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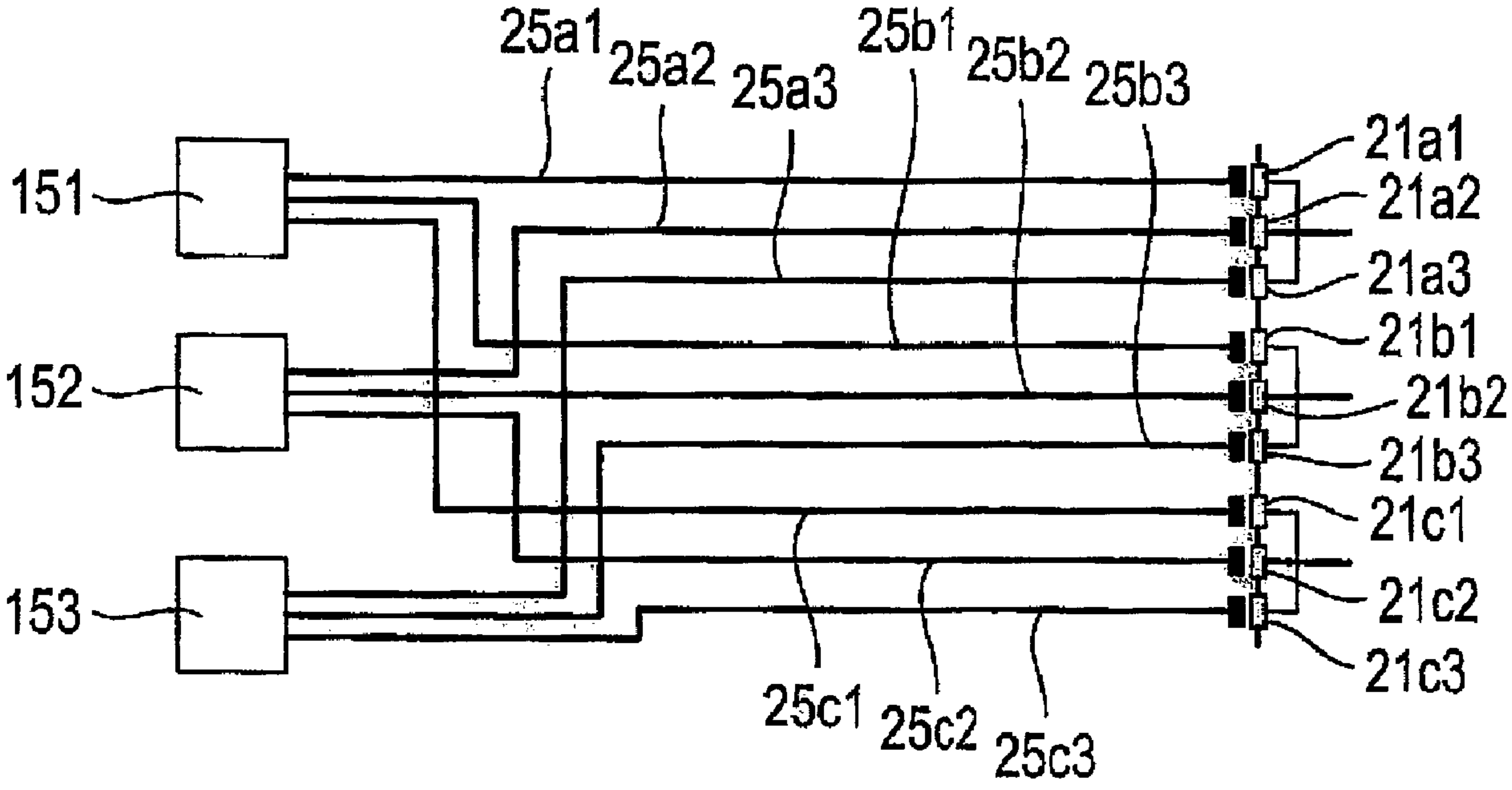


(57) **Abrégé/Abstract:**
A multi-phase electric circuit comprising an electric machine as well as comprising an inverter is described. The machine encompasses a rotor, which is connected to the inverter via at least two brushes (21a1 , ...) for each phase. Each of the brushes (21a1 , ...) of each phase is connected to the inverter via a separate brush line (25a1 , ...).

Multi-Phase Electric Circuit

Abstract

A multi-phase electric circuit comprising an electric machine as well as comprising an inverter is described. The machine encompasses a rotor, which is connected to the inverter via at least two brushes (21a1, ...) for each phase. Each of the brushes (21a1, ...) of each phase is connected to the inverter via a separate brush line (25a1, ...).

Multi-Phase Electric Circuit

Description

The invention relates to a multi-phase electric circuit comprising an electric machine, as well as comprising an inverter, wherein the machine encompasses a rotor, which is connected to the inverter via at least two brushes per phase.

Such an electric circuit is known, for example, from DE 10 2008 009 276 A1 or from DE 10 2008 064 079 A1. The stator of the asynchronous machine is connected therein to an electric energy supply grid and the rotor is connected to the energy supply grid via an inverter. The inverter can be constructed, for example, of two inverters, which are realized by means of power semiconductor devices, and a DC link, which is connected therebetween and which encompasses at least one capacitor.

The rotor can be set into rotation, for example with the help of wind power or water power or the like. If the rotor then carries out a rotation, electric energy is fed into the energy supply grid by means of the voltage, which is induced into the stator.

Due to its rotation, the rotor must be electrically connected to the inverter via brushes. In the case of asynchronous machines with higher performance, it can thereby be necessary to provide for a plurality of brushes for each phase. This can have the result that an undesired asymmetrical current flow is created via the brushes due to production-related differences between the brushes, which belong to a phase, for example.

A short-circuiting device, a so-called crowbar, is often connected to the connecting line between the rotor and the inverter. If a malfunction is determined during the operation of the electric circuit, the short-circuiting device is activated. This has the result that the three phases, which are supplied to the short-circuiting device, are short-circuited.

It is the object of the invention to create an electric circuit, which prevents the aforementioned asymmetrical current flow, namely without or with a short-circuiting device.

The invention solves this object by means of a multi-phase electric circuit according to claim 1.

According to the invention, each of the brushes of each phase is connected to the inverter via a separate brush line. This creates a series connection of the individual brushes to the respective assigned brush line. The current flow via this series connection is thus no longer solely dependent on the brush, but also on the brush line. Differences between the brushes of the same phase can thus no longer fully effect the current flow via the respective brush due to the series connection of each brush to the corresponding brush line, but only to a reduced extent. An asymmetric current flow via the brushes – which is present per se – can thus be reduced or even compensated completely.

In an embodiment of the invention, each of the brushes has a brush impedance and each of the brush lines has a line impedance, wherein the line impedance is preferably larger than the brush impedance. A series connection of the brush impedance and of the line impedance is created in this manner, which has the result that different brush impedances of brushes of the same phase do not have a full effect any longer, but only a reduced effect due to the respective assigned line impedances.

Preferably, an asymmetry of the brush impedances of the brushes of a phase is thereby prevented with the help of the line impedances of the respective corresponding brush lines.

In the case of a further embodiment of the invention, the brush impedance has a negative temperature coefficient. This negative temperature coefficient can then be compensated by a positive temperature coefficient of the respective corresponding line impedance.

It is particularly advantageous, if a separate brush line is assigned to each brush. The explained asymmetric current flow via the brushes can thus be prevented in a simple manner or can even be compensated completely.

In the case of a further embodiment of the invention, each of the brush lines is connected to a multi-phase short-circuiting device via a short-circuiting device impedance, wherein the short-circuiting device is embodied to short-circuit the phases, which are connected to it. It is thereby attained with the help of the short-circuiting device impedances that the mode of operation of the defined series connections does not get lost. In particular, it is attained by means of the short-circuiting device impedances that the individual brush lines of a phase are not short-circuited with one another.

Preferably, the short-circuiting device can thereby be configured from power semiconductor devices, which are connected anti-parallel and which are arranged in a star or delta connection. It is thereby particularly advantageous, if a separate pair of anti-parallel power semiconductor devices is assigned to each brush line.

In the case of a further advantageous embodiment of the invention, a separate current regulator is assigned to each inverter. It is thus possible to separately influence or to balance, respectively, the current across each of the brush lines and thus across each of the brushes.

Further features, potential applications and advantages of the invention follow from the below description of exemplary embodiments of the invention, which are illustrated in the corresponding figures. All of the described or illustrated features thus form the subject matter of the invention, either alone or in combination, regardless of the combination thereof in the patent claims or the dependency thereof as well as regardless of the wording or illustration thereof, respectively, in the description or in the figures, respectively.

