United States Patent

[11] 3,617,711

[72] Inventor Robert C. Smyth
Huntington Beach, N.Y.

[21] Appl. No. 23,300
[22] Filed Mar. 27, 1970
[45] Patented Nov. 2, 1971
[73] Assignee Digital Apparatus Corporation
Deer Park, N.Y.

[54] **APPARATUS FOR CHANGING A DIGIT OF A STORED NUMBER**
6 Claims, 6 Drawing Figs.

[52] U.S. Cl. .... **235/92 EA,** 235/92 SH, 307/221, 328/37, 328/48, 340/324 R, 340/347
[51] Int. Cl. **G06f 11/00,** H03R 21/00, G08c 11/00
[50] Field of Search .... 340/172.5, 324 R, 347 DA; 328/37, 48, 49; 307/221, 224; 235/92 EA, 92 SH, 153

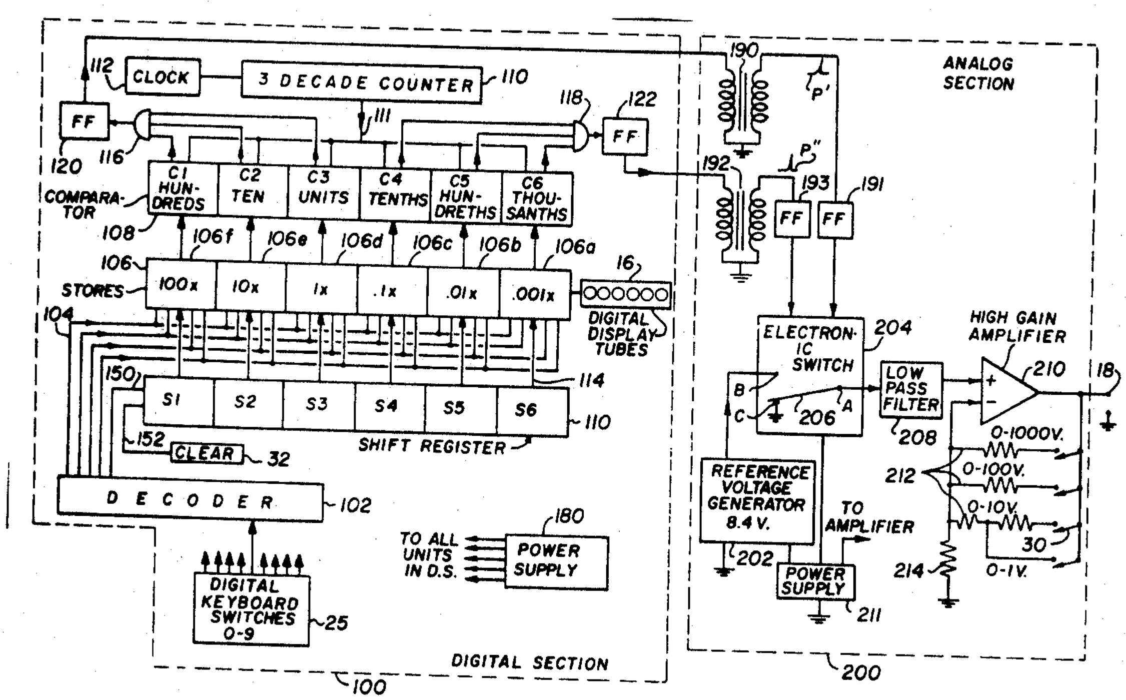
[56] **References Cited**

UNITED STATES PATENTS

3,258,696 6/1966 Heymann 328/48
3,492,656 1/1970 Hildebrandt 340/172.5
3,537,073 10/1970 Sakoda et al. .... 340/324 R

Primary Examiner—William H. Beha, Jr.
Attorney—Edward H. Loveman

ABSTRACT: A high-precision power supply generates voltage with an accuracy of at least 30 parts per million and is comprised of a digital section interconnected with an analog section by pulse transformers. Numbered keyboard switches in the digital section select a desired output voltage which is displayed numerically by electronic digital display tubes. A shift register in circuit with number storage means enables any one of the displayed numbers to be changed without changing any other displayed number. The analog section includes a stable reference voltage generator, electronic switch, filter and a high-gain amplifier which produces an output voltage corresponding to the displayed numbers. The electronic switch passes proportional parts of the reference voltage to the amplifier via the filter under control of pulses received from the digital section. The amplifier is capable of producing current in one of two ranges depending upon the output voltage.



