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CARRIER FREQUENCY HETERODYNE OSCILLATOR

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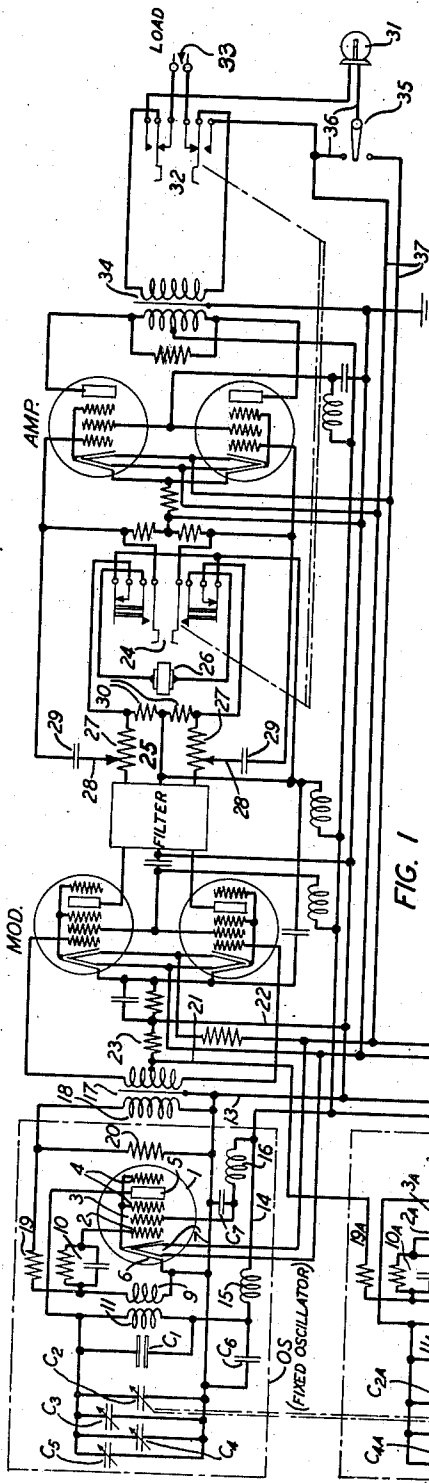


FIG. 1

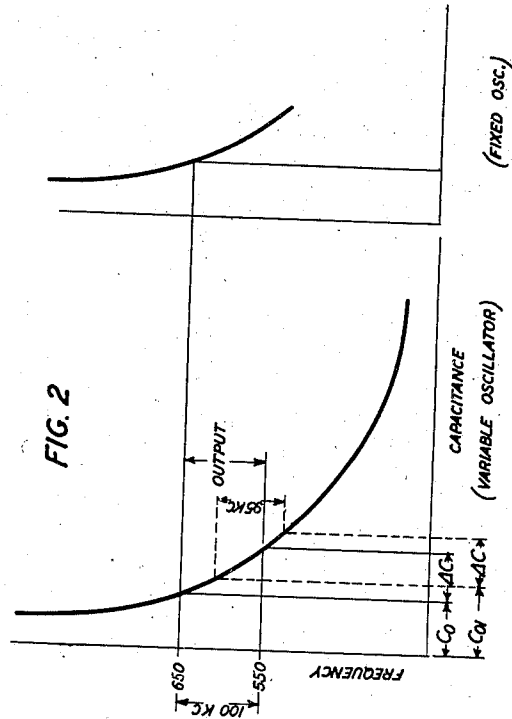


FIG. 2

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CARRIER FREQUENCY HETERODYNE
OSCILLATOR

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This invention relates to a heterodyne oscillator and especially to such an oscillator characterized by a capability, without sacrifice of accuracy, of varying the heterodyne frequency through a relatively very wide range, including those frequencies commonly used in carrier communication systems employing wires.

Although capable of use generally, where relatively great range of frequency is to be covered, so that the frequency may be varied, for example, between values differing by many hundred per cent from the lower value, even to the extent of varying from substantially zero frequency value to an upper value measured by hundreds of kilocycles, it perhaps, because of this special capability, is best adapted for sweep measurement of carrier current apparatus in which the frequency is changed continuously over the entire large range while the effect which is being studied is observed on an indicator connected to the apparatus under test or recorded automatically.

In general, for this type of service, that is, where the frequency is to be varied over a wide range, the heterodyne type of oscillator is recognized as most convenient to use, as compared with its alternative, the single unit oscillator which itself, as to its continuity somewhat closely approximates either unit of the heterodyne oscillator. For instance, not only does it permit the frequency to be controlled by a single condenser, but its output-frequency characteristic may readily be made substantially flat.

