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(54) Lighting control

(57) A lighting system is controlled by lighting control apparatus 40 dependent on a received input signal 41 representing a required perceived illumination level. The lighting control apparatus comprising a sigma-delta converter having an input filter 47 for providing a filtered input signal 411 from the input signal 41 to a precision comparator 44 for comparing the filtered input signal with a feedback input signal 451 from a system model module 45 simulating an effect of the input signal on the lighting system. A resultant perceived illumination level is compared with the required perceived illumination level, and the precision comparator provides an output signal 42 for controlling a power supply 43 to the lighting system 46 to provide the required perceived illumination level.

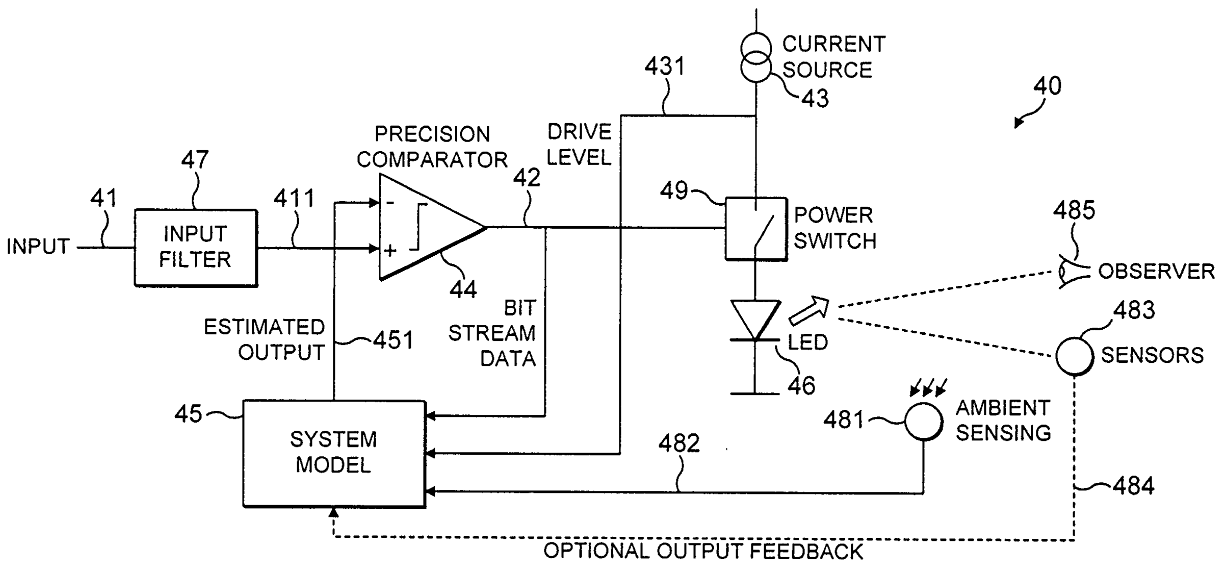

FIG. 4

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Description

[0001] This invention relates to lighting control.

[0002] Known drive or control techniques for light-emitting devices typically use pulse width modulation (PWM) to drive light-emitting diodes (LEDs) and LED arrays. These techniques have significant latency, in that a required change of illumination or display light level from the light-emitting device can be implemented only during a next complete PWM cycle after a new demanded level information is received.

[0003] Moreover, known PWM techniques typically provide only a linear scale of modulation in that each incremental change in demanded input level gives rise to a linear change in a width of a period for which a drive mechanism is switched on.

[0004] Such drive technologies are known from, for example, US-A-6,016,038 and US-A-6,150,774.

[0005] It is an object of the present invention at least to ameliorate the aforesaid deficiencies in the prior art.

[0006] According to a first aspect of the invention, there is provided a lighting control apparatus for controlling a lighting system dependent on a received input signal representing a required perceived illumination level, the apparatus comprising a sigma-delta converter having an input filter for providing a filtered input from the input signal to a precision comparator for comparing the filtered input signal with a feedback input signal from a system model module simulating an effect of a comparator output signal on the lighting system to compare a resultant perceived illumination level with the required perceived illumination level, such that the precision comparator provides the comparator output signal for controlling a power supply to the lighting system to provide the required perceived illumination level.

[0007] Preferably, the precision comparator outputs bit stream data to the system model module and as the output signal.

[0008] Conveniently, where the apparatus is for controlling a lighting system having a plurality of lighting array channels, the sigma-delta converter comprises a plurality of precision comparators for providing a plurality of output signals to the respective lighting array channels.

[0009] Advantageously, the system model module comprises a respective system model for each of the lighting array channels.

[0010] Conveniently, the lighting control apparatus further comprises means for monitoring a supply drive level to the lighting system for input to the system model module.

[0011] Advantageously, the lighting control apparatus further comprises ambient lighting sensing means for inputting an ambient lighting signal to the system model module.

[0012] Preferably, the ambient lighting sensing means provides signals corresponding to a plurality of discrete wavelengths to provide information on the effective colour characteristics of an ambient light level at a user's eyes.

[0013] Advantageously, the lighting control apparatus further comprises feedback illumination sensing means for sensing illumination received at a user location from the lighting system and for inputting an illumination feedback signal to the system model module.

[0014] Preferably, the system model module monitors and models at least one of lighting system supply drive level, time and linearity responses of lighting drive circuitry, time and linearity responses of the lighting system, models of light perception characteristics of a user's eyes, perception of ambient light levels and perception of ambient light colours.

[0015] Conveniently, the lighting control apparatus is arranged for controlling a light-emitting diode display or illumination system.

[0016] Advantageously, the output signal is arranged for controlling at least one power switch for controlling power supply to the lighting system.

[0017] Preferably, the lighting control apparatus is arranged for driving a three channel RGB array of light-emitting devices precisely to control a colour perceived by a user, dependent on ambient lighting colour and level.

[0018] Advantageously, the lighting control apparatus is arranged for controlling a lighting system precisely to control a colour perceived by a user, dependent on at least one of known characteristics and defects in the user's optical perception, and of characteristics of optical transmission media through which light from the lighting system reaches the user.

[0019] Advantageously, the lighting control apparatus is arranged to provide nonlinear modulation of an output power of the lighting system.