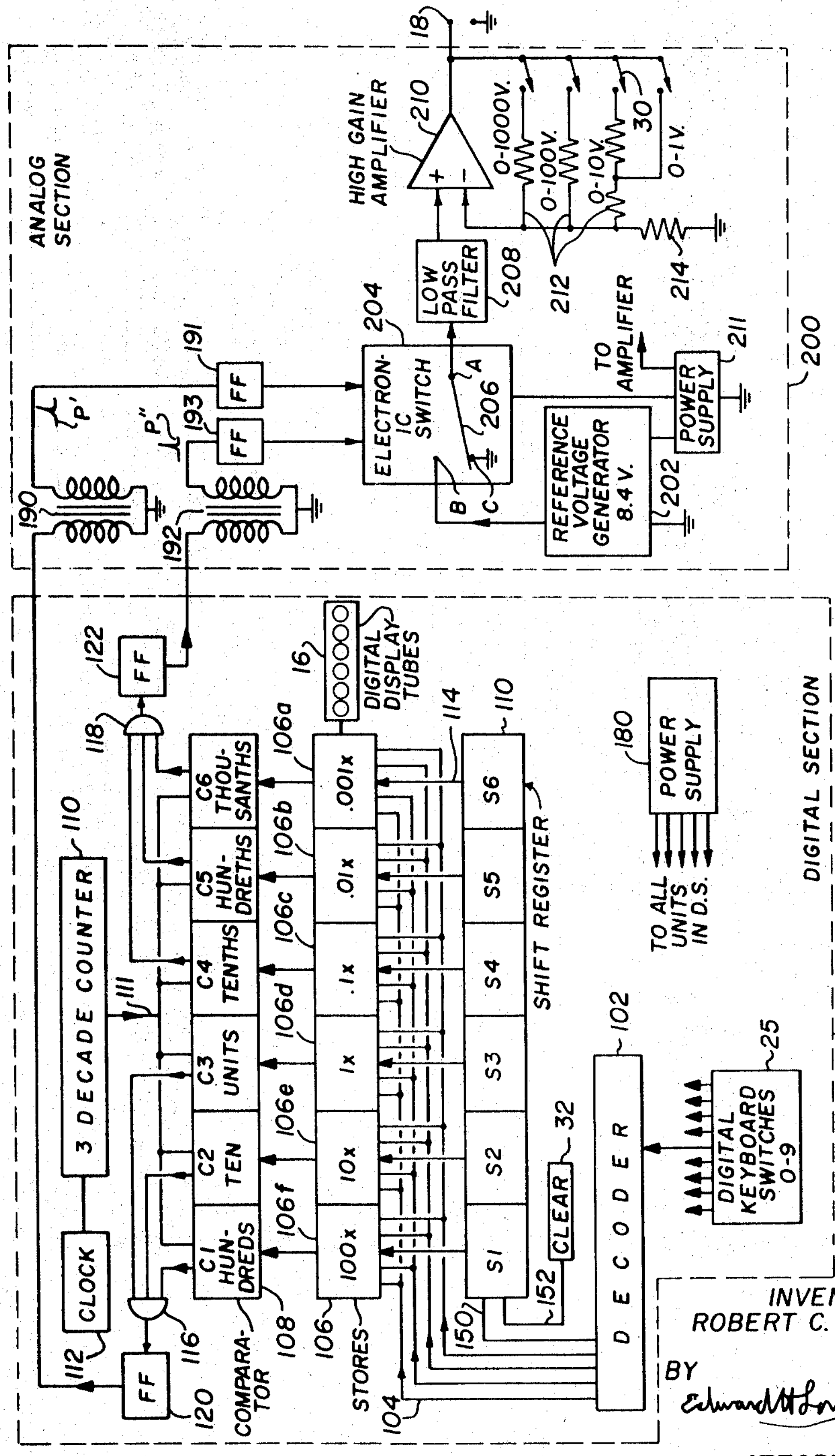


FIG. 1

INVENTOR
ROBERT C. SMYTH

BY Edward H. Loveman

ATTORNEY

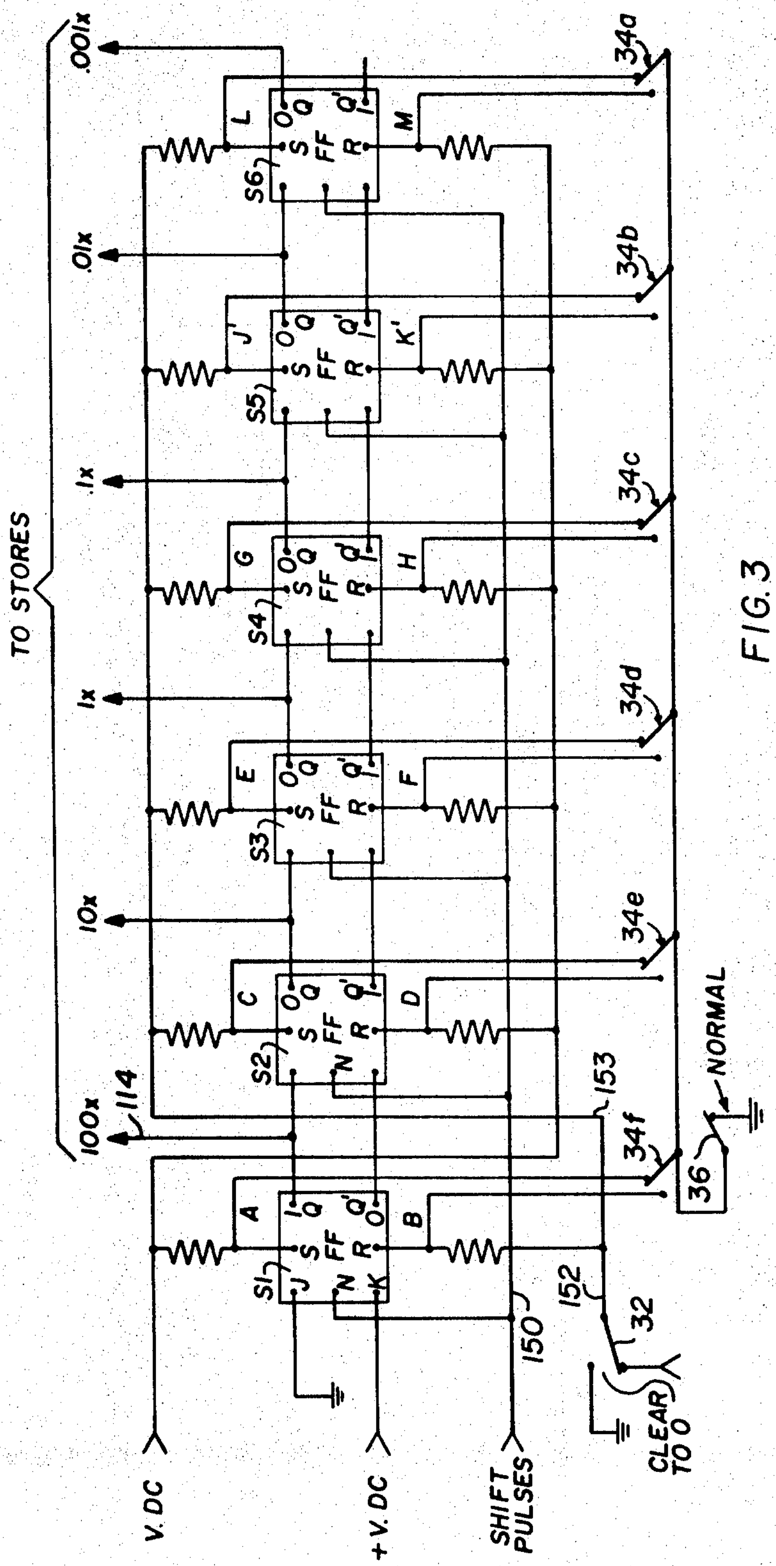


FIG. 3

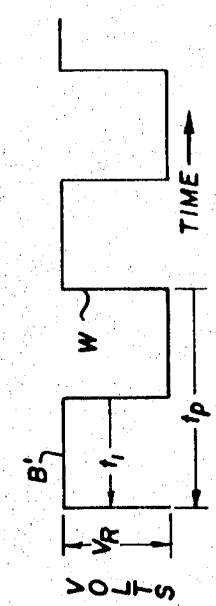


FIG. 2

INVENTOR
ROBERT C. SMYTH

BY Edward H. Loveman
ATTORNEY