The reasons for this are fairly obvious on a little consideration. Consider a single unit electron tube oscillator in relation to a heterodyne oscillator employing like unit, or component, oscillators. In such single unit oscillators, of course, the frequency is a function of the electrical condition of a tuned circuit, the so-called frequency determining circuit. The frequency of such an oscillator varies as the square root of the capacitance of the tuning condenser of such circuit so that in order to secure a frequency range of 100 to 1, for example, the capacitance will have to be varied over a range of 10,000 to 1. Since the condensers have always a quite appreciable minimum capacitance, the maximum value will become too high to be readily attained in any conventional condenser. Furthermore, a single coil could not well cover such a wide frequency range. Accordingly, besides necessitating the use of several condensers, such wide range oscillator would require the sequential substitution of a number of coils to cover the entire frequency range of the oscillator. More-

over, the output energy inherently varies with frequency to the extent that only over a comparatively narrow frequency range does it tend to remain substantially constant. Where a wide frequency range is required from a single unit oscillator, therefore, the output cannot be held constant.

In the instance of the heterodyne oscillator, in contrast to the above, the output energies of two separate single unit oscillators, one fixed in frequency and one variable in frequency, are combined in a modulator device and a difference frequency is selected as the characteristic oscillator output frequency. In order to secure a frequency range of variations from 1 to 100 kilocycles, for example, it would be practicable to employ one oscillator with a fixed frequency of 500 kilocycles and one whose frequency is variable from 499 to 400 kilocycles. The difference frequency would then be made variable from 1 to 100 kilocycles by varying the variable oscillator frequency from 499 to 400 kilocycles, a range of only about 20 percent of the upper boundary frequency. Over this comparatively narrow range, a single variable condenser and a single frequency significant coil may be used in the variable frequency oscillator, and likewise, because of the comparatively narrow range with the assistance of careful design, the output energy can be made substantially constant over the frequency range.

The particular oscillator developed by applicant and found to function with very great efficiency, as compared with the prior art alternatives, as a result of the inventive principles to be presently expounded, was variable over a range of from 1 to 150 kilocycles. Its frequency was varied by variation of a single condenser during normal operation, the frequency range indicated being read from a single indicator, analogous to a conventional dial although of different physical conformity, attached to said variable condenser, which, of course, was included in the frequency determining circuit of the variable frequency component oscillator. The indication was, as it had to be, accurate to 25 cycles and the output energy was essentially constant over the whole frequency range. Because of the practical necessity of reading the frequency to a closeness of 25 cycles, the frequency scale had to be much more extensive than the conventional frequency scale. That is, the indicator or effective dial, was constituted by a length of tape about eight feet long and therefore the equivalent of a conventional

dial having a scale of like dimensions. This indicator, which necessary physical environmental structure is disclosed and claimed in applicant's Patent 2,058,641, issued October 27, 1936. Principally because of the length of this indicator it was able to meet the precision requirement, since it enabled the scale impressed on said indicator to be provided with three thousand 50-cycle divisions. Since the mid-position between two closely spaced lines can readily be judged by the eye, this permits reading to the 25-cycle precision requirement. The variable condenser, which, solely, enabled this range of frequency variation was, as it had to be, capable of being reset to at least one part in 10,000 or 0.01 per cent.

Since, in the interest of convenience of use, it was not permissible to apply a correction to a given reading of frequency, in the alternative it was very important that the scale at all times during the operation of the oscillator involving frequency variation accurately conform to its nominal readings, for example, both as to an exact correspondence between the over-all frequency change and the calibrated length of the scale and as to the accurate distribution of the intermediate scale indications. Of course, it was permissible to make adjustment, in order to satisfy the above conditions, at reasonable intervals of time, and intervals large as compared to time required for a given frequency run.

Various factors enter into the determination of the frequency of each of the fixed and variable component oscillators and which tend to introduce inaccuracies in frequency indication of the class just described. These factors, of course, are the more important under the assumed condition of required very great accuracy of indication. Although these factors, or at least some of them are equally effective in the case of a single unit oscillator, their compensation or correction in the present instance, of course, is with reference to the particular type of oscillator assumed, namely, a heterodyne oscillator comprising therefore the joint operation of two of said single unit oscillators. A few such factors will be noted.

