

Feb. 21, 1939.

E L KENT ET AL

2,147,948

APPARATUS FOR THE GENERATION OF MUSICAL TONES

Filed Aug. 10, 1936

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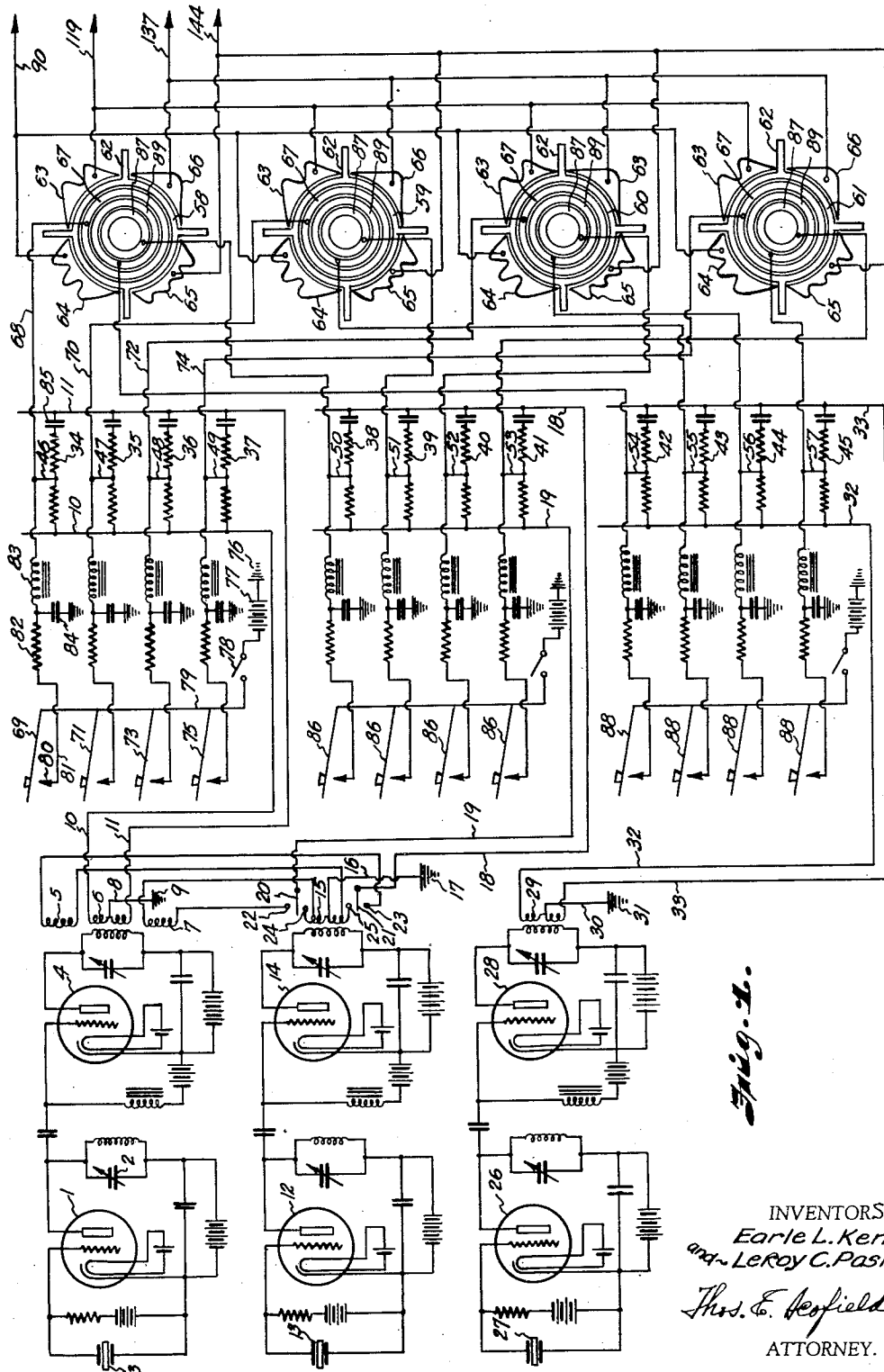


Fig. 1.

INVENTORS
Earle L. Kent
and Leroy C. Paslay
Thos. E. Keefield
ATTORNEY.

Feb. 21, 1939.

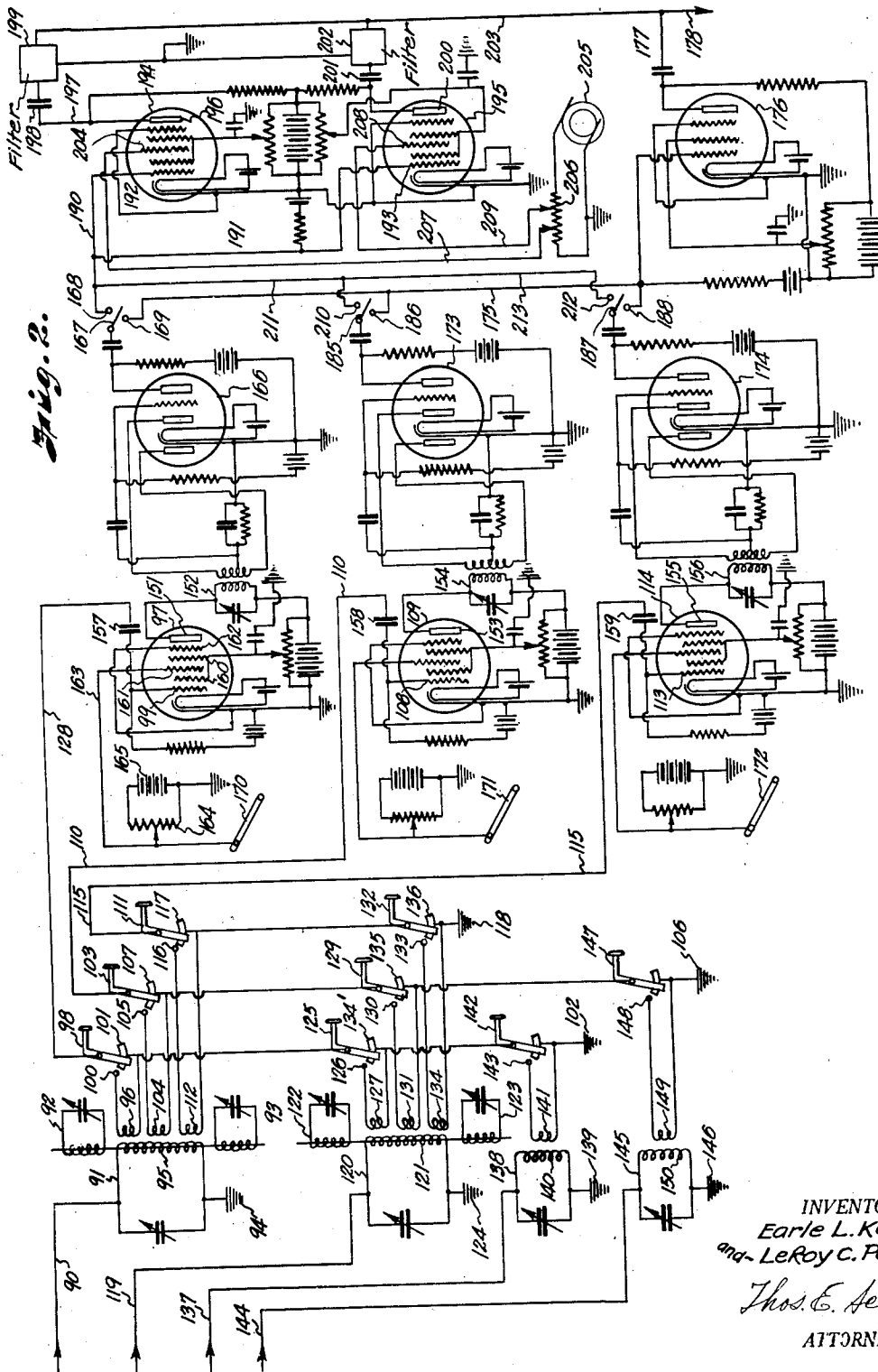
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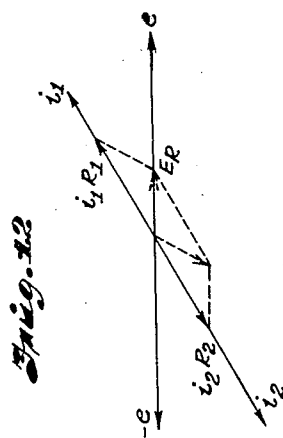
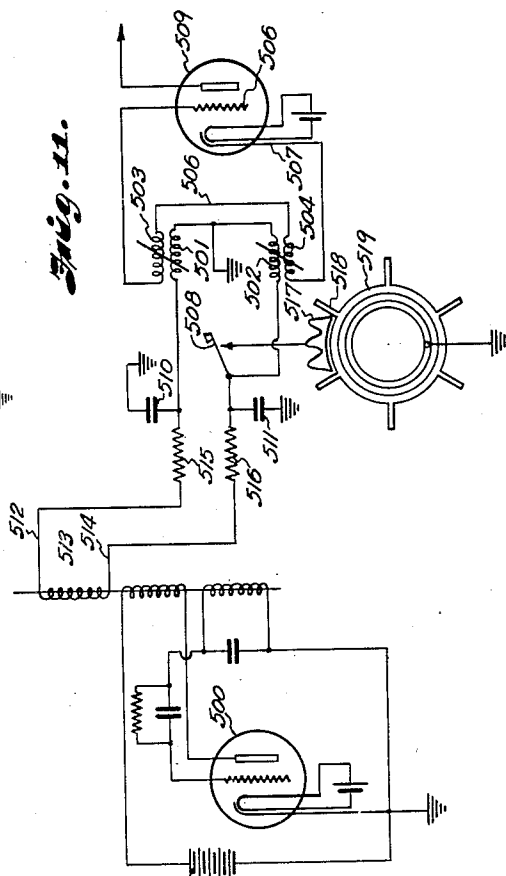
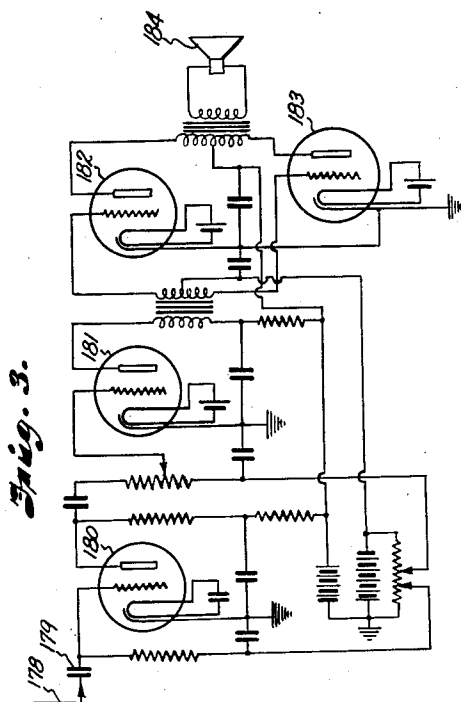
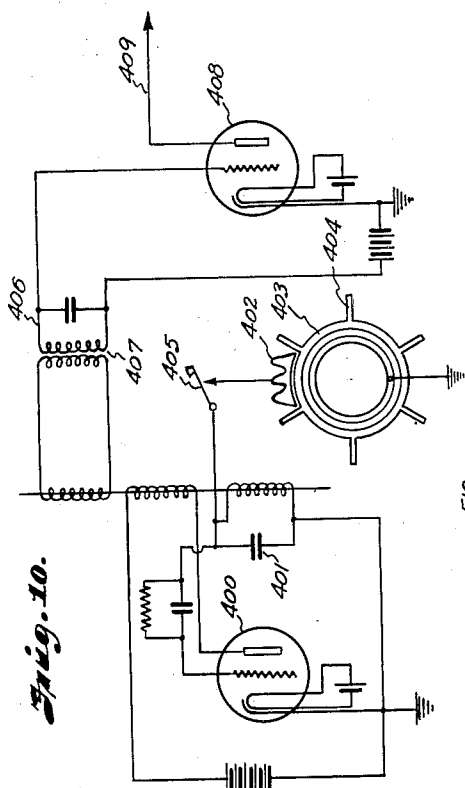
E L. KENT ET AL