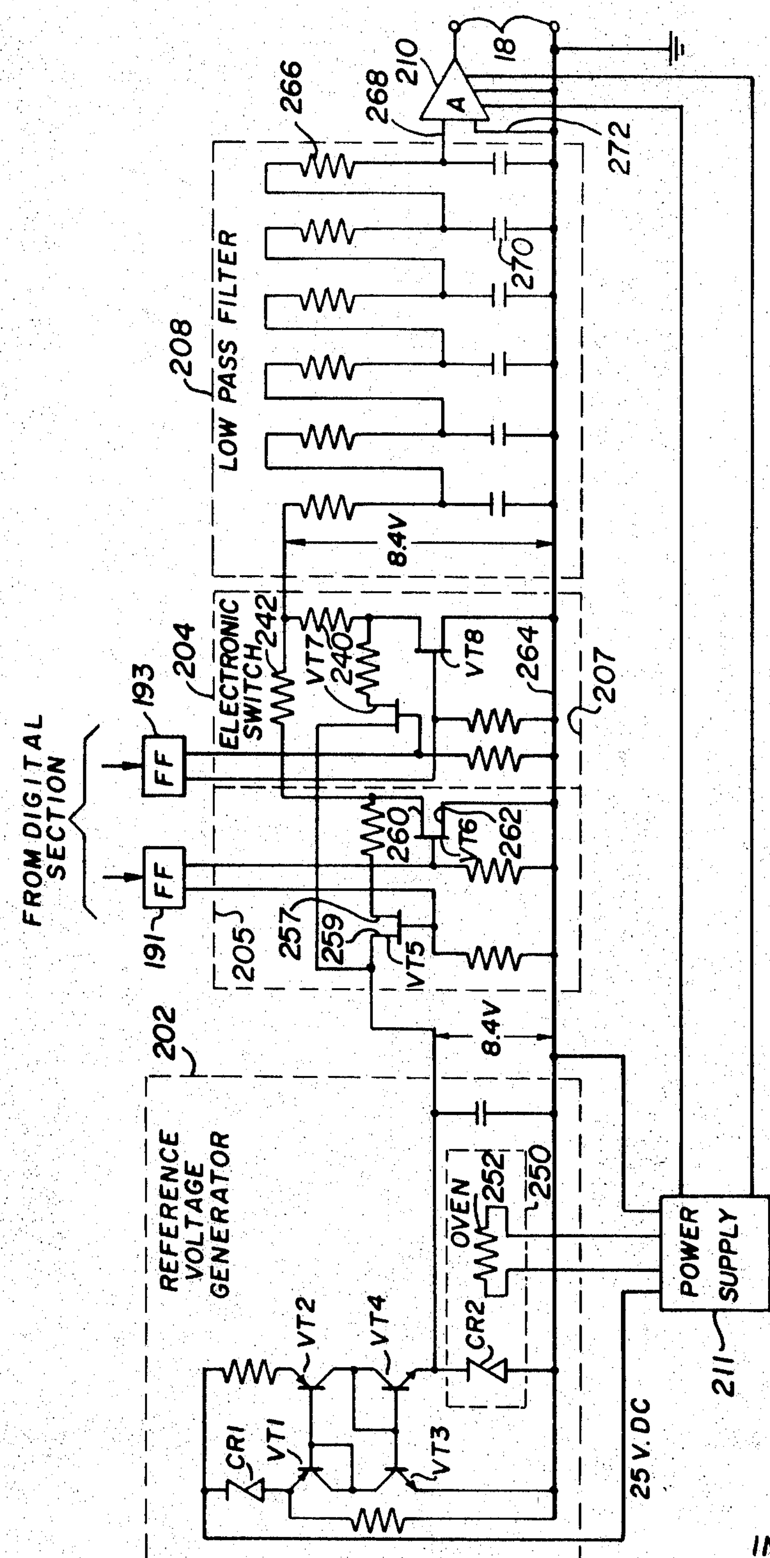


FIG. 4

INVENTOR
ROBERT C. SMYTH

BY Edward H. Loveman
ATTORNEY

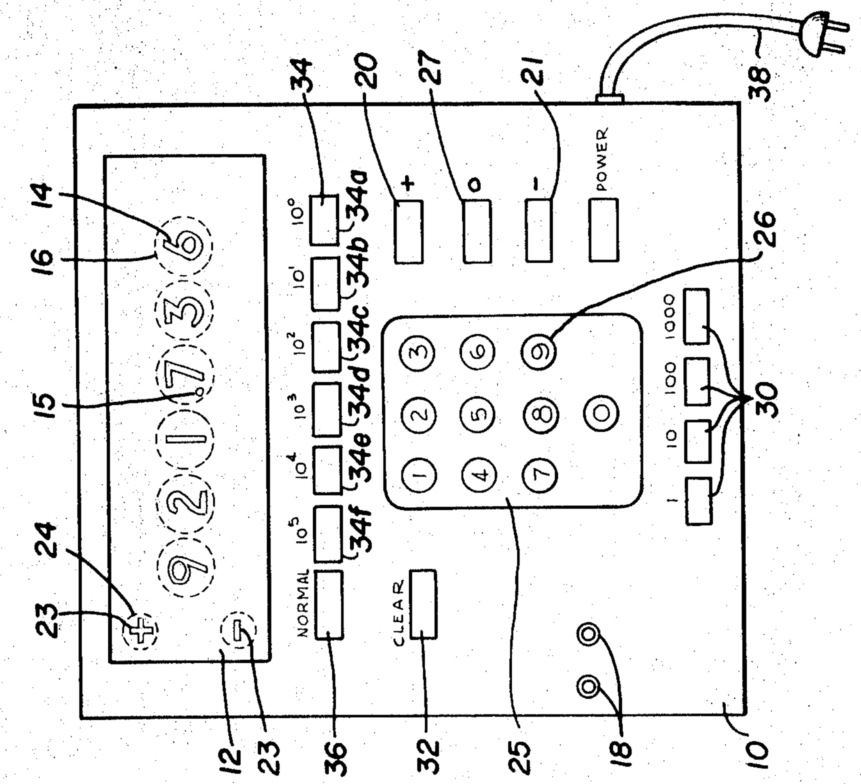


FIG.6

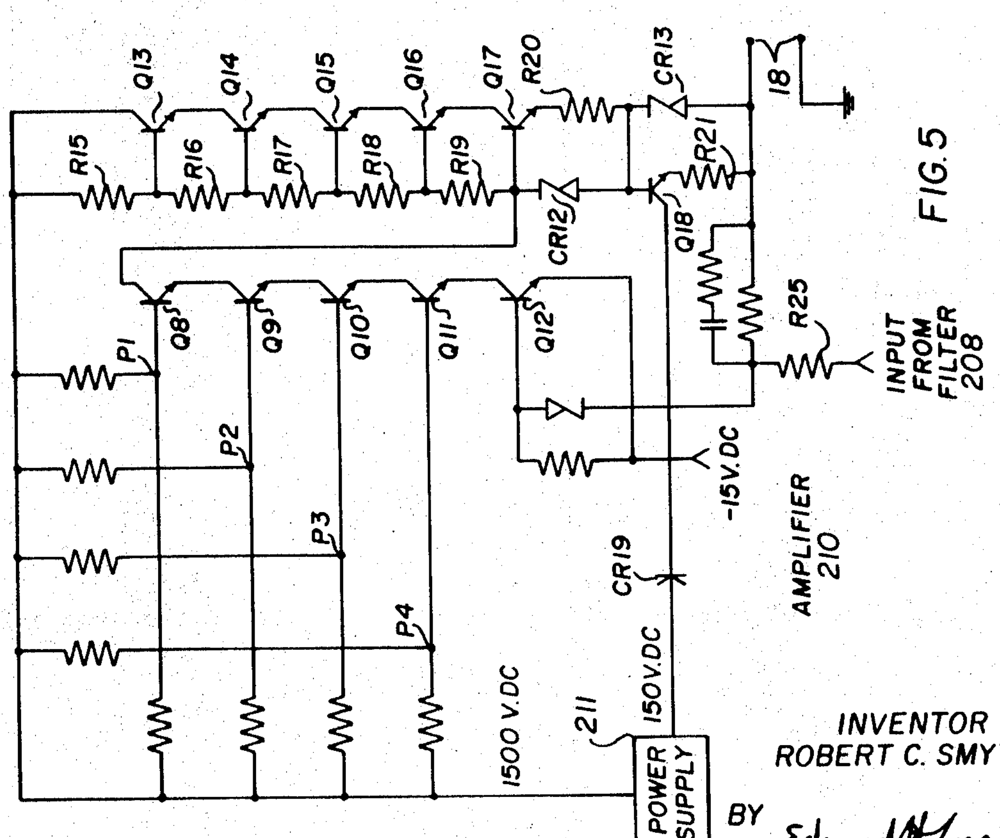


FIG.5

INVENTOR
ROBERT C. SMYTH
BY Edward H. Loveman
ATTORNEY

APPARATUS FOR CHANGING A DIGIT OF A STORED NUMBER

This invention relates to a power supply apparatus capable of producing a wide range of DC voltages with extreme accuracy, and more particularly relates to a power supply apparatus which uses pulse width modulation in a voltage regulator circuit.