[0020] According to a second aspect of the invention, there is provided a method of controlling a lighting system comprising the steps of: receiving an input signal representing a required perceived illumination level; passing the input signal through a sigma-delta converter comprising filtering the input signal to produce a filtered input signal, inputting the filtered input to a precision comparator, feeding back a comparator output signal from the precision comparator through a system model module, which simulates an effect of the comparator output signal on the lighting system, to the precision comparator to compare a resultant perceived illumination level with the required perceived illumination level; and outputting the comparator output signal from the precision comparator for controlling a power supply to the lighting system to provide the required perceived illumination level.

[0021] Preferably, the step of outputting the comparator output signal comprises outputting bit stream data.

[0022] Conveniently, where the method is for controlling a lighting system having a plurality of lighting array channels, the step of passing the input signal through a sigma-delta converter comprises passing a respective plurality of input signals and inputting the filtered input to a plurality of precision comparators for providing a plurality of comparator output signals to the respective lighting array channels.

[0023] Preferably, the system model module comprises a respective system model for each channel.

[0024] Advantageously, the method comprises a further step of monitoring a supply drive level to the lighting system for input to the system model module.

[0025] Conveniently, the method comprises a further step of sensing ambient light for inputting an ambient lighting signal to the system model module.

[0026] Preferably, the step of sensing ambient light comprises sensing ambient light corresponding to a plurality of discrete wavelengths to provide information on the effective colour characteristics of an ambient light level at a user's eyes.

[0027] Advantageously, the method comprises a further step of sensing illumination received from the lighting system at a user location and inputting a resultant illumination feedback signal to the system model module.

[0028] Preferably, the step of feeding back an output from the precision comparator through a system model module, simulating an effect of the comparator output signal on the lighting system, comprises monitoring with the system control module at least one of lighting system supply drive level, time and linearity responses of lighting drive circuitry and/or the lighting system, and/or modelling at least one of light perception characteristics of a user's eyes and a user's perception of ambient light levels and colours.

[0029] Advantageously, the method is arranged for controlling a light-emitting diode display or illumination system.

[0030] Conveniently, the step of outputting the output signal comprises controlling at least one power switch for controlling power supply to the lighting system.

[0031] Preferably, the method is arranged for driving a three channel RGB array of light-emitting devices precisely to control a colour perceived by a user, dependent on ambient lighting colour and level.

[0032] Advantageously, the method is arranged for controlling a lighting system precisely to control a colour perceived by a user, dependent on at least one of known characteristics or defects in the user's optical perception and on optical transmission media through which light from the lighting system reaches the user.

[0033] Conveniently, the method is arranged for providing nonlinear modulation of the lighting system.

[0034] According to a third aspect of the invention, there is provided a computer program comprising code means for performing all the steps of the method described above when the program is run on one or more computers.

[0035] The invention will now be described, by way of example, with reference to the accompanying drawings in which:

Figure 1 is a schematic diagram of a known digital audio system using sigma-delta modulation;

Figure 2 is a schematic drawing of a known lighting controller using pulse width modulation;

Figure 3 is a schematic drawing of a known multichannel light-emitting array controller using the light control system of Figure 2;

Figure 4 is a schematic diagram of a single channel LED controller according to the present invention; and

Figure 5 is a schematic diagram of a multi-channel light-emitting array controller according to the present invention.

[0036] In the Figures, like reference numerals denote like parts.

[0037] Referring to Figure 1, use of sigma-delta modulation techniques is known in, for example, a digital audio storage system 10. An input filter 17 receives an input signal 11 and outputs a filtered signal 111 to a first input of a precision comparator 14. A bit stream output 12 from the precision comparator 14 is input to a system model reconstruction filter 15. An output 151 of the system model reconstruction filter 15 is fed back to a second input of the precision comparator 14. The bit stream output 12 of the precision comparator is also output to a first data processing module 18. There is an output from the first data processing module 18 to a data storage device 13 and an output from the data storage device 13 to a second data processing module 19. Output from the second data processing module 19 is to an input of an audio system 16 having an output 161. The first data processing module 18 may, for example, be a component of a compact disc recording apparatus and the second data processing module 19 may be a component of a compact disc player. In this example, the sigma delta converter models an audio response of the compact disc player.

[0038] In use, the input signal 11 (which may be analogue or digital) is filtered by the input filter 17 and a filtered output 111 is translated by the precision comparator 14 into the single bit data stream 12 which is processed and stored on the suitable data storage device 13. A central feature of the conversion process or modulation technique is a precision switch mechanism of the precision comparator 14, and modelling of effects of the precision comparator on forward path system components by a suitable simulation of the audio system or by a suitable reconstruction filter 15, the output 151 of that filter being used as an estimate of the eventual system output which it is intended should accurately match the input data. This estimate is used instead of a feedback signal from the system output, which is not available, and is compared with the pre-processed demand input

111 filtered by the input filter 17 from the input signal 11. The input filter 17, precision comparator 14 and system model reconstruction filter 15 together form a sigma-delta converter. A comparison by the precision comparator 14 is used to select a most appropriate control switch action and may include elements of either hysteresis or dither in a decision process. Multiple weighted switched outputs may also be used, but are usually less advantageous in a practical situation where the relative weightings have to be precisely defined, so that sigma-delta modulation techniques have been developed essentially for use with single switch mechanisms.

[0039] With such single switch mechanisms, output of a switch forms a single bit stream 12 of high speed data representing the input data. This bit stream 12 may undergo data decimation, compression and further processing in a first data processing unit 18 before storage on, for example, a computer or compact disc 13. When data is retrieved from the computer or compact disc the data is reconstructed by a second data processing unit 19 for output through an audio system 16 with characteristics similar to those modelled by the system model reconstruction filter 15 in the sigma-delta conversion process. This total process forms the basis of many known digital audio data storage techniques.

[0040] Referring to Figure 2, a known light control system 20 uses pulse width modulation to control a light-emitting device 26. A power supply 23 is connected by means of an electrically controlled switch 29 to the light-emitting device 26. A ramp generator 22 is connected to a first input of a comparator 24 and a signal input to control the light-emitting device 26 is connected to a second input of the comparator 24. An output of the comparator 24 is connected to a control input of the switch 29.

