Dec. 5, 1967 A. A. VOLODIN 3,355,976

METHOD OF TUNING AN ELECTRONIC TONE GENERATOR

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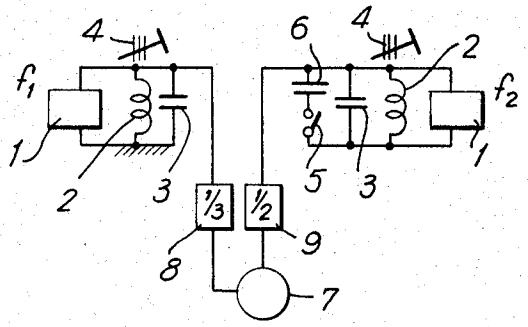
FIG. 1



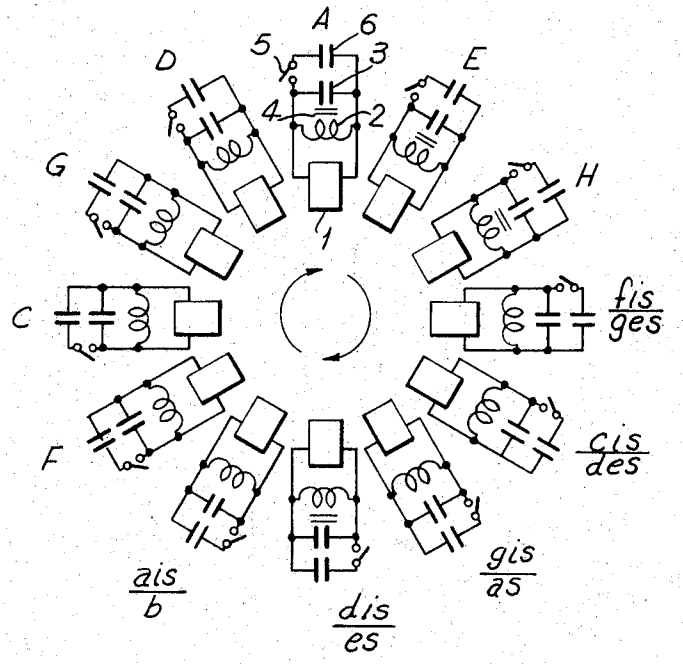


FIG. 2

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METHOD OF TUNING AN ELECTRONIC TONE GENERATOR

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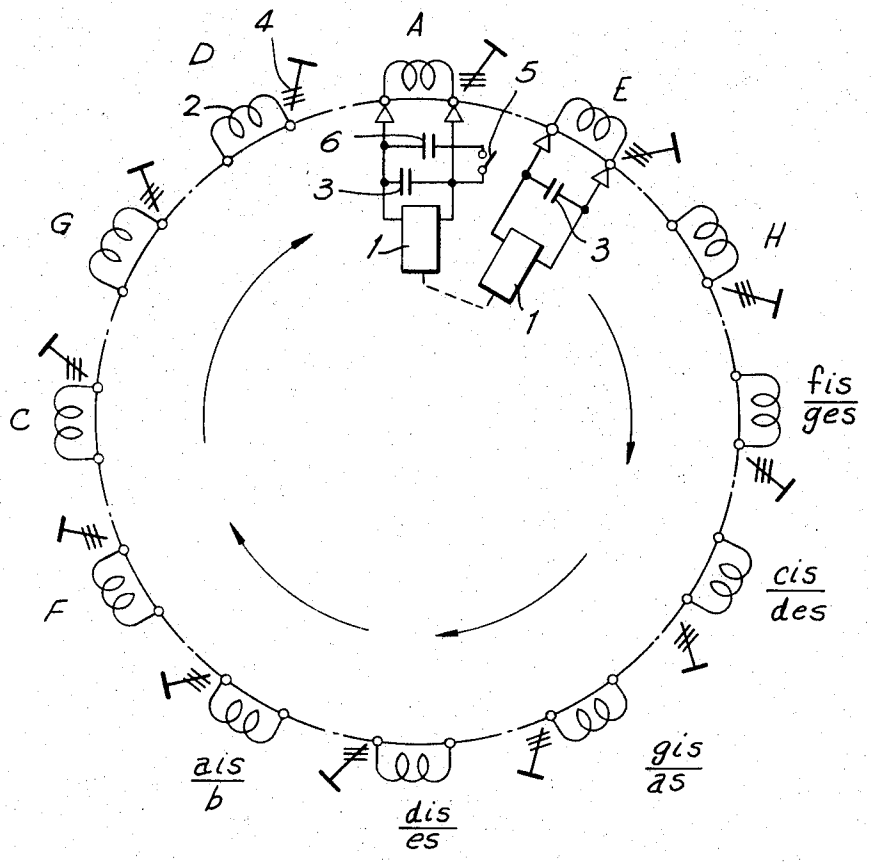

