United States Patent [19]

Kawamoto

[11] **3,718,871**

[45] **Feb. 27, 1973**

[54] **PHASE MODULATING DEVICE**

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[73] Assignee: **Matsushita Electric Industrial Co., Ltd.,** Osaka, Japan

[22] Filed: **July 23, 1971**

[21] Appl. No.: **165,558**

[52] **U.S. Cl.** ....**332/16 T,** 307/240, 307/271, 330/9, 332/9 T, 332/29 R, 332/30 R

[51] **Int. Cl.** **H03c 3/12**

[58] **Field of Search** ....332/9, 9 T, 16, 16 T, 29 R, 332/29 M, 30 R, 30 V; 330/9; 307/240, 271

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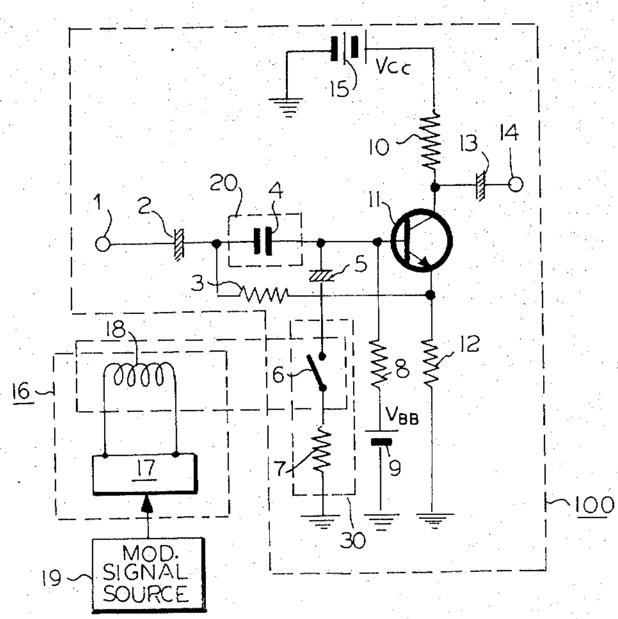
Primary Examiner—Alfred L. Brody
Attorney—E. F. Wenderoth et al.

[57] **ABSTRACT**

A phase modulating device for an electronic musical instrument has at least one phase shifting means essentially composed of at least one resistive branch and at least one reactive branch. The resistive branch has a resistive element and a switching means connected in series. The switching means is turned on and off alternatively by an actuating means at a frequency higher than twice that of an input signal to be modulated. The ratio of an on-period plus an off-period to the on-period changes according to a modulating signal generated by a modulating signal source. The phase characteristic of the device is changed in response to the modulating signal by the switching means actuated by the actuating means in order that the input signal be phase modulated.

21 Claims, 28 Drawing Figures



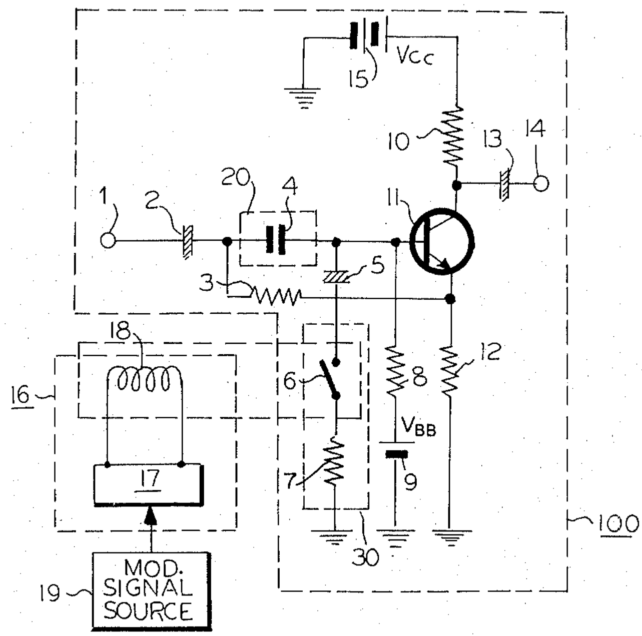


FIG. 1

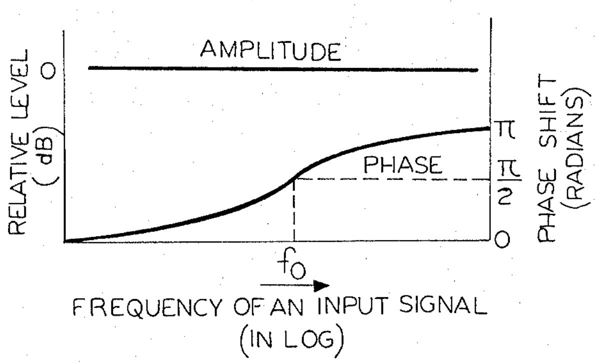


FIG. 2

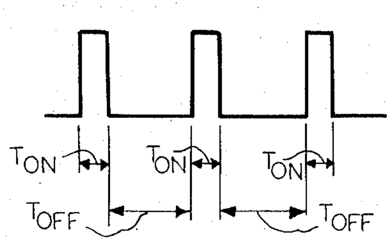


FIG. 3

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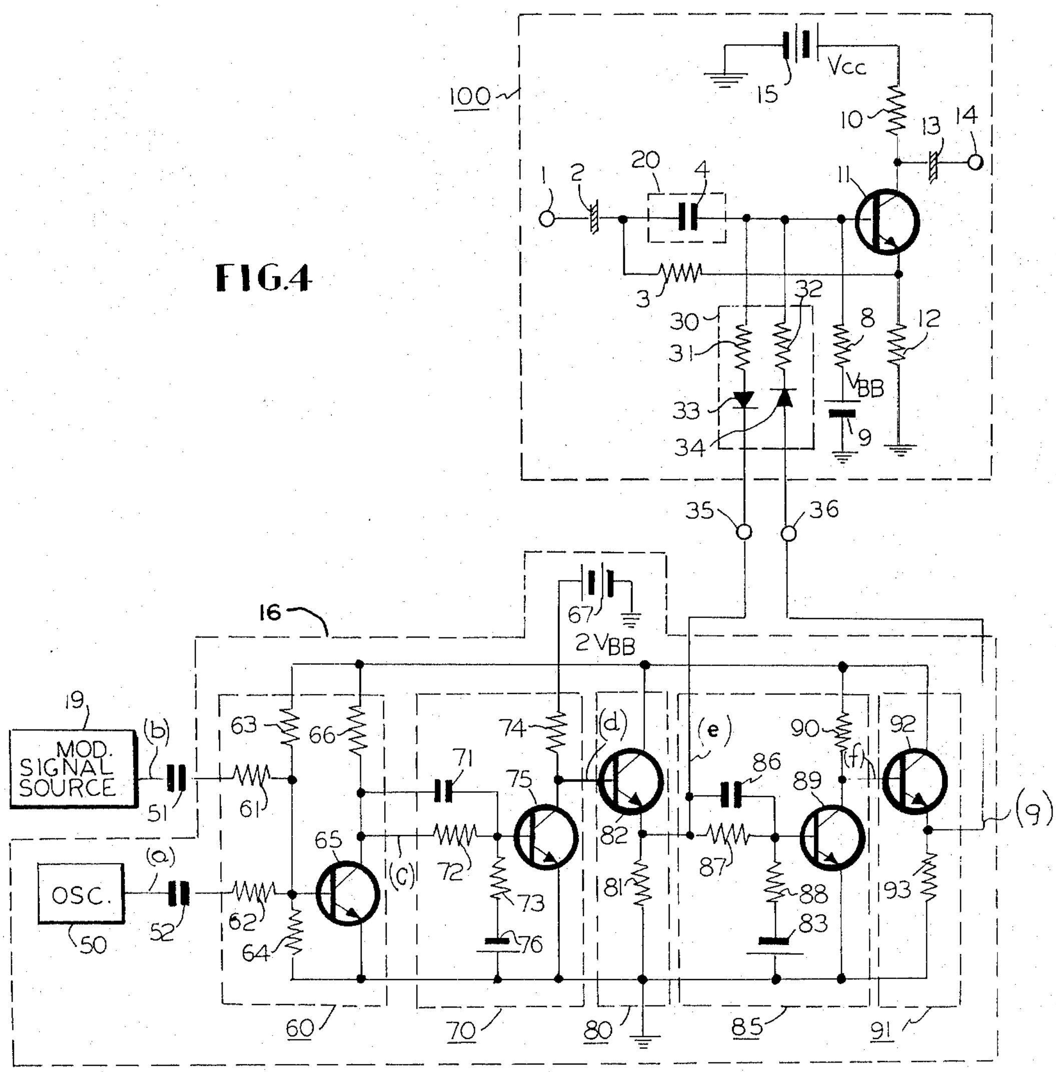

