

## **DIMMER ARRANGEMENT**

### **PRIORITY DOCUMENTS**

[0001] The present application claims priority from Australian Provisional Patent Application No. 2011904564 entitled "DIMMER ARRANGEMENT" and filed on 3 November 2011, the entire content of which is hereby incorporated by reference.

### **INCORPORATION BY REFERENCE**

[0002] The following publications are referred to in the present application:

International Patent Application No. PCT/AU03/00365 entitled "Improved Dimmer Circuit Arrangement";

International Patent Application No. PCT/AU03/00366 entitled "Dimmer Circuit with Improved Inductive Load";

International Patent Application No. PCT/AU03/00364 entitled "Dimmer Circuit with Improved Ripple Control";

International Patent Application No. PCT/AU2006/001883 entitled "Current Zero Crossing Detector in A Dimmer Circuit";

International Patent Application No. PCT/AU2006/001882 entitled "Load Detector For A Dimmer";

International Patent Application No. PCT/AU2006/001881 entitled "A Universal Dimmer";

International Patent Application No. PCT/AU2008/001398 entitled "Improved Start-Up Detection in a Dimmer Circuit";

International Patent Application No. PCT/AU2008/001399 entitled "Dimmer Circuit With Overcurrent Detection"; and

International Patent Application No. PCT/AU2008/001400 entitled "Overcurrent Protection in a Dimmer Circuit".

[0003] The content of each of these applications is hereby incorporated by reference in their entirety.

### **TECHNICAL FIELD**

[0004] The present invention relates to multi way control arrangements for phase controlled dimmer circuits.

## BACKGROUND

[0005] Phase control dimmer arrangements (also referred to as dimmer circuits or simply dimmers) are used to control the power provided to a load such as a light or electric motor from a power source such as 50-60HZ 120 or 240V AC mains power. Such dimmer arrangements often use a technique referred to as phase control dimming. This allows power provided to the load to be controlled by varying the amount of time that a switch connecting the load to the power source is conducting during a given cycle.

[0006] For example, if voltage provided by the power source can be represented by a sine wave, then maximum power is provided to the load if the switch connecting the load to the power source is on at all times. In this way the, the total energy of the power source is transferred to the load. If the switch is turned off for a portion of each cycle (both positive and negative), then a proportional amount of the sine wave is effectively isolated from the load, thus reducing the average energy provided to the load. For example, if the switch is turned on and off half way through each cycle, then only half of the power will be transferred to the load. The overall effect will be, for example in the case of a light, a smooth dimming action resulting in the control of the luminosity of the light.

[0007] Modern phase control dimming circuits generally operate in one of two ways – leading edge or trailing edge. In leading edge technology, the dimmer arrangement “chops out” or blocks conduction of electricity by the load in the front part of each half cycle (hence the term “leading edge”). In trailing edge technology, the dimmer arrangement “chops out” or blocks conduction of electricity by the load in the back part of each half cycle. Figure 1A shows a representation 10 of the function of a leading edge dimmer, illustrating the current  $I_L$  through the load while Figure 1B shows a representation 20 of the function of a trailing edge dimmer. The point within the half cycle that conduction is switched is referred to as the conduction angle or firing angle 11 21. Controlling the conduction angle thus controls the corresponding dimming level in dimmer arrangements. The conduction angle may be specified as a specific value (eg  $45^\circ$ ), or as a percentage (eg 30%) over a defined range such as half cycle ( $180^\circ$ ).

[0008] A typical prior art phase control dimmer arrangement comprises a switch (e.g. a solid state switch such as a triac), which switches current to the load in accordance with timing signals provided by a timing control circuit as will be understood by the person skilled in the art. The timing control circuit determines the angle at which the switch fires into conduction (the conduction or firing angle), to allow current to flow into the load. The output of the timing control circuit is controlled by the input of the timing control circuit which is a control voltage. The value of this control voltage may be varied by a user operating a user-settable interface such as a potentiometer or digital switch.

[0009] The higher the user sets the user-settable interface switch, the higher the control voltage applied to the timing circuit, the higher the drive signal, and the higher (or larger) the conduction angle. A higher conduction angle results in a higher brightness of the light. Figure 1C shows a representation 30 of a typical user control (or drive) signal vs conduction angle transfer function. In this case the transfer function is a 1:1 linear mapping over a range from 10% (18°) to 100% (180°). Conduction angles of less than 10% are excluded.

[0010] Figure 2A shows a typical prior art 2-wire based dimmer arrangement 200 comprising a dimmer circuit 210 connected to a load 220. The dimmer arrangement comprises a Line or Active (A) terminal and a Load terminal (LD), but no Neutral connection, as this is often unavailable in installations. Wires 212, 214 and 222 respectively connect the dimmer arrangement to the active line, the dimmer arrangement to the load, and the load to neutral. In operation, such a dimmer arrangement limits the magnitude of load current to a level slightly below full load level thus permitting diversion of a small amount of current to power the dimmer control electronic circuitry internally connected between the LINE and LOAD terminals. For example, in a 50Hz system with 10ms half-cycle period, a maximum dimmer conduction period of 80% (8ms) is typical, although other maximums may be set (eg 50%, 70%, 90%, etc) depending upon the power requirements of the dimmer arrangement. The dimmer arrangement also includes a user interface 215, such as a button, touch sensor, dial, etc to allow a user to change the dimming level, and an indicator 216 for indicating the dimming level, such as an Light Emitting Diode (LED), one or more lighting elements, an LCD display, or a speaker for providing an audio indication of the current dimming level.

[0011] In rooms having more than one doorway entry point, it is desirable to have multiple switches for control of lights. Practical implementation of the two-way switching function requires the use of two interconnecting wires between the change-over type switch at each of the control switch locations. Depending on the prevailing status of the switches, either of the interconnecting wires is used to carry the load current. However providing two way control of dimming is more difficult and often not feasible or cost effective. Two way control of dimming can be achieved by specifically designing the dimmer arrangement to have an additional input terminal for connection to a simple remote switch unit, positioned at the other control location. In such cases the remote switch unit merely comprises a simple mechanical switch of the momentary-press type and does not incorporate a power supply. Hence whilst control of the dimming can be provided there is no capacity for load status indication and implementation requires additional wiring.

[0012] Alternatively control systems using remotes with independent power supplies and connected to control units with control lines have been used. However these are more complex to install and utilise additional wiring which increases cost and thus is undesirable.

[0013] There is thus a need to provide a dimming arrangement utilising a single wire between a dimmer arrangement and a remote arrangement to allow common control and indication of the dimming level in dimmer and remote arrangements, or at least to provide a useful alternative.

## SUMMARY

[0014] According to a first aspect, there is provided a method for communicating and controlling the conduction angle in a system for controlling a phase controlled load, the system comprising a conduction angle controller which controls the conduction angle of the phase controlled load between a minimum conduction angle and a maximum conduction angle to define a conduction period and a non-conduction period, a first conduction angle switch input and a first conduction angle indicator, and at least one remote apparatus connected in series with the conduction angle controller via a wire, the at least one remote apparatus comprising a remote conduction angle switch input and a remote conduction angle indicator, the method comprising:

- generating a current pulse having a first amplitude level and a width during the non-conduction period and transmitting the generated current pulse to the at least one remote apparatus over the wire to power the at least one remote apparatus;

- mapping the conduction angle to a mapped time within the current pulse;

- changing the level of the current pulse by the conduction angle controller at the mapped time;

- indicating the conduction angle in the first conduction angle indicator, wherein the indicated conduction angle is determined based upon the time of the level change;

- monitoring the level of the current pulse in the conduction angle controller to detect a change in the level of the current pulse by the at least one remote apparatus or a signal from the first conduction angle input and producing a signal to the conduction angle controller to change the conduction angle in response to the detected change;

- monitoring the level of the current pulse in each of the at least one remote apparatus to detect a change in the level of the current pulse by the conduction angle controller; and

- indicating the conduction angle by the conduction angle indicator in each of the at least one remote apparatus, wherein the indicated conduction angle is determined based upon the time of the detected change in the level of the current pulse.

[0015] According to a second aspect, there is provided a current pulse generator and level change detector apparatus for use in a conduction angle controller which is connected in series via a wire to at least one remote conduction angle control apparatus, wherein the conduction angle controller controls the conduction angle of a phase controlled load between a minimum conduction angle and a maximum conduction angle to define a conduction period and a non-conduction period, and the conduction angle controller further comprises a first conduction angle switch input and a first conduction angle

indicator, and each of the at least one remote conduction angle control apparatus comprises a remote conduction angle input and a remote conduction angle indicator, the current pulse generator and level change detector apparatus comprising:

- a current pulse generator for generating a current pulse having a first amplitude and a width during the non-conduction period and for providing to the first conduction angle indicator and for transmitting the generated current pulse to the at least one remote apparatus over the wire to provide power to the at least one remote apparatus;

- a conduction angle mapping module for mapping the conduction angle to a mapped time during the current pulse and generating a signal at the mapped time;

- an amplitude level change generator which receives the signal from the conduction angle mapping module and generates a change in the level of the first amplitude; and

- a monitoring circuit for detecting a change in the level of the first amplitude of the current pulse generated by the at least one remote apparatus or a signal from the first conduction angle switch input, and generating a signal for the conduction angle controller to change the conduction angle.

[0016] According to a third aspect, there is provided a remote conduction angle control apparatus for series connection via a wire with a conduction angle controller which controls the conduction angle of a phase controlled load between a minimum conduction angle and a maximum conduction angle to define a conduction period and a non-conduction period and the conduction angle controller comprising a first conduction angle switch input and a first conduction angle indicator, the remote conduction angle control apparatus comprising:

- a power supply regulator for receiving a current pulse from the phase controlled conduction angle controller over the wire for powering the remote conduction angle control apparatus;

- a remote conduction angle input;

- a switch operation module for receiving a signal from a remote conduction angle input and generating a level change in the current pulse being received;

- a conduction angle indicator circuit comprising a remote conduction angle indicator and a level change detector for detecting a change in the level of the received current pulse and wherein the conduction angle indicator is powered by the current pulse from the start of the current pulse up until the detected level change.

