Jan. 19, 1960 R. L. BRIGHT ET AL 2,922,051

LOW VOLTAGE INVERTING DEVICE

Filed April 5, 1954

Fig. 1.

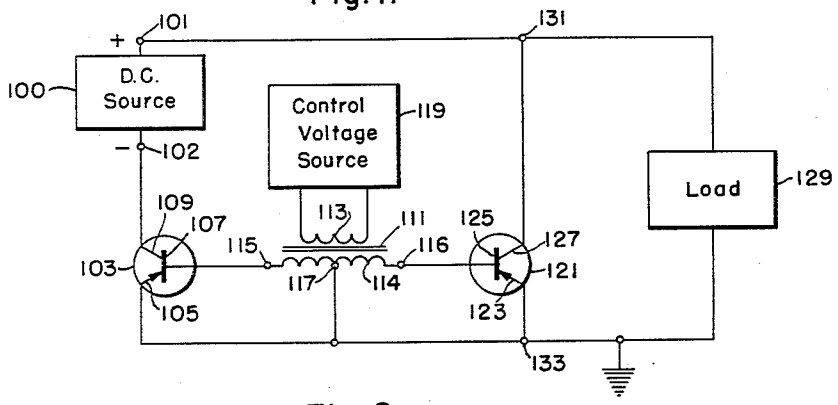


Fig. 2

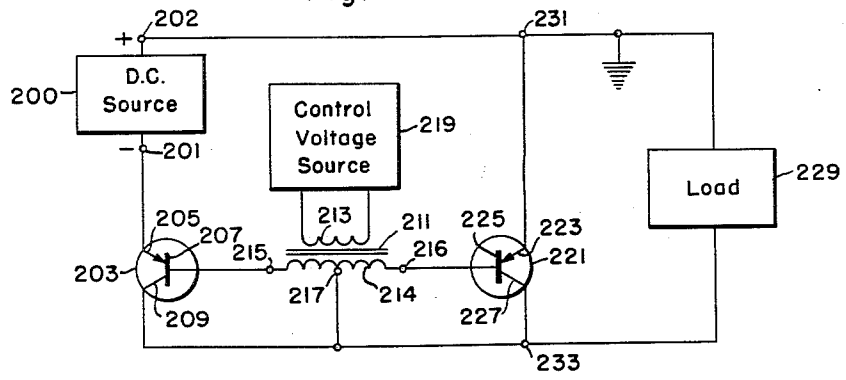
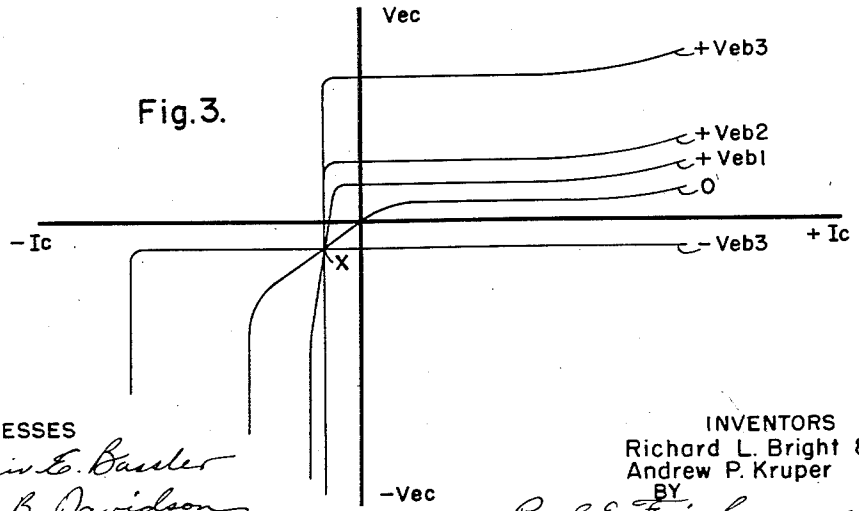


Fig. 3.



WITNESSES

Edwin E. Bassler

John B. Davidson

INVENTORS

Richard L. Bright &

Andrew P. Kruper

BY

Paul E. Friedemann

ATTORNEY

United States Patent Office 2,922,051 Patented Jan. 19, 1960

2,922,051

LOW VOLTAGE INVERTING DEVICE

Richard L. Bright, Adamsburg, and Andrew P. Kruper, Pittsburgh, Pa., assignors to Westinghouse Electric Corporation, East Pittsburgh, Pa., a corporation of Pennsylvania

Application April 5, 1954, Serial No. 420,988

8 Claims. (Cl. 307—88.5)

Our invention relates to devices for converting a variable unidirectional voltage to an alternating voltage having the same or a proportional amplitude.