FIG.4

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FIG. 5a

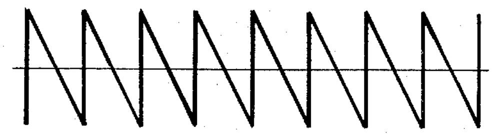


FIG. 5b

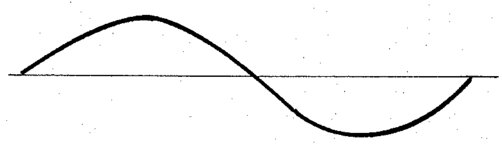


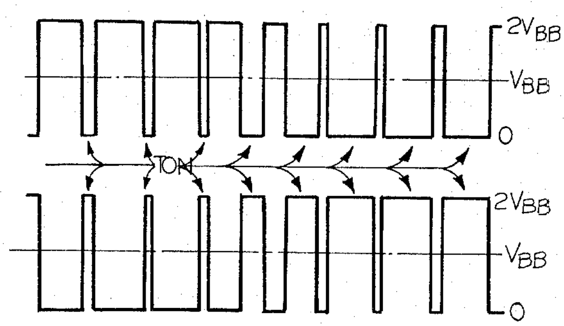
FIG. 5c

FIG. 5d

FIG. 5e

FIG. 5f

FIG. 5g



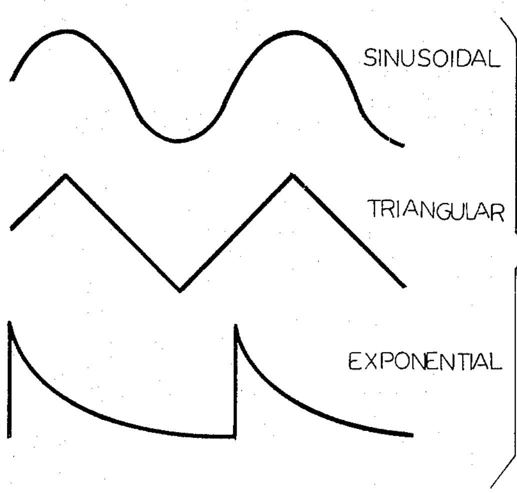


FIG. 6

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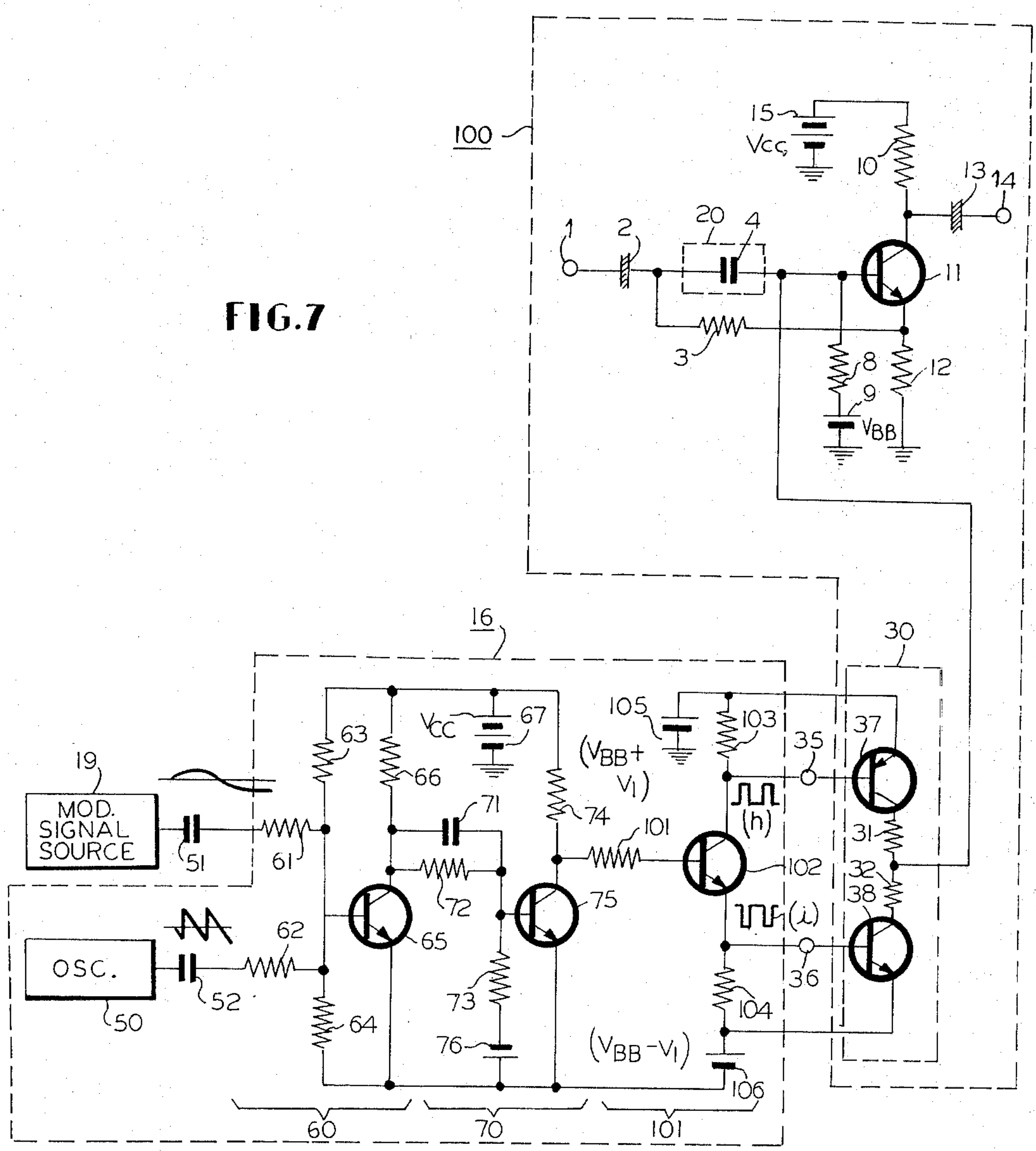
FIG.7



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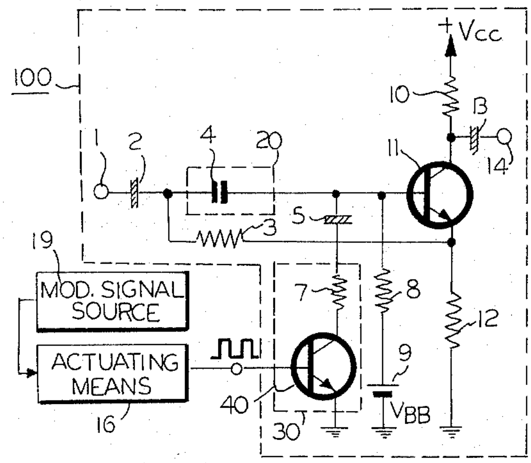

FIG.8

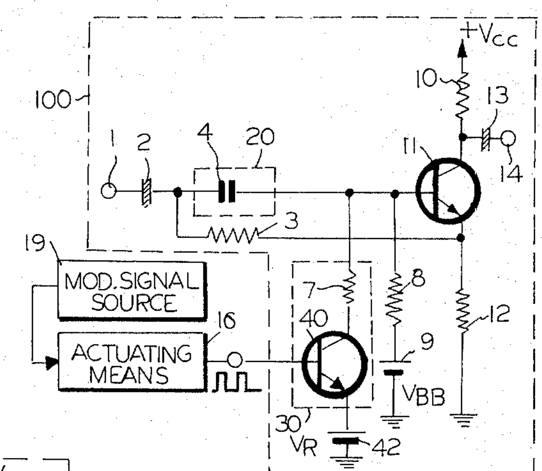

FIG.9

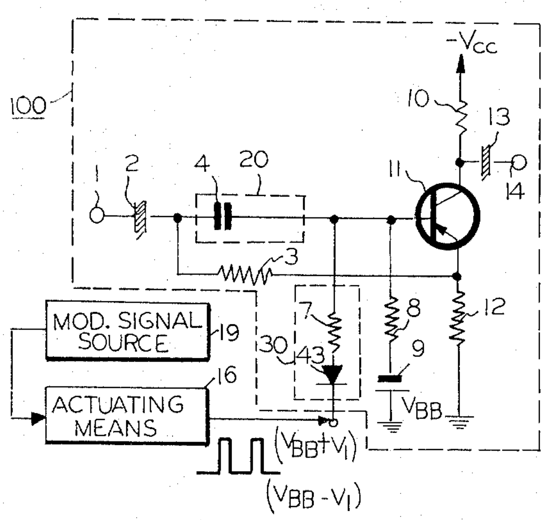

FIG.10

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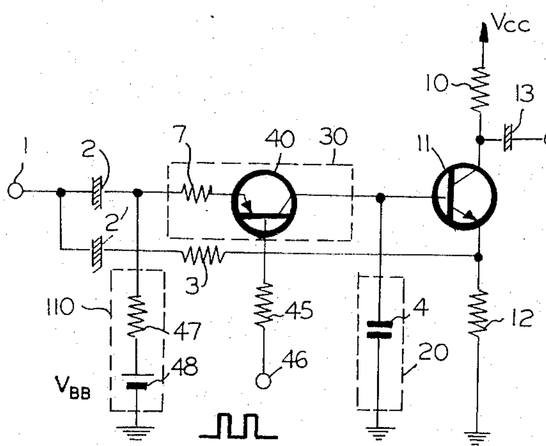

