

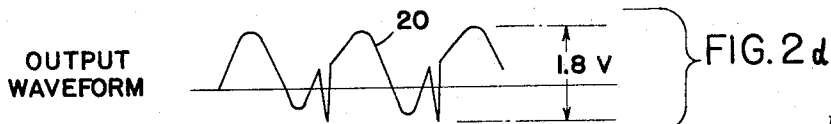
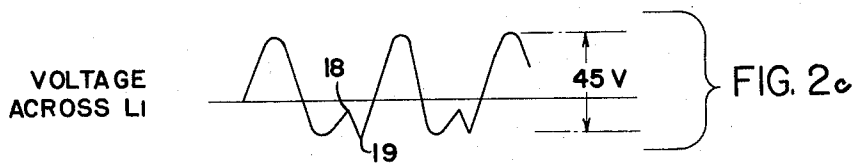
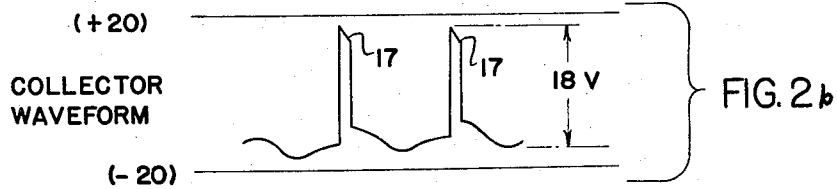
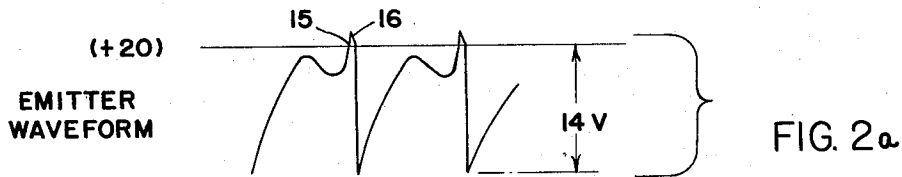
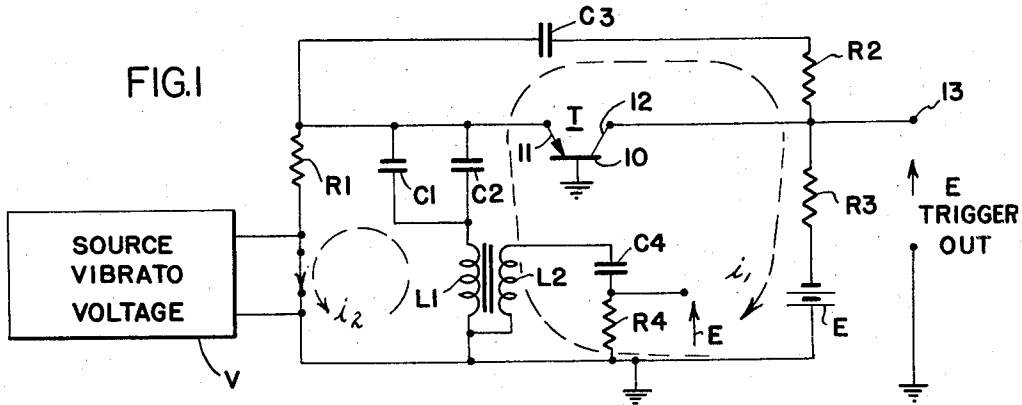
Sept. 1, 1959

