

[54] **AUTOMATIC LEVELLING SYSTEM FOR EARTH WORKING BLADES AND THE LIKE**

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[51] Int. Cl. **E02f 3/76**

[58] Field of Search **172/4.5, 779; 37/DIG. 20; 250/239; 356/138, 152, 153**

[56] **References Cited**

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Weissenberger Lempio & Strabala

[57] **ABSTRACT**

A laser beam or like radiant energy source is swept in a reference plane in order to generate pulsating radiant energy within the plane so a system can automatically adjust an earth working blade or the like in reference thereto. A special receiver is attached to the blade which has a plurality of vertically spaced energy receiving regions formed by solar cells or the like, arranged so each of the regions is isolated from the others so that only one region is excited by the beam at a given time. A central region in the receiver corresponds to a null point and circuitry in the system employs digital gating elements to avoid ambiguities and to effect relative fast blade movement when the null point of the receiver is out of the plane by a relatively large amount and relatively slow movement when the null point is only slightly off the plane.

11 Claims, 8 Drawing Figures

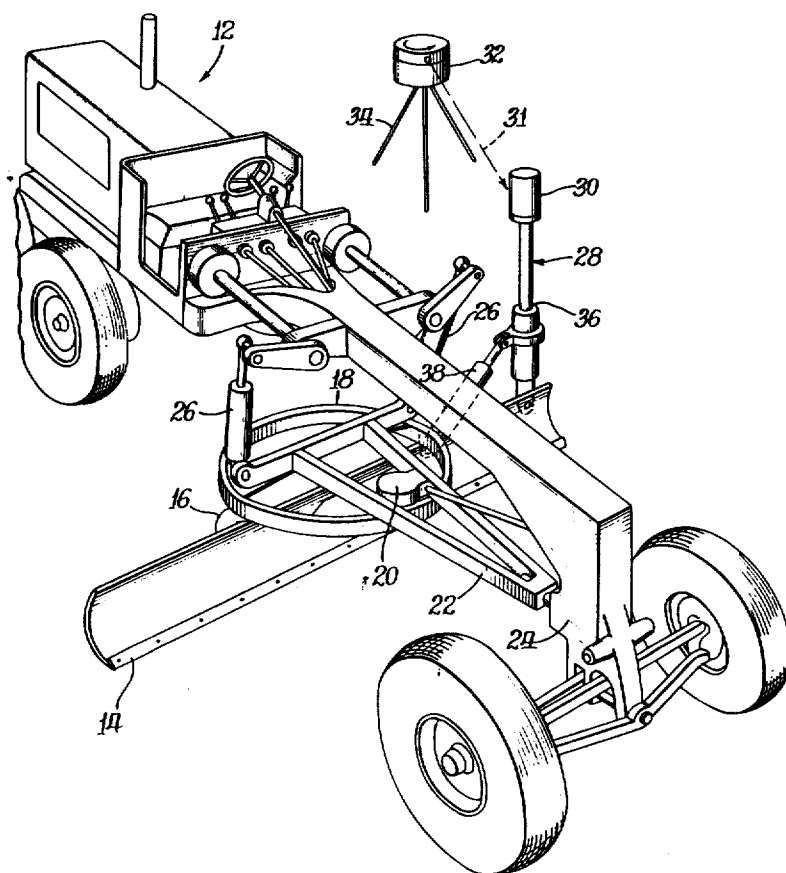
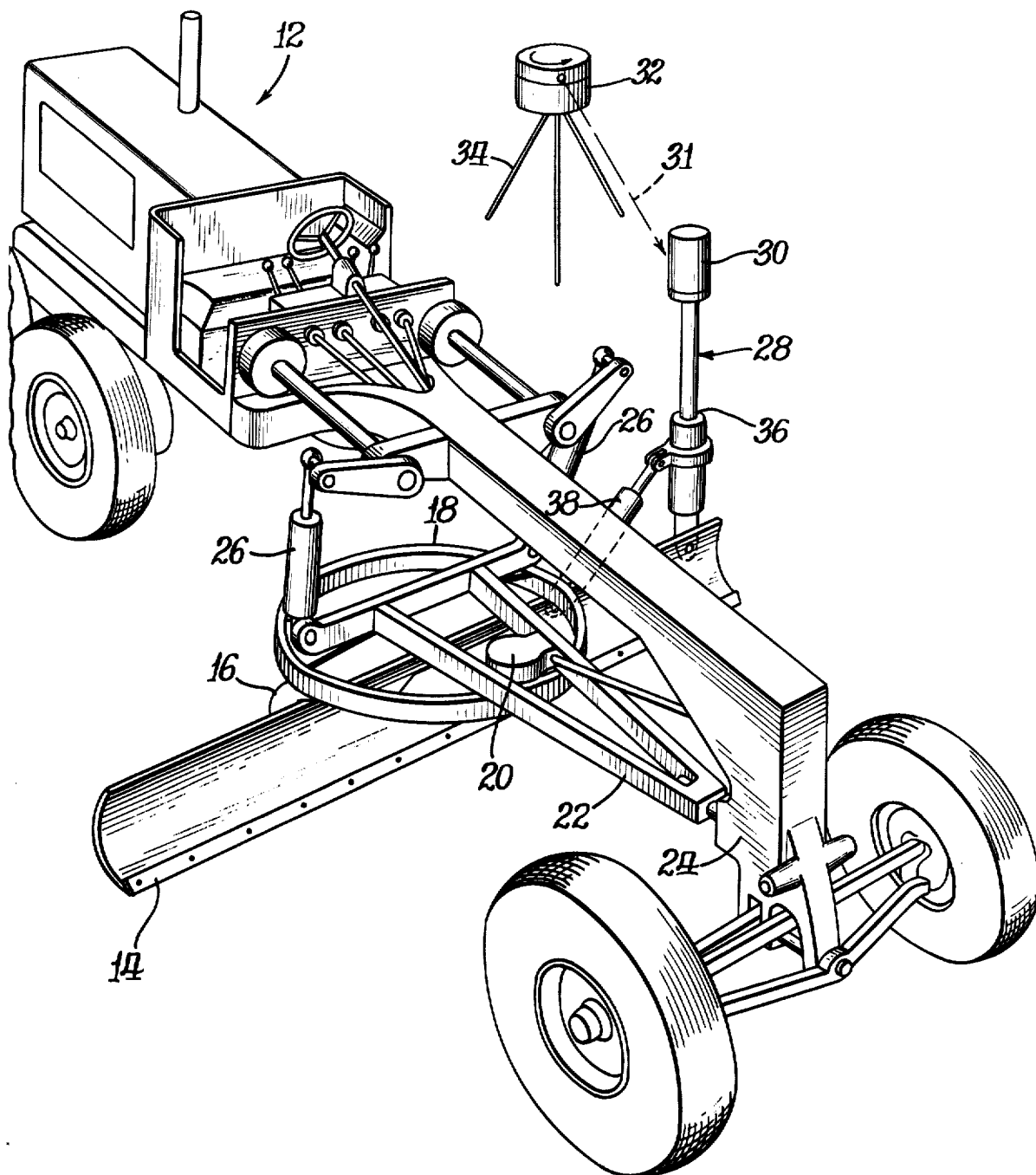
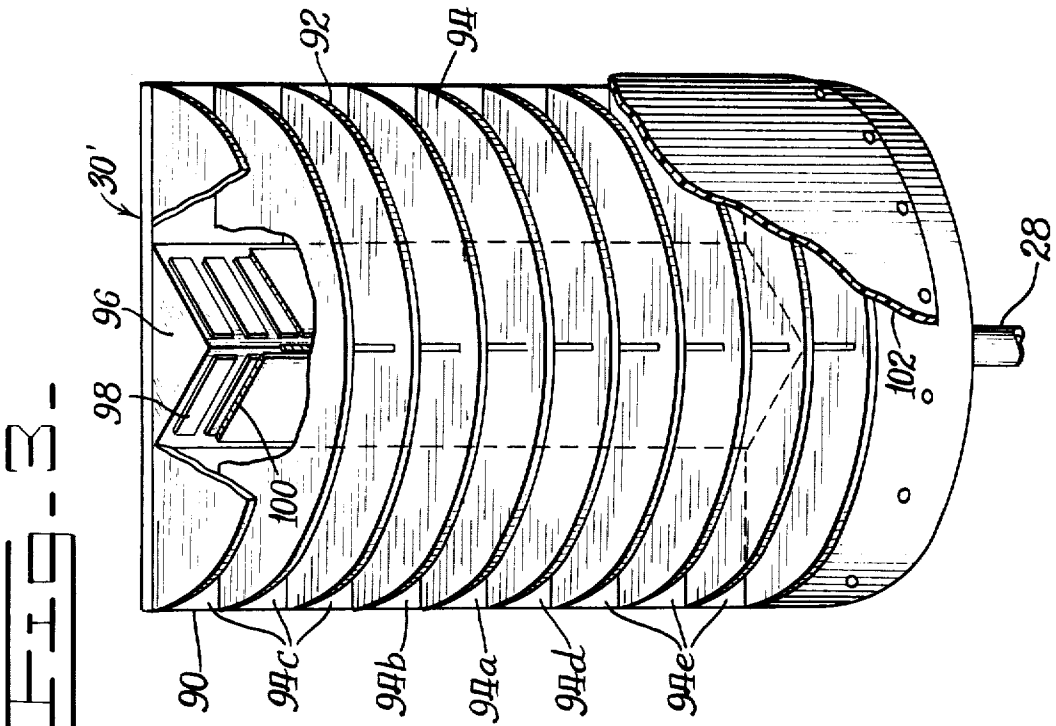
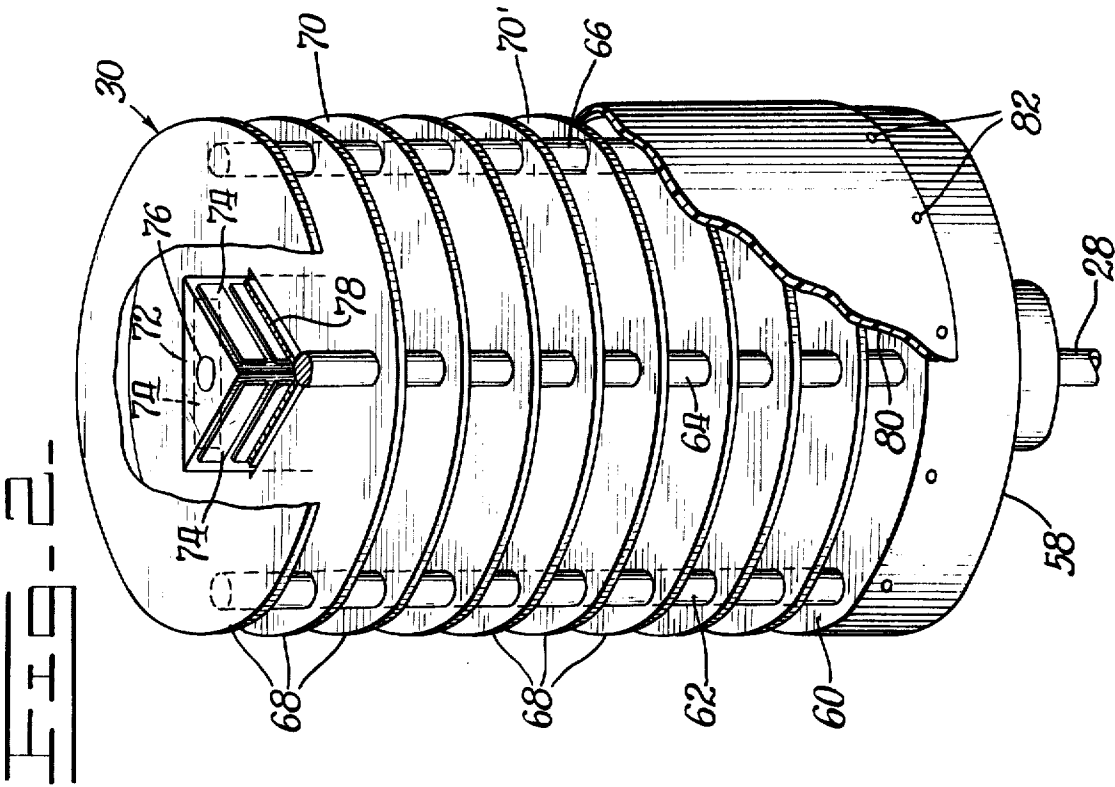


