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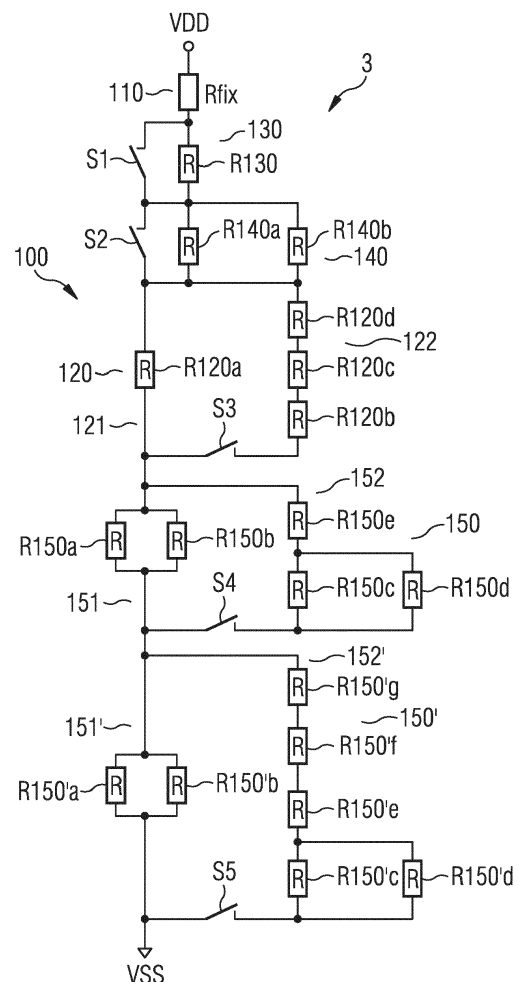
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(54) **AN ELECTRIC CIRCUIT FOR TRIMMING A RESISTANCE OF A RESISTOR**

(57) An electric circuit (3) for trimming a resistance of a resistor (R_{fix}) comprises a current path (100) including a first section (110) and at least one second section (150), wherein the first and the at least one second section (110, 150) are connected in series in the current path (100). The first section (110) of the current path includes the resistor (R_{fix}) to be trimmed. The at least one second section (150) of the current path (100) includes a first current branch (151) and a second current branch (152). The first current branch (151) of the at least one second section (150) of the current path (100) includes a first trimming resistor (R_{150a}) and a second trimming resistor (R_{150b}) being connected in parallel. The second current branch (152) of the at least one second section (150) of the current path (100) includes a third trimming resistor (R_{150c}) and a fourth trimming resistor (R_{150d}) being connected in parallel.

FIG 6



Description

Technical Field

5 **[0001]** The disclosure relates to an electric circuit for trimming a resistance of a resistor in a current path. The disclosure further relates to a method for trimming a resistance of the resistor.

Background

10 **[0002]** Integrated resistors usually undergo a large spread versus process. Starting from a typical value, a variation of a resistance of a resistor as large as +/- 20% can usually be observed in different production lots. One of the most typical applications which is affected by this problem is a voltage-to-current converter by means of which a precise reference current is obtained on a chip by loading a bandgap voltage with a resistor. Since the bandgap voltage is usually trimmed as well, the large resistor spread creates a 20% inaccuracy of the generated current.

15 **[0003]** To simplify calculations, assuming a +/- 16% spread of the resistance of a resistor, if the accuracy target is 0.5%, the resistance of the resistor should be tuned from 84% to 116% of its nominal value in 6 bits. The two extreme values of the resistance range correspond to the trimming options to be selected in cases where the process provides a resistance of the resistor that is 16% bigger than the nominal resistance and 16% smaller than the nominal resistance, respectively. Remarkably, the resistance of a resistor does not need to be trimmed from a value of 0 Ohm to the highest
20 possible value. The minimum value of the resistance is largely greater than 0 Ohm.

[0004] There is a need to provide an electric circuit for trimming a resistance of a resistor with a high accuracy, wherein the trimming circuit avoids a large area consumption. Furthermore, there is a need to provide a method for trimming a resistance of a resistor with a high accuracy without wasting a large area for the electric circuit.

25 Summary

[0005] An electric circuit for trimming a resistance of a resistor which does not consume a large area and allows to trim the resistance of the resistor with high accuracy is specified in claim 1.

30 **[0006]** The circuit for trimming the resistance of the resistor comprises a current path including a first section and at least a second section, wherein the first and the at least one second section are connected in series in the current path. The first section of the current path includes the resistor to be trimmed.

[0007] Depending on the accuracy/step size by which the (fixed) resistor of the first section of the current path is to be trimmed, the electric circuit may comprise several of the at least one second section in the current path. The at least one second section of the current path includes a first current branch and a second current branch being connected in
35 parallel. The first current branch of the at least one fifth section of the current path includes a first and a second trimming resistor being connected in parallel.

[0008] The second current branch of the at least one second section of the current path includes a third trimming resistor and a fourth trimming resistor being connected in parallel. The second current branch of the at least one second section of the current path includes at least one fifth trimming resistor being connected in series to the parallel connection
40 of the third and the fourth trimming resistor. Furthermore, the second current branch of the at least one second section of the current path includes a controllable switch. The controllable switch of the at least one second section of the current path is connected in series to the parallel connection of the third and the fourth trimming resistor.

[0009] The controllable switch of the at least one second section of the current path is configured to electrically connect the second current branch of the at least one second section of the current path, and thus the parallel connection of the
45 third and the fourth trimming resistor, in parallel to the first current branch of the at least one second section of the current path, when the controllable switch of the at least one second section of the current path is operated in the closed state. The controllable switch of the at least one second section of the current path is further configured to isolate the second current branch of the at least one second section of the current path, and thus the parallel connection of the third and the fourth trimming resistor, from the first current branch of the at least one second section of the current path, when
50 the controllable switch of the at least one second section of the current path is operated in the open state.

[0010] The current path may further comprise a third section being connected in series to the first section of the current path. The third section of the current path may comprise a sixth trimming resistor and a controllable switch. The controllable switch of the third section of the current path is configured to electrically connect the sixth trimming resistor in series to the first section of the current path and further in series to the at least one second section of the current path, when the
55 controllable switch is turned in an open state. In the closed state, the controllable switch of the third section of the current path is configured to bypass the sixth trimming resistor so that the first section of the current path is connected to the at least one second section of the current path via the closed controllable switch of the third section of the current path.

[0011] The current path may comprise a fourth section being connected in series to the third section and the at least

one second section of the current path. The fourth section of the current path may comprise a seventh trimming resistor and an eighth trimming resistor being connected in parallel. The fourth section of the current path may comprise a controllable switch that is configured to connect the parallel connection of the seventh and the eighth trimming resistor in series between the second section and the third section of the current path, when the controllable switch is operated in an open state. The controllable switch of the fourth section of the current path is further configured to bypass the parallel connection of the seventh and the eighth trimming resistor so that the third section of the current path is electrically connected to the at least one second section of the current path via the controllable switch of the fourth section of the current path, when the controllable switch of the fourth section of the current path is operated in the closed state.

[0012] The current path includes a fifth section comprising a first current branch and a second current branch. The first current branch of the fifth section of the current path includes at least a ninth trimming resistor. The second current branch of the fifth section of the current path includes a series connection of a controllable switch and at least a tenth and an eleventh and a twelfth trimming resistor. The controllable switch of the second current branch of the fifth section of the current path is configured to electrically connect the at least one tenth and eleventh and twelfth trimming resistor of the second current branch of the fifth section of the current path in parallel to the at least one ninth trimming resistor of the first current branch of the fifth section of the current path, when the controllable switch of the second current branch of the fifth section of the current path is operated in a closed state.

[0013] A method for trimming a resistance of a resistor is specified in claim 12.

[0014] According to the method, the resistance of the (fixed) resistor is trimmed by closing or opening at least one of the controllable switches of the at least one second, the third, the fourth and the fifth section of the current path in dependence on the sections provided in the current path and thus in dependence on the available trimming steps/sections.

