(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
28 February 2008 (28.02.2008)

PCT

(10) International Publication Number
WO 2008/023341 A2

(51) International Patent Classification: Not classified

(21) International Application Number: PCT/IB2007/053358

(22) International Filing Date: 22 August 2007 (22.08.2007)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/823,150 22 August 2006 (22.08.2006) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

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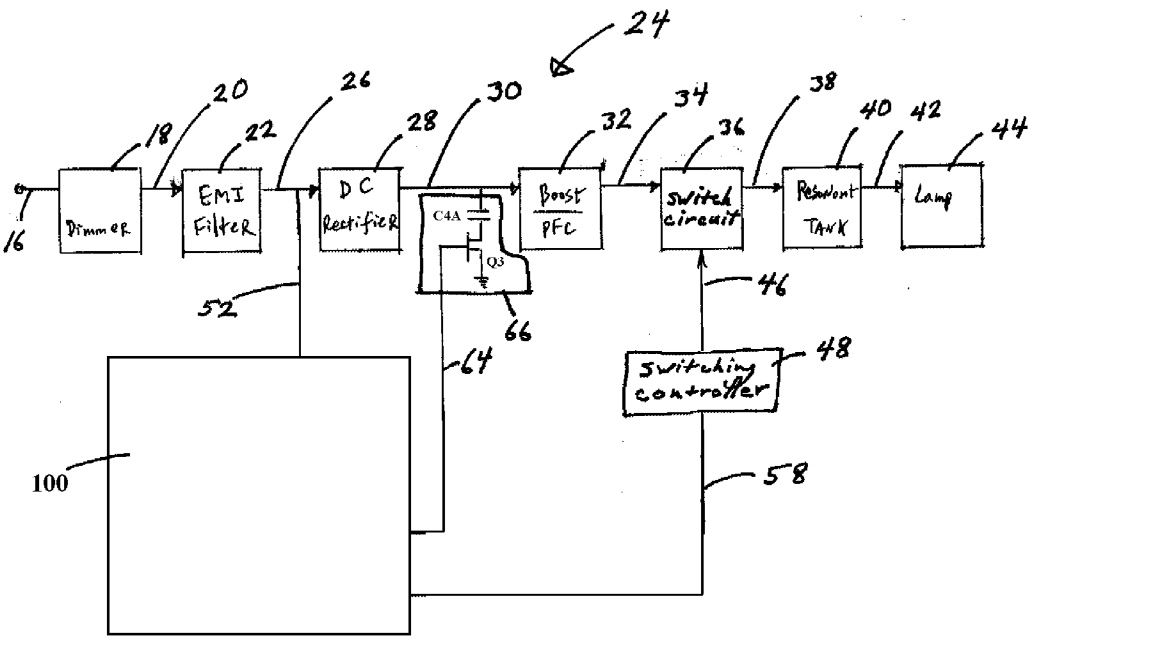
(54) Title: AUTOMATIC DIMMING RANGE RECOGNITION METHOD



(57) **Abstract:** An automatic dimming range recognition method for an electronic ballast including reading a control signal 802; determining whether the control signal is greater than control signal max 804; setting the control signal max to the control signal when the control signal is greater than the control signal max 806; determining whether the control signal is less than control signal min 808; setting the control signal min to the control signal when the control signal is less than control signal min 810; and calculating an output light level that corresponds to the control signal 812.

WO 2008/023341 A2

Published:

— *without international search report and to be republished upon receipt of that report*

AUTOMATIC DIMMING RANGE RECOGNITION METHOD

This invention relates generally to lamp dimming control, and more specifically to a method for automatic dimming range recognition.

Electronic ballasts for fluorescent lamps have become sophisticated and are widely used in a variety of applications. One application that has presented problems is dimmable electronic ballasts. Modern dimming switches, such as triac dimmers, generate a phase-controlled power with reduced on-time, i.e., the time in which the chopped phase-controlled power is non-zero. The line input power briefly crosses zero power between positive and negative, but the phase-controlled power holds the zero power longer to limit power to a load. Triac dimmers work well for resistive loads, such as incandescent lamps, but work poorly or not at all for non-linear loads, such as ballasts for fluorescent lamps. Non-linear loads can hum, buzz, run hot, or burn out.

Dimmable electronic ballasts have been designed to work with triac dimmers, but such dimmable electronic ballasts are limited to use with a predetermined line input voltage, e.g., a dimmable electronic ballast for triac dimmers designed to operate at 120 Volts cannot be used with a 277 Volt line input voltage. The dimming control voltage signal is generated within the dimmable electronic ballast, so the voltage of the dimming control voltage signal is affected by the line input voltage to the dimmable electronic ballast. Attempting to use present dimmable electronic ballasts for triac dimmers at a voltage other than the predetermined line input voltage gives rise to problems with power factor, total harmonic distortion, and stability. Components that are sized for one line input voltage, such as capacitors and inductors, may be the wrong size for another line input voltage. The requirement that different dimmable electronic ballasts be used for different predetermined line input voltages causes additional expense in manufacturing and stocking different dimmable electronic ballasts for different line input voltages.

Dimmable electronic ballasts are also designed to work with triac dimmers having a particular dimmer range corresponding to a particular light output range, e.g., minimum dimmer output should correspond to minimum light output and maximum dimmer output should correspond to maximum light output. Unfortunately, this is seldom the case. Triac dimmers between manufacturers and in different lots from a single manufacturer have different dimmer ranges. When the actual dimmer range is larger than the design dimmer range, there is a dead zone below the minimum light output and/or above the maximum light output so that the light output is insensitive to the dimmer adjustment. When the actual dimmer range is smaller than the design dimmer range, there is a light output loss above the minimum light output and/or below the maximum light output so that the light output fails to reach minimum light output at minimum dimmer output and/or fails to reach maximum light output at maximum dimmer output, respectively. The mismatch between dimmer range and light output range deduces the usefulness and desirability of the dimmable electronic ballasts.

It would be desirable to provide a method for automatic dimming range recognition that overcomes the above disadvantages.

One aspect of the invention provides an automatic dimming range recognition method for an electronic ballast including reading a control signal; determining whether the control signal is greater than control signal max; setting the control signal max to the control signal when the control signal is greater than the control signal max; determining whether the control signal is less than control signal min; setting the control signal min to the control signal when the control signal is less than control signal min; and calculating an output light level that corresponds to the control signal.

Another aspect of the invention provides an automatic dimming range recognition method for an electronic ballast including providing an electronic ballast having a dimming range that extends between a first control signal limit and a second control signal limit; reading a control signal; determining whether the control signal is beyond the first control signal limit and outside the dimming range; and setting the first control signal limit to the control signal when the control signal is beyond the first control signal limit and outside the dimming range.

Another aspect of the invention provides an automatic dimming range recognition method for an electronic ballast including initializing range values for the electronic ballast at power on; automatically recognizing the range values while operating the electronic ballast;

adjusting range copy for the range values; and storing the range values for the electronic ballast at power down.

Another aspect of the invention provides a control circuit for an electronic ballast including an on-time converter, the on-time converter having a scaling circuit operably connected to receive a sensed phase-controlled power signal and generate a scaled power signal, and a comparator operably connected to compare the scaled power signal to a comparison voltage to generate an on-time signal; a line voltage detector, the line voltage detector generating a line voltage signal in response to the sensed phase-controlled power signal; and a microcontroller, the microcontroller being responsive to the on-time signal to generate a dimming control signal, and being responsive to the line voltage signal to generate a mains bias signal; wherein the mains bias signal biases the comparison voltage.

The foregoing and other features and advantages of the invention will become further apparent from the following detailed description of the presently preferred embodiment, read in conjunction with the accompanying drawings. The detailed description and drawings are merely illustrative of the invention rather than limiting, the scope of the invention being defined by the appended claims and equivalents thereof.

FIG. 1 is a block diagram of a lighting system with a universal dimming electronic ballast made in accordance with the present invention;

FIG. 2 is a block diagram of a lighting system with a universal dimming electronic ballast made in accordance with the present invention;

FIG. 3 is a schematic diagram for the lighting system of **FIG. 2** for a universal dimming electronic ballast made in accordance with the present invention;

FIG. 4 is a flow chart for automatic dimming range recognition for a universal dimming electronic ballast made in accordance with the present invention; and

FIGS. 5-8 are flow charts for automatic dimming range recognition with range storage for a universal dimming electronic ballast made in accordance with the present invention.

FIG. 1 is a block diagram of a lighting system with a universal dimming electronic ballast made in accordance with the present invention. The electronic ballast adapts to any phase-controlled power provided by a dimmer to produce the lamp dimming desired. The waveform of the power to the lamp is unaffected by the line voltage. An on-time converter converts the phase-controlled power to a dimming control signal. A line voltage detector detects line voltage and adjusts boost circuit capacitance through a capacitance selection circuit. Those skilled in the art will appreciate that the phase-controlled power can be supplied by any phase-control device, such as a triac dimmer or the like.

