

"ELECTRONIC DRIVING CIRCUIT FOR DRIVING ELECTRODES OF A
MICROFLUIDIC DEVICE FOR MANIPULATION OF PARTICLES, AND
CORRESPONDING ANALYSIS APPARATUS"

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5 Technical Field of the Invention

The present invention relates to an electronic driving
circuit for driving electrodes of a microfluidic device for
manipulation of particles, and to a corresponding analysis
apparatus cooperating with the microfluidic device; in
10 particular, but without this implying any loss of generality,
the microfluidic device is a device for selection and sorting
of cells immersed in a fluid, by dielectrophoresis.

Prior Art

As it is known, micromachining techniques allow
15 manufacturing of microfluidic devices, including, in a same
chip, micromechanical structures, such as chambers,
channels or separation barriers, and electrical structures,
such as heaters, conductive paths, electrodes or processing
circuits. The micromechanical and electrical structures are
20 formed in one or more substrates, e.g. including
semiconductor material, and housed in a package, which
defines electrical contacts accessible to the outside and
also one or more fluidic inlets and/or outlets.

Microfluidic devices allow to perform complex
25 processing operations on particles, e.g. molecules, cells

or groups of cells, such as operations of cell detection and sorting, DNA analysis or RNA replication. These processing operations may advantageously be performed in an automatic manner by a suitable analysis apparatus, coupled
5 to the microfluidic devices.

Often, microfluidic devices define so called disposable "cartridges", which are to be filled with a fluid containing the particles to be analyzed.

In particular, the DEPArray™ is a known microfluidic
10 device by the present Applicant, which allows to select and sort cells that are to be analysed.

As disclosed e.g. in US patent no. 6,942,776 B2, in the name of the present Applicant, this microfluidic device is based on dielectrophoresis (DEP), i.e. the physical
15 phenomenon whereby neutral particles, when subject to non-uniform, time stationary (DC) or time varying (AC) electric fields, experience a net force directed towards locations with increasing (pDEP) or decreasing (nDEP) field intensity.

20 If the intensity of the dielectrophoretic force is comparable to the gravitational force, an equilibrium may be established allowing to levitate small particles, which may therefore be separated (to be available for further processing operations) from a solution in which the same
25 particles are contained.

In more detail, and as shown in Figure 1, the microfluidic device, denoted with 1, includes an array 2 formed by a number of rows and columns of electrodes 4, which are carried by a substrate 5 (being arranged on an insulating layer thereof, here not shown); the electrodes 4 are selectively addressable, e.g. by means of addressing electronic circuit elements that may be formed in the same substrate 5 (here not shown).

The microfluidic device 1 further includes an upper electrode plate 6, which is arranged above the array 2 and is separated by the electrodes 4, and an analysis chamber 7 is defined therebetween.

A buffer solution containing particles 8 that are to be analyzed (only one of which is shown in Figure 1, for clarity of depiction) may be introduced within the chamber 7, e.g. through at least one inlet defined in the package of the same microfluidic device 1 (here not shown).

As schematically shown, the package of the microfluidic device 1 also defines at least a first contact pad 9a, accessible from the outside, for electrically contacting the upper electrode plate 6; a second contact pad 9b, for electrically contacting a first group of electrodes 4 of the array 2; and a third contact pad 9c, for electrically contacting a second group of electrodes 4 of the array 2.

Driving electrical signals, e.g. sinusoidal periodic signals having suitable amplitude, frequency and phase-shift, are provided to the upper electrode plate 6, the first and the second group of electrodes 4 via the first, 5 second and, respectively, third contact pads 9a, 9b, 9c.

As schematically shown in Figure 1, these driving signals, denoted with V_1 , V_2 and V_3 are generated by an electronic driving circuit 10, including amplifier circuit stages; the electronic driving circuit 10 may for example 10 be part of an analysis apparatus cooperating with the microfluidic device 1.

In particular, by applying in-phase and counter-phase periodic driving signals to the electrodes 4, dielectric fields, in particular dielectrophoretic fields, more 15 particularly one or more independent potential cages 11, may be established in the chamber 7, the strength of which may be varied by acting on the frequency as well as on the amplitude of the driving signals V_1 , V_2 , V_3 (by "potential cage" is meant herein a portion of space enclosed by an 20 equipotential surface and containing a local minimum of the dielectrophoretic potential).