FIG. 1





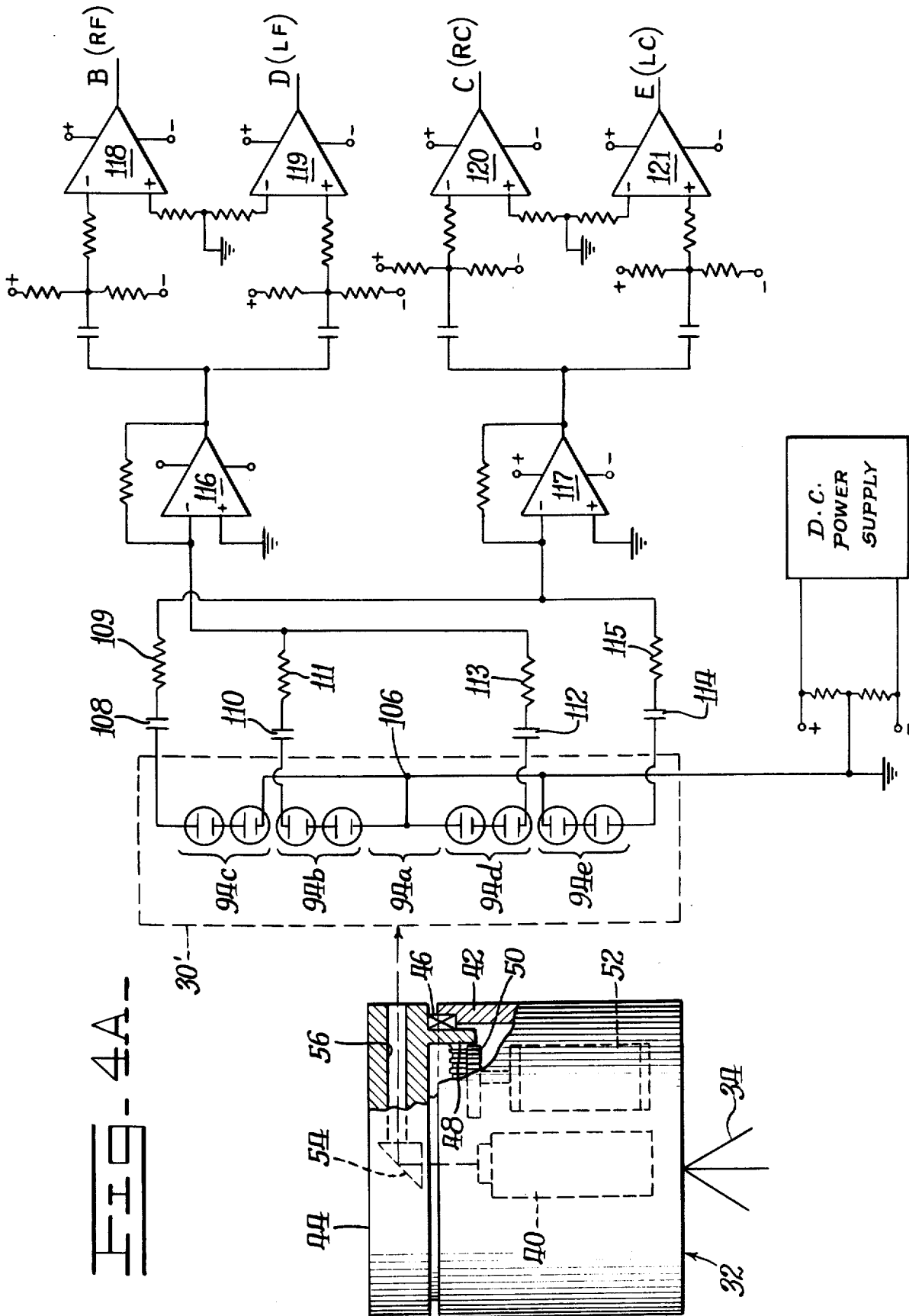
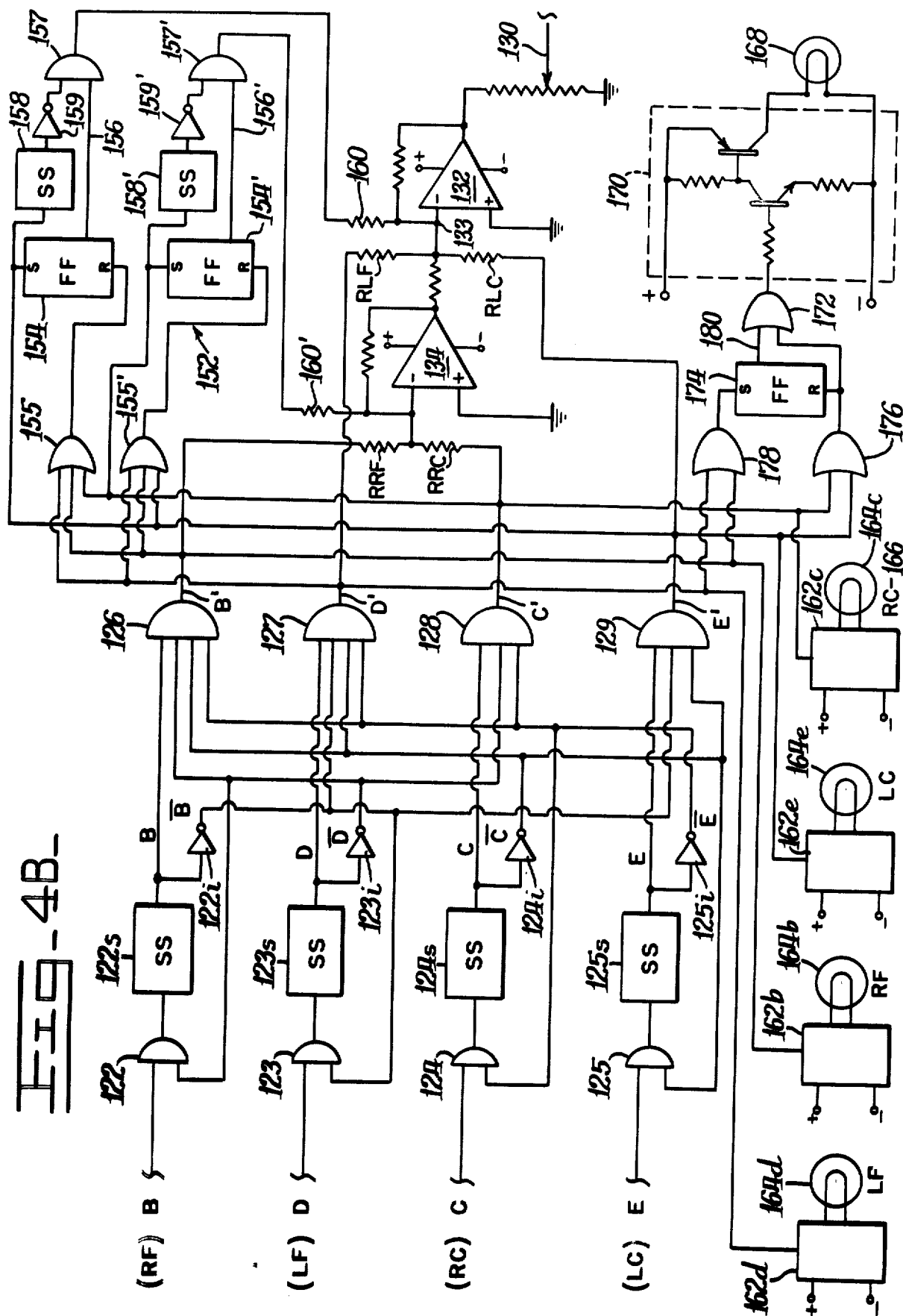


