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Bode

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[54] APPARATUS FOR PRODUCING SPECIAL AUDIO EFFECTS UTILIZING PHASE SHIFT TECHNIQUES

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[52] **U.S. Cl.** .... **179/1 J**
[51] **Int. Cl.** **H03h 7/00**
[58] **Field of Search**.......... 179/1 J, 1 SA; 84/1.24, 84/1.25, 1.26

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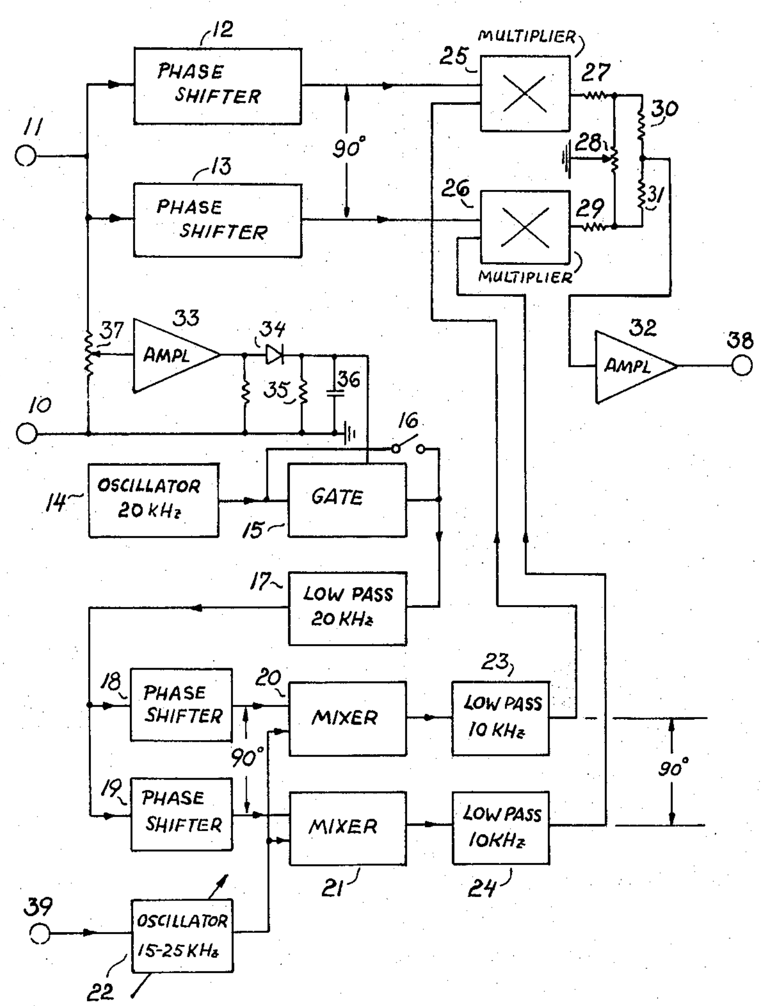
Assistant Examiner—Jon Bradford Leaheey

[57] **ABSTRACT**

This disclosure deals with significant innovations on an electronic apparatus for producing special effects by shifting the frequencies of audio signals through the use of the phase shifter technique for single sideband production. These innovations or the combination thereof consist of (1) the use of a beat frequency oscillator with two outputs in 90° phase relationship to facilitate frequency shifts of any amount and sign, exceeding the limitations of previously known phase shifter type audio frequency shifters by being capable of producing detuning effects down to and through zero frequency shift with a transition into sideband reversal, (2) the inclusion of an improved cascaded wideband audio frequency phase shifting circuit, (3) the addition of an inverse phase output circuit for the simultaneous production of an additive and a subtractive frequency shift, and (4) the exploitation of known means for making the beat frequency local oscillator voltage controllable.