[0017] According to a fourth aspect, there is provided a phase controlled load apparatus for series connection via a wire to at least one remote conduction angle control apparatus of the third aspect, the phase controlled load apparatus comprising:

- a zero crossing detector and low voltage supply circuit;

- a switch which supplies power to a load;

a conduction angle controller which controls the conduction angle of the switch between a minimum conduction angle and a maximum conduction angle to define a conduction period and a non-conduction period;

a first conduction angle switch input;

a first conduction angle indicator; and

a current pulse generator and level change detector of the second aspect.

**[0018]** According to a fifth aspect, there is provided a system for controlling a phase controlled load, the system comprising the phase controlled load apparatus of the fourth aspect connected in series via a wire to at least one remote conduction angle control apparatus of the third aspect.

**[0019]** In further aspects the system is a dimming system, the phase controlled load apparatus is a dimmer, and the conduction angle indicators are dimming indicators which indicate a dimming level corresponding to the conduction angle.

**[0020]** In further aspects the portion of the current pulse prior to the change in the level of the current pulse is provided to each conduction angle (dimming) indicator to power each conduction angle indicator which may be a LED. In a further aspect a shunt circuit is used to shunt the current pulse to the first conduction angle indicator from the time of the generated level change to the end of the current pulse.

**[0021]** The change in the level of the current pulse (the level change) may be a decrease or an increase. A decrease may be a drop to zero, a baseline level, a percentage decrease (10%, 25%, 50%, 75%, 90%) or a low threshold value, such as a percentage of the normal current level such as 10%, 25%, 50%, 75%, 90% etc. Similarly if the normal current level is less than an upper maximum value (such as the rail voltage), the change may be an increase such as by a specified amount (eg 10%, 20%) or to maximum threshold value, such as the maximum level. The level change may be a permanent change for the duration of the pulse (i.e. a step change), or a temporary change for some portion of the width of the current pulse (eg 1%, 5%, 10%, 20%, or 50%) or a defined time period (eg 500, 100, 50, 10, or 1 microseconds). In one aspect the change in the level of the current pulse is an interrupt pulse (or signal) which reduces the amplitude level of the current pulse to a baseline level for an interrupt period. In one aspect the interrupt period less than 5% of the width of the current pulse. The time of the level change may be understood as being a time relative to a reference such as the start of the current pulse (ie the time is a position or location with the pulse), or relative to the start of the non-conduction period, the zero crossing time (ie start of the current mains power waveform) or some other reference point..

[0022] In further aspects the remote apparatus changes the level of the current pulse during a switch operation portion of the current pulse and the conduction angle controller changes the level of the current pulse during a conduction angle indication portion of the current pulse. In one aspect the switch operation portion is a first portion of the current pulse and the conduction angle indication portion is a second portion of the current pulse after the first portion. In one aspect minimum conduction angle is non-zero, and the range of conduction angles is mapped to the width of the current pulse. In a further aspect the range of conduction angles mapped to the width is from zero to at least the maximum conduction angle, and the switch operation portion comprises the portion of the current pulse from the start to the non-zero minimum conduction angle. The mapping may be a linear mapping of conduction angle to time, e.g. from the pulse start to the finish.

## BRIEF DESCRIPTION OF DRAWINGS

[0023] A preferred embodiment of the present invention will be discussed with reference to the accompanying drawings wherein:

Figure 1A shows a representation of the function of a leading edge phase control dimmer;

Figure 1B shows a representation of the function of a trailing edge phase control dimmer;

Figure 1C shows a typical control voltage vs conduction angle transfer function;

Figure 2A shows a typical prior art phase control dimmer arrangement;

Figure 2B shows one example of a system comprising a phase control dimmer arrangement and a remote arrangement according to one aspect;

Figure 3 shows one example of a circuit arrangement for a phase control dimmer arrangement according to one aspect;

Figure 4A shows a representation of the sinusoidal line voltage waveform as timing reference;

Figure 4B shows a representation of the dimmer and associated load current waveform including the remote arrangement supply current pulses according to one aspect;

Figure 4C shows a representation of the dimmer line-load voltage waveform according to one aspect;

Figure 4D shows a representation of the output signal waveform from the dimmer voltage zero-crossing detector having a pulse width of  $t_{nc}$  according to one aspect;

Figure 4E shows a representation of the current waveform supplied to the remote arrangement in full-wave version according to one aspect;

Figure 4F shows a representation of the current waveform supplied to the remote arrangement in half-wave version according to one aspect;

Figure 5A shows a representation of the uninterrupted remote arrangement current pulse, of duration  $t_p$  and amplitude  $I_{pk}$  signalling maximum LED indicator brightness level;

Figure 5B shows a representation of the interrupted-remote arrangement current pulse signaling for minimum LED indicator brightness level;

Figure 5C shows a representation of the interrupted remote arrangement current pulse signaling medium LED indicator brightness level;

Figure 5D shows a representation of the interrupted remote arrangement current pulse signaling operation of the switch in a remote arrangement;

Figures 6A to 6D show various mapping curves for mapping the time of the interruption to a dimming level according to one aspect;

Figure 7A is an expanded representation of the output signal waveform from the dimmer voltage zero-crossing detector shown in Figure 4D;

Figure 7B shows a representation of the pulse used to establish a suitable time delay for start of remote arrangement current pulse;

Figure 7C shows a representation of the pulse used to establish desired duration of remote arrangement current pulse;

Figure 7D shows a representation of the pulse output used to establish a very short delay after the beginning of the remote arrangement current pulse after which a current pulse interruption may be present;

Figure 7E shows a representation of the pulse output used to establish a short delay after beginning of the remote arrangement current pulse where an interruption is to occur;

Figure 7F shows a representation of the pulse output used to create the momentary interruption of the remote arrangement current pulse;

Figure 7G shows a representation of the pulse output used to shunt the dimmer indicator LED for the remaining period of the remote arrangement current pulse;

Figure 7H shows a representation of the remote arrangement current pulse sent along the single wire joining a dimmer arrangement and a remote arrangement;

Figure 8 shows one example of a circuit arrangement for generation of the remote arrangement current pulse in the dimmer arrangement according to one aspect;

Figure 9 shows one example of a circuit arrangement for reception of, and for generation of an interrupt in, the remote arrangement current pulse in a remote arrangement according to one aspect; and

Figure 10 is a flowchart of a method for communicating and controlling the dimming level in a dimmer arrangement according to one aspect;

Figures 11A to 11C shows operation of the system illustrated in Figure 2B as the dimming level is increased from 50% to 100% according to one aspect; and

Figure 12 shows one example of a dimmer system comprising a phase control dimmer arrangement and two remote arrangements connected in series by a single wire according to one aspect.

**[0024]** In the following description, like reference characters designate like or corresponding parts throughout the figures.

## DESCRIPTION OF EMBODIMENTS

[0025] Embodiments are described which use a current pulse in the line voltage half-cycle non-conduction period of a phase control load such as a dimmer or electronic switch, to establish a functional remote unit. The embodiments provide a cost effective way to achieve true multi-way control and multi-way indication in dimming and related phase controlled systems.

[0026] Illustrative embodiments of phase controlled dimmers are described below, in which conduction angles correspond to dimming levels, and conduction angle inputs and indicators correspond to dimmer control inputs and dimming level indicators. However it is understood that the methods, apparatus and systems may be used with a system which control other phase controlled loads such as fans. In these applications an input is used to control the conduction angle between a minimum conduction angle (which may be zero or non-zero) and maximum conduction angle, and in which it is desirable to indicate the value of the conduction angle to the user at both the primary controller and the remote controllers. That is the dimming input and dimming indicator described above are more broadly a conduction angle input and a conduction angle indicator. Similarly the embodiments and methods may also be used with phase controlled electronic switch applications in which the on-state conduction angle for the switch corresponds to (or is similar to) that of a dimmer set at its maximum conduction angle. In these applications the indicator will simply have synchronized on or off states at both the primary controller and the remote controllers. For example in addition to dimmers and fans the methods used to control other sub systems of a building automation system (eg blinds, other lights, door latches etc).

[0027] An illustrative embodiment of a multi-way dimmer arrangement featuring enhanced functionality of the single interconnection wire will now be described. This arrangement is particularly suitable for press-switch or touch-switch types of dimmers - where line voltage is permanently applied, but differs from existing systems in that the single interconnection wire linking dimmer and remote arrangement control location conveys bi-directional signaling information to/from the remote control unit, in addition to conducting necessary power supply current to the remote control arrangement (for brevity hereafter referred to as the remote arrangement). The use of more sophisticated communication between the dimmer and remote arrangement enables the possibility of visual and/or audible dimmer load status indication at the remote arrangement in addition to that which may exist at the dimmer arrangement. Such a dimming arrangement effectively facilitates true multi-way dimming - where the load status/brightness can be controlled and indicated from multiple locations.

[0028] It is also noted that the arrangement described herein may be utilised to provide multiple remote arrangements connected in series to the dimmer arrangement via a single wire. In this case the "single wire" may comprise physically separate wires which are joined or connected in a series fashion to operatively form a single wire or single electrical path between the dimmer arrangement and each of the remote arrangements.

[0029] Figure 2B shows an embodiment of a system 202 for controlling a phase control load, which in this case is a dimming system. The system comprises a phase control dimmer apparatus 210 and a remote conduction angle (dimming level) control apparatus 230 (referred to as a dimmer apparatus and remote apparatus respectively for brevity) according to an embodiment. In this embodiment the dimmer apparatus 210 shown in Figure 2A has an additional terminal R for connection to a remote apparatus 230. The remote apparatus terminals comprise an active terminal A for connection to an active line 232 and a remote terminal R for connection to the dimmer apparatus via a single wire 236 (the interconnection link). The single wire 236 has dual functions of supply a small amount of power to the remote apparatus as well facilitating communication with the dimmer apparatus 210 installed at a different location to the remote apparatus (ie single power and communication line). In this embodiment only the dimmer apparatus can directly control the brightness level or on/off state of the load, with the remote apparatus providing indirect control of the load via communication with the dimmer apparatus over the one-wire interconnection link 236.