In the prior art it has been known to use vibrating mechanical devices for converting a low-level D.C. voltage to a proportional A.C. voltage where it is necessary to provide an amplified signal indicative of the amplitude of the D.C. voltage. Such devices have found particular use in control circuits wherein the very small D.C. voltage is derived from a thermocouple. Such mechanical devices, commonly known as "choppers," have numerous disadvantages. The electrical contacts have a tendency to arc and pit and oftentimes require considerable maintenance and replacement as a result thereof. The manufacturers' ratings are seldom over 300 hours' life and under severe operating conditions it has been found that even this figure is not often achieved. Furthermore, choppers have a tendency to fail prematurely when subjected to vibration. Their size and weight are oftentimes intolerable, particularly in aircraft applications where weight is of utmost importance. The upper frequency limit for these mechanical devices is about 2 kilocycles, but at this frequency they become so delicate as not to be commercially practical. Additionally, the phase relationship betwen the alternating-current actuating signal and the output voltage is usually of appreciable magnitude, typically 60°, and has a tendency to fluctuate considerably with change of frequency.

It has also been known in the prior art to use selenium diode bridges and vacuum tube bridges for converting a D.C. voltage to an A.C. voltage, but such devices are of no use for low-level signal inputs.

One object of our invention is to provide an all-electrical device for converting a small-amplitude, direct current voltage to an alternating current wave voltage of proportional amplitude.

Another object is to provide a device for converting a small-amplitude, direct current voltage to an alternating current voltage of proportional amplitude, which device is capable of withstanding severe shocks and vibration without impairment of the operating characteristics thereof.

Still another object is to provide a device for converting a small-amplitude, direct current voltage to an alternating current voltage of proportional-amplitude, and having an operating life of the order of the equipment in which it is meant to function.

A still further object is to provide a device for converting a small-amplitude, direct current voltage to an alternating current voltage of high frequency.

Yet another object is to provide a device for converting a small-amplitude direct current voltage to an alternating current voltage wherein the actuating signal therefor and the output voltage are in phase at all frequencies.

Other objects and features of our invention will become apparent upon consideration of the following detailed description when taken in connection with the accompanying drawings which illustrate various embodiments of the invention.

In the drawings:

Figures 1 and 2 show schematic diagrams of preferred embodiments of our invention;

Fig. 3 is a graph showing the variation of the emitter-collector voltage as a function of collector current for various emitter-base potentials, which graph is particularly useful in understanding the advantages of the embodiment of our invention depicted in Fig. 2.

In the copending application of R. L. Bright and G. H. Royer, entitled "Transistor Power Control Circuits," Serial No. 420,904, filed April 5, 1954, now Patent No. 2,885,570, there is described an electrical switch making use of a junction-type transistor. The reversible-polarity control voltage is connected to the base and either of the adjacent electrodes, which control voltage has an amplitude such that the emitter-collector current through the transistor is alternately cut-off and driven to saturation. (By saturation is meant that operation is in the region where a change in base current will produce substantially no change in emitter-collector current.) The cut-off condition occurs with a p-n-p transistor when the base electrode is positive with respect to both adjoining electrodes, and with an n-p-n transistor when the base electrode is negative with respect to both adjoining electrodes. Current saturation, as defined above, is brought about by driving the base of a p-n-p transistor to a sufficiently negative potential with respect to one adjoining electrode and by driving the base of an n-p-n transistor sufficiently positive with respect to one adjoining electrode.

In one aspect of our invention, two transistor switches of the type described above are utilized in a coupling network between a variable, very low voltage direct-current source and a load adapted to receive an alternating-voltage signal. One of the transistors is connected directly across the load; the other transistor couples one terminal of the D.C. source to the load. The other terminals of the source and load are connected together. A control voltage source, preferably having a rectangular wave form, coupled to each of the transistors renders them conducting alternately so that the load is alternately short circuited and connected to the D.C. source. The low impedance of the saturated coupling transistor (less than 2 ohms) insures that the amplitude of the rectangular wave voltage appearing across the load is substantially the same as the voltage output of the D.C. source; the similarly low impedance of the short-circuiting transistor provides against variations in the amplitude of th rectangular wave voltage due to stray voltages from extraneous sources appearing across the load.