FIG-4B-



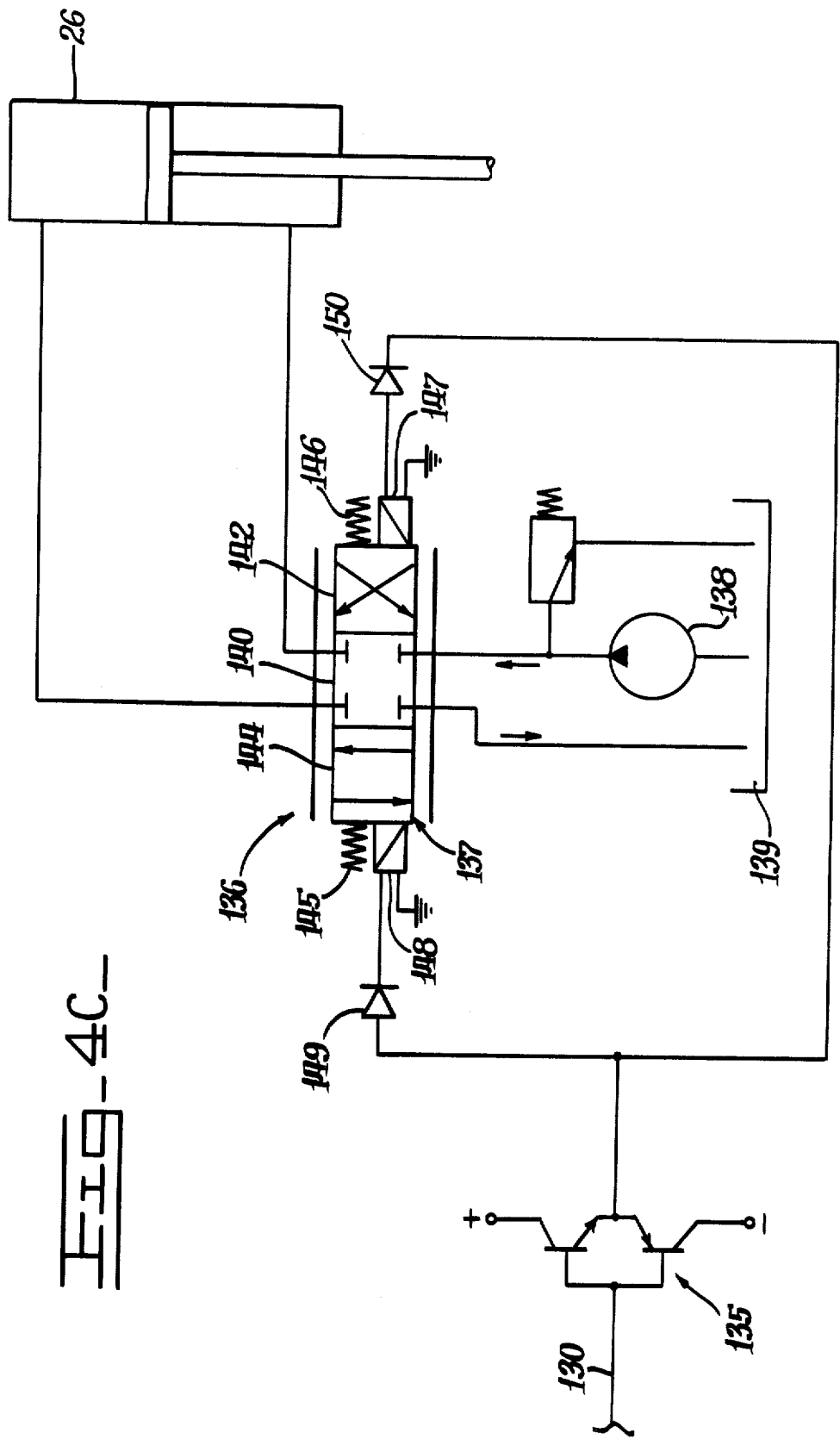


FIG-4C-

FIG. 5-

OUTPUT V_s INCIDENT ANGLE

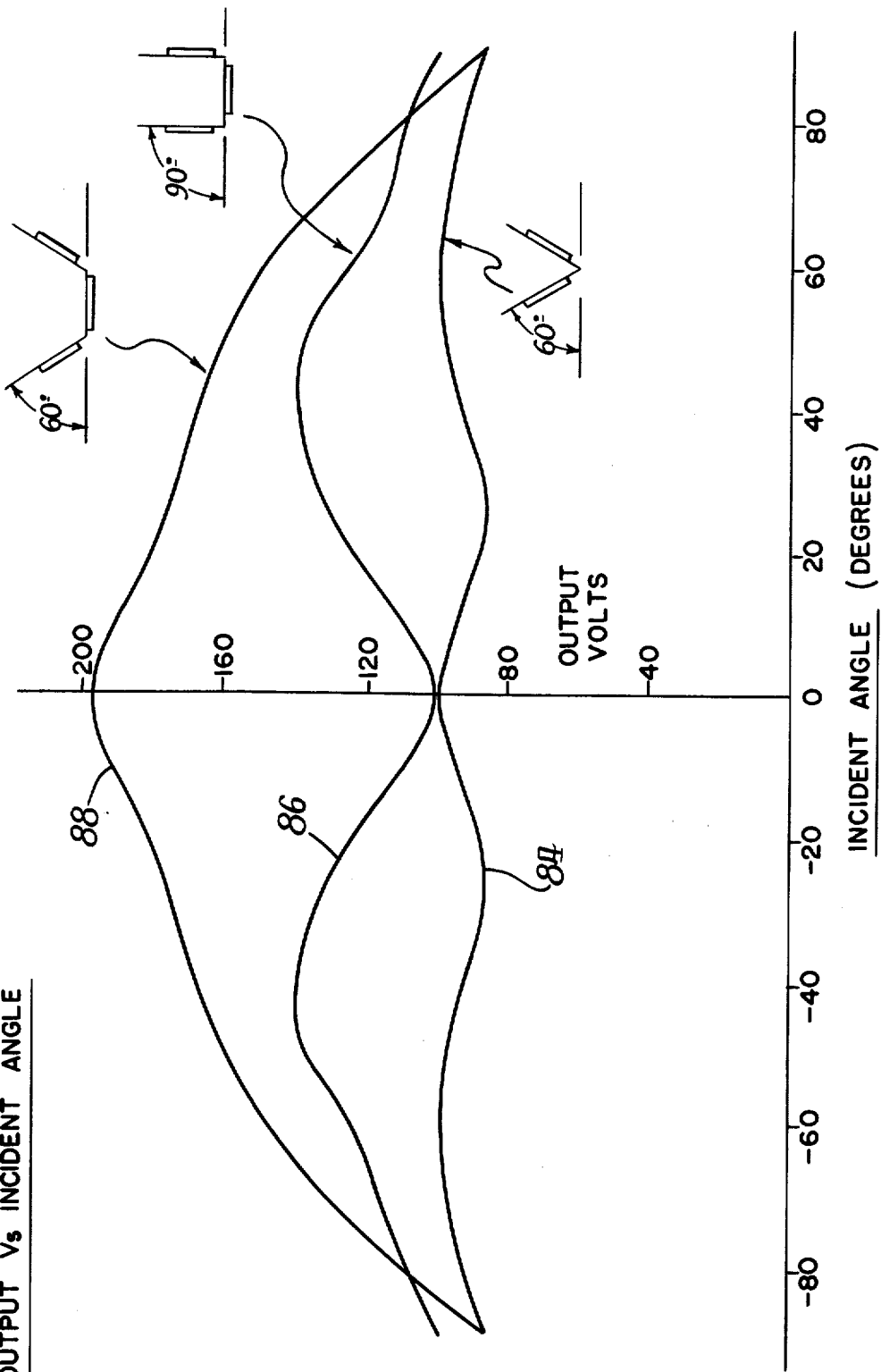
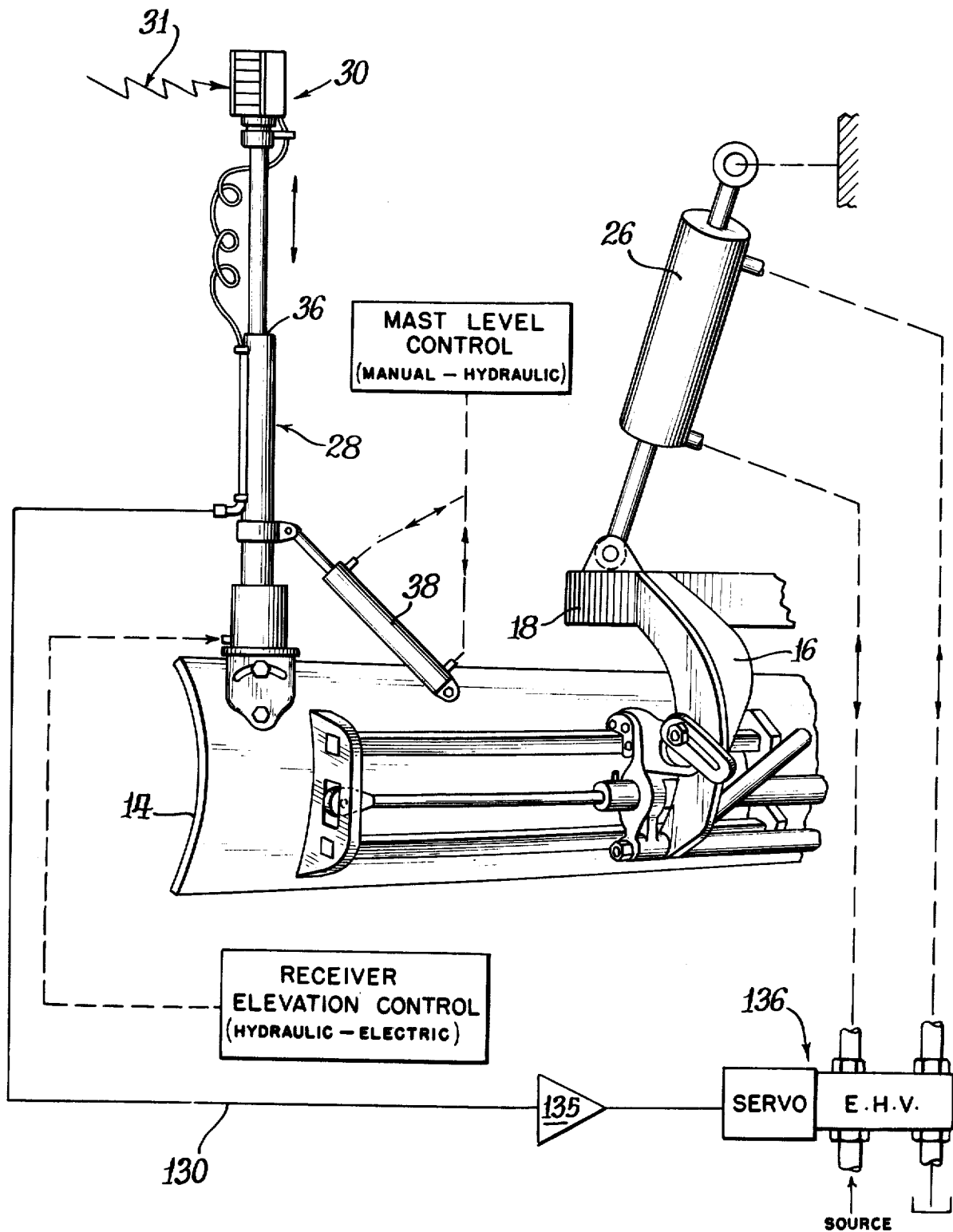


FIG. 6



AUTOMATIC LEVELLING SYSTEM FOR EARTH WORKING BLADES AND THE LIKE

BACKGROUND OF THE INVENTION

This invention relates to a system for automatically maintaining an earth working blade on a motor grader or the like in fixed relation to a plane in order to achieve an earth surface that conforms to a desired grade or plane. Because the system is totally independent of the terrain engaging wheels or tracks on the motor grader, employment of the system materially enhances the accuracy and speed with which a rough surface can be graded to a smooth surface of desired configuration.