5 Claims, 3 Drawing Figures



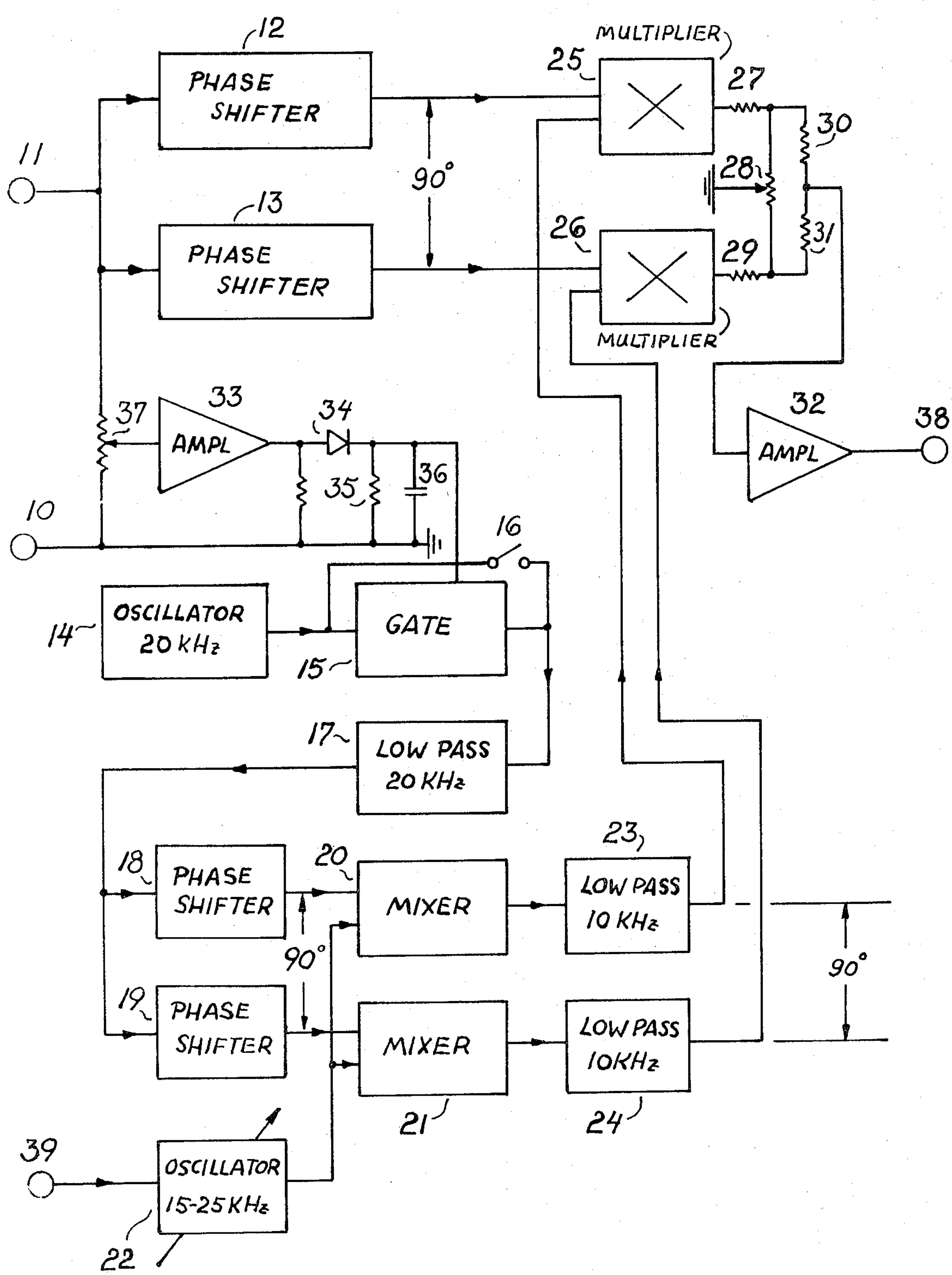

PHASE SHIFTER
12
PHASE SHIFTER
13
11
90°
MULTIPLIER
25
27
30
28
26
29
31
MULTIPLIER
37
AMPL
33
34
35
36
10
32
AMPL
38
16
OSCILLATOR 20 KHz
14
GATE
15
17
LOW PASS 20 KHz
18
PHASE SHIFTER
20
MIXER
23
LOW PASS 10 KHz
90°
19
PHASE SHIFTER
MIXER
LOW PASS 10KHz
21
24
90°
39
OSCILLATOR 15-25 KHz
22