FIG.11

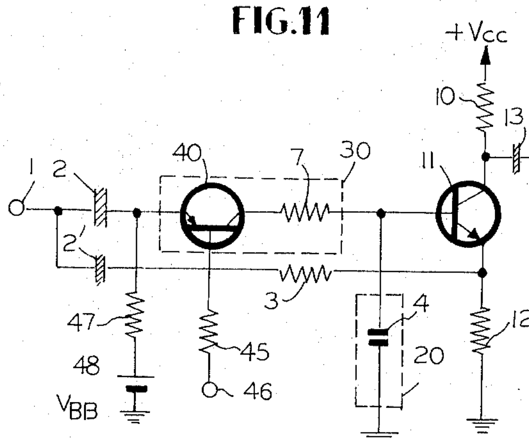

FIG.12

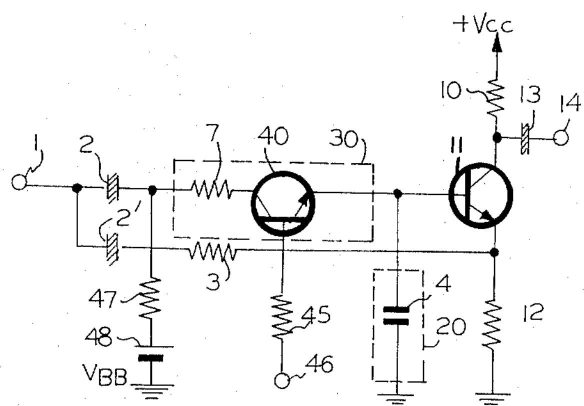

FIG.13

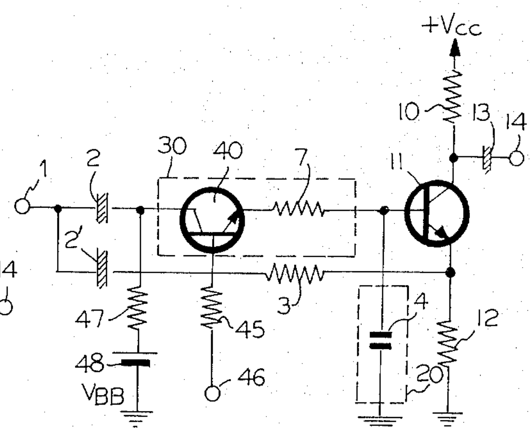

FIG.14

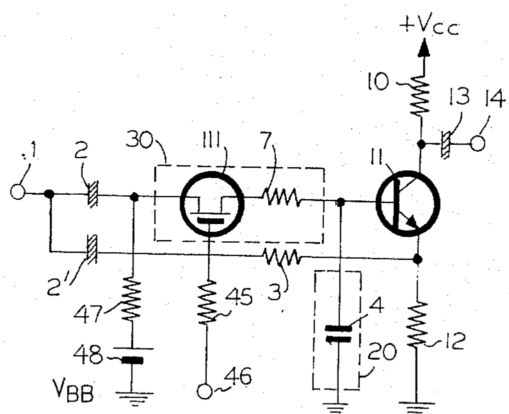

FIG.15

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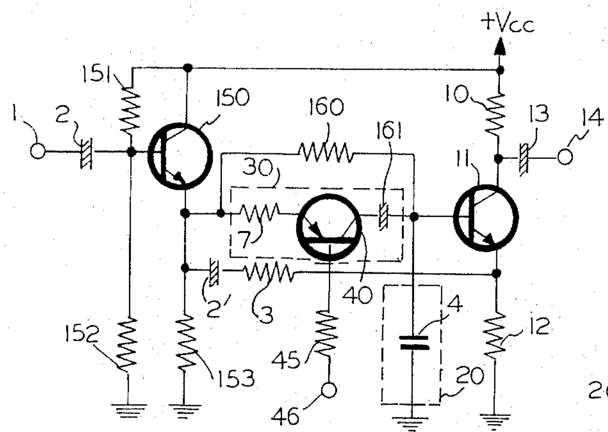

FIG.16

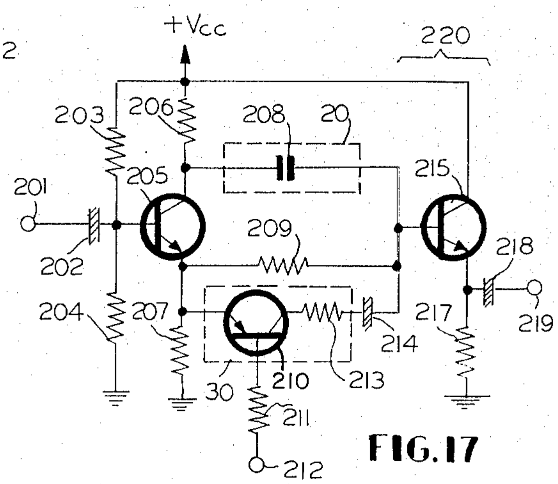

FIG.17

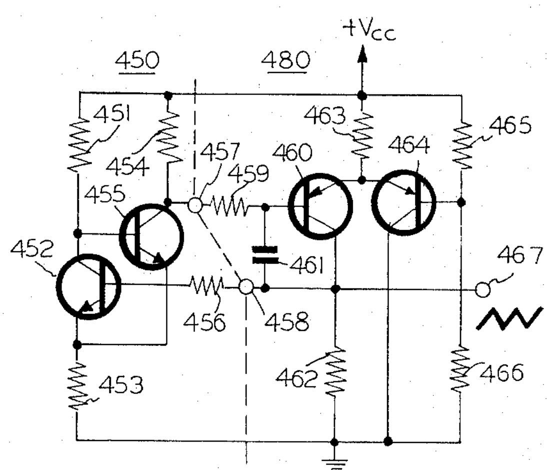

FIG.18

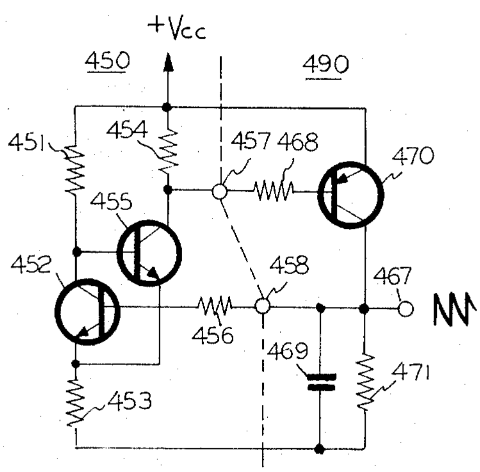

FIG.19

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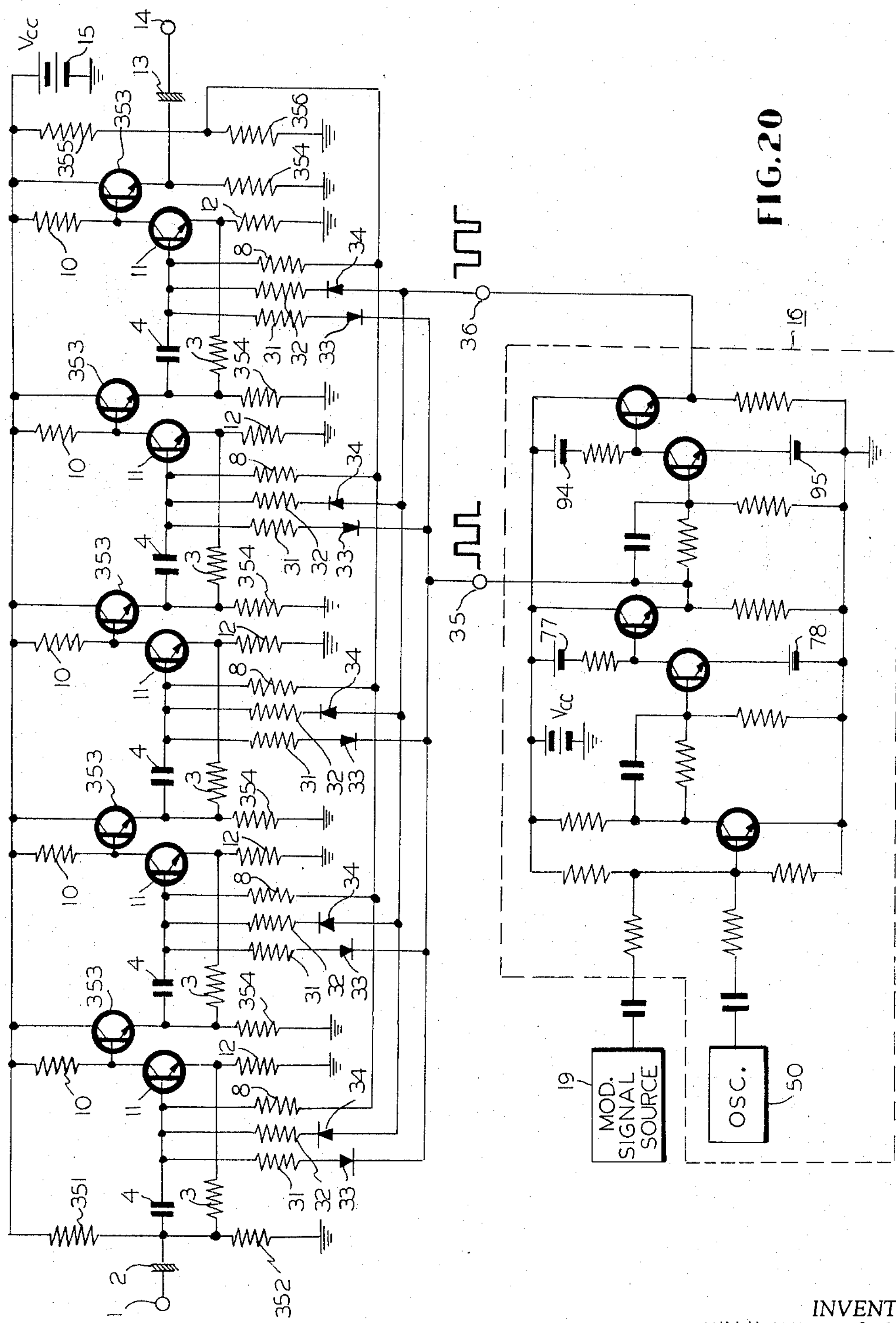

