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(54) METHOD FOR PROVIDING SELF-DETECTION OF AN OPEN-CIRCUIT OR CLOSED-CIRCUIT CONDITION IN A DIELECTRIC DEVICE

(57) An electrowetting on dielectric (EWOD) device for self-detection of an open-circuit or closed-circuit condition includes a detection chip, a power input module, a switch module, a detection module, and a determination module. The detection chip includes a channel, several driving electrodes, and a detection electrode. Each driving electrode can couple with the detection electrode to form the driving loop. The switch unit selects one of the driving electrodes to be electrically connected to the power input module for receiving a power voltage from the power input module. The detection module receives a detection voltage outputted by the detection electrode and accumulates the detection voltage to obtain an accumulated voltage. The determination module compares the accumulated voltage with a specified voltage for determining whether the driving loop is open-circuit or closed-circuit. A method for a self-detection circuit in EWOD device is also disclosed.

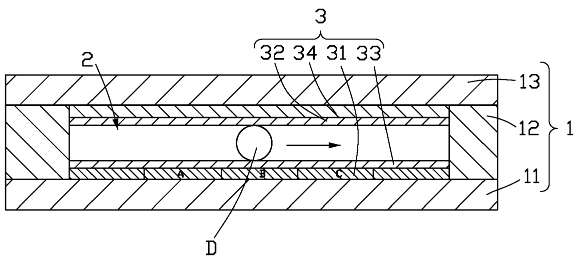


FIG. 1

EP 3 978 129 A1

Description

FIELD

[0001] The subject matter herein generally relates to nucleic acid testing, and particular to a method for circuit self-detection of an electrowetting on dielectric device.

BACKGROUND

[0002] A sample droplet of nucleic acid for an amplification reaction, for example, is tested by an electrowetting on dielectric (EWOD) principle. An EWOD device controls the sample droplet to move along a specified path, driven by an electrode, thus a nucleic acid amplification step can be completed. Before using the EWOD device, it is necessary to determine whether the EWOD circuit is working normally before executing the amplification step.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] Implementations of the present technology will now be described, by way of embodiment, with reference to the attached figures.

FIG. 1 is a diagram illustrating an embodiment of a detection chip according to the present disclosure.

FIG. 2 is a diagram illustrating electrowetting on dielectric (EWOD) device in one embodiment according to the present disclosure.

FIG. 3 is a circuit diagram illustrating a first embodiment of the EWOD device of FIG. 2 according to the present disclosure.

FIG. 4 is a circuit diagram illustrating an embodiment of the EWOD device of FIG. 2 in a normal state according to the present disclosure.

FIG. 5 are waveforms illustrating an embodiment of voltages of the EWOD device of FIG. 3 according to the present disclosure.

FIG. 6 is a circuit diagram illustrating an embodiment of the EWOD device of FIG. 3 in an open circuit state in one embodiment according to the present disclosure.

FIG. 7 are waveforms illustrating an embodiment of voltages of the EWOD device of FIG. 6 in an open circuit state according to the present disclosure.

FIG. 8 is a circuit diagram illustrating an embodiment of the EWOD device of FIG. 3 in the short circuit state according to the present disclosure.

FIG. 9 are waveforms illustrating an embodiment of voltages of the EWOD device of FIG. 8 in the short circuit state according to the present disclosure.

FIG. 10 is a circuit diagram illustrating a second embodiment of the EWOD device of FIG. 2 according to the present disclosure.

FIG. 11 is a circuit diagram illustrating an embodiment of the EWOD device of FIG. 10 in a normal state according to the present disclosure.

FIG. 12 are waveforms illustrating an embodiment of voltages of the EWOD device of FIG. 11 according to the present disclosure.

FIG. 13 is a circuit diagram illustrating an embodiment of the EWOD device of FIG. 10 in an open circuit state according to the present disclosure.

FIG. 14 are waveforms illustrating an embodiment of voltages of the EWOD device of FIG. 13 in an open circuit state according to the present disclosure.

FIG. 15 is a circuit diagram illustrating an embodiment of the EWOD device of FIG. 10 in the short circuit state according to the present disclosure.

FIG. 16 are waveforms illustrating an embodiment of voltages of the EWOD device of FIG. 15 in the short circuit state according to the present disclosure.

DETAILED DESCRIPTION

[0004] The present disclosure is described with reference to accompanying drawings and the embodiments. It will be understood that the specific embodiments described herein are merely some embodiments, not all the embodiments.

[0005] It is understood that, the term "coupled" is defined as connected, whether directly or indirectly through intervening components, and is not necessarily limited to physical connections. The connection can be such that the objects are permanently connected or releasably connected. The terms "perpendicular", "horizontal", "left", "right" are merely used for describing, but not being limited.

[0006] Unless otherwise expressly stated, all technical and scientific terminology of the present disclosure are the same as understood by persons skilled in the art. The terminology used in the description of the various described embodiments herein is for the purpose of describing particular embodiments only and is not intended to be limiting. The term "comprising" means "including, but not necessarily limited to"; it specifically indicates open-ended inclusion or membership in a so-described combination, group, series, and the like.

[0007] FIG. 1 illustrates one embodiment of a detection chip 10. The detection ship 10 includes a chip casing 1, a channel 2, and a driving loop 3. The channel 2 is disposed in the chip casing 1 and receives a droplet D with a sample of nucleic acid or other sample for testing. The droplet D will undergo a nucleic acid amplification reaction in the channel 2.

[0008] The chip casing 1 includes a first cover 11, a spacer layer 12, and a second cover 13. Two opposite surfaces of the spacer layer 12 are respectively adjacent to the first cover 11 and the second cover 13. The first cover 11, the spacer layer 12, and the second cover 13 cooperatively form the channel 2.

[0009] The driving loop 3 drives the droplet D to move along a specified path for executing the nucleic acid amplification reaction. The driving loop 3 includes some driving electrodes 31 disposed on a side surface of the first cover 11 adjacent to the channel 2, a first dielectric layer 33 disposed on a side of the driving electrodes 31 adjacent to the second cover 13, a detection electrode 32 disposed on a side surface of the second cover 13 adjacent to the channel 2, and a second dielectric layer 34 disposed on a side of the detection electrode 32 adjacent to the first cover 11. The driving electrodes 31 and the detection electrode 32 are disposed on opposite sides of the channel 2. By powering on and powering off the driving electrode 31 and the detection electrode 32, the droplet D in the channel 2 is moved along the specified path.

[0010] In one embodiment, as shown in FIG. 1, the driving electrodes 31 in the driving loop 3 are arranged in a matrix. A conductive layer disposed on a side surface of the second cover 13 adjacent to the channel 2 serves as the detection electrode 32.

[0011] In one embodiment, the driving electrodes 31 are disposed on a side of the first cover 11 adjacent to the channel 2. The driving electrodes 31 can be formed by a metal etching manner or by electroplating.

[0012] In detail, the driving loop 3 is a thin film transistor (TFT) driving loop. Based on a conductivity of the droplet D and the electrowetting on dielectric (EWOD) principle, the droplet D moves along the specified path in the channel 2. The TFTs enable a circuit between the driving electrode 31 and one of the detection electrodes 32 to be turned on or turned off, a voltage between the driving electrode 31 and the detection electrode 32 can be adjusted. A wetting property between the first dielectric layer 33 and the second dielectric layer 34 can be adjusted for controlling the droplet D to move along the specified path. In one embodiment, there are three electrodes 31, such as electrodes A-C, and the principle of the droplet D moving along the specified path is described as below.

[0013] As shown in FIG. 1, the droplet D can move on the electrodes A-C. When the droplet D is disposed on the electrode A, a voltage is applied on the electrode B and the detection electrode 32, and a voltage applied to the electrode A and the detection electrode 32 is turned off. The wetting property between the first dielectric layer 33 and the second dielectric layer 34 is changed, which causes a liquid-solid contact angle between the electrode A and the droplet D to increase, and a liquid-solid contact angle between the electrode B and the droplet D to decrease, thus the droplet D moves from the electrode A to the electrode B.

[0014] Obviously, a liquid driving principle of the detection chip 10 changes the voltage for adjusting hydrophobic characteristics of the first and second dielectric layers 33/34. An adsorption capacity of the first and second dielectric layers 33/34 for adsorbing the droplet D is changed, which makes the droplet D move. Thus, when being assembled and before using, the driving loop 3 of the detection chip 10 needs to be checked for an open circuit state or a short circuit state, thus the nucleic acid amplification reaction can be executed smoothly.

[0015] FIGS. 2 and 3 respectively show a first embodiment of a diagram and a circuit diagram of a dielectric wetting device 100 in a normal state. The dielectric wetting device 100 includes the detection chip 10, a power input module 20, a switch module 30, a detection module 40, and a determination module 50. The power input module 20 is electrically connected to the detection chip 10 through the switch module 30. In detail, the power input module 20 is electrically connected to the driving electrodes 31 of the detection chip 10 through the switch module 30 and applies a power voltage V_{in} to the driving electrodes 31.

[0016] The switch module 30 connects the driving electrodes 31 and the power input module 20. In detail, the switch module 30 includes a plurality of switch units 4. Each switch unit 4 is electrically connected to one of the driving electrodes 31. When the driving electrode 31 couples to the detection electrode 32, the detection electrode 32 receives a detection voltage V_{out} (coupled voltage) and outputs the detection voltage V_{out}.

[0017] The detection module 40 is electrically connected to the detection electrode 32. The detection module 40 receives the detection voltage V_{out} outputted by the detection electrode 32, and accumulates the detection voltage V_{out} to obtain an accumulation voltage V_p.

[0018] In one embodiment, the detection module 40 includes a voltage accumulation circuit 41. The voltage accumulation circuit 41 includes a first operational amplifier U_1, a first capacitor C_1, a first diode D_1, a second diode D_2, a second operational amplifier U_2, a first resistor R_1, a second resistor R_2, and a first capacitor C_1. A positive terminal of the first operational amplifier U_1 is electrically connected to the detection electrode 32, and a negative terminal of the first operational amplifier U_1 is electrically connected to an anode electrode of the first diode D_1 and a terminal of the second resistor R2. An output terminal of the first operational amplifier U_1 is electrically connected to an anode electrode of the second diode D_2 and a cathode electrode of the first diode D_1. A cathode electrode of the second diode D_2 is electrically connected to a terminal of the first resistor R_1, another terminal of the first resistor R_1 is electrically connected to a positive terminal of the second operational amplifier U_2 and a terminal of the first capacitor C_1. Another terminal of the first capacitor C_1 is grounded. A negative terminal of the second operational amplifier U_2 is electrically connected to another terminal of the second resistor R_2 and an output terminal of the second operational amplifier U_2. The output terminal of the second operation amplifier U_2 serves as an output terminal of the detection module 40 for outputting the accumulated voltage V_p of the detection voltage V_{out}.

[0019] The determination module 50 is electrically connected to the detection module 40. The determination module 50 receives the accumulated voltage V_p, and compares the received accumulated voltage V_p with the specified voltage V_r for determining whether a short circuit state or an open circuit state exists in the detection chip 10. A position of the detection chip 10 in the short circuit state or in the open circuit state can also be confirmed.

[0020] In one embodiment, the voltage accumulation circuit 41 can include the voltage accumulation circuit 41 (peak detector), not being limited. The detection module 40 also can include other circuits, such as a filter circuit.

[0021] In one embodiment, the first dielectric layer 33 and the second dielectric layer 34 are hydrophobic insulation layers, such as polytetrafluoroethylene coating. Thus, the first dielectric layer 33 and the second dielectric layer 34 present an insulating and hydrophobic function, the droplet D is moved smoothly along the specified path, and fragmentation or breakage of the droplet is prevented while the droplet D is being moved.