Fig. 1

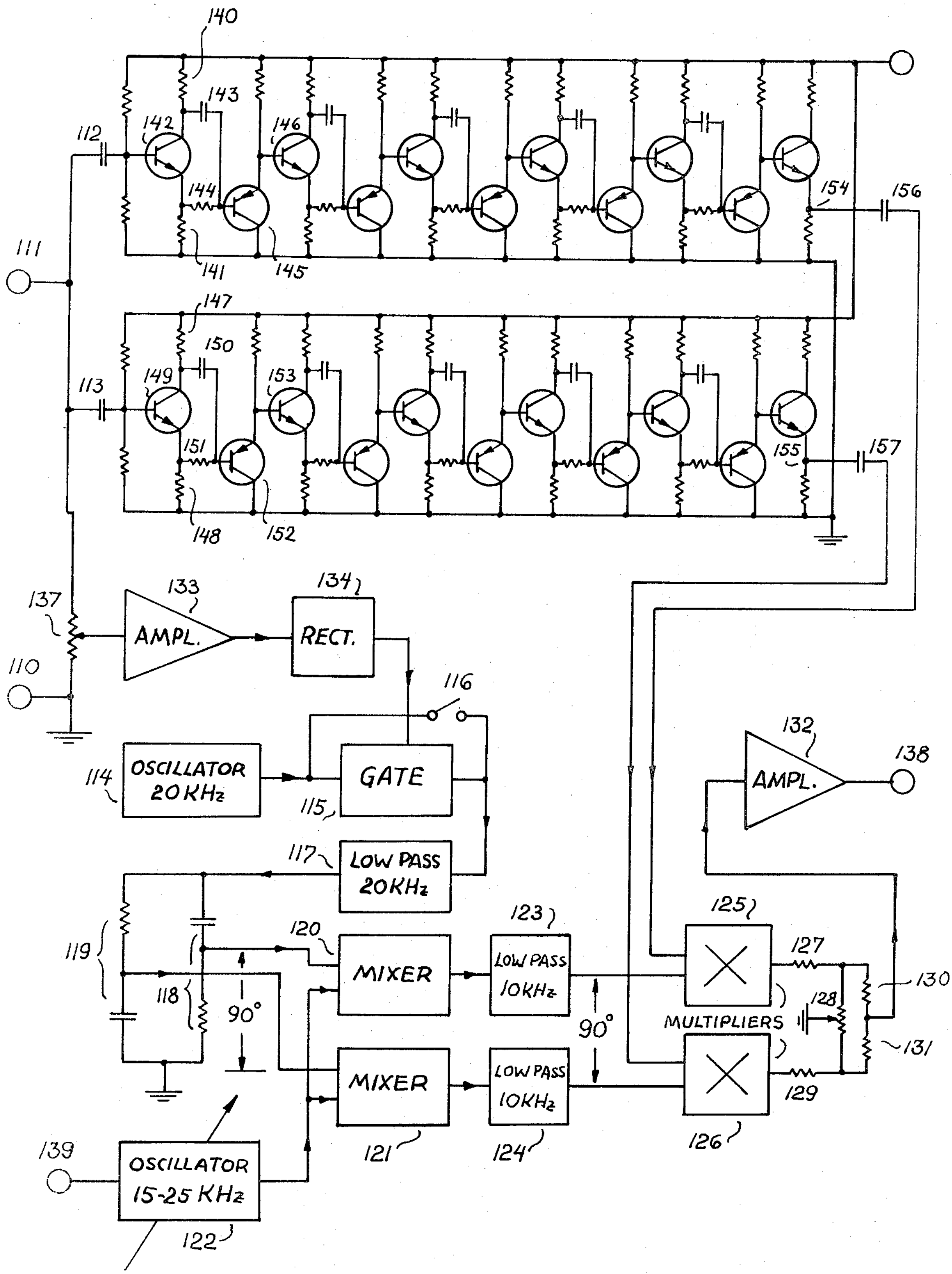

140
143
142
146
112
144
154
156
111
141
145
147
150
149
153
113
151
155
157
148
152
133
134
137
AMPL.
RECT.
110
116
OSCILLATOR
20 KHz
GATE
114
115
132
138
AMPL.
117
LOW PASS
20 KHz
123
125
120
MIXER
LOW PASS
10 KHz
127
119
118
90°
90°
128
130
MULTIPLIERS
131
MIXER
LOW PASS
10 KHz
129
126
121
124
139
OSCILLATOR
15-25 KHz
122

