A DC-to-DC converter employs four transistor switches in a bridge to chop DC power from a source, and a voltage multiplying diode rectifying ladder network to rectify and filter the chopped DC power for delivery to a load. The bridge switches are cross-coupled in order for diagonally opposite pairs to turn on and off together using RC networks for the cross-coupling to achieve the mode of operation of a free running multivibrator, and the diode rectifying ladder is configured to operate in a push-pull mode driven from opposite sides of the multivibrator outputs of the bridge switches. The four transistor switches provide a square-wave output voltage which has a peak-to-peak amplitude that is twice the input DC voltage, and is thus useful as a DC-to-AC inverter.


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8 Claims, 9 Drawing Figures
FIG. 1

FIG. 2

FIG. 3
POWER CONVERTER

ORIGIN OF INVENTION

The invention described herein was made by an employee of the United States Government and may be manufactured and used by and for the Government for governmental purposes without the payment of any royalties thereon or therefore.

BACKGROUND OF THE INVENTION

This invention relates to power converters, and more particularly to a circuit for efficient use of transistor switches to chop DC power from a source, and a voltage multiplying diode rectifying network to rectify and filter the chopped power delivered to a load.

Photo flash units for camera, geiger ladder networks, and other electronic equipment require a source of high voltage DC current to operate. Since the primary source is often an inexpensive low voltage battery, a step-up DC-to-DC converter is required. Long battery life is usually desirable and therefore a high conversion efficiency is required. This invention meets these requirements.

About one-half of the present integrated circuit equipments require, in addition to a low voltage source (such as +5 VDC), a higher voltage source (such as +10 VDC, -10 VDC, or -15 VDC). This is also true of many of the microprocessors which are currently in popular demand. To supply these higher voltage and mixed power requirements, power supplies using AC inputs with transformer-rectifiers, multi-battery packs, or DC-to-DC converters are available; however, they have undesirable features, such as requiring a source of AC voltage; transformers that are large or heavy; designs that are costly; and/or do not have a high conversion efficiency. There is a need for a step-up DC-to-AC or DC-to-DC converter that is not only efficient and inexpensive, but also light and not bulky, i.e., implemented without a transformer.

One application of particularly high potential use is in the displays for electronic calculators and instrument displays. There are four types of displays currently available: LED (light emitting diode); LCD (liquid crystal display); fluorescent; and neon. To date, the market prefers LEDs and LCDs, although some products, such as pocket calculators and cash registers, are using fluorescent displays which are aesthetically pleasing and brighter than LEDs. LEDs operate on low voltage, but have a high current drain upon the battery and present a rather harsh display. LCDs still have cost, response time, and temperature characteristic problems. And while neon displays have none of these drawbacks, they need a very efficient DC-to-DC step-up converter to operate from a low cost, low voltage battery source because they require 180 VDC starting potential. This invention may supply this need for neon displays. Many fluorescent lighting fixtures also require a source of high voltage for starting current. Cathode ray tubes, television picture tubes, and photo multipliers also require a high voltage, low current source. The list of potential users of this invention is extensive. For example, the invention was first developed and used to supply a 12 volt negative DC source to circuits in a television test signal generator. The invention was next used as a DC-to-AC inverter to power a gyro used on a remotely piloted airplane. Other immediate uses are contemplated wherever conversion of DC power is required, especially for battery operated systems which are weight and size limited and require high conversion efficiency to conserve battery power. Prior state-of-the-art systems tend to be heavier and less efficient than desired for spacecraft and other lightweight applications. Use is also contemplated whenever an efficient DC-to-AC conversion is required such as the gyro application mentioned above, in which case the circuit is often called an inverter.

OBJECTS AND SUMMARY OF THE INVENTION

An object of this invention is to provide a circuit for converting a source of DC power of one voltage to a source of power of another voltage. Another object is to provide such a circuit with high conversion efficiency. Still another object is to provide a converter with a minimum weight.

