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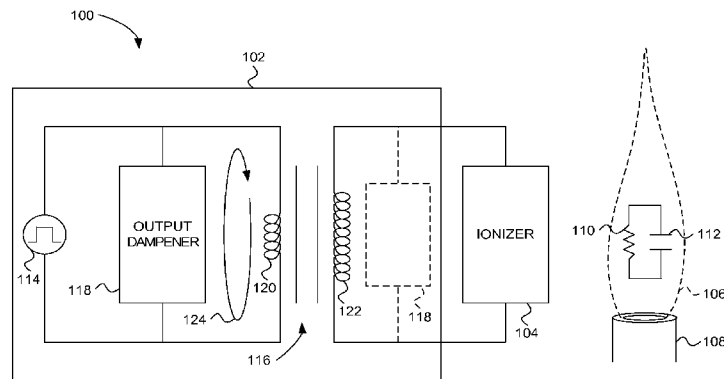
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FIG. 1



(57) **Abstract:** A system for electrically controlling a combustion flame may include a burner configured to generate the combustion flame. The combustion flame includes a resistance and a capacitance. The system may include an ionizer positioned proximate to the burner to supply ions of a first polarity to the combustion flame to charge the capacitance of the combustion flame to one or more voltage levels. The system may include a power supply coupled to the ionizer and configured to provide an output voltage signal of the first polarity to the ionizer to excite the ionizer to supply the ions of the first polarity to the combustion flame. The power supply may include a transformer and an output dampener operatively coupled in parallel to the transformer. The output dampener can suppress a second polarity of the output voltage signal to limit delivery of ions of the second polarity to the combustion flame by the ionizer.

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# ASYMMETRICAL UNIPOLAR FLAME IONIZER USING A STEP-UP TRANSFORMER

## 5                   **CROSS REFERENCE TO RELATED APPLICATIONS**

The present application claims priority benefit from U.S. Provisional Patent Application No. 62/030,960, entitled "ASYMMETRICAL UNIPOLAR FLAME IONIZER USING A STEP-UP TRANSFORMER", filed July 30, 2014 (Docket no.: 10 2651-220-02); which, to the extent not inconsistent with the disclosure herein, is incorporated by reference.

## **SUMMARY**

15

According to an embodiment, a system for electrically controlling a combustion flame may include a burner configured to generate the combustion flame. The combustion flame includes a resistance and a capacitance. The system may include an ionizer positioned proximate to the burner to supply ions 20 of a first polarity to the combustion flame to charge the capacitance of the combustion flame to one or more voltage levels. The system may include a power supply coupled to the ionizer and configured to provide an output voltage signal of the first polarity to the ionizer to excite the ionizer to supply the ions of the first polarity to the combustion flame. The power supply may include a 25 transformer and an output dampener operatively coupled in parallel to the transformer. The output dampener can suppress a second polarity of the output voltage signal to limit delivery of ions of the second polarity to the combustion flame by the ionizer.

According to an embodiment, a system for electrically controlling a 30 combustion flame may include a first power supply configured to generate a first

output voltage pulse of a first polarity in excess of a first predetermined threshold. The first power supply may include a first step-up transformer. The first power supply may include a first output dampener coupled to the first step-up transformer and configured to at least partially suppress a second output voltage pulse of a second polarity to prevent the second output voltage pulse from exceeding a second predetermined threshold. The system may include a second power supply configured to generate a third output voltage pulse of the first polarity in excess of the first predetermined threshold. The second power supply may include a second step-up transformer. The second power supply may include a second output dampener coupled to the second step-up transformer and configured to at least partially suppress a fourth output voltage pulse of the second polarity to prevent the fourth output voltage pulse from exceeding the second predetermined threshold. The second polarity may be different than the first polarity. The system may include a first ionizer operatively coupled to the first power supply and configured to supply first ions of the first polarity to a combustion flame to charge the combustion flame, in response to receipt of the first output voltage pulse. The system may include a second ionizer operatively coupled to the second power supply and configured to supply second ions of the first polarity to the combustion flame to charge the combustion flame, in response to receipt of the third output voltage pulse. The system may include a controller communicatively coupled to the first power supply and to the second power supply to selectively cause the first ionizer and the second ionizer to supply the first ions and the second ions to the combustion flame.

According to an embodiment, a method for electrically controlling a combustion flame may include generating, with a power supply, a voltage signal having a first portion of a first polarity and having a second portion of a second polarity. The first portion of the voltage signal is greater than or equal to a first predetermined threshold. The method may include suppressing the second portion of the voltage signal, with an output dampener, to prevent the second portion of the voltage signal from exceeding a second predetermined threshold, by reducing a rate of current change in a transformer of the power supply, while

generating the second portion of the voltage signal. The method may include generating ions of the first polarity, with an ionizer, in response to receiving the first portion of the voltage signal. Generating ions can include supplying the ions to a combustion flame to charge the combustion flame to a voltage to alter one or  
5 more characteristics of the combustion flame.

## BRIEF DESCRIPTION OF THE DRAWINGS

10 **FIG. 1** is a block diagram of a system for applying voltage to a combustion flame, according to an embodiment.

**FIG. 2** is a graphical illustration of a voltage suppression function of the system for applying voltage to a combustion flame, according to an embodiment.

15 **FIG. 3** is a block diagram of a system for applying voltage to a combustion flame, according to an embodiment.

**FIG. 4** is a block diagram of a system for applying voltage to a combustion flame, according to an embodiment.

**FIG. 5** is a flow diagram of a method for electrically controlling a combustion flame, according to an embodiment.

20

## DETAILED DESCRIPTION

In the following detailed description, reference is made to the  
25 accompanying drawings, which form a part hereof. In the drawings, similar symbols typically identify similar components, unless context dictates otherwise. Other embodiments may be used and/or other changes may be made without departing from the spirit or scope of the disclosure.

Electrodynamic combustion control may be used to control and/or vary  
30 characteristics of a combustion flame or combustion reaction. The application of a voltage, charge, current, and/or electric field to a combustion flame may be

used to improve heat distribution of the flame, to stabilize the flame, and/or to prevent flame impingement. The application of electrodynamic combustion control may also improve the energy efficiency, shape, and/or heat transfer of the flame.

5           The inventors have identified several issues that may be associated with applying a high-power voltage to a combustion flame. For example, if an electrode of a power supply is directly coupled or inserted within a combustion flame, and the combustion flame inadvertently contacts a grounded conductor or a grounded housing, the combustion flame can electrically couple the power  
10 supply to grounded contact point and potentially damage the power supply.

          Another example of an issue identified by the inventors is that traditional power supply configurations may be limited to charging a load with the voltage that is only as high as the power supply can generate. Accordingly, a power supply configuration that could charge a load to a voltage that is higher than the  
15 capacity of the power supply may enable the power supply to be designed or built to lower voltage specifications than the desired load voltage.

          Disclosed herein are methods and systems of applying a unipolar charge to a combustion flame. The methods and systems enable physical isolation between the power supply and the combustion flame while enabling the power  
20 supply to charge the combustion reaction to higher voltages than the power supply itself can output.

