Sept. 25, 1956 P. G. SULZER 2,764,643

OSCILLATORS

Filed March 23, 1954 4 Sheets-Sheet 1

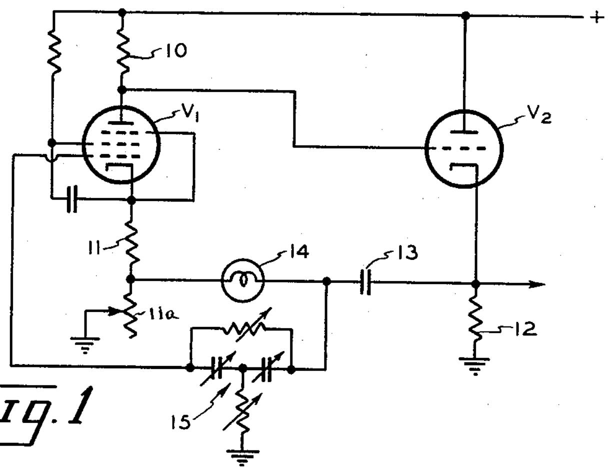

Fig. 1

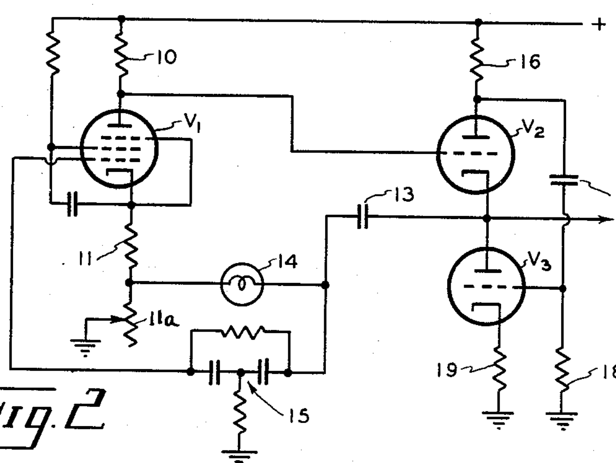

Fig. 2

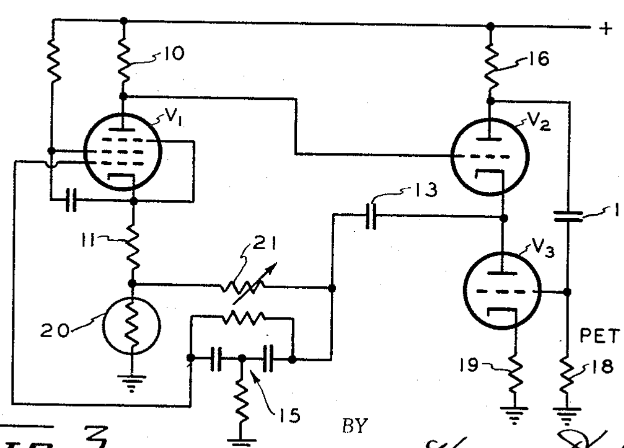

Fig. 3

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OSCILLATORS

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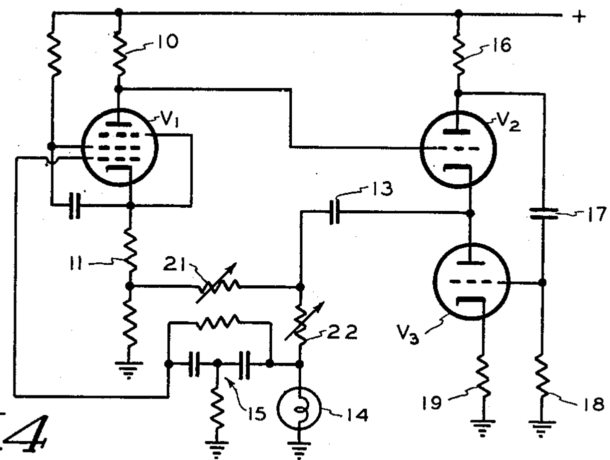