In summary, these and other objects of the invention are achieved by a self-oscillating, transformerless bridge circuit for chopping DC power from a source and with a peak-to-peak voltage amplitude that is twice the input DC voltage, and where DC-to-DC conversion is desired, a voltage multiplying rectifier and filter for delivery of DC power to a load with a minimum of components. The bridge circuit is comprised of a first pair of transistors of one conductivity type on adjacent sides of the bridge, and a second pair of transistors of opposite conductivity in the remaining sides of the bridge, each transistor being connected as a switch to control the flow of current through a side of the bridge in response to a voltage applied to control terminals thereof. A source of DC voltage is connected to the bridge across junctions where transistors of the same conductivity type are joined, and the control terminals of two joined transistors of opposite conductivity are connected to the junction between the other two transistors of opposite conductivity through an RC timing circuit such that diametrically opposite transistors of opposite conductivity types first conduct for a period determined by the RC timing circuit and then the other diametrically opposite transistors conduct in a free running multivibrator mode. A chopped output is obtained at terminals connected to the bridge at junctions where transistors of opposite conductivity types are joined. This chopped output is applied to a voltage multiplying rectifier and filter comprised of diodes and capacitors connected in a ladder configuration to provide half wave, or full wave rectification, and develop a DC output that is, except for forward diode voltage drops, a multiple of the peak-to-peak chopped output of the bridge, depending upon how many capacitor sections are stacked between the chopped input and DC output. For full wave rectification, two sets of diodes are connected in series between circuit ground and the output. Alternate junctions (odd numbered ones starting at ground) of one set are connected to receive one chopped voltage input through separate capacitors, and the remaining junctions of the one set are connected to receive the other chopped voltage input through separate capacitors. The same is true for the other set of diodes. The capacitors that receive each chopped voltage input are connected to receive the voltage in series or in parallel, or partly in series and in parallel. For a halfwave configuration, one set of series connected diodes is omitted, together with the capacitors that would normally be connected to it.
The novel features of the invention are set forth with particularity in the appended claims. The invention will best be understood from the following description when read in conjunction with the accompanying drawings.

**BRIEF DESCRIPTION OF THE DRAWINGS**

FIG. 1 is a schematic diagram of a free running chopper for inverting DC to AC with a voltage multiplying rectifier and filter of a configuration shown in FIGS. 6, 7, 8 or 9.

FIGS. 2 and 3 illustrate the operation of the free running chopper using idealized switches to represent transistors of the chopper.

FIGS. 4 and 5 illustrate prior-art voltage multiplying rectifiers which may be used in the combination of FIG. 1.

FIG. 6 illustrates a preferred embodiment of a full-wave voltage multiplying rectifier and filter in accordance with one part of the invention for use in the combination of FIG. 1.

FIG. 7 illustrates an alternative configuration for the voltage multiplying rectifier and filter of FIG. 6.

FIG. 8 illustrates an alternative for the embodiment of FIG. 7 useful for half-wave rectification and filtering.

FIG. 9 illustrates an embodiment that is half like that of FIG. 7 and half like that of FIG. 6.

**DESCRIPTION OF PREFERRED EMBODIMENTS**

Referring now to FIG. 1, there is shown a bridge circuit 10 comprised of bipolar power transistors Q1 through Q4. One pair, transistors Q1 and Q4, are of the same conductivity type shown as PNP junction transistors, although a P-channel field effect transistor could be used instead. The other pair, transistors Q2 and Q3, are of opposite conductivity type, namely NPN junction transistors, as shown, or N-channel. The emitters of transistors Q1 and Q4 are connected to a source of DC voltage (+VDC) and the emitters of the transistors Q2 and Q3 are connected to circuit ground (or the negative terminal of the voltage source). The bases (control terminals) of the transistors Q1 and Q2 on one side of the power supply connections are connected to one bridge output terminal B through RC timing circuits and also to each other through a resistor R3 and the bases of the transistors Q2 and Q4 on the other side of the power supply connections are connected to an output terminal A through RC timing circuits and also to each other through a resistor R1. The output terminal B is thus coupled to the bases of the transistors Q1 and Q3 through capacitors C3 and C4. Similarly the output terminal A is coupled to the bases of the transistors Q4 and Q2 through capacitors C1 and C2.

Operation of this configuration of cross-coupled transistors in a bridge circuit 10 is illustrated by FIGS. 2 and 3 in which transistors are represented by ideal switches controlled so that switches labeled S1 first close while those labeled S2 open (FIG. 2) so that output terminal B is at ground potential while the output terminal A is at a high frequency rate. The switches must also be precisely timed to preclude shorting the DC input to ground by switches S1 and S2 closing at the same time. This ideal switching is closely achieved by the invention as shown in FIG. 1. Zero contact resistance in the switching is effectively achieved by virtue of the fact that the only transistors present is the sample, at first turn on, transistors Q1 and Q2 through capacitors C1, C2, C3, and C4.

