

July 24, 1951

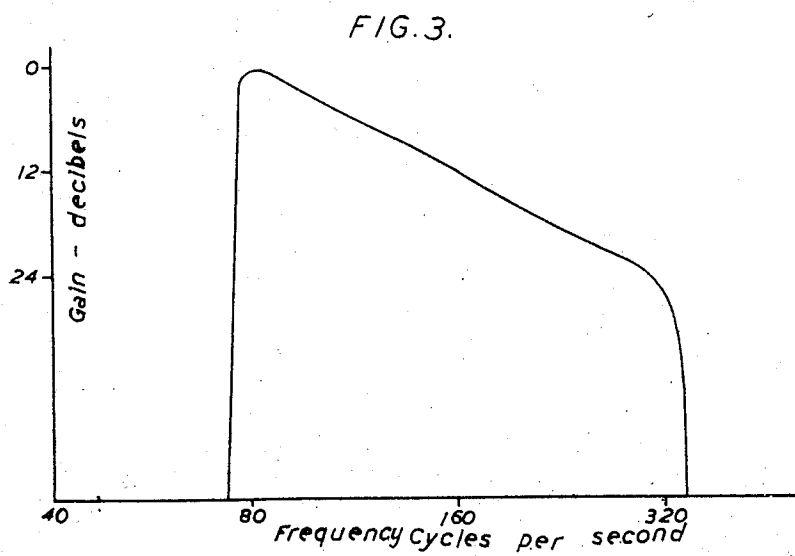
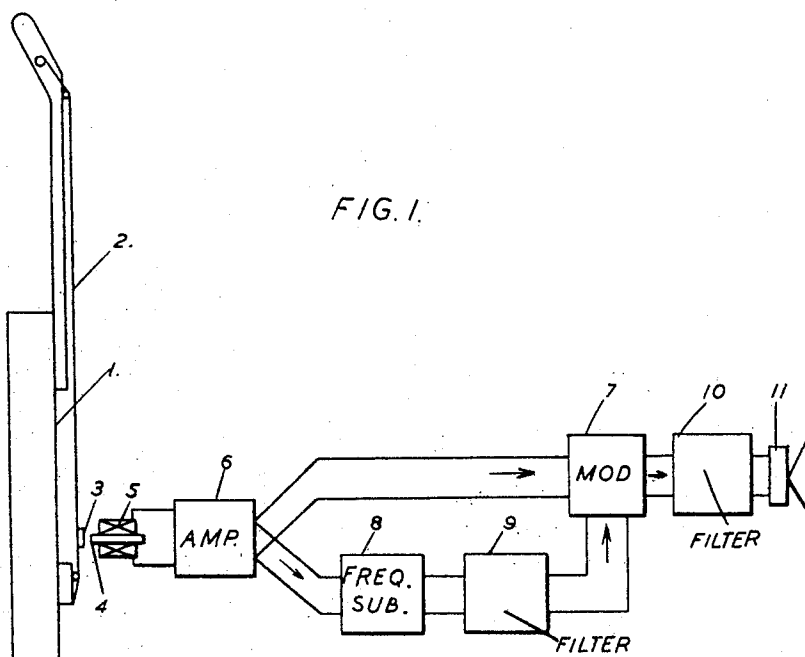
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2,561,349

