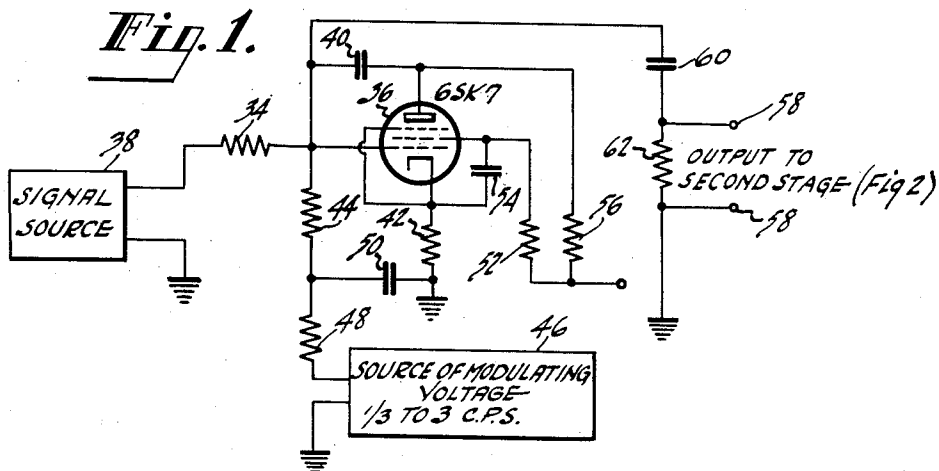
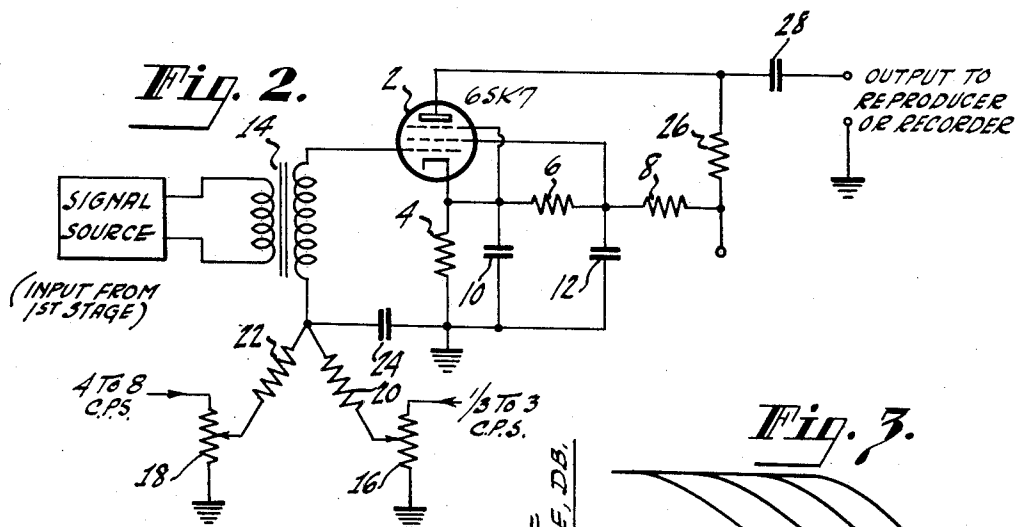
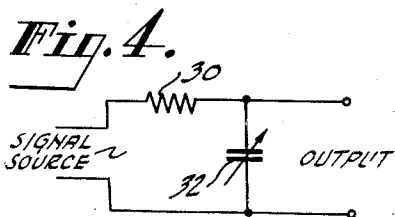
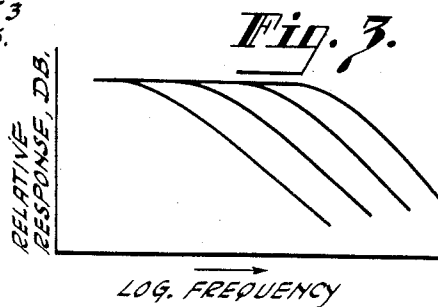


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ELECTRONIC SWINGING BELL

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ELECTRONIC SWINGING BELL

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This invention relates generally to electronic musical instruments and more particularly to apparatus and methods for producing a voltage output which may be translated into a musical tone simulating that of a swinging bell.