Figure 1 shows a schematic block diagram of an exemplary embodiment of an electric circuit comprising a double-fed asynchronous machine, Figure 2a shows a schematic circuit diagram of a part of the circuit of Figure 1, Figure 2b shows a schematic equivalent circuit diagram of a phase of the circuit of Figure 2a, Figure 3a shows a schematic circuit diagram of an exemplary embodiment of a part of the circuit of the figure according to the invention without a short-circuiting device, Figure 3b shows a schematic equivalent circuit diagram of a phase of the circuit of Figure 3a, Figure 4a shows a schematic circuit diagram of an exemplary embodiment of a part of the circuit of Figure 1 according to the invention comprising a short-circuiting device, Figure 4b shows a schematic equivalent circuit diagram of a phase of the circuit of Figure 4a, and Figures 4c, 4d show modifications of Figures 4a, 4b.

An electric circuit 10, which encompasses a double-fed asynchronous machine 11 comprising a stator 12 and a rotor 13, is illustrated in Figure 1. The stator 12 is connected to an electric energy supply grid 14. The rotor 13 is connected to the energy supply grid 14 via an inverter 15. It is pointed out that a parallel connection of a plurality of power converters can also be present instead of the inverter 15.

The inverter 15 is configured, for example, of two inverters 16, which are realized by means of power semiconductor devices, and a DC link 17, which is interconnected and which encompasses at least one capacitor. In addition, the inverter 15 typically encompasses a power choke or a separate transformer and, if applicable, an engine choke (not illustrated). A short-circuiting device 18, a so-called crowbar, is connected to the connecting line between the rotor 13 and the inverter 15.

For example, the electric circuit 10 is a three-phase circuit, only a one-phase illustration of which, however, is shown in Figure 1. The asynchronous machine 11, the energy supply grid 14, the inverter 15 and the short-circuiting device 18 are accordingly embodied in a three-phase manner.

During operation of the electric circuit 10, a line voltage of the energy supply grid 14 is applied to the stator 12 of the asynchronous machine 11. The rotor 13 is coupled to an energy-generation system and can be rotated, for example with the help of wind power or water power or the like. The voltage at the rotor 13, in particular the frequency thereof, can be adapted to the respective boundary conditions, which are at hand in each case, with the help of the inverter 15, for example as a function of the speed of the rotor 13 and/or the line voltage of the energy supply grid 14 and/or the like. If the rotor 13 performs a rotational movement, electric energy is fed into the energy supply grid 14 by means of the voltage, which is induced into the stator 12.

If a malfunction is determined within the power generation system and/or the asynchronous machine 11 and/or the inverter 15 during operation of the electric circuit 10, the short-circuiting device 18 is activated. As a result, the three phases, which are supplied to the short-circuiting device 18, are short-circuited with the help of a star or delta connection by power semiconductor devices, which are connected anti-parallel.

With regard to the rotational movement of the rotor 13, which was explained above, the asynchronous machine 11 is provided with brushes (not illustrated in Figure 1) for the purpose of an electric connection of the inverter 15 to the rotor 13. The phases of the asynchronous machine 11 are also electrically connected to the inverter 15 in response to a rotational movement of the rotor 13, so that phase currents flow from the rotor 13 to the inverter 15 and vice versa across said brushes.

Figure 2a illustrates that part of the electric circuit 10 of Figure 1, which relates to the connection of the inverter 15 to the rotor 13 of the asynchronous machine 11. In particular, the above-mentioned brushes, which are not shown in Figure 1, are illustrated in Figure 2a. It is pointed out that Figure 2a only serves to provide general explanations.

Figure 2a is a three-phase illustration. The three phases are thereby always identified with the letters a, b, c.

Figure 2a furthermore assumes an asynchronous machine 11 with a large output, which is why three inverters 151, 152, 153, which are connected in parallel to one another, are present.

Accordingly, Figure 2a assumes phase currents, which are so large that an individual brush for each phase is not sufficient. Three brushes 21a1, 21a2, 21a3, 21b1, 21b2, 21b3, 21c1, 21c2, 21c3 are thus in each case present for each phase, for example, which are connected in parallel to one another for each phase and which are short-circuited with one another on the inverter side and on the rotor side with regard to each phase.

The brushes 21 of each phase are connected to each of the three partial inverters 151, 152, 153. This is realized in that the three brushes 21 of each phase – as has already been explained – are short-circuit with one another on the inverter side, so as to then in each case be connected to an individual phase line 22a, 22b, 22c. In the direction of the three inverters 151, 152, 153, these three phase lines 22a, 22b, 22c then split in each case into three individual lines 23, so that each of the phase lines 22a, 22b, 22c is connected to each of the three inverters 151, 152, 153. A phase of the short-circuiting device 18 is furthermore in each case connected to the three phase lines 22a, 22b, 22c.

During operation of the electric circuit 10, phase currents flow from the three inverters 151, 152, 153 via the individual lines 23 and the phase lines 22a, 22b, 22c and via the respective three brushes 21 of the respective phase to the rotor 13 and vice versa. In response to a malfunction, the three phase lines 22a, 22b, 22c can be short-circuited with one another via the short-circuiting device 18.

Figure 2b illustrates a phase of Figure 2a, namely the phase, which belongs to the phase line 22a, for example. It is pointed out that Figure 2b – as well as Figure 2a – only serves to provide general explanations.

In Figure 2b, the brushes 21a1, 21a2, 21a3 are illustrated as equivalent circuit diagram, namely in each case substantially in the form of a brush impedance and of a voltage drop U1 or U2, respectively, or U3, respectively, wherein the brush impedance is embodied as series connection of a resistor R1 or R2, respectively, or R3, respectively, and of an inductor L1 or L2, respectively, or L3, respectively. A respective flowing brush current 11 or 12, respectively, or 13, respectively, is in each case shown in Figure 2b for each of the brushes 21a1, 21a2, 21a3. It is pointed out that the brush currents and the phase currents differ from one another. In Figure 2b, the sum of the three brush currents 11, 12, 13 thus forms the corresponding phase current Ia on the phase line 22a.

During operation of the electric circuit 10, the above-mentioned brush currents flow across the respective brushes of a phase and cause electric losses at that location in the respective brush impedance, which lead to a heat-up of the respective brush.

It is now assumed that the brushes 21 have a negative temperature coefficient. This means that the impedance of the individual brushes 21 decreases with an increasing temperature. As a result, the above-mentioned heat-up of the brushes 21 leads to a reduction of the impedance and thus to a larger current flow in the respective brushes 21.

In addition, it is assumed that the impedances of the individual brushes 21 are often not exactly the same due to production tolerances and/or other scattering, for example. This asymmetry of the impedances of the brushes 21 has the result that the brush 21, which has the smallest impedance, conducts the highest current and thus heats up most. Due to this highest heat-up and of the negative temperature coefficient, the impedance of this brush 21 also decreases most, so that the current flow across this brush 21 becomes even larger. This thus creates an asymmetrical current flow across the brushes 21 of a phase, which can have the result that the current-carrying capacity of the brush 21, which has the largest current flow, is exceeded.

Figure 3a illustrates that part of the electric circuit 10 of Figure 1, which relates to the connection of the inverter 15 to the rotor 13 of the asynchronous machine 11. Figure 3a is a three-phase illustration. The three phases are thereby always identified with the letters a, b, c.

In addition, Figure 3a assumes an asynchronous machine 11 with a large output, which is why three inverters 151, 152, 153, which are connected in parallel to one another, are present, for example. A separate current regulator can thereby be assigned to each of the inverters 151, 152, 153.

Accordingly, Figure 3a assumes phase currents, which are so large that an individual brush for each phase is not sufficient. Three brushes 21a1, 21a2, 21a3, 21b1, 21b2, 21b3, 21c1, 21c2, 21c3 are thus in each case present for each phase, for example, which are connected in parallel to one another for each phase and which are short-circuit with one another on the rotor side with regard to each phase. The number of the brushes 21 for each phase thus corresponds to the number of the inverters 151, 152, 153, for example. It is pointed out that the number of the brushes for each phase can also be larger or smaller and does not need to correspond to the number of inverters.

In contrast to Figure 2a, the brushes 21 of Figure 3a are not short-circuited with one another on the inverter side.

The three brushes 21 of each phase are connected to a respective other one of the three inverters 151, 152, 153. This is realized in that a separate brush line 25a1, 25a2, 25a3, 25b1, 25b2, 25b3, 25c1, 25c2, 25c3 leads from each brush 21 in a phase to the corresponding one of the three inverters 151, 152, 153.