[0030] The remote apparatus also includes a user interface including a conduction angle or dimming level switch input 237 for allowing a user to change the current conduction angle and thus dimming level via the input. The input may be a momentary contact push button, a dial, touch sensor etc. The user interface also includes a conduction angle and thus dimming level indicator 238 for indicating the dimming level. This indicator may be a LED, or a LED and light pipe, one or more lighting elements, an LCD display, or a speaker or tone generator for providing an audio indication of the conduction angle and thus dimming level. In one embodiment the indicator 216 in the phase control dimmer and the indicator 238 in the remote are identical in order to reduce manufacturing and maintenance costs. In other embodiments, the indicators may be different and need only to provide substantially identical responses to a common conduction angle/dimming level indication signal (ie to display similar dimming indications). The dimmer apparatus may comprise one or more circuits, modules, components, on one or more boards which perform the functions described herein. The dimmer apparatus may also include the housing or face plate, and may also perform additional functions to those described herein. The dimming input switches which allow users to change the dimming levels may be momentary push button type switches such as those available from Clipsal by Schneider Electric in the Saturn, Impress and 2000 series ranges. Alternatively other dimming inputs (for

example a continuous rotation potentiometer) which can be used to produce a signal to indicate a request to change the dimming may be used.

[0031] Figure 3 shows one embodiment 300 of a circuit for a phase control dimmer apparatus. The dimmer apparatus comprises a local press switch 302 for receiving input requests to turn on the light and to change the dimming level and an LED indicator signal 322 for indicating the dimming level or conduction angle. A dimmer conduction angle control circuit 320 receives the switch output, as well as power and zero crossing timing signals from a dimmer low voltage supply and zero crossing detector 310. The conduction angle controller (or apparatus or circuit) includes a conduction angle mapping module 326 for mapping the conduction angle to a mapped time during the non-conduction period, and produces an output signal via LED indicator 322 at the mapped time (this is discussed below). The conduction angle control circuit is used to control two switch elements, in this case MOSFETs Q1 332 and Q2 334 (for example SPB20N60C3). The switch elements turn on and off in response to dimmer gate drive signal 324 provided by the conduction angle control circuit 320 as will be understood by the person skilled in the art. The switch elements Q1 and Q2 operate/control the load alternately, each operating at different polarities during subsequent half-cycles of the power applied by the line. Each switch element has an associated respective anti-parallel diode D1 and D2.

[0032] It will be understood that the various aspects may be applied to any form of dimmer apparatus, such as those described in PCT/AU03/00365 entitled "Improved Dimmer Circuit Arrangement"; PCT/AU03/00366 entitled "Dimmer Circuit with Improved Inductive Load"; PCT/AU03/00364 entitled "Dimmer Circuit with Improved Ripple Control"; PCT/AU2006/001883 entitled "Current Zero Crossing Detector in A Dimmer Circuit"; PCT/AU2006/001882 entitled "Load Detector For A Dimmer"; PCT/AU2006/001881 entitled "A Universal Dimmer", PCT/AU2008/001398 entitled "Improved Start-Up Detection in a Dimmer Circuit"; PCT/AU2008/001399 entitled "Dimmer Circuit With Overcurrent Detection"; and PCT/AU2008/001400 entitled "Overcurrent Protection in a Dimmer Circuit"; the entire content of each of which is hereby incorporated by reference.

[0033] The remote apparatus is an active device and requires a power source to operate. In this scheme the power source is achieved via gating of short duration (compared to line voltage half-cycle period) current pulses supplied from the dimmer apparatus to the remote terminal over the single wire 236. Figure 4A shows a representation 410 of the sinusoidal line voltage waveform having a period T which is used as timing reference for the dimmer. For example in a 240V AC 50Hz system, T corresponds to 20ms, with zero crossing occurring every 10ms. Figure 4B shows a representation 420 of the dimmer and associated load current waveform. The dimmer conducts current to the load for a duration of  $t_c$ , based on the conduction angle 421 followed by a non-conduction period  $t_{nc} = T/2 - t_c$  into which a remote apparatus supply current pulse 422 is inserted. At the zero crossing point 423

( $T/2$ ) the dimmer again begins conducting for a duration  $t_c$ , followed by a non-conduction period during which another remote apparatus supply current pulse 424 is inserted. The cycle then repeats from the next zero crossing point 425 (T) with the next remote apparatus supply current pulse 426 being inserted in the next non-conduction period. The corresponding dimmer line voltage waveform 430 is illustrated in Figure 4C. The zero crossing detector 310 produces an output signal waveform 440 at point ZC 312 (See Figure 3) which is represented in Figure 4D as a square pulse of duration  $t_{nc} = T/2 - t_c$ . For example in the context of a 50Hz system with a maximum conduction angle of 80% of the line voltage half cycle period, the duration of the non-conduction period ( $t_{nc}$ ) is about 2ms.

[0034] As illustrated in Figure 4B, a current pulse is transmitted to the remote apparatus during the non-conduction period of the line voltage half-cycle period. These current pulses may be supplied at every half-cycle (full-wave mode) or only at alternate half-cycles (half-wave mode). Figure 4E shows a representation 450 of the current waveform supplied to remote apparatus 230 in a full-wave version in which current pulses 422 424 426 are sent each half cycle, and Figure 4F shows a representation 460 of the current waveform supplied to remote apparatus in the half-wave version in which current pulses are sent each at alternate half cycles 422 426. In each case the current pulse has a width of  $t_p$  (which is less than  $t_{nc}$ ). The latter has the advantage of reduced design implementation complexity, however it only provides half the magnitude of current, hence power available, to the remote apparatus. Furthermore, since the remote apparatus current is simultaneously directed through the dimmer load, it is desirable for the dimmer to permit an equivalent current pulse in the opposite polarity of voltage half-cycle so as to avoid the possibility of asymmetrical dimmer operation resulting from an associated dc current bias in the load.

[0035] The current pulse may be a square pulse, a square pulse with rounded edges or some other pulse shape such a Gaussian pulse which has a defined or nominal amplitude level and width (these may be defined at standard or specific operating conditions such as 25°C). The first amplitude level may be an average level, the maximum level, or some percentage (eg 10%, 25%, 50%, 75%, 80%, 90%, 95%, 99%) of the maximum level or reference level (eg 5V, 12V or upper rail voltage). The width may be based upon the time above some threshold (ie a point in time on the rising edge to a point in time on the trailing edge). The threshold may be 10%, 50% or 90% of the amplitude level.

[0036] Figure 5A shows an enlarged representation of the remote apparatus current pulse, which has a duration  $t_p$  and amplitude  $I_{pk}$ . For the above described 50Hz system, one example of a suitable remote apparatus current pulse has a 1ms duration (corresponding to  $T/20$  or 50% of the non-conduction period) and 10mA amplitude ( $I_{pk}$ ) to provide an average supply current to the remote of 0.5mA ( $I_{pk}/20$ ).

[0037] In addition to providing a power source to the remote apparatus via regular current pulses over the single wire joining the remote and dimmer apparatus, bi-directional signaling information to/from the remote control unit can be provided by suitable encoding of the current pulses. The use of more sophisticated communication between the dimmer and remote apparatus enables visual and/or audible dimmer load status indication at the remote apparatus in addition to that which may exist at the dimmer apparatus. Such a scheme facilitates true multi-way dimming – as the load status/brightness can be controlled and indicated from multiple locations using only a single wire to join the locations, which simplifies and reduces the cost of implementation.

[0038] In this embodiment the dimmer apparatus signals to the remote apparatus the required dimming level (eg LED brightness) by a change in the level of the current pulse (also referred to as a current level change or simply a level change), such as a momentary interruption in the normal level, at a specific point, dependent on desired brightness level, within the current pulse. That is the point in time (ie position or location) of the current level change within the pulse is used to indicate a desired brightness level. This allows the remote apparatus to indicate the dimmer load status in identical manner as performed by the dimmer apparatus. Similarly operation of the switch in the remote apparatus can be used to signal a request to change the current dimming level by causing a current level change such as an momentary interruption at a specific point or within a predefined time period (or range or location) in the current pulse.

[0039] The change or modulation in the normal or current level (voltage amplitude) of the current pulse may be an increase or a decrease. The decrease may be a decrease to zero, to a baseline level (ie the level before the current pulse), a low threshold value (eg 1mV down from 5mV), or a percentage of the normal current level such as 10%, 25%, 50%, 75%, 90% etc. Similarly if the normal current level is less than an upper maximum value (such as the rail voltage), the change may be an increase such as by a specified amount (eg 10%, 20%) or to threshold value, such as to the maximum (eg from 4mV to 5mv).

[0040] The magnitude of the current level change needs only to be sufficient so that a detection circuit can reliably detect the onset of this change in the normal (or initial) level of the current pulse, such as through the use of an edge detection circuit for detecting a rising or falling edge of the current pulse. The level change may be a permanent change for the duration of the pulse (i.e. a step change). In other embodiments the level change is a temporary change, such as the addition or subtraction (superposition) of a (level change indication) pulse to the current pulse. The time (or position) within the pulse of the level change may be detected using edge detection (rise or fall) and detect either the forward edge or trailing edge, or the detection may be based on detection of the change in the level of

the current pulse, such as by integrating the current pulse and monitoring a change in the level of the integrated signal.

[0041] A momentary or short duration interrupt pulse or signal to the current pulse is a convenient way to provide a detectable change in the level of the current pulse. However it is to be understood that this is a convenient implementation and other level changes including increases or decreases may be used to indicate the current brightness level or that the remote switch input has been pushed or actuated (ie to request a change in the dimming level). The interrupt signal or pulse reduces the amplitude level of the current pulse to a level below a predefined low threshold amount (eg 25%, 10%, 5%, 1% or less) or it may be a drop to a zero or baseline level. After the interrupt pulse the amplitude level may return to the first amplitude level or another level. As the current pulse is used to supply power, it is generally desirable to make the length of the interruption (ie width of the interrupt pulse) short compared to the current pulse width, as little or no power is delivered to the remote during the interrupt time period. For example the interrupt time period may be less than some fraction of the width of the current pulse, such as 10%, 5%, 2.5%, 1% etc. Alternatively it may be a defined time period such as 500, 100, 50, 10, 1, etc microseconds.