An ordinary bell produces sounds having certain distinctive characteristics which may be classified as follows:

a. Loud and prominent overtones, which are inharmonically related in frequency,

b. Long decay time,

c. "Beating" between overtones which are close together on the frequency scale, and

d. Space-pattern shifting when the bell swings.

When a bell swings, two audible changes are apparent to the listener. One of these is loudness variation and the other is timbre variation. The latter variation is a result of the directional characteristics of bells as acoustical radiators.

Previous electronic musical instruments of the carillon type have produced tones having characteristics (a) and (b) listed above. However, these instruments, by having inharmonicity of overtones, have shared with conventional carillons the characteristic of producing unpleasant discords which occur when two bells are sounded together or when one bell is accompanied by an organ having harmonic overtones or by a piano having overtones which are very nearly harmonic. The present invention includes means for producing voltage outputs which may be translated into audible sounds having characteristics (c) and (d) above. These means may be used either in conjunction with generators having voltage outputs which may be translated into audible signals having characteristics (a) and (b) or with generators having other characteristics. For example, a generator of harmonically related overtones having long decay time could advantageously be used in connection with the present invention, giving a tone which simulates ordinary bells in respects other than inharmonicity but which can be used in producing harmonics.

Even in carillons, where the bell generally remains stationary, and the hammer is actuated by a key or lever, a low frequency beat similar to a swing effect occurs. This is caused by the motion of the nodal pattern around the bell as it vibrates.

The primary object of the present invention is to provide methods and apparatus which will produce voltage outputs which may be translated into musical tones having the characteristics of swinging bells.

A more particular object is to provide methods

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and apparatus which will produce voltage outputs which, when translated into audible sounds, will simulate, in a bell-like signal, both the beating effect resulting from interference between nearby frequency components and the variations in intensity resulting from the oscillation or swinging of a bell.

Another object of this invention is to provide methods and apparatus which will produce voltage outputs that, when translated into audible sounds, will simulate bell-like tones by producing periodic variations in timbre as well as loudness.

Another object of the invention is to provide a method and apparatus for obtaining a bell-like tone which can be used for harmony effects.

These and other objects will be more apparent and the invention will be more readily understood from the following specification when taken in connection with the accompanying drawings of which:

Fig. 1 is a schematic diagram of a circuit arrangement for producing voltage outputs which can be translated into musical tones in which the harmonic content or timbre is periodically varied,

Fig. 2 is a circuit arrangement for amplitude modulating a signal source within two different frequency ranges,

Fig. 3 is a family of frequency-response curves obtainable with the circuits of Figs. 1 and 4, and

Fig. 4 is one embodiment of a circuit which may be used to produce a periodically variable frequency response characteristic.

Referring first to Fig. 2, a variable- μ (remote cutoff) tube 2 is employed as a variable-gain amplifier. Any of several tube types may be used, for example, 6K7, 6SK7 or 6BA6. Suitable cathode and screen potentials are applied to the tube through a voltage divider in which the bleeder current is large compared with the various electrode currents. The voltage divider comprises a resistor 4, connected between the cathode of the tube and ground, a resistor 6, connected between the cathode of the tube and the screen grid, and a resistor 8, connected between the B+ supply and the screen grid. A by-pass capacitor 10 is connected in parallel with the resistor 4 and another by-pass capacitor 12 is connected between the junction of resistors 6 and 8 and ground.

A plate load resistor 26 is also connected between the B+ supply and the anode of tube 2. A coupling capacitor 28 may be utilized to couple the anode of the tube to the next stage.

