Nov. 24, 1953 M. GARBUNY 2,660,711

SELF-TUNING RESONANT CAVITY

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Fig. 1.

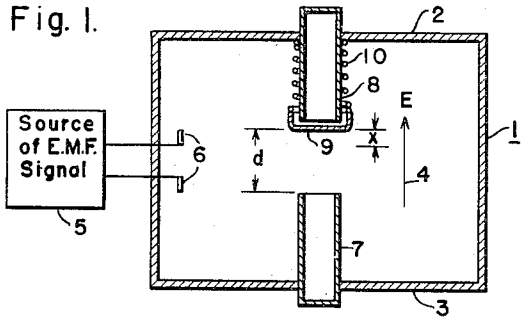


Fig. 2.

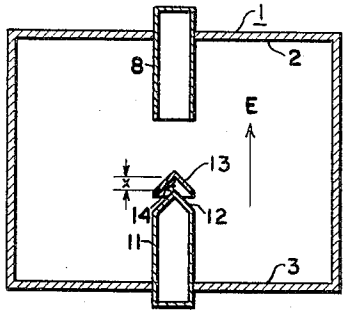


Fig. 3.

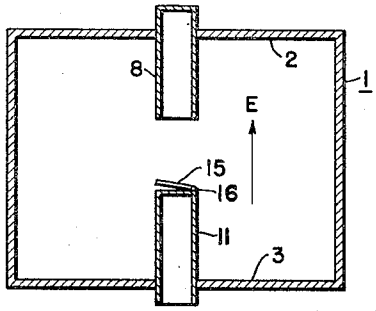
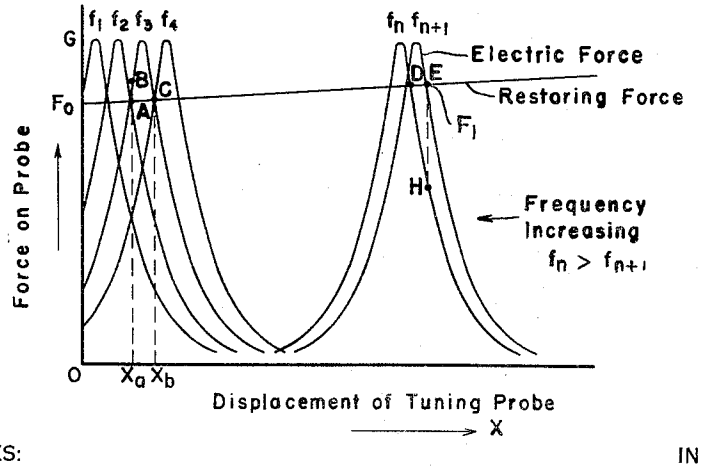


Fig. 4.



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SELF-TUNING RESONANT CAVITY

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3 Claims. (Cl. 333—17)

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This invention relates generally to resonant cavity devices and more particularly to self-tuning resonant cavity devices and to methods and apparatus for adjusting the resonant frequency of resonant cavity devices automatically with respect to the frequency of a driving signal.

Resonant cavities have been made in the form of hollow metallic structures of various shapes, the physical dimensions of the structure determining the resonant frequency of the cavity. It is known in the prior art to tune such resonant cavities by moving an end wall of the cavity, and thereby varying at least one of the physical dimensions thereof. It is further known that the resonant frequency of a resonant cavity may be varied by varying the position within the cavity of a relatively small conductive member, conductively connected with a wall of the cavity. A structure of this type is disclosed in the United States patent to Linder #2,356,414, issued August 22, 1944. In the latter patent, the position of the movable metallic element is determined by manual adjustment thereof, so that the cavity, while tunable, does not automatically tune itself to the frequency of a driving voltage.

The present invention has for one of its primary objects, a provision of means for automatically tuning a resonant cavity to the frequency of a driving signal.

It is a further object of the invention to provide a resonant cavity having a metallic tuning element internally therein, the position of which within the cavity is determined automatically in response to forces generated within the cavity, and the equilibrium position of the member being such that the cavity tunes itself automatically to the frequency of a driving signal.

It is still another object of the invention to utilize the electric fields generated in resonant cavities to modify the tuning of the cavities in such sense that these fields are maintained at substantially constant amplitude, during variations of amplitude or frequency, or both, of a driving signal.

The problem of maintaining the tuning of a resonant cavity in correspondence with the frequency of a driving voltage is particularly important in the field of micro-wave techniques, because of the high Q values utilized in resonant cavities, and because of the relatively great frequency instability of the signal generators utilized in the micro-wave art. Relatively slight variations of frequency of the driving signal with respect to the resonant frequency of the cavity results in great changes of amplitude of the response of the cavity to the signal.