These potential cages 11 trap one or more particles 8, allowing them either to levitate steadily, or to move within the chamber 7, by simply changing the subset of 25 electrodes 4 to which the driving signals V_1 , V_2 , V_3 are

applied and/or by modifying the values of the same driving signals.

For example, if a first electrode 4 is in-phase with the upper electrode plate 6 and is surrounded by electrodes receiving counter-phase driving signals, a potential cage 11 is established above the same first electrode 4. Then, by simply applying in-phase signals to one of the adjacent electrodes 4 (in the same direction as a desired motion), and then reversing the phase of the driving signal supplied to the first electrode, the potential cage 11 disappears and then reappears above the adjacent electrode, being displaced one cell-pitch away from the previous electrode.

By repeating this operation, the trapped particle (or particles) 8 move in adjacent positions in the plane of the array 2. For example, a particle 8 to be analyzed may be moved towards a pick-up location (here not shown), from which it may be extracted from the microfluidic device 1, or at which the same particle 8 may undergo desired processing operations.

The present Applicant has realized that the generation of the driving signals V_1 , V_2 and V_3 poses some issues, due to the particular nature of the load constituted by the microfluidic device 1, which may even compromise the correct operation and performance of the microfluidic device 1.

As shown in Figure 2, from an electric point of view, the active chip of the microfluidic device 1, filled with the conductive buffer solution, can be considered as an unbalanced three-phase non-linear low impedance load in a so called "Delta" configuration. In particular, a first impedance Z_{12} is defined between the first and second contact pads 9a, 9b; a second impedance Z_{31} is defined between the first and third contact pads 9a, 9c; and a third impedance Z_{23} is defined between the second and third contact pads 9a, 9b.

The non-linearity and the low impedance characteristics of the load cause a non-negligible harmonic distortion, which in turn yields to:

possible DC offset variations over-time between the driving signals V_1 , V_2 and V_3 ;

a worsening of the efficiency, since part of the electric energy is not transferred to the active chip load for generation of the potential cages 11, but it is instead wasted in the form of heat generation (i.e. by Joule effect) within the electronic driving circuit 10;

a non-reproducibility of the performances, depending on the cage pattern, buffer solution characteristics and active chip variability.

In particular, the present Applicant has realized that it may be desirable to control the DC (Direct Current)

components of the analog driving signals V_1 , V_2 and V_3 , in order to avoid:

electrolytic phenomena, since a DC voltage between two or more electrodes 4 close to each other may cause the generation of gases (i.e. bubbles) within the buffer solution inside the active area of the chip; and

electro-corrosion, since, due to ox-redox phenomena, a DC voltage component may trigger corrosion of one or more of the electrodes 4, impairing their operation.

Formation of bubbles and damaging of the electrodes 4 may clearly affect the sorting and routing capability of the particles within the microfluidic device 1, and thus compromise its general performance.

The present Applicant has moreover realized that use of traditional linear amplifier circuits (e.g. class AB amplifiers) in the electronic driving circuit 10 may not allow to achieve the desired performances, at least in given operating conditions.

Summary of the Invention

One object of the present invention is thus to provide an electronic driving circuit for a microfluidic device, allowing to overcome the limitations of known solutions, for example in terms of harmonic distortion and DC offset control.

The present solution relates to an electronic driving

circuit for a microfluidic device, and to a corresponding analysis machine, as defined in the appended claims.

Brief Description of the Drawings

Figure 1 shows a schematic view of a portion of a microfluidic device for manipulation of particles, with a related electronic driving circuit;

Figure 2 is an electric representation of the electric load defined by the microfluidic device;

Figure 3 is a schematic block diagram of the electronic driving circuit for the microfluidic device, according to one embodiment of the present solution;

Figure 4 is a schematic block diagram of an amplifier stage of the electronic driving circuit of Figure 3;

Figure 5 is a schematic block diagram of the electronic driving circuit for the microfluidic device, according to a possible implementation of the present solution;

Figure 6 is a schematic block diagram of an amplifier stage of the electronic driving circuit of Figure 5;

Figures 7a and 7b show plots of electrical quantities related to a known electronic driving circuit (Figure 7a) and to the electronic driving circuit, according to the present solution (Figure 7b); and

Figure 8 is a schematic block diagram of an analysis machine, operatively coupled to the microfluidic device.

