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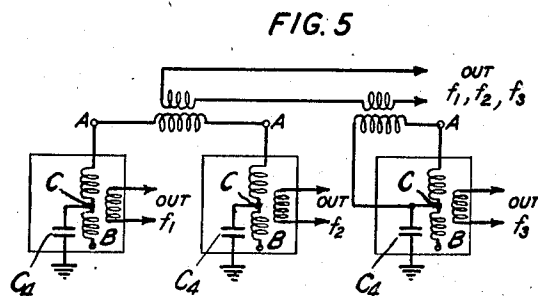
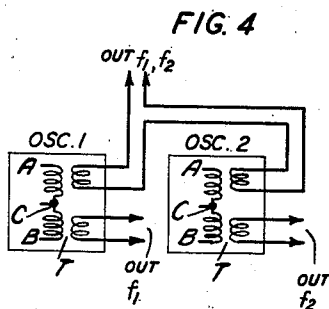
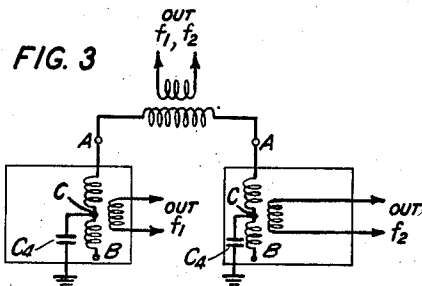
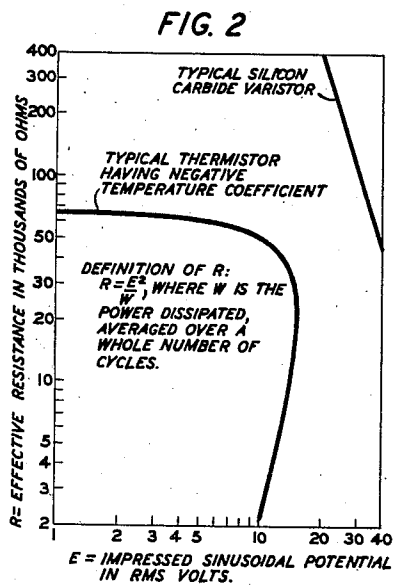
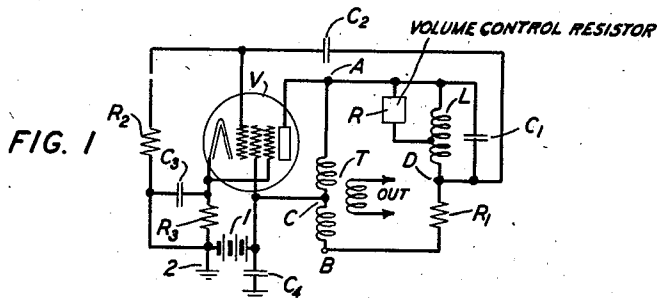
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2,303,485

BRIDGE-STABILIZED OSCILLATOR FOR VOICE FREQUENCY CIRCUITS

Filed Dec. 31, 1940

3 Sheets-Sheet 1



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FIG. 6

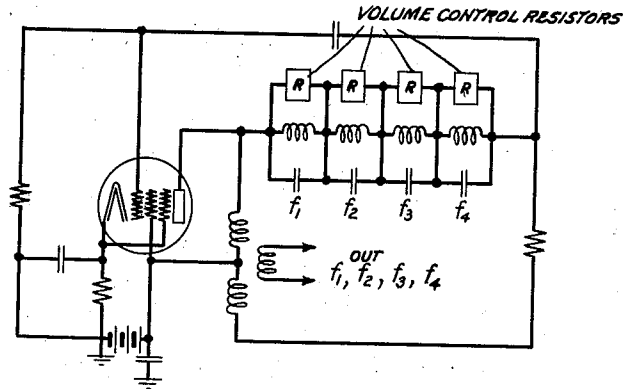
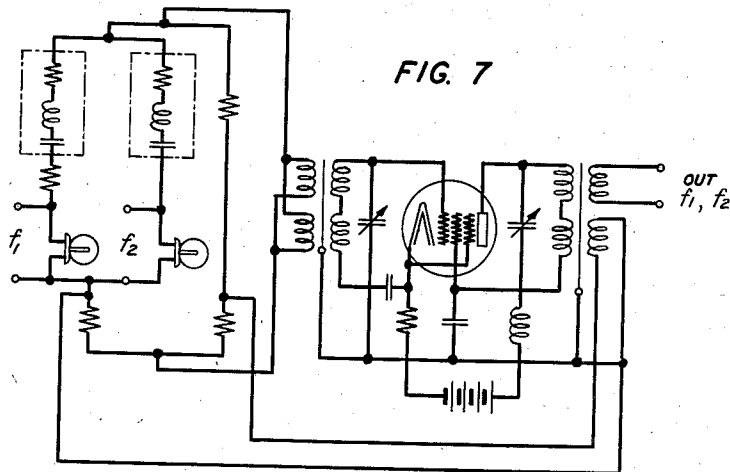