**FIG. 1** illustrates an electrodynamic flame control system 100 for charging a combustion flame to one or more voltage levels, according to one embodiment. As used herein “electrodynamic flame control” may refer to the application of a  
25 voltage, charge, current, and/or electric field to control combustion flame behavior and to improve heat distribution in a combustion volume. In one embodiment, the application of the charge or current to the combustion flame includes supplying ions or electrons to the combustion flame with an ionizer. The electrodynamic flame control system 100 includes a power supply 102 and an  
30 ionizer 104 for charging a combustion flame 106 to one or more voltage levels, according to one embodiment.

The power supply 102 may be configured to charge the combustion flame 106 to one or more voltage levels without physically contacting, connecting to, or coupling with the combustion flame 106, according to one embodiment.

Physically decoupling the power supply 102 from the combustion flame 106 can

5 protect the power supply 102 from inadvertent damage, e.g., short-circuiting through the combustion flame 106 to ground. The power supply 102 may be electrically coupled to the ionizer 104 to charge the combustion flame 106 to one or more voltage levels. In one embodiment, the ionizer 104 is disposed or positioned proximate to, but external to, the combustion flame 106 so that a  
10 physical connection or coupling is absent between the power supply 102 and the combustion flame 106. The power supply 102 can be configured to supply the ionizer 104 with a high-power voltage, e.g., greater than or equal to approximately 4 kilovolts ("kV"), to enable the ionizer 104 to ionize fluids that are proximate to or adjacent to the ionizer 104 and/or that are proximate to the  
15 combustion flame 106. According to one embodiment, the power supply 102 can be configured to supply the ionizer 104 with a high-power voltage that is less than or equal to a breakdown voltage, e.g., +/- 10 kV, of the fluid that is to be ionized. The corona onset voltage can be +/- 4 kV for some fluids. In one embodiment, the power supply 102 can be configured to supply the ionizer 104  
20 with a high-power voltage that is greater than or equal to the corona onset voltage of a fluid and that is less than or equal to a breakdown voltage for the fluid. By supplying ions to the combustion flame 106, rather than directly charging the combustion flame 106 with a voltage, the power supply 102 can selectively charge the combustion flame 106 to one or more voltage levels  
25 without physically contacting, connecting to, or coupling with the combustion flame 106.

The ionizer 104 can be implemented using any one of a number of ionizer configurations to supply ions to the combustion flame 106 in order to charge the combustion flame 106 to one or more voltage levels, according to one  
30 embodiment. For example, the ionizer 104 can include one or more electrodes, one or more fluid displacement mechanisms, one or more fluid supply

mechanisms, and/or one or more fluid delivery mechanisms, according to various embodiments. For example, the one or more electrodes can include a single emitter electrode, an emitter electrode and a collector electrode, or multiple emitter electrodes and multiple collector electrodes. Other names for the electrodes can include corona electrode, counter electrode, target electrode cathode, anode, or the like. In one embodiment, the ionizer 104 includes a single emitter electrode and uses the combustion flame 106 or a burner 108 as a collector electrode. When the voltage between the emitter electrode and collector electrode of the ionizer 104 approaches, equals, and/or exceeds the corona onset voltage, e.g., 4 kV, the carrier fluid molecules that are proximate to or in the vicinity of the emitter electrode begin ionizing. The ionizer 104 can be configured to provide a strong ionic stream, i.e., an ionic current, from just a few kilovolts of voltage. The ions can have a charge that is of the same polarity as the emitter electrode, and the ions are repulsed from the emitter electrode in the direction of the combustion flame 106 and/or in the direction of the collector electrode. Because the combustion flame 106 includes a resistance 110 (e.g., 3-4 megaohms) and a capacitance 112 (e.g., 3-5 picofarads "pF"), receipt of cations or anions (i.e., positive or negative charged ions) by the combustion flame 106 results in an increase in voltage or electrical potential in the combustion flame 106.

The voltage of the combustion flame 106 that results from injection of ions can be characterized, described, or defined in terms of charge, capacitance, and/or current. The voltage across the capacitance 112 of the combustion flame 106 can be expressed in terms of charge, capacitance, and/or current as:

$V = Q/C$  (Equation 1); and

$V = (I*t)/C$  (Equation 2),

where V is voltage,

Q is charge,

C is capacitance,

I is current, and

t is time.

Equation 1 simply states that the voltage is proportional to the charge Q stored by a capacitance C, so increasing charge on a fixed capacitance will proportionally increase the voltage across a capacitance. Similarly, Equation 2 expresses charge as a product of current and time and shows that providing  
5 current, such as a stream of ions, to a fixed capacitance for a period of time will also increase the voltage across the capacitance. Accordingly, by configuring the power supply 102 and the ionizer 104 to supply the combustion flame 106 with ions, i.e., charge, the power supply 102 and the ionizer 104 can selectively charge the combustion flame 106 to one or more voltage levels, according to  
10 various embodiments.

The power supply 102 may be configured to excite the ionizer 104 to generate unipolar ions, according to one embodiment. If the power supply 102 provides or excites the ionizer 104 with a voltage that is equal to or in excess of a positive corona onset voltage, the ionizer 104 generates positive ions. However,  
15 if the power supply 102 provides the ionizer 104 with a voltage that is equal to or less than a negative corona onset voltage, the ionizer 104 generates negative ions. Therefore, if the power supply 102 causes the ionizer 104 to supply the combustion flame 106 with positive ions, but then causes the ionizer 104 to supply the combustion flame 106 with negative ions, the power supply 102 may  
20 inadvertently, unintentionally, and/or undesirably discharge the combustion flame 106. The power supply 102 is configured to provide the ionizer 104 with one or more voltage signals that enable the ionizer 104 to generate unipolar ions, i.e., ions of a single polarity, according to one embodiment.

The power supply 102 includes a voltage supply 114, a transformer 116,  
25 and an output dampener 118, according to one embodiment. The voltage supply 114 selectively generates square-wave pulses of half a square-wave period, one square-wave period, or multiple square-wave periods, according to various embodiments. In one embodiment, the voltage supply 114 is implemented as a DC voltage supply in series with a switch that is operative to selectively decouple  
30 the DC voltage supply from the transformer 116 and/or from the output dampener 118, according to various embodiments.

The transformer 116 can be coupled between the voltage supply 114 and the ionizer 104 to convert a first voltage signal having a first voltage level into a second voltage signal having a second, higher, voltage level, according to one embodiment. The transformer 116 may be a step-up transformer that converts a voltage signal that is, for example, between 100-500 V into a voltage signal that is, for example, between 4-10 kV, according to one embodiment. The transformer 116 may include a primary winding 120 and a secondary winding 122. The primary winding 120 may have a number of turns that is less than a number of turns of the secondary winding 122. The primary winding 120 may be connected to the voltage supply 114, and the secondary winding 122 may be connected to the ionizer 104, according to one embodiment.

The output dampener 118 enables the power supply 102 to provide a first polarity output voltage signal that exceeds or surpasses a first polarity corona onset voltage while limiting, suppressing, dampening, and/or preventing a second polarity output voltage signal from exceeding or surpassing a second polarity corona onset voltage, according to one embodiment. For example, the output dampener 118 enables the power supply 102 to provide a first polarity output voltage signal that is above a first polarity corona onset voltage of 4 kV while prohibiting the power supply 102 from generating a second polarity output voltage signal that is below or more negative than -4 kV. In other embodiments, the output dampener 118 enables the power supply 102 to provide a first polarity voltage signal that is below or more negative than -4 kV while prohibiting the power supply 102 from generating a second polarity voltage signal that is above or more positive than 4 kV. Thus, the power supply 102 can be configured to generate a positive high-power voltage that is equal to or greater than a positive corona onset voltage, or the power supply 102 can be configured to generate a negative high-power voltage that is equal to or more negative than a negative corona onset voltage, according to various embodiments.