In contrast to Figure 1 and to Figures 2a, 2b, a short-circuiting device 18 is not present in Figure 3a.

During operation of the electric circuit 10, phase currents flow form the three inverters 151, 152, 153 across the brush lines 25 and across the respective three brushes 21 of the respective phase to the rotor 13 and vice versa.

Figure 3b illustrates a phase of Figure 3a, namely the phase, which belongs to the brush lines 25a1, 25a2, 25a3, for example.

Figure 3b illustrates the brushes 21a1, 21a2, 21a3 as equivalent circuit diagram, namely in each case substantially in the form of a brush impedance and of a voltage drop U1 or U2, respectively, or U3, respectively, wherein the brush impedance is embodied as series connection of a resistor R1 or R2, respectively, or R3, respectively and of an inductor L1 or L2, respectively, or L3, respectively. The respective flowing brush current 11 or 12, respectively, or 13, respectively, is further shown for each of the brushes 21a1, 21a2, 21a3 in Figure 3b. It is pointed out that the brush currents and the phase currents differ from one another. The sum of the three brush currents 11, 12, 13 thus forms the corresponding phase current Ia in Figure 3b.

Figure 3b furthermore illustrates the brush lines 25a1, 25a2, 25a3 as equivalent circuit diagram, namely in each case substantially in the form of a line impedance, which is embodied as series connection of a resistor R ZL1 or R ZL2, respectively, or R ZL3, respectively, and an inductor L ZL1 or L ZL2, respectively, or L ZL3, respectively.

During operation of the electric circuit 10, the above-mentioned brush currents flow across the respective brushes 21 of a phase and cause electric losses the respective impedance at that location, which leads to a heat-up of the respective brush 21.

It is now assumed that the brushes 21 have a negative temperature coefficient. This means that the impedance of the individual brushes 21 decreases with an increasing temperature.

According to Figure 3b, however, each of the brushes 21 is connected in series to the corresponding brush line 25. The line impedances of the brush lines 25 encompass a positive temperature coefficient. This means that the line impedances of the individual brush lines 25 increase with an increasing temperature. The line impedance is thereby in particular a function of the length of the respective brush line 25.

The series connection of the brush impedance of the individual brushes 21 and of the line impedance of the respective corresponding brush lines 25 now has the result that the negative temperature coefficient of the respective brush 21 is compensated at least partially with the positive temperature coefficient of the corresponding brush line 25. This is synonymous for the fact that, due to a corresponding length of the brush lines 25, the negative temperature coefficient of the brushes 21 can at least be decreased or even compensated for the most part.

In the event that the impedances of the individual brushes 21 differ from one another, for example due to production tolerances and/or other scatterings, this asymmetry of the impedances of the brushes 21 is reduced to very small values by means of the positive temperature coefficient of the brush lines 25. In contrast to Figure 2a, an asymmetrical current flow across the brushes 21 is thus not created at all in the case of Figure 3a or only to a very small extent. The brush currents are thus substantially equal. An exceeding of the current-carrying capacity of one of the brushes 21 is thus prevented.

It is pointed out that the above-explained reduction or even compensation of asymmetries of the brush impedances can also be reached with the help of the line impedances, if the brushes 21 do not encompass a negative temperature coefficient, but any behavior or even a positive temperature coefficient in this regard. This follows from the fact that the line impedance of one of the brush lines 21 is typically larger than the brush impedance of the corresponding brush 25, so that the asymmetries of the brush impedances as compared to the corresponding line impedance are very small and are thus substantially negligible.

If the brush impedances of the brushes 21 of one of the phases per se thus encompass an asymmetry, a symmetry is thus attained at least to a certain extent by connecting these brush impedances in series to the respective corresponding line impedances. This is synonymous with the fact that the brush currents, which flow across the individual brush lines 25, are substantially even. An asymmetry of the currents, which flow across the brushes 21 of a phase, is thus no longer at hand.

Figures 4a, 4b, 4c, 4d are based on Figures 3a, 3b. In this regard, reference is made to the above explanations relating to Figures 3a, 3b.

In contrast to Figures 3a, 3b, a short-circuiting device 18 is present in Figures 4a, 4b, 4c, 4d.

According to Figure 4a, each of the brush lines 25 of Figure 4a is connected to the one connection of a short-circuiting impedance Za1, Za2, Za3, Zb1, Zb2, Zb3, Zc1, Zc2, Zc3 for the purpose of connecting the short-circuiting device 18. The short-circuiting impedances Za1, Za2, Za3 or Zb1, Zb2, Zb3, respectively, or Zc1, Zc2, Zc3, respectively, which belong to a phase, are then in each case short-circuited with one another via the other connection thereof and are connected to the respective phase of the short-circuiting device 18. The above-mentioned impedances are connected in parallel to one another in this regard.

Figure 4b illustrates the short-circuiting impedances Za1, Za2, Za3 as equivalent circuit diagram, namely in each case as series connection of a resistor R Za1 or R Za2, respectively, or R Za3, respectively, and an inductor L Za1 or L Za2, respectively, or L Za3, respectively. As already mentioned, the three series connections of the phase at hand are then short-circuited with one another on the side of the short-circuiting device 18 and are connected to the corresponding phase of the short-circuiting device 18.

Figure 4c illustrates a modification of the circuit of Figure 4a. The modification is that the short-circuiting impedances Za1, Za3, Za3 or Zb1, Zb2, Zb3, respectively, or Zc1, Zc2, Zc3, which belong to a phase, are not in each case short-circuited with one another with the respective other connection thereof – as is the case in Figure 4a – but that the short-circuiting impedances Za1, Za2, Za3 or Zb1, Zb2, Zb3, respectively, or Zc1, Zc2, Zc3, respectively, which belong to a phase, are in each case separately connected to the short-circuiting device 18.

Figure 4d illustrates a modification of the circuit of Figure 4b. The modification is that the three series connections of a resistor R Za1 or R Za2, respectively, or R Za3, respectively, and of an inductor L Za1 or L Za2, respectively, or L Za3, respectively are not in each case short-circuited with one another on the side of the short-circuiting device 18 - as is the case in Figure 4b – but that the series connections are in each case separately connected to the short-circuiting device 18.

In Figures 4c, 4d, a separate pair of anti-parallel power semiconductor devices is thus assigned to each brush line 25a1, 25a2, 25a3, 25b1, 25b2, 25b3, 25c1, 25c2, 25c3 in the short-circuiting device 18, while in Figures 4a, 4b, the two power semiconductor devices, which are connected anti-parallel, are in each case always present in the short-circuiting device 18 at times.

As has already been explained, it is possible in a very general manner with the help of the brush lines 25 to attain a reduction or even a compensation of asymmetries of the brush impedances of a phase. Asymmetries of the current flow across the individual brushes of a phase can be reduced for the most part in this regard. In particular, it is possible with the help of the brush lines 25 to compensate for a negative temperature coefficient of the brushes 21.

As follows from Figures 4a, 4b, 4c, 4d, it is attained by means of the short-circuiting impedances Za1, Za2, Za3 or Zb1, Zb2, Zb3, respectively, or Zc1, Zc2, Zc3, respectively, that the brushes 21a1, 21a2, 21a3 or 21b1, 21b2, 21b3, respectively, or 21c1, 21c2, 21c3, respectively, are not short-circuited on the inverter side. Instead, one of the short-circuiting impedances Za1, Za2, Za3, which is in each case comprised of two series connections of the resistor R Za1, or R Za2, respectively, or R Za3, respectively, and the inductor L Za1 or L Za2, respectively, or L Za3, respectively, is in each case present between the individual brush lines 25a1, 25a2, 25a3 of the phase shown in Figure 4b or 4d, respectively.

On the one hand, an impedance is thus present between each of the phases of Figure 4a or 4c, respectively, and the short-circuiting device 18, namely the short-circuiting impedances Za1, Za2, Za3 or Zb1, Zb2, Zb3, respectively, or Zc1, Zc2, Zc3, respectively, which are connected in parallel for each phase. On the other hand, an impedance is in each case also always present between the individual brush lines 25 of each phase, which is always the sum of two of the above-mentioned short-circuiting impedances.

The short-circuiting impedances are thereby typically larger than the line impedances. It is attained with this that the short-circuiting impedances do not represent a short-circuiting of the individual brush lines of a phase, but that the above-mentioned reduction or even compensation of asymmetries of the brush impedances of a phase can continue to be attained with the help of the corresponding line impedances, even in the case of Figures 4a, 4b.