Detailed Description of the invention

Figure 3 shows an electronic driving circuit, denoted with 20, coupled to a microfluidic device, in the example the microfluidic device 1 discussed with reference to Figure 1, here shown with its electric-load equivalent representation (as discussed with reference to Figure 2).

Accordingly, the microfluidic device 1 here represents an unbalanced three-phase non-linear low impedance load in "Delta" configuration, with the first impedance Z_{12} between the first and second pads 9a, 9b; the second impedance Z_{31} between the first and third pads 9a, 9c; and the third impedance Z_{23} between the second and third pads 9a, 9b.

For example, in the simplified electrical model for the load: the first impedance Z_{12} has a resistive component R_{12} with a value comprised between 0,5 e 40 Ω and a capacitive component C_{12} with a value comprised between 24 pF e 2,4 nF; the second impedance Z_{31} has a resistive component R_{31} with a value comprised between 0,1 e 130 Ω and a capacitive component C_{31} with a value comprised between 70 pF e 7 nF; and the third impedance Z_{23} has a resistive component R_{23} with a value comprised between 0,01 e 1 Ω and a capacitive component C_{23} with a value comprised between 0,5 e 50 nF.

As discussed previously, a respective electrode or group of electrodes 4, 6 of the microfluidic device 1 is

coupled to each of the pads 9a, 9b, 9c.

The impedance of the active chip of the microfluidic device 1 may have real and imaginary part, be non-linear and change during time.

5 Electronic driving circuit 20 is configured to provide to each of the pads 9a, 9b, 9c a respective driving signals, again denoted with V_1 , V_2 and V_3 , for driving the respective electrode or group of electrodes.

10 In particular, the electronic driving circuit 20 includes a number of synchronized switching-mode amplifier stages 22, one for each electrode or group of electrodes to be driven with a respective driving signal V_1 , V_2 , V_3 , or, analogously, one for each pad 9a, 9b, 9c of the microfluidic device 1.

15 Each amplifier stage 22 has:

an output Out, that is to be coupled to a respective pad 9a, 9b, 9c of the microfluidic device 1 (and the respective electrode or group of electrodes), on which an output voltage V_{out} is present (defining the respective driving signal for the microfluidic device 1);

20

a first input IN_1 , designed to receive a clock signal CK, e.g. a pulse train (or square wave) signal with a given frequency f ;

a second input IN_2 , designed to receive a target signal V_t , in particular a voltage signal defining a target

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(or desired) amplitude for the output voltage V_{out} (as will be clarified hereinafter);

a feedback input IN_{fb} , designed to receive a feedback signal V_{fb} , for example a voltage signal, indicative of the driving signal supplied to the load (i.e., of the output voltage V_{out}).

In particular, the feedback signal V_{fb} is picked-up as close as possible to the load; in a possible embodiment, as shown in Figure 3, the pick-up point of the feedback signal V_{fb} is located within the active chip of the microfluidic device 1, in the example at the respective pad 9a, 9b, 9c.

In particular, clock signals CK received by the amplifier stages 22 are designed to synchronize operation of the same amplifier stages 22.

In detail, each amplifier stage 22 comprises:

a switching module 23, having a switching input coupled to the first input IN_1 and receiving the clock signal CK, an output coupled to a first internal node N_1 , a signal input coupled to a second internal node N_2 and receiving a control signal V_c , and also a reference input coupled to a reference terminal, or ground (GND);

a reconstruction filter module 25, in particular a band-pass filter, having an input terminal coupled to the first input IN_1 and an output terminal coupled to the output Out of the amplifier stage 22 via a blocking

capacitor 26; and

a feedback module 29, having an input coupled to the feedback input IN_{fb} of the amplifier stage 22, thereby being designed to receive the feedback voltage V_{fb} , a
5 reference input coupled to the second input IN_2 of the same amplifier stage 22 and a feedback output coupled to the second internal node N_2 (and to the switching module 23).