FIG. 20

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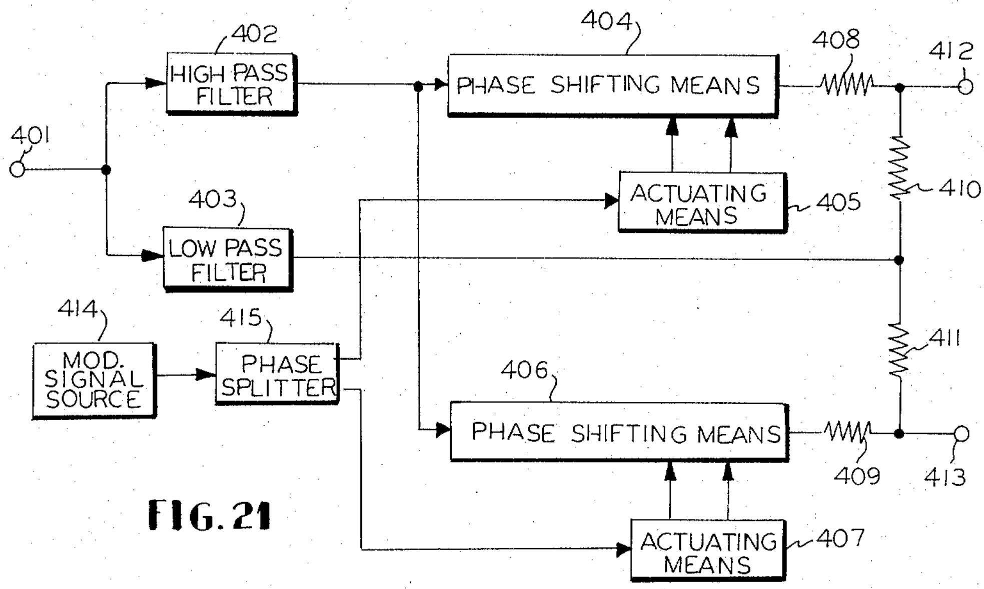

FIG. 21

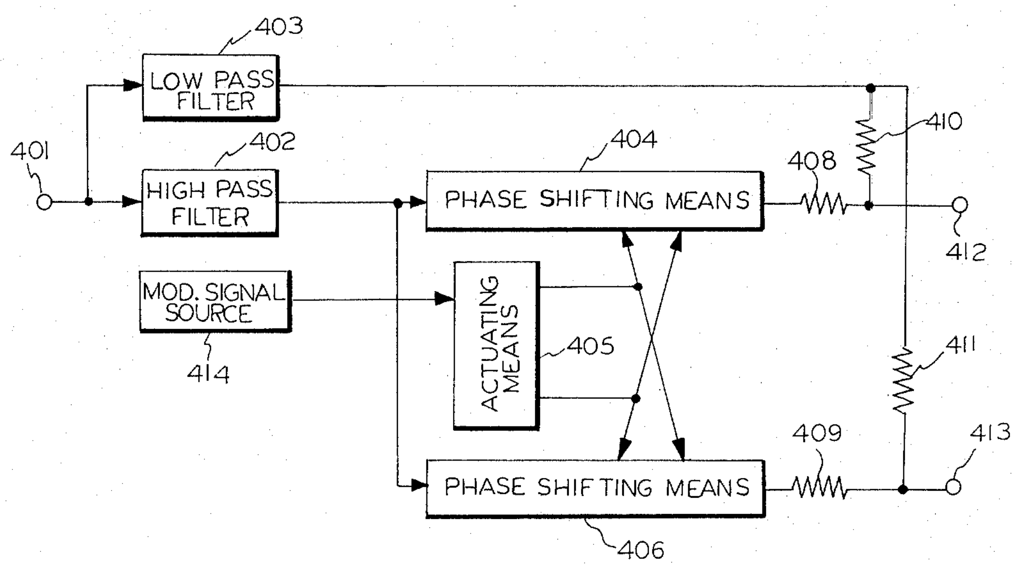

FIG. 22

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PHASE MODULATING DEVICE

This invention relates to a phase modulating device and particularly to a phase shifter type phase modulating device which is unable for an electronic musical instrument.

A conventional phase shifter type modulator comprises a Toulon circuit composed of a phase splitter which splits an input signal into a pair of output signals each having a phase which is different by π radians from the other, a resistive branch and a reactive branch for coupling together the output signals, wherein the resistive branch is a C*d*S or a C*d*S*e* photo-cell. The resistance of the photo-cell is changed by the light intensity of a lamp, and, the photo-cell is changeable in its resistance by the ambient temperature and humidity.

Usually, the lamp does not have a long life and also the light intensity thereof changes. Both the resistance of the photo-cell and the light intensity of the lamp are difficult to control so as to be the same magnitude in mass production. Accordingly in practice it is necessary to adjust the current flowing in the lamp for each circuit. Further, the resistance of the photo-cell does not respond rapidly and accurately to a modulating signal. Other conventional resistive elements having the voltage vs. current characteristic of a diode of a transformer is apt to distort the input signal to be modulated.

Therefore, an object of the present invention is to provide a phase modulating device which can modulate an electric signal rapidly in response to a modulating signal without causing a distortion to the electric signal.

Another object of the invention is to provide a phase modulating device which is suitable to be included in an integrated circuit.

A further object of the invention is to provide a phase modulating device which is reliable and stable in operation which has a long life and which requires hardly any adjustment in manufacturing.

These and other objects and features of the present invention will be made clear from the following detailed description of the invention considered together with the accompanying drawings wherein:

FIG. **1** is a schematic circuit diagram of an embodiment of the phase modulating device of the present invention;

FIG. **2** shows an example of an amplitude and a phase vs. frequency characteristics of a phase shifting means;

FIG. **3** shows an example of an actuating pulse signal for the phase modulating device of the invention;

FIG. **4** is a schematic circuit diagram of another embodiment of the phase modulating device of the present invention;

FIGS. **5*a*–5*g*** show examples of wave shapes of signals in an actuating means of the phase modulating device of the invention;

FIG. **6** shows examples of wave shapes usable in an actuating means instead of a saw-tooth wave shape;

FIG. **7** is a schematic circuit diagram of a further embodiment of the phase modulating device of the present invention;

FIGS. **8** to **16** are schematic circuit diagrams of further embodiments of the phase modulating devices of the present invention;

FIG. **17** is a schematic circuit diagram of a further embodiment of the phase modulating device of the invention using a Toulon circuit;

FIG. **18** is a schematic circuit diagram of an oscillator generating a triangle wave shape which is applicable to the device of the present invention;

FIG. **19** is a schematic circuit diagram of an oscillator generating an exponential wave shape which is applicable to the device of the present invention;

FIG. **20** is a schematic circuit diagram of a phase modulating device using the device of the present invention; and

FIGS. **21** and **22** are schematic block diagrams of a phase modulating device using the device of the present invention.

Referring to FIG. **1**, an embodiment of a phase modulating device of the present invention has a reactance-resistance type phase shifting means **100**, a switching means **6**, an actuating means **16** and a modulating signal source **19**. The reactance-resistance type phase shifting means **100** shifts the phase of an input signal applied to an input terminal **1** thereof and puts out an output signal at an output terminal **14** thereof. In the reactance-resistance type phase shifting means **100**, the input terminal **1** and the base of an npn type transistor **11** are coupled through a coupling capacitor **2** and a reactive branch **20** having a reactive element, for example a capacitor **4**. A coil is also usable for the reactive element. The capacitor **4** has a capacitance C. The input terminal **1** is also connected to the emitter of the transistor **11** through the coupling capacitor **2** and a resistor **3** having a resistance R_1. The emitter of the transistor **11** is connected to a ground potential through a resistor **12** having a resistance R_E. A positive D.C. voltage source **15** generating a voltage V_{cc} (volts) is connected to the collector of transistor **11** through a resistor **10** which has a resistance R_C. A coupling capacitor **13** couples the collector of the transistor **11** to an output terminal **14**.

