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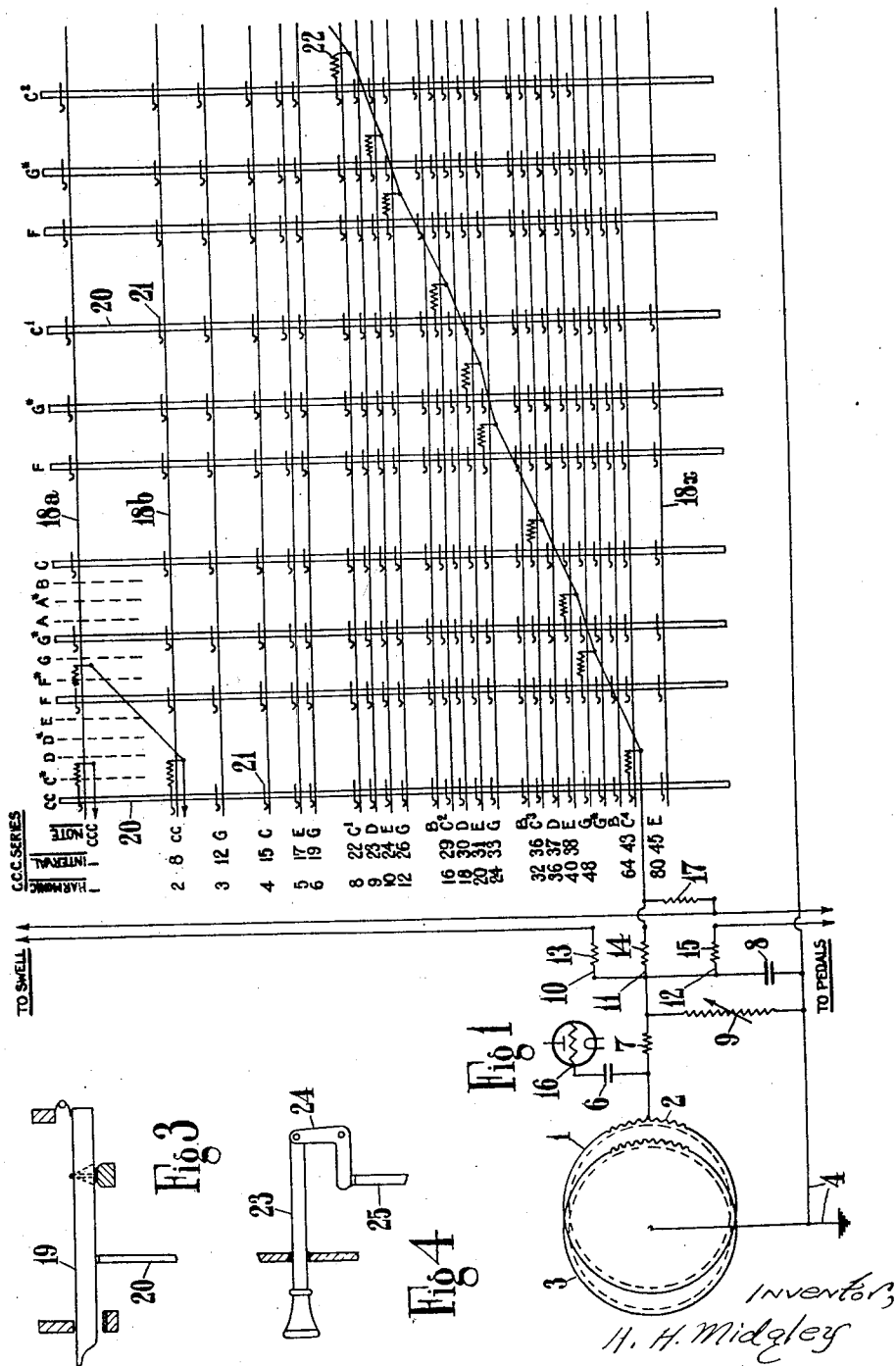
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ELECTRICAL PRODUCTION OF MUSICAL TONES BY ELECTROSTATIC MEANS

