United States Patent

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[54] **POWER SUPPLY SYSTEM**
7 Claims, 4 Drawing Figs.

[52] **U.S. Cl.** ..... **307/19,** 321/45 R, 321/49, 307/28, 307/44
[51] **Int. Cl.** **H02j 1/00**
[50] **Field of Search** 307/17, 18, 19, 21, 28, 51, 44, 70, 71, 74, 75, 80, 85, 86, 87; 321/49

[56] **References Cited**

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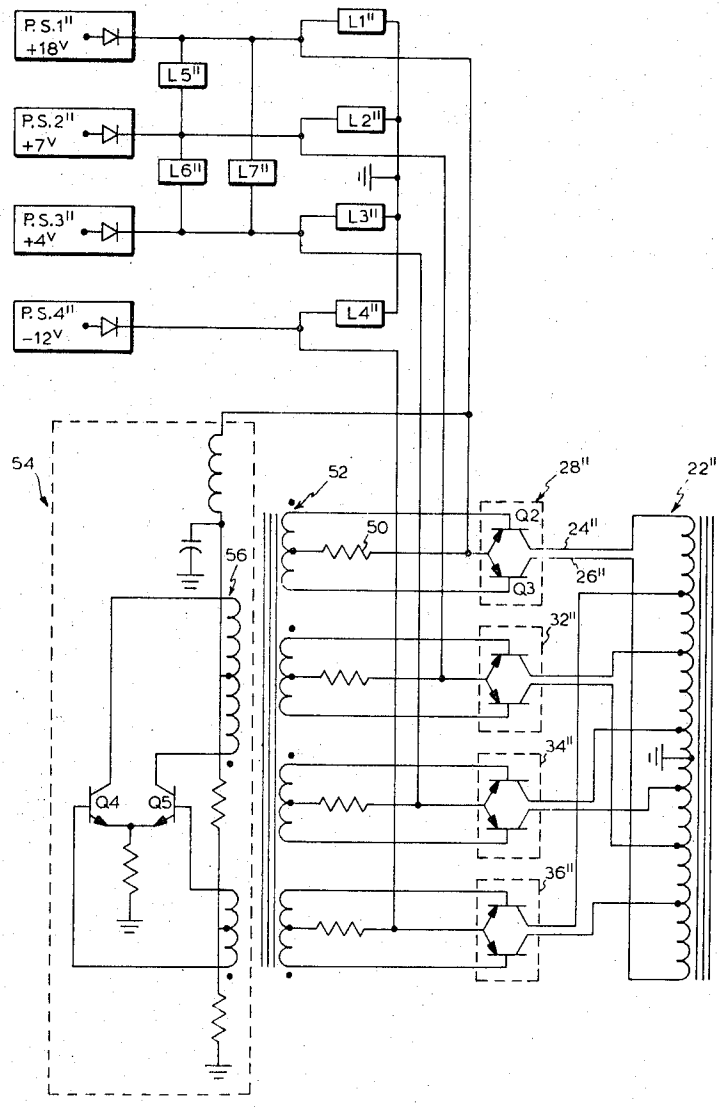
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ABSTRACT: An electrical power supply system for efficiently supplying power at multiple voltage levels to various loads. The system includes transformer means intercoupling a plurality of different voltage levels so as to automatically translate or redistribute power as load conditions change. For example, as load current directions change, power is translated with minimum loss from levels acting as a current sink to levels requiring a current source.



