United States Patent

[11] **3,547,127**

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[54] CARDIAC PACEMAKER WITH REGULATED POWER SUPPLY

3 Claims, 1 Drawing Fig.

[52] **U.S. Cl.** **128/421;** 320/39; 323/66
[51] **Int. Cl.** **A61n 1/36**
[50] **Field of Search** .... 128/419(P Digest), 419–422; 523/65, 66, 68; 320/39

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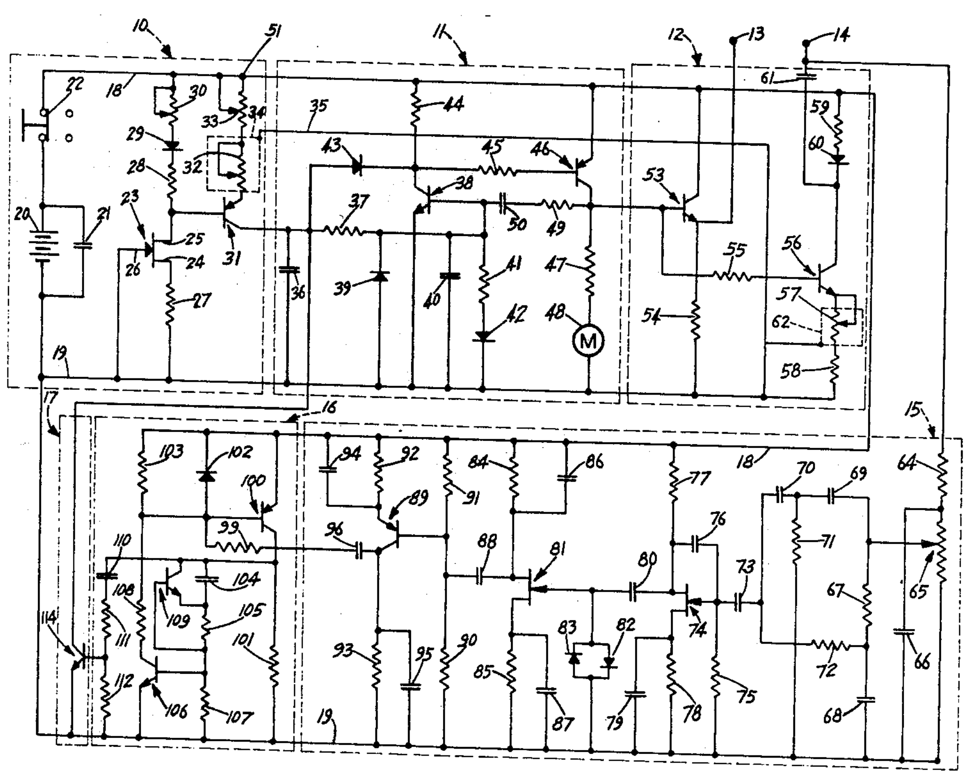
ABSTRACT: A cardiac pacer, which may be a demand pacer, with a calibrated stimulating pulse rate which is preferably adjustable. The pacer utilizes a low current drain, regulated power supply which provides a current into a timing circuit, the current being substantially independent of supply voltage over a large range of supply voltage variations.

The regulated power supply includes a series circuit containing a source of voltage, a field effect device for producing a constant current, and an impedance for providing a substantially constant voltage across it when a substantially constant current is applied to it. A transistor is connected across the constant voltage producing impedance so that it exhibits a high input impedance and provides a current, in its collector circuit, which varies substantially independently of the source voltage. In the preferred form, a variable resistor in the transistor emitter circuit makes the magnitude of the collector current adjustable over a predetermined range.