Filed Sept. 21, 1937

2 Sheets-Sheet 1



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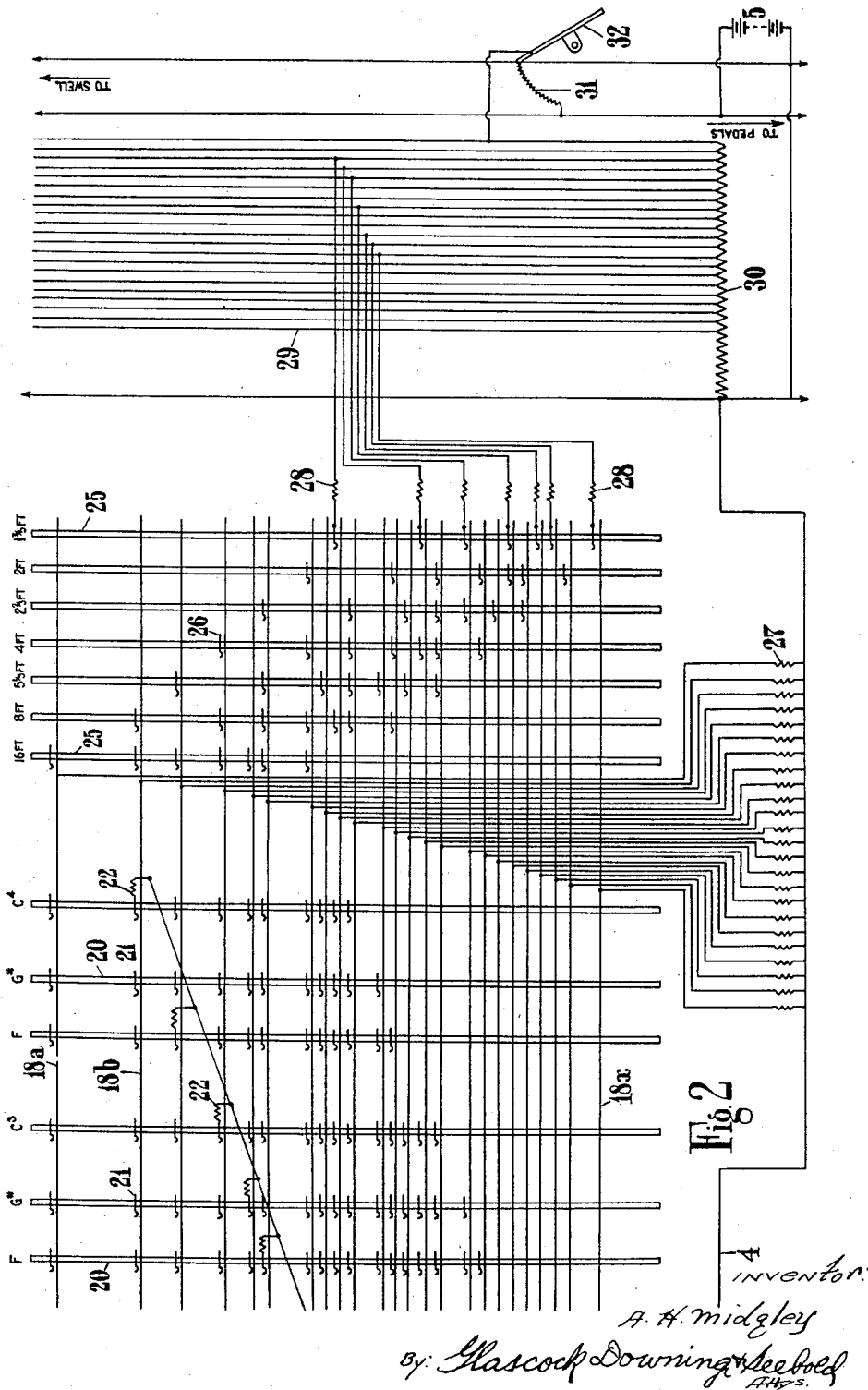
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UNITED STATES PATENT OFFICE

2,207,489

ELECTRICAL PRODUCTION OF MUSICAL
TONES BY ELECTROSTATIC MEANS

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9 Claims. (Cl. 84-1.21)

This invention relates to sound reproducing apparatus of the kind in which an undulating potential is produced electrostatically as by the relative rotation of charged and uncharged electrodes either or both of which is or are of undulating form and in which the charging of the charged electrodes is controlled by the operation of keys controlling key contacts, the arrangement being such that when any key is depressed selected electrodes to be charged for the partials of the note corresponding to the key actuated, are connected to a source of potential, the selection being according to the stop or stops drawn.

When two or more keys are simultaneously pressed or two or more stops are drawn or when two or more keyboards are played simultaneously any one electrode may be connected to a number of potential sources. The resultant potential on the electrode will therefore be the mean of these potentials and therefore the sound produced will not be a true reproduction of the combination of the several tones and notes played simultaneously.