The output dampener 118 can include one or more passive electronic components configured to suppress or dampen power supply output voltage surges or spikes of a particular polarity, according to one embodiment. The

output dampener 118 can be referenced by several different terms, such as output voltage controller, output voltage suppressor, output voltage filter, output filter, voltage filter, output limiter, output voltage limiter, field regulator, magnetic field regulator, magnetic field rate suppressor, or the like. In one implementation, the output dampener 118 is a resistor operatively or electrically coupled in parallel to the voltage supply 114 and to the transformer 116. In another implementation, the output dampener 118 is a resistor in series with a diode, with the resistor and diode being coupled in parallel to the voltage supply 114 and to the transformer 116. The output dampener 118 can be operatively or electrically coupled to the primary winding 120 of the transformer 116 or can be optionally and alternatively coupled to the secondary winding 122 of the transformer 116, according to various embodiments.

In one embodiment, the operation of the output dampener 118 can be described in terms of magnetic flux  $\Phi$ . After the voltage supply 114 applies a voltage to the primary winding 120, current begins flowing through the primary winding 120. As the current through the primary winding 120 increases with time, the magnetic flux  $\Phi$  that permeates the primary winding 120 and the secondary winding 122 also increases with time. The change in magnetic flux  $\Phi$  with respect to time determines the magnitude of the voltage generated across the secondary winding 122. Faraday's law describes the magnitude of the voltage across the secondary winding 122 as follows:

$$V = N \cdot (d\Phi/dt) \quad (\text{Equation 3}),$$

where  $V$  is the voltage across the secondary winding 122,

$N$  is the number of turns of the secondary winding 122, and

$d\Phi/dt$  is the rate of change of the magnetic flux  $\Phi$  through the secondary winding 122 with respect to time.

Since the voltage across the secondary winding 122 is proportional to the change in the magnetic flux  $\Phi$ , the increases in rate of the magnetic flux  $\Phi$  generate a positive voltage and decreases in the rate of the magnetic flux  $\Phi$  generate a negative voltage, across the secondary winding 122. Furthermore, faster magnetic flux  $\Phi$  changes, i.e., higher rates of change, generate higher

voltages across the secondary winding 122. Therefore, the output dampener 118 can enable the power supply 102 to generate a positive voltage that exceeds a positive corona onset voltage by not impeding increases in the magnetic flux  $\Phi$ , and the output dampener 118 can limit, suppress, or dampen the negative  
5 voltage generated by the power supply 102 by slowing the rate by which the magnetic flux  $\Phi$  collapses or decreases when the voltage supply 114 removes voltage from the primary winding 120, according to one embodiment. In another embodiment, the output dampener 118 is configured to enable the power supply 102 to generate a negative voltage that exceeds or is more negative than the  
10 negative corona onset voltage while limiting, suppressing, dampening, or preventing the power supply output voltage from exceeding the positive corona onset voltage.

The rate by which the magnetic flux  $\Phi$  decreases is proportional to the rate by which current through the primary winding 120 decreases. The output  
15 dampener 118 can reduce the maximum negative voltage across the secondary winding 122 by reducing the rate of change of the magnetic flux  $\Phi$  by reducing the rate of change of the current through the primary winding 120, according to one embodiment. Without the output dampener 118, when the power supply 102 removes voltage from across the primary winding 120, e.g., by opening a switch,  
20 the power supply 102 removes a path for current in the primary winding 120 to continue flowing. The current that was flowing through the primary winding 120 is abruptly changed from a first current level to a second current level that is approximately 0 amps ("A"). The abrupt change from the first current level to the second current level results in a rapid decrease in the magnetic flux  $\Phi$  and  
25 therefore can result in a large induced negative voltage across the secondary winding 122.

The output dampener 118 provides a current path 124 to allow current that was flowing through the primary winding 120 to at least partially continue flowing. In one embodiment, the output dampener 118 includes a resistor in series with a  
30 diode, and the diode is oriented to allow current to flow in the direction of the current path 124. The current that was flowing through the primary winding 120

gradually decreases as it dissipates through the resistance of the output dampener 118, but the initial rate of change of the current through the primary winding 120 from a first current level to a second current level can be significantly reduced, as compared to when the power supply 102 does not include the output dampener 118. As a result, the output dampener 118 enables the power supply 102 to excite the ionizer 104 to selectively generate ions of a single polarity for charging the combustion flame 106 to one or more voltage levels, according to one embodiment.

While the discussion above is generally directed towards embodiments where the output dampener 118 is connected in parallel to the primary winding 120, it is to be understood that in other implementations of the power supply 102, the output dampener 118 can perform the same function by being connected to the secondary winding 122, instead of to the primary winding 120.

**FIG. 2** illustrates graphs of the operation of the power supply 102 (shown in **FIG. 1**) with and without the implementation of the output dampener 118 (shown in **FIG. 1**), according to one embodiment. A graph 202 illustrates an example of an output voltage signal 203 that could be generated by the power supply 102, if the power supply 102 does not include the output dampener 118. The graph 202 includes an x-axis 204 that represents output voltage levels with respect to a y-axis 206 that represents time. The graph 202 also includes an indication of a first corona onset voltage 208 and an indication of a second corona onset voltage 210. In one embodiment, the first corona onset voltage 208 is a positive corona onset voltage, and the second corona onset voltage 210 is a negative corona onset voltage. In one embodiment, the first corona onset voltage 208 is approximately 4 kV, and the second corona onset voltage 210 is approximately -4 kV. The output voltage signal 203 includes a first section 212 and a second section 214. The first section 212 is generated when the voltage supply 114 (shown in **FIG. 1**) applies a first input voltage level to the transformer 116 (shown in **FIG. 1**). As shown, the first section 212 exceeds the first corona onset voltage 208 to cause the ionizer 104 (shown in **FIG. 1**) to generate positively charged ions. The second section 214 is generated when the voltage

supply 114 removes the first input voltage level from the transformer 116, or when the voltage supply 114 rapidly applies a second input voltage level to the transformer 116 that is lower than the first voltage level. The second section 214 exceeds the second corona onset voltage 210 and causes the ionizer 104 to generate negatively charged ions, resulting in the discharge of the combustion flame 106.

A graph 216 illustrates an example of an output voltage signal 218 that could be generated by the power supply 102, if the power supply 102 includes or implements the output dampener 118, according to one embodiment. The graph 216 includes an x-axis 220 that represents output voltage levels with respect to a y-axis 222 that represents time. The graph 216 includes an indication of the first corona onset voltage 208 and an indication of the second corona onset voltage 210. The output voltage signal 218 includes a first section 224 and a second section 226. The first section 224 is generated when the voltage supply 114 applies a first input voltage level to the transformer 116. As shown, the first section 224 exceeds the first corona onset voltage 208 to cause the ionizer 104 to generate positively charged ions. The second section 226 is generated when the voltage supply 114 applies a second input voltage level to the transformer 116, e.g., when the voltage supply 114 removes the first input voltage level from the transformer 116. As shown, by incorporating the output dampener 118 into the power supply 102, the maximum negative amplitude 228 of the second section 226 of the output voltage signal 218 can be limited, suppressed, or dampened so that the second section 226 does not exceed the second corona onset voltage 210. In other words, implementation of the output dampener 118 prevents the power supply 102 from causing the ionizer 104 to generate negatively charged ions, according to one implementation of the output dampener 118. In other implementations, the output dampener 118 can be used to enable the ionizer 104 to generate negatively charged ions while preventing the ionizer 104 from generating positively charged ions.