The variable condenser itself has a temperature-capacitance characteristic, signifying that the nominal capacitance value at any setting may be made inaccurate because of the effect of change of temperature, especially as effecting the physical dimensions entering into the equation of capacitance. Some relative compensation may be secured by the design of the condenser itself but this at best is not altogether effective and the alternative of accurately regulating the temperature of environment of the condenser would unduly increase the mass of the oscillator and its cost, and would also tend to detract from the convenience of operation of the oscillator. Temperature-significant effects on the remaining frequency-determining condensers and inductors in the heterodyne oscillator as a whole tend to produce like effects although in a somewhat different way. That is, for example, noting that the variable capacitance constitutes only a portion of the total capacitance of the variable frequency oscillator and that there is a non-linear relation between this capacitance as a whole and the frequency of the variable frequency oscillator, a variation of the capacitance outside that of the variable condenser tends to cause the change in capacitance of said variable condenser to occur over a different portion of this capacitance-frequency characteristic and a portion having a dif-

ferent slope and therefore a different intercept on the frequency coordinate. This ultimately results in an effective compression or expansion of the frequency band as measured by the over-all adjustment of the variable condenser and therefore a lack of correspondence between it and the boundary indications on the scale. Having in mind the impartiality of the capacitances in the respective component oscillators in affecting the difference frequency, that is, the characteristic frequency of the oscillator as a whole, it is evident that an effect like that just above described also occurs responsively to like changes in the condensers of the fixed oscillator and by an obvious extension of reasoning the same thing is perceived to be true of the frequency significant inductors in the respective component oscillators.

It, of course, is evident that a change in frequency of either component oscillator due to any of the above causes, has a considerable leverage on the difference frequency. For example, a change in frequency of the fixed oscillator of 0.01 per cent would affect the difference frequency to the extent of 65 cycles, which represents a change in frequency thereof of many times the given change in percentage frequency of the fixed oscillator and more than twice the allowable tolerance. Changes of this magnitude could readily occur since both the capacitances and inductances of the tuned circuits might easily have temperature coefficients of 15 parts in a million per degree Fahrenheit and with coefficients of this magnitude a temperature change of 8 degrees Fahrenheit would produce the above 65-cycle change. Some natural compensation occurs since the temperatures of the two oscillators tend to change simultaneously so as to cause the frequencies of the two oscillators to change in the same direction at the same time. Frequency change, sometimes described by the word "drift," may be further reduced by use of inductance coils and condensers having small temperature coefficients or by use of such elements so chosen as to have diverse characteristics as to temperature effects on frequency. These expedients, of course, are short of the impracticable ideal of complete temperature stabilization of all of the frequency-significant elements going into the make-up of the oscillator. Within the practical limitations imposed on an oscillator of this kind, a certain unavoidable frequency drift tends to be present.

It is an object of the invention to develop a heterodyne oscillator which, in the face of the above enumerated adverse conditions, can be made to very accurately indicate the characteristic difference frequency.

Another object of the invention is to insure, by simple and easily operable means an accurate correspondence between the characteristic frequency (heterodyne or difference frequency) of a heterodyne oscillator and the scale reading thereof, at all points in the variable range of said frequency.

A more specific object of the invention is to, in a heterodyne oscillator, provide means for independent scale adjustment corresponding to two points widely separated in the heterodyne frequency variable range.

In order to satisfy the above objects of the invention and therefore in order to correct for such frequency drift as unavoidably does exist, the heterodyne oscillator of the invention provides for two frequency adjustments, one at a frequency corresponding substantially to the lower

boundary of the frequency scale and the other at the frequency near the upper boundary of the frequency scale, the particular frequencies being chosen to serve practical convenience and as determined by the nature of the comparison frequency sources used in the adjustment. Since these two frequencies are accurately determined by standard sources the comprehensive heterodyne oscillator can be thought of as a circuit means, involving the heterodyne principle for deriving from a given two standardized frequencies, by interpolation and extrapolation, a complete and wide range of frequencies. The low frequency point is determined by simply equating the frequency with the frequency from a low frequency standard source. For convenience, in a practical embodiment of the invention, the 60-cycle power supply for filaments of the oscillator tubes was used for the standard source, the equality of frequency being indicated by the use of a small synchronizing lamp as in accordance with conventional synchronizing technique in the art of power supply. The frequency is caused to have this value, that is the 60-cycle value, at the 60-cycle point on the scale by a screwdriver adjustment of a trimming condenser, or trimming condensers, on one or the other of the two component oscillators.

The upper frequency adjustment is determined by use, for example, of a 100-kilocycle piezoelectric crystal which is connected across the oscillator output circuit, preferably across the input of the amplifier following the combining tube. A lamp, which might well be the synchronizing lamp above referred to, is likewise connected across the oscillator output and preferably across the output of said amplifier. A condition of resonance between the oscillator output frequency and the standard frequency from the crystal, that is equality between these frequencies, is attended by a phenomenon analogous to an effective short circuit of the lamp and therefore an extinguishment of its light.