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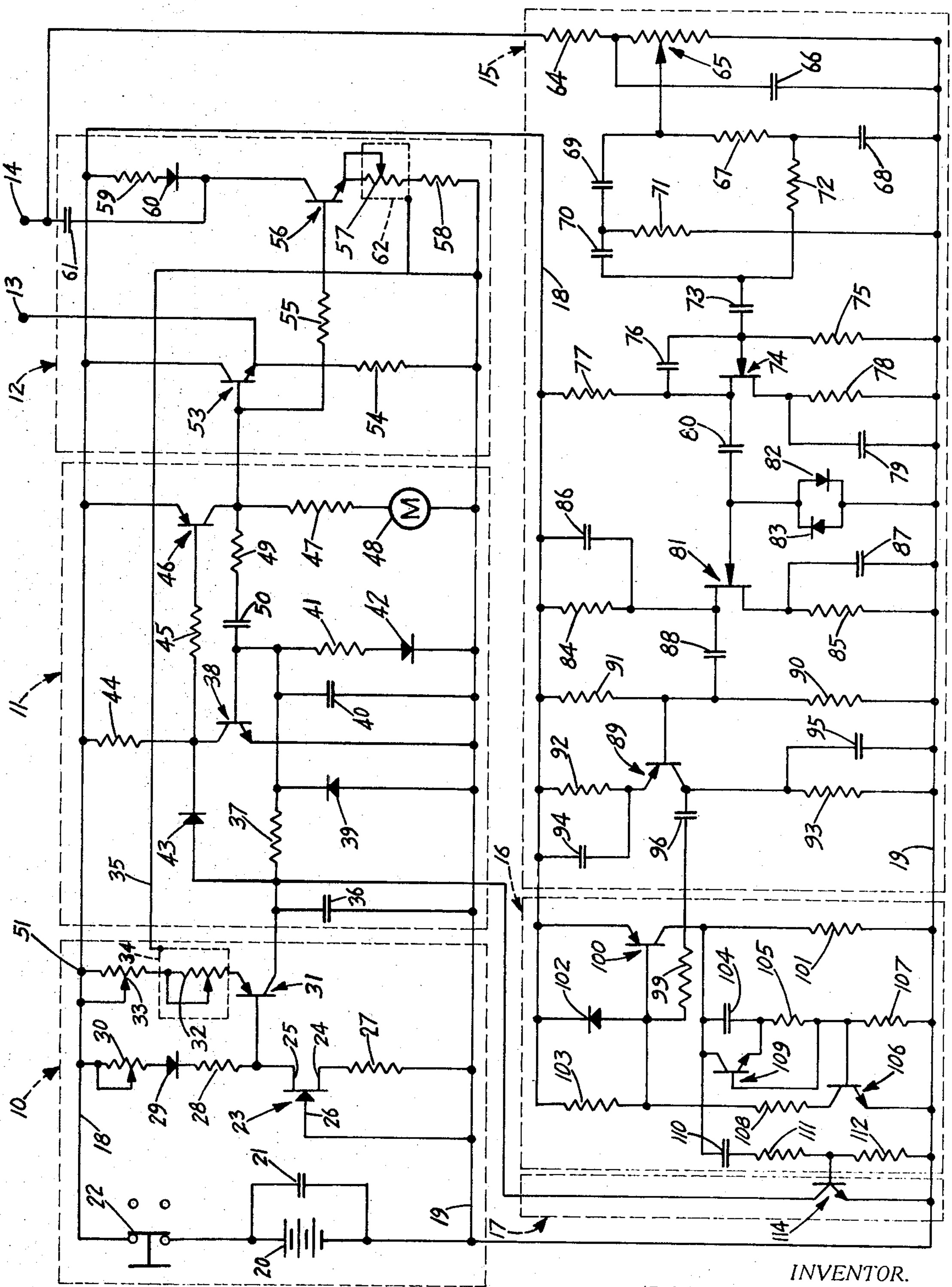

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CARDIAC PACEMAKER WITH REGULATED POWER SUPPLY

BACKGROUND OF THE INVENTION

This invention relates to electronic circuits, and more particularly to cardiac pacer circuits adapted to supply heart stimulating pulses to a patient on demand.

Cardiac pacers are well known, as are demand pacers which supply heart stimulating pulses only when the patient's heart skips one or more beats. Such demand pacers are often designed to respond to the R-wave produced by the patient's heart. Prior art pacers have been subject to the disadvantage, however, that the timing between pulses is dependent upon the supply voltage. That disadvantage is not great if the pacer is adapted to be powered from line current, but such devices are not portable with a mobile patient.

Portable pacer units should be usable over an extended period of time, preferably several years, without replacement of the batteries. For that reason, most portable pacers, both external and implantable, have been designed for low power drain. Even those devices were not completely acceptable because their pulse rate gradually changes as battery voltage deteriorates. An additional problem was created when it was desired to make an adjustable rate device with a rate calibration. As the battery voltage dropped due to continued use, the calibration, if in number of beats per minute, becomes erroneous. Zener diodes are often utilized to regulate supply voltage. However, those devices are not usable in low power drain pacers. Zener diodes draw a current which is at least an order of magnitude greater than the entire current drain desired in a portable battery powered pacer.

Field effect devices have also been used to provide a constant current source which is relatively independent of variations in the supply voltage. The difficulty with using such devices is that the actual current obtainable with the same gate bias varies as much as 20 percent from device to device. Thus, when it is desired to make a constant current of controlable magnitude, it is difficult, if not impossible, to obtain accurate variable resistors capable 1 controlling the current, which may vary as much as 20 20 from one device to the next, within a specified range for all the pacers.