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APPARATUS FOR THE GENERATION OF MUSICAL TONES.

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BY

INVENTOR.
Earle L. Kent
and LeRoy C. Paslay
Thos. E. Asfield
ATTORNEY.

Feb. 21, 1939.

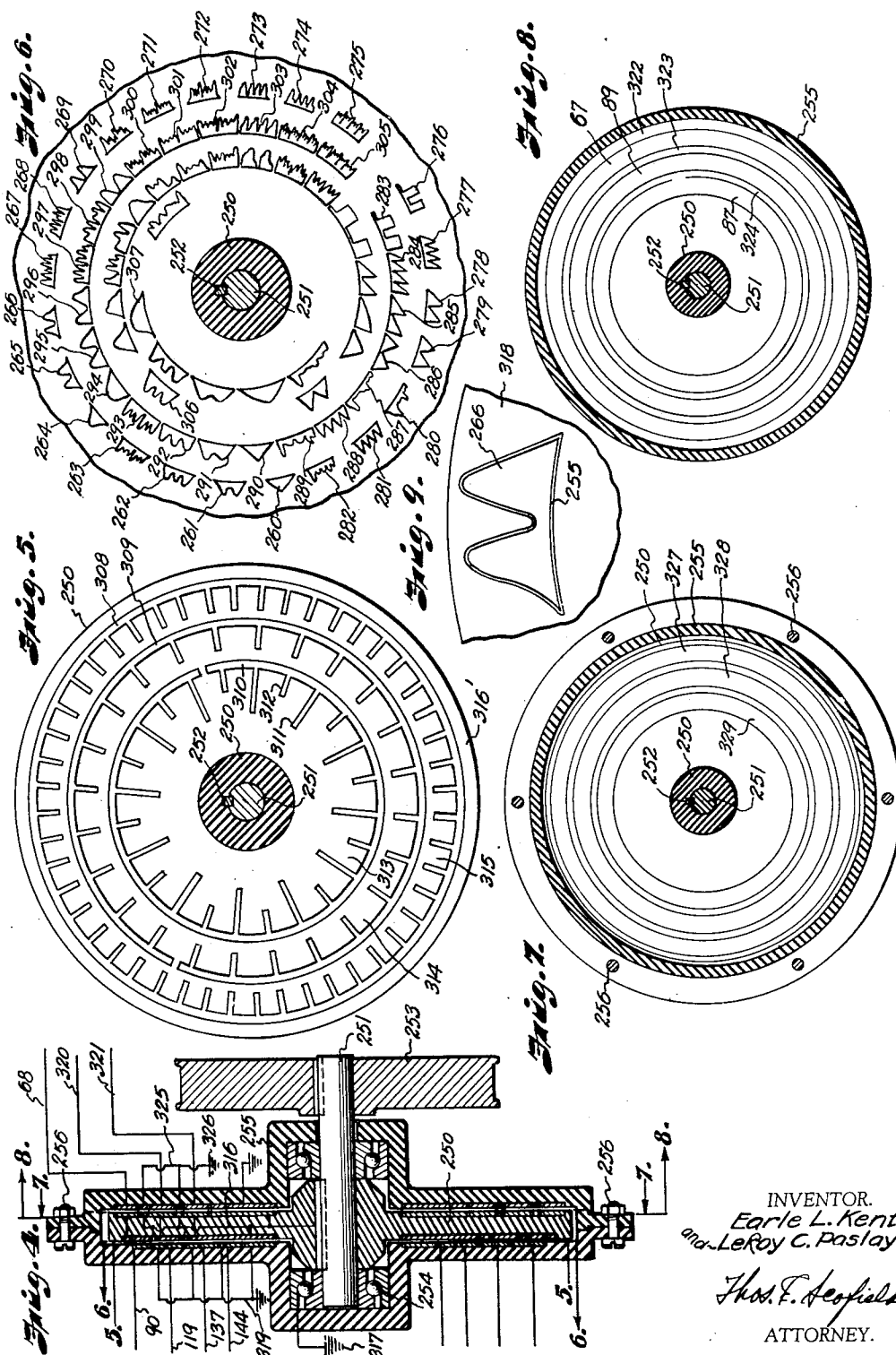
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APPARATUS FOR THE GENERATION OF MUSICAL TONES

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UNITED STATES PATENT OFFICE

2,147,948

APPARATUS FOR THE GENERATION OF
MUSICAL TONESEarle L. Kent, Manhattan, Kans., and Le Roy C.
Paslay, Kansas City, Mo.; said Paslay assignor
to said Kent

Application August 10, 1936, Serial No. 95,056

11 Claims. (Cl. 84-1)

Our invention relates to apparatus for the generation of musical tones and more particularly to an electric organ or organlike musical instrument.

