Aug. 20, 1968 D. G. OLSON 3,398,378

PHASE SHIFT FREQUENCY DIVIDERS

Original Filed April 5, 1965

Fig. 1

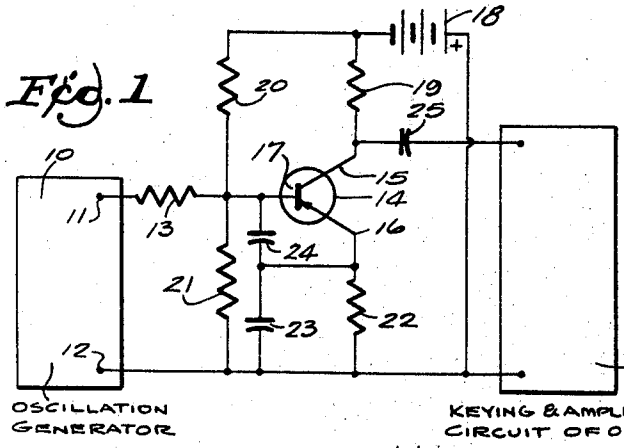
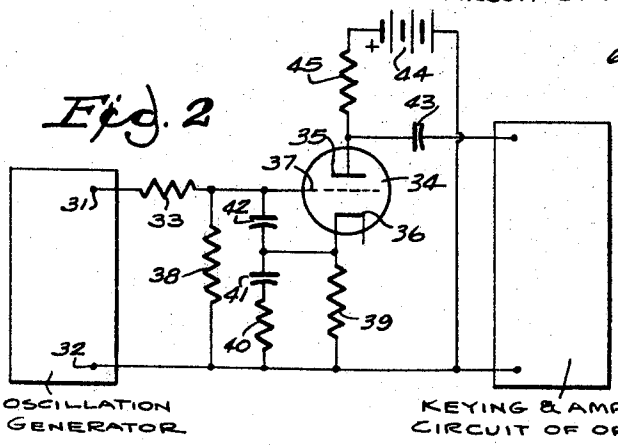


Fig. 2



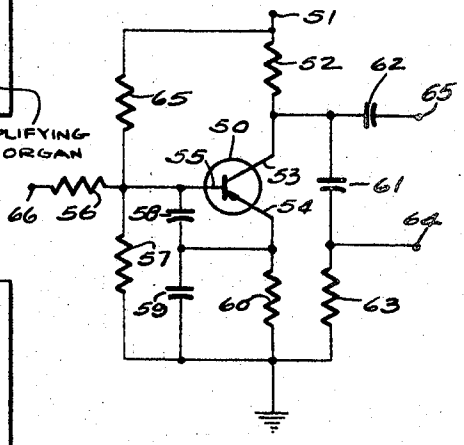


Fig. 3

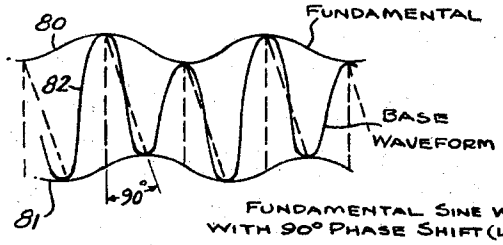


Fig. 5

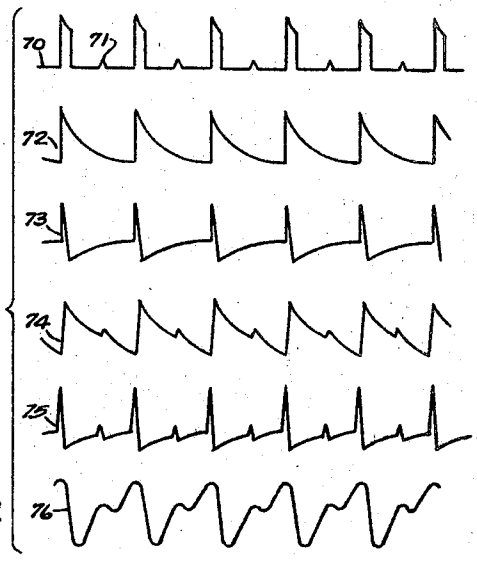


Fig. 4

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PHASE SHIFT FREQUENCY DIVIDERS

