Nov. 11, 1941. F. B. LLEWELLYN 2,262,020

FREQUENCY STABILIZATION AT ULTRA-HIGH FREQUENCIES

Filed Jan. 15, 1938 2 Sheets-Sheet 1

FIG. 1

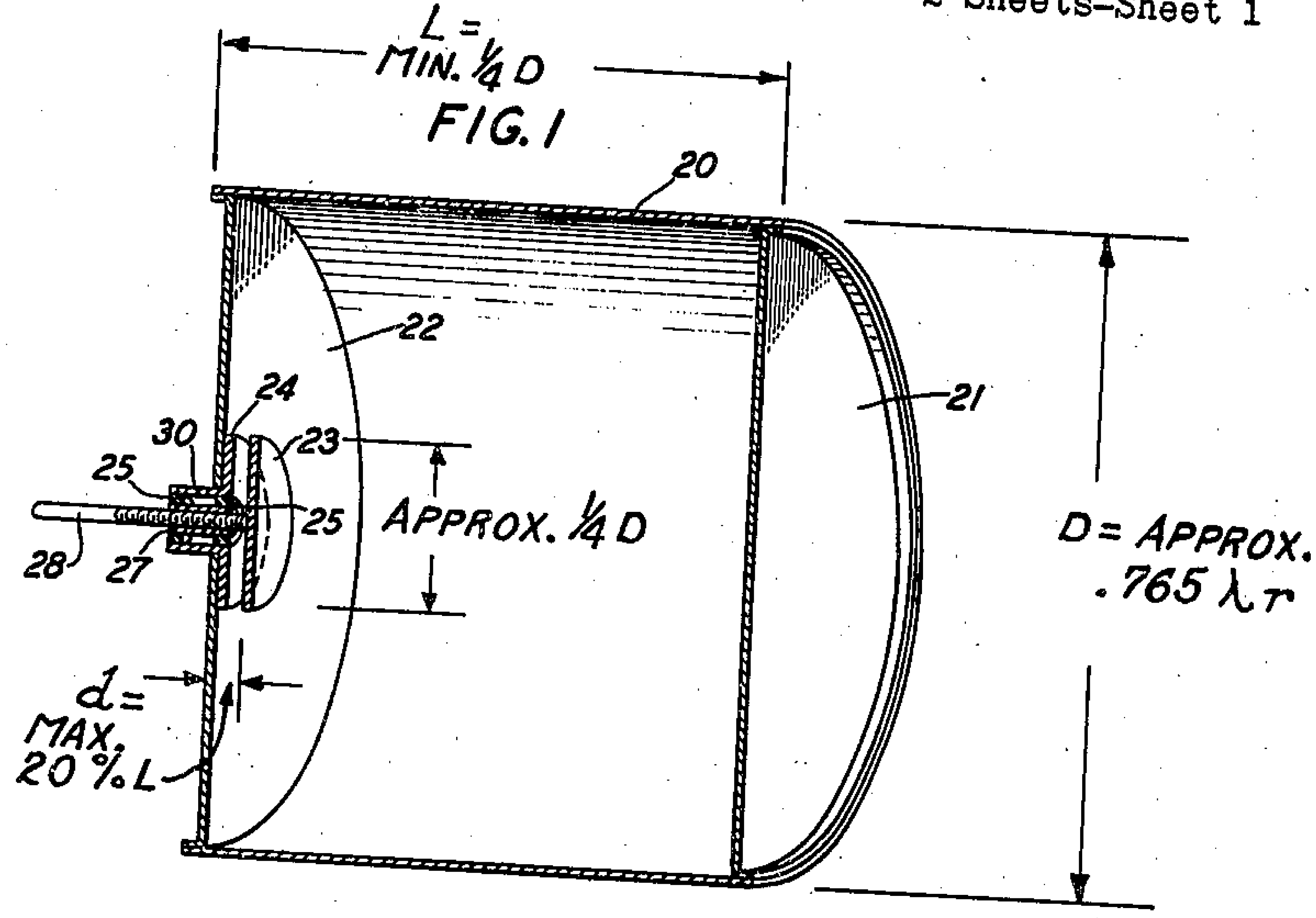