Fig. 2

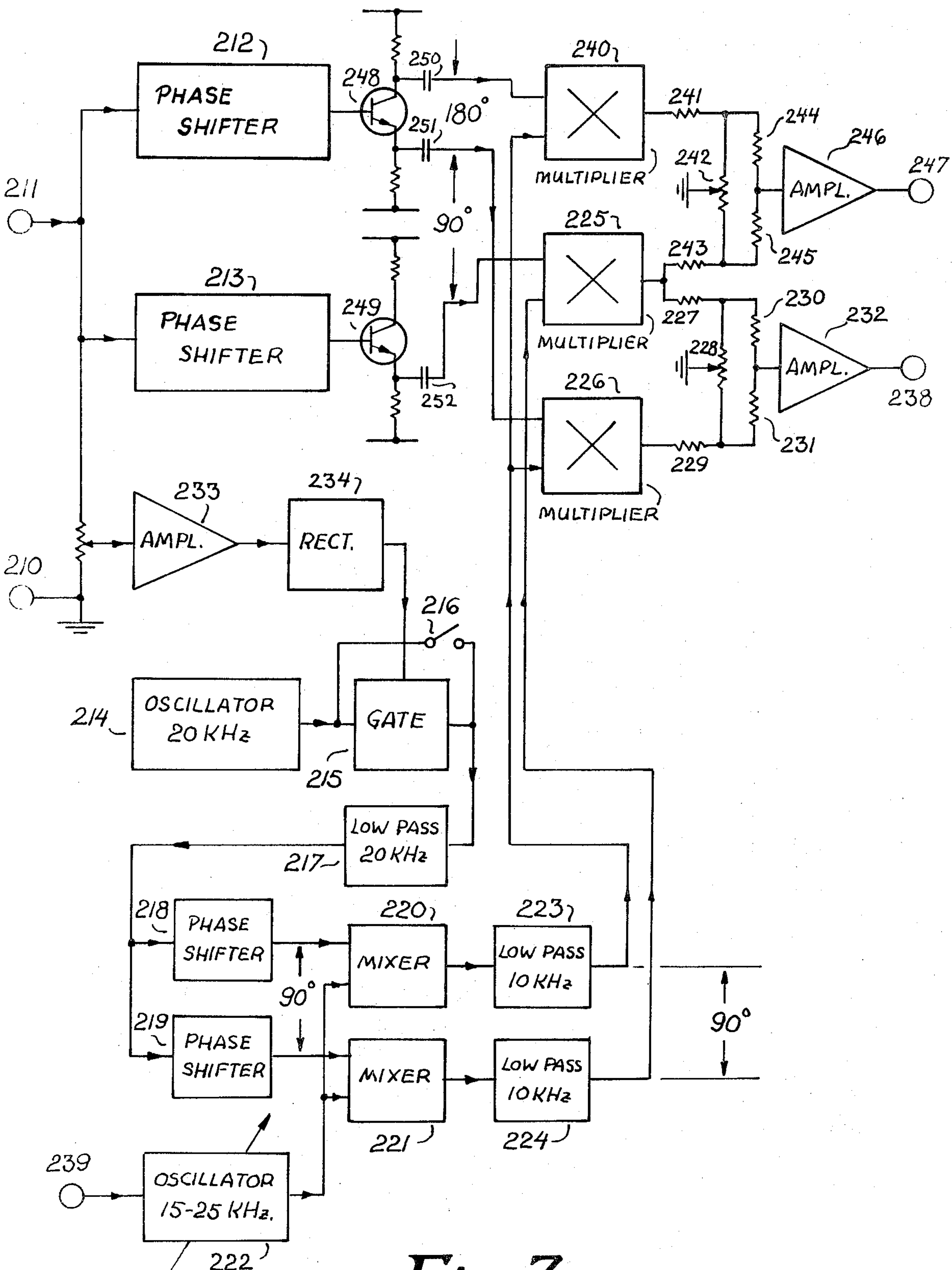

212
PHASE SHIFTER
248
250
251
180°
90°
240
MULTIPLIER
241
244
242
246
AMPL.
247
245
211
225
243
213
PHASE SHIFTER
249
252
227
230
232
AMPL.
228
238
226
229
231
MULTIPLIER
MULTIPLIER
233
AMPL.
234
RECT.
210
216
OSCILLATOR 20 KHz
214
GATE
215
LOW PASS 20 KHz
217
218
PHASE SHIFTER
220
MIXER
223
LOW PASS 10 KHz
90°
90°
219
PHASE SHIFTER
MIXER
LOW PASS 10 KHz
221
224
239
OSCILLATOR 15-25 KHz.
222

Fig. 3

APPARATUS FOR PRODUCING SPECIAL AUDIO EFFECTS UTILIZING PHASE SHIFT TECHNIQUES

This invention relates to an electronic apparatus for producing special effects upon audio signals and more particularly it is concerned with the means for shifting the frequencies of audio signals by utilizing the phase shifter approach for single sideband production.

It is an object of the present invention to provide a circuit, which is capable of continuous frequency shifting from additive to subtractive frequency changes or vise versa. It is a further object of the invention to provide means for simultaneous additive and subtractive frequency shifting.

