(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
2 April 2015 (02.04.2015)

(10) International Publication Number
WO 2015/048704 A2

(51) International Patent Classification: Not classified

(21) International Application Number: PCT/US2014/058168

(22) International Filing Date: 30 September 2014 (30.09.2014)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/884,444 30 September 2013 (30.09.2013) US
14/066,980 30 October 2013 (30.10.2013) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:
— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

(54) Title: METHOD AND CIRCUITRY FOR MULTI-STAGE AMPLIFICATION

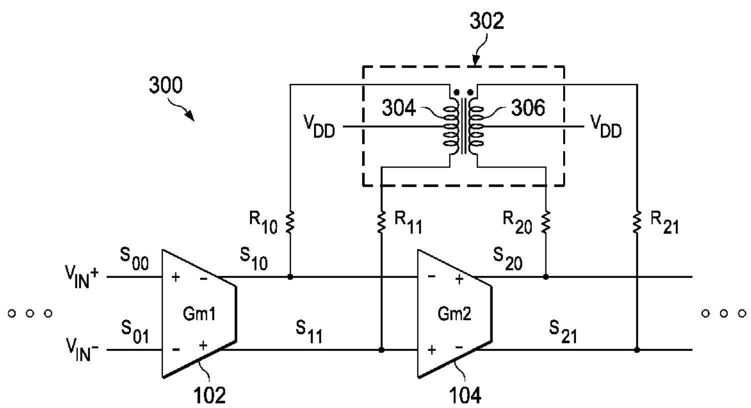

FIG. 3

(57) Abstract: In described examples of an amplifier (300), a first stage (102) receives a differential input voltage, which is formed by first and second input voltages (VIN+, VIN-), and outputs a first differential current in response thereto on first and second lines (S10, Sn) having respective first and second line voltages. A second stage (104) receives the first and second line voltages and outputs a second differential current in response thereto on third and fourth lines (S20, S21) having respective third and fourth line voltages. A transformer (302) includes first and second coils (304, 306). A first terminal of the first coil (304) is coupled through a first resistor (Rio) to the first line (S10). A second terminal of the first coil (304) is coupled through a second resistor (Rii) to the second line (Sn). A first terminal of the second coil (306) is coupled through a third resistor (R20) to the third line (S20). A second terminal of the second coil (306) is coupled through a fourth resistor (R21) to the fourth line (S21).

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METHOD AND CIRCUITRY FOR MULTI-STAGE AMPLIFICATION

[0001] This relates in general to electronic circuitry, and in particular to a method and circuitry for multi-stage amplification.

BACKGROUND

[0002] FIG. 1 (prior art) is a schematic electrical circuit diagram of a conventional multi-stage amplifier, indicated generally at 100. The amplifier 100 includes at least first and second stages 102 and 104, which are transconductance amplifiers whose gains are Gm1 and Gm2, respectively. The amplifier 100 receives a differential input voltage from lines S_{00} and S_{01}.

[0003] The first stage 102 applies the gain Gm1 to amplify a difference ("ΔV_{IN}") between S_{00}'s voltage ("$V_{IN}+$") and S_{01}'s voltage ("$V_{IN}-$"). Similarly, the second stage 104 applies the gain Gm2 to amplify a difference ("ΔV_1") between a line S_{10}'s voltage ("V_{10}") and a line S_{11}'s voltage ("V_{11}"). Accordingly: (a) in response to ΔV_{IN}, the first stage 102 generates a difference ("ΔI_1") between S_{10}'s current ("I_{10}") and S_{11}'s current ("I_{11}"); and (b) in response to ΔV_1, the second stage 104 generates a difference ("ΔI_2") between a line S_{20}'s current ("I_{20}") and a line S_{21}'s current ("I_{21}").

[0004] As shown in FIG. 1, S_{10} is connected to a resistor R_{10}, which is coupled through a first terminal of an inductor L_1 to a voltage supply node V_{DD}. Also, S_{11} is connected to a resistor R_{11}, which is coupled through a second terminal of L_1 to V_{DD}. Similarly, S_{20} is connected to a resistor R_{20}, which is coupled through a first terminal of an inductor L_2 to V_{DD}. Further, S_{21} is connected to a resistor R_{21}, which is coupled through a second terminal of L_2 to V_{DD}.