ELECTRICAL MUSICAL INSTRUMENT

Filed Feb. 7, 1947

3 Sheets-Sheet 1



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July 24, 1951

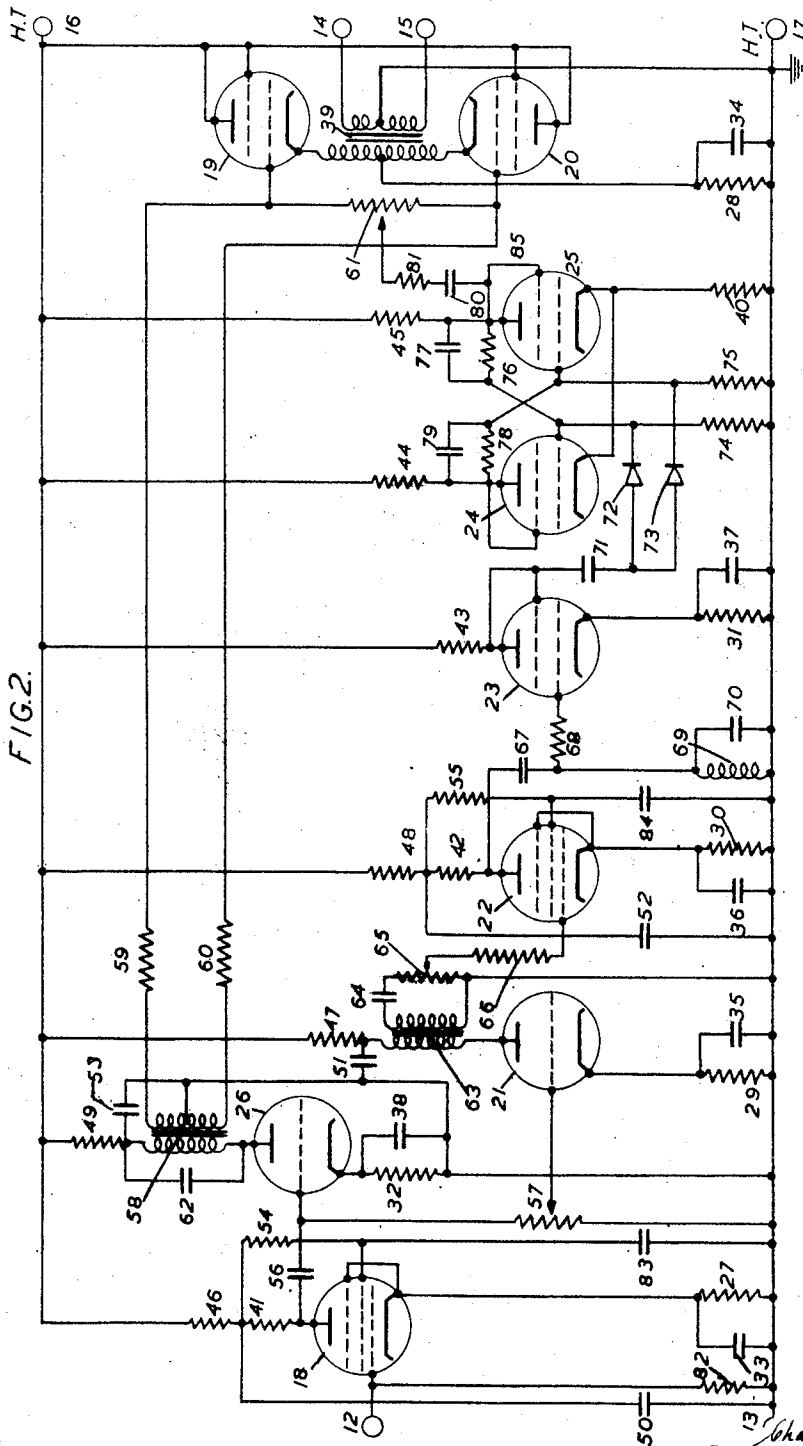
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ELECTRICAL MUSICAL INSTRUMENT

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3 Sheets-Sheet 2



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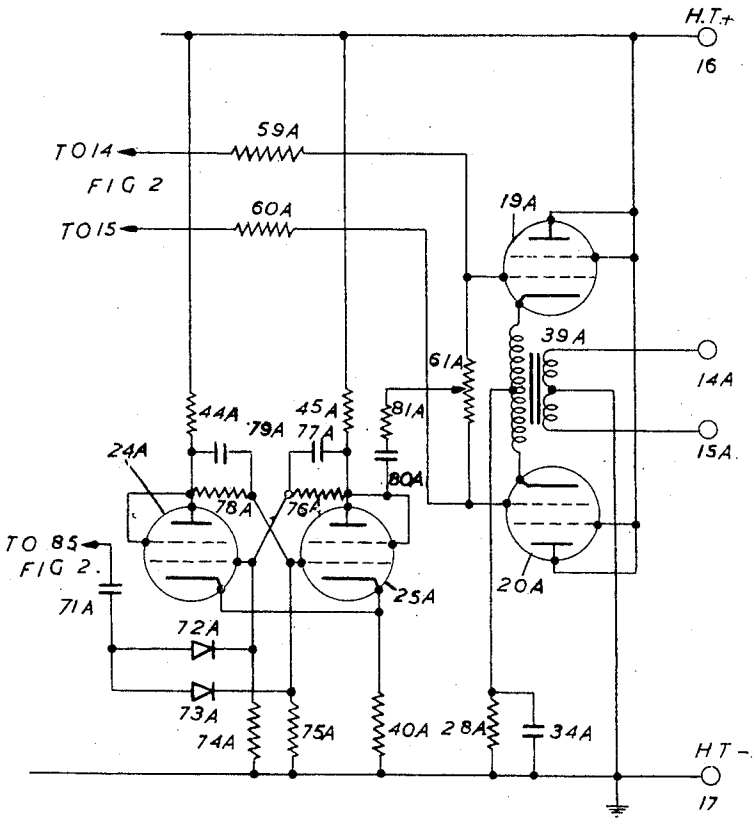
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ELECTRICAL MUSICAL INSTRUMENT