FIG. 7



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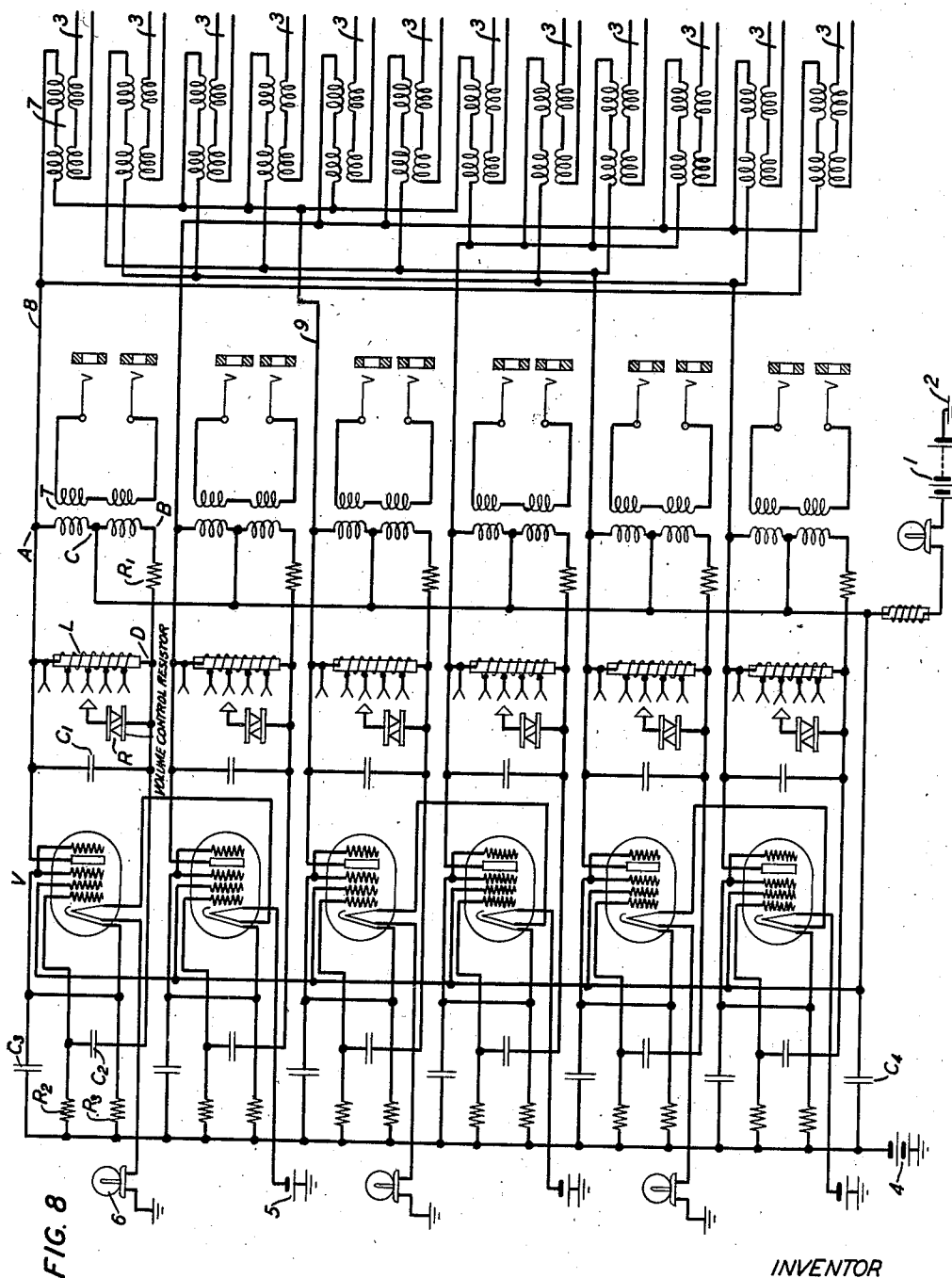
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UNITED STATES PATENT OFFICE

2,303,485

BRIDGE-STABILIZED OSCILLATOR FOR
VOICE FREQUENCY CIRCUITS

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Application December 31, 1940, Serial No. 372,557

7 Claims. (Cl. 250—36)

This invention relates to bridge-stabilized oscillators as adapted for use in voice frequency circuits and especially as adapted for conjoint use in a system for the simultaneous generation and use of the currents from a plurality of oscillators without undue cross-talk interference.

It is an object of the invention to extend the utility of the principles governing the operation of bridge-stabilized oscillators, as heretofore exemplified in comparatively high frequency services, to the low frequency field, while substantially preserving the properties of frequency and amplitude stability, simplicity, and others, which have characterized this generic type of oscillator as heretofore used.

It is a further object of the invention to develop ways and means whereby electron oscillators can be used in effectively series or parallel relationship so as to make possible simultaneous production and use of the currents individual to the respective oscillators, and at their respective frequencies, without cross-talk interference. It has been found, in accordance with the invention, that the bridge-stabilized type of oscillator is inherently adapted for this type of service, and especially an oscillator of this type as adapted for the purposes subserved by the first object of the invention, namely, as adapted for use in the low frequency range.

A still further object of the invention is to effectively combine oscillators of the bridge-stabilized type so as to enable the generation of a current having a plurality of frequencies from a single electron tube unit. The invention comprises two alternative means whereby this object may be achieved.