[0005] FIG. 2 (prior art) is a graph of an example curve 202 of gain (dB) versus frequency for the amplifier 100, having a 3 dB bandwidth region 204. As shown in FIG. 2, the 3 dB bandwidth region 204 is a range of frequencies whose gains are within 3dB of peak gain. Without L_1, L_2, R_{10}, R_{11}, R_{20} and R_{21}, performance the amplifier 100 could diminish, according to an example curve 206 having a 3 dB bandwidth region 208.

[0006] By comparison, with L_1, L_2, R_{10}, R_{11}, R_{20} and R_{21}: (a) in the region 208, a dominant contribution to the 3 dB bandwidth region 204 is provided by R_{10}, R_{11}, R_{20} and R_{21}; and (b) in a bandwidth expansion region 210, a significant contribution to the 3 dB bandwidth region 204 is provided by L_1 and L_2, in addition to contribution by R_{10}, R_{11}, R_{20} and R_{21}.

[0007] Nevertheless, the amplifier 100 has shortcomings. For example, the amplifier 100 has one passive magnetic component (e.g., inductor) per stage. As a precaution against possible interference through magnetic field coupling (e.g., between coil windings of nearby inductors), a spacing is imposed between those passive magnetic components, which increases silicon area in an integrated circuit that contains the amplifier 100.

SUMMARY

[0008] In described examples of an amplifier, a first stage receives a differential input voltage, which is formed by first and second input voltages, and outputs a first differential current in response thereto on first and second lines having respective first and second line voltages. A second stage receives the first and second line voltages and outputs a second differential current in response thereto on third and fourth lines having respective third and fourth line voltages. A transformer includes first and second coils. A first terminal of the first coil is coupled through a first resistor to the first line. A second terminal of the first coil is coupled through a second resistor to the second line. A first terminal of the second coil is coupled through a third resistor to the third line. A second terminal of the second coil is coupled through a fourth resistor to the fourth line.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. 1 (prior art) is a schematic electrical circuit diagram of a conventional multi-stage amplifier.

[0010] FIG. 2 (prior art) is a graph of an example curve of gain (dB) versus frequency for the amplifier of FIG. 1.

[0011] FIG. 3 is a schematic electrical circuit diagram of a multi-stage amplifier of the example embodiments.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

[0012] FIG. 3 is a schematic electrical circuit diagram of a multi-stage amplifier, indicated generally at 300, of the example embodiments. The amplifier 300 includes at least the first and second stages 102 and 104, and the resistors R_{10}, R_{11}, R_{20} and R_{21}. However, instead of L_1 and L_2 (FIG. 1), the amplifier 300 includes a transformer, indicated by dashed enclosure 302.

[0013] The first and second stages 102 and 104 are transconductance amplifiers whose gains are Gm1 and Gm2, respectively. The first stage 102 applies the gain Gm1 to amplify the difference ("ΔV_{IN}") between V_{IN}+ and V_{IN}–. Similarly, the second stage 104 applies the gain Gm2 to amplify the difference ("ΔV_1") between S_{10}'s voltage ("V_{10}") and S_{11}'s voltage ("V_{11}"). Accordingly: (a) in response to ΔV_{IN}, the first stage 102 generates the difference ("ΔI_1") between S_{10}'s current ("I_{10}") and S_{11}'s current ("I_{11}"); and (b) in response to ΔV_1, the second stage 104 generates the difference ("ΔI_2") between S_{20}'s current ("I_{20}") and S_{21}'s current ("I_{21}").

[0014] In this example: (a) if ΔV_{IN} is positive, then ΔI_1 is negative; and (b) conversely, if ΔV_{IN} is negative, then ΔI_1 is positive. Similarly, in this example: (a) if ΔV_1 is positive, then ΔI_2 is negative; and (b) conversely, if ΔV_1 is negative, then ΔI_2 is positive.