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3 Sheets-Sheet 3

FIG. 4.



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ELECTRICAL MUSICAL INSTRUMENT

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3 Claims. (Cl. 84-1.14)

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The present invention relates to frequency subdividing arrangements used in electrical sound reproducing systems, with particular reference to electrical musical instruments.

It is well known that conventional musical instruments adapted to produce low bass notes are very often inconveniently bulky because of the length required for the vibrating element to enable it to produce the low frequencies. In stringed instruments, the associated sounding board is also necessarily of large dimensions. Such large instruments are particularly inconvenient when portability is a consideration, for example in the case of instruments for dance bands, and they often present technical difficulties associated with the execution of the music, which may require considerable physical effort. These large instruments are also expensive, and there is another objection which applies more particularly to stringed instruments, namely, that the strings have to be unduly thickened in order to permit the low notes to be obtained with strings of practicable length, and the damping is therefore excessive and the tone quality is poor.

In connection with dance bands, there is now an increasing demand for the use of a strong bass to the music, and it is therefore the principal object of the present invention to provide electrical means for obtaining low frequency bass notes from instruments of conveniently small dimensions.

It is known to provide a guitar with a microphone connected to an amplifier and loud speaker by means of which the tones of the instrument may be considerably increased in power.

The principal object of the present invention is to provide an electric transmission system which may be applied to a musical instrument so that tones one or more octaves lower than that natural to the vibrating element of the instrument are obtained. The transmission system may, however, have other applications. This object is achieved according to the invention by providing an electric arrangement for subdividing the frequency of an acoustic wave comprising a transducer for converting the acoustic wave into an input electric wave, means for applying the said electric wave to subdividing means in such manner as to produce an output wave having a frequency which is an integral submultiple of the frequency of a component of the said input electric wave, and means for applying the output wave to a utilisation device.

The well known double stability type of electric multivibrator circuit employing thermionic valves is capable of sub-dividing the frequency of an applied wave by various ratios. In particular it is capable of control over a wide range of frequencies to give a subdivision of two. If

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therefore, the output from a microphone attached to a guitar be applied (after amplification if necessary) to synchronise a multivibrator of this type, an output tone of half frequency can be obtained, and the output wave will have a large harmonic content which could be modified by filters or other suitable means to produce a desired quality of tone. In this way low bass notes could be derived from strings of half the usual length. It is obvious that the same principle is applicable to wind and percussion instruments.

It is to be noted, however, that the output level of a controlled multivibrator is substantially constant and is independent of the input level; in other words, the performer could not vary the loudness of the notes produced, although he could vary their pitch as desired. This could be overcome by the use of an output or expression control at the output of the multivibrator; but there is an objection to this simple arrangement namely that the multivibrator would "cut out" at a certain low input level and would suddenly cease to give any output at all. This has been found to produce a somewhat unpleasant effect. According to another feature of the invention therefore, the original and subdivided waves are applied to a modulator, the output of which will then contain a half frequency wave which has an amplitude proportional to the amplitude of this wave before subdivision. The performer can now vary the loudness of the output tone by varying the strength with which the string is plucked, struck or bowed in substantially the same way as in the unmodified instrument.

The output of the modulator may also contain the natural frequency of the string, and if the cut-out level of the control of the multivibrator be arranged to be sufficiently low the disagreeable effect of the cutout will be substantially hidden because of the presence of the original string tone.