Fig. 4

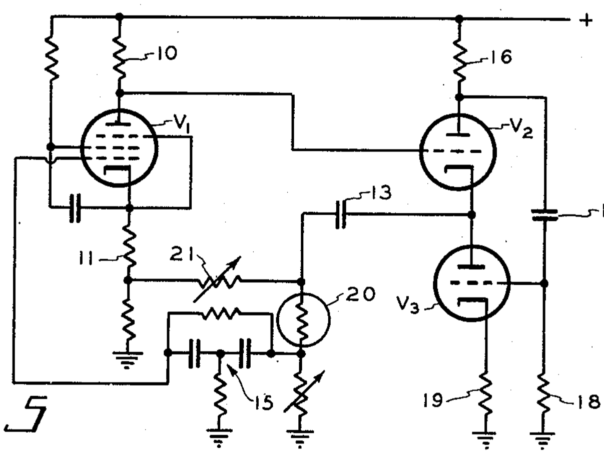

Fig. 5

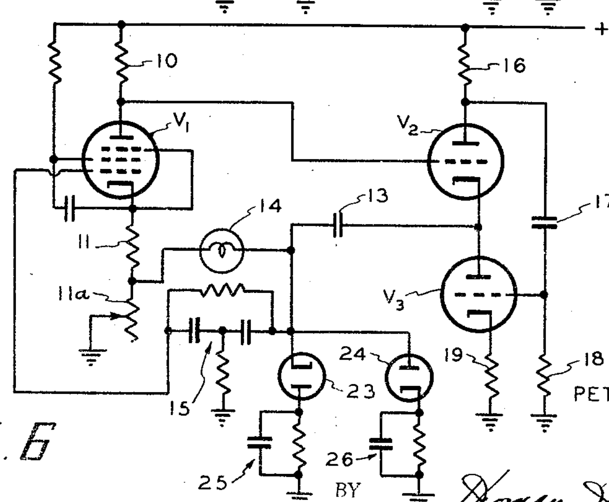

Fig. 6

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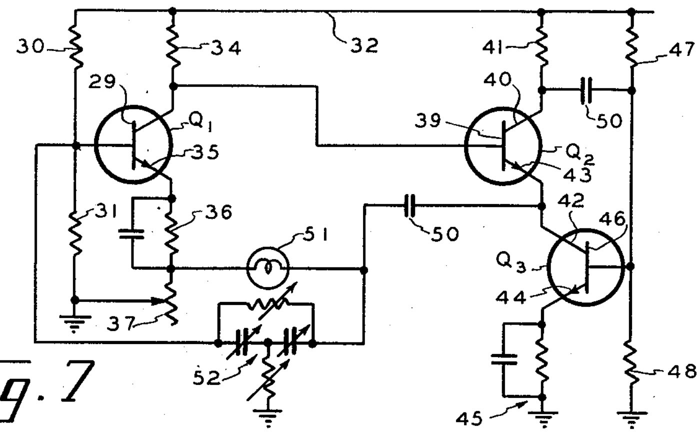