Electronic ballast **24** receives phase-controlled power **20** from dimmer **18** at EMI filter **22** and provides lamp power **42** for a lamp **44** from resonant tank **40**. The dimmer **18** receives mains power **16**, such as 120 Volt or 277 Volt power line power, and controls the phase of the mains power **16** to reduce the power provided to the electronic ballast **24** and dim the lamp **44**. The exemplary electronic ballast **24** includes the EMI filter **22** generating filtered mains power **26** operably connected to the dimmer **18** and a DC rectifier **28**, which provides rectified power **30** to boost/power factor controller (PFC) **32**. The boost/PFC **32** provides DC bus power **34** to switching circuit **36**, which provides switched power **38** to resonant tank **40**. The switching circuit **36** is responsive to switching control signal **46** from a switching controller **48**. The resonant tank **40** provides lamp power **42** to the lamp **44**.

The electronic ballast **24** can include a universal circuit **100** receiving a sensed phase-controlled power signal **52** from the filtered mains power **26** and generating a capacitance selector signal **64** and/or a dimming control signal **58**. Those skilled in the art will appreciate that the sensed phase-controlled power signal provided to the universal circuit **100** can be sensed at other points besides the filtered mains power **26**, such as being sensed from the rectified power **30**, for example.

The universal circuit **100** can include a dimming circuit responsive to the sensed phase-controlled power signal **52** to generate the dimming control signal **58**, which is provided to the switching controller **48**. The dimming circuit senses the phase-controlled power, determines on-time for the sensed phase-controlled power, and controls lamp dimming in response to the on-time. As defined herein, on-time is the duration for which each positive or negative voltage pulse of the sensed phase-controlled power signal **52** is non-zero.

The universal circuit **100** can also include a capacitance selection circuit responsive to the sensed phase-controlled power signal **52** to generate a capacitance selector signal **64**, which is provided to capacitance circuit **66**. The capacitance circuit **66** is operably connected to adjust the capacitance to the boost/PFC **32**. The capacitance selection circuit senses a phase-controlled power, determines line voltage for the sensed phase-controlled power, and adjusts boost/PFC capacitance in response to the line voltage.

FIG. 2, in which like elements share like reference numbers with **FIG. 1**, is a block diagram of a lighting system with a universal dimming electronic ballast made in accordance with the present invention.

The electronic ballast adapts to any phase-controlled power provided by a dimmer to produce the lamp dimming desired. The waveform of the power to the lamp is unaffected by the line voltage. An on-time converter converts the phase-controlled power to an on-time, which is converted to a dimming control signal. A line voltage detector detects line voltage and adjusts boost circuit capacitance through a capacitance selection circuit and/or adjusts the power factor controller internal multiplier through a stability circuit to maintain electronic ballast operating stability. Those skilled in the art will appreciate that the phase-controlled power can be supplied by any phase-control device, such as a triac dimmer or the like.

Electronic ballast **24** receives phase-controlled power **20** from dimmer **18** at EMI filter **22** and provides lamp power **42** for a lamp **44** from resonant tank **40**. The dimmer **18** receives mains power **16**, such as 120 Volt or 277 Volt power line power, and changes the controls the phase of the mains power **16** to reduce the power provided to the electronic ballast **24** and dim the lamp **44**. The exemplary electronic ballast **24** includes the EMI filter **22** generating filtered mains power **26** operably connected to the dimmer **18** and a DC rectifier **28**, which provides rectified power **30** to boost/power factor controller (PFC) **32**. The boost/PFC **32** provides DC bus power **34** to switching circuit **36**, which provides switched power **38** to resonant tank **40**. The switching circuit **36** is responsive to switching control signal **46** from a switching controller **48**. The resonant tank **40** provides lamp power **42** to the lamp **44**.

In this example, the electronic ballast **24** includes a universal circuit **100** with a dimming circuit, a capacitance selection circuit, and a stability circuit. The electronic ballast **24** can include a dimming circuit with an on-time converter **50** receiving a sensed phase-controlled power signal **52** and generating an on-time signal **54**. A microcontroller **56**, also known as an MCU, in the dimming circuit is responsive to the on-time signal **54** to generate a dimming control signal **58**, which is provided to the switching controller **48**. The dimming circuit senses the phase-controlled power, calculates on-time for the sensed phase-controlled power, and controls lamp dimming in response to the on-time. As defined herein, on-time is the duration for which each positive or negative voltage pulse of the sensed phase-controlled power signal **52** is non-zero. The microcontroller **56** receives DC power **70** from a DC power supply **72**. The DC power supply **72** can be powered from any suitable location within the electronic ballast **24**, such as the DC bus.

The electronic ballast **24** can include a capacitance selection circuit with a line voltage detector **60** receiving the sensed phase-controlled power signal **52** and generating a line voltage signal **62**. The microcontroller **56** is responsive to the line voltage signal **62** to generate a capacitance selector signal **64**, which is provided to capacitance circuit **66**. The capacitance circuit **66** is operably connected to adjust the capacitance to the boost/PFC **32**. The capacitance selection circuit implements a lamp control method that senses a phase-controlled power, determines line voltage for the sensed phase-controlled power, and adjusts boost/PFC capacitance in response to the line voltage.

The electronic ballast **24** can include a stability circuit with the line voltage detector **60** receiving the sensed phase-controlled power signal **52** and generating the line voltage signal **62**. The microcontroller **56** is responsive to the line voltage signal **62** to generate an internal multiplier signal **68**, which is provided to the boost/PFC **32**. The stability circuit implements a lamp control method that senses a phase-controlled power, determines line voltage for the sensed phase-controlled power, and selects a boost/PFC internal multiplier in response to the line voltage.

FIG. 3 is a schematic diagram for the lighting system of **FIG. 2** for a universal dimming electronic ballast made in accordance with the present invention. The universal circuit **100** includes dimming, capacitance selection, and stability circuits. The dimming circuit converts the sensed phase-controlled power signal to a dimming control signal, the capacitance selection circuit detects the line voltage and switches capacitance at the boost/PFC, and the stability circuit detects the line voltage and provides that information to the boost/PFC. DC power supply **72** receives DC bus power **380** and powers the microcontroller circuit, capacitance selection circuit, stability circuit, and other components as desired. The DC power supply **72** includes 15V power supply **382** and 5V power supply **384**.

The dimming circuit includes the on-time converter **50** and the microcontroller **56**. The on-time converter **50** receives the sensed phase-controlled power signal **52** and generates the on-time signal **54**. The microcontroller **56** receives the on-time signal **54** and generates dimming control signal **58**. The on-time converter **50** includes scaling circuit **402** and comparator **404**. The scaling circuit **402** scales and smoothes the sensed phase-controlled power signal **52** to generate a scaled power signal **403**, which is compared to a comparison voltage **405** at the comparator **404** to generate the on-time signal **54**. The mains bias signal **69** biases the comparison voltage **405** and indicates whether the mains power is low voltage or high voltage. In one embodiment, the mains bias signal **69** is a low level when the mains power is a low voltage, such as 120 Volts, and a high level when the mains power is a high voltage, such as 277 Volts. The mains bias signal **69** increases the comparison voltage when the mains power is a high voltage to balance the sensed phase-controlled power signal **52** and assure accurate measurement of the on-time pulse. The processing of the on-time signal **54** to generate the switching control signal **46** from the dimming control signal **58** is discussed above.

The capacitance selection circuit includes the line voltage detector **60**, microcontroller **56**, and capacitance circuit **66**. The line voltage detector **60** detects the voltage of the main power feeding the dimmer **18**. In this example, the line voltage detector **60** is a line peak detector which provides a line voltage signal **62** proportional to the peak voltage of the sensed phase-controlled power signal **52**. The microcontroller **56** detects the level of the line voltage signal **62** and determines whether the main power is high voltage, such as 277 Volts, or a lower voltage, such as 120 Volts. In this example, the microcontroller **56** generates an inverted capacitance selector signal **406**, which is inverted at inverter **408** to generate the capacitance selector signal **64**. When the main power is high voltage, the microcontroller **56** sets the inverted capacitance selector signal **406** to a first level and when the main power is not high voltage, the microcontroller **56** sets the inverted capacitance selector signal **406** to a second level. When the main power is high voltage as indicated by the capacitance selector signal **64**, transistor Q3 in the capacitance circuit **66** is off and no extra capacitance is added to the boost/PFC. When the main power is not high voltage as indicated by the capacitance selector signal **64**, transistor Q3 in the capacitance circuit **66** is on and extra capacitor C4A is added to the boost/PFC. Decreasing capacitance increases stability at the higher main power voltage. Using different capacitance values also improves power factor and total harmonic distortion at the different main power voltages.