The nature and advantages of the present invention can be more fully appreciated in the context of the known prior art, wherein:

U.S. Pat. No. 2,916,836, issued to Stewart, et al., discloses a transit mounted light source which produces a steady flat beam of non-coherent light in a plane used to activate two vertically spaced photo-electric cells on the vehicle, so one or the other is excited by the light beam when the structure supporting the photo cells deviates from the plane of the light beam. The patented structure is limited in its accuracy because the light beam is non-coherent, and the sensing mechanism is not adapted to detect the degree to which the vehicle deviates from the plane.

U.S. Pat. No. 3,009,271 issued to Kuehne et al employs an incandescent light source which is modulated and sensed by two horizontally spaced photo-electric devices mounted on an earth working vehicle. For successful operation of the device, rather precise alignment between the transit mounted light source and the earth working vehicle are required, thereby detracting from the utility and accuracy of the disclosed apparatus.

U.S. Pat. No. 3,046,681 issued to Kutzler discloses an earth working vehicle which carries a light source that is projected to a transit mounted reflector from which the light beam is returned to sensors carried on the vehicle. The reflector has limited angular effectiveness, thereby requiring rather precise positioning between the reflector and the earth working vehicle. Moreover, the system employs numerous moving parts on the vehicle which, in view of the severe environment of operation, are of marginal accuracy and longevity.

U.S. Pat. No. 2,796,685 issued to Bensinger discloses a transit mounted electromagnetic energy source which cooperates with an antenna mounted on an earth working vehicle to maintain the earth working parts of the vehicle in fixed relation to the plane of the radiation. The system disclosed employs very sensitive detectors which are subject to noise. Moreover, the system utilizes the output of the detectors in an analog system.

Lasers have been used in systems for controlling functions on vehicles as illustrated in U.S. Pat. No. 3,494,426 to Studebaker, No. 3,604,512 to Carter, et al., and No. 3,659,949 to Walsh and Apostolico.

An object of the present invention is to provide a system of the type referred to above wherein the location of the plane defining radiant energy source is not critical. This object is achieved according to the present invention by providing a receiver that has an extremely broad reception angle. As will appear in more detail hereinafter one form of receiver according to the pres-

ent invention is operative over 180° and another form is operative over 360°.

Another object of the present invention is to provide a receiver in which the response is substantially flat over all angles of incidence of the light beam thereon. Achievement of this object enhances the accuracy of the device and simplifies the circuitry contained therein. This object is achieved by providing two or more solar cells in each region of the receiver and orienting the solar cells with respect to one another so as to achieve the flat response.

Still another object of the present invention is to provide a system that generates an error signal that is proportional to the degree of displacement of the blade from the reference plane. Because the receiver of the present invention has a plurality of discrete spaced apart light sensitive regions, excitation of the remote regions results in an error signal of greater magnitude than is produced upon excitation of regions closer to the reference plane.

Yet another object of the present invention is to provide a system of the type referred to above, that is virtually immune to ambiguities arising from spurious light signals and/or minor misalignments of the apparatus. This object is achieved by providing a digital system for processing the outputs of the various radiant energy sensors. Appropriate gating of such signals renders the system virtually immune to ambiguities or false signals.

A feature and advantage of the present invention arising from employment of a pulsating radiant energy source is that the digital circuitry requires no internal clock, but relies on the repetitive pulses for timing.

A further object of the present invention is to provide a system that will restore the earth working blade to the correct position even when the blade has been displaced by a large amount as occurs at the outset of grading operations on extremely rough terrain. The provision of a plurality of energy sensors in the receiver of the present invention in cooperation with the digital circuitry employed makes achievement of this object possible.

A still further object of the present invention is to provide visual indicators to apprise the operator that the earth working machine system is operating correctly. This object is achieved in a simple straightforward way because of the digital elements used in the system.

The foregoing together with other objects, features and advantages of the present invention will be more apparent after referring to the following specification and accompanying drawings.

SUMMARY OF THE INVENTION

The present invention employs a transit mounted laser that includes a motor driven reflector for sweeping the beam from the laser throughout a reference plane so at any given location within the plane there is a pulsating radiant energy signal whereby a special receiver mounted on the blade of an earth working vehicle having a plurality of discrete active sensors, such as solar cells that are optically isolated from one another can generate outputs for a digital circuit that generates a corrective or error signal. The corrective signal has a polarity and magnitude proportional to the direction and amount that the receiver deviates from the plane, which signal is employed to move the blade so that the

receiver resumes proper orientation with respect to the plane.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a motor grader provided with a system according to the present invention.

FIG. 2 is a perspective view of one embodiment of a receiver according to the present invention, with portions being broken away to reveal internal details.

FIG. 3 is a perspective view of another embodiment of a receiver according to the present invention, portions being broken away to reveal internal details.

FIGS. 4A, 4B and 4C are schematic diagrams showing the circuitry employed in the present invention.

FIG. 5 is a graph of energy sensor output versus angular orientation for various configurations of light sensors employed in the present invention.

FIG. 6 is a perspective view of a fragment of the motor grader of FIG. 1, showing the general arrangement of the present invention in more detail.

DESCRIPTION OF A PREFERRED EMBODIMENT

Referring more particularly to the drawing, FIG. 1 shows a motor grader 12 which exemplifies an earth working vehicle with which the present invention can be used to advantage. Motor grader 12 has an earth working blade 14 that is carried on arms 16, the upper ends of which are supported on a circle 18. As is conventional, circle 18 is driven through a gear box 20 to establish the angular position of blade 14 and the circle is carried on a draw bar 22 which is pivotally mounted to the frame of grader 12 in bolster 24. Hydraulic actuators 26 move the free ends of the draw bar vertically so as to effect corresponding movement of blade 14. This structure is conventional and does not, per se, constitute a part of the present invention. As will appear in more detail, the system of the present invention controls hydraulic actuators 26 to maintain the position of blade 14 at a constant distance from a reference plane.

Mounted on blade 14, and extending upward therefrom, is a mast 28 which supports on its upper end a receiver 30. Receiver 30 is adapted to receive a pulsating radiant energy beam 31 from a source 32 which is supported on a tripod 34, which radiant energy beam is confined to a reference plane, which is above the finished grade which blade 14 is used to achieve. Mast 28 has a telescoping adjustment 36 to effect appropriate spacing between the reference plane and the plane of the finished grade. An angular adjustment, including a hydraulic cylinder 38, allows adjustment of the angular relationship between the reference plane and the mast when the slope of the blade is changed.

For producing beam 31 in a reference plane, radiation source 32 includes a laser 40 supported in a housing 42 as shown in FIG. 4A. Housing 42 is of hollow cylindric shape and has a cover 44 which is supported for rotation by a bearing 46 so that the cover can rotate with respect to the housing. Cover 44 has a depending ring gear 48 which meshes with a pinion 50 driven by a motor 52, so a reflecting prism in alignment with laser 40 and mounted in cover 44 reflects the energy from laser 40 through an opening 56 in the cover. Beam 31 is thus swept through a plane that is normal to the axis of rotation of the cover on the housing. Because the laser 40 produces a very narrow beam of coherent radiation and prism 54 is continuously rotated, beam 31 is

swept throughout the plane so that there exists at any given site in the plane a pulsating field of radiant energy. This radiant energy plane is monitored by receiver 30.