Fig. 7

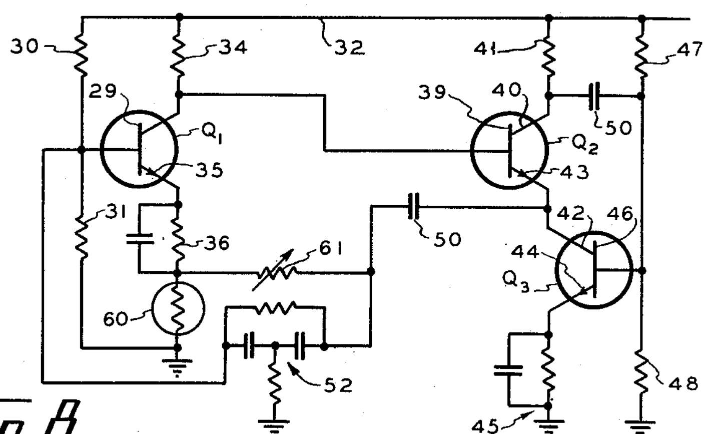

Fig. 8

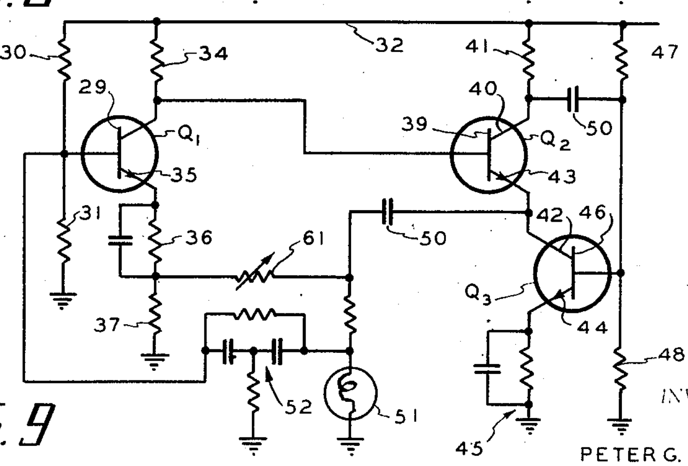

Fig. 9

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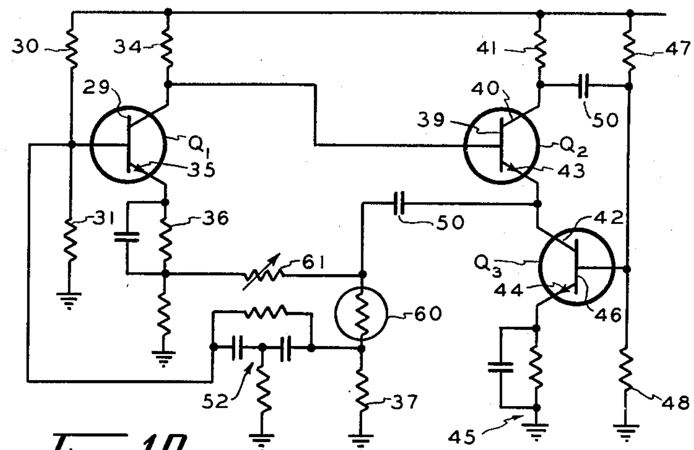

Fig. 10

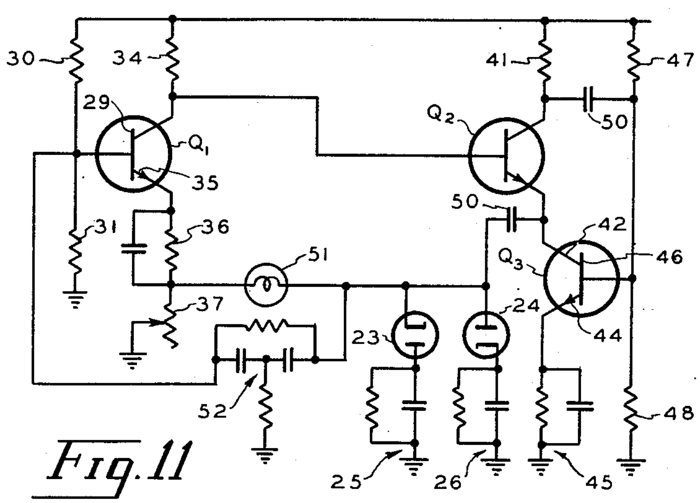

Fig. 11

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OSCILLATORS

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Application March 23, 1954, Serial No. 418,149

11 Claims. (Cl. 250—36)

The present invention relates generally to oscillators, and more particularly to wide band amplitude stabilized oscillators, capable of producing pure sinusoidal output.

RC oscillators, i. e. those tuned by a resistance-capacitance network, are well known, and have taken various forms. Such oscillators possess the advantages of simplicity, compactness, good frequency stability and relatively wide tuning range, and have been widely employed. In seeking to improve the general class of oscillators which rely upon an RC network to determine frequency, I have heretofore (Electronics, September 1950, a publication of McGraw-Hill Publishing Company, Inc.) disclosed an oscillator employing a pair of cascaded vacuum tubes which are cathode loaded, and in which regenerative feedback is provided by a connection, including a tungsten lamp stabilizer, from cathode to cathode of the pair of tubes. A degenerative frequency determining loop is also provided, which contains a bridged-T frequency determining network. Oscillation tends to take place at the frequency of minimum degeneration, and the positive-resistance-current characteristic of the lamp provides amplitude stabilization. The two vacuum tubes are connected in cascade, the first as an amplifier, plate loaded, and the second as a cathode follower, and output is derived from the cathode follower at low impedance.