FIG. 2

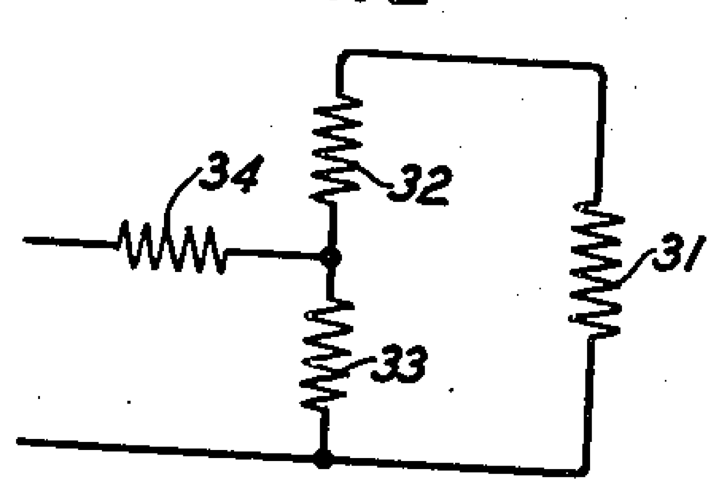


FIG. 3

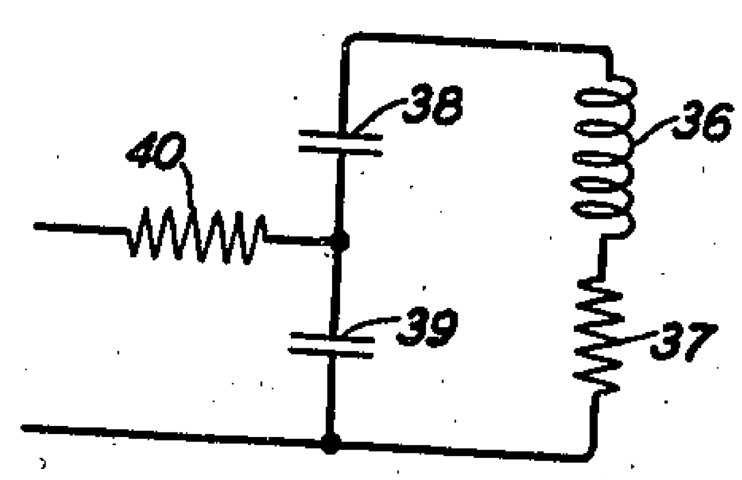
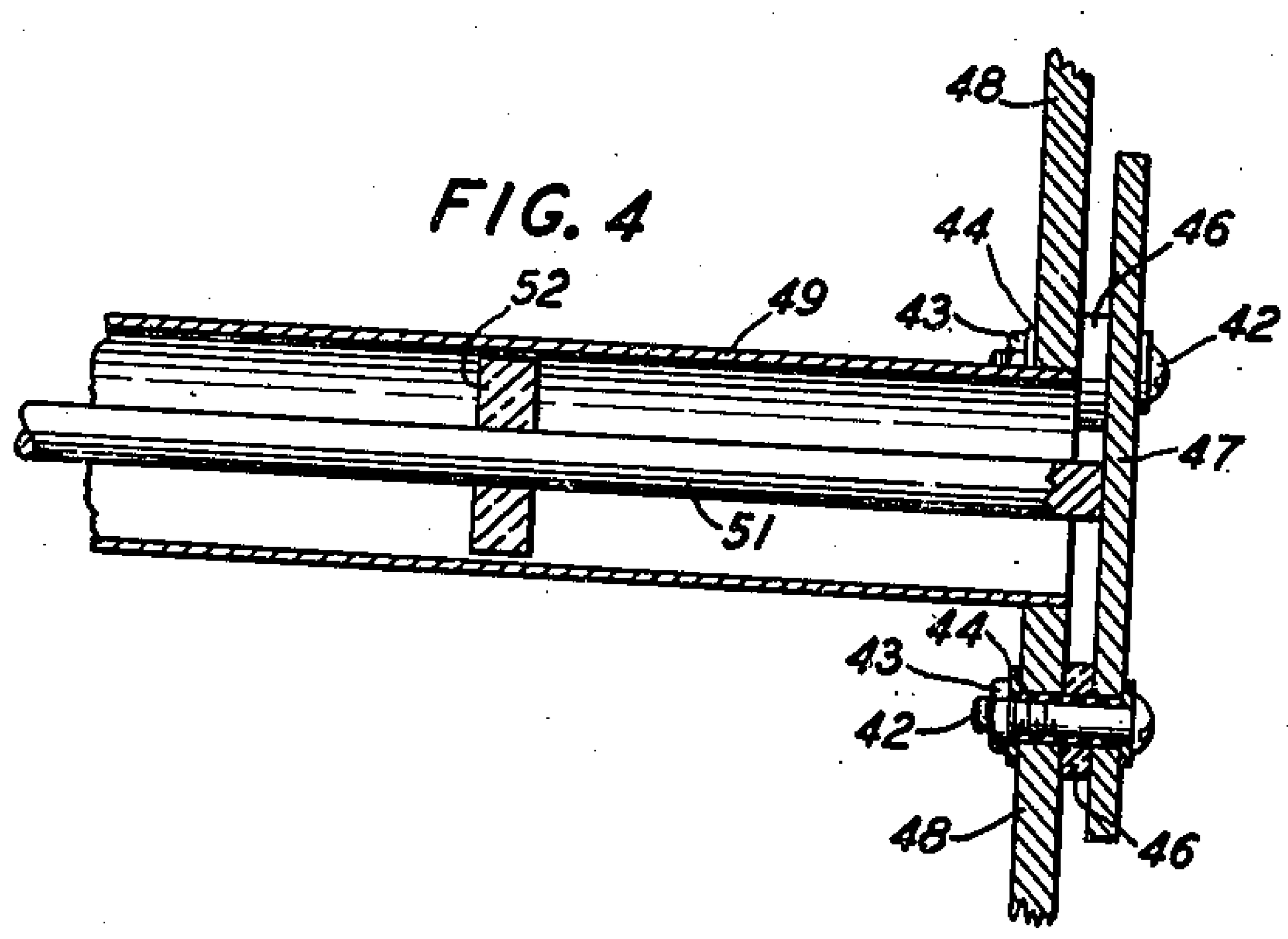