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TRANSISTOR OSCILLATORS

2,902,655

Filed Dec. 31, 1956

3 Sheets-Sheet 1



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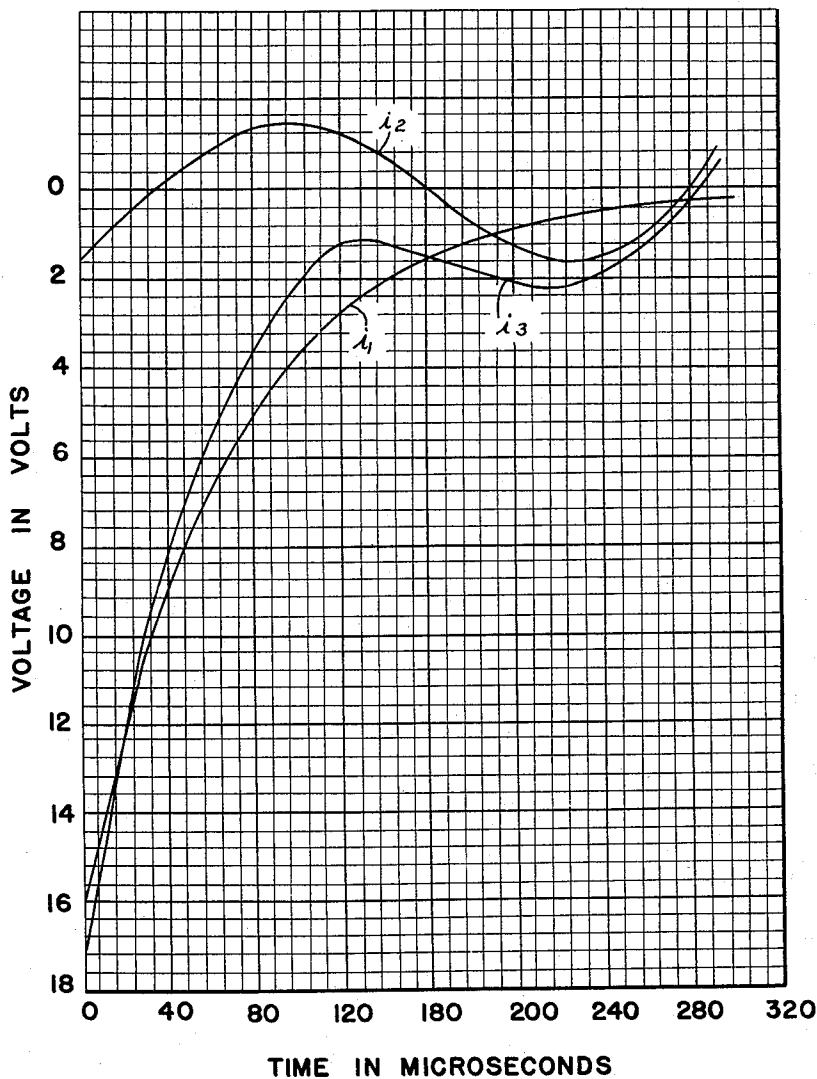