[0041] In use a ramp waveform 221 is output from the ramp generator 22 to the first input of the comparator 24. A control signal is input to the second input of the comparator 24. When the control signal is above the ramp waveform input the comparator 24 produces a high output, when the control signal is below the ramp waveform input the comparator produces a low output. By varying the control signal a variable width pulse output 211, 212 is produced by the comparator 24. The variable pulse width signal is input to the switch 29 to control the brightness of the light-emitting device 26.

[0042] Referring to Figure 3, three such circuits as described above in relation to Figure 2 may be used in a known multi-channel lighting controller 30 to control red, green and blue channels controlling arrays of red, green and blue light-emitting arrays respectively. Similarly to the control system of Figure 2, a power supply 37 is connected by a first switch 391 to an array of red light-emitting devices 361, 362. A first comparator 341 has a first ramp waveform 321 applied to a first input and a red control signal 31 input to a second input. A resultant pulse width modulated output 311 controls the switch 391 to control brightness of the red light-emitting array 361, 362.

[0043] Similarly, the power supply 37 is connected by a second switch 392 to a green light-emitting array 363, 364. A second comparator 342 has a second ramp waveform 322 applied to a first input and a green control signal 32 input to a second input. A resultant pulse width modulated output 321 controls the switch 392 to control brightness of the green light-emitting array 363, 364.

[0044] Similarly, the power supply 37 is connected by a third switch 393 to a blue light-emitting array 365, 366. A third comparator 343 has a third ramp waveform 323 applied to a first input and a blue control signal 33 input to a second input. A resultant pulse width modulated output 331 controls the switch 393 to control brightness of the blue light-emitting array 365, 366.

[0045] The first ramp waveform 321, the second ramp waveform 322 and the third ramp waveform 323 may be a same waveform or two or three different waveforms.

[0046] In accordance with the present invention, a related technique to that shown in an audio control system in Figure 1 may be applied to control of a light-emitting device or array similar to those shown in Figures 2 and 3 respectively.

[0047] The characteristics of this technique are as follows. A sigma-delta modulation technique is used to control light output from single channel or from multiple channels of light-emitting devices or arrays used for either display or illumination purposes. Modelling inherent in this technique may be used to compensate for linearity and time response characteristics of all system components including those in the drive circuitry, light-emitting devices and optical path, and of an observer's eye and colour perception. The modelling inherent in this technique may further be used to combine effects of several channels in a composite model which predicts an effect at an observer's position of a combination of channel outputs, e.g. of red, green and blue output wavelengths on a colour perceived by the observer.

[0048] Referring to Figure 4, a single channel LED control system 40 according to the invention has a LED lighting device or array 46 driven by a current source 43 through a power switch 49. An input filter 47 for receiving an input signal 41 for controlling the LED lighting device or array 46 has a filtered output 411 to a first input of a precision comparator 44. The input filter 47 is used to adjust an overall dynamic system response, typically being a low pass filter which both sets an overall system time constant and significantly in this application smoothes noise or sharp discontinuities in input demand data.

[0049] A bit stream data output 42 of the precision comparator 44 is output to a first input of a system model module 45. An estimated output signal 451 of the system model module 45 is fed back to a second input of the precision comparator 44. The input filter 47, precision comparator 44 and system model module 45 together form a sigma-delta converter. The bit stream data output 42 of the precision comparator is also output to a control input of the power switch 49 to control current from the current source 43 to the LED device or array 46. A drive level signal 431 from the current source 43 is input to a second input of the system model module 45. An ambient light sensor 481 provides an ambient light signal 482 to a third input of the system model module 45. Light from the LED light device or array may be observed at an observer's eye 485. An optional output feedback sensor 483 may read the illumination level received at the observer's eye 485 and provide an output feedback signal 484 to an output feedback input of the system model module 45.

[0050] A core of a drive mechanism of the control system 40 is the current source 43, being a transistor or similar device or a combined drive component, current from which can be switched either on or off by the power switch 49 to control the LED or light-emitting array 46. This type of drive mechanism has well-known advantages in relation to low dissipation levels within component parts of the system. In some systems this drive mechanism is a combination of such switches providing suitably weighted output drive levels. A drive mechanism with variable analogue drive level is equally within the scope of this light-emitting device driving mechanism although it is not normally associated with sigma-delta modulation.

[0051] In use, a decision about whether power to the light-emitting device or array 46 should be switched on or off is made by comparing a required output light level, from a pre-processed command present at the system input 41, with a current estimate of a perceived light level 451. This estimate is generated in the system model module 45 which may include some or all of the response characteristics of the system components including device supply drive level 431, time and linearity responses, and which may include models of light perception characteristics of the observer's eye 485, and may further include modelling to incorporate effects on perception of ambient light levels and colour, for example as received by the ambient light sensor 481. A comparison by the system model module 45 of an estimated output light level and the demand input 41 informs a decision of an optimum condition for the drive component 49, and the component 46 may then be switched on or off as most appropriate. Effects of this choice can then be estimated to great precision in the system model module 45 to inform a next decision.

[0052] In this application there is normally little advantage in storing the resultant high speed bit stream data 42, and the bit stream information is applied directly to the power switch 49 to control the light-emitting device or array 46 and hence system output.

[0053] The input filter 47, decision method and system model 45 can be realised either as physical components as illustrated or partially or wholly within software running on a suitable processor.

[0054] Resultant dynamics of the control system 40 may be manipulated by changing characteristics of the input filter 47, or characteristics of the system model module 45 as is most appropriate.

[0055] At its simplest, the control system 40 will work when the system model module 45 is given an impulse response of a form c(t) = k.exp(-t/tor), where tor defines an appropriate system time constant, and where the input filter 47 has unity gain. More generally models of, for example, the drive mechanism, light-emitting device, transmission media and eye response can be cascaded and combined into a total system model to give a required estimate of a system output to great precision.

[0056] The ambient light sensor 481 may typically measure an ambient light level over a broad spectrum, but may more usefully provide measurements at a number of discrete wavelengths, providing information as to effective colour characteristics of an ambient light level at the observer's eye 485.

[0057] A feedback signal 484 on an outer feedback loop, shown as a broken line in Figure 4, directly sensing the system output, or some relevant components of the system output, using the feedback sensor 483, can be used for periodic adjustment, calibration or correction of the system model or of its state or of its outputs. In zero ambient light conditions the ambient light sensor 481 might be used for this purpose.