A musical tone has two distinguishing characteristics, namely pitch and timbre. The pitch of a tone depends upon the rate of vibration producing it. The timbre of a tone depends upon the wave form of the vibration. Many attempts have been made to reproduce musical tones of predetermined timbre, but no practical method has been heretofore developed. Many schemes will produce notes of the desired pitch but the obtaining of tones of predetermined timbre has been accomplished only by photoelectric methods which have many disadvantages, foreclosing their employment in the confection of an electronic organ.

One object of our invention is to provide a means of and apparatus for producing any continuous tone with extreme fidelity.

Another object of our invention is to provide an instrument which will produce tones of every musical instrument which produces continuous tones similar to the timbre of the finest octave or finest note, or similar to the instrument over its entire range; that is to say, for example, the tones of a violin may be produced as the violin produces them over its entire range, or the violin tones in the organ may duplicate the timbre of one particularly rich violin tone over a complete range.

A further object of our invention is to provide an electric organ in which the harmonic content over the range may be varied, thereby eliminating the necessity of mixtures.

Another object of our invention is to provide an electric organ in which the tones are not initiated or terminated with a click or thump and which will permit the tones to be sounded as fast as the fingers can work the keys.

Another object of our invention is to provide an electric organ containing a complete specification of stops. 16 foot, 8 foot, 4 foot, and 2 foot stops are easily accomplished and other stops such as 32 foot, 10 $\frac{1}{2}$ foot, 2 $\frac{3}{4}$ foot, 1 foot, 1 $\frac{1}{2}$ foot, and celeste stops are possible with but small increase in complexity of the organ, the stops being brought into play in the conventional manner.

Another object of our invention is to provide a method and apparatus for producing musical tones in which standard organ consoles, built according to the specifications of the American Guild of Organists may be used.

Another object of our invention is to provide a method of and apparatus for producing continuous musical tones in which coupling may be obtained in a simple and expeditious manner.

Another object of our invention is to provide an electric organ in which the tremolo of tones is controllable by the musician both in intensity and in speed, enabling the tremolo to have its greatest effect upon the higher tones.

A further object of our invention is to provide an electronic organ having a plurality of manuals in which the volume of each manual is controllable in the usual manner, as well as having individual stop-volume control.

Another object of our invention is to provide an electric organ which may be designed for easy transposition from the tempered scale to the true scale.

A further object of our invention is to provide an instrument in which the pitch will not vary when used on any modern power line.

A further object of our invention is to provide a method of and means for producing musical tones in which the harmonics are true harmonics, enabling the organ to "wear" well with its listeners, or accompany other musical instruments of voices, thus avoiding "tempered" harmonics which have a tiring effect upon the ear, since sub-audible beats are produced between the tempered harmonics and the true harmonics supplied by non-linear characteristics of the ear.

Another object of our invention is to provide a small, light, economical instrument.

Other and further objects of our invention will appear from the following description.

In the accompanying drawings which form part of the instant specification and which are to be read in conjunction therewith and in which like reference numerals are used to designate like parts in the various views;

Figure 1 is a portion of a schematic drawing showing one means for practicing the method of our invention, and embodying one form of our invention.

Figure 2 is another portion of a schematic drawing, part of which is shown in Figure 1.

Figure 3 is another portion of a schematic drawing, the remainder of which is shown in Figures 1 and 2.

Figure 4 is a sectional elevation of a converter employed in carrying out the method of our invention, and forming part of the apparatus of our invention.

Figure 5 is a sectional view, taken on the line 55

5—5 of Figure 4, showing the scanning bars of the rotor of the converter shown in Figure 4.

Figure 6 is a sectional view taken on the line 6—6 of Figure 4, showing the capacity islands on the stator.

Figure 7 is a sectional view taken on the line 7—7 of Figure 4, showing the capacity rings on the rotor.

Figure 8 is a sectional view taken on the line 8—8 of Figure 4, showing the capacity rings on the stator.

Figure 9 is an enlarged plan view of a portion of the stator face in Figure 6 showing a capacity island.

Figure 10 is a partial schematic view, showing another embodiment of our invention in which the predetermined pitch and timbre are imposed upon a carrier wave by means of frequency modulation.

Figure 11 is a partial schematic view showing another embodiment of our invention in which a predetermined timbre and pitch are imposed upon a carrier wave by means of phase modulation.

Figure 12 is a vector diagram showing a portion of the currents in the form of the apparatus shown in Figure 10.

In general, our invention contemplates the generation of a high frequency carrier wave, the modulation of said high frequency carrier wave by mechanical means in accordance with a wave form having predetermined characteristics both as to frequency and form and the subsequent demodulation of said modulated carrier wave to obtain an electrical wave having the desired predetermined characteristics, and the conversion of said electrical wave into an acoustic wave having the characteristics of the predetermined wave form.

In our method and our apparatus we employ a high frequency current. A high frequency current is necessary in order to carry out the method of and employ the apparatus of our invention. In addition however, high frequency current has many advantages which will be hereinafter more fully pointed out. A tuned circuit resonating at the frequency of a high frequency current presents a very high impedance to its passage, while permitting high frequency currents of other frequencies to pass readily.

In its simplest aspect our apparatus comprises a superaudio generator producing a carrier wave impressed upon a tuned circuit, tuned to the frequency of the super-audio generator through a variable capacity adapted to modulate the carrier wave in accordance with a predetermined wave form, either by amplitude modulation, frequency modulation, or phase change modulation, as will be hereinafter more fully pointed out. The circuit is adjusted so that parallel resonance occurs in the entire circuit, eliminating the deleterious effects of capacity to ground. In this manner, a very small capacity change will effect a large modulation of the carrier wave.

More particularly referring now to the drawings and especially Figure 1, thermionic tube 1 is connected as an oscillator to produce a super-audio frequency wave, the frequency of which may be controlled by means of a crystal 3. The super-audio signal generated by the oscillator is amplified by thermionic tube 4, which is connected as an amplifier. It is to be understood that any suitable stable means may be used for the generation of the high frequency voltage.

The output of the amplifier is loosely coupled to coils 5, 6, and 7. Coil 6 is center tapped by conductor 8 which is grounded at 9. The ends of coil 6 are connected to conductors 10 and 11 which are leads passing to the first manual of the instrument.

Thermionic tube 12 is connected similarly to thermionic tube 1 to produce a super-audio frequency of a different frequency however, than tube 1. This frequency is controlled by crystal 13. The output of tube 12 is amplified by thermionic tube 14, the output of which is loosely coupled to a coil 15 which is center tapped by lead 16 to ground 17. The leads 18 and 19 to lead 16 to ground 17. The leads 18 and 19 to the second manual of the instrument are connectible by switches 20 and 21. If switch 20 is thrown upwardly to make contact with contact point 22 and switch 21 is thrown downwardly to make contact with contact point 23, some energy from oscillator 1 through coils 5 and 7 is fed in series with the output of oscillator 12 to the leads 18 and 19. In this manner, two frequencies are fed to the second manual of the organ so that, when the keys in this manual are played, it will be the same as though the first manual and the second manual were being played in unison, as will hereinafter be more fully described. In pipe organ practice it is desirable not only to couple in unison but also in other arrangements. This is usually taken care of in a pipe organ console in the construction. The need for couplers came about chiefly because of the lack of sufficient pipes, it being cheaper to couple than to put in duplicate pipes.

In the instant invention, it is possible to obtain a large number of pipe equivalents so economically that coupling need not be resorted to unless desired.

When the switch 20 is in contact with contact point 24 and the switch 21 is in contact with contact point 25, the high frequency voltage generated by tube 12 and amplified by tube 14 is directly coupled by coil 15 to the leads 18 and 19.

Thermionic tube 26 is connected similarly to thermionic tubes 1 and 12 to produce a high frequency voltage. Its frequency, however, is different from that generated by tubes 1 and 12 and this frequency is determined by the tuning of the circuit and is controlled by the crystal 27. The output of the oscillator 26 is amplified by the thermionic tube 28 and the amplified, high frequency voltage is loosely coupled to coil 29 which is center tapped by lead 30 to ground 31. The ends of coil 29 are connected to conductors 32 and 33, which are leads passing to the third manual of the instrument.

It is to be remembered that, in the schematic showing in this specification, a limited number of parts will be shown as illustrative of the principle and the construction to enable those skilled in the art to practice our invention. The showing and description are not to be construed by way of limitation but for purposes of illustration only. By using a number of different frequencies, additional manuals may be obtained.