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4 Claims. (Cl. 331—76)

ABSTRACT OF THE DISCLOSURE

A device for dividing the frequency of an AC signal, utilizing a single amplifying device, and employing phase-cancellation to eliminate every *n*th input signal pulse, such phase-cancellation occurring by taking from the amplifying device, a signal which has zero phase difference relative to the input signal, shifting it in phase by means of a phase-shift network, and applying the shifted signal back to the input where it may at least partially cancel out every *n*th input pulse due to the phase-difference between the input and the shifted signal fed back, and permitting control over the output of the amplifying device, which is 180 electrical degrees different, in terms of wave shaping without affecting the ability of the device to divide the frequency.

This is a continuation of application Ser. No. 445,537, filed Apr. 5, 1965.

This invention relates to frequency dividers of electrical oscillations in general, and more particularly to electrical frequency dividers adapted for use in electrical musical instruments.

Frequency division in electrical musical instruments is employed to produce required frequencies without need for more than a few oscillators. This is desirable since a frequency divider is normally more economical to construct, and because it requires no tuning, being locked into an exact mathematical relationship with its source of driving signals. Generally, frequency dividers are required to divide the driving signal by two, producing a note one musical octave lower, but may be made to divide in theory by almost any number. Many types of divider circuits require the use of two thermionic tubes or semi-conductors which makes them less economical than a divider which requires but one such device. In addition, many dividers produce only a single type of output wave and are not capable of being modified in various ways to produce different types of wave shapes or tone as might be required.

It is, therefore, an object of this invention to provide an improved frequency divider which requires but a single thermionic tube or semi-conductor amplifier.

It is another object of this invention to provide an improved frequency divider which will produce several different wave shapes simultaneously.

It is another object of this invention to provide an improved frequency divider which may be easily modified to produce still further wave shapes by the addition or modification of components, independent of its operation.

Another object of this invention is to provide an improved frequency divider which will operate over a relatively wide range of frequencies so that its operation is not impaired by the driving signal varying from the original frequency.

Still another object of this invention is to provide an improved frequency divider which will operate in a satisfactory manner even though there are variations in supply voltage to the thermionic tube or semi-conductor.

Other and further objects of this invention will become apparent as the following description proceeds, reference being had to the accompanying drawings, in which:

FIGURE 1 is a schematic of the circuit of an embodiment of this invention employing a semi-conductor amplifier.

FIGURE 2 is a schematic of the circuit of an embodiment of this invention employing a thermionic tube amplifier.

FIGURE 3 is another embodiment of the invention employing a semi-conductor device and having tone shaping elements added.

FIGURE 4 is an illustration of some of the various waveforms obtainable from the circuits.

FIGURE 5 is an illustration of the relationship of the fundamental sinewaves and their effect on the waveform at the base of the semi-conductor.

In an amplifying circuit, signals appearing at the input are reproduced at the output, generally in amplified form. In the use of an amplifying device for frequency division, it is necessary that only every *n*th signal to the input be present at the output, and the unique characteristics of the amplifying device are employed to prevent the unwanted input pulses from reaching the output. Where every second signal is obtained at the output, the divider is dividing by two, while where every fourth signal is present, it is dividing by four. While the description here is confined to such action occurring in a semiconductor device, it is equally applicable to a thermionic tube as well. In this patent, the phase relationship between emitter and base is used to control the frequency division, and determines the signal reaching the collector. This permits modifications of the collector circuit to produce varying types of waveforms without affecting the operation of the divider while in the convention divider, the collector is an integral part of the circuit so that modification of collector circuits will cause the divider to operate unsatisfactorily or require considerable revision to component values in other parts of the circuit. Adjustment of the strength of the driving signal will also have an effect on the output waveforms. Thus, while a change in driving signal strength will affect the tone quality to some extent, the divider will continue to produce the correct frequency over a relatively wide range of variation in input signal strength. Likewise, a change in supply voltage will alter the amplification characteristics of the semi-conductor and produce the same effect as altering the strength of the input signal, making it possible for the divider to operate satisfactorily over a relatively wide range of supply voltages as would be encountered in a commercial electronic musical instrument where a high degree of voltage regulation is not practical.