SUMMARY OF THE INVENTION

This invention is intended to overcome the aforementioned difficulties of prior art devices. The invention provides a low power drain pacer having a regulated power supply which drives a pulse generator at a rate which is substantially independent of the supply voltage over a wide range of such voltages. The power supply preferably includes a rate control, calibrated in beats per minute, which changes less than 1 percent even though supply voltage decreases by as much as 20 percent.

The invention provides a regulated power supply including a series circuit including a source of voltage, means for providing a substantially constant current independent of relatively wide variations in voltage thereacross, and a means for providing a substantially constant voltage when a substantially constant current is applied to it. The power supply further includes current control means having a high input impedance and providing an output current which is substantially independent of source voltage variations when a relatively constant voltage is connected between the input terminals. The constant voltage means is connected between the input terminals of the current control means. In the preferred structure, the current control means includes means for varying the output current.

The invention further provides a cardiac pacer having a regulated power supply, above described, connected to provide a current into the timing circuit of a pulse generator. The pacer also has electrodes for applying pulses from the pulse generator to the patient's heart. The pacer is preferably a demand device which also includes circuitry for sensing natural heartbeats intervening between pulses and for resetting the pulse generator timer to fire the next pulse the normal interval after the natural heartbeat. The pulse generator of such a device is set to 20 at a slightly slower rate than the natural heartbeat rate. Therefore, the demand pacer is continually reset and provides no pulse output so long as the heart beats naturally. Should the heart skip a beat, however, the pacer inserts that beat in the normal sequence. As long as the heart fails to provide natural beats in the normal sequence, the demand pacer stimulates beats at the pacer rate. The preferred form of the invention provides an adjustable rate, calibrated in beats per minute in which the rate is substantially unaffected by supply voltage variations of as much as 20 percent or by the stimulated heartbeat which immediately follows each pacer pulse.

BRIEF DESCRIPTION OF THE DRAWING

The single FIG. is a schematic circuit diagram of a cardiac demand pacer utilizing the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The single FIG. discloses a cardiac demand pacer including a regulated power supply **10** which provides power for a pulse generator **11**. Pulses from generator **11** are fed to a voltage increasing circuit **12** which applies an increases output voltage across a pair of electrodes **13** and **14**. Electrodes **13** and **14** are adapted to contact a patient so as to deliver heart stimulating pulses to the cardiac tissue. One or more of electrodes **13** and **14** may be designed to come directly in contact with cardiac tissue. The demand portion of the pacer includes an R-wave amplifier **15** which is connected to receive and amplify R-wave signals from electrodes **13** and **14** and to produce a signal output for a sensed R-wave of either polarity. The output signal from amplifier **15** is coupled to a refractory circuit **16** which is designed to receive a signal from amplifier **15**, activate a reset mechanism **17**, and prevent further signals received from amplifier **15** within a predetermined time period from reactivating reset mechanism **17**. Thus, refractory circuit **16** makes reset mechanism **17** insensitive to signals sensed by amplifier **15** within a predetermined time interval after a first signal is sensed. Reset mechanism **17** is connected to reset a timing mechanism within pulse generator **11** to a predetermined level in synchronism with the signal from amplifier **15**. Thus, the demand pacer provides a stimulating pulse if, and only if, a natural heartbeat does not occur within a predetermined time after the last reset signal, whether that signal was caused by a pacer pulse or by a prior natural heartbeat.

Power supply **10** includes a source of voltage, here shown as a battery **20**, with a capacitor **21** connected between the positive and negative terminals. Capacitor **21** extends battery life by reducing the effects of high current drain during the pacer pulse. The positive terminal of battery **20** is connected to a supply voltage conductor **18** through a pushbutton, on-off switch **22**. The negative terminal of battery **20** is connected to a ground conductor **19**. A device which provides a substantially constant current independent of relatively wide variations in the voltage across it, here shown as a field effect device **23** having a source electrode **24**, a drain electrode **25**, and a gate electrode **26** is provided with a resistor **27** connected between source electrode **24** and ground line **19**. Gate electrode **26** is directly connected to ground line **19**. Connected in series with the source-drain circuit of field effect device **23** is means for providing a substantially constant voltage when a substantially constant current is applied to it. That means, as here shown, includes a resistor **28** and a variable resistor **30**. One end of resistor **28** is connected to drain electrode **25** and the other end is connected to the cathode of a temperature compensating diode **29**. The anode of diode **29** is connected to one end of resistor **30** and the other end of resistor **30**, and the wiper thereof, are connected to supply voltage conductor **18**.

