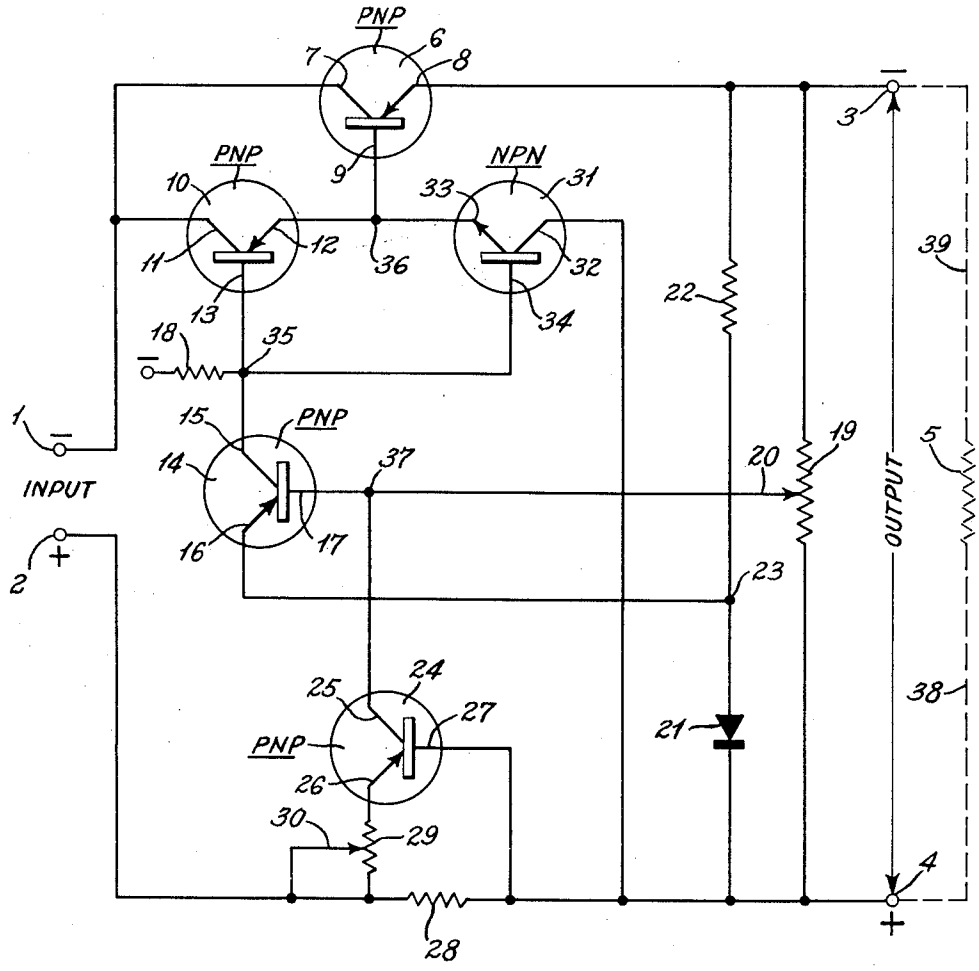
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D.C. VOLTAGE OR CURRENT REGULATOR

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D.C. VOLTAGE OR CURRENT REGULATOR

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This invention relates to transistorized voltage and current regulating systems. In such systems, the voltage across a load, or current through it, is maintained constant by varying the impedance of a transistor in series with the load. Impedance variations are made to respond to load voltage variations in such a sense that they will compensate for the voltage variations.

The input of the regulator is connected to an unregulated D.C. potential source. The output is connected to a load. A PNP regulating transistor is connected with its collector to an input terminal so that its internal impedance from collector to emitter is in series with the load. The internal impedance of the regulating transistor is varied by changing its base voltage.

A voltage divider is placed in parallel with the load to allow a part of the load voltage to be used to vary the regulating transistor impedance. A Zener diode and resistor are also in parallel with the load, providing a reference voltage substantially independent of load circuit variations. A PNP feedback transistor is connected to the voltage divider and Zener diode so that the base voltage relative to the emitter will be the difference between the divider and reference voltages. This is called the control voltage.

The control voltage applied to the base of the feedback transistor appears as an amplified voltage, of opposite phase, at the collector. A PNP control transistor is connected between the feedback transistor and the regulating transistor as an emitter follower to provide current amplification. However, the steady state voltage at the emitter of the control transistor will be substantially equal to the collector voltage in magnitude and phase. Variation in load voltage should therefore result in a variation of the base voltage of the regulating transistor. This base voltage will be opposite in phase to the load voltage variation and will have a magnitude sufficient to change the regulating transistor impedance the amount necessary to counteract the load voltage variation. So far, a standard voltage or current regulator 45 of the "Proceedings of the Institute of Radio Engi- has been described similar to the ones shown in volume neers," for November 1957, at pages 1503 and 1504.