FIG. 4



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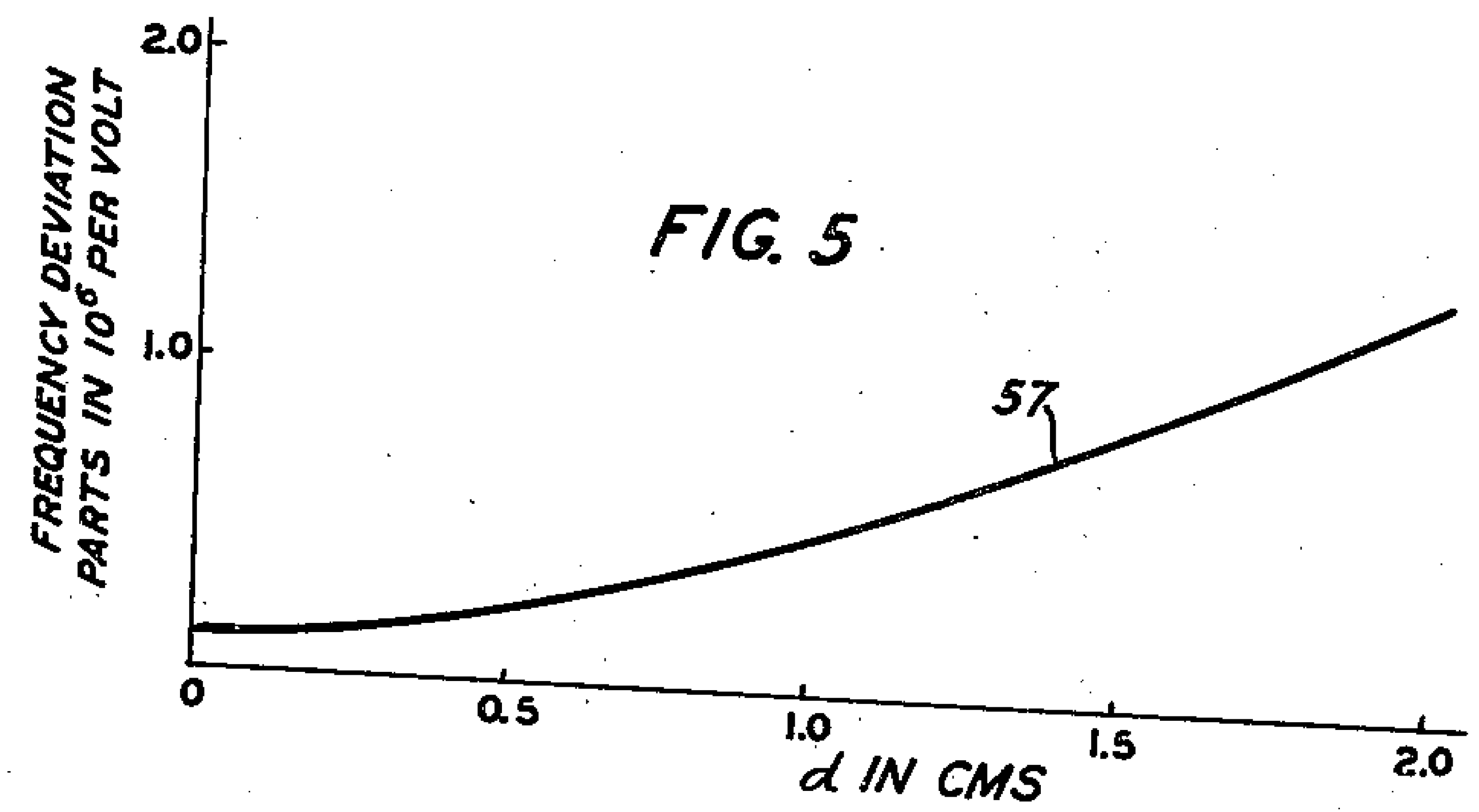