Power supply 10 also includes a current control means having a pair of input terminals and a pair of output terminals, exhibiting high impedance between the input terminals and providing a current between the output terminals which varies substantially independently of source voltage variations when a relatively constant voltage is applied across the input terminals, here shown as a transistor 31 and variable resistors 32 and 33. One of the input terminals of the current control means is preferably common with one of its output terminals as shown at junction 51. The base of transistor 31 is the other input terminal, and the collector of transistor then is the other output terminal. Transistor 31 has its base electrode connected to drain electrode 25 and its emitter electrode connected to one end of variable resistor 32. Variable resistor 32 has its opposite end connected to one end of a second variable resistor 33 which has its opposite end and wiper connected to supply voltage conductor 18 at junction 51. Regulated power supply 10 provides, at the collector of transistor 31, a current whose magnitude is controllable by varying the impedance of resistor 32. Resistor 32 is protected from extraneous magnetic fields by a shielding 34 connected to a conductor 35 which, in turn, is directly connected to ground conductor 19.

Proceeding now to pulse generator 11, the collector of transistor 31 is connected to one plate of a timing capacitor 36 whose opposite plate is connected to ground conductor 19. The collector of transistor 31 is also connected to one end of a resistor 37 whose opposite end is connected to the base of a transistor 38. The opposite end of resistor 37 is also connected to the cathode of a diode 39, whose anode is connected to ground conductor 19. A high frequency bypass capacitor 40 is connected between the base of transistor 38 and ground conductor 19. The base of transistor 38 is connected to ground conductor 19 through a resistor 41 and a temperature compensating diode 42. A diode 43 has its anode connected to the collector of transistor 31 and its cathode connected to the collector of transistor 38. A current limiting resistor 44 connects supply voltage conductor 18 to the collector of transistor 38.

The collector of transistor 38 is connected through a resistor 45 to the base of a transistor 46. The emitter of transistor 46 is directly connected to supply voltage conductor 18. The collector of transistor 46 is connected through a load resistor 47 and a meter 48 to ground conductor 19. The collector of transistor 46 is also connected through a resistor 49 and a capacitor 50 to the base of transistor 38. The output of pulse generator 11 appears at the collector of transistor 46.

In voltage increasing circuit 12, the collector of transistor 46 is directly connected to the base of a transistor 53. The collector of transistor 53 is directly connected to supply voltage conductor 18 and its emitter is connected through a current limiting resistor 54 to ground conductor 19. The emitter of transistor 53 is also connected directly to electrode 13. The base of transistor 53 is connected through a resistor 55 to the base of a transistor 56. The emitter of transistor 56 is connected through a variable resistor 57 and a resistor 58 to ground conductor 19. Supply voltage conductor 18 is connected through a resistor 59 and a diode 60 to the collector of transistor 56. The collector of transistor 56 is further connected to one plate of an output capacitor 61 whose opposite plate is connected to electrode 14. An interference shield 62 is disposed about variable resistor 57 to screen out unwanted external fields. Shield 62 is connected to conductor 35.

In R-wave amplifier 15, electrode 14 is connected to ground through a variable voltage divider which includes a resistor 64 and a resistor 65 which carries a movable wiper. A high frequency bypass capacitor 66 is connected between resistor 64 and ground conductor 19. The wiper on resistor 65 has its free end connected to one end of a resistor 67. The opposite end of resistor 67 is connected through a capacitor 68 to ground conductor 19. The wiper of resistor 65 is also connected to one plate of a capacitor 69 whose opposite plate is connected to one plate of the capacitor 70. A resistor 71 is connected from a point intermediate capacitors 69 and 70 to intermediate resistor 67 and capacitor 68 to the opposite plate of capacitor 70.

The opposite plate of capacitor 70 is also connected to one plate of a low frequency shaping capacitor 73, whose opposite plate is connected to the gate electrode of a field effect device 74. The gate electrode of field effect device 74 is connected through a biasing resistor 75 to ground conductor 19 and is also connected to the drain electrode of field effect device 74 through a high frequency rolloff capacitor 76. A resistor 77 is connected between supply voltage conductor 18 and the drain electrode of field effect device 74. A resistor 78 is connected between the source electrode of field effect device 74 and ground conductor 19. A low frequency shaping capacitor 79 is also connected between the source electrode of field effect device 74 and ground conductor 19.