In the case of an instrument such as a guitar in which two or more strings may be played simultaneously it would be possible to provide each string with its own microphone or pick-up and multivibrator, means being provided to prevent excessive interference between each microphone and the strings corresponding to the others. It is, however, not possible that an artistic result could be obtained by providing a guitar with one microphone and multivibrator, and sounding two or more strings simultaneously.

It is, however, not easy to predict what frequency would be obtained from the output of the single multivibrator, and such frequency might easily change during the sounding of any combination of strings.

In the case of an instrument like the organ in

which the loudness of the note obtained from any pipe is not under the control of the performer, low bass notes could be quite satisfactorily obtained from pipes of moderate dimensions without the necessity for any modulating arrangements.

It may be added that in the case of a multi-stringed instrument, the subdivided output from one of the strings may be used to modulate the normal output from any or all of the other strings.

Having given a general account of the possibilities of the invention, a detailed explanation of a preferred embodiment will be given with reference to the accompanying drawings in which:

Fig. 1 shows a block schematic diagram of the arrangement;

Fig. 2 shows a detailed schematic circuit diagram of the frequency subdivider and modulator of Fig. 1;

Fig. 3 shows a suitable gain-frequency characteristic for the amplifier which controls the multivibrator in Fig. 2; and

Fig. 4 shows a modification of Fig. 2.

Fig. 1 shows diagrammatically a guitar 1 (or other stringed instrument) having a string 2 on which is mounted a small iron plate 3. Close to the plate 3 is arranged the iron core 4 of an electromagnetic pickup device in which the magnetic circuit is energised by a permanent magnet or by an electromagnet (neither of which is shown), and having a winding 5 connected to an amplifier 6. It will be understood that the pick-up device is only diagrammatically shown and may take any known form.

The output of the amplifier is divided into two paths one of which goes directly to the modulator 7, and the other path includes a frequency subdivider 8, followed by a filter 9, which is not essential and may be omitted. The output of the filter 9 is applied to the modulator 7, to be modulated with the original output from the amplifier 6. The modulation products obtained at the output of 7 are passed through a second filter 10 (which also is not essential and may be omitted) to a loud speaker 11.

When the string 2 is set into vibration, the pick-up will generate waves of the fundamental frequency f of the string together with its harmonics. If, as is preferred, the modulator 7 is a balanced modulator, the waves applied to the filter 10 will contain the following components:

(a) The original musical wave generated by the string or other primary generator.

(b) The harmonic components of the original wave (including the fundamental component), all reduced in frequency by half the fundamental frequency of the original wave.

(c) The harmonic components of the original wave (including the fundamental component), all increased in frequency by half the fundamental frequency of the original wave.

(d) Various other components due to modulation of the original wave by harmonics of the constant amplitude multivibrator output.

One of the components (b) is the desired half-frequency wave, the amplitude of which is proportional to that of the original wave, and is therefore under the control of the operator.

It may be desirable in some cases, to provide some other type of modulator. For example, a two-valve balanced modulator in which each valve has two control grids could be used. In this case the original wave may be applied in push-pull to one grid of each valve and the sub-

divided wave in push-pull to the remaining grids, output being taken from a parallel connection of the two anodes. This modulator would give all the above components except (a).

Alternatively, a single-side-band type of modulator could be used, of the kind described in United States Patent No. 2,248,252. This can be arranged to give various component outputs, for example only (b) above, or only (c) above, or (a) and (b) or (a) and (c), or any of these with the corresponding (d) components.

The guitar 1 may be replaced by any other stringed or other type of instrument, and the pick-up may take any not necessarily electromagnetic form appropriate to the instrument. For example, it may be any of the known types of microphone, or a gramophone pick-up mechanically coupled in a suitable way to the vibrating element. In the case of an instrument with steel strings, a pick-up of the kind illustrated could, if desired, be used without providing the small plate 3.

It is evident, also, that if a microphone be used, the place of the musical instrument may be taken by a singer or speaker, and the voice will be considerably modified and deepened by the arrangement of Fig. 1, and the results may have artistic value.

It is evident also that the loud speaker 11 could be replaced by a sound-recording arrangement, or by a line leading to the speech input equipment of a broadcasting system, or by any other utilisation device.