It goes without saying that the electric circuit 10 can accordingly also encompass a different phase number larger than or smaller than three and can optionally be embodied in a multi-phase manner in this regard. In these cases, the number and/or embodiment of the inverter 15 or of the inverters 151, 152, 153, respectively, and/or of the short-circuiting device 18 can also change. In addition, it goes without saying that the number of the brushes 21 for each phase can also be two or larger than three.

In addition, it is possible for the short-circuiting impedances in the equivalent circuit diagram of Figure 4b to be connected in each case between the line impedances and the brush impedances. A reduction or even a compensation of asymmetries of the brush impedances of a phase can also be attained in this case with the help of the line impedances.

It goes without saying that either the respective resistance or the respective inductance can also be zero, if necessary, in the case of the mentioned impedances. Likewise, it is also not absolutely necessary for three inverters to be present, but it is easily possible for the exemplary embodiments of Figures 2a, 2b, 3a, 3b, 4a, 4c to also be realized with only a single inverter.

Claims

1. A multi-phase electric circuit (10) comprising an electric machine and an inverter (15), wherein the machine comprises a rotor (13) which is connected to the inverter (15) via at least two brushes (21) for each phase, characterized in that each of the brushes (21) of each phase is connected to the inverter (15) via a separate brush line (25).

2. The circuit (10) according to claim 1, wherein each of the brushes (21) has a brush impedance and each of the brush lines (25) has a line impedance.

3. The circuit according to claim 2, wherein the line impedance is larger than the brush impedance.

4. The circuit according to any one of claims 2 or 3, wherein an asymmetry of the brush impedances of the brushes (21) of a phase can be reduced by the line impedances of the respective corresponding brush lines (25).

5. The circuit according to claim 4, wherein the brush impedance has a negative temperature coefficient.

6. The circuit (10) according to any one of the preceding claims, wherein a separate brush line (25) is assigned to each brush (21).

7. The circuit (10) according to any one of the preceding claims wherein a number of inverters (151, 152, 153) is present, which corresponds to the number of brushes (21) for each phase, and wherein the brushes (21) of each phase are in each case connected to another one of the inverters (151, 152, 153).

8. The circuit (10) according to any one of the preceding claims, wherein a separate current regulator is assigned to each inverter (15).

9. The circuit (10) according to any one of the preceding claims, wherein each of the brush lines (25) is connected to a multi-phase short-circuiting device (18) via

a short-circuiting impedance (Za1, ...), and wherein the short-circuiting device (18) is embodied to short-circuit the phases, which are connected to it.

10. The circuit (10) according to claim 9, wherein the short-circuiting device (18) is configured from power semiconductor devices, which are connected anti-parallel and which are arranged in a star or delta connection.

11. The circuit (10) according to claim 10, wherein a separate pair of anti-parallel power semiconductor devices is assigned to each brush line (25).

12. The circuit (10) according to any one of the preceding claims, wherein a double-fed asynchronous machine (11) is provided, the stator (12) of which is connected to an electric energy supply grid (14), and wherein the inverter (15) is also connected to the energy supply grid (14).

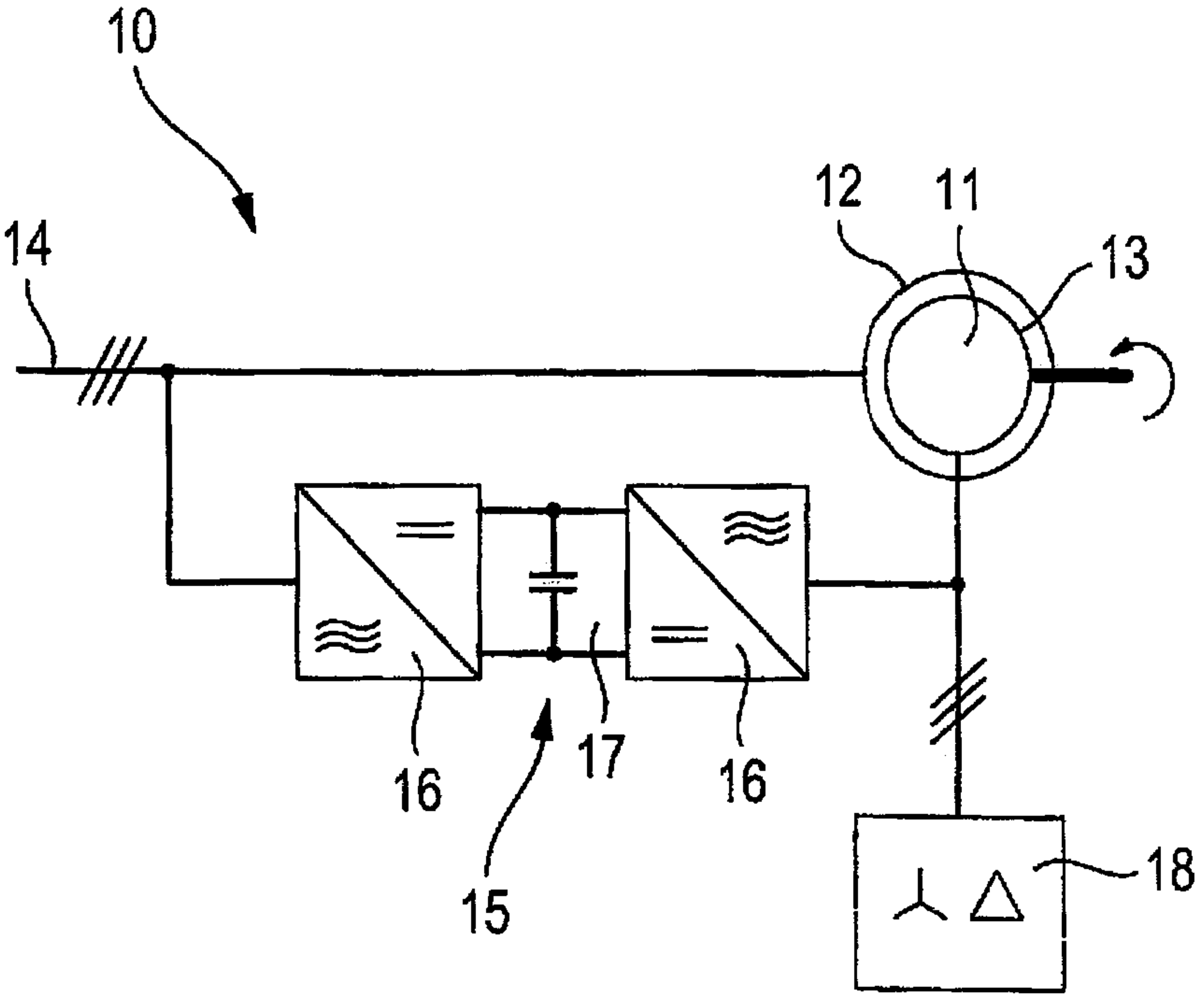
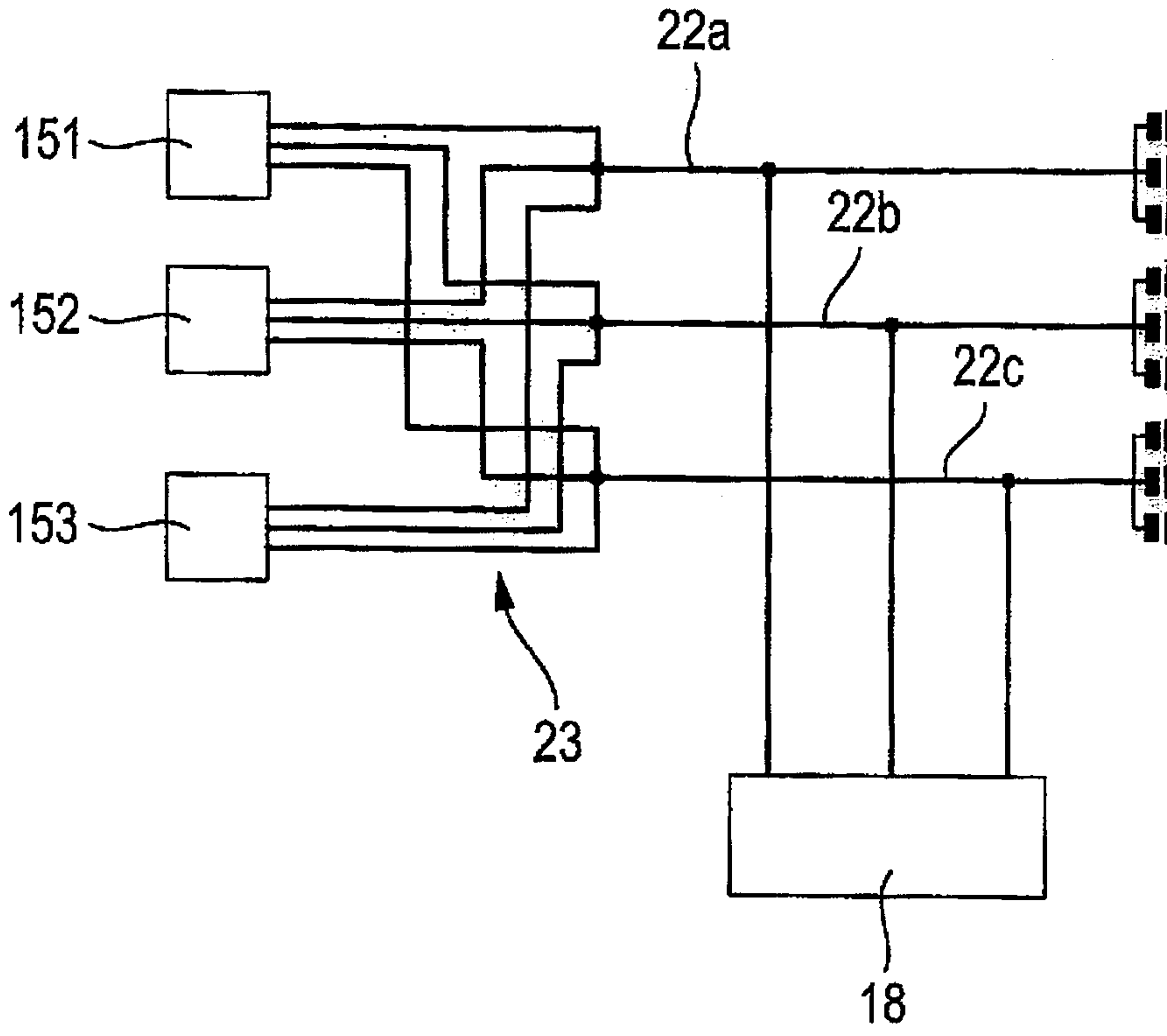