FIG. 3

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3 Sheets-Sheet 3

FIG. 5

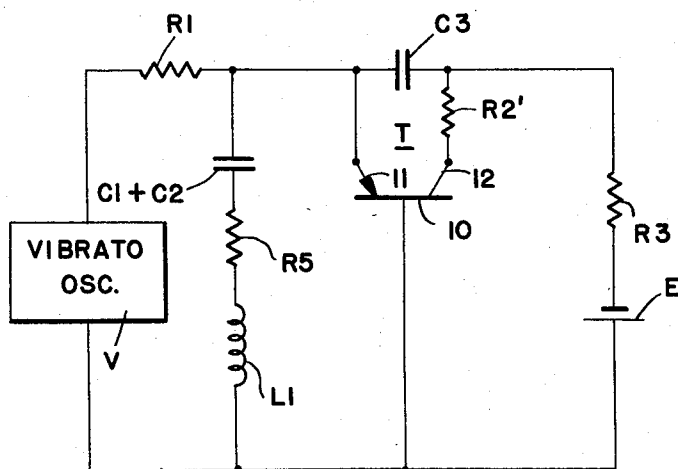
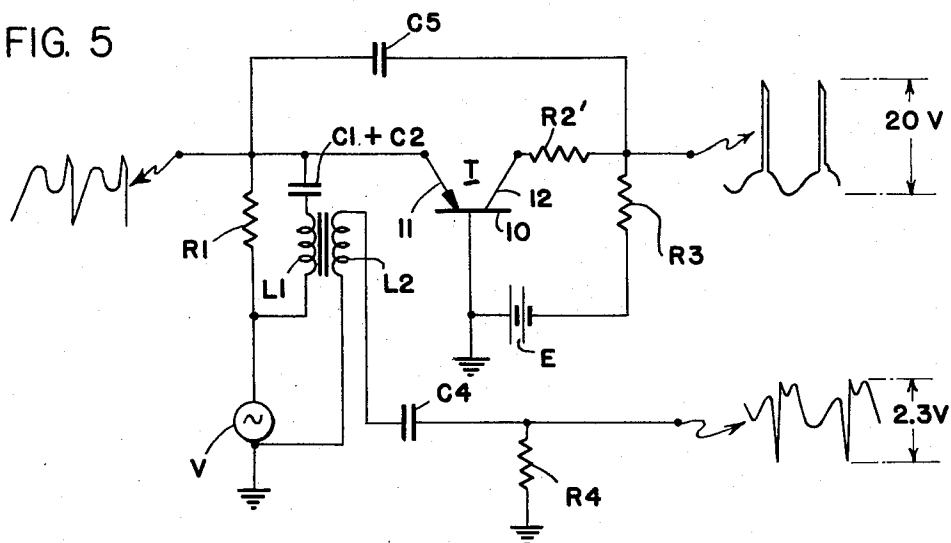


FIG. 4

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2,902,655

TRANSISTOR OSCILLATORS

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Application December 31, 1956, Serial No. 631,682

11 Claims. (Cl. 331—112)

The present invention relates generally to oscillators, and more particularly relates to pulse generators of the type employing a semi-conductor device or transistor.

Semi-conductor devices have recently been developed which have amplifying properties, and which may be utilized as a basis for a wide variety of circuits of the type previously encountered in the electronic art in conjunction with vacuum tubes. Such devices are commonly termed transistors, and have been disclosed and described in a series of letters to Physical Review, in July 1948, by Brattain, Brattain and Bardeen, and Shockley and Pearson. Various forms of the transistor have been developed since the publication of the aforementioned letters, but in general the new device employs a block of semi-conducting material such as silicon or germanium, which is provided with two electrodes called "emitter" and "collector" electrodes, and with a further electrode, called the "base" electrode. When the electrodes are properly biased injection of a given current in the emitter to base circuit causes flow of a larger current in the collector to base circuit, so that the device exhibits current gain.

Briefly describing the present invention, in a generic aspect thereof, a source of D.C. voltage is connected between collector and base of a transistor, the base being maintained positive by the source. A relatively large charging condenser is connected between collector and emitter, preferably in series with a small current limiting or protective resistance. A relatively large resistance is connected between emitter and base, and a series resonant circuit is connected between emitter and base.

When the source of D.C. voltage is initially connected in circuit the voltage across the condenser is zero, and substantially the entire voltage of the source appears between emitter and base, the emitter being negative with respect to the base, so that the transistor is in cut-off condition, or is nonconducting. In the course of time the condenser charges exponentially, which reduces the voltage available between the emitter and base exponentially, and eventually causes the emitter voltage to approach the base potential asymptotically. The step voltage applied to the resonant circuit, when the D.C. source is initially connected in circuit, effects ringing of the resonant circuit, and thereby application of a generally sinusoidal voltage between emitter and base. Passage of the sum of the sinusoidal voltage and the exponential voltage through a value for which base and emitter potentials are equal unblocks the transistor, i.e., causes emitter current to flow. The transistor now exhibits its current gain property, and collector current of greater magnitude than the emitter current commences to flow, the emitter to collector circuit being now effectively of high conductance. The condenser discharges rapidly through the transistor, and when discharged leaves the emitter at a high negative voltage, as at the commencement of the cycle of events. The cycle then repeats, and the discharge of the condenser is periodic, and synchro-

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nized with the oscillations of the resonant circuit. Sharp output pulses may be derived directly from the collector electrode, which coincide with condenser discharge, or distorted sinusoids of high harmonic content may be derived from the resonant circuit, the distortion consisting of a pulse superposed on the sinusoid when the emitter conducts.