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The input signal, which may be a voltage signal of complex waveform, having a long time decay characteristic, preferably, though not necessarily, such as obtained from a signal source as indicated at 38 and then modified by a circuit such as shown in Fig. 1, to be more particularly described later, is applied through a coupling transformer 14 to the grid circuit of tube 2. The outputs of two low-frequency signal generators (not shown), one of which may generate a signal of $\frac{1}{3}$ to 3 cycles per second and the other of which may generate a signal of 4 to 8 cycles per second, are connected to potentiometers 16 and 18, respectively, the settings of which control the relative (and absolute) magnitudes of the modulating signals.

The output voltages of the potentiometers 16 and 18 are applied through resistances 20 and 22 to a grid-circuit by-pass capacitance 24, the reactance of the latter at low modulating frequencies being small compared with that of resistances 20 and 22.

The series resistances 20 and 22, in combination with the shunt capacitance 24, produce a low pass filtering action between the low frequency generators and the grid of tube 2, thereby making the modulating waveforms more nearly sinusoidal. In addition, with resistances 20 and 22 high in value compared with the reactance of capacitor 24 at the modulating frequencies, the modulating voltage across capacitor 24 is proportional to the sum of the two potentiometer settings without the resultant effectiveness of one potentiometer being materially influenced by the setting of the other.

An inspection of the above described circuit indicates that there are three voltage sources in series acting between the grid and cathode of tube 2. These are the steady biasing voltage across resistance 4, the modulating voltage across capacitance 24 and the signal voltage induced in the secondary winding of the input coupling transformer 14.

In a variable-mu (remote cutoff) tube, the transconductance is easily controlled through variation of the control-grid bias. Insofar as the signal frequency is concerned, the grid bias, at any time, is the instantaneous sum of the modulating voltage across capacitance 24 and the steady voltage across resistance 4. Thus, the transconductance of the tube, and, hence, the amplification of the stage, varies in accordance with the magnitude of the modulating signals across capacitance 24. Thus, the output voltage at signal frequency across anode resistance 26 is amplitude modulated simultaneously at two low-frequency rates.

The lower of these two rates, $\frac{1}{3}$ to 3 cycles per second, is chosen to approximate the natural frequency of swing that a real bell would have. The swing frequency of a bell depends essentially on the distance between its axis of suspension and its center of mass and is independent of the mass and the amplitude of swing. Most bells, with the exception of the very small and the extremely large, would have swinging frequencies between $\frac{1}{3}$ and 3 cycles per second. Therefore, these frequencies have been chosen to illustrate the approximate limits for the lower modulating frequency. It is intended, however, that the scope of the invention shall cover all natural swinging frequencies except those of very small bells, which do not exhibit all of the characteristic tonal qualities of the larger members of the family.

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The other frequency rate, 4 to 8 cycles per second, has been chosen to agree with the observed frequencies of "beat" of a single swinging bell or of two or more swinging bells sounding together. "Beat" frequencies lower than 4 cycles per second are scarcely noticeable to the listener while "beat" frequencies above 8 cycles per second produce sound effects unpleasant to the human ear.

Due to the nonlinearity of the device that makes possible this modulation, a multiplicity of frequency components occur in the output for each component of signal frequency input. For each single frequency input signal, the output would contain as predominant components the original signal, sum and difference frequencies due to each modulating frequency, the modulating frequencies themselves, and modulation products of these low frequencies. The largest components in the output will be signals at modulating frequencies, due to the relative predominance of these signals in the grid circuit. It is necessary, of course, to remove these sub-audio components before application to the reproducer or recorder with which the device is to be used. By using sinusoidal modulating signals, a better ratio can be obtained between the amplitudes of the lowest frequency signal components of importance and the undesired output components resulting from cross-modulation.

Variations are possible in the circuit illustrated in Fig. 2, without departing from the spirit or scope of the invention. For example, a triode connection of the tube 2 could be used although, of course, the gain would be lower. Instead of the input coupling transformer 14, there could be utilized a resistance-capacitance type of input coupling circuit. Also, the capacitance 24 could be replaced with a resistance if the modulating waveforms were already of satisfactory shape.