Referring to FIGURE 1, a semi-conductor **14** is shown in a common emitter configuration. A battery **18** supplies current to the collector **15** through resistor **19** and a bias current to base **17** through resistors **20** and **21** act as a voltage divider. An oscillation generator **10** supplies a driving signal to the base **17** through resistor **13**, but this signal may be supplied by another divider as well. The output of the divider is taken from the collector **15** through capacitor **25** where it is shown going to the keying and amplifying circuit of an organ. This output may be used to drive another divider also. Resistor **22**, capacitors **23** and **24**, and resistor **21** form a phase-shift or time constant network between the emitter **16**, base **17**, and ground **12**. Capacitor **24** also constitutes a feedback path between emitter **16** and base **17**. Normally, if a conduct-

ing path having little or no phase-shift or time delay were connected between the collector-emitter circuit and the base-emitter circuit, a loss in overall gain would be the only result. If, however, this path takes the form of an integrating phase-shift network, two effects are obtained. In the first place, the integrating characteristics of the feedback path attenuate the higher frequency components present in the collector-emitter waveform. Second, the phase-shift characteristics of the feedback path retired the phase of the residual sinewave fundamental. It will be found that said fundamental component at the emitter lags by approximately 90 degrees, the semi-conductor current occasioned by the input signal peak. This is caused by the non-linear operating characteristics of the semi-conductor in conjunction with a capacitive base-emitter circuit. The resultant composite waveform now present at the base-emitter circuit is of such configuration as to cause collector current flow at periods equal to a sub-multiple of the period of applied signal. The phase-shift network can be designed to cause a phase-shift approaching 90 degrees without excessive attenuation. This phase-shift is dependent, for the most part, on the time constants of the two RC portions of the phase-shift network, namely, resistor **22** with capacitor **23**, and resistor **21** with capacitors **23** and **24** in series. When a signal is applied to the base **17** through resistor **13** from source **11**, the first negative pulse will be amplified by semi-conductor **14** and appear at the collector **15**. Due to the conduction of semi-conductor **14**, a similar waveform will appear at emitter **16** but opposite in phase to the collector waveform 180 degrees different. The double-phase shifting network consisting of resistor **22** and capacitor **23**, and secondly, of resistor **21** and capacitors **23** and **24** combine to produce the following effect: due to the integrating characteristics of these networks, the feedback path through capacitor **23** attenuates the high frequency components present in the emitter circuit waveform and, therefore, does not feed these components back to the base **17**. The phase-shifting characteristics of this feedback path are such as to retard the phase of the residual sinewave fundamental fed back from the emitter **16** circuit to the base **17**. However, because the source of feedback signal is in the base-emitter circuit rather than external to it, both the sinewave fundamental and the phase-shifted sinewave fundamental appear at the base **17** of the semi-conductor **14**. This results in the reduction in amplitude of both positive and negative peaks of the second input pulse as can be seen in FIGURE 5.

FIGURE 5 illustrates frequency division by two, in which every second input pulse is attenuated by phase cancellation. The fundamental input signal is represented by waveform **80**. The phase shifted signal feedback emitter **16** is represented by waveform **81**. For purposes of illustration, waveform **81** is shown as lagging waveform **80** by 90 degrees. The resultant waveform imposed on the semiconductor base **17** is represented by waveform **82**, in which every second peak is attenuated. The net effect of this feedback path is that during the time when the second input pulse from the oscillator **10** is applied to the base **17** through resistor **13**, the semiconductor is held almost completely below cutoff and, therefore, the input pulse does not appear in the collector output in any substantial amount. The phase of the shifted fundamental sinewave will lag the phase of the fundamental sinewave by 90 degrees. It should be noted that since there is no 180 degree phase inversion between the input signal and the fundamental sinewave at the emitter **16**, it is the fundamental sinewave that actually holds the sem-conductor below cut off on every other input pulse and not the phase-shifted fundamental sinewave. While resistor **21** and capacitor **24** are essential to the operation of this divider, a slightly different view of this network will show that resistor **21**, and capacitors **23** and **24** comprise an RC network with a time constant equal to the period of input waveform. It is this fact that accounts for the successful operation and stability of this divider. Without the parallel RC network for the fundamental sinewave at the emitter to modify, operation of this divider would not be possible.