[0042] Figures 5A to 5D show various representations of the remote apparatus current pulse used to signal various conditions. Figure 5A shows a representation 510 of the uninterrupted remote apparatus current pulse, of duration  $t_p$  and amplitude  $I_{pk}$  with no interruption, which is used to signal maximum indicator level (ie no dimming, maximum conduction angle). The current pulse starts at a zero level 512, and rises to nominal amplitude or pulse level 514. Figure 5B shows a representation 520 of the interrupted remote apparatus current pulse signal in which the interruption pulse 522 momentarily drops to the zero level 524 at a point  $t_2$  corresponding to the minimum indicator level (eg 10%). Figure 5C shows a representation 530 of the interrupted remote apparatus current pulse signal in which the interruption pulse 532 drops to the zero level at a time point  $t_2$  corresponding to a medium (50%) indicator level. Finally Figure 5D shows a representation 540 of the interrupted remote apparatus current pulse signal in which the switch interrupt pulse 542 occurs during an interrupt delay period  $t_{id}$  which is used to indicate operation of the switch in a remote apparatus. The duration of the switch interrupt pulse  $t_d$  is less than the interrupt delay period  $t_{id}$ . In some embodiments the indicators are LEDs, in which case the time of the interruption corresponds to the brightness levels of the indicator LEDs (ie the brightness level is proportional to the time of interruption).

[0043] In this embodiment the non-conduction period begins at time  $t_0$ , the pulse starts (rises) at a time  $t_1$  and the interruption begins at a time  $t_2$  and ends at a later time  $t_3$ , such that the duration of the current interruption is equal to  $t_3 - t_2$  (see Figures 5A to 5D). In one embodiment, in order to minimize the effect on average current level, the duration of current pulse interruption ( $t_3 - t_2$ ) or interrupt pulse

( $t_d$ ) is preferably short relative to the total duration of the remote apparatus current pulse, such as  $1/10^{\text{th}}$  or  $1/20^{\text{th}}$  of the total duration of the remote apparatus current pulse. For example with a 1ms pulse a  $1/20^{\text{th}}$  duration interruption corresponds to about 50 $\mu$ s.

[0044] As illustrated in Figure 5D, operation of the switch in the remote apparatus is signaled over the single wire by interrupting the current pulse immediately following reception of the beginning of the current pulse. In one embodiment the minimum start time  $t_2$  for signaling the minimum intensity is equal to an interrupt delay period  $t_{id}$  which is used to signal operation of the switch in the remote apparatus. The interrupt delay period  $t_{id}$  is defined to be longer than the length of the switch interrupt pulse  $t_d$ . More generally the current pulse can be divided into a switch operation portion, used for signaling operation of the switch in the remote apparatus, and a dimming indication portion, used for signaling the current dimming level (eg LED brightness). Additional buffer portions may also be inserted where interruptions are not allowed and may be used to provide clear separation between the portions, account for delays due to circuit response times and propagation delays, or to designate prohibited dimming levels (such as those greater than the maximum conduction angle). For example as shown in Figure 5A, a start delay period  $t_{sd}$  may be provided before the current pulse, and an end buffer period  $t_{eb}$  may be provided after the current pulse. In some embodiments the switch operation portion precedes the dimming indication portion and in other embodiments the dimming indication portion precedes the switch operation portion. A buffer period may be defined between the two portions.

[0045] The switch operation portion of the current pulse could occur at or near the start of the pulse, at or near the end of the pulse (with near indicating a short delay relative to the pulse width such as  $t_p/40$ ), or at some point in the middle of the pulse. For example the current pulse may have a duration  $t_p$ , and it may be desirable to limit the conduction angle to between a minimum conduction angle such as 10%, up to a maximum conduction angle such as 80%, so that the available dimming range is 10-80%. In this case the dimming indication portion corresponds to the 10-80% range of the current pulse, and the switch operation portion may be during the first 10% or the last 20% of the current pulse. The minimum conduction angle may be determined based on a minimum level required for stable or effective operation of the load (eg flickering or other problems may arise at low conduction angles). Alternatively the minimum level may correspond to a minimum appreciable (ie physiologically based) intensity level, such as 5%, 10% or 20% below which a user is either unlikely to be sensitive to, or marginally sensitive to, brightness level changes, in which case it is more efficient to save power by keeping the switch in the off state. Alternatively a minimum conduction angle may be set to define an initial portion of the current pulse reserved for use by the switch operation portion. This may be based upon the duration of the switch interrupt pulse  $t_d$ . The maximum conduction angle is as discussed above – a maximum value to ensure sufficient power is provided to

power the remotes via the current pulse. The maximum value may also be based upon the required size of an end buffer period to allow zero crossing to be detected.

[0046] The time (or location) of the interrupt pulse (or level change) in the dimming indication portion is used to indicate the current dimming level (or more generally the current conduction angle). A conduction angle mapping module 326 may be used to map the current conduction angle/dimming level to a mapped time during the current pulse. The mapped times may be during a dimming indication portion and may be a continuous range from a minimum conduction angle to a maximum conduction angle. For example the diming level could be determined by the start time of the interrupt pulse  $t_2 = d_1 * t_p$  where  $d_1$  is the desired dimming level expressed as a value between 0 (0%) and 1 (100%). In another embodiment a discretised (or digital or quantized) range may be used with the portion divided (or gated) into a series of steps, blocks, or regions each of which corresponds to a specific dimming level. For example the steps may have widths of 1%, 2%, 2.5%, 5%, 10%, 20%, or 25% of the pulse width, generating 100, 50, 40, 20, 10, 5 or 4 blocks or ranges respectively. Each block may have an associated, stored or predefined brightness level. For example if the current pulse is divided into 10% steps (10 blocks) then a pulse occurring between 40%-50% of the pulse duration may be interpreted as a brightness level of 45%. Alternatively a mapping function could also be used to map the time/location/ position (ie  $t_2$ ) of the interrupt within the current pulse to a dimming level (or conduction angle). A conduction angle mapping module may be implemented by suitable circuit or logic components or a microcontroller.

[0047] Figures 6A to 6D show various examples mapping curves for mapping the time of the interruption to a dimming level (or equivalently a conduction angle). In each example the minimum conduction angle is set to 10% and the maximum conduction angle is set to 80%. The switch operation portion occupies the first 10% of the width of the current pulse (0,  $0.1t_p$ ), the dimming indication portion occupies either the range from ( $0.1t_p$ ,  $0.8t_p$ ), followed by a buffer portion for the last 20% ( $0.8t_p$ ,  $t_p$ ). Alternatively the dimming indication portion occupies the range from ( $0.1t_p$ ,  $t_p$ ).

[0048] Figure 6A show a mapping curve 610 in which the dimming range is increased in a series of regular or linear steps between the minimum (10%) and maximum (80%) dimming levels. Each step corresponds to a 10% increase over the previous step (ie  $d_i = n*0.1$  for  $n=1..10$ ), such that a dimming level of  $n*0.1$  would correspond to an interrupt pulse in the range from  $[n*0.1 .. (n+1)*0.1)$  - ie inclusive of  $n*0.1$  but exclusive of  $(n+1)*0.1$ . Figure 6B shows a mapping curve 620 in which the dimming range is increased in a series of irregular steps which divides the dimming indication portion into 5 regions corresponding to dimming levels of (10%, 20%, 30%, 40%, 60%) with no interruption used to indicate the maximum dimming level of 80%.

[0049] As discussed above the dimming range may be a continuous range. The dimming indication portion may be expressed as a decimal range (0, 1) over the portion which is mapped by a function  $f(t)$  to dimming level in the range (min dimming level, max dimming level). Alternatively the range over the width of the current pulse that the dimming portion occupies, eg  $(0.1t_p, t_p)$  may be mapped to the dimming level range (min dimming level, max dimming level) or more succinctly  $(\min_d, \max_d)$ . Figure 6C illustrates a first linear mapping curve 630 using a linear mapping function  $f(t) = t$  for  $t$  in the range  $(0.1, 0.8)$ ,  $t=0$  for  $t < 0.1$ , and  $t=0.8$  for  $t > 0.8$  which corresponds to 1:1 mapping between time/location of the interrupt pulse in the pulse width with dimming intensity over the dimming portion. A second linear mapping curve 632 is also shown in which intensity linearly increases from 0 intensity at  $t_2=0.1t_p$  up to 80% intensity at  $t_2=t_p$  which corresponds to a mapping function of  $f(t)=(t - \min_d)*\max_d/(1 - \min_d)$ .

[0050] Nonlinear mapping functions may also be used as illustrated in Figure 6D. Suitable mapping functions include power law based curves generally defined as  $f(t) = t^k (\max_d - \min_d) + \min_d$  where  $k$  is the power and may be the range (0.3, 3) to give a range of concave and convex curves, or trigonometric based functions such as  $f(t) = \sin(\pi t/2) * (\max_d - \min_d) + \min_d$ . First curve 640 uses a sine function which increases the intensity from 0 to 80% over  $t=0.1t_p$  to  $t=t_p$  and the second curve 642 uses a sine function which increases the intensity from 0 to 80% over  $t=0.1t_p$  to  $t=0.8t_p$  after which it is held constant at 80%. Such mapping functions may be used to take into account physiological effects such as the eyes response to light intensity not being linear and can vary based upon the state of the light adaption of a person's eyes. For example a person entering a room from outdoors or a well lit room may not be able to distinguish differences at large intensities (ie between 70% and 80%) as well as they can distinguish differences at low intensities (ie between 40% and 50%) in which case it may be desirable to expand the range at lower intensities compared to higher intensities. Further the mapping function used could be modified based upon the temporal information (time of day and/or year) or based on ambient light level, such as obtained from a light sensor such as a photodiode.

