NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

REPLY TO
ATTN OF: GP

October 15, 1970

TO: USI/Scientific & Technical Information Division
Attention: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General
Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned
U.S. Patents in STAR

In accordance with the procedures contained in the Code GP to Code USI memorandum on this subject, dated June 8, 1970, the attached NASA-owned U.S. patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No. : 3,277,314

Corporate Source : Ames Research Center

Supplementary Corporate Source :

NASA Patent Case No.: XAC-00942

Parker

Gayle Parker

Enclosure:
Copy of Patent

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Oct. 4, 1966 R. M. MUÑOZ 3,277,314

HIGH-EFFICIENCY MULTIVIBRATOR

Filed Sept. 20, 1963 2 Sheets-Sheet 1

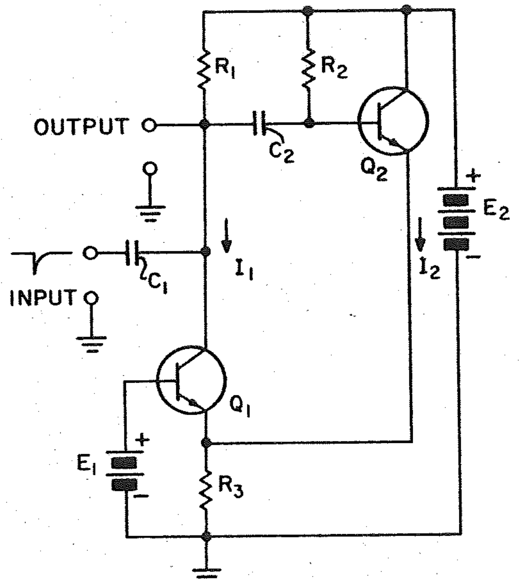

Fig. 1

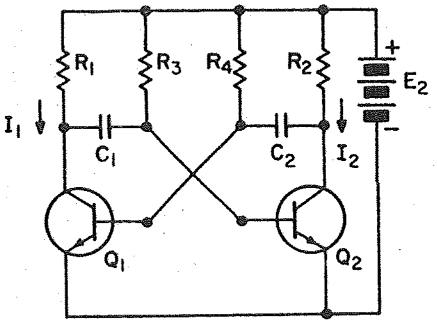

Fig. 2

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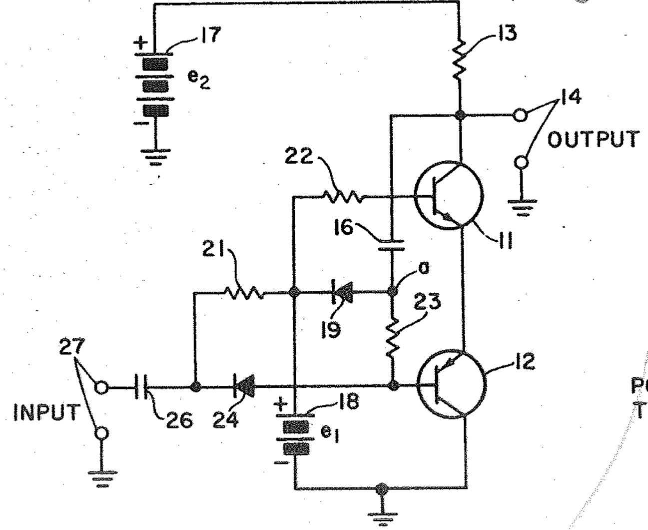
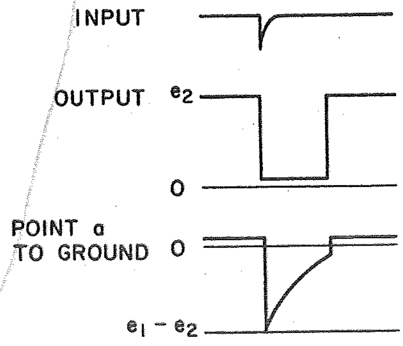


Fig. 3

Fig. 4



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Oct. 4, 1966 R. M. MUÑOZ 3,277,314