Across the leads 10 and 11 of the first manual, 19 and 18 of the second manual, 32 and 33 of the third manual are a plurality of parameters, one for each key of the manual. For simplicity's sake, we have shown only four keys to a manual, it being remembered that the showing is diagrammatic only, for purposes of illustration. It is possible to have any convenient number of octaves in a manual and we will show a converter which can be readily used to obtain a

range of six octaves without difficulty. The parameters in the first manual are designated by reference numerals 34, 35, 36, and 37. The parameters in the second manual are designated by reference numerals 38, 39, 40, and 41. The parameters in the third manual are designated by reference numerals 42, 43, 44, and 45. The parameters are center tapped by conductors 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, and 57 respectively. The parameters have impedance characteristics which vary with current. The parameters may be light bulbs, "Thyrite" or any material whose impedance varies with the current. Light bulbs are apt to be sluggish and unstable. We prefer to use "Thyrite" since its change in impedance is practically instantaneous with change in current and it always returns to its original impedance. "Thyrite" is the trade name for a dense, homogeneous, inorganic compound of a ceramic nature, manufactured by the General Electric Company. It is stable and strong and has a valve action in the passage of current, which enables its use in lightning arresters. It is an insulation at one voltage and an excellent conductor at another voltage. Its resistance is a function of voltage, the resistance decreasing and the current increasing approximately $12\frac{1}{2}$ times each time the voltage is doubled. This rule is applicable, regardless of the rate of change of voltage and there is no time lag. The resistance depends of course upon its thickness.

The converters for imparting to the high frequency carrier wave a predetermined pitch and a predetermined timbre are shown diagrammatically in Figure 1 and will be hereinafter more fully explained. In general, a converter consists of a scanning arrangement having a plurality of arms comparatively long with respect to their width. Such scanning devices are shown diagrammatically in Figure 1 and designated by reference numerals 58, 59, 60, and 61. The arms 62 of the scanners act as one plate of a condenser and are adapted to scan islands 63, 64, 65, and 66 of the respective converters. These islands will be hereinafter more fully described in connection with the description of the converter. They act as other plates of condensers and are adapted to give a varying capacity with scanner arms 62. Capacity islands 63 will give the timbre of the diapason, one of the two fundamental tones of an organ. Capacity island 64 will give the timbre of the cello. Capacity island 65 will give the timbre of a violin. Capacity island 66 will give the timbre of a harmonic flute. High frequency current is passed to the scanners by manual coupling. Each of the respective converters is provided with a capacity coupling ring 67 to which the leads of the first manual are connected. Lead 68, energized by key 69, is thus adapted to be coupled to the scanner 58. Lead 70, energized by key 71, is thus adapted to be connected to scanner 59. Lead 72, adapted to be energized by key 73, is thus adapted to be coupled to scanner 60. Lead 74, energized by key 75, is thus adapted to be coupled to scanner 61.

There are twelve converters, since there are only twelve notes in an octave. By using a plurality of scanners with corresponding islands, it is possible to obtain a plurality of octaves upon one converter. It is also possible to obtain various pitches, varying from each other by a whole octave with a single scanner by varying the shape of the islands. This will be hereinafter more fully explained.

Since the parameters are center tapped, no voltage will be impressed upon the leads 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, and 57, and hence between coupling rings 67 and ground, unless the balance in the parameters or a parameter is changed. When a key, for example key 69, is pressed, current will pass from ground 76 through battery 77, through switch 78 which it is understood is closed, through lead 79, key 69, contact point 80, lead 81, resistance 82, high frequency choke coil 83, through conductor 46, through the left hand section of parameter 34, through conductor 10, through one half of coil 6, through conductor 8, to ground 9, thence to ground 76, to the battery. The direct current from the battery passing through the circuit just described charges condenser 84 which is connected across the battery 77, through resistance 82 and the key 69. The voltage will not build up across condenser 84 and across the left hand section of parameter 34, which are in parallel, until the condenser 84 attains its charge. The time constant for the charge and discharge of condenser 84 will depend upon the voltage of battery 77, the value of resistance 82, the capacitance of condenser 84, and the impedance of the left hand section of parameter 34. When the key is closed, the parameter is unbalanced and the high frequency voltage will then pass from coil 6 through lead 10, through the left hand half of parameter 34, through lead 46, through lead 68, to capacity coupling ring 67, thence to scanner 58 which is being rotated at a predetermined speed. The construction of the converter is such that the scanning arms 62 pass closely adjacent to the various stator islands so that the high frequency current will flow to charge the stator islands. The coupling will vary as the projected area of scanner arm 62 upon the stator island, since the stator islands are made of such shape that they will give a predetermined timbre to the carrier wave. In the form shown in Figure 1, the arrangement is such as to give amplitude modulation to the carrier wave, the voltage transmitted varying as a function of the projected area between a scanner arm 62 and the island. It is important to notice, at this point, that the scanner arm 62 is comparatively narrow with respect to the island. The importance of this feature will be hereinafter more fully explained.

The distance between adjacent scanner arms 62 is exactly equal to the length of each island so that, as soon as one scanner arm leaves an island, the other is just starting to scan the island. The frequency with which the scanner arms pass over an island determines the pitch of the note produced as will hereinafter be more fully described.

The method of keying just described has several advantages. It is possible to use a standard organ console with all of its coupling and piston features. It is likewise possible to control the response of the tones for staccato or legato effects by changing the time constant of condenser 84 for each key. The use of direct current which is isolated from the tone producing high frequency current makes it possible to separate the tone producing unit in the console without noise pickup. It is only necessary to key a small amount of power so that there will be substantially negligible arcing at the contacts of the keys.

There are twelve converters, one for each of the twelve notes of the musical scale. All of the C's, for example, would be produced by the converter having scanner 58. All of the C#'s would 75

be produced by the converter having scanner 59. The frequency of each note in the scale differs from the frequency of its adjacent note by the twelfth root of 2. The following table will give the frequencies for the notes of the scale for six octaves, together with the revolutions per second made by a scanner similar to that shown in Figure 5 and the pulley diameter in inches to be used on the driving motor shaft at a speed of 20 revolutions per second of the motor. In each case in the following table the rotor pulley is 8 inches in diameter. The speed of 20 revolutions per minute for the driving motor is obtained by using a 6 pole synchronous motor with a 60 cycle alternating current found almost universally throughout the United States. It is to be understood, of course, that any ratio of motor speed and pulley diameters can be worked out to achieve the desired result.

20 *Tempered Musical Scale A-440 International Standard*

	First octave	Second octave	Third octave	Fourth octave	Fifth octave	Sixth octave	Rotor R. P. S.	Motor pulley diam. 20 R. P. S.
25 C	32.70	65.40	130.81	261.62	523.25	1046.50	3.2703	1.30812
C#	34.64	69.29	138.59	277.18	554.36	1108.73	3.4648	1.38592
D	36.70	73.41	146.83	293.66	583.32	1174.65	3.6708	1.46832
D#	38.89	77.78	155.56	311.12	622.25	1244.50	3.8890	1.55560
30 E	41.20	82.40	164.81	329.62	659.25	1318.51	4.1203	1.64812
F	43.65	87.30	174.61	349.22	698.45	1396.91	4.3653	1.74612
F#	46.24	92.49	184.99	369.99	739.98	1479.97	4.6249	1.84996
G	48.99	97.99	195.99	391.99	783.99	1567.98	4.8999	1.95997
G#	51.91	103.82	207.65	415.30	830.60	1661.21	5.1915	2.07651
A	55.00	110.00	220.00	440.00	880.00	1760.00	5.5000	2.20000
A#	58.27	116.54	233.08	466.16	932.32	1864.65	5.8270	2.33081
35 B	61.73	123.47	246.94	493.88	987.76	1975.53	6.1735	2.46941

It will be observed by reference to the above table that if there are 10 scanning arms for example upon the C-rotor, the frequency of 32.70 for C in the first octave is obtained. An octave higher can be obtained by the use of 10 scanning arms by making the wave form exactly half the distance between the scanning arms and duplicating the wave form. In this way, one wave form will be scanned twice by a single scanning arm so that a single wave form will be scanned 20 times for each revolution and, since there are 3.270 revolutions per second being made by the rotor, the frequency of 65.40 cycles per second will be obtained. Doubling the number of scanning arms will double the frequency of the wave form and will raise the pitch one octave. By the use of single and double wave forms, it is possible to obtain 6 octaves with 3 sets of scanning arms as will be hereinafter more fully explained. Each of the keys 86 of the second manual of the instrument operates similarly to key 69 and the operation of the keys 86 is adapted to selectively charge capacity coupling rings 87 of each of the 12 rotors. The voltage impressed upon the coupling rings 87 may be either that generated by oscillator 12 or a mixed voltage generated by both oscillators 1 and 12, depending upon the positions of switches 21 and 20 as hereinabove described. Similarly, keys 88 of the third manual of the organ are adapted to selectively charge the voltage generated by oscillator 26 to respective capacity coupling rings 89 of the rotors.