Referring now to FIG. 2, the receiver 30 includes a base 58 which is secured to the upper end of mast 28, and the base is preferably of hollow construction so electrical components can be mounted therein as described in more detail hereinafter. On the top 60 of the base three tiers of spacers 62, 64 and 66 are stacked at uniform intervals around the circumference thereof. The spacers support, parallel to top 60, a plurality of opaque circular members 68, shown in FIG. 2. These spaced apart opaque members preferably are coated on both upper and lower surfaces with a dull black paint to avoid energy reflection, and define therebetween energy channels 70, nine such channels being shown in FIG. 2. Located within each of the energy channels is a prism shaped support member 72, the upper and lower faces of which define equilateral triangles and which are secured to the respective surfaces of opaque members 68. On each of the three vertical faces of each prism shape support member, solar cells 74 are supported. A solar cell such as that distributed by Central Laboratories under the trade designation N 120 CGN/P is suitable. These cells produce an electrical voltage in response to impingement thereon of radiant energy of appropriate wave length and this voltage is carried by output conductors of the solar cells (not shown) through a central opening 76 to the base 58 for connection to the circuitry therein. Although the solar cells for only one channel 70 are shown in FIG. 2, it is to be understood that each of the channels, with the exception of a central or null channel 70', is provided with cells configured as shown in the uppermost channel shown in FIG. 2. In order to immunize the cells from spurious signals from sunlight and the like, it is desirable to interpose a filter medium between the solar cells and the energy entering channels 70. One form of filter medium shown at 78 is a red plastic transparent sheet directly overlaying the active faces of the solar cells when the laser 40 produces a beam of radiant energy of a wave length of 6328 angstroms. An alternate form of filter medium is a plastic sheet 80 of the same material as plastic sheet 78. Plastic sheet 80 is wrapped entirely around the exterior of the receiver and fastened by suitable means, such as rivets 82. Plastic sheet 80 has the additional advantage that it excludes deleterious substances from the interior of channels 70.

The solar cells 74 in each channel 70 are series connected and it has been found that the output of the solar cells within one channel when arranged at angles of 60° with respect to one another produces a substantially flat electrical output for most angles of impingement of the beam from radiant energy source 32. Referring to FIG. 5, the output for this configuration is depicted by curve 84, while other configurations exhibit more directional sensitivity. For example, curve 86 indicates the output response when the solar cells are oriented at 90° with respect to one another and curve 88 indicated the response when the solar cells are oriented at an angle of 120° with respect to one another. Thus FIG. 5 graphically illustrates the importance of a 60° angle between the solar cells, since it affords an optimally flat output response irrespective of the angle impingement of the radiant energy source.

An alternate form of receiver is shown at 30' in FIG. 3. The receiver has a response over a 180° angle in contrast to the 360° response angle of the receiver of FIG. 2. The details of construction of receiver 30' are substantially identical as those described hereinabove in respect to FIG. 2 except that the receiver is of semi-cylindric configuration having an opaque non-reflective vertical backing plate 90. Opaque non-reflective semi-circular plates 92 define a plurality of radiant energy channels 94 with prism shaped member 96 supporting solar cells 98 therein. The solar cells in each channel 94 are oriented at 60° with respect to one another and are provided with an overlying filter medium 100 and/or a filter medium 102 that entirely circumscribes and encloses the structure.

As both the embodiments of the invention shown in FIGS. 2 and 3 have nine channels, further description will be made with reference to FIG. 3, having its central channel identified by reference character 94a. This channel is referred to as a null channel in that there are no active solar cells in such channel. When the channel 94b above channel 94a receives energy from source 32, the blade on which the receiver is mounted is below the desired plane. As will appear hereinafter, excitation of channel 94b causes the blade to be raised at a slow rate in order to effect a relatively fine adjustment of the blade position. Channel 94b is consequently referred to as the raise-fine channel. When the channels 94c, above channel 94b, are excited by the energy from source 32, it indicates a situation wherein the blade 14 is well below the desired location, rapid corrective movement of blade 14 is thus required. Because the apparatus responds to excitation of channels 94c by effecting rapid upward movement of the blade, channels 94c are referred hereinafter as the raise-coarse channels.

When the channel 94d, immediately below null channel 94a, is excited by radiant energy source 32, the blade 14 is slightly above the desired location. Excitation of the solar cells in channel 94d thus effects relatively slow lowering of the blade and for that reason, channel 94d is referred to hereinafter as the lower-fine channel. When the channels 94e, below channel 94d, are excited, the blade is well above the desired location and rapid lowering movement is required, in consequence of which channels 94e are referred to hereinafter as lower-coarse channels. Channels 94b and 94d, because they are relatively close to null region 94a, are referred to as proximal regions. Excitation of either of the proximal regions effects relatively slow restorative movement of the blade 14. Channels 94c and 94e, because they are relatively remote from null region 94a, are referred to as distal regions, and excitation of either of the distal regions effects relatively rapid restorative movement of the blade 14.

In FIG. 4A solar cells 98 are shown schematically and are shown in positions approximating the relative position shown in FIG. 3, and in each channel there is a set of two solar cells that are series connected. With respect to a common or ground connection 106, the solar cells in channels 94b and 94c, located above null region 94a are arranged to produce a positive going output signal whereas the solar cells located below the null region in channels 94d and 94e are arranged to produce a negative going output. In FIG. 4A only one raise-coarse channel 94c and only one lower-coarse channel 94e is shown, because the other respective channels ef-

fect an equivalent response, i.e., to restore the blade and receiver toward a null position at a relatively rapid rate.

Because the radiant energy impinging on the solar cells is pulsating, due to rotation of reflecting prism 54, the output of the excited solar cells will be a pulse. The output of the solar cells in channel 94c and AC coupled to the input of an operational amplifier 117 through a capacitor 108 and an input resistor 109. Similarly, the output of the solar cells in channel 94b is AC coupled to the input of an operational amplifier 116 through a capacitor 110 and input resistor 111, the output of the solar cells in channel 94d is AC coupled to the input of amplifier 116 through a capacitor 112 and input resistor 113 and the output of the solar cells in channel 94e is AC coupled to the input of amplifier 117 through a capacitor 114 and input resistor 115. Thus, the signal appearing at the input of amplifier 116 is a positive pulse when there is an output from channel 94c and is a negative pulse where there is an output from channel 94d. The signal at the input of amplifier 117 is a positive pulse when there is an output from channel 94c and is a negative pulse when channel 94e has an output.

The outputs of channels 94b and 94d, which correspond to relatively small deviations from the desired location of blade 14, are connected to the input of operational amplifier 116 which is arranged to invert the signal supplied thereto and to produce at the output thereof an amplified signal having a polarity depending on whether the energy from source 32 impinges on channel 94b or channel 94d. Likewise, the outputs of the solar cells in channel 94c and 94e are connected to operational amplifier 117 which corresponds in structure and function to amplifier 116. The output of amplifier 116 is connected to an input network to a pair of operational amplifiers 118 and 119 that are connected as comparators so that when the signal input to amplifier 118 is above a reference signal, there will be at the output terminal of the amplifier a signal; this occurs when the solar cells in channel 94b are excited and accordingly the output of amplifier 118 is designated as B. When the output signal from amplifier 116 is a positive going signal, amplifier 119 produces an output signal; this occurs when the solar cells in channel 94d are excited and the output of amplifier 119 will therefore be referred to as D. In a similar fashion, the output of amplifier 117 is connected to an input network to amplifiers 120 and 121 which are identical in structure and function to amplifiers 118 and 119. Thus when the solar cells in channel 94c are excited, a positive pulse is produced at the input of amplifier 117 and inverted by that amplifier so as to produce an output at amplifier 120. The output of amplifier 120 is accordingly designated C. Excitation of the solar cells in channel 94e will produce an output signal at amplifier 121, such output being designated hereinafter as E.

With reference to FIG. 4B, the output of each of the amplifiers 118, 119, 120 and 121 is fed to an AND gate. More specifically, signal B from amplifier 118 is connected to one of two inputs of an AND gate 122; the output D of amplifier 119 is connected to one of two inputs of an AND gate 123; the output C of amplifier 120 is connected to one of two inputs of an AND gate 124; the output E of amplifier 121 is connected to one of two inputs of an AND gate 125. The other input of each of the AND gates is the complement or inverse of the output of the solar cells of the opposite channel.

This can be illustrated most concisely in Boolean notation as follows:

$$122 = B \cdot \bar{D}$$

$$123 = D \cdot \bar{B}$$

$$124 = C \cdot \bar{E}$$

$$125 = E \cdot \bar{C}$$

The output of each gate 122-125 is fed to the input of a single shot or monostable multi-vibrator. That is to say, the output of AND gate 122 is connected to the input of a single shot multi-vibrator 122s; the output of AND gate 123 is connected to the input of the one shot multi-vibrator 123s; the output of AND gate 124 is connected to the input of a single shot multi-vibrator 124s; the output of AND gate 125 is connected to the input of a single shot multi-vibrator 125s. In order to provide the complement of each of the signals there is an inverter in the output of each of the multi-vibrators, such inverter circuits 122i being identified with the reference characters corresponding to the AND gates. Thus it will be seen that only one of the single shot multi-vibrators will have a high output with the particular multi-vibrator being determined by the channel on which the radiation from source 32 impinges.