Fig. 2 shows the detailed circuit of a preferred arrangement according to the invention, the circuit covering elements 6, 7 and 8 of Fig. 1, the filters 9 and 10 being omitted. The winding 5 of the pick-up will be connected to terminals 12 and 13, and the loud speaker 11 to terminals 14 and 15. Terminals 16 and 17 are for the positive and negative terminals of the high tension operating source. Terminal 17 is connected to terminal 13, and is preferably also connected to ground.

The amplifier 6 of Fig. 1 is represented by a pentode 18, and the modulator 7 comprises two similar power tetrode valves 19 and 20 arranged in push-pull fashion. The frequency subdivider comprises a two-stage amplifier constituted by valves 21 and 22, and an amplitude limiting stage (valve 23) which controls a multivibrator formed from two cross-connected valves 24 and 25. The path connecting the amplifying valve 18 with the modulator valves 19 and 20 includes an amplifying valve 26.

The cathodes of the valves 18, 19 and 20, 21, 22, 23 and 26 are biased conventionally by series resistances 27, 28, 29, 30, 31 and 32 shunted respectively by by-pass condensers 33, 34, 35, 36, 37 and 38. In the case of the valves 19 and 20, the bias network is connected to the centre point of the primary winding of the output transformer 39 which connects the two cathodes. The secondary winding of this transformer is connected to the output terminals 14 and 15, and has its centre point connected to ground. The cathodes of valves 24 and 25 are biased by means of a resistance 40. It is not necessary to provide a by-pass condenser to shunt this resistance since the sum of the cathode currents of the two valves does not vary appreciably.

The valves 18 and 22 to 25 (inclusive) provided with anode load resistances 41 and 45 (inclusive) and decoupling arrangements are also provided for valves 18, 21, 22 and 26 including series anode

resistances 46, 47, 48 and 49 with corresponding condensers 50, 51, 52 and 53 connected to ground. Since the valves 19 and 20 are arranged in a cathode follower circuit, their anodes are connected directly to terminal 16. The screen grids of valves 18 and 22 are polarised through series resistances 54 and 55 respectively, and those of valves 19, 20, 23, 24 and 25 are directly connected to the corresponding anodes. The suppressor grids of the valves 18 and 22 are connected as usual to the corresponding cathodes.

The input terminal 12 is connected directly to the control grid of the amplifier valve 18, the anode of which is connected through a blocking condenser 56 to the control grid of the amplifier valve 26, and also to ground through a high resistance potentiometer 57. The primary winding of an output transformer 58 is connected in series with the anode of the valve 26, and the terminals of the secondary winding are respectively connected through equal high resistances 59 and 60 to the control grids of the modulator valves 19 and 20, which grids are connected together by a high resistance potentiometer 61. The primary winding of the transformer 58 is shunted by a condenser 62, and the secondary winding has a centre tap connected to ground.

The control grid of the valve 21 is connected to the movable contact of the potentiometer 57, and the primary winding of the output transformer 63 is connected in series with the anode of this valve. The secondary winding has one terminal connected to ground and the other through a condenser 64 to a grounded potentiometer 65, the movable contact of which is connected through a high resistance 66 to the control grid of the valve 22. The anode of valve 22 is connected through a condenser 67 and a resistance 68 to the control grid of the limiting valve 23. The junction point of the elements 67 and 68 is connected to ground through an inductance 69 shunted by a condenser 70. These last mentioned elements together with certain of the others already mentioned control the frequency characteristic of the two-stage amplifier, as will be explained more fully later.

The anode of the limiting valve 23 is connected through a differentiating condenser 71 and through respective rectifiers 72 and 73 to the control grids of the valves 24 and 25, which grids are also connected to ground through respective differentiating resistances 74 and 75. The rectifiers may be diodes, or any other suitable type, such as selenium or copper oxide rectifiers.

The control grid of the valve 24 is also connected to the anode of the valve 25 through a resistance 76 shunted by a condenser 77, and the control grid of the valve 25 is connected to the anode of the valve 24 through a resistance 78 shunted by a condenser 79. The elements 72, 74, 76 and 78 should preferably be respectively equal to the elements 73, 75, 77 and 79, and the two valves 24 and 25 should be similar. The anode of the valve 25 is connected through a blocking condenser 80 and a high resistance 81 to the movable contact of the potentiometer 61 connecting the control grids of the valves 19 and 20.

The usual grid resistance 82 is provided for the valve 18. The by-pass condensers for the screen grids of valves 18 and 22 are shown at 83 and 84, respectively.