FIG. 3

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METHOD OF TUNING AN ELECTRONIC TONE GENERATOR

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ABSTRACT OF THE DISCLOSURE

Apparatus and method for tuning an electronic tone generator having a frequency lower than a standard by an interval of the classical musical scale. Means are provided for lowering the generator frequency by the difference between the natural and tempered quint and for then bringing the generator-standard frequency ratio to that of the natural quint and standard whereby automatic tuning of the generator results. Also, an indicator can be provided operating with Lissajous figures.

The present invention relates to technical means and methods for making the classical uniformly tempered twelve-step musical scale of sounds, based on the application of electrical sources of musical tones.

It is well known that obtaining a perfect scale of uniformly tempered musical frequencies often entails considerable difficulties of various kinds due to the irrational character of the absolute values of the frequency of musical tones, and also of the interval coefficients of said scale, the basic coefficient of which is the ratio of the frequencies of a tempered semitone, of the value of 2^{-12} or, approximately, -1.05946. For obtaining or checking musical tones by the absolute method with the required precision it is necessary to use extremely fine and expensive apparatus, which is not generally available in musical practice, with the exception of making tuning forks for the standard tones A or C.

The obtaining of the full scale of twelve tones of the octave is generally practically realized by following the tone scale by the quint circle, the comparison of tones in the interval of a tempered quint being based on a subjective skill possessed only by a limited number of people with a definite acoustic gift and with constant training of the ear. An auxiliary technique is the counting of beats which takes a considerable time for successive approximations and counting of beats in order to obtain precise results.

I am aware that prior to my invention there were known certain partial solutions of the problem relating to electric musical instruments. On one of such solutions the system of Hammond organ is based and this solution, which is a development of earlier works of Ranger and Cachill, consisted of the securing of the ratio of rotation speeds of magnetoelectric sirens by the application of pre-calculated complicated gear transmissions, eventually providing for the ratio of the frequencies of reproduced electric oscillations with the coefficients of the uniformly tempered musical scale.

The disadvantages of such a solution are: the requirement of a high accuracy in making the mechanical elements, the necessity of using in the system a motor with a highly stable speed of rotation, the limited resources of the system in respect to wear, and the absence of the possibility of varying the frequency of tones near their rated values.

Another solution, used by Javelet and Couplieu in their organ with photoelectric sirens, consisted of making synthetic phonograms on transparent discs with a precalculation of the angular scale ratio of periods for separate tones with separation of the odd remainder of the period

of each tone into several phase junctions (jumps) along the ring of the given tone.

The disadvantages of such a solution were unavoidable irregularities of the reproduced tones owing to the presence of said junctions of the odd remainder of the period of audio frequency, and also most of the disadvantages at the above mentioned system of magnetoelectric sirens which are inherent in any system of rotating electromechanical generators of audio frequencies.

According to the invention, there is provided a method of correlation of frequencies, obtained from self-excited electric generators, according to a uniformly tempered scale by objective determination of the moment of exact correlation of each two tones of the scale in succession following the classical quint circle with the use of auxiliary, objectively adjusted circuit elements of said electric generators.

In a broad sense, the invention is intended for all cases in which it is necessary to obtain and check the scale of musical tones with the exact properties of a uniformly tempered twelve-step classical system.

To such cases pertain all types of technological and every day practice of tuning any musical instruments and checking of deviations from the exact tuning.

In accordance with the above and other of its objects, the invention consists in part of a new method of correlation tuning of tones in the interval of the tempered quint, permitting at the moment of comparing the frequencies of tones an objective checking of the exact ratio of frequencies by a Lissajous figure due to shifting at said moment of one of the tones by the difference of the interval of the natural and tempered quint ($3/2-2^{7/12}$). According to another aspect of the invention there is provided a device for realizing the above method, said device including tone generators with properly calculated frequencies in accordance with the steps of the musical scale, means for the smooth retuning of frequencies in the vicinity of the rated value for each generator and means for the calibrated frequency shift of each generator by said difference of the interval of the natural and tempered quint.