Fig. 1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151
21a1
21a2
21a3
22b
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152
21b2
21b3
22c
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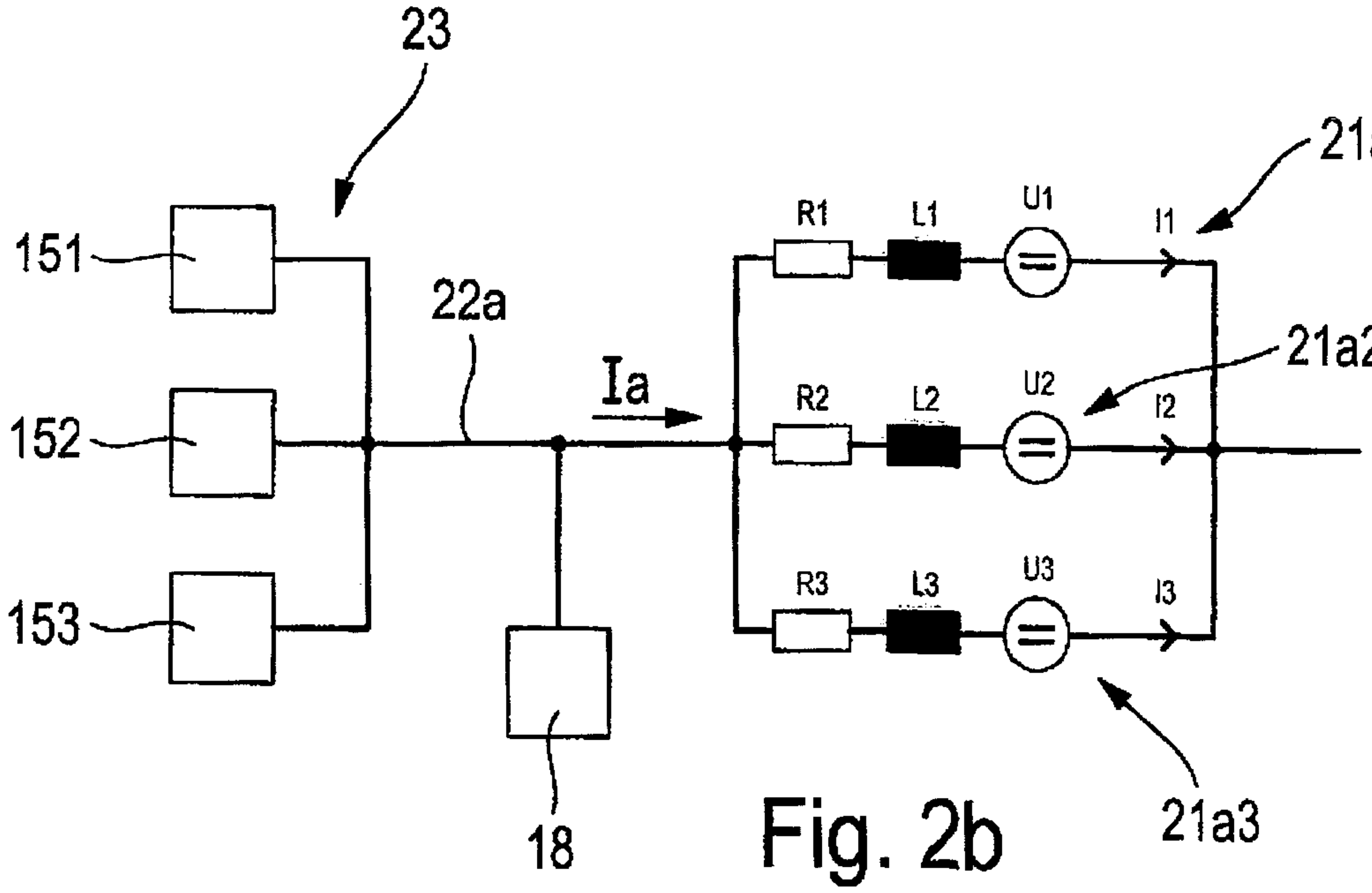
21c3
23
18

Fig. 2a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21a1
151
R1
L1
U1
I1
22a
21a2
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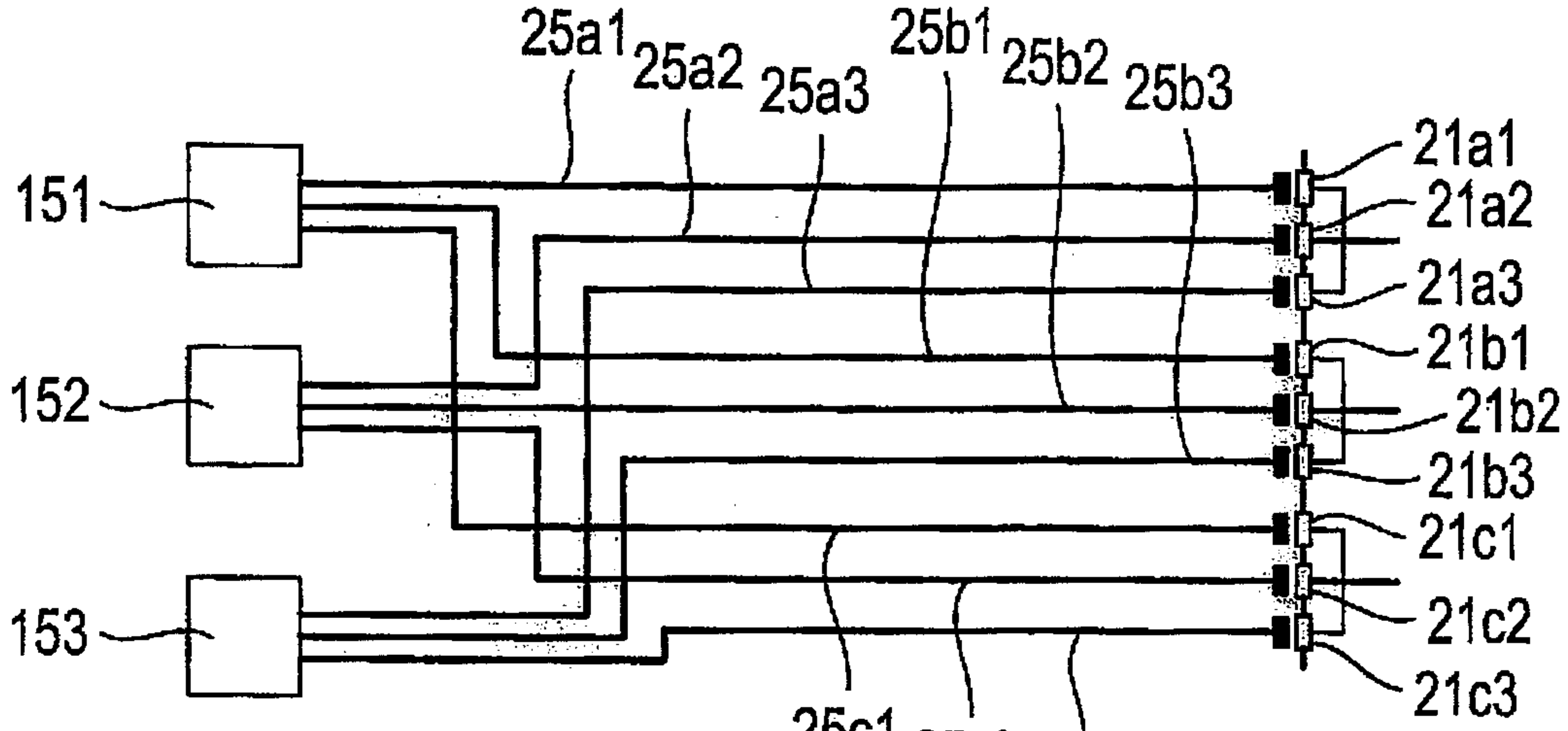
153
18
21a3