The fact that the cathode follower tube of the oscillator operates as a single ended amplifier output stage results in appreciable even harmonic content in the output voltage. My present invention resides in the provision of a third vacuum tube connected in the cathode circuit of the second tube, as its cathode load, and in providing the second tube with anode load, so that its plate voltage may drive the control grid of the third tube. The latter thus presents a cathode load of high dynamic resistance, and a relatively high current is available to drive the stabilizing lamp, or an external load. In addition, a form of push-pull operation is obtained, since the anode current of the second tube increases as the anode current of the third tube decreases, and vice versa. This results in a reduction of even-harmonic distortion in the output of the oscillator.

As a further feature, the feed-back from the anode of the second tube to the control grid of the third tube constitutes negative feed-back, which further decreases distortion, and decreases the effective output impedance of the system while increasing its input impedance.

I have found that oscillators constructed in accordance with my invention have extremely low harmonic content, of the order of .03 per cent, or lower, excellent frequency stability and constancy of output voltage, and further that these desirable attributes are attainable at higher frequencies, or over wider frequency range, than has heretofore been possible in RC oscillators, largely because of the increased effective input impedance of the output stage of oscillators constructed in accordance with the present invention.

The oscillator of the present invention may be arranged to utilize transistors, in place of vacuum tubes, and more

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particularly to employ junction transistors in various circuit arrangements, paralleling those employing vacuum tubes, and retaining the operating features and advantages hereinabove attributed to the basic circuit.

As a further modification, I may locate the amplitude stabilization device at various positions in the circuit, and may employ a thermistor or a tungsten filament lamp, as desired, for amplitude stabilization, by suitable location thereof in the circuit.

As still a further modification, I may include anti-hunt circuitry in the amplitude stabilization network of the oscillator, to reduce or eliminate amplitude hunting consequent on change of operating conditions of the oscillator, and due to the thermal lag of the amplitude stabilization element.

It is, accordingly, a broad object of my invention to provide a novel RC oscillator, having a high order of freedom from harmonic distortion, low output impedance, high output power, and high amplitude stability.

It is a further object of my invention to provide an RC oscillator having an output stage which operates effectively in push-pull relation, with consequent reduction in even harmonic distortion.

A further object of the invention resides in the provision of an RC oscillator having an output stage consisting of a pair of series connected unilateral conducting devices.

Another object of my invention resides in the provision of a novel output stage for an RC oscillator, which possesses high input resistance, low output resistance, low harmonic distortion in its output signal, and high power capability.

Still another object of the present invention resides in the provision of a novel stabilized RC oscillator employing transistors as amplifying elements.

It is another object of my invention to increase the amplitude stability of RC oscillators by the inclusion of a circuit which serves also to reduce distortion of wave form in the output of the oscillator.

Another object of the invention resides in the provision of various expedients for stabilizing the amplitude of an oscillator having both regenerative and degenerative networks.

A further object of my invention resides in the provision of a system for reducing hunting of the amplitude stabilization circuit of an RC oscillator, which is primarily stabilized by an element having a substantial co-efficient of resistance variation with temperature.

Still further features, objects and advantages of my invention will become apparent upon consideration of the following detailed description of specific embodiments thereof, especially when taken in conjunction with the accompanying drawings, wherein:

Figure 1 is a schematic circuit diagram of an RC oscillator, utilizing vacuum tube type unilateral control devices, and exemplifying prior art;

Figures 2–5 are schematic circuit diagrams respectively, of modifications of the basic system of Figure 1, utilizing vacuum tubes as unilateral control devices, and including my improvements;

Figure 6 is a schematic circuit diagram of a modification of the system of Figure 2, wherein is provided anti-hunt circuitry in the amplitude stabilization loop of Figure 2; and

Figures 7–11 inclusive are circuit diagrams of oscillators in accordance with Figures 2–6, respectively, but employing transistors as unilateral control devices.