Besides the more specific objects of the invention, as above, it is an object of the invention generally to further refine the bridge-stabilized oscillators of the prior art, having in mind especially applicant's Patent 2,163,403, June 20, 1939, to enhance their inherently favorable characteristics as to frequency and amplitude stability, simplicity, and purity of resultant wave form.

A part of the disclosure of this application, namely, Fig. 8 disclosing the organization of a plurality of unit oscillators of the invention to provide multi-frequency signals without appreciable cross-talk, is included in the disclosure of P. B. Murphy application Serial No. 372,560, filed currently herewith, which issued into Patent 2,288,251, June 30, 1942. The Murphy application claims novel features of a key pulsing system in which applicant's multifrequency organization is incorporated.

The invention is exemplified, as to its unit oscillators, in an oscillator of the bridge-stabilized type, as generically illustrated in applicant's above-identified Patent 2,163,403, June 20, 1939, but differing from the generically illustrated cir-

cuit, and even from the circuit of Fig. 3 of such patent which perhaps most nearly resembles the present circuit, in important particulars. As in said Fig. 3 of said patent, treated as included in a system like that of Fig. 1 of the patent, the frequency determining element is a parallel resonant, that is, antiresonant, circuit. In the present instance, the use of this frequency determining LC circuit, and its organization as an antiresonant circuit, is the result of the requirement, consistently with considerations of efficiency and stability, of a comparatively high impedance across the circuit. The circuit differs, however, from the patent circuit in that it is considerably simplified, especially as relates to the coupling of the bridge to the tube circuit, by complete avoidance of the two transformers shown in the patent, this simplification and avoidance also having beneficial effects on the desired characteristics of the oscillator having in mind the fact that the organization is intended to be effective at much lower frequencies than in the case of the patented circuit. To reconcile the requirement of a physical connection to only three points on the tube circuit, namely, the anode, control electrode and cathode, from a bridge structure necessarily comprising four balanced arms and, therefore, two pairs of connecting points, the expedient was used of constituting two arms of the bridge by the windings of a close coupled transformer, the primary winding of which is connected to the output terminals of the tube, namely, the anode and cathode, so that the potential across the two arms in series, constituted by said windings, effectively constitutes the potential impressed on a diagonal of the bridge from said electrodes, the unbalance potential which then appears across the other or conjugate diagonal being impressed on the input electrodes, that is, the control electrode and cathode. Because of the tight coupling the bridge arm constituted by transformer coils fulfill the essential functions performed by pure resistances in the patented circuit, and with all of the advantages thereto appertaining as pointed out in the patent.

A further difference between the circuit of the invention and that of the patent is that the amplitude limiting means is included in the bridge arm with the frequency determining circuit instead of in a different arm. This is predicated on the use of an antiresonant tuning element, conjointly with an amplitude limiting element the effective resistance of which decreases with increasing amplitude. It was shown in connection with Fig. 3 of the above-mentioned patent that stable oscillation in a bridge oscillator under control of such elements could be secured by connecting said elements in opposite, rather than adjacent, arms of the bridge. Because of

the use of the coupled transformer windings for two adjacent bridge arms, the connection of the above-mentioned tuning and amplitude limiting elements respectively in opposite bridge arms is impracticable. However, it has been found that connecting them in the same arm is functionally equivalent to connecting them in opposite arms. This is, therefore, the method employed in the present invention.

Simple LC bridge-stabilized oscillators of this type are suitable for generating frequencies in or above the voice range. They are highly stable in frequency and amplitude; harmonics and other kinds of interference are well suppressed in the output, and, which is very important in the present consideration, portions of the power from two or more of these unit oscillators may readily be combined to provide multifrequency signals without encountering appreciable cross-talk into the single frequency outputs of the individual oscillators. Such a multifrequency organization may be readily achieved by several alternative connections of the invention, each of which functionally involves the connection of an output circuit from anode to anode of each pair of oscillators the frequencies of which are to be simultaneously employed. The combination of the oscillators in this way is possible because of the discovery of characteristics of this type of oscillator which makes such oscillator especially useful in this way and which effectively excludes other types of electronic oscillators. The automatic amplitude regulation feature, while of great value in the individual functioning of the unit oscillators, contributes incidentally to the conjoint use of a plurality of unit oscillators in this way by making the potential across the output terminals of the unit oscillators nearly independent of the load.

In certain applications of the invention, the constancy of the output voltage is required to be maintained regardless of sudden large changes in load. In some such uses it has been found that the thermistor type of amplitude limiting element is not sufficiently rapid in its control function, depending as it does upon changes of temperature for its resistance variation, and hence that it allows the output to depart momentarily from the normal controlled value after each sudden change in load. It has been discovered that, alternatively to the use of thermistors, varistors as represented by, for example, copper oxide or silicon carbide resistance elements may well be used under certain conditions, described below. As the response of a varistor in its amplitude controlling function is instantaneous, its use is highly beneficial in the above-mentioned applications. The inherent non-linearity of a varistor tends to produce undesired harmonic components in the oscillator output, but these components are reduced in amplitude and hence are made unobjectionable by associating the varistor with the frequency determining element in such a way that the components are effectively by-passed. For example, this may be achieved by connecting the varistor in shunt to all or part of the antiresonant circuit of the invention.

