Sept. 10, 1946. S. Y. WHITE 2,407,360

METHOD OF TEMPERATURE COMPENSATING TUNED CIRCUITS

Original Filed Dec. 8, 1942 5 Sheets-Sheet 1

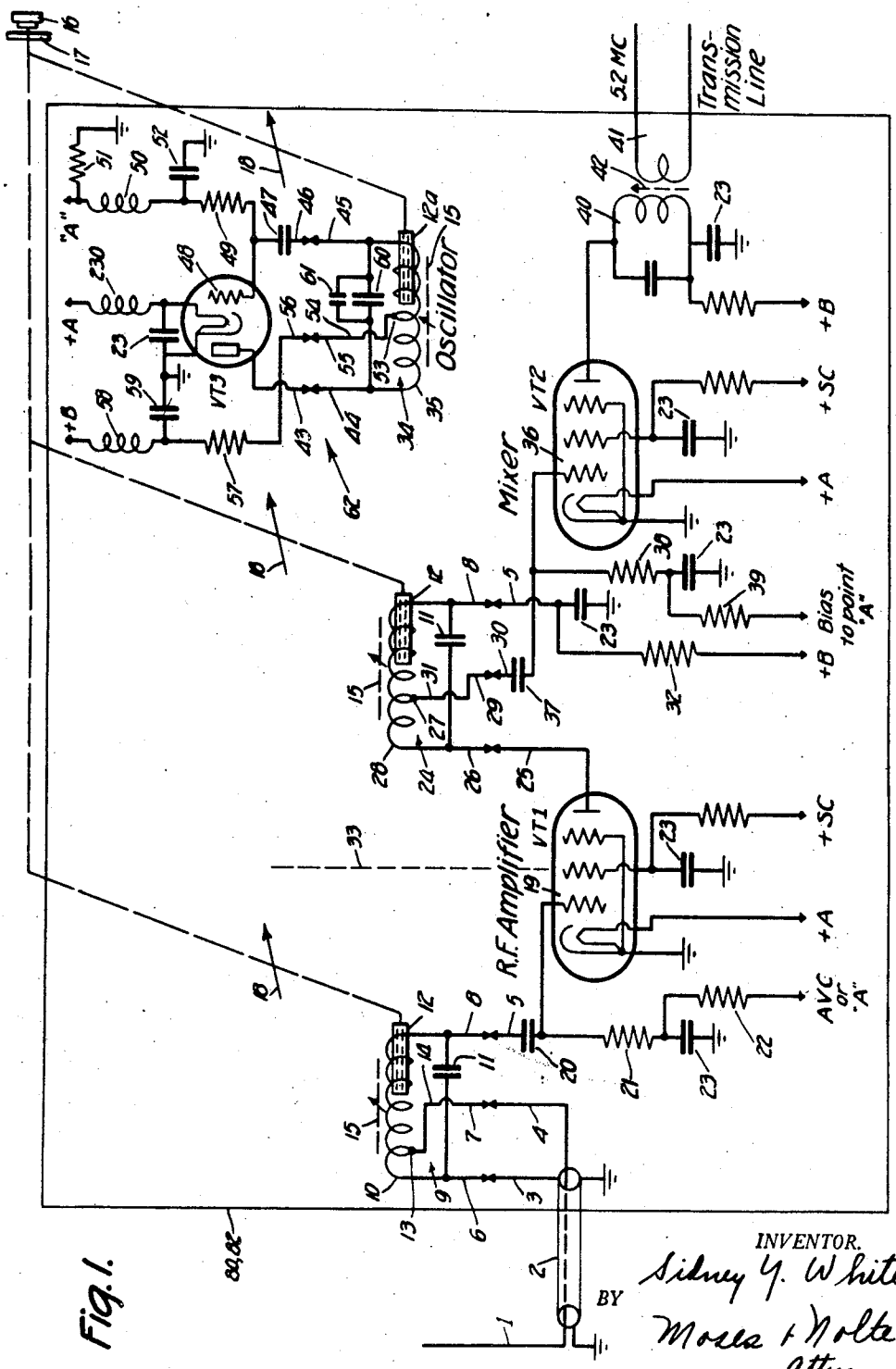


Fig. 1.

