Aug. 15, 1967 R. H. RUSSELL 3,336,521

CONVERTER/REGULATOR FEEDBACK REFERENCE

Filed Sept. 9, 1964

FIG. 1. Prior Art

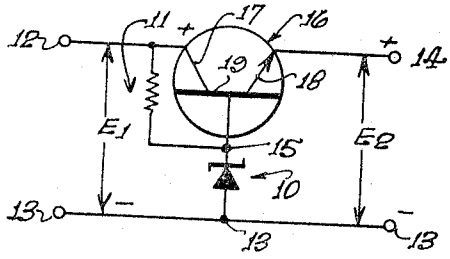


FIG. 2. Prior Art

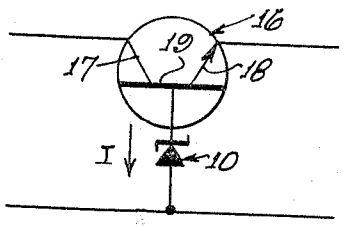


FIG. 3.

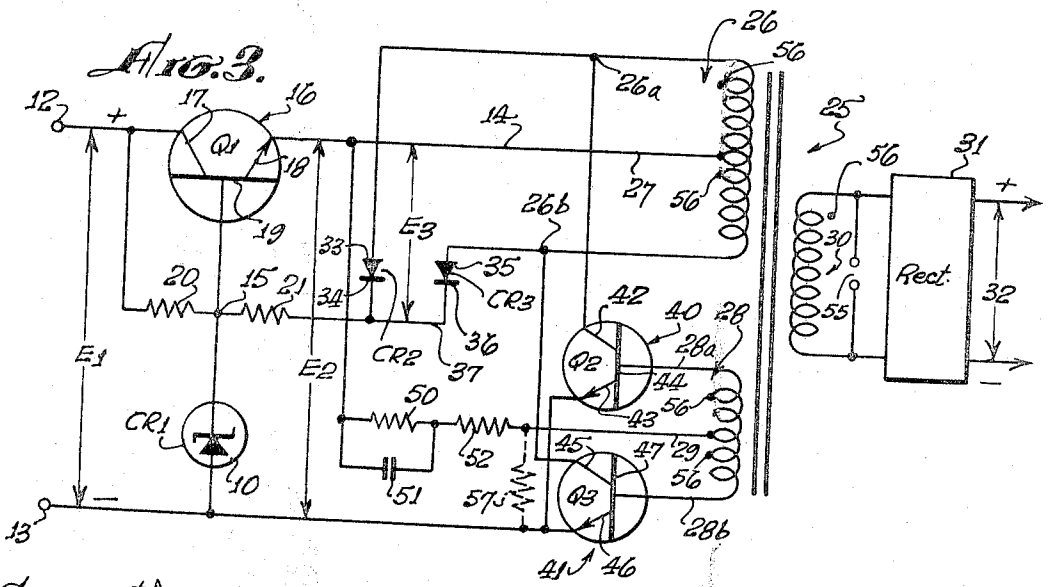
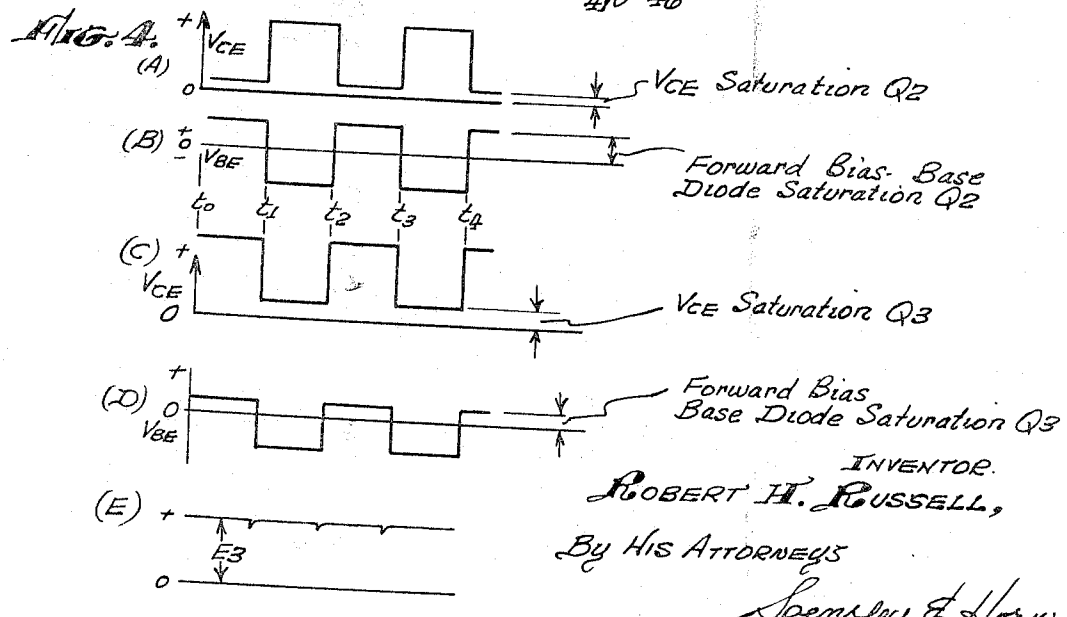