Referring now more particularly to the accompanying drawings, and particularly to Figure 1 thereof, there is illustrated in Figure 1 a known oscillator, which is modified in accordance with the present invention as illustrated in Figures 2–11, in order to improve its performance. In Figure 1, V_1 is a conventional voltage amplifier pentode having a plate load **10**, and two series connected unbypassed cathode resistances **11**, **11***a*, the latter being variable. V_2 is a cathode follower output triode having a cathode load **12**. The plate of pentode V_1 is connected directly with the control grid of triode V_2, so that current flow in tubes V_1 and V_2 are respectively of opposite phase. An a. c. connection is supplied, via coupling condenser **13**, and tungsten filament lamp **14**, from the cathode of triode V_2 to the junction of the cathode resistances **11**, **11***a* so that the voltage of the cathode of pentode V_1 is in phase with the voltage at the cathode of triode V_2. This constitutes a regenerative connection. The lamp **14** possesses resistance which increases with temperature, i. e. has a positive temperature co-efficient of resistance. Therefore, feed-back through the lamp tends to decrease as current through the lamp increases.

A negative feed-back loop exists from the cathode of triode V_2 through coupling condenser **13**, and via a bridged-T network **15** to the control grid of the pentode V_1. It is known that a wide variety of bridged-T networks exist, and it is contemplated that any suitable one of these may be employed, in place of the specific network **15** illustrated, in accordance with the judgment of the circuit designer.

If the positive feed-back through the lamp **14** exceeds the negative feed-back through the bridged-T network **15**, oscillations will commence, and will exist at the zero-phase-shift frequency of the network **15**. As the amplitude of the oscillations increases the resistance of the lamp **14** increases because of its positive temperature co-efficient of resistance, reducing the voltage available across resilstance **11***a*, until an equilibrium condition is reached such that an increase of oscillator output would cause a reduction of net positive feedback.

Variation of the value of variable resistance **11***a* may be employed to vary the output amplitude of the oscillator, by varying the value of regenerative voltage applied to pentode V_1.

In the oscillator of Figure 1 the cathode follower output stage V_2 is operated as a single ended amplifier, which for that reason has appreciable even-harmonic content in its output voltage. In addition, a portion of the signal power of triode V_2 is lost in its cathode-load resistance **12**, which reduces the power available to operate the stabilization lamp **14**. These defects and other defects of the system of Figure 1, are overcome in the herebelow described embodiments of my invention.

A first embodiment of the present invention is illustrated in Figure 2 of the accompanying drawings. It will be noted that the cathode resistance **12** of triode V_2, Figure 1, is replaced by a triode V_3, in Figure 2, having its anode connected directly to the cathode of triode V_2. An anode resistance **16** is connected in series with the anode of triode V_2. The anode of triode V_2 is coupled with the control grid of triode V_3, by means of coupling condenser **17**, the control grid being connected to ground via resistance **18**. The cathode of triode V_3 is connected to ground via an un-bypassed resistance **19**, which introduces a suitable bias and also provides some degeneration in triode V_3.

It will now be noted that the relatively high dynamic anode resistance of triode V_3 is employed as a load resistance for the cathode circuit of triode V_2. This permits more of the signal current of triode V_2 to be used for supplying current to lamp **14**, and to an external load. In addition, as the anode current of triode V_2 increases, the anode current of triode V_3 decreases, since an increase in current in triode V_2 causes a decrease in its anode voltage, which decreases the grid voltage of triode V_3, and hence its plate current.

The net result is, that triodes V_2 and V_3, considered as an output stage, operate in push-pull or balanced relation, resulting in a reduction of even-harmonic distortion.

Moreover, the feed-back from the anode of triode V_2 constitutes negative feed-back. This may be made evident

by considering that a positive voltage at the control grid of triode V_2 produces a positive voltage at the cathode of triode V_3, via the increase in resistance of triode V_3, which takes place as its grid voltage goes more negative. This negative feed-back decreases the distortion in the output stage consisting of triodes V_2 and V_3, and increases the effective input impedance. The increased effective input impedance increases amplitude and frequency stability at high frequency, and thus permits higher frequency operation. The local negative feed-back in the output stage results in very low harmonic content in the output, of the order of .03 per cent, or less. The stabilizing effect of the lamp **14** is enhanced by the action of triode V_3.

