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Popescu

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[54] **GENERATOR FOR PRODUCING ULTRASONIC ENERGY**

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Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 854,240, Aug. 29, 1969, Pat. No. 3,629,726.

[52] **U.S. Cl.** ....**317/146,** 310/8.1, 310/26, 331/109, 331/116 M, 331/157, 331/186

[51] **Int. Cl.** **H03b 5/40**

[58] **Field of Search**..................................310/8.1, 26; 331/116 M, 109, 157, 186

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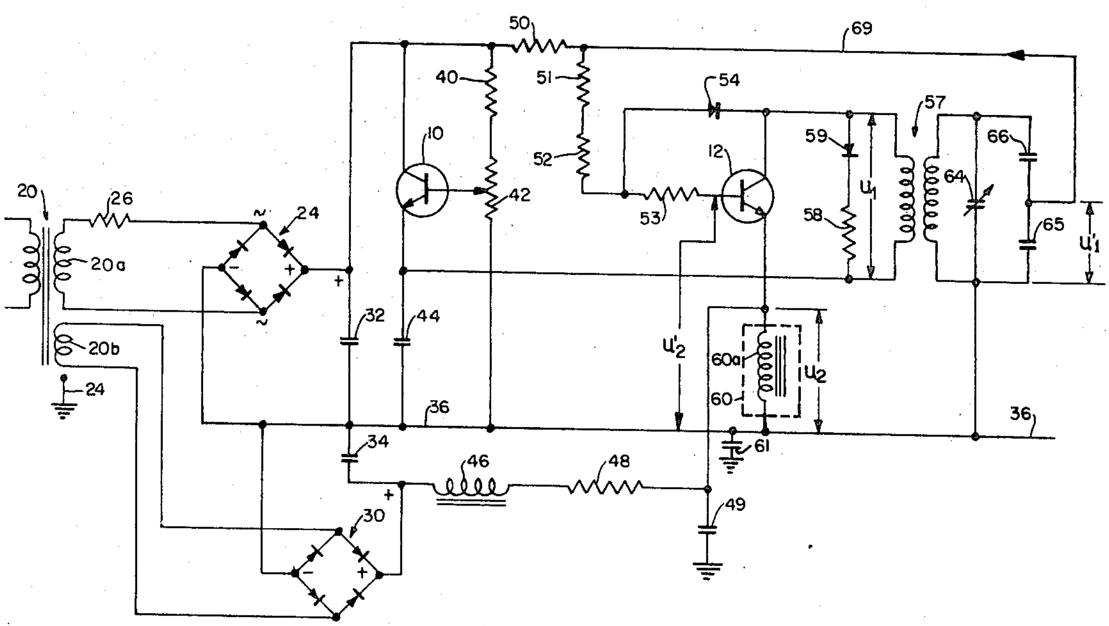
[57] **ABSTRACT**

A generator for producing energy in the ultrasonic range for driving a transducer having variable load characteristics in which the generator includes an oscillator circuit having the capability of accepting and operating with transducers whose natural resonant frequencies vary over a wide range; which has good frequency stability under low or no-load conditions of operation; and good frequency stability under loaded conditions of the transducer. The generator circuit also includes a self-monitoring circuit for keeping a relatively constant output power over wide ranges of loading of the transducer.