[0015] Additional features and advantages are set forth in the detailed description that follows and in part will be readily apparent to those skilled in the art from the description or recognized by practising the embodiments as described in the written description and claims hereof, as well as the appended drawings. It is to be understood that both the foregoing general description and the following detailed description are merely exemplary, and are intended to provide an overview or framework to understand the nature and character of the claims.

Brief Description of the Drawings

[0016] The accompanying drawings are included to provide further understanding, and are incorporated in and constitute a part of the specification. The drawings illustrate one or more embodiments, and together with the detailed description serve to explain principles and operation of the various embodiments. As such, the disclosure will become more fully understood from the following detailed description, taken in conjunction with the accompanying figures in which

Figure 1 shows a first embodiment of an electric circuit for trimming a resistance of a resistor;

Figure 2 shows a second embodiment of an electric circuit for trimming a resistance of a resistor;

Figure 3 illustrates different approaches of sections of an electric circuit to provide the same resistance variation of a resistor;

Figure 4 illustrates generalized different approaches of sections of an electric circuit to provide the same resistance variation of a resistor;

Figure 5 shows a first embodiment of an electric circuit realizing a 5 bit trimming approach;

Figure 6 shows a second embodiment of an electric circuit for trimming a resistance of a resistor using a 5 bit trimming approach;

Detailed Description

[0017] Reference is now made in detail to various embodiments of the disclosure, examples of which are illustrated in the accompanying drawings. Whenever possible, the same or like reference numbers and symbols are used throughout the drawings to refer to the same or like parts. The drawings are not necessary to scale, and one skilled in the art will recognize where the drawings have been simplified to illustrate the key aspects of the disclosure. The claims as set forth below are incorporated into and constitute part of this detailed description.

[0018] Figure 1 shows a first embodiment of an electric circuit 1 to trim a resistance of a fixed resistor R_{fix} . The electric circuit 1 comprises a current path 10 being connected between a supply potential VDD and a reference potential VSS. The current path comprises a section 11 comprising the (fixed) resistor R_{fix} . The electric circuit 1 may comprise a plurality

of sections 12, 13, 14, ..., 1m of the current path 10 in dependence on the trimming accuracy or trimming step size of the resistance of the resistor R_{fix}. Each of the sections may comprise a respective controllable switch S12, S13, S14, ..., S1m and a respective trimming resistor R12, R13, R14, ..., R1m. Figure 1 shows the trimming resistors having a resistance R. The sections 12, 13, 14, ..., 1m are connected in series in the current path 10 subsequent to the section 11 of the current path that includes the resistor R_{fix}.

[0019] Each of the respective controllable switches S12, S13, S14, ..., S1m of the sections 12, 13, 14, ..., 1m of the current path 10 may be configured to connect the respective trimming resistor R12, R13, R14, ..., R1m of the sections of the current path 10 in series to a previous and a subsequent section of the current path 10, when the respective controllable switch is operated in the open state. In the closed state, each of the controllable switches of the current section 12, 13, 14, ..., 1m is configured to bypass the respective trimming resistor of the respective section of the current path. In the case of the closed state of a respective controllable switch S12, S13, S14, ..., S1m of the sections 12, 13, 14, ..., 1m of the current path 10, the respective trimming resistor R12, R13, R14, ..., R1m of the sections 12, 13, 14, ..., 1m of the current path is not electrically effective in the current path and is rather bypassed by the respective closed controllable switch.

[0020] The electric circuit shown in Figure 1 enables to trim the resistance of the (fixed) resistor R_{fix} by controlling the respective controllable switches S12, S13, S14, ..., S1m of the sections 12, 13, 14, ..., 1m of the current path 10 in the closed or open state. It is clear that, still referring for the sake of simplicity, but not exclusively, to the range 84% to 116% of the resistance of the resistor R_{fix} with 6 trimming bits, the resistor R_{fix} is trimmed by using a respective trimming resistor in each of the sections 12, 13, 14, ..., 1m of the current path which is 0.5% of the nominal resistance of the fixed resistor R_{fix} and put 232 of these unity elements/trimming resistors in series.

[0021] Using the respective controllable switches in each of the sections 12, 13, 14, ..., 1m of the current path 10, it is possible to bypass one single trimming resistor, i.e. the LSB, to adjust the resistance of the fixed resistor by 0.5%, to bypass two series trimming resistors to obtain a 1% adjustment (second least significant digit) of the resistance of the fixed resistor R_{fix}, to bypass four series trimming resistors for a 2% adjustment of the resistance of the resistor R_{fix} and so on until the total trimming range is covered. Any possible combination of the open/closed state of the controllable switches of the respective sections 12, 13, 14, ..., 1m allows a 0.5% tuning all over the trimming range of the resistance of the resistor R_{fix}.

[0022] The use of small unity trimming resistors ensures a large degree of matching, all the elements being equal, which is a key feature to develop a trimming system with small DNL (differential non-linearity) and INL (integral non-linearity).

[0023] Anyhow, it is clear that 232 sections being connected in series in the current path 10 would take a large area due to the large number of contacts and wiring. At the same time, the layout effort to provide all these connections should not be under-evaluated.

[0024] Unfortunately, these are not the only defects of such an approach. In fact, it has to be considered that a unity trimming resistor should be shaped with an L/W ratio (Length/Width ratio) that is quite large so that parasitic contributions of contacts and border effects are negligible. This becomes a serious problem if the total resistance of the resistor to be trimmed is not very large. Under the recommendation that a unity resistor should have at least five (or even ten) squares, this means that if the total resistance of the resistor R_{fix} is below 1,160 (or 2,320) squares, the less significant bits should be obtained with more trimming resistors in parallel in each of the sections of the current path, as shown in Figure 2.

[0025] Figure 2 shows a second embodiment of an electric circuit for trimming a resistance of a (fixed) resistor R_{fix}. Figure 2 illustrates how the structure of Figure 1 changes in the case that the LSB trimming resistor should be obtained as a parallel connection of bigger elements to comply with the minimum L/W rule.

[0026] The embodiment of the electric circuit 2 shown in Figure 2 comprises a current path 20 comprising a plurality of sections 21, 22, 23, 24, ..., 2m. The current path 20 with the sections 21 to 20m is connected between a supply potential VDD and a reference potential VSS. The section 21 of the current path 20 comprises the (fixed) resistor R_{fix} to be trimmed. The subsequent section 22 that is connected in series to the section 21 of the current path 20 comprises a trimming resistor R22 that may be bypassed by a controllable switch S22. Each of the subsequent sections 23, 24, ..., 2m of the current path 20 comprises an increasing number of trimming resistors R22, R23, R24, ..., R2m per section, wherein the trimming resistors are connected in parallel in each of the sections 23, 24, ..., 2m.

[0027] Furthermore, each of the sections 23, 24, ..., 2m of the current path 20 comprises a respective controllable switch S22, S23, S24, ..., S2m to bypass the parallel connection of the trimming resistors of the respective section of the current path 20. In order to trim the (fixed) resistor R_{fix} in the section 21 of the current path 20, the respective controllable switch of each of the subsequent sections 22, 23, 24, ..., 2m of the current path 20 may be switched in a closed or open state.

[0028] As shown in Figure 2, the LSB generation in the last section 2m of the current path 20 comprises 2^{m-2} trimming resistors. This might lead to a significant waste of area. As an example, a polyh resistor (1,200 Ohm per square) is considered to realistically generate 16 μ A under a bandgap voltage. This requires a 75 kilo Ohm resistor, i.e. a little more than 60 squares. An accuracy target of 0.5%, i.e. 375 Ohm, means that 1LSB should be made by 32 unity trimming

resistors in parallel to comply with the 10 squares minimum rule for resistors. The second least significant digit would be made by connecting 16 trimming resistors in parallel, then 8 trimming resistors for the third least significant digit, then 4 trimming resistors, 2 trimming resistors and one trimming resistor to complete the trimming section, as shown in Figure 2. In the end, this allows the possibility to tune the resistance of the resistor Rfix in a range as large as 24 kilo Ohm, i.e. +/- 16% from the nominal resistance value.