Using the circuit shown schematically in Fig. 2 and as described above, one may thus modulate a signal simultaneously at two rates. For example, in electronic bells, the sound amplitude variation coincidental with the swinging of the bell is produced along with a complex pulsating phenomenon suggesting the beating between the various bell tones.

As previously pointed out, in simulating the sound of swinging bells, attention must also be given to the apparent change in timbre of the bell tones coincidental with the swinging of the bells. More precisely stated, the brilliance of the tone seems to be dependent upon the instantaneous position of the bell. In producing this effect electronically, the assumption is made that a satisfactory variation in tone brilliance is obtainable with a family of frequency-response curves such as shown in Fig. 3. The negative slope approached by each member of this curve family may be 6 db./octave, a filter characteristic produced with relative simplicity.

To produce a family of curves lying between the arbitrary extremes indicated in Fig. 3, one may employ a basic circuit arrangement of the type illustrated schematically in Fig. 4. Here, the signal source, which may be the basic electronic bell tone, is applied through a series resistance 30 to a variable shunt capacitance 32. The output voltage at signal frequencies is less than the input voltage, by an amount varying with frequency in a fashion represented by one response curve of Fig. 3. The particular curve produced; i. e., the position of the response curve

in the frequency spectrum, is dependent upon the ratio of the impedances involved. Thus, by periodically varying the shunt capacitance 32, one may vary the position of the frequency response curve between the desired limits. The particular type and repetition rate employed depend, of course, upon the specific results desired. In producing electronic swinging bell tones, one may use, for the same reasons previously described in connection with Fig. 2, a rate of the order of $\frac{1}{3}$ to 3 C. P. S. and a time-capacitance variation of simple waveform. This desired effect may be brought about utilizing apparatus such as illustrated schematically in the circuit diagram of Fig. 1. In this figure, the resistance 34 corresponds to the series resistance 30 of Fig. 4 and the vacuum tube 36 with its associated components forms the variable shunt capacitance corresponding to variable capacitance 32 of the apparatus of Fig. 4.

Referring now more particularly to the circuit of Fig. 1, a signal from a signal source 38 is applied through series resistor 34 to the control grid of a variable-mu pentode 36 which may be a 6SK7. In the broadest sense, the signal source 38 may be a generator of any audio frequency signals of complex nature. But if the tones of swinging bells are to be closely simulated, the voltage signals which are generated should at least have the long decay characteristics associated with the audible tones emanating from naturally swinging bells and, if the audible sounds into which the voltage output is to be later translated are to be pleasing to the human ear, the signal source 38 should also either be a generator which produces harmonically related overtones or one which produces inharmonically related overtones. The latter may include apparatus such as described in the literature, including those found in any of U. S. Patents 2,261,345, 2,261,346 or 2,321,366. An external capacitance 40 is shunted across the anode and the control grid of the tube. To vary this input capacitance in a suitable manner, an essentially sinusoidal low-frequency modulating voltage is applied to the control grid in series with the biasing voltage across cathode resistance 42 connected between the cathode and ground.

Instead of having separate sources of $\frac{1}{3}$ to 3 C. P. S. frequency applied through resistance 46 and potentiometer 16, it is preferable to use a single source for both connections so that they will act in a coordinated fashion. This single source may be the source 46 which should then also have an output connection to potentiometer 16.

The low-frequency modulating voltage is applied from a source 46 through a resistance 44. It may be passed through a low-pass filter comprising a resistance 48, connected between the source of modulating voltage 46 and resistance 44, and a capacitance 50 connected between ground and a point between the resistances 44 and 48. The low-pass filter may be dispensed with if the low-frequency, gain-modulating voltage source is already of suitably pure waveform.

A screen grid dropping resistance 52 is connected between the B+ supply and the screen grid, while a screen by-pass capacitance 54 is connected across the cathode and screen grid of the tube. A plate load resistance 56 may also be connected between the B+ supply and the anode of the tube. These components perform the conventional functions usually associated therewith.