While precision power supplies have been known heretofore they have suffered from a variety of difficulties and disadvantages. One objection has been the very high cost and complexity of apparatus capable of generating precision voltages. Another difficulty has been the inherent lack of stability of the power supply and the tendency to drift and change output over a period of time. The present invention is directed at overcoming the above and other difficulties and disadvantages of prior power supplies and at the same time provide a more reliable, simpler, less expensive, more easily operable precision apparatus. The apparatus of the invention consumes less power than prior precision power supplies and is smaller and lighter in weight.

In accordance with the invention, the apparatus uses pulse width modulation in a voltage regulator circuit. That is, a regulated direct current voltage is obtained by feeding an output-responsive, variable-width pulse train of a given polarity to a filter circuit which thereby provides a direct current output proportional to the average amplitude of the pulse width modulated pulse train. By varying the width of the pulses, the average value of the direct current output voltage can be controlled. This method of voltage regulation is relatively efficient since there is no appreciable power dissipated in resistors or other dissipation elements as in the case of other methods of voltage regulation heretofore practiced.

Accordingly the apparatus of the instant invention is capable of generating voltages in the range of 0–1,000 volts with such precision that the apparatus may be used as a secondary standard or calibrator for calibrating other electronic equipment. The apparatus is operated by pushbuttons and provides a direct digital display of voltage being generated. Output voltages may be displayed with six significant digits. The apparatus has two basic sections, a digital section and an analog section. The digital section includes manually operable pushbutton switches which actuate a shift register and digital store via a decoder. Electronic digital display tubes are connected in circuit with the store to indicate the numerical value of the voltage generated in the apparatus. In a preferred embodiment of the invention, this voltage is generated selectively in one of four ranges in increments of one part per million in each range. The digital section further includes circuits which drive electronic switches in the analog section. A single high-precision thermally stabilized voltage generator in the analog section is connected to the electronic switches which pass reference voltages via a filter to a high-gain multirange, feedback amplifier. This amplifier is so constructed that highly precise voltages are produced with negligible noise at its output.

A unique feature of the amplifier is the use of only two resistors in each of its four ranges nominally set at 0–1, 0–10, 0–100 and 0–1,000 volts. This contrasts with prior power supply devices which employ a multiplicity of resistors in each voltage range. A significant disadvantage of employing multiple resistors in each range aside from the high cost is the inherent lack of stability and reliability they cause. For example, when as many as 24 resistors have to be switched, the switch contacts become noisy and resistive and this changes the output, so that the high-precision character of the device is soon lost. The present invention avoids these undesirable conditions by avoiding switched resistors in each range within each of the four ranges. In the present invention switching is accomplished electronically by varying the gain of the amplifier so that the apparatus produces designated stable, precision voltages with negligible electrical noise. The apparatus produces the designated voltages with positive or negative polarity and with different selectable output currents.

It is therefore a principal object of the invention to provide a high-precision power supply having digital and analog sections, the digital section being operated by numerical pushbutton switches and providing a digital display of voltage generated; the analog section employing electronic switching in conjunction with a stable internally generated reference voltage to drive a high-gain, multiple range, feedback amplifier.

A further object is to provide a high-precision power supply employing a thermally stabilized internal reference voltage generator to drive electronic switching circuits employing field effect transistors.

Still another object is to provide a high-precision power supply with a high-gain multiple range output amplifier having only two fixed resistors determining the output of each range.

These and other objects and many of the attendant advantages of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, in which:

FIG. 1 is a block diagram of high-precision power supply apparatus embodying a preferred form of the invention, showing digital and analog sections of the apparatus;

FIG. 2 is a graphic diagram of pulses generated in the apparatus, and is used in explaining the invention;

FIG. 3 is a diagram of a shift register employed in the digital section of the apparatus;

FIG. 4 is a diagram of the analog section of the apparatus;

FIG. 5 is a diagram of the amplifier employed in the apparatus;

FIG. 6 is a front view of a control panel forming part of the apparatus.

Referring now to the drawings, wherein like reference numerals designate like parts throughout the figures thereof, there is shown in FIG. 6 a control panel 10 of the apparatus which has a digital display window 12 in which appear six numerals 14 on the faces of six electronic display tubes 16. The numerals may range from "0" to "9" on each tube and the number displayed indicates the voltage being generated by the apparatus at a pair of output jack terminals 18. Polarity pushbutton selector switches 20 and 21 determine the polarity of the DC voltage produced at the output terminals 18 and this polarity is indicated by a plus or minus symbol 23 on a display tube 24. Operation of a selector switch 27 results in the production of 0 output voltage, i.e. a short circuit is produced across the output terminals 18 without changing the numerical display 14. Appropriate plugs can be inserted into the jack terminals 18 for applying the generated precise output voltage to an external circuit for any desired purpose. A keyboard 25 on the panel 10 is provided with 10 pushbutton switches 26 designated respectively "0" to "9." When these pushbuttons are pushed in sequence to select a desired output voltage, the voltage will be numerically displayed at window 12. In the present embodiment, six numerals 14 with a decimal point 15 will appear. However, provision can be made for more or less numerals according to requirements by employing the principles of the invention described below. Four pushbutton switches 30 operate as range selectors wherein the operation of any one switch will set the apparatus to produce voltages in one of four designated ranges 0–1, 0–10, 0–100 or 0–1,000 volts. A CLEAR switch 32 will cause clearance of all numbers appearing in the window 12. Six switches 34 marked "10^0" to "10^5" can be selectively operated for enabling the change of any one of the six numbers 14 and the corresponding output voltage. After any one of the switches 34 is operated, any one of the switches 26 may be operated to obtain display of a corresponding digit on the selected tube 16. NORMAL switch 36 resets the switches 34 to open condition. A power cable 38 may be connected to any AC convenience outlet for applying power to the apparatus.