17 Claims, 4 Drawing Figures



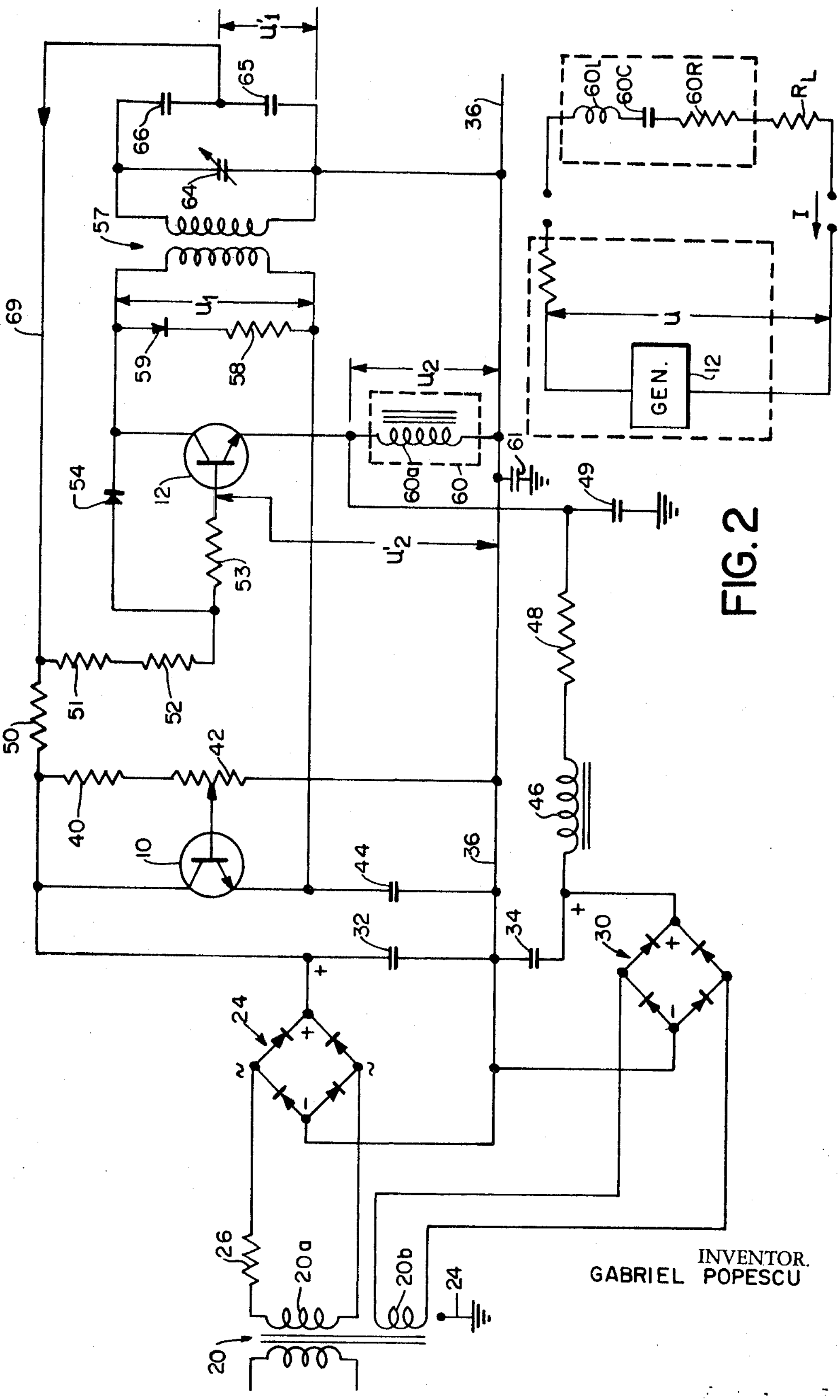


FIG. 1

FIG. 2

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FIG. 3

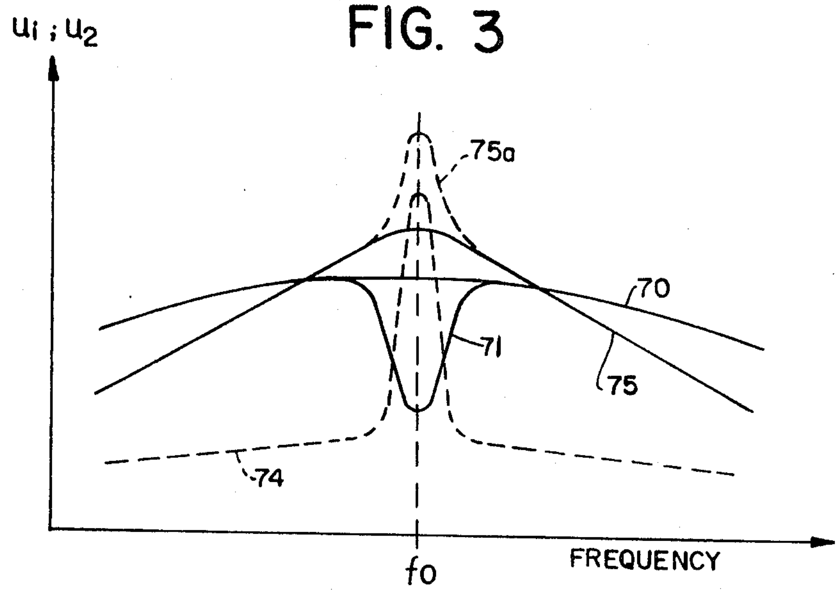
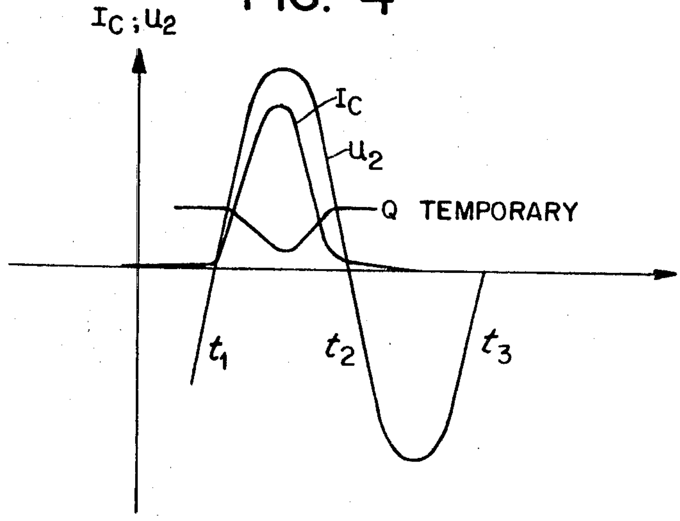