The preferred embodiment of the invention is an autonomous unit of electric generators constituting standards of musical tones with a sound reproducing device, in which for the initial tuning of generators and checking of maintaining this tuning is used the method described below, said method being the essence of the invention.

Another object of the present invention is to provide a set of master generators for an electric musical instrument built into the instrument and used as its functional unit.

Other objects and advantages of the invention will become apparent from the following detailed description and the accompanying drawings, in which:

FIG. 1 shows a system of two tone generators, comprising means for correlating their frequencies in the interval of the tempered quint with external objective signs that unison is present;

FIG. 2 shows a system of 12 generators of the musical scale tones, allowing the use of the method of correlation tuning in accordance with the system shown in FIG. 1; and

FIG. 3 shows a version of the device for obtaining any two of 12 musical tones with particularly high accuracy of correlation by the tempered quints in case the method of tuning is used as explained in the description of FIGS. 2 and 3.

In the drawing, the electric circuits of the various elements, with the exception of those which have principal importance for understanding the described method and device, are not shown as different possible versions of

such circuits will be apparent to those skilled in the art from the functions that said elements perform.

The proposed method and device for obtaining the tempered scale are based on the following initial considerations: The scale of musical tones is formed by tuning the sources of tones in successive steps along the tempered quints from any tone, taken as the initial one, for instance, from tone A upwards (regardless of the octave positions):

$$A \rightarrow E \rightarrow H \rightarrow \underset{ges}{fis} \rightarrow \underset{des}{cis} \rightarrow \underset{as}{gis} \rightarrow \underset{es}{dis} \rightarrow \underset{b}{ais} \rightarrow F \rightarrow C \rightarrow D \rightarrow A$$

Therefore, the process of forming the scale of musical tones is in fact a successive comparison of pairs of tones

$$A—E;\ E—H;\ H \rightarrow \underset{ges}{fis} \text{ etc.}$$

in the interval of the tempered quint. When comparing two tones or electric oscillations of sound frequency it is much easier to state the interval of the natural quint (3/2), than to state the interval of the tempered quint ($2^{7/12}$), while in the case of electric oscillations, owing to the possibility of using special means, reference to which will be given in a proper place of the description, this passes into the domain of objective methods. Apparently, it is desirable when following the quint circle to use comparison of the frequencies of the tones exactly in the interval of the natural quint. For this it is necessary that at the moment of comparison the frequency of the lower tone of the pair being compared be automatically lowered by the difference between the natural and tempered quint, i.e. by the value:

$3/2-2^{7/12}=0.00183$ from the frequency of the lower tone.

Then, if said lowering is excluded after obtaining the exact tuning, the pair of tones will be in the ratio of the tempered quint, and that is the desired result.

FIG. 1 represents two generators of electric oscillations, which make it possible to realize said method of tuning to the tempered quint, including the employment of means for objective determination of the moment of tuning. Here exciters **1** provide for the appearance of oscillations in the circuits consisting of inductance **2** and capacitor **3**. Inductance **2** has a para-magnetic core **4**, allowing within the necessary limits to retune the tuned circuit near its frequency (*f*1 or *f*2). The parameters of the circuits are such that the frequency **2** is, on an average, one quint down from the frequency *f*1 (*f*1:*f*2=3:2). By means of switch **5**, to basic capacitor **3** in the generator with frequency *f*2 an additional capacitor can be connected lowering the frequency *f*2 by the above-mentioned difference between the natural and tempered quint, i.e. by 0.183%.

For comparison in the process of tuning, the voltages of audio frequencies from generators **1** are fed to an electron-optical indicator **7**, securing the control of the moment of exact multiplicity of the frequencies being compared by means of a Lissajous figure, as shown in FIG. 1. For comparison on a 1:1 scale with the forming of the simplest figure on the screen in the shape of an ellipsoid, between the frequency *f*1 and the respective input of indicator **7**, is provided a frequency divider **8** with a division factor of 1/3, while between the frequency *f*2 and the other input of indicator **7** is provided a frequency divider **9** with a 1/2 factor.