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The problem of maintaining the frequency of a resonant cavity in correspondence with the frequency of its driving source is particularly acute where a multitude of cavities and signal sources are intended to work in unison, or where a plurality of cavities are connected in cascade with respect to a single driving generator. In such situations, extremely slight de-tuning effects, such as those due to heat expansion or contraction of the cavities, may prove to be extremely harmful.

Resonant cavities have, by reason of their high Q, the property of generating within themselves electric fields of extremely high intensity. It is a feature of the present invention to provide mechanical tuning elements within resonant cavities, which act under the influence of the electric forces present within the cavity to modify the resonant frequency of the cavities. The cavities are arranged to be tuned to a frequency very slightly below the driving frequency applied thereto when a predetermined electric force is applied to the mechanical tuning element by the electric field within the cavity.

In accordance with one modification of the invention, I provide a probe internally of the resonant cavity, the probe being so oriented with respect to the electric field generated in the cavity that it may have electric forces of attraction supplied thereto having a magnitude proportional to the square of the magnitude of the electric field. The probe may be subjected to the action of a restoring force which opposes the force generated by the electric field. The probe then assumes a position such that the force generated by the electric field and the restoring force are equal and opposite for any frequency at which the cavity may be driven. A change in driving frequency from that of the resonance equilibrium will cause an unbalance of the electric and restoring forces. This unbalance is in turn, used to change the position of the tuning probe in such a way as to restore the balance of forces and hence produce resonance to the changed driving frequency.

In a similar way, a constant power level is maintained inside the cavity. For a given probe position the electric force on it is sharply dependent on frequency in the resonance region. As long as the driving oscillations remain constant not only in frequency but also in power, the probe remains in its position.

Should the magnitude of the driving signal vary, however, without changing frequency, the magnitude of the force generated within the cavity will likewise change, and the response of the

tuning element to the change, will be to cause a small change in resonance frequency of the cavity such that the amplitude of the signals within the cavity will be maintained constant. Thus the cavity maintains a constant power level when the driving signal frequency is constant independent of signal power deviations.

Likewse should both the frequency and amplitude of the driving signal vary simultaneously from an original value the resonant frequency of the cavity will be modified to such a value that the force applied to the probe by the electric field within the cavity will precisely counterbalance the restoring force applied to the probe, with the result that the resonant frequency of the cavity will be maintained at such a value as to re-establish the amplitude of the field within the cavity.

In its broadest aspect, accordingly, the present system may be considered to be one for maintaining the amplitude of response of a cavity to an impressed signal at a constant value despite changes of either frequency or amplitude of the driving signal applied to the cavity. While the resonance frequency of the cavity adjusts itself only approximately to the driving frequency, the cavity oscillations will follow exactly the driving frequency, maintaining the same at a constant amplitude even if the signal changes not only in frequency but also in power.

Still further features, objects, and advantages of the present invention will become apparent upon consideration of the following specification wherein are described several embodiments of the invention by reference to the accompanying drawing wherein:

Figure 1 is a transverse section taken through a resonant cavity, and showing automatic tuning mechanism included therein;

Figure 2 illustrates a variation of the tuning mechanism included in the cavity of Figure 1;

Figure 3 illustrates a further modification of the automatic tuning mechanism illustrated in Figure 1; and,

Figure 4 is a graph utilized in the explanation of the mode of operation of the invention, and serving to clarify the latter.

The electric force per unit area measured in gms./cm.^{2} which is found to exist in an electric field is given by the following equation:

$$G=4.52\ E^2\times10^{-10}\text{gms./cm.}^2$$

where E, the electric field strength at the probe is measured in volts/cm.

The magnitude of the electric field existing in the considered type of high Q, high power cavity is in the order of 10^6 volts/cm. when, as an example, pulsed magnetrons are used. With a duty cycle of, say 2 microseconds at a repetition period of 1 millisecond, the average force per unit probe area is then in the order of 1 g./cm.^{2}.

Another equation to describe the electrical force on the probe is

$$G=9.04\frac{P.R.}{d^2}\ \text{g./cm.}^2$$

where P is the power level in watts which has been built up in the cavity, R the shunt resistance of the cavity in ohms and d the spacing in cm. in which the field acting on the probe is confined. Again using an example, if we assume a typical klystron, or a continuous wave magnetron, which generates 500 watts of power in a cavity of 1 cm. gap spacing and 2 million ohm shunt resistance, an electrical force on the probe in the order of 1 g./cm.^{2} is obtained.