FIG. 7

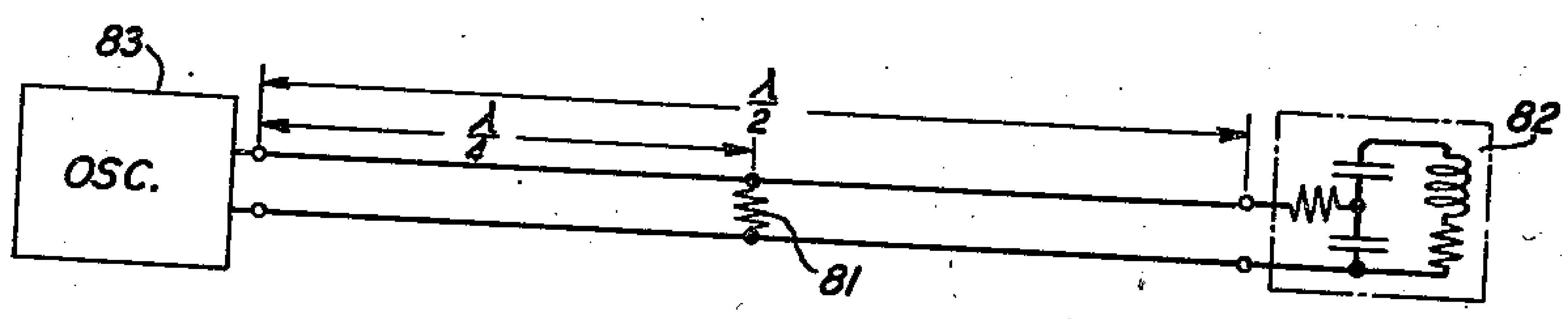
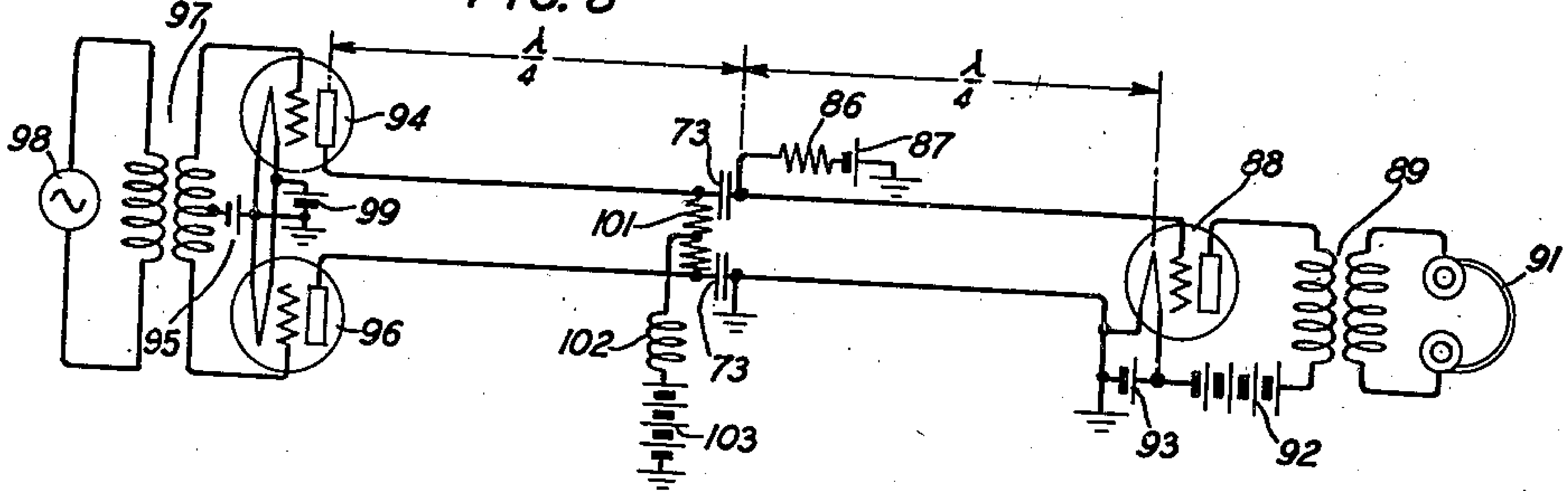
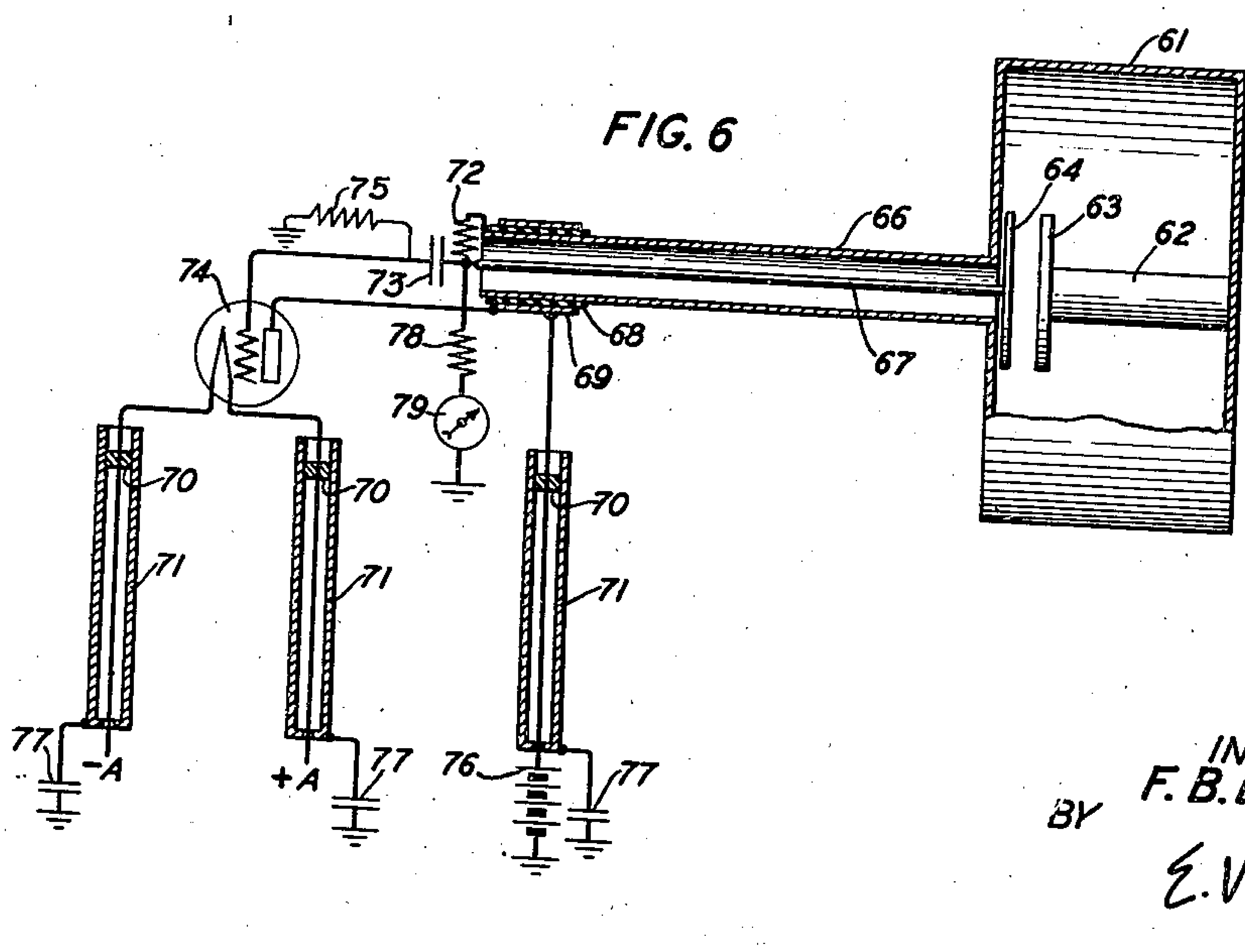


FIG. 8





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2,262,020

FREQUENCY STABILIZATION AT ULTRA-HIGH FREQUENCIES

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Application January 15, 1938, Serial No. 185,139

3 Claims. (Cl. 178—44)

This invention relates to methods of and apparatus for the effective coupling and frequency stabilization of circuits at ultra-high frequencies. More specifically, it relates to wave guides, "hollow" tank circuits and particular novel arrangements of the more usual tank circuits for which an increasingly wide field of usefulness at ultra-high frequencies is rapidly being developed.

