resistance of the iris or grating.

The construction of a conformal grating adapted for the suppression of higher order waves may be effected in the following manner: First the direction of the lines of force at every point in the cross-section of the wave guide will be determined by calculation or by experiment. Thus, in the case of a rectangular wave guide excited by the dominant transverse electric wave, the electric lines of force are known from theory to be everywhere parallel to the short sides of the wave guide. In the case of a wave guide of any other cross-section, for example, circular, it may be simpler to determine the direction of the lines of electric force experimentally by placing a fine wire across the guide in a direction more or less perpendicular to the electric field, and then bending and positioning the wire in such a way that it produces no reflection of power flowing through the wave guide. The direction of the wire at any point along its length will then be perpendicular to the lines of electric force. This procedure may be repeated as many times as necessary for different positions of the wire in the cross-section of the wave guide, so that finally a map may be drawn of contours, orthogonal to the electric field. The actual conformal grating will then consist of conducting wires more or less equally spaced and so shaped that they are everywhere perpendicular to the orthogonal contours aforementioned.

The susceptance of the grating will be essentially dependent on two principal factors, (1) the number of wires, (2) the diameter of the wires.

Having determined the number of higher order waves that the guide is capable of propagating and which must not be generated, the grating will then be provided with the appropriate number of wires. In general, if many uniformly spaced wires are used, for example, 20 or 30, the distribution of the electric field set up by a dominant wave across the grating would be approximately as illustrated in Fig. 2B. The distribution of electric field may in accordance with Fourier series analysis, be considered to consist of the fundamental component (the half sine wave of the dominant mode) and an infinite number of harmonically related, sinusoidal components corresponding to the higher order waves. In general, all higher order waves will be present in some amount. However, as the number of wires (m) is increased, the amplitude of the lower harmonic components will be decreased. As (m) becomes large, for example greater than 10, the first harmonic or higher order wave generated with any appreciable amplitude will be that one having a periodicity corresponding to the spacing between wires. Specifically, all higher order modes below the $TE_{2m+1,0}$ mode will be substantially eliminated. Consequently, by the use of a large number of wires in the grating, a corresponding number of higher order waves will be reduced to practically zero amplitude.

Normally, it will not be necessary to use such a closely spaced grating. A relatively few wires will suffice to suppress undesired higher order waves in such guides as are likely to be used in practice.

Having arranged the grating with a predetermined number of wires in accordance with the number of higher order waves to be suppressed, the inductance of the grating then may be adjusted by varying the diameter of the wires. The use of larger diameter wires will result in a lower inductance and conversely, fine wires will produce high inductance. The exact determinations are preferably made experimentally. In order that the Q of the grating may be as high as possible, the wires should possess good conductivity.

Referring to Fig. 1, a wave guide of the metal sheath type disclosed in the United States patent to G. C. Southworth 2,129,712 patented September 13, 1938, is shown, and a source 2 of microwaves is shown connected thereto for producing a dominant transverse electric wave.

The source **2** may be any suitable type of oscillator known to the art, such as the Barkhausen-Kurz, spark gap, the magnetron, the velocity variation tube, etc.

The oscillator **2** is connected to the wave guide by diametral wires **3**, whereby a substantially linearly polarized field vector E_0 is produced at the center of a dominant wave $TE_{1,0}$ pattern developed across the corresponding section of the guide.

The conformal grating **4**, whose wires **6** (Fig. 1A) conform at every point thereof, to the field pattern of the dominant wave, constitutes a shunt reactance across the guide, and to the extent that it discriminates against the generation and propagation of higher order waves, it is more effective and suitable as an element of an impedance network or filter. In lieu of conducting wires, bands or strips of metal **6'** of good conductance may be used in the grating, as shown in Fig. 1B.

Fig. 2 shows a rectangular wave guide **1'**, excited by an oscillator **2'**, to establish a dominant wave therein. The rectangular grating **4'** is placed across the guide, transverse to its principal axis, to constitute an effective reactance, with the disturbing effects of higher order waves substantially eliminated to a predetermined high order (m, n).

Fig. 2A shows the rectangular grating **4'** with an effective number and spacing of wires thereof, and Fig. 2B illustrates the field pattern developed by the grating.

In Fig. 3, a dominant $TE_{1,0}$ wave enters and excites a resonant chamber **4**. The chamber or cavity **4** is approximately

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

in length (where λ is the wavelength for which the chamber will show sharp resonance effects either in voltage or current), and is bounded at one end by a reflecting piston **5** and at the other end by a conformal grating **6**. Variable tuning of the cavity is effected by moving piston **5** along its length. Through the reduction or practical absence of higher order waves up to a predetermined high order mode, the Q of the cavity is considerably enhanced.

The modification illustrated in Fig. 4 shows a resonant chamber or cavity bounded by a pair of conformal gratings **7**, spaced a distance

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

apart. The resonant frequency, set up in the cavity may be transmitted to load **8**, all other frequencies being effectively discriminated against by virtue of the high Q. The conformal grating distributes the wave energy uniformly over the guide cross-section, thereby tending to foster the development of a wave front of the dominant mode in the resonant chamber.

Referring to Fig. 5, a source **9** of oscillations is applied to a coaxial line **10**, to excite the dominant coaxial mode therein, the corresponding lines of force being radial and extending between the inner and outer conductors. The conformal grating **11**, consisting of radial wires **12**, conformal to the dominant mode field pattern, is placed in the coaxial line as a shunt reactance thereto. The elimination of higher order waves,

consequent upon its use, renders the coaxial grating particularly suitable as a reactance element per se, or as a closure for the coaxial tuned section **13**. In the latter application, the Q of the coaxial resonant section is materially increased and certain higher order waves are appreciably reduced. Tuning of resonant section **13** to

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

may be effected by the reflecting piston **14** operated by handles **15**.

What is claimed is:

1. In combination, a wave guide, means for exciting in said guide electromagnetic waves of predetermined frequency and of a predetermined mode, said guide having a cross section large enough to permit propagation of higher order waves at said predetermined frequency, a conductively bounded cavity resonator comprising a section of said guide and a pair of conductive gratings disposed transversely of said guide and spaced apart therein, each of said gratings comprising a multiplicity of wires spaced apart and conforming in direction with the transverse electric field of the said waves of predetermined mode, said resonator being proportioned to resonate at the frequency of the said waves of predetermined mode, and a load coupled to said guide at a point separated from said exciting means by at least one of said gratings for utilizing the energy of the waves of said predetermined mode.

2. In combination, a main wave guide, means for exciting in said guide waves of the dominant mode at a predetermined operating frequency, said guide having a cross section dimensioned to support and propagate other modes at said predetermined operating frequency, a cavity resonator of high Q comprising a section of said guide and a conductive grating at each end of said section, said gratings being spaced apart a distance substantially equal to a half wavelength, and each of said gratings comprising uniform conductors conformal to the said dominant mode and equally spaced apart to inhibit the generation of modes below $TE_{2m+1,0}$ where m represents the number of wires in the grating, and a load in said main guide external to said resonator for utilizing the energy of said dominant mode.

ARTHUR GARDNER FOX.

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