The method of tuning the generators in the interval of the tempered quint consists in that first is obtained their exact tuning by shifting cores **4** in the interval of the natural quint while connecting additional capacitance **6** into the circuit of the generator with frequency *f*2. After a stationary ellipsoid is obtained on screen **7**, capacitor **6** is disconnected and the frequencies of the generators automatically assume the ratio of the tempered quint.

In FIG. 2 is shown a set of 12 generators, each of which

represents a respective tone of the musical scale within the octave.

For full performance of its functions the device (FIG. 2) must have the means for comparing the tones in the quint, mentioned in the description of FIG. 1, connected to a certain pair of generators in the process of the below-described correlation tuning, and also means for the output or reproduction of electric oscillations during operational use of the device, the forms and methods of application of which may be easily provided depending upon the particular task required of the device as a whole.

For exact correlation of the frequency of the tones reproduced by the device of FIG. 2, one of the generators, for instance one corresponding to tone A, is taken as the initial one. The frequency of its oscillations is first set by some primary standard with capacitor **6** disconnected from its tuned circuit. Then core **4** of tone generator A is fixed and the generator is tuned with tone E located next to the generator of tone A in accordance with the quint circle, by the method of comparing with tone A in the natural quint, described above for the system of two generators in FIG. 1.

In this case, capacitor **6** in the circuit of tone generator A should be switched on and the tone generator E switched off; the tuning is carried out only by core **4** of tone generator E. The tuning of the generator of the tone E makes it suitable for use as a reference standard for tuning the next generator along the quint circle by the method described above. Thus, repeating the method 12 times, it is possible to tune all the 12 generators in succession and from tone D generator it is possible to return to the tone A generator, not for the purpose of new tuning but for checking that the quint circle is closed.

The process of tuning by the described method and means is much more productive and exact than the subjective method of following the circle of tempered quints by ear, this usually requiring repeated runs for checking.

It should be also clear that the application of the described method does not require any special personal gift or special fine skills, but requires only an accuracy and understanding of technology of the process. For the sake of the precision, it should be pointed out that when following along the quint circle of tones, within the limits of only one octave, some tones in the process of comparison actually happen to be in the quart interval instead of the quint interval, as envisaged in the basic version of the method of FIG. 1. Therefore, to obtain the necessary result in this case, the inversion of the interval is required by connecting an additional step of frequency divsion with a factor of 1/2 into the indicating circuit, having, according to FIG. 1, a divider with a 1/2 factor.

Thus, in this circuit a full division factor of 1/4 will be obtained, which secures on the whole the comparison of tones in the ratio of 4:3 (taking into consideration the factor of division of the other tone) in unison.

In the description of the method and device set forth above, it was assumed that the values of additional capacitors **6** can be selected with enough precision in the tuned circuit of each generator to provide in the process of following the quint circle for an automatic shift of the frequency of the tone generator by the difference of the interval of the natural and tempered quints. This is achieved indeed by usual means of electric measurements, because the required 0.183% shift has a very small value, the error of which, caused by trimming the capacity of capacitors **3** and **6** with an accuracy up to units of percent in the absence of a systematic error, is practically immaterial.

However, if it is desirable to obtain a complete certitude in the result of tuning, the circuit of the device of FIG. 3 should be used where it is envisaged to use only two exciters **1** for all the 12 tones and in such a way that only one variable capacitor **6** be used with a possibility of trimming its effective value according to the results

of the preliminary run along the quint circle of tuning.

To realize such a version of the device, it is necessary that the capacitors 3 be fixed not to two inductances of the tuned circuits but be constantly connected to the inputs of said two exciters 1, so that the excitation of the necessary tone frequency be effected upon connection of inductance 2, rated accordingly for the given problem, with the input of exciter 1, containing capacitor 3. Capacitors 3 at the inputs of both exciters 1 should have absolutely equal capacity values which can be effected by trimming, for instance, under the conditions of comparative measurements of frequency obtained from each of the exciters (with the use as a temporary intermediate standard, of an additional generator not included in the device) upon connection of the exciters to the same inductance.