By reason of the fact that the frequency of oscillation of an oscillator arranged in accordance with the present invention is controlled primarily by an L-C series resonant circuit, pulse frequency is highly stable. The generated pulses may be extremely short, of the order of 10 microseconds or less, since the discharge path of the condenser may be made of extremely low resistance, being limited only by the maximum safe discharge current which the transistor can sustain.

Oscillators in accordance with the present invention may find particular application as master oscillators of electronic musical instruments. In that application the oscillator is utilized to drive a chain of 2:1 frequency dividers, to produce octavely related tones. In an electronic organ a complete tone generator may include twelve master oscillators, and usually six divider stages are connected to each master oscillator. The divider stages may advantageously be driven in response to short, sharp pulses of the type generated by the present system.

Additionally, it is useful in electronic musical instruments to provide an output waveform which contains considerable harmonic content, and a strong fundamental. Such a waveform may be derived, in the present oscillator, from the resonant circuit utilized to stabilize the oscillator, the latter being subject to short high amplitude transients when the transistor conducts, which distort the normally generally sinusoidal oscillatory current flowing in the resonant circuit.

A further desirable property of oscillators employed in electronic musical instruments is that they be susceptible of frequency modulation, for vibrato effects. Oscillators in accordance with the present invention are readily variable in frequency, by inserting a control voltage in the emitter circuit to vary the time of condenser discharge with respect to the phase of the sinusoidal component of voltage applied to the emitter. The control voltage may be a low frequency sine wave (7 c.p.s.), for the recited application.

Oscillator circuits in accordance with the present invention possess the advantageous feature that the base of the transistor may be operated at ground potential, which permits several transistors to be constructed on a common block of semiconductor material.

It is, accordingly, a primary object of the present invention to provide a transistor oscillator which is stabilized in respect to frequency by an L-C series resonant circuit, while operating with base grounded.

It is a further object of the present invention to provide a stable transistor oscillator, the frequency of oscillation of which may be varied in response to a control signal.

It is still another object of the present invention to provide a series L-C stabilized transistor oscillator which generates short duration pulses at equidistant intervals established in correspondence with the resonant frequency of the L-C circuit.

It is another object of the present invention to provide a stabilized periodic pulse generating system employing a transistor as an oscillation sustaining element, and in which the base of the transistor is maintained at a fixed voltage, to simplify interconnection of multiple transistors constructed of a single block of semiconductive material.

It is still a further object of the present invention to provide a periodic pulse signal having no steady D.C. component, and in which the frequency of oscillation is independent of transistor parameters and ambient conditions.

The above and still further objects, features and advantages of the present invention will become apparent upon consideration of the following detailed description of one specific embodiment thereof, especially when taken in conjunction with the accompanying drawings, wherein:

Figure 1 is a schematic circuit diagram of an oscillator in accordance with the invention;

Figures 2a to 2d are waveform diagrams, useful in the explanation of the circuit of Figure 1;

Figure 3 illustrates certain waveforms, generated by the system of Figure 1; and

Figures 4 and 5 are schematic circuit diagrams of modifications of the system of Figure 1.