The stability circuit includes the line voltage detector **60** and microcontroller **56**. As discussed above for the capacitance selection circuit, the line voltage detector **60** receives the sensed phase-controlled power signal **52** and generates the line voltage signal **62** at the microcontroller **56**. The microcontroller **56** detects the level of the line voltage signal **62** and determines whether the main power is high voltage, such as 277 Volts, or a lower voltage, such as 120 Volts. When the main power is high voltage, the microcontroller **56** sets the internal multiplier signal **68** to a first level and when the main power is not high voltage, the microcontroller **56** sets the internal multiplier signal **68** to a second level. The internal multiplier signal **68** is provided to the boost/PFC, such as the MULTIN pin of a PFC integrated circuit in the boost/PFC. When the main power is high voltage as indicated by the internal multiplier signal **68**, the MULTIN pin of a PFC integrated circuit is held at a first level. When the main power is not high voltage as indicated by the internal multiplier signal **68**, the MULTIN pin of a PFC integrated circuit is held at a second level. For example, in one embodiment the first level is low and the second level is high. Those skilled in the art will appreciate that the effect of feeding a small current to the MULTIN pin voltage to increase stability of the PFC integrated circuit depends on the particular electronic ballast design, so that whether the MULTIN pin is held high or low for high voltage depends on the particular electronic ballast design.

FIG. 4 is a flow chart for an automatic dimming range recognition method for a universal dimming electronic ballast made in accordance with the present invention. In this example, the automatic dimming range recognition method is implemented on a universal dimming electronic ballast employing a microcontroller **56** as described for **FIGS. 2 & 3** above. The microcontroller **56** stores a lighting function, such as a table or equations, that provides a dimming control signal **58** as an output light level in response to a sensed phase-controlled power signal **52** as a current control signal. In one embodiment, the lighting function is a logarithmic function that allows for the perception of light levels by human observers. The microcontroller **56** can also store a control signal min stored and a control signal max stored, which are stored when the electronic ballast is powered down and retrieved when the electronic ballast is powered up; a control signal min default and a control signal max default, which are the highest minimum and lowest maximum expected, respectively, for any phase-controlled dimmer that is expected to provide phase-controlled power to the electronic ballast; and/or a control signal min allowed and a control signal max allowed, which are the lowest minimum and highest maximum allowed, respectively, for the electronic ballast.

The automatic dimming range recognition method **800** includes reading a control signal **802**, such as a sensed phase-controlled power signal. The control signal is compared to a control signal max to determine whether the control signal is greater than the control signal max **804**. When the control signal is greater than the control signal max, the control signal max is set to the control signal **806**, and the method **800** continues with calculating the output light level **812**. When the control signal is not greater than the control signal max, the method **800** continues with comparing the control signal to a control signal min to determine whether the control signal is less than the control signal min **808**. When the control signal is less than the control signal min, the control signal min is set to the control signal **810**, and the method **800** continues with calculating the output light level **812**. When the control signal is not less than the control signal min, the control signal is between the existing values of the control signal min and the control signal max, and the method **800** continues with calculating the output light level **812**. Once the output light level has been calculated, the method **800** continues with reading the next control signal **802**.

Those skilled in the art will appreciate that the control signal min and control signal max defining the range value on starting the method **800** can be an allowed value, such as the control signal min allowed and the control signal max allowed; an expected value, such as the control signal min default and the control signal max default; or a learned value, such as the control signal min stored and the control signal max stored. The control signal min allowed and the control signal max allowed are the limiting values allowed for operation of the electronic ballast and define an allowed range. The control signal min default and the control signal max default are the values expected for any dimmer to be used with the electronic ballast and define an expected range, and lie within the allowed range formed by the control signal min allowed and the control signal max allowed. The control signal min stored and the control signal max stored are values based on operation of the electronic ballast when the control signal min and the control signal max are stored in the microcontroller in non-volatile memory, and lie between the allowed range and the expected range, i.e., the control signal min stored is less than or equal to the control signal min default and greater than or equal to the control signal min allowed, and the control signal max stored is greater than or equal to the control signal max default and less than or equal to the control signal max allowed.

The calculating the output light level **812** includes determining an output light level step. When the lighting function is a table providing a number of output light level steps as a function of a number of control signal steps, the output light level step can be determined by interpolating between the control signal min and the control signal max for the present control signal. The determination can be expressed algebraically as:

$$\text{Output Light Level[steps]} = \frac{\text{Control Signal - Control Signal Min}}{\text{Control Signal Max - Control Signal Min}} * \text{Resolution[steps]}$$

where the Resolution[steps] is the number of divisions of the control signal and Output Light Level[steps] is the particular step for the present Control Signal. The Output Light Level[steps] corresponds to an output light level that can be used to set the dimming control signal. The resolution can be determined by the memory space available in the microcontroller, such as 256, 512, 1024, etc. corresponding to 8, 9, 10, etc. bits, respectively.

The method **800** can run continuously when the electronic ballast is energized. In one embodiment, the control signal min and the control signal max are each set to predetermined values stored in the microcontroller when the electronic ballast is first energized. The control signal min and the control signal max are then adjusted as required by the method **800** as the user changes the control signal. In another embodiment, the control signal min and the control signal max from each time the electronic ballast is energized are each stored in the microcontroller in non-volatile memory, such as an EEPROM, so that the electronic ballast learns the values for the particular dimmer to which it is connected and keeps them when the electronic ballast is de-energized.

The method **800** can be illustrated by an example of the operation. In this example, the resolution is 256 steps, the control signal min is 25, and the control signal max is 75. Assuming the control signal on energizing the electronic ballast is read as 50 at **802**, the control signal is less than the control signal max of 75 at **804** and greater than the control signal min of 25 at **808**, so the output light level step is determined at **812** as:

$$\text{Output Light Level[steps]} = \frac{50 - 25}{75 - 25} * 256 = 128$$

The output light level step corresponds to an output light level in the middle of the output light level range that can be used to set the dimming control signal.

Next, assume the dimmer is adjusted upwards and the control signal is read as 100 at **802**. The control signal is greater than the control signal max of 75 at **804**, so the control signal max is set to 100 at **806**. When the control signal is next set to 50 as read at **802**, the output light level step is determined at **812** as:

$$\text{Output Light Level [steps]} = \frac{50 - 25}{100 - 25} * 256 = 85$$

Therefore, a control signal of 50 now results in an output light level step of 85, which is lower that the initial output light level step for a control signal of 50. The output light level step corresponds to an output light level that can be used to set the dimming control signal.

Next, assume the dimmer is adjusted downwards and the control signal is read as 20 at **802**. The control signal is less than the control signal min of 25 at **808**, so the control signal min is set to 20 at **810**. When the control signal is next set to 50 as read at **802**, the output light level step is determined at **812** as:

$$\text{Output Light Level [steps]} = \frac{50 - 20}{100 - 20} * 256 = 96$$

Therefore, a control signal of 50 now results in an output light level step of 96, which is lower that the initial output light level step for a control signal of 50 but higher than the output light level step after adjustment of the control signal max. The output light level step corresponds to an output light level that can be used to set the dimming control signal. The control signal min and the control signal max now match the range of the control signal from the phase-controlled dimmer associated with the electronic ballast.

Those skilled in the art will appreciate that the automatic dimming range recognition method can be used to adjust either the control signal max or the control signal min without adjusting both. The method of adjusting one includes providing an electronic ballast having a dimming range that extends between a first control signal limit and a second control signal limit; reading a control signal; determining whether the control signal is beyond the first control signal limit and outside the dimming range; and setting the first control signal limit to the control signal when the control signal is beyond the first control signal limit and outside the dimming range. The method can continue and adjust the other limit by determining whether the control signal is beyond the second control signal limit and outside the dimming range; and setting the second control signal limit to the control signal when the control signal is beyond the second control signal limit and outside the dimming range. The method can include calculating an output light level when the control signal is within the dimming range.

The control signal min and the control signal max from each time the electronic ballast is energized can be stored as control signal min stored and the control signal max stored in the microcontroller in non-volatile memory, such as an EEPROM, so that the electronic ballast learns the values for the particular dimmer to which it is connected and keeps them when the electronic ballast is de-energized. When the control signal min and the control signal max are stored, the lamp connected to the electronic ballast provides the same light output for a given dimmer switch position each time the electronic ballast is energized.

When the control signal min and the control signal max are stored, replacement of the dimmer switch with another dimmer switch can require reset of the control signal min and the control signal max to the default values. The replacement dimmer switch is unlikely to have the same dimmer range as the dimmer switch being replaced. When the replacement dimmer switch has a larger range, the electronic ballast can adjust for the range using the automatic dimming range recognition method **800**. When the replacement dimmer switch has a smaller range, the electronic ballast can be reset to adjust for the range.

The electronic ballast can be reset by providing a reset signal to the electronic ballast to direct the microcontroller to reset the control signal min to a control signal min default and the control signal max to a control signal max default. In one embodiment, the reset signal is a control sequence signal including turning the dimmer on and off and/or moving the dimmer between maximum and minimum in a predetermined time, such as turning the dimmer on and off a certain number of times with a certain speed, moving the dimmer between maximum and minimum a certain number of times with a certain speed, combinations thereof, or the like. In one example, a human operator manually enters the control sequence signal by manipulating the dimmer. In another example, the replacement dimmer has the control sequence signal stored in non-volatile memory of an automatic reset dimmer and the control sequence signal is transmitted to the electronic ballast automatically when the replacement dimmer is installed. In another embodiment, the reset signal is a no-dimmer signal, i.e., the mains voltage applied to the electronic ballast without the dimmer installed. The electronic ballast detects the regular AC voltage rather than the chopped voltage which is present when the dimmer is installed.