FIG. 4



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GENERATOR FOR PRODUCING ULTRASONIC ENERGY

RELATED APPLICATION

This application is a continuation-in-part of my copending application Ser. No. 854,240, filed Aug. 29, 1969, now U.S. Pat. No. 3,629,726, entitled "Oscillator and Oscillator Control Circuit", which is assigned to the same assignee.

DESCRIPTION OF PRIOR ART

In my aforesaid application, a generator (oscillator) and oscillator control circuit is provided for the production of electric energy which is used to supply an ultrasonic transducer. The transducer is of the magnetostrictive or piezoelectric type which converts the electrical energy into mechanical energy. The energy is in the frequency range of 1 khz to 100 khz, which is broadly called the ultrasonic frequency range where the transducer is to perform some work function. In a typical medical, dental or commercial application, the transducer drives a workpiece, such as the tip of a dental handpiece or a horn in a commercial application, to produce a useful work function at ultrasonic frequency.

As is known, in such applications, the transducer is subjected to varying loads. There loads are of the type, for example, wherein a tip of a handpiece, which the transducer drives when used by a dentist, is pressed down against the teeth of the patient; a horn in a commercial application is immersed into a fluid for agitating the fluid; the horn is loaded against an object to generate heat; the medium in which the transducer is located is changed, for example, from air to water, etc.

In the most common form of ultrasonic transducer, a stack of magnetostrictive elements of a suitable material, such as nickel or a nickel alloy are used. The elements of the stack are selected to have a predetermined resonant frequency and are connected together in a manner so that their outputs will be additive in phase to produce a desired power output at or near the resonant frequency. The magnetostrictive elements are supplied with the necessary electrical driving current through a single wound inductance coil, or several such coils located around the stack. The current causes the stack elements to undergo a stress or strain and the mechanical output is produced. Usually, an acoustic transformer is connected between the output end of the stack and the workpiece to transmit the vibrational energy of the stack to the workpiece.

Each stack of magnetostrictive elements has a natural resonant frequency. If the electrical current supplied to the stack is of this resonant frequency, then the stack will produce maximum mechanical output power. When the transducer is operated with a load, the net effect is to change the input impedance of the transducer from that at the natural resonant frequency. This effectively changes the resonant frequency. Thus, in order to provide maximum power transfer of driving current to the transducer, the output characteristics of the oscillator must be shifted in a corresponding manner to compensate for this change in the transducer input impedance and resonant frequency.

It has also been a problem that while transducers of the magnetostrictive type are designed to have a particular resonant frequency, due to variations in materials and tolerances during production, the natural resonant frequency of two transducers designed to be the same will not necessarily be so. Therefore, it is desirable to have an oscillator circuit that will accept transducers having natural resonant frequencies within a relatively wide range so that different oscillator circuits will not have to be designed to work with each transducer. The latter would be undesirable from a manufacturing point of view.

The present invention is an improvement over the oscillator and oscillator control circuit described in my aforesaid application. The improvements achieved by the invention of the subject application include the ability to accept and operate with transducers whose natural resonant frequencies vary over a wider bandwidth; a better frequency stability at lower output power levels, that is, when the transducer operates with little or no load, the frequency of the oscillator will not shift; an increased stability or oscillation frequency under a loaded condition; and the ability to self-monitor the amplitude of the output power to produce a fairly constant output power when the load varies over a relatively wide range without external control circuitry.

It is therefore an object of the invention to provide a generator for producing energy for driving an ultrasonic transducer and having a high efficiency of power transfer.

Another object is to provide a generator for driving an ultrasonic transducer which will operate with transducers whose natural resonant frequencies vary over a relatively wide range while maintaining good power transfer efficiency.

A further object is to provide a generator for producing energy to drive an ultrasonic transducer which is relatively simple, having one transistor for an oscillator and a second transistor for manual power setting.

An additional object is to provide a generator for an ultrasonic transducer which has good stability at low-load conditions of the transducer.

Other objects and advantages of the present invention will become more apparent upon reference to the following specification and annexed drawings, in which:

FIG. 1 is a schematic diagram of the generator of the subject invention;

FIG. 2 is a schematic diagram simplified for purposes of analysis;

FIG. 3 is a diagram illustrating certain operating principles of the generator; and

FIG. 4 is a diagram illustrating other operating principles of the generator.