[0015] The transformer 302 includes first and second coils 304 and 306. As shown in FIG. 3: (a) R_{10} is coupled through a first terminal of the coil 304 to V_{DD}; (b) R_{11} is coupled through a second terminal of the coil 304 to V_{DD} (which is coupled to a third terminal of the coil 304); (c) R_{21} is coupled through a first terminal of the coil 306 to V_{DD}; and (d) R_{20} is coupled through a second terminal of the coil 306 to V_{DD} (which is coupled to a third terminal of the coil 306). Current flows: (a) through the coil 304 in a first direction; and (b) through the coil 306 in a second direction that is substantially identical to (e.g., same as) the first direction.

[0016] If the transformer 302 is ideal, lossless and perfectly coupled, then $V_2 = n \bullet V_1$, $I_2 = I_1 / n$, and $P_{IN} = P_{OUT}$, where: (a) V_1 is a voltage across the first and second terminals of the coil 304; (b) V_2 is a voltage across the first and second terminals of the coil 306; (c) I_1 is a current through the coil 304; (d) I_2 is a current through the coil 306; (e) *n* is a winding turns ratio between the coils 304 and 306, so that *n* equals winding turns of the coil 306 divided by winding turns of the coil 304; (f) $V_1 \bullet I_1 = P_{IN}$, which is input power of the transformer 302; and (g) $V_2 \bullet I_2 = P_{OUT}$, which is output power of the transformer 302.

[0017] The coil 304 provides passive impedance boost to the output lines S_{10} and S_{11} of the stage 102. Similarly, the coil 306 provides passive impedance boost to the output lines S_{20} and S_{21} of the stage 104. Also, due to coupling between the coils 304 and 306: (a) the coil 304 provides active feedback to the output lines S_{20} and S_{21} of the stage 104; and (b) the coil 306 provides active feedback to the output lines S_{10} and S_{11} of the stage 102. Such active feedback reduces cost and size of the transformer 302.

[0018] Moreover, the stages 102 and 104 can be spaced more closely to one another, which reduces silicon area in an integrated circuit that contains the amplifier 300. For example, the amplifier 300 includes one transformer (e.g., the transformer 302) per two stages (e.g., the stages

102 and 104), instead of one passive magnetic component per stage. Also, instead of avoiding magnetic field coupling, the transformer 302 contains a magnetic field with controlled H-field coupling between the coils 304 and 306. Such containment reduces proliferation (adulteration) between nearby circuitry (e.g., nearby magnetic devices).

[0019] For these various reasons, 3 dB bandwidth of the amplifier 300 is expanded. For this purpose of bandwidth expansion, the quality factor ("QF") of the transformer 302 is not required to be high. Accordingly, the amplifier 300 can have a reduced form factor.

[0020] Modifications are possible in the described embodiments, and other embodiments are possible, within the scope of the claims.

CLAIMS

What is claimed is:

1. An amplifier, comprising:

a first stage for receiving a differential input voltage, which is formed by first and second input voltages, and outputting a first differential current in response thereto on first and second lines having respective first and second line voltages;

a second stage coupled to the first stage for receiving the first and second line voltages and outputting a second differential current in response thereto on third and fourth lines having respective third and fourth line voltages; and

a transformer coupled to the first and second stages, wherein the transformer includes first and second coils, wherein a first terminal of the first coil is coupled through a first resistor to the first line, wherein a second terminal of the first coil is coupled through a second resistor to the second line, wherein a first terminal of the second coil is coupled through a third resistor to the third line, and wherein a second terminal of the second coil is coupled through a fourth resistor to the fourth line.

2. The amplifier of claim 1, wherein a voltage supply node is coupled to: a third terminal of the first coil; and a third terminal of the second coil.

3. The amplifier of claim 1, wherein the first and second stages are first and second transconductance amplifiers having first and second gains, respectively.

4. The amplifier of claim 1, wherein the first coil is for conducting current in a first direction, and wherein the second coil is for conducting current in a second direction that is substantially identical to the first direction.

5. The amplifier of claim 1, wherein the first coil is for providing passive impedance boost to the first and second lines, and wherein the second coil is for providing passive impedance boost to the third and fourth lines.