The base of the transistor **11** is coupled to a reference potential, for example a ground, through a coupling capacitor **5** and a resistive branch **30**. The resistive branch **30** has a resistive element **7** and the switching means **6** which is connected in series with the resistive element **7**. The resistor **7** has a resistance R. The base of the transistor **11** is also connected to a biasing potential source **9** generating voltage V_{BB} (volts) through a resistor **8** having a high resistivity.

The reactance-resistance type phase shifting means **100** operates as follows. The input signal applied to the resistor **3** through the input terminal **1** and the coupling capacitor **2** is amplified by an amplifier comprising the resistor **3**, the transistor **11** and the resistor **10**, and appears at the collector of the transistor **11**. The gain of the amplification is R_c/R_1, assuming that h_{fe} of the transistor **11** is sufficiently larger than **1**. The signal at the base of the transistor **11** is amplified and also appears at the collector of the transistor **11**. The gain of the amplification is $-R_c(R_1+R_E)/R_1R_E$. The negative sign indicates that the phase of the signal is inverted by the amplification. Accordingly, the transistor **11**, the resistors **3**, **8**, **10** and **12**, the voltage source **15** and the biasing potential source **9** compose a differential amplifier having a positive gain of R_C/R_1 and a negative gain of $-R_C(R_1+R_E)/R_1R_E$.

Assuming that the switching means **6** switches on, the capacitor **4** and the resistor **7** compose a high pass filter having a cut-off frequency $f_c=(½\pi RC)$ and a transfer function $G_H(f)$ which can be represented as follows:

$$G_H(f)=(j2\pi fRC)/1+j2\pi fRC) \quad (1)$$

The transfer function $G(f)$ of the reactance-resistance type phase shifting means **100** can be respresented as follows.

$$G(f)=-\frac{R_C(R_1+R_E)}{R_1R_E}G_H(f)+\frac{R_C}{R_1} \quad (2)$$

When R_1 is equal to R_E, the gains of the differential amplifier become R_C/R_1 and $2R_C/R_1$, and $G(f)$ is expressed by the following equation:

$$G(f)=R_C/R_1\cdot(1-j2\pi fR_C)/(1+j2\pi fR_C) \quad (3)$$

The Equation (3) shows that the input signal applied to the input terminal **1** is amplified by R_C/R_1 and is shifted in phase by from 0 radian to $-\pi$ radians. FIG. **2** shows the transfer characteristic of the Equation (3). In FIG. 2, the amplitude is shown in a relative level (in dB).

Referring to FIG. **1**, the switching means **6** and a coil **18** compose a relay switch. The switching means **6** is actuated by the actuating means **16**. The actuating means **16** generates an actuating pulse signal, as shown in FIG. **3** for example, having two states, one of which is an on-period for maintaining the switching means **6** closed during period T_{ON} and the other of which is an off-period for maintaining the switching means **6** open during period T_{OFF}. The on-period and the off-period are alternatively repeated in an actuating frequency. The actuating frequency $f_A=(1/(T_{ON}+T_{OFF}))$ is higher than twice the frequency of the input signal applied to the input terminal **1**. The ratio of the on-period T_{ON} plus the off-period T_{OFF} to the on-period T_{ON}, i.e. $(T_{ON}+T_{OFF})/T_{ON}$, changes in response to a modulating signal generated by the modulating signal source **19**.

When the switching means **6** is actuated, the cut-off frequency fc is multiplied by $T_{ON}/(T_{ON}+T_{OFF})$.

The Equation (3) becomes the following Equation (4).

$$G(f)=\frac{R_C}{R_1}\frac{1-j2\pi fR^C(T_{ON}+T_{OFF})/T_{ON}}{1+j2\pi fR^C(T_{ON}+T_{OFF})/T_{ON}} \quad (4)$$

The transfer function $G(f)$ changes according to the change of the ratio $(T_{ON}+T_{OFF})/T_{ON}$, and the phase characteristic shown in FIG. **2** changes in a direction parallel to a frequency axis. Accordingly, the input signal applied to the input terminal **1** is phase modulated and then appears at the output terminal **14**.

The phase-modulated output signal at the output terminal **14** contains a component of the actuating frequency f_A. The component of the actuating frequency f_A can be eliminated by a low-pass filtering means (not shown in FIG. **1**) connected to the output terminal **14**.

The resistor **8** determines the lower limit of the cut-off frequency f_c, so its resistivity should be as large as possible, so far as the differential amplifier operates.

The switching means **6** and the coil **18** can be replaced by a semiconductor switching means for a switching operation at high frequency.

The reactance-resistance type phase shifting means **100** has a feature that the resistive branch **30** or the reactive branch **20** can be connected to ground.

FIG. **4** shows another embodiment of the phase modulating device of the present application. The reactance-resistance type phase shifting means **100** is similar to that of FIG. **1** except for the resistive branch **30**. Referring to FIG. **4**, the resistive branch **30** is composed of resistors **31** and **32**, diodes **33** and **34** and actuating terminals **35** and **36**. The base of the transistor **11** is connected to the actuating terminals **35** and **36** through the resistor **31** and the diode **33**, and through the resistor **32** and the diode **34**, respectively. The resistors **31** and **32** have the same resistance 2R. The diodes **33** and **34** are a pair of switching means.

The actuating means **16** is composed of an oscillator **50**, a comparator **60**, a pulse amplifier **70**, a pulse driver **80**, a pulse inverter **85** and a pulse driver **91**. The wave shapes of signals denoted as (a)~(g) in the actuating means **16** of FIG. **4** are shown in FIG. **5**. An oscillator **50** generates a saw-tooth signal (a) having an actuating frequency f_A.

The saw-tooth signal *a* and a modulating signal *b* generated by the modulating signal source **19** are superimposed and comparated with a comparison potential, for example a ground potential. The comparator **60** generates a pulse signal *c* the width of which changes in response to the modulating signal *b*. The pulse amplifier **70** amplifies the pulse signal *c* and produces a pulse signal *d*. The pulse signal *d* is applied to the actuating terminal **35** through the pulse driver **80**. The output pulse signal *e* is similar to the pulse signal *d* having an amplitude, for example, between 0 (volts) and 2 V_{BB} (volts). The pulse signal *e* is inverted by the pulse inverter **85**. The inverted signal *f* is boosted by the pulse driver and is applied to the actuating terminal **36** as the pulse signal *g*. The pulse signal *g* has an amplitude between 0 (volts) and 2 V_{BB} (volts). The pulse signals *e* and *g* are a pair of actuating pulse signals. When the pulse signal *e* is 2 V_{BB} (volts), the pulse signal *g* becomes 0 (volts). Accordingly, the diodes **33** and **34** are reversely biased and become OFF. The base of the transistor **11** is biased to V_{BB} (volts) by the biasing potential source **9**. When the pulse signal *e* is 0 (volts), the pulse signal *g* becomes $2V_{BB}$ (volts). So, the diodes **33** and **34** are forwardly biased and become ON. The base of the transistor **11** is biased to V_{BB} (volts) even when the diodes **33** and **34** are OFF.

Because the pulse drivers **80** and **91** have low output impedances, the base of the transistor **11** is connected to a reference potential through the resistors **31** and **32** when the diodes **33** and **34** are in the ON state, i.e. an on-period. The reference potential is substantially the same as a ground potential. Accordingly, the phase modulating device of FIG. **4** modulates the phase of an input signal applied to the input terminal **1** in the same manner as described in connection with FIG. **1**. Usually, the switching means **6** has a residual resistance even when it is closed, so the resistance of the resistor **7, 31** and **32** can be replaced by the residual resistance.

The phase modulating device of the present invention has the following merits as will be understood from the embodiments shown in FIG. **1** and FIG. **4**. The phase modulating device of the present invention operates accurately responding to the modulating signal with a high frequency. In other words, the device responds rapidly to the modulating signal. Because the resistive branch **30** does not produce any distortion in the signal to be modulated as the switching means performs accurately its on-off operation, the device of the present invention produces very little distortion.

The device is more reliable and stable and has a longer life-time compared to a conventional modulator which uses a light-sensitive resistor such as a CdS or CdSe cell and a lamp, because the device of the present invention can be made by using reliable components such as diodes and transistors. Because the actuating pulse signals can be obtained accurately by using ordinary pulse generating and shaping techniques and by using ordinary circuit components, the adjustment of phase shifting and phase modulating characteristics is easily done. An adjustment-free phase modulating device can be made for almost all uses. Accordingly, the device of the present invention is suitable for a system using a lot of the devices and is also suitable for mass production. The device of the present invention is easily incorporated in an integrated circuit because the device can be made by using mainly semiconductor devices and resistors.