An object of the invention is to provide a "hollow" tank circuit which will effectively extend the upper limit of the ultra-high frequency range within which precise frequency stabilization may be practicably attained by tank circuits of the prior art.

A further object is to provide a more effective method of coupling tank circuits to the oscillatory circuits, the frequencies of which they are designed to stabilize.

A further object of the invention is to provide tank circuits of greater efficiency at frequencies near the present practicable upper limit and considerably above this limit.

Other and further objects will be apparent in the following description and in the appended claims.

A large variety of tank circuits have been proposed in the prior art, a comprehensive collection of such devices being shown in U. S. Patent 2,030,178, issued to R. K. Potter on February 11, 1936. With such devices we may also logically include resonant sections of "wave guides" or what we will hereinafter refer to as "hollow" tank circuits. Some aspects of these are discussed by G. C. Southworth in the Bell System Technical Journal, vol. XV, No. 2, of April, 1936, pages 284 to 309, inclusive.

The present invention is concerned primarily with the attainment of effective correlation in practical use of the properties of tank and hollow tank circuits with those of the oscillatory circuits with which the former are intended to be employed. It proposes specific improvements in the arrangement or structure of the tank and hollow tank circuits which greatly increase their effectiveness.

The methods of attaining the objects of the invention will become apparent during the course of the following description and from the accompanying drawings, in which:

Fig. 1 shows, in cross-section, a hollow tank circuit of this invention;

Fig. 2 indicates the type of impedance structure contemplated in this invention;

Fig. 3 illustrates more specifically the nature of the impedances involved in the structure of Fig. 1;

Fig. 4 illustrates, in cross-section, one form of mechanical construction for obtaining the desired relation of the coupling disc to the near end of the tank circuit of this invention;

Fig. 5 shows graphically the correlation between coupling disc position and the stability afforded by the hollow tank of this invention;

Fig. 6 shows, in partial cross-section, a more usual type of tank circuit modified in accordance with the principles of this invention and also illustrates one effective method of connecting it, to stabilize the frequency of a vacuum tube oscillator;

Fig. 7 is illustrative of a principle by means of which stabilizing circuits may readily be connected to the circuits they are to stabilize, without encountering parasitic oscillations at lower frequencies; and

Fig. 8 is illustrative of one method of changing from a balanced to an unbalanced circuit arrangement at ultra-high frequencies without employing a transformer.

In more detail and with reference to Fig. 1, the form of hollow tank circuit of this invention there illustrated in section comprises a right circular cylinder **20** closed at both ends by discs **21** and **22**. Through the center of the left disc **22** a tube **30** projects which may, for mechanical strength and to insure good electrical contact between tube **30** and the end of the tank **22**, carry a flange **24**. Insulating rings **25** centrally support metallic bushing **27** in tube **30**. The inner surface of bushing **27** is threaded to accommodate threaded rod **28** at the right end of which coupling disc **23** is affixed by its center. By turning rod **28**, the separation and, therefore, the capacitance between disc **23** and flange **24** or end **22** may be varied.

Tube **30** and rod **28** may be extended to the left to any convenient distance, suitable ring insulators being introduced to maintain rod **28** centrally within tube **30**, in which case they may form a concentric pair of conductors the properties of which are, of course, well known.

All parts of this hollow tank, except, obviously, the insulators, should be made of highly conductive material, such as copper. All joints between parts should be tightly made and contiguous surfaces should be clean and untarnished so that good electrical contact will be effected and leakage and dissipation of energy prevented. All surfaces within the tank should be clean and bright since the ultra-high frequency currents, for which the tank is to be used as a frequency stabilizing circuit, will be concentrated on these surfaces.

To prevent oxidation, the surfaces when clean and bright may be gold plated, or they may be lacquered, though in the latter case some dielectric loss may be introduced. Oxidation and corrosion of the conducting surfaces of an experimental tank have been observed to decrease the index of electrical efficiency "Q" of the tank to less than 20 per cent of its original value. The above suggested precautions are, therefore, of substantial importance.

These observations obviously apply, though with somewhat less force, to the concentric conductors, where the outer surface of the inner conductor and the inner surface of the outer conductor are the current carrying surfaces.

The schematic circuit of Fig. 2 represents the general type of impedance which may be simulated by the tank of Fig. 1. In Fig. 2 impedance **34** is that of the tube **30** and rod **28** forming the connecting conductors to the tank, impedance **33** is that existing between the coupling disc **23** and the near end **22** of the tank and impedances **32** and **31** represent the remainder of the tank.

The nature of the component impedances of the equivalent tank impedance are indicated more specifically in Fig. 3, in which the impedance of the input circuit may, for most practical cases, be represented by a resistance **40**, the impedance between disc **23** and the near end of the tank may be represented by a capacitance **39** and the impedance of the remainder of the tank may be represented by a second capacitance **38** in series with an inductance **36** and a resistance **37**.

While, strictly speaking, capacitance **38**, inductance **36** and resistance **37** are distributed, each unit of area of the tank's internal surface having a particular capacitance relative to coupling disc **23** and each linear unit of the tank's internal surface having a particular resistance and contributing to the inductance; for many practical purposes, including those of this invention, it has been found that these properties may be considered as lumped and the impedance may be considered, within a degree of accuracy satisfactory for the practical purposes proposed, to be equivalent to that indicated in Fig. 3.