Referring now to FIG. 1, the electronic system is comprised of two sections, a digital section 100 and an analog section 200. The digital section is the control section and is programmed by switches on the panel 10 as hereinbefore described. The analog section 200 obtains signals from the digital section which actuate an electronic switch 204 to generate precision voltages. The analog section receives spike pulses P' and P'' from the digital section 100 via two small ferrite pulse transformers 190, 192. This is the only direct electrical connection between the two sections. There is no other and for this reason each section has its own power supply 180 and 211. This is an important feature of the present invention and insures stability and independence of operation in the two sections.

In digital section 100, the 10 decimal switches 26 designated respectively "0" to "9," as shown in FIG. 6, are selectively operated. A decoder 102 is connected to the switches via lines 103. From the decoder 102 lines 104 convey pulses in a conventional binary 1, 2, 4, 8 code in parallel to each one of a plurality of digital stores 106. Six stores are shown in FIG. 1, but more or less stores may be provided according to requirements. Numbers placed in the stores 106 remain there until they are cleared by operation of the CLEAR switch 32 connected in circuit with shift register 110. Electronic numerical display tubes 16 generally known as "-nixie" tubes are connected to the six stores respectively.

The shift register 110 is indicated diagrammatically in FIG. 3. This register has six stages designated S1–S6 and each is a conventional J-K flip-flop of the type wherein the output at terminals Q Q' assume logical states that were present at inputs J and K at the time the flip-flop is shifted. The stages are successively shifted by pulses generated by each of the first six actuations of a pushbutton switch 26 and further actuations thereof will not effect changes in the state of the stages. Operation of the CLEAR switch 32 connects a ground potential (via lead 152) to the Q' output of flip-flop S1 and to the Q output of flip-flop S2 through S6 (via lead 153) such that the first stage S1 is at a logical "1" and all other stages are at logical "0." At the same time, tubes 16 all display "0." Thereafter, actuation of any selected switch 26 causes a shift pulse and a code number pulse to be generated by decoder 102. The shift pulse is applied via line 150 to the N inputs of each of the stages, and the coded number pulse is passed to all of the stores 106. The first shift pulse shifts stage S1 to a logical "0 " and causes a transfer pulse to pass via the first one of lines 114 to the first store 106 which is thereby locked and prevented from changing the value of the first coded number pulse trapped therein by subsequent coded number pulses passed by the decoder 102. At the same time, stage S2 of the shift register 110 shifts to a logical "1." Thereafter, as any selected pushbutton decimal switch 26 is actuated, the next succeeding stage of the shift register 110 shifts to a logical "1" while the preceding stage shifts to logical "0." The entire numbers stored in stores 106 and displayed by tubes 16 remain until the CLEAR switch 32 is again operated.

Although the hereinabove described shift register structure and operation is fairly conventional, the register is provided with novel means whereby any one of the digits of the selected number may be selectively changed. Thus, at times it may be desirable to change only one of the digits of a selected and displayed number for example 921.736 to 921.836. In prior devices, it is necessary to recycle the entire register by actuating the CLEAR switch and entering the new number as previously described. In this novel apparatus any digit may be changed to another digit by merely depressing the pushbutton 34 which relates in the digit to be changed and then depressing a selected pushbutton switch 26. For example, it it is desired to change the fourth digit (7) of the number 921.736 illustrated in FIG. 6, then the pushbutton 34c is depressed to set stage S4 to a logical "1" and open the fourth store. That is, a ground potential, applied to the reset "R" terminal by the actuation of pushbutton 34c sets stage S4 to a logical "1" and thereafter actuation of the numeral 8 of pushbutton switches 26 will generate from the decoder 102 a coded number pulse which is applied to the open store 106C as hereinbefore described. The shift pulse which is also generated by decoder

102 will not shift the stage S4 flip-flop inasmuch as the ground potential applied by the actuation of pushbutton 34c to the reset "R" terminal has not been removed. If another pushbutton 34 is now depressed e.g. 34b, the S4 stage will revert to a logical "0" state since the ground potential is now on the set "S" terminal and a transfer pulse on line 114 will lock the coded number pulse in store 106c and, of course, the S 5 stage will revert to a logical "1" state. If it is desired to change all the digits of a number, then the normal switch 36 must be depressed to remove ground potential from switch 34 and then the CLEAR switch 32 must be actuated to set the stage S1 to logical "1" and the remaining stages S2 through S6 to logical "0" as hereinbefore described.