A low frequency shaping capacitor 80 is connected between the drain electrode of field effect device 74 and the gate electrode of a field effect device 81. A pair of opposed diodes 82 and 83 are connected in parallel between the gate electrode of field effect device 81 and ground conductor 19. A resistor 84 and a high frequency rolloff capacitor 86 are connected in parallel between supply voltage conductor 18 and the drain electrode of field effect device 81. A resistor 85 and a low frequency shaping capacitor 87 are connected in parallel between the source electrode of field effect device 81 and ground conductor 19.

A low frequency shaping capacitor 88 is connected between the drain electrode of field effect device 81 and a base electrode of a transistor 89. A biasing resistor 90 is connected between the base of transistor 89 and ground conductor 19. Another biasing resistor 91 is connected between supply voltage conductor 18 and the base of transistor 89. The emitter of transistor 89 is connected through the parallel combination of a resistor 92 and a capacitor 94 to supply voltage conductor 18. The collector of transistor 89 is connected through the parallel combination of a capacitor 95 and a resistor 93 to ground conductor 19.

The collector of transistor 89 is also connected to one plate of a low frequency shaping capacitor 96.

In the refractory circuit, the other plate of capacitor 96 is connected through a resistor 99 to the base of a transistor 100. The emitter of transistor 100 is directly connected to supply voltage conductor 18. The collector of transistor 100 is connected through a current limiting resistor 101 to ground conductor 19. A diode 102 has its cathode connected to supply voltage conductor 18 and its anode connected to the base of transistor 100. The base of transistor 100 is also connected to supply voltage conductor 18 through a resistor 103.

The collector of transistor 100 is also connected through a capacitor 104 and a resistor 105 to the base of transistor 106. The base of transistor 106 is connected through a biasing resistor 107 to ground conductor 19. The collector of transistor 106 is connected to the base of transistor 100 through a resistor 108. The emitter of transistor 106 is directly connected to ground conductor 19. A transistor 109 has its collector and emitter connected across the plates of capacitor 104 and its base connected to the base of transistor 106.

The collector of transistor 100 is also connected through a capacitor 110, a resistor 111, and a resistor 112 to ground conductor 19. The output from refractory circuit 16 is taken from a point intermediate resistors 111 and 112.

Reset circuit 17 comprises a reset transistor 114 which has its base connected to a point intermediate resistors 111 and 112. The emitter of transistor 114 is directly connected to ground conductor 19 and its collector is connected to the collector of transistor 31.

OPERATION

When switch 22 is closed, a circuit is completed from the positive terminal of battery 20 through resistor 30, diode 29, resistor 28, the drain-source circuit of field effect device 23 field effect device **23** is connected in the manner shown, the source-drain current is substantially independent of the source-drain voltage over a wide range of voltages. However, the particular current value obtainable in the source-drain circuit varies greatly from device to device. For that reason, either resistor **27** or resistor **28** can be chose as a "select" resistor which is experimentally chosen in each circuit to provide a source-drain current of a predetermined level. Final trim of the current through the circuit is done by adjustment of trim resistor **30**. Diode **29**, while desirable when the pacer is to be used over a relatively wide range of ambient temperatures, is not required. Diode **29** provides temperature compensation for the variation in emitter junction characteristics of transistor **31** with temperature variation. Since a predetermined magnitude constant current flows through the source-drain circuit of field effect device **23**, the voltage across resistor **30**, diode **29** and resistor **28** is constant so long as substantially all of the field effect device **23** source-drain current, and no other, flows through those components. A high input impedance device is presented between the base of transistor **31** and junction **51** so no appreciable current flows into field effect device **23** from that circuit branch. The base bias on transistor **31** is therefore constant regardless of supply voltage variations, and its collector current is controlled by the resistance in the emitter circuit. The magnitude of the current in the collector circuit of transistor **31** is controlled externally by variable resistor **32** whose wiper is connected to a dial on the case of the cardiac pacer. That dial is calibrated in beats per minute in ranges from about 50 beats per minute to about 150 beats per minute. Variable resistor **33** is used for final trim to calibrate the unit before it is put into use.

Current flowing from the collector of transistor **31** into pulse generator **11** charges timing capacitor **36** to provide the timing between pulses. Resistor **37** is a high valued resistor which allows little current to leak from capacitor **36** during the charging cycle. After a predetermined charge time, the voltage across resistor **41** becomes large enough to forward bias the base of transistor **38**. When transistor **38** starts to turn on, its collector potential falls toward ground, causing base current to flow through transistor **46** and resistor **45**, turning on transistor **46**. Turn on of transistor **46** brings its collector nearly to supply voltage and supplies base current for transistor **38** holding it on. Turn on of transistor **38** allows capacitor **36** to dump quickly through diode **43** and the collector emitter circuit of transistor **38**. As soon as capacitor **50** becomes fully charged, base current is cut off in transistor **38** and it turns off, thereby turning off transistor **46**. When transistors **38** and **46** turn off, capacitor **50** discharges through resistor **49**, resistor **47**, meter **48** and diode **39**. Capacitor **36** is then ready to begin timing for the next pulse. That timing begins immediately and proceeds uninterrupted in a nondemand unit, but is interrupted and reset in a demand unit as will be explained below. Diode **42** provides temperature compensation for the emitter base junction of transistor **38**.