When the DC source voltage is first applied, electron flow occurs from ground through Q3, R3, and Q1 in series and also through Q2, R1, and Q4 in series. This partially turns on all four transistors, Q1, Q2, Q3, and Q4. This is the first phase of the self starting feature which lasts only a fraction of a second. Next, noise which is always present at a very small amplitude triggers the system into oscillation through the coupling capacitors C1, C2, C3, and C4. For example, at first turn on, transistors Q1, Q2, Q3, and Q4 are all conducting approximately equally and if noise causes Q3 to conduct less, a positive going potential is present on output terminal A is passed through a resistor R3 in series with C3 to the base of Q4 turning Q4 off, and likewise the positive going potential at terminal A is passed through R1 in series with C1 to the base of Q3 turning Q3 off. This causes output terminal B to go more negative turning Q2 off and Q1 on, which further turns Q2 on and Q4 off until the state where both Q1 and Q4 are full off and Q1 and Q2 are full on is rapidly achieved. This state with transistors Q3 and Q4 full on and transistors Q1 and Q3 full off is maintained for a time determined by the RC time constants of the system capacitors such as capacitor C3 and resistor R1 for transistor Q4 while transistor Q3 is on. Thereafter, the state of the switches rapidly reverses. The result is a squarewave output of the desired frequency between output terminals A and B. Resistors R2 and R4 are used to limit base current flowing into or out of transistors Q1, Q2, Q3, and Q4 during the time of switching transition.

The second part of the invention is the voltage multiplying rectifier and filter (hereafter called a "stack"), variations of which are shown in FIGS. 6 through 9. The prior art method is shown in FIG. 4 and also in FIG. 5. A theoretical analysis of this prior art, as written under contract by Stanford University, is contained in a paper by J. S. Brugler, "Theoretical Performance of Voltage Multiplier Circuits," IEEE Journal of Solid State Circuits, June, 1971, pp. 132-135. A less theoretical discussion is contained in an article by Walter Wills, "Get high voltage with low-cost multipliers."
The operation of these new rectifier stacks are under-
"stood by first understanding the operation of the prior
art rectifier stack of FIG. 4. When the input voltage is
positive, a diode I shunts current to ground, but when it
is negative it charges a capacitor C11 negative through
diode 2. Subsequent cycles continue to charge the ca-
capacitor C11 more negative, and while diode 2 is
switched off during a positive half cycle capacitor C12
charges, through a diode 3, and so on, until all of the
capacitors are charged. The input capacitor C10 serves
merely to AC couple the input squarewave voltage, and
the odd numbered capacitors serve merely to bootstrap
the charge up the even numbered capacitors which, be-
cause they are in series, multiply the voltage rectified
by the diodes connected in series between ground and
the output terminal. This is perhaps the simplest ex-
planation that can be given to understand the operation of
this well known halfwave voltage multiplying rectifier
and filter. FIG. 5 shows two rectifier stacks of FIG. 4
back to back sharing four capacitors in common. These
four common capacitors will be found to have a DC
charge only (i.e., constant charge) due to the use of a
second squarewave input and therefore the four capaci-
tors serve no purpose and may be eliminated without
changing the operation of the circuit. Once the four
capacitors are eliminated, it can be seen that alternate
diodes 2 and 4 are redundant and can also be eliminated,
thus, further reducing the parts count and resulting in
one embodiment of the invention shown in FIG. 6. This
and all other embodiments are not limited to the number
of stages shown, but may be used with one or more
stages of any number.

FIG. 6 is a preferred form of the invention, and FIG.
7 is an alternate form of the invention. FIG. 8 is a half-
wave configuration of the invention, and FIG. 9 is a
form that combines the configuration of FIG. 7 with
that of FIG. 6. In these new and improved stacks, the
same reference numerals are being retained as for corre-
ponding elements in the prior art to facilitate under-
standing their organization and operation from the de-
scription of the prior art in FIGS. 4 and 5. Operation of
the elements remaining in the improved stacks is the
same; the improvement is in the elimination of elements
found to be not necessary. The invention in the stacks is
in the reduction of elements or parts which results in
greater conversion efficiency, with the further variation
of inputs A and B being applied directly to the capaci-
tors in series in the configuration FIG. 6 and in parallel
in the configurations of FIGS. 7 and 8, and in series-par-
allel in the combination of those configurations in FIG.
9. Note that in all of these configurations of FIGS. 6, 7,
8 and 9, diodes identified by the reference numeral 6 are
retained at the output for isolation of the last stage. In
the configuration of FIG. 9 there are two stages of the
configuration of FIG. 7 followed by two stages of the
configuration of FIG. 6. In the half-wave configuration
of FIG. 8, half the capacitors and diodes of the configu-
ration of FIG 7 are omitted, and an additional filter
capacitor C8 is added.