[0029] In the end, the resistor Rfix will be trimmed from 63 kilo Ohm to 87 kilo Ohm in steps of 375 Ohm, and a total of 63 unit 10 square resistors will be used for trimming. The remaining untrimmed contribution, amounting to 63 kilo Ohm, is easily arranged with five series units plus four units in parallel. As a result, the trimming part of the electric trimming circuit would be seven times larger than the untrimmed portion.

[0030] As explained above, in most applications the (fixed) resistor Rfix does not need to be trimmed from 0 Ohm. Regarding the approach of Figure 2, most of the area of the electric circuit for trimming the resistance of the resistor Rfix is lost to generate one LSB variation in the resistor value.

[0031] Figure 3 shows two alternative embodiments of sections of a trimming circuit to generate the same variation of a resistance for a fixed resistor.

[0032] Figure 3 shows, on the left side, the portion 24 of the electric circuit 2 for trimming the resistance of the resistor Rfix. The portion 24 comprises the four trimming resistors R24 having a resistance R. The trimming resistors may be bypassed by closing the controllable switch S24. The section 24 of the electric circuit 2 allows to vary the resistance of the resistor Rfix from 0 Ohm to R/4 Ohm depending on the switching status of the controllable switch S24.

[0033] Figure 3 shows, on the right side, a section 120 of another embodiment of an electric circuit 3 for trimming the resistance of the resistor Rfix. This structure also enables to vary the resistance of the resistor Rfix by R/4. The section 120 of the electric circuit 3 comprises a current branch 121 and a current branch 122 that may be connected in parallel by means of a controllable switch S3. The current branch 121 of the section 120 of the trimming circuit includes a single trimming resistor R120a having a resistance R. The current branch 122 includes a series connection of three trimming resistors R120b, R120c and R120d having a resistance R. The trimming resistors R120b, R120c and R120d can be electrically connected in parallel to the trimming resistor R120a, if the controllable switch S3 is turned in a conductive/closed state. In this way, the total resistance varies from $\frac{3}{4}R$ to R.

[0034] If the section 120 of the trimming circuit 3 is compared with a section 24 it may be realized that the variation of the resistance in both cases is R/4. Hence, both embodiments fit the requirement to vary a resistance of a resistor Rfix by the same resistance step, where a resistance of 0 Ohm is not an option. Indeed, regarding the architecture of the trimming circuit 3, the minimum resistance must be at least equal to $\frac{3}{4}R$. Besides the difference that the total resistance is increased starting from $\frac{3}{4}R$ to R in the case that the architecture of the right side in Figure 3 is used, the same tuning capability is ensured. The difference in the total resistance can be easily corrected by making the untrimmed part consequently smaller, if the architecture of the trimming circuit 3 shown in the right side of Figure 3 is used.

[0035] Figure 3 shows, in the bottom portion, on the left hand side a section 25 of the approach of the trimming circuit 2 and on the right hand side a section 150 of the approach of the trimming circuit 3 to arrange a smaller step of a resistance variation, i.e. a resistance variation of R/8. Starting from the two structures 24 and 120 on the top portion in Figure 3 to realize a resistance variation of R/4, it is sufficient to divide each of the sections 24 and 120 by two to obtain the resistance variation of R/8.

[0036] As concerns the approach of the trimming circuit 2 on the left side of Figure 3, the number of trimming resistors R25 being connected in parallel in the section 25 of the trimming circuit 2 is doubled in comparison to the number of trimming resistors R24 of the section 24 to realize the resistance variation of R/8. Instead of 4 parallel connected trimming resistors of the section 24 of the trimming circuit 2, the section 25 of the trimming circuit 2 comprises 8 trimming resistors. The 8 parallel connected trimming resistors R25 may be bypassed by a controllable switch S25.

[0037] If the section 120 of the trimming circuit 3 on the right side of Figure 3 is divided by two to realize a change of the resistance of R/8, any single trimming resistor in the current branches 121 and 122 is replaced by two trimming resistors in parallel, while the series of two trimming resistors in the current branch 122 is replaced by only one trimming resistor. In particular, the trimming resistor R120a is replaced by the two trimming resistors R150a and R150b connected in parallel in the current branch 151 of the section 150 of the trimming circuit 3. The series connection of the two trimming resistors R120c and R120d of the section 120 of the trimming circuit 3 is replaced by a single trimming resistor R150e. The single trimming resistor R120b is replaced by the two trimming resistors R150c and R150d being connected in parallel in the current branch 152 of the section 150 of the trimming circuit 3. The controllable switch S3 of the section 120 of the trimming circuit 3 arranged in the current branch 122 remains unchanged and corresponds to the controllable switch S4 included in the current branch 152 of the section 150 of the trimming circuit 3.

[0038] If the section 25 of the trimming circuit 2 and the section 150 of the trimming circuit 3 are compared, it can be realized that the number of trimming resistors in the section 150 of the trimming circuit 3 is only increased by one, whereas the number of trimming resistors in the section 25 is doubled in comparison to the section 24 of the trimming circuit 2. In particular, to realize the resistance variation of R/8, the architecture of the trimming circuit 3 using the section 150 only uses five trimming resistors instead of eight trimming resistors in the section 25 of the trimming circuit 2. The

configuration of the trimming circuit 3 enables to save area on a supporting substrate, for example a printed circuit board, of the trimming circuit.

[0039] Figure 4 generalizes the concept how the (N+1)th trimming section is obtained from the (N)th one for both approaches of the trimming circuits 2 and 3 shown in Figure 3. In particular, Figure 4 illustrates the two alternative embodiments of respective sections of the trimming circuits 2 and 3 to generate the resistance variation with a step size of $1/2^{N+1}$ starting from the $1/2^N$ step of resistance variation with M being a positive integer.

[0040] Section 50 of the circuit approach 3 on the top right side of Figure 4 is another way to make a $1/2^N$ step of resistance change if compared to the structure 40 shown on the top left side of Figure 4. Starting from the $1/2^N$ step of resistance change and considering section 40 of the circuit approach 2 on the left side and section 50 of the circuit approach 3 on the right side of the top portion of Figure 4, both sections 40 and 50 use the same number of trimming resistors. The section 40 of the trimming circuit approach 2 shown on the left side of the top portion of Figure 4 uses 2^N parallel trimming resistors 30 which can be bypassed by a controllable switch S40. The section 50 of the other trimming circuit approach 3 shown on the right side of the top portion of Figure 4 uses one trimming resistor 53a in a current branch 51 and a series connection of 2^N-1 trimming resistors 53a, 53b, ..., 53n in a second current branch 52 that can be electrically connected in parallel to the current branch 51 by a controllable switch S50. If the switchable series of 2^N-1 similar trimming resistors 53b, 53c, ..., 53n is put in parallel to the single trimming resistor 53a, the generation of a $R/2^N$ wide trimming step is obtained, changing the resistance from R to

$$R \times (1 - 1/2^N) .$$

[0041] Considering the starting blocks 40 and 50: Making half of these blocks 40 and 50 means to generate the $1/2^{N+1}$ step of resistance change. The respective section 60 of the trimming circuit 2 is illustrated in the bottom portion of Figure 4 on the left hand side, and the respective section 70 of the trimming circuit 3 is illustrated in the bottom portion of Figure 4 on the right hand side. For the approach of the trimming circuit 2 halving a given number of the parallel trimming resistors 30 means to double their number, as all elements/trimming resistors are still kept in parallel. This leads to $2 \times 2^N = 2^{N+1}$ trimming resistors 31 for the section 60 of the trimming circuit 2.