The output of pulse generator **11** is taken at the collector of transistor **46**. A positive pulse is generated at this point by turnon and turnoff of transistor **46**. The interval between pulses is determined by the magnitude of the current flowing in the collector circuit of transistor **31** and the size of timing capacitor **36**. The pulse width is determined by the magnitudes of resistor **49** and capacitor **50**. A visual indication of the generation of pulses is obtained from observation of meter **48**.

In portable cardiac pacers, it is highly desirable to apply a pulse to the cardiac tissue which is substantially in excess of the supply voltage, which is often about 10 volts. For this reason, pulses from pulse generator **11** are fed into a voltage increasing circuit **12** which is capable of producing pulses with nearly double the supply voltage. Immediately prior to a pulse from pulse generator **11**, capacitor **61** is fully charged from positive supply conductor **18** so that approximately 10 volts appears across its plates. Electrodes **13** and **14** are both at ground potential. Appearance of the positive going pulse at the collector of transistor **46** drives transistor **53** into saturation and raises electrode **13** to nearly supply voltage, approximately +10 volts. Resistor **58** is a small valued resistor and resistors **57** and **59** are of approximately equal values when the entire length of resistor **57** is in circuit with the emitter of transistor **56**. The positive going pulse also is transmitted through resistor **55** and turns on transistor **56** which brings the collector of transistor **56** rapidly toward ground potential (when resistor **57** is bypassed by its wiper). Since the voltage across capacitor **61** cannot change instantaneously, electrode **14** immediately falls to a level of almost supply voltage below ground potential. Therefore, the potential difference between electrodes **13** and **14** is approximately twice the supply voltage during a pulse.

Variable resistor **57** provides control of the current flowing between electrodes **13** and **14** during the pacer pulse. The wiper of resistor **57** is attached to an external control knob which is calibrated in milliamperes. As can readily be seen, as more resistance is inserted in the emitter circuit of transistor **56**, its collector-emitter current is reduced and the voltage difference between electrodes **13** and **14** is likewise reduced because the collector of transistor **56** falls to a point intermediate between supply voltage and ground.

During the pacer pulse, capacitor **61** discharges through the collector-emitter circuit of transistor **56**, resistor **57**, resistor **58**, resistor **54**, electrode **13**, the patient's body, and electrode **14**. Upon termination of the positive pulse from the collector of transistor **46**, transistors **53** and **56** turnoff and capacitor **61** begins charging again from supply voltage conductor **18**. When capacitor **61** is again fully charged, electrodes **13** and **14** are both at ground potential. It can also be seen that use of capacitor **61** in the output circuit provides a bidirectional current flow between electrodes **13** and **14** which is considered advantageous.

The portion of the pacer apparatus described above will, if used without the remainder of the circuitry, provide free running pulses at a rate chosen by positioning of the wiper on variable resistor **32** and having a magnitude chosen by positioning of the wiper on resistor **57**. The remainder of the circuitry pertains to demand pacer which is advantageous because energy is conserved in the battery when the heart is beating of its own accord and because pacer pulses are not supplied when they might compete with natural heartbeats.

R-wave amplifier **15** has a specially designed response curve which make it highly selective. Its response curve is shaped so that the amplifier rejects extremely low frequency signals, such as the heart's T-wave, rejects 60 hertz interference signals and rejects high frequency interference signals (e.g. 400 hertz). The amplifier sensitivity is relatively low for signals of less than 15 hertz and rapidly rises to peak sensitivity at about 25 hertz. The sensitivity remains high up to nearly 60 hertz and then drops sharply in a notch at 60 hertz and rises again quite sharply to a sensitivity less than that at 25 hertz for frequencies above 60 hertz. The sensitivity slowly decreases above about 100 hertz and the amplifier is substantially insensitive to signals of a frequency greater than 200 hertz.