Another object of the invention is to provide means for changing the amount of frequency shift by modulation or voltage control or both.

Still another object of the invention is to provide a circuit, which is capable of shifting the frequencies of the entire audio range with the same quality of performance.

A further object of the invention is to provide means for frequency shifting, which essentially eliminate the generation of unrelated signals.

A further object is to provide a highly compact apparatus and circuitry of the above mentioned character.

In order to provide a frequency shifter of the above mentioned type, one of the most important considerations is the provision of means for phase shifting the audio signals as well as the frequency shifting signal so as to obtain signal pairs with the closest possible approximation of a 90° phase difference relative to each other.

A further important consideration is the provision of a frequency shifter with the most flexible performance, so as to exceed the performance range as well as the features of the presently known designs.

In known frequency shifters of the phase shifting type both the program signal and the frequency shifting signal are processed through phase shifting circuits, which yield output signal pairs essentially 90° out of phase within the audio frequency range, for instance in a range from 40 Hz to 10,000 Hz.

Since frequency shifts of less than 40 Hz and down to and through zero are quite desirable, the known frequency shifter design poses severe performance limitations.

According to this invention, therefore, the frequency shifting signals are generated by a beat frequency oscillator with one fixed and one variable ultrasonic frequency, said beat frequency oscillator being capable of delivering two output frequencies with a precise phase difference of 90° over the entire range to and through zero beats by provision of phase shifting means in the fixed frequency channel to produce a pair of output signals with a 90° phase difference relative to each other, and by providing a pair of mixers, receiving one of the phase shifted, fixed frequency signals each at one of their inputs and the variable frequency signal at their other input so as to produce beat frequencies with a phase difference of 90° relative to each other. In a known manner the mixers of this dual beat frequency oscillator are followed by low pass filters for the suppression of any unwanted higher frequencies.

The novel feature of the invention, together with further objects and advantages thereof, will become more readily apparent when considered in connection with the accompanying drawings, in which:

FIG. 1 is a block schematic diagram of the apparatus according to the invention for the production of a single sideband,

FIG. 2 is a schematic diagram of the same apparatus depicting some pertinent circuit details, and

FIG. 3 is a block schematic diagram of the apparatus according to the invention for the simultaneous production of an additive and a subtractive frequency shift.

Referring now to the drawings and more particularly to FIG. 1, it will be observed, that the numerals **12** and **13** represent two phase shifting circuits, which receive audio signal from input **11**, and which produce output signals with essentially 90° phase difference relative to each other. A fixed frequency oscillator **14** of a frequency well above the highest audio signal frequency, for instance 20 kHz, feeds through the optional gate **15** and the low pass filter **17** to the two phase shifters **18** and **19** for obtaining two oscillator signals with 90° phase difference.

The phase shifted fixed frequencies are then fed to one of the inputs of the multiplicative mixers **20** and **21**, and a variable frequency signal from the oscillator **22**, the center frequency of which equals that of the fixed frequency oscillator, is fed to the other inputs of the multiplicative mixers **20** and **21**.

The beat frequencies produced in the mixers **20** and **21** display the same phase difference of 90° relative to each other as the signals processed through the phase shifters **18** and **19**. The low pass filters **23** and **24** are provided to suppress any unwanted higher frequencies leaving the mixers **20** and **21**. The signal pairs obtained at the outputs of the low pass filters **23** and **24** are further processed in the four quadrant multipliers **25** and **26**. The multiplier **25** receives one audio signal from the phase shifter **12** and an oscillator signal from the low pass filter **23**. The multiplier **26** receives one audio signal from the phase shifter **13** and an oscillator signal from the low pass filter **24**.

The outputs of the multipliers **25** and **26** feed into a summing network with the potentiometer **28** for combining and balancing the output signals of said two multipliers, thus generating a resultant signal, which represents the input audio signal shifted by the amount of the beat frequency. This resultant signal is then fed to the output **38** through the amplifier **32**. The sign of the frequency shift generated in the multipliers and the summing network depends upon the signs of the 90° phase relationships of the audio signals leaving the phase shifts **12** and **13** and the signs of the 90° phase relationships of the beat frequency signal pair leaving the low pass filters **23** and **24**. When the variable frequency oscillator **22** is tuned through zero beat against the fixed frequency oscillator **14**, the sign of the 90° phase relationship of the beat frequency signal reverses, which results in the change of an up-detuned signal at the output to a down-detuned signal and vise versa. An optional feature of the circuitry according to FIG. **1** is the inclusion of a threshold controlled gating circuit, which receives the audio signal through a potentiometer **37**, an amplifier **33**, a rectifier **34** with a charging capacitor **36** and a discharging resistor **35**, which provide the bias and time constant for opening and closing a gate, such as implemented by a diode switching circuit, a field effect transistor switch, a bias controlled amplifier or a multiplier, to pass the signal from the oscillator **14** to the low pass filter **17**, when an audio input signal is present, and when its amplitude has reached or exceeded a preset threshold level, which is determined by the setting of the potentiometer **37**. A gate bypass switch **16** is provided for disabling the muting circuit, if it is not required or desired.