[0058] Multiple light-emitting device arrays of two or more devices can be controlled by using multiples of this single channel system, using different system models to reflect different device, drive or eye characteristics appropriate to the components in use on each channel.

[0059] An embodiment of the invention applied to control of two arrays of light-emitting devices is illustrated in Figure 5.

[0060] Referring to Figure 5, a multi-channel lighting control system 50 according to the present invention has first and second light-emitting arrays 561, 562 driven independently by a current source 53 through respective first and second power switches 591, 592. An input filter 57 for receiving respective input signals 511, 512 for controlling the first and second light-emitting arrays 561, 562 has respective filtered first and second outputs 5111, 5121 to respective first inputs of respective first and second precision comparators 541, 542. Respective first and second bit stream data outputs 521, 522 of the respective first and second precision comparators are output to respective first and second inputs of a system model module 55. Respective estimated output signals 551, 552 of the system model module 55 are fed back to respective second inputs of the first and second precision comparators 541, 542. The input filter 57, first and second precision comparators 541, 542 and system model module 55 together form a sigma-delta converter. The respective bit stream data outputs 521, 522 of the first and second precision comparators 541, 542 are also output to respective control inputs of the first and second power switches 591, 592 to control currents from the power supply 53 to the first and second light-emitting arrays 561, 562 respectively. A drive level signal 531 from the power supply 53 is input to a third input of the system model module 55. An ambient light sensor 581 provides an ambient light signal 582 to a fourth input of the system model module 55. The first and second light-emitting arrays 561, 562 may be observed by an observer's eye 585, either directly or through an optional transmission medium 565, shown by broken lines in Figure 5. An optional output feedback sensor 583 may read an illumination level received at the observer's eye 585 and provide an output feedback signal 584 to an output feedback input of the system model module 55.

[0061] A particular advantage of this technique is an ability to combine modelling of two or more channels to model a total effect at the observer's eye 585 of light output or of differently coloured outputs from each channel. This enables sophisticated modelling and control of colour or illumination perception to be achieved, whilst often yielding an advantage in reducing a total execution period of the system models if realised in software. With sophisticated modelling of this type, input demand parameters may not be the same as those being controlled by the data bit streams, the conversions being executed in a multiple input, multiple output filter such as the input filter 57 or system model module 55. Similarly the components of the output which are sensed and fed back to the system model may not be directly related to the parameters controlled by the bit stream data or to the input data 511, 512.

[0062] A typical use of this technique is driving a three channel RGB array of light-emitting devices precisely to control a colour that an observer perceives, with compensation for ambient lighting colour and level, and modelling (if required) of known characteristics or defects in an observer's optical perception or in an optical transmission medium 365 through which light from the controlled lighting or display device is observed.

[0063] This three-channel, three-colour system is a main application for this drive or control technique. However, a four colour system, for example, may also be used.

[0064] The sigma-delta modulation technique described herein allows the implementation of lighting systems with latency periods typically hundreds of times shorter than in the prior art to give much improved speed of control over perceived light levels, with higher bandwidth compensation if required for 100 Hz supply variations. With much shorter cycle times and non-linear modelling available through sigma-delta modulation techniques, non-linear modulation schemes become available, and provide a technique of compensation for both system component and eye response non-linearities.

[0065] Some of the advantages of the present invention over existing technology are as follows. Existing drive techniques for light-emitting devices typically use PWM to drive LEDs (light-emitting diodes) and LED arrays. This technique has significant latency, in that a required change of illumination or display light level from the light-emitting device can only be implemented during a next complete PWM cycle after the new demanded level information is received. The sigma-delta modulation technique described herein is able to implement systems with latency periods typically hundreds of times shorter to give much improved speed of control over perceived light levels, with higher bandwidth compensation if required for 100 Hz supply variations.

[0066] Existing PWM techniques typically provide only a linear scale of modulation in that each incremental change in demanded input level gives rise to a linear change in a width of a period for which the drive mechanism is switched on. With the much shorter cycle times and non-linear modelling available through sigma-delta modulation techniques, non-linear modulation schemes become available, and provide a technique of compensation for both system component and eye response non-linearities. '

[0067] Advantages of this technique may therefore be summarised as one or more of the following:

- ability to use a relatively simple, switched, low-dissipation drive technique;
- superior time response over existing modulation techniques in use (for example, no period latency as with PWM);
- ability to use precision system modelling techniques in order to incorporate correction for non-linear system characteristics;
- use of a higher effective modulated carrier frequency so that drive circuit filter components are usually smaller and of lower dissipation than those necessary with other techniques;
- use of a higher effective modulated carrier frequency so that periodic supply current fluctuations associated, for example, with synchronous PWM are eliminated;
- ability to synchronise modulation process with disturbances on a power supply to minimise effects of the said fluctuations;
- precision control of single light-emitting device output with compensation for both non-linearities and time responses due to all system components such as power drive circuit, power drive circuit filtering, light-emitting device characteristics, light transmission media and receiver's eye response;
- precision control of multiple light-emitting device array light output with compensation for both non-linearities and time responses due to all system components such as power drive circuits, power drive circuit filtering, light-emitting device characteristics,

light transmission media and receiver's eye response;

- precision control of the light output of multi-coloured arrays of light-emitting devices with compensation for both non-linearities and time responses due to all system components such as power drive circuit, power drive circuit filtering, light-emitting device characteristics, light transmission media and receiver's eye response;
- a method of controlling the illumination/display colour perceived by an observer to provide correction for problems of colour perception including partial colour blindness; and
- a mechanism within the technique for compensation against changes in ambient light level or of ambient light colouration which will maintain a constant colour perception in the observer despite such changes.

Claims

1. A lighting control apparatus (40) for controlling a lighting system (46) dependent on a received input signal (41) representing a required perceived illumination level, the apparatus comprising a sigma-delta converter (44, 45, 47) having an input filter (47) for providing a filtered input (411) from the input signal to a precision comparator (44) for comparing the filtered input signal (411) with a feedback input signal (451) from a system model module (45) simulating an effect of a comparator output signal on the lighting system to compare a resultant perceived illumination level with the required perceived illumination level, such that the precision comparator (44) provides the comparator output signal (42) for controlling a power supply (43) to the lighting system to provide the required perceived illumination level.