[0022] FIG. 4 is a circuit diagram of the EWOD device 100 in one embodiment. Besides the power input module 20, the switch module 30, and the voltage accumulation circuit 41, equivalent capacitors are formed in the driving loop 3 between the first dielectric layer 33, the second dielectric layer 34, and the channel 2 of the detection chip 10. The first dielectric layer 33 forms a first dielectric capacitor $C_{di\text{-}B}$ in the driving loop 3. The second dielectric layer 34 forms a second dielectric capacitor $C_{di\text{-}T}$. The channel 2 between the first dielectric layer 33 and the second dielectric layer 34 without silicone oil forms an equivalent air capacitor C_{air}. The capacitance of the equivalent air capacitor C_{air} is changed according to a quantity of silicone oil in the channel 2 between the first dielectric layer 33 and the second dielectric layer 34. In each driving loop 3 formed by each driving electrode 31, the first dielectric capacitor $C_{di\text{-}B}$, the air capacitor C_{air}, and the second dielectric capacitor $C_{di\text{-}T}$ are electrically connected in series. A terminal of the first dielectric capacitor $C_{di\text{-}B}$ away from the air capacitor C_{air} is electrically connected to the corresponding driving electrode 31, and a terminal of the second dielectric capacitor $C_{di\text{-}T}$ away from the air capacitor C_{air} is electrically connected to the detection electrode 32.

[0023] In one embodiment, when the switch unit 4 connects with driving electrodes 31 by a wire, a first resistor (R_{BA}, R_{BB}, R_{BC}) (equivalent resistor) and a second capacitor (C_{BA}, C_{BB}, C_{BC}) (equivalent capacitor) are formed based on the wire connecting the switch unit 4 and the driving electrodes 31. In each driving loop 3 formed by each driving electrode 31, the first resistor (R_{BA}, R_{BB}, R_{BC}) and the second capacitor (C_{BA}, C_{BB}, C_{BC}) are electrically connected in series. A terminal of the first resistor (R_{BA}, R_{BB}, R_{BC}) is electrically connected to the switch unit 4, and another terminal of the first resistor (R_{BA}, R_{BB}, R_{BC}) is electrically connected to the corresponding second capacitor (C_{BA}, C_{BB}, C_{BC}) and the corresponding driving electrode 31. Another terminal of the second capacitor (C_{BA}, C_{BB}, C_{BC}) is grounded.

[0024] In one embodiment, the power voltage V_{in} outputted by the power input module 20 is a continuous square pulsed voltage. The detection voltage V_{out} is also a continuous square pulsed voltage.

[0025] In one embodiment, the switch module 30, by a controller (not shown), can turn on one of the driving electrodes 31 and the driving electrodes 31 for sequential detection, a position of the loop between the driving electrode 31 and the detection electrode 32 in the open circuit state or in the short circuit state can be accurately confirmed.

[0026] When the detection electrode 32 outputs the detection voltage V_{out} to the voltage accumulation circuit 41, the voltage accumulation circuit 41 accumulates the detection voltage V_{out} to obtain the accumulation voltage V_p. The detection module 40 outputs the accumulation voltage V_p to the determination module 50. The determination module 50 compares the accumulation voltage V_p with the specified voltage V_r. Either one of an open circuit state and a short circuit state in the driving loop 3 can be determined by a difference between the accumulation voltage V_p and the specified voltage V_r. The position of the driving loop 3 in the open circuit state or the short circuit state is also confirmed.

[0027] The accumulated voltage V_p of the driving loop 3 in a normal state firstly needs to be detected for serving as the specified voltage V_r. In the normal state, the accumulated voltage V_p of the driving loop 3 is equal to the specified voltage V_r. The circuit detection principle of the EWOD device 100 will be described.

[0028] FIG. 4 shows the circuit diagram of the EWOD device 100, and FIG. 5 shows waveforms of voltages of the EWOD device 100.

[0029] When the channel 2 of the detection chip 10 is without silicon oil, the power voltage V_{in} of the power input module 20 (the continuous square pulsed voltage as shown in FIG. 5) is provided to a driving loop 3 with a specified driving electrode 31 through the switch module 30. The detection voltage V_{out} is outputted by the detection electrode 32. The detection voltage V_{out} is accumulated by the voltage accumulation circuit 41 (peak detector) of the detection module 40 to obtain the accumulated voltage V_p (as shown in FIG. 5). The detection module 40 outputs the accumulated voltage V_p to the determination module 50 for comparison.

[0030] For example, when the switch unit 4 of the switch module 30 is electrically connected to the electrode A, the electrode A and the detection electrode 32 form a driving loop 3. The continuous square pulsed voltage of the power input module 20 is provided to the electrode A through the equivalent resistor RBA, the electrode A couples with the detection electrode 32, and the detection electrode 32 outputs the detection voltage V_{out} (coupled voltage) to the voltage accumulation circuit 41 (peak detector) through the equivalent resistor between the detection electrode 32 and the detection module 40. The voltage accumulation circuit 41 accumulates the detection voltage V_{out} to obtain the accumulated voltage V_p, and outputs the accumulated voltage V_p to the determination module 50. When receiving the accumulated voltage V_p, the determination module 50 computes the difference between the accumulated voltage V_p and the specified voltage V_r to determine whether the EWOD device 100 is in a normal state.

[0031] As shown in FIG. 5, in one cycle of the continuous square pulsed voltage, a peak voltage of the detection voltage V_{out} serves as the accumulated voltage V_p of the EWOD device 100 in the normal state. In one embodiment, the waveform of the accumulated voltage V_p is overlapped with the waveform of the specified voltage V_r, and the accumulated voltage V_p is equal to the specified voltage V_r. Therefore, the EWOD device 100 in this situation is in the normal state.

[0032] It is understood that, when the channel 2 of the detection chip 10 is filled with silicon oil, the circuit detection principle is same. The accumulated voltage V_p when the channel 2 is filled with silicon oil is different from the accumulated voltage V_p when the channel 2 of the detection chip 10 is without silicon oil.

[0033] FIG. 6 shows the circuit diagram of the EWOD device 100 in the open circuit state.

[0034] As shown in FIG. 6, the power voltage V_{in} of the power input module 20 (the continuous square pulsed voltage as shown in FIG. 7) is provided to a driving loop 3 with the specified driving electrode 31 through the switch module 30. When the driving loop 3 is in the open circuit state, the power voltage V_{in} of the power module 20 is not provided to the specified electrode 31 through the switch module 30 and the detection electrode 32, and the detection electrode 32 does not output the detection voltage V_{out}. Thus, the voltage accumulation circuit 41 (peak detector) of the detection module 40 does not receive the detection voltage V_{out}, and does not accumulate the detection voltage V_{out} to obtain the accumulated voltage V_p. Therefore, the determination module 50 can easily determine that the driving loop 3 of the specified driving electrode 31 is in the open circuit state.

[0035] When the circuit with the electrode A is in the open circuit state, the detection module 40 does not receive the detection voltage V_{out} to obtain the accumulated voltage V_p. The voltage difference ΔV_1 between the voltage detected by the detection module 40 and the specified voltage V_r is used for determining whether the driving loop 3 is in the open circuit state. FIG. 7 shows a curved voltage line b of the detection voltage V_{out} in the normal state with the peak voltage being equal to the specified voltage V_r. The line c of the detection voltage V_{out} is a straight line below the waveform of the detection voltage V_{out} in the normal state. The detection module 40 does not receive the detection voltage V_{out}, thus there is no accumulated voltage V_p. The straight line in FIG. 7 represents the accumulated voltage V_p. The voltage difference ΔV_1 is a difference between the accumulated voltage V_p and the specified voltage V_r. The voltage difference ΔV_1 becomes larger. By a shape of the curved line C and the voltage difference ΔV_1, it can be determined that the driving loop 3 of the electrode A is in the open circuit state.

[0036] Whether or not other wires which are connected to other driving electrode 31 or connected to the detection electrode 32 are in the open circuit state can be detected by the same detection principle as above.

[0037] FIG. 8 shows the circuit diagram of the EWOD device 100 in the short circuit state.

[0038] As shown in FIG. 8, the power voltage V_{in} of the power input module 20 (the continuous square pulsed voltage as shown in FIG. 9) is provided to a driving loop 3 with the specified driving electrode 31 through the switch module 30. The detection electrode 32 outputs the detection voltage V_{out}, and the voltage accumulation circuit 41 (peak detector) of the detection module 40 accumulates the detection voltage V_{out} to obtain the accumulated voltage V_p. The detection module 40 outputs the accumulated voltage V_p to the determination module 50 for comparison. When the driving loop 3 is in the short circuit state, the power voltage V_{in} of the power module 20 is not provided to the circuit through the switch module 30, different wires between the specified driving electrode 31 are electrically connected with each other, the resistance of one of the resistors R_{BA}-R_{BB} being driven is increased, and the accumulated voltage V_p decreases. The voltage difference ΔV_2 between the accumulated voltage V_p and the specified voltage V_r is used for determining whether the driving loop 3 is in the short circuit state. As shown in FIG. 9, the curved line b shows the detection voltage V_{out} in the normal state, and the curved line c shows the accumulated voltage V_p. When the driving loop 3 is in the short circuit state, a slope of the curved line c of the accumulated voltage V_p is less than a slope of the curved line b of the detection voltage V_{out} in the normal state. The voltage difference ΔV_2 in the short circuit state is less than the voltage difference ΔV_1 in the open circuit state. Therefore, the driving loop 3 with the specified driving electrode 31 is determined as being short circuited according to the voltage difference ΔV_2 and the accumulated voltage V_p.

[0039] When the wire connected to the electrode A is in the short circuit state, and is electrically connected to the wire connected to the electrode B, the resistance of the resistor RC of electrode A or B being driven increases. The accumulated voltage V_p detected by the voltage accumulation circuit 41 of the detection module 40 decreases, thus the slope of the curved line of the accumulated voltage V_p is less than the detection voltage V_{out} in the normal state. Therefore, the driving loop 3 with the specified driving electrode 31 is determined as being in the short circuit state according to the voltage difference ΔV_2 and the accumulated voltage V_p.

[0040] Whether or not other wires which are connected to other driving electrode 31 or connected to the detection electrode 32 are short circuited can be detected by the same detection principle as above.

[0041] When testing the EWOD device 100, the curved line of the EWOD device 100 being the normal state should first be detected as shown in FIG. 5. The curved line of the EWOD device 100 in the normal state serves as a standard line. When the EWOD device 100 is functioning abnormally, the change of the accumulated voltage V_p is detected for determining the short circuit state or the open circuit state of the circuit in the EWOD device 100, and the position of the circuit in the EWOD device 100 is also detected. The EWOD device 100 executes a self-detection of the detection chip 10 by the internal circuit of the EWOD device 100, and no external detection device is required. The method for detecting the circuit in the EWOD device 100 is simple, and easily operated. The result of detection is more accurate. The method has higher efficiency, and a determination as to abnormal functioning is more accurate.

[0042] A method for detecting a circuit in the EWOD device 100 includes at least the following steps, which also may be followed in a different order:

[0043] In a first step, the switch module 30 is electrically connected to the specified driving electrode 31, thus the power input module 20 provides the power voltage V_{in} to the specified driving electrode 31.

[0044] In a second step, the specified driving electrode 31 couples with the detection electrode 32 to generate the detection voltage V_{out} (coupled voltage), and the detection electrode 32 outputs the detection voltage V_{out} to the detection module 40.

[0045] In a third step, the detection module 40 accumulates the detection voltage V_{out} to obtain the accumulated voltage V_p.

[0046] In a fourth step, the determination module 50 compares the accumulated voltage V_p with the specified voltage V_r to determine whether the circuit with the specified driving electrode 31 is in the short circuit state or the open circuit state, and the position of the circuit in the short circuit state or the open circuit state is also confirmed.

[0047] The determination process is the same as the above detection principle.

[0048] The EWOD device 100 can execute a self-detection for detecting the internal circuits. By comparing the accumulated voltage V_p and the specified voltage V_r, the state of the circuit in the EWOD device 100 is confirmed, such as the open circuit state and the short circuit state, and the position of the circuit in the EWOD device 100 is also confirmed. The method for detecting the circuit in the EWOD device 100 is simple, and easily for operated. The result of detection is more accurate. The method has higher efficiency, and a determination as to abnormal functioning is more accurate.

[0049] FIG. 10 shows a second embodiment of a circuit diagram of a dielectric wetting device 100 in a normal state. The dielectric wetting device 100 includes the detection chip 10, a power input module 20, a switch module 30, a detection module 40, and a determination module 50. The power input module 20 is electrically connected to the detection chip 10 through the switch module 30. In detail, the power input module 20 is electrically connected to the driving electrodes 31 of the detection chip 10 through the switch module 30 and applies a power voltage V_{in} to the driving electrodes 31.