If the mentioned condition of the capacitors equality is fulfilled, the exciters for all the 12 inductances are adequate, and it is possible to use them for following the quint circle, having additional capacitor 6 permanently connected to the input of the exciter reproducing the lower of the frequencies, this frequency belonging to the pair of tones being compared in the quint. If during the initial run, the capacity of capacitor 6 is set insufficiently accurately, and it is discovered that correction of the circle is necessary when returning to the initial tone, it becomes possible by a respective correction of capacitance 6 to reach complete closing of the quint circle on repeat runs, with a certainty that the dulling of quints in all the 12 cases of comparison had an absolutely equal quantitative value.

With respect to the full set of the device of FIG. 3, the same remarks should be repeated concerning the necessity of connecting the means of comparison and objective indication of the coincidence of the frequencies of tones in a quint (quart), and also the tone reproduction means, as had been made in connection with the description relative to FIG. 2.

For the sake of accuracy, attention should be paid to the fact that in the device of FIG. 3 for simultaneous reproduction of two tones after tuning, capacitor 6 should be disconnected or else the tones will be reproduced in the interval containing a correction for the difference of the tempered and natural quint. It is obvious that the inputs of the reproducing amplifiers should be connected to the exciters bypassing the frequency dividers, which are included in the system of means of FIG. 1 for the comparison of tones in a quint (or quart).

It should also be noted here, that for the purpose of determining the deviation of the frequency of any autonomous source of tone from its correct value on comparison with a respective tone standard, acting in the device of FIG. 3, capacitor 3 of one of the exciters can be made with a small variable component, calibrated in deviations from the exact value of the musical scale (for instance in cents).

Comparing the circuits of the devices of FIGS. 2 and 3, it should be noted that the device of FIG. 3, having the advantage of absolute accuracy in the correlation of tones in the system of the tempered scale, does not allow to reproduce more than two tones simultaneously, whereas the device shown in FIG. 2, though it does not fully guarantee the accuracy of tuning, allows to reproduce all the tones independently of each other.

Therefore the device of FIG. 2 can be recommended mainly as a built-in unit for the master generators of an electronic musical instrument, while the device of FIG. 3 is of interest when making an autonomous system, intended for precise calibration of any other system, in particular for final adjustment of the unit for the master generators of an electronic musical instrument, made according to the circuit of FIG. 2.

As to the circuit of FIG. 1, apparently it can be considered that, after the description given above, its initial character for forming the devices of FIGS. 2 and 3 and the method of tuning inherent in them will be evident. Besides that, it should be noted that, depending upon modifications in the forms of the embodiment of the device, the means shown in FIG. 1 for the comparison of tones made as frequency dividers 8 and 9, and also electron-optical indicator 7 can be respectively changed, developed or excluded in accordance with any particular technical or economic requirements, for instance, in connection with the selected version of the device of FIG. 2 or 3.

In exactly the same way, other versions of electric generators can be used, pertaining to the circuits, not containing inductive elements. In such a case, smooth tuning of the generators can be effected by a variable resistor in the circuit determining the frequency of oscillations depending upon the effective value of its electrical resistance. Since the circuits of this kind, however, necessarily contain a frequency determining capacitor, the frequency shift by the difference between the natural and tempered quint can be effected by an additional capacitor in the same way as in the case of a generator containing a tuned circuit with an inductance and a capacitance.

In connection with the method of bringing the frequencies being compared to a simple multiple ratio, described in relation to the circuit of FIG. 1, an original version of tying bringing the scale of musical tones into correspondence with the frequency of alternating current electric mains, which in this case is used as the primary standard for tuning one of the tone generators, is included in the device of FIG. 2.

If, for instance, the frequency of tone generator "A flat," having in a respective octave position the value of 51.915 c.p.s., is lowered by 3.7% by the means shown in FIG. 1, then at this moment said generator will have a frequency (taking into account the necessary octave lowerings, obtained by respective frequency division) of oscillations equal to 50 c.p.s, which creates conditions for objective comparison of its frequency with the frequency of 50 cp.s. alternating current mains and in case of necessity by respective trimming with core 4.

In exactly the same way, the tone generator "H," in case of application of the necessary octave lowering of frequency, can be retuned by additional capacitor from 61.66 c.p.s. to a frequency of 60 c.p.s. for comparison with the frequency of 60 c.p.s. alternating current mains. In both cases, the mains frequency should be applied to one of the inputs of electron-optical indicator 7 instead of the frequency of the generator of the tone making a pair with the tone "A flat" (in case of 50 c.p.s. mains) or with the tone "H" (in case of 60 c.p.s. mains) on comparing the frequencies along the quint circle.

