Aug. 27, 1968 J. J. ANDREA 3,399,311

FREQUENCY DIVIDER EMPLOYING INDUCTIVE SWITCHING

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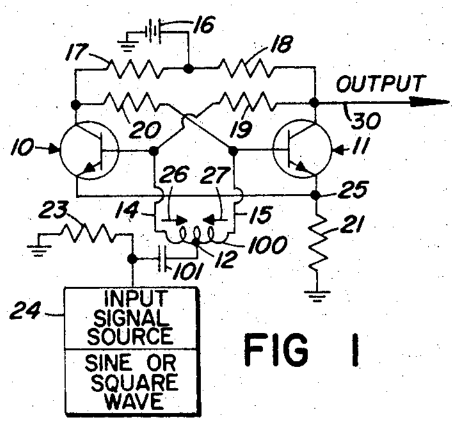

FIG 1

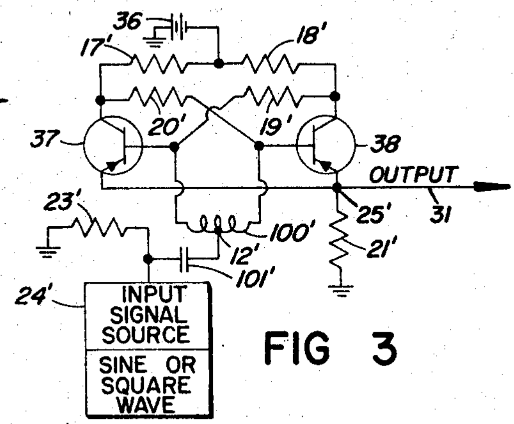

FIG 3

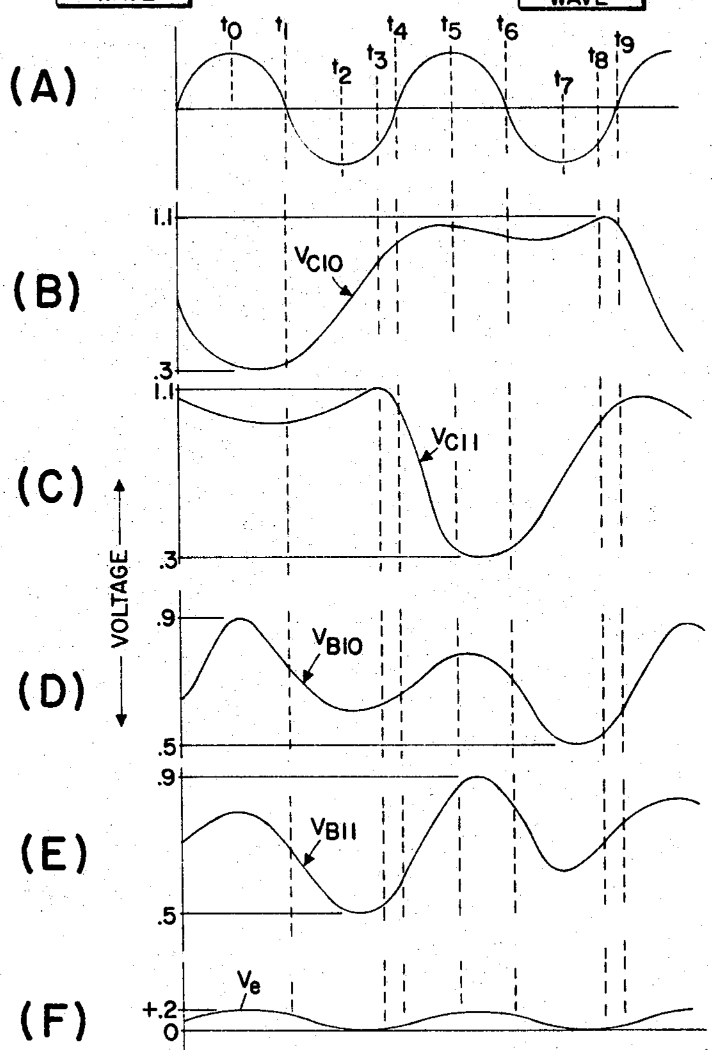

FIG 2

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1

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FREQUENCY DIVIDER EMPLOYING INDUCTIVE SWITCHING

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11 Claims. (Cl. 307—225)

ABSTRACT OF THE DISCLOSURE

A frequency divider employing a multivibrator type circuit having a pair of transistors with the base electrodes connected together by a tapped inductor. An A-C input signal is applied to the tap to control the switching rate of the multivibrator. The tapped inductor functions as a very stable, electrical flywheel to enable accurate frequency division over quite large frequency and temperature ranges. Output signals can be taken from the collector or emitter of either transistor.