The actuating means **16**, in FIG. **4**, can be replaced by another circuit having the same function described above. For example, a Schmitt trigger circuit, a monostable multivibrator and a differential pulse amplifier can be used as the actuating means **16**. Instead of the oscillators **50** generating a saw-tooth wave, an oscillator generating another wave shape, for example a sinusoidal, a triangular or an exponential wave shape as shown in FIG. **6**, can be used. Above all, the phase characteristic, as shown in FIG. **2**, moves in a direction parallel to the frequency axis (in log) proportionally to the modulating signal *b* of the modulating signal source **19** by using the exponential wave shape. The exponential wave shape can be approximately obtained by utilizing a voltage change across capacitors during discharging or charging. In order to change the ratio $(T_{ON}+T_{OFF})/T_{ON}$ of the actuating pulse signal, the actuating frequency f_A may be changed in response to the modulating signal while maintaining either the on-period or the off-period constant. The ratio can be changed by changing both the actuating frequency f_A and T_{ON} or T_{OFF}.

FIG. **7** shows a further embodiment of the phase modulating device of the present invention. The reactance-resistance type phase shifting means **100** is similar to that of FIG. **1** except for the resistive branch **30**. Referring to FIG. **7**, the resistive branch **30** is composed of resistors **31** and **32** each of which has a resistance **2R**, transistors **37** and **38**, actuating terminals **35** and **36**. The transistors **37** and **38** are a pair of switching means. The resistor **31** couples the base of transistor **11** to the collector of the pnp type transistor **37**. The emitter of the transistor **37** is connected to a voltage potential source **105** having a potential of $(V_{BB}+V_{b6})$ volts $(V_1<V_{BB})$. The base of the transistor **37** is connected to the actuating terminal **35**. The resistor **32** couples the base of the transistor **11** to a collector of the npn type transistor **38**. The emitter of the transistor **38** is connected to a voltage potential source **106** having a potential of $(V_{BB}-V_1)$ volts. The base of the transistor **38** is connected to the actuating terminal **36**. The actuating means **16** is composed of an oscillator **50**, a comparator **60**, a pulse amplifier **70** and a phase splitter **101**. The actuating means **16** generates a pair of actuating pulse signals *h* and *i*, the width of which is changed by the modulating signal generated by the modulating signal source **19**. The actuating signals *h* and *i* switch the transistors **37** and **38** simultaneously in an actuating frequency f_A of the saw-tooth signal generated by the oscillator **50**.

When the actuating signals *h* and *i* are $(V_{BB}+V_1)$ volts and $(V_{BB}-V_1)$ volts respectively, the transistors **37** and **38** are cut off and one end of the resistive branch **30** is not coupled to anywhere. The base potential of the transistor **11** becomes similar to the potential V_{BB} (volts) of the biasing potential source **9**. This is an off-period.

When the actuating signals *h* and *i* make the transistors **37** and **38** on, the potentials of the collectors of the transistors **37** and **38** become $(V_{BB}+V_1)$ volts $(V_{BB}-V_{b6})$ volts, respectively. The base of the transistor **11** is connected to a reference potential substantially similar to ground through the resistors **31** and **32** The D.C. potential of the base of the transistor **11** is maintained at the same potential as that during the off-period. This is an on-period. The embodiments shown in FIG. **4** and FIG. **7** do not put out a component of the modulating signal to the output terminal **14**, because the base of the transistor **11** is maintained at a substantially constant D.C. bias potential during the on-period and the off-period. The resistors **31** and **32** are not necessarily the same as each other for maintaining the base potential of the transistor **11** constant during the on-period and the off-period.

FIGS. **8**, **9** and **10** show other embodiments of the present invention, in which the reactance-resistance type phase shifting means **100** is similar to that of FIG. **1** except for the resistive branch **30**.

Referring to FIG. **8**, the resistive branch **30** is composed of a resistor **7** having a resistance R and a transistor **40**. One end of the resistor **7** is coupled to the base of the transistor **11** through a coupling capacitor **5**. The other end of the resistor **7** is connected to the collector of the transistor **40** which is used as a switching means. The emitter of the transistor **40** is connected to a reference potential, for example a ground potential. The actuating means **16** applies an actuating pulse signal to the base of the transistor **40** so as to switch the transistor **40** on and off at an actuating frequency f_A. The pulse width of the actuating pulse signal is changed (modulated) by a modulating signal generated by the modulating source **19**. Accordingly, the resistance of the resistive branch **30** is R during the on-period and almost infinite during the off-period.

Referring to FIG. **9**, the resistive branch **30** is composed of a resistor **7**, a transistor **40**, for example an npn type, and a reference potential source **42** having a voltage of V_R (volts) $(V_R<V_{BB})$. One end of the resistor **7** is directly connected to the base of the transistor **11**. The other end is connected to the collector of the transistor **40**. The emitter of the transistor **40** is connected to the reference potential source **42**. The actuating means **16** applies an actuating pulse signal to the base of the transistor **40**. The transistor is actuated to be ON during the on-period and OFF during the off-period in response to the actuating pulse signal having an actuating frequency F_A. The width of the actuating pulse signal is changed by the modulating signal generated by the modulating signal source **19**.

Referring to FIG. 10, the resistive branch 30 is composed of a diode 43 and a resistor 7. The resistor 7 couples the base of the transistor 11 to one end of the diodes 43. The other end of the diode 43 is connected to the actuating means 16. The actuating means 16 generates an actuating pulse signal the amplitude of which is, for example, between (V_{BB}+V_1) volts and (V_{BB}−V_{b6}) volt (V_1<V_{BB}). When the actuating pulse signal is (V_{BB}−V_1) volts, the diode 43 is forwardly biased and become ON. Accordingly, the base of the transistor 11 is connected through the resistor 7 to a reference potential (V_{BB}−V_1) volts. This is an on-period.

When the actuating pulse signal is (V_{BB}+V_1) volts, the diode 43 is reversely biased and becomes OFF. This is an off-period.

Accordingly, the embodiments shown in FIG. 8, 9 and 10 modulate a phase of an input signal thereto in the same manner as is explained in connection with FIG. 1.

In the embodiments of FIGS. 9 and 10, the base potential of the transistor 11 changes during the on-period and the off-period. Accordingly, the average of the base potential changes according to the modulating signal. This change causes a leakage of the modulating signal to the output terminal 14.

When an npn type transistor and a reference potential source having V_R, volts (V_R'>V_{BB}) are used instead of the npn type transistor 40 and the reference potential source 42, respectively in the embodiment of FIG. 9, the leakage modulating signal at the output terminal 14 has the phase inverted. When the diode 43 is reversely connected in the embodiment of FIG. 10, the phase of the leakage modulating signal is also inverted. Accordingly, if two stages of the phase modulating devices of FIGS. 9 or 10 are connected in cascade, it is better to use transistors opposite to each other in each device or to connect the diodes in the opposite direction to each other in each device so as to cancel the leakage of the modulating signal produced in each device.

FIGS. 11 to 16 show other embodiments of the phase modulating device of the present invention. Referring to FIG. 11, a reactance-resistance type phase shifting means is shown which is substantially similar to that of FIG. 1 except a resistive branch 30, the reactive branch 20 and a biasing means 110. The actuating means and the modulating signal source are not shown. They can be made using an ordinary pulse technique. The resistive branch 30 is composed of a resistor 7 and a switch means, for example a transistor 40, which is connected between one end of coupling capacitor 2 and the base of the transistor 11. The reactive branch 20 having a reactive element, for example capacitor 4, is connected between the base of the transistor 11 and ground. A resistor 47 is connected in series to a biasing potential source 48 and coupled between the junction of the coupling capacitor 2 and the resistive branch and ground for biasing the base potential of the transistor 11 to a biasing potential V_{BB} (volts).

The actuating pulse signal is applied to the base of the transistor 40 through an actuating terminal 46 and a resistor 45 in order to switch the transistor 40 on and off. The resistive branch 30 and the capacitor 4 compose the low pass filter. The cut-off frequency fc' of the low-pass filter can be changed by changing the width of the actuating pulse signal as well as can be done in the embodiments of FIGS. 1, 4, 7 and 8 to 10 which use a high pass filter having a cut-off frequency fc instead of the low pass filter.

FIGS. 12 to 16 are embodiments modified from the embodiment of FIG. 11.

Referring to FIGS. 12, 13 and 14, the resistive element 7 and the transistor 40 are connected differently from those of FIG. 11. In FIGS. 13 and 14, the transistors 40 are a different type, i.e. an npn type, from that of FIGS. 11 and 12, i.e. a pnp type. The respective transistors 40 operate as switching means for switching the resistive branches 30 on and off in response to an actuating pulse signal applied to the actuating terminals 46 in FIGS. 12–14.

In FIG. 15, the resistive element 30 has a field effect transistor 111 as a switching means. A field effect transistor usually has a high resistivity between a gate and a drain and between a gate and a source. Accordingly, the modulating signal applied to the actuating terminal 46 is easily isolated from he resistive branch 30.

In FIG. 16, the base biasing potential is applied from an emitter of the transistor 150 to a base of the transistor 11 through a high resistance resistor 160. A coupling capacitor 161 couples the resistive branch 30 to the base of the transistor 11 and prevents an alteration of the base potential according to the modulating signal.

