The invention provides a system of generation of multi-channel analog output signals, from a single analog input signal, and the controlled activation of peripheral devices responsive to the multi-channel analog output signals. A single-channel to multi-channel analog-to-analog converter is provided to convert the single analog input signal to multiple output channels. Uni-directional coupling is used for coupling and mixing the multi-channel outputs and transferring the mixed outputs to a data buss. Signals on the data buss are used to drive the multiple peripheral devices.
Title: SYSTEM OF MULTI-CHANNEL ANALOG SIGNAL GENERATION AND CONTROLLED ACTIVATION OF MULTIPLE PERIPHERAL DEVICES

Abstract: The invention provides a system of generation of multi-channel analog output signals, from a single analog input signal, and the controlled activation of peripheral devices responsive to the multi-channel analog output signals. A single-channel multi-channel analog-to-analog converter is provided to convert the single analog input signal to multiple output channels. Unidirectional coupling is used for coupling and mixing the multi-channel outputs and transferring the mixed outputs to a data bus. Signals on the data bus are used to drive the multiple peripheral devices.
Published:
— with international search report
— with amended claims and statement
SYSTEM OF MULTI-CHANNEL ANALOG SIGNAL GENERATION AND 
CONTROLLED ACTIVATION OF MULTIPLE PERIPHERAL DEVICES

Field of Invention

[0001] The invention relates generally to the field of controlling multiple devices. In particular, the invention relates to a system of generation of multi-channel analog output signals, from a single analog input signal, and controlled activation of multiple peripheral devices responsive to the multi-channel analog output signals.

Background of Invention

[0002] Currently, digital technologies are widely used in information and communication applications. While digital representation of information may provide improved precision, human sensory functions are believed to be fundamentally analog in nature. Frequently, information, although represented in digital form, is communicated to human users in analog form. For example, it is routine to digitize an image but present the image on a display device, with digitized signal strength converted to brightness of a light emitting element of the display device.

[0003] As is generally known, digitized signals are typically represented in discrete elements, such as bits. The relative range and resolution of a signal that can be represented in digital form are limited by the number of bits used to represent signal strength. Increasing the number of bits increases the range and resolution of the signal that can be represented in digital format. However, demand on data storage, data transmission and data generation also increases as more bits are used. Simply increasing the number of bits therefore may impose an unacceptable burden on energy consumption, data processing capability, and requirements on data transmission bandwidth and data storage.

[0004] It is an object of the present invention to mitigate or obviate at least one of the above mentioned disadvantages.

Summary of Invention

[0005] Briefly, the invention relates to a system that generates multi-channel analog output signals from a single analog input signal, and controlled activation of multiple peripheral devices responsive to the multi-channel analog output signals so generated. The system includes a single-channel to multi-channel analog-to-analog conversion engine, a uni-
directional coupling unit that provides a uni-directional coupling of output signals of the
cconversion engine to a multi-channel data buss but inhibits any feedback of information from
the data buss, and a drive module that interfaces the signals on the data buss to the peripheral
devices to achieve controlled activation of the peripheral devices responsive to signals on the
data buss.

[0006] In a first aspect of the invention, there is provided a system for controlling a group
of peripheral devices responsive to variation of a single analog input signal within a range.
The system includes a single-channel to multi-channel analog-to-analog signal converter for
converting the single-channel analog input signal to a plurality of analog signals, the range
being partitioned into a plurality of sub-ranges, a data buss having a plurality of buss lines,
each of the buss lines being operatively connected to each one peripheral device of the group
of peripheral devices for controlling operation thereof, and a uni-directional coupling unit,
the uni-directional coupling unit operatively transmitting each of the plurality of sub-range
analog signals to at least one of a plurality of buss lines of the data buss and inhibiting any
feedback from the buss being transmitted to the analog-to-analog signal converter. The
analog-to-analog signal converter has a plurality of sub-range signal generators, each of the
plurality of sub-range signal generators being responsive to the analog input signal within a
sub-range of the plurality of sub-ranges to generate a sub-range analog signal.

[0007] In a feature of this aspect of the invention, each sub-range signal generator
comprises a first circuit path and a second circuit path. The first circuit path is responsive to
the analog input signal within the sub-range and becomes gradually fully conducting in
response to increase of the analog input signal in the sub-range. The second circuit path is
responsive to the analog input signal within the sub-range and gradually inhibits the first
circuit path from being conducting in response to increase of the analog input signal in the
sub-range. The first circuit path and the second circuit path cooperate to generate the sub-
range analog signal in the sub-range.

[0008] In another feature, the analog-to-analog signal converter comprises a light source
and a plurality of light detectors. Each of the plurality of light detectors corresponds to one
of the plurality of sub-ranges. Detection of light from the light source by the each light
detector produces the sub-range analog signal. The plurality of light detectors are spaced
from each other, the light source is movable relative to the plurality of light detectors, and the
relative movement is responsive to the analog input signal.
In yet another feature, the analog-to-analog signal converter comprises a first magnetic coupling element and a plurality of secondary magnetic coupling elements, each of the plurality of secondary magnetic coupling elements corresponding to one of the plurality of sub-ranges, the plurality of secondary magnetic coupling elements being spaced from each other and from the first magnetic coupling element, the first magnetic coupling element being movable relative to the plurality of secondary magnetic coupling elements, the relative movement being responsive to the analog input signal, and variation of coupling between the first magnetic coupling element and the each secondary magnetic coupling element producing the sub-range analog signal.

In another feature, the uni-directional coupling unit comprises a plurality of diodes, each of the plurality of diodes coupling an output terminal of the each of the plurality of sub-range signal generators to at least one of the buss lines.

In yet another feature, the uni-directional coupling unit comprises a plurality of photo-electric couplers, each of the plurality of photo-electric couplers coupling an output terminal of the each of the plurality of sub-range signal generators to at least one of the buss lines.

In other aspects the invention provides various combinations and subsets of the aspects described above.

**Brief Description of Drawings**

For the purposes of description, but not of limitation, the foregoing and other aspects of the invention are explained in greater detail with reference to the accompanying drawings, in which:

Figure 1 is a block diagram illustrating components of a system according to an embodiment of the present invention;

Figure 2 illustrates an input analog signal within its range of variation and multiple analog output signals generated from the input analog signal;

Figure 3A, 3B and 3C are schematic diagrams illustrating ways to divide a voltage range into different sub-ranges;

Figures 4A through 4C are schematic diagrams illustrating three different ways of constructing a sub-range signal generator;
[0018] Figure 5A through 5D are schematic diagrams illustrating some possible connections to couple an analog-to-analog signal converter to a data buss;

[0019] Figure 6 illustrates schematically a gate/interface component constructed from transistors for driving three LEDs using signals on three buss lines;

[0020] Figure 7 is a schematic diagram showing a complete system as an alternative embodiment to that shown in Figure 1;

[0021] Figure 8 shows an alternative construction of an analog-to-analog signal converter that can be used in the system described herein, two embodiments of which are illustrated in Figure 1 and Figure 6; and

[0022] Figure 9 shows yet another alternative construction of an analog-to-analog signal converter that can be used in the system described herein, two embodiments of which are illustrated in Figure 1 and Figure 6.