Between the control grid of the tube and the output terminals 58 of the amplifier, there may be connected a coupling capacitor 60, while between the output terminals, themselves, there may be connected a coupling resistance 62. These coupling components should be chosen so as to pass the lowest signal frequency of importance and yet discriminate against the sub-audio modulating signals and harmonics thereof.

Consider the tube circuit of Fig. 1 as a high gain voltage amplifier with appreciable capacitance between anode and control grid. The interelectrode capacitance may be paralleled by an external capacitance 40 as required. Due to the normal amplifying properties of the stage, a phase reversal occurs between the alternating grid and anode voltages. For example, a positive excursion of grid voltage causes a negative excursion of the anode voltage, so that the instantaneous voltage across the grid-to-anode capacitance is equal to $(A+1)$ times the grid signal voltage, where A is the voltage amplification of the stage from grid to anode. Thus, the principal charge on the grid is due to the anode voltage, since A is ordinarily much greater than unity. There is, of course, an additional charge on the grid due to the signal voltage applied to the capacitance from grid to cathode (ground). Hence, the total input capacitance of the amplifier is:

$$C_{in} = C_{gk} + (A+1)C_{gp}$$

To the extent that $A \gg 1$ and $AC_{gp} \gg C_{gk}$,

$$C_{in} \cong AC_{gp}$$

Thus, the input capacitance of the amplifier is nearly proportional to the voltage amplification, and may be made as large as desired by increasing capacitance 40.

As previously indicated, the input capacitance is varied by applying an essentially sinusoidal modulating voltage to the control grid of the tube in series with the biasing voltage across cathode resistance 42. Due to the employment of a variable-mu tube, the periodic variations in bias cause periodic variations in the amplifying capability of the tube, thereby resulting in an input capacitance varying more or less in accordance with the low-frequency, gain-modulating signal.

The essential result of modifying the original voltage signal, received from source 38, by the circuit of Fig. 1, is to vary periodically the relative prominence of the high-frequency components of the complex wave form. The audible result, when the output voltage at terminals 58 is translated into audible sounds, is to produce changes in timbre such as occur in swinging bells.

As previously indicated, the output passed through terminals 58 may then be applied to the coupling transformer 14 where, in that part of the circuit shown in Fig. 2, the voltage signals are further modulated such that, when the modulated signals are translated into audible sounds, there is produced a "beating" effect as occurs between overtones which are close together on the frequency scale, and also "swinging" effects.

The output from the circuit of Fig. 2 may be applied to a recording device such as a magnetic recorder or disc record, or it may be applied directly to a loudspeaker or to a further stage of amplification and then to a loudspeaker to produce musical tones audible to a listener.

The final result is the production of musical sounds having the essential characteristics of

tones produced by swinging bells and this makes possible the manufacture of an electronic carillon having greatly improved sound output.

Various modifications and substitutions other than those already indicated may be made in the above described apparatus without departing from the spirit of the invention.

Instead of the pentode 2, a pentagrid tube, such as a 6L7 or 6SA7, can be used. In this case, the input signal is applied to the signal grid while the modulating voltages are applied to the injection grid. There could also be used, in connection with the circuit shown in Fig. 2, two amplification stages with one of the modulating voltages being applied to each stage. This introduces the advantage of decreasing cross modulation between the two modulating signals since the first modulating signal can be filtered out electrically between stages before the other modulating signal is applied.

Another variation which may be used is the entire omission of the stage, illustrated in Fig. 1, since, in some cases, the loudness variation accomplished by the circuit of Fig. 2 is adequate in itself to produce a desired effect without the added variation in timbre produced by a circuit such as illustrated in Fig. 1.

It is also possible to simulate fairly well some of the swinging bell sound characteristics by using only the circuit shown in Fig. 1 and omitting that of Fig. 2.