Referring now more specifically to the accompanying drawings, T is a transistor of the PNP point-contact type, having a base 10, an emitter 11 and a collector 12. A PNP type or any other type having a collector to emitter current gain greater than one may also be used. For a full discussion of the various transistors or combination of transistors that may be used, reference is made to the copending application in the name of Edward M. Jones, Serial No. 631,681, filed concurrently herewith, and assigned to the same assignee as the present application. The base 10 is grounded or otherwise connected to a point of reference potential. Between the base 10 and the collector 12 is connected, in series, a source of bias voltage E and a resistance R3. Between the collector 12 and the emitter 11 is connected a resistor R2 and a condenser C3. Between the emitter 11 and ground is connected a resistance R1. In parallel with the resistance R1 is connected a series resonant circuit consisting of a pair of parallel condensers C1 and C2 and an inductance L1. A further inductance L2 is inductively related to inductance L1, and is connected in series between ground and a differentiating circuit consisting of a condenser C4 and a resistance R4, connected in series. One end of the resistance R4 is grounded, and output voltage may be derived across R4.

Typical circuit values employed, to obtain an output frequency of 3520 c.p.s. are as follows:

R1	-----ohms----	5.6×10^3
R2	-----do-----	68
R3	-----do-----	10^3
C3	-----microfarads----	.01
C1	-----micromicrofarads----	65
C2	-----do-----	1473
L1	-----h-----	1.33
E	-----v-----	20

Explaining now the operation of the system of Figure 1 by reference to the waveforms of Figures 2 and 3, and assuming that D.C. source E is connected in circuit at time zero, on application of source E a negative voltage appears at emitter 11 with respect to base 10, equal approximately to

$$\frac{ER1}{R1+R2+R3}$$

Qualitatively, at the instant of application of voltage E the charge in the condenser C3 is zero, and the resistances R1, R2, R3 therefore divide the available voltage among themselves in proportion to their resistance values. Allowance must be made, however, for leakage current into the collector 12. This leakage current may produce a voltage drop across R3 equal to 2 or 3 volts, with the transistor in its cut off state.

The base to emitter voltage of transistor T is then of the order of 14-16 volts, the emitter being negative and the transistor therefore cut off. The transistor remains cut off so long as the emitter 11 is negative with respect to the base 10, and in the cut off state conduction through the transistor from emitter to base or from emitter to collector is negligible.

The combination of C1 and C2 with L constitutes a series resonant circuit which parallels resistance R1, and has impressed thereacross the same voltage as appears

between emitter 11 and base 10. This series resonant circuit oscillates in response to the step voltage E, at a frequency determined primarily by its own constants, since C3 is relatively great and R2 and R3 are of small magnitude.

At the same time that the first cycle of oscillation of circuit C1 and C2 and L1 commences, the condenser C3 begins to charge, and the net voltage across R1 in response to voltage E alone begins to drop. The component of voltage across R1 which is representative of the oscillating current rises and falls sinusoidally, while the decreasing drop across R1 due to current flow in condenser C3 causes the voltage of emitter 11 to approach ground potential exponentially.

Eventually a time will occur when the emitter voltage will attain ground value; i.e., when the sum of the oscillatory voltage and the condenser voltage across resistance R1 will equal zero. If the voltage across R1 due to current flow through condenser C3 is approaching zero at the time when the oscillatory voltage is beginning its second cycle, the period of the latter will determine this time, since the combined voltages will rise sharply at this instant.

When the voltage of emitter 11 attains near ground value the transistor T begins to conduct. As emitter to base current begin to flow a regenerative action occurs, in that the resistance from emitter to collector becomes low, the condenser C3 begins to discharge in the emitter to collector circuit, and the discharge still further reduces the emitter to collector resistance, accelerating the discharge. The condenser discharge maintains the emitter positive, so that the transistor remains in a high current gain region of its operating characteristic. The resistance R2 limits the discharge current to a value below that which may be tolerated by the transistor employed.

Eventually, in the course of discharge of condenser C3, the voltage of collector 12 is reduced, due to the decrease in the voltage drop across resistance R2, to a value such that current gain of the transistor falls to less than unity and the transistor passes into its cut-off condition. The circuit is then essentially in the same condition as when E was first connected, and the cycle of events above described repeats.