Signals from the heart and pacer pulses are sensed through electrode **14**. These signals are picked off by the wiper of variable resistor **65** and are fed into a twin-T filter network which includes capacitor **68**, **69** and **70**, and resistors **67**, **71** and **72**. The twin-T network is designed to provide the notch at 60 hertz for strong rejection of interference at that frequency. The output of the twin-T notch filter is fed into a field effect device **74** to prevent loading the twin-T, thereby making the notch sharper. Capacitors **73**, **80**, **88** and **96**, the network containing resistor **78** and **85** and capacitor **87** provide low frequency shaping to make the demand circuitry insensitive to T-waves generated by the heart and other low frequency signals. The R-C combinations of resistor **78** and capacitor **79** and resistor **85** and capacitor **87** in the source circuits of field effect devices **74** and **81**, respectively, provide low frequency shaping because those combinations provide an impedance which decreases with increasing frequency. Therefore, the output sensitivity of field effect devices **74** and **81** increase as the frequency increases. Capacitor **76** contributes to the high frequency rolloff in sensitivity.

Diodes **82** and **83** provide a gate reference for field effect device **81** and further provide signal level limiting at the gate of field effect device **81**. The primary purpose of diodes **82** and **83** is to prevent overdriving the amplifier when a pacer pulse is sensed at electrode **14** and transmitted back through R-wave amplifier **15**. Pacer pulses are of the order of 15 volts which is 15,000 times the one millivolt minimal R-wave which is required to be sensed. The amplifier must be sensitive enough to sense the R-wave yet must recover rapidly from a pacer pulse. Diodes **82** and **83** aid in this function by shunting most of the pacer pulse energy directly to ground conductor **19**.

The sensed signal from field effect device **74** turns on field effect device **81**, which in turn provides a signal at the base of transistor **89**. Transistor **89** is biased "on" continuously by bias resistors **90** and **91**. The purpose of transistor stage **89**, resistors **92** and **93** and capacitors **94** and **95** is to provide additional gain and to generate a bipolar output signal in response to a monopolar signal of either polarity applied at electrode **14**. This is necessary because R-waves of either polarity can be generated in the same patient. Resistors **92** and **93** are chosen to be of a magnitude which differs by a small factor, substantially less than **10**. Capacitor **94** forms a differentiating circuit with resistor **92**. In such a circuit, a monopolar input signal produces a bipolar output signal wherein the opposite polarity portions of the signal each have substantial magnitude.

The signal, then, which is fed into resistor **99** as a result of an R-wave of pacer pulse at electrode **14** contains both a positive going and a negative going component. The major difference in the output signal depending on whether the input signal is positive going or negative going is which of the positive going or negative going components is generated first.

To obtain a demand pacer as above described whose rate is calibrated correctly when pacer pulses are fired into either a purely resistive load or into the heart, a refractory circuit is required. This circuit is needed because a pacer pulse fired into the heart elicits a driven R-wave which closely follows the pacer pulse, whereas no such phenomenon occurs when the pacer is fired into a purely resistive load. Therefore, if no precautions are taken, the demand pacer will be reset by the pacer pulse, will begin timing for the next pacer pulse, and will be reset again by the driven R-wave which follows that pacer pulse. Therefore, in the absence of a refractory circuit, the pacer will generate pulses at one rate when connected across a resistive load and will generate pulses at a somewhat slower rate when connected to an actual heart. Such a response also results in a time interval between the last natural heartbeat and the first generated pulse which is different than the time interval between two succeeding generated pulses (and therefore that between two succeeding generated heart beats). Refractory circuit **16** is designed to eliminate rate variation due to sensing of the driven R-wave by making the reset mechanism insensitive to any signal which follows a first reset signal from amplifier **15** by less than a predetermined time interval.

The bipolar signal from amplifier **15** is transmitted to the base of transistor **100**. The negative going portion of that signal turns on transistor **100** bringing its collector to nearly supply voltage. Turn on of transistor **100** begins charging of capacitor **104** and provides base current for transistor **106** through capacitor **104** and resistor **105**. Transistor **106** then turns on bringing the voltage at the point intermediate resistors **103** and **108** to a predetermined level between supply voltage and ground, thereby holding transistor **100** on until capacitor **104** is charged. The "on time" of transistors **100** and **106** is determined by the magnitudes of capacitor **104** and resistor **105**. As soon as capacitor **104** is fully charged, transistor **106** turns off removing base current from transistor **100** and turning it off.

Diode **102** provides emitter junction protection for transistor **100** and speeds the recovery of capacitor **96** and resistor **99** after occurence of a high level signal.

Capacitor **104** and resistor **105** are chosen so that "on time" of transistors **100** and **106** is about 200 milliseconds. During that time, further pulses appearing at the base of transistor **100** have no effect on reset transistor **114** since transistor **100** is already turned on and neither a signal driving it on harder nor one tending to turn it off momentarily are felt by reset transistor **114**.