[0050] The switch module 30 connects the driving electrodes 31 and the power input module 20. In detail, the switch module 30 includes a plurality of switch units 4. Each switch unit 4 is electrically connected to one of the driving electrodes 31. When the driving electrode 31 couples to the detection electrode 32, the detection electrode 32 receives a detection voltage V_{out} (coupled voltage) and outputs the detection voltage V_{out}.

[0051] The detection module 40 is electrically connected to the detection electrode 32. The detection module 40 receives the detection voltage V_{out} outputted by the detection electrode 32, and accumulates the detection voltage V_{out} to obtain an accumulation voltage V_p. By accumulating the detection voltage V_{out}, a sight deviation signal can be accumulated, and when the accumulated voltage V_p reaches a specified voltage V_r, the accumulated voltage V_p is outputted. Thus, an error or potential error is removed, and veracity of detection is improved.

[0052] In one embodiment, the detection module 40 includes a voltage accumulation circuit 41. The voltage accumulation circuit 41 includes an operational amplifier U and a first capacitor C_1. An output terminal of the detection electrode 32 is electrically connected to a positive terminal of the operational amplifier U and a terminal of the first capacitor C_1. Another terminal of the first capacitor C_1 is electrically connected to an output terminal of the operational amplifier U. A positive terminal of the operational amplifier U is grounded. The output terminal of the operational amplifier U serves as an output terminal of the detection module 40 for outputting the accumulated voltage V_p of the detection voltage V_{out}.

[0053] In one embodiment, the voltage accumulation circuit 41 includes an integrator.

[0054] The determination module 50 is electrically connected to the detection module 40. The determination module 50 receives the accumulated voltage V_p, and compares the received accumulated voltage V_p with the specified voltage V_r for determining either a short circuit state or an open circuit state of the detection chip 10. A position of the detection chip 10 in the short circuit state or in the open circuit state can also be confirmed.

[0055] In one embodiment, the voltage accumulation circuit 41 can include the voltage accumulation circuit 41, not being limited. The detection module 40 also can include other circuits, such as a filter circuit.

[0056] In one embodiment, the first dielectric layer 33 and the second dielectric layer 34 are hydrophobic insulation layers, such as polytetrafluoroethylene coating. Thus, the first dielectric layer 33 and the second dielectric layer 34 present an insulating and hydrophobic function, the droplet D smoothly moves along the specified path, and fragmentation or breakage of the droplet is prevented while the droplet D being moved.

[0057] FIG. 11 is a circuit diagram of the EWOD device 100 in one embodiment. Equivalent capacitors are formed in the driving loop 3 between the first dielectric layer 33, the second dielectric layer 34, and the channel 2 of the detection chip 10. The first dielectric layer 33 forms a first dielectric capacitor $C_{di\text{-}B}$ in the driving loop 3. The second dielectric layer 34 forms a second dielectric capacitor $C_{di\text{-}T}$. The channel 2 between the first dielectric layer 33 and the second dielectric layer 34 without silicone oil forms an equivalent air capacitor C_{air}. The capacitance of the equivalent air capacitor C_{air} is changed according to a quantity of the silicone oil in the channel 2 between the first dielectric layer 33 and the second dielectric layer 34. In each driving loop 3 formed by each driving electrode 31, the first dielectric capacitor $C_{di\text{-}B}$, the air capacitor C_{air}, and the second dielectric capacitor $C_{di\text{-}T}$ are electrically connected in series. A terminal of the first dielectric capacitor $C_{di\text{-}B}$ away from the air capacitor C_{air} is electrically connected to the corresponding driving electrode 31, and a terminal of the second dielectric capacitor $C_{di\text{-}T}$ away from the air capacitor C_{air} is electrically connected to the detection electrode 32.

[0058] In one embodiment, when the switch unit 4 connects with driving electrodes 31 by a wire, a first resistor (R_{BA}, R_{BB}, R_{BC}) (equivalent resistor) and a second capacitor (C_{BA}, C_{BB}, C_{BC}) (equivalent capacitor) are formed based on the wire connecting the switch unit 4 and the driving electrodes 31. In each driving loop 3 formed by each driving electrode 31, the first resistor (R_{BA}, R_{BB}, R_{BC}) and the second capacitor (C_{BA}, C_{BB}, C_{BC}) are electrically connected in series. A terminal of the first resistor (R_{BA}, R_{BB}, R_{BC}) is electrically connected to the switch unit 4, and another terminal of the first resistor (R_{BA}, R_{BB}, R_{BC}) is electrically connected to the corresponding second capacitor (C_{BA}, C_{BB}, C_{BC}) and the corresponding driving electrode 31. Another terminal of the second capacitor (C_{BA}, C_{BB}, C_{BC}) is grounded.

[0059] In one embodiment, when the detection electrode 32 is electrically connected to the detection module 40 by a wire, a second resistor R_T (equivalent resistor) is formed by the wire connected between the detection electrode 32 and the detection module 40.

[0060] In one embodiment, the power voltage V_{in} outputted by the power input module 20 is a continuous square pulsed voltage. The detection voltage V_{out} also is a continuous square pulsed voltage.

[0061] In one embodiment, the switch module 30, by a controller (not shown), can turn on one of the driving electrodes 31 and the driving electrodes 31 are sequentially detected, a position of the loop between the driving electrode 31 and the detection electrode 32 in the open circuit state or in the short circuit state can be accurately confirmed.

[0062] When the detection electrode 32 outputs the detection voltage V_{out} to the voltage accumulation circuit 41, the voltage accumulation circuit 41 accumulates the detection voltage V_{out} to obtain the accumulation voltage V_p. The detection module 40 outputs the accumulation voltage V_p to the determination module 50. The determination module 50 compares the accumulation voltage V_p with the specified voltage V_r. An open circuit state and a short circuit state in the driving loop 3 can be determined by a difference between the accumulation voltage V_p and the specified voltage V_r. The position of the driving loop 3 in the open circuit state or the short circuit state is also confirmed.

[0063] The accumulated voltage V_p of the driving loop 3 in a normal state firstly needs to be detected for serving as the specified voltage V_r. In the normal state, the accumulated voltage V_p of the driving loop 3 is equal to the specified voltage V_r. The circuit detection principle of the EWOD device 100 will be described as below.

[0064] FIG. 11 shows the circuit diagram of the EWOD device 100, and FIG. 12 shows waveforms of voltages of the EWOD device 100.

[0065] When the channel 2 of the detection chip 10 is without the silicon oil, the power voltage V_{in} of the power input module 20 (the continuous square pulsed voltage as shown in FIG. 12) is provided to a driving loop 3 with a specified driving electrode 31 through the switch module 30. The detection voltage V_{out} is outputted by the detection electrode 32. The detection voltage V_{out} is accumulated by the voltage accumulation circuit 41 (an integrator) of the detection module 40 to obtain the accumulated voltage V_p (as shown in FIG. 12). The detection module 40 outputs the accumulated voltage V_p to the determination module 50 for comparing.

[0066] For example, when the switch unit 4 of the switch module 30 is electrically connected to the electrode A, the electrode A and the detection electrode 32 form a driving loop 3. The continuous square pulsed voltage of the power input module 20 is provided to the electrode A through the equivalent resistor R_{BA}, the electrode A couples with the detection electrode 32, and the detection electrode 32 outputs the detection voltage V_{out} (coupled voltage) to the voltage accumulation circuit 41 (integrator) through the equivalent resistor between the detection electrode 32 and the detection module 40. The voltage accumulation circuit 41 accumulates the detection voltage V_{out} to obtain the accumulated voltage V_p, and outputs the accumulated voltage V_p to the determination module 50. When receiving the accumulated voltage V_p, the determination module 50 computes the difference between the accumulated voltage V_p and the specified voltage V_r to determine whether the EWOD device 100 is in a normal state.

[0067] As shown in FIG. 12, in one cycle of the continuous square pulsed voltage, a peak voltage of the detection voltage V_{out} serves as the accumulated voltage V_p of the EWOD device 100 in the normal state. In one embodiment, the waveform of the accumulated voltage V_p is overlapped with the waveform of the specified voltage V_r, and the accumulated voltage V_p is equal to the specified voltage V_r. Therefore, the EWOD device 100 in this situation is in the normal state.

[0068] It is understood that, when the channel 2 of the detection chip 10 is filled with the silicon oil, the circuit detection principle is same. The accumulated voltage V_p when the channel 2 is filled with the silicon oil is different from the accumulated voltage V_p when the channel 2 of the detection chip 10 is without the silicon oil.

[0069] FIG. 13 shows the circuit diagram of the EWOD device 100 in the open circuit state.

[0070] As shown in FIG. 13, the power voltage V_{in} of the power input module 20 (the continuous square pulsed voltage as shown in FIG. 14) is provided to a driving loop 3 with the specified driving electrode 31 through the switch module 30. When the driving loop 3 is in the open circuit state, the power voltage V_{in} of the power module 20 is not provided to the specified electrode 31 through the switch module 30 and the detection electrode 32, and the detection electrode 32 does not output the detection voltage V_{out}. Thus, the voltage accumulation circuit 41 (integrator) of the detection module 40 does not receive the detection voltage V_{out}, and does not accumulate the detection voltage V_{out} to obtain the accumulated voltage V_p. Therefore, the determination module 50 easily determines that the driving loop 3 of the specified driving electrode 31 is in the open circuit state.

[0071] When the circuit with the electrode A is in the open circuit state, the detection module 40 does not receive the detection voltage V_{out} to obtain the accumulated voltage V_p. The voltage difference ΔV_1 between the voltage detected by the detection module 40 and the specified voltage V_r is used for determining whether the driving loop 3 is in the open circuit state. As shown in FIG. 14, the waveform of the detection voltage V_{out} in the normal state with the peak voltage is equal to the specified voltage V_r. The waveform of the detection voltage V_{out} is the straight line below the waveform of the detection voltage V_{out} in the normal state. The detection module 40 does not receive the detection voltage V_{out}, thus there is no accumulated voltage V_p. The straight line in FIG. 14 represents the accumulated voltage V_p. The voltage difference ΔV_1 is a difference between the accumulated voltage V_p and the specified voltage V_r. The voltage difference ΔV_1 becomes larger. By a shape of the curved line C and the voltage difference ΔV_1, it can be determined that the driving loop 3 of the electrode A is in the open circuit state.

[0072] Whether or not other wires connected to other driving electrode 31 or connected to the detection electrode 32 are the open circuit state can be detected by the same detection principle as above.

[0073] FIG. 15 shows the circuit diagram of the EWOD device 100 in the short circuit state.

[0074] As shown in FIG. 15, the power voltage V_{in} of the power input module 20 (the continuous square pulsed voltage as shown in FIG. 16) is provided to a driving loop 3 with the specified driving electrode 31 through the switch module 30. The detection electrode 32 outputs the detection voltage V_{out}, and the voltage accumulation circuit 41 (integrator) of the detection module 40 accumulates the detection voltage V_{out} to obtain the accumulated voltage V_p. The detection module 40 outputs the accumulated voltage V_p to the determination module 50 for comparing. When the driving loop 3 is in the short circuit state, the power voltage V_{in} of the power module 20 is not provided to the circuit through the switch module 30, different wires between the specified driving electrode 31 are electrically connected with each other, the resistance of the first resistors (R_{BA}, R_{BB}, R_{BC}) being driven is increased, and the accumulated voltage V_p decreases. The voltage difference ΔV_2 between the accumulated voltage V_p and the specified voltage V_r is used for determining whether the driving loop 3 is in the short circuit state. As shown in FIG. 16, the curved line b shows the detection voltage V_{out} in the normal state, and the curved line c shows the accumulated voltage V_p. When the driving loop 3 is in the short circuit state, a slope of the curved line c of the accumulated voltage V_p is less than a slope of the curved line b of the detection voltage V_{out} in the normal state. The voltage difference ΔV_2 in the short circuit state is less than the voltage difference ΔV_1 in the open circuit state. Therefore, the driving loop 3 with the specified driving electrode 31 is determined as being short circuited according to the voltage difference ΔV_2 and the accumulated voltage V_p.