FIGS. 5-8 are flow charts for automatic dimming range recognition with range storage for a universal dimming electronic ballast made in accordance with the present invention. The automatic dimming range recognition method **800** as described for **FIG. 4** can be included in the automatic dimming range recognition with range storage method **500** of **FIG. 5**. The method **500** includes starting the method **500** at **502**, initializing range values for the electronic ballast at power on **600**, automatically recognizing the range values while operating the electronic ballast by applying the automatic dimming range recognition method **800**, adjusting range copy for the range values **700**, storing the range values at power down **900**, and ending the method at **504**. In one embodiment, the range values are a minimum value and a maximum value for the control signal range. Depending on the operating history of the electronic ballast, the range values can be a control signal min allowed and/or a control signal max allowed; a control signal min default and/or a control signal max default; or a control signal min stored and/or the control signal max stored. Those skilled in the art will appreciate that in another embodiment the range values can be defined by one of the minimum value and the maximum value for the control signal range and the control signal range span. The method **500** is particularly useful when the control signal range has been expanded by the automatic dimming range recognition method **800** and the dimmer position is between control signal min and control signal max when the electronic ballast is powered down, i.e., the dimmer position is not at control signal min or control signal max. The method **500** is also self-healing so that errors in the variables are corrected as the electronic ballast is powered on and powered down over a number of cycles.

FIG. 6 is a flow chart for initializing range values for the electronic ballast at power on **600**. The initializing method **600** sets the control signal range to the allowed control signal range when the stored values of the control signal limits are at or outside the allowed control signal range. Starting the initializing **602**, the stored values of the control signal limits from the non-volatile memory are entered into the control signal limits, which are the working variables for the range values, and the control signal limit copies **604**. The control signal min and the control signal min copy are set to the control signal min stored. The control signal max and the control signal max copy are set to the control signal max stored. When the electronic ballast is powered on for the first time, the control signal min stored and the control signal max stored can be the control signal min default and the control signal max default.

The values of the control signal limit copies are checked relative to the control signal limit allowed values. The control signal limits and control signal limit copies are set to the control signal limit allowed when the control signal limit copies are outside the allowed control signal range. When the control signal max copy is greater than or equal to the control signal max allowed **606**, the control signal max and the control signal max copy are set equal to the control signal max allowed **608** and the method continues at **610**. When the control signal min copy is less than or equal to the control signal min allowed **610**, the control signal min and the control signal min copy are set equal to the control signal min allowed **612** and the method continues at **614**. The control signal limit and the control signal limit copy are equal throughout the initializing method **600** and so can be used interchangeably.

The initializing method **600** can continue with an optional validity checking of the range values, such as the control signal limit and/or the control signal limit copies. In one example, it is determined whether the control signal min copy is greater than the control signal max copy **614**. When the control signal min copy is greater than the control signal max copy, indicating the values are not valid, the control signal min and the control signal min copy are set equal to the control signal min default and the control signal max and the control signal max copy are set equal to the control signal max default **616**. In another example, the optional checking is a comparison of the control signal limit copies to expected values for the control signal limits, such as a fraction or multiple of the control signal limit default values. In another example, the optional checking is a data check of the control signal limit copies, such as a check sum of the control signal limit copies. An output max/min flag is reset to off limit and a rate change flag is reset to unchanged **617**, and the initializing method **600** ends at **618**. The automatic dimming range recognition with range storage method **500** can continue with the automatic dimming range recognition method **800** as described for **FIG. 4**. The method **500** automatically recognizes the appropriate range values for the dimmer switch while operating the electronic ballast, expanding the electronic ballast control signal range when the dimmer is moved beyond the present control signal min and/or control signal max.

FIG. 7 is a flow chart for adjusting range copy for the range values **700** so that the range values are available for storage when the electronic ballast is turned off. The control signal limit copies are set to the range values for the expanded signal control range when the range is expanded. Flags are set to indicate the expansion and/or the output light level at the output light level limit. After the automatic dimming range recognition method **800**, the automatic dimming range recognition with range storage method **500** can continue with adjusting the range copy **700**. The adjusting range copy **700** starts at **702**. When it is determined that the control signal max is greater than the control signal max copy **704** or that the control signal min is less than the control signal min copy **710**, the control signal max copy is set to the control signal max and the control signal min copy is set to the control signal min **706**. The range change flag is set to changed **708**, indicating that the control signal range of the electronic ballast changed during initializing the electronic ballast range after power on **600** or normal operation with the automatic dimming range recognition method **800**.

Referring to **FIG. 7**, the adjusting range copy for the range values **700** continues with determining whether the output light level is at the maximum or minimum. The output light level varies over a light output range as predetermined for a particular electronic ballast design, such as from 0 to 255. When it is determined that the output light level is at the output light level maximum **712** or that the output light level is at the output light level minimum **718**, the output max/min flag is set to limit **714**. When it is determined that the output light level is not at the output light level maximum **712** or that the output light level is not at the output light level minimum **718**, the output max/min flag is set to off limit **720**. The adjusting method **700** ends at **716**. The automatic dimming range recognition with range storage method **500** can continue with storing the range values at power down **900**.

FIG. 8 is a flow chart for storing the range values at power down **900** so that the values are available for use when the electronic ballast is next turned on. The control signal limits stored in non-volatile memory are set to the control signal limit default values when the output light level is at an output light level limit and are set to the expanded range values when the control signal range has expanded. The storing the range values at power down **900** starts at **902**. When it is determined that the output max/min flag is set to limit **904**, indicating that the output light level is at the maximum or minimum, the control signal limits, control signal limit stored values are set to the default values **906**. The control signal min stored is set to the control signal min default and the control signal max stored is set to the control signal max default **906**. In another optional embodiment that can be useful when the electronic ballast is subject to a brownout or power interruption and is not powering down, the working variables stored in volatile RAM memory can be set as well. The control signal limit copies and control signal limit stored values are set to the default values **907**. The control signal min and control signal min copy are set to the control signal min default **907**. The control signal max and control signal max copy are set to the control signal max default **907**. The output max/min flag is reset to off limit and the rate change flag is reset to unchanged **908**, and the storing method **900** ends at **910**. When it is determined that the output max/min flag is not set to limit **904** and the rate change flag is set to changed **912**, the control signal min stored is set to the control signal min copy and control signal max stored is set to the control signal max copy **914**. The output max/min flag is reset to off limit and the rate change flag is reset to unchanged **908**, and the storing method **900** ends at **910**. When it is determined that the output max/min flag is not set to limit **904** and the rate change flag is not set to changed **912**, the control signal min stored and control signal max stored remain the same. The output max/min flag and the rate change flag need not be reset. The storing method **900** ends at **910**.

The automatic dimming range recognition with range storage method **500** of **FIG. 5** does not require a reset of the electronic ballast for the replacement of the dimmer switch with another dimmer switch, unless the replacement dimmer switch has a smaller control signal range that the other dimmer switch. When the replacement dimmer switch has a smaller range, the electronic ballast can be reset to adjust for the range by providing a reset signal to the electronic ballast to direct the microcontroller to reset. The reset signal can be a control sequence signal or a no-dimmer signal that resets the control signal min to a control signal min default and the control signal max to a control signal max default.

While the embodiments of the invention disclosed herein are presently considered to be preferred, various changes and modifications can be made without departing from the scope of the invention. For example, the electronic ballast control signal ranges can be stored as an endpoint, such as the control signal max or min, with a span for the range, rather than the control signal max and min as described above. Those skilled in the art will appreciate that the embodiments described are exemplary and that alternative circuits can be used as desired for particular applications. The scope of the invention is indicated in the appended claims, and all changes that come within the meaning and range of equivalents are intended to be embraced therein.

CLAIMS

1. An automatic dimming range recognition method for an electronic ballast comprising:

reading a control signal **802**;

determining whether the control signal is greater than control signal max **804**;

setting the control signal max to the control signal when the control signal is greater than the control signal max **806**;

determining whether the control signal is less than control signal min **808**;

setting the control signal min to the control signal when the control signal is less than control signal min **810**; and

calculating an output light level that corresponds to the control signal **812**.

2. The method of claim 1 wherein the calculating comprises:

generating a fraction by dividing the difference between the control signal and the control signal min by the difference between the control signal max and the control signal min; and

generating an output light level step by multiplying the fraction by a resolution; and

determining the output light level corresponding to the output light level step.

3. The method of claim 2 wherein the determining the output light level comprises looking up the output light level on a table of output light levels for output light level steps.

4. The method of claim 3 wherein the output light levels in the table are a logarithmic function of the output light level steps.

5. The method of claim 1 further comprising storing the control signal max and the control signal min in non-volatile memory.

6. The method of claim 5 further comprising resetting the control signal min to control signal min default and the control signal max to control signal max default in response to a reset signal to the electronic ballast.

7. The method of claim 6 wherein the reset signal is a control sequence signal.

8. The method of claim 6 wherein the reset signal is a no-dimmer signal.

9. An automatic dimming range recognition method for an electronic ballast comprising:

providing an electronic ballast having a dimming range that extends between a first control signal limit and a second control signal limit;

reading a control signal;

determining whether the control signal is beyond the first control signal limit and outside the dimming range; and

setting the first control signal limit to the control signal when the control signal is beyond the first control signal limit and outside the dimming range.