**Detailed Description of Embodiments**

[0023] The description which follows and the embodiments described therein are provided by way of illustration of an example, or examples, of particular embodiments of the principles of the present invention. These examples are provided for the purposes of explanation, and not limitation, of those principles and of the invention. In the description which follows, like parts are marked throughout the specification and the drawings with the same respective reference numerals.

[0024] Figure 1 illustrates schematically components of a system according to an embodiment of the present invention. As shown in Figure 1, the system 100 has an input module 102. The input module receives as input a single-channel analog signal. The single-channel analog signal is then processed by a single-channel to multi-channel analog-to-analog signal converter 104 to convert the single-channel analog signal to multiple analog signals. The analog-to-analog signal converter 104 has multiple output channels. Each of the multiple output channels corresponds to one of the multiple output analog signals. The output analog signals may be electric current, for example. They may also be variations in electric voltage, as an increase or decrease from a neutral value. Or, they may be intensity of light beams. A uni-directional coupling unit 106 between the analog-to-analog signal
converter 104 and an analog data buss 108 transmits the multi-channel analog signals to the analog data buss 108 but inhibits any feedback from the data buss 108 to the analog-to-analog signal converter 104. This provides a one-way coupling between the data buss 108 and the analog-to-analog signal converter 104. Conveniently, the uni-directional coupling unit 106 may also combine the multi-channel analog signals from different channels in different mixing arrangements prior to transmitting the mixed signals to the data buss 108. Operation or activation of the peripheral devices (not shown in Figure 1) is controlled by signals supplied by each buss lines of the data buss 108. An optional gate/interface component 110 may be disposed between data buss 108 and peripheral devices to enable the information, i.e., signals on the data buss 108, to be utilized by a wide range of peripheral devices.

[0025] In one embodiment, the input analog signal is a voltage value of an input source. Conveniently, this input analog signal can be supplied to the system through a power supply wire. An optional DC (direct current) overflow circuit 112 is provided that is coupled to both the analog-to-analog signal converter 104 and the input module 102. The overflow circuit 112 passes power supply voltage to the analog-to-analog signal converter 104 to power its operation. The overflow unit 112 also allows a margin voltage extracted from supply voltage, namely a portion of the supply voltage in excess of the system’s internal regulated voltage, to be used as input, thereby allowing a single wire control and powering of the entire device or system. The internal regulated voltage is lower than the supply voltage and is used as a reference voltage for the overflow unit 112 to extract the margin voltage.

[0026] As described above, the input module 102 accepts as input a single-channel analog signal. Input is generally an analog, continuous signal. The input signal may be continuous voltage or current signal representing (i.e., converted from) a variety of monitored signals, such as temperature, speed, relative position, ambient brightness, or applied force. The input signal also may be stepped composition of signals, represented in a cumulated analog form, such as accumulated unit number from a production line. The input also may be manually adjustable electric voltage or current. The analog signal may take the form of alternating current (AC), direct current (DC), value of variable resistor (VR), or as photoelectric input (PE), just to name a few examples. Conveniently, converters to convert one type of input signal, such as temperature, sound or speed, to another type of signal, such as electric current or voltage, can be provided in the input module 102.
[0027] The single-channel analog signal varies within a range, between a minimum and a maximum value. The range can be partitioned into a number of sub-ranges, the union of all sub-ranges being the range of the analog signal. Each of the sub-ranges overlaps with its neighbors, though it is understood that at either end of the range a sub-range has only one and therefore can only overlap with one neighbor. Figure 2 illustrates a single channel signal $V_{IN}$ varying linearly within a range 200. Range 200 is partitioned into sub-ranges $R_1$ (202), $R_2$ (204), $R_3$ (206), $R_4$ (208),..., $R_N$ (210), $N$ being the total number of sub-ranges, which can be any integer number. Each sub-range can be any value, as required by the application. These sub-ranges each overlap with their respective neighboring sub-ranges. For example, the sub-range $R_2$ overlaps with both its neighbor $R_1$ at its lower end (lower overlap region 212) and $R_3$ at its upper end (upper overlap region 214).

[0028] As $V_{IN}$ varies within the range 200, the system 100 generates, as an intermediate step, a multiplicity of output analog signals, namely $V_1$, $V_2$, $V_3$, $V_4$,..., $V_N$, corresponding to the sub-ranges. In other words, the system 100 maps an analog input ($V_{IN}$) in a single channel to outputs of multiple channels ($V_1$, $V_2$, $V_3$, $V_4$,..., $V_N$). The mapping is typically continuous. Each output analog signal is mapped from the variation of $V_{IN}$ within its corresponding sub-range $R_1$ (202), $R_2$ (204), $R_3$ (206), $R_4$ (208),..., $R_N$ (210), to $V_1$, $V_2$,...,$V_N$, as $V_{IN}$ increases from a lower bound of a sub-range to an upper bound of the sub-range. The variation of $V_i$ in its corresponding sub-range $V_i$ defines a wave form 216. For example, as $V_{IN}$ increases, the output signal 216 corresponding to a sub-range $V_i$ increases gradually from its initial value (for example, zero) in an up-take region 218 until it reaches a peak value. The output signal 216 may remain generally constant in a portion of the sub-range as $V_{IN}$ continues its increase (thereby forming a peak region 220) and then decreases gradually, generally back to (but not necessarily) its initial value (forming a decay region 222). The up-take region 218, peak region 220 and decay region 222 together form a profile of the output signal, or “wave form” of the output signal. The durations of each of up-take region 218, peak region 220 and decay region 222 are adjustable, as will be described later in more detail in examples provided below. For example, up-take region 218 may have a duration longer than the decay region, or vice versa. The increase in the up-take region 218 and the decrease in the decay region do not need to be linear, and can take any shape, or even with reflection points, as long as the general trend remains generally increasing or decreasing.
Similarly, the peak region 220 may have any duration and may be absent (zero duration) and is not necessarily flat.