FIG. 17 shows another embodiment of a phase modulating device of the present invention. Referring to FIG. 17, a reactance resistance type phase shifting means comprises an input terminal 201, a coupling capacitor 202, biasing resistors 203 and 204, a transistor 205, a resistor 206, a resistor 207, a reactive branch 20 having a capacitor 208 therein, a D.C. coupling high resistance resistor 209, a resistive branch 30 having a switching means, for example a transistor 210 and a resistor 213, a coupling capacitor 214 and an emitter follower 220 composed of a transistor 215, a resistor 217, a coupling capacitor 218 and an output terminal 219.

The transistor 205, and the resistors 206 and 207 compose a phase splitter for splitting an input signal applied to the input terminal 201 into two signals having phases differing by π radians with respect to each other appeared at the emitter and a collector of the transistor 205.

An actuating pulse signal applied to an actuating terminal 212 switches the transistor 210 on and off through an isolating resistor 211. Accordingly, the phase characteristic of the reactance-resistance type phase shifting means changes according to the width of the actuating pulse signal, in other words, the ratio of the on-period plus the off-period to the on-period.

FIG. 18 shows an example of the oscillator 50 for generating a triangular wave. Referring to FIG. 18, the oscillator is composed of a hysterisis-switching circuit means 450 and a charge-discharge means 480. The hysterisis-switching circuit means has an input terminal 458 and an output terminal 457 and generates either a high level voltage or a low level voltage as an output voltage at the output terminal 457 accompanying hysterisis such that, when an input terminal 458 exceeds the first threshold voltage, the output voltage at the input voltage will change from a high level voltage to a low level voltage or vice versa. The first threshold voltage of the hysterisis-switching circuit means will also change to the second threshold voltage at the same time. When the input voltage exceeds the second threshold voltage, the output voltage will change back from a low level voltage to a high level voltage, or vice versa, and the second threshold voltage will also change to the first threshold voltage.

Such a hysterisis-switching circuit means can be made by using, for example, a hysterisis Schmitt trigger circuit composed of transistors **452** and **455** and resistors **451**, **453**, **455** and **456** as shown in FIG. **18**.

The charge-discharge means **480** has at least one capacitor, an input terminal connected to the output terminal **457** of the hysterisis-switching means **450** and one output terminal connected to the input terminal **458** of the hysterisis-switching means **450**, and generates either an increasing voltage or a decreasing voltage at the another output terminal. Referring to FIG. **18**, the charge-discharge means **480** is an integrating circuit composed of transistors **460**, **464**, resistors **459**, **462**, **463**, **465** and **466** and a capacitor **461**. The transistor **464**, the resistors **463**, **465** and **466** stabilize the base potential of the transistor **460** and achieve a stable integration of the input signal at the input terminal **457**.

The operation of the oscillator of FIG. **18** is as follows. The hysterisis-switching circuit means generates one of either a high level voltage or a low level voltage. For example, when generating a high level voltage, the high level voltage makes the integrating circuit **480** charge or discharge. While charging the capacitor **461**, the charging voltage corresponds to the decreasing voltage. When the decreasing voltage reaches the first threshold voltage, the hysterisis-switching circuit means changes its output voltage from the high level voltage to the low level voltage. The first threshold voltage also changes itself to the second threshold voltage, which is higher than the first threshold voltage. The low level voltage makes the integrating circuit **480** discharge the capacitor **461** and generate an increasing voltage at the terminal **458**. When the increasing voltage reaches the second threshold voltage, the hysterisis-switching circuit means **450** changes its output voltage from the low level to the high level voltage and changes its threshold to the first threshold voltage.

Accordingly, the decreasing voltage and the increasing voltage appear alternatively at the other output terminal **467**. This wave shape is a triangular wave shape. The oscillating frequency depends on the time constant of the integrating circuit **480** and the difference between the first threshold voltage and the second threshold voltage.

FIG. **19** shows another example of an oscillator **50** for generating an exponential wave shape. Referring to FIG. **19**, the hysterisis-switching circuit means **450** is similar to that of FIG. **18**. A charge-discharge means **490** is composed of at least one capacitor **469**, a transistor **470** and resistors **468** and **471**. The transistor switches the current to the capacitor **469** on and off. The resistor **468** and the transistor **470** charge the capacitor **469** when the output voltage at the output terminal **457** is low. As the conductivity of the transistor **470** is high, the capacitor **469** is charged instantly through the transistor **470**. The voltage at a terminal **467** increases in a very short period and reaches a second threshold voltage. Then the output voltage at the output terminal **457** becomes a high level voltage and the transistor **470** is cut off. During the time the transistor **470** is off, the capacitor **469** discharges through the resistor **471** and the voltage at the terminal **467** decreases exponentially until it reaches the first threshold voltage. Accordingly, the voltage at the terminal **467** becomes an exponential wave as shown in FIG. **6**. The capacitor **469** in FIG. **19** can be connected in parallel with the transistor **470**. The oscillating frequency depends on the resistor **471**, the capacitor **469** and the difference between the first threshold voltage and the second threshold voltage.

The oscillators in FIGS. **18** and **19** have the features that the amplitude of the output wave shape at the terminal **467** depends on the first and the second threshold voltages. Accordingly, the amplitude is stable even if the oscillating frequency is changed.

FIG. **20** shows an example of a phase modulating device which is a practical embodiment of the present invention. Referring to FIG. **20**, the phase modulating device has five phase shifting means similar to that described in FIG. **4**. The five phase shifting means are connected in cascade. Each phase shifting means has a switching means therein. Each stage of the phase shifting means is coupled through emitter follower circuits composed of transistors **353** and resistors **354**. The base potential of the transistors **11** is applied through resistors **355** and **356** and through resistors **8**. A pair of the switching means, i.e. the diodes **33** and **34**, are coupled together respectively to the actuating terminals **35** and **36**. The actuating means **16** which is similar to that described in FIG. **4**, generates a pair of actuating pulse signals for switching on and off alternatively the switching means **33** and **34**. D.C. potential sources **77**, **78**, **94** and **95** limit the amplitudes of the pair of actuating pulse signals. The signal at the output terminal **14** is preferably connected to a low pass filter (not shown in FIG. **20**) for eliminating a component of the actuating pulse signal.

The phase modulating device of FIG. **20** can modulate an input signal such as a signal of a musical instrument for producing a vibrato effect. Referring to FIG. **20**, most parts are resistors, transistors and diodes except five capacitors **4** substantially necessary for modulation. Accordingly, the vibrato modulator can easily be constructed as an integrated circuit. Other merits described in connection with FIG. **1** and **4** are also obtainable.

When the saw-tooth oscillator **50** is replaced with an oscillator such as is shown in FIG. **19**, generating an exponential wave the phase of the input signal will be changed in proportion to the modulating signal generated by the modulating signal source **19**. Accordingly a very natural vibrato effect is produced.

FIG. **21** shows an example of a phase modulating device for an electronic musical instrument which is a practical application of the present invention. The phase modulating device comprises an input terminal **401**, a high-pass filter **402**, a low-pass filter **403**, a 1st group of phase shifting means **404**, a second group of phase shifting menas **406**, two coupling means composed of resistors **408** and **410**, and resistors **409** and **411** respectively, output terminals **412** and **413**, actuating means **405** and **407**, a phase splitter **415** and a signal source **414**. The first and second groups of phase shifting means **404** and **406** are similar to the phase shifting means connected in cascade as shown in FIG. **20**. The actuating means **405** and **407** are like the actuating means **16** shown in FIG. **20**.

Referring to FIG. **21**, the signal of an electronic musical instrument is applied to the input terminal **401** and separated into a low frequency signal and a high frequency signal by the low-pass filter **403** and the high-pass filter **402**. The high frequency signal is modulated by the phase shifting means **404** and **406** which are actuated by the actuating means **405** and **407**, respectively, and coupled again with the low frequency signal through the pairs of the resistors **408**, **410** and **411**, **413**. The coupled output signals at the output terminal **412** and **413** are transduced into sounds by amplifiers and loudspeakers (not shown). The coupled signals are preferably filtered through low pass filters for eliminating the components of the actuating pulse signals. A modulating signal generated by the signal source **414** is split into two modulating signals opposite in phase to each other. The two modulating signals are applied to the actuating means **405** and **406**, respectively, for modulating the high frequency signal applied to the first and the second groups of a phase shifting means **404** and **406** with opposite phases to each other.

Because the phase modulating device of the present invention is reliable and requires almost no adjustment, the phase modulating device of FIG. **21** is suitable for manufacturing notwithstanding the fact that the phase shifting means are used in large numbers, for example 10 to 12.

FIG. **22** shows another example of a simplified phase modulating device. Referring to FIG. **22**, the first and the second groups of the phase shifting means are actuated by one actuating means **405**. A pair of the actuating pulse signals are applied to the first group and the second group inversely to each other. Accordingly, the actuating pulses switch on the switching means in the first group and switch off the switching means in the second group during the on-period. During the off-period, the switching means in the first group becomes off and the switching means in the second group becomes on.