The feedback input of feedback module 29 is positioned as close to the load as possible, typically not inside the
10 amplifier stage 22; according to a possible solution, the feedback input is within the active chip of the microfluidic device 1.

The electronic driving circuit 20 has a supply input 20a designed to receive a power supply voltage V_{DD} , and
15 further comprises, common to all the amplifier stages 22, a DC offset generator 30, configured to generate, at an offset output thereof, a controlled DC offset voltage V_{off} (the DC offset generator 30 may include a voltage generator of a known type, e.g. of the band-gap type, here not
20 discussed in detail).

According to a possible embodiment, the DC offset voltage V_{off} is equal to 50% of the supply voltage V_{DD} of the microfluidic device 1, for example 2,5 V in the case in which the supply voltage V_{DD} is 5 V.

25 Each amplifier stage 22 is coupled to the offset

output of the DC offset generator 30 via a respective offset inductor 32, which is coupled between the offset output and the output Out of the same amplifier stage 22.

As shown in the same Figure 3, therefore, the offset
5 inductors 32 of the various amplifier stages 22 are connected in a so-called "Wye" configuration, having a first terminal in common (coupled to the output of the DC offset generator 30), and a second terminal coupled to the output Out of the respective amplifier stage 22, injecting
10 therein the DC offset voltage V_{off} .

Electronic driving circuit 20 operates to generate at the output Out of the amplifier stages 22 output signals V_{out} having desired frequency, amplitude and mutual phase-shift (as discussed, these output signals V_{out} are to be
15 supplied as driving signals to the microfluidic device 1). According to a possible embodiment, the output signals V_{out} are analog sinusoidal signals.

In particular, the frequency and phase-shift characteristics of each output signal V_{out} are determined by
20 the clock signal CK received at the first input IN_1 of the respective amplifier stage 22, which determines the switching timing of the switching element 24.

The reconstruction filter module 25 has a very narrow bandwidth, centered at the desired operating frequency for
25 the output signal V_{out} , thus selecting from the signal at

the first internal node N_1 only this fundamental operating frequency and transferring it to the output Out.

The desired amplitude of the output signal V_{out} is instead controlled by the target signal V_t received at the
5 second input IN_2 of the respective amplifier stage 22, via the closed feedback loop defined by the feedback module 29.

In particular, the feedback module 29 is configured to generate, based on the comparison between the feedback signal V_{fb} and the target signal V_t , a control signal V_c .

10 The control signal V_c , provided to the switching module 23, defines the amplitude of the voltage that is selectively provided at the first internal node N_1 , when the switching module 23 internally defines a coupling between the first and second internal nodes N_1 , N_2 . The
15 control signal V_c thus defines the amplitude of the output signal V_{out} , amplitude-modulating the clock signal CK received at the first input IN_1 of the amplifier stage 22.

The blocking capacitor 26, before the output Out, blocks any spurious DC component at the output of the
20 reconstruction filter module 25, so that the DC offset voltage V_{off} , provided by the DC offset generator 30 via the offset inductor 32, comes to constitute the only DC component in the output signal V_{out} .

In particular, a unique and controlled DC offset value
25 is therefore present in all the output signals V_{out} of the

various amplifier stages 22.

It is noted that the offset inductor 32 moreover decouples the DC offset generator 30 from the AC output signal V_{out} .

5 With reference to Figure 4, a possible circuit embodiment for the feedback module 29 of each amplifier stage 22 is now discussed; in the same Figure 4, a buffer amplifier 34 is also shown, receiving the clock signal CK and providing a switching signal to the switching input of
10 the switching module 23 based on the same clock signal CK (the signal switching between 0 V and the power supply voltage V_{DD}).