[0029] One example of output analog signals is illustrated in Figure 2. Output signals illustrated in Figure 2 all have an approximate trapezoidal wave form 216. As the input sweeps through its own range 200, each of the output channels in its corresponding sub-range Vₐ also generates a corresponding output analog signal. As illustrated in Figure 2, the up-take region 218 of one wave in one channel overlaps with the decay region 222 of the wave of the previous channel. The overlap of the up-take and decay regions of neighboring sub-ranges (or neighboring channels) leads to a smooth transition of signals from one channel to the next in a transition region. A transition region is the portion of neighboring sub-ranges where they overlap. In addition to partial overlap, there also can be complete overlap, i.e., simultaneous turning on of multiple channels. Similarly, as Vₐ increases from its lower bound to its upper bound, an output channel may be responsive to Vₐ in more than one sub-ranges and generate more than one wave form 216. Figure 2 shows two such simultaneous “ON” signals, 216’, 216”, in channels V₂ and V₃, with two wave forms in each channel.

[0030] The output analog signals are generated by the analog-to-analog signal converter 104. Conveniently, the analog-to-analog signal converter (or the input module itself) partitions the input range 200 into multiple sub-ranges. Figures 3A, 3B and 3C provide three examples of partitioning a voltage range. As will be appreciated, there are numerous methods to partition (or, where there is no overlapping, to divide) a voltage range or current range into a selected number of sub-ranges. Figure 3A illustrates schematically a method of dividing a voltage range into multiple sub-ranges using a series of diodes Dₐ, Dₐ, Dₐ, Dₐ, Dₐ etc. with voltage outputs at nodes Vₐ, Vₐ, Vₐ, Vₐ, Vₐ etc. Figure 3B provides another example, in which sub-ranges determined by diodes Dₐ and Dₐ are further divided using voltage dividers consisting of two resistors each, thus providing narrower sub-ranges with voltage outputs at nodes Vₐ, V’ₐ, Vₐ, V’ₐ, Vₐ, Vₐ etc. It should be noted that while two resistors are shown, a voltage divider consisting of resistors may use any number of resistors. Figure 3C illustrates another example of voltage dividers consisting of two rails of diodes, each rail being connected in series. Voltage output at V₁ and voltage output at V₃ are adjustable by varying values of resistors connecting the respective voltage outputs to different diode rails, thereby providing even more refined voltage differences between voltage outputs V₁ and V₃.
Conveniently, the analog-to-analog signal converter 104 provides a sub-range signal generator 400 for each sub-range. The waveform within each sub-range is determined by the construction of the corresponding sub-range signal generator 400. The width and position of a sub-range can be further fine tuned by adjusting component properties of circuit components employed in the corresponding sub-range signal generator 400.

Referring to Figure 4A, there is illustrated schematically a sub-range signal generator 400 constructed from bipolar junction transistors and resistors. The sub-range signal generator 400 shown in Figure 4A consists of two NPN bipolar junction transistors T1 and T2. The base of each bipolar junction transistors is connected through a current limiting transistor R1, R2 to the output of voltage divider, such as VA or VB. If the sub-range signal generator 400 is connected to VA and VB of a sub-range divider shown in Figure 3A, the voltage difference between the connectors VA and VB of sub-range signal generator 400 is approximately the voltage drop across diode DA, or approximately 0.6V. If the sub-range signal generator 400 is connected to VA and V'A of a sub-range divider shown in Figure 3B, the voltage difference between the connectors VA and VB of sub-range signal generator 400 is a fraction of the voltage drop across diode DA, i.e., less than 0.6V. For the purpose of illustrating the operation of the sub-range signal generator 400, the following description assumes that they are connected to a sub-range divider as shown in Figure 3A.

Each of the transistors T1, T2 is part of a circuit path in the sub-range signal generator 400. The first circuit path 402 consists of transistor T1 and its base current limiting resistor R1. The base current limiting resistor R1 is connected to sub-range output VA, i.e., directly to the input voltage, VIN. The second circuit path 404 consists of transistor T2 and its base current limiting resistor R2. The base current limiting resistor R2 is connected to sub-range output VB, i.e., at a level approximately 0.6V lower than VA. The first circuit path 402 drives the load resistor RL, supplying the current source for the signal at the resistor RL. The second circuit path 404 is a shunting path to switch off the first circuit path 402 and therefore may also be regarded as a self-shunting circuit path.

Referring to Figure 4A and Figure 3A, the operation of sub-range signal generator 400 is now described in further detail. As the input voltage, VIN, increases from 0, transistor T1 becomes forward biased. This provides a biasing current to enable T1 to first operate in its linear amplification region. This allows a collector current of transistor T1 to flow through load resistor RL and produces an output voltage signal VOUT proportional to the biasing
current. This current flowing through \( R_L \) and \( T_1 \) increases monotonically in the linear amplification region of \( T_1 \) until \( T_1 \) is saturated, i.e., the circuit path is in the pulled on state, at which point the current flowing through \( T_1 \) reaches a plateau. This forms the up-take region of the waveform 216.

[0035] The bipolar junction transistor \( T_1 \) may remain in the saturated state for some value of the input, thereby forming the peak region 220. Meanwhile, as input voltage continues its increase, \( V_B \) will start to increase and will eventually overcome the voltage drop across diode \( D_A \) and provide a forward biasing for the second transistor \( T_2 \). This represents the on-set of switching off of the first circuit path 402. As the input continues its increase, the collector current of \( T_2 \) will increase. However, any current flowing through the collector of \( T_2 \) shunts the current flowing into the base of transistor \( T_1 \), thus gradually returning \( T_1 \) from its saturated, switched-on state to its linear region, until \( T_2 \) is saturated, i.e., completely switched on, to switch off \( T_1 \), i.e, effectively inhibit \( T_1 \) from conducting. This forms the decay region of the waveform 216 and completes the output wave form shown in Figure 2.

[0036] In other words, while transistor \( T_1 \) in the first circuit path 402 provides pull-on of signal, i.e., current in \( R_L \), transistor \( T_2 \) in the second circuit path 404 provides a self-shunt, pull off of the first circuit path 402. The on-set of pull-on determines the lower bound of the sub-range. The complete pull off effected by the switching on of the second circuit path 404, determines the upper bound of the sub-range. The delayed switching on of the second circuit path 404 cooperates with the pull on of the first circuit path 402 to produce a desired profile of the output wave form. Both the width and the position of the sub-range are affected by the sub-range voltage outputs at, for example, \( V_A, V_B \), and by values of the base resistors, \( R_1 \) and \( R_2 \), and therefore can be adjusted by adjusting characteristic values of these circuit elements. For further adjustment, emitter resistors may also be added to each transistors to fine tune the range and overlap. It will be appreciated that adjusting the profile in one sub-range also changes the overlap with profiles of neighboring sub-ranges when the profiles of the neighboring sub-ranges remain the same.