As a further modification, illustrated in Figure 3 of the accompanying drawings, a thermistor **20** is employed as an amplitude stabilizing element. To this end the thermistor **20** is connected in the cathode circuit of pentode V_1, and is coupled in series with condenser **13** via variable resistance **21**. The thermistor **20** is a negative temperature co-efficient device, so that as its resistance decreases with increasing output voltage, the positive feed-back of the system will decrease. In other respects, the embodiments of my invention illustrated in Figures 2 and 3 operate in similar manner, and possess the same advantages. Variations of resistance **21** now serve to control output amplitude.

In the system illustrated in Figure 4 of the accompanying drawings, a tungsten filament **14** is employed for amplitude stabilization. The lamp **14** is connected, however, in shunt to the negative feed-back loop of the oscillator, so that as output voltage increases and the resistance of the lamp increases, the current flow to bridged-T network increases and thus the value of negative feed-back, which stabilizes the amplitude of oscillation. A resistive connection **21** is provided between condenser **13** and cathode resistance **11**, which controls regeneration and hence output amplitude of the oscillator. The lamp **14** is connected in shunt to the bridged-T network **15**, and may be connected to the condenser **13**, via a voltage dropping resistance **22**. Positive feed-back is thus relatively constant, but negative feed-back is amplitude stabilized by lamp **14**. It will be noted that variation of resistance **22** may be employed to control oscillator output amplitude.

As a further embodiment of my invention, illustrated in Figure 5 of the accompanying drawings, the thermistor **20** may be connected in the negative feed-back path, by connecting same in series with the bridged-T network **15**, so that an increase in output will reduce the resistance of the thermistor **20**, and thereby increase the voltage across the network **15**, and thus increase the negative feed-back voltage. In order to provide a voltage divider, the thermistor **20** is connected to ground via resistance **23**, the bridged-T network being in shunt to the latter. Resistance **23** may now be employed as an output control.

The embodiments of my invention illustrated in Figures 4 and 5 respectively are equivalent in operation, the lamp **14** in Figure 4 replacing the voltage divider resistance **20** in Figure 5, and the thermistor in Figure 5 replacing the voltage divider resistance **22** in Figure 4. The interchange is, of course, made necessary by the fact that the lamp **14** has a positive co-efficient of resistance with temperature, while the corresponding co-efficient in the case of the thermistor **20** is negative.

It has been found that the amplitude stabilization process, in circuits of the type illustrated in Figures 1–5, inclusive, involves a form of amplitude hunting at relatively low frequency since as the lamp temperature increases because of an amplitude increase of the oscillator, the lamp resistance exceeds that required to establish equilibrium. Consequently, the amplitude starts to decrease, and the lamp resistance decreases in following relation. However, the lamp possesses considerable thermal inertia, and will in consequence of that fact decrease in resistance below that required to establish equilibrium. Several cycles of relatively slow amplitude variation have been found to subsist after any adjustment of the oscillator, either as respects amplitude or frequency of output, or on first supplying power to the oscillator.

The magnitude and duration of the hunting effect may be radically reduced by utilization of the circuit devices of Figure 6 of the accompanying drawings. Referring to Figure 6, a pair of cross-connected biased diode limiters **23**, **24**, are connected in series respectively, with parallel RC networks **25**, **26**, having time constant small relative to the thermal lag of lamp **14**, but longer than the period of the oscillator at its lowest frequency. Under equilibrium conditions the condenser C of RC networks **25**, **26**, require respectively a negative and a positive potential, which are equal in magnitude to the peak magnitude of the oscillations. The diodes **23**, **24**, remain non-conductive, and the system operation remains unaffected. If a sudden increase of signal output amplitude takes place, for any reason, heavy clipping of both half cycles of the output signal occurs, by conduction of the diodes **23**, **24**. This largely prevents hunting in one sense or direction, and operates practically instantaneously, regardless of the time lag of the operation of lamp **14**. Since the lamp **14** cannot be supplied with a heavy sudden surge of current, or a rapidly increasing current, its resistance value cannot overshoot, and the hunting action is largely damped out. In a broad sense the clipped network comprising diodes **23**, **24**, is an amplitude stabilizing network which operates extremely rapidly unidirectionally, i. e. to prevent increase of amplitude, and also which operates transiently, i. e. only during the increase. It operates then, to absorb transient increases of voltage, from any preceding stable value, and is then more effective the more rapid the increases.