FIG. 4.



INVENTOR.
ROBERT H. RUSSELL,
By His Attorneys
Spensley & Horn

United States Patent Office 3,336,521 Patented Aug. 15, 1967

3,336,521

CONVERTER/REGULATOR FEEDBACK REFERENCE

Robert H. Russell, Altadena, Calif., assignor to Electro-Optical Systems, Inc., Pasadena, Calif., a corporation of California

Filed Sept. 9, 1964, Ser. No. 395,130
6 Claims. (Cl. 321—18)

This invention relates to voltage regulator circuits and more particularly to an improved voltage regulator for direct-current (D-C) to D-C conversion systems which renders the alternating current (A-C) output component of the converter relatively immune to voltage variations of the D-C source over a wide range.

In the prior art, circuits for the regulation of the D-C output of power supply devices have incorporated zener diode reference elements. The current supplied to the zener diode reference element has generally been taken from the source voltage through an appropriate dropping resistor. Since the best use of the zener diode element in regulating action can only be achieved when the current through the zener diode is constant, the prior art circuits are critically dependent on the zener diode, its particular operating point, impedance, and the power handling capability of the dropping resistor. The equivalent resistance of the zener diode is another factor in the regulation capability of the circuit and this is a function of the changes in zener diode voltage with changes in the current supplied to the zener diode from the source. Obviously, source variations will be reflected in the zener current.

So as not to impose severe requirements on the resistance elements through which current is supplied to the zener diode regulator these prior art circuits required somewhat higher zener supply voltages limited by the abovementioned resistance elements and by the power dissipation characteristics of the zener diode element itself.

In some prior art circuits a separate zener diode supply has been provided but these suffer from the same limitations as those in which a common source provides both input or output and zener reference current for the regulator.

Ideally, for good output regulation of a DC supply in the face of input supply voltage variations the current flowing through a zener diode reference in the regulating circuit should be held constant. If either the source or zener supply voltages change, the current through the zener diode cannot be held constant due to the abovementioned characteristics of the zener device where the equivalent resistance changes as a result of changes in current supplied thereto.

This invention contemplates a novel means of supplying a constant current to the zener diode reference element in a D-C voltage regulating circuit which yields a constant voltage from the zener diode which in turn maintains the regulated D-C output voltage constant.

The novel means employed in this invention is to derive the current supply to the reference diode from a high voltage source generated by the regulated output voltage of the regulator system.

By the use of this novel system an improvement of line or output voltage regulation by a factor of 20 is achieved over prior art systems. A further advantage of the novel regulator of this invention is the more efficient use of the input power.

When circuits according to this invention are used in D-C regulators the problems resulting from supply voltage variation are substantially eliminated.

Accordingly, it is an object of this invention to provide

circuit means for D-C regulators which substantially eliminate any variation in the output due to a wide range of variation in the supply voltage applied thereto.

It is a further object of this invention to provide a substantially constant current to a zener reference element in a voltage regulator thereby to insure the constancy of the output voltage thereof.

It is another object of this invention to derive a current for a zener reference diode in a regulator from a regulated high voltage portion of a regulated D-C generated by the circuit thereby to insure a constant current for the zener diode without the attendant limitations on the source of input supply, the diode power dissipation limitations, or variations in diode equivalent resistance usually resulting therefrom.

These and other objects of this invention will become more clear from the specification which follows in which a representative embodiment of the invention is described. The circuit described in the specification is not to be construed as the only means by which the invention may be implemented but it should be understood that variations thereof may occur to those skilled in the arts applying thereto when considered together with the claims and the accompanying figures in which:

FIGURE 1 is a representative illustration of a prior art form of shunt D-C regulator employing a zener diode;

FIGURE 2 is an explanatory detail of the circuit of FIGURE 1 to illustrate a characteristic thereof;

FIGURE 3 is a circuit diagram of a representative embodiment of this invention; and

FIGURE 4 is a chart showing a series of waveforms which explain the operation of the invention.