Although the use of the amplitude limiting element in the same arm as the frequency determining circuit is largely predicated on the choice and characteristics of the desired limiting means, it incidentally makes possible, in one form of the invention, a multifrequency generator based on a single tube unit, this by duplicating the frequency determining circuit and the

individual limiting means, in a single arm of the bridge. Frequency determining and amplitude limiting units so constituted may be connected in parallel if the frequency determining circuits are series resonant, and in series if such circuits are antiresonant as in the unit oscillator above assumed.

Other objects and features of the invention will be explained hereinafter and will be particularly pointed out in the appended claims.

In the accompanying drawings:

Fig. 1 illustrates an embodiment of the unit bridge-stabilized oscillator of the invention;

Fig. 2 illustrates certain characteristic curves, significant in the explanation of the invention, of two alternative volume control means that may be used in the oscillator of Fig. 1;

Figs. 3, 4 and 5 illustrate means for combining two or more unit oscillators of the invention to effect an organization for simultaneously generating and utilizing a plurality of signal currents having different frequencies;

Figs. 6 and 7 illustrate alternative means of achieving multifrequency signal current generation in what amounts otherwise to a single unit oscillator, each of these means being alternative to the means for achieving the same ultimate purpose illustrated in the next above figures; and

Fig. 8 illustrates a practical embodiment of an organization making use of a combination of unit oscillators in accordance with the teaching of said Figs. 3, 4 and 5.

Fig. 1 illustrates a very simple type of bridge-stabilized oscillator. While developed for use in low frequency, and specifically voice frequency, circuits, the principle of the circuit is adaptable, and may even be used in the specific form shown, for a wide range of frequencies so as to be capable of being treated as a near-equivalent of the oscillators disclosed in applicant's Patent 2,163,403, June 20, 1939, supra, but with the great advantage of simplicity and its concomitants. Partly by the employment of inductance and capacitance, as distinguished from their piezoelectric crystal analog, but mostly because of the variances from former practice in regard to the form of the bridge itself and its relation to the immediately associated circuits, the oscillator may be thought of as making possible the utilization of the very unusual properties of the bridge-stabilized type of oscillator in telephone, or the like, plant applications, as distinguished from utilizations as frequency standards, where extremely great frequency and amplitude stability are important. In the form to be illustrated in this figure and as combined with like units illustrated in higher numbered figures, the circuit of the invention has the various qualities and characteristics pointed out in the statement of invention.

The tube used in this circuit should have a high mutual conductance in order that the bridge may be operated with a high degree of balance and hence be highly sensitive in its frequency and amplitude controlling functions, in accordance with established bridge oscillator principles. As illustrated, it is a pentode tube, the elements of which are related to the associated circuit elements in a conventional manner. It is supplied with plate power through the upper half A—C of the high winding A—B of transformer T from source 1 and obtains control grid bias from the cathode resistor R₃ shunted by by-pass condenser C₃. A grid leak resistance R₂ and blocking condenser C₂ are provided to isolate the control elec-

trode from the direct current plate potential. Of course, a bias alternatively may be obtained by means of a battery, by the passage of control electrode current through the leak resistance R_a , or by other well-known methods.

The choice of the transformer T depends upon the particular conditions of frequency, load impedance, and output level to be satisfied. In general, however, it is desirable to let the tube work into a fairly high impedance, so as to increase its effective voltage amplification, and to use a transformer with a reasonably low loss and with reasonably tight coupling between the two halves of its high winding shown. With the satisfaction of these conditions the high winding of the transformer constitutes, by its two coupled portions, effectively a pair of serially connected resistances, so that the Wheatstone bridge per se, as constituted by said effective resistances, together with resistance R_1 , the frequency determining circuit comprising inductance L and capacitance C_1 , which circuit is connected to resistance R_1 at point D and the volume control element R, is the functional equivalent of the bridge of applicant's patent.

Again assuming a tightly coupled, low-loss, transformer, the alternating current potentials to ground at the operating frequency, measured at points A and B, are approximately equal in amplitude, and opposite in phase. The output of the tube is thus applied, in effect, approximately balanced to ground across said points A and B, which may, therefore, be considered as two corners of the Wheatstone bridge above described. Accordingly, the tube output is effectively impressed across the diagonal A—B of this bridge and the tube input is supplied from the conjugate diagonal C—D. It is apparent that the above assumes that the point C and also the cathode are at ground potential with respect to current of the operating frequency. To this end the capacitance C_4 may be used as shown between the point C and ground or between point C and the cathode. The equivalent effect would be achieved without the use of a condenser at this point, provided that the impedance of the plate source was low. It is apparent that, by the expedients of the invention as above described, it has been made possible to connect an essentially four-terminal network, that is, the bridge, with what amounts to a three-terminal circuit constituted by the tube, while avoiding the complexities, as by way of transformers connecting this network with the tube, that would be normally attendant on the achievement of this result. The resultant simplification, with its attendant economy of plant, and other practical advantages, is an important ingredient of the invention.