This invention relates generally to frequency dividers and, more particularly, to a frequency divider employing a nonresonant inductive switching means which functions to enable the frequency divider to operate over a wide range of frequencies.

In the prior art there are many multivibrator circuits which employ flip-flop type circuits. Some of these multivibrator circuits employ a parallel resonant circuit to control the frequency of operation. For example, in one prior are circuit, the parallel tuned circuit is transformer coupled, by the end terminals of a center tapped secondary winding, to the bases of two transistors which form the heart of the flip-flop circuit. The center tap itself is connected to the common junction of the emitters of the two transistors. Properly timed bursts of energy are supplied through feedback means from the output of the multivibrator to the parallel tuned circuit to maintain operation of the tuned circuit.

One of the limitations encountered with the use of a parallel tuned circuit in a multivibrator is the resultant limited range of frequencies. It is apparent that the resonant frequency of the tuned circuit must be changed in order to change the operating frequency of the multivibrator. The range of such tuning is limited.

A further disadvantage of many prior art multivibrator systems lies in the use of cross-coupling circuits which contain capacitors. Such capacitors introduce delays in the circuits and also result in limitation of the upper frequency of operation.

An object of the present invention is to provide a frequency divider which will operate at frequencies up to the order of 250 megacycles and higher.

A second purpose of the invention is to provide a frequency divider which will operate over a band of frequencies of the order of ten to one.

A third object is to provide a frequency divider which will operate reliably over a wide range of temperatures.

A fourth aim of the invention is to provide a frequency divider which will operate over a wide range of frequencies of the order of 25 to 250 megacycles or better and over a range of temperatures of approximately —50°–100° C.

A fifth object of the invention is to provide a frequency divider employing the controlled stored energy of an inductor to actuate the divider.

A sixth purpose of the invention is the improvement of frequency dividers generally.

In accordance with the invention there is provided a pair of electron valves, such as transistors, with the emitters thereof connected through a common impedance to a first terminal of a power supply, and with the collectors

2

connected to the other terminal of the power supply through individual collector load impedances. The base electrodes of the transistors are connected together through an inductor which has a tap thereon. Resistive cross coupling circuits connect the collector of each transistor to the base electrode of the other transistor. An A-C input signal is supplied to the tap of the inductor through a coupling capacitor. Such input signal will function to control the switching of the two transistors in a manner described generally as follows:

During the operation of the circuit, the two transistors become alternately conductive, with the other transistor being nonconductive. When a given first transistor is conductive, a current will flow through the tapped inductor in a given first direction and will also flow, in completing its path, through the conductive transistor. Assume that such condition will exist during the positive half cycle of the input pulse. When the input pulse goes negative, the conductive first transistor is cut off, thereby opening the current path for the current flowing through the inductor, and the polarity of the voltage across the inductor reverses. At that point in time, the inductor changes from a load to a source. When the polarity of the input signal then next crosses zero and goes positive, the other, second transistor becomes conductive. During the conductive time interval of said second transistor, the current through the inductor reverses and it again becomes the load rather than a source, in preparation for the next cycle of operation. The frequency of operation of the circuit is determined primarily by the frequency of the input signal.

In accordance with the feature of the invention, the tapped inductor is employed to provide the necessary kick of energy to cause the transistors to switch states, i.e., for the conductive transistor to become nonconductive and for the nonconductive transistor to become conductive.

The above-mentioned and other objects and features of the invention will become more fully understood from the following detailed description thereof when read in conjunction with the drawings in which:

FIG. 1 is a schematic diagram of the invention;

FIG. 2 is a set of waveforms A through F identifying the voltages at various points of the circuit of FIG. 1 during the operation of said circuit; and

FIG. 3 shows a schematic diagram of another form of the invention.

Referring now to FIG. 1, transistors **10** and **11** function as switches in the circuit with one transistor being conductive while the other is nonconductive. The emitters of transistors **10** and **11** are connected to ground potential through common resistor **21** and the collectors thereof are connected to the positive terminal of battery source **16** through collector load resistors **17** and **18**, respectively. Cross coupling circuits, comprising resistors **20** and **19**, connect the collectors of transistors **10** and **11**, respectively, to the bases of transistors **11** and **10**.

An inductor **100** with a tap thereon connects the bases of the transistors **10** and **11** together. An input signal shown in FIG. 2A is supplied from the input signal source **24** through coupling capacitor **101** to tap **12** on inductor **100**. Resistor **23** functions to provide a discharge path for the left-hand plate of capacitor **101**, thus preventing accumulation of charge on said capacitor.