[0042] In order to halve the change of the resistance of the section 50 of the trimming circuit 3 from $1/2^N$ to $1/2^{N+1}$, the resistances in both current paths 51 and 52 are halved. That means that the single resistor 53a in the current branch 51 is replaced by a parallel connection of two trimming resistors 73a and 73b in the current branch 71. Furthermore, the series connection of the trimming resistors 53b, 53c, ..., 53n in the current branch 52 is replaced by a series connection of $2^{N-1}-1$ trimming resistors in the current branch 72 and a parallel connection of two trimming resistors 73c and 73d. Likewise/Similar to the controllable switch S50 of the section 50 of the trimming circuit 3, the section 70 of the trimming circuit 3 comprises a controllable switch S70 that is configured to connect the current branches 71 and 72 electrically in parallel. Hence, as a result, the $1/2^{N+1}$ step of resistance change is obtained with $3 + 2^{N-1}$ trimming resistors, if the embodiment of the trimming circuit 3 is used.

[0043] When compared to the section 60, making the impedance halved using the approach of the trimming circuit 3 means to halve the number of trimming resistors connected in series in the current branch 72, not doubling them as shown for the configuration of the section 60 of the trimming circuit 2. Being the switchable path 52 including an odd number of trimming resistors, the next LSB generation according to the scheme of the trimming circuit 3 requires $3 + 2^{N-1}$ trimming resistors in total instead of 2^{N+1} trimming resistors for the respective section of the trimming circuit 2. Large area savings follows, especially for large values of N.

[0044] The table below shows the trimming step size ($1/2^{N+1}$) of the resistance change and the number of trimming resistors used in the last sections of the trimming circuits 2 and 3. For N being an integer with $N \geq 1$, the number of trimming resistors in the last section of the current path of the trimming circuit 2 according to the embodiment 2 results in 2^{N+1} , and number of trimming resistors in the last section of the current path of the trimming circuit 2 according to the embodiment 3 results in $3 + 2^{N-1}$.

Trimming step size	N	Number of trimming resistors in last section of current path of embodiment 2 of trimming circuit	Numbers of trimming resistors in last section of current path of embodiment 3 of trimming circuit
1/4	1	4	4
1/8	2	8	5
1/16	3	16	7
1/32	4	32	11

(continued)

Trimming step size	N	Number of trimming resistors in last section of current path of embodiment 2 of trimming circuit	Numbers of trimming resistors in last section of current path of embodiment 3 of trimming circuit
1/64	5	64	19

[0045] Figures 5 and 6 respectively show an example for the trimming circuit 2 and 3 of the different approaches. Figure 5 shows an embodiment of an electric circuit 2 for trimming a resistance of a resistor R_{fix} using the approach illustrated on the left side of Figure 4. Figure 6 shows an electric circuit 3 for trimming a resistance of a resistor R_{fix} using the approach shown on the right side of Figure 4.

[0046] Figure 5 shows an embodiment of a 5-bit trimming approach of an electric circuit for trimming a resistance of the resistor R_{fix}. The configuration of the electric circuit 2 is based on the approach illustrated in Figure 2 or in the left portions of Figures 3 and 4. The electric circuit 2 comprises a current path 20 including a plurality of sections 21, 22, 23, 24, 25 and 26 being connected in series between a supply potential VDD and a reference potential VSS. The section 21 of the current path 20 comprises the (fixed) resistor R_{fix} of which its resistance is trimmed by the trimming sections 22, 23, 24, 25 and 26. The trimming section 22 comprises a single resistor R₂₂ that can be bypassed by a controllable switch S1. The subsequent trimming section 23 comprises the two parallel connected resistors R₂₃ that may be bypassed by the controllable switch S2. The trimming circuit 2 further comprises the trimming section 24 including the four parallel connected trimming resistors R₂₄ that may be bypassed by a controllable switch S3. The subsequently arranged trimming section 25 comprises eight trimming resistors R₂₅ that can be bypassed by the controllable switch S4. The last trimming section 26 comprises sixteen trimming resistors R₂₆ that can be bypassed by the controllable switch S5.

[0047] The controllable switches S1, ..., S5 may be controlled to be turned in a closed or open state by means of a controller circuit not shown in Figure 5. In dependence on the state of the controllable switches S1, ..., S5 the (fixed) resistor R_{fix} can be trimmed to different resistances.

[0048] The embodiment of the electric trimming circuit 2 shown in Figure 5 to realize the 5-bit trimming approach includes 31 trimming resistors in the several trimming sections 22 to 26 having the same resistance R. Figure 5 illustrates that a trimming section is doubled with parallel resistors in the subsequent trimming section to generate the next lower LSB. Each trimming section can be bypassed by the corresponding controllable switch S1, ..., S5 to modulate the value of the (fixed) resistor R_{fix}. Figure 5 clearly shows that the area increase for the trimming circuit 2 is exponential with the number of bits. K bits require $2^K - 1$ trimming resistors.

[0049] Figure 6 shows an embodiment of an electric circuit 3 for trimming a resistance of a (fixed) resistor R_{fix}. The circuit 3 comprises a current path 100 including a section 110 and a section 120. The section 110 and the section 120 are connected in series in the current path 100. The section 110 includes the fixed resistor R_{fix} to be trimmed. The section 120 of the current path 100 includes a current branch 121 and a current branch 122. The current branch 121 of the trimming section 120 of the current path 100 includes at least a trimming resistor R_{120a}. The current branch 122 of the trimming section 120 of the current path 100 includes a series connection of a controllable switch S3 and at least a trimming resistor R_{120b}, a trimming resistor R_{120c} and a trimming resistor R_{120d}. The current branch 122 comprises at least three trimming resistors. The controllable switch S3 of the current branch 122 of the trimming section 120 of the current path 100 is configured to connect the current path 122, i.e. the trimming resistors R_{120b}, R_{120c} and R_{120d} in parallel to the current path 121, i.e. the trimming resistor R_{120a}, when the controllable switch S3 is operated in the closed state.

[0050] The current path 100 further comprises a trimming section 130 being connected in series to the section 110 of the current path 100. The trimming section 130 of the current path 100 includes a trimming resistor R₁₃₀ and a controllable switch S1. The controllable switch S1 is configured to connect the trimming resistor R₁₃₀ in series to the section 110 of the current path 100, i.e. to the (fixed) resistor R_{fix}, when the controllable switch S1 is turned in an open state. The controllable switch S1 is further configured to bypass the trimming resistor R₁₃₀ so that the section 110 of the current path 100, i.e. the (fixed) resistor R_{fix} is connected to the trimming section 120 of the current path 100 by/via the controllable switch S1, when the controllable switch S1 of the trimming section 130 of the current path 100 is turned in the closed state.

[0051] The current path 100 further comprises a trimming section 140 being connected in series between the trimming section 130 and the trimming section 120 of the current path 100. The trimming section 140 includes a trimming resistor R_{140a} and a trimming resistor R_{140b} being connected in parallel. The trimming section 140 further comprises a controllable switch S2 being configured to be operated in a closed and an open state. The controllable switch S2 of the trimming section 140 of the current path 100 is configured to connect the parallel connection of the trimming resistors R_{140a} and R_{140b} in series between the trimming section 120 and the trimming section 130 of the current path 100, when the controllable switch S2 is operated in the open state. The controllable switch S2 of the trimming section 140 is further configured to bypass the parallel connection of the trimming resistors R_{140a} and R_{140b} so that the trimming

section 130 is connected to the trimming section 120 of the current path by/via the controllable switch S2, when the controllable switch S2 is operated in the closed state.

[0052] The current path 100 includes at least one other trimming section being connected in series to the first, the second, the third and the fourth trimming section 110, 120, 130, 140 of the current path 100. According to the exemplified embodiment of the current path 100 of the electric circuit 3, the current path 100 comprises the trimming section 150 and the additional trimming section 150' that are both connected in series to the first, the second, the third and the fourth trimming section 110, 120, 130, 140 of the current path 100.

[0053] The trimming section 150 of the current path 100 includes a current branch 151 and a current branch 152. The current branch 151 of the trimming section 150 includes a trimming resistor R150a and a trimming resistor 150b being connected in parallel. The current branch 152 includes a trimming resistor R150c and a trimming resistor R150d being connected in parallel. The current branch 152 of the trimming section 150 of the current path 100 further includes at least one trimming resistor R150e being connected in series to the parallel connection of the trimming resistors R150c and R150d.