The above frequency adjustment at the 100-kilocycle scale point is accomplished like the lower scale adjustment by a screwdriver adjustment of capacitance. Here, however, in order to insure that the adjustment does not disturb the lower scale adjustment, it is accomplished by equal or near-equal adjustments of capacitance in both component oscillators. At frequencies approximately the upper region of the frequency band characteristic of the oscillator, the two component frequencies, that is the frequencies of the two component oscillators, are so widely different, especially in the case of such a wide frequency variation as is contemplated by the present oscillator, that these changes of capacitance, while equal or approximately equal have widely different effects relative to the two oscillators so as to enable this adjustment to be as effective except in degree as if the adjustment were in one component oscillator only. However, at the lower scale regions where the component frequencies are nearly equal, these capacitance adjustments having like effect on the two component oscillators, are mutually compensatory and therefore have small net effect. By this expedient of the invention therefore the two scale adjustments may be made functionally independent of each other.

In the drawing, Fig. 1 illustrates in detail a preferred embodiment of the heterodyne oscillator of the invention including the two standard frequency sources, with associated circuits

adapted to be used to determine two fixed points on the variable frequency scale, and Fig. 2 represents a graphical device for illustrating the effect of variation of frequency significant circuit elements with respect to a given frequency scale, and therefore teaching, among other things, the importance of standardizing the frequency at two widely separated points on the scale.

Referring to Fig. 1, the heterodyne oscillator of the invention comprises generally the two component oscillators OS and OSA, the combining device or modulator MOD on which are impressed the output waves of the component oscillators and from which is derived the difference frequency, that is the characteristic frequency of the over-all oscillator, and the push-pull amplifier AMP. Of these elements of course only the component oscillator and modulator elements are essential to make up the heterodyne oscillator, although the amplifier is of practical utility as being responsible for the major part of the energy content of the system as a whole.

The component oscillators OS and OSA, may be of similar type or of different type with complete impartiality so far as concerns the ultimate result achieved although they must equally be capable of frequency variation by variation of the frequency significant reactance in order to make possible the independent scale adjustment at widely separated points of the scale as pointed out in the statement of invention. In the particular oscillator disclosed, these two component oscillators are substantially identical. In the description thereof in the specification, specific attention therefore needs to be directed to only one such oscillator to the extent that the other one has duplicate elements. Where the elements are so duplicated (duplication has, of course, to do only with the continuity of circuit not with the electrical values) the relationship between the elements are indicated by the use of literal subscripts in the instance of one of said oscillators. The oscillator OS is here treated, as it is designated, as the fixed frequency oscillator. In a particular heterodyne oscillator of the invention which was found very successful in practice, one component oscillator generated a wave of a frequency of 650 kilocycles, while the other component oscillator, namely, the variable frequency oscillator OSA, generated a wave of a frequency variable by manipulation of a single variable condenser between the frequencies of 650 kilocycles and 500 kilocycles. Accordingly, the variable range, and therefore the characteristic frequency range of the oscillator as a whole, was 150 kilocycles, the frequency varying in this range from substantially zero to the higher value. It should immediately be appreciated that this range is not only of large absolute value but that there are represented in it frequencies differing enormously in value on a percentage basis, as compared with more conventional heterodyne oscillators.

Considering first the component oscillator OS, and again remembering that except where especially noted otherwise the description applies likewise to the oscillator OSA, the oscillator comprises the electron tube 1 together with associated circuits made up of resistance, inductance and capacitance constituting the whole a quite conventional vacuum tube oscillator of the type sometimes denominated by the term "reversed feedback" and especially a reversed feedback oscillator of the tuned output type. The tube 1 comprises the usual control grid 2, screen grid 3,

suppressor grid 4, plate or anode 5 and cathode 6. Of course other types of tubes, for instance employing three electrodes, may be substantially equally well used with the associated circuits to achieve the same result. The cathode is indirectly heated by filament heater 7 energized from source 8 which may well be a source of a regulated low frequency so as to enable the same source to be used in the lower scale adjustment as in accordance with the procedure pointed out in the statement of invention. Since the 60-cycle current used for domestic power purposes is very commonly so regulated as to frequency and is universally available, current from such source may be effectively used in this place. Of course, so far as concerns the operation of the oscillator itself, it would be immaterial as to the type of current or even as to whether it is direct or alternating and in fact the indirect heated cathode principle would not have to be employed.

The input circuit of the tube comprises the coupling coil 9 and grid leak condenser combination 10 connected in series between the control electrode 2 and cathode 6. The alternating current output circuit correspondingly is connected between the cathode 6 and plate or anode 5 and comprises the coil 11 coupled to the input coil 9 and condensers C_1 , C_2 , C_3 , C_4 and C_5 in shunt thereto. These condensers with the coil 11 constitute the conventional frequency determining circuit of a reversed feedback tuned output vacuum tube oscillator. The anode is supplied from direct current source 12 which, of course, may be a prime source or the output circuit of a combination of elements adapted to generate an alternating current and rectify the same. This current supply goes through leads 13 and 14, from the former directly to the cathode and from the latter to the plate through the ripple filter constituted by coil 15 and condenser C_6 and thence through the tuned circuit directly to the plate. The screen grid 3 is supplied with potential, as in accordance with conventional practice, from a potentiometer-like circuit connected across the plate source and comprising inductance coil 16 and condenser C_7 and the suppressor grid 4, as in accordance with convention, is connected directly to the cathode.