The waves of fundamental frequency f are applied to the valves 26 and 21 in parallel and are applied directly to the control grids of the

valves 19 and 20 in push-pull. The condenser 82 is provided to improve the response of the amplifier over part or the whole of the frequency band for which it is designed and may also be omitted in some circumstances.

The amplifier including the valve 18 and the two valves 21 and 22 should preferably have a frequency characteristic of the type shown in Fig. 3. In this figure the frequency scale of abscissae is logarithmic, and the decibel scale of ordinates is uniform. It is assumed that the fundamental frequency generated by the guitar string may lie between the limits 80 and 320 cycles per second. The preferred gain characteristic of the amplifier shown in Fig. 3 therefore has a maximum at 80 cycles, corresponding to a gain arbitrarily designated zero; below 80 cycles, the gain should fall very steeply so that lower frequencies are substantially cut off. In the range between 80 cycles and 320 cycles the gain should fall uniformly at the rate of about 12 decibels per octave. After 320 cycles the gain should again fall very steeply so that higher frequencies are substantially cut off.

This characteristic may be obtained by suitably proportioning the elements 41, 42, 56, 57 and 64 to 73 inclusive. The coupling elements 46, 56 and 57 will also affect the frequency characteristic of the path of the waves through the valve 26, and should be designed so that the fall in gain at frequencies down to 80 cycles per second is not excessive. The elements 69 and 70 are intended to produce the cut-off below 80 cycles per second, and should be parallel resonant at about 90 cycles per second, for example. These elements could alternatively have been placed between the valves 21 and 22.

The output of the valve 22 is applied to the limiting valve 23 with such excessive amplitude that flat topped waves with very steep flanks are produced at the output of the limiting valve, which is appropriately biased by the elements 31, 37. The flat topped waves are differentiated by the condenser 71 acting through the rectifiers 72 and 73 with resistances 74 and 75, so that a pair of very short positive pulses are simultaneously applied to the control grids of both the valves 24 and 25. These pairs of pulses occur once per cycle for the waves generated by the guitar, the corresponding negative pulses being eliminated by the rectifiers.

The two valves 24 and 25 form a multivibrator device having two stable conditions in each of which one valve is conducting and the other cut off. If it be assumed that the valve 25 is cut off, then the anode voltage is high and is determined by the values of the resistances 45, 76 and 74. The control grid voltage of the valve 24 is also high, and the valve 24 will be conducting, so that the anode voltage is low, and therefore the control grid voltage of valve 25 is also low. The potential of the two cathodes will be determined by the resistance 40. When a positive pulse is applied to the control grid of the valve 25 through the rectifier 73, this valve suddenly conducts, and the anode voltage suddenly falls. This sudden change is communicated through the resistance 76 to the control grid of the valve 24 which is thereby cut off. The potential of the control grid of the valve 24 rises to a value determined by the resistances 45, 76 and 74. This value should however not be sufficient to unblock the valve 24. The multivibrator now remains in this condition until the next positive pulse arrives through

the rectifier 72, when the valve 24 is rendered conducting and valve 25 is cut off in a similar manner, the circuit being back in its original condition, where it remains until the next positive pulse is received. It will be understood that although positive pulses are applied to both valves simultaneously, the valve which is already conducting will not be directly affected, as it cannot pass more current.

The condensers 77 and 79 are not absolutely necessary; they are of small capacity and are provided to compensate for the stray capacity which shunts the resistances 74 and 76. This stray capacity tends to limit the speed of operation of the multivibrator.

It follows that the multivibrator makes one complete oscillation for the two cycles of the wave applied at terminal 12 so that the frequency f of that wave is divided by two.

The waves of frequency $f/2$ obtained from the anode of the valve 25 are applied in parallel to the control grids of the modulator valves 19 and 20 through the potentiometer 61, the movable contact of which may be adjusted to balance the modulator in the usual ways. The original waves of frequency f are also applied in push-pull to the two grids from the valve 26, through the resistances 59 and 60 which are provided to prevent short circuiting the control grids to ground when they are operated in parallel from valve 25. Thus the output at terminals 14 and 15 will contain modulation products including frequencies $f/2$, f and $3f/2$ and others harmonically related thereto. Thus, for example, when the guitar string produces a frequency of 80 cycles per second, the output at terminals 14 and 15 includes frequencies of 40 cycles, 80 cycles, and others harmonically related. Furthermore, the amplitudes of all these products are proportional to the amplitude of the original wave, so that the player can vary the loudness of the bass note by varying the force with which the string is sounded, in the usual way. Furthermore, when the amplitude of the original wave falls below the value at which pulses can be produced at the output of the valve 23 for switching the multivibrator, the original frequency f still persists in the output of the modulator even though the half frequency $f/2$ has disappeared, so that the "click" produced by the cutting out of the multivibrator is masked.