Referring again to FIG. 1, it will now be understood that six coded digits can be stored in succession in the six stores 106 and that any one of the digits in the six stores can be changed without changing the other digits in the stores. Connected to the respective stores is a comparator 108 having six comparison stages C1–C6. This circuit is a dynamic device and compares fixed numbers stored in the stores 106 with numbers produced continuously by a 3-decade counter 110 pulsed by a clock pulse generator 112. The counter continuously produced 999 pulses in succession and then returns to 0. These pulses are applied via line 111 to all comparison stages and at instants of coincidence, coincidence pulses are passed to AND-gates 116 from comparators C1–C3 and to AND-gate 118 from comparators C4–C6. The outputs from AND-gates 116 and 118 actuate flip-flops 120, 122 respectively which pass spike pulses to transformers 190 and 192 respectively. Spike pulses P' and P'' in turn are applied via flip-flops 191, 193 to electronic switch circuit 204 in analog section 200.

In analog section 200 as shown in FIG. 1, there is a reference voltage generator 202 which generates a single fixed DC reference voltage. This voltage is for practical purposes set at 8.4 volts. The reference voltage is applied between points B and C of an electronic switching circuit 204 which, although comprised of two switches 205 and 207, is symbolically shown in FIG. 1 as comprising a single pole switch 206 movable between reference voltage point B and ground point C. The switches 205 and 207 are, as shown in FIG. 4, comprised of field effect transistors VT5, VT6, VT7 and VT8, the operation of which will be more clearly described below. The electronic switching is actuated by spike pulses P' and P'' obtained from the digital section 100 via isolating transformers 190, 192 connected to the electronic switching circuit 204. The voltage output of the electronic circuit 204 is a proportional part of the references voltage. It is applied from point A via a low-pass filter 208 to a high-gain multirange amplifier 210. Power supply 211 energizes the various units and is independent of power supply 180 in the digital section 100.

The waveform W of voltage applied to the filter is shown in FIG. 2. The reference voltage is applied to the filter for time duration t_1 which occurs during a portion of time period t_p. When point A is grounded to point C, then the voltage applied to the filter 208 has zero amplitude. During time periods t_1, the reference voltage is applied to the filter. The mean voltage B' can be expressed at $B' = V_R(T_1;\ t_p)$since V_R is the constant reference voltage (8.4 volts), and since t_P which represents the switching period can be maintained constant, then the mean voltage applied to the amplifier will vary linearly with time t_1. Thus, by varying time t_1, i.e. the time duration between applications of pulses P' and P'' it is possible to vary the mean voltage output B' of the electronic switch between $V_R$and 0. The filter 208 smooths out ripples in the applied voltage so that pure DC is applied to amplifier 210. The amplifier in turn amplifies the input voltage in any one of four ranges 0–1, 0–10, 0–100 and 0–1,000 volts depending on the setting of switches 30 at panel 10. The voltage range is determined by the feedback through one of the resistors 212, depending on which one is selected for the desired amplification range. The voltage output for any one range is therefore determined only by one of resistors 212 and resistor 214 connected between ground and the amplifier input. The voltage output of the amplifier appears at terminals **18** located at panel **10**. It should be understood that the voltage output obtained at terminals **18** is varied by changing the voltage input to the amplifier. This is accomplished by the electronic switch **204**. This contrasts with conventional power supplies known in the prior art where voltage output is varied by changing the values of resistance at the output in each voltage range. In the present apparatus, by contrast, the resistance remains constant for each voltage range, and only the input voltage to the amplifier is electronically varied by electronic switching. Thus, the instability and inaccuracy caused by rotary switching employed in conventional variable power supplies is completely avoided. Amplifier **210** produces voltage of one polarity but by inverting the output voltage the polarity with respect to ground can be reversed. This is a valuable convenience feature for use in calibrating other instruments.

FIG. **4** shows schematically further details of the analog section **200**. In this section is the reference voltage generator **202**. A zener diode CR2 which generates the reference voltage is maintained in an oven **250** at a constant temperature of about 80° C. The oven is heated by a solid-state heater **252** energized by power supply **211**. This power supply also supplies a DC voltage which is applied to a zener diode CR1 . Transistors VT1, VT2, VT3 and VT4 are connected in a loop or bridge circuit with zener diode CR1 and feed a constant current to the zener diode CR2. This constant current is required in order that zener diode CR2 can produce the fixed reference voltage indicated as 8.4 volts DC, which is applied to the electronic switch **204**. Transistor VT3 which is an emitter follower may tend to vary in internal resistance due to aging, heating or other causes and this would tend to vary the current fed to zener diode CR2. To compensate for this, transistor VT4 is provided, which is identical in characteristics to transistor VT3. Identical resistors R1 and R2 carry the same current and are connected in circuit with transistors VT3, VT4 respectively. The bases of the two transistors are connected together. Any drift which occurs in one transistor also occurs to substantially the same extent in the other transistor. As a result, the effect of drift is cancelled and the current fed to zener diode CR2 remains constant. Similar drift compensation or cancellation is accomplished between identical transistors VT1 and VT2 connected base to base with substantially no base current and constant collector-emitter current.

As hereinabove mentioned, the electronic switch **204** is comprised of switches **205** and **207** which are identical and are controlled respectively by the flip-flops **191** and **193**. The signals from the flip-flop **193** represent the first three digits and the signals from the flip-flop **191** represent the last three digits of the selected number. Thus, outputs from the switches **205** and **207** (FIG. 4) are combined in a resistive network wherein the resistor **240** has a value 1,000 times greater than the resistor **242**. Since both switches **205** and **207** are identical, only the operation of switch **205** will be hereinbelow described in detail.