With respect to the frequency determining circuit, as above identified, although it was indicated above that all of the shunt condensers were impartially and in like manner connected in shunt to the tuning coil 11, it might be noted that this is true strictly only of condenser C_1 , the other condensers being connected thereacross in series with the condenser C_6 . However, this deviation from strict convention is of small import and the above statement as to the constitution of the frequency determining circuit is correct except for the very slight effect of said condenser C_6 , which, to that extent may be treated as part of the frequency determining circuit.

With further reference to this frequency determining circuit, it may be noted that although for many purposes these several condensers could be replaced by a fewer number down to the limit of a single condenser, each subserves a particular function in a commercial form of oscillator of which the one described is a representation. The condenser C_1 is the principal frequency determining condenser. Condenser C_2 , which is mechanically coupled, as indicated with the corresponding condenser of the variable oscillator component, makes possible the upper scale correction as in accordance with an im-

portant principle of the invention, as briefly explained in the statement of invention. Condenser C_5 correspondingly provides the lower scale adjustment, as explained. This condenser could substantially equally well be positioned in the other component oscillator circuit. Because of the compensatory effect achieved by the use of the coupled condensers used for the upper scale correction, the adjustment for upper and lower scales are functionally independent so that there is no analogous reason for utilizing more than the single condenser, such as C_6 , for the lower scale adjustment. Since this condenser C_5 is a very small, trimming, condenser, it is backed up by condensers C_3 and C_4 covering widely different variable capacitance ranges. That is, these two condensers are varied as necessary, probably at widely spaced intervals of time, to insure that at all times during a test the lower scale adjustment may be achieved by operation of condenser C_5 alone. With the exception of the very small capacity scale adjusting condenser C_5 , which is variable in the usual way, the condensers shown variable are varied, when necessary, by screwdriver adjustment. In a particular instance in which the circuit of the invention was found effective, these condensers C_1 , C_2 , C_3 , C_4 and C_5 , normally had about the values of capacitance, respectively, of 1050 micro-microfarads, 8 micro-microfarads, .5 micro-microfarad, 50 micro-microfarads and 1 micro-microfarad, while the series condenser C_6 had the value of capacitance of .7 microfarad.

As has been indicated, the circuit of the variable oscillator OSA is like that of the fixed oscillator OS , except as now to be noted. Of course, the condensers corresponding to those in the fixed frequency oscillator and which likewise have the screwdriver adjustment, would normally be adjusted to be slightly different as compared thereto because of unavoidable differences in, for example, the cooperating tuning coils. The distinctive feature of this variable frequency component oscillator is the variable condenser C_5 . This condenser constitutes the only element varied during the frequency traverse whereby the difference frequency, and therefore the characteristic frequency of the oscillator may be varied from substantially zero to 150 kilocycles. It constitutes per se no part of the present invention, but is the subject-matter especially as to its frequency scale, as above indicated, of applicant's Patent 2,058,641, issued October 27, 1936.

The output waves of the two component oscillators are combined by modulator MOD to realize the difference, that is the characteristic, frequency. The resultant wave is amplified by amplifier AMP if necessary and as would serve practical convenience in most instances. The circuits of said modulator and amplifier are shown in considerable detail but do not require specific comment except as to associated circuit features which pertain to the invention since said modulator and amplifier themselves are quite conventional representatives of push-pull circuits as adapted to perform these two functions.

Because the modulator is a push-pull modulator, the circuits from the component oscillators for impressing the combining waves on the modulator must be so impressed in push-pull or conjugate relation. The wave from oscillator OS is impressed on the modulator through transformer 17 by primary circuits comprising in series the primary coil 18 and the resistance 19 connected

between the control electrode and cathode of the tube 1, although of course the wave could be derived from the component oscillator in other ways without in any way effecting the operation of the principle of the invention. The resistance 20 connected across the primary transformer coil 18 serves, as in analogous circuits, to more nearly fix and stabilize the potential impressed on the transformer primary. Although this impressing circuit is not connected directly to the control electrode but thereto through the grid leak-condenser combination 10, the effect is the same; or, which perhaps is a better way of stating it, the impressing circuit may be thought of as connected across the primary coupling coil 9 between the terminals of which occurs, equally well as between certain other points of the component oscillator circuit including the control-electrode-cathode circuit itself, a potential which reflects the oscillation generating characteristic of the component oscillator.