A further optional feature of the apparatus according to FIG.1 within the state of the art is the provision of means to make the variable frequency oscillator **22** voltage controllable and to provide a control input **39**.

In FIG. **2** the design of the input circuits preceding the multipliers **125** and **126** is shown in detail. From FIG. **2** it will be observed, that the numerals **111** and **110** refer to the input signal and input signal return terminals respectively, and that the audio signal is fed through a capacitor **112** to a phase splitting circuit comprising the transistor **142** with the collector resistor **140** and the emitter resistor **141**, both of which are essentially of equal resistive value in order to generate two signals of equal amplitude and opposite phase. A phase shifting network comprising a capacitor **143** and a resistor **144** is serially connected between the collector and the emitter of transistor **142** to produce an output signal at the base of transistor **145**, which differs in phase from the input signal by approximately 139.5° at 40 Hz. This phase shifter stage is followed by an emitter follower stage comprising transistor **145** and a second phase splitter stage comprising transistor **146** with an associated phase shifting network similar to that of the preceding stage, which yields a phase shift of 110.28° at 170 Hz. The subsequent stages in conjunction with the said preceding stages yield cumulative phase shifts at increasing frequencies.

By the way of example the cumulative phase shifts of the five phase shifting stages of the just described circuit between the input capacitor **112** and the output transistor terminal **154** are 188.42° at 40 Hz, 328.72° at 170 Hz, 495.44° at 725 Hz, 662.32° at 3080 Hz, and 803.72° at 13090 Hz.

In a similar way a second phase shifting circuit is provided, in which the input audio signal is fed through capacitor **113** to a phase splitting circuit comprising the transistor **149** with the collector resistor **147** and the emitter resistor **148**, and a phase shifting network with the capacitor **150** and the resistor **151** serially connected between the collector and the emitter of said transistor **149** to produce an output signal at the base of transistor **152**, which differs in phase from the input signal by approximately 74° at 40 Hz. The emitter follower with transistor **152** is connected to a second phase splitter stage comprising transistor **153**, with an associated phase shifting network similar to that of the preceding stage, which yields a phase shift of 69.86° at 170 Hz. The subsequent stages in conjunction with the stages just referred to yield again a cumulative phase shift at increasing frequencies.

By the way of the same example referred to earlier, the cumulative phase shifts of the five phase shifting stages between the input capacitor **113** and the output terminal **155** are 98.42° at 40 Hz, 238.72° at 170 Hz, 405,44° at 725 Hz, 572.32° at 3080 Hz, and 713.72° at 13090 Hz. As it can be recognized easily by comparing these cumulative phase angles at the given reference frequencies with those of the previously described phase shifter, the phase differences between the above circuits are 90° for all of the indicated frequencies.

Phase measurements on a dual phase shifter of the kind just described showed a deviation of a maximum of 0.7° from the ideal phase difference of 90° over a frequency range from 45 Hz to 16,000 Hz, which, in combination with the beat frequency oscillator signal pair with its ideal phase relationship of 90°, leads to a very high quality performance with a rejection of the unwanted sideband in excess of 45 db. The performance improvement of the five stage cascaded phase shifters is in part made possible by the fact, that the emitter followers preceding the individual phase splitter stages increase the input impedances of said phase splitter circuits, thereby improving the performance of the overall phase shifting circuit. Furthermore the emitter followers compensate the base to emitter voltage drop of the phase splitter transistors by a base to emitter voltage drop of reverse polarity, which allows direct coupling without the otherwise observed cumulative D.C. level changes from the base of transistor **142** to the collector **154** of the last transistor of the upper circuit per FIG. **2**, and from the base of transistor **149** to the collector **155** of the last transistor of the lower circuit per FIG. **2**.