PRIOR ART

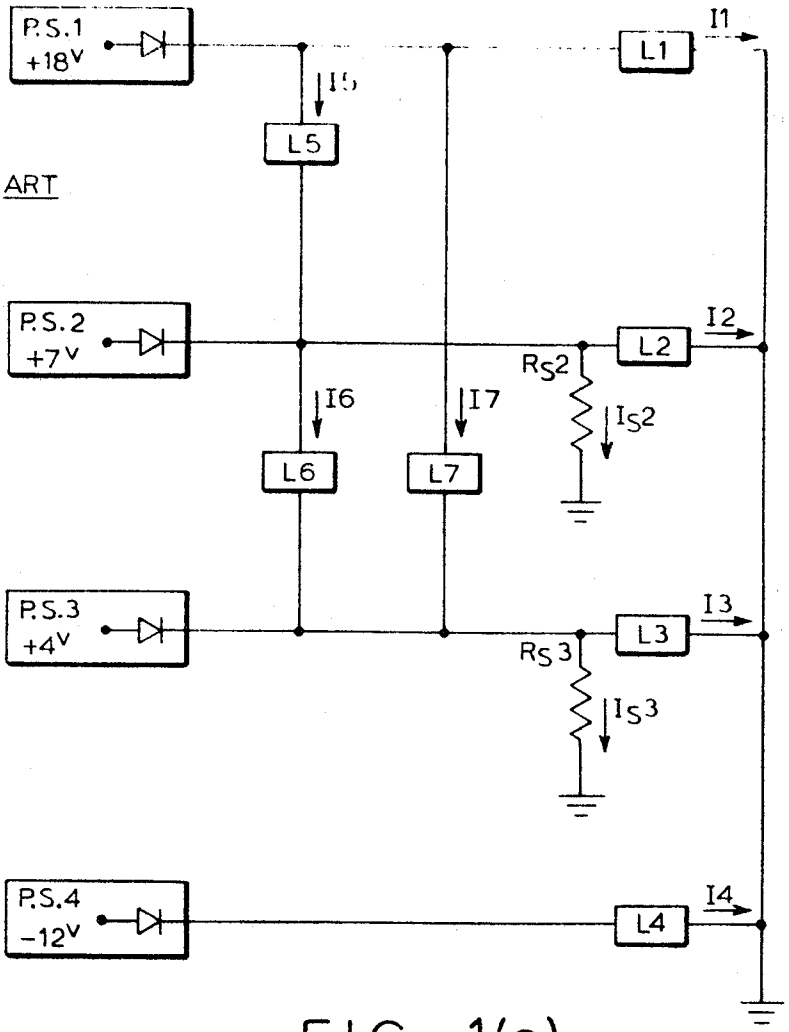


FIG. 1(a)

PRIOR ART

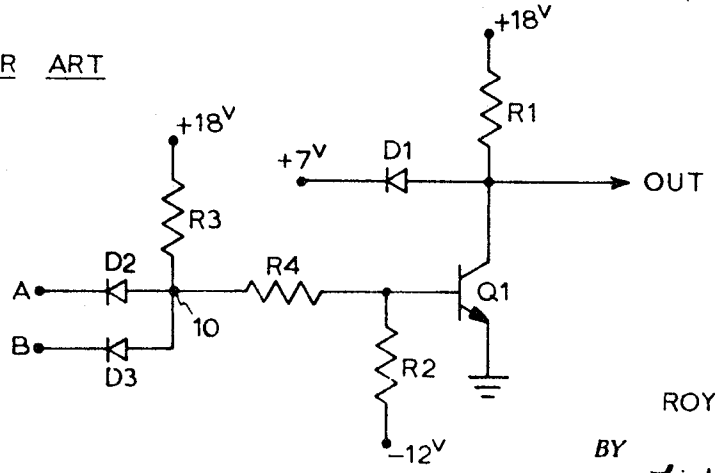


FIG. 1(b)

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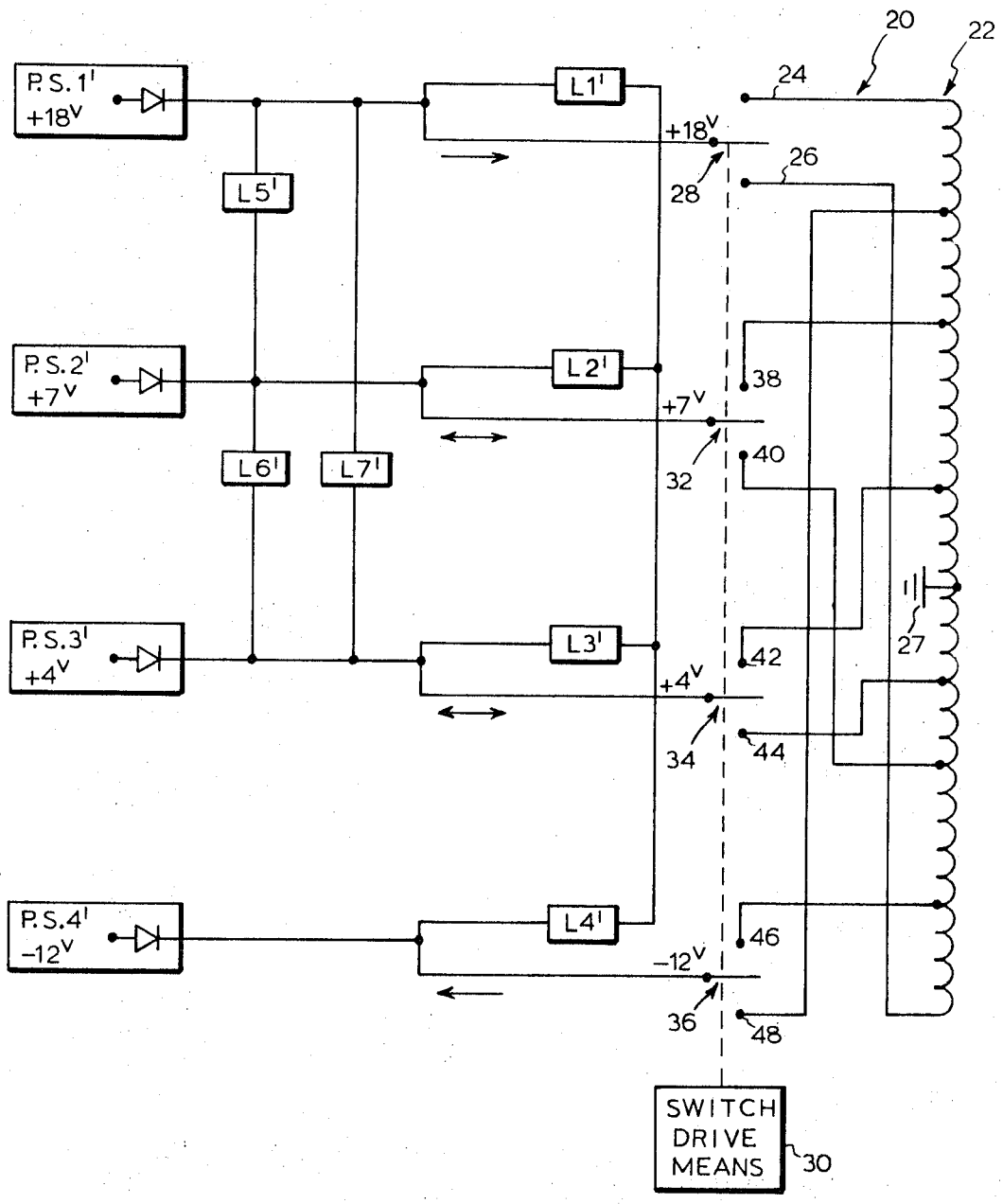


FIG. 2

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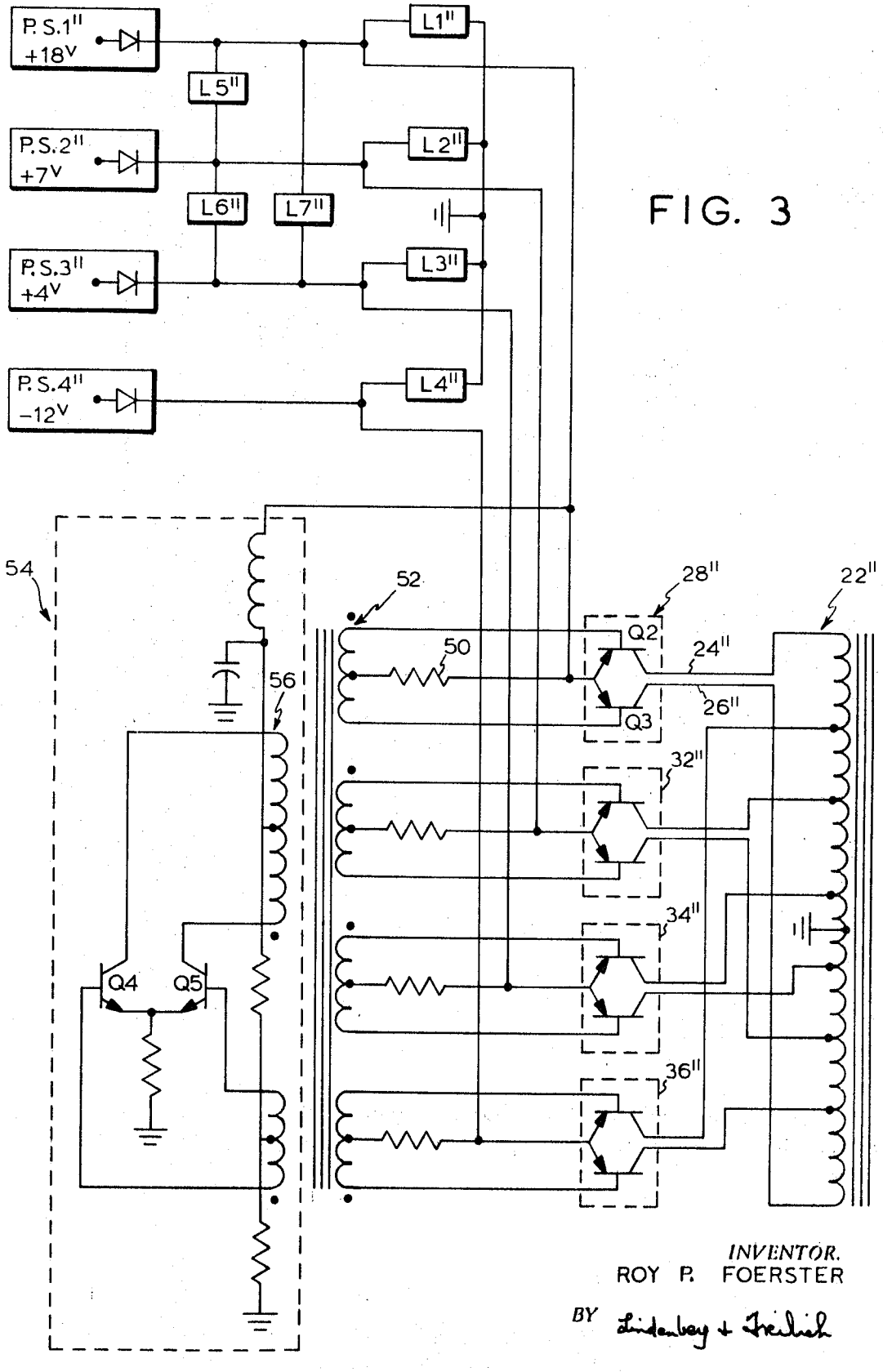


FIG. 3

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POWER SUPPLY SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to improvements in power supply systems particularly useful in electronic systems such as digital computer systems for supplying power thereto at multiple voltage levels.

Many electronic systems, and particularly digital computer systems, incorporate multiple voltage levels for such purposes as "clamping" logic levels, "decision" reference levels and bias supplies. The use of multiple voltage levels is desirable inasmuch as it permits the design of a more rigorous system and generally improves circuit flexibility and reliability. There are, however, a number of problems arising from the need for supplying these multiple voltage levels. Some of the problems involve: (1) the sheer bulk of the power supply hardware required, (2) the number of adjustments which must be made in the power supplies, and (3) the complexity of design analysis needed to accommodate multiple and independent power supply variations.

An additional problem arises due to the fact that conventional power supplies conduct current unilaterally while power supply loads in typical electronic systems vary widely and may even become negative. That is, a particular voltage level may have to act as a current source one moment and as a current sink the next moment.

Description of the Prior Art

The prior art in power supply design cannot realistically achieve a supply which will conduct current bilaterally. Thus, the conventional solution to this problem has been to design the power supply with a shunt preload so that it is never necessary for a reverse current to flow within the power supply itself. In this way, the power supply only sees a unilateral load which it can handle in a normal manner. It will be readily recognized, however, that this technique results in a considerable amount of lost power in the shunt path.

SUMMARY OF THE INVENTION

Power supply systems embodying the present invention function to automatically redistribute power between voltage levels as load conditions change. That is, as load current directions change, power from a voltage level bus acting as a current sink can be translated, with minimum loss, to a different voltage level bus requiring a current source, thus enabling embodiments of the invention to operate at very high power efficiencies.

Briefly, in accordance with the present invention, a power supply system is provided which uses a plurality of pairs of bilateral synchronous switches in conjunction with a transformer to supply multiple DC potential levels as defined by the transformer turns ratios. The bilateral switch pairs permit the flow of power to the various levels to be automatically balanced with very low loss.

In a preferred embodiment of the invention, a single main DC power supply is connected through a pair of switches to the terminals of an autotransformer. The switches are alternately driven on and off by a square wave oscillator to convert the supplied DC potential to AC. Other switch pairs driven by the same oscillator are connected to appropriately located taps along the autotransformer to convert AC back to DC at the desired voltage levels.

In accordance with a significant aspect of the invention the switch pairs are operated bilaterally to thus permit power to flow from a transformer tap to a potential level supply bus or from a bus through a tap for redistribution by the transformer to other voltage levels.

A system in accordance with the invention can be very simply and reliably implemented. By using only low loss elements, e.g., transistor switches, very high power efficiencies are readily realized. No adjustments are required within the power supply system and output voltage levels are inherently

fixed by the level of the main power supply and the turns ratios of the transformer. This arrangement assures that voltage variations occur proportionately, rather than independently, as is the case in conventional prior art systems. The number of voltage levels which can be provided is limited only by the number of taps on the transformer and the number of transistor switch pairs utilized.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1(*a*) is a block diagram of a typical prior art power supply system;

FIG. 1(*b*) is a schematic diagram of a typical digital computer circuit shown for the purpose of demonstrating how loads can sometimes act as sinks and at other times act as sources with respect to particular potential levels in a multilevel system;

FIG. 2 is a block diagram of a power supply system embodying the present invention; and

FIG. 3 is a more detailed block diagram of the system of FIG. 2.

Attention is now called to FIG. 1(*a*) which illustrates a typical prior art power supply system for supplying DC power at multiple voltage levels to an electronic system such as a digital computer system. The electronic system is normally comprised of many different loads intended to operate between various potential levels. Thus, for example, the exemplary system of FIG. 1(*a*) includes loads L1, L2, L3 and L4 intended to operate respectively between +18 volts, +7 volts, +4 volts, −12 volts, and ground. Additionally, a load L5 is intended to operate between +18 volts and +7 volts, a load L6 between +7 volts and +4 volts, and a load L7 between +18 volts and +4 volts.

In order to apply the indicated voltage levels across the various loads, it is common practice to utilize a plurality of separate power supply modules, each providing DC power at a different voltage level. For example, power supply module PS1 can provide DC power at +18 volts. Similarly, power supply modules PS2, PS3, and PS4 can respectively provide DC power at +7 volts, +4 volts, and −12 volts. Thus, as is shown in FIG. 1(*a*), loads L1, L2, L3, and L4 will be respectively connected between ground and the output terminals of power supply modules PS1, PS2, PS3, and PS4. Load L5 is connected between the output terminals of power supply modules PS1 and PS2, load L6 between the output terminals of power supply modules PS2 and PS3, and load L7 between the output terminals of power supply modules PS1 and PS3.

Typical power supply modules constitute unilateral current conducting devices and are schematically illustrated in FIG. 1(*a*) as including a diode. Thus, each of the power supply modules of FIG. 1(*a*) can act as a current source providing DC power at a specific voltage level. However, in typical electronic systems, it is sometimes necessary for the various voltage levels to function at one moment as a current source and at another moment as a current sink.

More particularly, as is shown in FIG. 1(*a*) power supply module PS1 provides an output current comprised of load current components I1, I5, and I7 respectively flowing through loads L1, L5, and L7. Power supply module PS2 supplies load currents I2 and I6 through loads L2 and L6 respectively. As load conditions change, it may occur that the load current component I5 exceeds the magnitude of the sum of the load current components I2 and I6. Since the power supply module PS2 is a unilateral current conducting device, some means must be provided for handling the excess current supplied by component I5. In typical prior art systems, this excess current is handled by providing a shunt resistor R_s2 connected between the output of power supply module PS2 and ground. That is, when the +7 volt level is acting as a current sink, resistor R_s2 passes the current $I_s2=I5-(I2+I6)$.

Similarly, the +4 volt level will act as a current sink when the sum of the current components I6 and I7 exceeds current component I3. In order to handle this excess current, a resistor

R_s3 is connected between the output of power supply module PS3 and ground. Resistor R_s3 will draw the current $I_S3=(I6+I7)-I3$.

In order to better understand why certain ones of the various voltage levels in the system of FIG. 1(*a*) can at different times operate as either current sources or current sinks, attention is now called to FIG. 1(*b*) which illustrates a circuit typical of the type employed in digital computer systems. Briefly, the circuit of FIG. 1(*b*) comprises an AND gate controlling a transistor switch Q1. When the potentials applied to the input terminals A and B are both high, e.g., +18 volts, then the output potential will be at ground. On the other hand, when ground potential is applied to either input terminal A or B, then the output potential will be at +7 volts.

More particularly, the circuit of FIG. 1(*b*) includes an NPN switching transistor Q1 whose collector is connected through a resistor R1 to the +18 volt level. Additionally, the collector of transistor Q1 is connected through clamping diode D1 to the +7 volt level. The emitter of transistor Q1 is grounded. The base of transistor Q1 is connected through a resistor R2 to the −12 volt level and through resistor R4 to the output and an AND gate comprised of diode D2 and D3 and resistor R3. The other terminals of diodes D2 and D3 are respectively connected to input terminals A and B and the other terminal of resistor R3 is connected to the +18 volt level.

In the operation of the circuit of FIG. 1(*b*), assume binary "o" and "1" levels at input terminals A and B are respectively represented by ground and +18 volt potentials. If a binary "o" is applied to either input terminal A or B, the AND gate output terminal **10** will be at ground. On the other hand, if binary "1's" are applied to both input terminals A and B, then the AND gate output terminal **10** will be at some positive potential level sufficient to forward bias transistor Q1 to thus draw an increased current from the +18 volt level through resistor R1. In the absence of the clamping diode D1 the collector of transistor Q1 would be at about +18 volts when transistor Q1 is not conducting and at about ground potential when transistor Q1 is conducting. However, as a consequence of the diode D1, when transistor Q1 is not conducting, its collector is at about +7 volts and when transistor Q1 conducts, its collector falls to about ground potential.

Thus, from the foregoing explanation of the operation of the circuit of FIG. 1(*b*), it will be recognized that clamping diode D1 will draw current from +18volt level only when transistor Q1 is not conducting. If the current through diode D1 is considered the component **15** in FIG. 1(*a*), then it will be recognized that in a complex digital computer system comprised of a multiplicity of circuits of the type generally shown in FIG. 1(*b*), many of the voltage levels can at different times act as current sources or current sinks. As previously pointed out in conjunction with FIG. 1(*a*), in order to tolerate this condition utilizing unilaterally conducting power supply modules, it is necessary to provide shunt resistor, as R_s2 and R_s3, so that the power supply modules will at all times see a unidirectional load. However, it will be recognized that the current drawn through the shunt resistors represents wasted power. The present invention is directed to a system which automatically redistributes power between the various voltage levels as needed. That is, as load current directions change, power from a level acting as a current sink is translated, with minimum loss, to a level requiring a current source.

Attention is now called to FIG. 2 of the drawing which illustrates a block diagram of a power system embodying the present invention. The system of FIG. 2 employs the same power supply modules as in the system of FIG. 1(*a*). That is, the system of FIG. 2 includes a +18 volts, +7 volt, +4 volt, and −12 volt power supply, respectively identified as PS1′, PS2′, PS3′, and PS4′. As previously pointed out, the power supply modules can be considered as unilaterally current conducting modules, as represented by the diodes contained within the power supply module blocks. The same load devices as are shown in the system of FIG. 1(*a*) are also shown in the system of FIG. 2. Thus, loads L1′, L2′,L3′ and L4′ are respectively connected between the output terminals or supply busses of the power supply modules PS1′, PS2′, PS3′, PS4′ and ground. Loads L5′, L6′, and L7′ are connected similarly to the corresponding loads shown in FIG. 1(*a*).

In accordance with the present invention, a transformer **20**, preferably an autotransformer, is provided for redistributing power between the various voltage levels so that as load current directions change, power from a level acting as a current sink can be translated, with minimum loss, to a level requiring a current source.

The autotransformer is comprised of a single coil **22** having first and second terminals **24** and **26** and a center tap **27** connected to ground. A single pole double throw switch **28** couples the supply bus of power supply module PS1′ to the terminals **24** and **26**. The switch **28** is driven by switch drive means **30** between the terminals **24** and **26** to thereby apply a square wave across the winding **22**.

Each of the other power supply modules PS2′, PS3′, and PS4′ is connected through single pole double throw switches **32, 34**, and **36** respectively to pairs of taps appropriately positioned along the winding **22**. More particularly, the pole of switch **32** cooperates with taps **38** and **40**, the pole of switch **34** with taps **42** and **44** and the pole of switch **36** with taps **46** and **48**. All of the switches **28, 32 34** and **36** are synchronously driven by the drive means **30**. Thus, as +18 volt power supply module PS1′ applies a square wave across the winding **22**, each of the synchronously driven poles of switches **32 34** and **36** picks up a DC potential defined by the transformer turns ratio for application to the supply bus of the power supply module to which it is connected. In the event the load L5′, for example, supplies more current than is drawn by loads L2′ and L6′, the excess current, instead of being shunted through a resistor, is applied through the switch **32** to the transformer winding **22** for redistribution to one of the other levels requiring a current source.

It will be noted that in order to derive the −12 volt level from the transformer winding **22**, the taps **46** and **48** associated with switch **36** are merely reversed with respect to the center tap **27** of the winding **22**.

Whereas the system shown in FIG. 2 has been illustrated as utilizing electromechanical single pole double throw switches, it will be recognized that in an actual embodiment of the invention, it would be preferable to utilize electronic switches such as transistors. A practical implementation of an embodiment of the invention is illustrated in FIG. 3 wherein the primed elements of FIG. 2 are double primed.

More particularly, the embodiment of FIG. 3 includes power supply modules PS1″, PS2″, PS3″, and PS4″ respectively providing DC power at voltage levels of +18 volts, +7 volts, +4 volts, and −12 volts. Loads L1″ - L7″ are connected to the power supply modules in the same manner as the corresponding loads in FIG. 2. In the embodiment of FIG. 3 each of the bilaterally conducting switches **28″, 32″, 34″** and **36″** is comprised of a pair of PNP transistors Q2 and Q3. The emitters of transistors Q2 and Q3 are connected in common and to the supply bus of the corresponding power supply module. Thus, the output of power supply module PS1″ is connected to the emitters of transistors Q2 and Q3 of switch **28′**. The collectors of the transistors are connected to terminals **24″** and **26″** of a transformer winding **22″**. The emitters of transistors Q2 and Q3 of a switch **28″** are connected through a resistor **50** to the center tap of a transformer secondary winding **52**. The terminals of winding **52** are connected across the bases of transistors Q2 and Q3 of switch **28″**. The switches **32″, 34″** and **36″** are implemented identically to the switch **28″**.

The transistors Q2 and Q3 of each of the switches are alternately energized by an oscillator **54** (corresponding in function to the switch drive means **30** of FIG. 2) comprised of transistors Q4 and Q5 and driven by the output of the +18 volt power supply module PS1 ″. The collectors of transistors Q4 and Q5 are coupled to each other through a transformer winding **56** inductively coupled to the plurality of secondary windings **52** each synchronously driving the different one of

the switches 28'', 32'', 34'' and 36''. The oscillator 54 construction shown in FIG. 3 is conventional and is only exemplary of several different circuit arrangements which can be employed.

The embodiment of FIG. 3 operates identically to the schematically illustrated embodiment of FIG. 2 in that each of the transistors Q2 and Q3 of each of the switches can bilaterally conduct current to and from the autotransformer winding 22' to thus enable the winding 22' to automatically redistribute power between the various voltage levels.

From the foregoing, it should be recognized that a particularly efficient power supply system has been disclosed herein for providing DC power to a plurality of loads at multiple voltage levels. Power efficiency is achieved by utilizing a transformer for automatically redistributing power between various voltage levels through bilateral switches, as load current conditions change.

I claim:

1. A power supply system for supplying DC power at different voltage levels to multiple supply busses for application to independently operated loads connected between various busses and wherein at least some of said busses can at various times act either as a current sink or a current source, said system comprising:

a transformer having first and second terminals and at least two tap pairs each comprised of spaced first and second taps;

a main power supply module capable of providing DC power at a first potential level;

second and third power supply modules respectively capable of providing DC power at second and third potential levels each different from said first level;

a first switching means for selectively defining first and second states respectively coupling said main power supply across said first and second terminals in first and second polarity directions;

a second switching means including first and second bidirectional current conducting switches respectively connected between first and second taps of one of said tap pairs and a common second switching means output terminal;

means for connecting said second power supply module to said second switching means output terminal;

a third switching means including first and second bidirectional current conducting switches respectively connected between first and second taps of a second of said tap pairs and a common third switching means output terminal;

means for connecting said third power supply module to said third switching means output terminal;

said tap pairs being located in accordance with the potential levels of the power supply modules to which they are to be connected; and

means for alternately switching said first switching means between said first and second states and for synchronously closing said second and third switching means first switches coincident with said first state and said second and third switching means second switches coincident with said second state so as to convert the AC signals produced at said tap terminals into DC levels appropriate for said second and third power supply modules respectively connected thereto.

2. The system of claim 1 wherein said transformer means comprises an autotransformer.

3. The system of claim 1 wherein each of said second switching means current conducting switches comprises a semiconductor having a control terminal and first and second current conducting terminals; and

means connecting said first current conducting terminals of said second switching means current conducting switches to said first and second taps of said one tap pair and said second current conducting terminals of said second switching means current conducting switches to said second switching means output terminal.

4. The system of claim 3 including oscillator means; and means coupling said oscillator means to said control terminals of said second switching means current conducting switches.

5. In an electronic system including a plurality of power supply modules each providing DC power at a different voltage level to a plurality of load devices each connected between a pair of voltage levels, a power distribution system for distributing power from a level which would otherwise act as a current sink to a level acting as current source, said distribution system including:

a transformer means including a pair of terminals and a plurality of pairs of taps located in accordance with the signal levels to be provided thereat;

a first switching means coupling one of said power supply modules across said pair of terminals;

a plurality of additional switching means each coupling a different one of said power supply modules across a different pair of said taps, said pairs of taps being located in accordance with the potential levels of the power supply modules to which they are to be connected;

each of said switching means including first and second bidirectional current conducting switches, each connected between a power supply module and different taps or terminals of a common pair; and

means for alternately switching said first and second current conducting switches of all of said switching means in synchronism so as to convert the AC signals produced at said tap terminals into DC levels appropriate for said second and third power supply modules respectively connected thereto.

6. The system of claim 5 wherein each of said bidirectional current conducting switches comprises a semiconductor having a control terminal and first and second current conducting terminals; and

means connecting the first current conducting terminals in each switching means in common and the second current conducting terminals in each switching means to different taps or terminals of a common pair.

7. The system of claim 6 including oscillator means; and means coupling said oscillator means to the control terminals of all of said switching means.