6. The amplifier of claim 1, wherein the first coil is for providing active feedback to the third and fourth lines, and wherein the second coil is for providing active feedback to the first and second lines.

7. The amplifier of claim 1, wherein the transformer is for containing a magnetic field with controlled H-field coupling between the first and second coils.

8. An amplifier, comprising:

a first stage for receiving a differential input voltage, which is formed by first and second input voltages, and outputting a first differential current in response thereto on first and second lines having respective first and second line voltages, wherein the first stage is a first transconductance amplifier having a first gain;

a second stage coupled to the first stage for receiving the first and second line voltages and outputting a second differential current in response thereto on third and fourth lines having respective third and fourth line voltages, wherein the second stage is a second transconductance amplifier having a second gain; and

a transformer coupled to the first and second stages, wherein the transformer includes first and second coils, wherein a first terminal of the first coil is coupled through a first resistor to the first line, wherein a second terminal of the first coil is coupled through a second resistor to the second line, wherein a first terminal of the second coil is coupled through a third resistor to the third line, wherein a second terminal of the second coil is coupled through a fourth resistor to the fourth line, wherein the first coil is for conducting current in a first direction, and wherein the second coil is for conducting current in a second direction that is substantially identical to the first direction;

wherein a voltage supply node is coupled to: a third terminal of the first coil; and a third terminal of the second coil.

9. The amplifier of claim 8, wherein the first coil is for providing passive impedance boost to the first and second lines and providing active feedback to the third and fourth lines, and wherein the second coil is for providing passive impedance boost to the third and fourth lines and providing active feedback to the first and second lines.

10. The amplifier of claim 9, wherein the transformer is for containing a magnetic field with controlled H-field coupling between the first and second coils.

11. A method, comprising:

with a first stage of an amplifier, receiving a differential input voltage, which is formed by first and second input voltages, and outputting a first differential current in response thereto on first and second lines having respective first and second line voltages;

with a second stage of the amplifier, receiving the first and second line voltages and outputting a second differential current in response thereto on third and fourth lines having respective third and fourth line voltages; and

coupling: a first terminal of a first coil of a transformer through a first resistor to the first line; a second terminal of the first coil through a second resistor to the second line; a first terminal of a second coil of the transformer through a third resistor to the third line; and a second terminal of the second coil through a fourth resistor to the fourth line.

12. The method of claim 11, wherein the coupling includes:

coupling a voltage supply node to: a third terminal of the first coil; and a third terminal of the second coil.

13. The method of claim 11, wherein the first and second stages are first and second transconductance amplifiers having first and second gains, respectively.

14. The method of claim 11, and comprising: through the first coil, conducting current in a first direction; and, through the second coil, conducting current in a second direction that is substantially identical to the first direction.

15. The method of claim 11, and comprising: with the first coil, providing passive impedance boost to the first and second lines; and, with the second coil, providing passive impedance boost to the third and fourth lines.

16. The method of claim 11, and comprising: with the first coil, providing active feedback to the third and fourth lines; and, with the second coil, providing active feedback to the first and second lines.

17. The method of claim 11, and comprising: with the transformer, containing a magnetic field with controlled H-field coupling between the first and second coils.

18. A method, comprising:

with a first stage of an amplifier, receiving a differential input voltage, which is formed by first and second input voltages, and outputting a first differential current in response thereto on first and second lines having respective first and second line voltages, wherein the first stage is a first transconductance amplifier having a first gain;

with a second stage of the amplifier, receiving the first and second line voltages and outputting a second differential current in response thereto on third and fourth lines having respective third and fourth line voltages, wherein the second stage is a second transconductance amplifier having a second gain;

coupling: a first terminal of a first coil of a transformer through a first resistor to the first line; a second terminal of the first coil through a second resistor to the second line; a first terminal of a second coil of the transformer through a third resistor to the third line; and a second terminal of the second coil through a fourth resistor to the fourth line;

through the first coil, conducting current in a first direction;

through the second coil, conducting current in a second direction that is substantially identical to the first direction; and

coupling a voltage supply node to: a third terminal of the first coil; and a third terminal of the second coil.