**FIG. 3** illustrates an electrodynamic flame control system 300 for charging the combustion flame 106 to one or more voltage levels, according to one

embodiment. The electrodynamic flame control system 300 represents one particular implementation of the electrodynamic flame control system 100 of **FIG. 1**, according to one embodiment. In the electrodynamic flame control system 300, the output dampener 118 includes a resistor 302 electrically connected or coupled to a diode 304 to enable current to flow from a first node 306 to a second node 308. The resistor 302 and the diode 304 reduces the negative rate of current change through the primary winding 120 when the voltage supply 114 removes voltage from the primary winding 120. By reducing the negative rate of current change through the primary winding 120, the output dampener 118 reduces the negative rate of magnetic flux  $\Phi$  change and therefore reduces the peak value of the voltage that is induced across the secondary winding 122 when the voltage supply 114 removes voltage from across the primary winding 120, according to one embodiment. In other implementations of the output dampener 118, the orientation of the diode 304 can be changed to allow current to flow from the second node 308 to the first node 306. Such a reversal in orientation could be used to apply a negative polarity voltage to the transformer 116 while limiting the peak value of a positive voltage induced across the secondary winding 122 when the voltage supply 114 removes the negative polarity voltage from across the primary winding 120, according to one embodiment.

In one embodiment, the ionizer 104 of the electrodynamic flame control system 100 can be implemented in the electrodynamic flame control system 300 as a first electrode 310 and a second electrode 312. The first electrode 310 can be electrically coupled or connected to a first output terminal 314 and the second electrode 312 can be electrically coupled or connected to a second output terminal 316. The electrodes 310, 312 receive voltage, energy, and/or power from the power supply 102, to supply ions to the combustion flame 106 to charge the combustion flame 106 to one or more voltage levels. In one embodiment, the first electrode 310 is a conductor such as a wire, a piece of metal, and/or a needle. In one embodiment, second electrode 312 is a conductor that is larger, e.g., has more surface area and/or more volume, than the first electrode 310. In one embodiment, the first electrode 310 is positioned proximate to and external

to the combustion flame 106. In one embodiment, proximate to and external to the combustion flame 106 include being positioned at least 1 inch away from the combustion flame 106. In one embodiment, the second electrode 312 is positioned proximate to and external to the combustion flame 106. In one  
5 embodiment, the first electrode 310 is positioned on one side of the combustion flame 106 and the second electrode 312 is positioned on another side of the combustion flame 106. In alternative implementations, the second electrode 312 is positioned within the combustion flame 106. In one embodiment, the second  
10 output terminal 316 of the power supply 102 is electrically coupled or connected to the burner 108 so that the burner 108 functions as the second electrode 312. In one embodiment, the second electrode 312 is omitted from the electrodynamic flame control system 300 and the first electrode 310 is used to supply ions to the combustion flame 106.

The power supply 102 may be configured to charge the combustion flame  
15 106 to a particular voltage that may be higher than an output voltage of the power supply 102, according to one embodiment. The combustion flame 106 includes the capacitance 112, which may be charged by the receipt of ions from the electrodes 310, 312. As described previously in Equation 1 and Equation 2, the voltage across the capacitance 112 can be expressed in terms of charge,  
20 e.g.,  $V=Q/C$ , or in terms of current, e.g.,  $V=(I*t)/C$ . The power supply 102 may be configured to provide an output voltage to the ionizer 104 (shown in **FIG. 1**) or to the electrodes 310, 312 that is between 4-10 kV because 4 kV can be the corona onset voltage and because 10 kV can be the breakdown voltage of the surrounding or proximate fluid. Assuming, the capacitance 112 is approximately  
25 3 pF, the power supply 102 and the electrodes 310, 312 can charge the combustion flame 106 to 15 kV by supplying 45 nanocoulombs (“nC”) to the capacitance 112. Described in another way, the power supply 102 and electrodes 310, 312 can charge the combustion flame 106 to 15 kV by supplying 45 nanoampere-seconds (“nA-s”), which can be supplied with an ion current of  
30 4.5 milliamperes (“mA”) for 10 microseconds (“ $\mu$ s”). Alternatively, the power supply 102 and the electrodes 310, 312 can charge the combustion flame 106 to

40 kV by supplying 120 nA-s with 12 mA for 10  $\mu$ s (i.e., 100 kHz pulse). Thus, by using the ionizer 104 or the electrodes 310, 312, the power supply 102 can be configured to charge the combustion flame 106 to a voltage that is higher than the output voltage of the power supply 102, according to various embodiments.

5           **FIG. 4** illustrates an electrodynamic flame control system 400 for charging the combustion flame 106 to one or more voltage levels, according to one embodiment. The electrodynamic flame control system 400 includes a controller 402 that is communicatively coupled or operatively coupled to control multiple instances of the power supply 102 (inclusive of power supplies 102a, 102b, 102c,  
10 102d), according to one embodiment. The controller 402 can be configured to selectively operate the voltage supplies 114 (shown in **FIG. 1**) of the power supplies 102 and the corresponding ionizers 104 (inclusive of ionizer 104a, 104b, 104c, 104d). The controller 402 can be configured to customize the quantity, duration, and polarity of ions supply to the combustion flame 106. In one  
15 embodiment, the controller 402 causes the power supplies 102a, 102b, 102c, 102d to sequentially provide ions of a single polarity to the combustion flame 106 by time-multiplexing the ion generation. In another embodiment, the controller 402 causes one or more of the power supplies 102a, 102b, 102c, 102d to generate positive ions to selectively charge the combustion flame 106 while  
20 causing others of the power supplies 102a, 102b, 102c, 102d to selectively and sequentially generate negative ions to selectively discharge the combustion flame 106. In one implementation, the controller 402 time-multiplexes the operation of the power supplies 102a, 102b, 102c, 102d by: causing the power supply 102a to selectively charge the combustion flame 106; causing the power  
25 supply 102b to selectively discharge the combustion flame 106; causing the power supply 102c to selectively charge the combustion flame 106; and causing the power supply 102d to selectively discharge the combustion flame 106. More or less power supplies 102 and ionizers 104 can be implemented to customize the quantities, polarity, and duration of ions supply to the combustion flame 106,  
30 according to various embodiments.

**FIG. 5** illustrates a method 500 for operating an electrodynamic combustion system, according to one embodiment.

At block 502, the method generates, with a power supply, a voltage signal having a first portion of a first polarity and having a second portion of a second polarity, according to one embodiment. The first portion of the voltage signal can be greater than or equal to a first predetermined threshold.

At block 504, the method suppresses the second portion of the voltage signal, with an output dampener, to prevent the second portion of the voltage signal from exceeding a second predetermined threshold, by reducing a rate of current change in a transformer of the power supply, while generating the second portion of the voltage signal, according to one embodiment.

At block 506, the method generates ions of the first polarity, with an ionizer, in response to receiving the first portion of the voltage signal, according to one embodiment. Generating ions can include supplying the ions to a combustion flame to charge the combustion flame to a voltage to alter one or more characteristics of the combustion flame.