Although the outputs of the multi-vibrators are substantially accurate and free of ambiguities, a further gating stage is desirable to reduce further the possibility of erroneous control signals. The gating stage includes AND gates 126 and 127 which have four inputs and AND gates 128 and 129 which have three inputs. The output of AND gate 126 will be referred to herein as B'; the output of AND gate 127 will be referred to herein as D'; the output of AND gate 128 will be referred to herein as C'; the output of AND gate 129 will be referred to herein as E'. The following equations taken in conjunction with FIG. 4B define the operations performed in the gating stage:

$$B \cdot \bar{D} \cdot \bar{C} \cdot \bar{E} = B'$$

$$D \cdot \bar{B} \cdot \bar{C} \cdot \bar{E} = D'$$

$$C \cdot \bar{D} \cdot \bar{E} = C'$$

$$E \cdot \bar{B} \cdot \bar{C} = E'$$

It will be seen from the foregoing that in order to produce a signal for moving the blade 14 slowly, it is necessary that there be no signal in the other three active channels. For moving the blade rapidly, however, AND gates 128 and 129 afford priority of a coarse signal in a given direction over the fine signal in the same direction. Stated otherwise, a signal C' (corresponding to raise-coarse) is produced without regard to the presence or absence of a signal in the raise-fine channel. Similarly, signal E' (corresponding to lower-coarse) is produced without regard to the presence or absence of a signal in the lower-fine channel.

The signals B', C', D' and E', because of the circuitry described up to this point, are highly immune to ambiguities such as might arise from noise and/or the entry of spurious radiation into one or more of the channels in receiver 30'. Such signals are used to derive an output that has a magnitude and polarity corresponding to the direction and amount that is necessary to restore receiver 30' so that null region 94a is within the reference plane produced by source 32. Such output signal appears at 130.

Output signal 130 is constituted by the output signal from an operational amplifier 132 which is arranged so that the output corresponds in magnitude but is of opposite polarity relative to the magnitude and polarity of the input signal. Signal D' (corresponding to the lower-fine channel) is fed to the input through a resistor RLF and the signal E' (corresponding to the lower-coarse channel) is fed to the input through a resistor RLC. Resistor RLF has a higher resistance (e.g., 5 times) than the resistance of RLC so that amplifier 132 produces a greater output in response to signal E' than the amplifier produces in response to signal D'. The difference in magnitude is reflected at output 130.

Signal B' (corresponding to the raise-fine channel) is connected to an inverting amplifier 134 through a resistor RRF. Signal C' (corresponding to the raise-coarse channel) is connected to the input of inverting amplifier 134 through a resistor RRC. Resistor RRF is greater than (e.g., 5 times) the resistance of RRC so that the magnitude of the output of amplifier 134 is proportional to the speed at which it is desired to restore the blade toward the null position. The output of inverting amplifier 134 is connected to input 133 of amplifier 132 so that the signal at the output of amplifier 132 has a polarity and magnitude that corresponds to the desired direction and speed of movement of blade 14.

Referring to FIG. 4C the signal at output 130 is connected to a power amplifier 135 which activates an electrohydraulic transducer 136. The transducer controls cylinder 26, the piston and rod of which are attached to blade 14.

The transducer 136 includes a hydraulic valve 137 which controls delivery of hydraulic fluid from a pump 138 and a reservoir 139 to cylinder 26. Valve 137 includes a valve body having a center section 140 ported to inhibit fluid communication between pump 138 and cylinder 26, a down section 142 which is ported to deliver hydraulic fluid from pump 138 to the top of cylinder 26, and an up section 144 which is ported to deliver hydraulic fluid to the lower end of cylinder 26. The valve body is maintained in the position shown in FIG. 4C by springs 145 and 146. Up section 144 is moved into an active position in response to energization of the solenoid 147 and down section 142 is moved into active position by energization of a solenoid 148. The inputs to the solenoids are derived through oppositely polarized diodes 149 and 150 from power amplifier 135 so that depending on the polarity of the output of the power amplifier, hydraulic fluid will be delivered to the end of cylinder 26 appropriate for the direction of desired movement. When the magnitude of the signal at lead 130 is of relatively high magnitude (corresponding to a relatively large deviation of receiver 30 from the null position) the valve body is fully displaced toward one extreme or the other. When the signal on output lead 130 is of relatively low magnitude (corresponding to a slight deviation of the receiver from the null position) the valve body is only partially displaced, thereby affording a restricted path for the hydraulic fluid and a corresponding slow movement of the piston rod associated with cylinder 26. Accordingly, blade 14 is moved in a direction and at a speed appropriate for the direction and degree of deviation from the null position.

In order to limit the size of receiver 30, the circuitry of the present invention is arranged to produce an error

signal of correct magnitude and polarity even though blade 14 and receiver 30 deviate from the null position to such a large degree that the radiant energy from source 32 impinges on no part of the receiver. For achieving this advantageous mode of operation, the invention provides a receiver extender circuit 152 (see FIG. 4B). The receiver extender circuit includes two substantially identical sections, one for moving the blade in each direction, depending on the direction from which receiver 30 leaves the plane of radiant energy. The upper section of the receiver extender circuit, as viewed in FIG. 4B acts to lower the receiver and blade 14 should the entire receiver reach a position totally above the plane of radiant energy from source 32. Such section includes a flip-flop 154 which is set by signal E' (corresponding to the lower-coarse channels). The flip-flop 154 is reset by the output of an OR gate 155. As is clear from FIG. 4B, OR gate 155 functions according to the following equation:

$$155 = D' + B' + C'.$$

Thus, flip-flop 154 is reset when the system has responded to signal E' to return the receiver to a position at which beam 31 impinges on one of channels 94d, 94b or 94c. If receiver 30 is totally above the plane of the radiant energy from source 32, OR gate 155 will not produce a signal to reset flip-flop 154 whereupon the output 156 of the flip-flop, which is connected to one input of an AND gate 157, will remain high. The other input of AND gate 157 is supplied with a high input when the receiver is totally above the plane of the radiant energy beam. Because signal E' (lower-coarse) also triggers a single shot multi-vibrator 158, the output of which is inverted by an inverter 159 before connection to the input of AND gate 157. Single shot multi-vibrator 158 produces a high output in response to signal E' that has a duration in excess of the rate of pulsations of the energy in the reference plane, i.e., a period in excess of the time required for one revolution of prism 54. By virtue of inverter 159, there is a low input to gate 157 for such extended duration. If on the succeeding pulse, however, no energy is received by any of the channels in receiver 30, flip-flop 154 is not reset and output lead 156 thereof remains high. When the period of multi-vibrator 158 ends, the output of the multi-vibrator goes down and the output of inverter 159 goes up, whereupon a signal is produced at the output of AND gate 157. Such signal is connected through a resistor 160 to the input of amplifier 132, whereby an error signal of appropriate magnitude and polarity is produced at output 130, thereby activating transducer 136 and cylinder 26 to restore the receiver and blade to a position within the reference plane. At such time as the receiver returns to the plane of the beam, multi-vibrator 158 is triggered when beam 31 impinges on channel 94e. This causes the output of inverter 159 to go down so as to turn off gate 157. As the receiver approaches the null point, OR gate 155 is activated so as to reset flip-flop 154, which also turns off gate 157.

The lower section of receiver extender circuit 152 operates identically except that it is arranged to raise the receiver and blade 14 when those elements assume a position below the reference beam. Accordingly, no description of the lower section is considered necessary and each element of corresponding function has the same reference character as used with the upper section with the addition, however, of a prime.