In the regulator described, the time required for a change in the load voltage to be counteracted is retarded by the effect of the collector to emitter capacitance of the regulating transistor and control transistor. For instance, a sudden removal of the load from the regulator causes an increase in input voltage, due to the reduction of current flowing through the potential source's internal resistance. The collector-emitter voltage drop of the regulating transistor must be increased if the output voltage is to be brought back to its correct magnitude. This cannot occur immediately for the collector to emitter capacitance of the regulating transistor prevents any change faster than the time constant of its charging circuit. It cannot charge through the load circuit, for the load has been removed. It must charge through very high resistances in parallel with the output. This

charging will not start however until its base voltage has changed as a result of the control voltage, which will not occur until the collector-emitter capacitance of the control transistor has charged. Thus it is seen that the effect of the collector-emitter capacitances is cumulative. Reducing the charging time of any one of the capacitances will greatly increase the system response time.

A primary object of my invention therefore is to provide novel means that will permit transistor collector-emitter capacitances in a voltage or current regulator to rapidly charge and discharge.

In accordance with the invention this object is achieved by providing a controlled shunting circuit to discharge collector-emitter capacitance.

A further object of the present invention is to provide a novel voltage regulator with extremely close regulation, by virtue of the elimination of certain capacitive effects from the circuit.

Another object is to combine with the invention means to compensate for voltage drops in the lines connecting the output terminals with the load.

Since the voltage across the load is held constant with reference to the fixed drop across the Zener diode, any changes in circuit parameters causing a change in the output, will be compensated for by the regulating action.

Still another object therefore is to provide a regulation system for current or voltage which has a regulated output independent of circuit parameter changes, load variations and input voltages, over a wide range of values.

Other objects of the invention will be pointed out in the following description and claims and illustrated in the accompanying drawings, which disclose, by way of example, the principle of the invention and the best mode which has been contemplated of applying that principle.

In the drawings:

The numerals **1**, **2** denote the potential input terminals of a voltage regulator system arranged in accordance with the invention. The output terminals **3**, **4** are connected by leads **38**, **39** to the load **5**. The terminals **2**, **4** are connected through series resistor **28**, the function of which will be explained later. The terminals **1**, **3** are connected through the emitter-collector circuit of PNP regulating transistor **6**, having a collector **7**, an emitter **8** and a base **9**. The collector **7** is connected to the input terminal **1**, and the emitter **8** is connected to the output terminal **3**. The difference in potential between terminals **1** and **3** is then determined by the internal voltage drop between collector **7** and emitter **8**. This voltage drop is in turn controlled, from one point of view, by the voltage at base **9**. From another point of view, current flow to base **9** controls current flow into emitter **8** and out of collector **7**, and hence current in the load **5**.

Connected to the output terminals **3**, **4** is a tapped resistor **19** having a movable tap **20**. The voltage at the tap **20** relative to terminal **4** is a proportion of the output voltage present at terminals **3**, **4**. Also connected to the output terminals **3**, **4** is a Zener diode **21** and a resistor **22**, connected in series at junction **23**. The Zener diode **21** is operated over a range wherein voltage across the diode remains constant over a large range of current values. It follows then that substantial changes in current, due to output voltage variations, through the series circuit of resistor **22** and Zener diode **21** will not appreciably affect the voltage, with respect to terminal **4**, present at junction **23**.

The tap **20** is connected to the base **17** of a PNP feedback transistor **14**. The junction **23** is connected to the emitter **16**. Feedback transistor **14** acts as an inverter and voltage amplifier. Therefore the collector voltage will be a negative function of the voltage at tap **20** with respect to the reference voltage at junction **23**.

Only one PNP control transistor **10** is shown in the diagram. Its base **13** is connected to the collector **15** of the feedback transistor **14** at junction **35**. However, there may be any number of PNP control transistors with connected collectors, each succeeding one having its emitter connected to the base of the preceding transistor. If control transistor **10** were to represent the first of the control transistors, the others would be connected below it so that instead of base **13** being connected at junction **35**, the base of the last control transistor would be connected there. A bias resistor **18** connects junction **35** to a source of bias potential. The emitter **12** of control transistor **10** is connected to base **9** of regulating transistor **6** at junction **36**, and the collector **11** is joined to the collector **7**. The voltage at junction **35** is, in a steady state condition, applied to junction **36** through the base-emitter path of the control transistor **10**. The voltage at junction **36** is used to change the impedance of regulating transistor **6** an amount necessary to compensate for output voltage variations.

Shunting transistor **31**, of the NPN type, is placed with its collector **32** connected to terminal **4**, emitter **33** connected to junction **36** and base **34** connected to junction **35**.

As an example of the operation of the regulator, if the load **5** is removed from terminals **3**, **4**, the input potential at terminal **1** will start to become more negative. This occurs because the reduction in current being drawn from the potential source reduces the voltage drop inside the potential source due to its internal impedance. As the potential at the collector **7** of the regulating transistor **6** becomes more negative, so does the potential at the emitter **8**, which is connected to the output terminal **3**. The collector-emitter voltage drops of the regulating transistor **6** and the control transistor **10** must increase in a positive direction, if the increasingly negative input voltage is to be counteracted. The inertial tendency of the collector-emitter capacitances hinder such a change. The collector-emitter capacitance of the regulating transistor **6** will charge only as determined by the voltage at junction **36**, relative to terminal **1**. The voltage at junction **36** will not normally follow the positive increase at junction **35** immediately because the collector-emitter capacitance of control transistor **10** must charge slowly through the very high resistance of resistor **19**, by way of the base-emitter path of regulating transistor **6**. The addition of the shunt transistor **31** provides a low resistance path from junction **36** to the positive input terminal **2** for as long as junction **36** is less positive than junction **35**. Once the collector-emitter capacitance of control transistor **10** has begun charging to the potential of junction **35** relative to terminal **1**, the collector-emitter capacitance of regulating transistor **6** will have begun charging toward the same charge. This charge results in the required voltage drop.

A portion of the negatively changing output voltage is fed back by means of tapped resistor **19** and feedback transistor **14** to junction **35** as an increasingly positive voltage. PNP control transistor **10** has normally been held conductive, and NPN shunting transistor **31** has normally been held non-conductive, by the negative bias at junction **35**. But, as feedback transistor **14** drives junction **35** positive, these conditions will reverse. As shunting transistor **31** conducts it provides a path through its emitter **33** and collector **32** to charge the collector-emitter capacitance of control transistor **10**. This continues until junction **36** is so positive that control transistor **10** will again conduct and shunting transistor **31** stops conducting.

Simultaneously, while junction **36** has been approaching the positive potential of junction **35**, the collector-emitter capacitance of regulating transistor **6** has begun charging.

It is therefore easily seen how the shunting transistor acts, upon removal of the load, to permit rapid charging of the collector-emitter capacitances. Ordinarily the charging path would be such as to require a much longer time for the collector-emitter voltage drops to reach the value required to compensate for the increased input voltage.

The emitter **26** of a PNP compensating transistor **24** is connected to one end of variable resistor **29** which has a movable tap **30**. The other end of variable resistor **29** and tap **30** are connected to input terminal **2**. Base **27** is connected to terminal **4**. The base-emitter voltage of the compensating transistor **24** will be a function of the voltage drop across resistor **28** in series with the load **5**. Variations in load current will therefore cause changes in the voltage applied by collector **25** to junction **37** of a magnitude determined by variable resistor **29**. Proper adjustment of resistor **29** will result in a condition wherein a change in voltage at junction **37** due to current dependent voltage drops in lines **38**, **39** to load **5** will be exactly balanced by an opposite voltage change through the action of compensating transistor **24**.

While the described embodiment of the invention employs several PNP transistors and only one NPN transistors, transistors of opposite conductivity may be substituted upon reversal of appropriate voltages and polarities.

While there have been shown and described and pointed out the fundamental novel features of the invention as applied to the preferred embodiment, it will be understood that various omissions and substitutions and changes in the form and details of the device illustrated and in its operation may be made by those skilled in the art without departing from the spirit of the invention. It is the intention, therefore, to be limited only as indicated by the scope of the following claims.

What is claimed is:

1. In a voltage or current regulator, a pair of input terminals for connection to a potential source, a pair of output terminals for connection to a load, a first of each pair of said input and output terminals being connected, a regulating transistor having a collector, an emitter and a base, means for supplying current from the source to the load through the collector-emitter path of the regulating transistor, a series circuit path, comprising a Zener diode and a first resistor connected across the output terminals, a second resistor, having a center-tap, connected across the output terminals, a feedback transistor having a collector, an emitter and a base, the base of the feedback transistor being connected to the center-tap of the second resistor, the emitter of the feedback transistor being connected to the junction formed by said Zener diode and the first resistor, a control transistor having a collector, an emitter and a base, the collector of the control transistor being connected to the collector of the regulating transistor, the emitter of the control transistor being connected to the base of the regulating transistor, the base of the control transistor being connected to the collector of the feedback transistor, biasing means connected to the collector of the feedback transistor, a shunting transistor, of a type complementary to the control transistor, having a collector, an emitter and a base, said shunting transistor being so connected in said regulator circuit that when the collector potential of the feedback transistor passes a critical point determined by the biasing means the base of the regulating transistor will be shunted to the first of the input terminals through the collector-emitter path of the shunting transistor.

2. In a voltage or current regulator, a pair of input terminals for connection to a potential source, a pair of output terminals for connection to a load, a series resistor, a first of each pair of said input and output terminals being connected through the series resistor, a regulating transistor having a collector, an emitter and a base, means for supplying current from the source to the load through the collector-emitter path of the regulating transistor, a series circuit path, comprising a Zener diode and a first resistor connected across the output terminals,

a second resistor having a center-tap, connected to respective ones of the output terminals, a feedback transistor having a collector, an emitter and a base, the base of the feedback transistor being connected to the center-tap of the second resistor, the emitter of the feedback transistor being connected to the junction formed by the Zener diode and the first resistor, a control transistor having a collector, an emitter and a base, the collector of the control transistor being connected to the collector of the regulating transistor, the emitter of the control transistor being connected to the base of the regulating transistor, the base of the control transistor being connected to the collector of the feedback transistor, biasing means connected to the collector of the feedback transistor, a shunting transistor, of a type complementary to the control transistor having a collector, an emitter and a base, said shunting transistor being so arranged that when the collector potential of the feedback transistor passes a critical point determined by the biasing means the base of the regulating transistor will be shunted to the first of the input terminals through the collector-emitter path of the shunting transistor, a compensating transistor having a collector, an emitter and a base, a variable resistor, the emitter of the compensating transistor being connected to the first input terminal on one side of said series resistor through the variable resistor, the base of the compensating transistor being connected to the first output terminal on the other side of said series resistor, the collector of the compensating transistor being connected to the base of the feedback transistor.

3. In a voltage or current regulator with a potential source for supplying current to a load circuit including a load, a plurality of transistors including a first and a last, each of the transistors having a collector, an emitter and a base, means for supplying current from the source to the load through the collector-emitter path of the first transistor, feedback means for deriving from the load circuit and impressing upon the base with respect to the emitter of the last transistor a control voltage, control means comprising a control transistor connected as an emitter follower to provide current amplification from the collector of the last transistor to the base of the first transistor, biasing means connected to the collector of the last transistor, a shunting transistor, of a type complementary to the control transistor having a collector, an emitter and a base, said shunting transistor being so connected in said regulator circuit that when the collector potential of the last transistor passes a critical point determined by the biasing means the base of the first transistor will be shunted through the collector-emitter path of the shunting transistor, to the source without passing through the load.

4. In a voltage or current regulator with a potential source relative to a reference point for supplying current to a load circuit including a load, a plurality of transistors including a first and a last, each of the transistors having a collector, an emitter and a base, means for supplying current from the source to the load through the collector-emitter path of the first transistor, feedback means for deriving from the load circuit and impressing upon the base with respect to the emitter of the last transistor a control voltage, control means comprising a control transistor connected as an emitter follower to provide current amplification from the collector of the last transistor to the base of the first transistor, biasing means connected to the collector of the last transistor, a shunting transistor having a collector, an emitter and a base, the emitter of the shunting transistor being connected to the base of the first transistor, the collector of the shunting transistor being connected to the reference point, the base of the shunting transistor being connected to the collector of the last transistor.

5. In a voltage or current regulator with a potential source for supplying current to a load circuit including a load, a plurality of transistors including a first and a last, each of the transistors having a collector, an emitter and a base, means for supplying current from the source to the load through the collector-emitter path of the first transistor, feedback means for deriving from the load circuit and impressing upon the base with respect to the emitter of the last transistor a control voltage, control means comprising a control transistor connected as an emitter follower to provide current amplification from the collector of the last transistor to the base of the first transistor, biasing means connected to the collector of the last transistor, shunting transistor means connected in said regulator circuit and operable to remove capacitive potential from between the collector and emitter of said control transistor.

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UNITED STATES PATENT OFFICE

CERTIFICATION OF CORRECTION

Patent No. 2,974,270 March 7, 1961

Richard A. Christiansen

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 1, line 54, strike out "45 of the "Proceedings of the Institute of Radio Engi-" and insert the same after "in volume" in line 55, same column.

Signed and sealed this 25th day of July 1961.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

DAVID L. LADD
Commissioner of Patents

UNITED STATES PATENT OFFICE
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