While various aspects and embodiments have been disclosed herein, other aspects and embodiments are contemplated. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope and spirit being indicated by the following claims.

## CLAIMS

What is claimed is:

1. A system for electrically controlling a combustion flame, comprising:  
a burner configured to generate the combustion flame,  
wherein the combustion flame includes a resistance and a capacitance;  
an ionizer positioned proximate to the burner to supply ions of a first polarity to the combustion flame to charge the capacitance of the combustion flame to one or more voltage levels; and  
a power supply coupled to the ionizer and configured to provide an output voltage signal of the first polarity to the ionizer to excite the ionizer to supply the ions of the first polarity to the combustion flame,  
wherein the power supply includes a transformer and an output dampener operatively coupled in parallel to the transformer,  
wherein the output dampener suppresses a second polarity of the output voltage signal to limit delivery of ions of the second polarity to the combustion flame by the ionizer.
2. The system of claim 1, wherein the capacitance is between three and five picofarads (3-5 pF).
3. The system of claim 1, wherein the ionizer is positioned at least 1 inch away from combustion flame.
4. The system of claim 1, wherein the first polarity is positive and the second polarity is negative.
5. The system of claim 1, wherein the first polarity is negative and the second polarity is positive.

6. The system of claim 1, wherein the ionizer includes an emitting electrode.
7. The system of claim 6, wherein the ionizer includes a collecting electrode.
8. The system of claim 7, wherein the emitting electrode and the collecting electrode are positioned on opposite sides of the combustion flame to direct a flow of the ions into the combustion flame.
9. The system of claim 7, wherein the collecting electrode is the burner that is configured to generate the combustion flame.
10. The system of claim 1, wherein the ionizer is configured to supply the ions upon excitation with approximately 4 kV.
11. The system of claim 1, wherein output voltage signal of the first polarity is a square-wave pulse.
12. The system of claim 1, wherein the power supply includes a primary winding and a secondary winding.
13. The system of claim 12, wherein the output dampener is electrically coupled in parallel to the primary winding.
14. The system of claim 12, wherein the output dampener is electrically coupled in parallel to the secondary winding.
15. The system of claim 12, wherein the output dampener includes a resistor.
16. The system of claim 15, wherein the output dampener includes a diode electrically coupled in series to the resistor.

17. The system of claim 16, wherein the diode is oriented to allow current to continue flowing through the primary winding of the transformer after power is removed from the primary winding.
18. A system for electrically controlling a combustion flame, comprising:  
a first power supply configured to generate a first output voltage pulse of a first polarity in excess of a first predetermined threshold,  
wherein the first power supply includes a first step-up transformer,  
wherein the first power supply includes a first output dampener coupled to the first step-up transformer and configured to at least partially suppress a second output voltage pulse of a second polarity to prevent the second output voltage pulse from exceeding a second predetermined threshold;  
a second power supply configured to generate a third output voltage pulse of the first polarity in excess of the first predetermined threshold,  
wherein the second power supply includes a second step-up transformer,  
wherein the second power supply includes a second output dampener coupled to the second step-up transformer and configured to at least partially suppress a fourth output voltage pulse of the second polarity to prevent the fourth output voltage pulse from exceeding the second predetermined threshold,  
wherein the second polarity is different than the first polarity;  
a first ionizer operatively coupled to the first power supply and configured to supply first ions of the first polarity to a combustion flame to charge the combustion flame, in response to receipt of the first output voltage pulse;  
a second ionizer operatively coupled to the second power supply and configured to supply second ions of the first polarity to the

combustion flame to charge the combustion flame, in response to receipt of the third output voltage pulse; and  
a controller communicatively coupled to the first power supply and to the second power supply to selectively cause the first ionizer and the second ionizer to supply the first ions and the second ions to the combustion flame.

19. The system of claim 18, wherein the first predetermined threshold is approximately 4 kV and the second predetermined threshold is approximately -4 kV.

20. The system of claim 18, wherein the first polarity is positive and the second polarity is negative.

21. The system of claim 18, wherein the controller time-multiplexes operation of the first power supply and the second power supply so that the first output voltage pulse and the third output voltage pulse are generated sequentially.

22. The system of claim 18, wherein the first output dampener includes a first resistor and a first diode, wherein the first diode is oriented to enable a first current to continue flowing through a primary winding of the first transformer, wherein the second output dampener includes a second resistor and a second diode, wherein the second diode is oriented to enable a second current to continue flowing through a primary winding of the second transformer.

23. The system of claim 18, wherein the first ionizer includes a first emitter electrode and a first collector electrode, wherein the second ionizer includes a second emitter electrode and a second collector electrode.

24. The system of claim 23, wherein the first emitter electrode and the first collector electrode are positioned on first opposite sides of the combustion flame,

and the second emitter electrode and the second collector electrode are positioned on second opposite sides of the combustion flame.

25. The system of claim 18, further comprising:  
a third power supply configured to generate a fifth output voltage pulse of the second polarity in excess of the second predetermined threshold,  
wherein the third power supply includes a third step-up transformer,  
wherein the third power supply includes a third output dampener coupled to the third step-up transformer and configured to at least partially suppress a sixth output voltage pulse of the first polarity to prevent the sixth output voltage pulse from exceeding the first predetermined threshold; and  
a third ionizer operatively coupled to the third power supply and configured to supply third ions of the second polarity to the combustion flame to charge the combustion flame, in response to receipt of the fifth output voltage pulse,  
wherein the controller is configured to time multiplex operation of the third power supply to selectively cause the third power supply to generate the fifth output pulse to supply the combustion flame with the third ions of the second polarity.
26. The system of claim 18, wherein the combustion flame includes a resistance and a capacitance, wherein the capacitance is approximately 3-5 pF.
27. A method for electrically controlling a combustion flame, comprising:  
generating, with a power supply, a voltage signal having a first portion of a first polarity and having a second portion of a second polarity,  
wherein the first portion of the voltage signal is greater than or equal to a first predetermined threshold;

suppressing the second portion of the voltage signal, with an output dampener, to prevent the second portion of the voltage signal from exceeding a second predetermined threshold, by reducing a rate of current change in a transformer of the power supply, while generating the second portion of the voltage signal; and generating ions of the first polarity, with an ionizer, in response to receiving the first portion of the voltage signal, wherein generating ions includes supplying the ions to a combustion flame to charge the combustion flame to a voltage to alter one or more characteristics of the combustion flame.

28. The method of claim 27, wherein the combustion flame includes a capacitance.
29. The method of claim 28, wherein the capacitance is between three and five picofarads (3-5 pF).
30. The method of claim 27, wherein the first polarity is positive and the second polarity is negative.
31. The method of claim 27, wherein the first predetermined threshold is 4 kV and the second predetermined threshold is -4 kV.
32. The method of claim 27, wherein the output dampener includes a resistor and a diode coupled in series, wherein the output dampener is coupled in parallel to the transformer.
33. The method of claim 27, wherein the transformer includes a primary winding and a secondary winding and the output dampener is coupled to the primary winding.