Sept. 10, 1946. S. Y. WHITE 2,407,360

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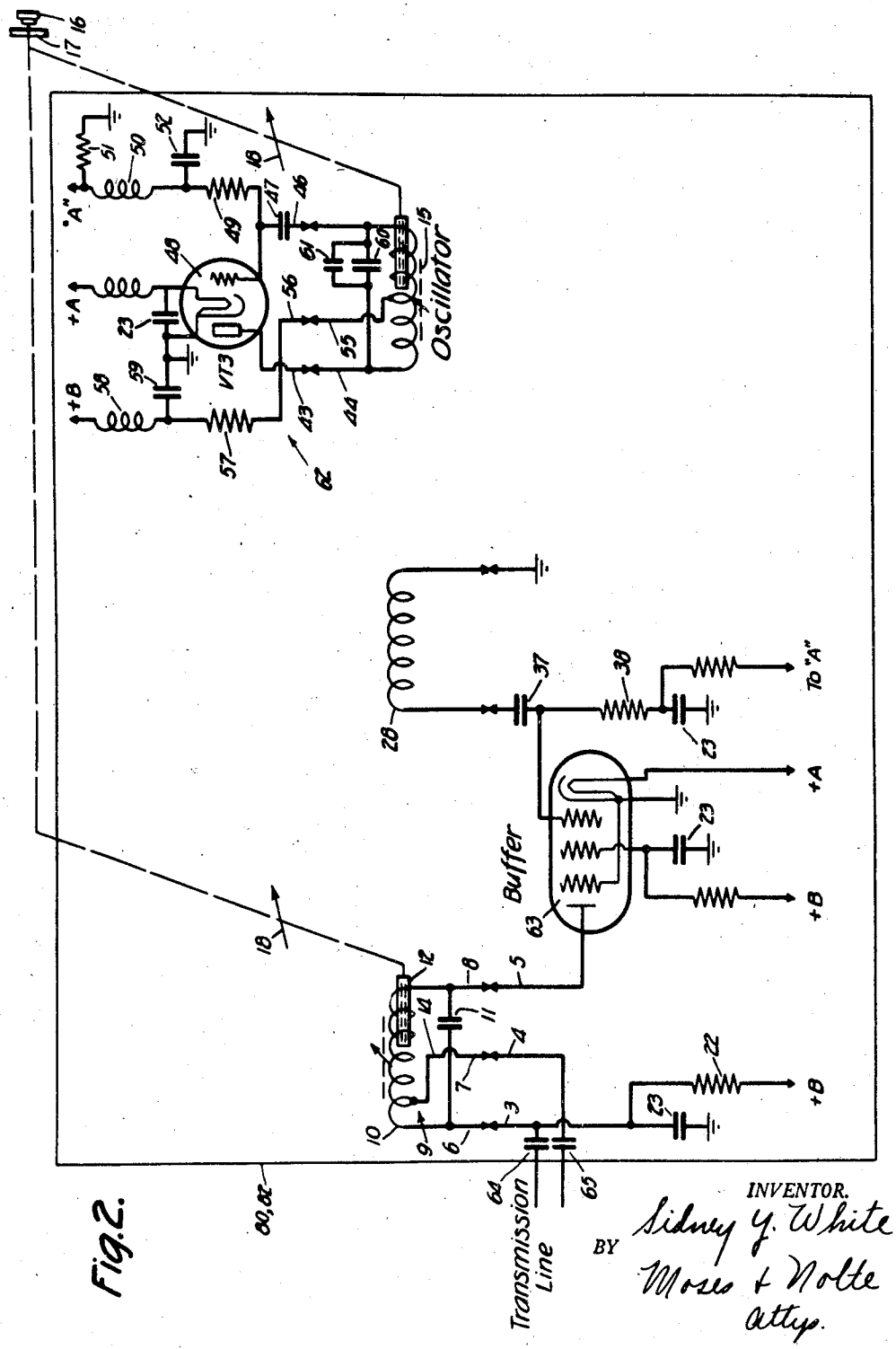


Fig. 2.

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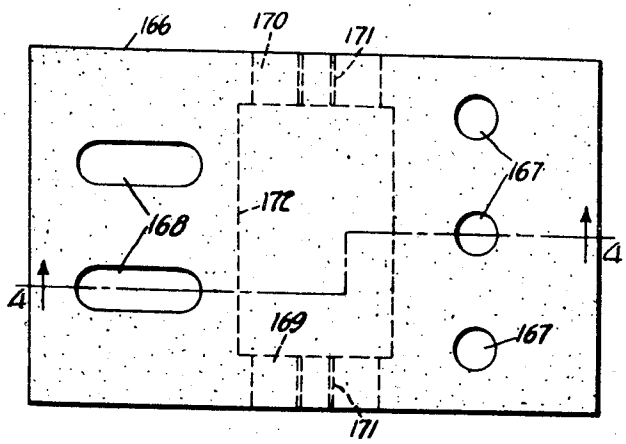


Fig. 3.

Fig. 4.

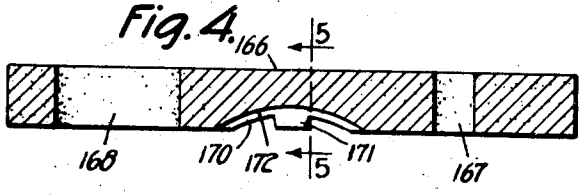
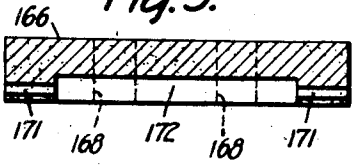


Fig. 5.



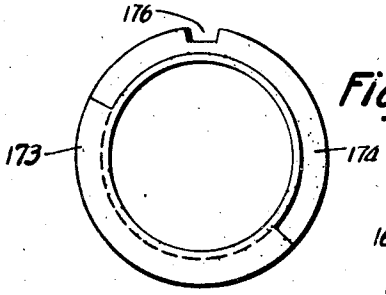


Fig. 6.

Fig. 8.

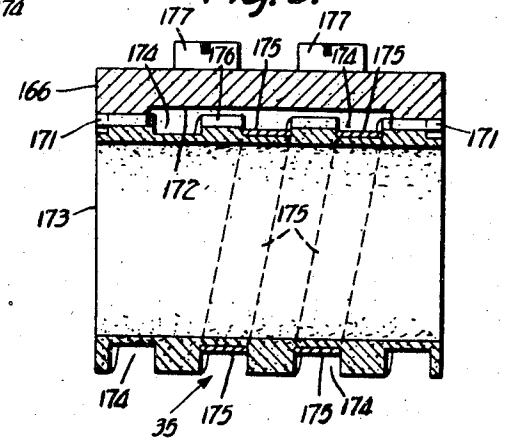
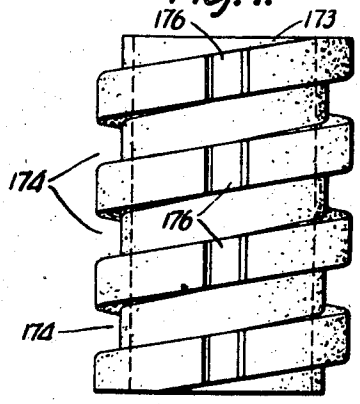


Fig. 7.



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METHOD OF TEMPERATURE COMPENSATING TUNED CIRCUITS

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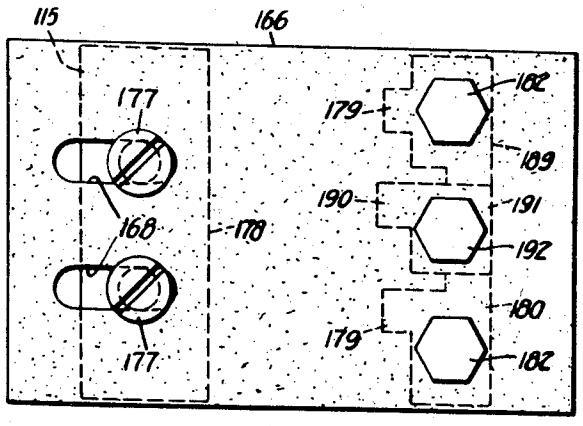


Fig. 9.

