April 20, 1965 R. B. SCHRECONGOST 3,179,812

SINE WAVE DIVIDER FOR ELECTRICAL MUSICAL INSTRUMENTS

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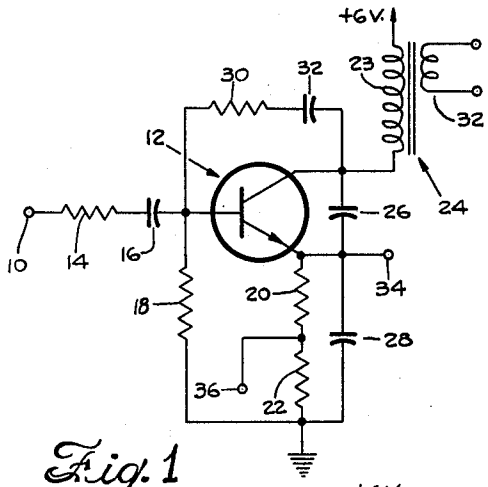


Fig. 1

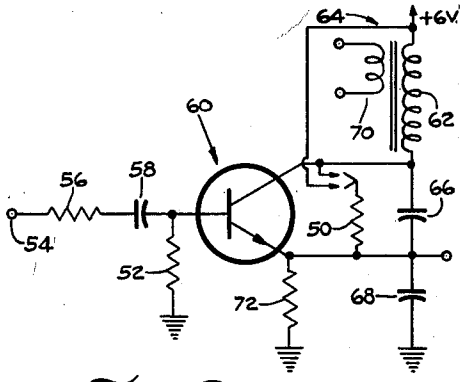


Fig. 2

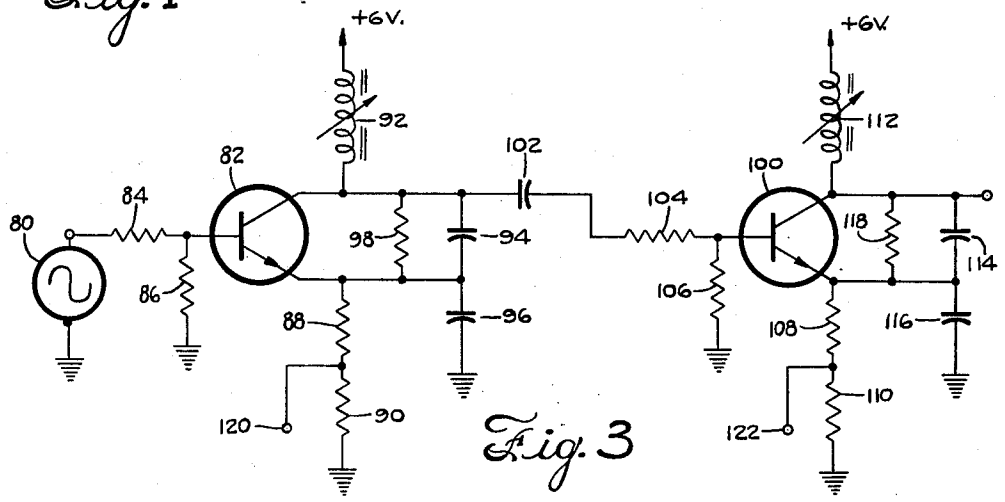


Fig. 3

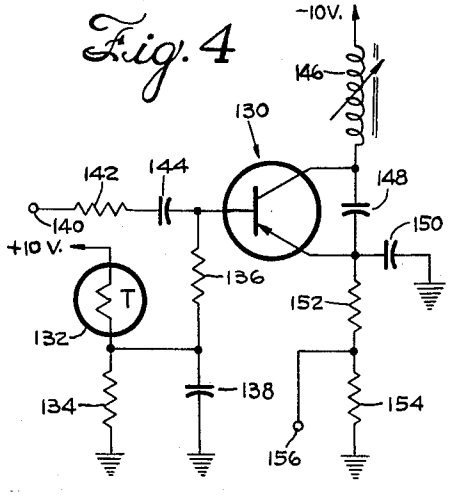


Fig. 4

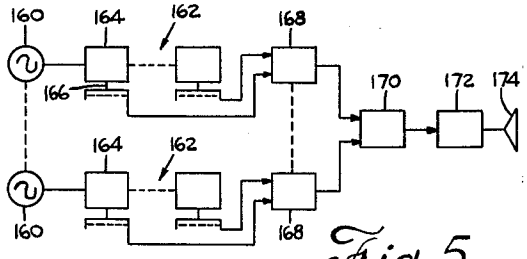


Fig. 5

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SINE WAVE DIVIDER FOR ELECTRICAL MUSICAL INSTRUMENTS

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This application relates generally to improvements in electronic musical tone generators for use in musical instruments, such as organs, and more particularly to a tone generator including an improved cascaded frequency divider network, each section of which comprises an improved transistorized sine wave divider section.

In musical instruments of the type shown in United States Patent No. 1,956,350, issued April 24, 1934 to Laurens Hammond, each musical tone signal is produced by the synthesis of the fundamental tone with various proportions of its harmonics. Each of the partial signals is preferably a relatively distortionless sine wave of desired pitch so that the composite signal comprises only those octavely related signals in the desired relative amplitudes. The musical impression exhibited by this organ technique has become very popular, and as a result there have been attempts to design a similar system with electronic oscillators without too disadvantageous a cost problem. The patent is incorporated herein by reference at if it were set forth in complete detail.

With the advent of the transistor in the last decade, there has been a desire to make use of the compactness, ruggedness, and long life chracteristics of the transistor in an electric organ which exhibits the same musical impression as one constructed according to the Hammond patent.

Accordingly, it is a primary object of the present invention to provide an improved, low cost electronic transistorized tone generator for an electric organ in which each of the complex musical tone signals is produced by the synthesis of the fundamental tone with various proportions of its harmonics, which generator is stable and reliable in operation and low in cost.