In the circuit diagram shown in FIGURE 1 there is illustrated a typical series-shunt regulator for a D-C supply employing a zener diode **10**. A resistor **11** in series with zener diode **10** is connected across the D-C source of supply voltage (E1) applied between terminals **12** and **13**. A transistor **16** is connected in series with the D-C supply between input **12** and an output terminal **14**. The collector **17** of transistor **16** is connected to the positive input terminal **12**. The emitter **18** of transistor **16** is connected to the positive output terminal **14**. Zener diode **10** is connected from base **19** of transistor **16** to the common return line **13**. The regulated output voltage E2 appears across terminals **13–14**. The unregulated input voltage E1 is applied at input terminals **12–13**.

Excitation voltage for zener diode **10** is supplied through resistor **11** from source of voltage E1. Obviously any change in the supply voltage at **12–13** will result in a variation in current I, as indicated in FIGURE 2, through zener diode **10** and consequently will result in a variation in the reference voltage at base **19** of transistor **16**.

However, in normal operation zener current supplied through resistor **11** must be from a minimum voltage source at **12–13** somewhat larger than the zener reference voltage. The reference voltage is a characteristic of the particular zener—the voltage which it maintains as a reference. If the source voltage is not enough the current will fall to zero. The maximum voltage that may be supplied is limited by the power dissipation of the zener diode and the resistor **11**. If resistor **11** is designated R_1 the zener current can be defined as

$$I_z=\frac{E_1-E_2}{R_1}$$

The degree of regulation provided by the circuit shown in FIGURE 1 or the usual variations thereof is critically dependent on the impedance of the zener diode and its particular operating point and also on its equivalent resistance which will be due to changes in zener diode volt-

age as the supply voltage (E1) changes, and consequently the current supplied to the zener diode changes.

The circuit diagram of FIGURE 3 shows how the necessary constant current to the zener diode such as **10** can be provided for a zener diode regulator according to this invention as employed in a converter/regulator configuration.

In FIGURE 3 transistor Q1 and zener diode CR1 which correspond generally to the same devices shown in FIGURES 1 and 2 have been given reference characters the same as those in FIGURE 1 so that wherever a relationship or change exists between the invention and prior art this can be clearly seen. As connected in FIGURE 3 transistor Q1 is in an emitter-follower configuration in series with the source voltage E1 applied at **12–13**.

The circuit of FIGURE 3 includes a transformer **25** which has a pair of secondary windings **28** and **30** and a primary winding **26** which serves a dual function. In one phase of its operation winding **26** is for full-wave rectifier diodes designated as CR2 and CR3. In another phase of the operation of winding **26** it acts as the collector winding which in conjunction with base feedback winding (secondary **28**) produces the square wave oscillation by which D-C to D-C or D-C to A-C converter action is achieved with transistors Q2 and Q3.

Referring now to transformer **25**, primary winding **26** has leads **26***a* and **26***b* and a center tap **27**. Lead **26***a* is connected to the anode **33** of diode CR2 and to collector **42** of transistor **40** (Q2). Lead **26***b* is connected to anode **35** of diode CR3 and to collector **45** of transistor **41**(Q3). Center tap **27** is connected to emitter **18** of transistor **16** (Q1).

Secondary winding **28** of transformer **25** has leads **28***a* and **28***b* and a center tap **29**. Lead **28***a* is connected to the base **44** of transistor **40** and lead **28***b* is connected to the base **47** of transistor **41**. The center tap **29** is connected through a resistance and capacitance network **50, 51, 52** further described below to center tap **27** of winding **26** and to emitter **18** of transistor **16**.

The emitters **43** and **46** respectively of transistors **40** and **41** are connected together and to the D-C input return line **13**.

The cathodes **34** and **36** respectively of diodes CR2 and CR3 are connected together by lead **37**.

A resistor **21** is connected from lead **37** to the junction **15** of zener diode **10** and the base **19** of transistor **16**. Another resistor **20** is connected between junction **15** and the high side **12** of D-C input source **12–13**.

The winding **30** of transformer **25** will have an A-C output when the circuit of this invention oscillates in normal operation thereof. The A-C output may be utilized at terminals **55** for application of the circuit as a D-C to A-C converter. The circuit may otherwise be used as a D-C to D-C converter in which case the A-C output of winding **30** is applied to a D-C rectifier circuit of conventional design as indicated by box **31** to provide a D-C output at **32**.