[0051] In one embodiment the remote apparatus current pulse is generated in the dimmer apparatus by a current pulse generator through the use of an on/off switchable constant current circuit to create current pulses of pre-determined duty-cycle. In one half-cycle polarity of line voltage the established current pulses are first directed through an LED indicator 216 associated with the dimmer apparatus 210 and then, via the remote terminal and one-wire connection, through an LED indicator 238 associated with the remote apparatus 230. In this manner the respective LED indicators (dimmer and remote) are illuminated with identical brightness level via the half-wave current pulses. The equivalent current pulses associated with the opposite half-cycle polarity of line voltage flow via the dimmer load terminal, but these are shunted past the LED indicator associated with the dimmer apparatus.

[0052] Figures 7A to 7H illustrate a series of signals that may be used generate the current pulse and interrupt pulse current pulse. Figure 8 illustrates an embodiment of current pulse generator and level change detector circuit 800 for generation of the remote apparatus current pulse and an interrupt detector in the dimmer apparatus. Figure 9 illustrates an embodiment of circuit 900 for a remote apparatus that is powered by the remote apparatus current pulse and is capable of interrupting the remote apparatus pulse to signal operation of a switch in the remote apparatus. In these embodiments the interrupt is a drop to zero voltage, but as discussed above other current level changes may be used (eg a drop to 10%, 25%, etc of the normal level).

[0053] The current pulse generator and level change detector broadly comprises a current pulse generator for generating a current pulse during the non-conduction period. The current pulse is provided to a LED indicator and is transmitted to the remote apparatus over the wire to provide power to the remote apparatus. The current pulse generator and level change detector also comprises a conduction angle mapping module for mapping the conduction angle to a mapped time during the current pulse and generating a signal at the mapped time, and an amplitude level change generator which receives the signal from the conduction angle mapping module and generates a change in level of the first amplitude. Finally a monitoring circuit for detecting a change in the level of the current pulse generated by the remote apparatus or a signal from the press switch input is included. This generates a signal for the conduction angle controller to change the conduction angle.

[0054] The remote conduction angle control apparatus comprises a power supply regulator for receiving the generated current pulse over the wire, and is used for powering the remote apparatus. The remote apparatus also comprises a remote conduction angle input (ie press button), a switch operation module for a receiving a signal from a remote conduction angle input and generating a level change in the current pulse being received, and a conduction angle indicator circuit comprising a remote conduction angle indicator and a level change detector for detecting a change in the level of the received current pulse. The conduction angle indicator is powered by the current pulse from the start of the current pulse up until the detected level change.

[0055] Referring to Figure 8, resistor R16 provides bias current to transistor Q4, from either load 214 or remote 236 terminal (for connection to a wire), depending on prevailing line voltage half-cycle polarity. This permits Q4 collector current which is directed to the anode of LED indicator 802. The current flowing out of LED cathode 802 is directed through transistor Q5 but only when Q5 is already driven via resistor R10. The emitter current from Q5 then flows through current sense resistors R11 & R12 to 0V rail and then out to the dimmer line 236 or load terminal 214 according to prevailing line voltage half-cycle polarity. Transistor Q7 senses current pulse magnitude flowing through R12, to perform required current limiting action, via restriction of bias current available to Q4.

[0056] During the period when the current pulse is required to be absent (ie after the current pulse interruption), drive to transistor Q5 must be removed, which results in any residual LED current being directed into the base terminal of transistor Q6, which, due to high current-gain factor, acts to shunt a significant proportion of the bias current available to Q4, and hence the resulting LED current magnitude is effectively zero. When the dimmer indicator LED is required to represent a load off-state condition, the current pulse is shunted past the LED using transistor Q3, which is in turn driven by transistor Q2.

[0057] The existing line-load voltage zero-crossing detector 310 (see Figure 3) associated with the dimmer is used to trigger the current pulse generator and uses a circuit comprising a series of precision monostable multivibrator integrated circuits (eg CD3458s) arranged into functional blocks or modules to produce the output current pulse and to control LED function.

[0058] As illustrated in Figure 7A, the non-conduction period occurs from  $t_0$  to  $t_6$ , and is represented by a zero crossing waveform 710 of duration  $t_{nc}$  generated by zero crossing detector  $zc$  (312 in Figure 3). Upon entering the non-conducting portion the current pulse generator module 810 generates the remote apparatus current pulse of width  $t_p$  after a suitable start delay  $t_{sd}$  from the start of the non-conduction period. This can be achieved by generating a start delay pulse which is triggered by the rising edge of the non-conduction pulse generated from the zero crossing detector. The remote apparatus current pulse can then be triggered from the falling edge of the start delay pulse. This apparatus is illustrated in Figures 7B and 7C which show representations 720 730 of the start delay pulse and remote apparatus current pulse respectively. For example if the maximum conduction period is 80% of the period  $T$ , the width of the current pulse can be set to 10% of the half cycle ( $T/20$  or 1ms in a 50Hz system) and this can be centered in this non-conduction period by setting the start delay to 5% of the half cycle from the start of the non-conduction period ( $t_{sd}=T/40$ ). However this start delay may be varied as desired provided that the delayed pulse is not truncated short by the end of the non-conduction period (ie  $t_p + t_{sd} < t_{nc}$ ).

[0059] Referring to Figure 8, an embodiment of the current pulse generator module 810 comprises monostable IC1A and IC1B and associated RC circuits R1, C1, and R2, C2. Monostable IC1A is used to generate the start delay pulse 720 illustrated in Figure 7B. The zero crossing detector output  $zc$  (312 in Figure 3) is operatively connected to non-inverting input  $IN\_A$  to receive the zero crossing waveform 710. An RC circuit R1 C1 is used to generate a 0.5ms start delay pulse as shown in Figure 7B. The start delay pulse is received on the inverting input of monostable IC1B so that monostable IC1B will trigger on the falling edge of the start delay pulse. An RC circuit R2 C2 is used to generate the output 1ms current pulse 730 ( $Q\_B$  of IC1B) which is illustrated in Figure 7C. The output current

pulse is used to drive the gate of transistor Q5 to allow current to flow through LED and to supply power to the remote apparatus.

[0060] The amplitude level change generator 820 (which may be referred to as an interrupt module) is used to produce the interrupt pulse (or current level change) which interrupts the current pulse to indicate (or signal) the dimming level or a request to change a dimming level. The start of the interrupt pulse is delayed with respect to the start of the current pulse by an interrupt delay  $t_{id}$  (ie to time  $t_2$ ). As mentioned above the location ( $t_2$ ) of the start of the interrupt within the current pulse is used to indicate the current dimming level, and thus the length of interrupt delay  $t_{id}$  is controlled via LED output 322 of the dimmer conduction angle control circuit 320. In one embodiment, as no power is supplied to the remote during the interrupt, the width of the interrupt pulse 760  $t_{int}$  is kept short with respect to the width of the current pulse, such as 5% ( $t_{int} = t_p/20 = T/400$ ). Generation of the interrupt pulse is illustrated in Figures 7E and 7F. An interrupt delay pulse 750 of width  $t_{id}$  is triggered from the falling edge of the start delay pulse 720 shown in Figure 7B. The falling edge of the interrupt delay pulse is then used to trigger the interrupt pulse 760, which has a pulse width  $t_{int}$  during which the remote apparatus current pulse will be interrupted. In the example shown in Figure 7E, the dimming level is set to 10% and thus the start delay is  $T/200$  or 100microseconds in a 50Hz system.

[0061] Referring to Figure 8, an embodiment of the interrupt module 820 comprises monostables IC3A and IC3B used to generate the pulses, associated RC circuits R5 C5 and R6 C6 which set the pulse widths, and R19 and Q9 used to invert the LED signal 322 from the dimmer conduction angle control circuit 320, and R9 and Q1 which is used to shunt Q5 so as to cause interruption of the current pulse. Monostable IC3A is used to generate the start delay pulse illustrated in Figure 7E. The output (Q\_A) of IC2A is connected to the inverting input of IC3B so that the falling edge of the start delay pulse at  $t_1$  will trigger generation of an interrupt delay pulse 750 of pulse width 100microseconds based on R5 and C5. The output pulse is connected to the non-inverting input of monostable IC3B, so that the falling edge of this pulse provides the trigger for generation of the interrupt pulse 760 by IC3B as shown in Figure 7F. The length of the interrupt pulse 760 is controlled by RC circuit R6 C6 and is set to 50 microseconds. This output pulse controls the gate of transistor Q1 so as to create the interruption in the remote apparatus current pulse by shunting the gate drive of transistor Q5, which results in the required substantial reduction in magnitude of the remote apparatus current pulse.

[0062] The interrupt pulse 760 from IC3B is based upon the falling edge of the start delay pulse from IC3B, and thus timing of the interrupt pulse can be controlled by control of pulse generation or width of the start delay pulse. In this embodiment the conduction angle controller 320 includes a conduction angle mapping module for mapping the conduction angle to a mapped time during the non-conduction period. At the mapped time, the conduction angle controller generates a signal via LED output 322.

This output signal is directed (via R19) to the gate of Q9 so as to provide an inverted signal to the clear (CLR\_A) input of IC3A. Thus IC3A is only enabled to initiate current pulse interruption when the dimmer control circuit (which implements a conduction angle mapping module) provides a corresponding logic low level LED indicator status signal. As previously discussed the conduction angle controller 320 receives a zero crossing signal and shuts down the switch at the current conduction angle value. The conduction angle mapping module is also configured the current pulse width  $t_p$ , and thus can map the current conduction angle to a time over the current pulse width using an appropriate circuit or logic controller as discussed previously. The mapped time may be delayed by the start delay 720, and a signal generated at LED output 322 at the appropriate time (ie start delay + mapped time from start of the non-conduction period). Whilst in this embodiment the conduction angle control circuit provides the conduction angle mapping module, this could be provided as a separate circuit component using appropriate logic and circuit components.