The wave from the component oscillator OSA is similarly impressed through resistance 19A and conductors 21 and 22, across resistance 23 of the push-pull modulator. The relationship of this resistance 23 and the secondary coil of the transformer 17, both as related to the modulator tube circuit, is obviously conjugate, that is, is such that the wave from the oscillator OSA, or the potential corresponding thereto, is impressed in like phase on the control electrodes of the modulator tubes whereas the potential correspondingly impressed from component oscillator OS is impressed in opposite phase on such control electrodes. This satisfies the necessary condition of operation of such a modulator, so far as pertains to the input circuit thereof.

The key 24, shown between the output of the modulator and the input of the amplifier is used in combination with the potentiometer 25 to provide an efficient way of connecting into the oscillator circuit the piezoelectric crystal 26. Normally, that is when the crystal is not so connected, the connecting circuit goes from points on potentiometer resistances 27 directly to the control electrodes of the amplifier by leads 23 and blocking condensers 29, the series potentiometer resistances 30 being short-circuited through the outer contacts of the key. By operating the key, the crystal 26 is directly connected to the amplifier control electrodes, through the inner contacts, without disturbing any other circuit except that the short circuit across said series resistances 30 is removed to enable an increased potential from the modulator to be impressed on the amplifier.

This crystal, in the particular oscillator here in mind, has a characteristic frequency of 100 kilocycles and constitutes the primary standard heretofore described for establishing one of the two significant frequencies of the heterodyne oscillator, the other frequencies being determined by interpolation and/or extrapolation. In another sense the function of the crystal is to enable an accurate adjustment of the scale near the upper end thereof, the necessary adjustment of the frequency to cause correspondence between the standard frequency of the crystal and the like scale reading being accomplished by the ganged condensers C₂ and C_{2A}, as has been explained. In the procedure for achieving this upper scale adjustment, the ganged condensers are varied slightly while holding the frequency reading at 100 kilocycles by adjustment of variable condenser C₈ until, at this point of the scale, there is a coincidence of the oscillator frequency and

the characteristic frequency of the crystal as indicated by a dimming of the switchboard light 31 in the output circuit of the amplifier.

This switchboard light derives its current from the output circuit of the oscillator, that is from the output circuit of the amplifier thereof, by actuation of a key 32 in the output circuit of the amplifier. As is obvious the actuation of this key disconnects the output circuit from the load line 33 and connects it to the switchboard light. In the normal condition of the circuit, when the key is in the position shown, the switchboard light is disconnected from the oscillator and the oscillator is connected to the load circuit.

This lamp 31 is also used, alternatively, for the 60-cycle synchronization for lower scale adjustment. The key 35 makes possible this joint use, that is, when the key 35 is actuated upwardly the light circuit 36 is closed at the key and removed from the circuit 37 whereas in the alternate position of the key it derives current from the filament source 8 as has been before explained, this source 8 supplying the filaments for the modulator and amplifier as well as for the component oscillator tubes. For practical convenience, keys 24 and 32 may be mechanically coupled, so that as key 24 is actuated to connect the crystal the key 32 is actuated to connect the lamp.

In the procedure for the lower scale setting with the use of the synchronizing lamp 31, the key 32 is actuated, as before, to connect the synchronizing lamp 31 and the key 35 is actuated downwardly to connect the lamp also through circuit 37 to the 60-cycle source. The variable condenser C₃ is set for a scale reading of 60 cycles, similarly as it is set for the upper scale adjustment for a scale reading of 100 kilocycles. Then the trimming condenser C₅ in the fixed frequency component oscillator is adjusted while holding the 60-cycle reading until the frequency is accurately 60 cycles as indicated by an alternate dimming and brightening of the switchboard light exactly as in conventional power-house practice. It is noted that, with the keys 24 and 32 mechanically coupled as above suggested, it must result that in order to connect the switchboard light to the oscillator output, the crystal would also have to be connected to the oscillator at the input of the amplifier thereof. Although, of course, the crystal as so connected would have no utility, its connection is permissible because the frequency of the oscillator at that point is so very far removed from the crystal frequency as to effectively disconnect the crystal. If it were not desired that the key should be connected as described, of course this slight circuit ambiguity would not occur.

Fig. 2 is a graphical device to at least partially explain the necessity for independent upper and lower scale adjustments and the operation of the means to secure such independence. The two curves are intended to indicate by two independent sets of coordinate axes, although shown superposed to a certain extent for a reason which will be obvious in a moment, the relationship between frequency significant capacitance and frequency for the respective component oscillators, the curve at the left relating to the variable oscillator and that at the right to the fixed frequency oscillator. The frequency characteristic of the fixed frequency oscillator is predetermined to be approximately 650 kilocycles. As shown correspondingly on the other curve, this is the upper frequency of the range of frequency variation of the variable frequency oscillator. There-

fore, the capacitance C_0 in Fig. 2 represents the capacitances of all of the condensers except that of the variable condenser C_s , taken together, while ΔC represents the sole frequency variation during the operation of the oscillator in traversing the range of variation of the variable frequency oscillator from 650 kilocycles corresponding to the bottom of the scale, that is, at the approximate point at which the first scale adjustment is made, and 550 kilocycles corresponding to the difference frequency of 100 kilocycles at which the second scale adjustment is made. Of course, the capacitance of this condenser is made further variable to include the complete scale traverse of 150 kilocycles but attention here is confined only to that portion of the variation between the two independent scale adjustment frequencies.