In FIGURE 2, the comparable circuit is shown employing a thermionic tube **34**, having a plate **35**, a grid **37**, and a cathode **36**. A source of voltage, a battery **44** supplies voltage to the plate **35** through resistor **45**. Driving signal is supplied to the grid **37** through resistor **33** from source **31**. Phase-shift network is comprised of resistors **38**, **39** and **40**, and capacitors **41** and **42**. Resistor **40** is not essential to the operation, but may be added to obtain an additional waveform at point **46** without affecting the operation of the divider. Output is obtained from the plate **35** through capacitor **43**. The principle of operation is similar with cutoff occurring at the grid of the tube.

FIGURE 3 illustrates another version of the divider where capacitor **61** and resistor **63** are connected in series to produce a different waveform at the collector **53** of semi-conductor **50**. An additional waveform may be obtained at point **64**, or the circuit may be operated without resistor **63**. Varying the values of both resistor **63** and capacitor **61** will produce various waveforms at the collector **53**. The effect of these additional components on the operation of the divider is limited to their effect on the waveshape obtained at the collector **53**.

FIGURE 4 illustrates the various waveforms which may be obtained from the divider operating under various conditions. Waveform **70** is obtained from the collector of the semi-conductor in FIGURE 1 or the plate of the tube in FIGURE 2. The slight pulse **71** may be increased in size or eliminated by varying the value of resistor **13** in FIGURE 1 or resistor **33** in FIGURE 2 which alters the strength of the driving signal. Waveform **72** is obtained from the collector at point **65** in FIG. 3 while waveform **73** is obtainable from point **64** in FIG. 3. Waveform **74** is obtained from point **65** in FIG. 3 when the strength of the driving signal is increased by lowering the value of the resistor **56** in FIG. 3 and waveform **75** is obtained from point **64** in FIG. 3 under the same conditions. Waveform **76** is obtained from the emitter **16** in FIG. 1. Other waveforms may be obtained from the emitter **54** in FIG. 3.

What is claimed and desired to be secured by Letters Patent of the United States, is:

1. An apparatus for dividing the frequency supplied by a source of electrical oscillations having a predetermined frequency, said apparatus comprising a semi-conductor device having a base, an emitter, and a collector, said base comprising the input circuit connected to said source of electrical oscillations, a phase-shift network connected between the base and emitter of said semi-conductor, said phase-shift network producing a phase-shift of the electrical oscillations fed back from the emitter to the base of said semi-conductor such that phase cancellation externally of the semi-conductor attenuates every *n*th input pulse of said electrical oscillations received at the input and producing a frequency at the collector of said semi-conductor equal to the input frequency divided by *n*.

2. The apparatus of claim **1** in combination with a wave shaping network connected with the collector of the semi-conductor device, for determining the harmonic content of the output frequency.

3. An apparatus for dividing the frequency supplied by a source of electrical oscillations having a predetermined frequency, said apparatus comprising a thermionic tube having a grid, a cathode and a plate, said grid comprising the input circuit connected to said source of electrical oscillations, a phase-shift network connected between the grid and cathode of said tube, said phase-shift network producing a phase-shift of the electrical oscillations fed back from the cathode to the grid of said tube such that

phase cancellation externally of the tube attenuates every *n*th input pulse of said electrical oscillations received at the input and producing a frequency at the plate of said tube equal to the input frequency divided by *n*.

4. The apparatus of claim 3 in combination with a wave shaping network connected with the plate of said tube for determining the harmonic content of the output frequency.

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