The circuit of FIG. 4B includes means for affording to the operator of earth working vehicle 12 a visual indication of the particular mode at which the system is operating at any given time. For indicating that the system is operating in the lower-fine mode, the output D' of AND gate 127 is connected to an amplifier 162d which actuates a lamp 164d which is visible to the operator. When lamp 164d is illuminated, it apprises the operator that the receiver is in the lower-fine mode of operation, i.e., that beam 31 is impinging upon channel 94d of receiver 30. A similar amplifier 162b is activated by AND gate 126 to cause illumination of a lamp 164, illumination of which apprises the operator that the system is operating in the raise-fine mode. An amplifier 162e receives its input from AND gate 129 and drives a lamp 164e to apprise the operator that the system is operating in the lower-coarse mode. An amplifier 162c is connected to the output of AND gate 128 and drives a lamp 164c, illumination of which apprises the operator that the system is operating in the raise-coarse mode. Adjacent lamps 164 are indicia 166 so that the operator can understand the significance of the lamps.

To afford an indication to the operator that the system is in the null region or either the raise or lower fine region, a panel lamp 168 is provided. Lamp 168 is driven by an amplifier 170, the input of which is controlled by an OR gate 172. As can be seen in FIG. 4B, OR gate 172 produces an output which energizes amplifier 170 to illuminate lamp 168 if a flip-flop 174 is set or if an OR gate 176 is on. OR gate 176 also causes flip-flop 174 to reset. The operation of OR gate 176 is most clearly described by the following equation:

$$176 = C' + E'$$

Thus, when the system is correcting in either the raise-coarse mode or the lower-coarse mode, a pulsating signal, corresponding to the rotative speed of energy source 32 is applied to amplifier 170, whereby lamp 168 is activated in an intermittent or blinking mode. When the system is operating in either the raise-fine mode or the lower-fine mode, flip-flop 174 is set by virtue of an OR gate 178. The function of OR gate 178 is defined by the following equation:

$$178 = B' + D'$$

When flip-flop 174 is set, a continuous signal appears at its output 180 which is fed through OR gate 172 to amplifier 170. Accordingly, lamp 168 will be illuminated continuously. Lamp 168 is also illuminated continuously when the reference beam 31 is within null region 94a, because the beam in reaching the null region goes through either channel 94b or channel 94d so as to set flip-flop 174 through OR gate 178. The flip-flop is reset only when beam 31 impinges on channels 94c or 94e. Accordingly, even though none of the lamps 164 are illuminated, the operator of the grader is apprised of the mode of system operation by lamp 168.

The system of the present invention operates as follows: Usually radiation source 32 is set up at the job site and is adjusted in accordance with conventional surveying procedures to produce a reference plane. Telescoping joint 36 assists in establishing receiver 30 at the correct height. Radiation source 32 is then activated, thereby producing a pulsing energy beam 31 in a reference plane above the desired plane of the finished grade with motor 52 adjusted to provide a suitable sweep frequency; in one system designed according to

the present invention, a sweep frequency between 4.5 cycles per second and 10.5 cycles per second was found satisfactory.

Although the invention is exemplified hereinabove in connection with a horizontal reference plane, it will be obvious that the system can be adapted for use with respect to a plane oriented in any direction and that receiver 30, by use of the system of this invention, can be restored in an appropriate direction so that null region 94a intersects the beam produced by source 32.

While the receivers exemplified in FIGS. 2 and 3 employ nine channels, this number is merely exemplary and in certain instance, a greater or lesser number of channels can be employed. Thus, it will be seen that the present invention provides a substantially automatic system for maintaining a working member in a proper relation to a plane. The employment of digital circuitry in generating the error signal enhances the accuracy of the system and avoids ambiguities such as might arise from the entrance of spurious energy into receiver 32.

Although one embodiment of the invention has been shown and described, it will be obvious that other adaptations and modifications can be made without departing from the true spirit and scope of the invention.

What is claimed is:

1. In an earthworking implement control system for maintaining an implement in a fixed relationship to a plane comprising means for producing a narrow beam of radiant energy of a fixed wave length, means for sweeping said beam throughout the plane to produce pulsating radiation at any site in the plane, a multidirectional receiving control mounted on the implement for receiving the beam comprising a receiving means including a plurality of sets of at least two series connected angularly disposed light actuated cells for producing an electric signal in response to impingement of said beam thereon, spacer means for supporting said sets of cells in a stacked vertical relationship so that there is at least a first set of said cells and a second set of said cells spaced from said first set across a null region, a plurality of mutually parallel opaque planar members horizontally disposed on opposite sides of said sets of cells and thereby defining said null region between said sets so said planar members are operable to define at least three beam defining channels, and circuit and power means responsive to an electric signal from said cells for moving said implement in a direction when one of said sets produces an electrical signal whereby the null region of said receiving means is moved into the plane of said beam.

2. The receiving control defined in claim 1 wherein the receiving means includes filtering means for excluding radiant energy from the cells at wave lengths below that of said beam producing means.

3. The receiving control defined in claim 2 wherein said filtering means includes a deformable tinted impervious plastic sheet overlying the peripheral edges of the opaque planar members for excluding deleterious matter from the channels.

4. The receiving control defined in claim 1 wherein the individual cells of each said set are angularly displaced from one another by an angle of about 60° so that the receiving means has a substantially flat response to beams impinging thereon from all directions within $\pm 90^\circ$ of a plane bisecting the 60° angle.

5. The receiving control defined in claim 1 in combination with a plurality of third cells one of which is as-

sociated with each said set of cells, the individual cells of each set being displaced about 60° from one another so that said receiving means has a substantially flat response to beams impinging thereon from all directions.

6. The receiving control defined in claim 1 including a third set of cells adjacent said first set and opposite said null region and a fourth set of cells adjacent said second set and opposite said null region, whereby the circuit and power means responding to said third and fourth sets of said cells moves the implement faster than when responding to said first and second sets.

7. The receiving control defined in claim 1 wherein circuit and power means comprises a source of pressurized fluid, a double acting cylinder having a piston and rod in driving relation to said implement, a valve for controllably delivering fluid to said cylinder to selectively move said piston in said cylinder, and electrical means for controlling said valve in response to the signals from the cells.

8. The receiving control defined in claim 7 wherein the electrical means comprises circuit means for producing a DC signal having a first polarity when said receiving means is in a position such that the beam impinges on said first set of cells and a second polarity when said receiving means is in a position such that the beam impinges on said second set of cells.

9. The receiving control defined in claim 8 wherein said DC signal producing means including means for connecting the cells of said first set in series opposition of the cells of said second set so that the polarity of the output voltage is indicative of the direction that the receiving means is displaced from said plane, first and second comparators having input terminals connected to the series connected cells, said first comparator producing an output signal when said first set of cells receives said beam and said second comparator producing an output signal when said second set of cells receives said beam, logic means for generating an inverse of the output of said first comparator, logic means for generating an inverse of the output of said second comparator, a first gate for producing a first control signal when there coexists at the input thereof an output signal from said first comparator and the inverse of said second comparator, a second gate for producing a second control signal when there coexists at the input thereof an output from said second comparator and the inverse of said first comparator, means for inverting the output of said first gate, and means for combining the outputs of said inverting means and said second gate.

10. The receiving control defined in claim 6 wherein said circuit and power means includes means for generating an A binary signal responsive to impingement of said beam on said first set of light activated cells, a B binary signal responsive to impingement of said beam on said second set of light activated cells, a C binary signal responsive to impingement of said beam on said third set of light activated cells, and a D binary signal responsive to impingement of said beam on said fourth set of light activated cells, first logic means responsive to the signals $A\bar{B}\bar{C}\bar{D}$ and $B\bar{A}\bar{C}\bar{D}$ for transmitting to the power means a signal of relative low magnitude of appropriate polarity to move the implement and sets of cells in a direction to bring said null region of said receiving control into the plane, and second logic means responsive to the signals $C\bar{B}\bar{D}$ and $D\bar{A}\bar{C}$ for transmitting to said circuit and power means a relatively high magnitude signal of appropriate polarity to move the

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implement and sets of cells in a direction to bring said null region of said receiving means into the plane.

11. The receiving control defined in claim 10 wherein the circuit and power means includes a third

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logic means operable to indicate the last polarity registered by the second logic means when the receiving means completely leaves the plane.
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