In this embodiment, the feedback module 29 includes:

a high-pass-filter 36, coupled to the feedback input
15 IN_{fb} of the amplifier stage 22 and configured to perform a high-pass filtering of the feedback signal V_{fb} , thereby blocking-out the low frequency (particularly the DC) components thereof;

a rectifier 37, coupled to the output of the high-pass
20 filter module 36 and configured to extract the amplitude value from the filtered feedback signal V_{fb} ;

a low-pass filter 38 coupled to the output of the
rectifier module 37 and configured to perform a low-pass
filtering operation, for generating a comparison signal
25 V_{FB}' , that is therefore indicative of the amplitude value

of the output signal V_{out} ;

a subtraction unit 39, receiving the comparison signal V_{FB}' from the rectifier 37 and the target signal V_t provided at the second input IN_2 of the amplifier stage 22, and
5 configured to generate a difference (or error) signal V_e , based on the difference between the comparison signal V_{FB}' and the target signal V_t ; and

a voltage converter 40, in particular a step-down voltage converter, which receives the error signal V_e and
10 generates a regulated DC output voltage representing the control signal V_c that is fed-back to the switching module 23, for modulating the input clock signal CK and setting the amplitude of the output signal V_{out} .

As shown in Figures 5 and 6 (that correspond to above
15 Figures 3 and 4, respectively), in a possible implementation, the switching module 23 comprises:

a switching element 24, in particular a transistor, e.g. a MOSFET transistor (a BJT, or any other suitable transistor), coupled between the reference terminal, or
20 ground (GND), and the first internal node N_1 , and having a control terminal (gate terminal of the MOSFET transistor) coupled to the first input IN_1 and receiving the clock signal CK;

an impedance element 28, in particular including an
25 inductor element, coupled between the first internal node

N_1 (being connected to the switching element 24) and the second internal node N_2 , thus receiving the control signal V_c .

As will be evident, in this implementation, the impedance element 28 defines coupling between the first and second internal nodes N_1 , N_2 , selectively bringing the same second internal node N_2 to the control signal V_c , when the switching element 24 is open (the second internal node N_2 being instead brought to ground, when the same switching element 24 is closed).

The performance of the electronic driving circuit 20 has been evaluated by the present Applicant by means of extensive simulations and tests.

A comparison between the plots shown in Figures 7a and 7b allow to immediately perceive the improved performance of the electronic driving circuit 20 according to the present solution (plots of Figure 7b) with respect to that of a traditional solution (plots of Figure 7a).

In particular, Figure 7a refers to an electronic driving circuit of a traditional type, including class-AB amplifiers; the generated sine waves show a strong harmonic distortion, and a maximum power higher than 150 W is required from the power supply source.

As shown in Figure 7b, the sine waves generated by the electronic driving circuit 20 according to the present

solution show negligible harmonic distortion and a desired phase shifting (the driving signals V_1 and V_2 being in-phase signals, while the driving signal V_3 being a counter-phase signal). Moreover, a maximum power lower than 70 W is
5 required from the power supply source, in the same operating conditions.

As schematically shown in Figure 8, the electronic driving circuit 20 may be included in an electronic analysis apparatus 50, e.g. performing analysis operations
10 on cells that are selected and sorted via the microfluidic device 1.

Analysis apparatus 50 is provided with a receptacle 51, designed to receive the microfluidic device 1 filled with a buffer solution wherein the particles 8 (e.g. cells)
15 to be analyzed are immersed.

A control unit 52 of the analysis apparatus 50 controls the electronic driving circuit 20 in order to provide the driving signals V_1 , V_2 , V_3 to the electrodes 4, 6 of the same microfluidic device 1; in particular, the
20 control unit 52 provides the clock signals CK and target signals V_t to the amplifier stages 22, according to the analysis operations to be performed.

The analysis apparatus 50 may further include an imaging device 54, controlled by the control unit 52 to
25 image the chamber 7 of the microfluidic device 1 and the

particles 8 contained therein.

Control unit 52 is provided with suitable software to process the images acquired by the imaging device 54 and provide to a user visual depictions of the particles 8 in the microfluidic device 1 via a display (here not shown).

Particles 8 of interest may thus be identified and suitable driving signals V_1 , V_2 , V_3 may be provided to the electrodes 4, 6 in order to move the same particles towards a reservoir of the microfluidic device 1, from which the same particles 8 may be extracted by a pick-up device 56 of the analysis apparatus 50.

The advantages of the solution described emerge clearly from the previous discussion.

In particular, the amplifier stages 22, implementing the discussed closed-loop control, allow to minimize the non-linearity introduced by the low-impedance active chip load, thereby offering a drastic reduction of the total harmonic distortion (THD).