34. The method of claim 27, wherein suppressing the second portion of the voltage signal to prevent the second portion of the voltage signal from exceeding the second predetermined threshold prevents the ionizer from generating ions of the second polarity.
35. The method of claim 27, wherein the first predetermined threshold is a corona onset voltage for a fluid that is proximate to the ionizer.
36. The method of claim 27, wherein the second predetermined threshold is a negative corona onset voltage.
37. The method of claim 27, wherein the ionizer includes an emitter electrode and a collector electrode.
38. The method of claim 27, wherein the ionizer includes an emitter electrode and the combustion flame functions as a collector electrode.
39. The method of claim 27, wherein the ionizer includes an emitter electrode and a burner is coupled to the power supply to function as a collector electrode, wherein the burner generates the combustion flame.
40. The method of claim 27, wherein the power supply generates the voltage signal in response to receiving a command signal from a controller.

FIG. 1

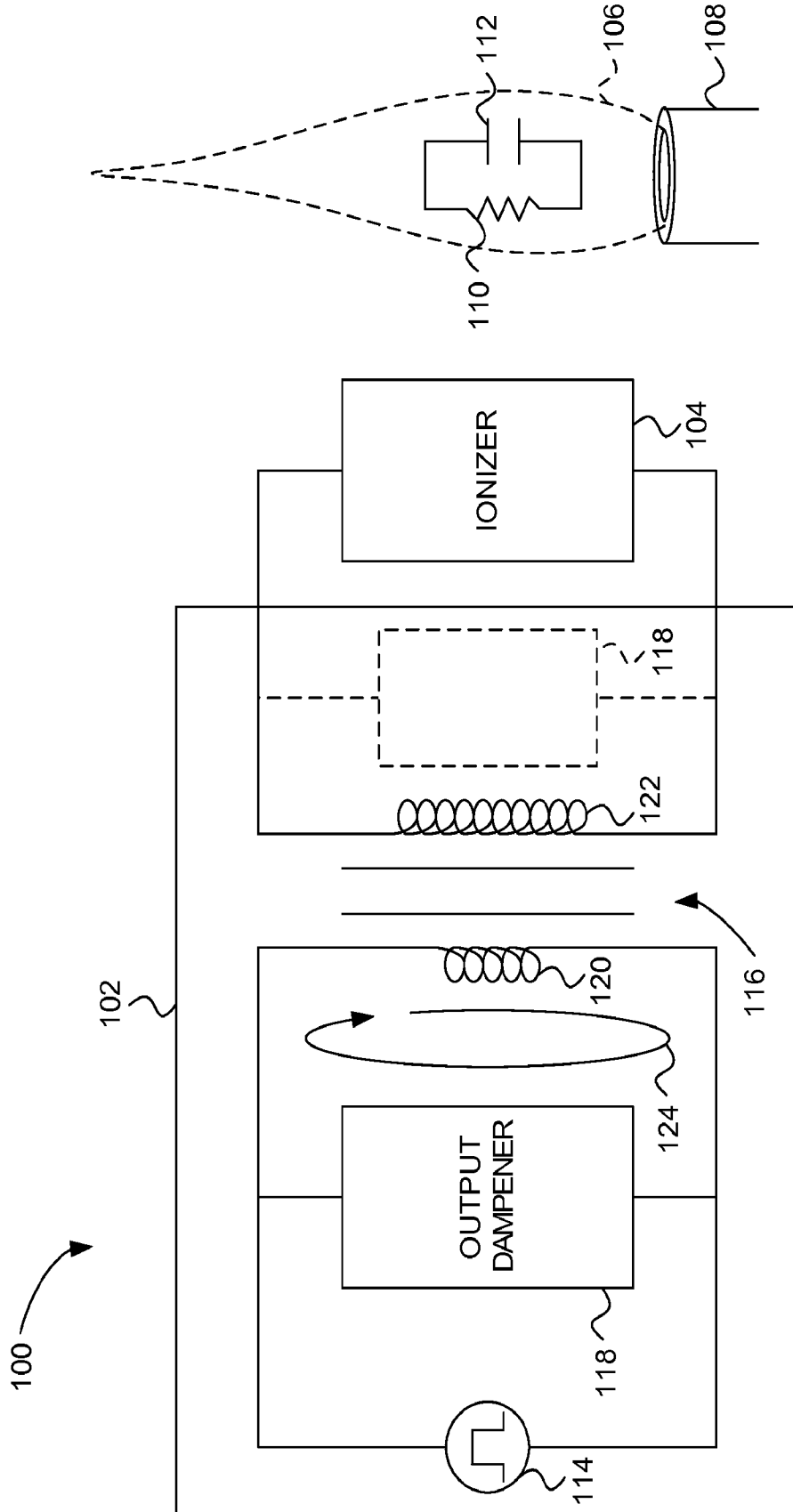


FIG. 2