It is another object of the present invention to provide a musical tone generator comprising a plurality of master oscillators each of which is connected to and drives a transistorized cascaded frequency divider network in which each divider produces a sine wave with a relatively small harmonic content and in which stable operation of the dividers is assured, even with a substantial drift in the frequency of the master oscillator, without appreciable attenuation of the output signals. Each master oscillator has an output frequency corresponding to one of the tones of the tempered musical scale in the highest octave. Each divider in a network connected to a tone generator then produces an output signal of the same tone but one octave lower than the preceding stage which drives it.

It is another object of the present invention to provide an improved transistor sine wave divider which is low in power consumption and relatively stable with variations in ambient temperature.

It is another object of the present invention to provide an improved transistorized sine wave divider which is temperature and voltage stable whereby inexpensive components may be utilized in the circuit.

Other objects and the many features of the invention will be evident upon a perusal of the following description taken in conjunction with the accompanying drawings in which:

FIG. 1 illustrates one stage of a frequency divider embodying the invention;

FIG. 2 illustrates another embodiment of the invention;

FIG. 3 illustrates several stages of a frequency divider embodying the principles of the invention;

FIG. 4 illustrates one stage of a frequency divider embodying the principles of the invention and including temperature compensating means; and

FIG. 5 is a block diagram of a musical instrument employing the improved divider circuit.

FIG. 1 shows one embodiment of the improved sine wave divider. Signals from a master oscillator or from a preceding divider stage are applied to an input terminal **10** and are fed to the base of a transistor **12** by way of a coupling resistor **14** and a capacitor **16**. A resistor **18** is connected between the base and ground and a pair of series-connected resistors **20** and **22** are connected between the emitter and ground. The collector is connected to a positive six-volt battery supply by means of the primary winding **23** of a transformer **24**.

The primary winding and a capacitive divider network comprising capacitors **26** and **28**, connected between the collector and ground, form a parallel resonant circuit. The values of the capacity and the inductance of the parallel resonant circuit are selected so that their resonant frequency is equal to that of the desired output frequency of the divider circuit. A resistor **30** and a capacitor **32** provide a negative feedback circuit between the collector and the base, the resistor **30** preventing self oscillation of the divider section. The capacitive divider provides a regenerative feedback action between the collector and the emitter.