[0075] When the wire connected to the electrode A is in the short circuit state, and is electrically connected to the wire connected to the electrode B, the resistance of the resistor R_{BA}-R_{BB} of electrode A or B being driven increases, the accumulated voltage V_p detected by the voltage accumulation circuit 41 of the detection module 40 decreases, thus the slope of the curved line of the accumulated voltage V_p is less than the detection voltage V_{out} in the normal state. Therefore, the driving loop 3 with the specified driving electrode 31 is determined as being in the short circuit state according to the voltage difference ΔV_2 and the accumulated voltage V_p.

[0076] Whether or not other wires connected to other driving electrode 31 or connected to the detection electrode 32 are short circuited can be detected by the same detection principle as above.

[0077] When detecting the EWOD device 100, the curved line of the EWOD device 100 being the normal state should be detected firstly as shown in FIG. 12. The curved line of the EWOD device 100 in the normal state serves as a standard line. When the EWOD device 100 is functioning abnormally, the change of the accumulated voltage V_p is detected for determining the short circuit state or the open circuit state of the circuit in the EWOD device 100, and the position of the circuit in the EWOD device 100 is also detected. The EWOD device 100 executes a self-detection of the detection chip 10 by the internal circuit of the EWOD device 100, and no external detection device is required. The method for detecting the circuit in the EWOD device 100 is simple, and is easy for operation. The detection result is more accurate. The method has higher efficiency, and a determination as to abnormal functioning is more accurate.

[0078] A method for detecting a circuit in the EWOD device 100 includes at least the following steps, which also may be followed in a different order:

[0079] In a first step, the switch module 30 is electrically connected to the specified driving electrode 31, thus the power input module 20 provides the power voltage V_{in} to the specified driving electrode 31.

[0080] In a second step, the specified driving electrode 31 couples with the detection electrode 32 to generate the detection voltage V_{out} (coupled voltage), and the detection electrode 32 outputs the detection voltage V_{out} to the detection module 40.

[0081] In a third step, the detection module 40 accumulates the detection voltage V_{out} to obtain the accumulated voltage V_p.

[0082] In a fourth step, the determination module 50 compares the accumulated voltage V_p with the specified voltage V_r to determine whether the circuit with the specified driving electrode 31 is in the short circuit state or the open circuit state, and the position of the circuit in the short circuit state or the open circuit state is also confirmed.

[0083] The determination process is the same as the above detection principle.

[0084] The EWOD device 100 can execute a self-detection for detecting the internal circuits. By comparing the accumulated voltage V_p and the specified voltage V_r, the state of the circuit in the EWOD device 100 is confirmed, such as the open circuit state and the short circuit state, and the position of the circuit in the EWOD device 100 is also confirmed. The method for detecting the circuit in the EWOD device 100 is simple, and is easy for operation. The detection result is more accurate. The method has higher efficiency, and a determination as to abnormal functioning is more accurate

[0085] Besides, many variations and modifications can be made to the above-described embodiment(s) of the disclosure without departing substantially from the spirit and principles of the disclosure. All such modifications and variations are intended to be included herein within the scope of this disclosure and protected by the following claims. The foregoing description, for purpose of explanation, has been described with reference to specific embodiments. However, the illustrative discussions above are not intended to be exhaustive or to limit the invention to the precise forms disclosed. Many modifications and variations are possible in view of the above teachings. The embodiments were chosen and described in order to best explain the principles of the invention and its practical applications, to thereby enable others skilled in the art to best use the invention and various described embodiments with various modifications as are suited to the particular use contemplated.

Claims

1. An electrowetting on dielectric (EWOD) device (100) comprising:

   a detection chip (10) with a channel (2) and a driving loop (3) disposed on opposite sides of the channel (2); the driving loop (3) with several driving electrodes (31) and a detection electrode (32); the driving electrodes (31) disposed on a side of the channel (2), and the detection electrode (32) disposed on a side of the channel (2) opposite to the driving electrodes (31); each driving electrode (31) configured to couple with the detection electrode (32) to form the driving loop (3);
   a power input module (20), electrically connected to the driving electrodes (31), and configured to output a power voltage to the driving electrodes (31);
   a switch module (30), disposed between the driving electrodes (31) and the power input module (20), and configured to select one of the driving electrodes (31) to be electrically connected to the power input module (20);
   a detection module (40), electrically connected to the detection electrode (32), and configured to receive a detection voltage (V_{out}) outputted by the detection electrode (32), and accumulate the detection voltage (V_{out}) to obtain an accumulated voltage (V_p); and
   a determination module (50), electrically connected to the detection module (40), configured to compare the accumulated voltage with a specified voltage (V_r) for determining the driving loop (3) in a short circuit state or in an open circuit state.

2. The EWOD device (100) of claim 1, wherein when the driving loop (3) is determined in a short circuit state or in an open circuit state, the determination module (50) further confirms a position of the EWOD device (100) in the short circuit state or in the open circuit state.

3. The EWOD device (100) of claim 1, wherein the detection module (40) comprises a voltage accumulation circuit (41); the voltage accumulation circuit (41) comprises an operational amplifier (U_1) and a first capacitor (C_1); an output terminal of the detection electrode (32) is electrically connected to a positive

terminal of the operational amplifier (U_1) and a terminal of the first capacitor (C_1); another terminal of the first capacitor (C_1) is electrically connected to an output terminal of the operational amplifier (U_1); a positive terminal of the operational amplifier (U_1) is grounded; the output terminal of the operational amplifier (U_1) is served as an output terminal of the detection module (40) for outputting the accumulated voltage of the detection voltage (V_{out}).

4. The EWOD device (100) of claim 3, wherein the voltage accumulation circuit (41) comprises an integrator.

5. The EWOD device (100) of claim 1, wherein the driving loop (3) comprises a first dielectric layer (33) disposed on a side of the driving electrode (31) away from the channel (2) and a second dielectric layer (34) disposed on a side of the detection electrode away from the channel (2).

6. The EWOD device (100) of claim 1, wherein the channel (2) is filled with air and/or silicon oil.

7. The EWOD device (100) of claim 1, wherein the power voltage is a continuous square pulsed voltage.

8. The EWOD device (100) of claim 1, wherein the detection chip (10) comprises a chip casing (1); the chip casing (1) comprises a first cover (11), a spacer layer (12), and a second cover (13); two opposite surfaces of the spacer layer (12) are respectively adjacent to the first cover (11) and the second cover (13); the first cover (11), the spacer layer (12), and the second cover (13) form the channel (2); the driving electrodes (31) arranged in a matrix are disposed on a surface of the first cover (11) adjacent to the channel (2); the detection electrode (32) is disposed on a surface of the second cover (13) adjacent to the channel (2).

9. The EWOD device (100) of claim 1, wherein the detection module (40) comprises a voltage accumulation circuit (41); the voltage accumulation circuit (41) comprises a first operational amplifier (U_1), a first diode (D_1), a second diode (D_2), a second operational amplifier (U_2), a first resistor (R_1), a second resistor (R_2), and a first capacitor (100); a positive terminal of the first operational amplifier (U_1) is electrically connected to the detection electrode (32), and a negative terminal of the first operational amplifier (U_1) is electrically connected to an anode electrode of the first diode (D_1) and a terminal of the second resistor (R_2); an output terminal of the first operational amplifier (U_1) is electrically connected to an anode electrode of the second diode (D_2) and a cathode electrode of the first diode (D_1); a cathode electrode of the second diode (D_2) is electrically connected to a terminal of the first resistor (R_1), another terminal of the first resistor (R_1) is electrically connected to a positive terminal of the second operational amplifier (U_2) and a terminal of the first capacitor (C_1); another terminal of the first capacitor (C_1) is grounded; a negative terminal of the second operational amplifier (U_2) is electrically connected to another terminal of the second resistor (R_2) and an output terminal of the second operational amplifier (U_2); the output terminal of the second operation amplifier (U_2) serves as an output terminal of the detection module (40) for outputting the accumulated voltage of the detection voltage (V_{out}).

10. The EWOD device (100) of claim 9, wherein the voltage accumulation circuit (41) comprises a peak detector.

11. A method for detecting a circuit in an electrowetting on dielectric (EWOD) device (100) with a detection chip (10); the method comprising:

electrically connecting a switch unit (4) with a specified driving electrode for providing a power voltage from a power input module (10) to the specified driving electrode;
forming a driving loop (3) and generating a detection voltage (V_{out}) when the specified driving electrode (31) being coupled to a detection electrode (32);
accumulating the detection voltage (V_{out}) by a detection module (40) to obtain the accumulated voltage (V_p); and
comparing the accumulated voltage by a determination module (50) with a specified voltage (V_r) to determining whether a driving loop (3) is in a short circuit state or in an open state.

12. The method of claim 11, wherein the method further comprising:
confirming a position of the driving loop (3) in the short circuit state or in the open circuit state, when the driving loop (3) is in the short circuit state or in the open circuit state.

13. The method of claim 11, wherein the detection module (40) comprises a voltage accumulation circuit (41); the voltage accumulation circuit (41) comprises an operational amplifier (U) and a first capacitor (C_1); an output terminal of the detection electrode (32) is electrically connected to a positive terminal of the operational amplifier (U) and a terminal of the first capacitor (C_1); another terminal of the first capacitor (C_1) is electrically connected to an output terminal of the operational amplifier (U); a positive terminal of the operational amplifier (U) is grounded; the output terminal of the operational amplifier (U) is served as an output terminal of the detection module (40) for outputting the accumulated voltage of the detection voltage (V_{out}).

14. The method of claim 13, wherein the voltage accumulation circuit (41) comprises an integrator.

15. The method of claim 11, wherein the driving loop (3) comprises a first dielectric layer (33) disposed on a side of the driving electrode (31) away from the channel (2) and a second dielectric layer (34) disposed on a side of the detection electrode (32) away from the channel (2).

16. The method of claim 11, wherein the channel (2) is filled with air and/or silicon oil.

17. The method of claim 11, wherein the power voltage is a continuous square pulsed voltage.

18. The method of claim 11, wherein the detection chip (10) comprises a chip casing (1); the chip casing (1) comprises a first cover (11), a spacer layer (12), and a second cover (13); two opposite surfaces of the spacer layer (12) are respectively adjacent to the first cover (11) and the second cover (13); the first cover (11), the spacer layer (12), and the second cover (13) form the channel (2); the driving electrodes (31) arranged in a matrix are disposed on a surface of the first cover (11) adjacent to the channel (2); the detection electrode (32) is disposed on a surface of the second cover (13) adjacent to the channel (2).

19. The method of claim 11, wherein the detection module (40) comprises a voltage accumulation circuit (41); the voltage accumulation circuit (41) comprises a first operational amplifier (U_1), a first diode (D_1), a second diode (D_2), a second operational amplifier (U_2), a first resistor (R_1), a second resistor (R_2), and a first capacitor (100); a positive terminal of the first operational amplifier (U_1) is electrically connected to the detection electrode (32), and a negative terminal of the first operational amplifier (U_1) is electrically connected to an anode electrode of the first diode (D_1) and a terminal of the second resistor (R_2); an output terminal of the first operational amplifier (U_1) is electrically connected to an anode electrode of the second diode (D_2) and a cathode electrode of the first diode (D_1); a cathode electrode of the second diode (D_2) is electrically connected to a terminal of the first resistor (R_1), another terminal of the first resistor (R_1) is electrically connected to a positive terminal of the second operational amplifier (U_2) and a terminal of the first capacitor (C_1); another terminal of the first capacitor (C_1) is grounded; a negative terminal of the second operational amplifier (U_2) is electrically connected to another terminal of the second resistor (R_2) and an output terminal of the second operational amplifier (U_2); the output terminal of the second operation amplifier (U_2) serves as an output terminal of the detection module (40) for outputting the accumulated voltage of the detection voltage (V_{out}).