[0037] As described above, each sub-range has a corresponding sub-range signal generator 400. Referring to Figure 3A, the difference between voltage outputs \( V_B \) and \( V_C \), namely, a voltage drop across diode \( D_B \), corresponds to another sub-range. Another sub-range signal generator 400' (not shown in Figure 1; but see Figure 7) is connected to voltage outputs \( V_B \) and \( V_C \). As bipolar junction transistor \( T_2 \) in the sub-range signal generator 400,
connected between $V_A$ and $V_B$, starts to shunt current, signal in the next sub-range, a sub-range defined by $V_B$ and $V_C$, is activated in that transistor $T_1'$ of converter $400'$ starts to allow current to flow, following the profile of an up-take region $218$ of output wave form, until it reaches its peak. As input voltage continues to increase, $T_1'$ will be switched off by its corresponding second circuit path in the converter $400'$ in a decay region $222$. Meanwhile, the output signal of the next sub-range will start its up-take growth. This process will repeat for each sub-range as the input value continues, as illustrated in Figure 2 and described earlier.

[0038] The combination of the voltage divider portion and the series of sub-range signal generators $400$ forms an analog, self-shunting DC voltage/current ladder. The ladder can be of any length. In other words, range $200$ of input signal can be of any value and can be partitioned into any number of sub-ranges. As the input varies from its minimum to its maximum, a wave having the wave form $216$ transitions from the lowest step, namely the lowest sub-range, progressively, to the top of the ladder, namely the highest sub-range.

[0039] As will be appreciated, voltage dividers may be conveniently formed using resistors, or any other suitable means, not necessarily diodes. For example, a voltage divider consisting of only resistors can be used to replace the string of diodes in Figure 3A. Any number of resistors can be used in such a resistor divider ladder. Such a resistor ladder can provide finer voltage drops at each step of the ladder. Similarly, although a sub-range generator $400$ shown in Figure 4A provides a circuit example using discrete transistors, other devices, such as linear gates, logic diode gates, comparators, among others, may replace the transistors circuitry for constructing the single-channel to multi-channel analog-to-analog converter. Figure 4B shows an example, in which the voltage divider $410$ is formed from resistors connected in series and the conversion of input analog signal in each sub-range is provided by two op-amps $1A$, $1B$ connected in cascade. In this example, the first op-amp $1A$ and in second op-amp $1B$ cooperate to provide switch-on and the second op-amp $1B$ and an op-amp $2A$ of the next sub-range provide switch-off. Initially, $V_{IN}$ is at zero, which sets the negative terminal $414$ of the first op-amp $1A$ at level “L”. The resistor ladder is configured to set each sub-range at 0.1V, though it will be understood that each sub-range (or sub-range generator) can be configured to have any value (for example, several volts or more if necessary or a few millivolts or less if required). The positive terminal $412$ of the first op-amp $1A$ is at 0.1V, a voltage supplied by the voltage divider $410$. Consequently, the output terminal $416$ of the first op-amp $1A$ is at level “H”, so is the positive terminal $418$ of the
second op-amp 1B, which is electrically connected to and at the same level as the output terminal 416 of the first op-amp 1A. The negative terminal 420 of the first op-amp 1B is also electrically coupled to and at the same level as the output terminal of the second op-Amp 2A, which is also at “H”. Consequently, the output terminal 422 of the second op-Amp is initially at “H”. As $V_\text{IN}$ increases and exceeds 0.1V, the first output terminal 416 is first set to “L” which subsequently toggles the output level of second op-Amp 1B and sets the second output terminal 422 to “L”. As $V_\text{IN}$ continues to increase, but still remains smaller than the 0.2V, the second op-Amp 2A the level at the second output terminal 422 remains at “L”. When $V_\text{IN}$ exceeds 0.2V, the second op-Amp 2A is switched to “L”, which causes the second op-Amp 1B to switch off the first channel and returns the output at the second output terminal 422 to “H”. The resistors $R_1A$ and $R_1B$ connected between the output and negative terminals of the op-Amps 1A, 1B, respectively are to configure the op-Amps 1A and 1B to operate also in the linear region, in addition to being able to switch between “H” and “L” levels. In another embodiment, a sub-range signal generator 400 is constructed from logic gates. Figure 4C provides such an example. The operation of the signal generator constructed from logic gates is similar to that shown in Figure 4B, described above.

[0040] The output signals of all sub-range signal generators 400 form the outputs of the analog-to-analog signal converter 104, each sub-range corresponding to a unique channel. Referring to Figure 1, the multi-channel outputs of the analog-to-analog signal converter 104 are transmitted to data buss 108 through a uni-directional coupling unit 106. The uni-directional coupling unit 106 allows signals (i.e., information) from the analog-to-analog signal converter 104 to be coupled to the data buss 108 but does not permit electric signals on data buss 108 communicated back to the analog-to-analog signal converter 104. In one embodiment, the uni-directional coupling unit 106 consists of a diode array 500. Information at output of the analog-to-analog signal converter is communicated to data buss via the diode array 500. Because of uni-directional characteristics of diodes, no information from data buss 108 is allowed to be transmitted back to the analog-to-analog signal converter 104.

[0041] Figure 5A illustrates one arrangement, where output from each channel is coupled to a single buss line, i.e., one of buss lines $L_1$, $L_2$ and $L_3$ of the data buss 108. Similarly, information from a single output channel can be coupled to multiple buss lines of the data buss 108, thus for driving multiple peripheral devices each connected to a buss line. When signal from each buss line drives a color LED, sending signal from one output channel to
multiple buss lines provides color mixing. Figure 5B illustrates an arrangement, in which output of \( V_M \) is coupled to more than one buss line, thereby driving more than one device, which can be used for color light mixing. The example in Figure 5B shows a coupling to two buss lines \( L_1 \) and \( L_2 \). Figure 5C illustrates an arrangement, in which output of \( V_N \) is coupled to three buss lines \( L_1, L_2 \) and \( L_4 \). On the other hand, signals from different output channels can be combined and transmitted to a single buss line, so that the peripheral devices connected to that buss line is driven by a composite signal mixed from more than one output channel. For example, in the example shown in Figure 5B, output of \( V_M \) is combined with signal from output \( V_1 \) at buss line \( L_1 \), and signal from output \( V_2 \) at buss line \( L_2 \).