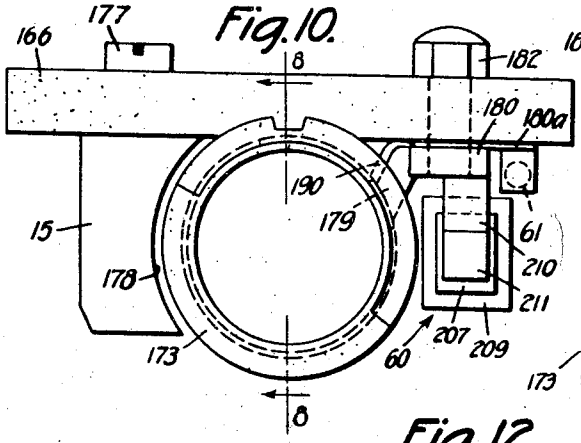


Fig. 10.

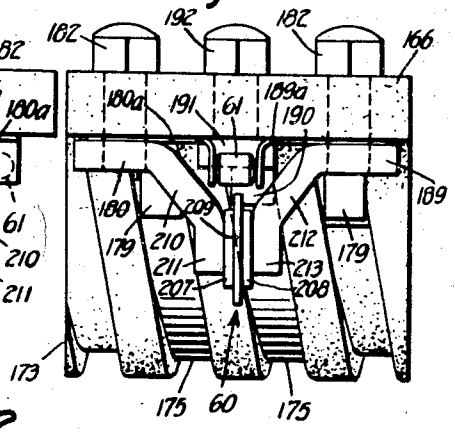


Fig. 11.

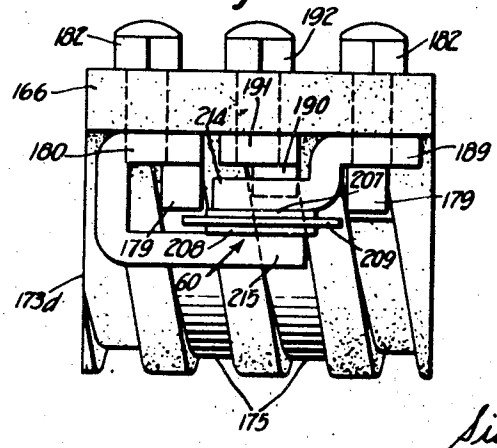


Fig. 12.

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Fig. 14.

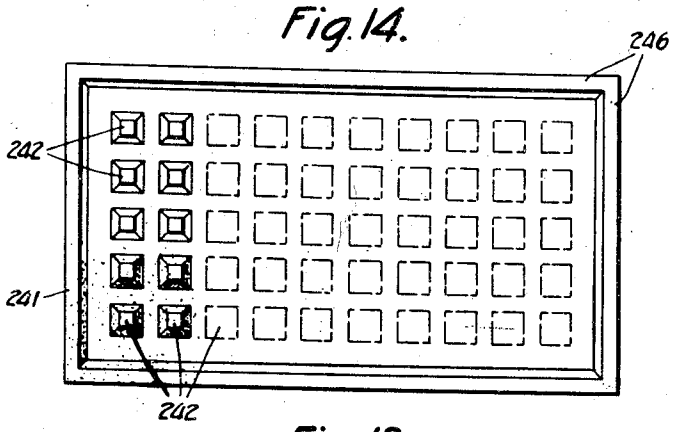
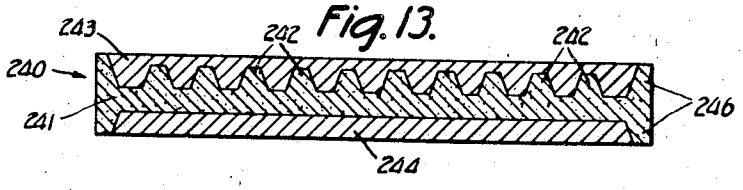


Fig. 13.



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Patented Sept. 10, 1946

2,407,360

UNITED STATES PATENT OFFICE

2,407,360

METHOD OF TEMPERATURE COMPENSATING TUNED CIRCUITS

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Original application December 8, 1942, Serial No. 468,195. Divided and this application October 15, 1943, Serial No. 506,377

1 Claim. (Cl. 250—36)

1

This invention relates to a method of limiting changes in frequency of a core tuned oscillator assembly circuit in response to temperature changes.

The present application is a division of my pending application Serial No. 468,195, filed December 8, 1942, for Precision radio apparatus. The complete disclosure of said application is made a part of the present specification by reference.

While the present invention is of broad utility, an important field of use occurs in the illustrative apparatus of Serial No. 468,195, and the invention will be illustratively disclosed and explained herein by reference to that use. In Serial No. 468,195 mobile radio apparatus is disclosed which is adapted for precision preset dial tuning in the ultra-high frequency range. The crucial elements affecting the precision and the permanence of the precision of receiver tuning and transmitter tuning are found in or in close association with the ultra-high frequency circuits. These elements are chosen of such materials, are constructed in such forms, and are associated and combined with one another into a head unit in such manner that the influence of temperature changes upon frequency is drastically and definitely limited, and that such slight changes of frequency with temperature as do occur are unalterable, so that the initial limitation will be dependably maintained.

To this end the illustrative apparatus of Serial No. 468,195 employs highly disciplined tube socket assemblies in combination with highly disciplined coil and condenser assemblies which are adapted to be combined with one another without the employment of any wiring whatever.

The combined assemblies, independent of compensation have a slight frequency temperature coefficient. The purpose of the present invention is to provide a procedure whereby this change of frequency with temperature may be compensated to reduce it to a small fraction of the value which it would have if such compensation were not provided.