[0063] A LED shunt module 830 is used to produce an LED shunt pulse which shunts the dimmer indicator LED for the duration of the pulse so that no (or minimal) current flows through the LED and the LED brightness consequently falls to the appropriate level. Generation of the LED shunt pulse 770 is illustrated in Figure 7G. The shunt pulse is triggered by the rising edge of the interrupt pulse shown in Figure 7F (or the falling edge of the interrupt delay pulse) and generates a pulse of width  $t_{sp}$  which extends past the end of the current pulse 730  $t_4$  to a time  $t_5$ . This may be achieved by making the pulse of the same width of the remote apparatus current pulse 730 illustrated in Figure 7C so that it will also extend past the end of that pulse. Alternatively the current pulse could be generated so that the falling edge of the current pulse at  $t_4$  triggers the shunt pulse to terminate.

[0064] Referring to Figure 8, an embodiment of the LED shunt module 830 comprises monostable IC4B, RC circuit C7R7 and shunt transistors Q2 and Q3 and associated resistors R13, R14, R15. The inverting output of IC3B is connected to the inverting input of IC4B so that IC4B is triggered by the rising edge of the interrupt pulse generated by IC3B. A 1ms shunt pulse is generated and this is used to drive the gate of transistor Q2, which in turn drives the gate of transistor Q3, thereby resulting in shunting of dimmer indicator LED current for remaining period of remote apparatus current pulse. The LED brightness consequently falls to a substantially dim level to represent the dimmer load off-state condition.

[0065] The overall current pulse is shown in Figure 7H along with relevant timings. The non-conduction period begins at  $t_0$  and ends at time  $t_6$  (zero crossing) so that  $t_{nc} = t_6 - t_0$ . The current pulse begins at  $t_1$  (ie after an initial delay) and ends at time  $t_4$  so that  $t_p = t_4 - t_1$ . The current pulse is interrupted from time  $t_2$  to  $t_3$  (ie  $t_{int} = t_3 - t_2$ ) and the LED is then shunted until time  $t_5$ .

[0066] Operation of the switch at the remote can also be signaled by causing interruption of the remote apparatus current pulse at or near the start of the pulse, and thus dimmer apparatus includes a remote switch operation monitoring module 840 or more simply a monitoring module, to detect the interruption by the remote and provide this to the dimmer conduction angle control circuit via input 304. The monitoring module may also monitor for actuation of the local button press switch SW1.

[0067] The (remote switch operation) monitoring module 840 includes an interrupt pulse delay generator which is used to produce a short delay after the beginning of remote apparatus current pulse from module 810 during which current pulse interruptions to indicate dimming level may not be present (ie the switch operation portion or the remote apparatus current pulse). This short delay is necessary to accommodate the expected response time of several microsecond for the remote apparatus to detect the current pulse and initiate a current pulse interruption to indicate switch operation. The interrupt delay pulse 740 is illustrated in Figure 7D and is triggered off the start of the current pulse at time  $t_i$ , and has a duration of  $t_{rd}$ . To ensure that remote apparatus current interruptions can be detected, the pulse width of the interrupt delay pulse should be less than the width of the interrupt delay pulse as shown in Figure 7E (i.e.  $t_{rd} < t_{id}$ ).

[0068] A retriggerable pulse generator is used to sense switch operation through detection of an interruption in the current pulse and to provide a logic signal to the dimmer conduction angle control circuit 320 indicating pressing of the remote apparatus switch (see Figure 3). The output of the interrupt pulse delay generator is used to suppress detection of any interruption at other times. Thus the output pulse corresponds to the switch operation portion as discussed above.

[0069] Referring to Figure 8, an embodiment of the remote switch operation monitoring module 840 comprises monostable IC2A and RC circuit R3 C3 which is used to generate the interrupt pulse delay generator comprises, and monostable IC2B, RC circuit R4 C4 and transistor Q8 and associated resistors R17 and R18 which is used as a retriggerable pulse generator module. Monostable IC2A is triggered by the falling edge of the delay pulse from IC1A, and RC circuit R3 C3 is used to generate a 27microsecond delay pulse as shown in Figure 7D which is provided to the input of retriggerable monostable IC2B. The non-inverting input of IC2B is connected to the collector of Q8, whose gate is controlled by the output of Q5. Thus when Q5 is conducting, the gate of Q8 is active and the non-inverting is pulled low, and when the current pulse is interrupted by the remote apparatus, no (or minimal) current flows through Q5 so the gate of Q8 is inactive and the non-inverting input is pulled high. Hence IC2B will be held in the low state during the remote apparatus current pulse, except when the remote apparatus current pulse is interrupted.

[0070] When the non-inverting input of IC2B is high (ie current pulse interruption), the falling edge of the interrupt pulse of IC2A (which is connected to the input of IC2B) will generate a 27ms pulse on the output of IC2B which is provided to switch input 304 of the dimmer control circuit via resistor R8. IC2B is configured as a retriggerable pulse generator, where the triggered pulse duration (27ms) exceeds the period between trigger pulses from IC2A (20ms).

[0071] Triggering of IC2B is thus only effective when the associated inverting input pin is high and the pulse width of the current pulse interruption generated by the remote apparatus exceeds the pulse width of the interrupt delay pulse ( $t_{rd}$ ) so that the falling edge can be used to trigger IC2B. This apparatus allows the IC2B output state to indicate and thus reflect the status of remote apparatus press-button so that this logic output can be provided to the dimmer control circuit 320.

[0072] An embodiment of circuit apparatus 900 for a remote apparatus is illustrated in Figure 9. The remote apparatus is powered by the remote apparatus current pulse produced by the dimmer apparatus and is capable of interrupting the remote apparatus pulse to signal operation of a switch in the remote apparatus. The internal current path for the remote apparatus comprises three primary series elements, comprising a current limiter module 910, a conduction angle indicator module comprising a dimming level LED indicator 902 and a shunt circuit 920 for the LED indicator, and zener-diode power supply regulator 930. The conduction angle indicator is configured to activate the shunt circuit when a level change or interrupt is detected in the received current pulse.

[0073] The current limiter is arranged to have a current limit threshold exceeding that of the magnitude of remote apparatus current sourced by the dimmer apparatus, hence under steady-state conditions incurs little voltage drop. The current limit threshold can however be momentarily reduced, to a value significantly lower in magnitude than the remote apparatus current source, as a means to signal information, eg press-button event, to the dimmer apparatus. During this brief interruption of current a large voltage drop appears across the current limiter circuit in the remote apparatus.

[0074] The current limiting module 910 operates as follows. Diode D1 performs blocking function necessary for a half-wave operating scheme. Current limiter transistor Q6 is self-biased via resistor R13, where resulting emitter current through R11 and transistor Q4 develops voltage to drive base of transistor Q7 which conducts to diminish Q6 bias, hence current limiting function is achieved. Current limiter enable transistor Q4, is normally biased via transistor Q2 and resistor R6, where Q2 is normally biased by resistor R5. Transistor Q1 functions to bypass Q2 bias current when the current limiter is required to interrupt the remote apparatus current pulse. Under these circumstances the larger proportion of emitter current from Q6 is available to drive Q7 hence overall current is limited to comparatively low level.

[0075] Current emerging from the current limiter is next directed through the LED indicator, or, in a similar apparatus to the dimmer apparatus, the remote LED indicator current can be bypassed via a shunting circuit 920, as a means to alter the effective brightness level of the LED indicator. This ensures that the indicator is only powered from the start of the current pulse to the detected level change. The shunting circuit comprises transistors Q3 and Q5 with shunting transistor Q5 driven by transistor Q3, and Q5 is configured to bypass LED current when Q3 is driven.

[0076] The remote apparatus current pulse is finally directed through the zener-diode power supply regulator 930 for establishment of a local power supply rail. At each remote apparatus half-wave current pulse, LED or associated bypass current is initially directed through diode D2 to maintain the charge voltage level in storage capacitor C3 to derive the low voltage dc rail. Excess current is directed through zener voltage regulation diode DZ1. Under the conditions where the current limiter is interrupting the remote apparatus current pulse and also in the remaining part of line voltage half-cycle where current pulse is not present, resistor R12 functions to shunt remaining current emerging from Q7 emitter, thereby defining a low voltage logic state input condition to IC1A & IC1B.

[0077] The remote apparatus includes a switch SW2 to allow a user to alter the dimming level and a remote apparatus switch operation module 940. As illustrated in Figure 5D, operation of the switch in the remote apparatus is signaled to the dimmer apparatus by momentarily interrupting the remote apparatus current pulse. Interruption of the remote apparatus current pulse is performed using monostable IC1A timer function to control the current limiter, with enablement of IC1A only occurring whilst switch SW1 is pressed. Monostable IC1A is triggered by the initial rising edge of the remote apparatus current pulse to create an immediate interruption pulse having time period, or pulse width, defined by RC circuit R2 C2 which in this embodiment is 50 microseconds. The interrupt pulse operates the gate of transistor Q1 to bypass Q2. Switch SW1 is connected to the enable or clear input (CLR\_A) of IC1A so that interruption of the half-cycle remote apparatus current pulse only occurs if SW1 is pressed (operated). In some embodiments the remote switch element SW2 is identical to the switch element SW1 used in the dimmer apparatus.

[0078] The LED brightness level is controlled in a similar manner to that used in the dimmer apparatus by using a remote apparatus LED current bypass module 950 so that current is only supplied to the LED prior to interruption of the current pulse. The remote apparatus LED current bypass module comprises monostable IC1B operating as a timer in conjunction with transistors Q3 and Q4. IC1B is triggered by the falling edge of the voltage appearing across resistor R12, associated with the current pulse interruption and generates a shunt pulse to activate the gate of Q3, leading to activation of Q5 and bypassing of the LED. The pulse width of the shunt pulse is determined by RC circuit R1 C1, and is selected to exceed the remaining duration of current pulse. In this embodiment the shunt

pulse is 1ms, which is equal to the length of the current pulse so that this condition will always be met if an interruption is present. However shorter lengths could be chosen provided this condition is met. As a result of the shunting of LED, the average LED brightness drops. For example if the current pulse interrupt occurs at 10% of the current pulse width then the LED will indicate a dimming level of 10% of maximum.