HIGH-EFFICIENCY MULTIVIBRATOR

Filed Sept. 20, 1963 2 Sheets-Sheet 2

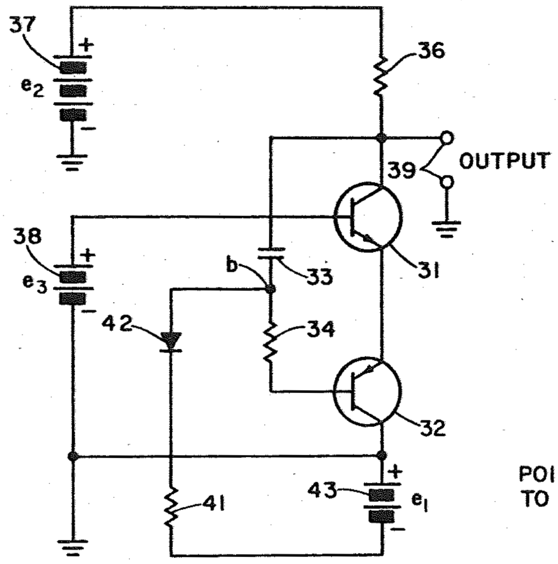

Fig. 5

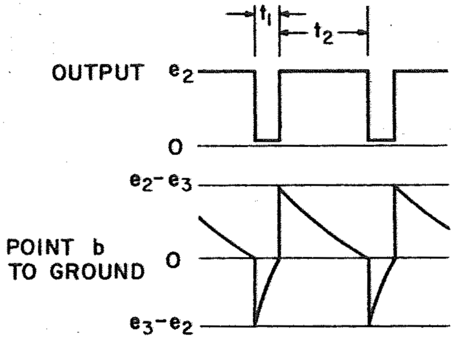

Fig. 6

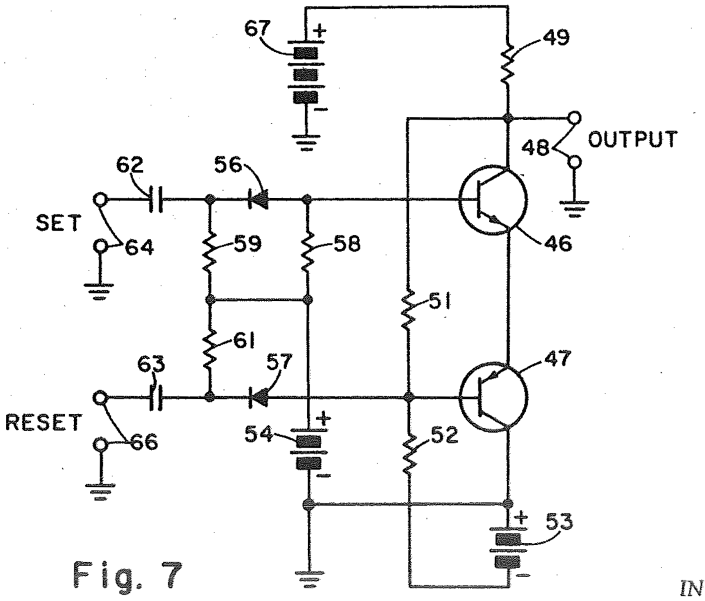

Fig. 7

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United States Patent Office

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3,277,314

HIGH-EFFICIENCY MULTIVIBRATOR

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Filed Sept. 20, 1963, Ser. No. 310,506
5 Claims. (Cl. 307—88.5)

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

This invention relates to improved semiconductor multivibrator circuits.

Multivibrator circuits are of three types, namely, astable, bistable or monostable. An astable multivibrator is free-running, that is, self-oscillating. A monostable multivibrator has one stable state of operation and a second quasi-stable state. A trigger pulse applied to a monostable type multivibrator causes the circuit to shift to its quasi-stable state. After a given period of time the monostable multivibrator circuit returns to its stable state. A bistable multivibrator (often referred to as a flip-flop) is a multivibrator in which the two active elements are biased so that the circuit has two stable states and a trigger pulse is required to make a change or switch from one state to the other. The stable states of the bistable multivibrator or the flip-flop are referred to as the set and reset states. This same terminology is used to designate the two pulse inputs of the multivibrator, namely, set input and reset input. The bistable multivibrator has two pulse inputs. The output of the bistable multivibrator is often given the Boolean tags of "one" and "zero." An input pulse at the set input sets the multivibrator and a high output voltage (one) is produced at the output. When an input pulse is applied to the reset input the multivibrator is reset and a low voltage (zero) is produced at the output. Many bistable multivibrators have complementary outputs. That is, a (zero) is available at one terminal at the same time that a (one) is available at another terminal.

In many applications of electronics, the efficient use of power is of relatively little importance but with the advent of satellite instrumentation, power efficiency has become a critical factor. Of the many circuits used in satellite electronics, only a few approach 100 percent efficiency. This invention is one falling within that category.