The capacity islands are charged with high frequency voltage, the charge being determined by the capacity coupling between a scanner arm and that portion of the island projected by the scanner arm. The voltage, therefore, will vary in amplitude as a function of the shape of the capacity island being scanned. The frequency of the

change of amplitude will vary as the rotor speed and the number of scanner arms. Each of the capacity islands is connected by a conductor to a tuned circuit. Conductor 90 connects each of capacity islands 64 to a tuned circuit 91. Tuned circuit 91 has coupled thereto circuit 92 and circuit 93 and the tuning of all three circuits is such that a high impedance to ground 94 is presented to each of the three frequencies generated by oscillators 1, 12, and 26. In other words, the circuit is triple tuned. The arrangement makes it possible to tune out the stray capacity to ground of the lead 90. Loosely coupled to coil 95 of the tuned circuit 91 is a coil 96 making it possible to mix energy from the tuned circuit 91 into tube 97. A stop switch 98 is adapted to place coil 96 in a circuit for impressing energy picked up thereby upon the grid 99 of tube 97. This occurs when the switch makes contact with contact point

100. It will be noted that the arm of switch 98 is contacted with contact segment 101 when the switch is in open position. This completes the main line from ground 102 to grid 99. The construction is such that contact is made with contact point 100 before the switch arm moves off from contact with segment 101. Stop switch 98 determines whether or not energy will pass from tuned circuit 91 to the tube 97. A similar stop switch 103, adapted to complete the circuit from ground 106 through a loosely coupled coil 104 by making contact with contact point 105 and completing the circuit from ground 106 through a conducting segment 107, is provided. A stop switch 103 is adapted to connect coil 104 to the grid 108 of tube 109 through conductor 110. Similarly, a stop switch 111 is adapted to place loosely coupled coil 112 in connection with the grid 113 of tube 114, through conductor 115 when contact is made by stop switch 111 with contact point 116. A contact segment 117, similar to contact segments 101 and 107, is provided for completing the main line to ground 118, when the stop switch is in open position. Capacity islands 63 of each of the 12 rotors are connected by conductor 119 to a tuned circuit 120, the inductance 121 of which has coupled thereto tuned circuits 122 and 123, tuned circuits 120, 122, and 123 being tuned together to give a tuned circuit which is triple tuned so that the impedances of the circuit 120 to ground 124 is high to each of the three peaks of resonance to which the circuit is tuned. The retuning, of course, as in circuit 91, is to the frequencies generated by oscillators 1, 12, and 26. The island 63 will give the timbre of the diapason. If it is desired to play the diapason in manual 1 only, the stop switch 125, similar to the stop switch 98, is moved to closed position to make contact with contact point 126. This places coil

127 to loosely couple energy from coil 121, which energy will be passed through conductor 128 to the grid 99 of tube 97 to which the energy from generator 1 is passed, as will hereinafter be more fully explained. If it is desired to play the diapason in manual 2, stop switch 129 is moved to make contact with contact point 130, thus loosely coupling coil 131 with coil 121 so that energy from the oscillator 12 will pass through conductor 110 to grid 108 of tube 109 to which the energy from generator 12 passes. Similarly, if it is desired to play the diapason in manual 3, stop switch 132 is moved to make contact with contact point 133 to loosely couple coil 134 with coil 121 to pass energy originating in oscillator 26 through conductor 115 to the grid 113 of tube 114 to which the energy developed by generator 26 passes. Stop switch 125 is provided with a contact segment 134', stop switch 129 is provided with a contact segment 135, and stop switch 132 is provided with a contact segment 136 to complete the circuits from grid to ground similar to contact segments 101, 107 and 117. Capacity islands 66 of all of the rotors are connected to conductor 137 which leads to a tuned circuit 138. This circuit is tuned to the frequency of oscillator 1 and is connected to ground 139. Tuned circuit 138 will present a high impedance only to the frequency of oscillator 1 so that, if the other frequencies are imposed upon capacity islands 66, these frequencies will be passed to ground 139. Circuit 133 resonates only at the frequency of oscillator 1 so that, if an island 66 is scanned by the frequency of oscillator 1, energy may be coupled from coil 140 to coil 141 as when circuit 133 is resonating the impedance to ground is very high. Islands 66 are shaped to give the timbre of a harmonic flute so that, if it is desired to play the harmonic flute on manual 1, stop switch 142 is moved to make contact with contact point 143, thus enabling energy to pass through conductor 128 to grid 99 of tube 97.

Islands 65, which are shaped to give the timbre of a violin, are connected to conductor 144 which leads to a tuned circuit 145, the other side of which is grounded at 146. Tuned circuit 145 is tuned to the frequency of oscillator 12. If it is desired to play the violin on manual 2, stop switch 147 is moved to make contact with contact point 148, thus coupling coil 149 with coil 150 of the tuned circuit 145, enabling energy to pass through conductor 110 to the grid 108 of tube 109. Similarly, stops in the third manual (not shown) are led by a conductor to a tuned circuit, tuned to the frequency of oscillator 26, and stop switches are provided for coupling coils to said tuned circuit to the grid 113 of tube 114.

Plate 151 of tube 97 is connected in a circuit containing a tuned circuit 152 which is tuned to the frequency of oscillator 1. The plate 153 of tube 109 is connected in a circuit containing tuned circuit 154 which is tuned to the frequency of oscillator 12. The plate 155 of tube 114 is connected in a circuit containing tuned circuit 156 which is tuned to the frequency of oscillator 26.

It is desired to play the violin, for example, in manual 1, the capacity islands 65 giving the timbre of a violin, are provided with another conductor leading to a tuned circuit similar to circuit 138.

Tubes 97, 109, and 114 are connected to their respective leads 128, 110, and 115, through blocking condensers 157, 158, and 159. The tubes 97, 109, and 114 are shown as pentagrid mixer tubes. The tubes can be of any suitable type such as

a variable mu tube for example. Taking tube 97 as typical, the energy is fed to the first control grid 99 of the tube. Grids 160 are screen grids. Grid 161 is a second control grid. Grid 162 is a suppressor grid. Tube 97 acts as an amplifier, a frequency selector and as a volume control. The second control grid 161 is connected by conductor 163 to a potentiometer 164 which makes it possible to vary the bias voltage from battery 165 and thereby control the output of tube 97. The tuned output of tube 97 is coupled to tube 166 which acts as a full wave detector and amplifier. The carrier wave is cancelled by tube 166 and the audio signal passes from tube 166 to a switch 167 which is adapted to make contact with either contact point 168 or contact point 169.

The volume control, as determined by the bias upon the second control grid is operated from a pedal 170. Similar pedals 171 and 172 are provided for the second and third manuals of the instrument. Tubes 109 and 114 are in all respects similar to tube 97 just described, with the exception that the plate circuit in tube 109 is tuned to the frequency of oscillator 12 and the plate circuit in tube 114 is tuned to the frequency of oscillator 26. The full wave detector and amplifier for tube 109 is tube 173 and the full wave detector and amplifier for tube 114 is tube 174. When switch 167 is in contact with contact point 169, the output of tube 166 passes through conductor 175 to tube 176 and thence through blocking condenser 177 to conductor 178, through blocking condenser 179, through amplifier tubes 180, 181, 182, and 183, to the loud speaker 184 (Figure 3). The output of full wave detector and amplifier tube 173 can be passed to conductor 175 by moving switch 185 into contact with contact point 186. Likewise, the output of full wave detector and amplifier 174 can be passed to conductor 175 by moving switch 187 into contact with contact point 188.

If switch 167 is moved into contact with contact point 168, the energy passes through conductors 190 and 191 to the first control grids 192 and 193 of tubes 194 and 195. The output of tube 194 passes from the plate 196 thereof through conductor 197, through blocking condenser 198 to a selective filter 199 having the following characteristic. The filter 199 is such that the attenuation varies directly as a function of the frequency. The output of tube 195 passes from the plate 200 thereof through blocking condenser 201 to a filter 202, which has the following characteristic. The attenuation of filter 202 varies inversely as a function of the frequency. The output of filters 199 and 202 passes through conductor 203 to conductor 178 to the main audio amplifier shown in Figure 3, to the loud speaker 184. The second control grid 204 of tube 194 receives a low frequency voltage from generator 205 through a potentiometer 206, through conductor 207 and thereby varies the plate output of tube 194 in accordance with the frequency of generator 205, thus causing a tremolo. The second control grid 208 of tube 195 receives low frequency voltage from generator 205 through potentiometer 206 and conductor 209. The purpose of the two tubes 194 and 195 is to afford two channels, making it possible to give the higher frequencies more tremolo than the low tones. The balance of tremolo is controlled by the filters. The volume of tremolo is controlled by the potentiometer and the speed of the tremolo may be controlled if the generator 205 is so constructed as to give a choice of tremolo frequency. Switch 75

167 controls the tremolo for the first manual. If switch 185 is moved to make contact with contact point 210, tremolo is given to the second manual as the output of tube 173 then passes to conductor 190 through conductor 211. If switch 187 is moved to make contact with contact point 212, tremolo is then had on the third manual of the instrument, since the output of tube 174 then passes to conductor 213, thence through conductor 211 to conductor 190. In this way, tremolo may be put upon each manual independently.