[0079] The LED indicators associated with the dimmer apparatus and remote apparatus are electrically operated in series fashion which facilitates matching of respective illumination levels. That is each LED indicator sees the same portion of the current pulse prior to any interruption so that they will indicate the same dimming level. The dimming level can be indicated relative to the maximum by inserting the interruption relative to the end of the current pulse. Further if a minimum interruption level is defined (eg 10%), then the portion of the current pulse prior to that minimum level (ie the first or start 10% of the current pulse) can be used as the switch operation portion to allow the remote apparatus to indicate operation of the switch at the remote. Further the indicated dimming level can be continuously variable between the minimum dimming level and the maximum dimming level. Also as interpretation of switch operation and control of the timing of interruption is performed by the dimmer conduction angle control circuit (320) the current pulse generation circuit and remote apparatus circuit which keeps the cost of the down. In other embodiments, rather than use only the portion of the current pulse prior to the interrupt to power the LED indicators, an indicator circuit apparatus can be included which directly detects the location of the interrupt or receives a signal indicating the dimmer level, and generates a separate power pulse for powering the dimming indicator (eg LED) at the indicated dimming level.

[0080] The method for communicating and controlling the dimming level in a dimmer apparatus described herein is further illustrated in figure 10. Flowchart 1000 illustrates a method for communicating and controlling a phase controlled load such as a dimmer. The system comprises a conduction angle controller (which may be part of a dimmer) which controls the conduction angle of a phase controlled load between a minimum conduction angle and a maximum conduction angle to define a conduction period and a non-conduction period. The conduction angle controller also comprises a first conduction angle switch input (ie push button on faceplate for the dimmer controller) and a first conduction angle indicator (eg LED to indicate the dimming level). The controller (eg dimmer apparatus) is connected to at least one remote apparatus and is connected in series via a wire. Similar to the controller (dimmer), each of the remote apparatus also comprising a remote conduction angle switch input (ie push button on a remote dimmer faceplate) and a remote conduction angle indicator (eg LED to indicate the dimming level).

[0081] The method comprises:

generating a current pulse having a first amplitude level and a width during the non-conduction period and transmitting the generated current pulse to the at least one remote apparatus over the wire to power the at least one remote apparatus 1002;

mapping the conduction angle to a mapped time within the current pulse 1004;

changing the level of the current pulse by the conduction angle controller at the mapped time 1006;

indicating the conduction angle in the first conduction angle indicator, wherein the indicated conduction angle is determined based upon the time of the level change 1008;

monitoring the level of the current pulse in the conduction angle controller to detect a change in the level of the current pulse by the at least one remote apparatus or a signal from the first conduction angle input and producing a signal to the conduction angle controller to change the conduction angle in response to the detected change 1010;

monitoring the level of the current pulse in each of the at least one remote apparatus to detect a change in the level of the current pulse by the conduction angle controller 1012; and

indicating the conduction angle by the conduction angle indicator in each of the at least one remote apparatus, wherein the indicated conduction angle is determined based upon the time of the detected level change 1012.

**[0082]** Figures 11A to 11C shows operation of the system (eg a dimmer) illustrated in Figure 2B as the dimming level is increased from 50% to 100% according to one aspect. Figure 11A illustrates the system as illustrated in Figure 2C operating at half (50%) power 1110. A half (50%) power (or intensity) signal 1112 (see Figure 5C) is generated on line 236 and the LED indicator 1114 in the dimmer apparatus 210 and the LED indicator 1116 in the remote apparatus 230 are both shown operating at half power (or half intensity). Figure 11B illustrates the system as illustrated in Figure 11A during a request to increase the dimming level from 50% to 100% 1120. The user interface 1127 on the remote apparatus 210 is operated (eg button is pressed) and an interrupt signal 1122 (see Figure 5D) is generated on line 236. LED indicator 1124 in the dimmer apparatus 210 and the LED indicator 1126 in the remote apparatus 230 are inactive (bypassed or zero power) whilst the button is pressed and the dimming level is changed from 50% to 100%. Figure 11C illustrates the system as illustrated in Figure 11A operating at full intensity 1130 after the dimming level change operation shown in Figure 11B. A full (100%) power (or intensity) signal 1132 (see Figure 5A) is generated on line 236 and the LED indicator 1134 in the dimmer apparatus 210 and the LED indicator 1136 in the remote apparatus 230 are both operating at full power (or intensity).

**[0083]** Figure 12 shows one example of a dimmer system comprising a phase control dimmer apparatus and two remote apparatus connected in series by a single wire according to one aspect. The system as shown in Figure 2C is illustrated, but a second remote apparatus 250 is connected in series

with the first remote apparatus 230 via internal electronic circuitry within the first remote apparatus 230, which is in turn connected to the dimmer apparatus 210 via single wire 236. As wires 256 and 236 are connected in series, all three apparatus are effectively (or operatively) connected via a single wire. That is the single wire may be formed from multiple individual wire elements which are operatively connected (spliced, joined, etc). The remote unit 250 is equivalent to the remote unit 230, and includes an Active terminal 252, a user interface 257 and an indicator 258.

[0084] Embodiments have been described which use a current pulse in the line voltage half-cycle non-conduction period of a phase control dimmer or electronic switch, to establish a functional remote unit. The embodiments provide a cost effective way to achieve true multi-way control and multi-way indication in dimming and related systems.

[0085] Whilst the embodiments have been described in relation to phase controlled dimmers, it is to be understood that the technique may be used in other phase controlled loads such as fans. In these applications an input is used to control the conduction angle between a minimum conduction angle (which may be zero or non-zero) and maximum conduction angle, and in which it is desirable to indicate the value of the conduction angle to the user at both the primary controller and the remote controllers. That is the dimming input and dimming indicator described above are more broadly a conduction angle input and a conduction angle indicator.

[0086] Similarly the embodiments and methods may also be used with phase controlled electronic switch applications in which the on-state conduction angle for the switch corresponds to (or is similar to) that of a dimmer set at its maximum conduction angle. In these applications the indicator will simply have synchronized on or off states at both the primary controller and the remote controllers. For example in addition to dimmers and fans the methods used to control other sub systems of a building automation system (eg blinds, other lights, door latches etc).

[0087] As discussed above multiple remote switches may be wired together in series to achieve true multi-way control and multi-way indication. In the end product application, the remote switch arrangements or apparatus can appear functionally and physically identical to the load control unit, as perceived by the user. That is to the same face plate with the same push button dimming switch and dimming indicator may be used for both the dimmer and the remote switch (for example those manufactured under the Saturn, Impress or 2000 series ranges under the Clipsal by Schneider Electric brand). However the remote dimmer or switch unit does not directly control load current, but communicates with dimmer or switch unit to effect or change load brightness level or status. Furthermore, whilst described in relation to a dimming system using a single wire between the dimmer and remotes, the techniques described could be used in two-wires (or more) applications in which two

wires are run between the dimmer and remotes. In these cases the remote unit current pulse will also flow through the load. However the magnitude of the current pulse will be small in comparison to the normal load current and thus will not be noticeable or adversely affect the system. Thus whilst this current pulse technique enables use in a single wire application it is to be understood that it could also be used to as a control and power supply means for a remote apparatus to control three-wire phase controlled load devices.

[0088] The above described embodiments illustrate suitable circuits for enabling multi-way control (switching) and indication of dimming level in phase controlled applications for loads such as lighting or fan loads. This is achieved through the use of a single interconnection wire between the dimmer or switch and the remote apparatus location which is used for power control and bi-directional signaling. Power to the remote apparatus is supplied via a remote apparatus current pulse in the line voltage half cycle non-conduction period of a phase control dimmer or electronic switch (so as to establish a functional remote apparatus). The remote apparatus current pulse is modulated (ie the level is changed or interrupted) as a means for communicating information to the remote apparatus, such as LED brightness level or status. In some embodiments the portion of the pulse prior to the interrupt can be provided to the dimmer indicators (in both the dimmer and remote) to enable the common display of the current dimming level. Additionally the remote apparatus can modulate the current pulse to communicate information to the dimmer or switch unit such as operation of the switch at the remote. The current pulse may be divided into a switch operation portion and a dimming indication portion. A pulse during the switch operation portion is interpreted as a request for a change in the current dimming level, and is processed by the dimming circuitry (for example by incrementing or decrementing the dimming level by a predefined amount). The timing of an interrupt pulse during the dimming indication portion can be used to indicate the current dimming level (for example an interrupt beginning at a time 50% of the current pulse duration may indicate a dimming level of 50%). For ease of discussion an interrupt pulse has been used to indicate a level change in the current pulse. However it is to be understood that the use of an interrupt pulse (or reference to an interruption) is for ease of discussion and is intended to be more broadly interpreted as one way (or means) to change or modulate the normal (i.e. initial or current) level (i.e. voltage amplitude) of the current pulse. This change may be an increase or a decrease which can be detected and used to indicate the current brightness level or that a user input to request a change in the dimming level has been actuated (eg a button pushed).

[0089] Those of skill in the art would understand that information and signals may be represented using any of a variety of technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols, and chips may be referenced throughout the above description may

be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof.

[0090] Those of skill in the art would further appreciate that the various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the embodiments disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope

[0091] The steps of a method or algorithm described in connection with the embodiments disclosed herein may be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. For a hardware implementation, processing may be implemented within one or more application specific integrated circuits (ASICs), digital signal processors (DSPs), digital signal processing devices (DSPDs), programmable logic devices (PLDs), field programmable gate arrays (FPGAs), processors, controllers, micro-controllers, microprocessors, other electronic units designed to perform the functions described herein, or a combination thereof. Software modules, also known as computer programs, computer codes, or instructions, may contain a number a number of source code or object code segments or instructions, and may reside in any computer readable medium such as a RAM memory, flash memory, ROM memory, EPROM memory, registers, hard disk, a removable disk, a CD-ROM, a DVD-ROM or any other form of computer readable medium. In the alternative, the computer readable medium may be integral to the processor. The processor and the computer readable medium may reside in an ASIC or related device. The software codes may be stored in a memory unit and executed by a processor. The memory unit may be implemented within the processor or external to the processor, in which case it can be communicatively coupled to the processor via various means as is known in the art.