19. The method of claim 18, and comprising:

with the first coil, providing passive impedance boost to the first and second lines, and providing active feedback to the third and fourth lines; and

with the second coil, providing passive impedance boost to the third and fourth lines, and providing active feedback to the first and second lines.

20. The method of claim 19, and comprising: with the transformer, containing a magnetic field with controlled H-field coupling between the first and second coils.

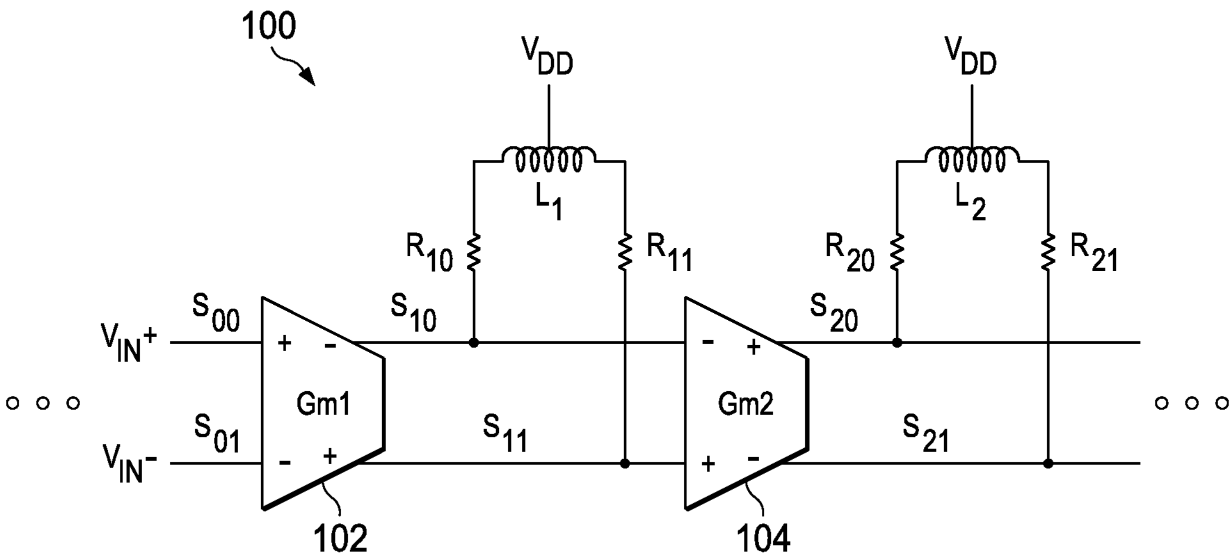

FIG. 1
(PRIOR ART)