Fig. 2b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25b1
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25b3
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152
153
21a1
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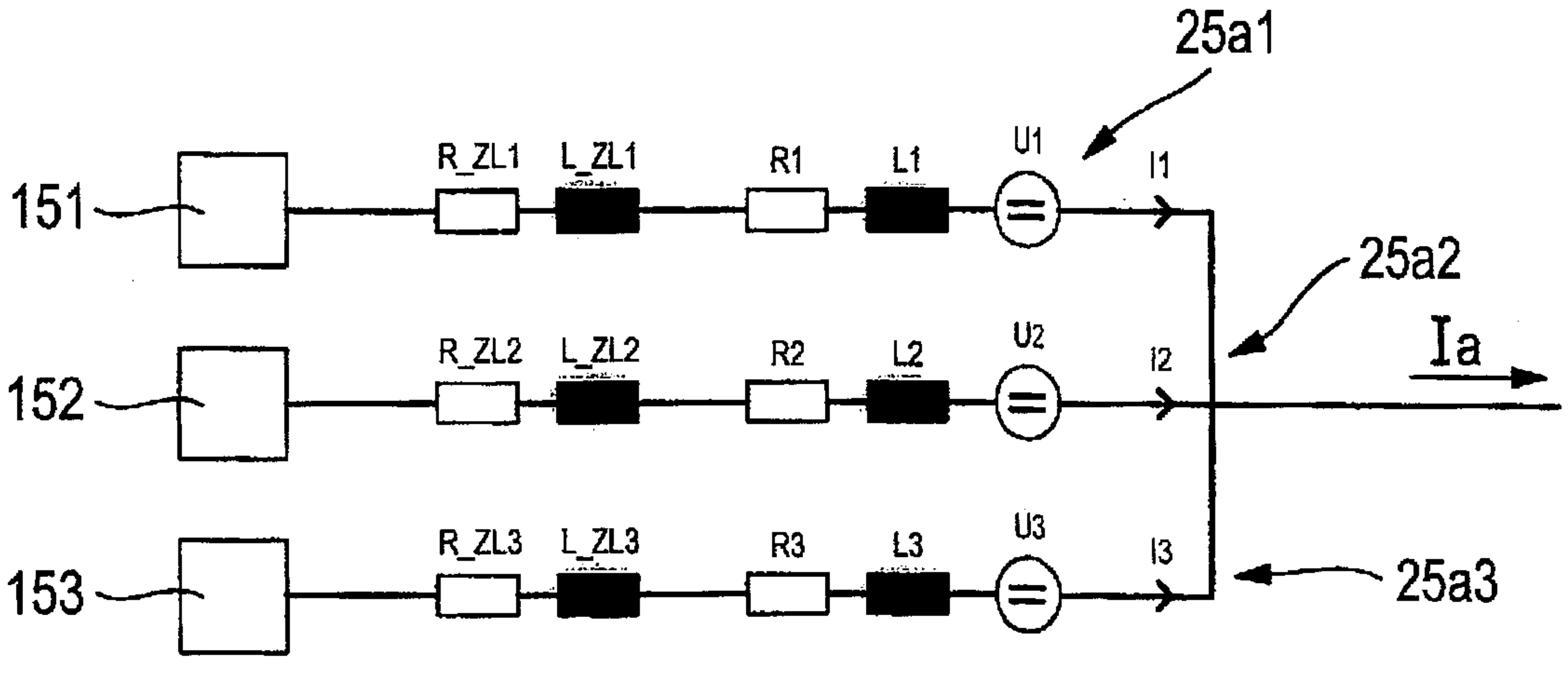
25c2
25c3

Fig. 3a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U1
I1
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L_ZL2
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L2
U2
I2
R_ZL3
L_ZL3
R3
L3
U3
I3
25a2
Ia
25a3

Fig. 3b

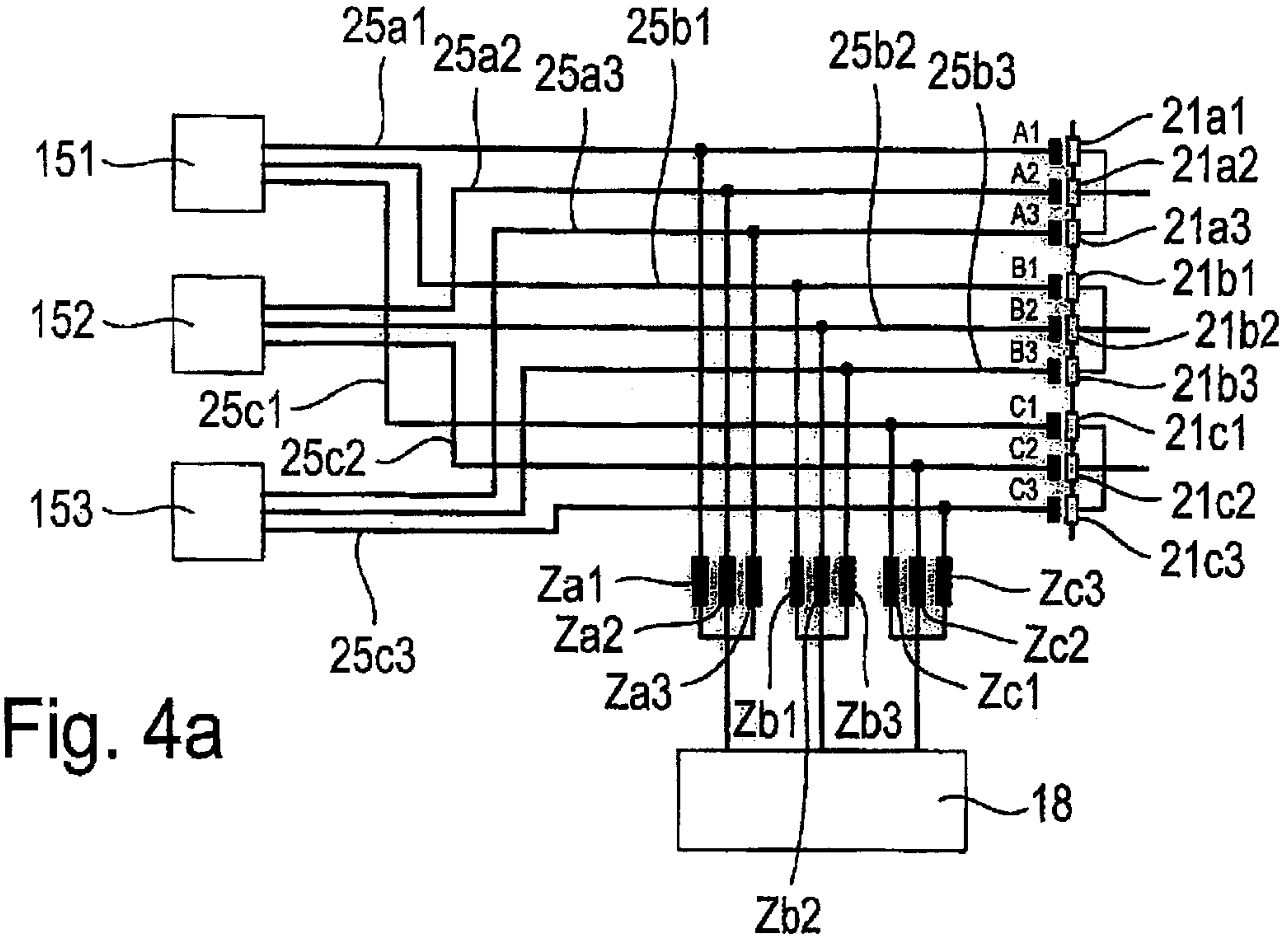

25a1
25a2
25a3
25b1
25b2
25b3
151
152
153
A1
A2
A3
B1
B2
B3
C1
C2
C3
21a1
21a2
21a3
21b1
21b2
21b3
21c1
21c2
21c3
25c1
25c2
25c3
Za1
Za2
Za3
Zb1
Zb2
Zb3
Zc1
Zc2
Zc3
18