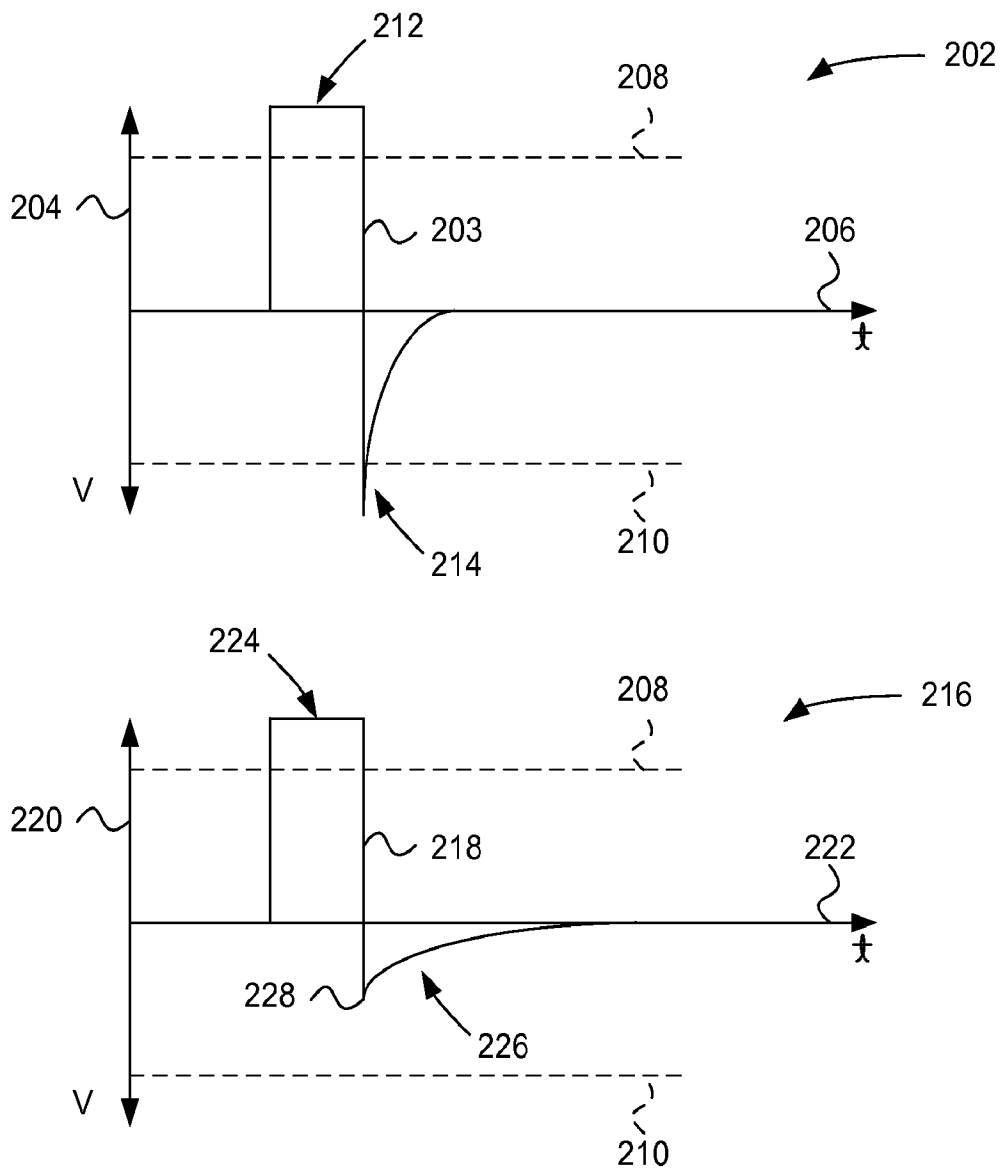


FIG. 3

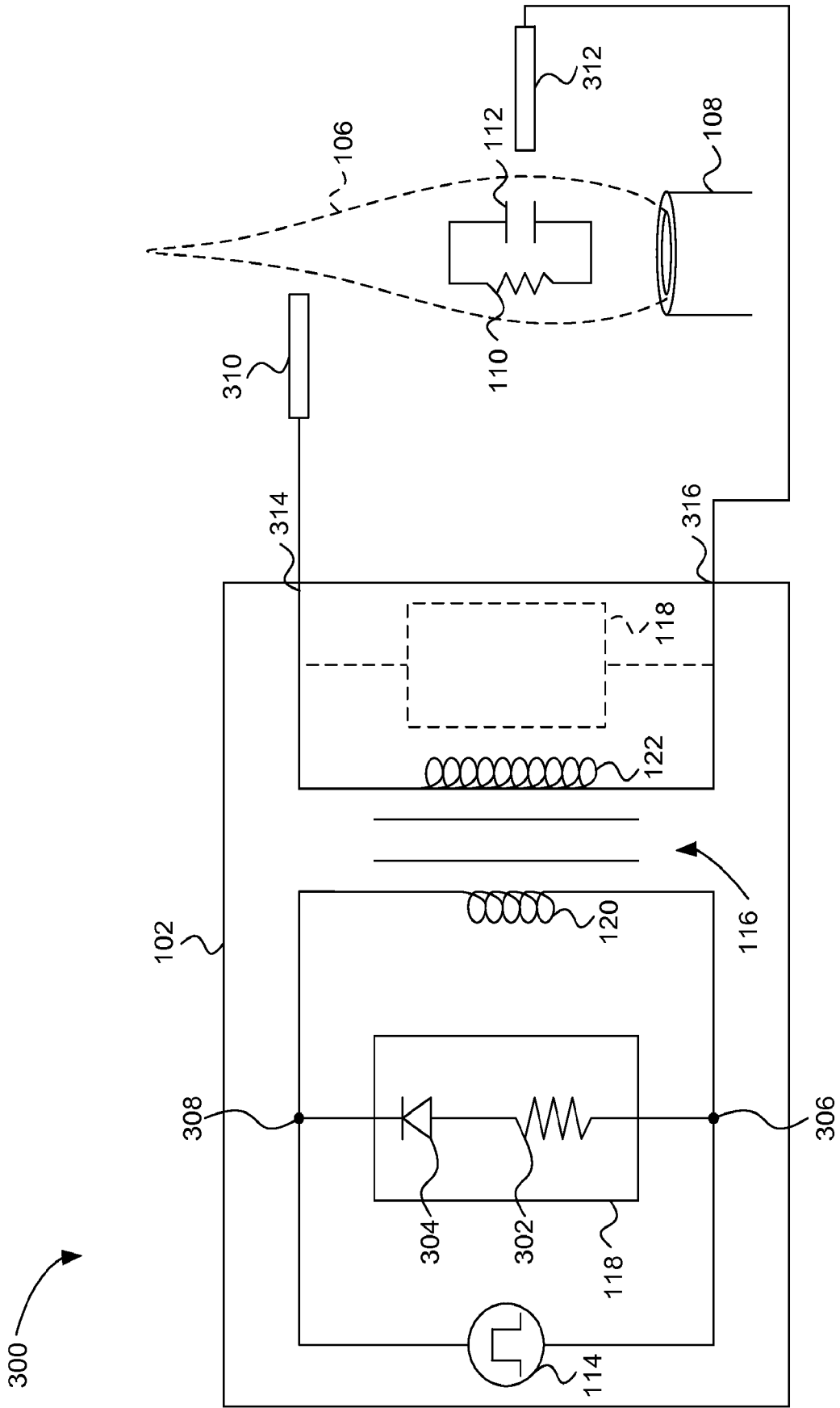


FIG. 4

400

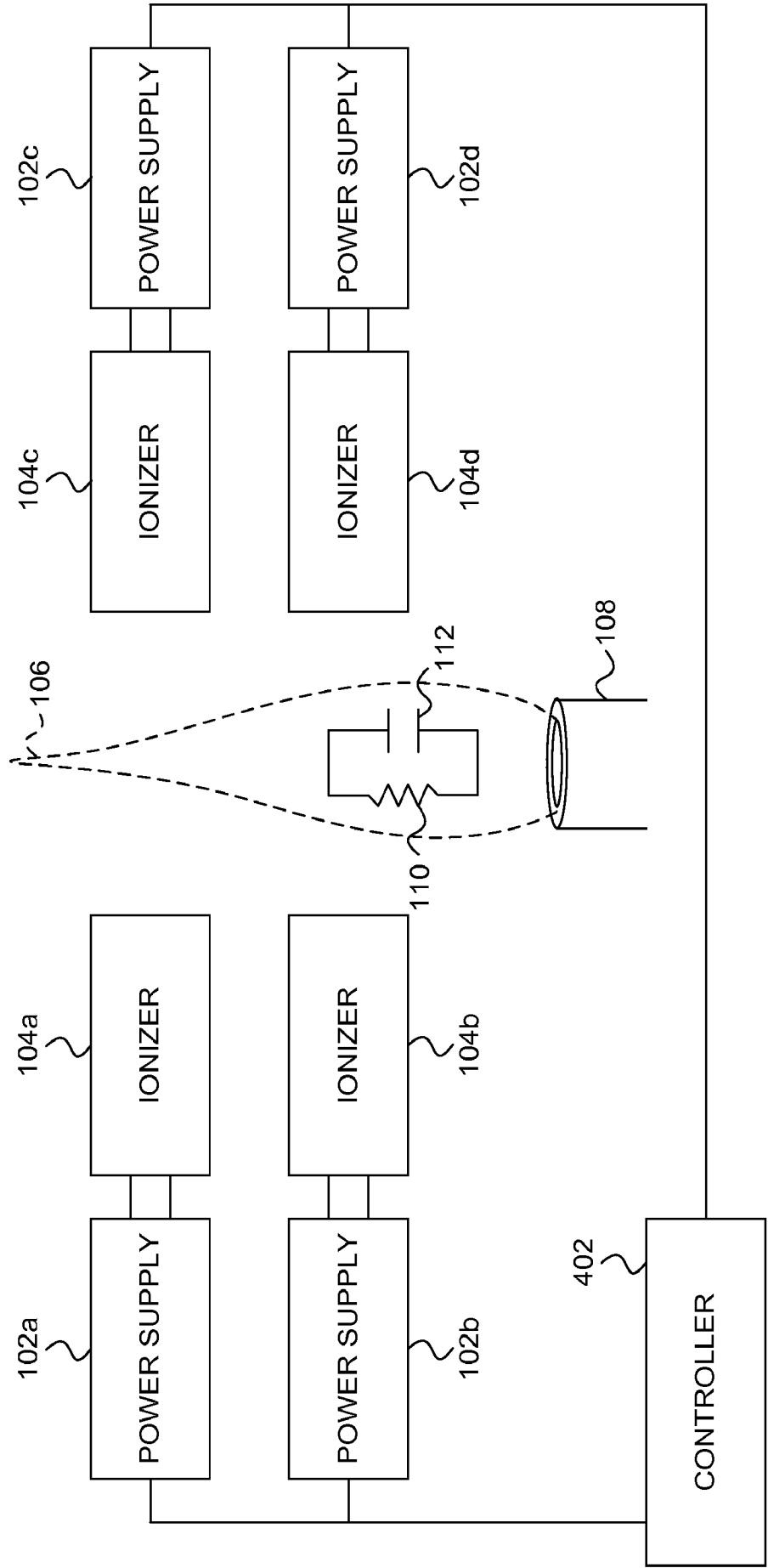
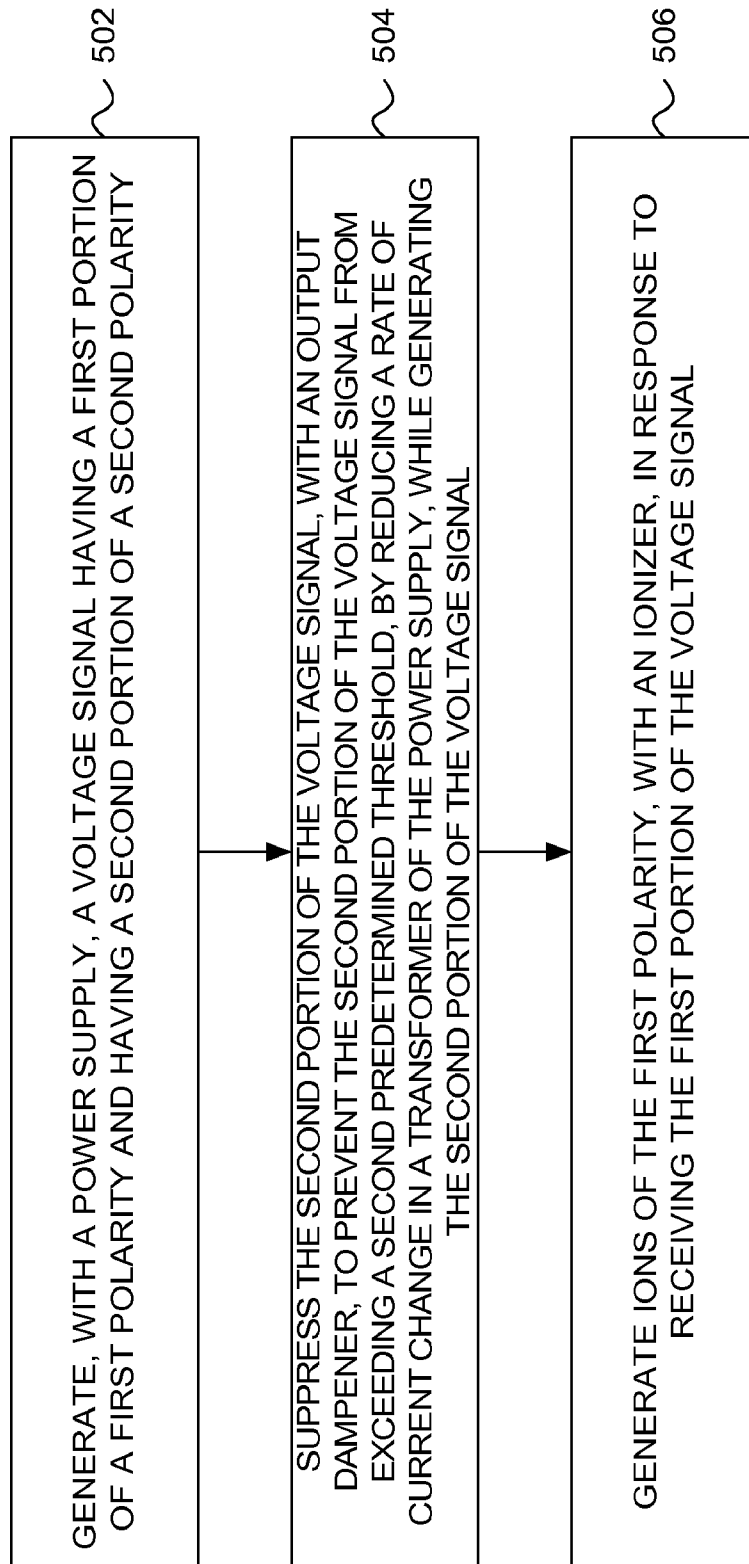




FIG. 5



<b>A. CLASSIFICATION OF SUBJECT MATTER</b> <b>F23N 5/12(2006.01)i, F23D 14/72(2006.01)i</b>		
According to International Patent Classification (IPC) or to both national classification and IPC		
<b>B. FIELDS SEARCHED</b>		
Minimum documentation searched (classification system followed by classification symbols) F23N 5/12; H02M 7/537; F23D 11/32; H01T 23/00; F23Q 3/00; F23N 5/00; F23D 14/72		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Korean utility models and applications for utility models Japanese utility models and applications for utility models		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) eKOMPASS(KIPO internal) & Keywords: combustion flame, burner, charge, ionizer, electrode, control, voltage, dampener, transformer, power supply, capacitance		
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2014-0162198 A1 (CLEARSIGN COMBUSTION CORPORATION) 12 June 2014 See abstract; paragraphs [0023]-[0034]; claims 1, 3, 41, 46-52; and figures 1, 2A, 3B-4, 6-8.	1-40
A	US 2012-0153055 A1 (IMAI et al.) 21 June 2012 See abstract; paragraphs [0016]-[0021], [0025]-[0026]; and figure 1.	1-40
A	US 2014-0162195 A1 (CLEARSIGN COMBUSTION CORPORATION) 12 June 2014 See abstract; paragraphs [0011]-[0013], [0015], [0017], [0022]-[0024]; and figures 1-5.	1-40
A	US 2010-0061034 A1 (KAPLAN et al.) 11 March 2010 See abstract; paragraphs [0014]-[0019]; and figure 1.	1-40
A	US 2011-0027734 A1 (HARTWICK et al.) 03 February 2011 See abstract; paragraphs [0020]-[0021], [0037]-[0041]; and figures 1-4.	1-40
<input type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 25 September 2015 (25.09.2015)		Date of mailing of the international search report <b>30 September 2015 (30.09.2015)</b>
Name and mailing address of the ISA/KR  International Application Division Korean Intellectual Property Office 189 Cheongsa-ro, Seo-gu, Daejeon Metropolitan City, 35208, Republic of Korea Facsimile No. +82-42-472-7140		Authorized officer LEE, Dal Kyong Telephone No. +82-42-481-8440 

**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No.

**PCT/US2015/040277**

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