[0092] The reference to any prior art in this specification is not, and should not be taken as, an acknowledgement of any form of suggestion that such prior art forms part of the common general knowledge.

[0093] It will be appreciated by those skilled in the art that the invention is not restricted in its use to the particular application described. Neither is the present invention restricted in its preferred embodiment with regard to the particular elements and/or features described or depicted herein. It will

be appreciated that the invention is not limited to the embodiment or embodiments disclosed, but is capable of numerous rearrangements, modifications and substitutions without departing from the scope of the invention as set forth and defined by the following claims.

**CLAIMS**

1. A method for communicating and controlling the conduction angle in a system for controlling a phase controlled load, the system comprising a conduction angle controller which controls the conduction angle of the phase controlled load between a minimum conduction angle and a maximum conduction angle to define a conduction period and a non-conduction period, a first conduction angle switch input and a first conduction angle indicator, and at least one remote apparatus connected in series with the conduction angle controller via a wire, the at least one remote apparatus comprising a remote conduction angle switch input and a remote conduction angle indicator, the method comprising:

generating a current pulse having a first amplitude level and a width during the non-conduction period and transmitting the generated current pulse to the at least one remote apparatus over the wire to power the at least one remote apparatus;

mapping the conduction angle to a mapped time within the current pulse;

changing the level of the current pulse by the conduction angle controller at the mapped time;

indicating the conduction angle in the first conduction angle indicator, wherein the indicated conduction angle is determined based upon the time of the level change;

monitoring the level of the current pulse in the conduction angle controller to detect a change in the level of the current pulse by the at least one remote apparatus or a signal from the first conduction angle input and producing a signal to the conduction angle controller to change the conduction angle in response to the detected change;

monitoring the level of the current pulse in each of the at least one remote apparatus to detect a change in the level of the current pulse by the conduction angle controller; and

indicating the conduction angle by the conduction angle indicator in each of the at least one remote apparatus, wherein the indicated conduction angle is determined based upon the time of the detected change in the level of the current pulse.

2. The method as claimed in claim 1, wherein the portion of the current pulse prior to the change in the level of the current pulse is provided to each conduction angle indicator to power each conduction angle indicator.

3. The method as claimed in claim 1, wherein a change in the level of the current pulse is an interrupt signal which reduces the first amplitude level of the current pulse to a baseline level for an interrupt period.

4. The method as claimed in claim 3, wherein the interrupt period is less than 5% of the width of the current pulse.

5. The method as claimed in claim 1, wherein the remote apparatus changes the level of the current pulse during a switch operation portion of the current pulse and the conduction angle controller changes the level of the current pulse during a conduction angle indication portion of the current pulse.
6. The method as claimed in claim 5 wherein the switch operation portion is a first portion of the current pulse and the conduction angle indication portion is a second portion of the current pulse after the first portion.
7. The method as claimed in claim 6 wherein the minimum conduction angle is non-zero, and conduction angles are mapped from a range defined by a zero conduction angle to the maximum conduction angle to a range defined by the width of the current pulse, and the switch indication portion comprises the mapped time period defined by the zero conduction angle to the non-zero minimum conduction angle, and the conduction angle indication portion comprises the mapped time period defined by the non-zero minimum conduction angle to the maximum conduction angle.
8. The method as claimed in claim 1, wherein the conduction angle indicators are Light Emitting Diodes (LEDs).
9. The method as claimed in claim 1, wherein changing the level of the current pulse by the conduction angle controller at the mapped time is suppressed if a change in the level of the current pulse of the first amplitude of the current pulse is generated by the at least one remote apparatus or a signal from the first conduction angle switch input is received.
10. The method as claimed in claim 1, wherein the system is a dimming system and the conduction angle indicators are dimming indicators which indicate a dimming level corresponding to the conduction angle.
11. A current pulse generator and level change detector apparatus for use in a conduction angle controller which is connected in series via a wire to at least one remote conduction angle control apparatus, wherein the conduction angle controller controls the conduction angle of a phase controlled load between a minimum conduction angle and a maximum conduction angle to define a conduction period and a non-conduction period, and the conduction angle controller further comprises a first conduction angle switch input and a first conduction angle indicator, and each of the at least one remote conduction angle control apparatus comprises a remote conduction angle input and a remote conduction angle indicator, the current pulse generator and level change detector apparatus comprising:

a current pulse generator for generating a current pulse having a first amplitude and a width during the non-conduction period and for providing to the first conduction angle indicator and for transmitting the generated current pulse to the at least one remote apparatus over the wire to provide power to the at least one remote apparatus;

a conduction angle mapping module for mapping the conduction angle to a mapped time during the current pulse and generating a signal at the mapped time;

an amplitude level change generator which receives the signal from the conduction angle mapping module and generates a change in the level of the first amplitude; and

a monitoring circuit for detecting a change in the level of the first amplitude of the current pulse generated by the at least one remote apparatus or a signal from the first conduction angle switch input, and generating a signal for the conduction angle controller to change the conduction angle.

12. The apparatus as claimed in claim 11 wherein the portion of the current pulse from the start to the generated level change is used to power the first conduction angle indicator.

13. The apparatus as claimed in claim 11 or 12, wherein the amplitude level change generator generates an interrupt pulse to reduce the first amplitude level of the current pulse to a baseline level for an interrupt period.

14. The apparatus as claimed in claim 13, wherein the interrupt period is less than 5% of the width of the current pulse.

15. The apparatus as claimed in claim 13 wherein the amplitude level change generator is configured to generate a change in the level of the first amplitude of the current pulse during a conduction angle indication portion of the current pulse.

16. The apparatus as claimed in claim 15 wherein the monitoring circuit is configured to detect a change in the level of the first amplitude of the current pulse generated by the at least one remote apparatus during a switch operation portion of the current pulse.

17. The apparatus as claimed in claim 16 wherein the switch operation portion is a first portion of the current pulse and the conduction angle indication portion is a second portion of the current pulse after the first portion.

18. The apparatus as claimed in claim 17 wherein the minimum conduction angle is non-zero, and the conduction angle mapping module is configured to map conduction angles from a range defined by a zero conduction angle to the maximum conduction angle to a range defined by the width of the

current pulse, wherein the switch indication portion comprises the mapped time period defined by the zero conduction angle to the non-zero minimum conduction angle, and the conduction angle indication portion comprises the mapped time period defined by non-zero minimum conduction angle to the maximum conduction angle.

19. The apparatus as claimed in claim 12, wherein a shunt circuit is used to shunt the current pulse to the first conduction angle indicator from the time of the generated level change to the end of the current pulse.

20. The apparatus as claimed in claim 11 wherein the conduction angle indicator is a light emitting diode (LED).

21. The apparatus as claimed in claim 13 wherein the monitoring circuit is further configured to generate a signal to suppress the amplitude level change generator from generating a change in level of the first amplitude in response to detecting a change in the level of the first amplitude of the current pulse generated by the at least one remote apparatus or a signal from the first conduction angle switch input.

22. The apparatus as claimed in claim 11, wherein the conduction angle controller is for use in a dimmer and the conduction angle indicators are dimming indicators which indicate a dimming level corresponding to the conduction angle.

23. A remote conduction angle control apparatus for series connection via a wire with a conduction angle controller which controls the conduction angle of a phase controlled load between a minimum conduction angle and a maximum conduction angle to define a conduction period and a non-conduction period and the conduction angle controller comprising a first conduction angle switch input and a first conduction angle indicator, the remote conduction angle control apparatus comprising:

- a power supply regulator for receiving a current pulse from the phase controlled conduction angle controller over the wire for powering the remote conduction angle control apparatus;

- a remote conduction angle input;

- a switch operation module for a receiving a signal from a remote conduction angle input and generating a level change in the current pulse being received;

- a conduction angle indicator circuit comprising a remote conduction angle indicator and a level change detector for detecting a change in the level of the received current pulse and wherein the conduction angle indicator is powered by the current pulse from the start of the current pulse up until the detected level change.

24. The apparatus as claimed in claim 23, wherein the switch operation module generates a level change during a switch operation portion of the current pulse.
25. The apparatus as claimed in claim 23, wherein the switch operation module generates an interrupt pulse to reduce the level of the current pulse to a baseline level for an interrupt period.
26. The apparatus as claimed in claim 23, wherein the interrupt period is less than 5% of the width of the current pulse.
27. The apparatus as claimed in claim 23, wherein a shunt circuit is used to shunt the current pulse to the first conduction angle indicator from the time of the generated level change to the end of the current pulse.
28. The apparatus as claimed in claim 23 wherein the conduction angle indicator is a light emitting diode (LED).
29. The apparatus as claimed in claim 23, wherein the conduction angle controller is for use in a dimmer and the conduction angle indicators are dimming indicators which indicate a dimming level corresponding to the conduction angle.
30. A phase controlled load apparatus for series connection via a wire to at least one remote conduction angle control apparatus as claimed in anyone of claims 23-28, the phase controlled load apparatus comprising:
- a zero crossing detector and low voltage supply circuit;
  - a switch which supplies power to a load;
  - a conduction angle controller which controls the conduction angle of the switch between a minimum conduction angle and a maximum conduction angle to define a conduction period and a non-conduction period;
  - a first conduction angle switch input;
  - a first conduction angle indicator; and
  - a current pulse generator and level change detector as claimed in any one of claims 11 to 22.
31. A system for controlling a phase controlled load, the system comprising the phase controlled load apparatus as claimed in claim 30 connected in series via a wire to at least one remote conduction angle control apparatus as claimed in anyone of claims 23-28.

32. The system as claimed in claim 32, wherein the phase controlled load apparatus is a dimmer and the conduction angle indicators are dimming indicators which indicate a dimming level corresponding to the conduction angle.