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(54) **CONTROLLER FOR OPTICALLY-SWITCHABLE WINDOWS**

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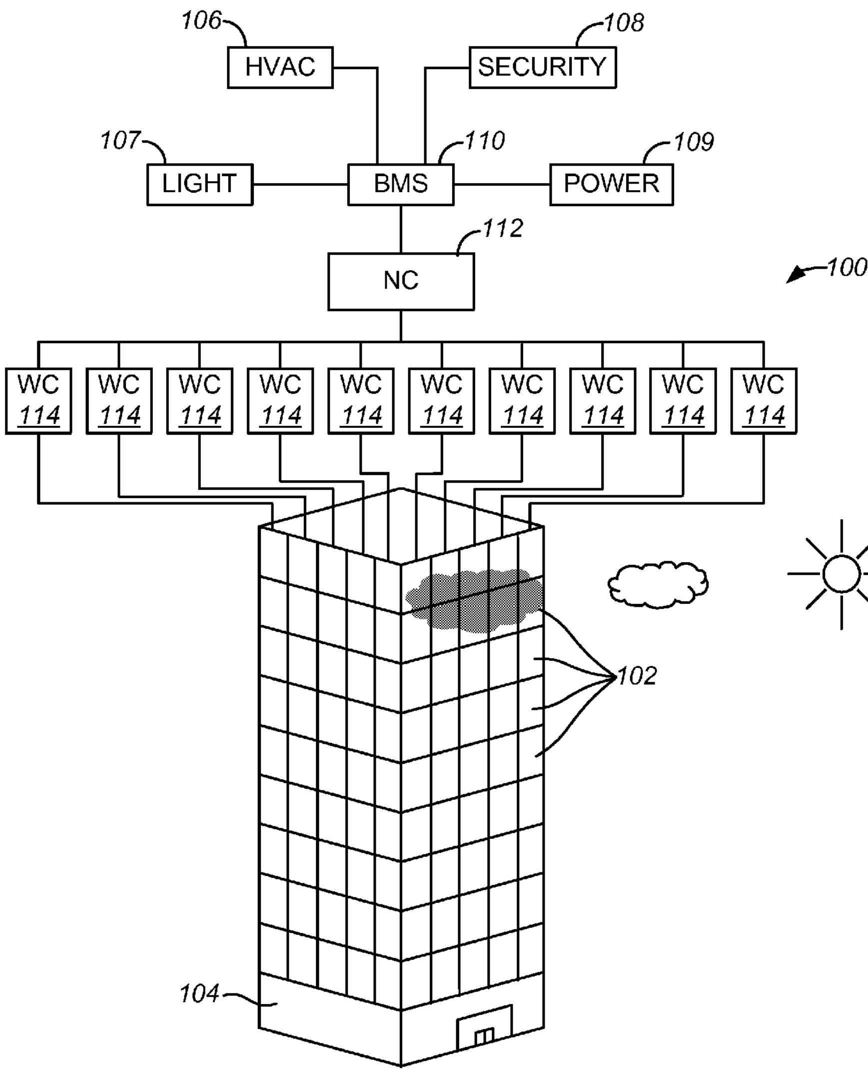
(57) **ABSTRACT**

This disclosure provides a window controller that includes a command-voltage generator that generates a command voltage signal, and a pulse-width-modulated-signal generator that generates a pulse-width-modulated signal based on the command voltage signal. The pulse-width-modulated signal drives an optically-switchable device. The pulse-width-modulated signal comprises a first power component having a first duty cycle and a second power component having a second duty cycle. The first component delivers a first pulse during each active portion of the first duty cycle, and the second component delivers a second pulse during each active portion of the second duty cycle. The first pulses are applied to a first conductive layer and the second pulses are applied to a second conductive layer. The relative durations of the active portions and the relative durations of the first and second pulses are adjusted to result in a change in an effective DC voltage applied across the optically-switchable device.



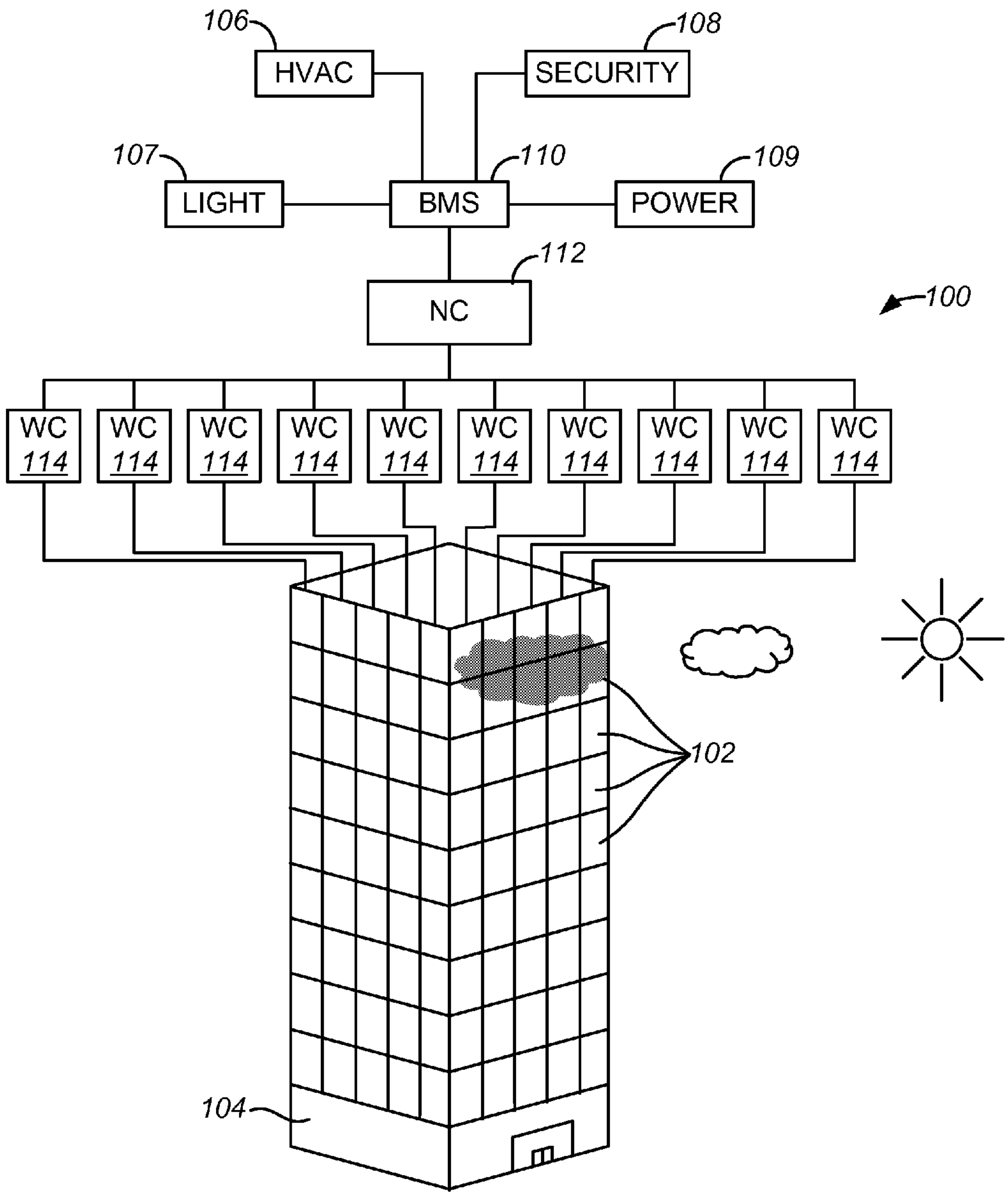

106
HVAC
108
SECURITY
107
LIGHT
110
BMS
109
POWER
112
NC
100
WC 114
WC 114
WC 114
WC 114
WC 114
WC 114
WC 114
WC 114
WC 114
WC 114
102
104

FIG. 1

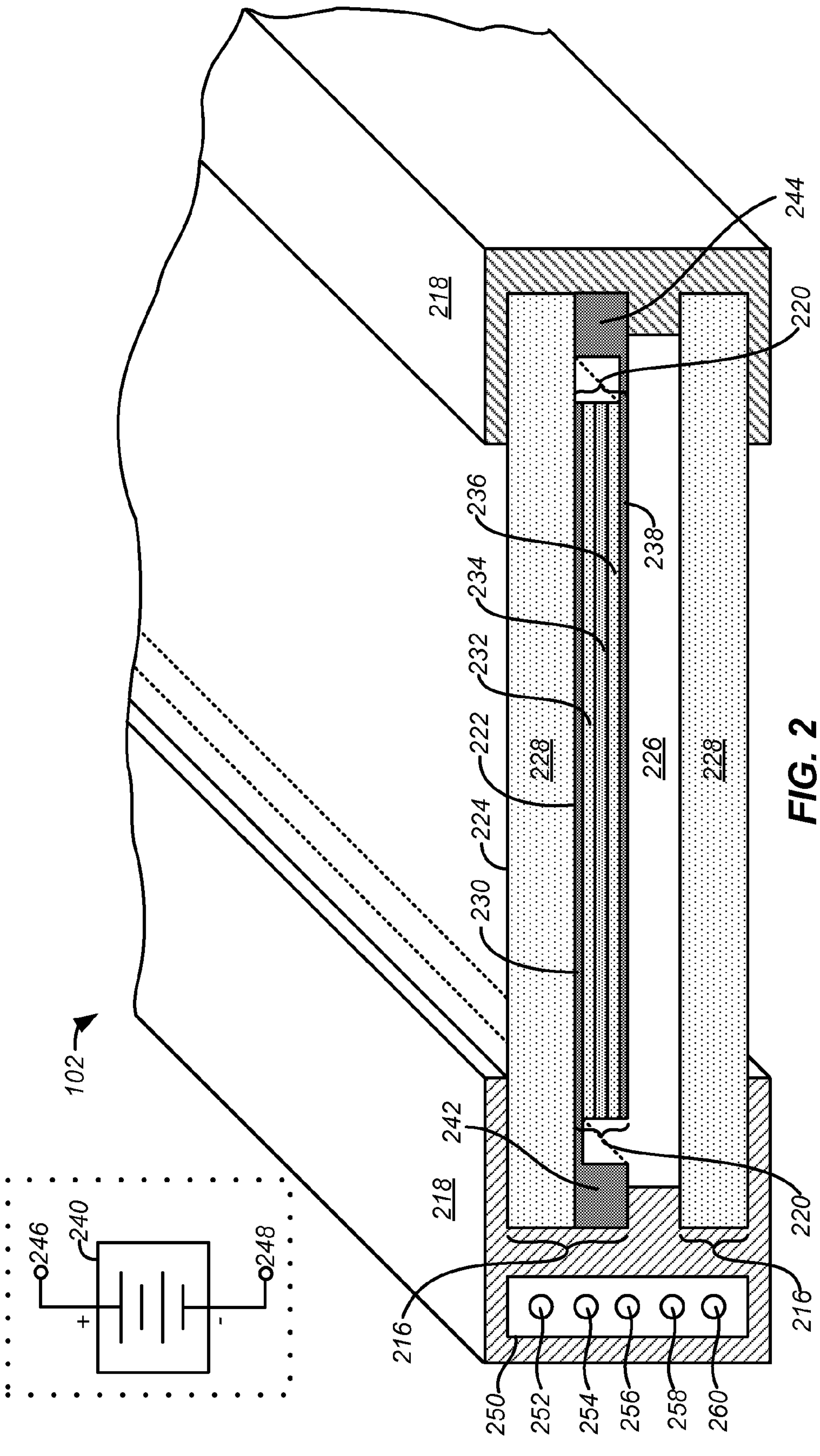

244
218
220
236
234
232
222
224
230
238
228
226
228
102
242
218
220
240
246
248
+
-
216
216
250
252
254
256
258
260