With reference now to Fig. 1, there is shown one embodiment of our invention. A D.C. source **100**, having positive terminal **101** and negative terminal **102**, is coupled to load **129** by means of transistor **103**. Source **100** is typically a low voltage generating device such as a thermocouple. The emitter **105** and collector **109** of transistor **103** are respectively connected to load terminal **133** and source terminal **102**. Source terminal **101** is connected to the other load terminal **131**. Load **129** is typically the input circuit of an alternating-current amplifier.

A second transistor **121** is connected directly across the load with the emitter **123** and collector **127** thereof connected to load terminals **133** and **131**, respectively. In the ensuing discussion it will be assumed that transistors **103** and **121** are of the p-n-p type.

The conduction states of the transistors are controlled by a control voltage source **119**. This source is preferably a rectangular wave generator such as the device shown and described in Fig. 171, and page 162 of Radar Electronic Fundamentals, U.S. Navy publication Nav-Ships 900,016 (1944). A rectangular wave generator is desir-

able so that the transistors can go from a non-conducting to a saturated-conducting condition without an interval of class A operation in order to minimize distortion in the output signal. Control voltage source **119** is coupled to the primary winding **113** of the transformer **111**. Secondary terminals **115** and **116** of transformer **111** are directly connected to the bases **107** and **125**, respectively, of transistors **103** and **121**. The center tap **117** of the secondary winding **114** is joined to emitter electrodes **105** and **123**. Transformer **111** may be an audio transformer when the frequency of source **119** is 60 cycles per second, in order to have a square wave output voltage across terminals **115**, **116** of reasonable fidelity. The frequency of control voltage source **119** may be 60 cycles per second where convenient but is not necessarily limited to this value. It is perfectly feasible for source **119** to have frequencies of the order of 1 megacycle or higher depending upon the design of the transistors.

Before proceeding to a description of the operation of the embodiment of Fig. 1, reference is made to the curves of emitter-collector voltage as a function of collector current depicted in Fig. 3. The curves shown are for a p-n-p type transistor having various emitter-base voltages applied thereacross. Typical values for V_{eb3}, V_{eb2}, and V_{eb1} are 1 volt, .5 volt, and .2 volt, respectively. It will be noted that the intersection of these curves does not pass through the origin as one would normally expect, but instead passes through a coordinate slightly removed from the origin corresponding to a very small negative collector current at a very small negative emitter-collector potential.

Typical values for the coordinates of this cross-over point may be of the order of 5 to 30 millivolts and 4 to 20 microamperes negative. Examination of these curves will further indicate that if sufficient drive is applied to the base, such as between the limits $-V_{eb3}$ and $+V_{eb3}$, the family of curves is symmetrical about the crossover point enabling the circuit to operate with either polarity of input voltage. This is important in servo applications where a circuit such as this would commonly be used and is called upon to detect very small values of voltage difference about a balance point, which voltages can be either positive or negative depending upon the direction of unbalance.

The operation of the embodiment of Fig. 1 is as follows. Assume that source terminal **116** is positive with respect to source terminal **117** as shown in the figure, and that the voltage between terminal **116** and center tap **117** is substantially greater than the output potential of source **100** (preferably twice as great). The voltage appearing between base **107** will be driven negative with respect to emitter **105** and current will flow from emitter to collector of transistor **103**. A voltage substantially the same as that of source **100** will appear across load terminals **131** and **133** and, therefore, between emitter **123** and collector **127** of transistor **121**. Base **125** will manifestly be at a positive potential with respect to emitter **123** and since this base-emitter voltage is substantially greater than that of source **100**, base **125** will likewise be at a positive potential with respect to collector **127**. As described above, this is the condition for cut-off of emitter-collector current through a transistor so there will be no current conduction through transistor **121**.

On the next half-cycle of operation, and on alternate half-cycles thereafter, terminal **115** will be positive with respect to terminal **116**. Base **107** will be driven positive with respect to emitter **105** and likewise with respect to collector **109**. Therefore, there will be no conduction of current from emitter to collector of transistor **103**. However, inasmuch as base **125** is now negative with respect to emitter **123**, transistor **121** presents a low impedance to the circuit and load **129** will be effectively short circuited.