Figure 5D provides another example. The embodiment illustrated in Figure 5D has more output channels than buss lines, or more output channels than peripheral devices. As shown in Figure 5D, there are three buss lines, each for connecting to a light emitting diode (LED) of a distinct color. These buss lines are labeled R for red color, G for green color and B for blue color. Signals \( V_{out1}, V_{out2} \) and \( V_{out3} \) are each connected, through diodes \( D_1, D_2 \) and \( D_3 \), to one of R, G, B buss lines, respectively. Signal \( V_{out4} \) is transmitted to both R and G buss lines, through diodes \( D_4 \) and \( D_4' \), respectively, thereby providing a mixing of \( V_{out4} \) with signal \( V_{out1} \) at R buss line and a mixing of \( V_{out4} \) with signal \( V_{out2} \) at G buss line. Similarly, signal \( V_{out5} \) is transmitted to all three R, G and B buss lines, through diodes \( D_5, D_5' \) and \( D_5'' \), respectively, thereby providing a mixing of \( V_{out5} \) with signal \( V_{out1} \) at R buss line, a mixing of \( V_{out5} \) with signal \( V_{out2} \) at G buss line, and a mixing of \( V_{out5} \) with \( V_{out3} \) at B buss line. Similar or other manners of connecting to the data buss 108, namely to its buss lines R, G or B or any combinations of the buss lines, may be made for other output signals from other output channels.

The selection of diodes and connection to different buss lines depend on the designation of each individual output channel. For example, in the example illustrated in Figure 5D, \( V_{out4} \) is designated as R/B mixing, i.e., mixing of R and B signals. Two diodes are provided, each connecting the R/B channel to one of R and B data lines, respectively. Similarly, \( V_{out5} \) is designated as R/G/B mixing. Three diodes are provided, to connect output of the R/G/B channel to each one of R, G and B buss lines, respectively. Resistors may be used, for example, connected in series with the diodes, to control mixing ratios. It will be understood that in other applications, an output channel may represent a mixing of more than three signals in these situations. More than three diodes therefore may be necessary in these
saturations to connect an output channel to the data buss, each diodes for coupling the output channel to one of these buss lines.

[0044] Figure 5D also shows an additional output channel, \( V_{out6} \), that is coupled to the R buss line only. This provides a return to the initial color as input signal varies from its minimum to its maximum. As signal on each buss lines varies from a minimum (typically zero) to a peak and then back to the minimum, brightness of R, G, B lights, such as LEDs, packaged in a lighting unit housing, also varies accordingly. As the input value varies from the minimum to the maximum, the color of light emitted from the lighting unit changes continuously from, for example, red to green and then to blue, covering all colors in the spectrum from the red light when the input value is the smallest, to the blue color when the input value is the largest. The connection of the final output channel to the R buss line allows the LEDs, starting from red, transitioning to other colors as the input analog signals varying from its minimum to maximum, to return to red, the initial color.

[0045] As another example, a further “white” data buss line \( L_W \) may be provided, for coupling to signal \( V_w \) that is generated when the input has a value between that to generate \( V_{OUT5} \) and \( V_{OUT6} \). Signal on the buss line \( L_W \) controls on/off of a white color LED. Thus, when \( V_{IN} \) increases within its range, the color of light varies from red to green, from green to blue, from blue to white and then back to red. Other methods of providing white light also may be used to generate this color sequence. For example, “white” color may be generated by mixing suitable amount of red, green and blue colors. Empirically, it is found that a R:G:B ratio of 30:59:11 produces an acceptable “white” color as perceived by human eyes (“perceived white”).

[0046] These diodes, \( D_1, D_2, D_3, D_4, D_4', D_5, D_5', D_5'' \), \( D_6 \) etc. form a diode array 500. This diode array 500 provides a one-way isolation between output channels of the analog-to-analog signal converter 104 and the data buss 108. The uni-directionality here is provided by diodes in the diode array. The uni-directionality allows DC information to pass through and to be transmitted to the data buss 108 but does not allow any feedback from the data buss 108 to be transmitted back to the analog-to-analog signal converter 104. As will be appreciated, coupling elements other than diodes can be used for providing the required one-way coupling. Examples will be provided later of uni-directional coupling units that use other coupling elements possessing uni-directionality.
[0047] The provision of the data buss 108 helps streamlining the passing of information from the analog-to-analog signal converter 104 to data buss 108 and the driving of the peripheral devices, namely, the control of operation of the peripheral devices. In the embodiment shown in Figure 5D, there are only three peripheral devices, i.e., red, blue and green colored LEDs. Each color has its own corresponding buss line, namely one of R, G, and B buss lines. Both splitting of signals from channels representing mixed colors and mixing of outputs from different channels are facilitated by the data buss 108. Signals on each buss lines are passed directly to these color LEDs. As will be described below, data buss 108 may also be operatively connected to these peripheral devices through a gate/interface module, which enables the system to drive an increased range of peripheral devices.

[0048] Although LED arrays are used in these examples to illustrate the output characteristics, the signals on these buss lines can be used to drive other peripheral devices, not necessarily an LED array. For example, the LED examples provided herein illustrate the lighting of LEDs driven by the resulting drive currents. These same currents may also be used to drive a multitude of motors, provided the driver circuitry supplies sufficient current. The motors may be used to manipulate (or control) motion of a robot, for example. These currents also can be used to control operation of peripheral devices requiring input of more than one phase, such as multi-phased currents or voltages. For example, the multi-channel output signals may be conveniently used as the output of a single phase to multi-phase converter for driving a multi-phase motor, using a single phase alternating current input. Alternatively, each output channel may also drive an analog/digital converter thereby interfacing the system with a digitally driven device, or devices. In general, a driver circuitry is used to convert the signal on data buss to drive current or voltage loads.

[0049] Optionally, a gate/interface component 110 is provided between data buss 108 and peripheral devices as the driver circuitry, to enable the information, i.e., signals on the data buss 108, to be utilized by a wide range of peripheral devices. In one embodiment shown in Figure 6, the gate/interface component 110 has individual bipolar junction transistors TR1, TR2, TG1, TG2, TB1, TB2, for driving each one of the output phases, namely, each one of the R, G and B LEDs. The gate/interface component 110 also includes a bipolar junction transistor that is used to gate the entire drive circuitry. The example in Figure 6 shows two groups of bipolar junction transistors, with opposite output polarities. The first group consist of three
transistors $T_{R1}$, $T_{G1}$, and $T_{B1}$, and the second group consists of transistors $T_{R2}$, $T_{G2}$, $T_{B2}$. The on/off of the entire drive circuitry is controlled by a “high” gate transistor $T_{H1}$ for gating the first group of transistors, and a “low” gate transistor $T_{L}$ for gating the second group of transistors, each of the gate transistors being controlled by the signal on a control bus line C.