The operation of the circuit of FIGURE 3 may be more clearly understood when taken together with the waveforms shown in FIGURE 4. In FIGURE 4 the waveforms to be anticipated at the collector **42** of transistor Q2 during the oscillation of the circuit are shown at (A); those to be anticipated at the collector **45** of Q3 are shown at (B); those to be found at the base **44** of transistor Q2 are shown at (C); and those to be found at the base **47** of transistor Q3 are shown at (D). At (E) is shown the voltage waveform appearing at the full-wave rectifier output lead **37** where cathodes of diodes CR2 and CR3 join together.

Transformer **25** is a "square core" transformer. That is, it is one which has a hysteresis loop that is essentially rectangular. If at time t_1 transistor Q2 is conducting as indicated at (A) in FIGURE 4, due to the fact that the base-emitter bias as indicated at (B) is positive the supply voltage is almost completely dropped across the section

26*a*–**27** of winding **26**. A linear change of flux occurs in the core of transformer **25**. This induces a voltage in the other windings with negative polarities as indicated by the dots **56** and with a magnitude proportional to the turns ratios one to the other of the respective windings. This biases transistor Q3 *on* because winding **28***b*–**29** is positive and transistor Q3 is rendered conductive by the resulting positive base voltage applied to base **47** and Q2 is turned *off* due to the negative bias applied at base **45** from winding **28***a*–**29**. The turning off of Q2 reverses the direction of flux change and at t_2 causes a return to the starting condition which began at t_0, the cycle repeating continuously.

It should be noted that when transistor Q2 is conducting the collector winding **26***b*–**27** of Q3 has an induced voltage of such polarity that it adds to the supply voltage. Similarly when Q3 is conducting winding **26***a*–**27** has an induced voltage which adds to the supply voltage. Thus twice the supply voltage appears across each transistor Q2 or Q3 during its non-conducting period. Since the supply voltage applied to transformer winding **26** in this instance is E2 then across each winding **26***a*–**27** and **26***b*–**27**, when the respective transistors Q2 and Q3 are not conducting there is a total voltage of approximately $2\times E2$. Thus during the non-conduction of Q2 the voltage $2\times E2$ or (E3) appears on the anode **34** of CR2 and similarly during the non-conduction of Q3 the voltage E3 appears across winding **26***b*–**27** and on the anode **36** of CR3. Therefore at line **37** there is always a voltage E3 equal to substantially twice the regulated supply voltage E2. Through resistor **21** from the voltage E3 the dominant excitation current is supplied to zener diode **10** at junction **15**. A minor current is supplied to zener diode **10** through resistor **20** from the source voltage E1 to start the circuit in operation. Once started the current for zener diode **10** is provided from voltage E3 due to rectification of the collector voltages on collectors **42** and **45** when each is not conducting and the voltages thereon equal E3.

By this technique the current supplied to zener diode **10** (CR1) will be

$$I_z=\frac{E_3-E_z}{R_{21}}$$

Where

I_Z is zener diode current
R_{21} is the resistance of resistor **21**, and
E_Z is the voltage on zener diode CR1.

I_Z is a constant current and therefore yields a constant voltage from the zener diode CR1 which in turn maintains the regulated output voltage E2 a constant value.

Since the current supply to the zener diode CR1 due to the circuit of this invention is now constant the value of resistor **20** may be made approximately 20 times greater than in prior art designs since its only function is for starting the circuit. Thus the increase in the value of resistor **20** (which coresponds to resistor **11** in FIGURE 1) makes the voltage E2 independent of supply voltage E1. In the circuit of FIGURE 1 E2 is not constant for more than a very limited range of variation of E1 with the circuit of this invention an increase of B times in the range of variation of supply voltage it will still provide a regulated output. The only requirement as to supply voltage E1 in the use of the circuit of this invention is that E1 only be sufficiently larger than the zener diode voltage to provide the correct base-collector bias on the series regulator transistor Q1. The maximum voltages of E1 is only limited by the collector base breakdown voltage of series regulator transistor Q1.