An object of the invention is to devise improved apparatus of a simple character so that one or more manual keyboards and pedal keyboards may be employed and so that various tones may be played in several registers or pitches.

A further object of the invention is to devise suitable apparatus to obtain improved quality of tone when notes are played together, as for example in chords.

In order that the invention may be more clearly understood it will now be described by way of example with reference to the accompanying drawings in which:

Figure 1 shows diagrammatically the lower range of the "great" manual and an electrostatic generator.

Figure 2 shows diagrammatically the upper range of the great manual and the stops associated with this manual.

Figure 3 shows a side elevation (in section) of a playing key.

Figure 4 shows a side elevation (in section) of a draw stop.

Referring now to Figures 1 and 2 which show when taken together the great manual of a musical instrument having for example two manual keyboards designated the swell manual and the great manual and one pedal keyboard, it will be clear from Figure 1 that the electrostatic generator comprises a stationary disc 1 of insulating material to the face of which are secured a number of concentric electrode rings 2 of con-

ducting material, the inner and outer surfaces of each ring 2 being of sine wave formation.

There is provided one ring 2 for each semi-tone of the musical scale and the total number of rings will be dependent upon the number of octaves of the musical scale which it is desired to produce; in the present example five octaves with extra rings for partials of the higher notes. The numbers of undulations of successive rings 2 progress geometrically in the ratio of 1 to the $12\sqrt{2}$ which is the interval of a semi-tone of the tempered musical scale.

A second circular disc 3 provided with concentric electrode rings of exactly similar construction to that already described is adapted to rotate about the axis of the said rings so that the surfaces of both sets of rings are in close proximity. All the rings on the rotating disc are connected together and through the medium of a slip ring and brush are connected to the negative or earth lead 4 which is connected to one pole of the source of current 5 (Figure 2). Each ring of the stationary disc 1 is connected to one terminal of a condenser 6 having a capacity of about .01 to .1 microfarad, the opposite terminals of the condensers being all connected to the grid of the first valve of a suitable thermionic amplifier. Each ring 2 is also connected through a charging resistance 7 of about 5 megohms to one terminal of a condenser 8 the other terminal of which is connected to the negative or earth lead 4. In parallel with the condenser 8 is connected a leak resistance 9. The purpose of this condenser and leak resistance will be hereinafter described.

To the junction of the charging resistance 9 with the condenser 8 are connected the ends 10, 11, 12 of three coupling resistances 13, 14 and 15 respectively, the other end of the coupling resistance 14 being connected to a regulating resistance 17, and also to the end of one or more key resistances which will be more fully described hereafter. The other ends of the resistances 13 and 15 are similarly connected to regulating resistances associated with the swell manual and the pedal keyboard and to the ends of one or more key resistances associated with the said manual and keyboard. The other end of the regulating resistance 17 is connected to the negative or return lead 4.

In the embodiment shown there are associated with the playing keys of the great manual twenty-four bus bars 18a-18x. Each playing key 19 (Figure 3) is adapted when depressed to actuate its associated key switch rod 20, which rod causes movement of a plurality of contacts 21

so as to cause them to make contact with said bus bars. Each contact 21 is connected through a resistance 22 to the appropriate ring 2 of the generator to be charged. It will be clear, therefore, that each ring 2 is connected to the junction of all those key resistances 22 which represent the fundamental or a harmonic of certain notes. In Figures 1 and 2 the ring 2 is adapted to generate a frequency of 2,048 cycles per second and it will be seen that this frequency forms the fundamental (first partial) of the note c4 in 8 ft. pitch and corresponding harmonics of other lower notes in the lower octaves.

There are preferably employed seven partials including the fundamental tone to each note, but it will be clear that a larger number of partials may be employed for each note if desired. Further, stops of seven registers or pitches are also employed, namely 16 ft., 8 ft., $5\frac{1}{2}$ ft., 4 ft., $2\frac{1}{2}$ ft., 2 ft. and $1\frac{1}{2}$ ft. The partials used are the fundamental, second, third, fourth, fifth, sixth and eighth. They are taken from notes in the tempered musical scale. Thus, assuming the 16 ft. fundamental be CCC, the seven harmonics would be CCC, CC, GG, C, E, G, c. The same note is used for different partials in several tones and therefore in the present example the number of bus bars is twenty-four.