The unique and controlled DC offset voltage V_{off} , simultaneously injected at the output Out of the various amplifier stages 22, eliminates DC offset differences between the driving signals V_1 , V_2 , V_3 and thus allows to avoid possible electrolytic and electro-corrosion phenomena, gas bubbles formation and damages to the electrodes 4, 6.

Moreover, the electrical characteristics of the output signals V_{out} may advantageously be controlled by varying the input clock and target signals ck , V_t , thus providing an easy to be configured driving solution (e.g. in terms of
5 programmable amplitude, frequency and phase-shift of the driving signals V_1 , V_2 , V_3).

In general, the present solution allows to achieve, with respect to traditional solutions: a high efficiency with low impedance loads; a high reliability due to lower
10 heat dissipation; a high thermal stability; and cost, size and weight reduction.

Finally, it is clear that modifications and variations can be made to what described and illustrated herein, without thereby departing from the scope of the present
15 invention as defined in the appended claims.

In particular, it is underlined that the electronic driving circuit 20 may include a different (e.g. higher) number of amplifier stages 22, in the case in which it is required to drive a different (e.g. higher) number of
20 electrodes or group of electrodes (that may in that case constitute a different electric-load configuration).

Moreover, the output signals V_{out} may have different patterns, e.g. may be square waves, instead of sine waves.

The frequency of the same output signals V_{out} may be
25 fixed, chosen for example between 100 kHz and 100 MHz (e.g.

2 MHz), or variable during time, e.g. in the same range 100 kHz - 100 MHz.

As an alternative, the feedback signals V_{fb} may be picked-up at pick-up points external to the chip of the microfluidic device 1, for example within interface electronic devices that couple the electronic driving circuit 20 to the same chip of the microfluidic device 1.

It is moreover underlined that the discussed electronic driving circuit 20 may advantageously be used in different applications, where it is required to drive electrodes or group electrodes with driving signals, providing a low total harmonic distortion and a controlled DC offset.

C L A I M S

1. An electronic driving circuit (20) for a microfluidic device (1) having a number of electrodes (4,6), comprising a number of synchronized driving stages configured to generate a respective driving signal (V_1, V_2, V_3) for each electrode or group of electrodes (4,6), the driving signals (V_1, V_2, V_3) having a desired amplitude, frequency and phase-shift,

wherein each driving stage includes a switching-mode amplifier stage (22) configured to receive a clock signal (CK) and a target signal (V_t) and to generate, at an output (Out) thereof, an output signal (V_{out}) defining a respective driving signal, the amplifier stage (22) comprising:

a switching module (23), coupled to a first internal node (N_1) and controlled by the clock signal (CK) for selectively bringing said first internal node (N_1) to a control signal (V_c);

a filter module (25,26), coupled between the first internal node (N_1) and the output (Out) and configured to provide the output signal (V_{out}); and

a feedback module (29), coupled to a feedback input (IN_{fb}) of said driving stage, designed to receive a feedback signal (V_{fb}) indicative of the value of the respective driving signal, and configured to generate, as a function of the comparison between said feedback signal

(V_{fb}) and said target signal (V_t), the control signal (V_c) for said switching module (23).

2. The circuit according to claim 1, wherein the clock signals (CK) of the amplifier stages (22) are designed to
5 define the frequency and phase-shift of the respective driving signals (V_1, V_2, V_3); and the target signals (V_t) are designed to define the amplitude of the respective driving signals (V_1, V_2, V_3).

3. The circuit according to claim 1 or 2, wherein the
10 feedback module (29) is configured to feed-back the control signal (V_c) towards the switching module (23), to amplitude-modulate the clock signal (CK), and thus define the amplitude of the output signal (V_{out}).

4. The circuit according to any of the preceding
15 claims, wherein the filter module (25,26) includes a band-pass filter (25) configured to select an operating frequency of the output signal (V_{out}), and a blocking capacitor (26), at the output of the band-pass filter (25), configured to block any DC component.

20 5. The circuit according to any of the preceding claims, further including an offset generator (30), coupled to all the amplifier stages (22), configured to generate a unique offset voltage (V_{off}) that is injected at the output (Out) of said amplifier stages (22), to define a controlled
25 DC offset value of the respective driving signals

(V_1, V_2, V_3) .