The potentiometers 57 and/or 65 may be used to set the circuit so that the multivibrator just operates at some appropriate minimum level of the waves derived from the guitar.

The shape of the characteristic curve shown in Fig. 3 is determined by the following considerations. The reduction in gain at the rate of 12 decibels per octave is desirable in order to attenuate harmonics of the original wave so that they will be likely to modify the waveform in such manner that the multivibrator is irregularly switched. The cut-off below 80 cycles is arranged in order that low frequency effects may be entirely prevented from affecting the multivibrator, as it is found that very unpleasant effects may thereby be produced. The cut off above 320 cycles is provided for similar reasons.

It will be understood that the frequency range between the two cut-off frequencies will usually be determined by the maximum and minimum frequencies likely to be produced from the guitar string concerned.

It is possible according to the invention to obtain subdivision by factors other than two. It

is obvious, for example, that the subdividing process described with reference to Fig. 2 can be repeated by providing two circuits similar to Fig. 2 and by connecting the output of the first to the input of the second, the only difference between the two circuits being that the second will be designed for frequencies one half those for which the first is designed, and this process may be repeated as often as desired. By this means subdivision by any power of two is possible.

An alternative method of subdividing by four, for example, is indicated in Fig. 4, which shows apparatus to be added to Fig. 2. The additional apparatus comprises a multivibrator and a modulator, both of which are exactly similar to those shown in Fig. 2, and the component elements are given the same designation numbers with the addition of the letter A.

As indicated, the condenser 71A is connected to the point 85 of Fig. 2, which is the anode of the valve 25, and the control grids of the valves 19A and 20A are connected through the resistances 59A and 60A to the output terminals 14 and 15 of Fig. 2, the loud speaker or other utilisation device being connected to terminals 14A and 15A of Fig. 4.

It will be seen that in this case, the additional multivibrator will operate at half the frequency of the original one shown in Fig. 2 that is, at a frequency of $f/4$. The half frequency output $f/2$ obtained from the original modulator of Fig. 2 is then modulated with the frequency $f/4$ in the additional modulator of Fig. 4 in exactly the same way. If necessary, of course, a suitable filter (not shown) may be inserted in the connection between the terminals 14 and 15 of Fig. 2 and the modulator of Fig. 4 in order to isolate the frequency $f/2$.

Still another arrangement is possible by inserting in Fig. 2 an additional exactly similar multivibrator (not shown) between the valve 23 and the condenser 71.

In this case the output of the valve 25 contains the frequency $f/4$ together with its harmonics, one of which is the frequency $3f/4$, and so the modulator products at the output at terminals 14 and 15 will clearly include the frequency $f/4$.

This process can evidently be extended by providing any number of multivibrators in tandem, producing a subdivision by 2^n where n is any integer. The output will then contain the frequency $f/(2^n)$, derived from the component of frequency $(2^n - 1)f/(2^n)$.

As explained with reference to Fig. 1, suitable filters (not shown) may be inserted in Fig. 2 between the multivibrator and the modulator or between the terminals 14 and 15 and the loud speaker or other utilisation device (not shown in Fig. 2) by means of which the quality of the tones produced may be controlled.

It has already been pointed out that the modulating arrangement is provided in order to overcome the lack of expression control, and also the unpleasant effects of the cutting out of the multivibrator. When neither of these objections hold, as in the case of tones from organ pipes which are of constant unalterable amplitude, the modulator valves 19 and 20, and the amplifier valve 26 are not necessary and can be omitted together with the associated circuit elements. The output of the valve 25 will then be applied (possibly through a suitable filter not shown) to an appropriate amplifier, and thence to the loud

speaker or the like, neither of which are shown in Fig. 2. The pick-up device may in this case be a suitable microphone (not shown) connected to terminals 12 and 13, and arranged opposite the mouth of the pipe, for example. In this way, a base note of say 32 cycles per second, normally requiring an open pipe 16 feet long or a stopped pipe 8 feet long would be obtained from an open pipe 8 feet long or a stopped pipe 4 feet long using one stage of subdividing by two; or these lengths could be reduced by any desired amount by using larger subdividing factors in any of the ways which have been explained.