FIG. 2

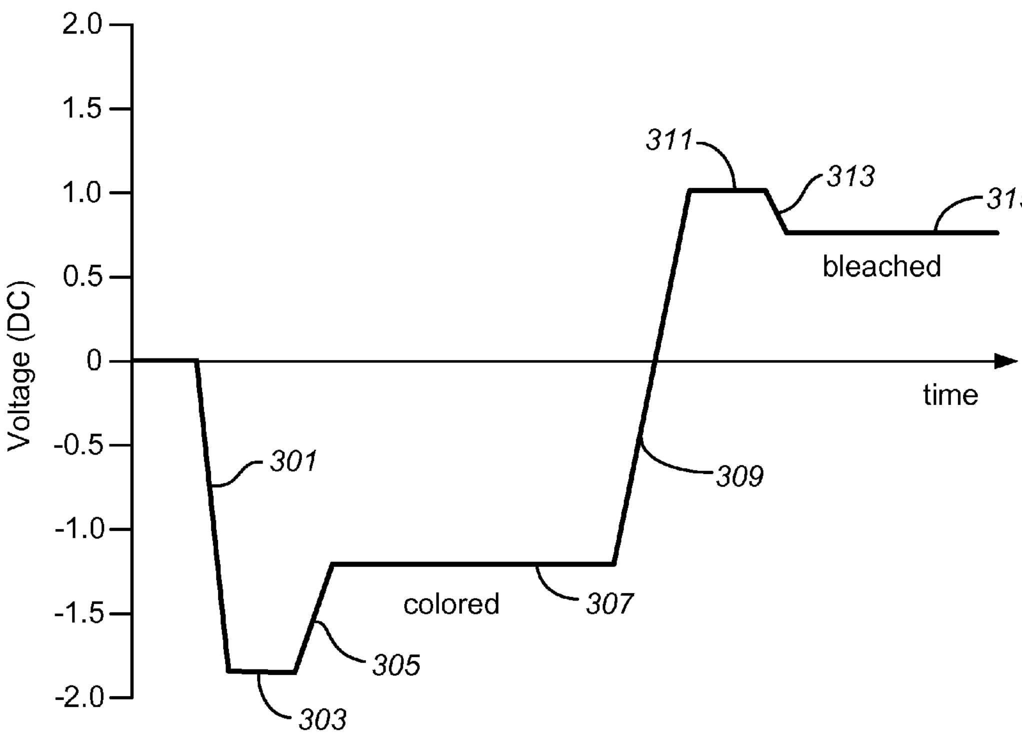
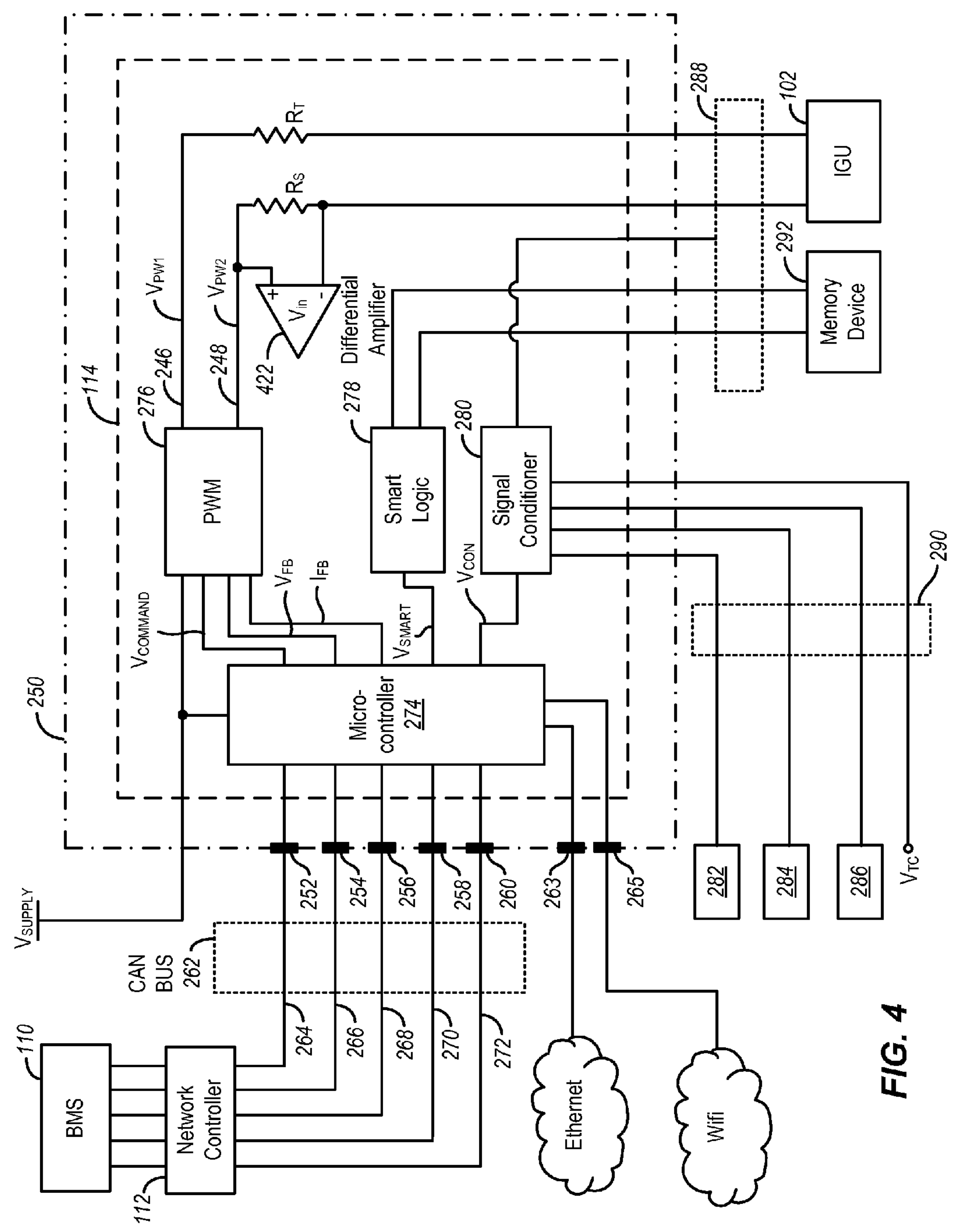
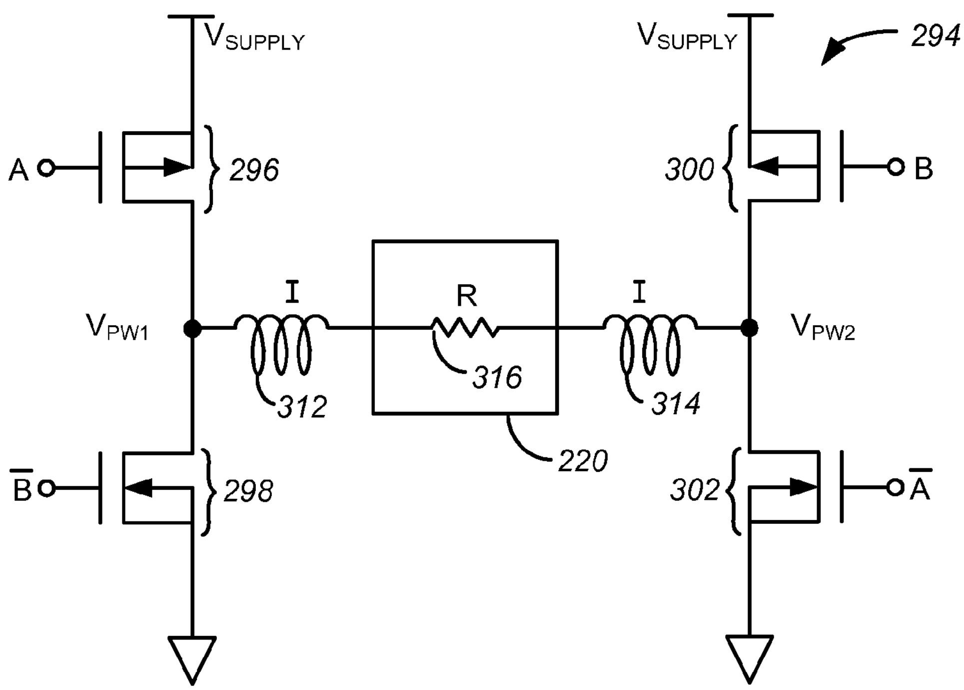

2.0
1.5
1.0
0.5
0
-0.5
-1.0
-1.5
-2.0
Voltage (DC)
time
301
303
305
colored
307
309
311
313
315
bleached

FIG. 3



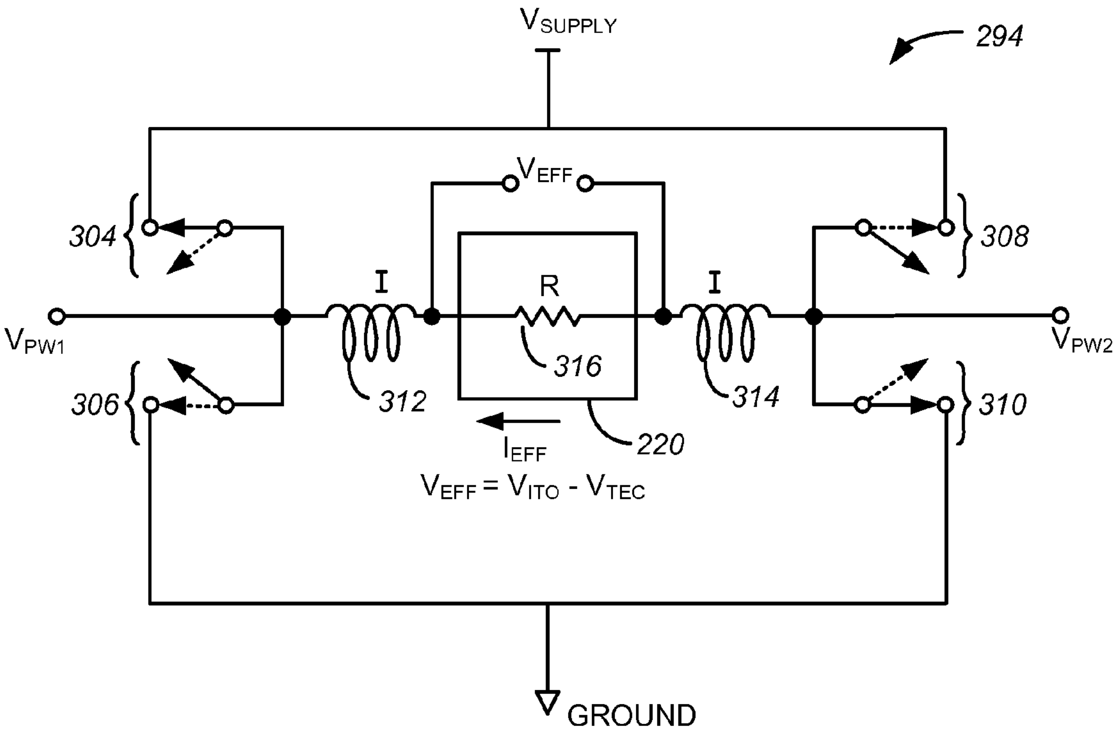
114
250
276
246
248
PWM
V_{PW1}
V_{PW2}
R_T
R_S
422
V_{in}
Differential Amplifier
278
Smart Logic
280
Signal Conditioner
288
102
IGU
292
Memory Device
V_{FB}
I_{FB}
$V_{COMMAND}$
V_{SMART}
V_{CON}
Micro-controller
274
290
V_{SUPPLY}
252
254
256
258
260
263
265
282
284
286
V_{TC}
CAN BUS
262
110
BMS
Network Controller
112
264
266
268
270
272
Ethernet
Wifi

FIG. 4



V_{SUPPLY}
V_{SUPPLY}
294
A
296
300
B
I
R
I
V_{PW1}
V_{PW2}
316
312
314
220
$\overline{B}$
298
302
$\overline{A}$

FIG. 5A



V_{SUPPLY}
294
V_{EFF}
304
308
I
R
I
V_{PW1}
V_{PW2}
316
306
312
314
310
I_{EFF}
220
$V_{EFF} = V_{ITO} - V_{TEC}$
GROUND

FIG. 5B

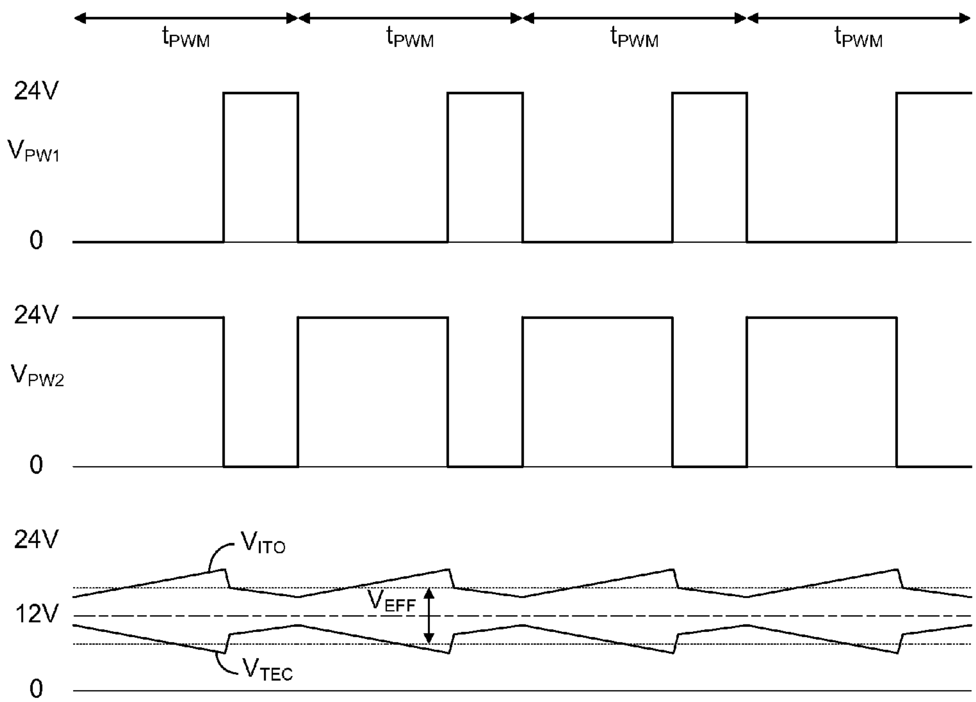
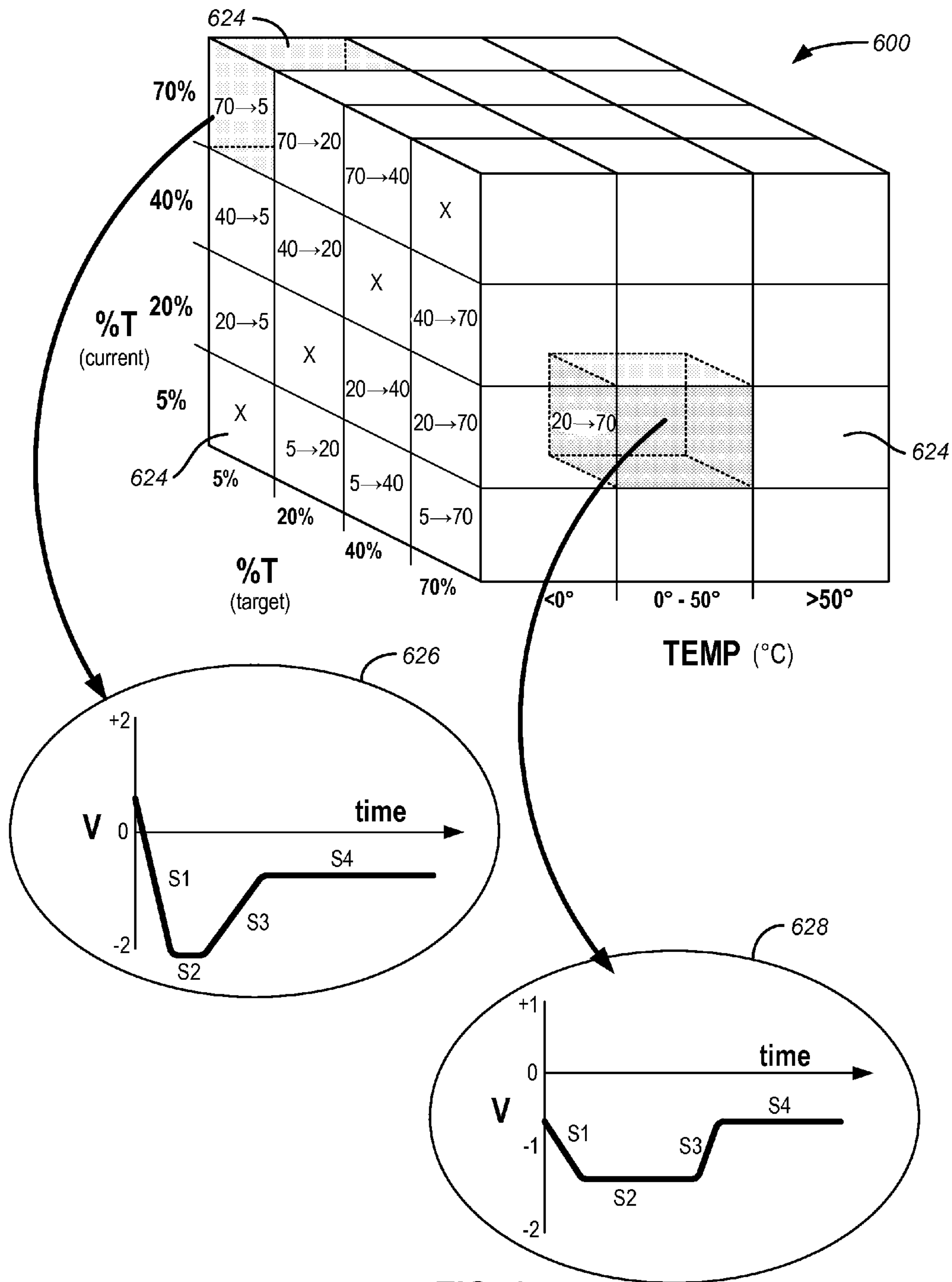