2. A lighting control apparatus as claimed in claim 1, wherein the precision comparator outputs bit stream data to the system model module and as the comparator output signal.

3. A lighting control apparatus as claimed in claims 1 or 2, for controlling a lighting system (561, 562) having a plurality of lighting array channels, wherein the sigma-delta converter comprises a plurality of precision comparators (541, 542) for providing a plurality of comparator output signals (521, 522) to the respective lighting array channels.

4. A lighting control apparatus as claimed in claim 3, wherein the system model module (55) comprises a respective system model for each of the lighting array channels.

5. A lighting control apparatus as claimed in any of the preceding claims, further comprising means for monitoring a supply drive level to the lighting system for input (531) to the system model module.

6. A lighting control apparatus as claimed in any of the preceding claims, further comprising ambient lighting sensing means (481) for inputting an ambient lighting signal (482) to the system model module (45).

7. A lighting control apparatus as claimed in claim 6, wherein the ambient lighting sensing means (481) provides signals corresponding to a plurality of discrete wavelengths to provide information on effective colour characteristics of an ambient light level at a user's eyes (485).

8. A lighting control apparatus as claimed in any of the preceding claims, further comprising feedback illumination sensing means (483) for sensing illumination received at a user location from the lighting system and for inputting an illumination feedback signal (484) to the system model module (45).

9. A lighting control apparatus as claimed in any of the preceding claims, wherein the system model module monitors and models at least one of lighting system supply drive level, time and linearity responses of lighting drive circuitry, time and linearity responses of the lighting system, models of light perception characteristics of a user's eyes, perception of ambient light levels and perception of ambient light colours.

10. A lighting control apparatus as claimed in any of the preceding claims arranged for controlling a light-emitting diode display or illumination system.

11. A lighting control apparatus as claimed in any of the preceding claims, wherein the comparator output signal is arranged for controlling at least one power switch (49) for controlling power supply to the lighting system.

12. A lighting control apparatus as claimed in any of the preceding claims arranged for driving a three channel RGB array of light emitting devices precisely to control a colour perceived by a user, dependent on ambient lighting colour and level.

13. A lighting control apparatus as claimed in any of the preceding claims arranged for controlling a lighting system precisely to control a colour perceived by a user, dependent on at least one of known characteristics and defects in the user's optical perception, and characteristics of optical transmission media through which light from the lighting system reaches the user.

14. A lighting control apparatus as claimed in any of the preceding claims arranged to provide nonlinear modulation of the lighting system.

15. A method of controlling a lighting system (46) comprising the steps of:

a. receiving an input signal (41) representing a required perceived illumination level;

b. passing the input signal through a sigma-delta converter (44, 45, 47) comprising filtering the input signal to produce a filtered input signal (411), inputting the filtered input to a precision comparator (44), feeding back a comparator output signal (42) from the precision comparator through a system model module (45), which simulates an effect of the comparator output signal on the lighting system, to the precision comparator (44) to compare a resultant perceived illumination level with the required perceived illumination level; and

c. outputting the comparator output signal (42) from the precision comparator (45) for controlling a power supply (43) to the lighting system (46) to provide the required perceived illumination level.

16. A method as claimed in claim 15, wherein the step of outputting the comparator output signal comprises outputting bit stream data.

17. A method as claimed in claims 15 or 16, for controlling a lighting system (561, 562) having a plurality of lighting array channels, wherein the step of passing the input signal through a sigma-delta converter comprises passing a respective plurality of input signals (511, 512) and inputting the filtered input (5111, 5121,) to a plurality of precision comparators (541, 542) for providing a plurality of comparator output signals (521, 522) to the respective lighting array channels.

18. A method as claimed in claim 17, wherein the system model module (55) comprises a respective system model for each channel.

19. A method as claimed in any of claims 15 to 18, comprising a further step of monitoring a supply drive level to the lighting system for input (531) to the system model module (55).

20. A method as claimed in any of claims 15 to 19 comprising a further step of sensing ambient light for inputting an ambient lighting signal (582) to the system model module (55).

21. A method as claimed in claim 20, wherein the step of sensing ambient light comprises sensing ambient light corresponding to a plurality of discrete wavelengths to provide information on effective colour characteristics of an ambient light level at a user's eyes.

22. A method as claimed in any of claims 15 to 21, comprising a further step of sensing illumination received from the lighting system at a user location and inputting a resultant illumination feedback signal (584) to the system model module (55).

23. A method as claimed in any of claims 15 to 22, wherein the step of feeding back an output from the precision comparator through a system model module, simulating an effect of the comparator output signal on the lighting system comprises monitoring with the system control module at least one of lighting system supply drive level, time and linearity responses of lighting drive circuitry and/or the lighting system, and/or modelling at least one of light perception characteristics of a user's eyes and a user's perception of ambient light levels and colours.

24. A method as claimed in any of claims 15 to 23 arranged for controlling a light-emitting diode display or illumination system.

25. A method as claimed in any of claims 15 to 24, wherein the step of outputting the output signal comprises controlling at least one power switch (49) for controlling power supply to the lighting system.

26. A method as claimed in any of claims 15 to 25 arranged for driving a three channel RGB array of light emitting devices precisely to control a colour perceived by a user, dependent on ambient lighting colour and level.

27. A method as claimed in any of claims 15 to 26 arranged for controlling a lighting system precisely to control a colour perceived by a user, dependent on at least one of known characteristics or defects in the user's optical perception or on optical transmission media (565) through which light from the lighting system reaches the user.

28. A method as claimed in any of claims 15 to 27 arranged to provide nonlinear modulation of the lighting system.

29. A computer program comprising code means for performing all the steps of the method of any of claims 15 to 28 when the program is run on one or more computers.

30. A lighting control apparatus substantially as hereinbefore described with reference to and as illustrated in Figures 4 or 5 of the accompanying drawings.

31. A method of controlling a lighting system substantially as hereinbefore described with reference to and as illustrated in Figures 4 or 5 of the accompanying drawings.