20. The method of claim 19, wherein the voltage accumulation circuit (41) comprises a peak detector.

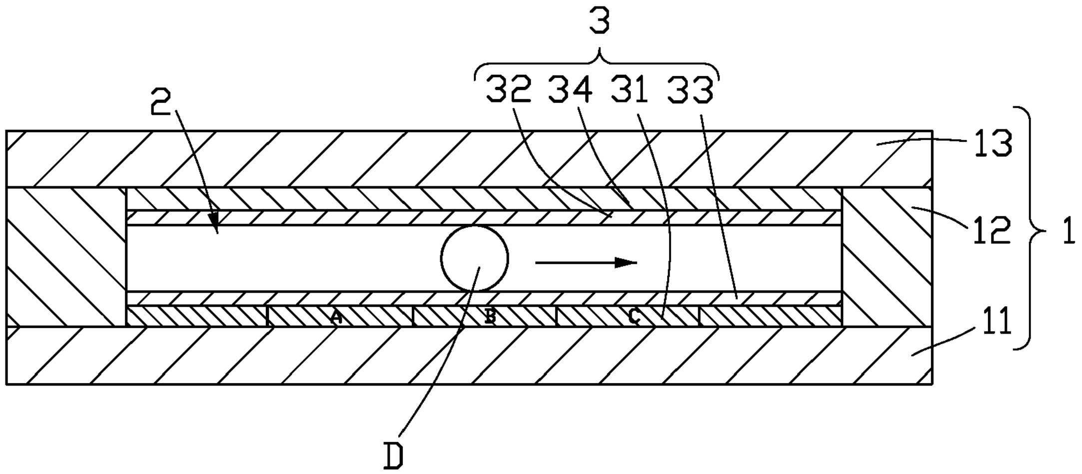


FIG. 1

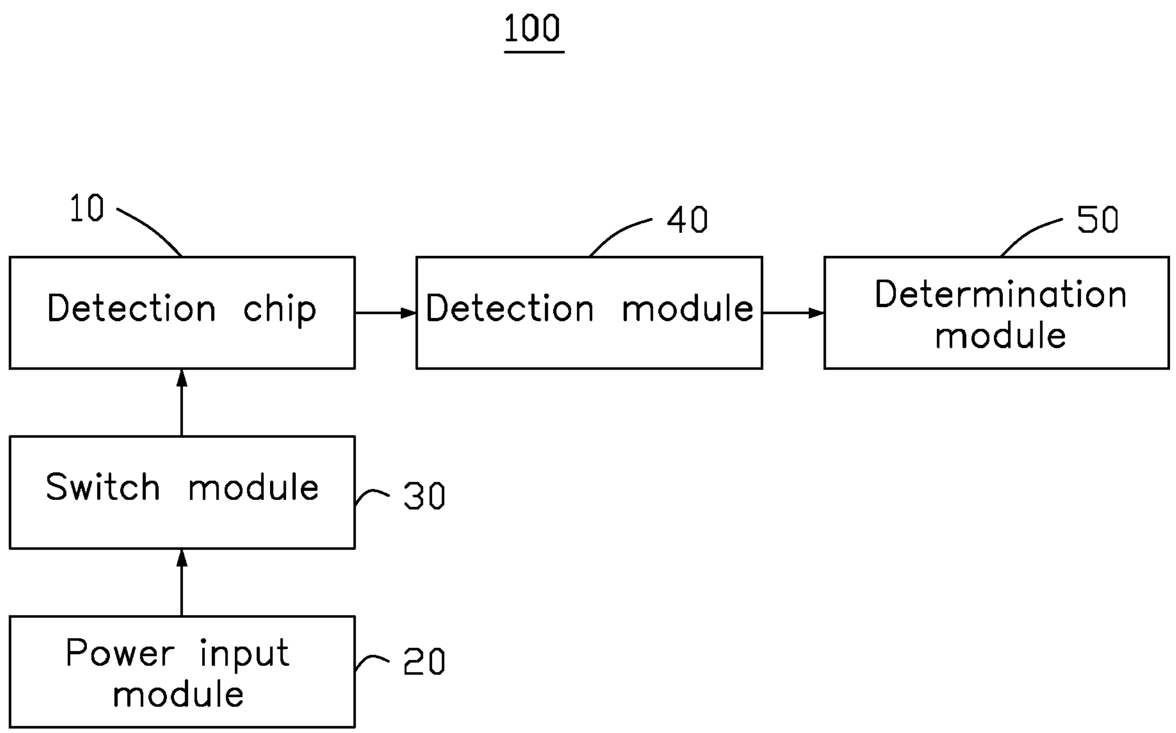

100
10
Detection chip
40
Detection module
50
Determination module
Switch module
30
Power input module
20

FIG. 2

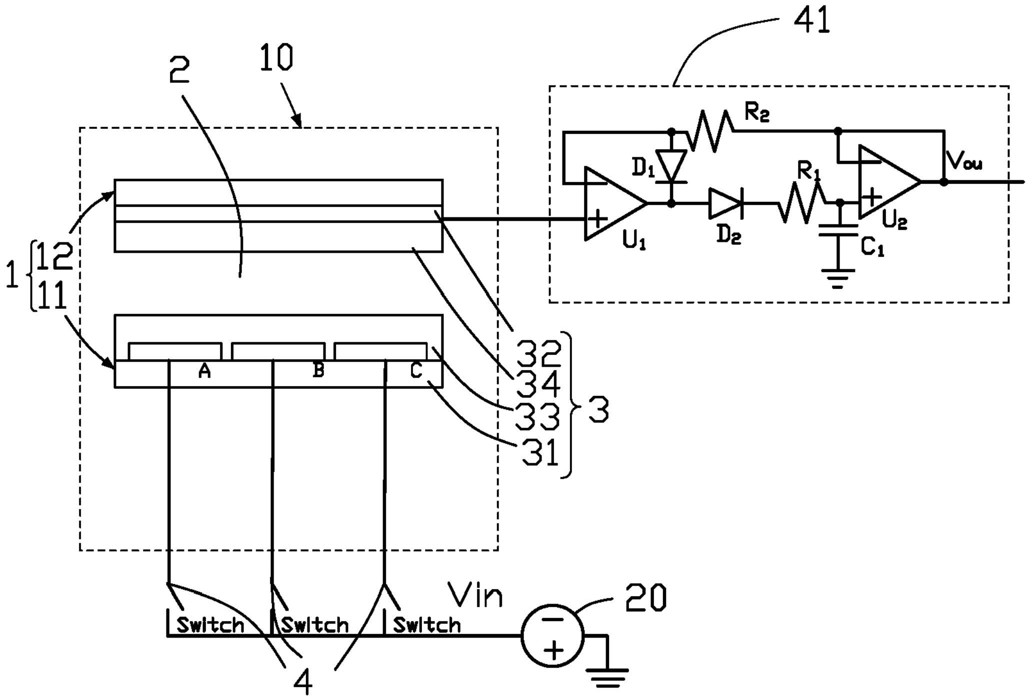
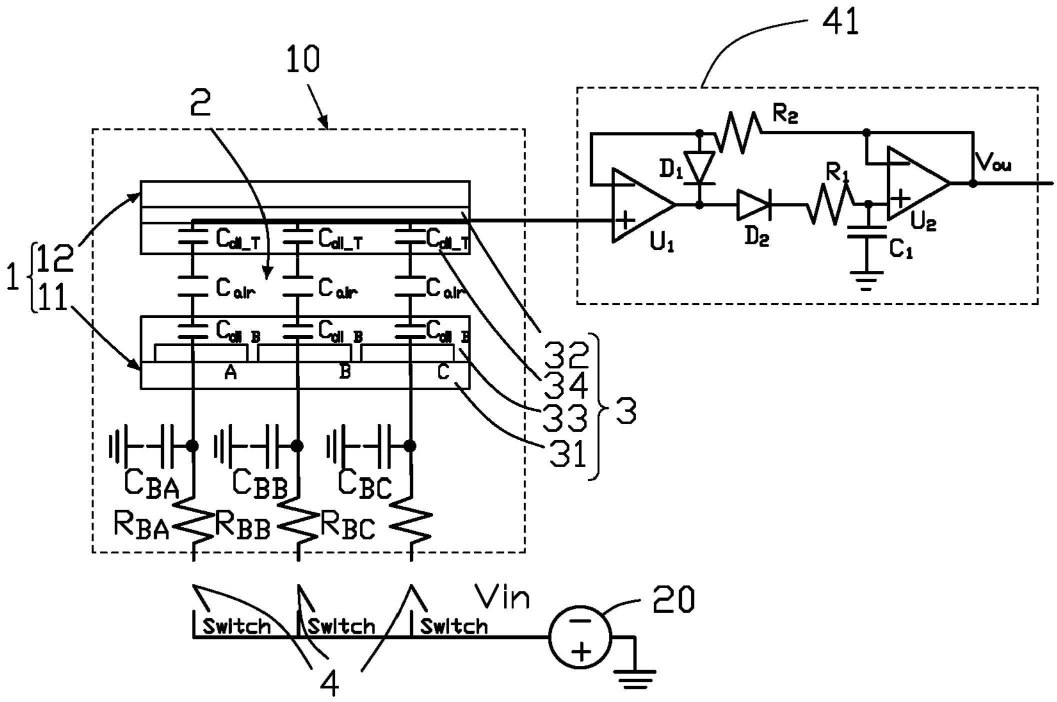

41
2
10
R2
D1
R1
Vou
U1
D2
U2
C1
1
12
11
A
B
C
32
34
33
3
31
Vin
20
Switch
Switch
Switch
4

FIG. 3



41
10
2
R_2
D_1
R_1
V_{ou}
U_1
D_2
U_2
C_1
1
12
11
C_{dl_T}
C_{air}
C_{dl_B}
A
B
C
32
34
33
31
3
C_{BA}
C_{BB}
C_{BC}
R_{BA}
R_{BB}
R_{BC}
Vin
20
Switch
Switch
Switch
4