The necessary development of the circuit of FIG. 2 for the case of application of the described method of establishing correspondence between the tone generators and the mains frequency will be evident to those skilled in the art without additional illustrations.

It is now established that the proposed method and device are based on very simple engineering means and inexpensive elements and provide a fully objective tuning process for tuning tone generators to the tempered musical scale, which, on the whole, creates the conditions for the commercial success of the invention.

Although the present invention is described in connection with the preferred embodiment, it is understood that changes and variations can take place without departing from the spirit and scope of the invention, as will be easily understood by those skilled in the art.

These changes and variations are to be considered to be within the limits of the nature and scope of the invention if defined by appended claims.

What I claim is:

1. A method of tuning an electronic tone generator to a frequency lower, by an interval of the tempered quint of the classical musical scale, than the frequency of a standard, said generator having a tuned circuit capacity,

and including means for smooth variation of frequency near the trimming frequency at a fixed value of the tuned circuit capacity and means for objective comparison of the frequencies as a simple multiple ratio of the frequencies of the generator being tuned and the standard, said method comprising connecting to the capacity of the tuned circuit at the time the frequencies are compared an additional capacitor of relatively small capacitance, said additional capacitor lowering the generator frequency by the difference of the interval of the natural and tempered quint ($3/2-2^{7/12}$), bringing the generator frequency by said means for continuous tuning to the ratio between the natural quint and the frequency of the standard, and disconnecting said additional capacitor whereby the generator is automatically tuned to the interval of the tempered quint and the frequency of the standard and, thus, in the process of tuning the irrational character of the factor of comparison of the frequencies is excluded and a possibility of objective comparison of frequencies in the simple ratio by Lissajous figures is provided.

2. A method of tuning an electronic tone generator to a frequency lower, by an interval of the tempered quint of the classical musical scale, than the frequency of a standard, said generator including a tuned circuit and a partly variable inductance in the tuned circuit which has a fixed value of capacity, and means for objective comparison of the frequencies as a simple multiple ratio of the frequencies of the generator being tuned and the standard, said method comprising connecting to the capacity of the tuned circuit at the time the frequencies are compared an additional relatively small capacity, said additional capacity lowering the generator frequency by the difference of the interval of the natural and tempered quint ($3/2-2^{7/12}$), bringing the frequency of the generator by said partly variable inductance to the ratio between the natural quint and the frequency of the standard, and disconnecting said additional capacitor whereby the generator is automatically tuned to the interval of the tempered quint and the frequency of the standard and, thus, in the process of tuning the irrational character of the factor of comparison of the frequencies is excluded and a possibility of objective comparison of frequencies in the simple ratio by Lissajous figures is provided.

3. A method of tuning an electronic tone generator to a frequency lower by an interval of the classical musical scale than the frequency of a standard, said generator including a tuned circuit and a variable active resistance, affecting the frequency of the tuned circuit at a fixed value of the capacity of the tuned circuit, and means for objective comparison of the frequencies as a simple multiple ratio of the frequency of the generator being tuned and the standard, said method comprising connecting to the capacity of the tuned circuit at the moment of comparing the frequencies an additional relatively low capacity, said capacitor lowering the generator frequency by the difference of the interval of the natural and tempered quint ($3/2-2^{7/12}$), bringing the generator frequency by said variable active resistor to the ratio of the natural quint and the frequency of the standard, and disconnecting said additional capacity whereby the generator is automatically tuned to the interval of the tempered quint and the frequency of the standard and thus, in the process of tuning the irrational character of the factor of comparison of the frequencies is excluded and a possibility of objective comparison of frequencies in the simple ratio by Lissajous figures is provided.

4. A method of tuning a system consisting of twelve electronic generators, intended for reproduction of twelve tones of the classical tempered musical scale, each of said generators comprising means for smooth variation of frequency near the frequency of its tuning at a fixed value of capacitance of the tuned circuit, while the system is provided with means for objective comparison of the frequencies of the generators being tuned in pairs in a simple multiple ratio, said method comprising comparing the frequencies of the generators in pairs and tuning the frequencies in respect of the interval of the quint in the sequence of the classical quint circle with the aid of an electron-optical indicator included in said means for objective comparison in pairs and lowering the frequency of the generator, is in the given pair of tones is a lower tone of the quint, in the process of comparison of tones by a value corresponding to the difference of the factors of the natural and tempered quint ($3/2-2^{7/12}$) by connecting a relative small capacity provided in each generator and to the capacity of the tuned circuit, effecting the tuning for each pair of generators in the interval of the natural quint, and disconnecting said relatively small capacity whereby the generators are automatically tuned both in pairs and along the entire quint circle in the intervals of tempered quints.