The nature of the coupling elements between the two active elements in a multivibrator determines whether it is monostable, bistable or astable. The general purpose of the monostable circuit is to produce a rectangular pulse of constant width. The start of the pulse is determined by an input signal (not necessarily periodic) and the pulse width is determined by physical constants within the circuit. Circuits of this type are used widely in the fields of radar, sonar, communications, television, computing and instrumentation. A conventional transistor monostable multivibrator is illustrated in FIG. 1. In this circuit, transistor Q_1 is normally cut off and transistor Q_2 is normally conducting because of the current that flows through R_2 into the base of transistor Q_2. Under these conditions, the voltage drop across R_3 must be greater than e_1 (the potential produced by power supply E_1), the base voltage of transistor Q_1, to insure that transistor Q_1 is cut off. When a negative pulse appears at the collector of transistor Q_1, it passes through capacitor C_1 to the base of transistor Q_2 causing a reduction in current I_2 which in turn reduces the voltage drop across resistor R_3 to a value less than e_1. This action turns transistor Q_1 on and positive feedback in the circuit rapidly switches transistor Q_1 to saturation and transistor Q_2 to cut off.

This condition of saturation remains until resistor R_2 charges capacitor C_1 thus allowing transistor Q_2 to conduct again (the time constant R_2C_1 determines the pulse duration). Then the reverse action occurs to return the circuit to its original stable state. While transistor Q_1 is conducting, a current I_1 flows through resistors R_1 and R_3. One requirement for stability is that current I_1 be less than current I_2. The total average power P, consumed by this circuit can be expressed as follows:

$$P=e_2[I_1+(I_2-I_1)(I-tf)]$$

where

t=pulse duration
f=repetition rate and
e_2=the potential of the power supply E_2.

This represents a very inefficient use of power because much of it is used only to maintain the circuit in readiness and only a small amount is consumed in the load resistor R_1, especially if the pulse duration is small. The efficiency, E, of this circuit is given by the following expression:

$$E=\frac{I_1tfR_1}{[I_1+(I_2-I_1)(1-tf)](R_1+R_3)}$$

If I_1 and I_2 are approximately equal, and if R_3 is much less than R_1, this equation reduces to:

$$E=tf$$

For low repetition rates and for short pulse durations, this circuit has very low efficiency.

In the circuit of FIG. 1, the output current flows through resistor R_3 and causes a voltage drop. The total output voltage is the power supply potential e_2 less the saturation voltage of transistor Q_1 and the voltage drop across resistor R_3.

The purpose of the astable multivibrator is to produce periodic waveforms of high harmonic content, for example, rectangular waveforms, square waves, trapezoids, and pulses. Proper selection of circuit parameters determines the frequency and symmetry of these waveforms. FIG. 2 illustrates a conventional transistor astable multivibrator. In this circuit, the time constants C_1R_3 and C_2R_4 determine the frequency of operation and the time constants R_1C_1 and R_2C_2 determine the recovery of the circuit. When transistor Q_1 is saturated, transistor Q_2 draws no current until capacitor C_1 is charged through resistor R_3 and transistor Q_2 just begins to conduct. The voltage at the collector of transistor Q_2 drops and passes through capacitor C_2, lowering the base voltage of transistor Q_1 and bringing it out of saturation. This allows the collector of transistor Q_1 to increase in voltage which increase is coupled through capacitor C_1 to the base of transistor Q_2, causing positive feedback. The recovery of the collector of transistor Q_1 to the voltage e_2 (the potential of power supply E_2) is limited by the time constant C_1R_1 because capacitor C_1 is effectively tied to ground through the base of transistor Q_2. Collector recovery limits the amount of dissymmetry in the output waveform. If capacitor C_1 is made large with respect to capacitor C_2 to produce a highly asymmetric output waveform, the time that the collector has to recover to potential e_2 is reduced in direct proportion. The efficiency of the circuit is limited in a manner similar to that of the conventional monostable multivibrator shown in FIG. 1 and can be expressed by the same equation used to measure the efficiency of that circuit.

Accordingly, it is an object of this invention to provide an improved semiconductor multivibrator that is substantially 100 percent efficient.

Another object of this invention is to provide an improved multivibrator that produces an output voltage which is nearly equal to the power supply voltage.

A further object of this invention is to provide an improved transistor multivibrator with a shorter response time which allows the shortest possible rise and fall times in the output waveform.