Individual stop control is easily obtained by changing the voltage of stop pickup coils 96, 104, 112, 127, 131, 134, 141, and 149. This voltage is easily adjusted by the degree of coupling. In voicing an organ to an auditorium, it is very desirable to be able to set the maximum value on each stop separately. This can easily be done with our arrangement.

It is believed that the operation of the foregoing modification shown in Figures 1, 2, and 3 will be clear from the foregoing description. A high frequency current is generated, which is passed to a scanner rotating at a predetermined speed and having a predetermined number of scanner arms. These scanner arms pass the islands having a predetermined form and charge the same with a high frequency current with an amplitude varying as the capacity coupling varies. The energy from the capacity islands is selectively picked up by the operation of stops and is demodulated, amplified and sent to a loud speaker directly or through a channel which imposes a tremolo upon the tone. The stops in each manual may be controlled as to volume and the tremolo may be selected for each manual. By the operation of switches 20 and 21, a plurality of manuals may be played in unison by operating the keys of one manual.

The keys select the pitch, that is, the particular notes in the particular octave to be played, while the stops select the particular instrument or instruments to be played. If a number of stops are put in operation, the pressing of a key of a manual will play a number of instruments in unison. It will be observed that our instrument can be made more varied in resources than the largest of organs, not only producing all known musical instruments but being able to produce new sounds by drawing arbitrary timbres not now producible by any known instrument.

At this point, we would like to call attention to the importance of high frequency current in our invention. With a high frequency current, we are enabled to obtain a higher gain per stage of amplification than is possible at audio frequency. There is also less trouble with frequency discrimination by obtaining amplification of the high frequency carrier wave. The use of a high frequency current enables the elimination of extraneous noises which are due to audio pickup. Such an audio frequency as a 60 cycle hum, for example, which is picked up in the circuit before the detector, will not be passed along with the high frequency current. We obtain our modulation by scanning an insulated plate having a desired wave form. By using high frequency current, the shape of the island will govern the shape of the wave form since the voltage output will vary directly with the area covered by a scanning bar and is not dependent upon the rate of change of area or upon any other known linear function. This has an additional advantage since the output of our converters, not being dependent upon the rate of change of capacity, the strength of

low tones will be the same as the high tones. If direct current were used, any tone which would be obtained would have to depend on the rate change of capacity. With direct current, therefore, the high tones will have a much greater output than the low tones, making the design complicated for overcoming the unbalance and making it difficult in general to obtain a sufficiently high level for low tones.

By using high frequency current, we are enabled to employ very small converters. By means of tuning or resonance, eliminating the voltage divider effect of stray capacity, we are able to obtain a high output from a converter. The same converter unit may be used for several manuals since carrier currents can be mixed and separated as they are in telephony, making it possible to obtain the maximum intelligence from the smallest space. The use of high frequency currents makes it possible to obtain a greater impedance change in a small space. High frequency current enables capacity coupling to be used for keying or for stopping.

Referring now to Figures 4, 5, 6, 7, 8, and 9, our organ normally employs 12 converters. Each of the converters may be identical in construction, thus simplifying the manufacture, the pitches being obtained by using different sized pulleys upon the motors. If desired, one motor having a shaft with 12 different sized pulleys may be employed. 12 individual motors of smaller size may be employed, each driving a single converter. If celeste effects are desired, additional converters operating at a slightly different speed may be employed so that a note may be sounded at two slightly different frequencies to produce beats giving the celeste effect.

The rotor 250 of the converter is keyed to a shaft 251 by key 252. To the shaft 251 is keyed a pulley 253 for rotating the shaft 251. The shaft operates on ball bearings 254 and is housed in a two-part casing 255, held in assembled position by bolts 256. In making the converters, we took oscillograms of the tones which we wished to reproduce. The oscillograms may be taken with a cathode ray oscillograph or with a string galvanometer type of instrument. After recording the wave shape on film, the film was placed in an enlarging machine and one cycle of the particular tone was reproduced on rectangular coordinate paper. A circle was then drawn on drawing paper and divided into a number of equal spaces as accurately as possible. The tone wave shape was then transposed from rectangular coordinates to polar coordinates, placing it in its allotted place on the drawing. This transfer was done with a pair of proportional dividers, one point at a time every few degrees along the curve. The drawing was made three times actual size in order to obtain accuracy when reduced. The line widths were checked with a Brinell microscope for uniformity. A drawing was then made for the rotor to correspond with the stator. The construction of the rotor was such that scanning bars pass in succession over a stator island so that, just as one scanning bar leaves an island, another bar starts across, that is to say the distance between scanner bars is exactly equal to the width of an island. The bars were made of such width as to offer a maximum area without exceeding the point where important harmonic content of the wave would be cut off. The width of the bar should be at least one half the length of one cycle of the highest harmonic to be produced in a large magnitude; for example, if the

fundamental cycle is one inch long and the tenth harmonic is the largest or highest harmonic to be produced at 100 percent magnitude, the width of the bar cannot be over one twentieth of an inch. The twentieth harmonic can be had at 50 percent magnitude and the highest harmonic can be had in proportion with this width. It is essential that the bars be of uniform width and spacing in order to produce a uniform continuous tone.

If two identical wave forms are placed in the distance between two scanning bars, a double frequency will result, thus making it possible to put an 8' and a 4' stop on one ring to be scanned by a single set of scanning bars. It is possible to put four identical wave forms in the space occupied by the distance between scanning bars and obtain an additional octave with the same scanning bars. In one case, we recorded octaves in unison on an oscillograph and got the effect of a 4' stop and a 2' stop combined, by using the cycle as a 4' stop. After the drawings are completed, they are photographed on a glass plate and a positive is made upon glass. Glass is necessary since film changes shape when developed and dried. The positive was reduced to one third size. The stator is made of a phenol condensation product and one face was evenly coated with a special cement and a sheet of copper .002 of an inch thick was cemented to the phenol condensation product under a total pressure of about 50,000 pounds, or a pressure of about 2,000 pounds per square inch. A polished steel plate was placed next to the copper during the pressing operation, to obtain a smooth surface. After cementing, the copper is sensitized with photo-engraver's enamel. The positive for the stator was then placed on the sensitized copper and it was printed with an arc lamp to permit the light to harden the enamel everywhere except where the lines appeared. Upon development, the lines were washed out, exposing a copper surface where the lines appeared upon the drawing. The plate thus prepared was then etched with ferric chloride, the etching process continuing to dissolve all of the copper not protected by the hardened photo-engraver's enamel. The finished stator appears in Figure 6 which is taken on the line 6-6 of Figure 4. Each of the lines around the islands represents the phenol condensation product showing through.

Island 260 represents a synthetic tone on a 16' stop. Island 261 is the wave form of a 16' stop diapason. Island 262 is the wave form of a 16' stop cello. Island 263 is the wave form of an 8' stop cello. Island 264 is the wave form of a concert flute 16' stop. Island 265 is the wave form of a phillomela 8' stop. Island 266 is the wave form of a diapason 8' stop. Island 267 is the wave form of an 8' stop of vox humana. Island 268 is the wave form of an 8' stop oboe. Island 269 is the wave form of an 8' stop of a harmonic flute. Island 270 is the wave form of a clarinet on an 8' stop. Island 271 is the wave form of a violin on an 8' stop. Island 272 is the wave form of a horn on an 8' stop. Island 273 is the wave form of a flute d'amour on a 4' stop. Island 274 is an octave of a diapason 4' and 2' stops. Island 275 is a cello on a 4' stop. Island 276 is a synthetic tone on an 8' stop. Island 277 is a synthetic tone on a 4' stop. Island 278 is the same synthetic tone as island 277 on an 8' stop. Island 279 is the synthetic tone of island 268 on an 8' stop. Island 280 is

a baritone voice on a 16' stop. Island 281 is the same synthetic tone as island 260 on a 4' stop. Island 282 is a bass voice on a 16' stop. Island 283 is one of the islands which is scanned by half the number of scanning bars than the outer circle of islands. It will give the same tone as island 276 but an octave lower. Island 284 will give the same tone as island 277 but an octave lower. Island 285 will give the same tone as island 278 but an octave lower. Island 286 will give the same tone as island 279 but an octave lower. Island 287 will give the same tone as island 280 but an octave lower. Island 288 is the same wave form as island 281 but, being scanned by half the frequency, will give a tone an octave lower. Island 289 is used to give the same timbre as island 282, an octave lower. Island 290 has the same wave form as island 260. Island 291 has the same wave form as island 261. Island 292 has the same wave form as island 262. Island 293 has the same wave form as island 263. Island 294 has the same wave form as island 264. Island 295 has the same wave form as island 265. Island 296 has the same wave form as island 266. Island 297 has the same wave form as island 267. Island 298 has the same wave form as island 268. Island 299 has the same wave form as island 269. Island 300 has the same wave form as island 270. Island 301 has the same wave form as island 271. Island 302 has the same wave form as island 272. Island 303 has the same wave form as island 273. Island 304 has the same wave form as island 274. Island 305 has the wave form of a cello on a 4' stop.