10. The method of claim 9 further comprising:

determining whether the control signal is beyond the second control signal limit and outside the dimming range; and

setting the second control signal limit to the control signal when the control signal is beyond the second control signal limit and outside the dimming range.

11. The method of claim 9 further comprising calculating an output light level when the control signal is within the dimming range.

12. The method of claim 9 further comprising storing the first control signal limit and a second control signal limit in non-volatile memory.

13. The method of claim 12 further comprising resetting the control signal min to control signal min default and the control signal max to control signal max default in response to a reset signal to the electronic ballast.

14. The method of claim 13 wherein the reset signal is a control sequence signal.

15. The method of claim 13 wherein the reset signal is a no-dimmer signal.

16. An automatic dimming range recognition method for an electronic ballast comprising:
initializing range values for the electronic ballast at power on **600**;
automatically recognizing the range values while operating the electronic ballast **500**;
adjusting range copy for the range values **700**; and
storing the range values for the electronic ballast at power down **900**.

17. The method of claim 16 wherein the range values are a minimum value selected from the group consisting of a control signal min allowed, a control signal min default, and a control signal min stored, and a maximum value selected from the group consisting of a control signal max allowed, a control signal max default, and a control signal max stored.

18. The method of claim 16 wherein the automatically recognizing comprises:
reading a control signal **802**;
determining whether the control signal is greater than control signal max **804**;
setting the control signal max to the control signal when the control signal is greater than the control signal max **806**;
determining whether the control signal is less than control signal min **808**;
setting the control signal min to the control signal when the control signal is less than control signal min **810**; and

calculating an output light level that corresponds to the control signal **812**.

19. The method of claim 18 further comprising storing the control signal min as control signal min stored, and storing the control signal max as control signal max stored; and wherein the initializing range values comprises:

setting both the control signal min and a control signal min copy equal to the control signal min stored **604**;

setting both the control signal max and a control signal max copy equal to the control signal max stored **604**;

determining whether the control signal max copy is greater than or equal to a control signal max allowed **606**;

setting both the control signal max and the control signal max copy equal to the control signal max default when the control signal max copy is greater than or equal to the control signal max allowed **608**;

determining whether the control signal min copy is less than or equal to a control signal min allowed **610**; and

setting both the control signal min and the control signal min copy equal to the control signal min default when the control signal min copy is less than or equal to the control signal min allowed **612**.

20. The method of claim 19 further comprising:

checking validity of the range values **614**;

setting both the control signal min and the control signal min copy equal to a control signal min default when the range values are not valid **616**; and

setting both the control signal max and the control signal max copy equal to a control signal max default when the range values are not valid **616**.

21. The method of claim 19 wherein the adjusting range copy comprises:

determining whether the control signal max is greater than the control signal max copy **704**;

setting the control signal min copy equal to the control signal min **706**, the control signal max copy equal to the control signal max **706**, and a rate change flag to changed **708** when the control signal max is greater than the control signal max copy;

determining whether the control signal min is less than the control signal min copy **710**;

setting the control signal min copy equal to the control signal min **706**, the control signal max copy equal to the control signal max **706**, and the rate change flag to changed **708** when the control signal min is less than the control signal min copy;

determining whether output light level is at output light level maximum **712**;

setting an output max/min flag to limit when the output light level is at the output light level maximum **714**;

determining whether the output light level is at output light level minimum **718**;

setting the output max/min flag to limit when the output light level is at the output light level minimum **714**; and

setting the output max/min flag to no limit **720** when the output light level is not at the output light level maximum and the output light level is not at the output light level minimum.

22. The method of claim 21 wherein the storing the range values comprises:

determining whether the output max/min flag is set to limit **904**; and

setting the control signal min stored equal to the control signal min default and the control signal max stored equal to the control signal max default **906** when the output max/min flag is set to limit.

23. The method of claim 22 further comprising:

setting both the control signal min and the control signal min copy equal to the control signal min default **907** when the output max/min flag is set to limit; and setting both the control signal max and the control signal max copy equal to the control signal max default **907** when the output max/min flag is set to limit.

24. The method of claim 21 further comprising:

determining whether the range change flag is set to changed **912**; and

setting the control signal min stored equal to the control signal min copy and the control signal max stored equal to the control signal max copy **914** when the range change flag is set to changed.

25. A control circuit for an electronic ballast comprising:

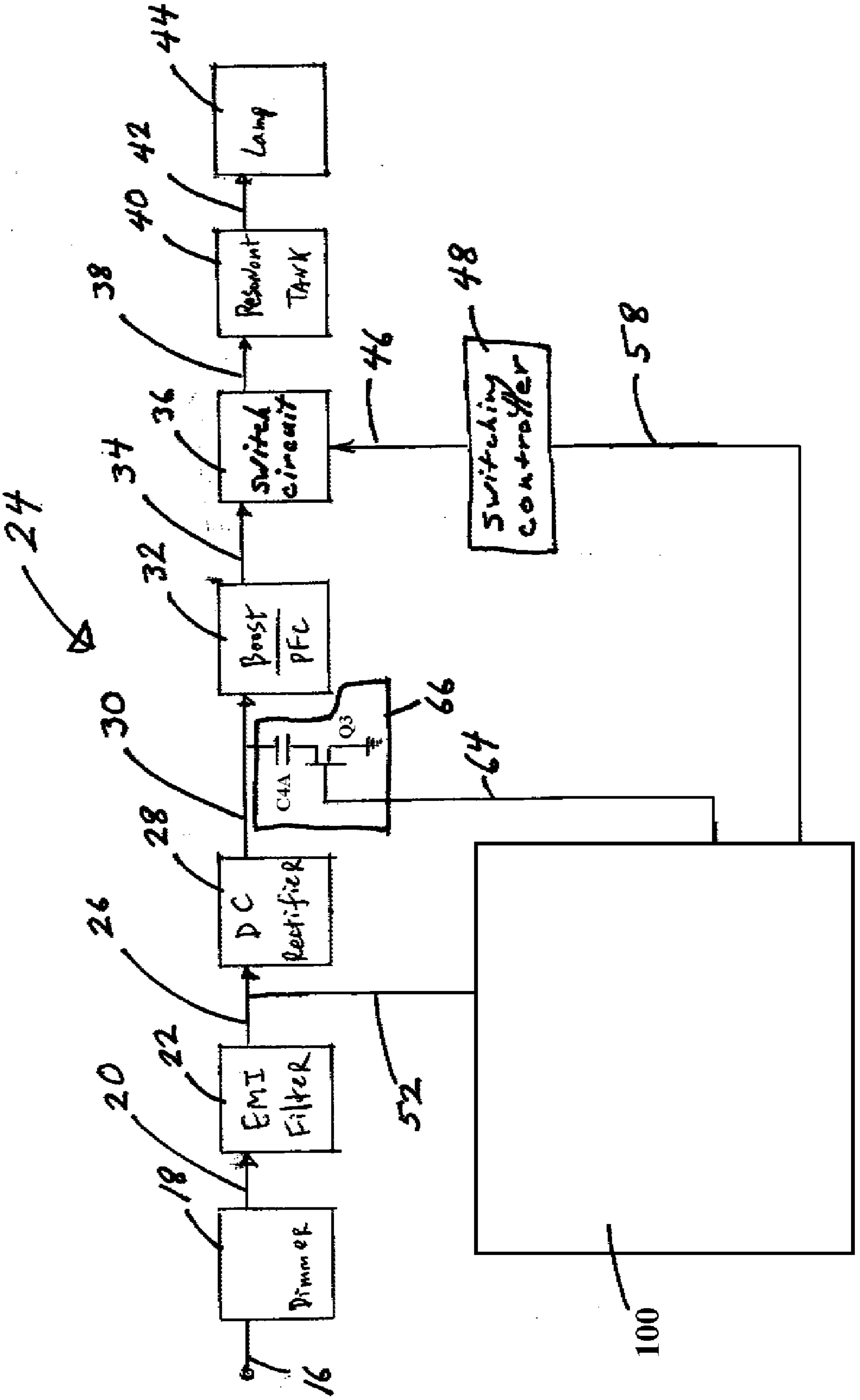
an on-time converter **50**, the on-time converter **50** having a scaling circuit **402** operably connected to receive a sensed phase-controlled power signal **52** and generate a scaled power signal **403**, and a comparator **404** operably connected to compare the scaled power signal **403** to a comparison voltage **405** to generate an on-time signal **54**;

a line voltage detector **60**, the line voltage detector **60** generating a line voltage signal **62** in response to the sensed phase-controlled power signal **52**; and

a microcontroller **56**, the microcontroller **56** being responsive to the on-time signal **54** to generate a dimming control signal **58**, and being responsive to the line voltage signal **62** to generate a mains bias signal **69**;

wherein the mains bias signal **69** biases the comparison voltage **405**.