It will be clear that when two or more playing keys are depressed in each of which a particular frequency forms the fundamental or a harmonic then the potential of the charged member should rise in accordance with the number of keys depressed and in accordance with the desired intensity of this particular frequency. The leak resistance 9 together with the key switch resistances 22 perform this desired function. In order that the potential across the leak resistance 9 shall increase in proportion to the potential of the bus bars connected when a plurality of playing keys are depressed and so that the greatest additive effect shall be produced it is essential that the value of the leak resistance 9 be less than the individual value of the key switch resistances 22.

Assuming that the values of the resistances 22 are all equal then if X equals the value of a resistance 22 divided by the value of the leak resistance 9 and N equals the number of bus bars connected at any one time to a ring 2 the percentage of the true additive effect of the bus bar potentials on the member will be as follows:

X	N					
	1	2	3	4	5	6
3	100	54	37	28	23	19
5	100	60	43	33	27	23
10	100	66	50	40	33	28
20	100	75	60	50	43	37
50	100	85	75	66	60	55
100	100	91	83	77	71	66
200	100	95	91	87	84	81

It will therefore be seen from the last four lines of the above table that it is possible to obtain a greatly increased additive effect and that when X is (according to the invention) greater than unity and when several keys are depressed simultaneously the potential of the charged member increases substantially with the number of keys depressed and that it is approximately proportional to the addition of the several potentials to which the member may be connected.

The manner in which the bus bars 18a-18x are energized to the necessary predetermined po-

tentials to obtain sounds of different stop pitches or qualities will now be described.

Draw stops 23 (Figure 4) are provided which, through the medium of suitable linkage, for example the bell crank lever 24 operate stop rods 25.

Each stop rod carries switches 26 so disposed as to make contact with certain of the bus bars 18a-18x, so as to produce the correct stop pitch or quality of tone desired. If the first bus bar 18a be used for the fundamental of the 16 ft. pitch then the switches 26 are arranged to make contact as follows:—

Partial	16 ft.	8 ft.	$5\frac{1}{2}$ ft.	4 ft.	$2\frac{1}{2}$ ft.	2 ft.	$1\frac{1}{2}$ ft.
	Number of bus bar						
1	18a	18b	18c	18d	18f	18g	18i
2	18b	18d	18f	18g	18j	18l	18n
3	18c	18f	18h	18j	18m	18o	18p
4	18d	18g	18j	18l	18o	18q	18s
5	18e	18i	18k	18n	18p	18s	18u
6	18f	18j	18m	18o	18r	18t	18v
8	18g	18l	18o	18q	18t	18w	18x

Each bus bar 18a-18x is connected to the negative or earth lead 4 through a resistance 27 (Figure 2) and each stop switch contact 26 is connected to one end of a stop resistance 28 the other end of any one of which may be connected to any one of twenty-one potentiometer bus bars 29. These bus bars 29 are connected to tapping points on a potentiometer resistance 30 one end of which is connected to the positive pole of the source of current 5, which may be a battery, the negative pole of which is connected to the negative or earth return 4.

In order to vary the intensity of the sound produced by the instrument the positive end of the potentiometer 30 may be connected to the positive pole of the source of current 5 through a variable resistance 31 the moving member 32 of which may be conveniently constructed as a pedal to be operated by the foot of the performer, which pedal corresponds to the swell pedal on an organ.

It will be seen from an inspection of the apparatus as above described that the potentials of the twenty-four bus bars 18a-18x will vary according to the combination of stops 23 drawn (and to the chosen bus-bars 29 to which they have been connected to preselect the individual tones of the pitch stops as hereinafter described), and when the playing keys 19 are depressed the rings 2 will be charged to suitable potentials for the desired tone. On rotation of the disc 3 electrical vibrations or an undulating potential will be electrostatically induced in each ring that is charged, and such undulating potential will pass through the condensers connected between the rings and the amplifier and will be amplified and converted into sound waves by the loud speaker. It will also be clear that the charging potential of each ring will depend upon the number of stops drawn and the number of keys depressed in each keyboard.

The condenser 8 associated with each ring maintains the charge on the ring after the key or keys have been released and thereby produces a reverberation or sustaining effect, the length of time of which is governed by the values of the condenser 8 and resistance 9.

The energy of the sound produced will be proportional to the square of the charging potential. Therefore to produce double the sound energy the charging potential must increase 1.414

times, which is equivalent to a gain of 3 decibels.