In accordance with the invention, transistors of the opposite conductivity type are coupled in a novel manner to form a multivibrator. The complementary transistors are connected in series with each other and a load resistance. The load resistance is connected to the collector of the first transistor. The emitter of the first transistor is connected directly to the emitter of the second transistor. Current flows in both transistors simultaneosuly, or alternatively, both transistors are cut off. This arrangement produces a nearly 100 percent efficient multivibrator. The series connection of the two complementary transistors results in a reduction in the effective collector shunt capacity and provides a shorter response time. A circuit embodying the invention may be any one of the three types of multivibrators, namely, monostable, bistable, or astable. A single network coupling the complementary transistors determines whether this circuit is monostable, bistable or astable.

The novel features of this invention as well as the invention itself, both as to its organization and method of operation, will be best understood from the following description, when read in connection with the accompanying drawings, in which like reference symbols refer to like parts, in which:

FIG. 1 is a circuit diagram of a conventional semiconductor monostable multivibrator;

FIG. 2 is a circuit diagram of a conventional transistor astable multivibrator;

FIG. 3 is a circuit diagram of a monostable multivibrator embodying this invention;

FIG. 4 illustrates waveforms associated with the circuit of FIG. 3;

FIG. 5 is a circuit diagram of an astable multivibrator embodying this invention;

FIG. 6 illustrates waveforms generated in the circuit of FIG. 5; and

FIG. 7 is a circuit diagram of a bistable multivibrator embodying this invention.

The embodiment shown in FIG. 3 contains a NPN transistor **11**, the emitter of which is connected to the emitter of a PNP transistor **12**. The collector of transistor **11** is connected to one of output terminals **14**, a load resistor **13**, and a capacitor **16**. The remaining output terminal is grounded. The positive and negative terminals of a power supply **17**, generating a potential e_2, are connected to resistor **13** and ground, respectively. The negative terminal of a power supply **18**, generating a potential e_1, is grounded and the positive terminal is connected to the cathode of a diode **19**, a resistor **21**, and a resistor **22**. The anode of diode **19** is connected to capacitor **16** and a resistor **23**. Capacitor **16** is connected to the collector of transistor **11** and resistor **23** is connected to the base of transistor **12**. Resistor **21** is connected between the cathode of a diode **24** and a coupling capacitor **26**. Capacitor **26** and diode **24** are connected in series between one of input terminals **27** and the base of transistor **12**. The other input terminal is grounded.

In operation, both transistors **11** and **12** are normally cut off because no voltage appears between the base of transistor **11** and the base of transistor **12**. When a negative pulse appears at the input terminals **27**, it passes through coupling capacitor **26** and the input diode **24** to the base of transistor **12**, causing transistor **12** to conduct. The voltage at the emitter of transistor **11** is reduced since the emitter of transistor **12** is connected to the emitter of transistor **11**. This causes transistor **11** to begin conducting. Current then flows through resistor **13** producing positive feedback because of the voltage drop across resistor **13**. The circuit quickly saturates and remains saturated until capacitor **16** is discharged through resistor **23** (capacitor **16** and resistor **23** determine the pulse duration) and removes the forward bias current from transistor **12** at which time the reverse action occurs and the transistors switch to the cut-off state. Recovery of the circuit is accomplished when capacitor **16** charges through resistor **13** and diode **19**. Some of the circuit waveforms are illustrated in FIG. 4.

FIG. 4 illustrates the input waveform, the output waveform, and the waveform between the junction of capacitor **16** and resistor **23**, point a, and ground for the circuit depicted in FIG. 3.

In the conventional transistor monostable multivibrator illustrated in FIG. 1, the output current flows through resistor R_3 and causes a voltage drop. The total output voltage is the power supply voltage e_2 less the saturation voltage of transistors Q_1 and Q_2 and the voltage drop across resistor R_3. In the circuit of FIG. 3, however, the output voltage is equal to the power supply voltage less only the saturation voltages of transistor **11** and **12**. This insures pulse height stability and produces a higher output voltage for a given power supply. The output voltage is nearly equal to the power supply voltage. The reduction in the effective collector shunt capacity, by series connection of transistors **11** and **12**, contributes to the speed of response of the circuit and allows the shortest possible rise and fall times in the output waveform. The power consumed in the circuit of FIG. 4 is only the power consumed in the load plus the very small power consumed in the base circuit of transistor **12** during switching. Stand-by power is zero. Thus, the circuit is substantially 100 percent efficient. This makes the circuit ideally suited for those applications where power consumption is of the utmost importance, for example, in satellite instrumentation.