Accordingly, the first group and the second group modulate the phases of the high frequency signal so that they are opposite to each other without the phase splitter **415** and the additional actuating means **407** which are shown in FIG. **21**.

What is claimed is:

1. A phase modulating device comprising:

a reactance-resistance type phase shifting means consisting essentially of at least one resistive branch having a resistive element therein and at least one reactive branch having a reactive element therein, both of said resistive and reactive elements being coupled to each other for determining a phase characteristic of said phase shifting means for shifting the phase of an input signal;

at least one switching means included in said resistive branch and being series connected with said resistive element;

an actuating means coupled to said switching means for actuating said switching means to switch on during an on period and to switch off during an off period alternatively at an actuating frequency higher than twice the frequency of said input signal;

a modulating signal source coupled to said actuating means for generating a modulating signal for changing the ratio of said on period plus said off period to said on period; and

a low pass filtering means connected to the output end of said phase shifting means for eliminating a component of said actuating frequency which is contained in the output signal of said phase shifting means, whereby the phase characteristic of said phase shifting means is changed in accordance with said modulation signal by said switching means actuated at said actuating frequency.

2. A phase modulating device as claimed in claim **1** wherein said phase shifting means further comprises a first input terminal, a first output terminal, a phase splitter having a phase splitter input terminal connected to said first input terminal and two phase splitter output terminals for splitting an input signal supplied to said phase splitter input terminal into two signals having phases different by π radians from each other at said two phase splitter output terminals, respectively, said reactive branch being connected between one of said two phase splitter output terminals and said first output terminal, and said resistive branch being connected between the other of said two phase splitter output terminals and said first output terminal.

3. A phase modulating device as claimed in claim **1** wherein said phase shifting means comprises:

a first input terminal;

a differential amplifier having two differential input terminals, one of said differential input terminals being connected to said first input terminal; and

a filter connected between said first input terminal and the other of said differential input terminals.

4. A phase modulating device as claimed in claim **3** wherein said filter consists essentially of said resistive branch and said reactive branch, one of said branches being connected between said first input terminal and the other of said differential input terminals, and the other of said branches being connected between said other differential input terminal and a reference potential, and the sum of the gain of said filter at the frequency of the pass-band and the gain of said differential amplifier at said other of said differential input terminals is twice the gain of said differential amplifier at said one of said differential input terminals.

5. A phase modulating device as claimed in claim **4** wherein said reactive branch is connected between said first input terminal and said one of said differential input terminals, said resistive branch is connected between said one of said differential input terminals and a reference potential, and said resistive branch contains said at least one switching means connected in series with said resistive element in said resistive branch for connecting said one of said differential input terminals to said reference potential through said resistive element during said on period.

6. A phase modulating device as claimed in claim **1** wherein said switching means is composed of at least one semiconductor switching means.

7. A phase modulating device as claimed in claim 6 wherein said switching means is composed of at least one transistor.

8. A phase modulating device as claimed in claim 6 wherein said switching means is composed of at least one diode.

9. A phase modulating device as claimed in claim 6 wherein said switching means is composed of at least one field effect transistor.

10. A phase modulating device as claimed in claim 1 wherein said actuating means comprises means for generating at least one pulse signal having two states corresponding to said on period and said off period for switching said switching means on and off according to sad two states.

11. A phase modulating device as claimed in claim 10 wherein said generating means generates a pulse signal having a constant actuating frequency.

12. A phase modulating device as claimed in claim 10 wherein said pulse generating means includes means for generating at least one pulse signal having two states corresponding to said on period and said off period, one of said on period and said off period being constant and the other being variable corresponding to said modulating signal from said modulating signal source.

13. A phase modulating device as claimed in claim 10 wherein said pulse generating means includes means for at least one pulse signal having two states corresponding to said on period and said off period, both of said on period and said off period and the actuating frequency being variable responding to said modulating signal from said modulating signal source.

14. A phase modulating device as claimed in claim 10 wherein the ratio of the on plus the off period to the on period changes proportional to an exponential function of said modulating signal.

15. A phase modulating device as claimed in claim 1 wherein said actuating means includes an oscillator device which is composed of:

a hysterisis-switching circuit means having an input terminal and an output terminal for generating a high level voltage of a low level voltage as an output voltage at said output terminal with hysterisis in response to an input voltage at said input terminal exceeding a first threshold voltage, said output voltage thereby changing from one of said high or low level voltages to the other thereof and said first threshold voltage also changing to a second threshold voltage, and said output voltage changing from said other of said voltages to said one voltage in response to an input voltage exceeding the second threshold voltage and said second threshold voltage also changing to said first threshold voltage; and

a charge-discharge means having at least one capacitor, a further input terminal connected to said hysterisis-switching circuit output terminal and a further output terminal connected to said hysterisis-switching circuit input terminal for generating an increasing voltage or a decreasing voltage at said other output terminal;

whereby said hysterisis-switching circuit means generates either a high level voltage or a low level voltage so as to make said charge-discharge means either charge or discharge said capacitor for generating a changing voltage of either an increasing voltage or a decreasing voltage, and when said first threshold voltage is reached, said changing voltage causes said hysterisis switching circuit means to generate the other level voltage so as to make said charge-discharge means either discharge or charge the opposite from the way it was operating previously until said other changing voltage reaches the second threshold voltage and causes said hysterisis-switching circuit means to change back to said original condition.

16. A phase modulating device as claimed in claim 15 wherein said hysterisis-switching circuit means is composed of a hysterisis Schmitt trigger circuit having a large hysterisis voltage.

17. A phase modulating device as claimed in claim 15 wherein said charge-discharge means is an integrating circuit means.

18. A phase modulating device as claimed in claim 15 wherein said charge-discharge means is composed of a current switching means connected in series with said capacitor for charging said capacitor and a resistor connected in parallel with said capacitor for discharging said capacitor.

19. A phase modulating device as claimed in claim 15 wherein said charge-discharge means is composed of a current switching means connected in parallel with said capacitor for discharging said capacitor and a resistor connected in series with said capacitor for charging said capacitor.

20. A phase modulating device comprising:

a plurality of reactance-resistance type phase shifting means each consisting essentially of at least one resistive branch having a resistive element therein and at least one reactive branch having a reactive element therein, both of said resistive and reactive elements being coupled to each other for determining a phase shifting characteristic of said phase shifting means for shifting the phase of an input signal thereto, said phase shifting means being connected in cascade;

a plurality of switching means, one in each of the respective resistive branches connected in series with the resistive elements therein;

an actuating means coupled to the switching means for actuating said plurality of switching means to switch them on during an on period and to switch them off during an off period alternatively at an actuating frequency higher than twice the frequency of said input signal;

a modulating signal source coupled to said actuating means for generating a modulation signal for changing the ratio of said on period plus said off period to said on period corresponding to said modulating signal; and

a low-pass filtering means connected to the output of said cascade connected phase shifting means for eliminating a component of said actuating frequency contained in the output signal of said phase shifting means.

21. A phase modulating device comprising:

first and second reactive-resistive type phase shifting means each having at least one reactive-resistive phase shifting devices each consisting essentially of at least one resistive branch having a resistive element therein, and at least one reactive branch having a reactive element therein, both of said resistive and reactive elements being coupled for determining the phase shifting characteristics of said phase shifting means for shifting the phase of an input signal thereto;

a switching means in each phase shifting device in said resistive branch and connected in series with said resistive element;

an actuating means connected to said first phase shifting means for actuating said switching means contained in said first phase shifting means to switch on during an on period and to switch off during an off period alternatively and connected to said second phase shifting means for actuating said switching means contained in said second phase shifting means to switch on during said off period and to switch off during said on period, alternatively at an actuating frequency higher than twice the frequency of said input signal;

a modulating signal source coupled to said actuating means for generating a modulating signal for changing the ratio of said on period plus said off period to said on period in response to said modulating signal; and

two low-pass filtering means connected to the outputs of said first and said second phase shifting means, respectively, for eliminating components of said actuating frequency contained in the output signals of said first and second phase shifting means, whereby said first and second phase shifting means modulate each input signal with an opposite modulation phase.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,718,871 Dated February 27, 1973

Inventor(s) Kinji Kawamoto

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Page one, first column, below the line reading "[21] Appl. No.: 165,558", insert the following:

-- Foreign Application Priority Data
July 29, 1970 Japan.......45-66964/1970
August 7, 1970 Japan.......45-69442/1970
September 18, 1970 Japan.......45-82332/1970
November 20, 1970 Japan.......45-102890/1970 --.

Column 3, change formula (3) to read:

$$-- G(f) = R_C/R_1 \cdot (1-j2\pi fRC)/(1+j2\pi fRC) \quad (3) --;$$

change formula (4) to read:

$$-- G(f) = \frac{R_C}{R_1} \frac{1-j2\pi fRC(T_{ON}+T_{OFF})/T_{ON}}{1+j2\pi fRC(T_{ON}+T_{OFF})/T_{ON}} \quad (4) --.$$

Column 13, line 15, change "sad" to -- said --;
line 30, after "for" insert -- generating --;
line 44, change "of" to -- or --.

Signed and sealed this 20th day of November 1973.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

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Acting Commissioner of Patents