When the first cycle of an input frequency is applied to the divider stage of FIG. 1, the transistor will begin conducting. As the transistor begins to conduct, the parallel resonant circuit comprising the inductor **24** and the capacitive divider will initiate a cycle of oscillation at its resonant frequency which is approximately one half of the input frequency. During the second half of the cycle of oscillation of the parallel resonant circuit, the feedback circuit, comprising the resistor **30** and the capacitor **32**, which improves stability and prevents sustained oscillations at the resonant frequency, will cut off the transistor even though the second cycle of the input frequency is applied to the base. At the end of its cycle of oscillation, the resonant circuit and its driving transistor are conditioned for a second cycle of operation under the control of the next succeeding cycle of input frequency. The output signal is taken from the secondary **32** of the transformer. The signal for driving the next succeeding divider stage is taken from the terminal **34** at the junction between the capacitors **26** and **28**.

The gain of the signal level in each divider stage can be made relatively high, whereby only a small portion of the output signal is required for driving the succeeding stage with equal signal levels being derived from each of the stages.

This circuit will provide a sine wave of half the frequency of the input signal with a very low harmonic content. It has been assumed in the preceding description of FIG. 1, however, that the voltage level of the input signals is such that the divider stage will not be overdriven; and, therefore, a relatively distortionless sine wave cycle of oscillation will occur in the resonant circuit. However, the divider stage may be overdriven by signals of higher voltage intensity, in which event a substantially distorted wave will appear in the parallel resonant circuit. It has been found that, with a relatively small value resistor **22** and a substantially larger resistor **20** in the emitter circuit, output signals may be taken from the junction **36** between the resistors which will have a relatively distortionless sine wave with minimum harmonic content.

Typical values for the components in the circuit of FIG. 1 are as follows:

Resistor 14	ohms	22,000
Resistor 18	do	47,000
Resistor 20	do	6,800
Resistor 22	do	100
Resistor 30	do	300,000
Capacitor 16	microfarads	.0039
Capacitor 26	do	.022
Capacitor 28	do	.1
Capacitor 32	do	.015
Transistor 12		2N1101

With the above circuit values, a 2800 c.p.s. input signal of .45 volts R.M.S. produces a 1400 c.p.s. output signal across the primary winding in the order of 4 volts R.M.S.

The embodiment of FIG. 2 is similar to that of FIG. 1 except that a resistor 50 and a base resistor 52 are effective to prevent self oscillation in the divider stage. The resistor 50 is connected to the emitter and to either the collector or the positive power supply terminal. Thus, the divider of FIG. 2 includes an input signal terminal 54, a coupling resistor 56, and a coupling capacitor 58 connected to the base of a transistor 60. The collector is connected to a positive potential by the primary winding 62 of a transformer 64. The collector is also connected to ground by means of a capacitive divider comprising capacitors 66 and 68.

The emitter is connected to ground by a resistor 72. Output signals may be taken from a secondary winding 70 of the transformer 64. When the output is derived from the transformer, the level of the input signals must not overdrive the transistor. However, as in the embodiment of FIG. 1, the transistor may be overdriven and the output signal taken from the emitter circuit in a manner substantially the same as in FIG. 1. The output wave form of the embodiment of FIG. 2 is even more free of harmonic content than that of FIG. 1.

Typical values for the components of FIG. 2 which have provided satisfactory operation are as follows:

Resistor 50	ohms	100,000
Resistor 52	do	47,000
Resistor 56	do	22,000
Resistor 72	do	6,800
Capacitor 58	microfarads	.0056
Capacitor 66	do	.027
Capacitor 68	do	.1
Transistor 60		2N1101

With these values, a 3600 cycle input signal of 1.2 volts R.M.S. produced an 1800 cycle output signal of 5.5 volts R.M.S. across the primary winding 70.