In accordance with the present invention, changes of frequency of a core tuned oscillator assembly circuit in response to temperature changes are limited by providing in the circuit a main condenser having a predetermined change of capacity with temperature of an extremely low order, temporarily connecting in parallel with the main condenser a second condenser of minute capacity in relation to the main condenser whose law of capacity variation with temperature is

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known, heat cycling the entire oscillator assembly at least once through at least a substantial portion of the operative temperature range to stabilize the assembly, heat cycling the assembly a second time through at least a substantial portion of the operative range to determine the change of frequency with temperature, and replacing the second condenser with another condenser having the same capacity as the second condenser and known to have a coefficient of capacity change with temperature suitable for compensating the observed change.

Other objects and advantages will hereinafter appear.

Features of Serial No. 468,195 disclosed but not claimed herein are claimed in Serial No. 468,195 and in other divisional applications thereof; to wit Serial No. 506,372, filed October 15, 1943, for Radio apparatus, Serial No. 506,373, filed October 15, 1943, for Radio apparatus, Serial No. 506,374, filed October 15, 1943, for Electrical condenser, Serial No. 506,375, filed October 15, 1943, for Method of lining up unicontrolled tuned radio apparatus, Serial No. 506,376, filed October 15, 1943, for Method of making inductance coils and Serial No. 555,805, filed August 30, 1944, for Electrical condensers.

In the drawings forming part of this specification

Fig. 1 is a diagrammatic view illustrating principally circuits employed in a receiver which embodies features of the invention;

Fig. 2 is a view similar to Fig. 1 illustrating principally circuits employed in a transmitter which embodies features of the invention;

Fig. 3 is a top plan view of a coil and condenser supporting plate employed in the transmitter and in the receiver;

Fig. 4 is a sectional view of the supporting block shown in Fig. 3, taken on the line 4—4 of Fig. 3 looking in the direction of the arrows;

Fig. 5 is a sectional view of the block shown in Figs. 3 and 4 taken upon the line 5—5 of Fig. 4, looking in the direction of the arrows;

Fig. 6 is an end view of a coil form employed in both the transmitter and the receiver;

Fig. 7 is a plan view of the coil form shown in Fig. 6;

Fig. 8 is a longitudinal sectional view showing the plate of Figs. 3 to 5 and the coil form of Figs. 6 and 14 in assembled relation and with a coil wound on the latter, the section being taken on the line 8—8 of Fig. 10 looking in the direction of the arrows;

Fig. 9 is a plan view of the coil assembly of Fig. 8;

Fig. 10 is a rear end view of the coil and condenser assembly;

Fig. 11 is a view in side elevation of the assembly of Fig. 10;

Fig. 12 is a view in side elevation of a modified form of coil and condenser assembly;

Fig. 13 is a view in sectional elevation of an improved condenser which may be reduced in capacity to predetermined accuracy by grinding, and which may then be employed to advantage in the transmitter and in the receiver; and

Fig. 14 is a plan view of the body of the condenser of Fig. 13.

An illustrative embodiment of an ultra high frequency superheterodyne radio receiver in connection with which the invention may be employed with advantage is shown in Fig. 1. In Fig. 1 reference numeral 1 designates the antenna, 2 designates a 36 ohm coaxial transmission line, the outer conductor of which is grounded and is connected to a switch contact 3, while the inner conductor of the line is connected to a switch contact 4. A third switch contact 5 is provided, the aforesaid switch contacts cooperating with switch contacts 6, 7 and 8 of a tuned circuit assembly 9. The assembly 9 comprises in inductance coil 10, whose ends are conencted to switch contacts 6 and 8 and a fixed condenser 11, the tuning of the circuit to different carrier frequencies being effected by means of a movable core 12 which may be of the powdered iron type. An intermediate tap 13 on coil 10 is conencted to switch contact 7 to provide a 36 ohm coupling point for the transmission line, the connection to switch contact 7 being designated by reference numeral 14. The slope of the tuning curve of circuit 9 is adjusted to a desired value by means of a movable slug 15 positioned alongside the coil 10. The core 12 is adjusted by the operator to tune in the desired station by means of a unicontrol knob 16 associated with a precalibrated dial 17. In order that the resonant frequency of circuit 9 may be made to agree with the calibrations of dial 17, adjustable means as indicated by the arrow 18 is provided whereby the relative position of the coil 10 and core 12 may be adjusted through a slight range independently of the dial setting.

The voltage developed in circuit 9 is supplied to the control grid 19 of radio frequency amplifier tube VT1 through the condenser 20. Grid 19 is connected through the circuit shown, including resistors 21 and 22 and filter capacitor 23 to a source of AVC voltage or source of bias potential such as the voltage source indicated at point A.

Capacitor 23 is of a type construction found highly advantageous and desirable, and universally employed by me in the ultra-high frequency range, and consists of a sheet of metal separated from the body of the set by a sheet of mica, forming a non-inductive bypass to ground. This form of construction insures freedom from unwanted resonant circuit combinations formed by the wiring of the set and wherever a bypass condenser to ground is indicated in the drawings it is of this type. All leads have resistances in them, also to prevent formation of resonant loops. Resistance 22 is of the wire wound type, being embedded in a grounded metallic block and acts as a radio frequency choke to prevent all radio frequency voltage from entering the supply leads.

The tube VT1 is supplied with the usual voltages for its electrodes and suitably bypassed. The plate of VT1 is connected to a resonant mixer circuit 24 thorugh a pair of switch contacts 25—26. This circuit differs from circuit 9 mainly in the position of the tap 27 on the coil 28 of the circuit, this tap being connected to switch contact 29, which engages a switch contact 30 by means indicated by reference numeral 31, the construction of which will be hereinafter described in detail. The other connections of circuit 24 are similar to those of circuit 9 and are indicated by the same reference numerals. The tap 27 is provided to minimize grid circuit loading. Switch contact 5 is connected to a suitable source of B voltage through a resistor 32, and is also bypassed to ground by condenser 33 as shown. The input and output circuits of VT1 are electrically shielded from each other by a grounded shield as diagrammatically indicated at 33 in Fig. 1.