[0054] The current branch 152 of the trimming section 150 of the current path 100 further includes a controllable switch S4. The controllable switch S4 is connected in series to the parallel connection of the trimming resistors R150c and R150d. The controllable switch S4 of the trimming section 150 is configured to connect the current branch 152 in parallel to the current branch 151, when the controllable switch S4 of the trimming section 150 is operated in the closed state. The controllable switch S4 is further configured to isolate/separate the current branch 152 from the current branch 151, when the controllable switch S4 is operated in the open state.

[0055] According to the 5-bit trimming scheme shown in Figure 6, the current path 100 comprises the additional trimming section 150' being connected in series to the previous trimming sections 110, 120, 130, 140 and 150. The trimming section 150' includes a current branch 151' and a current branch 152' being connected in parallel. The current branch 151' comprises a trimming resistor R150'a and a trimming resistor R150'b being connected in parallel in the current branch 151'. The current branch 152' includes a trimming resistor R150'c and a trimming resistor R150'd being connected in parallel. The current branch 152' includes three trimming resistors R150'e, R150'f and R150'g being connected in series to the parallel connection of the trimming resistors R150'c and R150'd.

[0056] The current branch 152' further comprises a controllable switch S5 that is connected in series to the parallel connection of the trimming resistors R150'c and R150'd. The controllable switch S5 of the current branch 152' is configured to connect the current branch 152' in parallel to the current branch 151', when the controllable switch S5 is operated in the closed state. The controllable switch S5 is further configured to isolate/separate the current branches 151' and 152' and thus the parallel connection of the trimming resistors R150'c and R150'd of the current branch 152' from the current branch 151', when the controllable switch S5 is operated in the open state.

[0057] As illustrated in Figure 6, the at least one other trimming section comprises the trimming section 150 and the trimming section 150'. Each of the current branches 152 and 152' includes an odd number of trimming resistors R150e or R150'e, R150'f and R150'g being connected in series to the parallel connection of the trimming resistors R150c, R150d or R150'c, R150'd. Each of the trimming resistors in the trimming sections 130, ..., 150, 150' can have the same resistance R. In order to vary/trim the value of the (fixed) resistor R_{fix}, each of the controllable switches S1 to S5 can be switched in the open or closed state.

[0058] As is apparent from the embodiment of the electric circuit 3 of Figure 6 in comparison to the electric circuit 2 shown in Figure 5, increasing the number of bits makes the approach of the electric trimming circuit 3 increasingly convenient. For a 5-bit trimming scheme, only 19 trimming resistors are used for the electric trimming circuit 3 of Figure 6 instead of 31 trimming resistors used for the approach of the electric trimming circuit 2 shown in Figure 5. The trend would converge to four times less area for a large number of trimming bits. For a very large number of trimming bits K, the trend would be frustrated by the fact that the total resistance would increase to far beyond the target limits. Any additional K-th bit introduces an offset equal to $R/2 - 1/2^K$ over the minimum achievable resistance. Hence, the number K of the bits is limited by the relationship $K \times R/2 < R_{\max}$. Anyhow this constraint is fully acceptable in any practical implementation.

[0059] If the approaches of the electric trimming circuits 2 and 3 are compared, it can be asserted that, as any bit adds an offset. This means that the untrimmed part of the resistance is smaller if the approach of the electric trimming circuit 3 is used. This saves additional area. Moreover, it has to be emphasized that the controllable switches of the sections of the electric trimming circuit 3 are always connected in series to several trimming resistors, unlike in the approach of the trimming circuit 2. In this way, the on-resistance of the controllable switches is less relevant in determining the trimming accuracy. This makes another remarkable saving of area. Moreover, the switch size of the controllable switches in the trimming sections of the trimming circuit 3 is smaller in comparison to the switch size of the controllable switches in the trimming sections of the trimming circuit 2. In the end, despite the reduced area, INL (integral non-linearity) and DNL (differential non-linearity) are not frustrated in the approach of the electric trimming circuit 3 because the area saving is achieved in the generation of the LSB, where a large percentage error is easily tolerated.

List of Reference Signs

[0060]

5	1, 2, 3	embodiments of electric trimming circuits
	10	current path
	11, ..., 1m	section of current path
	20	current path
	21, ..., 2m	sections of current path
10	30	trimming resistor
	40, 50, 60, 70	section of current path
	100	current path
	110, ..., 150'	section of current path
	S	controllable switch
15	Rfix	(fixed) resistor

Claims

- 20 1. An electric circuit for trimming a resistance of a resistor, comprising:
- a current path (100) including a first section (110) and at least a second section (150), wherein the first and the at least one second section (110, 150) are connected in series in the current path (100),
 - wherein the first section (110) of the current path includes the resistor (Rfix) to be trimmed,
 - 25 - wherein the at least one second section (150) of the current path (100) includes a first current branch (151) and a second current branch (152),
 - wherein the first current branch (151) of the at least one second section (150) of the current path (100) includes a first trimming resistor (R150a) and a second trimming resistor (R150b) being connected in parallel,
 - wherein the second current branch (152) of the at least one second section (150) of the current path (100)
 - 30 includes a third trimming resistor (R150c) and a fourth trimming resistor (R150d) being connected in parallel.
2. The electric circuit of claim 1,
- wherein the second current branch (152) of the at least one second section (150) of the current path (100) includes at least one fifth trimming resistor (R150e) being connected in series to the parallel connection of the third and the
- 35 fourth trimming resistor (R150c, R150d).
3. The electric circuit of claim 2,
- wherein the second current branch (152) of the at least one second section (150) of the current path (100) includes an odd number of the at least one fifth trimming resistor (R150e) being connected in series to the parallel connection
- 40 of the third and the fourth trimming resistor (R150c, R150d).
4. The electric circuit of claims 1 to 3,
- wherein the second current branch (152) of the at least one second section (150) of the current path (100) includes a controllable switch (S4).
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5. The electric circuit of claim 4,
- wherein the controllable switch (S4) of the second current branch (152) of the at least one second section (150) of the current path (100) is connected in series to the parallel connection of the third and the fourth trimming resistor (R150c, R150d).
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6. The electric circuit of claims 4 or 5,
- wherein the controllable switch (S4) of the second current branch (152) of the at least one second section (150) of the current path (100) is configured to electrically connect the second current branch (152) of the at
 - 55 least one second section (150) of the current path (100) in parallel to the first current branch (151) of the at least one second section (150) of the current path (100), when the controllable switch (S4) of the second current branch (152) of the at least one second section (150) of the current path (100) is operated in the closed state,
 - wherein the controllable switch (S4) of the second current branch (152) of the at least one second section

(150) of the current path (100) is configured to isolate the parallel connection of the third and the fourth trimming resistor (R150c, R150d) from the first current branch (151) of the at least one second section (150) of the current path (100), when the controllable switch (S4) of the second current branch (152) of the at least one second section (150) of the current path (100) is operated in the open state.

7. The electric circuit of claim 1,

- wherein the current path (100) comprises a third section (130) being connected in series to the first section (110) of the current path (100),
- wherein the third section (130) of the current path (100) includes a sixth trimming resistor (R130) and a controllable switch (S1),
- wherein the controllable switch (S1) of the third section (130) of the current path (100) is configured to connect the sixth trimming resistor (R130) in series to the first section (110) and the at least one second section (150) of the current path, when the controllable switch (S1) of the third section (130) of the current path (100) is turned in an open state,
- wherein the controllable switch (S1) of the third section (130) of the current path (100) is configured to bypass the sixth trimming resistor (R130) so that the first section (110) of the current path (100) is electrically connected to the at least one second section (150) of the current path (100) via the controllable switch (S1) of the third section (130) of the current path, when the controllable switch (S1) of the third section (130) of the current path is operated in the closed state.