FIG. 4

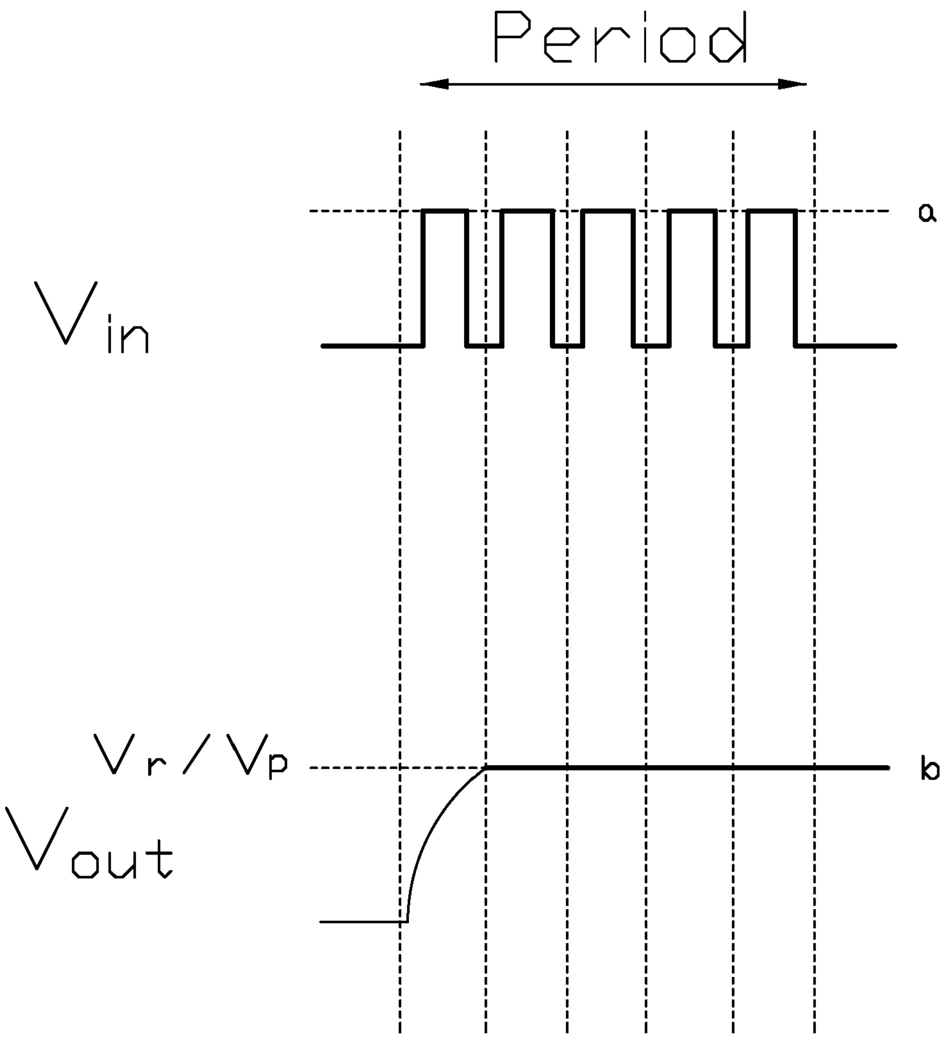


FIG. 5

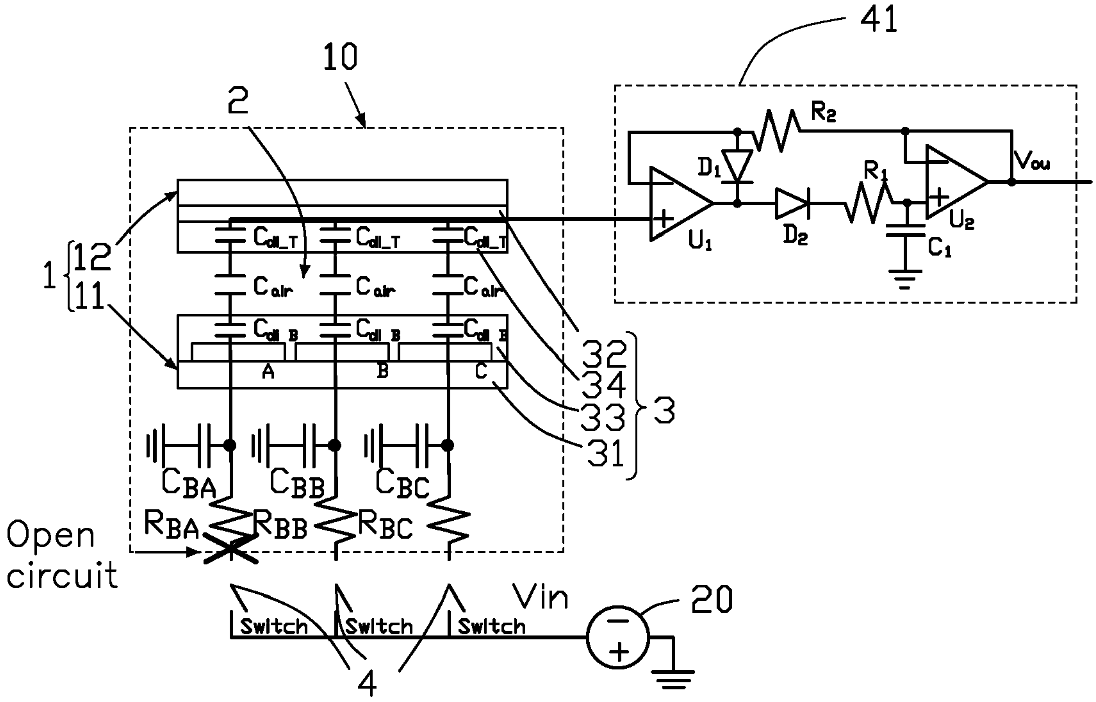

41
10
2
R2
D1
Vou
R1
1
12
11
C_{dl_T}
C_{air}
C_{dl_B}
A
B
C
U1
D2
U2
C1
32
34
33
31
3
CBA
CBB
CBC
Open circuit
RBA
RBB
RBC
Vin
20
Switch
Switch
Switch
4

FIG. 6

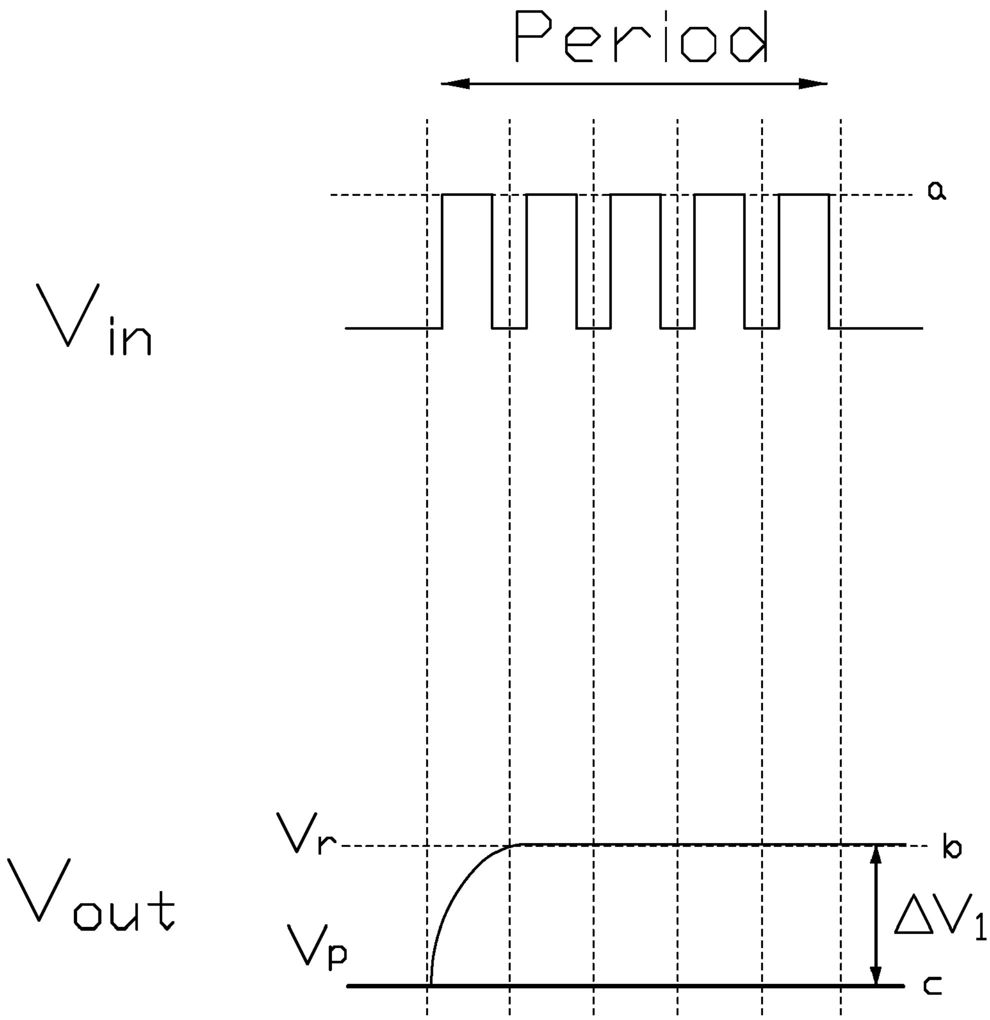


FIG. 7

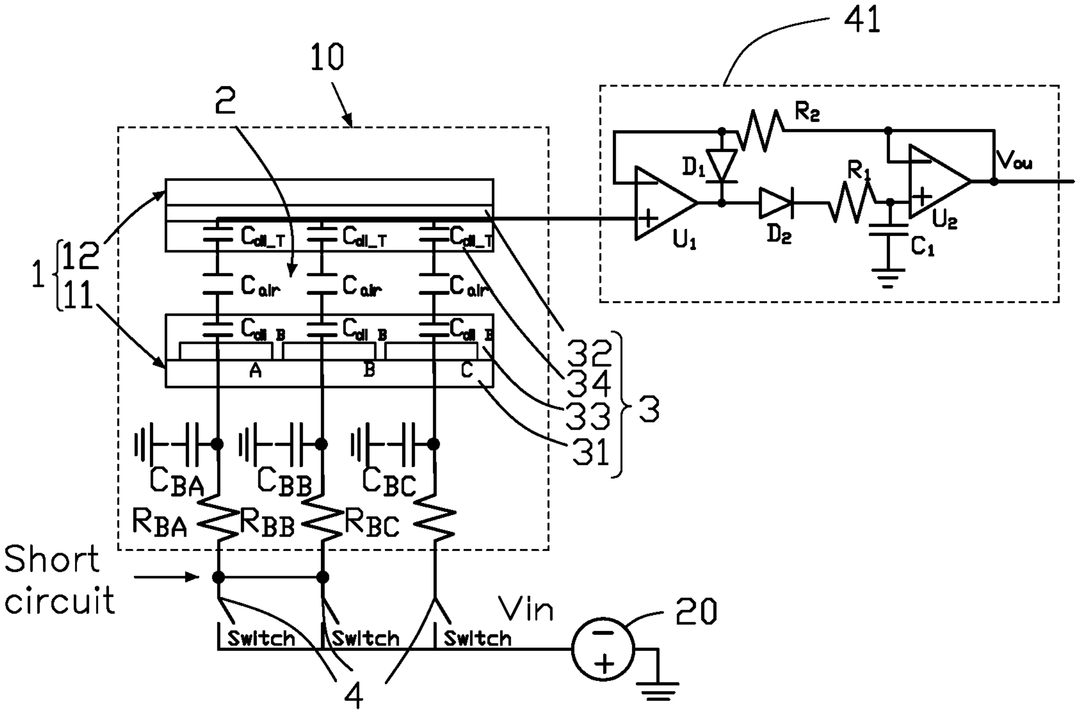

41
10
2
R_2
D_1
V_{ou}
R_1
1
12
11
C_{dl_T}
C_{air}
C_{dl_B}
A
B
C
U_1
D_2
U_2
C_1
32
34
33
31
3
C_{BA}
C_{BB}
C_{BC}
R_{BA}
R_{BB}
R_{BC}
Short circuit
Vin
Switch
Switch
Switch
20
4