5. A device for tuning an electronic tone generator to a frequency lower, by the interval of the tempered quint of the classical musical scale, than the frequency of a standard, comprising means for smoothly varying the generator frequency, means for the calibrated lowering of the generator frequency by the difference of the interval of the natural and tempered quint ($3/2-2^{7/12}$) and adapted for being actuated at the time the generator is tuned for obtaining the simple multiple ratio of the frequencies 3/2 of the generator and the standard, means for objective comparison of the frequencies of the generator being tuned and the standard in the simple multiple ratio, an electron-beam optical indicator means for receiving the frequencies being compared and frequency dividers with a 3:1 factor for the upper tone of the quint and with a 2:1 factor for the lower tone of the quint connecting the indicator means to the generator and standard.

6. A device intended for obtaining the frequencies of the full chromatic scale of the tones of the classical tempered musical scale, comprising twelve electronic generators, each of which includes means for smoothly trimming a frequency near the rated frequency of the given tone and means for calibrated lowering of the generated frequency by the difference of the interval of the natural and tempered quint ($3/2-2^{7/12}$), the latter said means being adapted for being connected at the time of tuning each said generator to the interval of the quint to another of said generators corresponding to said first generator in this interval in the system of the classical quint circle; means for the objective comparison of pairs of the frequencies of said generators in the simple multiple ratio in the sequence of the classical quint circle the latter said means including an electron-beam optical indicator connected to the compared pair of generators in the interval of the quint in the process of their correlation tuning, frequency dividers with a 3:1 factor for the upper tone of the guint and with a 2:1 factor for the lower tone of the quint, and with a 4:1 factor for an inverted interval of the quint, means for reproducing the frequencies in the form of sound and means for transducing the form of oscillations and the output of the voltages of the frequency of tones.

7. A method of tuning a musical tone generator in the device, according to claim 6, by the frequency of the alternating current mains with the purpose of obtaining the reference frequency in the circuit of the quint circle frequencies, said reference frequency belonging to the tone the frequency of which in the corresponding octave position is in the simple multiple ratio with the mains frequency with a slight excess, said method consisting in that at the moment the frequency of said tone is compared with the mains frequency to the capacitor of tuned circuit of tone generator, an additional capacitor is connected, lowering the frequency of the generator by the frequency difference of the exact (rated) tone value and that of the mains frequency in such a way that the tuning of the generator can be brought to the simple multiple ratio to the mains frequency, and after said additional capacitor is disconnected the generator is automatically

tuned to the rated frequency of the tone with an accuracy equal to the correspondence of the mains frequency to the rated frequency thereof.

8. A device, intended for obtaining the frequencies of the full chromatic scale of tones of the classical tempered musical scale, comprising at least two exciters of electric oscillations respectively including identical capacitors; twelve partly variable inductances for twelve tones of the musical scale adapted for forming generators of tones when connected with said exciters and said capacitors; a commutator, providing for the connection of two said exciters with corresponding of said capacitors to said twelve inductances in succession of pairs of tones of the quint circle; one additional capacitor, acting in parallel with the capacitor of the exciter for the lower tone of the quint in the process of tuning of tone pairs along the quint circle and lowering the frequency of said tone by the difference of the interval of the natural and tempered quint ($3/2-2^{7/12}$); means for objective comparison of pairs of frequencies of said generators in a simple multiple ratio, adapted for being connected to said exciters in the process of the correlation tuning of the generators along the quint circle, and frequency dividers

with a 3:1 factor for the upper tone of the quint and with a 2:1 factor for the lower tone of the quint, and with a 4:1 factor for an inverted interval of the quint; and means for generating sound reproduction of tone frequencies and electrical signals corresponding to the frequencies.

9. A device, according to claim 8, in which the additional capacitor has a variable capacity, the value of which is selected by successive approximations on a repeated run by a pair of exciters along the quint circle with a correlated trimming of the inductances of all the twelve tones while following each circle.

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