If the output signal is taken from the emitter circuit as in FIG 1, and if the divider stage is overdriven, the divider stage maintains stable frequency division of a 3600 cycle input signal even when the resonant circuit, formed by capacitors 66 and 68 and winding 62, is adjusted in frequency from 1770 cycles to 1970 cycles. As a result, this circuit will maintain stable frequency division with an appreciable shift in the driving frequency, which is of particular importance in electronic organ tone generators because only the frequencies of the master oscillators which drive the cascaded divider stages need be adjusted; and this stability of operation is, so far as is known, lacking in all previous attempts at transistorized sine wave division.

FIG. 3 discloses another embodiment of the invention which shows a master oscillator 80 coupled to the base of a transistor 82 by means of a coupling resistor 84. A base resistor 86 connects the base to ground. The emitter is connected to ground by a pair of series connected resistors 88 and 90. The collector is connected to a positive source of voltage by an adjustable inductance 92 and is connected to ground by a capacitive divider comprising capacitors 94 and 96. As in the embodiment of FIG. 2, a resistor 98 is connected between the collector and emitter and cooperates with the base resistor 86 to prevent self oscillation of the divider section. The output from the collector is coupled to the base of a transistor 100 in a second divider stage by means of a coupling capacitor 102 and a resistor 104.

The base of the second divider stage is connected to ground by means of a base resistor 106 and the emitter is connected to ground by means of resistors 108 and 110. The collector is connected to a positive source of voltage by an adjustable inductor 112, is connected to ground by capacitors 114 and 116, and is coupled to the emitter by a resistor 118.

In the embodiment of FIG. 3, each of the divider stages is preferably overdriven by its input signals, and therefore the oscillation in the parallel resonant circuits comprising the inductors and the capacitive dividers will be substantially distorted. Accordingly, the output signals which are to be utilized in the organ circuits for energizing the speakers will be taken off the terminals 120 and 122 which are connected to the junctions between the resistors in the emitter to ground circuits. A capacitive coupling between the stages in the embodiment of FIG. 3 provides economies in the circuit without my adverse effects upon the output signals.

This particular embodiment has been found to provide unusually low harmonic content; in a typical circuit, the second harmonic content being in the order of 3.5%, and the third harmonic content in the order of .3%. In addition, the circuits maintain stable frequency division with a drift in frequency as high as 15%, depending upon the input drive level signals. The dividers maintain stable frequency division with a shift in the order of one semitone (approximately 6% change in frequency) with a loss in output signal level of only one decibel and with a frequency drift of two semitones, stable frequency division was maintained with only a two decibel drop in signal level.

In this embodiment, however, it will be noted that the major portion of the signal developed by the capacitive divider sections is utilized to overdrive the next succeeding stage, and therefore the output signal level for energizing the speakers has a substantially lower value whereby additional amplification is necessary.

Typical values for the components of FIG. 3 are as follows:

Resistor 84	ohms	100,000
Resistor 86	do	47,000
Resistor 88	do	6,800
Resistor 90	do	100
Resistor 98	do	100,000
Capacitor 94	microfarad	.1
Capacitor 96	do	.68
Capacitor 102	do	.01
Resistor 104	ohms	100,000
Resistor 106	do	47,000
Resistor 108	do	6,800
Resistor 110	do	100
Resistor 118	do	100,000
Capacitor 114	microfarads	.22
Capacitor 116	microfarads	1.2
Transistors 82 and 100		2N1101

The signal generator provided a 440 cycle input signal at 2.5 volts R.M.S. The output signals for driving succeeding stages were 3.5 volts R.M.S. at the collector of transistor 82 and 3.7 volts R.M.S. at the collector of transistor 100. The 220 cycle output signals at terminal 120 were 9 millivolts R.M.S., and the 110 cycle signals at terminal 122 were 7.9 millivolts R.M.S.