In the waveforms of FIG. 2, waveform B represents the collector potential of transistor **10** and waveform C represents the collector potential of transistor **11**, over a complete cycle of operation. The waveforms of FIGS. 2B and 2C were taken from an oscilloscope tracing made during a test of the circuit of FIG. 1. It will be observed that beginning at times t_3 and t_8 the transistors **11** and **10**, respectively, are switched on. Such switching on is evidenced by the decrease in the waveforms of FIGS. 2C and 2B at times t_3 and t_8.

The waveforms of FIGS. 2D and 2E show the voltage at the bases of transistors **11** and **10**, respectively, with the same time base as the waveforms of FIGS. 2A, 2B, and 2C. The waveform of FIG. 2F represents the emitter potential at the point **25**, and varies between ground, during a short time interval when both transistors are turned off, and plus 0.2 volt and when one or the other of the transistors are conductive at its maximum conductivity.

The invention is best understood by describing the operation thereof. Assume that the circuit is already operating and that the input signal from source **24** at the tap **12** is at its maximum positive value, as indicated at time t_0 in FIG. 2A. Assume further that transistor **10** at time t_0 is conductive and that transistor **11** is nonconductive. Under such conditions the collector of transistor **11** will be at a higher potential than that of the collector of transistor **10** since there is a current flowing from battery **16** through resistor **17**, transistor **10**, and emitter resistor **21** to ground.

Another current, however, is established from battery **16** through resistor **18**, resistor **19**, inductor **100**, resistor **20**, conductive transistor **10**, and resistor **21** to ground. The reason for the second current path is simply that the potential of the collector of transistor **11** is higher than that of the collector of transistor **10**. The current flowing through inductor **100** will be in the direction of arrow **26**, and inductor **100** will be acting as a load to the current therethrough.

As the input signal applied to tap **12** goes to zero at time t_1, and then begins to go negative, transistor **10** will remain conductive since there is a certain RC time delay within transistor **10** itself due to inherent capacitances therein. However, when the input voltage of waveform 2A is near its most negative point at time t_2, transistor **10** will be well on the way to becoming completely turned off. Observations made during the testing of the circuit indicate that transistor **10** will become substantially turned off at about time t_3. At time t_3, the current path for the current through inductor **100** opens and such current tends to go rapidly towards zero. Because of this rapidly decreasing current in inductor **100**, the voltage across the inductor reverses polarity, and the stored energy in the inductor causes it to become an energy source rather than a load.

The right-hand terminal of inductor **100** is now positive. Said positive voltage is supplied to the base of transistor **11** causing transistor **11** to become conductive beginning at a time just immediately after time t_3 in FIG. 2.

As transistor **11** becomes more conductive and the potential of the collector voltage thereof falls, as shown in the curve FIG. 2C, beginning at time t_3 and extending through to time t_5, it is apparent from waveforms 2B and 2C that the collector potential of transistor **10** is much greater than the collector potential of transistor **11**. Consequently, the current flow through the inductor **100** will have begun to flow in the direction of arrow **27** at some point between time t_3 and t_5. When such current begins to flow through inductor **100** in such a direction the inductor will be acting as a load rather than a source.

The transistor **11** will remain conductive during the positive half cycle of the waveform of FIG. 2A, between times t_4 and t_6, and on into the next negative half cycle. However, as the waveform of FIG. 2A begins to go negative at time t_6 transistor **11** will begin to turn off and will be completely turned off at time t_8 which corresponds to the time t_3 discussed above in connection with transistor **10** being turned off. At time t_8 when transistor **11** becomes completely turned off, the current path through inductor **100** will again be open circuited and the voltage across the inductor **100** will again reverse so that a positive potential is supplied to the base of transistor **10** from the left-hand terminal thereof. Thus conduction of transistor **10** is begun at time t_8, as shown in the curve of FIG. 2B.

In the curves of FIGS. 2D and 2E, there are shown, respectively, the waveforms of the voltages of the bases of transistors **10** and **11**. At time t_3 when transistor **10** was turned off and the polarity in the inductor **100** reversed so that the right-hand terminal **15** thereof was positive, the waveform of FIG. 2E shows that the base voltage V_{B11} of transistor **11** began to rise rather sharply. The rise of the base voltage V_{B11} during time interval t_3–t_5 corresponds closely to the drop in the collector voltage V_{C11} of FIG. 2C.

It should be noted that the base voltage V_{10} of transistor **10**, shown in FIG. 2D, also begins to rise at time t_3, but not nearly as much as that of the base of transistor **11**. The rise of the voltage V_{B10} at time t_3 is due to the fact that the potential of the point **12** is increasing, as shown in the curve of FIG. 2A.