tPWM
tPWM
tPWM
tPWM
24V
VPW1
0
24V
VPW2
0
24V
VITO
VEFF
12V
VTEC
0

FIG. 5C



600
624
70%
40%
20%
5%
%T
(current)
70→5
70→20
70→40
X
40→5
40→20
X
40→70
20→5
X
20→40
20→70
X
5→20
5→40
5→70
20→70
5%
20%
40%
70%
%T
(target)
<0°
0° - 50°
>50°
TEMP (°C)
626
+2
V
0
time
S1
S4
S3
-2
S2
628
+1
0
time
V
-1
S1
S3
S4
S2
-2

FIG. 6

CONTROLLER FOR OPTICALLY-SWITCHABLE WINDOWS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] The application is related to: U.S. patent application Ser. No. 13/049,756 (Attorney Docket No. SLDMP007) naming Brown et al. as inventors, titled MULTIPURPOSE CONTROLLER FOR MULTISTATE WINDOWS and filed 16 Mar. 2011; U.S. patent application Ser. No. ______ (Attorney Docket No. SLDMP035) naming Brown as inventor, titled CONTROLLING TRANSITIONS IN OPTICALLY SWITCHABLE DEVICES and filed 17 Apr. 2012; and U.S. patent application Ser. No. ______ (Attorney Docket No. SLDMP042) naming Brown as inventor, titled CONTROLLER FOR OPTICALLY SWITCHABLE WINDOWS and filed 17 Apr. 2012; all of which are incorporated herein by reference in their entireties and for all purposes.

TECHNICAL FIELD

[0002] This disclosure relates generally to optically-switchable devices including electrochromic windows, and more particularly to controllers for controlling and driving optically-switchable devices.

DESCRIPTION OF THE RELATED TECHNOLOGY

[0003] Optically-switchable devices can be integrated with windows to enable control over, for example, the tinting, transmittance, or reflectance of window panes. Optically-switchable devices include electrochromic devices. Electrochromism is a phenomenon in which a material exhibits a reversible electrochemically-mediated change in one or more optical properties when stimulated to a different electronic state. For example, the electrochromic material can be stimulated by an applied voltage. Optical properties that can be reversibly manipulated include, for example, color, transmittance, absorbance, and reflectance. One well known electrochromic material is tungsten oxide (WO_3). Tungsten oxide is a cathodic electrochromic material that undergoes a coloration transition—transparent to blue—by electrochemical action via intercalation of positive ions into the tungsten oxide matrix with concurrent charge balance by electron insertion.

[0004] Electrochromic materials and the devices made from them may be incorporated into, for example, windows for home, commercial, or other uses. The color, transmittance, absorbance, or reflectance of such electrochromic windows can be changed by inducing a change in the electrochromic material. For example, electrochromic windows can be darkened or lightened in response to electrical stimulation. For example, a first voltage applied to an electrochromic device of the window may cause the window to darken while a second voltage may cause the window to lighten. This capability can allow for control over the intensities of various wavelengths of light that may pass through the window, including both the light that passes from an outside environment through the window into an inside environment as well as potentially the light that passes from an inside environment through the window out to an outside environment.

[0005] Such capabilities of electrochromic windows present enormous opportunities for increasing energy efficiency, as well as for aesthetic purposes. With energy conservation being foremost in the minds of many modern energy policy-makers, it is expected that the growth of the electrochromic window industry will be robust. An important consideration in the engineering of electrochromic windows is how best to integrate them into new as well as existing (e.g., retrofit) applications. Of particular importance is how best to organize, control, and deliver power to the electrochromic windows.

SUMMARY

[0006] According to one innovative aspect, a window controller includes a command-voltage generator configured to generate a command voltage signal. The window controller also includes a pulse-width-modulated-signal generator configured to generate a pulse-width-modulated signal based on the command voltage signal. The pulse-width-modulated signal is configured to drive an optically-switchable device on a substantially transparent substrate. In some embodiments, the pulse-width-modulated signal comprises a first power component having a first duty cycle and a second power component having a second duty cycle. In some embodiments, the first power component is configured to deliver a first pulse during each active portion of the first duty cycle, and the second power component is configured to deliver a second pulse during each active portion of the second duty cycle. In some embodiments, during operation, the first pulses are applied to a first conductive electrode layer of the optically-switchable device and the second pulses are applied to a second conductive electrode layer of the optically-switchable device. In some embodiments, the relative durations of the active portions of the first and second duty cycles and the relative durations of the first and second pulses are adjusted to result in a change in an effective DC voltage applied across the optically-switchable device.

[0007] In some embodiments, the substantially transparent substrate is configured in an IGU. In some embodiments, the window controller is located at least partially within a seal of the IGU. In some embodiments, the optically-switchable device is an electrochromic device formed on a surface of the substantially transparent substrate and adjacent an interior volume of the IGU.

[0008] In some embodiments, the first duty cycle has a first time period and a first voltage magnitude, the second duty cycle has a second time period and a second voltage magnitude, the first time period equals the second time period, and the first voltage magnitude equals the second voltage magnitude. In some embodiments, the window controller also includes first and second inductors that couple the first and second power components to the optically-switchable device, the voltage applied across the optically-switchable device resulting from the applied first and second power components is effectively a DC voltage. In some embodiments, the active portion of the first duty cycle comprises a first fraction of the first time period, the active portion of the second duty cycle comprises a second fraction of the second time period, the magnitude of the voltage applied to a first conductive layer of the optically-switchable device is substantially proportional to the product of the first fraction and the first voltage magnitude, the magnitude of the voltage applied to a second conductive layer of the optically-switchable device is substantially proportional to the product of the second fraction and the second voltage magnitude, and the effective DC voltage applied across the optically-switchable device is substantially equal to the difference between the magnitude of the voltage applied to the first conductive layer and the magnitude of the voltage applied to the second conductive layer.

[0009] In some embodiments, the command-voltage generator includes a microcontroller configured to generate the command voltage signal. In some embodiments, the microcontroller generates the command voltage signal based at least in part on a voltage feedback signal that is itself based on an effective DC voltage applied across the optically-switchable device. In some embodiments, the microcontroller generates the command voltage signal based at least in part on a current feedback signal that is itself based on a detected current transmitted through the optically-switchable device.

[0010] In some embodiments, the window controller also includes a memory device configured to store one or more drive parameters. In some embodiments, the drive parameters include one or more of a current outside temperature, a current inside temperature, a current transmissivity value of the electrochromic device, a target transmissivity value of the electrochromic device, and a transition rate. In some embodiments, the microcontroller is further configured to modify the command voltage signal based on one or more other input, feedback, or control signals. The window controller of claim **15**, wherein the microcontroller modifies the command voltage signal based at least in part on a voltage feedback signal that is itself based on a detected actual level of the effective DC voltage applied across the optically-switchable device.

[0011] According to another innovative aspect, a system includes: a plurality of windows, each window including an optically-switchable device on a substantially transparent substrate; a plurality of window controllers such as those just described; and a network controller configured to control the plurality of window controllers. In some embodiments, each window controller is configured to generate a command voltage signal based at least in part and at least at certain times on an input received from the network controller.

[0012] In some embodiments, the network controller is configured to communicate with a building management system and the microcontroller of each window controller is configured to modify the command voltage signal based on input from the building management system. In some embodiments, the network controller is configured to communicate with one or more lighting systems, heating systems, cooling systems, ventilation systems, power systems, and/or security systems and the microcontroller of each window controller is configured to modify the command voltage signal based on input from the one or more lighting systems, heating systems, cooling systems, ventilation systems, power systems, and/or security systems.

[0013] Details of one or more embodiments or implementations of the subject matter described in this specification are set forth in the accompanying drawings and the description below. Other features, aspects, and advantages will become apparent from the description, the drawings, and the claims. Note that the relative dimensions of the following figures may not be drawn to scale.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] FIG. **1** shows a depiction of a system for controlling and driving a plurality of electrochromic windows.

[0015] FIG. **2** shows a cross-sectional axonometric view of an example electrochromic window that includes two window panes.

[0016] FIG. **3** shows an example of a voltage profile for driving an optical state transition in an electrochromic device.

[0017] FIG. **4** shows a depiction of an example plug-in component including a window controller.

[0018] FIG. **5**A shows a depiction of an example transistor implementation of a pulse-width modulator circuit.

[0019] FIG. **5**B shows a depiction of an equivalent H-bridge configuration representation of the pulse-width modulator circuit of FIG. **5**A.

[0020] FIG. **5**C shows voltage profiles for the configurations of FIGS. **5**A and **5**B.

[0021] FIG. **6** shows an example 3-dimensional data structure including drive parameters for driving an electrochromic device.

[0022] Like reference numbers and designations in the various drawings indicate like elements.

DETAILED DESCRIPTION

[0023] The following detailed description is directed to certain embodiments or implementations for the purposes of describing the innovative aspects. However, the teachings herein can be applied and implemented in a multitude of different ways. Furthermore, while the disclosed embodiments focus on electrochromic windows (also referred to as smart windows), the concepts disclosed herein may apply to other types of switchable optical devices including, for example, liquid crystal devices and suspended particle devices, among others. For example, a liquid crystal device or a suspended particle device, rather than an electrochromic device, could be incorporated into some or all of the disclosed embodiments.

[0024] Referring to FIG. **1** as an example, some embodiments relate to a system, **100**, for controlling and driving (e.g., selectively powering) a plurality of electrochromic windows, **102**. System **100**, adapted for use in a building, **104**, is used for controlling and driving a plurality of exterior facing electrochromic windows **102**. Some embodiments find particularly advantageous use in buildings such as commercial office buildings or residential buildings. Some embodiments can be particularly suited and adapted for use in the construction of new buildings. For example, some embodiments of system **100** are designed to work in conjunction with modern or novel heating, ventilation, and air conditioning (HVAC) systems, **106**, interior lighting systems, **107**, security systems, **108**, and power systems, **109**, as a single holistic efficient energy control system for the entire building **104**, or campus of buildings **104**. Some embodiments are particularly well-suited for integration with a building management system (BMS), **110**. A BMS is a computer-based control system that can be installed in a building to monitor and control the building's mechanical and electrical equipment such as HVAC systems, lighting systems, power systems, elevators, fire systems, and security systems. A BMS consists of hardware and associated firmware or software for maintaining conditions in the building according to preferences set by the occupants or a building manager or other administrator. The software can be based on, for example, internet protocols or open standards.

[0025] A BMS is typically used in large buildings, and typically functions at least to control the environment within the building. For example, a BMS may control lighting, temperature, carbon dioxide levels, and humidity within a building. Typically, there are many mechanical or electrical devices that are controlled by a BMS such as, for example, heaters, air conditioners, blowers, and vents. To control the building environment, a BMS may turn on and off these various devices according to pre-defined rules or in response to pre-defined conditions. A core function of a typical modern BMS is to maintain a comfortable environment for the building's occupants while minimizing heating and cooling energy losses and costs. A modern BMS can be used not only to monitor and control, but also to optimize the synergy between various systems, for example, to conserve energy and lower building operation costs.

[0026] Some embodiments are alternatively or additionally designed to work responsively or reactively based on feedback sensed through, for example, thermal, optical, or other sensors or through input from, for example, an HVAC or interior lighting system, or an input from a user control. Some embodiments also can be utilized in existing structures, including both commercial and residential structures, having traditional or conventional HVAC or interior lighting systems. Some embodiments also can be retrofitted for use in older residential homes.