26. The circuit of claim 25 wherein the microcontroller **56** is further responsive to the line voltage signal **62** to generate an internal multiplier signal **68** provided to a boost/PFC **32**, the boost/PFC **32** being responsive to the internal multiplier signal **68** to select a boost/PFC internal multiplier.



24
16
Dimmer
18
20
EMI Filter
22
26
DC Rectifier
28
30
C4A
Q3
66
64
Boost PFC
32
34
switched circuit
36
38
Resonant TANK
40
42
Lamp
44
46
Switching controller
48
58
52
100

Fig. 1

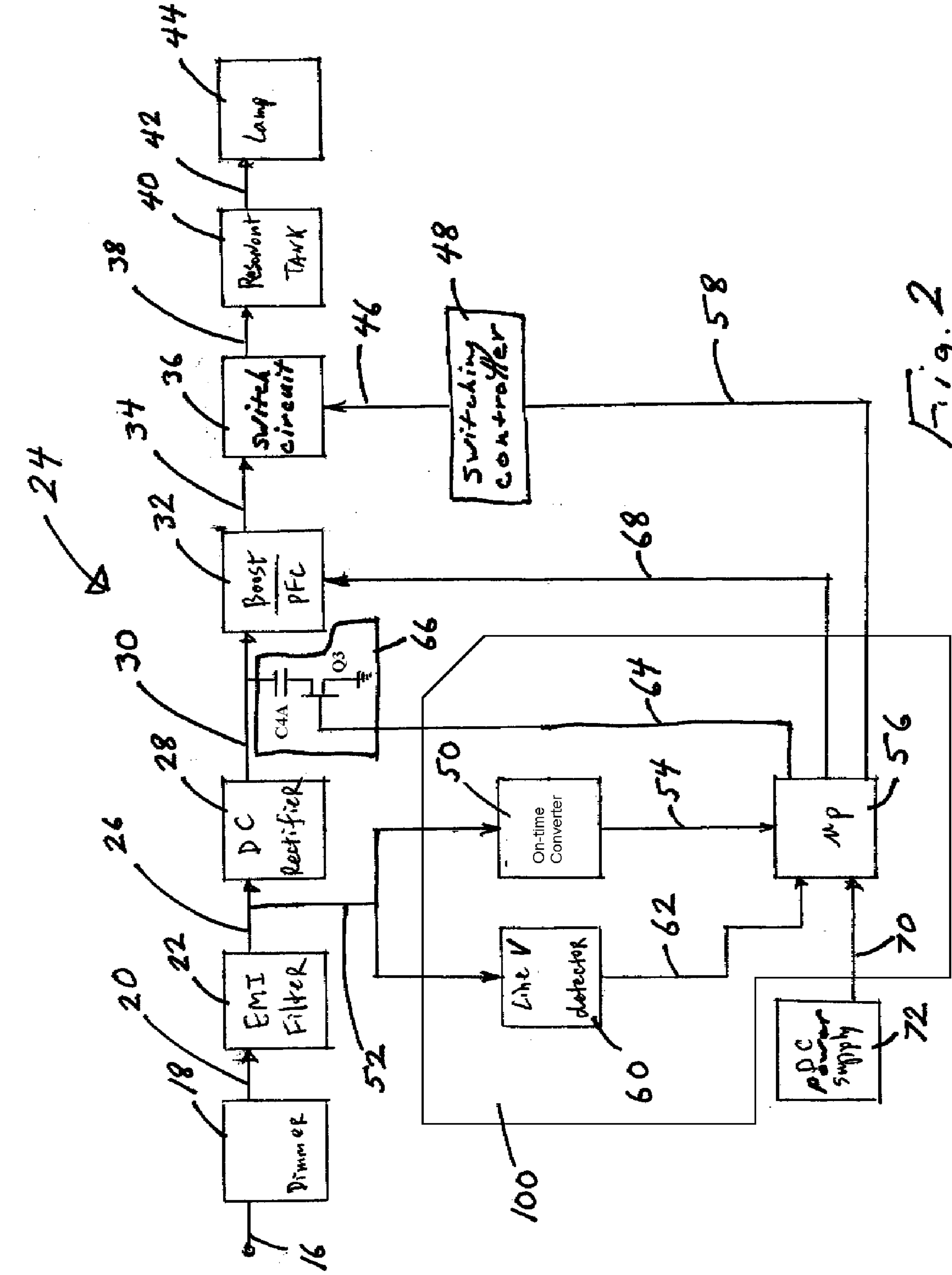

Dimmer
EMI Filter
DC Rectifier
Boost PFC
Switch circuit
Resonant Tank
Lamp
Switching controller
On-time Converter
Line V detector
µP
DC power supply
C4A
Q3
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
54
56
58
60
62
64
66
68
70
72
100