Fig. 4a

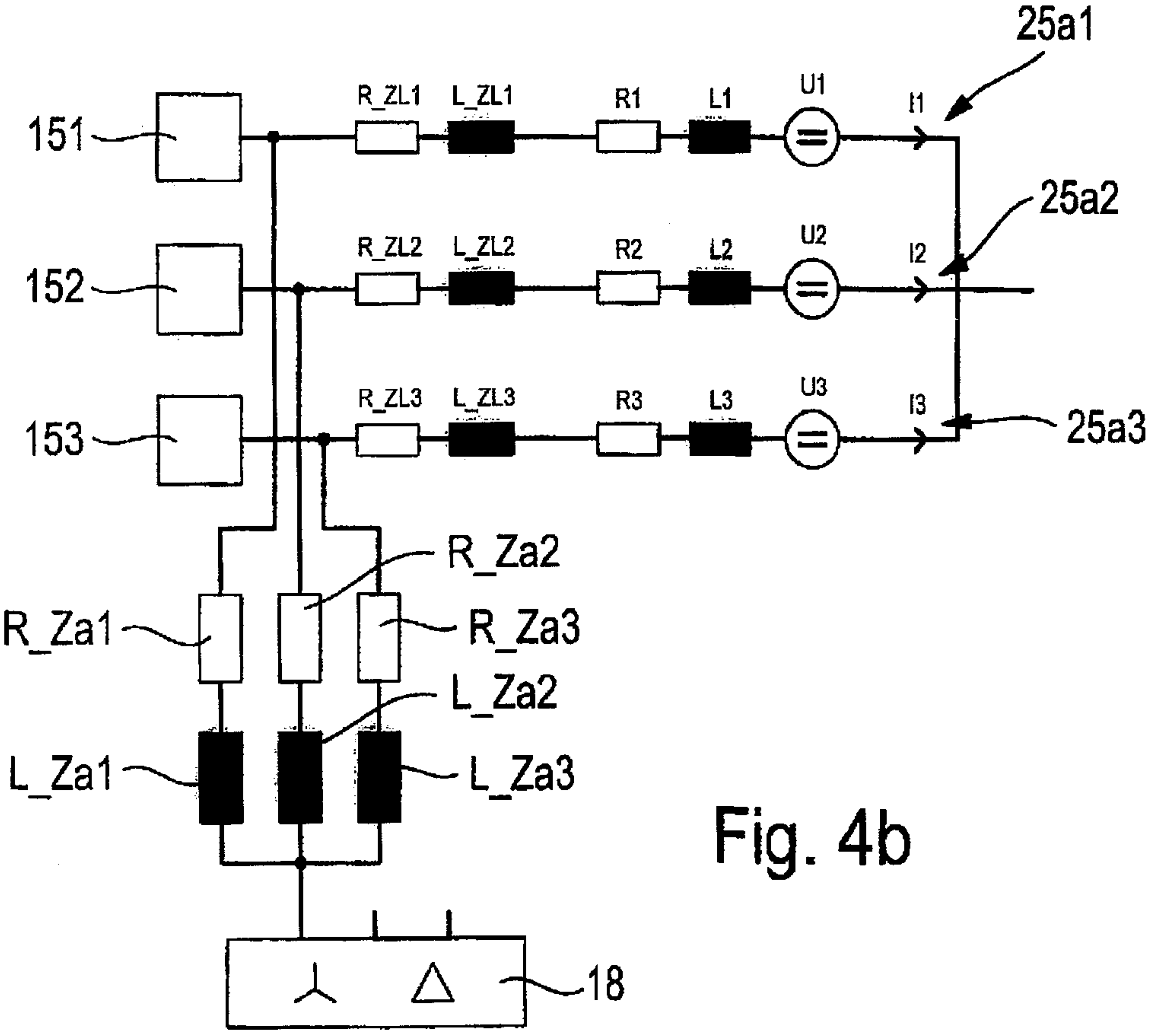

25a1
25a2
25a3
151
152
153
R_ZL1
L_ZL1
R1
L1
U1
I1
R_ZL2
L_ZL2
R2
L2
U2
I2
R_ZL3
L_ZL3
R3
L3
U3
I3
R_Za1
R_Za2
R_Za3
L_Za1
L_Za2
L_Za3
18