FIG. 8

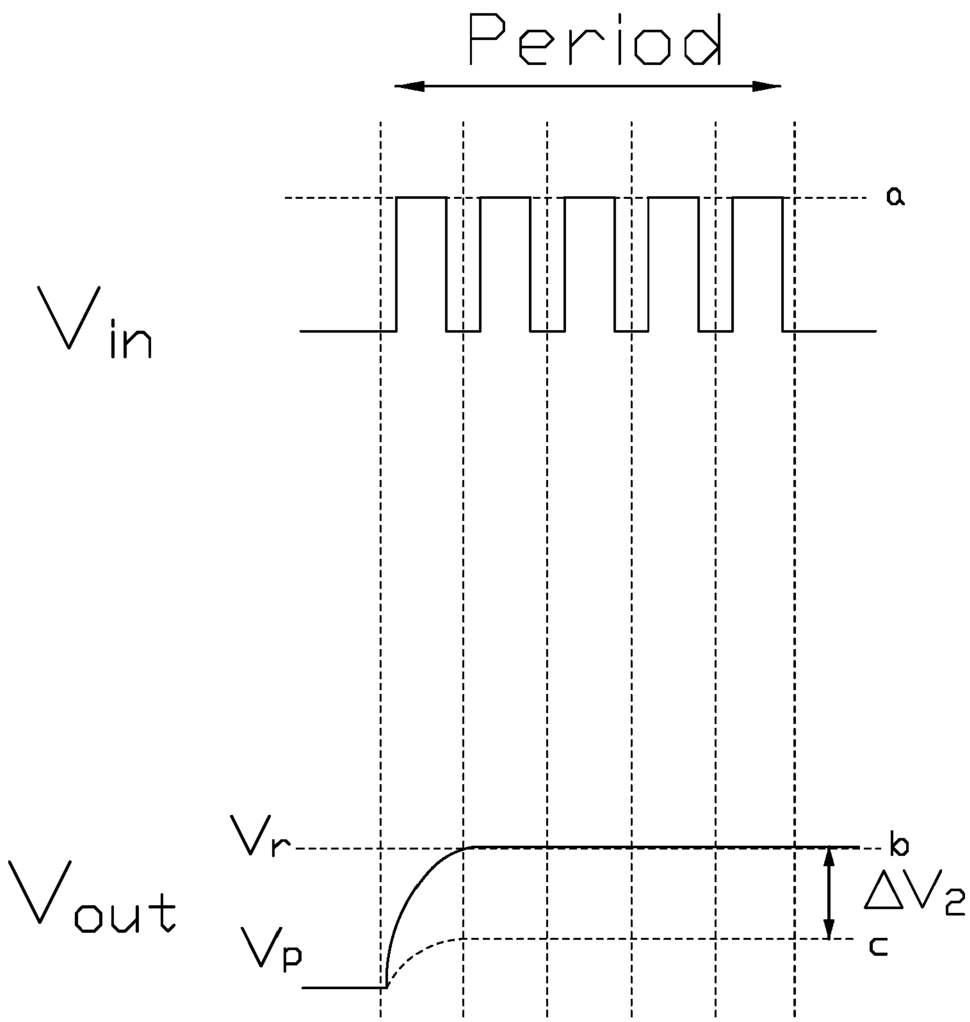


FIG. 9

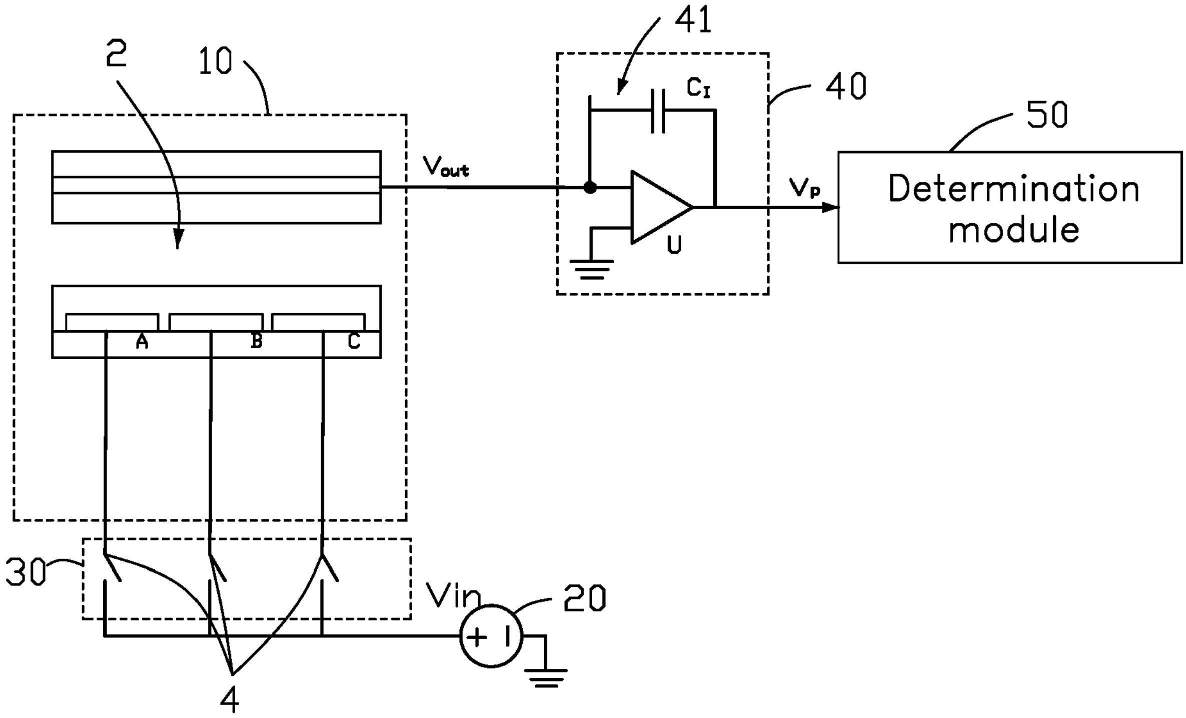


FIG. 10

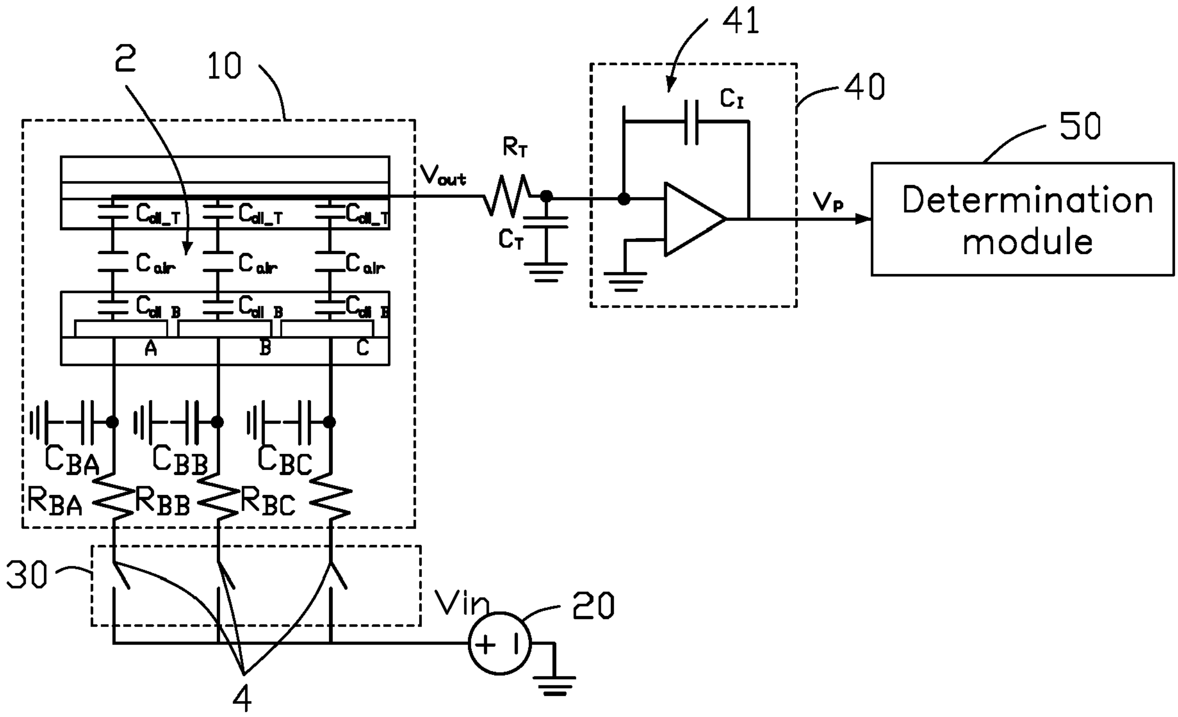

2
10
41
40
50
C_I
R_T
V_{out}
C_T
V_P
Determination module
C_{oil_T}
C_{air}
C_{oil_B}
A
B
C
C_{BA}
C_{BB}
C_{BC}
R_{BA}
R_{BB}
R_{BC}
30
Vin
20
4

FIG. 11

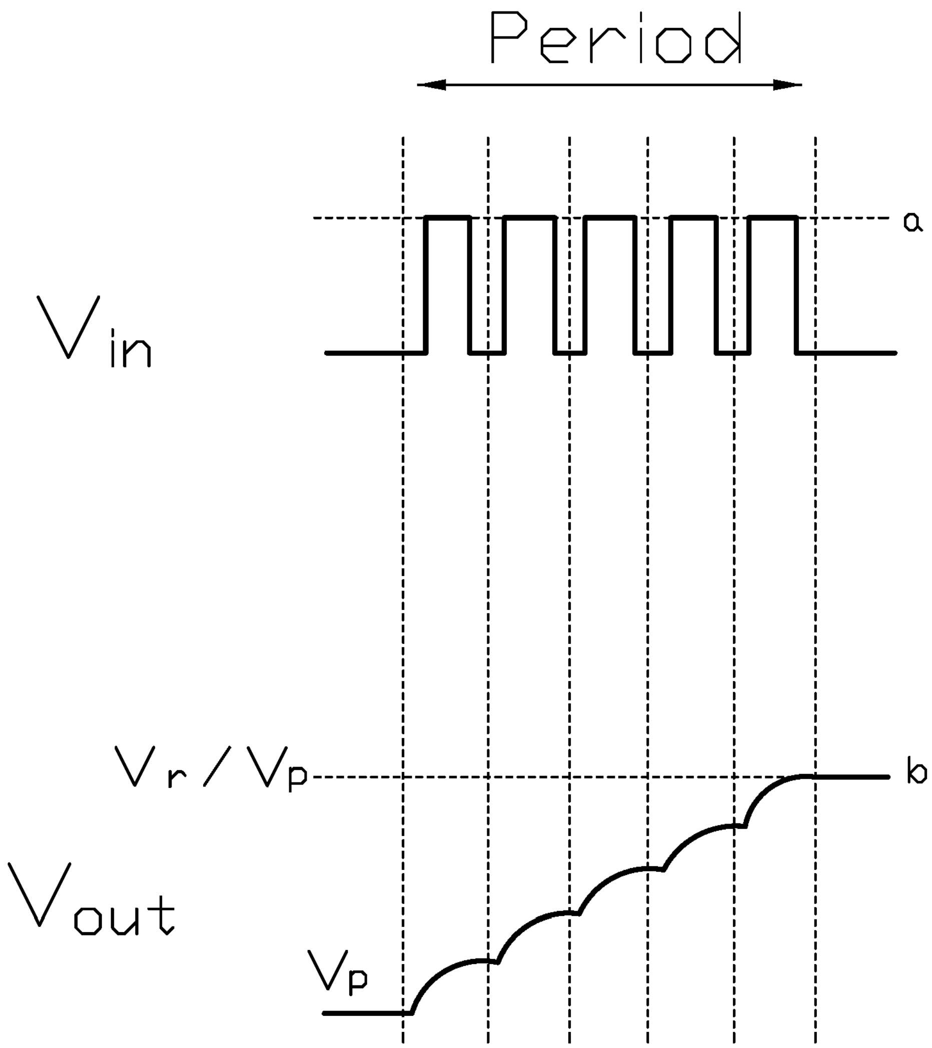


FIG. 12

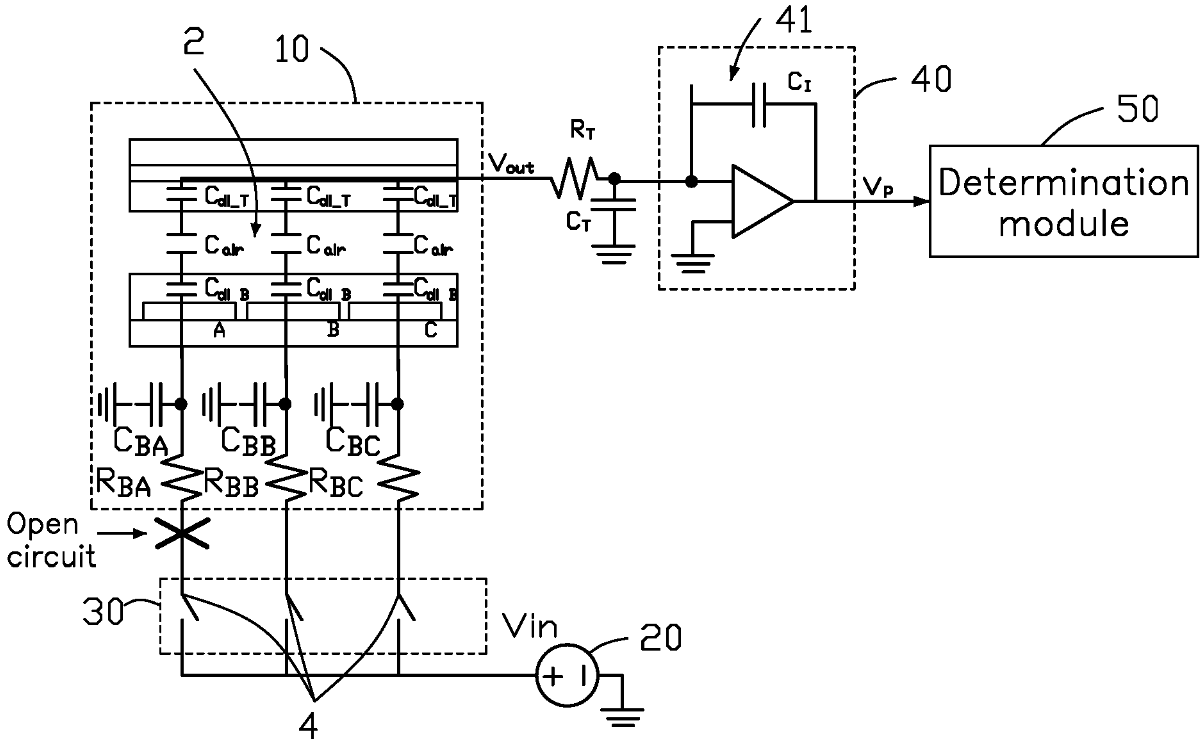

2
10
41
40
50
C_I
R_T
V_{out}
C_{dl_T}
C_{air}
C_{dl_B}
A
B
C
C_T
V_P
Determination module
C_{BA}
C_{BB}
C_{BC}
R_{BA}
R_{BB}
R_{BC}
Open circuit
30
Vin
20
4