The constant reference voltage is applied between a drain **259** of a field effect transistor VT5 and a ground line **264**. Field effect transistor VT6 has one electrode **260** connected to an electrode **257** of transistor VT5 and the other electrode **262** connected to the ground line **264**. Transistors VT5 and VT6 have only two operating states. When the reference voltage is to be applied to the filter **208** there is an infinite resistance between the electrodes **260** and **262** and a low finite resistance between the electrodes **259** and **257**. When the electronic switch **205** is to be grounded, there is a low finite resistance between electrodes **260** and **262** of transistor VT6 and an infinite resistance between the electrodes **259** and **257** of VT5. Thus, when the VT5 transistor is conducting, the VT6 transistor is off and a proportional part of 8.4 volts, the reference voltage, is applied to the filter **208**, and when VT5 is off and VT6 is conducting, zero voltage is applied to the low-pass filter **208**. The switch **207** operates in a very similar fashion.

The low-pass filter **208** which is used to produce a pure DC signal has a plurality of resistors **266** connected in series with input **268** of amplifier **210**, and a plurality of capacitors **270** connected in parallel between the resistors and ground line **264**. The ground line is connected to the other input **272** of the amplifier **210**. Output terminals **18** of the apparatus are connected to the output of the amplifier.

FIG. **5** shows the basic circuit of amplifier **210** which is controlled by the input from filter **208** through a resistor R25. The amplifier **210** is required to produce output variable between 0 and 1,000 volts and also a 5-milliampere current above 150 volts and a 50-milliampere current below 150 volts. Rather than use an amplifier comprised of single load or drive transistor to produce the voltage and a single output transistor as emitter-follower or impedance matching, there is shown in the preferred embodiment of FIG. **5** two groups of series-connected transistors Q8 through Q12 and Q13 through Q17, each transistor having an equal voltage rating less than the maximum 1,000 voltage output of the amplifier; for example, each transistor is rated at 300 volts. This type of transistor circuit is preferable inasmuch as the total cost of the ten transistors rated at 300 volts each is substantially less than even a single 1,000 volt transistor. The five drive transistors Q8 through Q 12 are connected in series with each other, thereby sharing the load equally from 0 to 1,000 volts. The voltage applied at P1 varies between 0 and 1,000 volts. Five resistors R15 through R19 are connected to the respective bases of transistors Q13 through Q17. The total output voltage of the amplifier **210** appears across the chain of output transistors Q13 through Q17 which share the voltage equally and in effect constitute a first impedance follower. The current output from the amplifier of 5 milliamperes is determined by a zener diode CR12 and an output resistor R20. A second emitter-follower is comprised of a transistor Q18 which is controlled by the output voltage taken from resistor **20**. A diode CR19 is connected to a power supply **211** which provides 150 volts to the collector of transistor Q18. Current output from transistor Q18 of 50 milliamperes is limited by resistors R21 and zener diode CR13 in the same fashion as the current output from transistor Q17. In operation, when the voltage applied to transistor Q18 is less than 150 volts, the transistor Q18 will pass 50 milliamperes of current. However, when the voltage applied from the resistor R19 is above 150 volts, the base collector of transistor Q18 stops conducting and the diode CR19 becomes reversed biased so it does not conduct. Transistor Q18 then merely becomes a base emitter diode in effect and the output of the amplifier will be reduced to the 5 milliamperes of current as determined by resistor R20 and the diode Cr12. This then is a simple and novel amplifier which will produce two output current ranges dependent only on the output voltage.

It should be understood that the foregoing disclosure relates to only a preferred embodiment of the invention and that it is intended to cover all changes and modifications of the examples of the invention herein chosen for the purpose of the disclosure, which do not constitute departures from the spirit and scope of the invention.

The invention claimed is:

1. An apparatus for changing a digit of a stored number comprising

a keyboard having a plurality of different switches, each one of which when actuated produces a voltage indicative of a particular digit,

a decoder means coupled to said keyboard for coding each of said voltages into a pulse train,

storage means connected to said decoder means and comprising a plurality of stores each associated with a different digit of said number whereby each when open receives each of said pulse trains from said decoder means, upon actuation of one of said switches,

a shift register having a plurality of bistable stages, each of which is sequentially shifted by each actuation of said switches from an open 0 state to a blocked 1 state thereby producing a signal which locks the corresponding digit store in said storage means such that further actuation of said switches on said keyboard will not admit any new pulse train into said locked store, said register further including

a switching means connected to each of said bistable stages which when actuated shifts the corresponding stage from a 1 state to a 0 state, thereby unlocking the corresponding digit store to permit reception of a new pulse train from said decoder upon actuation of said switches in said keyboard.

2. An apparatus as recited in claim 1 further including a display means connected to said storage means for digitally displaying numerals corresponding to the numbers stored in said storage means.

3. An apparatus as described in claim 2 wherein said digital display means comprises a plurality of digital display tubes corresponding respectively to said stores whereby each tube displays only the digit stored in a corresponding store of said storage means.

4. An apparatus as recited in claim 1 wherein said keyboard further includes a CLEAR switch connected in circuit with said shift register whereby actuation of said CLEAR switch will set the first stage to an open "0" state and all of the other stages to a locked "1" state.

5. An apparatus as recited in claim 1 wherein said switching means, when actuated, provides a ground potential to the respective bistable stage.

6. An apparatus as recited in claim 5 wherein said switching means further includes a normal switch which removes ground potential from said switching means.

* * * * *