6. The circuit according to claim 5, further including an offset inductor (32) for each of the amplifier stages (22), the offset inductors (32) of the amplifier stages
5 (22) having a first terminal in common, coupled to the output of the offset generator (30), and a second terminal coupled to the output (Out) of the respective amplifier stage (22).

7. The circuit according to any of the preceding
10 claims, wherein the feedback module (29) includes: a filter-and-rectifier module (36-38), coupled to the feedback input (IN_{FB}) of the amplifier stage (22) and configured to provide a comparison signal (V_{FB}'), as a function of said feedback signal (V_{FB}); a subtraction unit
15 (39), configured to receive the comparison signal (V_{FB}') and the target signal (V_t), to generate an error signal (V_e), based on the difference between the comparison signal (V_{FB}') and the target signal (V_t); and a voltage converter (40), coupled at the output of the subtraction unit (39)
20 and configured to generate the control signal (V_c) based on the error signal (V_e).

8. The circuit according to claim 7, wherein the filter-and-rectifier module (36-38) includes: a high-pass filter (36), coupled to the feedback input (IN_{FB}) of the
25 amplifier stage (22); a rectifier (37), coupled to the

output of the high-pass filter (36); and a low-pass filter (38), coupled to the output of the rectifier (37).

9. The circuit according to any of the preceding claims, wherein the switching module (23) of the amplifier stage (22) comprises:

a switching element (24), coupled between a reference terminal (GND) and the first internal node (N_1), and having a control terminal designed to receive the clock signal (CK); and

10 an impedance element (28), coupled between the first internal node (N_1) and a second internal node (N_2) designed to receive the control signal (V_c);

and wherein said feedback module (29) is connected between the feedback input (IN_{FB}) of said driving stage and
15 the second internal node (N_2), and is configured to generate said control signal (V_c) on said second internal node (N_2).

10. The circuit according to claim 9, wherein said impedance element (28) includes an inductor element.

20 11. The circuit according to any of the preceding claims, wherein the microfluidic device (1) defines a non-linear variable impedance load for the electronic driving circuit (20).

12. The circuit according to any of the preceding
25 claims, wherein the driving signals (V_1, V_2, V_3) are designed

to generate dielectric fields at the electrodes (4,6) of the microfluidic device (1), as a function of the frequency, time-shift and amplitude of the driving signals (V_1, V_2, V_3).

5 13. The circuit according to claim 12, wherein said dielectric fields are dielectrophoretic fields.

14. The circuit according to claim 13, wherein said dielectrophoretic fields define closed dielectrophoretic potential cages (11), designed to trap one or more
10 particles (8) immersed in a fluid contained in the microfluidic device (1).

15. The circuit according to any of the preceding claims, wherein the output (Out) of the amplifier stages (22) are designed to be coupled to respective contact pads
15 (9a, 9b, 9c) of the microfluidic device (1), electrically contacting respective electrode or group of electrodes (4,6).

16. The circuit according to any of the preceding claims, wherein said feedback signal (V_{FB}) is designed to
20 be picked-up within said microfluidic device (1).

17. An automated analysis apparatus (50), configured to cooperate with the microfluidic device (1) to perform analysis and/or separation operation on one or more particles (8) immersed in a fluid contained in the
25 microfluidic device (1); the automated analysis apparatus

(50) including the electronic driving circuit (20) according to any of the preceding claims.

18. The apparatus according to claim 16, including a control unit (52), configured to control the driving
5 circuit (20) and to provide the clock signals (CK) and target signals (V_t) to the amplifier stages (22) thereof.

19. A microfluidic device (1), configured to manipulate particles (8) immersed in a fluid, the microfluidic device (1) including an array (2) of
10 electrodes (4) carried by a substrate (5), and a plate electrode (6), arranged suspended above the array (2), an analysis chamber (7) containing the fluid being defined between the array (2) and the plate electrode (6), the microfluidic device (1) being configured to cooperate with
15 the electronic driving circuit (20) according to any of claims 1-16; wherein the driving signals (V_1, V_2, V_3) are designed to drive electrodes or group of electrodes (4, 6), to generate dielectric fields at the electrodes (4), as a function of the frequency, time-shift and amplitude of the
20 driving signals (V_1, V_2, V_3).