8. The electric circuit of claim 7,

- wherein the current path (100) comprises a fourth section (140) being connected in series to the third section (130) and the at least one second section (150) of the current path,
- wherein the fourth section (140) of the current path (100) includes a seventh trimming resistor (R140a) and an eighth trimming resistor (R140b) being connected in parallel,
- wherein the fourth section (140) of the current path (100) includes a controllable switch (S2) being configured to be operated in a closed and an open state.

9. The electric circuit of claim 8,

- wherein the controllable switch (S2) of the fourth section (140) of the current path (100) is configured to electrically connect the parallel connection of the seventh and the eighth trimming resistor (R140a, R140b) in series to the at least one second section (150) and the third section (130) of the current path, when the controllable switch (S2) of the fourth section (140) of the current path (100) is operated in the open state,
- wherein the controllable switch (S2) of the fourth section (140) of the current path (100) is configured to bypass the parallel connection of the seventh and the eighth trimming resistor (R140a, R140b) so that the third section (130) of the current path is electrically connected to the at least one second section (150) of the current path via the controllable switch (S2) of the fourth section (140) of the current path, when the controllable switch (S2) of the fourth section (140) of the current path (100) is operated in the closed state.

10. The electric circuit of claims 3 or 4,

- wherein the current path (100) includes a fifth section (120) being connected in series to the first section (110), the at least one second section (150), the third section (130) and the fourth section (140) of the current path (100),
- wherein the fifth section (120) of the current path includes a first current branch (121) and a second current branch (122),
- wherein the first current branch (121) of the fifth section (120) of the current path (100) includes at least a ninth trimming resistor (R120a),
- wherein the second current branch (122) of the fifth section (120) of the current path (100) includes a series connection of a controllable switch (S3) and at least a tenth and an eleventh and a twelfth trimming resistor (R120b, R120c, R120d),
- wherein the controllable switch (S3) of the second current branch (122) of the second section (120) of the current path (100) is configured to electrically connect the at least one tenth and eleventh and twelfth trimming resistor (R120b, R120c, R120d) of the second current branch (122) of the second section (120) of the current path (100) in parallel to the at least one ninth trimming resistor (R120a) of the first current branch (121) of the second section (120) of the current path (100), when the controllable switch (S3) of the second current branch

(122) of the second section (120) of the current path is operated in a closed state.

11. The electric circuit of claims 9 or 10,
wherein the trimming resistors (R150a, ..., R150e) of the at least one second section (150), the trimming resistor
(R130) of the third section (130), the trimming resistors (R140a, R140b) of the fourth section (140) and the trimming
resistors (R120a, ..., R120d) of the fifth section (120) of the current path (100) have the same resistance (R).

12. A method for trimming a resistance of a resistor, comprising:

- providing an electric circuit (10) for trimming a resistance of a resistor as claimed in claim 1,
- wherein the resistance of the resistor (Rfix) to be trimmed is trimmed by closing or opening the controllable switch (S4) of the at least one second section (150) of the current path (100).

13. The method of claim 12, comprising:

- providing the electric circuit (10) for trimming the resistance of the resistor (Rfix) to be trimmed as claimed in claim 7,
- wherein the resistance of the resistor (Rfix) to be trimmed is trimmed by closing or opening the controllable switch (S1) of the third section (130) of the current path.

14. The method of claim 13, comprising:

- providing the electric circuit for trimming the resistance of the resistor (Rfix) to be trimmed as claimed in claim 8,
- wherein the resistance of the resistor (Rfix) to be trimmed is trimmed by closing or opening the controllable switch (S2) of the fourth section (140) of the current path.

15. The method of claim 14, comprising:

- providing the electric circuit for trimming the resistance of the resistor (Rfix) to be trimmed as claimed in claim 10,
- wherein the resistance of the resistor (Rfix) to be trimmed is trimmed by closing or opening the controllable switch (S3) of the fifth section (120) of the current path.