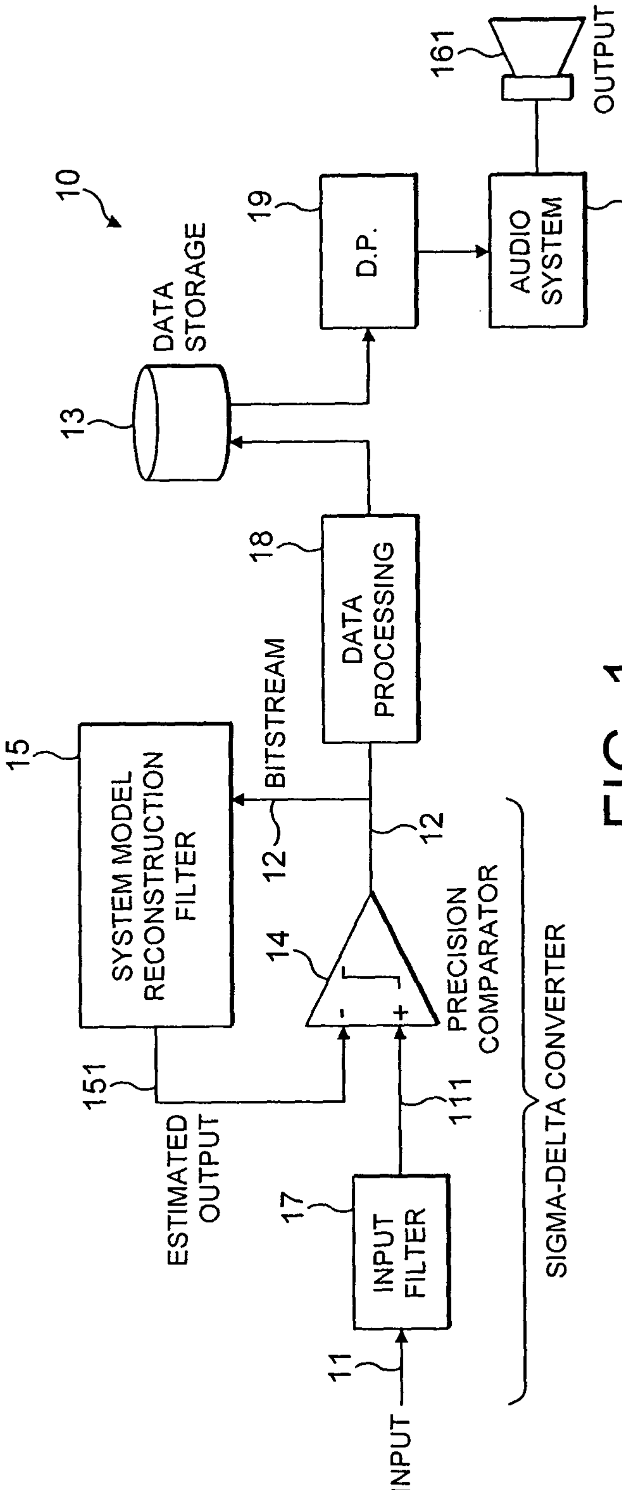
10
DATA STORAGE
13
19
D.P.
161
OUTPUT
AUDIO SYSTEM
16
15
SYSTEM MODEL RECONSTRUCTION FILTER
BITSTREAM
18
DATA PROCESSING
12
12
14
PRECISION COMPARATOR
151
ESTIMATED OUTPUT
17
INPUT FILTER
111
SIGMA-DELTA CONVERTER
11
INPUT

FIG. 1

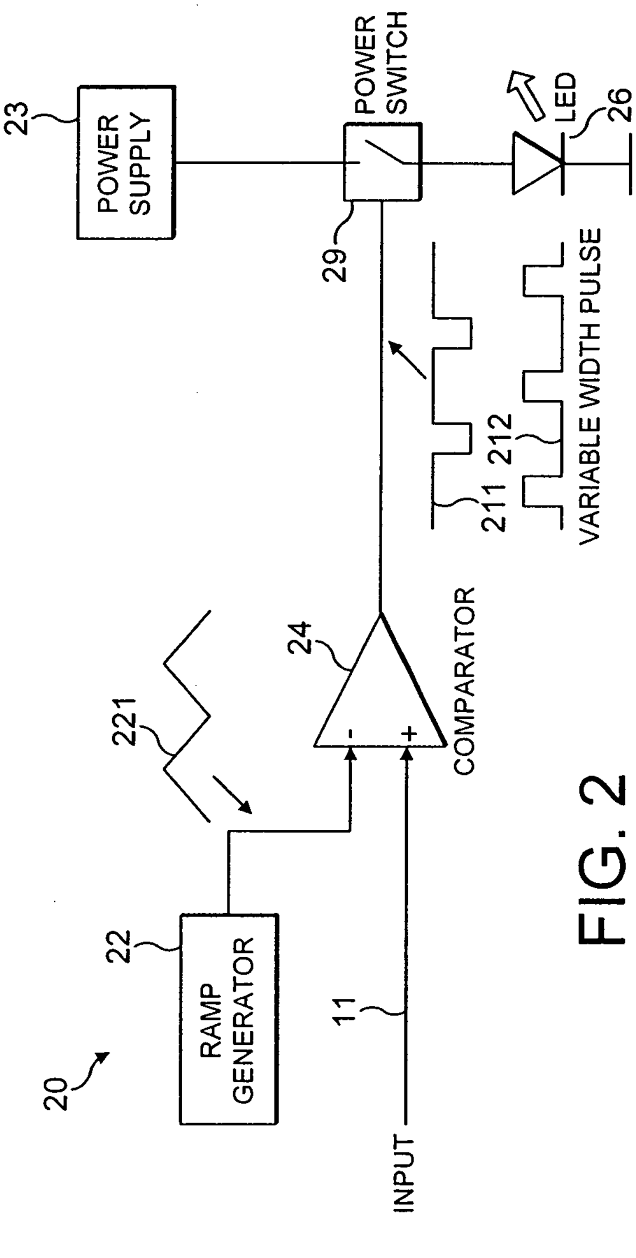
20
RAMP GENERATOR
22
221
INPUT
11
-
+
24
COMPARATOR
211
212
VARIABLE WIDTH PULSE
29
POWER SUPPLY
23
POWER SWITCH
LED
26