It is immediately evident that if C_0 should increase to C_{01} , ΔC remaining the same, the variation of frequency resulting from a movement of condenser C_s between the 60-cycle and 100-kilocycle scale points would occur over a portion of the capacitance-frequency curve having a different slope with the result that a frequency variation between these scale points would differ from before, in the instance graphically illustrated being distinctly smaller, specifically 95 kilocycles as compared with 100 kilocycles.

It is obvious that the scale may be made to give the correct indication at the lower point simply by varying a capacitance in either component oscillator until by comparison with the standard frequency at that point, the frequency is made arbitrarily to check with the scale reading corresponding to said standard frequency. Where this variation is made to occur in the fixed frequency oscillator as described, this means that the fixed oscillator frequency is caused to be accurately the frequency of the variable oscillator when the variable condenser C_s in the variable frequency component oscillator is at a position corresponding to the bottom of the difference frequency scale. In other words the conditions are made, in this manner, to be initially as shown in Fig. 2, except that because of changes in capacitance C_0 , as above pointed out, this frequency point may not be exactly at 650 kilocycles. If subsequently this frequency differs from 650 kilocycles as indicated by the dash lines so that a scale error would occur along the length of the scale, cumulative towards the other end and therefore appearing at all points of the scale including the 100 kilocycle point, the second scale adjustment, namely, the upper scale adjustment, introduces or removes a capacitance so as to effectively compensate for said change in capacitance C_0 , and therefore so as to restore the portion of the curve over which the capacitance change ΔC occurs to its intended position.

It is believed to be clear from Fig. 2 that the upper and lower scale adjustments must be independent. Only under those conditions would the result pointed out occur in the sequence given. That they are independent results from the fact that the two component oscillator frequencies are substantially equal at the lower scale point so that the effects of the two ganged condensers used in the upper scale adjustment mutually compensate each other at this point, whereas at the upper scale adjustment point, the two component oscillator frequencies differ so greatly that the substantially equal increments or decrements of frequency introduced by opera-

tion of the ganged condensers have a differential effect with respect to the two oscillators so that so far as concerns this upper scale adjustment, and therefore entirely aside from all other considerations, the effect is merely that of a similar capacitance change in one only of the two component oscillators.

Although it is believed that Fig. 2 may be useful in illustrating the principle of the invention so far as pertains to the purpose of the scale adjustment, it must be recognized that it must be, at the best, incomplete without resort to a much greater complication of disclosure in the figure than has been thought best to use. This is because attention was directed, in connection with Fig. 2, only to variations in capacitances. Of course, like effects would accrue from variations of any other frequency-significant quantities, in either component oscillator, such as tuning inductances. Even the variation of physical dimension of the frequency scale itself would tend to induce a necessity for an upper scale adjustment even assuming a perfect lower scale adjustment. The working of the principle of the invention with respect to these and all other variations beyond those specifically contemplated in the above description is quite analogous to that assumed and the desired results are equally effectively achieved by the disclosed scale adjustment means. It should be noted also that although the particular means for achieving these scale adjustments are shown, in each instance, as a variable capacitance or variable capacitances, the principle of the invention could equally well be subserved by using a variable inductance or variable inductances in either or both of these places. It should be noted also that the working principle of the invention, so far as pertains to the upper scale adjustment, is effective, except as to degree, even if the increments or decrements of capacitance of the two component oscillators are not precisely the same.

In fact, practical considerations, perhaps having to do with the comparative design of condensers and inductors in the component oscillators, might well induce the use of slightly different design values for scale adjusting condensers C_2 and C_{2A} , or the capacitances of these condensers might, without deleterious effects, obey slightly different laws of variation when the condensers themselves are constrained by their mechanical coupling to move together.

The high frequency adjustment can also be obtained by adjustment of elements in the variable oscillator only. To this end a variable inductance may be inserted in series with the coil 11A and a variable condenser ganged with said inductance may be added in parallel with coil 11A. The inductance and capacitance may be so proportioned and the sign of their variation so chosen that when the capacitance of the main tuning condenser is practically zero at the low check frequency the change in frequency due to the variation in inductance is equal and opposite in sign to the variation due to the capacitance variation, the two effects canceling each other so that no frequency variation obtains.