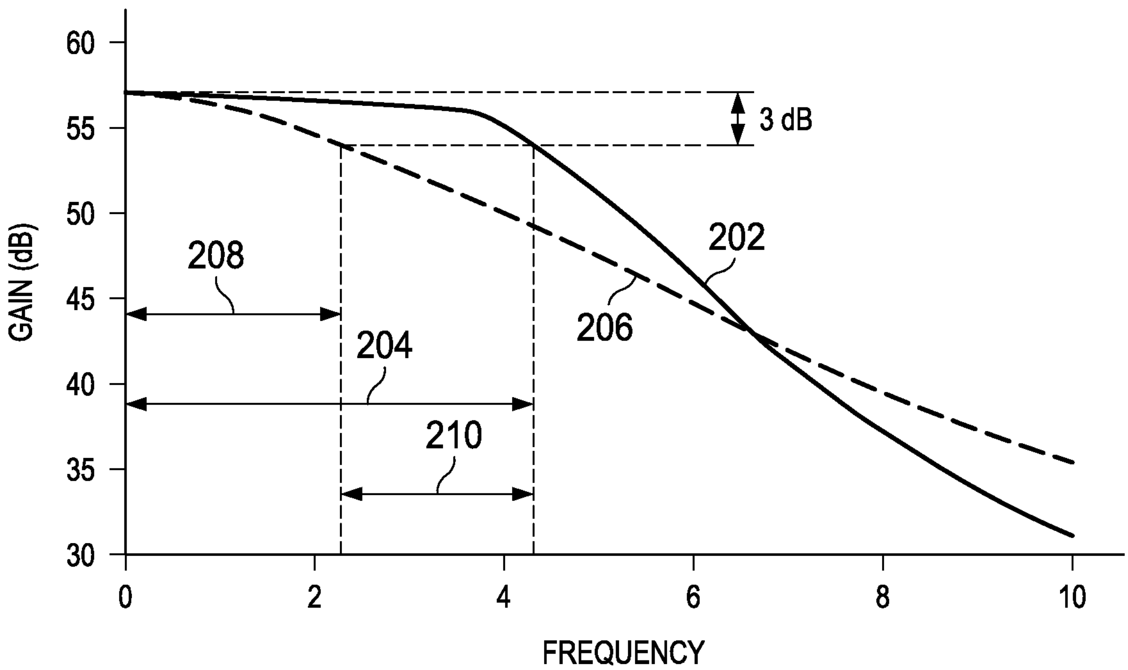

FIG. 2
(PRIOR ART)

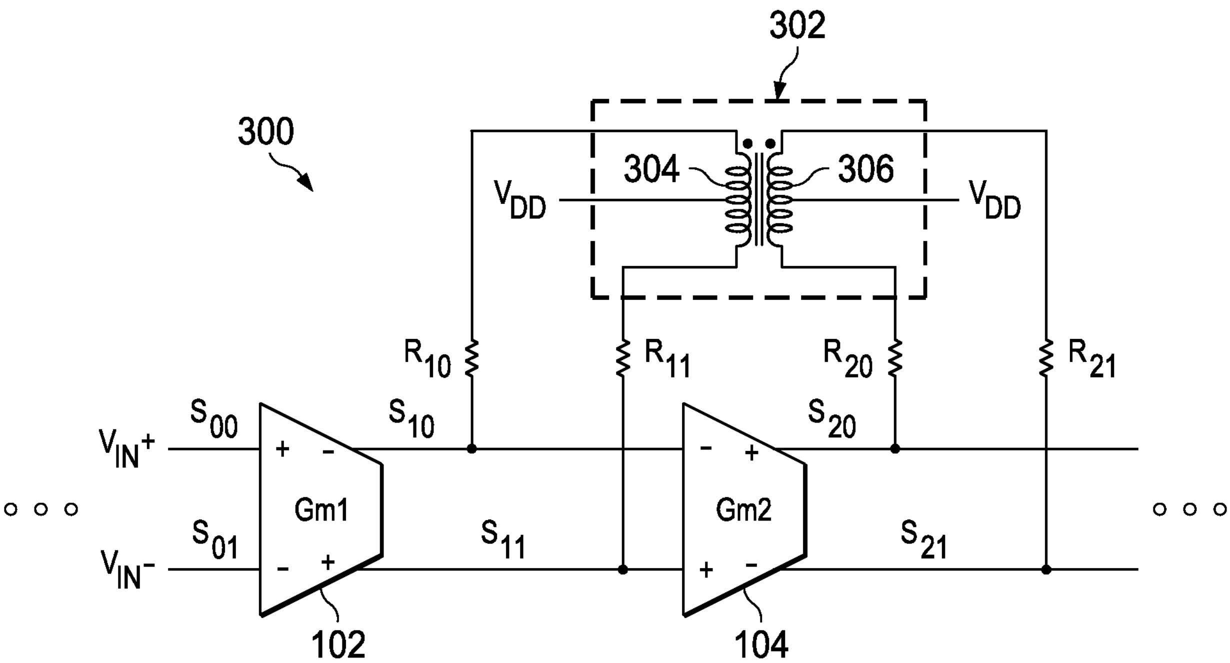
302
300
304
306
V_{DD}
V_{DD}
R_{10}
R_{11}
R_{20}
R_{21}
S_{00}
S_{10}
S_{20}
$V_{IN}+$
S_{01}
S_{11}
S_{21}
$V_{IN}-$
Gm1
Gm2
102
104

FIG. 3