Although particular embodiments of the invention
have been described and illustrated herein, it is recog-
nized that modifications and variations may readily
occur to those skilled in the art and consequently, it is
intended that the claims be interpreted to cover such
modifications and equivalents.

What is claimed is:
1. A converter having four transistors interconnected
at four junctions to form a four-sided bridge circuit,
with one transistor on each of the four sides of the
bridge, and means for alternately turning on and off said
transistors in pairs on opposite sides so that an AC volt-
age is obtained from one pair of opposite junctions
while a DC voltage is applied to the remaining pair
ofjunctions, one of said switching devices being of one
conductivity type and the other of said switching devices
in each pair being of opposite conductivity type, with transis-
tors connected to common DC junctions being of the
same conductivity type, said means for alternately turn-
ning on and off said transistors comprising RC timing
circuits cross coupling control terminals of said transis-
tors with control terminals of both transistors in adja-
cent sides of said bridge being AC coupled to an AC
junction on the opposite side of said bridge, each of said
RC timing circuits being comprised of a resistor con-
ected between control terminals of said transistors on
adjacent sides of said bridge, and a capacitor connected
between the AC junction on the opposite side of said
bridge and a junction between said series connected
capacitors, whereby said transistors connected in a
bridge circuit are operated in a free running multivibra-
tor mode for converting said DC voltage to AC volt-
age.
2. A converter as defined in claim 1 including means
connected to said one pair of AC junctions for voltage
multiplying, rectifying and filtering the AC voltage
obtained from said bridge circuit, wherein said voltage
multiplying, rectifying and filtering means is comprised
of a set of diodes connected in series between circuit
ground and a DC output terminal, and a plurality of
 capacitors divided into two sets, one set connected to
alternate junctions between diodes beginning with the
junction of the first diode connected to circuit ground
and the next diode in series, and the other set of capaci-
tors connected to the remaining junctions, said one set
of capacitors being connected to one of said pair of AC
junctions and the other set of capacitors being con-
ected to the other one of said pair of AC junctions.
3. A converter as defined in claim 2 wherein each of
said one set of capacitors is connected directly to said
one of said pair of AC junctions, and each of said other
set of capacitors is connected directly to the other of
said pair of AC junctions.
4. A converter as defined in claim 2 including a sec-
ond set of diodes connected in series between circuit
ground and said DC output terminal and additional
capacitors in said first and second sets of capacitors for
connection to said second set of diodes, and wherein
said additional capacitors divided into two sets are con-
ected to alternate junctions between said second set of
diodes.
5. A converter as defined in claim 4 wherein each of
said one set of capacitors is connected directly to said
one of said pair of AC junctions, and each of said other
set of capacitors is connected directly to said other of
said pair of AC junctions.
6. A converter as defined in claim 4 wherein each of
said one set of capacitors is connected to said one of said
pair of AC junctions in series sequence, and each of said
other set of capacitors is connected to said other of said
pair of AC junctions in series sequence.

7. A converter as defined in claim 4 wherein each of
a portion of each of said one set and said other set of
capacitors is connected directly to said one pair of AC
junctions and each of another portion of said one set and
said other set of capacitors is connected in series se-
quence to said DC output terminal.

8. An oscillator having four transistors intercon-
ected at four junctions to form a four-sided bridge
circuit, with one transistor on each of the four sides of
the bridge, and means for alternately turning on and off
said transistors in pairs on opposite sides so that an AC
voltage is obtained from one pair of opposite junctions
while a DC voltage is applied to the remaining pair of
junctions, one of said switches in each pair being of one
conductivity type and the other of said switches in each
pair being of opposite conductivity type, with transis-
tors connected to DC junctions being of the same con-
ductivity type, said means for alternately turning on and
off said transistors comprising RC timing circuits cross
coupling control terminals of said transistors with con-
trol terminals of both transistors in adjacent sides of said
bridge being coupled to an AC junction on the opposite
side of said bridge, each of said RC timing circuits being
comprised of a resistor connected between control ter-
minals of said transistors on adjacent sides of said
bridge, two capacitors connected in series between
control terminals of said transistors on adjacent sides of
said bridge, and a resistor connected between the AC
junction on the opposite side of said bridge and a junct-
ion between said series connected capacitors, whereby
said transistors connected in a bridge circuit are oper-
ated in a free running multivibrator mode.