Referring to FIG. 1, the circuit of the subject invention includes a first transistor **10**, which is the amplitude monitoring transistor for setting the desired power level for the generator, and a second transistor **12** connected as an oscillator for producing the electrical current to drive a transducer **60**. The power for the circuit is supplied from a suitable transformer **20** which has a pair of isolated secondary windings **20*a*** and **20*b***. The primary of the transformer is to be connected to a suitable source of A.C. voltage. A ground terminal at the secondary side is shown by reference numeral **21**. An isolated transformer is used since the circuit, when used for dental and medical applications, is preferably isolated from ground for safety purposes. Of course, in some cases this may not be necessary.

The first secondary 20*a* of transformer 20 is connected across the upper and lower terminals of a full wave bridge rectifier circuit 24. The upper end of the secondary 20*a* is connected to the top terminal of the bridge through a resistor 26.

The secondary winding 20*b* of the transformer 20 supplies voltage to the upper and lower terminals of a second bridge rectifier 30. As is explained below, the output of bridge 30 is used to supply a polarizing current to he transducer. A pair of filter capacitors 32 and 34 are connected across the output terminals of the respective bridge rectifier circuits and connected together at a common neutral potential point 36.

The unregulated D.C. output voltage fro the upper end of capacitor 32 is applied to the collector of the first transistor 10. The base of transistor 10 is biased by a voltage divider formed by series connected resistors 40 and 42, connected between the point of unregulated potential at the upper end of capacitor 32 and the neutral line 36. A capacitor 44 is connected between the emitter of transistor 10 and the neutral point 36. The reactance of capacitor 44 is low at the natural resonant frequency of the oscillator and transducer. Therefore, the A.C. component of the transducer is not reflected back at the power supply.

Transistor 10 functions as a series voltage regulator. The conducting level of the transistor is set by the amount of voltage at its base as selected from the slider of potentiometer 42 which is part of a voltage divider 40, 42. The voltage at the emitter of transistor 10, which is supplied to the collector of oscillator transistor 12, is maintained substantially constant for variations in power supply voltage. The ratio of the two resistors of the voltage divider is selected preferably so that the minimum voltage output will be approximately one-tenth of the maximum.

The second bridge rectifier circuit 30 provides a D.C. polarizing current to the transducer 60 which is connected between the emitter of the oscillator transistor 12 and the neutral line 36. This current is supplied through an inductor 46 and a resistor 48 from he positive output terminal of bridge 30 to the top end of a single coil 60*a* which drives the transducer stack. A capacitor 49 is connected from the top end of coil 60*a* to ground. The inductor 46 and the capacitor 49 prevent the transducer oscillations from shorting to ground. The positive current from bridge 30 is supplied to the transducer coil 60*a* to pre-bias the elements of the stack, i.e., to shift the point of operation of the magnetostrictive elements to a desired point on the hysteresis curve where the stack elements will respond to signals of relatively low level to produce a magnetostrictive effect. If the polarizing current were not used, the output of the oscillator would have to be of a greater amplitude to produce magnetostrictive action of a magnitude sufficient to operate the transducer with a reasonable quantity of output power.

The collector of transistor 12 receives operating potential from the regulated output at the emitter of transistor 10 which is applied to the collector through the primary winding of a feedback transformer 57. A series circuit of a resistor 58 and a diode 59 is connected across the primary of transformer 57. The purpose of this is described below.

The transducer 60 is connected between the emitter of transistor 12 and neutral point 36. FIG. 2 shows schematically the transducer and the effect of loading. A stack of magnetostrictive elements can be represented for purposes of analysis as capacitance, inductance and resistance elements connected in series. This, of course, is only a rough approximation which in the present case is sufficient. The three elements are designated 60C, 60L and 60R and they are the mechanical impedance components at the resonant frequency of the transducer. The transducer load is designated as Z_L . When the load is of the damping variety, such as when a tip attached to the transducer is pressed against an object, the load is primarily resistive. In this case it can be designated R_L . The driving coil 60*a* of the transducer which is actually connected to the emitter of transistor 12, is not shown in FIG. 2. In the circuit of FIG. 1, the effect of the driving coil inductance is neutralized by the capacitors 61 and 49 connected in parallel with coil 60*a*. (The capacitors 49 and 61 are part of a bridge containing the ends of the transducer coil. By grounding the junction of the capacitors the voltages across the coil ends are transmitted to the stack in phase opposition. This brings the stack voltage to ground potential.)