Fig. 4b

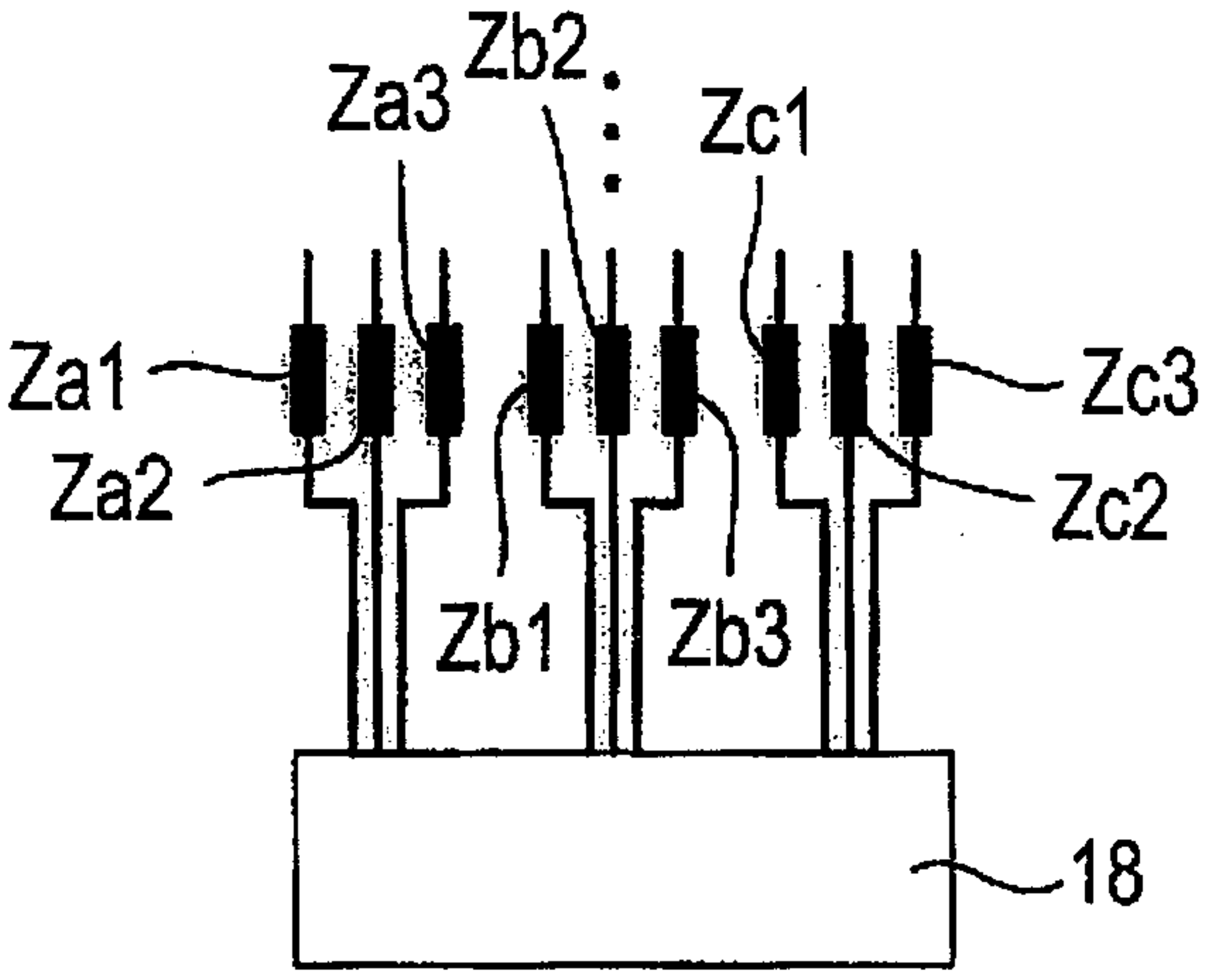

Zb2
Za3
Zc1
Za1
Zc3
Za2
Zc2
Zb1
Zb3
18

Fig. 4c

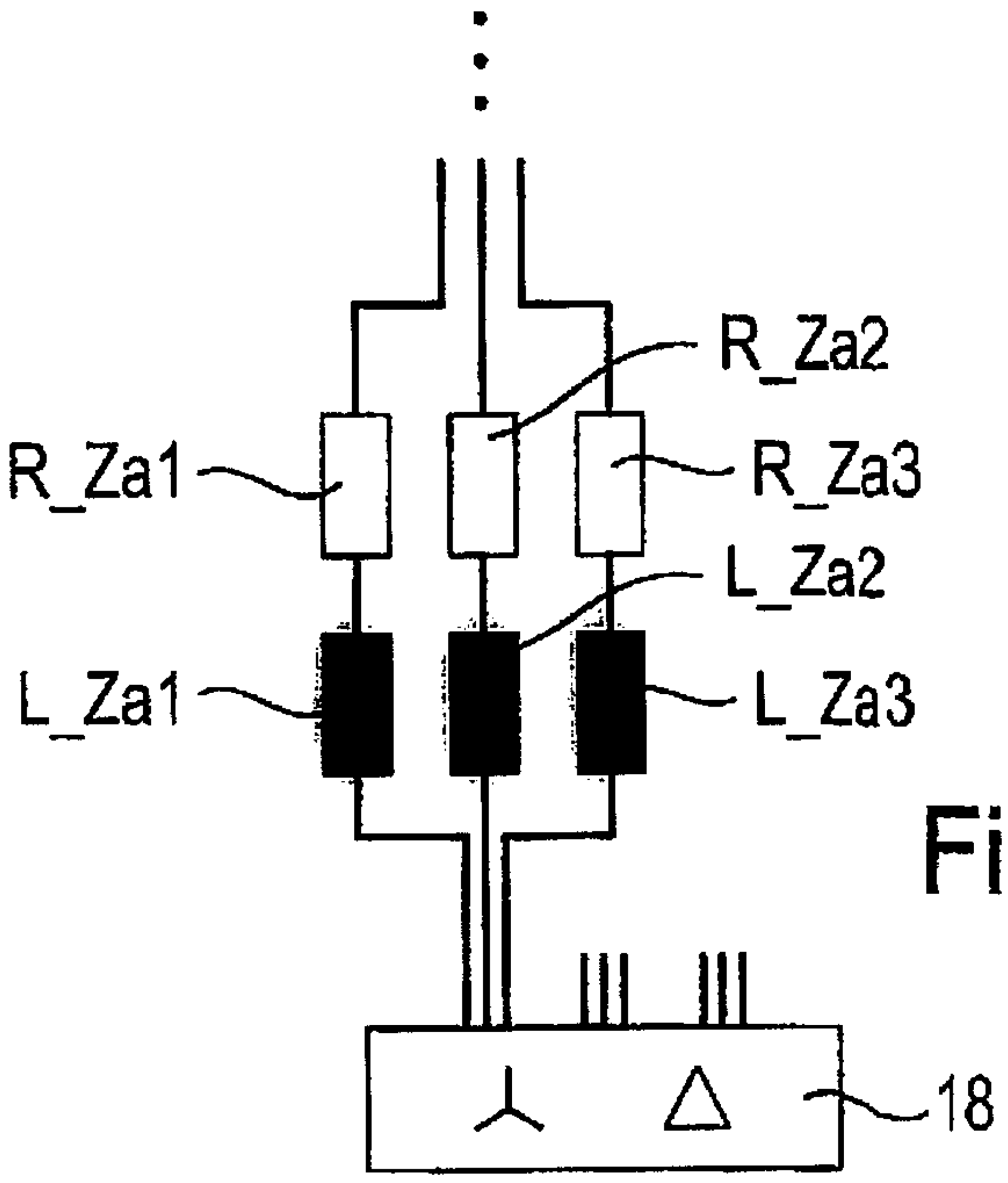
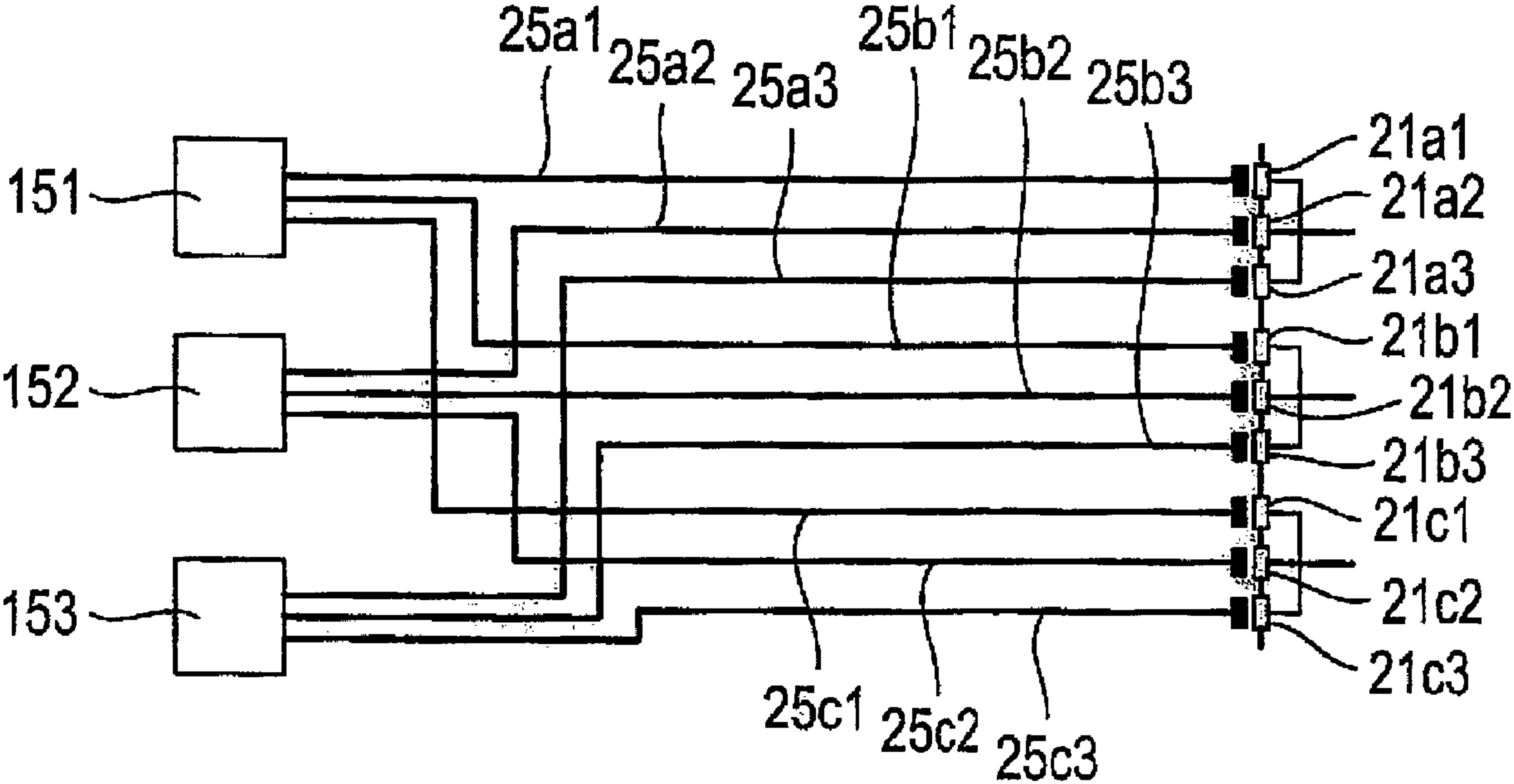

R_Za2
R_Za1
R_Za3
L_Za2
L_Za1
L_Za3
18

Fig. 4d


25a1
25a2
25a3
25b1
25b2
25b3
151
152
153
21a1
21a2
21a3
21b1
21b2
21b3
21c1
21c2
21c3
25c1
25c2
25c3