Since the total time of discharge of condenser C3 is of the order of 10 microseconds, the period of condenser discharge is synchronized by the oscillatory circuit C1+C2 and L, and one discharge may occur for each cycle of oscillation of the oscillatory circuit. Obviously, the charge time of condenser C3 may be adjusted to approximate two or more oscillations of the oscillatory circuit, in which case the condenser C3 will discharge once for each two or more cycles of oscillation of the oscillatory circuit.

The frequency of discharge of condenser C3 may be varied by connecting in series with the resistance R1 a source of low frequency A.C. voltage, V. This voltage, being in series with the voltage existent across resistance R1 serves to vary the time in the oscillatory cycle of the circuit C1+C2 and L when the emitter 11 attains or passes through ground voltage, and therefore varies the frequency of the generated pulses about a mean frequency determined by the constants of the oscillatory circuit.

Output pulses may be derived directly from the collector 12, at a terminal 13. The oscillatory current flowing in inductance L1 is not purely sinusoidal, due to the periodic sharp drain of current to emitter 11 which occurs when the emitter circuit becomes conductive, and in fact the waveform of current in inductance L1 is rich in harmonics. The winding L2, wound on the same core with winding L1, and inductively related thereto, couples a signal from winding L1 into differentiating circuit C4R4. The latter enhances the harmonic content of the available waveform, in accordance with well understood principles.

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Calculation indicates that, for the circuit values listed, the equation of voltage across resistance R1 due to current flow via condenser C3 is

$$(1) \quad i_1 R_1 = -15.9 \times 10^{-3} e^{-1.475 \times 10^4 t}$$

which is approximately equal to

$$(2) \quad (E R_1 / R_1 + R_2 + R_3) e^{\frac{-t}{(R_1 + R_2 + R_3) C_3}}$$

and that the oscillatory voltage across R1 is given by

$$(3) \quad i_2 R_1 = 1.53 e^{-575t} \cos(221 \times 10^4 t - 126.7^\circ)$$

In Figure 3 is illustrated a plot of i_1 and i_2 and of their sum, i_3 .

The waveform at emitter 11 is duplicated, repetitively, in Figure 2a. At the point 15 of the plot is shown the cross over point of emitter voltage for which discharge occurs, and at 16 is shown the positive spike, occurring at emitter 11 due to discharge of condenser C3, followed by a sharp drop in voltage when the condenser C3 has completed its discharge through the transistor T3. The sharp drop appears because the condenser C3, across which had appeared substantially the entire voltage E, assumes a net voltage of zero thereacross before any appreciable recharging can occur. This is precisely the condition which obtained on initial application of voltage E.

Figure 2b illustrates variations of collector voltage. The peak 17 represents the discharge of condenser C3, at which time the collector 12, which was negative by almost the entire voltage of source E, i.e., by almost 18 v. momentarily rises to almost zero volts and then assumes the voltage dictated by the values of resistances R1, R2 and R3, no voltage appearing across condenser C3.

At Figure 2c is indicated the voltage across inductance L1. This is a sinusoidal waveform, except for the peaks 18, 19 which occurs when emitter current flows during discharge of condenser C3. The sinusoidal wave has a peak to peak amplitude of 45 v., indicating a resonant rise across the inductance. The value of the negatively going increase of voltage across inductance L1, due to the sudden negative transition of the emitter voltage, is of the order of 10 v.

At 2d is indicated the modification which occurs in the voltage across inductance L1 on differentiation. The pulse is sharpened, and its amplitude equals about one-half the amplitude of the output waveform, 20, which remains generally sinusoidal.

The oscillator in accordance with the present invention is designed and intended for application as the master oscillator of an electronic organ, and may drive a series of frequency dividers, in order to provide octavely related complex oscillations for such instruments. The provision of vibrato effects in such instruments is of particular importance, and such effects may be accomplished by time position modulation of the output pulses, in accordance with the present invention. It has been found that application of a 7 c.p.s. sinusoidal voltage, of peak value of .6 v., in series with resistance R1, effects a frequency deviation of 1½% about the mean value of oscillator frequency.