Mixer circuit 24 is tuned to the signal frequency by means of a second core 12 and the adjusting means 18 and 15 for this circuit are similar to those described in connection with circuit 9. Voltage is injected into the resonant mixer circuit 24 from a resonant oscillator circuit 34 whose coil 35 is mounted coaxially with the coil 28, and at a critical distance therefrom. Voltage is supplied to the signal grid 36 of mixer tube VT2 through the circuit shown including a condenser 37, and bias is supplied thereto through the circuit shown including resistors 38—39, the latter resistor being connected to bias point A. Suitable voltages are supplied to the other elements of tube VT2 through the circuits shown, and the output of the tube is connected to a resonant circuit 40, which in the illustrated embodiment of the invention is tuned to a frequency of 5.2 megacycles. Resonant circuit 40 is coupled to a transmission line 41 through a transformer 42 or other suitable coupling means, as it has been found desirable in some cases to allow for a considerable physical separation of the whole tuning unit from its intermediate frequency amplifier and power supply, and also from its antenna.

The oscillator circuit shown is of the "ultra-audion" type, which combines the advantages of requiring no feedback winding, as well as allowing grounding the heater and cathode. The fact that tuned circuit 34 is at high potential to ground is of little interest in core tuning, and grounding the cathode is of great practical advantage, as it has been found that the capacity from heater to cathode is effective in introducing circuit noises, which show up as frequency fluctuations in the oscillator if it is attempted to run the cathode at some potential higher than ground. The plate of tube VT3 is connected to one end of coil 35 through a pair of switch contacts 43—44, and the other end thereof is connected to the grid of the tube through the switch contacts 45—46 and capacitor 47. The oscillator grid 48 has a divided grid leak consisting of resistor 49, choke 50 and resistor 51 to ground, and an isolation condenser 52. By suitable proportioning of resistor 49 and resistor 51 a negative voltage is built up at A suitable for supplying bias to the control grids of mixer tubes VT2 and/or vacuum tube VT1.

Tap 53 is brought out through switch contacts 55 and 56 by connector 54 and is energized through resistor 57 and choke 58 by a suitable source of B voltage. Isolation is effected by condenser 59 in the usual manner. Capacitor 60 performs the same function as 11 in tuned cir-

cuits 9 and 24, but it has been found desirable to also employ a condenser 61 for more complete thermal stability of the oscillator. The action of condenser 61 will be more fully discussed later herein.

The oscillator circuit 34 is tuned by means of a movable core 12a which is in turn operated through the adjustable connection 18 and control knob 16, thereby providing unicontrol tuning of the resonant circuit 9, mixer circuit 24 and oscillator circuit 34.

The oscillator 62 of Fig. 2 shows the same general structure used as a transmitter instead of a receiver. The entire oscillator assembly 62 is identical in every way with the oscillator assembly shown in Fig. 1. It is possible at times that this oscillator will be fed with somewhat higher plate voltage. Its components and performance will be otherwise identical. The R. F. amplifier shown in Fig. 1 is physically reversed so that its input and output circuits are interchanged, forming the buffer tube 63. Its input circuit may well be untuned and a coil 28 used to pick up some energy from the oscillator for exciting the grid through the condenser 37, its grid leak being 38 as shown. The tube is energized in the usual way and its output goes to tuned circuit assembly 9 through the contacts 5 and 8. Tuning condenser 11 resonates this combination whose frequency is controlled also by the core 12 physically connected to the dial through the adjustable means 18. The output transmission line is connected to the tuned circuit 9 through contacts 4 and 7, and plate voltage is applied to contacts 3 and 6 filtered by the condenser 23 and a resistor 22. Contact 3, being at ground potential to radio frequency by virtue of condenser 23, is connected to an output transmission line shown through condenser 64 and contact 4, likewise connected to the line by condenser 65, the purpose of condensers 64 and 65 being to remove D. C. potential from the line.

This assembly, therefore, forms a very low power continuous wave transmitter, but its main use is to energize either a final stage or a buffer meeting a final stage to provide reasonable power outputs.

As has already been indicated, the crucial and significant parts of the transmitter and of the receiver from the standpoint of dependable precision performance are those parts which control the frequency characteristics of the ultra-high frequency circuits of the structure, and those parts included in or closely associated with such circuits, which bear upon the precision of such control.

Figs. 3 to 11, and 12, disclose desirable forms of tuned circuit assemblies and parts thereof, each employing a cylindrical coil form and a solenoidal coil wound thereon.

Referring to Figs. 3 to 5 and 10, the means for supporting the coil 35 and its associated condenser is shown as comprising a generally rectangular shaped plate 166 molded of ceramic insulation material and having formed therein three cylindrical holes 167 and a pair of elongated slots 168. Centrally of the block at its front and rear it is provided with arcuate shaped portions 169 and 170 from which depend the short tapered tongues 171, and between the arcuate portions 169 and 170 the middle portion of the plate is undercut in an arcuate shape as indicated at 172. The entire plate is finished to the shape shown by a molding operation and is then baked at a high temperature.