FIG 1

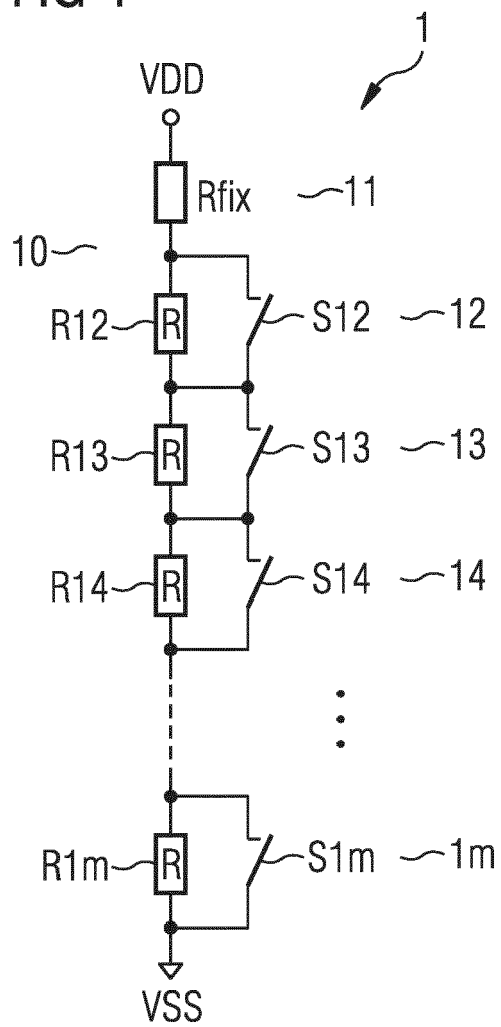


FIG 2

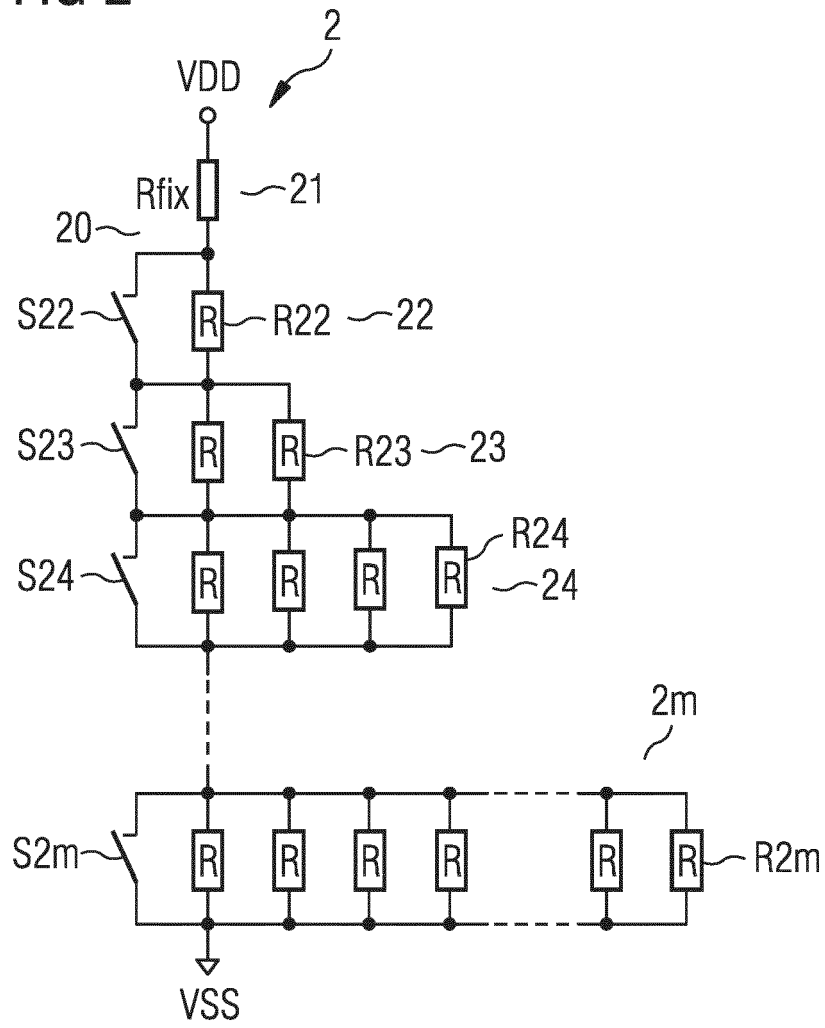


FIG 3

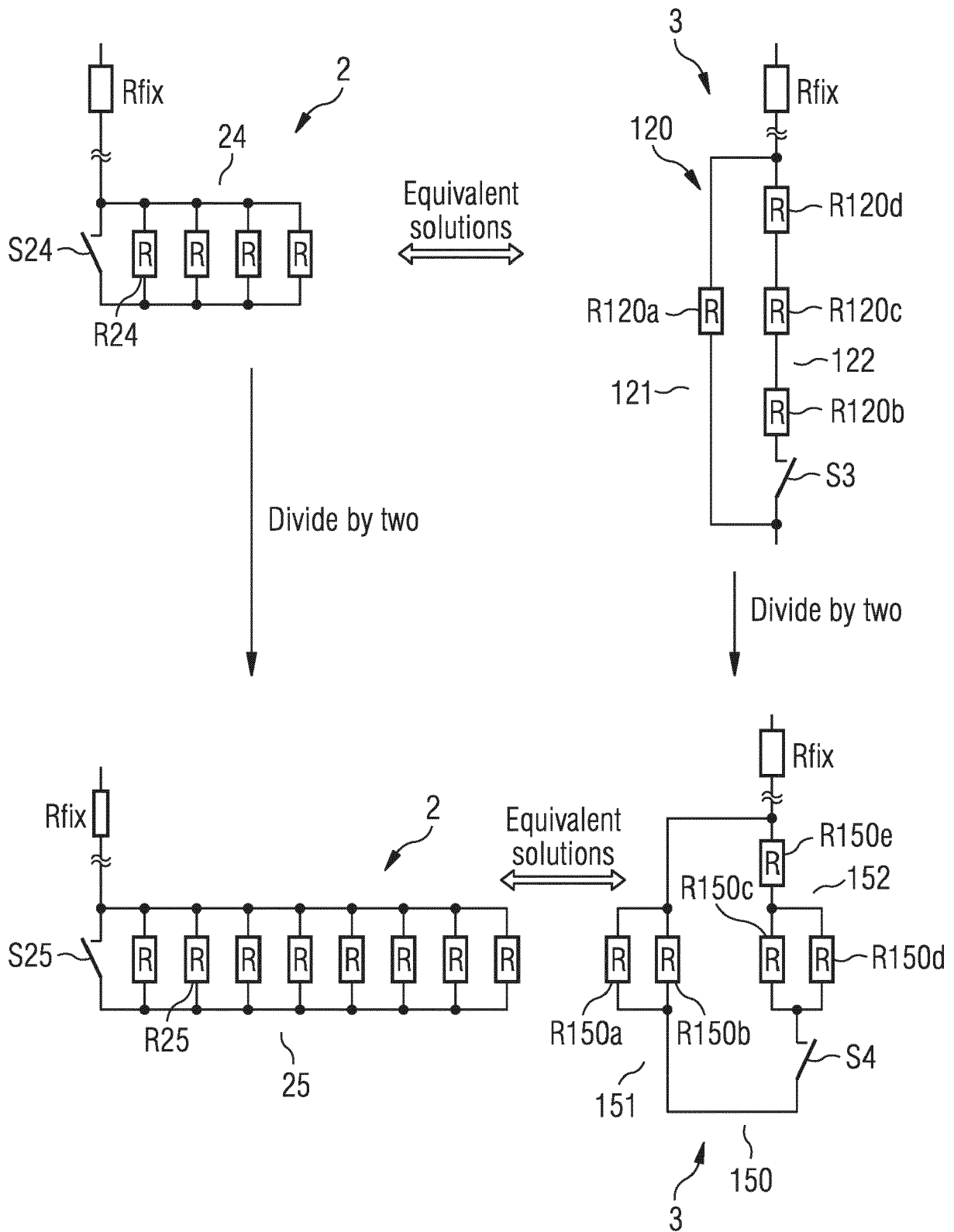


FIG 4

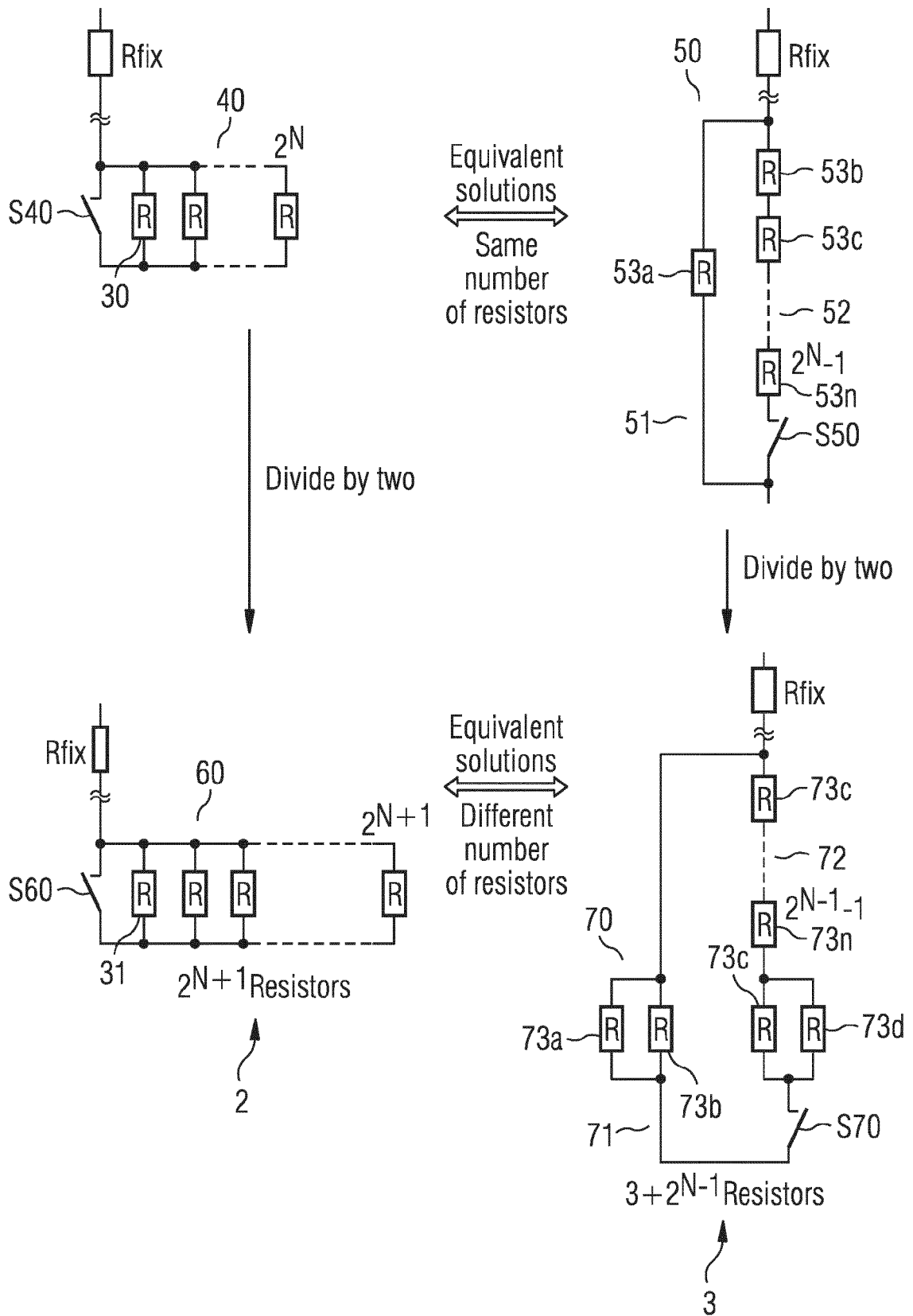


FIG 5

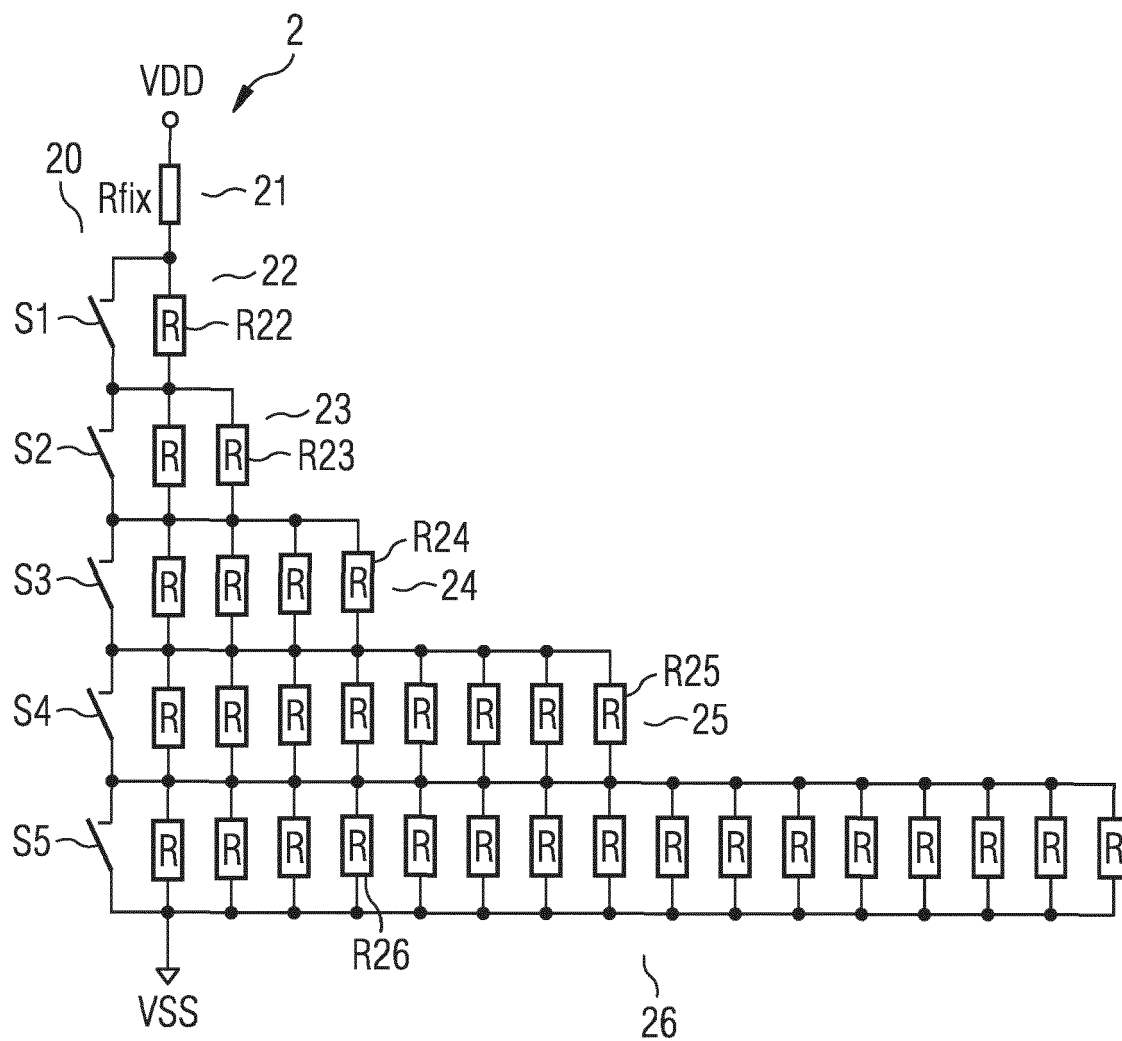
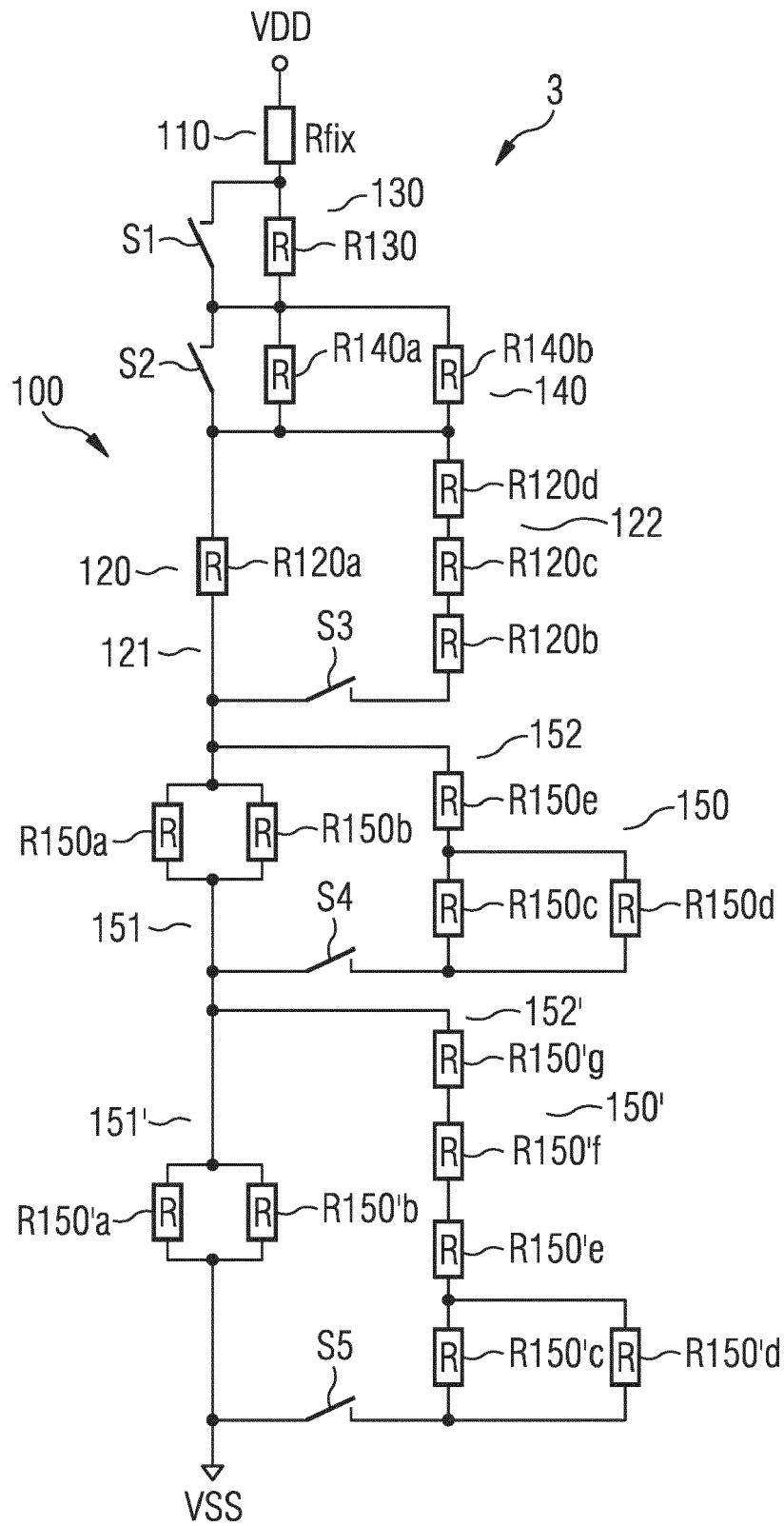


FIG 6





EUROPEAN SEARCH REPORT

Application Number
EP 17 17 0814

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The present search report has been drawn up for all claims			
Place of search Berlin		Date of completion of the search 19 June 2017	Examiner Pantelidis, D
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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