The analysis given in applicant's paper "The bridge stabilized oscillator" in the Bell System Journal for October 1938, pages 574 to 591, as well as that included in his patent, supra, may readily be applied to this circuit by making the proper, and obvious, substitutions. Rather than repeat that analysis here, it will be sufficient to describe the operation qualitatively as follows: The circuit may be thought of as providing a composite path for feeding back energy from the output of the tube to the input of the tube. The potential at B, because of the phase reversal achieved by the tightly coupled halves of the transformer high winding, affords a positive feedback to the control electrode when supplied through a resistance, as the bridge resistance R_1 ,

and, therefore, can sustain oscillations at the frequency for which proper phase relations exist. On the other hand, the potential at A, as applied to the control electrode through the remaining arm of the bridge affords negative feedback which tends to suppress oscillations. The bridge arrangement provides an automatically self-adjusted near-balance between these two effects. That is, the small vector sum of the two feedbacks, which is supplied to the control electrode, is automatically adjusted to be correct in phase and amplitude so that the oscillations are sustained at a uniform amplitude. The frequency in this as in any other oscillator assumes a steady state value for which the net phase shift about the oscillating group or feedback path is zero or some multiple of 360 degrees. Similarly, the amplitude is self-regulating. In most oscillators, that is, in oscillators not using the bridge principle, the tube is permitted to overload until the gain drops to meet the requirement that the net steady-state voltage gain about the loop must be unity. The bridge-stabilized oscillator utilizes another method for satisfying this requirement. That is, it employs an amplitude limiting means in the bridge in such a manner that as the amplitude increases the bridge approaches the condition of true balance more closely. This diminishes the net feedback and tends to control the amplitude at a constant value. Of course, the element R, which is a resistance variable with the potential impressed thereacross, is the means here had in mind. The independence of function of the tube and amplitude control means, as above, and the extreme sensitivity of the bridge to small departures from normal make possible the achievement of a frequency and amplitude stability not capable of achievement by alternative types of oscillators without resort to very elaborate and complex expedients. The present considered oscillator has all of the desirable attributes of applicant's other bridge-stabilized oscillators as pointed out in the above paper and patent. One of the most important of these attributes is the change in the impedance condition of the bridge at frequencies differing from the operating frequency, to the extent that there is such a negative or degenerative feedback as to practically annul the generation of harmonics by the oscillator circuit as a whole. The electrical mechanics by which this result is achieved are obvious from the analysis provided by the above items, and especially by the vector diagram in the patent.

In pursuance of the simplification of the bridge oscillator, as achieved by the method of the invention through the elimination of coupling transformers and through the use of high impedance bridge arms, it has been found desirable to use, where a thermistor is to be the amplitude limiting element, a radically different type from the lamp type contemplated in applicant's patent. The lamp type of thermistor has relatively low resistance and a positive temperature coefficient. A more suitable type for the considered circuit has high resistance and a negative temperature coefficient. This thermistor, in a practical case, was of the type known as the Western Electric 1A thermistor, which is made up principally of uranium oxide. Its potential-resistance characteristic is shown in Fig. 2. As is apparent from the curve the resistance of this material has a falling characteristic, which implies a negative temperature coefficient of resist-

ance, since the temperature is a direct function of the potential. It may be observed also that a portion of the curve, namely the lower end, exhibits one of the interesting properties often associated with an extremely large negative temperature coefficient. As increasing power is supplied to the thermistor, its resistance falls so rapidly that a point is reached where the voltage across its terminals reaches a maximum value, and thereafter the voltage drops, although the current and the dissipated power continue to increase. If a voltage greater than the above-mentioned maximum is applied from a low impedance source, such as a battery, the current will rapidly become so large as to destroy the thermistor. In determining the characteristic curve of such an element, it is essential to supply the measuring current through a large protective resistance. In the circuit of the invention, however, it has been found experimentally that there is no tendency toward unstable action during operation at any point on the characteristic. By operating at about 20,000 ohms, which is close to the voltage maximum point, it has been found experimentally that small readjustments of bridge balance are associated with no appreciable change of operating level, which is a considerable advantage in itself. The operating point may readily be chosen by properly proportioning the bridge elements.

The upper curve of Fig. 2 illustrates, correspondingly, the usable part of the characteristic of a typical silicon carbide varistor. This is the familiar thyrite resistance element. It may be used interchangeably with the thermistor in the circuit of Fig. 1. The use of a varistor of either this type or alternative types, because of being non-linear in character, as distinguished from the linear thermistor resistance, was originally tried with many misgivings as to wave form distortion and possible cross-talk effects when used in combination with other unit oscillators. However, this distortion was found to be extremely small. Harmonics generated by the non-linear element appeared with negligibly low level in the oscillator output for the reason that the varistor was connected in parallel with the antiresonant bridge arm, which presented a low impedance to the principal distortion currents, leaving the potential across this arm essentially sinusoidal. It had distinct advantages over the thermal type of element, even that shown in Fig. 2, in that the thermal type of element, but not the varistor type, tended to cause the output level to "bounce" or go through a damped oscillatory transient lasting for about one quarter of a second when a sudden change of load occurred.

Although the varistor characteristic appears as a straight line in Fig. 2, it should be borne in mind that logarithmic coordinates are there indicated. Actually the relationship between the resistance R and the potential E is approximately as follows, where P is a constant of the particular varistor:

$$R = \frac{P}{E^3}$$

If E is a sinusoidal voltage, as it is in the actual circuit considered, the instantaneous resistance varies extensively, throughout each cycle of oscillation. This is the cause of the generation of harmonic frequencies. In dealing with the damping effect of the varistor upon the antiresonant circuit, it is convenient to use an effective

value for R , defined as noted in Fig. 2, this value actually expressing the magnitude of the ordinary linear resistance which would absorb an equal amount of energy from the antiresonant circuit.

The copper oxide type of varistor was found to be usable, comparably with the thyrite type, although, because of having a lower impedance it had to be bridged across a very much smaller number of turns of the tuning inductance.

This invention pertains not only to the novel type of unit oscillator, by reason of the new conformity of circuit and the use of the novel type of amplitude control element, but in the combination of two or more of these unit oscillators to provide multifrequency signal current without appreciable cross-talk into the single frequency outputs of the individual oscillators. This is made possible by the inherent properties of the bridge stabilized oscillator, as exemplified both in applicant's patent and in Fig. 1 of this application. The truth of this statement is evident from the analysis below.

In the theory of feedback circuits, developed by Black, Nyquist and others, there is a well-established rule that if two points in a feedback circuit are chosen so that connecting them together reduces the transmission about the loop to zero, and if the impedance between these points is measured at any given frequency under two conditions, namely, (1) without feedback, for example, with the control electrode of the tube V disconnected from the circuit and grounded, and (2) with feedback, as when the oscillator operates normally, then the following relation holds:

$$Z_f = \frac{Z_0}{1 - \mu\beta}$$

where Z_0 is the impedance without feedback, Z_f is the impedance measured with feedback, and $\mu\beta$ is the complex voltage gain encountered by a wave of the frequency at which the measurements are made in passing once about the feedback loop. It will be seen that if the absolute magnitude of $\mu\beta$ is large Z_f will be much smaller than Z_0 .

In the circuit of Fig. 1 $\mu\beta=1$ at the operating frequency as required for steady-state oscillation. At frequencies sufficiently removed from the antiresonant frequency of the circuit $L-C_1$, however, the impedance of this tuned circuit is low and the control electrode and plate of the tube become closely tied together. It follows that $\mu\beta$ is then large, and negative in sign because of the 180-degree phase turn-over introduced by the tube.

If G_m is the mutual conductance of the tube, and Z_f and Z_0 are the impedance measured between points A and C with and without feedback, we have (assuming the grid and plate to be connected together)

$$\mu\beta = -G_m Z_0$$

$$Z_f = \frac{Z_0}{1 - \mu\beta} = \frac{Z_0}{1 + G_m Z_0}$$

or

$$Z_f = \frac{1}{\frac{1}{Z_0} + G_m}$$

and if

$$\frac{1}{Z_0}$$

is much smaller than G_m , as is generally the case,

$$Z_f \doteq \frac{1}{G_m}$$

For a typical tube (Western Electric 310-A) $G_m = 1800$ micromhos, and

$$Z_f \doteq \frac{1}{1800 \times 10^{-6}} = 556 \text{ ohms}$$

This impedance is low in comparison with the plate circuit impedance (approximately 50,000 ohms) into which the pentode tube delivers its output.

The purpose of this analysis is to show that the impedance between the plate of the oscillator and ground is made very low by feedback for frequencies removed from the antiresonance of circuit L—C₁. A useful consequence of this property is that current for these frequencies may be passed between point A and ground without introducing the amount of cross-talk into the oscillator output or into the voltage existing between point A and ground that would ordinarily be expected and would tend to result from the use of other types of oscillators.

This property makes it possible to add together the outputs of a plurality of oscillators of the considered type by various means and in various combinations without the additional costs and complications of isolating attenuators, amplifiers or filters, and without the presence of appreciable amplitudes of undesired frequencies among the wanted components of each combination.

If the outputs of oscillators not of the bridge stabilized type were so intercombined, these oscillators would necessarily be required to have comparably low output impedances. Such low impedances might conceivably be obtained by one or the other or a combination of two general methods, both of which are believed by applicant to have severe disadvantages. First, each oscillator might be proportioned to deliver its output at an inherently low impedance. This, it is believed, would involve use of a vacuum tube of relatively large power capacity and operating it at very low efficiency. Second, some method might be used to connect the output circuits to the oscillators in such a way that the frequency determining element of each oscillator would act as a filter which effectively would present a low impedance to frequencies other than its own by virtue of its natural properties of frequency discrimination. It is believed that such an intimate association of the loads and the frequency determining elements of the oscillators would lead inevitably to poor frequency stability, obviously an important disadvantage.

Of course, attenuating networks, buffer amplifiers, filters, or equivalent apparatus for preventing cross-talk, might alternatively be connected between each oscillator and each point of combination of the different frequencies, as mentioned previously, but this additional equipment would be objectionable from obvious practical considerations.

A means of using the above described property of a bridge-stabilized oscillator, whereby a plurality of such oscillators may be effectively interconnected to provide multifrequency current generation and use without appreciable cross-talk, is shown in Fig. 3. Here a transformer is bridged between the points A of two oscillators generating currents of different frequencies. Both frequencies are supplied to a load through this

transformer, but cross-talk into the single frequency outputs of the oscillators is effectively suppressed. Furthermore, the constant amplitude properties of these generators make the three outputs practically independent, for loads limited only by the power capacities of the vacuum tubes used.

Fig. 4 illustrates an alternative means for combining the outputs of Fig. 1 oscillators. An additional low winding in the output transformer of one oscillator is connected in series with a similar winding associated with the second source. The circuit, it is believed, does not require further detailed description. This means has at least one advantage over that of Fig. 3 in that no additional transformer is required although an additional winding must be used on the transformer core of each of the two unit oscillators. That is, the means illustrates the more efficient use of transformers than does the means of Fig. 3.

In order to obtain the outputs of three or more frequencies by the means of Fig. 3, and still realize optimum discrimination, it is necessary to go to some such arrangement as is illustrated by Fig. 5. Here, two transformers are used for the three-frequency output. Other outputs of one or two frequencies may, of course, be drawn simultaneously from this system merely by applying more transformers as in Fig. 3. Also, the outputs of more than three oscillators may be combined by obvious extension of the principle illustrated by this Fig. 5. It is obvious that the means of Fig. 4 likewise may be elaborated so as to obtain outputs of more than two frequencies. In order to do so it is not necessary to resort to the comparative complexity of the Fig. 5 expedient since all that is necessary is to add low windings in series to those shown, each individual to an oscillator the output of which is to be added.

It has been shown that a bridge-stabilized oscillator operates without tube overloading, its amplitude being controlled at some predetermined value by a thermistor or varistor, affecting the bridge balance. The essential absence of non-linearity makes it possible to excite more than one frequency determining circuit at separated independent frequencies, deriving the power from the same vacuum tube. This may be accomplished very simply by connecting additional antiresonant circuits, each shunted in whole or in part by its own controlling thermistor or varistor, in series with the L—C₁—R group of elements in Fig. 1. The resulting configuration is shown in Fig. 6. In the interest of simplicity and because of the obvious relationship to Fig. 1, the labeling has been omitted.

The description of the operation of the single frequency oscillator of Fig. 1 applies to each of the separate modes of oscillation in the multifrequency circuit of Fig. 6. The different modes are nearly independent because each antiresonant circuit presents low values of impedance at the frequencies of the others. The thermistors or varistors act almost independently since each is shunted by a low reactance for any frequency except the one in which its own circuit is antiresonant. A reasonable precaution to take in designing this circuit is that the range for which the tube is linear is not exceeded by the sum of the peak amplitudes of the several components since these amplitudes do add when the phases happen to be in proper relation. If this caution is not observed the component frequencies may

still exist together but cannot be as nearly independent.

Fig. 7 illustrates, alternatively to Fig. 6, a means for generating a plurality of frequencies using a common tube. In this instance series resonant, instead of antiresonant, circuits are used to determine the respective frequencies, so that the component parts of the circuit are of the type illustrated by Fig. 1 of applicant's Patent 2,163,403, June 20, 1939, above mentioned several times. The oscillator accordingly comprises a bridge, all of the arms of which comprise resistors except the arm containing the series resonant circuits for determining the respective frequencies. There are a plurality of such series resonant circuits in parallel in this arm. Of course, at the significant frequency the particular series resonant circuit in question becomes effectively a pure resistance so that the bridge is strictly a resistance bridge. As in the patented circuit alternate pairs of diagonally opposite corners of the bridge are connected to the input and output circuits of the translating device, the bridge being operated at a near-balance. Of course the amplitude controlling means are included in the same arm with the respective resonant circuits, as in Fig. 6, since it is largely because of the unitary grouping of all of the elements pertaining to a given frequency, namely, the amplitude controlling means and the inductance and capacitance of the frequency controlling means, that permits the duplication of effect that characterizes this circuit, like the circuit of Fig. 6 and therefore makes possible the simultaneous generation of a plurality of frequencies. Because the frequency determining circuits are thus series resonant instead of antiresonant, the respective frequency determining circuits are connected in parallel instead of in series, as is obviously necessary. Also, because of the series resonance, the circuit favors the use of a lower impedance amplitude controlling means and there is illustrated for this purpose the use of thermistors of the lamp type as in applicant's patent. The circuit is otherwise like those of the patent although it is to be understood that alternatively the expedient illustrated by Fig. 1 herein for simplifying the circuit may be adapted to the multifrequency circuit of Fig. 7 without sacrifice of any essential function as to either the outstanding attributes of the Fig. 1 circuit or as to the efficient generation of a plurality of frequencies as by the Fig. 7 circuit.