At the high check frequency, however, when a large portion of the tuning condenser capacitance is in circuit, the variation in the inserted capacitance represents a smaller percentage of total capacitance for the same adjustment than at the low frequency, while, the total tuning inductance being the same, the per cent variation in inductance is the same as at low fre-

quency. At a result, the variation in frequency due to the inductance variation predominates and the oscillator frequency is changed.

Two different methods of adjusting the frequency at the high end without changing it at the low end have just been described. Suppose now we build means for achieving one of each of these adjustments into a heterodyne oscillator and arrange the constants so that as the adjustment is made one device increases the frequency at the high end just as much as the other decreases it. Since neither one of them affects the low frequency, the net effect will be that of changing the frequency slightly at all points except the two chosen frequencies. By this method the scale may be adjusted to read correctly at a third point also. For this third point check all the elements for the above two adjustments can be combined into one variable condenser in each oscillator and one variable inductor in the variable oscillator, all three operated by a single control. Therefore, for independent frequency adjustments at all three points there would be required, besides the variable reactance in one oscillator for the low frequency adjustment one of the above described means for the upper scale adjustment and additionally a combination of said two above described means for the third frequency adjustment.

Although only one specific circuit arrangement of the invention has been illustrated, with certain suggestions as to variances therefrom, it is to be understood that the invention is not to be limited to the particular arrangement so illustrated or as otherwise disclosed, but covers all such modifications and rearrangements as fall within the scope of the appended claims.

What is claimed is:

1. A method of calibrating the heterodyne frequency scale of a variable frequency heterodyne oscillator having a frequency variation between relatively great extremes of frequency, comprising adjusting the frequency to accord with the corresponding scale reading at a point near the lower extreme of the scale by adjustment of a frequency significant element in one component oscillator only, thereby affecting the heterodyne frequencies throughout the variable range, and adjusting the frequency to accord with a scale reading at a point near the upper extreme of the scale by variations of frequency significant elements in both component oscillators, whereby the last-mentioned scale adjustment tends to be substantially independent of the first-mentioned scale adjustment, which first-mentioned scale adjustment corresponds to a condition when there is a near-equality of component oscillator frequencies.

2. The method recited in claim 1 in which the upper scale adjustment consists of varying the reactances of mechanically coupled variable reactive elements, each individual to a component oscillator.

3. The method recited in claim 1 in which the upper scale adjustment consists of varying ganged substantially equal variable capacitors, each individual to a component oscillator.

4. A heterodyne oscillator comprising in combination, a relatively fixed frequency oscillator, a relatively variable frequency oscillator, means

for combining the waves from said oscillators to derive the heterodyne frequency, said relatively variable frequency oscillator including a variable frequency significant impedance adapted for, solely, determining the desired range of variation of the heterodyne frequency, a frequency scale, the frequency readings of which are responsive to the variations of said impedance element, a scale adjusting variable impedance in one of the oscillators, and a pair of ganged scale adjusting variable impedances, one individual to each of said oscillators, said respective adjusting means being adapted for scale adjustment for widely diversified frequencies within the heterodyne scale.

5. The heterodyne oscillator recited in claim 4 in which said last-mentioned scale adjustment means comprises ganged, equal variable capacitors.

6. The method of calibrating and adjusting the heterodyne frequency scale of a variable frequency heterodyne oscillator having a relatively wide range of variations dependent on the values of frequency significant impedance which comprises the steps of, adjusting the frequency to a given value at a point near the lower end of the frequency scale by adjusting a frequency determining element in at least one of the component oscillators, adjusting the scale at this frequency by varying an individual frequency determining element in one of the component oscillators which differs from said first frequency determining element, said two adjustments being performed mutually so as to preserve the scale reading, adjusting the frequency through the variable range by said first-mentioned frequency determining element to a point near the upper end of the scale and correspondingly adjusting to scale at said point while preserving the scale reading, said upper scale adjustment being achieved by making impedance variations, in the same direction, of frequency significant impedances in the respective component oscillators, whereby when the heterodyne oscillator is operating near the lower end of the scale at which point the component oscillator frequencies are nearly equal there will be a tendency towards a mutual compensation of said impedances.

7. A heterodyne oscillator comprising in combination, a relatively fixed frequency oscillator, a relatively variable frequency oscillator, means for combining the waves from said oscillators to derive the heterodyne frequency, said relatively variable frequency oscillator including a variable frequency significant impedance adapted for, solely, determining the desired range of variation of the heterodyne frequency, a frequency scale, the frequency readings of which are responsive to the variations of said impedance element, a scale adjusting means for a point near the lower boundary of the scale and which is individual to one of said oscillators, and a scale adjusting means for a point near the upper boundary of the scale which is common to said oscillators and adapted to have substantially equal frequency significant effects on said oscillators when the frequencies characteristic of said oscillators are substantially equal corresponding to said point near the upper boundary of the frequency scale.

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