Various modifications of the system of Figure 1 are possible. For example in the systems of Figure 4 and Figure 5 the limiting resistance R2 is no longer in the charging circuit of condenser C3, but is replaced by a resistance R2' included in the discharge circuit, where it performs a current limiting function during discharge of the condenser C3. The resistance R5 is that inherent in the resonant circuit. In the system of Figure 4 the vibrato oscillator V is connected in series with both the voltage dropping resistance R1 and the series resonant circuit C1+C2 and L1. In either case the function and

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operation of the limiting resistance and of the vibrato voltage generator remain essentially unchanged.

Further variations of circuit detail and arrangement may be resorted to, pursuant to principles well understood in the art, without departing from the teaching of the invention as defined in the appended claims.

What we claim is:

1. A transistor oscillator for generating short periodic pulses of predetermined frequency, comprising a transistor having a base, an emitter and a collector, means directly connecting said base to a point of reference potential, a source of direct current voltage, a first resistance, means connecting said source of direct current voltage and said first resistance in series between said collector and said base, a second resistance, a condenser, means connecting said condenser and said second resistance between said emitter and said collector, a third resistance connected between said emitter and said base, and a series resonant circuit connected in shunt to said third resistance and having a frequency of resonance substantially integrally related to said predetermined frequency.

2. The combination in accordance with claim 1 wherein is provided a pulse output terminal connected directly to said collector.

3. The combination in accordance with claim 1 wherein is provided means for inserting a variable voltage in series with said third resistance.

4. The combination in accordance with claim 1 wherein is provided means for deriving a signal wave of high harmonic content from said series resonant circuit.

5. In an oscillator, a transistor having at least an emitter, a collector and a base, a discharge condenser connected between said emitter and said collector, a voltage dropping resistance connected between said emitter and said base, a source of direct current voltage connected between said collector and said base, and a series resonant circuit connected between said emitter and said base and resonant at substantially an integral multiple including unity of the frequency of said oscillator.

6. The combination in accordance with claim 5 wherein is provided a second resistance in series between said source of direct current voltage and said collector, and a protective resistance in series with said discharge condenser between said collector and said emitter, and wherein said voltage dropping resistance is large compared with either of said second resistance and said protective resistance.

7. The combination in accordance with claim 6 wherein said series resonant circuit includes a capacitance and an inductance resonant at an integral multiple including unity of the frequency of said oscillator, and wherein said capacitance is very small compared with the capacitance of said discharge condenser.

8. The combination in accordance with claim 7 wherein is provided means for inserting a variable voltage in series with said voltage dropping resistance.

9. A transistor oscillator including a transistor having a base, an emitter and a collector, a circuit including a condenser arranged for storing electrical energy connected between said emitter and said collector, a source of bias voltage connected between said collector and said base, said base being at reference potential, a voltage dropping resistance connected between said emitter and said base, whereby an exponentially decreasing voltage drop is developed between said emitter and said base during charging of said condenser, and a series resonant circuit connected between said emitter and said base, whereby a generally sinusoidally varying voltage is developed between said emitter and said base, and wherein said transistor is conductive and has a current gain of greater than unity when the potential of said emitter substantially equals the potential of said base, said exponentially decreasing voltage drop being arranged to ap-

proach zero as said sinusoidially varying voltage passes through a zero value.

10. A transistor oscillator in accordance with claim 9 wherein is provided means for frequency modulating said oscillator, said last means including means for varying instantaneous values of said exponentially decreasing voltage drop.

11. The combination according to claim 4, wherein said series resonant circuit includes a first winding having a terminal connected to said point of reference potential, a second winding, a condenser and a load re-

sistance, said second winding condenser and load resistance being connected in a series circuit, the junction of said load resistance and said second winding being connected to said point of reference potential, and said first and second winding being inductively coupled.

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