[0027] In some embodiments, system **100** includes a network controller, **112**. In some embodiments, network controller **112** controls a plurality of window controllers, **114**. For example, network controller **112** can control tens, hundreds, or even thousands of window controllers **114**. Each window controller **114**, in turn, can control and drive one or more electrochromic windows **102**. The number and size of the electrochromic windows **102** that each window controller **114** can drive is generally limited by the voltage and current characteristics of the load on the window controller **114** controlling the respective electrochromic windows **102**. In some embodiments, the maximum window size that each window controller **114** can drive is limited by the voltage, current, or power requirements to cause the desired optical transitions in the electrochromic window **102** within a desired time-frame. Such requirements are, in turn, a function of the surface area of the window. In some embodiments, this relationship is nonlinear. For example, the voltage, current, or power requirements can increase nonlinearly with the surface area of the electrochromic window **102**. For example, in some cases the relationship is nonlinear at least in part because the sheet resistance of the first and second conductive layers **230** and **238** (see FIG. **2**) increases nonlinearly with distance across the length and width of the first or second conductive layers. In some embodiments, the relationship between the voltage, current, or power requirements required to drive multiple electrochromic windows **102** of equal size and shape is, however, directly proportional to the number of the electrochromic windows **102** being driven.

[0028] In the following description, each electrochromic window **102** will be referred to as an insulated glass unit (IGU) **102**. This convention is assumed, for example, because it is common and can be desirable to have IGUs serve as the fundamental construct for holding an electrochromic lite or pane. Additionally, IGUs, especially those having double or triple pane window configurations, offer superior thermal insulation over single pane configurations. However, this convention is for convenience only because, as described below, in many implementations the basic unit of an electrochromic window can be considered to include a pane or substrate of transparent material, upon which an electrochromic coating or device is deposited, and to which associated electrical connections are coupled to power the electrochromic coating or device.

[0029] FIG. **2** shows a cross-sectional axonometric view of an embodiment of an IGU **102** that includes two window panes, **216**. In various embodiments, each IGU **102** can include one, two, or more substantially transparent (e.g., at no applied voltage) window panes **216** as well as a frame, **218**, that supports the panes **216**. For example, the IGU **102** shown in FIG. **2** is configured as a double-pane window. One or more of the panes **216** can itself be a laminate structure of two, three, or more layers or panes (e.g., shatter-resistant glass similar to automotive windshield glass). In each IGU **102**, at least one of the panes **216** includes an electrochromic device or stack, **220**, disposed on at least one of its inner surface, **222**, or outer surface, **224**: for example, the inner surface **222** of the outer pane **216**.

[0030] In multi-pane configurations, each adjacent set of panes **216** can have a volume, **226**, disposed between them. Generally, each of the panes **216** and the IGU **102** as a whole are rectangular and form a rectangular solid. However, in other embodiments other shapes (e.g., circular, elliptical, triangular, curvilinear, convex, concave) may be desired. In some embodiments, the volume **226** between the panes **116** is evacuated of air. In some embodiments, the IGU **102** is hermetically-sealed. Additionally, the volume **226** can be filled (to an appropriate pressure) with one or more gases, such as argon (Ar), krypton (Kr), or xenon (Xn), for example. Filling the volume **226** with a gas such as Ar, Kr, or Xn can reduce conductive heat transfer through the IGU **102** because of the low thermal conductivity of these gases. The latter two gases also can impart improved acoustic insulation due to their increased weight.

[0031] In some embodiments, frame **218** is constructed of one or more pieces. For example, frame **218** can be constructed of one or more materials such as vinyl, PVC, aluminum (Al), steel, or fiberglass. The frame **218** may also include or hold one or more foam or other material pieces that work in conjunction with frame **218** to separate the window panes **216** and to hermetically seal the volume **226** between the panes **216**. For example, in a typical IGU implementation, a spacer lies between adjacent panes **216** and forms a hermetic seal with the panes in conjunction with an adhesive sealant that can be deposited between them. This is termed the primary seal, around which can be fabricated a secondary seal, typically of an additional adhesive sealant. In some such embodiments, frame **218** can be a separate structure that supports the IGU construct.

[0032] Each pane **216** includes a substantially transparent or translucent substrate, **228**. Generally, substrate **228** has a first (e.g., inner) surface **222** and a second (e.g., outer) surface **224** opposite the first surface **222**. In some embodiments, substrate **228** can be a glass substrate. For example, substrate **228** can be a conventional silicon oxide (SO_x)-based glass substrate such as soda-lime glass or float glass, composed of, for example, approximately 75% silica (SiO_2) plus Na_2O, CaO, and several minor additives. However, any material having suitable optical, electrical, thermal, and mechanical properties may be used as substrate **228**. Such substrates also can include, for example, other glass materials, plastics and thermoplastics (e.g., poly(methyl methacrylate), polystyrene, polycarbonate, allyl diglycol carbonate, SAN (styrene acrylonitrile copolymer), poly(4-methyl-1-pentene), polyester, polyamide), or mirror materials. If the substrate is formed from, for example, glass, then substrate **228** can be strengthened, e.g., by tempering, heating, or chemically strengthening. In other implementations, the substrate **228** is not further strengthened, e.g., the substrate is untempered.

[0033] In some embodiments, substrate **228** is a glass pane sized for residential or commercial window applications. The size of such a glass pane can vary widely depending on the specific needs of the residence or commercial enterprise. In some embodiments, substrate **228** can be formed of architectural glass. Architectural glass is typically used in commercial buildings, but also can be used in residential buildings, and typically, though not necessarily, separates an indoor environment from an outdoor environment. In certain embodiments, a suitable architectural glass substrate can be at least approximately 20 inches by approximately 20 inches, and can be much larger, for example, approximately 80 inches by approximately 120 inches, or larger. Architectural glass is typically at least about 2 millimeters (mm) thick and may be as thick as 6 mm or more. Of course, electrochromic devices **220** can be scalable to substrates **228** smaller or larger than architectural glass, including in any or all of the respective length, width, or thickness dimensions. In some embodiments, substrate **228** has a thickness in the range of approximately 1 mm to approximately 10 mm.

[0034] Electrochromic device **220** is disposed over, for example, the inner surface **222** of substrate **228** of the outer pane **216** (the pane adjacent the outside environment). In some other embodiments, such as in cooler climates or applications in which the IGUs **102** receive greater amounts of direct sunlight (e.g., perpendicular to the surface of electrochromic device **220**), it may be advantageous for electrochromic device **220** to be disposed over, for example, the inner surface (the surface bordering the volume **226**) of the inner pane adjacent the interior environment. In some embodiments, electrochromic device **220** includes a first conductive layer (CL) **230**, an electrochromic layer (EC) **232**, an ion conducting layer (IC) **234**, a counter electrode layer (CE) **236**, and a second conductive layer (CL) **238**. Again, layers **230**, **232**, **234**, **236**, and **238** are also collectively referred to as electrochromic stack **220**. A power source **240** operable to apply an electric potential across a thickness of electrochromic stack **220** effects the transition of the electrochromic device **220** from, for example, a bleached or lighter state (e.g., a transparent, semitransparent, or translucent state) to a colored or darker state (e.g., a tinted, less transparent or less translucent state). In some other embodiments, the order of layers **230**, **232**, **234**, **236**, and **238** can be reversed or otherwise reordered or rearranged with respect to substrate **238**.

[0035] In some embodiments, one or both of first conductive layer **230** and second conductive layer **238** is formed from an inorganic and solid material. For example, first conductive layer **230**, as well as second conductive layer **238**, can be made from a number of different materials, including conductive oxides, thin metallic coatings, conductive metal nitrides, and composite conductors, among other suitable materials. In some embodiments, conductive layers **230** and **238** are substantially transparent at least in the range of wavelengths where electrochromism is exhibited by the electrochromic layer **232**. Transparent conductive oxides include metal oxides and metal oxides doped with one or more metals. For example, metal oxides and doped metal oxides suitable for use as first or second conductive layers **230** and **238** can include indium oxide, indium tin oxide (ITO), doped indium oxide, tin oxide, doped tin oxide, zinc oxide, aluminum zinc oxide, doped zinc oxide, ruthenium oxide, doped ruthenium oxide, among others. First and second conductive layers **230** and **238** also can be referred to as "transparent conductive oxide" (TCO) layers.

[0036] In some embodiments, commercially available substrates, such as glass substrates, already contain a transparent conductive layer coating when purchased. In some embodiments, such a product can be used for both substrate **238** and conductive layer **230** collectively. Examples of such glass substrates include conductive layer-coated glasses sold under the trademark TEC Glass™ by Pilkington, of Toledo, Ohio and SUNGATE™ 300 and SUNGATE™ 500 by PPG Industries of Pittsburgh, Pa. Specifically, TEC Glass™ is, for example, a glass coated with a fluorinated tin oxide conductive layer.

[0037] In some embodiments, first or second conductive layers **230** and **238** can each be deposited by physical vapor deposition processes including, for example, sputtering. In some embodiments, first and second conductive layers **230** and **238** can each have a thickness in the range of approximately 0.01 μm to approximately 1 μm. In some embodiments, it may be generally desirable for the thicknesses of the first and second conductive layers **230** and **238** as well as the thicknesses of any or all of the other layers described below to be individually uniform with respect to the given layer; that is, that the thickness of a given layer is uniform and the surfaces of the layer are smooth and substantially free of defects or other ion traps.

[0038] A primary function of the first and second conductive layers **230** and **238** is to spread an electric potential provided by a power source **240**, such as a voltage or current source, over surfaces of the electrochromic stack **220** from outer surface regions of the stack to inner surface regions of the stack, with relatively little Ohmic potential drop from the outer regions to the inner regions (e.g., as a result of a sheet resistance of the first and second conductive layers **230** and **238**). In other words, it can be desirable to create conductive layers **230** and **238** that are each capable of behaving as substantially equipotential layers across all portions of the respective conductive layer along the length and width of the electrochromic device **220**. In some embodiments, bus bars **242** and **244**, one (e.g., bus bar **242**) in contact with conductive layer **230** and one (e.g., bus bar **244**) in contact with conductive layer **238** provide electric connection between the voltage or current source **240** and the conductive layers **230** and **238**. For example, bus bar **242** can be electrically coupled with a first (e.g., positive) terminal **246** of power source **240** while bus bar **244** can be electrically coupled with a second (e.g., negative) terminal **248** of power source **240**.

[0039] In some embodiments, IGU **102** includes a plug-in component **250**. In some embodiments, plug-in component **250** includes a first electrical input **252** (e.g., a pin, socket, or other electrical connector or conductor) that is electrically coupled with power source terminal **246** via, for example, one or more wires or other electrical connections, components, or devices. Similarly, plug-in component **250** can include a second electrical input **254** that is electrically coupled with power source terminal **248** via, for example, one or more wires or other electrical connections, components, or devices. In some embodiments, first electrical input **252** can be electrically coupled with bus bar **242**, and from there with first conductive layer **230**, while second electrical input **254** can be coupled with bus bar **244**, and from there with second conductive layer **238**. The conductive layers **230** and **238** also can be connected to power source **240** with other conventional means as well as according to other means described below with respect to window controller **114**. For example, as described below with reference to FIG. **4**, first electrical input **252** can be connected to a first power line while second electrical input **254** can be connected to a second power line.

Additionally, in some embodiments, third electrical input **256** can be coupled to a device, system, or building ground. Furthermore, in some embodiments, fourth and fifth electrical inputs/outputs **258** and **260**, respectively, can be used for communication between, for example, window controller **114**, or microcontroller **274**, and network controller **112**, as described below.

[0040] In some embodiments, electrochromic layer **232** is deposited or otherwise formed over first conductive layer **230**. In some embodiments, electrochromic layer **232** is formed of an inorganic and solid material. In various embodiments, electrochromic layer **232** can include or be formed of one or more of a number of electrochromic materials, including electrochemically cathodic or electrochemically anodic materials. For example, metal oxides suitable for use as electrochromic layer **232** can include tungsten oxide (WO_3), molybdenum oxide (MoO_3), niobium oxide (Nb_2O_5), titanium oxide (TiO_2), copper oxide (CuO), iridium oxide (Ir_2O_3), chromium oxide (Cr_2O_3), manganese oxide (Mn_2O_3), vanadium oxide (V_2O_5), nickel oxide (Ni_2O_3), and cobalt oxide (Co_2O_3), among other materials. In some embodiments, electrochromic layer **232** can have a thickness in the range of approximately 0.05 μm to approximately 1 μm.

[0041] During operation, in response to a voltage generated across the thickness of electrochromic layer **232** by first and second conductive layers **230** and **238**, electrochromic layer **232** transfers or exchanges ions to or from counter electrode layer **236** resulting in the desired optical transitions in electrochromic layer **232**, and in some embodiments, also resulting in an optical transition in counter electrode layer **236**. In some embodiments, the choice of appropriate electrochromic and counter electrode materials governs the relevant optical transitions.

[0042] In some embodiments, counter electrode layer **236** is formed of an inorganic and solid material. Counter electrode layer **236** can generally include one or more of a number of materials or material layers that can serve as a reservoir of ions when the electrochromic device **220** is in, for example, the transparent state. For example, suitable materials for the counter electrode layer **236** include nickel oxide (NiO), nickel tungsten oxide (NiWO), nickel vanadium oxide, nickel chromium oxide, nickel aluminum oxide, nickel manganese oxide, nickel magnesium oxide, chromium oxide (Cr_2O_3), manganese oxide (MnO_2), and Prussian blue. In some embodiments, counter electrode layer **236** can have a thickness in the range of approximately 0.05 **82** m to approximately 1 μm. In some embodiments, counter electrode layer **236** is a second electrochromic layer of opposite polarity as electrochromic layer **232**. For example, when electrochromic layer **232** is formed from an electrochemically cathodic material, counter electrode layer **236** can be formed of an electrochemically anodic material.

[0043] During an electrochromic transition initiated by, for example, application of an appropriate electric potential across a thickness of electrochromic stack **220**, counter electrode layer **236** transfers all or a portion of the ions it holds to electrochromic layer **232**, causing the optical transition in the electrochromic layer **232**. In some embodiments, as for example in the case of a counter electrode layer **236** formed from NiWO, the counter electrode layer **236** also optically transitions with the loss of ions it has transferred to the electrochromic layer **232**. When charge is removed from a counter electrode layer **236** made of NiWO (e.g., ions are transported from the counter electrode layer **236** to the electrochromic layer **232**), the counter electrode layer **236** will transition in the opposite direction (e.g., from a transparent state to a darkened state).