The base of oscillator transistor 12 is biased through a network comprising the series resistors 50, 51, 52 and 53. The resistor 50 is connected to the collector of the regulator transistor 10. A positive feedback path is provided from the collector to the base of the transistor 12 through the secondary of transformer 57. A trimming capacitor is connected in parallel with the secondary of transformer 57 to adjust the phase of the feedback voltage to secure oscillation. A pair of series connected capacitors 65 and 66 are connected across the secondary winding and capacitor 64 to improve the power transfer, as is explained below. A feedback connection is provided from the junction of capacitors 65, 66 over line 69 to the junction of resistors 50 and 51. A diode 54 is connected between the collector of transistor 12 and resistor 53 connected to the base. The purpose of this device is also explained below.

As in the circuit of my aforesaid patent application, the oscillator transistor 12 has the transducer 60 connected thereto so that the voltage appearing across the transducer 60 appears at the emitter of the transistor 12 and the current flowing through the transducer flows through the transistor and therefore through the primary winding of feedback transformer 57. Thus, the feedback voltage produced on line 69 and applied back to the base of transistor 12 through the resistors 51, 52 and 53 corresponds to the current through the transducer. As explained before, the transducer changes its characteristics, essentially its input impedance, in response to changes in load. Therefore, both the voltage across the transducer and the current through it will vary, depending upon the loading conditions.

The oscillator portion of the circuit of FIG. 1 operates by having a collector to base feedback path through the transformer 57 which is phase inverted to produce a positive feedback signal and thereby sustain oscillations. The oscillator output voltage u_1 appears across the combination of the diode 59 and resistor 58 which is in the collector circuit of transistor 12. A portion of this collector voltage is transformed by the tuned transformer 57 to provide a feedback voltage u_1'

appearing across capacitor 65 which is applied through the resistors 51, 52, 53 to the transistor base electrode. Voltage u_1' is proportional to the current through the transducer 60 since the current passing through the transducer is effectively the same current (less the base current), passing through the transistor 12. This current appears across diode 59 – resistor 58 as the output voltage. The feedback voltage u_1' applied to the base is therefore proportional to the current through transducer 60.

The voltage across transducer 60 appears as a voltage u_2 between the emitter of transistor 12 and the neutral point 36. This voltage is in phase opposition with the feedback voltage u_1' applied to the transistor base so that the effect of the two voltages u_1' and u_2 with respect to the transistor is vectorially additive.

FIG. 3 shows graphically the effect of the circuit of FIG. 1 on the transducer. The X axis of the graph is in the frequency scale while the Y axis is the amplitude scale for u_1' and u_2. The series resonant frequency of the transducer is designated f_o. Curve 70 is the voltage u_2 appearing at the emitter of the transistor 12. In the absence of the transducer stack, this voltage maintains a fairly level amplitude over a relatively wide range of frequencies due to the presence of the coil for transducer 60 of value L and the neutralizing capacitor 61 of value C in parallel with the coil. The voltage u_2 has a sharp dip, shown by the portion 71, around the resonance frequency f_o which is caused by the resonance frequency of the stack of magnetostrictive elements.

Curve 75 represents the voltage u_1'. The voltage U_1' is directly proportional to the transducer current as previously explained. The slowly changing amplitude portion on each side of the resonant frequency f_o is due to the presence of the tuned feedback circuit transformer 57 and capacitors 64, 65 and 66. This voltage peaks, as shown by the curve *75a*, at the resonant frequency due to the presence of the transducer stack in the emitter circuit. The solid portion of the curve 75 below the peak *75a* indicates the voltage which would appear without the transducer stack being in the emitter circuit. With the transducer stack there is a resonance of the transducer which causes an additional peaking of the voltage at and on either side of the resonant frequency f_o.

Curve 74 is a combination of the two voltage $u_1' - u_2$ which is shown as the base to neutral voltage in FIG. 1. Here it can be seen that there is a peak voltage at the resonant frequency of the stack. In normal operation of the circuit, the resonant frequency of the stack will change due to loading of the transducer. Also, for a number of transducers designed for a certain resonant frequency, some of these will fall on each side of the design center by varying amounts. In the oscillator circuit of FIG. 1, the oscillator will accommodate for both types of variations within a relatively wide range. That is, the oscillator will deliver good power output as the transistor shifts on either side of f_o due to loading, as shown by FIG. 3. Also, it will operate with transducers whose resonant frequencies are on either side of the design center f_o. The oscillator circuit of FIG. 1 is highly effective since two feedback signals are used, one to the base and one to the emitter, both of which have peak values at the transducer stack resonant frequency.