[0050] Conveniently, for certain applications, it is desirable to use a single wire to supply voltage to the system as the power source and to the input module as input signal. This may be, for example, an application where three colored LEDs are used to indicate the voltage of a power supply by changing emitted colors. A DC overflow circuit 112 extracts any excess voltage above a nominal (i.e., internal regulation) voltage of the system and provides this “overflow” to the input module 102 as an input signal. This is illustrated in Figure 7. The overflow circuit 112 includes diodes $D_{X}$, $D_{Y}$, $D_{Z}$ connected in series to provide a voltage drop to bring the supply voltage $V_{S}$ down to the expected range of input voltage $V_{IN}$. A protective diode $D$ couples the supply voltage $V_{S}$ to the circuitry of the system 100', to supply power at $V_{+}$. An internal voltage regulator (not shown) stabilizes the voltage powering the system 100' at $V_{+}$.

[0051] Referring to Figure 7, a complete system 100' according to an embodiment of the invention is illustrated with representative circuits shown for each of the components. This is an application for driving brightness of three individual lights, though it will be understood that more lights can be added easily or the circuit arrangement can be easily modified to drive other types of output devices. One common arrangement is to drive Red (R), Green (G) and Blue (B) LEDs, packaged in a single lighting unit 702. Alternatively, the same circuit arrangement can be used to drive grayscale lamps and UV or I/R lamps. Grayscale lamps may be “cold white” (i.e., with a relatively stronger contribution from higher spectrum end, or with less red component than a typical “perceived white”), “perceived white”, or “warm white”, respectively. The input to the system 100' can be taken either from a variable resistor connected between $V_{+}$ and the ground, or driven by the power supply voltage through a voltage overflow circuit 112, as described above. As the input value varies from the minimum to the maximum, the color of light emitted from the lighting unit 702 changes continuously from, for example, blue to green and then to red, covering all colors in the spectrum from a blue light when the input value is the smallest, to a red color when the input value is the largest.
In Figure 7, only two sub-range signal generators 400 are shown in detail. In combination, a series of diodes and the corresponding analog-to-analog converters form a static, analog, self-shunting DC voltage/current ladder 704. As described before, a number of diodes, connected in series, partition the entire input range into a plurality of sub-ranges, each about 0.6V. The width and end points of each sub-range can be further fine tuned by, for example, values of resistors employed in the analog-to-analog converter 104. Each level of the ladder 704 corresponds to an output channel. Each channel generates an output signal that generally has a single peak, as that shown in Figure 2. The up-take region 218 of a channel, i.e., a sub-range, overlaps with the decay region 222 of its previous channel, so that as the input signal increases gradually, the overlap provides a smooth transition from the previous channel to the now activated channel. Similarly, the decay region 222 overlaps with the up-take region 218 of the next channel. As the present channel fades out, the overlap between the up-take region of the present channel and the up-take region of the next channel provides a smooth transition to the next channel. Preferably, the combined output signal strength from neighboring channels adds up to 100% so that when the lighting unit transitions from one color to the other, there is no perceivable change in light intensity.

Output of each channel is coupled to a buss line through a diode in the uni-directional coupling unit 106. The diodes for coupling each output channel to the data buss form a diode array 500. As describe earlier, the diode array 500 provides a uni-directional coupling of output signals from sub-range signal generators 400 to the data buss 108 and isolation of any feedback from the data buss 108. In addition, as described earlier, the diode array 500, with its connections to the data buss 108, also provides mixing of signals from different output channels, for example, a mixing of signals from R/B channel and R channel at the R buss line and a mixing of signals from R/B channel and B channel at the B buss line. Also provided by the diode array 500, with its connections to the data buss 108, is the splitting of signals from a selected output channel for coupling to different buss lines.

Each output phase, i.e., signal from each buss line, has its own drive circuit to drive a peripheral device, in this case, a colored LED. The LED array 706, consisting of LED diodes D_B, D_G and D_R, is the peripheral devices in this example. Each drive circuit works in its linear, amplification portion. For example, the output of the blue channel, or signal on the blue buss line, is coupled to the base of the bipolar junction transistor T_B, which in turn amplifies the signal and drives a blue color LED LED_B. The intensity of drive current
corresponds to the strength, or value of the output received from the conversion engine. As
the signal on the blue buss line reaches its peak, the drive current also reaches its peak,
thereby driving the intensity of blue LED to its brightest level. Similarly, LEDs of other
colors, namely a green LED LED_\text{G} and a red LED LED_\text{R}, are driven by their respective drive
circuits comprising bipolar junction transistors T_\text{G} and T_\text{R}.

[0055] To provide further control, a gate circuit comprising a first gating bipolar junction
transistor T_{G_1} controls all drive circuits for all channels in the gate/interface component 110.
Thus, the transistor T_{G_1}, controlled by the control signal, can selectively decouple all
peripheral devices from signals on the data buss. The control signal may be supplied through
a control buss line (not shown) or any other suitable means. Controlling the on and off of the
entire LED array enable the system 100' to produce many visual effects, such as strobe
lighting effects. Although only one LED is shown for each phase in this example, it will be
appreciated that several LEDs can be connected in parallel, if low voltage V+ is used, or in
series if high voltage is used, or in any suitable combination of serial and parallel connections,
depending on the voltage and current requirement.

[0056] Similarly, a gating bipolar junction transistor T_{G_2} is provided to control the entire
ladder 704. This allows selective enabling of analog-to-analog converters connected to the
uni-directional coupling unit 106. For example, an alternative analog-to-analog converter
(not shown) can be connected to the uni-directional coupling unit 106, operation of which
enabled through another gating transistor (not shown). Which analog-to-analog converter is
enabled therefore depends on which gating transistor is switched on. The gating transistor
T_{G_2} therefore provides a selection function, allowing selection of one of analog-to-analog
converters to transmit multi-channel output signals to the data buss.