As the islands are disposed upon circles of smaller diameters, as for example island 306 which is a cello wave form and island 307 which is the wave form for a concert flute on a 16' stop, the notes may be in succeeding lower octaves.

Referring now to Figure 5, the rotor 250 is likewise made out of insulating material such as, for example, a phenol condensation product upon which is cemented a thin copper sheet which is etched through to form scanning rings 308, 309, and 310. It will be noted that, by making scanning arms 311 longer than scanning arms 312, scanning ring 310 can be made to scan for two frequencies. The copper rings 313, 314, 315 and 316 formed by the scanning rings are interconnected by conductor 316 as can be seen by reference to Figure 4, and grounded to the shaft 251 which is in turn grounded at 317 so that each one of the scanning rings will be isolated by grounded shields. The copper back-ground 318 which surrounds the capacity islands is also grounded by conductor 319 as can be readily seen by reference to Figure 4. Each capacity island is connected by an appropriate conductor 90, 119, 137, 144, which is adapted to connect a particular island to a particular tuned circuit, as hereinbefore more fully described, so that the particular island can be brought into operation by means of the stop switches as heretofore described.

Referring to Figure 8, three capacity coupling rings 67, 89, and 87 are connected by conductors 68, 320, and 321 to the keying arrangement so that, by means of the keying hereinbefore described, a particular scanning ring in a particular rotor is adapted to be charged with high frequency voltage. Normally, for six octaves, there would be six scanning rings. This could be accomplished very easily by placing the scanning rings on each

side of the rotor 250 or by making the rotors of a slightly larger diameter, and placing a larger number of scanning rings thereon. The spaces 322, 323, and 324 between the coupling rings are grounded as shown in Figure 4 by conductor 325, at ground 326. The energy is adapted to pass from coupling ring 67 to coupling ring 327 by capacity coupling. Energy is adapted to pass from coupling ring 89 to coupling ring 328 by capacity coupling and energy is adapted to pass from coupling ring 87 to coupling ring 329 by capacity coupling. Coupling rings 327, 328 and 329 are shown in Figure 7 and are positioned upon one face of the rotor 250. The spaces between coupling rings 327, 328 and 329 are connected to the conductor 316, which goes to ground 317. Coupling ring 327 is directly connected by a conductor to scanning ring 308. Coupling ring 328 is directly connected by a conductor to scanning ring 309, and coupling ring 329 is directly connected by a conductor to scanning ring 310. This can readily be seen by reference to Figure 4.

It will be seen that keyed energy passes to the coupling rings in the stator through conductors, to the coupling rings in the rotor by capacity coupling, to the scanning rings by direct connection, from the scanning rings by capacity coupling, to the capacity islands, and from the capacity islands energy is selectively passed through demodulation channels for conversion into an acoustic wave either with or without tremolo, as hereinbefore described.

The grounding of the copper around the islands and around the scanning rings shields the islands and prevents distortion due to fringing.

In operation, high frequency voltages are generated by each of the oscillating tubes 1, 12, and 26, and impressed upon the respective manuals of the organ. When it is desired to play a note, a key is pressed. As long as the keys are open, the high frequency voltage is passed to parameters each of which is center tapped by a lead to a stator coupling ring. Being center tapped, no voltage will flow until the balance in the parameters is changed. For example, if scanner 58 is on a C-rotor and it is desired to play a C in the first manual upon a diapason, the key 69 is pressed, permitting direct current to flow from the battery 77 through the key 69, through the center tap 46, through the left hand portion of parameter 34, through conductor 10, through one portion of coil 6, through conductor 8 to ground 9, thence to the other side of the battery. The passing of direct current through the left hand portion of parameter 34 disturbs the balance permitting the high frequency voltage to flow from coil 6 through the lead 10, through the left hand side of parameter 34, through center tap 46, through lead 68, to capacity coupling ring 67 of the C-rotor. The capacity coupling ring will charge a coupling ring upon the rotor which is directly connected to the scanner ring 58, having scanner arms 62. The scanner arms 62 will charge the capacity island 63 representing the diapason, as well as all of the other capacity islands scanned. The carrier wave envelope will be changed in accordance with the wave form of island 63 and at a speed determined by the number of scanning arms and the speed of rotation of the rotor of the converter. The arrangement is such that the pitch will be to give the note C. Stop switch 125 has been pulled to make contact with contact point 126 to give the diapason upon the first manual. The high frequency voltage thus modulated by the converter will be im-

pressed upon the tuned circuit 120. The tuned circuit 120 is triple tuned so that it will present a high impedance to ground for the frequency of generator 1 as well as generators 12 and 26. Energy of the modulated carrier wave is picked up by coupling coil 127 and impressed upon the pentagrid mixer tube 97 through lead 128. Here the volume control 170 will determine the volume of the note. Tube 97 acts not only as an amplifier but also acts as a frequency selector having a plate circuit tuned to the frequency of generator oscillator 1. The tuned output of tube 97 passes to tube 166 which acts as a full wave detector and amplifier. The output of tube 166 may be passed directly to an audio amplifier for conversion into an acoustic wave by a loud speaker which acoustic wave will have a predetermined pitch and timbre in accordance with the characteristics impressed upon the carrier wave by the converter. If it is desired to add tremolo, the output of tube 166 is passed into tubes 194 and 195 by means of switch 167. The incoming signal goes to the first control grids of the tubes. The second control grids of the tubes are impressed with a low frequency alternating current in order to impart a tremolo. The output of the tubes will pass to respective filters, one of which has a characteristic of varying the attenuation directly as a function of the frequency, and the other of which has a characteristic of varying attenuation inversely as a function of the frequency in order that higher frequencies may be given more tremolo than the low tones.

If desired, energy from a plurality of generators may be mixed so that the operation of the keys of one manual will give the effect of a plurality of manuals played in unison.

In the above operation, which has reference to Figures 1 and 2, the wave form of predetermined characteristics is impressed upon a high frequency carrier wave by means of amplitude modulation.

Referring now to Figure 10, a simplified schematic showing of an arrangement to give frequency modulation is shown. The tube 400 is an oscillator having a capacity 401 in the circuit to govern its frequency. A capacity island 402 is scanned by a scanning ring 403 having scanning arms 404. The capacity of the condenser formed by a scanning arm as one plate, and the capacity island as the other plate, is in parallel with capacity 401. When a key 405 is actuated, the capacity of the converter is placed in parallel with the capacity governing frequency of the oscillating tube 400, so that the frequency of the oscillator will vary in accordance with the variation of the converter. The output of the converter is inductively coupled to a tuned circuit 406 which is tuned to the original frequency of the oscillator. The coupling between the tuned circuit of the oscillator and the tuned circuit 406 will vary as the frequency varies, that is, the transfer of energy will vary due to the frequency varying from the frequency at which the transformer 407 was peaked. The amplitude carrier wave is passed to an amplifying tube 408, the output of which passes through a lead 409 to a demodulator for demodulation and amplification, and conversion into an acoustic wave by loud speaker similar to that of the modification shown in Figures 2 and 3.

In connection with the form of the invention shown in Figure 10, it should be remembered that in each case the modulated carrier wave is impressed upon a tuned circuit, tuned to the frequency of the oscillator, that is, the frequency of the carrier wave, in order that the tuned circuit ma-

present a high impedance to ground for all currents of a frequency near the point of resonance. While the peak of resonance is fairly sharp, the variation in frequency is not so great that the resonating circuit will fail to present a high impedance to ground for the frequency of the generator 40, while permitting all other frequencies to pass to ground without affecting the acoustic channel.