[0044] In some embodiments, ion conducting layer **234** serves as a medium through which ions are transported (e.g., in the manner of an electrolyte) when the electrochromic device **220** transitions between optical states. In some embodiments, ion conducting layer **234** is highly conductive to the relevant ions for the electrochromic and the counter electrode layers **232** and **236**, but also has sufficiently low electron conductivity such that negligible electron transfer occurs during normal operation. A thin ion conducting layer **234** with high ionic conductivity permits fast ion conduction and hence fast switching for high performance electrochromic devices **220**. In some embodiments, ion conducting layer **234** can have a thickness in the range of approximately 0.01 μm to approximately 1 μm.

[0045] In some embodiments, ion conducting layer **234** also is inorganic and solid. For example, ion conducting layer **234** can be formed from one or more silicates, silicon oxides, tungsten oxides, tantalum oxides, niobium oxides, and borates. The silicon oxides include silicon-aluminum-oxide. These materials also can be doped with different dopants, including lithium. Lithium-doped silicon oxides include lithium silicon-aluminum-oxide.

[0046] In some other embodiments, the electrochromic and the counter electrode layers **232** and **236** are formed immediately adjacent one another, sometimes in direct contact, without separately depositing an ion conducting layer. For example, in some embodiments, electrochromic devices having an interfacial region between first and second conductive electrode layers rather than a distinct ion conducting layer **234** can be utilized. Such devices, and methods of fabricating them, are described in U.S. patent application Ser. Nos. 12/772,055 and 12/772,075, each filed 30 Apr. 2010, and in U.S. patent application Ser. Nos. 12/814,277 and 12/814,279, each filed 11 Jun. 2010, all four of which are titled ELECTROCHROMIC DEVICES and name Zhongchun Wang et al. as inventors. Each of these four applications is incorporated by reference herein in its entirety.

[0047] In some embodiments, electrochromic device **220** also can include one or more additional layers (not shown), such as one or more passive layers. For example, passive layers used to improve certain optical properties can be included in or on electrochromic device **220**. Passive layers for providing moisture or scratch resistance also can be included in electrochromic device **220**. For example, the conductive layers **230** and **238** can be treated with anti-reflective or protective oxide or nitride layers. Other passive layers can serve to hermetically seal the electrochromic device **220**.

[0048] Additionally, in some embodiments, one or more of the layers in electrochromic stack **220** can contain some amount of organic material. Additionally or alternatively, in some embodiments, one or more of the layers in electrochromic stack **220** can contain some amount of liquids in one or more layers. Additionally or alternatively, in some embodiments, solid state material can be deposited or otherwise formed by processes employing liquid components such as certain processes employing sol-gels or chemical vapor deposition.

[0049] Additionally, transitions between a bleached or transparent state and a colored or opaque state are but one example, among many, of an optical or electrochromic transition that can be implemented. Unless otherwise specified herein (including the foregoing discussion), whenever reference is made to a bleached-to-opaque transition (or to and from intermediate states in between), the corresponding device or process described encompasses other optical state transitions such as, for example, intermediate state transitions such as percent transmission (% T) to % T transitions, non-reflective to reflective transitions (or to and from intermediate states in between), bleached to colored transitions (or to and from intermediate states in between), and color to color transitions (or to and from intermediate states in between). Further, the term "bleached" may refer to an optically neutral state, for example, uncolored, transparent or translucent. Still further, unless specified otherwise herein, the "color" of an electrochromic transition is not limited to any particular wavelength or range of wavelengths.

[0050] Generally, the colorization or other optical transition of the electrochromic material in electrochromic layer **232** is caused by reversible ion insertion into the material (for example, intercalation) and a corresponding injection of charge-balancing electrons. Typically, some fraction of the ions responsible for the optical transition is irreversibly bound up in the electrochromic material. Some or all of the irreversibly bound ions can be used to compensate "blind charge" in the material. In some embodiments, suitable ions include lithium ions (Li+) and hydrogen ions (H+) (i.e., protons). In some other embodiments, however, other ions can be suitable. Intercalation of lithium ions, for example, into tungsten oxide ($WO_{3-y}(0<y\leq\sim0.3)$) causes the tungsten oxide to change from a transparent (e.g., bleached) state to a blue (e.g., colored) state.

[0051] In particular embodiments described herein, the electrochromic device **220** reversibly cycles between a transparent state and an opaque or tinted state. In some embodiments, when the device is in a transparent state, a potential is applied to the electrochromic stack **220** such that available ions in the stack reside primarily in the counter electrode layer **236**. When the magnitude of the potential on the electrochromic stack **220** is reduced or its polarity reversed, ions are transported back across the ion conducting layer **234** to the electrochromic layer **232** causing the electrochromic material to transition to an opaque, tinted, or darker state. In certain embodiments, layers **232** and **236** are complementary coloring layers; that is, for example, when ions are transferred into the counter electrode layer it is not colored. Similarly, when or after the ions are transferred out of the electrochromic layer it is also not colored. But when the polarity is switched, or the potential reduced, however, and the ions are transferred from the counter electrode layer into the electrochromic layer, both the counter electrode and the electrochromic layers become colored.

[0052] In some other embodiments, when the device is in an opaque state, a potential is applied to the electrochromic stack **220** such that available ions in the stack reside primarily in the counter electrode layer **236**. In such embodiments, when the magnitude of the potential on the electrochromic stack **220** is reduced or its polarity reversed, ions are transported back across the ion conducting layer **234** to the electrochromic layer **232** causing the electrochromic material to transition to a transparent or lighter state. These layers may also be complementary coloring.

[0053] FIG. **3** shows an example of a voltage profile for driving an optical state transition in an electrochromic device (e.g., electrochromic device **220**). The magnitude of the DC voltages (e.g., supplied by power source **240**) applied to an electrochromic device **220** may depend in part on the thickness of the electrochromic stack and the size (e.g., surface area) of the electrochromic device **220**. A voltage profile **300** can include the following sequence of applied voltage or current parameters for driving electrochromic device **220** from a first state to a colored state, and from a colored state to a bleached state: a negative ramp **301**, a negative hold **303**, a positive ramp **305**, a negative hold **307**, a positive ramp **309**, a positive hold **311**, a negative ramp **313**, and a positive hold **315**. In some embodiments, the voltage remains constant during the length of time that the device remains in its defined optical state, e.g., in negative hold **307** or positive hold **315**. Negative ramp **301** drives the device to the colored or opaque state (or an intermediate partially transparent state) and negative hold **307** maintains the device in the transitioned-to state for a desired period of time. In some embodiments, negative hold **303** may be applied for a specified duration of time or until another condition is met, such as a desired amount of ionic charge being passed sufficient to cause the desired change in coloration, for example. Positive ramp **305**, increases the voltage from the maximum magnitude negative voltage (e.g., negative hold **303**) to the smaller magnitude negative voltage (e.g., negative hold **307**) used to hold the desired optical state. By performing a first negative ramp **301** (and a first negative hold voltage **303** at this peak negative voltage) to "overdrive" electrochromic device **220**, the inertia of the ions is overcome more rapidly and the desired target optical state is reached sooner. The second negative hold voltage **307** effectively serves to counteract the voltage drop that would otherwise result from the leakage current. As the leakage current is reduced for any given electrochromic device **220**, the hold voltage required to hold the desired optical transition can approach zero.

[0054] In some embodiments, positive ramp **309** drives the transition of the electrochromic device from the colored or opaque state (or an intermediate less transparent state) to the bleached or transparent state (or an intermediate more transparent state). Positive hold **315** maintains the device in the transitioned-to state for a desired period of time. In some embodiments, positive hold **311** may be applied for a specified duration of time or until another condition is met, such as a desired amount of ionic charge being passed sufficient to cause the desired change in coloration, for example. Negative ramp **313**, decreases the voltage from the maximum magnitude positive voltage (e.g., positive hold **311**) to the smaller magnitude positive voltage (e.g., positive hold **315**) used to hold the desired optical state. By performing a first positive ramp **309** (and a first positive hold voltage **311** at this peak positive voltage) to "overdrive" electrochromic device **220**, the inertia of the ions is overcome more rapidly and the desired target optical state is reached sooner. The second positive hold voltage **315** effectively serves to counteract the voltage drop that would otherwise result from the leakage current. As the leakage current is reduced for any given electrochromic device **220**, the hold voltage required to hold the desired optical transition can approach zero.

[0055] The rate of the optical transition can be a function of not only the applied voltage, but also the temperature and the voltage ramping rate. For example, since both voltage and temperature affect lithium ion diffusion, the amount of charge passed (and hence the intensity of the ionic current peak) increases with voltage and temperature. Additionally, because voltage and temperature are interdependent, this implies that a lower voltage can be used at higher temperatures to attain the same transition rate as a higher voltage at lower temperatures. This temperature response can be exploited in a voltage-based switching algorithm as described below. The temperature is used to determine which voltage to apply in order to effect rapid transitioning without damaging the device.

[0056] In some embodiments, electrical input **252** and electrical input **254** receive, carry, or transmit complementary power signals. In some embodiments, electrical input **252** and its complement electrical input **254** can be directly connected to the bus bars **242** and **244**, respectively, and on the other side, to an external power source that provides a variable DC voltage (e.g., sign and magnitude). The external power source can be window controller **114** itself, or power from building **104** transmitted to window controller **114** or otherwise coupled to electrical inputs **252** and **254**. In such an embodiment, the electrical signals transmitted through electrical inputs/outputs **258** and **260** can be directly connected to memory device **292**, described below, to allow communication between window controller **114** and memory device **292**. Furthermore, in such an embodiment, the electrical signal input to electrical input **256** can be internally connected or coupled (within IGU **102**) to either electrical input **252** or **254** or to the bus bars **242** or **244** in such a way as to enable the electrical potential of one or more of those elements to be remotely measured (sensed). This can allow window controller **114** to compensate for a voltage drop on the connecting wires from the window controller **114** to the electrochromic device **220**.

[0057] In some embodiments, the window controller **114** can be immediately attached (e.g., external to the IGU **102** but inseparable by the user) or integrated within the IGU **102**. For example, U.S. patent application Ser. No. 13/049,750 (Attorney Docket No. SLDMP008) naming Brown et al. as inventors, titled ONBOARD CONTROLLER FOR MULTISTATE WINDOWS and filed 16 Mar. 2011, incorporated by reference herein, describes in detail various embodiments of an "onboard" controller. In such an embodiment, electrical input **252** can be connected to the positive output of an external DC power source. Similarly, electrical input **254** can be connected to the negative output of the DC power source. As described below, however, electrical inputs **252** and **254** can, alternately, be connected to the outputs of an external low voltage AC power source (e.g., a typical 24 V AC transformer common to the HVAC industry). In such an embodiment, electrical inputs/outputs **258** and **260** can be connected to the communication bus between window controller **114** and the network controller **112** as described below. In this embodiment, electrical input/output **256** can be eventually (e.g., at the power source) connected with the earth ground (e.g., Protective Earth, or PE in Europe) terminal of the system.

[0058] As just described, although the voltages plotted in FIG. **3** are expressed as DC voltages, in some embodiments, the voltages actually supplied by the external power source are AC voltage signals, In some other embodiments, the supplied voltage signals are converted to pulse-width modulated voltage signals. However, as described below with reference to FIG. **4**, the voltages actually "seen" or applied to the bus bars **242** and **244** are effectively DC voltages. The frequency of the oscillations of the applied voltage signal can depend on various factors including the leakage current of the electrochromic device **220**, the sheet resistance of the conductive layers **230** and **238**, the desired end or target state (e.g., % T), or a critical length of a part (e.g., the distance between bus bars **242** and **244**). Typically, the voltage oscillations applied at terminals **246** and **248** are in the range of approximately 1 Hz to 1 MHz, and in particular embodiments, approximately 100 kHz. The amplitude of the oscillations also can depend on numerous factors including the desired level of the desired intermediate target state. However, in some example applications, the amplitude of the applied voltage oscillations can be in the range of approximately 0 volts (V) to 24 V while, as described below, the amplitude of the DC voltage actually applied to bus bars **240** and **242** can be in the range of approximately 0.01 V and 10 V, and in some applications, in the range of approximately 0.5 V and 3 V. In various embodiments, the oscillations have asymmetric residence times for the darkening (e.g., tinting) and lightening (e.g., bleaching) portions of a period. For example, in some embodiments, transitioning from a first less transparent state to a second more transparent state requires more time than the reverse; that is, transitioning from the more transparent second state to the less transparent first state. As will be described below, a controller can be designed or configured to apply a driving voltage meeting these requirements.

[0059] The oscillatory applied voltage control allows the electrochromic device **220** to operate in, and transition to and from, one or more intermediate states without any necessary modification to the electrochromic device stack **220** or to the transitioning time. Rather, window controller **114** can be configured or designed to provide an oscillating drive voltage of appropriate wave profile, taking into account such factors as frequency, duty cycle, mean voltage, amplitude, among other possible suitable or appropriate factors. Additionally, such a level of control permits the transitioning to any intermediate state over the full range of optical states between the two end states. For example, an appropriately configured controller can provide a continuous range of transmissivity (% T) which can be tuned to any value between end states (e.g., opaque and bleached end states).

[0060] To drive the device to an intermediate state using the oscillatory driving voltage, as described above, a controller could simply apply the appropriate intermediate voltage. However, there are more efficient ways to reach the intermediate optical state. This is partly because high driving voltages can be applied to reach the end states but are traditionally not applied to reach an intermediate state. One technique for increasing the rate at which the electrochromic device **220** reaches a desired intermediate state is to first apply a high voltage pulse suitable for full transition (to an end state) and then back off to the voltage of the oscillating intermediate state (just described). Stated another way, an initial low frequency single pulse (low in comparison to the frequency employed to maintain the intermediate state) of magnitude and duration chosen for the intended final state can be employed to speed the transition. After this initial pulse, a higher frequency voltage oscillation can be employed to sustain the intermediate state for as long as desired.