Again at time t_8, when transistor **11** becomes nonconductive, the potential of the base of transistor **10** will increase sharply due to the reversal of potential in inductor **100**.

In FIG. 2F there is shown the voltage appearing at the point **25**, which is the emitter voltage of the system. It will be noted that such emitter voltage has the same frequency and phase as the input signal supplied to tap **12** of inductor **100**.

The output of the circuit of FIG. 1 can be taken either from the collector electrode as indicated by lead **30** in FIG. 1 or, alternatively, across the emitter resistor **21'**, as shown by output lead **31** of FIG. 3. Further, the output can be taken from either transistor of FIGS. 1 or 3. In order to obtain the fundamental sine wave contained in the waveforms of FIGS. 2B and 2C, a conventional filter means can be employed. It is apparent from the waveforms of FIGS. 2B and 2C that the fundamental frequency therein is one-half that of the input signal of FIG. 2A.

Referring now to FIG. 3, there is shown another form of the invention employing PNP type transistors **37** and **38** rather than the NPN type transistors **10** and **11** of FIG. 1. With the use of PNP type transistors of FIG. 3 the battery source **36** must be negative rather than positive in polarity. The remaining components of the circuit of FIG. 3 are similar to those of FIG. 1 and are identified by the same reference character, although primed

The operation of the circuit of FIG. 3 is much the same as that of FIG. 1 except that the polarities are reversed. For example, the switching occurs during the positive half cycle of the input waveform from source **24'** rather than the negative half cycle. Generally speaking, the operating waveforms relating to the circuit of FIG. 3 correspond to inversions of the waveforms shown in FIGS. 2B and 2F.

In one preferred embodiment of the invention the components of the circuit of FIG. 1 can have the following values:

R_{17}=1K
R_{18}=1K
R_{20}=1K
R_{19}=1K
R_{23}=1K
R_{21}=50Ω
C_{101}=.005 μf.
E_{16}=1.5 volts
$L_{100}\cong 1\mu$h.

The transistors can be of type 2N2784.

It is to be understood that the forms of the invention shown and described herein are but preferred embodiments thereof and that various changes may be made in circuit design and in circuit component values without departing from the spirit or scope of the invention.

I claim:

1. A frequency divider for dividing the frequency of an input signal and comprising:

first and second electron valves each having an electron emitting electrode, an electron collecting eectrode, and an electron control electrode;

battery source means;

impedance means connecting said battery source means across the electron collecting electrode-electron emitting electrode circuits of said first and second electron valves;

cross coupling circuits connecting the electron collecting electrodes of said first and second electron valves to the electron control electrodes of the second and first electron valves, respectively;

tapped inductive means connecting together the electron control electrodes of said first and second electron valves;

means for supplying said input signal to the tap of said inductive means; and

means for extracting an output signal having a fundamental frequency one-half that of said input signal across a portion of said impedance means.

2. A frequency divider in accordance with claim **1** in which:

said battery source means comprises first and second terminals; and

said impedance means comprises first and second resistive impedance means individually connecting the electron collecting electrodes of said first and second electron valves to a first terminal of said battery source means.

3. A frequency divider in accordance with claim **2** in which said cross coupling circuits comprise third and fourth resistive means.

4. A frequency divider in accordance with claim **2** in which said impedance means further comprises third resistive impedance means connecting said first and second electron emitting means to the second terminal of said battery source means.

5. A frequency divider in accordance with claim **4** in

which said cross coupling circuits comprise fourth and fifth resistive means.

6. A frequency divider means in accordance with claim **5** in which said means for supplying said input signal to the tap of said inductive means comprises capacitive impedance means.

7. A frequency divider in accordance with claim **1** in which said impedance means further comprises third resistive impedance means connecting said first and second electron emitting means to the second terminal of said battery source means.

8. A frequency divider in accordance with claim **7** in which said cross coupling circuits comprise fourth and fifth resistive means.

9. A frequency divider means in accordance with claim **8** in which said means for supplying said input signal to the tap of said inductive means comprises capacitive impedance means.

10. A frequency divider in accordance with claim **1** in which said cross coupling circuits comprise second and third resistive means.

11. A frequency divider means in accordance with claim **10** in which said means for supplying said input signal to the tap of said inductive means comprises capacitive impedance means.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,399,311 August 27, 1968

John J. Andrea

It is certified that error appears in the above identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 31, "are" should read -- art --. Column 4, line 49, "and" should read -- through --; line 74, "eectrode' should read -- electrode --.

Signed and sealed this 20th day of January 1970.

(SEAL)
Attest:

Edward M. Fletcher, Jr.
Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents