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## ELECTRIC ARC WELDING SYSTEM

The present invention relates to the art of electric arc welding and more particularly to an electric arc welding system for combining power supplies to operate tandem electrodes.

### INCORPORATION BY REFERENCE

5 The present invention is directed to an electric arc welding system utilizing high capacity alternating circuit power supplies for driving two or more tandem electrodes of the type used in seam welding of large metal blanks. Although the invention can be used with any standard AC power supply with switches for changing the output polarity, it is preferred that the power supplies use the switching concept disclosed in Stava 6,111,216 wherein the power supply is an inverter having two large output polarity switches with the arc current being reduced before the switches reverse the polarity. Consequently, the term "switching point" is a complex procedure whereby the power supply is first turned off awaiting a current less than a preselected value, such as 100 amperes. Upon reaching the 100 ampere threshold, the output switches of the power supply are reversed to reverse the polarity from the D.C. output link of the inverter. Thus, the 10 "switching point" is an off output command, known as a "kill" command, to the power supply inverter followed by a switching command to reverse the output polarity. The kill output can be a drop to a decreased current level. This procedure is duplicated at each successive polarity reversal so the AC power supply reverses polarity only at a low current. In this manner, snubbing circuits for the output polarity controlling switches are reduced in size or eliminated.

15 Since this switching concept is preferred to define the switching points as used in the present invention, Stava 6,111,216 is incorporated by reference. The concept of an AC current for tandem electrodes is well known in the art. Prior Application Serial No. 09/336,804 filed June 12, 1999 discloses a system whereby tandem electrodes are each powered by a separate inverter type power supply. The frequency is varied to reduce the interference between alternating current in the adjacent tandem electrodes. Indeed, this application relates to single power sources for driving either a DC powered electrode followed by an AC electrode or two or more AC driven electrodes. In each instance, a separate inverter type power supply is used for each electrode and, in the alternating current high capacity power supplies, the switching point concept of Stava 6,111,216 is employed. This system for separately driving each of the tandem 20 electrodes by a separate high capacity power supply is background information to the present

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invention and is incorporated herein as such background. In a like manner, United States application 09/406,406 filed September 27, 1999 discloses a further arc welding system wherein each electrode in a tandem welding operation is driven by two or more independent power supplies connected in parallel with a single electrode arc. The system involves a single set of 5 switches having two or more accurately balanced power supplies forming the input to the polarity reversing switch network operated in accordance with Stava 6,111,216. Each of the power supplies is driven by a single command signal and, therefore, shares the identical current value combined and directed through the polarity reversing switches. This type system requires large polarity reversing switches since all of the current to the electrode is passed through a single set 10 of switches. This application does show a master and slave combination of power supplies for a single electrode and discloses general background information to which the invention is directed. For that reason, this application is also incorporated by reference.

#### BACKGROUND OF INVENTION

Welding applications, such as pipe welding, often require high currents and use several 15 arcs created by tandem electrodes. Such welding systems are quite prone to certain inconsistencies caused by arc disturbances due to magnetic interaction between two adjacent tandem electrodes. A system for correcting the disadvantages caused by adjacent AC driven tandem electrodes is disclosed in prior application Serial No. 09/336,804 filed June 21, 1999 by assignee of this invention. In that prior application, each of the AC driven electrodes has its own 20 inverter based power supply. The output frequency of each power supply is varied so as to prevent magnetic interference between adjacent electrodes. This system requires a separate power supply for each electrode. As the current demand for a given electrode exceeds the current rating of the inverter based power supply, a new power supply must be designed, engineered and manufactured. Thus, such system for operating tandem welding electrodes require high capacity 25 or high rated power supplies to obtain high current as required for pipe welding. To decrease the need for special high current rated power supplies for tandem operated electrodes, assignee developed the system disclosed in application Serial No. 09/406,406 wherein each AC electrode is driven by two or more inverter power supplies connected in parallel. These parallel power supplies have their output current combined at the input side of a polarity switching network. 30 Thus, as higher currents are required for a given electrode, two or more parallel power supplies

are used. In this system, each of the power supplies are operated in unison and share equally the output current. Thus, the current required by changes in the welding conditions can be provided only by the over current rating of a single unit. A current balanced system did allow for the combination of several smaller power supplies; 5 however, the power supplies had to be connected in parallel on the input side of the polarity reversing switching network. As such, large switches were required for each electrode. Consequently, such system overcame the disadvantage of requiring special power supplies for each electrode in a tandem welding operation of the type used in pipe welding; but, there is still the disadvantage that the switches must be quite large and the 10 input, paralleled power supplies must be accurately matched by being driven from a single current command signal. This prior application does utilize the concept of a synchronizing signal for each welding cell directing current to each tandem electrode. However, the system still required large switches. This type of system was available for 15 operation in an ethernet network interconnecting the welding cells. In ethernet interconnections, the timing cannot be accurately controlled. In the system described, the switch timing for a given electrode need only be shifted on a time basis, but need not be accurately identified for a specific time. Thus, the described system requiring balancing the current and a single switch network has been the manner of obtaining high capacity 20 current for use in tandem arc welding operations when using an ethernet network or an internet and ethernet control system. There is a desire to control welders by an ethernet network, with or without an internet link. Due to timing limitation, these networks dictated use of tandem electrode systems of the type using only general synchronizing 25 techniques.

Thus, a need exists to provide an arc welding cell or system including two 25 parallel power supplies for driving a single electrode, wherein the power supplies are interconnected for coordinating the switching points or commands, but are independently controlled by an external network providing non-time sensitive parameters.

Another need exists to provide the arc welding cell or system, as defined above, which cell or system can be used for driving two or more tandem mounted electrodes with 30 offset phase relationship to prevent or reduce electrode interference.

Still a further need exists to provide an arc welding cell or system, as defined above, which cell or system utilizes a series of smaller power supplies that are combinable to create a high capacity welding power supply for a single electrode. In this manner, several small power supplies can be combined to produce larger power supplies 35 as greater current demands are experienced.

Still another need exists to provide an arc welding cell or system, as defined above, which cell or system allows control of one power supply in the cell by parameters different from any other power supply. In this manner, one power supply can be 5 maintained at a higher level while the other power supplies have a greater range for responding to larger current demands.

Another need exists to provide an electric arc system including paralleled power supplies driving a single electrode with AC current, where there is matching of the polarity reversing switches to provide current added together at the electrode.

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#### SUMMARY

It is advantageous in high current systems for arc welding to drive one electrode with several paralleled inverter type power supplies while accommodating network control. The disadvantage has been that such systems required the current to be accurately balanced and required a single high capacity output switching network. Such 15 systems could be controlled by a network; however, the parameter to each paralleled power supply could not be varied. Each of the cells could only be offset from each other by a synchronizing signal. Such systems were not suitable for central control by the internet and/or local area network control because an elaborate network to merely provide offset between cells was not advantageous.

The present invention utilizes the concept of a single AC arc welding cell for each electrode wherein the cell itself includes one or more paralleled power supplies each of which has its own switching network. The output of the switching network is then combined to drive the electrode. This allows the use of relatively small switches for polarity reversing of the individual power supplies paralleled in the system. In addition, relatively small power supplies can be paralleled to build a high current input to each of several electrodes used in a tandem welding operation. The use of several independently controlled power supplies paralleled after the polarity switch network for driving a single electrode allows advantageous use of a network, such as the internet or ethernet.

In accordance with the invention, smaller power supplies in each system are connected in parallel to power a single electrode. By coordinating switching points of each paralleled power supply with a high accuracy interface, the AC output current is the sum of currents from the paralleled power supplies without combination before the polarity switches. By using this concept, the ethernet network, with or without an internet link, can control the weld parameters of each paralleled power supply of the welding system. The timing of the switch points is accurately controlled by the novel interface, whereas the weld parameters directed to the controller for each power supply can be provided by an ethernet network which has no accurate time basis. Thus, an internet link can be used to direct parameters to the individual power supply controllers of the welding system for driving a single electrode. There is no need for a time based accuracy of these weld parameters coded for each power supply. In the preferred implementation, the switch point is a "kill" command awaiting detection of a current drop below a minimum threshold, such as 100 amperes. When each power supply has a switch command, then they switch. The switch points between parallel power supplies, whether instantaneous or a sequence involving a "kill" command with a wait delay, are coordinated accurately by an interface card having an accuracy of less than  $10 \mu s$  and preferably in the range of  $1-5 \mu s$ . This timing accuracy coordinates and matches the switching operation in the paralleled power supplies to coordinate the AC output current.

By using the internet or ethernet local area network, the set of weld parameters for each power supply is available on a less accurate information network, to which the controllers for the paralleled power supplies are interconnected with a high accuracy digital interface card. Thus,

the switching of the individual, paralleled power supplies of the system is coordinated. This is an advantage allowing use of the internet and local area network control of a welding system. The information network includes synchronizing signals for initiating several arc welding systems connected to several electrodes in a tandem welding operation in a selected phase 5 relationship. Each of the welding systems of an electrode has individual switch points accurately controlled while the systems are shifted or delayed to prevent magnetic interference between different electrodes. This allows driving of several AC electrodes using a common information network. The invention is especially useful for paralleled power supplies to power a given electrode with AC current. The switch points are coordinated by an accurate interface and the 10 weld parameter for each paralleled power supply is provided by the general information network. This network can also operate a DC electrode which does not require the interconnected switching points used in the present invention.

In accordance with the present invention, there is provided an electric arc welding system for creating an AC welding arc between the electrode and workpiece. As will be explained, the 15 system can drive one electrode by a single inverter. As a feature of the system, two or more power supplies can drive a single electrode. Thus, the system comprises a first controller for a first power supply to cause the first power supply to create an AC current between the electrode and workpiece by generating a switch signal with polarity reversing switching points in general timed relationship with respect to a given system synchronizing signal received by the first controller. This first controller is operated at first welding parameters in response to a set of first 20 power supply specific parameter signals directed to the first controller. There is provided at least one slave controller for operating the slave power supply to create an AC current between the same electrode and workpiece by reversing polarity of the AC current at switching points. The slave controller operates at second weld parameters in response to the second set of power supply specific parameter signals to the slave controller. An information network connected to the first controller and the second or slave controller contains digital first and second power supply 25 specific parameter signals for the two controllers and the system specific synchronizing signal. Thus, the controllers receive the parameter signals and the synchronizing signal from the information network, which may be an ethernet network with or without an internet link, or merely a local area network. The invention involves a digital interface connecting the first 30

controller and the slave controller to control the switching points of the second or slave power supply by the switch signal from the first or master controller. In practice, the first controller starts a current reversal at a switch point. This event is transmitted at high accuracy to the slave controller to start its current reversal process. When each controller senses an arc current less 5 than a given number, a "ready signal" is created. After a "ready" signal from all paralleled power supplies, all power supplies reverse polarity. This occurs upon receipt of a strobe or look command each 25  $\mu$ s. Thus, the switching is in unison and has a delay of less than 25  $\mu$ s. Consequently, both of the controllers have interconnected data controlling the switching points 10 of the AC current to the single electrode. The same controllers receive parameter information and a synchronizing signal from an information network which in practice comprises a combination of internet and ethernet or a local area ethernet network. In accordance with the invention, the timing accuracy of the digital interface is less than about 10  $\mu$ s and, preferably, in the general range of 1-5  $\mu$ s. Thus, the switching points for the two controllers driving a single electrode are commanded within less than 5  $\mu$ s. Then, switching actually occurs within 25  $\mu$ s. 15 At the same time, relatively less time sensitive information is received from the information network also connected to the two controllers driving the AC current to a single electrode in a tandem welding operation. The 25  $\mu$ s maximum delay can be changed, but is less than the switch command accuracy.

In accordance with another aspect of the present invention there is provided an electrical 20 arc welding system for creating an AC welding arc between an electrode and workpiece. The system comprises a first power supply to create a first AC current with first weld parameters between the electrode and workpiece by generating a first switch controlling signal reversing polarity of the first current at a specific switch time. A second power supply is provided to create a second AC current with second weld parameters between the same electrode and workpiece by 25 a second switch controlling signal reversing polarity of the second current at a switch time coordinated with the specific switch time of the first power supply. The invention involves a timing interface between the first and second power supplies to create the second switch reversing signal by the first switch reversing signal where the switch signals are 10  $\mu$ s and preferably less than 5  $\mu$ s of the specific switch time. Consequently, the paralleled individually 30 switched power supplies are coordinated by accurately matching the switch reversing times. The

master controller has a switch command signal synchronized with a phase signal. The command signal is transmitted rapidly by the digital interface to the controller of the paralleled power supply. The second power supply then processes its switch point. In one embodiment, these switch points cause the reversal of polarity. Preferably, these switch points merely cause the inverters to be "killed" so they decrease the currents by a time constant curve. When both currents are reduced below a given amount, the paralleled power supplies switch.

In the invention, the interconnected controllers have a polarity logic indicating the polarity of the two output currents. This merely assures that the two power supplies are switched with matching polarities. In this manner, the controller of the first power supply tells the controller of the second power supply which polarity is being reversed. The polarity logic is not a part of the invention although it is used in implementing the invention. The accuracy of the switching commands is the critical aspect of the digital high speed interconnecting interface between controllers that are otherwise controlled by an information network, such as an ethernet network with or without an internet link.

In accordance with still a further aspect of the invention, an electric arc welding system is provided for creating a first AC welding arc between a first weld electrode and a workpiece and a second AC welding arc between a second weld electrode and the same workpiece as the first and second electrodes move along the workpiece. This is the definition of a tandem mounted welding operation. The invention also comprises a system including a first cell with at least two power supplies connected to the first arc and operated at a first synchronized time determined by a first synchronized signal with first weld parameters and a high accuracy interconnection interface between the power supplies of the first cell to correlate polarity switching of the power supplies in the first cell. There is also provided a second cell with at least two power supplies connected to the second arc and operated at a second synchronized time determined by a second synchronized signal offset from the first synchronized signal with second weld parameters and a high accuracy interconnection interface between the power supplies of the second cell to correlate polarity switching of the power supplies of the second cell. A low accuracy information network, such as an internet link connected to a local area network, is connected to the first and second cells and contains digital signals including the first and second weld parameters and digitized first and second synchronizing signals. In this manner, the paralleled power supplies

of each cell are interconnected by a high accuracy interface whereas the several controllers are operated with signals in the information network that are not time sensitive.

According to another aspect of the invention, there is provided an electric arc welding system for creating an AC welding arc between an electrode and a workpiece, said system comprising a first power supply to create a first AC current with first weld parameters between said electrode and workpiece by generating a first switch controlling signal reversing polarity of said first current at a specific active switch time, a second power supply to create a second AC current with second weld parameters between said electrode and workpiece by a second switch controlling signal reversing polarity of said second current at a switch activate time, and a timing interface between said first and second power supplies to create said second signal by said first signal where said switch activate time of said second power supply is within about 10  $\mu$ s of said specific switch activate time of said first power supply.

According to a further aspect of the invention, there is provided an electric arc welding system for creating an AC welding arc between an electrode and a workpiece, said system comprising a first power supply to create a first AC current with first weld parameters between said electrode and workpiece by generating a first switch signal for reversing polarity of said first current at a specific time, a second power supply to create a second AC current with second weld parameters between said electrode and workpiece by a second switch signal for reversing polarity of said second current at a given time, a timing interface between said first and second power supplies to create said second signal by said first signal, and a circuit to switch said power supplies after said first and second signal, said circuit includes a detector to switch said power supplies when the current of said power supplies is less than a given amount.

According to a still further aspect of the invention, there is provided an electric arc welding system for creating an AC welding arc between an electrode and a workpiece, said system comprising a first power supply to create a first AC current with first weld parameters between said electrode and workpiece by generating a first switch controlling signal reversing polarity of said first current at a specific active switch time, a second power supply to create a second AC current with second weld parameters between said electrode and workpiece by a second switch controlling signal reversing polarity of said second current at a switch activate time, and a timing interface between said first and second power supplies to create said second signal by said first signal where said first and second signals are within about 10  $\mu$ s.

According to another aspect of the invention, there is provided an electric arc welding system for creating an AC welding arc between an electrode and workpiece, said system comprising a first power supply to create a first AC current waveform between said electrode and a workpiece by generating a first switch controlling signal reversing polarity of said first current at a specific active switch time, a second power supply to create a second AC current waveform between said electrode and workpiece by a second switch controlling signal reversing polarity of said second current at a switch activate time, and a timing interface between said first and second power supplies to create said second signal by said first signal.

According to a further aspect of the invention, there is provided an electric arc welding system comprising a first power source with a first output polarity changing switch network creating a first AC output with first output leads connected across an electrode and a workpiece and a second power source with a second output polarity changing switch network creating a second AC output with second output leads connected across said electrode and workpiece in parallel with said first leads whereby the current from said power sources is added.

According to a further aspect of the invention, there is provided in an electric arc welding system for creating a first waveform across a first gap between an first electrode and a workpiece and a second waveform across a second gap between a second electrode and said workpiece while said electrodes are moved relative to said workpiece, the improvement comprising: two power sources for creating at least one of said waveforms, said at least one waveform created by a number of current pulses occurring at a frequency of at least 18 kHz with a magnitude of each pulse controlled by a wave shaper and a circuit synchronizing said first and second waveforms.

According to a further aspect of the invention, there is provided an electric arc welding system for creating a first AC welding arc with a first current waveform between a first electrode and a workpiece by a first power supply and a second AC welding arc with a second current waveform between a second electrode and a workpiece by a second power supply as said first and second electrodes are moved in unison along a welding path, said first and second power supply each comprising a high speed switching inverter creating its waveform by a number of current pulses occurring at a frequency of at least about 18 kHz with the magnitude of each current controlled by a wave shaper and the polarity of said waveform controlled by a switching signal, said first waveform being offset from said second waveform by a controlled length of time.

These and other features and advantages will become apparent from the following description taken together with the accompanying drawings.

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#### BRIEF DESCRIPTION OF DRAWINGS

FIGURE 1 is a block diagram of the preferred embodiment of the present invention;

FIGURE 2 is a wiring diagram of two paralleled power supplies, each of which include a switching output which power supplies are used in practicing the invention;

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FIGURE 3 is a pictorial view showing three tandem operated electrodes each of which is driven by a welding system of the present invention with the offset synchronizing signals from

the information network shown in the graph of FIGURE 3A and using the general schematic diagram of FIGURE 3B;

FIGURE 4 is a block diagram showing in more detail the preferred embodiment of the present invention to operate two separate welding systems or cells from a single central control;

5 FIGURE 5 is a schematic layout of the invention used to drive several tandem electrodes as shown in the pictorial view of FIGURE 5A;

FIGURE 6 is a schematic layout of the invention used for driving two tandem electrodes as shown pictorially in FIGURE 6A;

10 FIGURE 7 is a pictorial view showing two tandem mounted electrodes operated by offset switching operation shown in the graphs of FIGURE 7A using the switch point concept of Stava 6,111,216; and,

FIGURE 8 is a schematic layout of the software program to cause switching of the paralleled power supplies as soon as the coordinated switch commands have been processed and the next coincident signal has been created.

15 **PREFERRED EMBODIMENT**

Referring now to the drawings wherein the showings are for the purpose of illustrating a preferred embodiment of the invention only and not for the purpose of limiting same, in FIGURE 1 there is a single electric arc welding system S in the form of a single cell to create an alternating current as an arc at weld station WS. This system or cell includes a first master welder A with output leads 10, 12 in series with electrode E and workpiece W in the form of a pipe seam joint or other welding operation. Hall effect current transducer 14 provides a voltage in line 16 proportional to the current of welder A. Less time critical data, such as welding parameters, are generated at a remote central control 18. In a like manner, a slave following welder B includes leads 20, 22 connected in parallel with leads 10, 12 to direct an additional AC current to the weld station WS. Hall effect current transducer 24 creates a voltage in line 26 representing current levels in welder B during the welding operation. Even though a single slave or follower welder B is shown, any number of additional welders can be connected in parallel with master welder A to produce an alternating current across electrode E and workpiece W. A novel feature is the combining of AC current at the weld station instead of prior to a polarity switching network. Each welder would include a controller and inverter based power supply

illustrated as a combined master controller and power supply 30 and a slave controller and power supply 32. In accordance with the invention, controllers 30, 32 receive parameter data and synchronization data from a relatively low level logic network. The parameter information or data is power supply specific whereby each of the power supplies is provided with the desired 5 parameters such as current, voltage and/or wire feed speed. A low level digital network can provide the parameter information; however, the advantage of the invention relates to the ability to parallel several controller and power supply units having AC output currents in a manner that the switching of the AC current for polarity reversal occurs at the same time. The "same" time indicates a time difference of less than 10  $\mu$ s and preferably in the general range of 1-5  $\mu$ s. To 10 accomplish precise coordination of the AC output from power supply 30 and power supply 32, the switching points and polarity information can not be provided from a general logic network wherein the timing is less precise. Thus, in accordance with the invention, the individual AC power supplies are coordinated by high speed, highly accurate DC logic interface referred to as 15 "gateways." As shown in FIGURE 1, power supplies 30, 32 are provided with the necessary operating parameters indicated by the bi-directional leads 42m, 42s, respectively. This non-time sensitive information is provided by a digital network shown in FIGURE 1 and to be described later. Master power supply 30 receives a synchronizing signal as indicated by unidirectional line 40 to time the controllers operation of its AC output current. The polarity of the AC current for power supply 30 is outputted as indicated by line 46. The actual switching command for the AC 20 current of master power supply 30 is outputted on line 44. The switch command tells power supply S, in the form of an inverter, to "kill," which is a drastic reduction of current. In an alternative, this is actually a switch signal to reverse polarity. The "switching points" or command on line 44 preferably is a "kill" and current reversal commands utilizing the "switching points" as set forth in Stava 6,111,216. Thus, timed switching points or commands are outputted 25 from power supply 30 by line 44. These switching points or commands may involve a power supply "kill" followed by a switch ready signal at a low current or merely a current reversal point. The switch "ready" is used when the "kill" concept is implemented because neither inverters are to actually reverse until they are below the set current. The polarity of the switches of controller 30 controls the logic on line 46. Slave power supply 32 receives the switching point or command logic on line 44b and the polarity logic on line 46b. These two logic signals are 30

interconnected between the master power supply and the slave power supply through the highly accurate logic interface shown as gateway 50, the transmitting gateway, and gateway 52, the receiving gateway. These gateways are network interface cards for each of the power supplies so that the logic on lines 44b, 46b are timed closely to the logic on lines 44, 46, respectively. In 5 practice, network interface cards or gateways 50, 52 control this logic to within 10  $\mu$ s and preferably within 1-5  $\mu$ s. The invention involves a low accuracy network controlling the individual power supplies for data from central control 18 through lines 42m, 42s, illustrated as provided by the gateways or interface cards. These lines contain data from remote areas (such 10 as central control 18) which are not time sensitive and do not use the accuracy characteristics of the gateways. The highly accurate data for timing the switch reversal uses interconnecting logic signals through network interface cards 50, 52. The system in FIGURE 1 is a single cell for a 15 single AC arc.

The invention is primarily applicable for tandem electrodes wherein two or more AC arcs are created to fill the large gap found in pipe welding. Thus, the master power supply 30 receives 20 a synchronization signal which determines the timing or phase operation of the system S for a single electrode, i.e. ARC 1.

System S is used with other identical systems to generate ARCs 2, 3, and 4. This concept is schematically illustrated in FIGURES 5 and 6. The synchronizing or phase setting signals are shown in FIGURE 1 with only one of the tandem electrodes. An information network N comprising a central control computer and/or web server 60 provides digital information or data relating to specific power supplies in several systems or cells controlling different electrodes in a tandem operation. Internet information is directed to a local area network in the form of an ethernet network 70 having local interconnecting lines 70a, 70b, 70c. Similar interconnecting lines are directed to each power supply used in the four cells creating ARCs 1, 2, 3 and 4 of a tandem welding operation. The description of system or cell S applies to each of the arcs at the 25 other electrodes. If AC current is employed, a master power supply is used. In some instances, merely a master power supply is used with a cell specific synchronizing signal. A single arc welding installation will not require synchronizing signals. If higher currents are required, the systems or cells include a master and slave power supply combination as described with respect 30 to system S of FIGURE 1. In some instances, a DC arc is preferred, such as the leading electrode

in a tandem electrode welding operation. A DC power supply need not be synchronized, nor is there a need for accurate interconnection of the polarity logic and switching points or commands. Some DC powered electrodes may be switched between positive and negative, but not at the frequency of an AC driven electrode. Irrespective of the make-up of the arcs, ethernet or local area network 70 includes the parameter information identified in a coded fashion designated for specific power supplies of the various systems used in the tandem welding operation. This network also employs synchronizing signals for the several cells or systems whereby the systems can be offset in a time relationship. These synchronizing signals are decoded and received by a master power supply as indicated by line 40 in FIGURE 1. In this manner, the AC arcs are offset on a time basis. These synchronizing signals are not required to be as accurate as the switching points through network interface cards or gateways 50, 52. Synchronizing signals on the data network are received by a network interface in the form of a variable pulse generator 80. The generator creates offset synchronizing signals in lines 84, 86 and 88. These synchronizing signals dictate the phase of the individual alternating current cells for separate electrodes in the tandem operation. Synchronizing signals can be generated by interface 80 or actually received by the generator through the network 70. In practice, network 70 merely activates generator 80 to create the delay pattern for the many synchronizing signals. Also, generator 80 can vary the frequency of the individual cells by frequency of the synchronizing pulses if that feature is desired in the tandem welding operation.

A variety of controllers and power supplies could be used for practicing the invention as described in FIGURE 1; however, preferred implementation of the invention is set forth in FIGURE 2 wherein power supply PSA is combined with controller and power supply 30 and power supply PSB is combined with controller and power supply 32. These two units are essentially the same in structure and are labeled with the same numbers when appropriate. Description of power supply PSA applies equally to power supply PSB. Inverter 100 has an input rectifier 102 for receiving three phase line current L1, L2, and L3. Output transformer 110 is connected through an output rectifier 112 to tapped inductor 120 for driving opposite polarity switches Q1, Q2. Controller 140a of power supply PSA and controller 140b of PSB are essentially the same, except controller 140a outputs timing information to controller 140b. Switching points or lines 142, 144 control the conductive condition of polarity switches Q1, Q2

for reversing polarity at the time indicated by the logic on lines 142, 144, as explained in more detail in Stava 6,111,216 incorporated by reference herein. The control is digital with a logic processor; thus, A/D converter 150 converts the current information on feedback line 16 or line 26 to controlling digital values for the level of output from error amplifier 152 which is illustrated as an analog error amplifier. In practice, this is a digital system and there is no further analog signal in the control architecture. As illustrated, however, amplifier has a first input 152a from converter 150 and a second input 152b from controller 140a or 140b. The current command signal on line 152b includes the wave shape required for the AC current across the arc at weld station WS. The output from amplifier 152 is converted to an analog voltage signal by converter 160 to drive pulse width modulator 162 at a frequency controlled by oscillator 164, which is a timer program in the processor software. This frequency is greater than 18 kHz. The total architecture of this system is digitized in the preferred embodiment of the present invention and does not include reconversion back into analog signal. This representation is schematic for illustrative purposes and is not intended to be limiting of the type of power supply used in practicing the present invention. Other power supplies could be employed.

Implementation of the present invention is by driving separate electrodes in a tandem welding process with AC current creating the welding arc at the individual electrodes. Such a tandem arrangement is illustrated in FIGURES 3, 3A, and 3B wherein workpiece W is in the form of spaced edges of plates 200, 202 to define a longitudinal gap 204. Electrodes 210, 212 and 214 are melted by AC arcs to deposit beads 210a, 212a and 214a, respectively. Each of the arcs, 1, 2 and 3 has a different phase relationship from information received through network N as shown in FIGURE 1. Specific digital synchronizing signals 220, 222 and 224 are offset by distances X and Y shown in FIGURE 3A, and have frequencies x, y, and z. These frequencies may be the same or different. These electrode or cell specific synchronizing signals are communicated to the various cells from central control 60 through internet 62 to the phase generator 80, as shown in FIGURE 1. The individual synchronizing pulses are directed through lines 82, 84 and 86 for controlling the timing and/or frequency of the individual welding cells for the electrodes 210, 212 and 214. In practice, the leading electrode may involve use a DC arc, which need not be synchronized. Further, the synchronizing signals 220, 222 and 224 can be in phase. Each synchronizing signal sets the timing of the individual welding systems or cells as

shown in FIGURE 1.

FIGURE 4 shows a general layout illustrating the present invention when used for two cells S', S" or two arc formed by electrodes E<sub>1</sub> and workpiece W<sub>1</sub> and electrode E<sub>2</sub> and workpiece W<sub>2</sub>. In practice, the workpieces are both identical and only the electrodes are separate; however, they do define separate arcs in the welding process. To use the present invention for the two arcs as shown in FIGURE 4, network 300 includes a central control 302 to which is loaded power supply specific parameters as indicated by interface block 304. These parameters are stored as indicated by block 306 for interrogation by network 300 whenever desired. The network server is connected through internet 310 to the local area network 312 from which weld parameters are loaded into the individual control and power supply combinations M<sub>1</sub>, S<sub>1</sub>, M<sub>2</sub>, and S<sub>2</sub> through interconnections illustrated as lines 320-326. In a like manner, the synchronizing signals for the individual systems S', S" are available on network 312 and are communicated as illustrated as line 330 with the pulse generator or clock 340. The output of the generator is represented as synchronizing data lines 332, 334 for individually controlling the delay or synchronization of systems S', S". This dictates the time relationship between the two arcs of the dual electrode system shown in FIGURE 4. Cell S' includes master power supply M<sub>1</sub> connected in parallel with slave power supply S<sub>1</sub>. In a like manner, system S" includes master M<sub>2</sub> connected in parallel with the output of slave power supply S<sub>2</sub>. Network interface cards 342, 344 communicate the timing from the master to the slave and directs the polarity logic as indicated with respect to the disclosure shown in FIGURE 1. In this manner, two separate electrodes used in tandem are driven separately with the parameters and synchronizing signals being directed through a network which can include an internet link. Actual implementation of a timing block control is located inside the master control board. The interface card S', S" translates and isolates the signals between the master control and the slave control.

The invention can be expanded to include any number of electrodes. Three electrodes 350, 352 and 354 are shown in FIGURES 5 and 5A. Network 360 as previously described communicates with system S shown in FIGURE 1 together with two additional systems 370, 372. Network 360 controls the logic to and through gateways 50 and 52 shown in FIGURE 1 together with similar gateways 380 and 382 for systems 370, 372, respectively. This embodiment of the invention illustrates two power supplies PSA and PSB for providing

synchronized and timed AC current through one electrode 356. Electrode 352 is connected with network 360 by gateway 380 so power supply PSC uses only a single master to produce an AC current for electrode 352. Electrode 354 is driven by power supply PSD which is a DC power supply without output polarity switches and is driven through gateway 382 by network 360.

5 Other arrangements are used to construct architecture of different tandem electrodes process. For instance, two electrodes 400, 402 are shown in the layout of FIGURES 6 and 6A. Four separate power supplies  $PSA_1$ ,  $PSB_1$ ,  $PSC_1$ , and  $PSD_1$  are connected in parallel to produce an AC current across electrode 402. Power supply PSE is a DC power supply without output polarity switches. All of the power supplies are provided with individual gateways or network interface cards 410, 10 412, 414, 416 and 418, respectively. Each of the gateways receives parameters for the individual power supplies. Gateways 410-416 are interconnected to assure that the timing and polarity of the switches in the first four power supplies are correlated accurately. Although gateways 414, 416 are indicated to be driven in series with gateway 412, in practice, they are driven directly from the output of gateway 410 in parallel fashion. This prevents the stacking of timing 15 differences in the individual gateways.

As indicated, the switching points of the master and slave power supplies are really a switching sequence wherein the inverter is first turned off and then the switches are reversed to change the polarity after the power supply reaches a low current. When the inverter is turned off, the current is reduced. Then reversal of polarity is effected. This concept is shown in Stava 20 6,111,216. This patented switching technique is disclosed in FIGURES 7 and 7A, wherein two electrodes 420, 422 having AC current curves schematically illustrated as curve 424 and curve 426. In curve 424, the power supply is turned off at point 430. The current decays to a low current level 432 at which time there is a reversal to a negative polarity. This negative current level is maintained until the desired parameter has been reached. The power supply is then 25 turned off at point 434 and the negative current pulse decays to switch point 436 at which time the switches reverse to a positive polarity. With a master and one or more slave power supplies, it is necessary to coordinate the kill points 430, 434, as well as the switch points or times 432, 436. For simplicity, this polarity reversal sequence is referred to as the "switching time." Curve 426 is offset by the distance  $e$  and is provided by one or more power supplies connected in series. 30 This curve has power supply kill point 440 and kill point 444. The switching points 442, 446

correspond with the current reversal switching points 432, 436. Even though the technique set forth in FIGURE 7A is preferred, a direct current reversal at the switching points is also used with the present invention. In that instance, the switches must be larger and require a snubber network or a larger snubber network in parallel with the switches.

5 As indicated, when the master controller is to switch, a switch command is issued to the master controller. This causes a "kill" signal to be received by the master so a kill signal and polarity logic is rapidly transmitted to the controller of one or more slave power supplies connected in parallel with a single electrode. If standard AC power supplies are used with large snubbers in parallel with the polarity switches, the slave controller or controllers are immediately 10 switched within 1-10  $\mu$ s after the master power supply receives the switch command. This is the advantage of the high accuracy interface cards or gateways. In practice, the actual switching for current reversal of the paralleled power supplies is not to occur until the output current is below a given value, i.e. about 100 amperes. This allows use of smaller switches.

15 The implementation of the invention using this delayed switching technique requires the actual switch only after all power supplies are below the given low current level. The delay process is accomplished in the software of the digital processor and is illustrated by the schematic layout of FIGURE 8. When the controller of master power supply 500 receives a command signal as represented by line 502, the power supply starts the switching sequence. The master outputs a logic on line 504 to provide the desired polarity for switching of the slaves to 20 correspond with polarity switching of the master. In the commanded switch sequence, the inverter of master power supply 500 is turned off or down so current to electrode E is decreased as read by hall effect transducer 510. The switch command in line 502 causes an immediate "kill" signal as represented by line 512 to the controllers of paralleled slave power supplies 520, 522 providing current to junction 530 as measured by hall effect transducers 532, 534. All power 25 supplies are in the switch sequence with inverters turned off or down. Software comparator circuits 550, 552, 554 compare the decreased current to a given low current referenced by the voltage on line 556. As each power supply decreases below the given value, a signal appears in lines 560, 562, and 564 to the input of a sample and hold circuits 570, 572, and 574, respectively. The circuits are outputted by a strobe signal in line 580 from each of the power supplies. When 30 a set logic is stored in a circuit 570, 572, and 574, a YES logic appears on lines READY<sup>1</sup>,

READY<sup>2</sup>, and READY<sup>3</sup> at the time of the strobe signal. This signal is generated in the power supplies and has a period of 25  $\mu$ s; however, other high speed strobes could be used. The signals are directed to controller C of the master power supply, shown in dashed lines in FIGURE 8. A software ANDing function represented by AND gate 580 has a YES logic output on line 582 when all power supplies are ready to switch polarity. This output condition is directed to clock enable terminal ECLK of software flip flop 600 having its D terminal provided with the desired logic of the polarity to be switched as appearing on line 504. An oscillator or timer operated at about 1 MHz clocks flip flop by a signal on line 602 to terminal CK. This transfers the polarity command logic on line 504 to a Q terminal 604 to provide this logic in line 610 to switch slaves 520, 522 at the same time the identical logic on line 612 switches master power supply 500. After switching, the polarity logic on line 504 shifts to the opposite polarity while master power supply awaits the next switch command based upon the switching frequency. Other circuits can be used to effect the delay in the switching sequence; however, the illustration in FIGURE 8 is 10 15 the present scheme.

15 The interface timing is disclosed as less than 10  $\mu$ s. This value is to be substantially more accurate than the ethernet accuracy. Thus, it can be as high as about 100  $\mu$ s and still provide an advantage. But, coordinated switching is facilitated with an accuracy of less than about 10  $\mu$ s with a READY strobe at 25  $\mu$ s. Each power supply is ready to switch polarity before the switch command is generated. One can reduce before the ready current and then come back up while 20 the other is reducing to the ready current. The key is accurate control and switching at low current. In addition, the power supplies could be back-to-back reverse polarity choppers with the positive state of the reverse polarity chopper switch by the accurate interface. A back-to-back AC chopper power supply is shown in prior United States Application Serial No. 09/575,264, filed May 22, 2000 and incorporated by reference herein.

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**The claims defining the invention are as follows:**

1. An electric arc welding system for creating an AC welding arc between an electrode and a workpiece, said system comprising a first controller for a first power supply to cause said first power supply to create an AC current between said electrode and workpiece by generating a switch signal with polarity reversing switching points in general timed relationship with respect to a given system specific synchronizing signal to said first controller, said first controller operated at first welding parameters in response to first power supply specific parameter signals to said first controller, at least one slave controller for operating a slave power supply to create an AC current between said electrode and workpiece by reversing polarity of said AC current at switching points, said slave controller operated at second welding parameters in response to second power supply specific parameter signals to said slave controller, an information network connected to said first controller and said slave controller and containing digital first and second power supply specific parameter signals for said first controller and said slave controller and said given system specific synchronizing signal, and a digital interface connecting said first controller with said slave controller to control said switching points of said second power supply by said switch signal from said first controller.
2. The electric arc welding system as defined in claim 1, wherein said power supplies switch polarity in unison after said switch signal.
3. The electric arc welding system as defined in claim 1 or 2, wherein said information network includes an internet link and an ethernet communicated with said link.
4. The electric arc welding system as defined in claims 1-3, wherein said information network contains a second given system specific synchronizing signal offset in time from said first mentioned given signal and at least a third power supply specific parameter signal.
5. The electric arc welding system as defined in claims 1-4, wherein said digital interface has a timing accuracy of less than about 10  $\mu$ s.

6. The electric arc welding system as defined in claim 5, wherein said accuracy is about 1-5  $\mu$ s.

7. The electric arc welding system as defined in claims 1-5, including a software circuit to switch said polarity only after a "ready" signal has been created by each of said power supplies.

8. The electric arc welding system as defined in claims 1-7, wherein said AC power supplies include inverters.

10

9. The electric arc welding system as defined in claims 1-8, wherein said AC power supplies include back-to-back choppers.

10. An electric arc welding system for creating an AC welding arc between an electrode and a workpiece, said system comprising a first power supply to create a first AC current with first weld parameters between said electrode and workpiece by generating a first switch controlling signal reversing polarity of said first current at a specific switch time, a second power supply to create a second AC current with second weld parameters between said electrode and workpiece by a second switch controlling signal reversing polarity of said second current at a switch time near said specific switch time, and a timing interface between said first and second power supplies to create said second signal by said first signal where said switch time of said second power supply is within about 5  $\mu$ s of said specific switch time.

25 11. The electric arc welding system as defined in claim 10, wherein said first and second weld parameters are directed to said first and second power supplies by an information network with a time accuracy of substantially greater than 1  $\mu$ s.

30 12. The electric arc welding system as defined in claim 11, wherein said first and second weld parameters include output current for said power supplies.

13. The electric arc welding system as defined in claims 10-12, wherein said output current of said first power supply is generally a fixed value.

14. The electric arc welding system as defined in claims 11-13, wherein said information network includes an internet link and an ethernet communicated with said link.

5 15. The electric arc welding system as defined in claims 10-14, including a software circuit to switch said polarity only after a "ready" signal has been created by each of said power supplies.

10 16. An electric arc welding system for creating a first AC welding arc between a first weld electrode and workpiece and a second AC welding arc between a second weld electrode and said workpiece as said first and second electrodes move along said workpiece, said system comprising a first cell with at least two power supplies connected to said first arc and operated at a first synchronized time determined by a first synchronized signal with first weld parameters and a high accuracy interconnection 15 interface between said power supplies of said first cell to correlate polarity switching of said power supplies of said first cell, a second cell with at least two power supplies connected to said second arc and operated at a second synchronized time determined by a second synchronize signal offset from said first synchronize signal with second weld parameters and a high accuracy interconnection interface between said power supplies of said second cell to correlate polarity switching of said power supplies of said second cell 20 and a low accuracy information network connected to said first and second cells and containing digital signals including said first and second weld parameters and digitized first and second synchronize signals.

25 17. The electric arc welding system as defined in claim 16, wherein said information network includes an internet link and an ethernet communicated with said link.

30 18. The electric arc welding system as defined in claim 16 or 17, wherein said first and second parameters are selected from the class consisting of current, voltage and wire feed speed.

35 19. The electric arc welding system as defined in claims 16-18, including a software circuit to switch said polarity only after a "ready" signal has been created by each of said power supplies.

20. An electric arc welding system for creating an AC welding arc between an electrode and a workpiece, said system comprising a first power supply to create a first AC current with first weld parameters between said electrode and workpiece by generating a first switch controlling signal reversing polarity of said first current at a specific active switch time, a second power supply to create a second AC current with second weld parameters between said electrode and workpiece by a second switch controlling signal reversing polarity of said second current at a switch activate time, and a timing interface between said first and second power supplies to create said second signal by said first signal where said switch activate time of said second power supply is within about 10  $\mu$ s of said specific switch activate time of said first power supply.

10 21. The electric arc welding system as defined in claim 20, wherein said first and second weld parameters are directed to said first and second power supplies by an information network with a time accuracy of substantially greater than 1  $\mu$ s.

20 22. The electric arc welding system as defined in claim 20 or 21, wherein said first power supply creates a first "ready" signal when said first power supply is ready to shift polarity, said second power supply creates a second "ready" signal when said second power supply is ready to shift polarity, and a software circuit to switch both of said power supplies after said first and second ready signals are created.

25 23. An electric arc welding system for creating an AC welding arc between an electrode and a workpiece, said system comprising a first power supply to create a first AC current with first weld parameters between said electrode and workpiece by generating a first switch signal for reversing polarity of said first current at a specific time, a second power supply to create a second AC current with second weld parameters between said electrode and workpiece by a second switch signal for reversing polarity of said second current at a given time, a timing interface between said first and second power supplies to create said second signal by said first signal, and a circuit to switch said power supplies after said first and second signal, said circuit includes a detector to switch said power supplies when the current of said power supplies is less than a given amount.

24. The electric arc welding system as defined in claim 23, wherein said first and second weld parameters are directed to said first and second power supplies by an information network with a time accuracy of substantially greater than 1  $\mu$ s.

5 25. The electric arc welding system as defined in claim 23 or 24, wherein said given amount is about 100 amperes.

10 26. An electric arc welding system for creating an AC welding arc between an electrode and a workpiece, said system comprising a first power supply to create a first AC current with first weld parameters between said electrode and workpiece by generating a first switch controlling signal reversing polarity of said first current at a specific active switch time, a second power supply to create a second AC current with second weld parameters between said electrode and workpiece by a second switch controlling signal reversing polarity of said second current at a switch activate time, and a 15 timing interface between said first and second power supplies to create said second signal by said first signal where said first and second signals are within about 10  $\mu$ s.

20 27. The electric arc welding system as defined in claim 26, including a sensor for detecting the output current of each of said power supplies and a circuit to cause said activated time and said specific activated time when said output current is at or below a specific level.

25 28. The electric arc welding system as defined in claim 26 or 27, wherein said AC power supplies include inverters.

29. The electric arc welding system as defined in claims 26-28, wherein said AC power supplies include back-to-back choppers.

30 30. The electric arc welding system as defined in claims 26-29, wherein said switch activated time and said specific activated time are generally the same.

35 31. An electric arc welding system for creating an AC welding arc between an electrode and workpiece, said system comprising a first power supply to create a first AC current waveform between said electrode and a workpiece by generating a first switch controlling signal reversing polarity of said first current at a specific active switch time, a

second power supply to create a second AC current waveform between said electrode and workpiece by a second switch controlling signal reversing polarity of said second current at a switch activate time, and a timing interface between said first and second power supplies to create said second signal by said first signal.

5

32. The electric arc welding system as defined in claim 31, wherein said first and second signals are within about 10  $\mu$ s.

10

33. The electric arc welding system as defined in claim 31 or 32, including a sensor for detecting the output current of each of said power supplies and a circuit to cause said activated time and said specific activated time when said output current is at or below a specific level.

15

34. The electric arc welding system as defined in claims 31-33, wherein said AC power supplies are inverters.

35. The electric arc welding system as defined in claims 31-34, wherein said switch activated time and said specific activated time are generally the same.

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36. The electric arc welding system as defined in claims 31-35, wherein at least one of said current waveforms is created by a number of current pulses occurring at a frequency of at least 18 kHz with a magnitude of each pulse controlled by a wave shaper.

25

37. The electric arc welding system as defined in claims 31-36, including a synchronizing circuit for controlling the phase of said first and second waveforms.

38. The electric arc welding system as defined in claims 31-37, wherein each of said waveforms has a shape controlled by a dedicated set of parameters.

30

39. An electric arc welding system comprising a first power source with a first output polarity changing switch network creating a first AC output with first output leads connected across an electrode and a workpiece and a second power source with a second output polarity changing switch network creating a second AC output with second output leads connected across said electrode and workpiece in parallel with said first leads whereby the current from said power sources is added.

40. The electric arc welding system as defined in claim 39, wherein each of said AC outputs has a waveform created by a number of current pulses occurring at a frequency of at least 18 kHz with the magnitude of each pulse controlled by a wave shaper.

41. The electric arc welding system as defined in claim 39 or 40, wherein said workpiece is an open root joint.

42. In an electric arc welding system for creating a first waveform across a first gap between a first electrode and a workpiece and a second waveform across a second gap between a second electrode and said workpiece while said electrodes are moved relative to said workpiece, the improvement comprising: two power sources for creating at least one of said waveforms, said at least one waveform created by a number of current pulses occurring at a frequency of at least 18 kHz with a magnitude of each pulse controlled by a wave shaper and a circuit synchronizing said first and second waveforms.

43. The electric arc welding system as defined in claim 42, wherein said workpiece is an open root joint.

44. An electric arc welding system for creating a first AC welding arc with a first current waveform between a first electrode and a workpiece by a first power supply and a second AC welding arc with a second current waveform between a second electrode and a workpiece by a second power supply as said first and second electrodes are moved in unison along a welding path, said first and second power supply each comprising a high speed switching inverter creating its waveform by a number of current pulses occurring at a frequency of at least about 18 kHz with the magnitude of each current controlled by a wave shaper and the polarity of said waveform controlled by a switching signal, said first waveform being offset from said second waveform by a controlled length of time.

45. The electric arc welding system as defined in claim 44, wherein said first and second waveform are substantially the same.

46. An electric arc welding system for creating an AC welding arc between an electrode and a workpiece, said system being substantially as described herein with reference to Figs 1 to 6 and Fig. 8 of the accompanying drawings.

5 47. An electric arc welding system for creating a first AC welding arc between a first weld electrode and a second AC welding arc between a second weld electrode and said workpiece as said first and second electrodes move along said workpiece, said system being substantially as described herein with reference to Figs 1 to 6 and Fig. 8 of the accompanying drawings.

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48. An electric arc welding system substantially as described herein with reference to Figs 1 to 6 and Fig. 8 of the accompanying drawings.

15

49. An electric arc welding system for creating a first waveform across a first gap between a first electrode and a workpiece and a second waveform across a second gap between a second electrode and said workpiece while said electrodes are moved relative to said workpiece, said system being substantially as described herein with reference to Figs 1 to 6 and Fig. 8 of the accompanying drawings.

20

50. An electric arc welding system for creating a first AC welding arc with a first current waveform between a first electrode and a workpiece by a first power supply and a second AC welding arc with a second current waveform between a second electrode and a workpiece by a second power supply as said first and second electrodes are moved in unison along a welding path, said system being substantially as described herein with reference to Figs 1 to 6 and Fig. 8 of the accompanying drawings.

25

DATED this thirteenth Day of October, 2005

**Lincoln Global, Inc.**

Patent Attorneys for the Applicant

SPRUSON & FERGUSON

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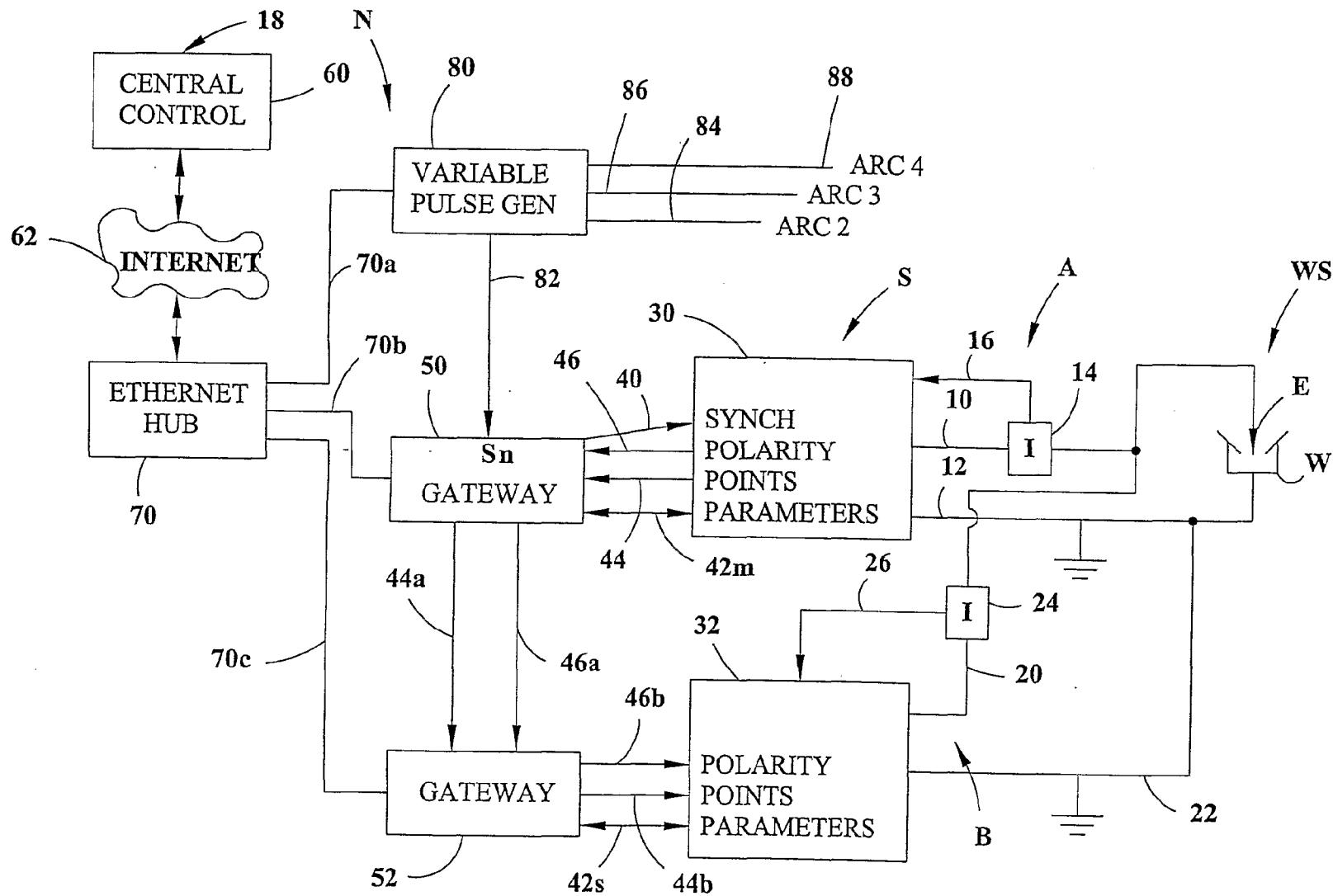


FIG. 1

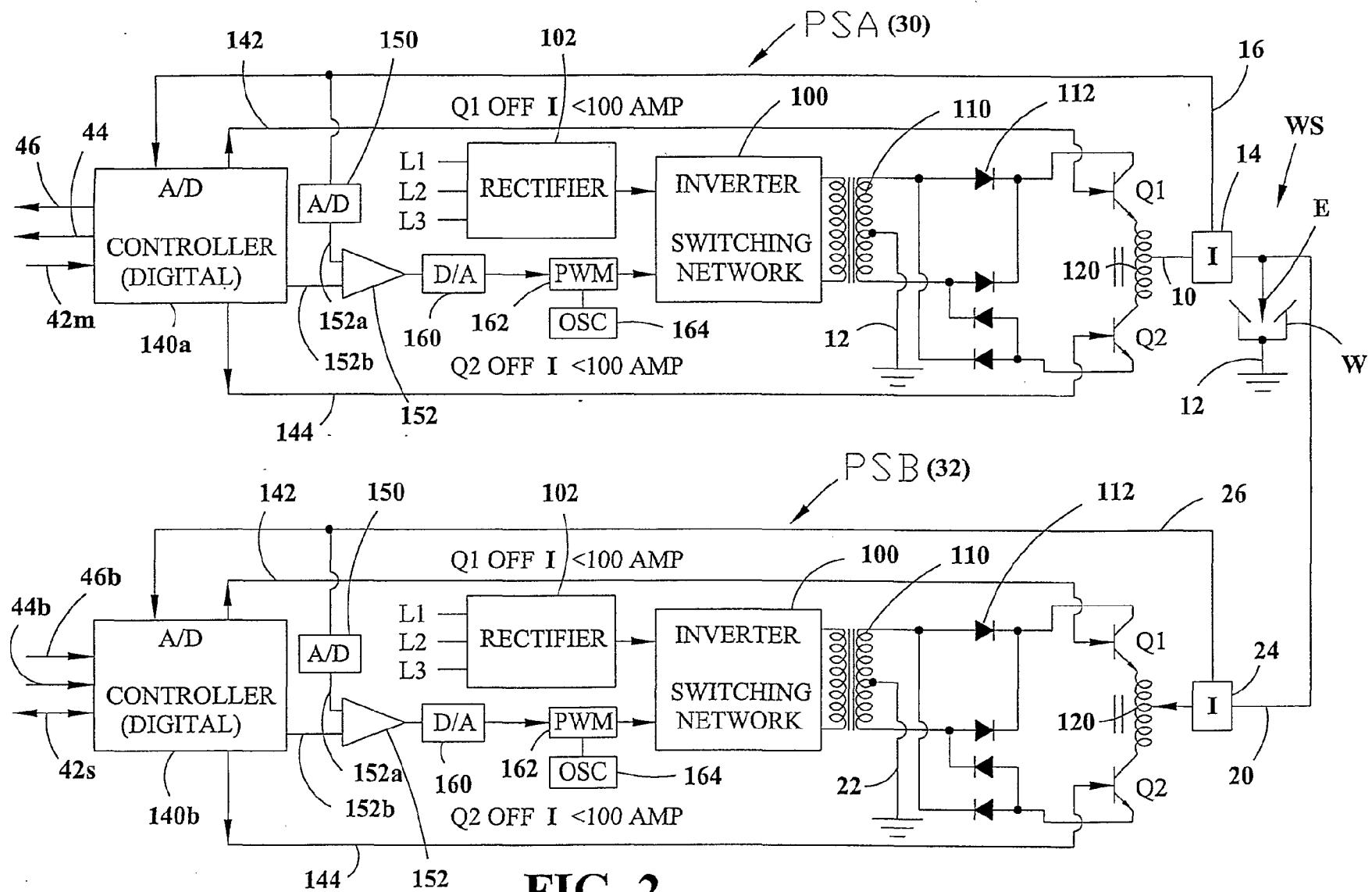


FIG. 2

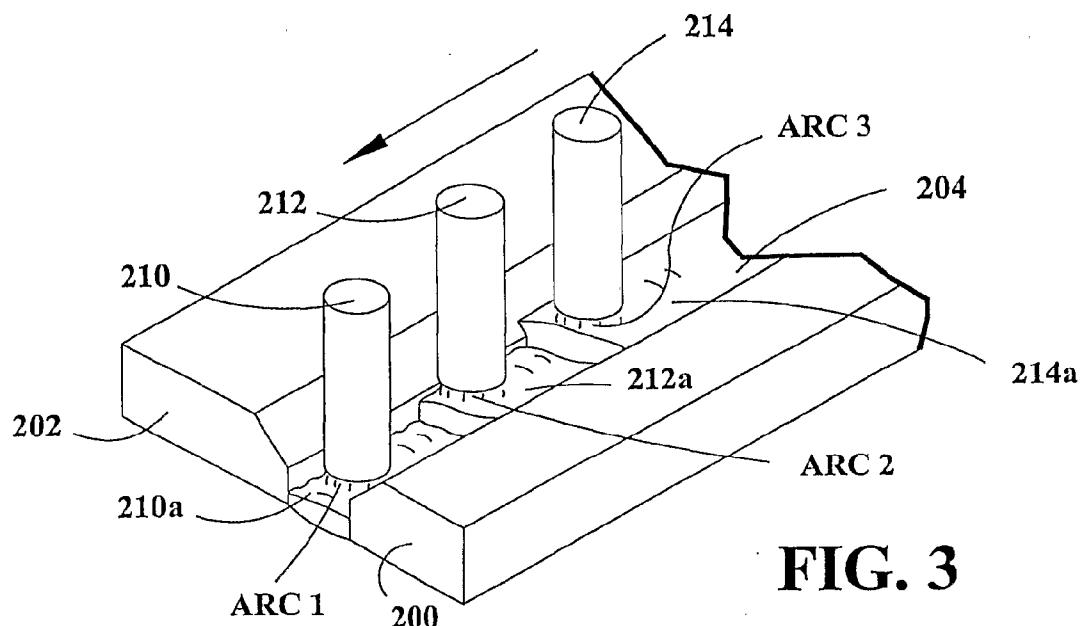


FIG. 3

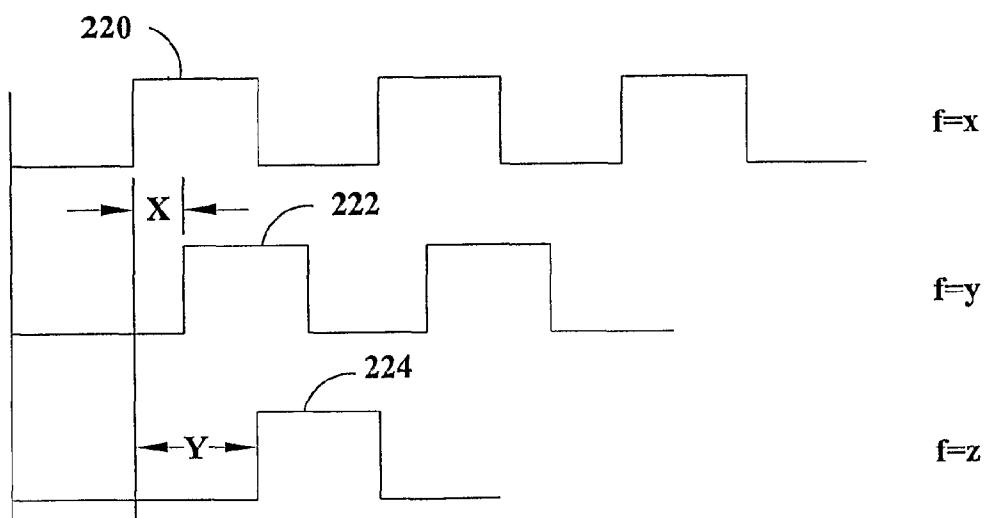


FIG. 3A

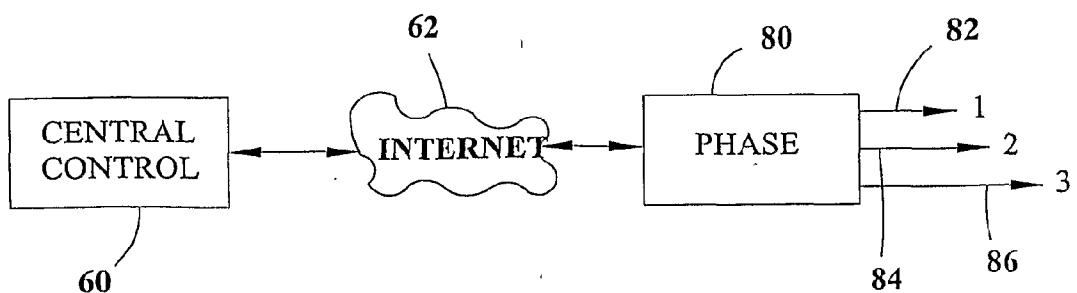
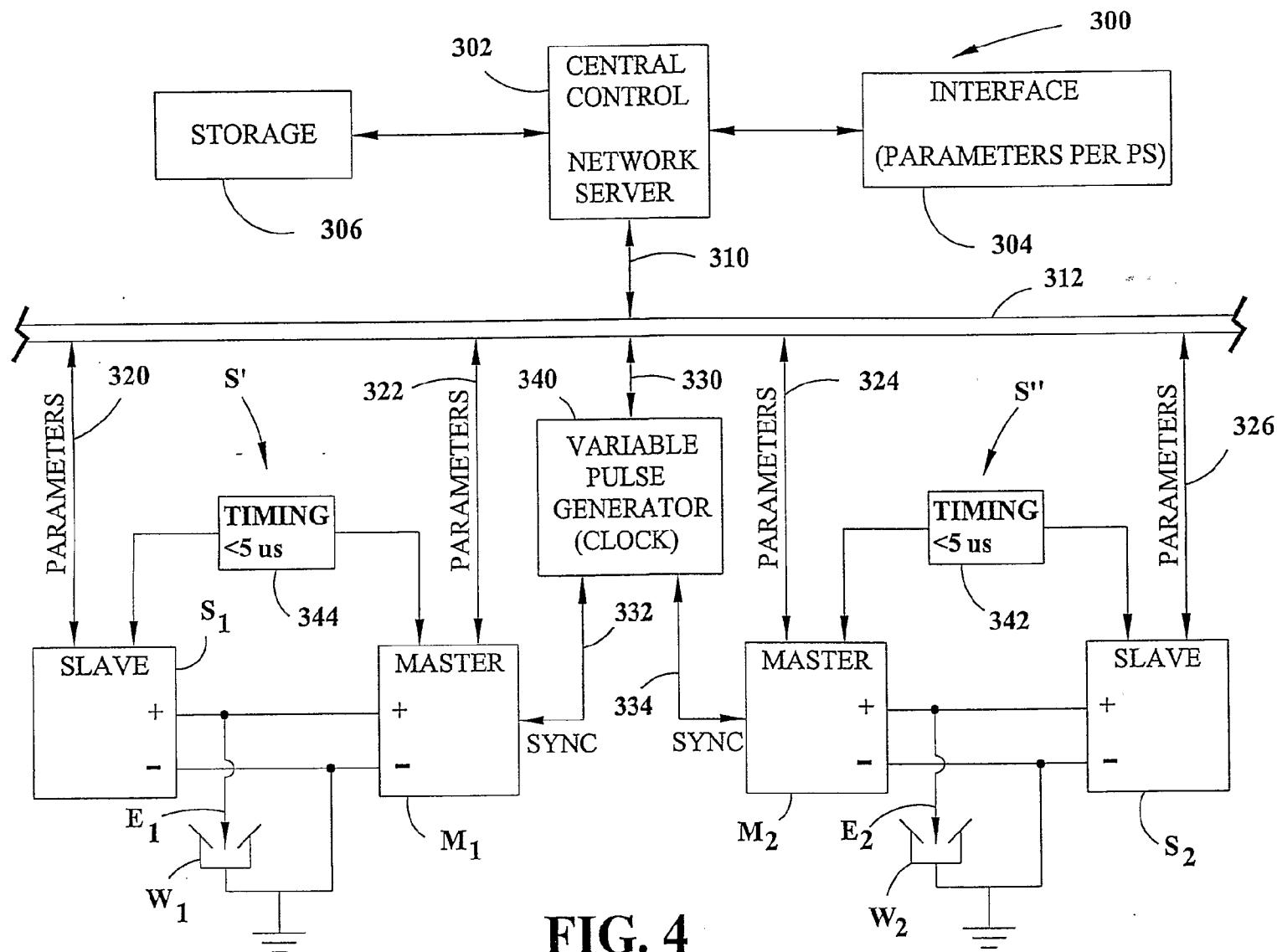


FIG. 3B



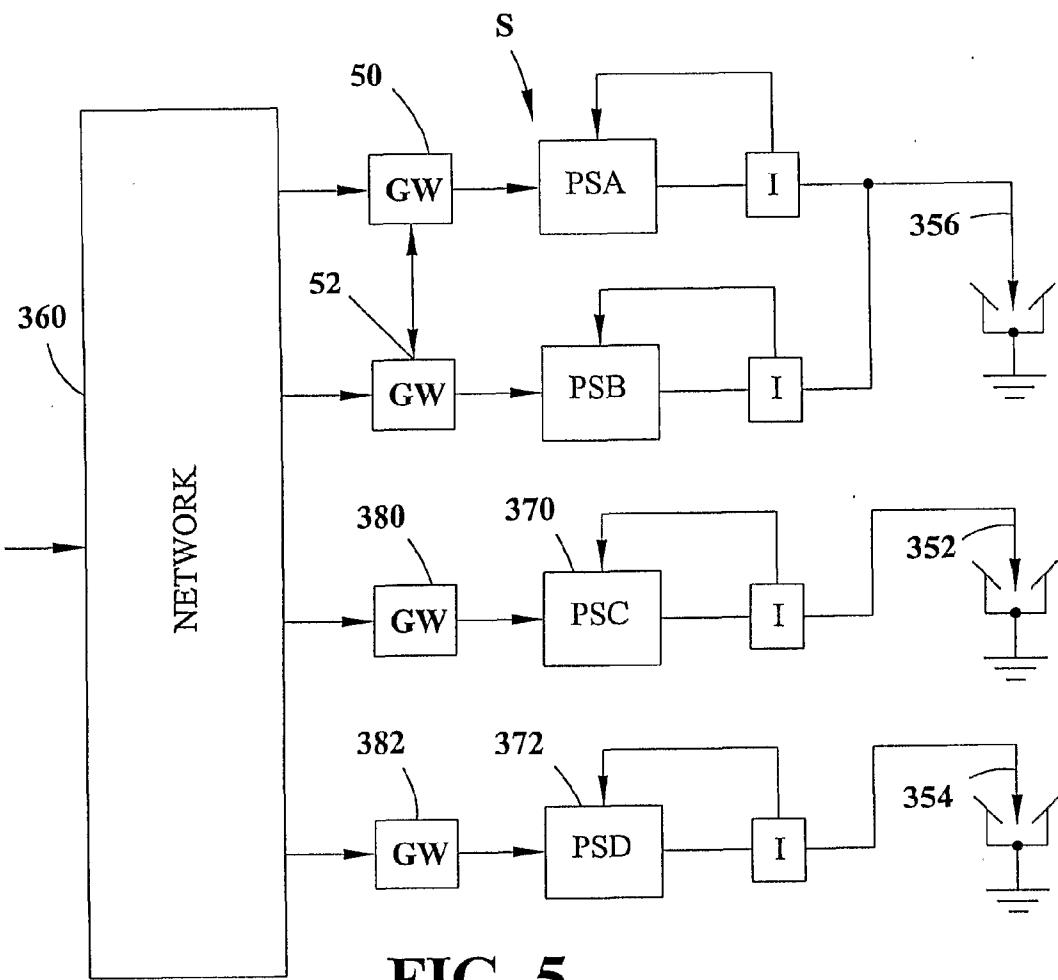


FIG. 5

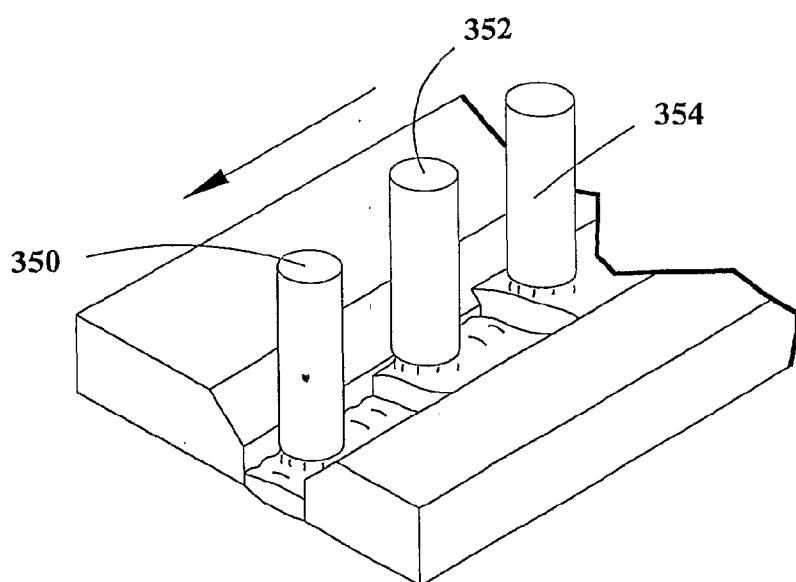
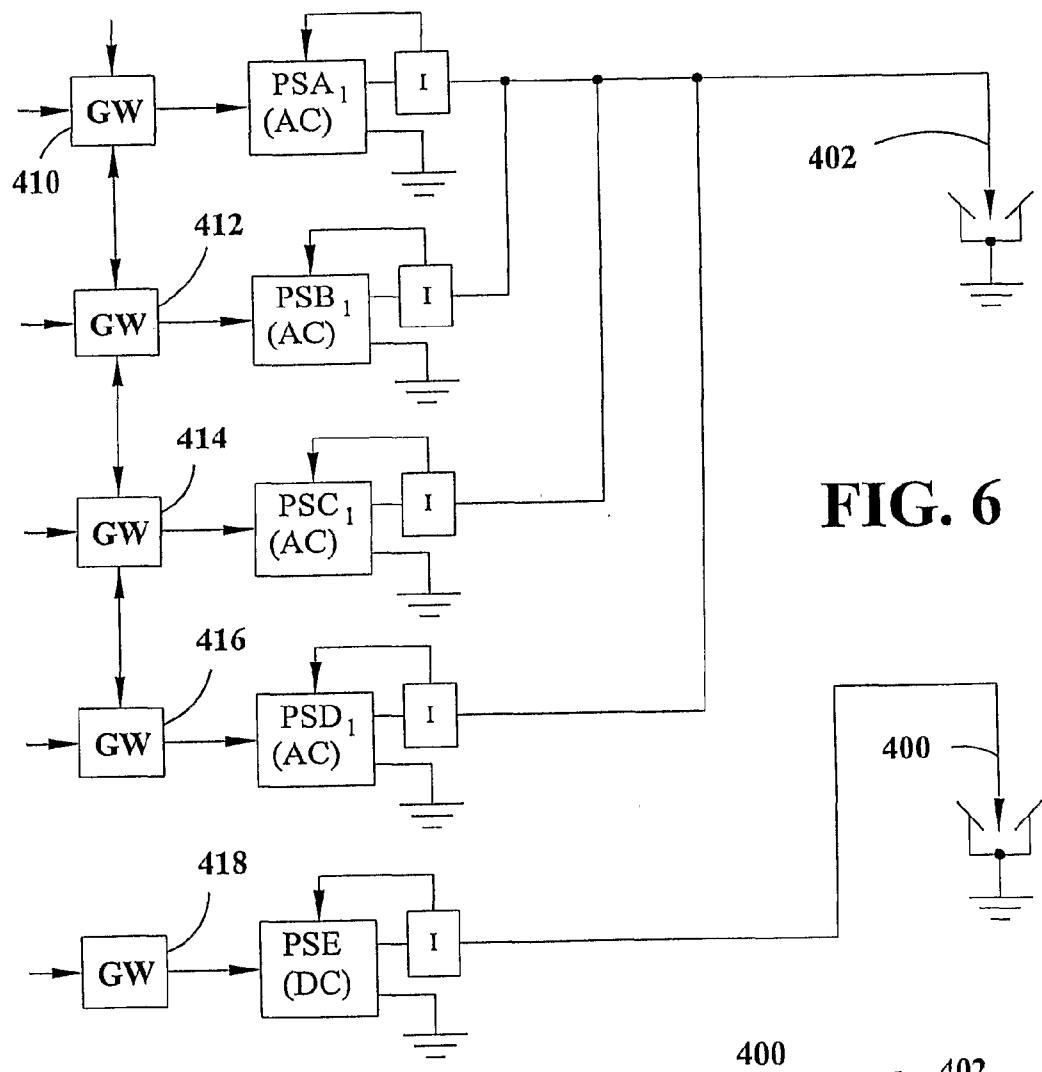
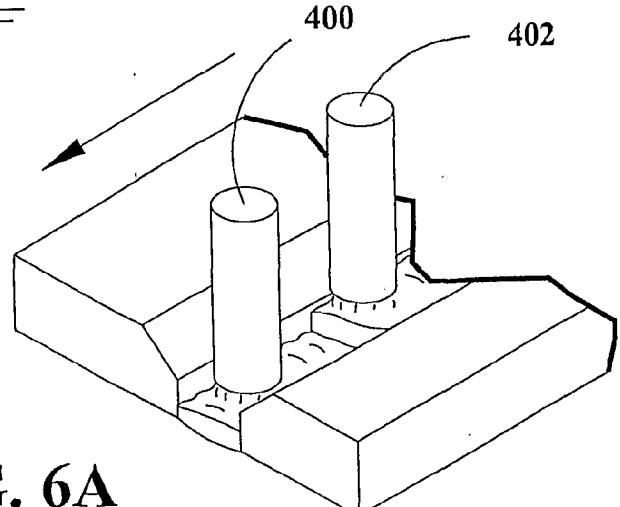


FIG. 5A

**FIG. 6****FIG. 6A**

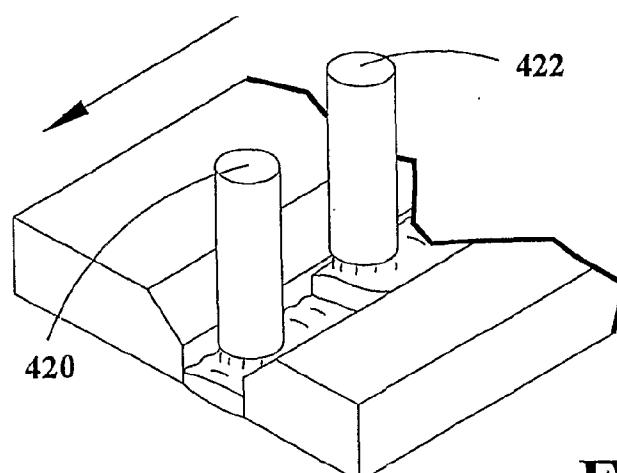


FIG. 7

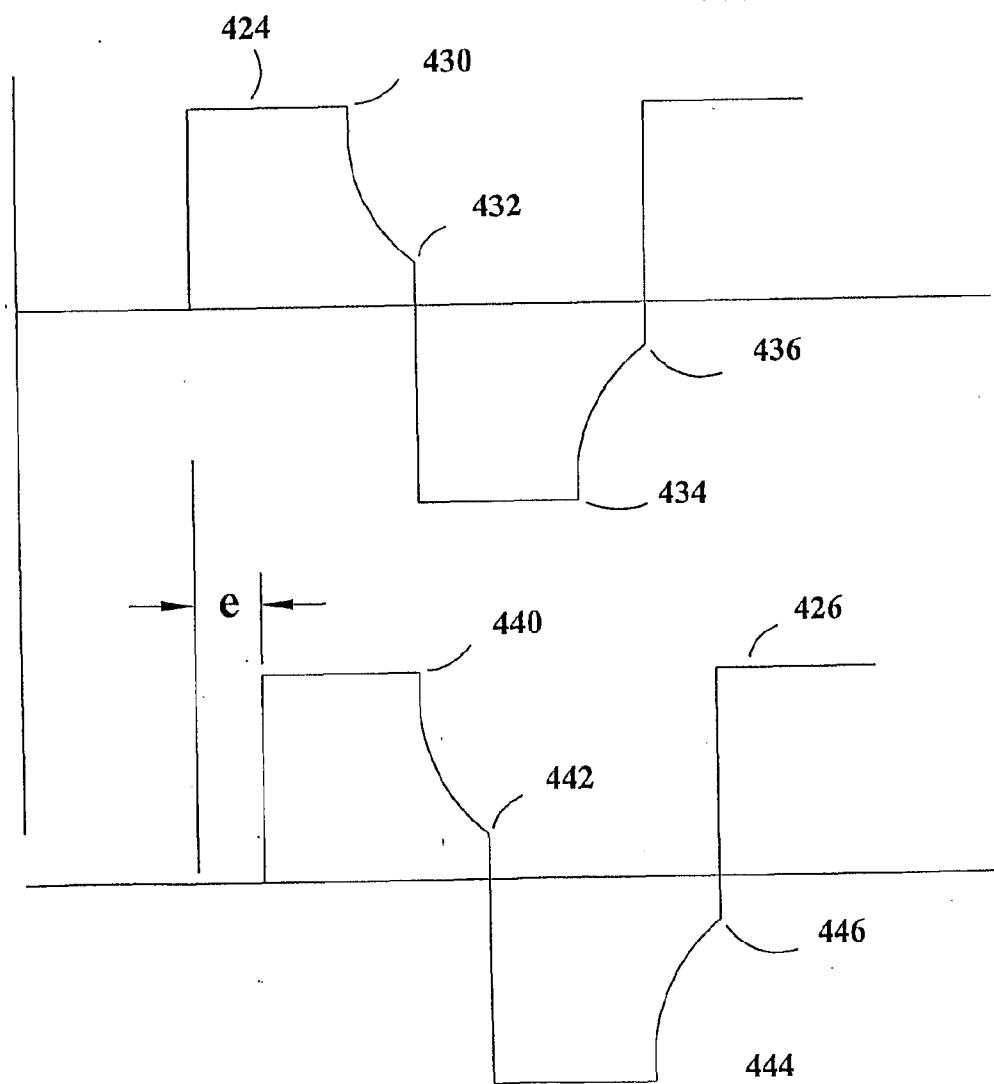


FIG. 7A

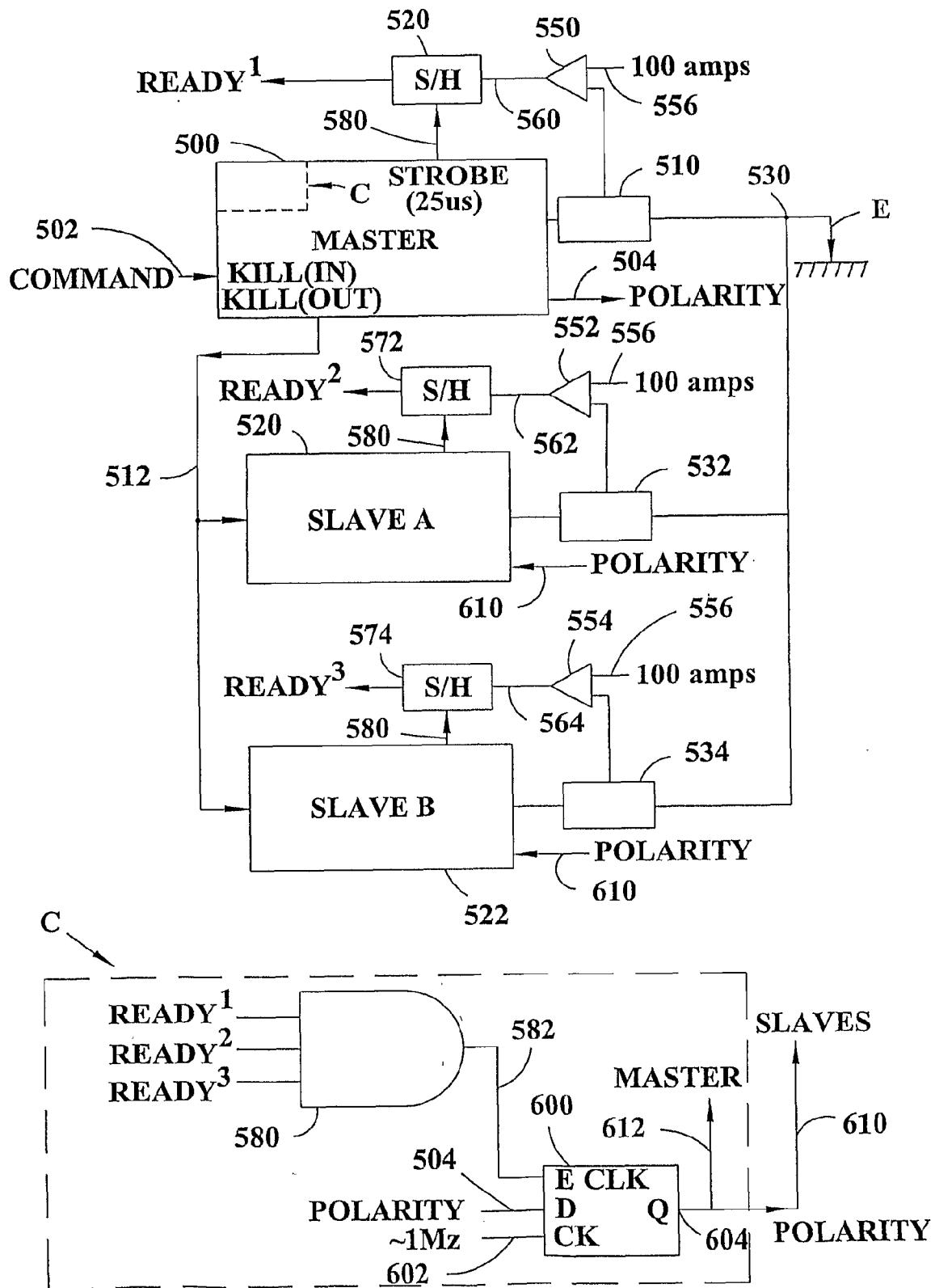


FIG. 8