FIG. 13

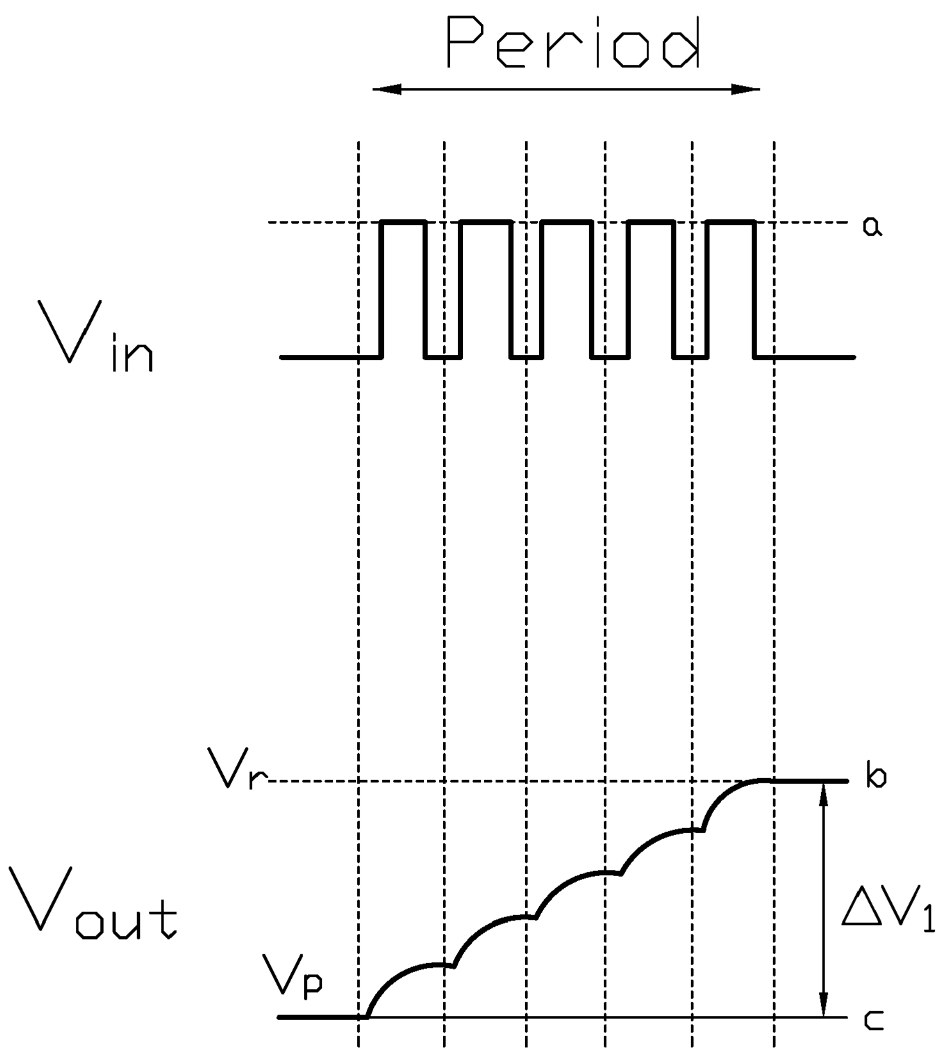


FIG. 14

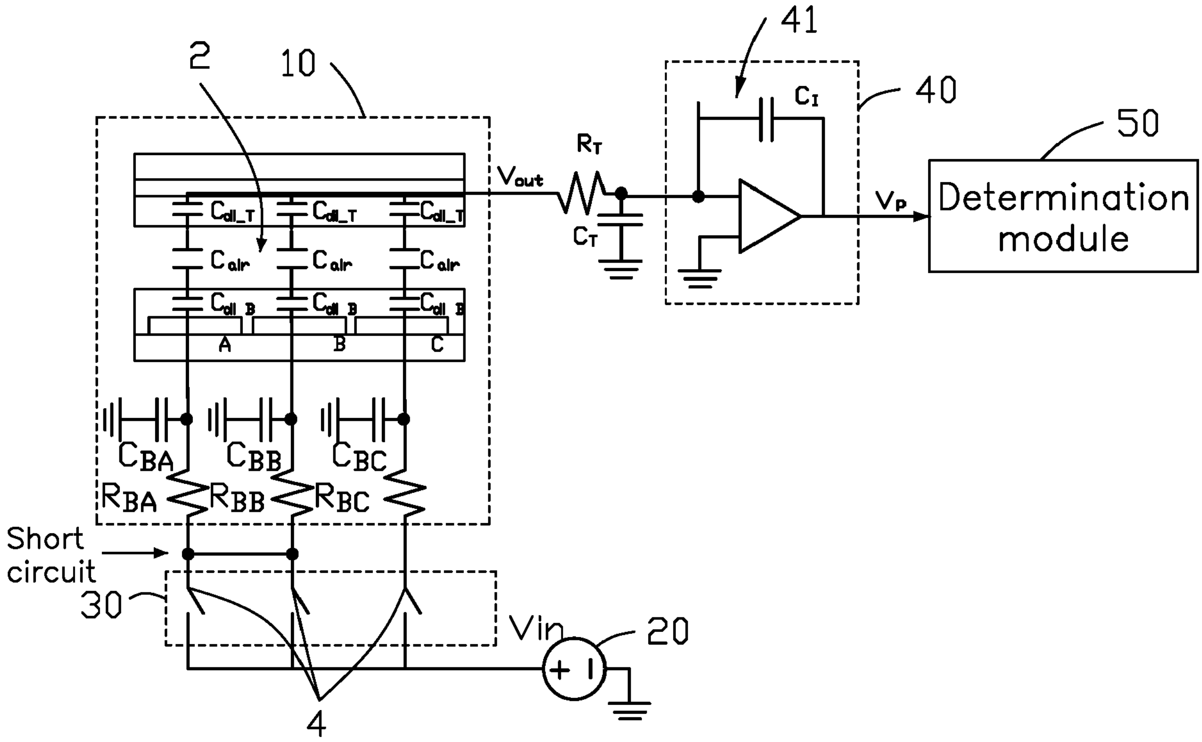

2
10
41
40
50
C_I
R_T
V_{out}
C_T
V_P
Determination module
C_{dl_T}
C_{air}
C_{dl_B}
A
B
C
C_{BA}
C_{BB}
C_{BC}
R_{BA}
R_{BB}
R_{BC}
Short circuit
30
Vin
20
4

FIG. 15

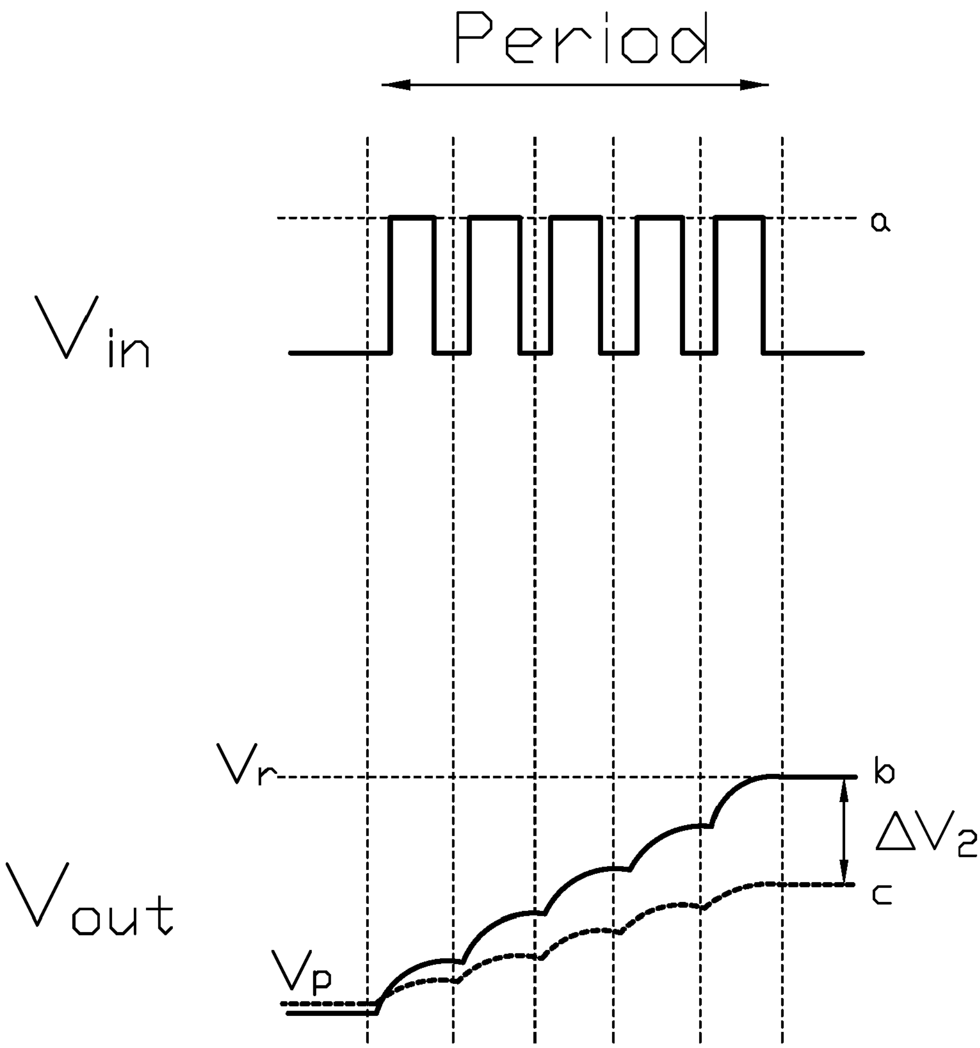


FIG. 16

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 21 19 9850

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	WO 2018/039281 A1 (MIROCULUS INC [US]) 1 March 2018 (2018-03-01) * paragraphs [0039] - [0040], [0055] - [0061]; figure 2A * -----	1,2,5-8, 10-12, 15-18,20	INV. B01L3/00
X	US 2020/175932 A1 (HADWEN BENJAMIN JAMES [GB] ET AL) 4 June 2020 (2020-06-04) * paragraphs [0055] - [0059], [0072], [0075] - [0079]; figures 7-8, 11-12 * -----	1,3,4,8, 9,11,13, 14,18,19	
A	US 2020/222899 A1 (MOON HYEJIN [US] ET AL) 16 July 2020 (2020-07-16) * paragraphs [0078] - [0081], [0086] - [0087]; figures 5-7 * -----	1,8,11, 18	

TECHNICAL FIELDS SEARCHED (IPC)

B01L

1 The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	25 January 2022	Ruiz-Echarri Rueda

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2018039281 A1	01-03-2018	CA 3034064 A1	01-03-2018
		CN 109715781 A	03-05-2019
		EP 3500660 A1	26-06-2019
		JP 2020501107 A	16-01-2020
		US 2019217301 A1	18-07-2019
		US 2020254458 A1	13-08-2020
		WO 2018039281 A1	01-03-2018
US 2020175932 A1	04-06-2020	CN 111250178 A	09-06-2020
		EP 3662998 A1	10-06-2020
		US 2020175932 A1	04-06-2020
US 2020222899 A1	16-07-2020	NONE	

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