In previous instruments of this nature (see for example original U. S. Patent No. 1,996,669, Reissue 19,702, September 10, 1935), the charging potential to any one ring 2 is the result of applying a number of potentials to resistances connected in parallel and one member may short circuit several bus bars. The resulting potential is therefore only the mean of these potentials.

In the present invention whenever several potentials are applied to a single electrode they are applied through resistances in parallel and the electrode is always connected through a resistance to the negative or earth lead and as previously indicated the leak resistance in the case of an electrode must be less than each of the parallel key resistances.

I have also found that by correctly proportioning the resistances 27 and 28 it is possible to obtain a potential on the conductor or bus-bar which shall increase in the desired proportion in order to maintain the energy of the harmonic tones at their correct levels either when sounded singly or in combination. The parallel resistances 28 should all be of the same value and as will be shown the value of the coupling resistance 27 between the conductor and the negative lead 4 should be less than that of a single parallel resistance 28.

If N be the number of parallel resistances, R^1 the value of each parallel resistance, R the value of the coupling resistance, then it can be shown mathematically that the gain in decibels is equal to:

$$20 \log_{10} \left(\frac{R^1}{R} + 1 \right) \times N \frac{R^1}{R} + N$$

Therefore in order to obtain the correct potential gain the value of

$$\frac{R^1}{R}$$

should be from 1.5 to 3.0 according to the number of parallel resistances connected simultaneously. In order easily to adjust the power and tone quality of the various stops the potential of the potentiometer bus bars 29 should increase in equal decibel increments. Thus if the increments are 3 decibels then the power of any stop can be increased or reduced by one half by simply connecting each stop resistance 28 to the next higher or lower potential bus bar 29. An individual harmonic in any stop can also easily be altered by a given amount and records can equally easily be kept of the levels of the various harmonics in any tone so that it can be repeated in manufacture.

The resistance of the potentiometer associated with each manual (or pedal keyboard) should be of low value in order that when a number of stops are drawn and keys depressed the increased current shall not appreciably affect the potentials of the potentiometer bus bars 29.

It will be understood that the above described arrangements incorporated in the great manual may be employed for the swell manual and for the pedal keyboard. In the latter case the compass will, as is usual, be much smaller.

Although the invention has been described in its application to a musical instrument in which the electrical vibrations are generated electrostatically and the tempered musical scale is employed both for the fundamental and harmonic tones, I may, however, use the tempered scale

for the fundamental tones and true harmonics instead of tempered harmonics.

Further, the invention is described as employing an electrostatic generator having rotating rings to generate the desired wave forms, but it is to be understood that any other form of generator which is capable of generating undulating potentials of controlled frequency and wave form electrostatically may be employed.

I claim:

1. An electrical musical instrument comprising an electrostatic generator for producing electrical oscillations or undulating potentials of any desired frequencies and wave forms, comprising a plurality of condensers, one electrode of each of said condensers being adapted to be charged, and means for continuously varying the capacity of each of said condensers in accordance with said wave forms, a set of key contacts for controlling the charging of the charged electrodes, a source of potential, a set of controlling resistances and a set of key switch resistances, each electrode to be charged being connected to one pole of the source of potential by one of said controlling resistances, and being connected to each key contact appropriate to such electrode and to the other pole of the source of potential through a key switch resistance which is greater than the controlling resistance employed.

2. An electrical musical instrument comprising an electrostatic generator for producing electrical oscillations or undulating potentials of any desired frequencies and wave forms, comprising a plurality of condensers, one electrode of each of said condensers being adapted to be charged, and means for continuously varying the capacity of each of said condensers in accordance with said wave forms, a set of key contacts for controlling the charging of the charged electrodes, a source of potential, a set of controlling resistances and a set of key switch resistances, one end of each key switch resistance being connected to the appropriate key contact, while the other ends of said resistances are connected together and to the electrode to be charged.

3. An electrical musical instrument comprising an electrostatic generator for producing electrical oscillations or undulating potentials of any desired frequencies and wave forms, comprising a plurality of condensers, one electrode of each of said condensers being adapted to be charged, and means for continuously varying the capacity of each of said condensers in accordance with said wave forms, a set of key contacts for controlling the charging of the charged electrodes, a source of potential, a set of controlling resistances and a set of key switch resistances, each electrode to be charged being connected to one pole of the source of potential by one of said controlling resistances, and being connected to each key contact appropriate to such electrode and to the other pole of the source of potential through a key switch resistance which is greater than the controlling resistance employed, a charging resistance being inserted in the conductor connecting the controlling resistance to the generator electrode to be charged.