FIG. 2

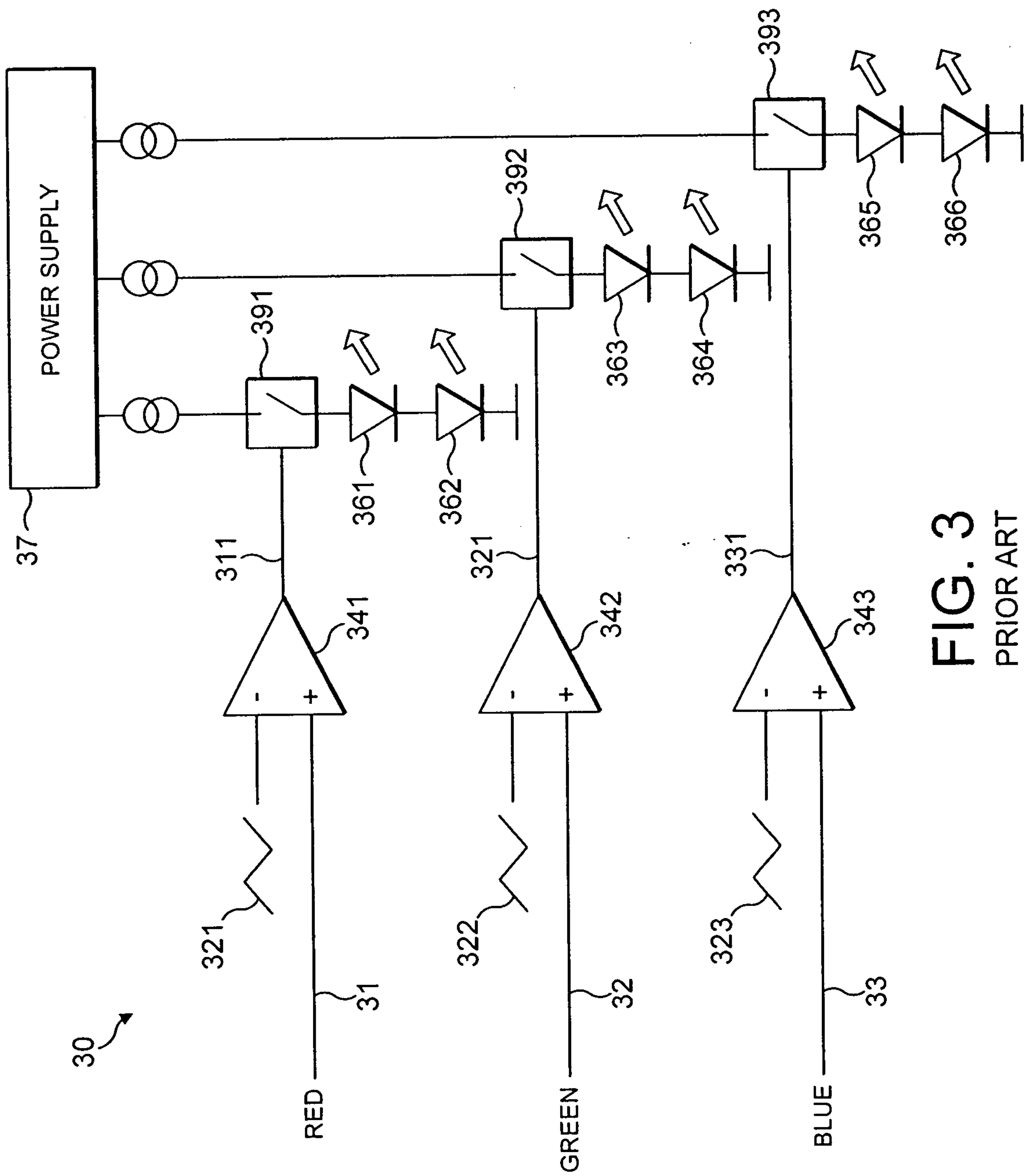

FIG. 3
PRIOR ART

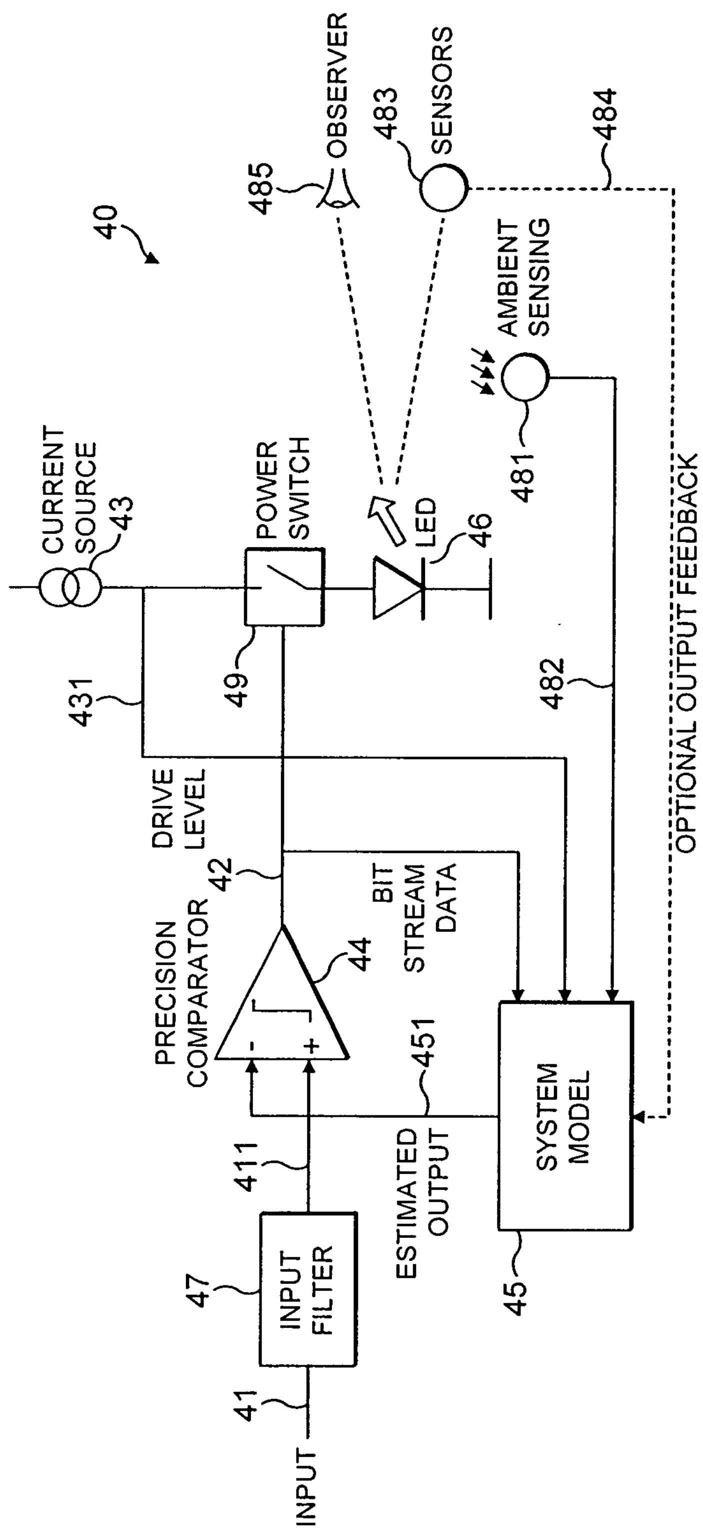
40
CURRENT SOURCE
43
POWER SWITCH
49
LED
46
OBSERVER
485
483
SENSORS
484
AMBIENT SENSING
481
482
431
DRIVE LEVEL
42
BIT STREAM DATA
PRECISION COMPARATOR
44
-
+
451
ESTIMATED OUTPUT
SYSTEM MODEL
45
OPTIONAL OUTPUT FEEDBACK
INPUT
41
INPUT FILTER
47
411