Fig. 2

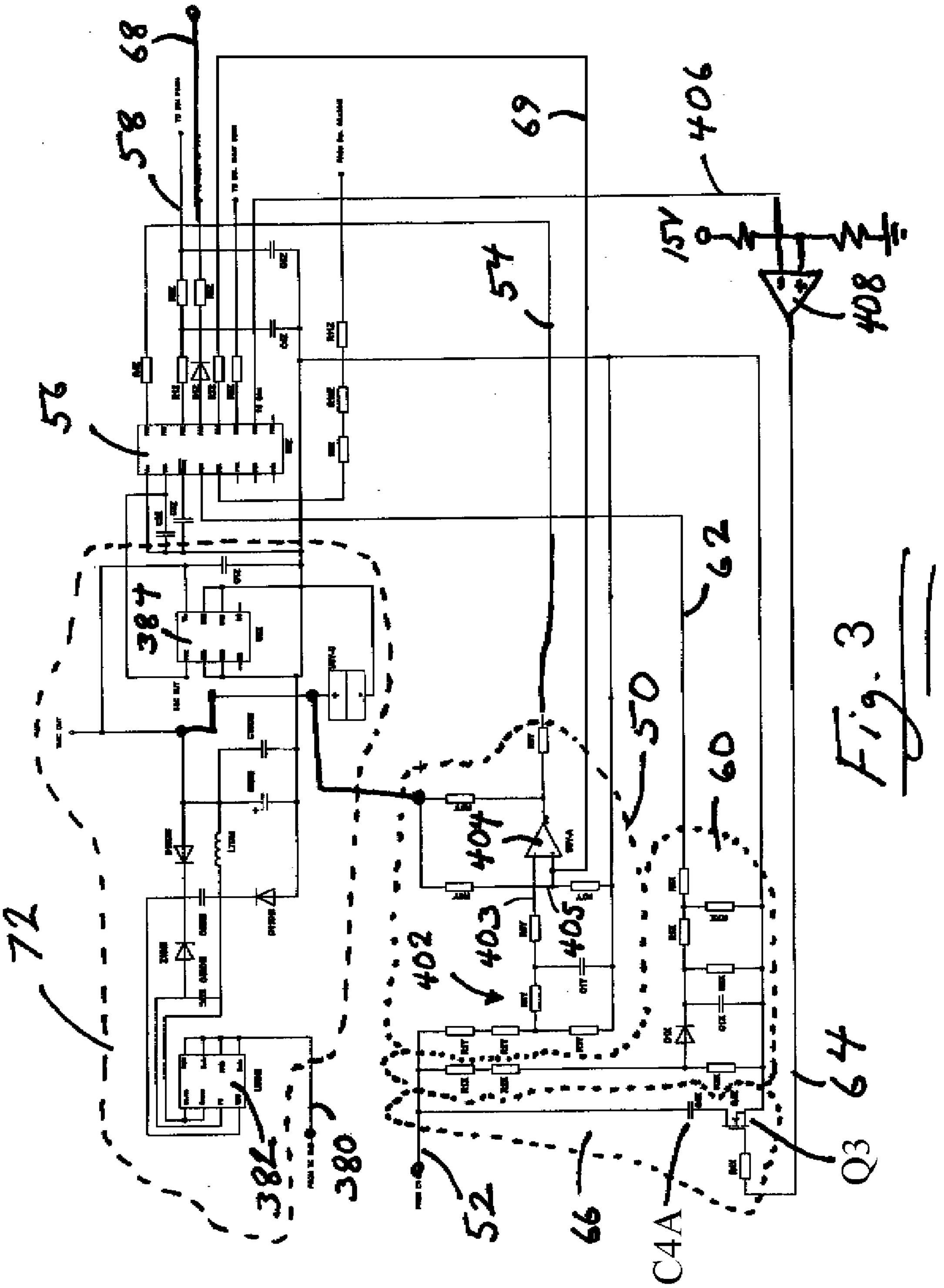

68
58
69
406
15V
408
56
54
384
62
50
60
72
402
403
404
405
64
382
380
52
66
C4A
Q3

Fig. 3

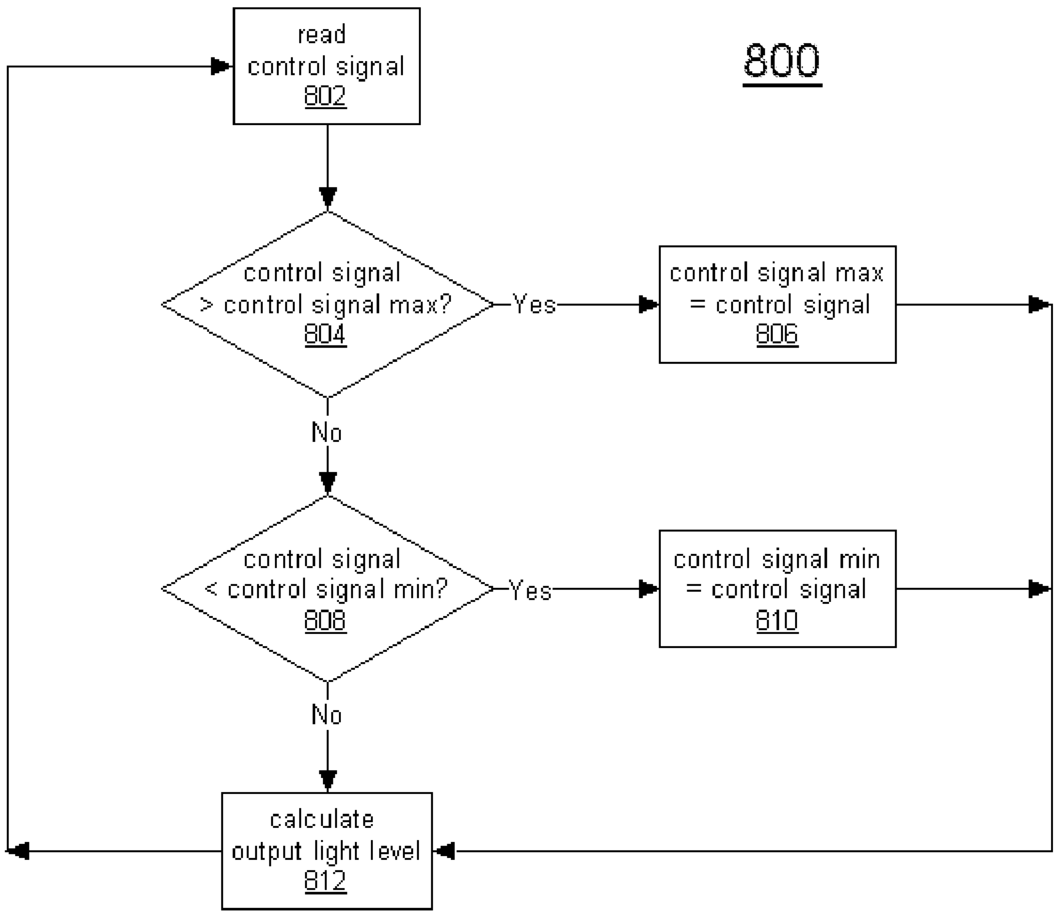
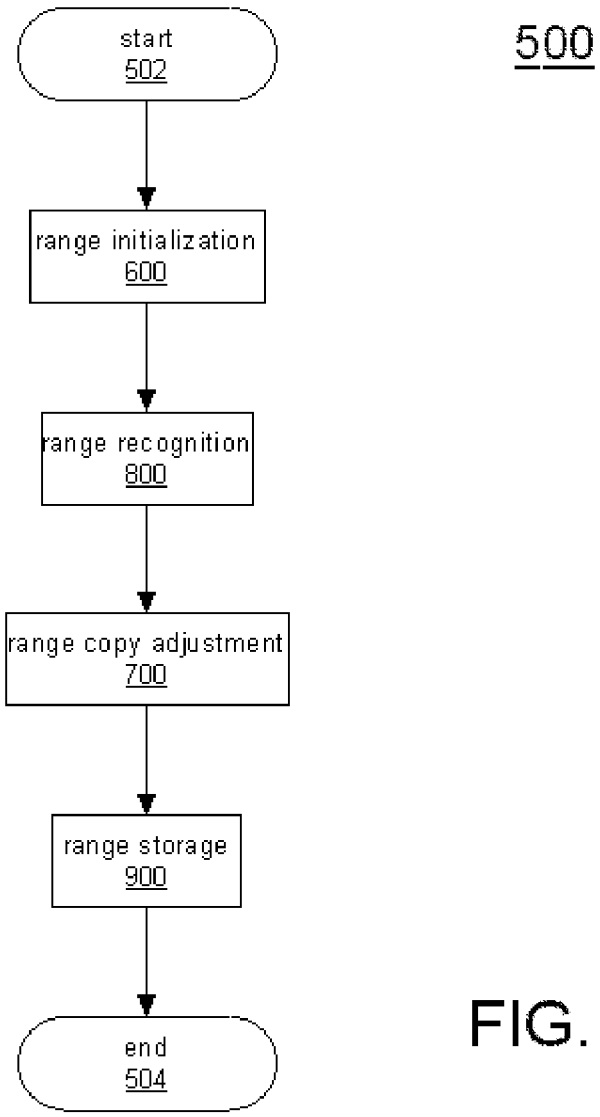

800
read
control signal
802
control signal
> control signal max?
804
Yes
control signal max
= control signal
806
No
control signal
< control signal min?
808
Yes
control signal min
= control signal
810
No
calculate
output light level
812

FIG. 4



500
start
502
range initialization
600
range recognition
800
range copy adjustment
700
range storage
900
end
504

FIG. 5

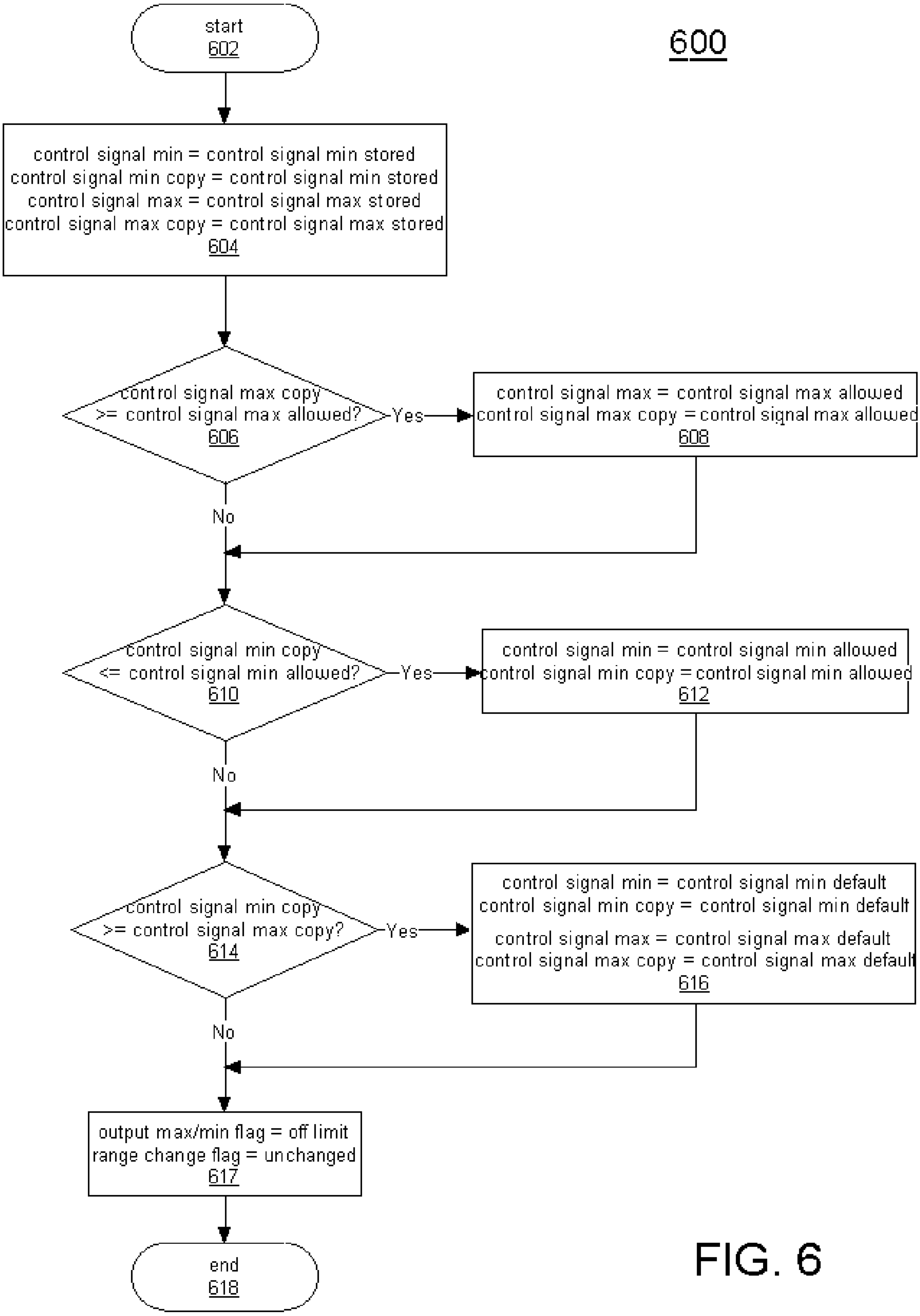

600
start
602
control signal min = control signal min stored
control signal min copy = control signal min stored
control signal max = control signal max stored
control signal max copy = control signal max stored
604
control signal max copy >= control signal max allowed?
606
Yes
No
control signal max = control signal max allowed
control signal max copy = control signal max allowed
608
control signal min copy <= control signal min allowed?
610
Yes
No
control signal min = control signal min allowed
control signal min copy = control signal min allowed
612
control signal min copy >= control signal max copy?
614
Yes
No
control signal min = control signal min default
control signal min copy = control signal min default
control signal max = control signal max default
control signal max copy = control signal max default
616
output max/min flag = off limit
range change flag = unchanged
617
end
618