Although sinusoidal modulating signals are preferred, since they produce the best simulation of a swinging bell and since they are more easily separated from the audio frequency signals which are desired to be retained, interesting effects may be produced by the use of other waveforms such as reverse saw-tooth waves.

There have thus been described improved apparatus and improved methods for obtaining novel sound effects which may be controlled to closely resemble those produced by swinging bells. The improved apparatus may thus be utilized in providing an electronic carillon having a sound output which closely resembles that of an ordinary carillon and which may be installed in a relatively small space at a moderate cost compared with that of a carillon of cast metal bells.

We claim as our invention:

1. In an apparatus for producing a musical tone the combination of means for producing a complex voltage signal having long time decay characteristics, means for applying said voltage signal to a modifying circuit comprising a series resistance-shunt capacitance combination, resistance-shunt capacitance combination, means for periodically varying said shunt capacitance at a low-frequency rate of $\frac{1}{3}$ to 3 cycles per second, thereby varying the frequency response of said resistance-capacitance combination, and means for amplitude modulating the thus modified signal voltage with two different low-frequency voltages, one of said two voltages having a frequency of about $\frac{1}{3}$ to 3 cycles per second and the other of said two voltages having a frequency of about 4 to 8 cycles per second.

2. Apparatus according to claim 1 including means for applying said two different low-frequency voltages simultaneously.

3. In an apparatus for producing a musical tone the combination of means for producing a complex audio frequency voltage signal having long time decay characteristics, means for applying said voltage signal to a modifying circuit

comprising a series resistance-shunt capacitance combination, means for periodically varying said shunt capacitance at a low frequency of $\frac{1}{3}$ to 3 cycles per second, means for amplitude modulating the thus modified voltage signal with two different low-frequency voltages, one of said two voltages having a frequency of about $\frac{1}{3}$ to 3 cycles per second and the other of said two voltages having a frequency of about 4 to 8 cycles per second, and means for filtering out from the modulated voltage sub-audio frequencies introduced by the application of said low-frequency voltages.

4. In an apparatus for producing a musical tone the combination of means for producing a complex audio frequency voltage signal having long time decay characteristics, means for applying said voltage signal to a modifying circuit comprising a series of resistance-shunt capacitance combination, means for periodically varying said shunt capacitance at a low frequency of about $\frac{1}{3}$ to 3 cycles per second to vary the frequency response of said resistance-capacitance combination, means for applying the thus modified voltage signal to the grid circuit of a variable-gain amplifier, and means for amplitude modulating the output voltage of said amplifier with two different low-frequency voltages of predetermined magnitude, one of said two voltages having a frequency of about $\frac{1}{3}$ to 3 cycles per second and the other of said two voltages having a frequency of about 4 to 8 cycles per second.

5. Apparatus according to claim 5 including also means for removing sub-audio frequencies from the modulated output voltage of said variable-gain amplifier.

6. In an apparatus for producing a musical tone simulating that of a swinging bell the combination of means for producing a complex audio frequency voltage signal having long time decay characteristics, means for amplitude modulating said voltage signal with two different low-frequency voltages, one of said two voltages having a frequency of about $\frac{1}{3}$ to 3 cycles per second and the other of said two voltages having a frequency of about 4 to 8 cycles per second.

7. A method of producing a musical tone comprising producing a complex audio frequency voltage signal having long time decay characteristics, amplitude modulating said signal at a frequency rate of about $\frac{1}{3}$ to 3 cycles per second to simulate loudness variations and amplitude modulating said signal at a frequency rate of about 4 to 8 cycles per second to simulate beating between frequency components closely spaced in the frequency spectrum.

8. A method according to claim 7 which includes also amplifying said signal while periodically varying certain frequency components of said signal to simulate the varying tonal qualities characteristic of swinging bells.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,104,616	Fyler	Jan. 4, 1938
2,292,757	Hathaway	Aug. 11, 1942
2,340,001	McKellip	Jan. 25, 1944