4. An electrical musical instrument comprising an electrostatic generator for producing electrical oscillations or undulating potentials of any desired frequencies and wave forms, comprising a plurality of condensers, one electrode of each of said condensers being adapted to be charged, and means for continuously varying the capacity of each of said condensers in accordance with said

wave forms, means for supplying charging potentials to a set of bus-bars associated with the playing keys of the instrument, a plurality of stops each of which actuates a plurality of switches to energise said bus-bars to predetermined potentials from a source of current and means associated with said switches for controlling, proportioning and combining the sound energy of the various harmonic tones when a plurality of keys are played simultaneously and a plurality of stops are drawn.

5. An electrical musical instrument comprising an electrostatic generator for producing electrical oscillations or undulating potentials of any desired frequencies and wave forms, comprising a plurality of condensers, one electrode of each of said condensers being adapted to be charged, and means for continuously varying the capacity of each of said condensers in accordance with said wave forms, means for supplying charging potentials to a set of bus-bars associated with the playing keys of the instrument, and switching means for energising selected bus-bars to predetermined potentials corresponding to the required pitch or combination of pitches whereby musical sounds of the desired quality in the required pitch or combination of pitches are obtained when a plurality of keys are depressed simultaneously.

6. An electrical musical instrument comprising an electrostatic generator for producing electrical oscillations or undulating potentials of any desired frequencies and wave forms, comprising a plurality of condensers, one electrode of each of said condensers being adapted to be charged, and means for continuously varying the capacity of each of said condensers in accordance with said wave forms, means for supplying charging potentials to a set of bus-bars associated with the playing keys of the instrument, a plurality of stops each of which actuates a plurality of switches to energise said bus-bars to predetermined potentials from a source of current, said bus-bars being connected to one pole of the source of potential through resistances while any potentials supplied to said bus-bars are applied through parallel resistances which are all of the same value and each of which is greater than each of said first-mentioned resistances.

7. An electrical musical instrument comprising an electrostatic generator for producing electrical oscillations or undulating potentials of any desired frequencies and wave forms, comprising a plurality of condensers, one electrode of each of said condensers being adapted to be charged, and means for continuously varying the capacity of each of said condensers in accordance with said wave forms, means for supplying charging potentials to a set of bus-bars associated with the playing keys of the instrument, a plurality of

stops each of which actuates a plurality of switches to energise said bus-bars to predetermined potentials from a source of current and a potentiometer having tapping points being shunted across the source of current, the tappings being connected to said switches through resistances while further resistances are connected between each of the bus-bars and one pole of the source of current and having a variable resistance controlled by a pedal connected in series with said potentiometer for varying the voltage across said potentiometer.

8. An electrical musical instrument comprising an electrostatic generator for producing electrical oscillations or undulating potentials of any desired frequencies and wave forms, comprising a plurality of condensers, one electrode of each of said condensers being adapted to be charged, and means for continuously varying the capacity of each of said condensers in accordance with said wave forms, means for supplying charging potentials to a set of bus-bars associated with the playing keys of the instrument, a plurality of stops each of which actuates a plurality of switches to energise said bus-bars to predetermined potentials from a source of current and a potentiometer being shunted across said source of current, the tappings being connected to stop switches through resistances, while further resistances are connected between each of the bus-bars and one pole of the source of current, the value of each stop resistance being from 1.5 to 3 times the value of each resistance connecting a bus-bar to one pole of the source of current.

9. An electrical musical instrument comprising an electrostatic generator for producing electrical oscillations or undulating potentials of any desired frequencies and wave forms, comprising a plurality of condensers, one electrode of each of said condensers being adapted to be charged, and means for continuously varying the capacity of each of said condensers in accordance with said wave forms, a source of current, a plurality of bus-bars, a plurality of stops, a plurality of stop switches actuated by each of said stops to contact selected ones of said bus-bars, means for energising said stop switches to predetermined potentials, a plurality of playing keys, a plurality of switches actuated by each key to contact said bus-bars, resistances connected to each of said switches, a conductor connecting the resistances associated with selected ones of said playing key switches together, a coupling resistance connected to said conductor, a charging resistance connected to said coupling resistance and to the electrode to be charged, a regulating resistance connected to the junction of said coupling and charging resistances and to one pole of the source of current.

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