Resistor **50** and **52** connected between emitter **18** of series regulator transistor Q1 and the center tap **29** of base winding **28** of transformer **25** are series dropping resistors for providing positive base bias to transistors Q2 and Q3. The sum of the resistances of the two resistors **50** and **52** in series is chosen to limit current consump-

tion in the base-emitter circuit and to give good starting characteristics to the oscillator formed by transistors Q2 and Q3. The addition of capacitor 51 in parallel with resistor 51 improves the switching characteristics of the oscillator. An alternative base biasing technique would be to provide a single resistor in place of resistors 50 and 52 and as shown in dashed line at 57 add a resistance between center tap 29 and the supply voltage return at 13. This forms a bleeder with a tap across the regulated voltage E2. This technique, however, places a constant current drain on the voltage E2 which is uneconomical and, therefore, undesirable. While the circuits shown herein have been illustrated with NPN transistors for Q_1, Q_2, Q_3, PNP transistors may be used as well in which case the polarities of E_1 and of diodes CR2 and CR3 will be reversed. Likewise, the collector and base voltage polarities indicated in FIGURE 4 will be reversed.

There has been described hereinabove a novel regulated power source for a converter of the D-C to D-C or D-C to A-C type in which constant current for a zener diode in the regulator is provided from the rectification of the voltages appearing on the converter oscillator transistor collectors during their nonconducting conditions when the voltages are twice that normally available for such service and thereby eliminate the dependence of the regulated voltage on the supply voltage and reduce the drain on the source for zener voltage and current sources.

What is claimed is:

1. In a voltage regulator wherein a series regulating device is provided in the high potential line of a source of unregulated DC voltage, and a zener diode connected between said series regulating device and the reference potential line of said source to provide said series regulating device with a reference voltage to stabilize operation thereof, a means for providing a constant current excitation potential to said zener diode, comprising:

(a) square wave oscillator means connected between the output of said series regulating device and said reference potential line for energization therefrom; and

(b) full wave rectifier means connected between said square wave oscillator means and the junction of said zener diode and said series regulating device for rectifying the square wave output of said oscillator means to provide a constant direct current to said zener diode.

2. In an apparatus as defined in claim 1, wherein the rectified output of said square wave oscillator means is about twice the voltage appearing between the output of said series regulating device and said reference potential line.

3. In an apparatus as defined in claim 1, wherein said square wave oscillator means includes first and second transistors operated in a switching mode to conduct alternately.

4. In an apparatus as defined in claim 3, further including a transformer having a center-tapped primary winding, the center tap being connected to the output of said series regulating device, one end of the primary winding being connected to the collector of said first transistor, the other end of said primary winding being connected to the collector of said second transistor.

5. In an apparatus as defined in claim 4, wherein said full wave rectifier means comprises first and second diodes, said first diode being connected to the collector of said first transistor, said second diode being connected to the collector of said second transistor, said first diode being poled for conduction when said first transistor is switched off, said second diode being poled for conduction when said second transistor is switched off.

6. In a direct current voltage regulator wherein a series regulating transistor having a collector, a base, and an emitter is provided in the high potential line of a source of unregulated direct current voltage, the collector of said regulating transistor being connected to the high potential end of said source, the emitter of said regulating transistor being the regulated voltage output terminal of said source, and a zener diode reference voltage device connected between said base of said regulating transistor and the reference potential end of said source, a means for providing a constant current excitation potential to said zener diode reference potential device, said means comprising:

a square core transformer having at least a primary winding with a first end lead, a second end lead and a center-tap, and having a base feedback winding;

a pair of switching transistors, each of said transistors having a collector, a base and an emitter;

the collector of one of said switching transistors being connected to said first end lead of said primary winding, the collector of the other of said pair of switching transistors being connected to said second end lead of said primary winding;

the bases of said switching transistors being connected in regenerative relation to said feedback winding, and the emitters of said switching transistors being connected together and to said reference potential end of said source, said center tap of said primary winding being connected to said emitter of said series regulating transistor; and,

a pair of rectifier diodes each respectively having an anode and a cathode, said cathodes being connected together and being coupled through a resistance to the junction of said zener diode reference voltage device and the base of said regulating transistor, the anode of one of said pair of diodes being connected to said first end lead of said primary winding, the anode of the other of said pair of diodes being connected to said second end lead of said primary winding, whereby during the switching operation of said pair of switching transistors when either of said pair of switching transistors is not conducting, said rectifier diode, the anode of which is connected to the same end lead of said primary winding of said transformer as said collector of said nonconducting transistor, conducts the direct current appearing thereon to said junction of said series regulating transistor and said zener diode reference voltage device, thereby performing a full-wave rectification of the alterations in nonconduction of each of said switching transistors, to provide a constant direct current to said zener diode reference voltage device.

References Cited

UNITED STATES PATENTS

3,046,417	7/1962	Garcia	307—88.5
3,103,617	9/1963	Schneider et al.	307—88.5
3,200,327	8/1965	Fleming	323—22

JOHN F. COUCH, *Primary Examiner.*

M. WACHTELL, *Assistant Examiner.*