Variations in the input voltage from the D.C. source will thus be reflected as a proportional variation in the amplitude of the output voltage on first alternate half-cycles as described above. The very low impedance of transistor **121** on second alternate half-cycles will insure that substantially zero voltage will appear across the load terminals on second alternate half-cycles so that the amplitude of the output voltage of the device will at all times be proportional to the voltage of source **100**.

If transistors **103** and **121** are selected so as to have similar values for the crossover point, the voltages which would appear across the load (independent of the voltage from the D.C. source) from each transistor would be equal and will average out to provide a constant reference potential, thereby providing zero A.C. output with zero D.C. input. Residual currents would not be serious with a low impedance source.

As has been previously noted in connection with Fig. 3, a small negative current will flow for all positive values of base-emitter voltage, even though the emitter-collector voltage is zero. Obviously, this may offer serious operating difficulties in those applications requiring a high impedance source and a high impedance load. It is desirable, therefore, to reduce this quiescent current as much as possible, i.e., to bring the point of intersection "*x*" of the curves of Fig. 3 as close as possible to the origin of the coordinate system. It has been found that by reversing the emitter and collector connections of the transistors, as shown in Fig. 2, that the quiescent current can be reduced not uncommonly by two orders of magnitude. The value of the voltage at the crossover point is correspondingly reduced. The embodiment of Fig. 2 is exactly the same as that of Fig. 1 except for the interchange of transistor emitter and collector electrodes, emitters **205** and **223** now being respectively connected to source terminal **201** and load terminal **231**, with collector electrodes **209** and **227** being connected together, to load terminal **233** and to center tap **217** of transformer secondary **214**. (It is to be noted that reference numerals in Figs. 1 and 2 wherein the last two digits correspond, refer to identical circuit components.) Fig. 2 also illustrates a common ground for input and output. The operation of the embodiment of Fig. 2 is the same as that of Fig. 1, current conduction for each transistor occurring in this embodiment when the base is negative with respect to the collector thereof and cut-off occurring when the base is positive with respect to the collector.

It should also be pointed out that it is equally possible to operate the circuits in Fig. 1 and Fig. 2 with only one transistor (**103** or **203**). The control voltage source **219** effectively modulates the D.C. source producing an A.C. output voltage of one phase if the D.C. input is positive and an A.C. output voltage 180 degrees opposite phase if the D.C. input is negative. The disadvantage of using only one transistor is that zero input voltage does not produce zero output voltage due to the crossover point, the family of curves being shifted from the origin of the ordinates. This effect would be less pronounced in the circuit shown in Fig. 2 wherein the functions of emitter and collector are interchanged. It would be less by perhaps several orders of magnitude in the latter case as previously explained. However, the preferred embodiments are as shown since practically complete compensation is obtained by the use of two transistors.

There has been produced by our invention an alternating-current wave generator, the amplitude of the output voltage of which is proportional to that of a D.C. input voltage of very small amplitude. The operating life of this device is limited only by the operating lifetime of the transistors used therein, which elements may conservatively be expected to be many thousands of hours. The upper frequency limit of the device may be measured in megacycles rather than hundreds of cycles as for the prior art devices described above. All of the circuit components are inherently rugged and are capable of withstanding severe vibration and rough handling.

Substantially zero phase shift relationship obtains between the output voltage and the actuating signal.

Having described the principle of the invention and the best modes in which we have contemplated applying that principle, we wish it to be understood that the apparatus described is illustrative only, and that other means can be employed without departing from the true scope of the invention.

We claim as our invention:

1. Apparatus for generating across first and second utilization circuit terminals an alternating wave voltage, the amplitude of which is proportional to the output of a unidirectional voltage source, comprising: means coupling said source to said utilization circuit terminals including first junction transistor means having at least emitter, base and collector electrodes, said collector and emitter being respectively coupled to the positive terminal of said source and to said first utilization circuit terminal; second junction transistor means having emitter, base and collector electrodes, said collector and emitter of said second transistor means being respectively connected to said first and second utilization circuit terminals, and alternating rectangular wave control voltage means coupled to base and emitter of each of said transistor means adapted to produce saturation of the emitter to collector current of said first transistor means on first alternate half-cycles and of said second transistor means on second half-cycles, and to cut off the flow of emitter-collector current of said first transistor means on second alternate half-cycles and of said second transistor means on first alternate half-cycles.