[0061] As described above, in some particular embodiments, each IGU **102** includes a plug-in component **250** that in some embodiments is "pluggable" or readily-removable from IGU **102** (e.g., for ease of maintenance, manufacture, or replacement). In some particular embodiments, each plug-in component **250** itself includes a window controller **114**. That is, in some such embodiments, each electrochromic device **220** is controlled by its own respective local window controller **114** located within plug-in component **250**. In some other embodiments, window controller **114** is integrated with another portion of frame **218**, between the glass panes in the secondary seal area, or within volume **226**. In some other embodiments, window controller **114** can be located external to IGU **102**. In various embodiments, each window controller **114** can communicate with the IGUs **102** it controls and drives, as well as communicate to other window controllers **114**, network controller **112**, BMS **110**, or other servers, systems, or devices (e.g., sensors), via one or more wired (e.g., Ethernet) networks or wireless (e.g., WiFi) networks, for example, via wired (e.g., Ethernet) interface **263** or wireless (WiFi) interface **265**. Embodiments having Ethernet or Wifi capabilities are also well-suited for use in residential homes and other smaller-scale non-commercial applications. Additionally, the communication can be direct or indirect, e.g., via an intermediate node between a master controller such as network controller **112** and the IGU **102**.

[0062] FIG. **4** shows a depiction of an example plug-in component **250** including a window controller **114**. In some embodiments, window controller **114** communicates with network controller **112** over a communication bus **262**. For example, communication bus **262** can be designed according to the Controller Area Network (CAN) vehicle bus standard. In such embodiments, first electrical input **252** can be connected to a first power line **264** while second electrical input **254** can be connected to a second power line **266**. In some embodiments, as described above, the power signals sent over power lines **264** and **266** are complementary; that is, collectively they represent a differential signal (e.g., a differential voltage signal). In some embodiments, line **268** is coupled to a system or building ground (e.g., an Earth Ground). In such embodiments, communication over CAN bus **262** (e.g., between microcontroller **274** and network controller **112**) may proceed along first and second communication lines **270** and **272** transmitted through electrical inputs/outputs **258** and **260**, respectively, according to the CANopen communication protocol or other suitable open, proprietary, or overlying communication protocol. In some embodiments, the communication signals sent over communication lines **270** and **272** are complementary; that is, collectively they represent a differential signal (e.g., a differential voltage signal).

[0063] In some embodiments, plug-in component **250** couples CAN communication bus **262** into window controller **114**, and in particular embodiments, into microcontroller **274**. In some such embodiments, microcontroller **274** is also configured to implement the CANopen communication protocol. Microcontroller **274** is also designed or configured (e.g., programmed) to implement one or more drive control algorithms in conjunction with pulse-width modulated amplifier or pulse-width modulator (PWM) **276**, smart logic **278**, and signal conditioner **280**. In some embodiments, microcontroller **274** is configured to generate a command signal $V_{COMMAND}$, e.g., in the form of a voltage signal, that is then transmitted to PWM **276**. PWM **276**, in turn, generates a pulse-width modulated power signal, including first (e.g., positive) component V_{PW1} and second (e.g., negative) component V_{PW2}, based on $V_{COMMAND}$. Power signals V_{PW1} and V_{PW2} are then transmitted over, for example, interface **288**, to IGU **102**, or more particularly, to bus bars **242** and **244** in order to cause the desired optical transitions in electrochromic device **220**. In some embodiments, PWM **276** is configured to modify the duty cycle of the pulse-width modulated signals such that the durations of the pulses in signals V_{PW1} and V_{PW2} are not equal: for example, PWM **276** pulses V_{PW1} with a first 60% duty cycle and pulses V_{PW2} for a second 40% duty cycle. The duration of the first duty cycle and the duration of the second duty cycle collectively represent the duration, t_{PWM} of each power cycle. In some embodiments, PWM **276** can additionally or alternatively modify the magnitudes of the signal pulses V_{PW1} and V_{PW2}.

[0064] In some embodiments, microcontroller **274** is configured to generate $V_{COMMAND}$ based on one or more factors or signals such as, for example, any of the signals received over CAN bus **262** as well as voltage or current feedback signals, V_{FB} and I_{FB} respectively, generated by PWM **276**. In some embodiments, microcontroller **274** determines current or voltage levels in the electrochromic device **220** based on feedback signals I_{FB} or V_{FB}, respectively, and adjusts $V_{COMMAND}$ according to one or more rules or algorithms to effect a change in the relative pulse durations (e.g., the relative durations of the first and second duty cycles) or amplitudes of power signals V_{PW1} and V_{PW2} to produce the voltage profiles described above with respect to FIG. **3**. Additionally or alternatively, microcontroller **274** can also adjust $V_{COMMAND}$ in response to signals received from smart logic **278** or signal conditioner **280**. For example, a conditioning signal V_{CON} can be generated by signal conditioner **280** in response to feedback from one or more networked or non-networked devices or sensors, such as, for example, an exterior photosensor or photodetector **282**, an interior photosensor or photodetector **284**, a thermal or temperature sensor **286**, or a tint command signal V_{TC}. For example, additional embodiments of signal conditioner **280** and V_{CON} are also described in U.S. patent application Ser. No. ______ (Attorney Docket No. SLDMP035) naming Brown as inventor, titled CONTROLLING TRANSITIONS IN OPTICALLY SWITCHABLE DEVICES and filed 17 Apr. 2012.

[0065] Referring back, V_{TC} can be an analog voltage signal between 0 V and 10 V that can be used or adjusted by users (such as residents or workers) to dynamically adjust the tint of an IGU **102** (for example, a user can use a control in a room or zone of building **104** similarly to a thermostat to finely adjust or modify a tint of the IGUs **102** in the room or zone) thereby introducing a dynamic user input into the logic within microcontroller **274** that determines $V_{COMMAND}$. For example, when set in the 0 to 2.5 V range, V_{TC} can be used to cause a transition to a 5% T state, while when set in the 2.51 to 5 V range, V_{TC} can be used to cause a transition to a 20% T state, and similarly for other ranges such as 5.1 to 7.5 V and 7.51 to 10 V, among other range and voltage examples. In some embodiments, signal conditioner **280** receives the aforementioned signals or other signals over a communication bus or interface **290**. In some embodiments, PWM **276** also generates $V_{COMMAND}$ based on a signal V_{SMART} received from smart logic **278**, as described below. In some embodiments, smart logic **278** transmits V_{SMART} over a communication bus such as, for example, an Inter-Integrated Circuit (I^2C) multi-master serial single-ended computer bus. In some other embodiments, smart logic **278** communicates with memory device **292** over a 1-WIRE device communications bus system protocol (by Dallas Semiconductor Corp., of Dallas, Tex.).

[0066] In some embodiments, microcontroller **274** includes a processor, chip, card, or board, or a combination of these, which includes logic for performing one or more control functions. Power and communication functions of microcontroller **274** may be combined in a single chip, for example, a programmable logic device (PLD) chip or field programmable gate array (FPGA), or similar logic. Such integrated circuits can combine logic, control and power functions in a single programmable chip. In one embodiment, where one pane **216** has two electrochromic devices **220** (e.g., on opposite surfaces) or where IGU **102** includes two or more panes **216** that each include an electrochromic device **220**, the logic can be configured to control each of the two electrochromic devices **220** independently from the other. However, in one embodiment, the function of each of the two electrochromic devices **220** is controlled in a synergistic fashion, for example, such that each device is controlled in order to complement the other. For example, the desired level of light transmission, thermal insulative effect, or other property can be controlled via a combination of states for each of the individual electrochromic devices **220**. For example, one electrochromic device may be placed in a colored state while the other is used for resistive heating, for example, via a transparent electrode of the device. In another example, the optical states of the two electrochromic devices are controlled so that the combined transmissivity is a desired outcome.

[0067] As described above, in some embodiments, microcontroller **274**, or window controller **114** generally, also can have wireless capabilities, such as wireless control and powering capabilities. For example, wireless control signals, such as radio-frequency (RF) signals or infra-red (IR) signals can be used, as well as wireless communication protocols such as WiFi (mentioned above), Bluetooth, Zigbee, EnOcean, among others, to send instructions to the microcontroller **274** and for microcontroller **274** to send data out to, for example, other window controllers **114**, network controller **112**, or directly to BMS **110**. In various embodiments, wireless communication can be used for at least one of programming or operating the electrochromic device **220**, collecting data or receiving input from the electrochromic device **220** or the IGU **102** generally, collecting data or receiving input from sensors, as well as using the window controller **114** as a relay point for other wireless communications. Data collected from IGU **102** also can include count data, such as a number of times an electrochromic device **220** has been activated (cycled), an efficiency of the electrochromic device **220** over time, among other useful data or performance metrics.

[0068] Window controller **114** also can have wireless power capability. For example, window controller **114** can have one or more wireless power receivers that receive transmissions from one or more wireless power transmitters as well as one or more wireless power transmitters that transmit power transmissions enabling window controller **114** to receive power wirelessly and to distribute power wirelessly to electrochromic device **220**. Wireless power transmission includes, for example, induction, resonance induction, RF power transfer, microwave power transfer, and laser power transfer. For example, U.S. patent application Ser. No. 12/971,576 (Attorney Docket No. SLDMP003) naming Rozbicki as inventor, titled WIRELESS POWERED ELECTROCHROMIC WINDOWS and filed 17 Dec. 2010, incorporated by reference herein, describes in detail various embodiments of wireless power capabilities.

[0069] In order to achieve a desired optical transition, the pulse-width modulated power signal is generated such that the positive component V_{PW1} is supplied to, for example, bus bar **244** during the first portion of the power cycle, while the negative component V_{PW2} is supplied to, for example, bus bar **242** during the second portion of the power cycle. As described above, the signals V_{PW1} and V_{PW2} are effectively DC signals as seen by electrochromic device **220** as a result of, for example, the inductance of series inductors **312** and **314** (see FIGS. **5**A and **5**B) within PWM **276**, or of various other components of window controller **114** or electrochromic device **220** in relation to the frequency of the pulse-width modulated power signals V_{PW1} and V_{PW2}. More specifically, referring now to FIG. **5**C, the inductance is such that the inductors **312** and **314** effectively filter out the highest frequency components in the voltages V_{TEC} and V_{ITO}, the voltages applied to the first and second conductive layers **230** and **238**, respectively, and thus the effective voltage V_{EFF} applied across the bus bars **242** and **244** is effectively constant when the first and second duty cycles are constant.

[0070] In some cases, depending on the frequency (or inversely the duration) of the pulse-width modulated signals, this can result in bus bar **244** floating at substantially the fraction of the magnitude of V_{PW1} that is given by the ratio of the duration of the first duty cycle to the total duration t_{PWM} of the power cycle. Similarly, this can result in bus bar **242** floating at substantially the fraction of the magnitude of V_{PW2} that is given by the ratio of the duration of the second duty cycle to the total duration t_{PWM} of the power cycle. In this way, in some embodiments, the difference between the magnitudes of the pulse-width modulated signal components V_{PW1} and V_{PW2} is twice the effective DC voltage across terminals **246** and **248**, and consequently, across electrochromic device **220**. Said another way, in some embodiments, the difference between the fraction (determined by the relative duration of the first duty cycle) of V_{PW1} applied to bus bar **244** and the fraction (determined by the relative duration of the second duty cycle) of V_{PW2} applied to bus bar **242** is the effective DC voltage V_{EFF} applied to electrochromic device **220**. The current IEFF through the load—electromagnetic device **220**—is roughly equal to the effective voltage VEFF divided by the effective resistance (represented by resistor **316**) or impedance of the load.

[0071] In some embodiments, the relative durations of the first and second duty cycles—the durations of the V_{PW1} and V_{PW2} pulses, respectively—are based on $V_{COMMAND}$. In some embodiments, in order to generate the two opposing polarity signals V_{PW1} and V_{PW2}, PWM **276**, and IGU **102** generally, is designed according to an H-bridge configuration **294**. In some embodiments, PWM **276** is constructed using four transistors **296**, **298**, **300**, and **302** powered by a supply voltage V_{SUPPLY} as shown in FIG. **5**A. Transistors **296**, **298**, **300**, and **302** can be, for example, metal-oxide-semiconductor field-effect transistors (MOSFETs). In some implementations, transistors **296** and **300** are n-type MOSFET transistors while transistors **298** and **302** are p-type MOSFET transistors. In some implementations, during a first portion of operation, the gate of transistor **296** receives signal A, while the gate of transistor **302** receives its complement $\overline{A}$ such that when signal A is high $\overline{A}$ is low, and thus, transistors **296** and **302** are conducting while transistors **298** and **300** are not. In this configuration, current from V_{SUPPLY} is transferred through transistor **296**, through the load, including electromagnetic device **220**, through transistor **302** and ultimately to ground. This results in a power signal pulse V_{PW1} during this portion of operation. Similarly, in some implementations, during a second portion of operation, the gate of transistor **300** receives signal B, while the gate of transistor **298** receives the complement of signal B, and thus, transistors **300** and **298** are conducting while transistors **296** and **302** are not. In this configuration, current from V_{SUPPLY} is transferred through transistor **300**, through the load, including electromagnetic device **220**, through transistor **298** and ultimately to ground. This results in a power signal pulse V_{PW2} during this portion of operation.