The oscillator 12 is biased so that it operates substantially in a Class B manner. Accordingly, selecting the proper values for the feedback components 57, 64, 65, 66 can be accomplished quite readily but certain precautions have to be taken for certain conditions. Because of the Class B type operation, power (current) is transmitted to the transducer substantially only on positive half cycles of the oscillator output, that is, when the oscillator 12 is conductive. FIG. 4 shows a cycle from time t_1 to t_3 with the middle at t_2. Collector current I_c flows from t_1 to t_2, the positive half cycle, and there is no current from t_2 to t_3. The voltage across the transducer is again shown as u_2 and it follows I_c.

The power required to drive the transistor oscillator base electrode can put a large stress on the Q (quality factor) of the oscillator circuit and bring it down. Thus, precautions should be taken to see that the feedback path to the base electrode does not load the Q of the circuit unnecessarily.

Referring to FIG. 1, resistor 50 feeds the junction of capacitors 65, 66 from the output of the rectifier bridge 24. This provides an essentially constant current source to the junction of capacitors 65, 66 and sets up the bias at the base of transistor 12 through resistors 51, 52, 53. As indicated above, current flows through the transducer only on positive half cycles of input signal to the transistor base. Thus, during the negative half cycles of base input signal transistor 12 does not conduct and the secondary of transformer 57 is substantially unloaded due to the equilibrium condition established by the two capacitors 65, 66 whose junction is supplied with a voltage from resistor 50.

The Q of the secondary of transformer 57, called $Q_{temporary}$ in FIG. 4, is given by

$$Q_{temp} = (R_o)/(\omega_{oL}) \qquad (1)$$

where

R_o = the load on the secondary of transformer 57 presented by the load on the base of transistor 12

ω_o = the center frequency of transformer 57

L = the inductance of transformer 57.

The load R_o can be represented generally by an equivalent resistance in parallel with a single equivalent capacitor, which represents the combined capacitance of capacitors 64, 65, 66. Both the equivalent resistor and the capacitor parallel the transformer secondary. The Rload varies as a function of time, due to whether or not current is flowing in the oscillator circuit. Thus, referring to FIG. 4,

$$R_d(t) = R_1 \text{ for } t_1 < t < t_2 = \infty \text{ for } t_2 < t < t_3 \qquad (2)$$

(since the transistor current is effectively zero) where $R_d(t)$ is the varying value of the load.

R_o is obtained by integration of the effect of $R_d(t)$ for the whole period t_1 to t_3 and multiplied by a function of the capacitors 65, 66. It can be shown mathematically that R_o remains relatively high over the period t_1 to t_3 compared to the load resistor. Resistors 51 and 52 keep the circuit Q reasonably high during the time the integrations are made. Thus, there is a good power transfer from the tank circuit 57, 65, 66 to the base without seriously lowering the Q of the tank circuit.

An essentially constant current is also supplied from the rectifier bridge 24 through the resistors 50, 51, 52, 53. However, the resistor 58 between the terminals of the primary of transformer 57 should be kept small for the positive values of current through the transistor 12 and transducer 60. If this is not done, then power is transferred to the collector of transistor **12** from the emitter, where it should be delivered. When the voltage at the upper terminal of the primary winding of **57** is more positive than the lower terminal (t_1 to t_2), diode **59** will conduct and resistor **58** will appear a the collector load. When the voltage at the upper terminal is less than that at the lower terminal (t_2 to t_3), diode **59** is non-conductive and the resistor **58** is not in the circuit. This results in a better Q for the tank **57** for negative voltages (t_2 to t_3) across the transducer **60** and no collector current flowing, that is, the primary of transformer **57** is not loaded by resistor **58** since diode **59** is non-conductive. It also results in a poorer Q for tank **57** when the current flows through the transistor (t_1 to t_2) and the feedback is active, since resistor **58** loads the primary of transformer **57**. The latter is desirable since for active periods of the transducer the feedback is more decided primarily by the resonant characteristics of the transducer itself. During inactive periods of the transducer (t_2 to t_3), the oscillation of the circuit is maintained by the higher Q of the tank circuit **57**.

Another way of viewing the circuit is that when transistor **12** conducts and diode **59** becomes conductive the resistance of resistor **58** placed across the primary of transformer **57** lowers the impedance in the collector circuit. This results in a greater voltage (u_2) being developed across transducer **60** and an increase in the power delivered to the transducer. When transistor **12** is non-conductive, the resistor **58** is not effective and the collector load impedance is higher. The larger portion of the current flowing through transistor **12** will now appear as a voltage drop across transformer **57** and be used on the feedback signal.

The feedback between collector and base of transistor **12** should be sufficiently high to maintain oscillations even when the load on the transducer is small and there is high current flowing through transistor **12**. Peak currents developed under little or no load condition could produce direct conduction between the collector and base electrode, that is, I_{CB} would be high. This could either destroy the transistor or latch up the circuit in a conducting state with little or no effect or further base excitation.