When transistors **100** and **106** turn off, capacitor **104** begins to discharge through resistor **101**, resistor **107** and resistor **105**. As soon as current flows through resistor **105** from this discharge current, a forward bias is created on the base of transistor **109** and capacitor **104** rapidly dumps through the collector-emitter circuit of transistor **109**. Thus, the refractory circuit has a quick recovery time.

As transistor **100** turns on, charge current flows through capacitor **110** and provides base current for reset transistor **114** until capacitor **110** becomes fully charged. Reset transistor **114** then turns on, shorting the collector of transistor **31** directly to ground conductor **19** and dumping timing capacitor **36**. When transistor **100** turns off, capacitor **110** discharges quickly through resistors **101**, **112** and **111**. Reset action occurs in response to either a sensed natural R-wave or to a generated pacer pulse. In either case, it resets timing capacitor **36** to a predetermined level and starts the timing cycle again in synchronization with the sensed signal.

The signal transit times in voltage increasing circuit **12**, amplifier **15**, refractory circuit **16**, and reset circuit **17** and the fact that capacitor **36** is normally dumped to a slightly different reference level by reset transistor **114**, than it is by diode **43** and transistor **38** make it clear that the time between pulses in the pacer described normally is slightly different when the demand circuitry is disabled and when it is active. In the preferred form, the pulse rate scale is calibrated when the demand circuitry is active, because that is the normal use mode.

It is obvious that transistors and field effect devices of the opposite conductivity type can be used in the invention by simply reversing battery polarities and making appropriate biasing adjustments.

I claim:

1. A regulated power supply providing a current which is substantially independent of relatively large supply voltage variations; the supply comprising:

- a source of voltage;
- constant current means providing a substantially constant current independent of relatively wide variations in voltage thereacross;
- constant voltage means for providing a substantially constant voltage thereacross when a substantially constant current is applied thereto, serially connected to the means for providing a substantially constant current;
- circuit means connecting the serial combination of the constant current means and the constant voltage means across the source of voltage;
- current control means having a pair of input terminals and a pair of output terminals, exhibiting a high input impedance between the input terminals, providing a current between the output terminals which is substantially independent of source voltage variation when a relatively constant voltage is applied between the input terminals, and having the input terminals connected across the constant voltage means;
- the constant current means comprising a field effect device having source, drain, and gate electrodes with the drain electrode serially connected to the constant voltage means, the gate electrode connected to the source of voltage, and impedance means connecting the source electrode to the source of voltage;
- the current control means including variable resistance means, a transistor having emitter, base and collector electrodes with the base electrode connected to one end of the constant voltage means the variable resistance means connected between the emitter electrode and the other end of the constant voltage means, and the collector electrode connected to one of the output terminals.

2. A cardiac pacer having a highly stable, controllable pulse generating rate comprising:

a power supply according to claim 3;

pulse generating means connected to the source of voltage, the pulse generating means including current controlled timing means connected to at least one of the output terminals of the current control means;

electrode means, including at least one electrode adapted to contact cardiac tissue, connected to the pulse generating means;

condition responsive means adapted to be responsive to the beating action of a patient's heart to provide a signal indicative of a heartbeat; and

reset means connected to receive signals from the condition responsive means and to reset the timing means to a predetermined level in response thereto.

3. A regulated power supply providing a controllable magnitude current which is substantially independent of relatively large supply voltage variations, the supply comprising:

a voltage source;

a field effect device, having source, drain, and gate electrodes;

first resistance means connected between the source electrode the gate electrode;

second resistance means;

circuit means serially connecting the first resistance means, the source and drain electrodes, and the second resistance means across the voltage source, thereby providing a predetermined voltage drop across the second resistance means so long as substantially all the current flowing through the source-drain circuit of the field effect transistor, and no other current, flows through the second resistance means;

a transistor having emitter, base and collector electrodes, with the base electrode connected to one end of the second resistance means; and

variable resistance means connected between the emitter and the opposite end of the second resistance means for controlling the magnitude of the current at the collector.

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,547,127 Dated December 15, 1970

Inventor(s) Robert K. Anderson

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 41, "20 20" should read -- 20% --. Colu 2, line 26, "increases" should read -- increased --. Column line 6, "chose" should read -- chosen --. Column 6, line 67, following 78 and, insert -- capacitor 79 and that containing resistor --. Claim 2, line 3, "3" should read -- 1--.

Signed and sealed this 30th day of March 1971.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

WILLIAM E. SCHUYLER, J
Commissioner of Patent