Clearly, the anti-hunting expedient of Figure 6 may be applied to any of Figures 1–5 inclusive, and the illustration as applied in Figure 6, i. e. to the embodiment of my invention illustrated in Figure 2, is for example only.

Referring now more particularly to Figure 7 of the accompanying drawings, there is illustrated a modification of the system of Figure 2, in which junction transistors are employed, rather than vacuum tubes as unilaterally conducting control devices.

The junction transistor Q_1 is connected at its base **29**, to the mid-point of a pair of resistances **30**, **31**, the latter connected in series between the voltage supply lead **32** and ground. The collector **33** of the transistor Q_1 is connected in series with a resistance **34** to the voltage supply lead **32**, and the emitter **35** is connected via a fixed resistance **36** and a variable resistance **37** to ground. The resistance **36** may be shunted by a smoothing condenser **38**.

The base **39** of junction transistor Q_2 is connected directly with the collector **33** of transistor **33**, and consequently is driven by the voltage appearing across resistance **34**. The collector **40** of transistor Q_2 is connected to the voltage supply lead **32** via resistance **41**, across which is available voltage output deriving from transistor Q_2 in response to its base drive.

A third transistor, Q_3, is connected with its collector **42** directly in circuit with emitter **43** of transistor Q_2, and with its emitter **44** connected to ground via an RC parallel network **45**, arranged to supply bias for the emitter. The base **46** of the transistor Q_3 is connected to the junction of a pair of resistors **47**, **48**, which extend in series from the voltage supply lead **32** to ground, and a condenser **50** is connected from the collector **4** of transistor Q_2 to the base **46** of the transistor Q_3.

The various resistors are selected to provide proper operating voltages for the elements of the transistors Q_1, Q_2, Q_3, in accordance with principles well understood in the art of transistor circuit design.

It will now be clear that the dynamic collector resistance of transistor Q_3 is used as a load resistance for the emitter **43** of transistor Q_2, and that the base **46** of the transistor Q_3 is driven by the voltage available at the collector of transistor Q_2. Two consequences ensue. First, the emitter **43** of transistor Q_3 operates into a relatively high internal load, which increases the output power or signal current available to an external load. In addition, a form of push-pull operation is attained, in which the collector current of transistor Q_2 increases as the collector current of transistor Q_3 decreases, and vice versa, resulting in reduction of even-harmonic distortion. Moreover, feed-back from the collector **40** of transistor Q_2 is negative feed-back, since an increase of voltage at the base of transistor Q_2 will produce a positive voltage at the emitter of transistor Q_2 via the amplifier comprising transistor Q_3.

Transistors Q_2, Q_3 together constitute an output stage for the oscillator, and the negative feed-back of the stage decreases the distortion of the stage, increases its effective input impedance, thus permitting greater gain, and decreases the effective output impedance.

In order to effect self-oscillation of the system a stabilized positive feed-back loop is provided, in the form of a condenser **50** and tungsten filament amplitude stabilizing lamp **51**, in series between the collector **42** of transistor Q_3 and the junction point of the resistances **36**, **37** in the emitter circuit of transistor Q_1. At the same time a frequency determining degenerative network is supplied, in the form of a bridged-T network **52** coupled via condenser **50**, from the collector **42** of transistor Q_3 to the base **29** of transistor Q_1.

The system of Figure 8 is generally similar to the system of Figure 7, except in respect to the mode of stabilizing. In the embodiment of my invention illustrated in Figure 8 a thermistor **60** is included in series with the emitter to ground circuit of transistor Q_1, and the connection from condenser **50** to bias resistance **36** provided via a variable resistance **61** of substantially zero temperature co-efficient. In this respect the system of Figure 8 parallels that of Figure 3.

Similarly, the embodiment of my invention illustrated in Figure 9 parallels that of Figure 4, in that a tungsten element lamp **51** is employed for amplitude stabilization, included in shunt with the bridged-T network **52**. Further, the embodiments of my invention illustrated in Figures 10 and 11 parallel those of Figures 5 and 6, except for the substitution of transistor control devices for vacuum tube control devices, following the teaching of Figure 7. Further detailed description of the construction of these embodiments of my invention is, therefore, dispensed with.