In Fig. 1 the coupling disc **23**, as above described, is supported by a threaded rod **28** held by a threaded bushing **27** so that by turning the rod **28** the capacitance between the disc **23** and the near end of the tank **22**, represented by capacitance **39** in the schematic circuit of Fig. 3, may be adjusted.

From the standpoint of maintenance, it may frequently be deemed more advisable to fix definitely the position of the coupling disc. A construction adapted to this end is shown in Fig. 4 where coupling disc **47** is held a definite distance from the near end of the tank **48** by bolts **42**, secured by nuts **43** and spacing washers **46**. Insulating bushings **44** prevent short-circuiting of the disc to the tank by the bolts. Insulating spacer **52** positions the inner conductor **51** concentrically within the outer conductor **49**.

Where variations with temperature become important, as they frequently do in the precise stabilization of ultra-high frequencies, all parts the dimensions of which affect the natural frequency of the combinatiton may be made of fused quartz, invar, or some other material having a substantially zero temperature coefficient. Surfaces of the tank which in normal operation carry current may then be given a thin coating of copper or other highly conductive material which may be lacquered or gold-plated to prevent tarnishing, as described in connection with Fig. 1. In many instances the stability of the hollow tank of this invention with temperature variations will be satisfactory if only the coupling disc and the spacing washers be constructed of fused quartz, invar, etc. as above mentitoned. The spacing washers and insulating bushings should, of course, be of good insulating material, fused quartz having been found entirely satisfactory for such use.

With regard to the electrical properties which should be imparted by design to the tank, a number of somewhat conflicting requirements must be taken into consideration. For sharp frequency control it is desired that the constituent reactances which are combined to produce the controlling resonance effect should themselves be impedances of inherently large magnitude so that steep impedance-frequency characteristics will be obtained. With such a control a very large impedance change occurs for a small frequency variation.

On the other hand, the efficiency of the usual forms of electrical oscillator employing vacuum tubes is definitely limited by the impedance of the frequency stabilizing circuit associated therewith.

Furthermore, if a sharply resonant control circuit of high impedance is coupled directly to the oscillator, it is practically impossible to maintain the stabilizing advantages of the sharp resonance, because of damping introduced by the oscillator circuit.

These difficulties may to a large extent be overcome by loosely coupling the control circuit and the oscillator, that is, by effectively stepping down the impedance of the control circuit and connecting the stepped down impedance to the oscillator. It may then be shunted by an impedance of the order of magnitude and the character produced by operation of the oscillator, and the sharp resonant effect will nevertheless be maintained. However, it should be noted that for efficient operation, the impedance presented to the oscillator by the control circuit must not be decreased too much.

It is to accomplish these results that the particular construction of tank circuit, illustrated by Fig. 1, has been chosen. The coupling disc **23** is maintained in relatively close proximity to the near end of the tank **22** so that the input is shunted by a relatively large capacitance having at ultra-high frequencies a relatively low impedance. Referring to Fig. 3, the capacitance **39** is thus made relatively much larger than capacitance **38**. The impedance of capacitance **39** is therefore relatively much less than that of capacitance **38**. The impedance of capacitance **39** is made such that when the combination of capacitance **38** and inductance **36** are at some point near resonance the input impedance of the tank circuit will be that required for operation of the associated oscillator with the desired degree of stability and/or efficiency. If the impedance of capacitance **39** is made smaller than a particular value for a given oscillator the efficiency of the oscillator will be impaired but its stability will be improved until a point is reached at which the capacitance is so large and its impedance so small that oscillations are prevented.

It is, therefore, apparent that by properly choosing the value of capacitance **39** and coupling the resonant circuit through this capacitance loosely to the oscillator the full steepness of slope of the impedance of the resonant circuit may be utilized and at the same time an impedance suitable for effective operation may be presented to the oscillator. This arrangement has the further very real advantage, as intimated above, of rendering the control circuit largely independent of dissipation in the oscillatory circuit to which it is coupled.

In Fig. 5 the effect on the frequency stability of decreasing d, the distance between the coupling disc and the near end of a particular hollow tank circuit of this invention, is graphically illustrated. Curve **57** shows for each indicated value of d, the variation of frequency for a change of 1 volt in the operating potential applied to the associated vacuum tube oscillator.

The resonant frequency of a hollow tank circuit of the form shown in Fig. 1 is determined almost entirely by its diameter. The length affects primarily the magnitude of the components of the resonant impedance. If it is made too small, difficulty in "tapping down" sufficiently, while still retaining a suitable impedance for operation with the associated oscillator, will be experienced.

Laboratory tests indicate that the length should generally be at least half the diameter, but that in some instances it may be satisfactory to employ lengths as short as one-quarter of the diameter. In other instances, to obtain higher impedance components and more effective "tapping down," lengths equaling or exceeding the diameter may be employed.

At extremely high frequencies it may, from the standpoints of size and ease of construction, be desirable to employ a length equaling or exceeding the diameter. At such frequencies it may also in some instances be desirable deliberately to induce secondary resonances at frequencies above the major resonant frequency and employ one of them for frequency stabilization, so that the dimensions of the tanks will not be so small that they may not, as a practical matter, be conveniently constructed. In such cases, the length will, in general, appreciably exceed the diameter. The tank diameter should be, for normal operation, approximately 0.765 times the free-space wave-length of the resonant frequency desired. The number 0.765 is the first root of the Bessel function

$$J_0\left(\frac{2\pi r}{\lambda}\right)$$

A coupling disc having a diameter of approximately one-fifth that of the tank was found suitable with an experimental hollow tank of the type illustrated in Fig. 1. Other experiments indicated that the operation of this type of hollow tank was not critically affected by the size of the coupling disc.