The astable embodiment illustrated in FIG. 5 has no stable states and provides a free-running oscillator. An R-C circuit comprising capacitor **33** and resistor **34** is connected between the base of a PNP transistor **32** and the collector of an NPN transistor **31**, the capacitor **33** being connected to the collector of the latter transistor. The emitters of transistors **31** and **32** are directly coupled. The collector of transistor **31** is connected to capacitor **33**, a resistor **36** and one of output terminals **39**. The other output terminal is connected to ground. The positive and negative terminals of a power supply **37**, generating a potential e_3, are connected to resistor **36** and ground, respectively. The positive and negative terminals of a power supply **38**, generating a potential e_3, are connected to the base of transistor **31** and ground, respectively. The anode of diode **42** is connected to resistor **34** and capacitor **33** and the cathode is connected to resistor **41**. A power supply **43** is connected between ground and resistor **41**, the positive terminal of the power supply being connected to ground. The negative terminal of power supply **38**, and the collector of transistor **32** are all grounded.

The circuit shown in FIG. 5 is self-starting and no input pulse is required. Transistors **31** and **32** act similarly to the transistors in the monostable multivibrator circuit of FIG. 3 in that they both are saturated or are both cut off at any given time. When transistors **31** and **32** are saturated, capacitor **33** discharges through resistor **34**. Diode **42** is employed as a disconnect diode to isolate capacitor **33** and resistor **34** from resistor **41**. Two of the waveforms generated in the circuit of FIG. 5 are illustrated in FIG. 6. The period t_1 during which time transistors **31** and **32** are saturated is regulated by the time constant $R_{34}C_{33}$ wherein R_{34} is the resistance of resistor **34** and C_{33} is the capacitance of capacitor **33**. The period t_2 during which time the transistor **31** and **32** are cut off is controlled by the time constant $(R_{41}+R_{36})C_{33}$ wherein R_{41} is the resistance of resistor **41**. When transistors 31 and 32 are cut off and capacitor 33 is charging, the voltage at the base of transistor 32 is going more negative. As the forward bias is increased, transistor 32 begins to conduct. This causes the emitter voltage of transistor 32 to drop and, accordingly, so does the emitter voltage of transistor 31. Transistor 31 then conducts and a voltage drop is produced across resistor 36 which drop is coupled back to the base of transistor 32 through capacitor 33 and resistor 34. This regenerative action drives transistor 31 and 32 into saturation. The conduction of transistor 31 and transistor 32 results in the discharge of capacitor 33 through resistor 34. The base current of transistor 32 becomes more positive and finally transistor 32 falls out of conduction and transistor 31 does likewise. Once transistors 31 and 32 are cut off, capacitor 33 again charges through diode 42 and resistor 41 and the cycle repeats itself.

Resistor 34 may be made very small and resistor 41 made very large without affecting the circuit adversely, thus permitting a high degree of asymmetry in the multivibrator output. This makes the circuit an ideal generator of pulses. Since current flows through the transistor 31 and 32 only during the interval of output pulse generation (t_1), the circuit is nearly 100 percent efficient. The series arrangement of the transistors reduces the effective collector capacity and decreases the rise and fall time of the output waveform.

In the bistable embodiment shown in FIG. 7, two complementary transistors 46 and 47 are connected in series. Transistor 46 is of the NPN type and transistor 47 is of the PNP type. The emitters of these transistors are directly coupled together. The collector of transistor 46 is connected to one of output terminals 48, a resistor 49 and a resistor 51. Resistor 51 and a resistor 52 are connected in series between the collector of transistor 46 and the negative terminal of a power supply 53, resistor 52 being connected to the power supply. The positive terminal of power supply 53 is connected to the collector of transistor 46, ground, and the negative terminal of a power supply 54. The positive terminal of power supply 54 is connected to a resistor 58, a resistor 59, and a resistor 61. A coupling capacitor 62 is connected between one of set input terminals 64 and the cathode of a diode 56. The other set input terminal is connected to ground. A coupling capacitor 63 is connected between one of the reset input terminals 66 and the cathode of a diode 57. The other reset input terminal is connected to ground. The anode of diode 56 is connected to the base of transistor 46 and resistor 58. The anode of diode 57 is connected to the base of transistor 47, resistor 51 and resistor 52. The positive and negative terminals of a power supply 67 are connected to resistor 49 and ground, respectively.