FIG. 6

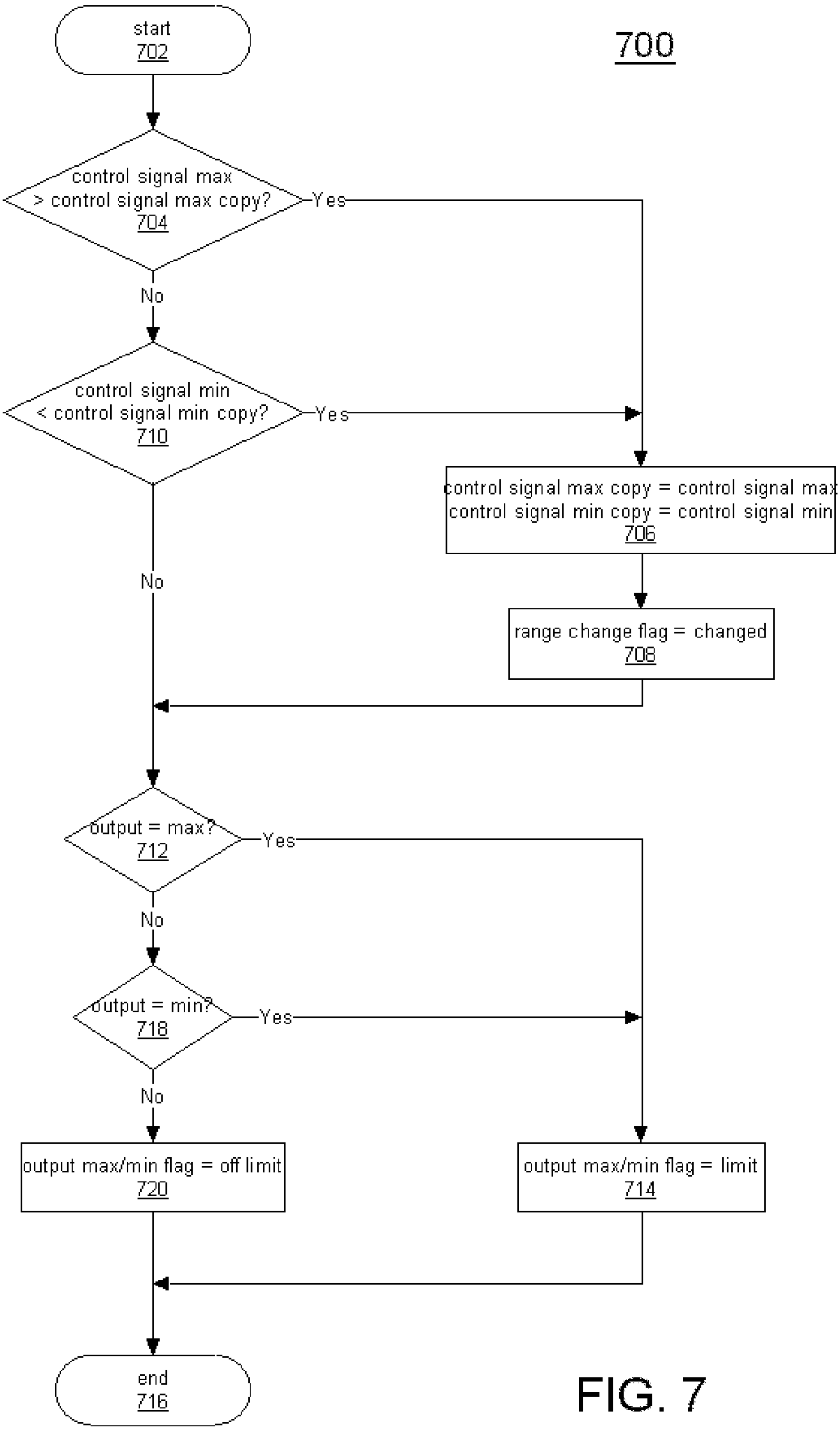

700
start
702
control signal max
> control signal max copy?
704
Yes
No
control signal min
< control signal min copy?
710
Yes
No
control signal max copy = control signal max
control signal min copy = control signal min
706
range change flag = changed
708
output = max?
712
Yes
No
output = min?
718
Yes
No
output max/min flag = off limit
720
output max/min flag = limit
714
end
716

FIG. 7

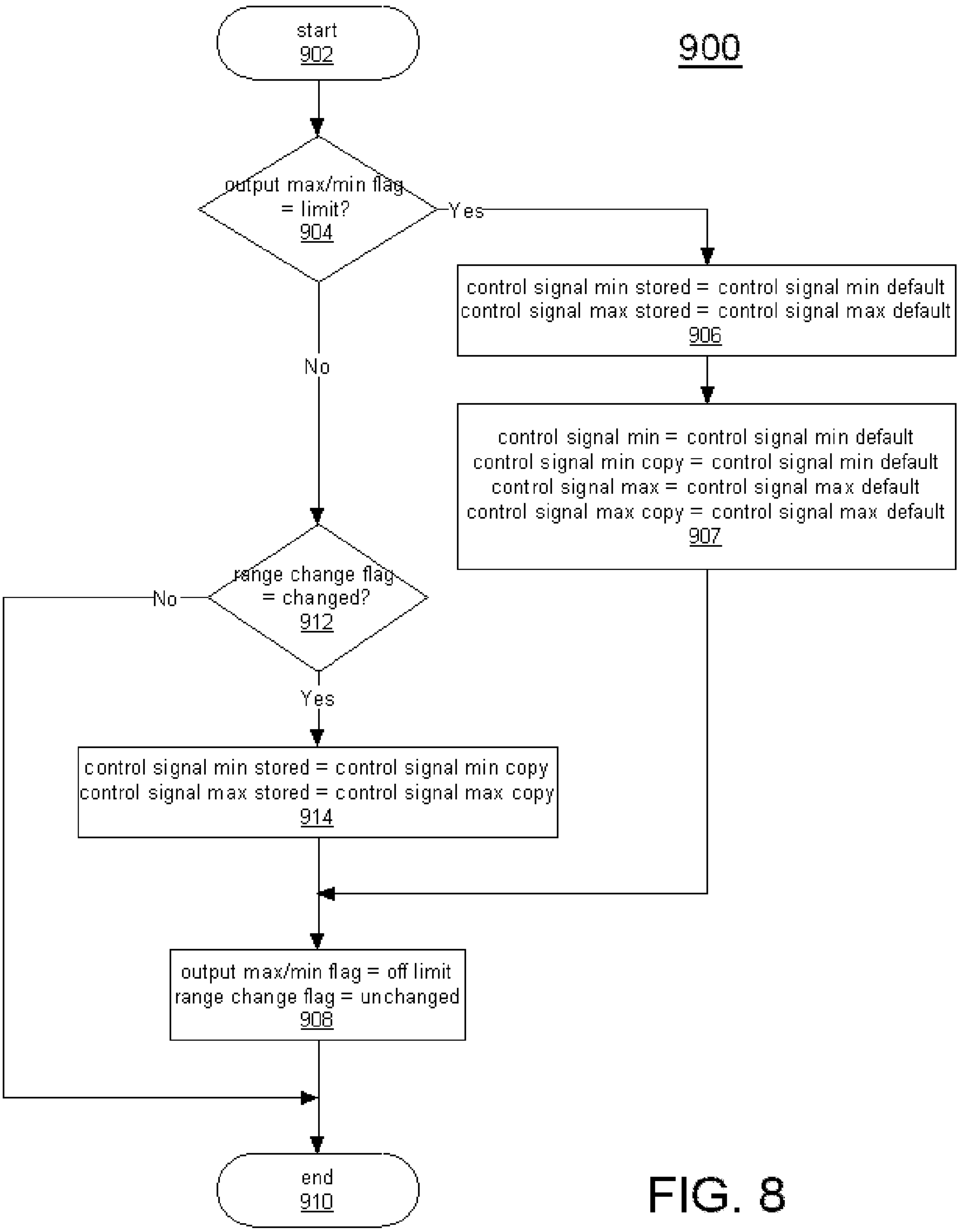

900
start
902
output max/min flag = limit?
904
Yes
No
control signal min stored = control signal min default
control signal max stored = control signal max default
906
control signal min = control signal min default
control signal min copy = control signal min default
control signal max = control signal max default
control signal max copy = control signal max default
907
range change flag = changed?
912
No
Yes
control signal min stored = control signal min copy
control signal max stored = control signal max copy
914
output max/min flag = off limit
range change flag = unchanged
908
end
910

FIG. 8