[0072] FIG. **5**B shows a depiction of an equivalent H-bridge configuration representation **294** in which switches **304**, **306**, **308**, and **310** represent transistors **296**, **298**, **300**, and **302**. Based on $V_{COMMAND}$, H-Bridge **294** synchronously transitions from a first state (represented by solid arrows), to generate the first duty cycle (V_{PW1} pulse), to a second state (represented by dotted arrows), to generate the second duty cycle (V_{PW2} pulse). For example, in the first state the switches **304** and **310** can be closed (e.g., transistors **296** and **302** are conducting) and switches **306** and **308** can be open (e.g., transistors **298** and **300** are not conducting). Similarly, in the second state switches **306** and **308** can be closed (e.g., transistors **298** and **300** are conducting) and switches **304** and **310** can be open (e.g., transistors **296** and **302** are not conducting). As described above, in some embodiments, the first and second duty cycles of the pulse-width modulated signals V_{PW1} and V_{PW2} are not symmetric; that is, neither the first nor the second duty cycle is a 50% duty cycle. For example, in the case of a 100 kHz signal, V_{PW1} could be pulsed for more than half the time constant t_{PWM} (e.g., more than 5 micro-seconds (μs)) followed by V_{PW2} being pulsed for less than half the time constant t_{PWM} (e.g., less than 5 μs), and so on resulting in a first duty cycle of greater than 50% and a second duty cycle of less than 50%. As a result, even when the magnitudes of V_{PW1} and V_{PW2} are equal and remain constant, the effective voltage at the load (e.g., electrochromic device **220**) can be changed from the static DC voltage generated across the load when the duty cycles are symmetric (e.g., $(V_{PW1}-V_{PW2})/2$). Thus, by varying the duty cycles such that they are non-symmetric, a voltage ramp (e.g., ramps **301**, **305**, **309**, or **313**) can be applied across the electrochromic device **220**. It is this DC voltage that drives the additional ion transfer that causes the optical transitions in electrochromic device **220**. Additionally, the duty cycles also can be varied such that a static DC voltage is developed to compensate, for example, for ions trapped in defects.

[0073] This method—pulse-width modulation—of applying the DC voltage across electrochromic device **220** provides increased protection from damage as compared to, for example, devices that simply use a battery or other DC voltage source. DC voltages sources such as batteries can result in initial current spikes that can permanently damage the electrochromic device **220** in the form of, for example, defects that trap ions. Furthermore, by adjusting the relative durations of the pulses V_{PW1} and V_{PW2} of each duty cycle based on the command signal $V_{COMMAND}$, the command signal $V_{COMMAND}$ can be used to change the applied DC voltage at the electrochromic device **220** (e.g., to produce ramps **301**, **305**, **309**, and **313**) continuously without changing the magnitude of the supply voltage V_{SUPPLY}.

[0074] Additionally, in some embodiments, the transistors **296**, **298**, **300**, and **302** (or switches **304**, **306**, **308**, and **310**) can be configured at certain times to all be insulating (or open) enabling certain embodiments of electrochromic device **220** to hold at a desired optical state without an applied voltage. In some embodiments, this configuration can be used to save energy by not drawing power from V_{SUPPLY}, which is typically the main electrical power for the building **104**. In such a configuration, the electrochromic device **220** could be left floating. In some other embodiments, in this configuration, the electrochromic device **220** could receive power from another source to hold the desired optical state, such as from, for example, a photovoltaic cell on or within the IGU **102**. Similarly, in some embodiments, the transistors **296**, **298**, **300**, and **302** (or switches **304**, **306**, **308**, and **310**) can be configured at certain times to all be conducting (or closed) and shorted to ground enabling a discharge of electrochromic device **220**. In such embodiments, appropriately sized resistors can be arranged within the H-bridge configuration **294** between each transistor or switch and ground to ease or to make more graceful the discharge of the electrochromic device **220**.

[0075] In some embodiments, microcontroller **274** is programmed to darken or lighten (e.g., change the % T of) the windows on various sides, surfaces, or zones of a building **104** at certain times of day as well as according to certain times of year, according to certain conditions or in response to other feedback, or based on manual input. For example, microcontroller **274** can be programmed to darken east-facing IGUs **102** at 9:00 am for 1 hour during winter months while at the same time lightening west-facing IGUs. As another example, microcontroller **274** can be programmed to darken an IGU **102** based on light intensity detected outside by a photodetector. In some such embodiments, microcontroller **274** can be programmed to continue to darken the IGU **102** as long as light detected inside by a second photodetector remains above a threshold amount of interior light intensity, or until a lighting system **107** or network controller **112** transmits an input command to window controller **114** commanding the window controller **114** to stop tinting such that the lighting system can remain off or at a lower energy operational level while enabling workers to have enough ambient light or other light to continue working. As another example, microcontroller **274** can be programmed to darken an IGU **102** based on a manual input from a user, for example, in his or her own office relative to a baseline % T commanded by network controller **112**.

[0076] In some embodiments, the drive or device parameters for a given IGU **102** are stored within the IGU **102**, in the frame **218**, or in an internal or external electrical connection assembly wired to the frame or IGU. In particular embodiments, the drive and device parameters for the IGU **102** are stored within the plug-in component **250**. In some particular embodiments, the drive and device parameters are stored within non-volatile memory device **292**, which may be included within or be external to window controller **114** or plug-in component **250**, but which, in particular embodiments, is located within IGU **102**. In some embodiments, upon inserting and connecting plug-in component **250** into IGU **102** or upon powering or otherwise activating window controller **114**, memory device **292** transfers or loads the drive or device parameters to a fast dynamic memory (e.g., a random access memory (RAM), DRAM, NVRAM, or other flash memory) location within microcontroller **274** for quick access by microcontroller **274**. In some embodiments, window controller **114** can periodically poll for memory device **292**, and when window controller **114** detects memory device **292**, it can transfer the drive parameters to the RAM or other faster memory location within microcontroller **274**. In some embodiments, memory device **292** can be a chip (e.g., computer chip having processing or logic capabilities in addition to storing capabilities) designed according to the 1-WIRE device communications bus system protocol. In some embodiments, memory device **292** can include solid state serial memory (e.g. EEPROM (E^2PROM), I^2C, or SPI), which can also be programmable memory.

[0077] In some embodiments, the drive parameters can be used by microcontroller **274** in conjunction with one or more voltage profiles, current algorithms, or voltage and current operating instructions for transitioning electrochromic device **220** from a first optical state to a second optical state. In some embodiments, microcontroller **274** uses the drive parameters to calculate or select a voltage profile (e.g., a portion of voltage profile **300**) and, using the voltage profile, to generate the associated command voltages $V_{COMMAND}$ to achieve the calculated or selected voltage profile. For example, in some embodiments, a voltage profile can be selected from a number of pre-determined profiles (e.g., stored or loaded within microcontroller **274** or other suitable accessible memory location) based on one or more of a multitude of drive parameters including, for example, a current temperature outside, a current temperature inside, a % T of the first or current optical state, a % T of the second or desired optical state, or a desired transition or ramp (e.g., ramp **301** or **309**) rate, as well as various initial driving voltages, holding voltages, among other parameters. Some drive parameters, such as % T and ramp rate, can be generated prior to manufacture of the device, for example, based theoretically or empirically on a number of device parameters including, for example, the size, shape, thickness, age, or number of cycles experienced by electrochromic pane **216**. In some embodiments, each voltage profile can, in turn, be determined theoretically or empirically prior to manufacture of the device based on the drive and device parameters.

[0078] In some embodiments, microcontroller **274** calculates $V_{COMMAND}$ values during operation of IGU **102** based on the selected voltage profile and drive parameters. In some other embodiments, microcontroller **274** selects discrete $V_{COMMAND}$ values previously calculated and stored based on the selected voltage profile and drive parameters. However, as described above, in some cases $V_{COMMAND}$ can additionally be modified according to one or more other input or feedback signals, such as signals V_{CON}, V_{FB}, or I_{FB}, for example, based on input from temperature sensors or photodetectors, voltage feedback from electrochromic device **220** or PWM **276**, or current feedback from electrochromic device **220** or PWM **276**. For example, as the outside environment becomes brighter, the microcontroller **274** can be programmed to darken the electrochromic device **220**, but as the electrochromic device **220** darkens the temperature of the device can rise significantly as a result of the increased photon absorption and, because the tinting of the electrochromic device **220** is dependent on the temperature of the device, the tinting could change if not compensated for by, for example, modifying $V_{COMMAND}$ in response to a signal, such as V_{CON}, V_{FB}, or I_{FB}. Furthermore, in some cases, the voltage profiles themselves stored in the microcontroller **274** or memory device **292** can be modified temporarily (e.g., in RAM) or permanently/perpetually (e.g., in memory device **292**) based on signals received from, for example, network controller **112**.

[0079] In some embodiments, the drive and device parameters stored within a given IGU **102** can be transmitted, for example via CAN communication bus **262**, to network controller **112** periodically, in response to certain conditions, or at other appropriate times. Additionally, in some embodiments, drive parameters, voltage profiles, current algorithms, location or zone membership parameters (e.g. at what location or in what zone of the building **104** is this IGU **102** and controller **114**), digital output states, and generally various digital controls (tint, bleach, auto, reboot, etc.) can be transmitted from network controller **112** to window controller **114** and microcontroller **274** as well as to memory device **292** for storage and subsequent use. Network controller **112** also can be configured to transmit to microcontroller **274** or memory device **292** information relating to a location of the IGU **102** or building **104** (e.g., a latitude, longitude, or region parameter), a time of day, or a time of year. Additionally, the drive or device parameters can contain information specifying a maximum voltage or current level that can safely be applied to electrochromic device **220** by a window controller **114**. In some embodiments, network controller **112** can be programmed or configured to compare the actual current being output to a particular IGU **102** and electrochromic device **220** to the current expected to be output to the IGU **102** based on the device or drive characteristics (e.g., transmitted from the memory device **292** to the microcontroller **274** and to the network controller **112**), or otherwise determine that they are different or different beyond a threshold range of acceptability, and thereafter signal an alarm, shut off power to the IGU **102**, or take some other action to, for example, prevent damage to the electrochromic device **220**. Furthermore, memory device **292** also can include cycling or other performance data for electrochromic device **220**.

[0080] In some embodiments, the drive parameters are organized into an n-dimensional data array, structure, or matrix. FIG. **6** shows an example **3**-dimensional data structure **600** of drive parameters for driving an electrochromic device **220**. Data structure **600** is a 3-by-4-by-4 matrix of elements **624**. A voltage profile is associated with each element **624**. For example, matrix element (0, 3, 3) is associated with voltage profile **626** while matrix element (1, 0, 1) is associated with voltage profile **628**. In the illustrated example, each matrix element **624** is specified for three drive parameters that define the element **624** and thus the corresponding voltage profile. For example, each matrix element **624** is specified for a given temperature range value (e.g., <0 degrees Celsius, 0-50 degrees Celsius, or >50 degrees Celsius), a current % T value (e.g., 5%, 20%, 40%, or 70%), and a target % T value (e.g., 5%, 20%, 40%, or 70%).

[0081] In some embodiments, each voltage profile includes one or more specific parameters (e.g., ramp rate, target voltage, and applied voltage duration) or a combination of one or more specific parameters. For example, each voltage profile can include one or more specific parameters for each of one or more profile portions or zones (e.g., S1, S2, S3, S4) for making the desired optical transition from the current % T, at a current temperature, to a target % T at the same or a different temperature. For example, voltage profile **626** contains parameters to transition a electrochromic window from 70% T to 5% T, at a temperature less than zero degrees Celsius. To complete this transition, voltage profile **626** provides an initial ramp S1 (e.g., a rate in mV/s for a specified time duration or to a specified target voltage value), a first hold S2 (e.g., specified in V for a specified time duration), a second ramp S3 (e.g., a rate in mV/s for a specified time duration or to a specified target voltage value), and a fourth hold S4 (e.g., a specified holding voltage to maintain the target % T). Similarly, voltage profile **628** can provide a different initial ramp S1 (e.g., a flatter voltage ramp), a different hold S2 (e.g., a longer hold at this holding voltage), a different second ramp S3 (e.g., a shorter but steeper ramp), and a different fourth hold S4 (e.g., the holding voltage to maintain the target % T) based on the different drive parameters associated with that element (in this example, transitioning from 20% T to 70% T at a temperature of between zero and fifty degrees Celsius).

[0082] Each voltage profile in the n-dimensional data matrix may, in some implementations, be unique. For example, because even at the same temperature, transitioning from 70% T to 5% T often cannot be achieved by a simple reversal of the voltage profile used to transition from 5% T to 70% T, a different voltage profile may be required or at least desirable. Put another way, by virtue of the device architecture and materials, bleaching is not simply the reverse of coloring; devices often behave differently for each transition due to differences in driving forces for ion intercalation and deintercalation to and from the electrochromic materials.

[0083] In other embodiments, the data structure can have another number of dimensions n, that is, be more or less granular than matrix **600**. For example, in some embodiments, more drive parameters can be included. In one embodiment, 288 drive parameters are used including three temperature range values, four current % T values, and four target % T values resulting in a 3-dimensional matrix having 36 matrix elements and 72 corresponding voltage profiles, each of which has one or more specific parameters (e.g., ramp rate, target voltage, and applied voltage duration, or a combination of one or more specific parameters) for each of one or more profile portions or zones (e.g., S1, S2, S3, . . .). In other embodiments, the number of temperature bins or ranges of values can be increased or decreased (e.g., 5 or more temperature range values), the number of possible current % T values can be increased or decreased (e.g., there could be eight possible optical states such as 5% T, 15% T, 25% T, 35% T, 45% T, 55% T, 65% T, and 75% T), the number of possible target % T values can be increased or decreased (e.g., to match the possible current % T states), among other suitable modifications. Additionally, the voltage profiles associated with each element of the matrix may have more than four profile portions or zones (e.g. S1-S8) with associated parameters. In some embodiments, for example, 8 zones are permitted to be specified for each voltage profile, 12 voltage profiles are permitted to be specified for the current ambient temperature range, and 3 sets of 12 profiles are permitted to be specified for the 3 temperature ranges specified. That combines to 288 parameters for the voltage profile alone. Additional information also can be stored within memory device **292**.

[0084] Additionally, in some embodiments in which a single window controller **114** controls and drives two or more IGUs **102**, each IGU **102** can still include its own memory device **292**. In such embodiments, each memory device **292** transmits its drive parameters to the single window controller **114** and window controller **114**, and particularly microcontroller **274**, uses the drive parameters for the IGU having the smallest size (and hence the lowest power requirements) to calculate $V_{COMMAND}$ as an added safety to prevent damage. For example, window controller **114** can include logic to identify the IGU size (e.g., length, width, thickness, surface area, etc.) or the IGU **102** can store size information within memory that can then be read by controller **114**, e.g., by microcontroller **274**. In some embodiments, the microcontroller can compare the drive parameters for two coupled IGUs **102**, determine that incompatible IGUs have been connected based on the compared drive parameters, and send an alarm to the BMS **110** or network controller **112**. In some embodiments, the microcontroller **274** can use the drive parameters of the parallel-connected IGUs **102** to determine a safe maximum current drive for the aggregate group to further prevent damage to the IGUs.