In either case, then, it will be evident that enough mechanical force is generated within a cavity operating at conventional power levels to actuate a probe for a distance of a few hundredths of a millimeter. Calculations show that a probe displacement equal to one hundredth of one percent of the length of a typical cavity would change the resonant frequency of a cavity having a resonant frequency of 3000 megacycles by an amount of the order of one megacycle, indicating that the orders of magnitude of the effects involved in the system are sufficient to produce the results desired.

One preferred arrangement of an automatic tuning device for a resonant cavity, constructed in accordance with the present invention, is illustrated in Figure 1 of the drawing. Referring now specifically to Figure 1 of the drawing, the reference numeral 1 denotes a cross section taken through a resonant cavity, in the form of a hollow shell, having opposing surfaces 2, 3, and wherein an electric field E exists in the direction of the arrow 4 in response to signal provided by the source 5, and introduced into the cavity 1 by the probes 6. Cavity 1 is provided with two inwardly projecting metallic members 7 and 8, which are in electrical contact respectively with the opposite walls 3 and 2 of the cavity 1, adjacent ends of the members 7 and 8 being separated by a distance d. A cap is provided for one of the structures, and specifically the structure 8, which operates as a movable probe 9, being normally retained in withdrawn position against the structure 8 by means of a helical spring 10, designed to have a predetermined restoring force which is exerted on the probe 9 against the force established by the electric field E which tends to move the probe 9 toward the member 7, in opposition to the force exerted by the restoring spring 10, independently of the direction which the alternating field might have at a given moment.

The action of the probe 9 in controlling the frequency of the resonant cavity 1 may best be explained by reference to the graph provided in Figure 4 of the drawing, to which reference is now made. Assume first that the cavity is in resonance with a generated frequency f_2, probe 9 having been manually, or otherwise, positioned to accomplish this purpose. Suppose now that the frequency of the source changes from frequency f_2 to a lower frequency, frequency f_3. Assume further that the restoring force on the probe 9 produced by the helical spring 10 is established at a value F, shown on the graph of Figure 4 as a force increasing by a negligible amount with the displacement of the probe 9. While the cavity was tuned to the frequency f_2, the electric force generated within the cavity corresponded with the force F represented at the point A on the graph. Upon change of the source frequency to a new frequency f_3, the displacement of the tuning probe 9 being assumed to have a value x_a, the total force exerted on the probe by the electric field E rises to the value B, coinciding with the intersection of the ordinate x_a with the resonance characteristic corresponding with the frequency f_3. Accordingly, the probe 9 will move into the cavity, and toward the member 7, in order to equalize the applied and the restoring forces. Equalization will occur when the probe has attained a displacement x_b, operation now taking place at the point C on the graph. In a similar manner, the

cavity will follow further frequency decreases, say, until the signal frequency has been decreased to f_{n+1}, when the probe will arrive at a position corresponding to point E.

The probe has accordingly adjusted itself to a new position, such that a relatively great reduction of frequency of the cavity has taken place, without material change in the amplitude of the oscillations within the cavity.

In one specific embodiment, illustrated in Fig. 1, the cavity has an internal diameter of $2\frac{1}{2}$ inches and an internal height of $1\frac{3}{4}$ inches. The probe has a diameter of ½ inch. It was found that the resonant frequency of this cavity was of the order of 2,765 megacycles and it could be varied over a range of 200 to 300 megacycles by moving the probe over a range of about $\frac{1}{10}$ inch. It was also found that the electric force was of the order of $1\frac{2}{10}$ grams and the spring force was of the order of 1 gram.

Assume now that the probe 9 has a displacement such that the operating point thereof is at E, in Figure 4 of the drawing, the frequency of the cavity being f_{n+1}, the frequency of the generator being also f_{n+1}, and the forces on the probe being F_1. Assume now that the frequency of the generator increases to a high value f_n. The force on the probe immediately decreases to the value H, as the electric field within the cavity decreases in amplitude, and the restoring spring 10 accordingly draws the probe 9 back until the forces are in balance again at a new operating point D. At the operating point D the probe 9 tunes the cavity 1 to a frequency very slightly below the new frequency f_n. It will be evident that the amplitude of the field E has not changed materially, due to the small slope of the line representing variations of restoring force F on the probe 9, with displacements x of the probe 9, in the graph of Figure 4 of the drawing. It has, accordingly, been demonstrated that the probe will assume a position such as to retune the cavity to a frequency very slightly below the frequency of the driving signal in response to either a decrease or an increase of the latter, maintaining the amplitude of response of the cavity to the driving signal substantially constant over a relatively wide range of frequencies.