Referring to Figs. 6 and 7, the coil supporting form 173 is shown as comprising a generally cylindrical shaped tube composed of the same ceramic material of which the plate 166 is formed. The coil form has a spiral shaped groove 174 ground therein adapted to accommodate the coil 35 which is herein shown as comprising a thin metallic ribbon 175 of two turns (see Fig. 8), which may be heated when applied to the coil form, so that it may develop tension through shrinkage as it cools. The coil form is also longitudinally slotted as at 176, the slot being tapered to accommodate the tongues 171 so that the slot 178 and tongues 171 provide means for locating the coil form in a definite position on the supporting plate 166. A material which will glaze is applied to the portions of the coil form and plate 166 which are to be brought into contact with each other and the members then baked to glaze the material which thereupon unites the supporting blocks and coil form into a unitary rigid stable assembly. The ceramic material is preferably of such a nature that its surface contains a large number of small particles which project beyond the general surface level and puncture the skin of the ribbon 175 in numerous places, thereby entirely preventing any slippage of the ribbon on the coil form. The result is that the coil is maintained tightly in engagement with the coil form at all times and does not change in shape due to any changes in temperature or humidity. In other words, the coil and coil form are, as it were, locked together throughout the full length of the coil and the size and shape of the coil remain at all times the same as those of the coil form. This arrangement obviates any non-cyclic variation in distance between one turn of the coil and another and also any non-cyclic variations in the diameter of the coil so that once the coil is wound, its inductance thereafter is not subject to non-cyclic variations due to temperature or aging. The ribbon of the coil is desirably a semi-elastic material such as sterling silver. Such material combines with high conductivity a softness permitting ready penetration by the coil form crystals and an elasticity capable of maintaining the required tension. Pure silver has been found unsuitable because it does not have the required elasticity.

The powdered iron slug 15 is secured against the lower surface of the block 166 by means of a pair of screws 177 which pass through the slots 168. The inner face 178 of the slug 15 is arcuate in shape so that it may be moved inwardly into engagement with the surface of the coil form 173. The slug 15 is adjustable for controlling the slope of the tuning curve of the oscillator.

The left-hand end of the ribbon 175 is soldered to an inwardly extending tongue 179 formed on a metallic coil terminal 180 which has a flat portion held against the lower face of the block 166 by a threaded hexagon head screw 182. The width of the tongue 179 is substantially equal to that of the groove 174 in the coil form so that it engages the sides of the groove and thereby prevents the coil terminal 180 from rotating when the screw 182 is tightened up.

The coil terminal 189 for the other end of the coil is similar in construction to coil terminal 180, except that its parts are reversed, and corresponding parts of the two terminals are designated by the same reference numerals. The tongue 179 of terminal 189 is secured and soldered to the other end of the ribbon 175. The mid-tap 53 (Fig. 1) of the coil is soldered to a

tongue 190 formed on the center terminal 191 whose main body portion is flat and is threaded to receive the securing screw 192. The tongue 190 extends substantially the full width of the spiral groove in the coil form, thus preventing rotation of coil tap 191 when the screw 192 is tightened. The upper ends of the hexagon securing screws 182 and 192 are rounded off as indicated in Figs. 10 and 11, thereby providing switch contacts for the coil and condenser assembly.

A flat condenser 60 (in Figs. 10 and 11) is provided which may be of the mica and silver type. The condenser 60 comprises two metallic plates 207, 208 which are disposed against the opposite faces of a thin sheet of mica 209 which is of substantially larger area than the plates 207, 208. Coil terminal 180 is provided with an integrally formed extension 210 whose lower end 211 is vertical and bears against condenser plate 207. Coil terminal 189 is provided with an integrally formed extension 212 whose lower portion 213 is vertical and bears firmly against the plate 208 of the condenser. The condenser 60 is thus entirely supported by the extensions 210 and 212 of coil terminals 180 and 189, these extensions being short and massive so that their inductance is kept at a minimum value.

It will be noted that the condenser construction described forms the condenser 60 of Fig. 1 of fixed value and which is connected across the ends of the oscillator coil 35, and that the securing screws 182 and 192 form the switch contacts 44, 45 and 55 of said figure.

Spring fingers 180*a* and 189*a* are clamped between the plate 166 and the respective blocks 180 and 189 by screws 182. The fingers 180*a* and 189*a* extend toward one another and have upturned ends disposed in confronting relation. The upturned ends jointly form a conductive, spring holder for a second condenser 61, the purpose of which will be fully explained hereinafter.

The coil and condenser assembly shown in Fig. 12 is similar to that shown in Fig. 11 and corresponding parts are designated by the same reference numerals. In this case, however, the condenser is disposed horizontally, coil terminal 189 being provided with a flat horizontally extending portion 214 which bears against the upper condenser plate 207, and coil terminal 180 being provided with a flat horizontal portion 215 which bears against the lower condenser plate 208 as shown. In both forms of construction no wires are required for connecting the condenser in the circuit, the connections thereto being provided by portions of the coil terminals themselves, these portions being massive and their inductance, therefore, being negligible in comparison with the inductance of the coil itself.

The choice of tuning condenser for use in these circuits is guided by several considerations. The silver and mica condenser as shown in Figs. 10, 11 and 12 have, if properly made, a high order of cyclical stability. The change of dielectric constant with temperature is rather large, however, and is unpredictable, mica being a natural product.

Suitable ceramic condensers 240 (see Figs. 13 and 14) may be employed in place of the mica condensers 60, of the type that have very small temperature coefficients of dielectric constant, and are quite satisfactory.

The ceramic base 241 of condenser 240 is produced by pressing, and not by extrusion, and is provided with a number of pyramids 242, so that the base resembles a waffle iron. Silver is flowed into the base 241 and over the tops of these pyramids 242 to form one plate 243 of the condenser. The silver is also flowed over the other side of the base 241 which has no detail, to form the other plate 244 of the condenser. A wheel of very small radius is used to grind the silver off the top of these pyramids and to grind away the pyramids to a depth sufficient to clean off any ambiguous traces of silver which might otherwise be left on the tops of the pyramids because of the depth of detail in the surface of the ceramic. Every time we grind all the metal off the top of one of these pyramids, we have reduced the capacity of the condenser by a definite amount, and since we are grinding the ceramic on edge, as it were, a sharp line of demarcation is left with no zone of uncertainty. A long leakage path between the two plates of the condenser is assured by the provision of rims 246.

Experience has shown that, if we attempt to grind away a thin flat condenser by grinding away its edge, due to the small cross-section of the condenser and its consequent thinness a very small leakage path is left, and in addition streaks of silver may be deposited across the small area of ceramic to form partial or complete short circuits. The rims 246 obviate these difficulties.