[0085] Additionally, in some embodiments, each window controller **114** also can be configured to compensate for transmission losses such as, for example, voltage drops across bus bars **242** or **244** or down other transmission lines in between PWM **276** and bus bars **242** and **244**. For example, because PWM **276** (or some other component of window controller **114** or IGU **102**) can be configured to provide current feedback (e.g., I_{FB}), microcontroller **274** (or some other logic component of window controller **114**) can be configured to calculate the voltage drop caused by transmission losses. For example, resistor R_T in FIG. **4** models the transmission line resistance while resistor R_S in FIG. **4** models a series resistance. R_T and R_S are inherent to the transmission line or other system components. As current is supplied from the window controller **114** it passes through R_T, through IGU **102**, and through R_S, before returning to the window controller **114** closing the loop. Because the current through R_T, IGU **102**, and R_S is known—by using I_{FB} to set a fixed current output of the PWM **276** (e.g. 1 Ampere)—and because the differential amplifier **422** can be used to effectively measure the voltage drop across R_S, the values of R_S and R_T can be calculated. For all intents and purposes, R_T can be approximated by R_S. Now, during normal operation of the device **220**, because the current demand through the IGU **102** is not constant, knowing the effective resistance of the combination Rs+Rt allows for dynamically adjusting the voltage output from the window controller **114** so the developed voltage V_{ACTUAL} at the terminals of the IGU **102** can be calculated as $V_{ACTUAL}=V_{TARGET}+I_{ACTUAL}*(R_S+R_T)$ or $V_{ACTUAL}=V_{TARGET}+2V(R_S)$, where $V(R_S)$ is the voltage drop across R_S.

[0086] In one or more aspects, one or more of the functions described may be implemented in hardware, digital electronic circuitry, analog electronic circuitry, computer software, firmware, including the structures disclosed in this specification and their structural equivalents thereof, or in any combination thereof Certain embodiments of the subject matter described in this specification also can be implemented as one or more computer programs, i.e., one or more modules of computer program instructions, encoded on a computer storage media for execution by, or to control the operation of, data processing apparatus.

[0087] Various modifications to the embodiments described in this disclosure may be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other implementations without departing from the spirit or scope of this disclosure. Thus, the claims are not intended to be limited to the implementations shown herein, but are to be accorded the widest scope consistent with this disclosure, the principles and the novel features disclosed herein. Additionally, a person having ordinary skill in the art will readily appreciate, the terms "upper" and "lower" are sometimes used for ease of describing the figures, and indicate relative positions corresponding to the orientation of the figure on a properly oriented page, and may not reflect the proper orientation of the devices as implemented. Additionally, as used herein, "or" may imply "and" as well as "or;" that is, "or" does not necessarily preclude "and," unless explicitly stated or implicitly implied.

[0088] Certain features that are described in this specification in the context of separate embodiments also can be implemented in combination in a single implementation.

Conversely, various features that are described in the context of a single implementation also can be implemented in multiple implementations separately or in any suitable subcombination. Moreover, although features may be described above as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination can in some cases be excised from the combination, and the claimed combination may be directed to a subcombination or variation of a subcombination.

[0089] Similarly, while operations are depicted in the drawings in a particular order, this does not necessarily mean that the operations are required to be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results. Further, the drawings may schematically depict one more example processes in the form of a flow diagram. However, other operations that are not depicted can be incorporated in the example processes that are schematically illustrated. For example, one or more additional operations can be performed before, after, simultaneously, or between any of the illustrated operations. In certain circumstances, multitasking and parallel processing may be advantageous. Moreover, the separation of various system components in the implementations described above should not be understood as requiring such separation in all implementations, and it should be understood that the described program components and systems can generally be integrated together in a single software product or packaged into multiple software products. Additionally, other implementations are within the scope of the following claims. In some cases, the actions recited in the claims can be performed in a different order and still achieve desirable results.

What is claimed is:

1. A window controller comprising:

a command-voltage generator configured to generate a command voltage signal;

a pulse-width-modulated-signal generator configured to generate a pulse-width-modulated signal based on the command voltage signal, the pulse-width-modulated signal configured to drive an optically-switchable device on a substantially transparent substrate, wherein:

the pulse-width-modulated signal comprises a first power component having a first duty cycle and a second power component having a second duty cycle;

the first power component is configured to deliver a first pulse during each active portion of the first duty cycle;

the second power component is configured to deliver a second pulse during each active portion of the second duty cycle; and

during operation, the first pulses are applied to a first conductive electrode layer of the optically-switchable device and the second pulses are applied to a second conductive electrode layer of the optically-switchable device; wherein the relative durations of the active portions of the first and second duty cycles and the relative durations of the first and second pulses are adjusted to result in a change in an effective DC voltage applied across the optically-switchable device.

2. The window controller of claim **1**, wherein the substantially transparent substrate is configured in an IGU.

3. The window controller of claim **2**, wherein the window controller is located at least partially within a seal of the IGU.

4. The window controller of claim **2**, wherein the optically-switchable device is an electrochromic device formed on a surface of the substantially transparent substrate and adjacent an interior volume of the IGU.

5. The window controller of claim **4**, wherein the electrochromic device is entirely comprised of inorganic solid-state materials.

6. The window controller of claim **1**, wherein:

the first duty cycle has a first time period and a first voltage magnitude;

the second duty cycle has a second time period and a second voltage magnitude;

the first time period equals the second time period; and

the first voltage magnitude equals the second voltage magnitude.

7. The window controller of claim **6**, further comprising first and second inductors that couple the first and second power components to the optically-switchable device, wherein the voltage applied across the optically-switchable device resulting from the applied first and second power components is effectively a DC voltage.

8. The window controller of claim **7**, wherein:

the active portion of the first duty cycle comprises a first fraction of the first time period; and

the active portion of the second duty cycle comprises a second fraction of the second time period.

9. The window controller of claim **8**, wherein:

the magnitude of the voltage applied to a first conductive layer of the optically-switchable device is substantially proportional to the product of the first fraction and the first voltage magnitude;

the magnitude of the voltage applied to a second conductive layer of the optically-switchable device is substantially proportional to the product of the second fraction and the second voltage magnitude; and

the effective DC voltage applied across the optically-switchable device is substantially equal to the difference between the magnitude of the voltage applied to the first conductive layer and the magnitude of the voltage applied to the second conductive layer.

10. The window controller of claim **1**, wherein the command-voltage generator includes a microcontroller configured to generate the command voltage signal.

11. The window controller of claim **10**, wherein the microcontroller generates the command voltage signal based at least in part on a voltage feedback signal that is itself based on an effective DC voltage applied across the optically-switchable device.

12. The window controller of claim **10**, wherein the microcontroller generates the command voltage signal based at least in part on a current feedback signal that is itself based on a detected current transmitted through the optically-switchable device.

13. The window controller of claim **10**, further comprising a memory device configured to store one or more drive parameters.

14. The window controller of claim **13**, wherein the drive parameters include one or more of a current outside temperature, a current inside temperature, a current transmissivity value of the electrochromic device, a target transmissivity value of the electrochromic device, and a transition rate.

15. The window controller of claim **14**, wherein the microcontroller is further configured to modify the command voltage signal based on one or more other input, feedback, or control signals.

16. The window controller of claim **15**, wherein the microcontroller modifies the command voltage signal based at least in part on a voltage feedback signal that is itself based on a detected actual level of the effective DC voltage applied across the optically-switchable device.

17. The window controller of claim **15**, wherein the microcontroller modifies the command voltage signal based at least in part on a current feedback signal that is itself based on a detected current transmitted through the optically-switchable device.

18. The window controller of claim **15**, wherein the window controller further comprises one or more communication interfaces.

19. The window controller of claim **18**, wherein:

the window controller is configured to communicate with a network controller;

the network controller is configured to communicate and control a plurality of window controllers; and

the microcontroller is configured to modify the command voltage signal based on input from the network controller.

20. The window controller of claim **19**, wherein:

the window controller or network controller is configured to communicate with a building management system; and

the microcontroller is configured to modify the command voltage signal based on input from the building management system.

21. The window controller of claim **19**, wherein:

the window controller or network controller is configured to communicate with one or more lighting systems, heating systems, cooling systems, ventilation systems, power systems, and/or security systems; and

the microcontroller is configured to modify the command voltage signal based on input from the one or more lighting systems, heating systems, cooling systems, ventilation systems, power systems, and/or security systems.

22. The window controller of claim **19**, wherein:

the window controller is configured to communicate with one or more photodetectors; and

the microcontroller is configured to modify the command voltage signal based on input from the one or more photodetectors.

23. The window controller of claim **19**, wherein:

the window controller is configured to communicate with one or more temperature sensors; and

the microcontroller is configured to modify the command voltage signal based on input from the one or more temperature sensors.

24. The window controller of claim **19**, wherein:

the window controller or network controller is configured to communicate with one or more manual user-input devices; and

the microcontroller is configured to modify the command voltage signal based on input from one or more of the manual user-input devices.

25. A system comprising:

a plurality of windows, each window comprising an optically-switchable device on a substantially transparent substrate;

a network controller configured to control a plurality of window controllers;

a plurality of window controllers, each window controller comprising:

a command-voltage generator configured to generate a command voltage signal; and

a pulse-width-modulated-signal generator configured to generate a pulse-width-modulated signal based on the command voltage signal, the command voltage signal being based at least in part and at least at certain times on an input received from the network controller, the pulse-width-modulated signal configured to drive a respective one or more of the optically-switchable devices,

one or more communication interfaces that enable the window controller to communicate with the network controller;

wherein:

the pulse-width-modulated signal comprises a first power component having a first duty cycle and a second power component having a second duty cycle;

the first power component is configured to deliver a first pulse during each active portion of the first duty cycle;

the second power component is configured to deliver a second pulse during each active portion of the second duty cycle; and

during operation, the first pulses are applied to a first conductive electrode layer of the optically-switchable device and the second pulses are applied to a second conductive electrode layer of the optically-switchable device; wherein the relative durations of the active portions of the first and second duty cycles and the relative durations of the first and second pulses are adjusted to result in a change in an effective DC voltage applied across the optically-switchable device.

26. The system of claim **25**, wherein each substantially transparent substrate is configured in an IGU.

27. The system of claim **26**, wherein one or more of the window controllers are located at least partially within a seal of a respective IGU.

28. The system of claim **26**, wherein the optically-switchable device is an electrochromic device formed on a surface of the substantially transparent substrate and adjacent an interior volume of the IGU.

29. The system of claim **25**, wherein, for each window controller:

the first duty cycle has a first time period and a first voltage magnitude;

the second duty cycle has a second time period and a second voltage magnitude;

the first time period equals the second time period; and

the first voltage magnitude equals the second voltage magnitude.

30. The system of claim **29**, wherein each window controller further comprises first and second inductors that couple the first and second power components to the optically-switchable device, wherein the voltage applied across the optically-switchable device resulting from the applied first and second power components is effectively a DC voltage.

31. The system of claim **30**, wherein:

the active portion of the first duty cycle comprises a first fraction of the first time period; and the active portion of the second duty cycle comprises a second fraction of the second time period.

32. The system of claim **31**, wherein:

the magnitude of the voltage applied to a first conductive layer of the optically-switchable device is substantially proportional to the product of the first fraction and the first voltage magnitude;

the magnitude of the voltage applied to a second conductive layer of the optically-switchable device is substantially proportional to the product of the second fraction and the second voltage magnitude; and

the effective DC voltage applied across the optically-switchable device is substantially equal to the difference between the magnitude of the voltage applied to the first conductive layer and the magnitude of the voltage applied to the second conductive layer.

33. The system of claim **25**, wherein the command-voltage generator of each window controller includes a microcontroller configured to generate the command voltage signal.

34. The system of claim **33**, wherein the microcontroller generates the respective command voltage signal based at least in part on a voltage feedback signal that is itself based on an effective DC voltage applied across the respective optically-switchable device.

35. The system of claim **33**, wherein the microcontroller generates the respective command voltage signal based at least in part on a current feedback signal that is itself based on a detected current transmitted through the respective optically-switchable device.

36. The system of claim **33**, wherein each window controller further comprises a memory device configured to store one or more drive parameters.

37. The system of claim **36**, wherein the drive parameters include one or more of a current outside temperature, a current inside temperature, a current transmissivity value of the electrochromic device, a target transmissivity value of the electrochromic device, and a transition rate.

38. The system of claim **37**, wherein the microcontroller modifies the command voltage signal based at least in part on a voltage feedback signal that is itself based on a detected actual level of the effective DC voltage applied across the respective optically-switchable device.

39. The system of claim **37**, wherein the microcontroller modifies the command voltage signal based at least in part on a current feedback signal that is itself based on a detected current transmitted through the respective optically-switchable device.

40. The system of claim **33**, wherein:

the network controller is configured to communicate with a building management system; and

the microcontroller of each window controller is configured to modify the command voltage signal based on input from the building management system.

41. The system of claim **33**, wherein:

the network controller is configured to communicate with one or more lighting systems, heating systems, cooling systems, ventilation systems, power systems, and/or security systems; and

the microcontroller of each window controller is configured to modify the command voltage signal based on input from the one or more lighting systems, heating systems, cooling systems, ventilation systems, power systems, and/or security systems.

42. The system of claim **33**, wherein:

each window controller is configured to communicate with one or more photodetectors; and

the respective microcontroller is configured to modify the command voltage signal based on input from the one or more photodetectors.

43. The system of claim **33**, wherein:

each window controller is configured to communicate with one or more temperature sensors; and

the respective microcontroller is configured to modify the command voltage signal based on input from the one or more temperature sensors.

44. The system of claim **33**, wherein:

the network controller is configured to communicate with one or more manual user-input devices; and

the microcontroller of each window controller is configured to modify the command voltage signal based on input from one or more of the manual user-input devices.

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