Diode **54** and resistor **53** prevent I_{CB} from reaching dangerous levels. When the operating condition of the circuit is such that the collector voltage (u_c) is less than the base voltage (u_b), which would cause the latch-up condition, the diode conducts. The voltage from base to collector (u_{bc}) is given as:

$u_{bc} = u_b - u_c$.

When diode **54** conducts, u_b will exceed u_c only by the voltage drop across the diode (u_d) which can be, for example, about 1 volt. Thus, I_{bc} becomes

$I_{bc} = u_d$/resistance of **53**.

Since u_d can be small, I_{bc} will be small an the transistor will not latch up.

Referring to FIG. **2**, since the transducer circuit is of the series resonant type, for a high value of Z_L the of the transducer will decrease to values where the regular variations of the transducer impedance with frequency will be too small to control the oscillator of the generator. This is seen from the following formula:

$$\phi \cong \text{arc tan}\left(\frac{\omega}{\omega_o}-\frac{\omega_o}{\omega}\right)Q = \text{arc tan}\left(\frac{\omega}{\omega_o}-\frac{\omega_o}{\omega}\right)\frac{\omega_o L}{R+R_L} \quad (3)$$

where

ϕ = the phase angle of the feedback voltage

ω_o = the resonant frequency of the transducer

ω = the operating frequency

Q = the quality factor of the transducer

L and R = the values of the inductance and resistance of the transducer at resonance

R_L = the impedance of the load.

A resistive load is assumed for purposes of simplicity, the total reactive expression being somewhat complicated.

By keeping the current through the transducer constant, the power in the transducer will increase with increasing load. The power P delivered to a load represented by a resistance R_L is equal to:

$$P = I^2 R_L. \quad (4)$$

Thus, if the load increases causing an increase in R_L, the total power P will increase if I is held constant.

The circuit of FIG. **1** maintains a relatively constant current I to the transducer and its load R_L. Referring to FIG. **2**, the generator which includes the oscillator circuit **12**, behaves essentially as a constant current generator. In the equivalent circuit of FIG. **2**, the current I through the transducer end load is given as:

$$I = (u)/R_{gen} + R_{TR} + R_L + {}_jX_{TR} \quad (5)$$

where

u = the output voltage of the generator

R_{gen} = the equivalent circuit output resistance of the generator

R_{TR} = the resistance of the transducer stack which is **60R** in FIG. **2**

${}_jX_{TR}$ = the reactive component of the transducer stack impedance formed by **60L** and **60C**; and

R_L = the load.

At resonance, the ${}_jX_{TR}$ component vanishes. Therefore, the current I_o at resonance is:

$$I_o = (u)/R_{gen} + R_{TR} + R_L \quad (6)$$

As a practical matter

$$R_{gen} >> R_L \text{ and } R_{gen} >> R_{TR}$$

Therefore:

$$R_{gen} + R_{TR} >> R_L$$

This means that I_o is substantially independent of the load resistance, or

$$I_o \cong (u)/R_{gen} + R_{TR} \quad (7)$$

Thus, for changes in load R_L, the power P will follow as per equation (4) since the current I remains substantially constant.

As should be apparent, a relatively simple but highly efficient circuit has been provided for driving an ultrasonic transducer. The circuit comprises only two transistors but yet provides all of the advantages discussed above.

What is claimed is:

1. In combination ultrasonic transducer means whose impedance varies as a function of its loading, oscillator circuit means including amplifying means having at least a control electrode and first and second output electrodes, means for connecting said transducer means to one of said output electrodes to receive driving current from said amplifying means, frequency responsive circuit means including at least one reactive circuit element connected to the output electrode of said amplifying means to serve as the load impedance therefor, means coupling energy from said frequency responsive circuit means to said control electrode to provide a positive feedback signal to produce and sustain oscillations of said amplifying means, and means connected to said frequency responsive circuit means for changing the load impedance seen by said other output electrode during a given portion of each cycle of its oscillations to increase the power delivered to the transducer.

2. The combination of claim 1 wherein said means for changing the load impedance of the frequency responsive circuit means includes means responsive to the current through said amplifying means to lower the Q of the frequency responsive circuit means when current is flowing through said amplifying means.

3. The combination of claim 2 wherein said ultrasonic transducer means includes means forming a frequency responsive circuit.

4. The combination of claim 1 wherein said frequency responsive circuit means includes a tuned resonant circuit, said means for changing the load impedance seen by said other output electrode comprising a diode and a first means having a resistive component which are connected to said resonant circuit, said diode becoming conductive during said give portions of each cycle of oscillation of said amplifying means to place said first means in circuit with said resonant circuit means to lower the impedance of the latter, said diode being non-conductive during the remainder of each cycle of oscillation of said amplifying means.