Fig. 8 illustrates a practical use of the system of combining waves from unit oscillators, as per Figs. 3 to 5. The system is that disclosed in the Murphy application referred to in the statement of invention and relating to a toll line key pulsing system in telephony wherein twelve different tone signals, each comprising two distinct frequencies, are made available continuously on respective pairs of conductors for use in the transmitting apparatus. To supply the base frequencies in the particular system disclosed, six unit oscillators of the Fig. 1 type are employed. There are twelve output circuits 3. Each of the frequencies individual to the six oscillators is, of course, different from the others and the multifrequency signal current for each of said lines 3 is made up of the currents from a combination of oscillators each combination individual to one of said lines. The combination of the two oscillators in each instance is achieved by the means of Fig. 3, although the alternative means of Fig. 4 might have been used. Systems alternative to this

system have been proposed making use not only of currents of two frequencies, therefore requiring the combination of the outputs of two oscillators, but of three frequencies as well, correspondingly requiring a combination of the outputs of three oscillators. When this is done the combination could well be achieved by the arrangement of Fig. 5. In the system of Fig. 8 besides the individual frequencies corresponding to the six unit oscillators, there are only combinations of two frequencies.

Although shown somewhat differently, the oscillators of Fig. 8 are the functional equivalents of the Fig. 1 oscillators. To show the equivalency one oscillator of the figure has been labeled similarly as Fig. 1. One slight difference, which is without significance except as showing how the circuit may be varied in obvious ways with respect to such collateral features as potential supply means and the like, is the use of an auxiliary source 4 having negative potential with respect to ground, to supplement the voltage of the plate supply 1. For reasons of practical expediency only, a source 5 is used to supply the cathode heaters of each pair of oscillators, through current regulating and signaling lamp 6. The cathodes of all six oscillators could alternatively have been supplied from the common source, as in the instance of common source 1 for the plate of all of the oscillators.

To illustrate how pairs of oscillators taken from the six oscillators of the system are combined in Fig. 8 according to the means disclosed in Fig. 3, observe that oscillators 1 and 3, numbered from the top, are combined through transformer 7, connected to the plates of said oscillators through leads 8 and 9, respectively, exactly as in Fig. 3. By a similar combination of oscillators, according to a frequency allocation not of present interest, two frequencies are similarly applied to each of the other eleven circuits 3.

While the invention has been described in connection with particular embodiments, certain variations have been suggested, and it is to be understood that many additional changes are possible within the scope of the invention.

What is claimed is:

1. An organization for simultaneous generation of a plurality of waves, comprising a plurality of unit generators and circuit means interconnecting the same, each said unit generator comprising an electronic amplifier having an anode and cathode constituting output electrodes and a control electrode constituting, with said cathode, the input electrodes, and a feedback circuit between said pair of output and input electrodes comprising a substantially balanced lattice network including a frequency determining means, conjugately related pairs of termini thereof being connected to said respective pairs of electrodes, and said circuit means for interconnecting said unit oscillators comprising means for connecting the cathodes of said generators and a circuit for connecting the anodes of said generators in pairs, and a load circuit coupling said pairs of generators in series-energy relation and likewise in series-energy relation with the output electrodes of any residuary unit generator if an odd number of unit generators are used, the characteristic frequencies of said unit generators being substantially different from each other.

2. A system for the simultaneous generation and utilization of a plurality of waves having discrete frequencies comprising a plurality of unit oscillators and circuit means connecting them

and a load circuit in series-energy relation, said unit oscillators each comprising an amplifier and a bridge network conjugately connected to the input and output circuits of said amplifier and arranged as a regenerative coupling therebetween, said bridge including a frequency stabilizing means and an inductance adapted for use as an output coil, and said connecting means comprising a coil coupled to the output coil of each unit oscillator and a circuit serially connecting said coupled coils and said load circuit.

3. An oscillation generator comprising an amplifier, a pair of input and output electrodes therefor, and a pair of Wheatstone bridge network directly connected to and coupling said pairs of input and output electrodes in conjugate relation, said bridge comprising a frequency determining element and an amplitude controlling element.

4. An oscillator comprising an amplifier having an anode, control electrode and cathode, a feedback circuit therefor including a Wheatstone bridge network containing a frequency determining element and a resistance which constitute two arms the remaining arms being constituted by coupled inductances, the control electrode and cathode being connected to the two diagonally opposite corners of the bridge identified by the junction points of said inductances on the one hand and of the frequency determining element and resistance on the other hand, and the anode and cathode being connected across one of said coupled inductances, whereby the input and output circuits of the amplifier having the cathode in common may be effectively connected across alternate and con-

jugate pairs of bridge corners without the interpolation of transformers or the like.

5. The combination recited in claim 4 in which the frequency determining means is a parallel resonant circuit and including additionally an amplitude control means comprising a resistor of comparatively large resistance and having a negative temperature coefficient at least partially in shunt with said parallel resonant circuit.

6. The organization recited in claim 4 in which the frequency determining means is a parallel resonant circuit and including additionally a current responsive variable resistance in at least partial shunt to said resonant circuit to control the volume of the resultant output wave.

7. In a multifrequency oscillation generator an amplifier, a pair of input and a pair of output electrodes therefor and, conjugately connected to said pairs of electrodes, a Wheatstone bridge with a frequency determining element and an amplitude controlling element in one bridge arm, said frequency determining element having a desired characteristic frequency, and one or more functionally duplicate units of frequency determining elements and amplitude controlling elements also in said bridge arm, each said unit being related to the other units in such a way, depending on whether the frequency determining element has a shunt or series characteristic, that with respect to each frequency, which is individual to one of said units, the impedance of said bridge arm is substantially that of the unit corresponding to said frequency.

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