2. Apparatus for generating across first and second utilization circuit terminals an alternating wave voltage, the amplitude of which is proportional to the output of a unidirectional voltage source, comprising: means coupling said source to said utilization circuit terminals including first junction transistor means having at least emitter, base and collector electrodes, said emitter and collector being respectively coupled to the negative terminal of said source and to said first utilization circuit terminal; second junction transistor means having emitter, base and collector electrodes, said collector and emitter of said second transistor means being respectively connected to said first and second utilization circuit terminals; and alternating rectangular wave control voltage means coupled to base and emitter of each of said transistor means adapted to render said first and second transistor means conducting in alternation.

3. In combination: a voltage source, a two terminal load therefor; first junction transistor means coupling said source to said load through the emitter-collector current conduction path thereof; second junction transistor means connected across the terminals of said load through the emitter-collector current conduction path thereof; and means coupled to said first and second junction transistor means adapted to render said transistor means conducting in alternation.

4. In combination: a voltage source; first and second load terminals; means including first junction transistor means coupling said source to said load through the emitter-collector current conduction path of said first junction transistor means; second junction transistor means coupling said first and second load terminals together through the emitter-collector current conduction path thereof; and alternating control voltage means coupled to the base and an adjacent electrode of each of said transistor means, said alternating control voltage means controlling said first and second transistor means to be driven alternately during each cycle to collector current saturation and cutoff, respectively, and to cutoff and saturation, respectively.

5. In combination: a voltage source; first and second load terminals; means including first junction transistor means coupling said source to said load through the emitter-collector current conduction path of said first junction transistor means, the emitter and collector electrodes thereof being respectively connected to the negative terminal of said source and to said second load terminal; second junction transistor means, the emitter and collector electrodes of which are respectively coupled to said first and second load terminals; and alternating control voltage means coupled to the base and collector of each of said transistor means adapted to cutoff current conduction from emitter to collector of said first transistor on one and its corresponding half cycles and of said second transistor on the other and its corresponding half cycles, and to saturate current conduction through said first transistor means on said other and its corresponding half cycles and through said second transistor on said one and its corresponding half cycles.

6. In combination: a voltage source; first and second junction transistor means each comprising a semiconductive body having first and second zones of one conductivity type separated by an intermediate zone of the opposite conductivity type; first and second load terminals; said first and second zones of said first transistor means being respectively connected to said voltage source and to said first load terminal; said first and second zones of said second transistor means each being respectively connected to a load terminal; and means connected to said intermediate zone and to an adjacent zone of each of said transistor means adapted to render said transistor means conducting in alternation and to cut off the collector current of said transistor means in alternation.

7. In combination: a voltage source; first and second junction transistor means each comprising a semiconductive body having first and second zones of one conductivity type separated by an intermediate zone of the opposite conductivity type; first and second load terminals; said first and second zones of said first transistor means being respectively connected to said voltage source and to said first load terminal; said first and second zones of said second transistor means each being respectively connected to a load terminal; and means coupled to the intermediate electrode and an adjacent electrode of each of said transistor means adapted to drive said transistor means to collector current saturation in alternation and to drive said transistor means to collector current cutoff in alternation.

8. In combination: a voltage source; first and second junction transistor means each comprising a semiconductive body having first and second zones of one conductivity type separated by an intermediate zone of the opposite conductivity type; first and second load terminals; said first and second zones of said first transistor means being respectively connected to said voltage source and to said first load terminal; said first and second zones of said second transistor means each being respectively connected to a load terminal; and means coupled to each of said junction transistor means adapted to drive said transistor means to collector current saturation in alternation and to drive said transistor means to collector current cutoff in alternation, each of said transistor means being successively driven to collector current cutoff and to collector current saturation.

References Cited in the file of this patent

UNITED STATES PATENTS

2,323,966	Artzt	July 13, 1943
2,508,082	Wald	May 16, 1950
2,594,449	Kircher	Apr. 29, 1952
2,614,142	Edson	Oct. 14, 1952
2,643,359	Shenk et al.	June 23, 1953
2,666,819	Raisbeck	Jan. 19, 1954
2,680,160	Yaeger	June 1, 1954
2,693,568	Chase	Nov. 2, 1954
2,695,993	Haynes	Nov. 30, 1954
2,698,392	Herman	Dec. 28, 1954
2,698,416	Sherr	Dec. 28, 1954
2,751,550	Chase	June 19, 1956