The output terminals **154** and **155** of said two phase shifting circuits are connected through capacitors **156** and **157** to the four quadrant multipliers **125** and **126** in a similar way as described under FIG. **1** with reference to the phase shifters **12** and **13**, leading to the multipliers **25** and **26** respectively. As a further circuit detail FIG. **2** shows the two phase shifters following the low pass **117**. One of the phase shifters comprising a resistor and capacitor combination identified by the numeral **118** feeds into the fixed frequency input of mixer **120**. The other phase shifter with the resistor and capacitor combination **119** feeds into the fixed frequency input of mixer **121**. The components of the phase shifters **118** and **119** are selected to yield outputs with a relative phase relationship of 90°.

In FIG. **3** the apparatus according to the invention is augmented by a second output for supplying a frequency shift, which is the inverse of that obtained at the first output. In detail the phase shifters **212** and **213** of substantially the same circuitry as the corresponding ones described in FIG. **2** are terminated by phase splitter stages with the transistors **248** and **249**, respectively. The signal from the emitter of transistor **248** is fed through capacitor **251** to the audio signal input of the multiplier **226**. The signal from the emitter of transistor **249** is fed through capacitor **252** to the audio signal input of multiplier **225**. The summing network at the outputs of multipliers **225** and **226**, comprising the balancing potentiometer **228** and followed by the amplifier **232**, combines the two signals, which are processed with the beat frequency so as to produce a frequency shift at the output **238** in the same way as described under FIG. **1**.

Multiplier **240** receives an audio signal from the collector of transistor **248** through capacitor **250**, which is the inverse of the audio signal fed to multiplier **226**. Since the beat frequency fed to the second inputs of multipliers **240** and **226** is the same, the output product of multiplier **240** is the inverse of that of multiplier **226**. Thus, when combined with the output product of multiplier **225** in the summing network comprising the potentiometer **242**, and followed by the amplifier **246**, a frequency shift is obtained, at the output terminal **247**, which is the inverse of that at the output terminal **238**.

Evidently the same result could be obtained by feeding the audio signal from the emitter of transistor **248** through capacitor **251** to the audio signal input of the multiplier **240** and by feeding a phase inverted signal from the output of the low pass filter **223** to the beat frequency input of multiplier **240.** Furthermore it will be evident to those skilled in the art, that the output signal of one or two four quadrant multipliers can be inverted by an inverter stage and summed with the output signal of the other four quadrant multiplier to obtain an inverse frequency shift.

Evidently the circuit shown in FIG. **3** and the modifications thereof described herein, can be enhanced by means to combine the two output signals so as to continuously blend from one sideband to the other.

Furthermore it will be evident, that the input circuits for phase shifting the audio signals as shown in FIG. **2** and described herein can be used in combination with a low frequency signal source, for instance of 5 Hz, with phase shifters for obtaining two signals in 90° phase relationship and feeding into the frequency shifting inputs of two four-quadrant multipliers, followed by a summing network and an output circuit for the production of high quality frequency shifted signals, and for the use in public address systems for the suppression of acoustical feedback.

Other means for enhancing the performance of an apparatus according to the invention or for modifying or simplifying the circuitry within the scope of the invention will be found by those skilled in the art. Therefore, the invention should not be deemed to be limited to the details of what has been described herein by way of example, but it should be rather deemed to be limited only to the scope of the appended claims.

What is claimed is:

1. Electronic apparatus for producing special effects upon audio signals, said apparatus comprising an input circuit feeding into two separate phase shifting networks for the production of output signals with essentially 90° phase difference relative to each other; and a beat frequency oscillator, comprising one fixed frequency ultrasonic oscillator with a sinusoidal output and one variable frequency ultrasonic oscillator, and two phase shifting networks in the signal path of the fixed frequency oscillator for obtaining two signals with 90° phase difference; two multiplicative mixers feeding into low pass filters, said multiplicative mixers receiving one of the 90° phase related fixed frequency signals and one variable frequency signal each for producing two beat frequencies, which are 90° apart in phase; and two four quadrant multipliers, which receive the 90° out-of-phase audio signals at one of their inputs and the 90° out-of-phase beat frequencies at their other inputs, and means to add the output signals of said four quadrant multipliers so as to obtain a resultant signal, which is frequency shifted relative to the input audio signal by the amount of the beat frequency, said means to add the output signals of the four quadrant multipliers being followed by an output circuit.