In the case of the single frequency tones from organ pipes, the amplifier preceding the multivibrator could probably be greatly simplified: one fairly sharply tuned amplifying stage preceding the valve 23 might be sufficient.

In a particular arrangement of Fig. 2 according to the invention, and having a frequency characteristic similar to Fig. 3, the component elements had the values given in the following table:

Resistances:

54, 55, 57, 61, 65, 66, 74, 75,	
76, 78, 82	ohms
59, 60, 81	do
41, 42	do
46, 47, 48, 49, 68	do
43, 44, 45	do
40	do
28	do
27, 29, 30, 31, 32	do
	500,000
	250,000
	200,000
	100,000
	50,000
	25,000
	2,200
	1,000

Condensers:

33, 34, 35, 36, 37, 38	microfarads
50, 51, 52, 53	do
70	do
83, 84	do
62	do
56, 64, 67, 80	do
71	do
77, 79	do
	50
	8
	1
	0.5
	0.05
	0.01
	0.0007
	0.0005

Inductance: 69 henrys 4

Some of the possible applications of the invention are given below:

1. A small electric guitar possibly having one or more buttons or switches enabling one or more low frequency octaves to be obtained therefrom.

2. A bass drum of very small dimensions.

3. An electric organ in which a small number of pipes or other primary generators of small dimensions are required for the whole range of the instrument. Each key of the manuals would be associated with one of these primary generators either directly or through a subdivision system according to the invention.

4. A piano with a very few strings on similar lines.

5. A violoncello adapted to produce the same range of tones as a double bass.

6. A bass trumpet possibly not larger than the ordinary cornet.

7. Modification of the singing voice by the use of a loud speaker system including frequency subdivision and modulation.

It will be understood that many of the details of the circuits and arrangement which have been described are capable of variation in a number of ways known to those skilled in the art.

What is claimed is:

1. An electric arrangement comprising a musical instrument having a vibratory element adapted to generate an acoustic tone having a given

frequency, a transducer adapted to derive an input electrical wave of the given frequency from the said tone, subdividing means controlled by the said wave for generating an output wave of a frequency which is an integral submultiple of the given frequency, means for applying said input wave and said output wave of subdivided frequency to a utilization device, said subdividing means including a plurality of two-condition multivibrator devices arranged in a tandem series, each of which except the first is adapted to be synchronized by the preceding multivibrator, the first multivibrator being synchronized by the input wave, the arrangement being such that an integral frequency subdivision is produced by each multivibrator, a modulator, means for applying thereto the input wave and also the fundamental or components of the wave of subdivided frequency at the output of the last of the series of multivibrators, and means for deriving the said output wave from said modulator.

2. An electric arrangement comprising a musical instrument having a vibratory element adapted to generate an acoustic tone having a given frequency, a transducer adapted to derive an input electrical wave of the given frequency from the said tone, subdividing means controlled by the said wave for generating an output wave of a frequency which is an integral submultiple of the given frequency, means for applying said input wave and said output wave of subdivided frequency to a utilization device, said subdividing means including a plurality of two-condition multivibrator devices arranged in a tandem series, each of which except the first is adapted to be synchronized by the preceding multivibrator, the first multivibrator being synchronized by the input wave, the arrangement being such that an integral frequency subdivision is produced by each multivibrator, a first modulator, means for applying thereto the input wave and also the fundamental component of the wave of subdivided frequency at the output of a particular one of the multivibrators not being the last one of the series, a second modulator, means for applying to said second modulator a wave of subdivided frequency derived from the output of said first modulator, means for applying to said second modulator the fundamental of the wave of further subdivided frequency at the output of said second multivibrator following the said particular multivibrator in the series, and means for deriving the said output wave from said second modulator.

3. An arrangement according to claim 2 in which said series of multivibrators is preceded by an amplifier adapted to pass waves having substantially only those frequencies included between two specified limits.

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