In the embodiment of FIG. 4, a special circuit for applying a bias cutoff voltage to the base of the transistor 130 of the divider is utilized to prevent self oscillation by the divider due to the cut off bias variation in the transistor with temperature change. The previous circuits

utilized NPN transistors, and the use of a PNP transistor by way of example is shown in FIG. 4. Thus a positive ten volt potential is applied across a thermistor 132 and a resistor 134. The junction between the resistor and thermistor is connected to the base of the transistor 130 by a base resistor 136, and is also connected to ground potential by a capacitor 138. The thermistor has a high negative temperature coefficient and therefore, as the ambient temperature changes, the thermistor varies in resistance to change the voltage applied to the base for greater stability of operation with wide changes in ambient temperature and to a lesser extent in the bias voltage.

Input signals are applied to a terminal 140 and are coupled to the base of the transistor by a resistor 142 and a capacitor 144. The collector is connected to a negative 10 volt potential by means of an adjustable inductor 146, and is connected to ground by a capacitive voltage divider comprising capacitors 148 and 150. An emitter is connected to ground by resistors 152 and 154, and output signals are taken from the terminal 156 which is connected to the junction of the resistors 152 and 154, whereby the input signals may be applied at a level which overdrives the transistor. Signals from the collector may be coupled to the next succeeding stage in a manner similar to that shown in FIG. 3. As in previous embodiments, the winding 146 and the capacitors 148 and 150 form a tank circuit with a resonant frequency approximately equal to the desired output frequency. During the second half of each cycle of output signal, the capacitive divider coacts with the fixed base bias to cut off the transistor 130.

Typical values for the components of FIG. 4 are as follows:

Resistor 134	ohms	100
Resistor 136	do	47,000
Resistor 142	do	270,000
Resistor 152	do	3,300
Resistor 154	do	100
Capacitor 138	microfarads	100
Capacitor 144	do	.001
Capacitor 148	do	.0082
Capacitor 150	do	.033
Inductor 146	henry	.6
Thermistor 132, ohms at 25° C.		3,000
Transistor 130		GT1137

FIG. 5 illustrates diagrammatically a single manual, multi-octave organ employing the improved divider circuit. A group of sources of alternating current 160, one for each note of the tempered musical scale, are each provided with a series 162 of cascade dividers 164. Each of the sources may comprise an electronic oscillator tuned to the highest octave of the organ or one octave higher, the latter being assumed for the following description. The first divider 164 produces at its output 166 the same note as its oscillator but one octave lower, and succeeding dividers in each series produce the note in succeeding lower octaves.

The outputs of the dividers are connected to respective playing key actuated switches 168 in the manner shown and described in the said Hammond patent, and the switches are connected to a drawbar assembly 170 for synthesis into complex tones. The assembly 170 is connected to an output circuit 172 for application of the tones to a speaker 174. The details of this type of tone synthesis are fully described in the Hammond patent.

While I have shown and described the preferred embodiments of my invention, it will be apparent that numerous modifications and variations thereof may be made without departing from the underlying principles of the invention. I therefore desire, by the following claims, to include within the scope of the invention all such variations and modifications by which substantially the results of my invention may be obtained through the use of substantially the same or equivalent means.

I claim:

1. A plurality of sine wave frequency dividers for coupling to an oscillator in cascaded form, each divider comprising a transistor having a base, an emitter, and a collector, an input circuit coupled to the base, a resistance connecting the emitter to a source of one potential, a resonant circuit having an inductive winding and series connected capacitors resonant at approximately the desired output frequency, the capacitors connecting the collector to the one potential source and the inductive winding connecting the collector to a source of another potential, the junction between the capacitors being connected to the emitter to provide a regenerative feedback, means normally maintaining the divider inoperative in the absence of input signals at the input circuit, an output circuit for driving a succeeding stage in the cascade connected to the collector, and a sine wave output circuit connected to the emitter.

2. In the circuit claimed in claim 1, the capacitor connected between the collector and the emitter having a value which is between one-fourth and one-tenth the value of the other capacitor.

3. In the circuit claimed in claim 1, a resistor connected between said collector and said emitter for controlling the Q of said resonant circuit.

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