It will be noted that the capacity is removed by equal increments, and consequently an assured limit of inaccuracy less than one-half of one of these increments is not possible. For a great variety of purposes, however, accuracy within 0.1% or 0.2% is sufficient, and is sufficient for the purposes of Serial No. 468,145.

In the tuned circuit assemblies described, a ribbon having a thickness of about three mils and a width of fifty to seventy mils may be advantageously employed. These dimensions are cited by way of example, however, and not as defining practical limits.

Since such high sustained accuracy is sought for, no structure or material can be used except of the most unchanging nature. Physically, glass quartz and ceramic are most suitable and have good retrace characteristics of dielectric constant and physical size when varied with temperature. No structure can be employed where there is the slightest possibility of any permanent change to any degree, either electrical or mechanical.

The tuned circuit is designed with the requirements of core tuning in mind. It is basic, however, that before we can tune the circuit over a range, the circuit without such tuning means must in itself maintain a fixed frequency to a high order of accuracy.

The concentration of over 90% of the inductance is actually in the coils of the tuned circuit assemblies described where it is capable of being acted on by a core.

The diameter of the coil is chosen to be about 405 mils in the present instance for use with a 375 mil core. Considerable difficulty is had in the ceramic art in making thin walled tubes beyond a certain minimum thickness of wall. Maximum tuning ranges obtainable with core tuning are reached where the core substantially fills up the coil, but it must still freely pass through the bore of the coil form. If we chose this same ratio with a 125 mil core, the wall thickness would be less than 5 mils, an impracticable figure for quantity production in the present state of the ceramic art.

The coil form is made with grooves for receiving the conductor. The form is thin in the

grooved portions and thick in the ungrooved portions. The thick portions support the thin portions during firing, and also provide guiding side walls for the grooves.

Since the conductor chosen must have high conductivity, its thermal coefficient of expansion must also be high, at least two or three times that of the coil form. A spiral winding inherently has no strength of its own, so it must be the mechanical slave of the coil form. This means the wire must be wound under sufficient tension and have enough elasticity to cling to the form at the most adverse temperature.

The cross-section of the conductor is a very thin strap, rather wide. If large, round conductors are used, such as #14 round wire, the current tends to hug the coil form as it is the smallest diameter of the turn. Any good conductor has a large temperature coefficient of resistance, however, and if the temperature be raised the resulting increased resistance causes a redistribution of the current, causing the diameter of the mean current path to be increased. This markedly increases the inductance, since diameter of the current path is square in the formula for the inductance coil, and great changes in frequency result.

By using a very thin strap of the order of three mils in thickness, this effect is minimized and a disciplined current path results. Instead of using pure silver, sterling silver is used for greater toughness and elasticity and may be wound on the form quite hot by passing a heavy current through it while winding, in which case it shrinks on the form. Tension may be used also, sufficient to stress it nearly half way to its elastic limit so it hugs the coil form like a rubber band.

Silver plated "Invar" or "Nilvar" used in large cross-section maintains its cross-section under temperature variation, but the current redistribution is the same as for pure sliver, and it must be wound under tension and in general has no advantage over the thin sterling silver strap, which may be flattened wire.

It is of great advantage to use ceramics of the low loss type such as Al Si Mag 196 because of the presence on the surface of minute sharp crystal structures which apparently pierce the skin of any unhardened metal pressed firmly against them. Repeated temperature cycling of these coils from −40 to +217° F. show no creepage of the winding, since each unit length is captured by its adjacent crystals and held firmly in place.

The length of coil chosen must also depend in part upon the tuning curve desired and upon the length of core travel most easily obtained with a desirable dial mechanism. A coil 375 mils long, measured center of winding strap to center of winding strap gives an active core movement of about 250 mils for 25% tuning range.

In any coil to be used with a core, the inside of the coil form must be left free to pass the core. Most methods of terminating coils use rivets, eyelets, or passing the conductor through holes in the form, all of which would interfere with core movement. Some structure outside the simple cylindrical coil form is, therefore, required. This takes the form of the plate or block **166** with its associated terminal blocks **180, 189** and **191** (see Figs. 10 and 11).

The block **166** is preferably glazed to the coil form. Plastic cements are undesirable because of cold flow and change with age, but a good glaze in the joint fired at 1700° really makes the two pieces unitary.

Plate **166** allows use of massive structures such as blocks **180** and **189** to be employed to give a rigid and definite termination of the inductance at either end. These blocks are given large cross-section so that they will have a minimum possible inductance, and the tongues **179** provide exact termination of the inductance wound on the form, in that the take-off of the current is normal to the axis of the coil. Each tongue **179**, being the full width of groove **174**, provides a rigid non-turning structure when the contact screws **182** are tightened up. Shaping of these blocks to include the flat portions **211** and **213** (Fig. 11) or **214** and **215** (Fig. 12) allow either a cylindrical or flat type of condenser to be used for tuning the circuit.

When the condenser is laid in the cradle formed by the connecting blocks **183** it will be seen that an absolute minimum inductance return path closing the physical separation between the ends of the coil proper has been achieved.

It is found to be a considerable advantage in this self-contained structure that rounded contacts can be used as a switch in the case of multi-band apparatus. There is a real problem in switching ultra-high frequency circuits where the switch is placed within the tuned circuit. A coil in the broadcast band may easily have an R. F. resistance of 5 ohms, or 5000 milliohms. A satisfactory commercial type of small switch may have contact resistances of 5 to 40 milliohms, which is negligible in proportion to 5000 milliohms. A two-turn coil such as shown in Fig. 18, however, may have a total R. F. resistance in the entire tuned circuit of only 40 milliohms, and consequently the contact resistance of any practical form of switch, which of necessity must be small because of the small physical dimensions of these circuits, becomes a substantial portion of the total resistance. It is an advantageous feature that each coil carries its own tank condenser with it, allowing switching of the charging current to the electrodes of the tubes only, a much easier matter.

Provision of these contacts also allows desirable slipping of the whole tuned circuit assembly axially. The advantages of this slipping have to do with alignment procedure with which the present invention is not directly concerned. Plate **166** also provides a fastening means for the assembly.