The form of hollow tank illustrated in Fig. 1, that is, a right circular cylinder closed at each end by a disc and provided with a coupling disc concentrically supported near, and parallel to, one end, has a number of outstanding advantages. Of these, its mechanical symmetry is one, the ease with which it may be accurately constructed is another, and a third, resulting from the former two, is that its two dimensions, diameter and length may be said to control almost independently its two important electrical characteristics, namely, the fundamental resonance and the magnitude of the impedance components respectively.

A hollow tank having any shape of cavity and coupling disc would, however, have resonant properties. A rectangular hollow tank, for example, would have three "fundamental" resonant frequencies each being determined by one of its major dimensions, namely, width, height and length. If made in the form of a perfect cube these three could be caused to coincide and such a tank would be well adapted to use as a frequency controlling device. Such a tank would, however, lack the symmetry of coupling of the tank of Fig. 1 and would be more difficult to construct accurately than a right circular cylinder. The coupling element may be of nearly any shape or size, subject however to the following requirements. First, the capacitance of the element to one surface of the tank should furnish an impedance of approximately the desired magnitude for operation with the external circuit, second its capacitance to the other surfaces of the tank should be substantially less than the first-mentioned capacitance and third, mechanical symmetry should be maintained so that disturbing irregularities will not be introduced into the resonant phenomena obtained.

For the more usual types of tank circuits having rods and auxiliary discs within the cavity to contribute more nearly "lumped" capacitance and inductance to the resonant impedance, the dimensions of the enclosing vessel for a particular resonant frequency may be varied over wide ranges with but small change in operating efficiency. It should be noted, however, that for a particular resonant frequency and impedance values optimum dimensions may be mathematically derived. In such tanks approximate mechanical symmetry is also desirable to obtain uniform distribution of current over the conducting surfaces.

Considerations of size indicate that hollow tanks will ordinarily be used at very high frequencies since, for example, at 300 megacycles (one meter wave-length) the tank diameter should be approximately 76.5 centimeters, when a hollow tank of the type illustrated in Fig. 1 is employed.

The principle involved in loosely coupling the hollow tank to the oscillatory circuit mentioned above can be applied equally well to the coupling of any resonant circuit to any oscillatory circuit and its application to a more usual form of tank circuit is illustrated in Fig. 6.

In Fig. 6 the tank circuit comprising the right circular cylindrical vessel **61**, coupling disc **64**, auxiliary disc **63** and central supporting tube or rod **62** is very similar in its general features to several disclosed in the above-mentioned patent to R. K. Potter. In the present instance, however, the coupling and auxiliary discs **64** and **63**, respectively, are so placed that the capacitance between disc **64** and the near end of the enclosing vessel **61** is very much larger than that between the discs **64** and **63**. Again, the tank may be represented for most practical purposes by the electrical schematic circuit of Fig. 3.

Because of the additional inductance contributed by central tube **62** and the increased capacitance contributed by the auxiliary disc **63** the physical dimensions of this form of tank are approximately one-fifth those of a corresponding hollow tank circuit of Fig. 1, for operation at a particular frequency.

The practical significance of this is that the tank circuits of the type illustrated in Fig. 6 will have favorable mechanical dimensions over a frequency range below that over which it may be convenient, considering bulk, to employ the hollow tank type of circuit. Conversely, there is an upper frequency limit of practical usefulness for tank circuits of the type illustrated by Fig. 6 because its dimensions become unduly small and its resistive component, represented by resistance 37 of Fig. 3, becomes unduly large; especially the resistive component contributed by the smaller central supporting tube 62 of Fig. 6, over the surface of which a relatively heavy concentration of current will result. If the resistive component becomes large, the index of electrical efficiency, commonly designated "Q," of the circuit is reduced and the effectiveness of the resonant circuit as a frequency stabilizer is substantially prejudiced by the damping of the resistive component.

The "hollow" tank may be made inherently more efficient electrically because its conducting surfaces have a much larger area for a given resonant frequency and it need have no conductive members other than the coupling disc itself within it. The latter feature is important since eddy currents will be established in all conductors within the tank by the radiant energy filling the tank while in operation. Furthermore the relatively large concentration of current on the internal tube of the usual type of tank circuit does not take place in the "hollow" tank.

Referred again to Fig. 6, the concentric conductors 66 and 67 connecting to the tank circuit are extended to the left approximately one-fourth wave-length to provide a potential node at which to connect to the parallel pair of conductors from the vacuum tube oscillator.

In this figure the tank circuit is shown connected between the plate and grid circuits of the vacuum tube. This arrangement has been found to have particular merit at ultra-high frequencies but involves a difficulty in that the tank circuit may not conveniently be left at a high potential with respect to ground because of its relatively large exterior surface area. Therefore, in the arrangement of Fig. 6 the tank circuit is isolated from direct potentials by condenser 73 and the capacitance between metallic band 69 and the outer conductor 66 of the concentric pair, insulating bushing 68 being interposed to prevent the plate voltage from battery 76 reaching the tank circuit. Bushing 68 may conveniently be of mica to aid in obtaining a suitable capacitance.

Resistance 72 is placed across the potential node at the end of the concentric pair, its function being to prevent oscillation at lower frequencies. Its value may conveniently be made somewhere near the mean of the surge impedances of the concentric line 66, 67 and the open line connecting to the vacuum tube. The value, however, is not critical. Resistance 75 constitutes a leak means for the grid of vacuum tube 74. Its value should be sufficiently large to avoid substantially changing the impedance of the open line circuit connecting to the vacuum tube.