In operation, the bistable circuit is in either the reset stable state wherein both transistors 46 and 47 are saturated or in the set stable state wherein transistors 46 and 47 are cut off. When a negative-going input signal is applied to either set of input terminals the circuit switches to the other stable state where it remains until another trigger pulse is applied to the other set of input terminals. Assume that transistors 46 and 47 are cut off and the circuit is in the set stable state. A negative trigger pulse applied at input terminals 66 will be coupled through capacitor 63 and diode 57 to the base of transistor 47. This pulse will increase the forward bias of transistor 47, causing it to conduct and decrease the emitter voltage of transistors 46 and 47. Transistor 46 will likewise conduct, producing a voltage drop across resistor 49. The voltage drop will be reflected back to the base of transistor 47 and the regenerative action will drive transistors 46 and 47 into saturation. The circuit will remain in this stable state (reset) until a negative-going pulse is applied to the input terminals 64. Such a pulse will be coupled through capacitor 62 and diode 56 to the base of transistor 46. The pulse will reverse-bias transistor 46 and drive it into cut off. The positive pulses applied to the emitter and base of transistor 47 will likewise cause that transistor to be cut off. The circuit will then remain in the set stable state until a negative-going pulse is applied to the reset input terminals 66. The series connection of transistors 46 and 47 results in a reduction in the effective collector shunt capacity and results in an output waveform with improved rise and fall times. An improvement in power efficiency may be achieved over that of a conventional bistable multivibrator if the probability of occurrence of the set state is greater than that of the reset state.

There has thus been described a novel transistor multivibrator circuit which may be employed to function either as a monostable, an astable or a bistable element. The multivibrator provides an improved output waveform, improved power efficiency and an improved output voltage amplitude.

Although the invention has been described in considerable detail, it is to be understood that such description is illustrative rather than limiting, as the invention may be variously embodied otherwise than is shown and is to be interpreted only as claimed.

I claim:

1. A multivibrator circuit comprising a first semiconductor device of one conductivity type, a second semiconductor device of another conductivity type, each of said devices including a base electrode, a collector electrode and an emitter electrode, the emitter electrodes of said first and second semiconductor devices being coupled together, a resistor, a power source, said resistor and said power source being series connected and connected between the collector electrodes of said semiconductor devices, biasing means connected between said base electrode of said first semiconductor device and said collector electrode of said second semiconductor device, an R-C circuit connected between said collector electrode of said first semiconductor device and said base electrode of said second semiconductor device, means for coupling said R-C circuit to said biasing means, first and second rectifying means, said first rectifying means being coupled between said biasing means and said R-C circuit, input signal coupling means, said second rectifying means being coupled between said input signal coupling means and said base electrode of said second semiconductor device, and a resistor coupled between said first and second rectifying means.

2. A multivibrator circuit in accordance with claim 1 in which said input signal coupling means includes a coupling capacitor, a pair of input terminals and a pair of output signal terminals connected across said collector electrodes of said semiconductor devices.

3. A multivibrator circuit comprising first and second transistors of opposite conductivity type, said transistors each having a base electrode, a collector electrode and an emitter electrode, said emitter electrodes of said first and second transistors being coupled together, a power supply, a load resistor, said resistor and said power supply being connected in series and connected between said collector electrodes thereby reducing the effective collector capacity, a first biasing means coupled between said base electrode of said first transistor and said collector electrode of said second transistor, a series R-C circuit coupled between said collector electrode of said first transistor and said base electrode of said second transistor, and a second biasing means coupled between the midpoint of said R-C circuit and said collector electrode of said second transistor.

4. A multivibrator circuit according to claim 3, wherein said second biasing means comprises a rectifier, a resistor and a power supply, said rectifier, said resistor and said power supply being connected in series with said resistor being interposed between said rectifier and said power supply.

5. A bistable multivibrator comprising first and second transistors each having base, emitter and collector electrodes, said emitter electrodes of said transistors being coupled together, a first resistor and a power supply connected in series between said collector electrodes of said first and second transistors, a set input, a first diode and a first capacitor coupled between said set input and said base electrode of said first transistor, a reset input, a second diode and a second capacitor coupled between said reset input and said base electrode of said second transistor, a pair of resistors serially connected between the junction of said first diode and said first capacitor and the junction of said second diode and said second capacitor, first biasing means coupled to said pair of resistors, said diodes and said base electrode of said first transistor, second biasing means coupled between said base and collector electrodes of said second transistor, and a resistor coupled between said collector electrode of said first transistor and said base electrode of said second transistor.

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