FIG. 4

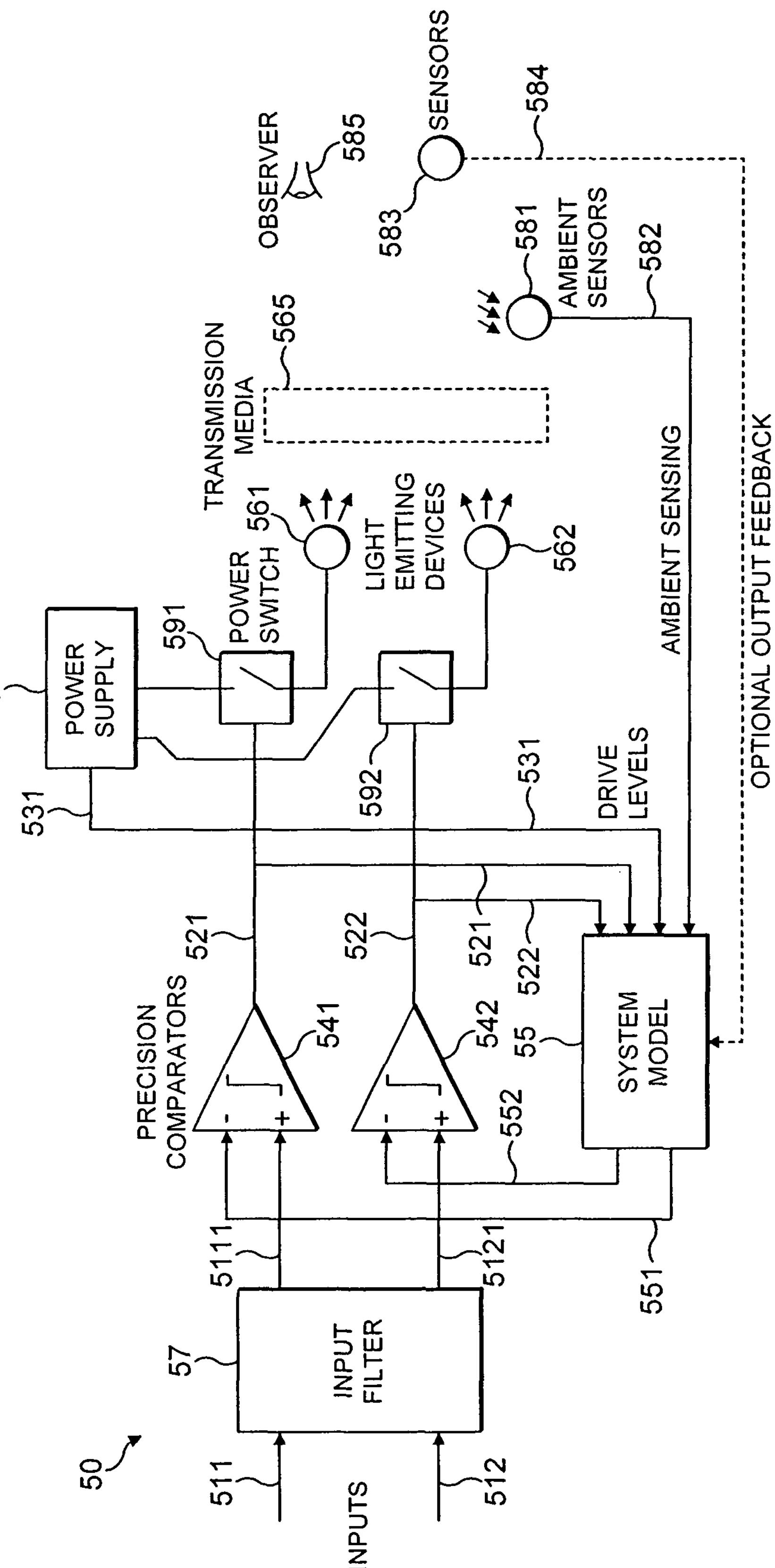
50
INPUTS
511
512
57
INPUT FILTER
5111
5121
551
PRECISION COMPARATORS
541
542
552
521
522
SYSTEM MODEL
55
53
POWER SUPPLY
531
DRIVE LEVELS
591
POWER SWITCH
592
561
LIGHT EMITTING DEVICES
562
TRANSMISSION MEDIA
565
OBSERVER
585
583
SENSORS
584
581
AMBIENT SENSORS
582
AMBIENT SENSING
OPTIONAL OUTPUT FEEDBACK

FIG. 5