It will be recalled that the operation of a grounded emitter junction transistor, driven at its base, is similar to that of a grounded cathode vacuum tube, circuitwise, but that account must be taken of the low input impedance of the transistor in designing useful circuits. It is this fundamental transistor circuit which is employed through the present invention. In the circuits of the present invention, the input circuit of transistor Q_1 loads the bridged-T network **52**. This loading is decreased radically, however, in the present circuits by the feed-back to the emitter. The fact that feed-back power may be increased, by the novel output stage of my invention, is particularly important in the case of transistor circuits, to enable adequate amplitude stabilization, and transistor circuits being prone to non-linearity the specific output stage, having effectively push-pull operation and negative feed-back, is desirable if freedom from harmonic output, or purity of wave form, is to be obtained. In practical embodiments of the present invention, constructed with commercially available transistors, excellent performance was attained over a wide band of operation. Harmonic distortion of the order of .03 per cent and lower was attained, and frequency and amplitude stability was excellent, while the range of stable operation, both in respect to amplitude and frequency was radically increased.

While I have described and illustrated various modifications of the present invention it will be clear that variations thereof may be resorted to in respect of circuit details, and of general arrangement, without departing from the true spirit and scope of the invention as defined in the appended claims.

What I claim is:

1. An RC oscillator, comprising a first amplifier having at least two input terminals and an output terminal, a second amplifier having an output terminal, said second amplifier including a pair of series connected unilateral control devices, means for driving said unilateral control devices in 180° out-of-phase relation in response to alternating current signals on said output terminal of said first amplifier, the output terminal of said second amplifier subsisting at the junction of said series connected control devices, a degenerative feedback loop extending from the output terminal of said second amplifier to one of the input terminals of said first amplifier, said degenerative feed-back loop including circuit means for determining the frequency of oscillation of said oscillator, a regenerative feedback loop extending from the output terminal of said second amplifier to the other input terminal of said first amplifier, and an amplitude stabilizing thermal element connected in one of said feedback loops.

2. The combination in accordance with claim 1 wherein said circuit means is a bridged-T network.

3. The combination in accordance with claim 1 wherein said unilateral control devices are vacuum tubes.

4. The combination in accordance with claim 1 wherein said unilateral control devices are transistors.

5. The combination in accordance with claim 1 wherein said first amplifier is a plate loaded vacuum tube, and wherein said series connected unilateral control devices are series connected vacuum tubes having each an anode, a cathode, and a control electrode.

6. The combination in accordance with claim 1 wherein said first amplifier includes only transistors as amplifying elements, and wherein said second amplifier includes a pair of series connected transistors having control elements.

7. The combination in accordance with claim 1 wherein said amplitude stabilizing thermal element has inherent thermal inertia and means comprising cross-connected rectifying elements for reducing hunting of the amplitude of the output voltage of said oscillator due to the thermal inertia of said element.

8. An oscillator comprising a first amplifier including a unilateral control device having a first control electrode, a first emitter electrode, and a first electron collector

electrode, a second amplifier comprising a second unilateral control device having a second control electrode, a second emitter electrode and a second collector electrode, said second amplifier further including a third unilateral control device having a third control electrode, a third emitter electrode and a third collector electrode, means connecting said first collector electrode with said second control electrode, a source of supply voltage, means connecting said second collector electrode to said source of supply voltage, means connecting said second emitter electrode to said third collector electrode, means connecting said third emitter electrode to a point of reference potential, means A. C. coupling said second collector electrode to said third base electrode, and means for A. C. coupling said third collector electrode respectively to said first collector electrode and to said first control electrode via feedback paths having relatively different phase shifts at different frequencies, and an amplitude responsive thermal element connected in one of said feedback paths.

9. The combination in accordance with claim 8 wherein said temperature co-efficient is positive.

10. The combination in accordance with claim 8 wherein said temperature co-efficient is negative.

11. In a relatively high frequency oscillator having a feedback loop, an amplitude stabilizing element for said oscillator comprising a temperature sensitive circuit in said feedback loop, said circuit having sufficient thermal lag to lead to relatively slow oscillation of amplitude of signal output of said oscillator, and means for preventing said relatively slow oscillation comprising means for shunting only transient relatively rapid rises of said amplitude of signal output around said temperature sensitive circuit.

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