Referring now to Figure 11, a simplified diagrammatic view is shown in which the modulation in accordance with a wave form of predetermined characteristics is accomplished by phase modulation. A tube 500 is connected as an oscillator to produce a high frequency voltage which is passed through coils 501 and 502 coupled to coils 503 and 504, which are wound exactly equal and opposite, having one end of each connected by lead 505, and respective other ends passing to grid 506 and cathode 507. When a key 508 is in the open position, there is no voltage across the grid of the tube 509 because the voltages induced in coils 503 and 504 are exactly equal and opposite. Current from the high frequency generator is caused to lead the voltage by condensers 510 and 511. The currents are shown in the vector diagram in Figure 12. The current flowing through the conductor 512 connected with the upper branch of coil 513 is represented in Figure 12 as i_1 . The current flowing through conductor 514, connected with the lower branch of coil 513, which is coupled to the output of the oscillator 500, is shown in the vector diagram in Figure 12 as i_2 and 180 degrees out of phase with i_1 . This is the manner in which the coils 501 and 502 are connected. The voltage drop across resistance 515, which resistance is designated as R_1 , will be in phase with the current i_1 , and this drop is shown in the vector diagram as $i_1 R_1$. Since the voltage $i_1 R_1$ will exactly neutralize the voltage $i_2 R_2$ if they are equal in magnitude and opposite in phase, there will be no voltage across the grid of the tube 509. The resistance 516 is designated as R_2 . If the variable capacity between capacity island 517 and arms 518 of the scanning ring 519 is added in parallel with the capacity 511 to ground by pressing the key 508, the phase of $i_2 R_2$ is shifted and the net voltage E_R will result as shown by dotted lines in the vector diagram of Figure 12. E_R will depend upon the phase change caused by the converter and this will be a direct function of the wave form of the capacity island 517 and the frequency of phase change will depend upon the speed of rotation of the scanner and the number of scanner arms necessary to give a note of the desired pitch. The output of the amplifier tube 509 is handled similarly to the other modifications.

It will be observed that we have accomplished the objects of our invention. We have provided a musical instrument of great wealth of resource and great flexibility, surpassing that of the organ. The instrument is organlike in character and can be made to produce any continuous tone with extreme fidelity. The shielding of the islands prevents distortion and fringing. Our instrument can produce tones of every musical instrument capable of producing a continuous tone similar to the instrument, over its entire range. The harmonic content over the range may be varied thereby eliminating the necessity of mixtures. The keying is such that the tones do not start or stop with a click or a thump because they are not caused to act instantaneously, due to the time constant in-

troduced by condensers 84. The tones, however, will sound as fast as the finger can work the keys. A complete specification containing a wide variety of stops can be easily produced and celeste stops are possible with but small increase in the complexity of the organ. The stops are brought into play in the conventional manner. Standard organ consoles complete, according to the specifications of the American Guild of Organists may be used. Coupling may be obtained simply. The tremolo is controllable by the musician both in intensity and speed and the arrangement is such that the tremolo has its greatest effect upon the higher tones due to the use of filters. The volume of each manual is controllable in the usual manner by the pedals 170, 171, and 172. By variation of coupling of the stop transformers, individual stop volume is controllable. The pitch of the instrument will not vary when used on any modern power line since a synchronous motor sets the pitch. The organ may be quickly changed from the tempered scale to the true scale by using different sized pulleys for driving the rotors. The harmonics produced are true harmonics, enabling the organ to wear well with its listeners or to accompany other instruments or voices. The instrument is small, light and economical in operation, consisting of only 12 small moving parts beside the motor or motors, depending on the construction used. A large number of stops are possible in a small space.

It will be understood that certain features and sub-combinations are of utility and may be employed without reference to other features and sub-combinations. This is contemplated by and is within the scope of our claims. It is further obvious that various changes may be made in details within the scope of our invention. It is, therefore, to be understood that our invention is not to be limited to the specific details shown and described.

Having thus described our invention, what we claim is:

1. In an apparatus for generating musical sounds of predetermined pitch and wave form including in combination a high frequency current generator adapted to generate a voltage of a given frequency, a resonating circuit tuned to the frequency of said generator, means for coupling said generator and said tuned resonating circuit, means for varying said coupling means as a function of a predetermined wave form and in accordance with the frequency of a predetermined pitch, means coupled to said tuned circuit for demodulating the output thereof, and means for converting the demodulated output of said tuned circuit into an acoustic wave of the desired pitch and timbre, the construction being such that the output of said demodulating means is a voltage varying in accordance with a predetermined wave form and at a predetermined frequency.

2. In a musical instrument, a condenser, means for periodically varying the capacity of said condenser at a frequency within the audible range, a source of potential of predetermined frequency, a thermionic tube having at least two elements, said condenser coupling one side of said potential source to one of said elements, the other side of said potential source being connected to the other of said elements, a resonating circuit tuned to offer a high impedance to the passage of current of said predetermined frequency, said tuned circuit being interposed

between said elements, and means for converting the output of said tube into an acoustic wave of a frequency at which the capacity of said condenser is being varied.

- 5 3. In a musical instrument, a source of high frequency potential of predetermined frequency, a resonating circuit tuned to the frequency of
10 said high frequency potential source, a variable condenser for coupling the output of said high frequency generator and said tuned circuit, said
15 variable condenser comprising at least two plates, one of which is shaped in accordance with a predetermined wave form, the other of which comprises a plurality of scanning arms
20 relatively narrow with respect to the width of said plate of predetermined wave form, means for passing said scanning arms over said plate of predetermined wave form at a predetermined velocity, and means for converting the output
25 of said resonating circuit into an acoustic wave in sympathy with the wave form of said condenser plate and at a frequency determined by the speed at which said scanning arms pass over said condenser plate.

4. In a musical instrument in which a high frequency current is generated, modulated in accordance with a predetermined wave form, demodulated to produce an electrical wave of said
30 predetermined wave form, said demodulated wave converted into an acoustic wave of said predetermined wave form, a variable condenser comprising a pair of relatively movable members, one of said members supporting a capacity
35 island shaped in accordance with a predetermined wave form, the other of said members supporting a plurality of capacity arms, each of said arms being relatively narrow in width with respect to its length, and means for relatively moving said capacity arms over said capacity island at a predetermined speed.

5. In a musical instrument as in claim 4 in which the distance between adjacent capacity arms is exactly equal to the length of said capacity island.

- 45 6. In a musical instrument as in claim 4 in which said capacity arms are surrounded by a grounded metallic shield.

7. In a musical instrument as in claim 4 in which said capacity island is surrounded by a grounded metallic shield.

- 50 8. In a musical instrument for electrically producing sounds in which an alternating voltage is selectively impressed upon a sound producing means through a key, a pair of impedance
55 branches having a center tap, said sound producing means being electrically connected between said center tap and ground, means for impressing an alternating potential across the im-

pedance branches, means connecting the mid point of said alternating potential to ground, said center tap being connected to said impedance branches at a point at which no potential exists between it and ground, means for varying the impedance of one of said impedance branches and key operated means for actuating said impedance varying means.

9. A musical instrument as in claim 8 in which said impedance branches are made of a material
10 whose impedance varies as a function of the voltage impressed on it and said means for varying the impedance includes key controlled means for impressing voltage across the impedance branch whose impedance is to be varied.

10. In a musical instrument, means for generating a high frequency voltage of predetermined frequency, a resonating circuit tuned to said predetermined frequency, a plurality of variable condensers, means to vary the capacities of said condensers in accordance with respective predetermined wave forms and at
20 predetermined frequencies within the audible range, said condensers coupling the output of said high frequency voltage generator to said resonating circuit, means for demodulating the output of said resonating circuit to obtain an electrical wave of predetermined characteristics, and means for converting said demodulated wave
25 into an acoustic wave of predetermined pitch and timbre.

11. In a musical instrument, means for generating a high frequency voltage of predetermined frequency, a resonating circuit tuned to said predetermined high frequency, a plurality of variable condensers, means to vary the capacities of said condensers in accordance with respective predetermined wave forms and at
30 respective predetermined frequencies within the audible range, said condensers adapted to couple the output of said high frequency voltage generator to said resonating circuit, means for selectively rendering respective variable condensers effective as coupling means, means for demodulating the output of said resonating circuit to obtain an electrical wave of predetermined characteristics, means for impressing a low frequency current upon said demodulated electrical wave to obtain a varying demodulated wave of
35 predetermined characteristics, and means for converting said varying, demodulated wave into an acoustic wave having a predetermined pitch and timbre and a tremolo, the frequency of which is determined by the frequency of said low frequency current.

EARLE L. KENT.
LE ROY C. PASLAY.