Resistance 78 and thermal meter 79 are also introduced, as shown, at this nodal point for the purpose of facilitating the adjustment of the lengths of the concentric line 66, 67 and the parallel wires leading to the oscillator tube, in order to secure the location of the nodal point accurately at the junction of the concentric line 66, 67 and the parallel wire line to the oscillating tube. Correct adjustment is indicated by the minimum of current in the meter.

Obviously, the one-fourth wave-length concentric line and parallel pair to the oscillator tube may be omitted and the tank connected directly to the tube, provided the tube is designed in accordance with well-known principles for such direct connection. Or, alternatively any odd number of quarter wave-lengths of parallel pair or concentric pair or both may be employed in connecting the oscillator tube and the tank so long as the circuits are joined at a mutual node.

Obviously, also, the tank circuits of this invention may be connected in oscillator circuits in any of the well-known ways in which frequency stabilizing devices, such for example as piezoelectric crystals, are employed, though of course the frequencies at which these tank circuits are employed are generally much higher than those at which piezoelectric crystals may be used conveniently.

High frequency concentric line chokes 71, short-circuited at the near ends by adjustable plungers 70, are introduced in the filament and plate supply leads to prevent parasitic coupling with the ultra-high frequency circuits. By moving plungers 70 these chokes respectively may be adjusted to maximum impedance and the stability of the circuit thereby somewhat improved. Such adjustment mainly compensates for slight deviations which not infrequently are encountered between true electrical nodes and their apparent mechanical locations determined by mechanical measurements of the system. Condensers 77 maintain the outer conductors of the chokes at ground potential for high frequencies.

Fig. 7 is illustrative of the principles involved in connecting a tank circuit 82 and oscillatory circuit 83 as was done in Fig. 6. Each circuit is built out to one-quarter wave-length to reach a potential node; they may then be joined and a resistance 81 connected across the "mutual" nodal point as above mentioned.

Fig. 8 is illustrative of a method of changing from a balanced to a single-side unbalanced circuit and shows in somewhat more obvious form the nature of the connections made between the tank and oscillatory circuits in Fig. 6. An important advantage of such a coupling is that it avoids the use of a transformer. Transformers suitable for use at ultra-high frequencies are difficult to construct. Also, as mentioned above, because of the relatively large exterior surface of tank circuits, it is desirable to avoid having them at an appreciable potential above ground. The method illustrated in Fig. 8, applied as shown in Fig. 6, avoids this latter objection.

In general, where two lines are joined at their mutual node and a shunting resistance inserted across the junction as indicated in Figs. 6, 7 and 8, the lines may be of substantially different surge impedances and the shunting resistance may have a value intermediate to the individual surge impedances of the lines. For example, satisfactory results were obtained in a system of the type illustrated in Fig. 6 where the impedance of the coaxial line was 36 ohms, that of the parallel conductor line 214 ohms and the resistance was given a value of 100 ohms. The value of the resistance was found to be not critical.

It should be noted in passing that the method of loosely coupling a hollow tank and an oscillatory circuit, as described in this specification, may equally well be applied to the coupling of a concentric or other two-conductor type line with wave guides of the types described in the above-mentioned paper by Southworth and offers means for obtaining the proper impedances at such junction points. In such instances, the energy is transmitted down the guide instead of being confined in a cavity of a particular character to obtain resonant effects. However, the principles involved in coupling the circuits are with respect to many points identical to those involved in coupling hollow tanks with other circuits.

The arrangements above described are illustrative of the principles of the present invention. Numerous embodiments of these principles will occur to those skilled in the art and no attempt has here been made to be exhaustive. The scope of the invention is defined in the following claims.

What is claimed is:

1. An ultra-high frequency device for precisely fixing the frequency of an ultra-high frequency system, said device comprising a closed cylindrical vessel of conductive material, the axial length of said vessel being at least one quarter of its diameter, a coupling disc of conductive material positioned coaxially within said vessel and insulated therefrom, the plane of said disc being normal to the axis of the vessel, the diameter of the disc being approximately 20 per cent of the diameter of the vessel, the disc being positioned within 20 per cent of the axial length of the vessel from one end of said vessel, the electrostatic capacity of said disc with respect to the nearer end of the vessel being substantially greater than its electrostatic capacity with respect to all other portions of the vessel, and a conductor electroconductively connected to said disc and passing directly from said disc through the nearer end of said vessel but electroconductively insulated from said vessel, whereby a loose electrical coupling to said device is obtained.

2. An ultra-high frequency device for precisely fixing the frequency of an ultra-high frequency system, said device comprising a closed vessel of conductive material and of cylindrical shape, the axial length of said vessel being at least one quarter of its diameter, a coupling disc of conductive material positioned within said vessel and insulated therefrom, the plane of said disc being normal to the axis of the vessel, the disc being positioned within 20 per cent of the axial length of the vessel from one end of said vessel, the electrostatic capacity of said disc with respect to the nearer end of the vessel being substantially greater than its electrostatic capacity with respect to all other portions of the vessel, and a conductor electroconductively connected to said disc and passing directly from said disc through the nearer end of said vessel but electroconductively insulated from said vessel, whereby a loose electrical coupling to said device is obtained.

3. The device of claim 2, the enclosing vessel, the coupling element and the conductor connecting to said element being arranged mechanically to provide electrical symmetry whereby a uniform distribution of electrical energy will obtain throughout the device and its efficiency will be increased.

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