The tuned circuit assembly in either of the forms illustrated makes provision for a single unit that has in effect fastening means, tuning means, switch, tank condenser, trimming, tracking and aligning means in a single simple structure, so that all the frequency determining elements are well within a cubic inch, and under temperature, vibration and shock, all travel together. There is no influence of the chassis upon the frequency. There is thus provided a single universal unit that can be used for transmitter, receiver, wave trap, or any of the numerous uses to which tuned circuits can be put.

The Q of these assemblies is found to be quite high without the core. If measured in air without any associated apparatus, the Q is about 700. When measured in the coil holder and with an oscillator tube assembly attached, with the tube in place but not lit, the Q exceeds 400.

A further advantage of this type of construction is that no parasitic loops of any kind are formed to give resonant absorptive effects or resonant voltage rises at any frequency within

the operating range of the current acorn tubes, and in no case below 1500 m. c.

Since an oscillator is by all means the most difficult unit to design in regard to frequency stability and resettability, great attention must be paid to all elements cooperating with this basic circuit to give a complete oscillator. Referring to the wiring diagram of Fig. 1, it will be noted that the ultraaudion oscillator is used, which is the simplest of all circuits. Elimination of the center tap might have been accomplished by shunt feeding the plate through a resistance. Such an arrangement is not considered most advantageous, however, because of the wattage dissipation and the voltage drop in such a resistor. Since it is desired to maintain the universality of application of this unit, it is often desirable to operate with such low plate voltages, as for instance in the battery type of acorns, that 20 volts drop in the plate shunt resistor would force the use of a higher voltage battery.

An approximate center tap shown has an isolation resistor **57** associated with it, since with core tuning with the core introduced at one end the null point (that point which is at zero potential to ground) shifts as the core is inserted. This shifting null is taken care of by the resistor, which prevents any substantial radio frequency energy from flowing down to ground through the plate energizing connection.

The ultraaudion circuit has the advantage that the cathode and heater are at ground potential, thus eliminating frequency fluctuations introduced by way of the cathode to heater capacity, when the heater is energized from an alternating or fluctuating source of voltage.

It has been found that the capacity ratios between the electrodes of the acorn tube as now manufactured, both battery and 6 volt types, is very nearly ideal for this type of oscillator.

In distributed capacities the circuit in which the coil and condenser assembly is employed is exceptionally low. All capacities, including the tube capacities, other than the tank condenser **60** itself, average about 3.8 mmf. A two-turn coil such as shown in Fig. 11, with the tank condenser **60** omitted, will oscillate at 400 m.c., showing that, when the tank condenser is inserted to bring its frequency down to an operating range in the neighborhood of 150 mc., we have a highly disciplined circuit of great stability.

The true inductance of the coil varies at a rate proportional to the thermal coefficient of expansion of the coil form which is six parts per million per degree. Current redistribution due to the increased resistance of the winding conductor with heat is practically eliminated by the use of an extremely thin strap for the conductor.

The change in the capacity of the tuned circuit assembly parts to each other through ceramic as a dielectric, as well as the change in capacity between the parts mounted on the socket **228**, is of a rather high order, but since the total value of this capacity lies between 1 and 2 mmf., it forms a rather small part of the entire tuning capacity, being often of the order of 5% to 10% of such capacity.

Both the real and apparent inductance of the tuned circuit assembly lower the frequency as the temperature increases so a slightly negative temperature coefficient condenser **240** is used for tuning the circuit to provide a balance, resulting in very small change in frequency with temperature. These condensers employ generally available ceramic materials which may be chosen to yield a temperature coefficient which is highly negative, such as an almost pure titanium dioxide mix, which gives —750 parts per million per degree, up to those going slightly positive in their temperature coefficient of capacity. Some difficulty is had in manufacturing these condensers in quantity closer than several parts per million of a predetermined frequency coefficient.

Since these high percision devices must be heat cycled at least once to mechanically stabilize them, it has been found desirable to include the condenser **61** in the circuit. When the set is first assembled condenser **61** is an extremely small capacity in shunt with the main tuning capacitor **60**, having for instance 1% of the value of the main tuning capacitor. It is a replaceable device and quite close to zero temperature coefficient.

A second heat run is then made with this same condenser in place, and the change in frequency with heat noted. It has been found that this second run can well be made from the ambient temperature to some higher temperature only, such as for instance 130° F. The shift in frequency caused by the heating is then noted which may be for instance +60 kc. for the entire assembly. The original condenser **61** is then removed and another condenser **61** substituted having a predetermined temperature coefficient, and one so chosen as to compensate for the +60 kc. temperature drift. Since this very tiny capacitor **61** must affect the whole circuit, of which it composes only about 1%, it must have a very high temperature coefficient, either positive or negative. By arranging to have a series of such capacitors available, as for instance fifteen different types, all of about the same capacity but forming a continuous series with respect to temperature coefficients, an over-all temperature correction for each individual set is accomplished before the set is actually calibrated.

The core employed has almost no temperature coefficient of its own, as otherwise either incomplete or very elaborate compensating means would have to be used.

I have described what I believe to be the best applications of my invention. I do not wish, however, to be confined to the applications disclosed, but what I desire to cover by Letters Patent is set forth in the appended claim.

I claim:

The method of limiting changes of frequency of a core tuned oscillator assembly circuit in response to temperature changes, which comprises providing in the circuit a main condenser having a predetermined change of capacity with temperature of an extremely low order, temporarily connecting in parallel with the main condenser a second condenser of minute capacity in relation to the main condenser whose law of capacity variation with temperature is known, heat cycling the entire oscillator assembly at least once through at least a substantial portion of the operative temperature range to stabilize the assembly, heat cycling the assembly a second time through at least a substantial portion of the operative temperature range to determine the change of frequency with temperature, and replacing the second condenser with another condenser having the same capacity as the second condenser and known to have a coefficient of capacity change with temperature suitable for compensating the observed change.

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