[0057] Figure 8 illustrates the use of an alternative analog-to-analog converter. This is a
photoelectric analog-to-analog converter 800. In this example, a light source 802 is provided,
movable along a path, such as an arc 804. A plurality of light detectors 806 are arranged on a
base 808, the light detectors being spaced from each other. The base 808 is spaced from the
path 804 of the light source 802. Each detector 806 is assigned to a different channel, the
output of the detector being the output value of the assigned channel. The light source 802
has a light beam 810 of a limited, yet adjustable, width. The width of light beam 810 is
selected such that it does not illuminate all light detectors 806 simultaneously, though it
illuminates at least two light detectors 806 simultaneously. Preferably, the width of light
beam 810 and the spacing between light detectors 806 are such that the light source 802 can at most illuminate two detectors at the same time. As the light source 802 moves from one end of the arc 804 to the other end, each of the light detectors 806 is first partially illuminated, fully illuminated, partially illuminated, and then not illuminated. A light detector 806 is generally illuminated simultaneously with its closest neighbor during at least a part of the partial illumination period. The output values of the channel corresponding to the light detector 806 then follow the profiles like that shown in Figure 2. Adjusting positioning of light detections 806 relative to each other, relative to light source 802 and relative to the width of light beam 810 allows one to adjust the profiles of signals of each sub-range and overlapping of these profiles. Alternatively, width of light beam 810 can be adjusted for this purpose. In addition, while electrical signal at detector 806 may be forwarded to multiple buss lines of data buss 108, multiple light detectors 108 may also be arranged at the same location, each detector being coupled to a single buss line. When these light detectors at the same location are illuminated, signals can be passed to all data buss lines connected to these detectors at the same location, which provides an alternative method of activating multi-phased arrangements simultaneously.

[0058] The output values from this conversion engine can be delivered to the analog data buss 108 and to drive the multi-channel drive module, namely a gate/interface component 110, in the same manner as described above. In this example, the input is relative position of the light source 802 in reference to each of the light detectors arranged on the base 808. As will be appreciated, any relative motion between the light source and the base can be used to vary the input signal and therefore generate the multi-channel output signals. The relative position can be varied manually, using a dial, or driven by the variation of another input signal, such as temperature or voltage of a power supply. The variation of relative position also can be achieved by moving the base 808 relative to a fixed light source 802. Light detectors 806 also may be arranged on a wheel and the rotation of the wheel relative to the fixed light source may be utilized for converting an analog signal to a multi-channel analog output signals. An input signal can be utilized to drive a step motor (not shown) to rotate the wheel, thereby driving the generation of multi-channel analog output signals.

[0059] It will be appreciated that conversion from a single-channel analog signal can be achieved in many different ways, not restricted to examples provided herein. Some further examples are provided below, for illustration. For example, magnetic coupling based on
magnetic induction may be utilized. A magnet may be used as a primary coupling element and a number of coils may be used as secondary coupling elements. In response to motion of the magnet in the vicinity of the coils, current may be generated in these coils as output signals. Similarly, a primary coil can be used as a primary coupling element. A plurality of secondary coils can be arranged in a manner similar to that of light detectors illustrated in Figure 8. As the primary coil with electric current flowing therein is moved relative to the plurality of secondary coils, induced currents in the secondary coils form the multi-channel outputs.

[0060] As also will be appreciated, the uni-directional coupling unit is not required to use diodes. Other uni-directional couplers can be used. For example, in one alternative embodiment, photo-electric coupling is used. This is illustrated in Figure 9. As shown in Figure 9, a photoelectric coupler 900 comprising a light detector in the nature of a photosensitive transistor 904 and a light emitting element 902, such as a white or infrared LED, replaces a diode in diode array 500. The light emitting element 902 is driven by the output signal from the analog-to-analog converter 104. Each photosensitive transistor 904 is connected to data base 808. While light emitted from the lights emitting element 902 transmits the output signal from analog-to-analog converter 104 to the light detector, no signal from data buss 108 can be transmitted back to the light emitting element 902 by the photosensitive transistor 904.

[0061] Various embodiments of the invention have now been described in detail. Those skilled in the art will appreciate that numerous modifications, adaptations and variations may be made to the embodiments without departing from the scope of the invention. Since changes in and or additions to the above-described best mode may be made without departing from the nature, spirit or scope of the invention, the invention is not to be limited to those details but only by the appended claims.
WHAT IS CLAIMED IS:

1. A system for controlling a group of peripheral devices responsive to variation of a single-channel analog input signal within a range, said system comprising:
   a single-channel to multi-channel analog-to-analog signal converter for converting said single-channel analog input signal to a plurality of analog signals, said range being partitioned into a plurality of sub-ranges, said analog-to-analog signal converter comprising:
   a plurality of sub-range signal generators, each of said plurality of sub-range signal generators being responsive to said analog input signal within a sub-range of the plurality of sub-ranges to generate a sub-range analog signal, a data bus having a plurality of bus lines, each of the bus lines being operatively connected to each one peripheral device of the group of peripheral devices for controlling operation thereof; and
   a uni-directional coupling unit, said uni-directional coupling unit operatively transmitting each of said plurality of sub-range analog signals to at least one of a plurality of bus lines of the data bus and inhibiting any feedback from said bus being transmitted to said analog-to-analog signal converter.

2. The system of claim 1, wherein said each sub-range signal generator comprises a first circuit path and a second circuit path, said first circuit path being responsive to said analog input signal within the sub-range and becoming gradually fully conducting in response to increase of said analog input signal in the sub-range, the second circuit path being responsive to said analog input signal within the sub-range and gradually inhibiting the first circuit path from being conducting in response to increase of said analog input signal in the sub-range, said first circuit path and said second circuit path cooperating to generate said sub-range analog signal in said sub-range.

3. The system of claim 2, wherein said first circuit path comprises a first bipolar junction transistor circuit configured to operate in linear and switching modes and said second circuit path comprises a second bipolar junction transistor circuit
configured to operate in linear and switching modes, said second bipolar junction transistor circuit providing a shunting path of forward biasing current of said first bipolar junction transistor circuit for turning off said first bipolar junction transistor circuit when said second bipolar junction transistor circuit becomes conducting.

4. The system of claim 3, wherein said first and second bipolar junction transistor circuits further comprise circuit elements for adjusting a first profile of said subrange analog signal and overlap of said first profile with a second profile of a neighboring sub-range.

5. The system of claim 4, wherein said circuit elements include resistors and diodes.

6. The system of claim 2, wherein said first circuit path comprises a first op-amp circuit configured to operate in linear and switching modes and a second op-amp circuit configured to operate in linear and switching modes, said second op-amp circuit being electrically coupled to the second circuit path to control state of said second op-amp.

7. The system of claim 2, wherein said first circuit path comprises a first logic gate and a second logic gate coupled to said first logic gate, said second logic gate being electrically coupled to the second circuit path to control state of said second logic gate.