5. The combination of claim 2 wherein said frequency responsive circuit means includes a tuned resonant circuit, said means for changing the load impedance of said circuit comprising a diode and a first means having a resistive component which are connected to said resonant circuit, said diode becoming conductive during said given portions of each cycle of oscillation of said amplifying means to place said first means in circuit with said resonant circuit means to lower the Q of the latter, said diode being non-conductive during the remainder of each cycle of oscillation of said amplifying means.

6. The combination of claim 1 wherein said means for connecting said transducer to said amplifying means connects it in series with said one electrode and a point of reference potential so that the current through said amplifying means is proportional to the current through said transducer means and a first voltage is present between said one output electrode and said point of reference potential which is proportional to the voltage across said transducer, means for connecting said frequency responsive circuit means to said other electrode so that a second voltage is present thereon which is proportional to the current through said amplifying means, said coupling means applying said second voltage to said control electrode so that said first and second voltages are vectorially additive with respect to the operation of said amplifying means to produce said oscillations.

7. In the combination of claim 6 wherein said three electrode amplifying means is a semiconductor device having an emitter, a collector and a base electrode which are respectively said first and second output electrodes and said control electrode.

8. In the combination of claim 7 wherein said transducer is connected to said emitter electrode and said frequency responsive circuit means for applying the second voltage to said base electrode comprises tuned feedback circuit means connected between the collector and base electrodes.

9. In combination an ultrasonic transducer means whose impedance varies as a function of its loading, oscillator circuit means including amplifying means having at least a control electrode and first and second output electrodes, means for connecting said transducer means in series between a point of reference potential and said first output electrode so hat the current through said amplifying means is proportional to the current through said transducer means and a first voltage appears between said first output electrode and said point of reference potential which is proportional to the voltage across said transducer, and means connected to said second output electrode for producing a second voltage proportional to the current through said amplifying means and for applying said second voltage to said control electrode so that said first and second voltages are vectorially additive with respect to the operation of said amplifying means to produce and sustain oscillations, said last named means comprising a tune resonant circuit including a transformer having a primary and a secondary winding, a pair of series connected capacitors connected in parallel across said secondary winding and means connected between the junction of said pair of capacitors and said control electrode for supplying said second voltage to said control electrode.

10. The combination of claim 9 further comprising means connected to said frequency responsive circuit means for changing the impedance load that it presents to said second output electrode during a given portion of each cycle of its oscillations.

11. The combination of claim 1 wherein said tuned resonant circuit means comprises a transformer having primary and secondary windings, said means for changing the impedance load presented by said tuned resonant circuit means being connected to said primary winding, said means for coupling energy to said control electrode comprising a pair of series connected capacitors connected across said secondary winding, and means connected between the junction of said pair of capacitors and said control electrode to supply said positive feedback signal to said control electrode.

12. The combination of claim 7 further comprising diode means connected between said collector and base electrodes to prevent the potential at the base electrode from exceeding the potential at the collector electrode.

13. In combination an ultrasonic transducer means whose impedance varies as a function of its loading, said ultrasonic transducer means including a plurality of magnetostrictive elements and a single coil in proximity thereto for supplying driving current to said elements, oscillator circuit means including amplifying means having at least a control electrode and first and second output electrodes, means for connecting said single coil of said transducer means in series between a point of reference potential and said first output electrode so that the current through said amplifying means if proportional to the current through the coil of said transducer means and a first voltage appears between said first output electrode and said point of reference potential which is proportional to the voltage across

said transducer, circuit means connected to said second output electrode for producing a second voltage proportional to the current through said amplifying means and for applying said second voltage to said control electrode so that said first and second voltages are vectorially additive with respect to the operation of said amplifying means to produce and sustain oscillations, circuit means comprising at least in part the load impedance for said second output electrode and including first means responsive to the conduction level of said amplifying means for varying the load impedance presented by said circuit means.

14. The combination of claim **13** wherein circuit last means comprises a tuned resonant circuit including a transformer having a primary and a secondary winding, a pair of series connected capacitors connected in parallel across said secondary winding and means connected between the junction of said pair of capacitors and said control electrode for supplying said second voltage to said control electrode.

15. The combination of claim **13** further comprising an additional impedance element, said circuit means including a tuned resonant circuit, and said first means including second means for placing said additional impedance element in circuit with said tuned resonant circuit.

16. The combination of claim **15** wherein said tuned resonant circuit includes a transformer having a primary winding with one end connected to the said second output electrode, said second means and said additional impedance element connected in series across at least a portion of said transformer.

17. The combination of claim **16** wherein said second means is a diode and said diode and said additional impedance element are connected in series across the primary winding of the transformer.

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