2. Electronic apparatus for producing special effects upon audio signals, said apparatus comprising an input circuit feeding into two separate phase shifting circuits for the production of output signals with essentially 90° phase difference relative to each other, each of said phase shifting circuits comprising a cascaded arrangement of individual phase shifting stages being directly coupled to each other, and emitter follower stages arranged in direct coupling between said phase shifting stages; and a beat frequency oscillator, comprising one fixed frequency ultrasonic oscillator with a sinusoidal output and one variable frequency ultrasonic oscillator and two phase shifting networks in the signal path of the fixed frequency oscillator for obtaining two signals with 90° phase difference; two multiplicative mixers feeding into low pass filters, said multiplicative mixers receiving one of the 90° phase related fixed frequency signals and one variable frequency signal each for producing two beat frequencies, which are 90° apart in phase; and two four quadrant multipliers, which receive the 90° out-of-phase audio signals at one of their inputs and the 90° out-of-phase beat frequency signals at their other inputs, and means to add the output signals of said four quadrant multipliers so as to obtain a resultant signal, which is frequency shifted relative to the input audio signal by the amount of the beat frequency, said means to add the output of the four quadrant multiplier being followed by an output circuit.

3. Electronic apparatus for producing special or desirable effects upon audio signals, said apparatus comprising an input circuit feeding into two separate phase shifting circuits for the production of output signals with essentially 90° phase difference relative to each other, each of said phase shifting circuits comprising a cascaded arrangement of individual phase shifting stages being directly coupled to each other, and emitter follower stages arranged in direct coupling between said phase shifting stages; and a subsonic oscillator with two outputs in sine/cosine phase relationship; and two four-quadrant multipliers, which receive the 90° out-of-phase audio signals at one of their inputs and the 90° out-of-phase or sine/cosine phase related frequency shifting signals at their other inputs, and means to add the output signals of said four quadrant multipliers so as to obtain a resultant signal, which is frequency shifted relative to the input signal by the frequency of the subsonic oscillator; and said means to add the output signals of said four quadrant multipliers being followed by an output circuit.

4. Electronic apparatus for producing special effects upon audio signals, said apparatus comprising an input circuit feeding into two separate phase shifting networks for the production of output signals with essentially 90° phase difference relative to each other; and a beat frequency oscillator, comprising one fixed frequency ultrasonic oscillator with a sinusoidal output and one variable frequency ultrasonic oscillator, and two phase shifting networks in the signal path of the fixed frequency oscillator for obtaining two signals with 90° phase difference; two multiplicative mixers feeding into low pass filters, said multiplicative mixers receiving one of the 90° phase related fixed frequency signals and one variable frequency signal each for producing two beat frequencies, which are 90° apart in phase; and three four-quadrant multipliers, the first two of which receive the 90° phase related audio signals at one of their inputs and the 90° phase related beat frequency signals at their other input, said first two four-quadrant multipliers being followed by a first summing network and an output circuit; and the third four-quadrant multiplier receiving a phase shifted audio signal at one of its inputs and a phase shifted beat frequency signal at its other input, said audio signal or said beat frequency signal being in opposite phase to the corresponding signal fed to the input of the first four-quadrant multiplier so as to produce a signal at the output of the third four-quadrant multiplier, which is in opposite phase to the one at the output of the first four-quadrant multiplier, and said second and third four-quadrant multiplier being followed by a second summing network and a second output circuit so as to produce a frequency shift, which is of opposite polarity relative to that obtained at the first output circuit.

5. Electronic apparatus for producing special effects upon audio signals, said apparatus comprising an input circuit feeding into two separate phase shifting networks for the production of output signals with essentially 90° phase difference relative to each other; and a beat frequency oscillator, comprising one fixed frequency ultrasonic oscillator with means to make the output signal sinusoidal, and one variable frequency oscillator with means to make the frequency voltage controllable, and two phase shifting networks in the signal path of the fixed frequency oscillator for obtaining two signals with 90° phase difference; two multiplicative mixers feeding into low pass filters, said multiplicative mixers receiving one of the 90° phase related fixed frequencies and one variable frequency signal each for producing two beat frequencies, which are 90° apart in phase; and two output circuits, receiving their signals from two summing networks, said summing networks receiving their signals from at least two four quadrant multipliers, with one of the four quadrant multiplier outputs feeding one of the inputs of both summing networks, and the other input of one of the summing networks receiving a four quadrant multiplier output signal, which is in opposite phase to that received by the other input of the second summing network; and said four quadrant multipliers receiving one signal each from one of the audio input phase shifting circuits and one signal each from one of the beat frequency oscillator outputs.

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