In order to initiate an operation of the present system, it is essential that the generated frequency be started at a value for which the cavity is resonant in the rest position of the probe 9, and thereafter varied gradually to a final desired value, the probe acting continually to retune the cavity, and to maintain correspondence between the cavity frequency and the driving frequency. In the alternative, the generator or driving frequency may be pre-established at a desired value and the probe may be moved to a suitable position to establish frequency correspondence between the frequency of the source and the tuning of the cavity by means of a magnet, or manually, from externally of the cavity.

It is evident, from the above discussion, that the present system serves not only to adjust the frequency of a cavity, but also to keep the power level within the cavity relatively constant and independent of variations of generated power beyond the adjusted value, since an increase or a decrease in input power level acts on the probe precisely as does a variation in frequency, by establishing a modified force on the probe, which serves to vary the displacement thereof, whereby a new cavity resonance frequency is established, which serves to re-establish substantially the original amplitude of the field E which still alternates with the signal frequency.

Reference is now made to Figure 2 of the drawing, wherein is illustrated a modification of the tuning system of Figure 1, which differs from the latter in that in the system illustrated in Figure 2 of the drawing, the restoring force acting on the tuning probe is a gravitational force. A structure 11 is provided having a conical nose 12, over which is fitted a conically shaped tuning probe 13, secured to the structure 11, and electrically connected therewith, by means of a flexible wire 14, but free to move co-axially with the structure 11. The system of Figure 2 operates in a manner quite similar to that of Figure 1, differing, however, in that the motion of the probe 13 into the electric field E is effected against the gravitational force or weight of the probe 13. This type of operation has an advantage over the type of operation envisaged in the structure of Figure 1 in that the total restoring force applied to the probe 13 is constant in magnitude, rather than a function of the displacement of the probe. As a further advantage, it is found that the conical probe is subjected, for a given size thereof, to a field E of higher intensity than is the flat probe 9 utilized in the embodiment illustrated in Figure 1 of the drawing, and that the position of the probe 13 is relatively uninfluenced by mechanical vibrations to which the cavity 1 may be subject.

The system of Figure 2 operates in a manner substantially similar to that of Figure 1, in the presence of continuous fields, or in pulse operation with long duty cycle. If, however, the pulse lengths are short in comparison with the period between pulses, the probe will fall between pulses, through a distance which is not negligible. The equilibrium position of the probe is then dynamic rather than static, the probe being accelerated in one direction in the presence of pulses, and falling in response to the force of gravity in the period between pulses. In practical systems, however, and assuming a constant pulse rate, the total vibration of the probe is relatively slight, and the constants of the system may be so arranged that the tuning of the cavity remains substantially constant, the slight variations which do occur, however, having an average value such that the frequency of the cavity will attain the same value as in the case of C. W. operation, at the times the pulses occur.

Still a further embodiment of the invention is illustrated in Figure 3 of the drawing, wherein the structure 11 is surmounted by a lever 15, constituting a tuning probe or electrode, which is pivoted at one end 16, and free to assume various angular positions. In the system of Figure 3, as in the system of Figure 2, the restoring force applied to the electrode 15 is the force of gravity. However, the restoring force is no longer constant, but varies with the angular position of the electrode 15, so that the restoring force slowly decreases with increasing displacements of the electrode 15. The arrangement of Figure 3 operates, however, generally in accordance with the mode of operation herein before described in connection with the embodiment illustrated in Figures 1 and 2 of the drawing.

The terms "means for biasing" and "means for applying a biasing force" as used herein include any force which may be employed to effect biasing including the force of gravity.

While I have described various embodiments of the present invention, it will be evident that variations of the structure disclosed may be resorted to

without departing from the true spirit and scope of the invention.

I claim as my invention:

1. A self-tuning cavity resonator adapted to be coupled with a source of periodic signals of variable frequency and energized thereby to provide an electric field internally thereof comprising a conductive probe so constructed, supported and located internally of said cavity as to be movable as a unit in response to the forces exerted thereon by said electric field in a first predetermined direction, said resonator including means for applying mechanical force to said probe and tending to move said probe in a direction opposite to said first predetermined direction, said mechanical force having a total magnitude of the same order as said forces of the electrical field for all positions of said probe across said cavity, said resonator and said means being so constructed that for any given signal frequency, the opposed mechanical and electrical forces balance the probe at a position which determines the resonant frequency of said resonator.

2. The combination in accordance with claim 1 wherein the mechanical force comprises the force of gravity due to weight of the probe.

3. The combination in accordance with claim 1 wherein the mechanical force comprises spring means.

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