8. The system of claim 1, wherein said analog-to-analog signal converter comprises a light source and a plurality of light detectors, each of said plurality of light detectors corresponding to one of said plurality of sub-ranges, detection of light from said light source by said each light detector producing said sub-range analog signal, said plurality of light detectors being spaced from each other, said light source being movable relative to said plurality of light detectors, and said relative movement being responsive to said analog input signal.
9. The system of claim 1, wherein said analog-to-analog signal converter comprises a first magnetic coupling element and a plurality of secondary magnetic coupling elements, each of said plurality of secondary magnetic coupling elements corresponding to one of said plurality of sub-ranges, said plurality of secondary magnetic coupling elements being spaced from each other and from said first magnetic coupling element, said first magnetic coupling element being movable relative to said plurality of secondary magnetic coupling elements, said relative movement being responsive to said analog input signal, and variation of coupling between said first magnetic coupling element and said each secondary magnetic coupling element producing said sub-range analog signal.

10. The system of claim 1, wherein said uni-directional coupling unit comprises a plurality of diodes, each of said plurality of diodes coupling an output terminal of said each of said plurality of sub-range signal generators to at least one of said bus lines.

11. The system of claim 10, wherein an output terminal of at least one of said plurality of sub-range signal generators is connected to at least two of said plurality of diodes, each of said least two diodes being connected to one of said bus lines.

12. The system of claim 1, wherein said uni-directional coupling unit comprises a plurality of photo-electric couplers, each of said plurality of photo-electric couplers coupling an output terminal of said each of said plurality of sub-range signal generators to at least one of said bus lines.

13. The system of claim 12, wherein an output terminal of at least one of said plurality of sub-range signal generators is connected to at least two of said plurality of photo-electric couplers, each of said least two photo-electric couplers being connected to one of said bus lines.
14. The system of claim 1, wherein the peripheral devices include light emitting elements of three distinct colors, said data bus includes three bus lines, each bus line for driving light emitting elements of one of said three distinct colors.

15. The system of claim 14, wherein said light emitting elements are light emitting diodes and said distinct colors are red, green and blue, respectively.

16. The system of claim 2, wherein the peripheral devices further include a white color light emitting diode ("LED") and said data bus includes a bus line for driving said white color LED.

17. The system of claim 1, further comprising a driver circuit disposed between said data bus and said group of peripheral devices, said driver circuit being configured to drive said group of peripheral devices responsive to said sub-range analog signals on said data bus.

18. The system of claim 17, wherein said driver circuit is configured to be responsive to a control signal for decoupling said group of peripheral devices from said data bus.

19. The system of claim 2, further comprising a second analog-to-analog converter and a second selector circuit, said second selector circuit being responsive to a selection control signal for selecting one of said analog-to-analog converter and said second analog-to-analog converter for providing said plurality of analog signals to said data bus.

20. The system of claim 2, further comprising an overflow circuit, said overflow circuit extracting a portion of a power supply voltage in excess of a reference voltage as said analog input signal and providing a regulated supply voltage to the system, said regulated supply voltage being lower than said power supply voltage.

21. Lighting apparatus comprising:
an analog input;

a plurality of analog outputs;

a control circuit configured to provide analog output signals at each of the analog outputs, the control circuit embodying mappings corresponding to each of the analog outputs, the mappings relating values of an analog input signal presented at the analog input to corresponding values of the analog output signals, wherein, the mappings are such that increasing the value of the analog input signal from a minimum value to a maximum value causes each of the analog output signals to vary according to a corresponding waveform; and

wherein the waveforms each include a ramp portion wherein the corresponding analog output signal ramps up to a peak value and holds at the peak value for a sub-range of values of the analog input signal.

22. Lighting apparatus according to claim 21 wherein, in the ramp portion, the waveforms provide linear relations between the values of the corresponding analog output signal and the values of the analog input signal.

23. Lighting apparatus according to claim 22 wherein one or more of the waveforms comprises a decay region wherein an increase in the value of the analog input signal provides a corresponding decrease in the value of the corresponding analog output signal.

24. Lighting apparatus according to claim 22 wherein one or more of the waveforms is trapezoidal in form.

25. Lighting apparatus according to claim 21 wherein each of the waveforms has at least one energized portion wherein the value of the corresponding output signal is non-zero and wherein the energized portions of at least two of the waveforms overlap.
26. Lighting apparatus according to claim 21 comprising a plurality of drive circuits, a different one of the drive circuits associated with each of the outputs, wherein each drive circuit is connected to apply the output signal to the associated output.

27. Lighting apparatus according to claim 21 comprising three outputs, a first output connected to drive a red light-emitting diode (LED), a second output connected to drive a green light-emitting diode and a third output connected to drive a blue light-emitting diode.

28. Lighting apparatus according to claim 27 wherein the waveforms provide analog output signals for the first, second and third outputs having a ratio of 30:59:11 for at least some values of the input signal.

29. Lighting apparatus according to claim 21 comprising a plurality of bus lines, the plurality of bus lines each connected to drive one or more light-emitting diodes, wherein each of the plurality of outputs is coupled to drive at least one of the bus lines.

30. Lighting apparatus according to claim 29 wherein one or more of the plurality of outputs is coupled to drive two or more of the bus lines.

31. Lighting apparatus according to claim 30 wherein:
   the bus lines comprise at least first second and third bus lines,
   a first one of the outputs is connected to drive the first bus line,
   a second one of the outputs is connected to drive the first and second bus lines, and,
   a third one of the outputs is connected to drive the first, second and third bus lines.

32. Lighting apparatus according to claim 31 wherein the one or more light-emitting diodes connected to the first bus line emit red light when driven, the one or more light-emitting diodes connected to the second bus line emit green light when
driven; and the one or more light-emitting diodes connected to the third bus line emit blue light when driven.

33. Lighting apparatus according to claim 31 wherein the bus lines comprise a fourth bus line connected to drive a white light-emitting diode and red, green and blue light emitting diodes are each connected to be driven by one of the first, second and third bus lines.

34. Lighting apparatus according to claim 21 wherein, for at least some values of the analog input signal, all of the analog output signals are off.

35. Lighting apparatus according to claim 29 comprising a uni-directional coupler connected between the outputs and the bus lines.

36. Lighting apparatus according to claim 21 wherein the waveforms are configured such that each of the outputs is off unless the value of the input signal is within a sub-range corresponding to the output.

37. Lighting apparatus according to claim 36 wherein two or more of the waveforms overlap completely.

38. Lighting apparatus according to claim 29 wherein the bus lines are connected to the light-emitting diodes by way of a gate/interface component, the gate/interface component comprising a gate operative to simultaneously enable or disable all of the light-emitting diodes.