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(54) **TRANSFORMER STRUCTURE**

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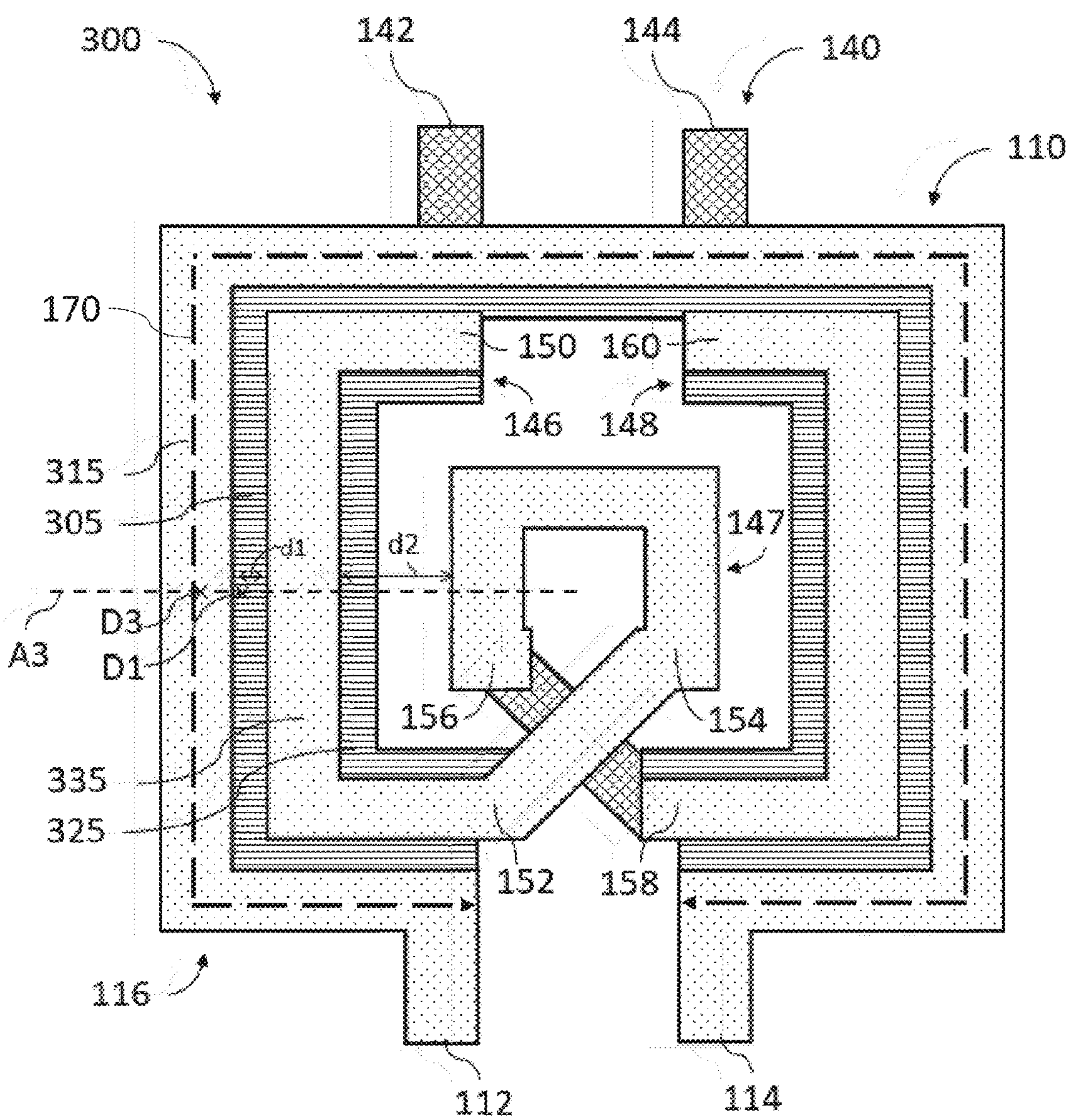
(57) **ABSTRACT**

A transformer is provided. An example transformer comprises two inductors. The first inductor comprising a loop comprising conductive tracks in first and second levels of the structure, the conductive tracks being adapted to being electrically connected to each other directly, or via an intermediate conductive track, over at least half the length of the loop. Over at least half the length of the loop, the conductive tracks are arranged so that, in a cross-section view perpendicular to the length of the first loop, the center of mass of the first conductive track is laterally offset from the center of mass of the second conductive track in the cross-section plane, and in a direction parallel to the plane formed by the first level.



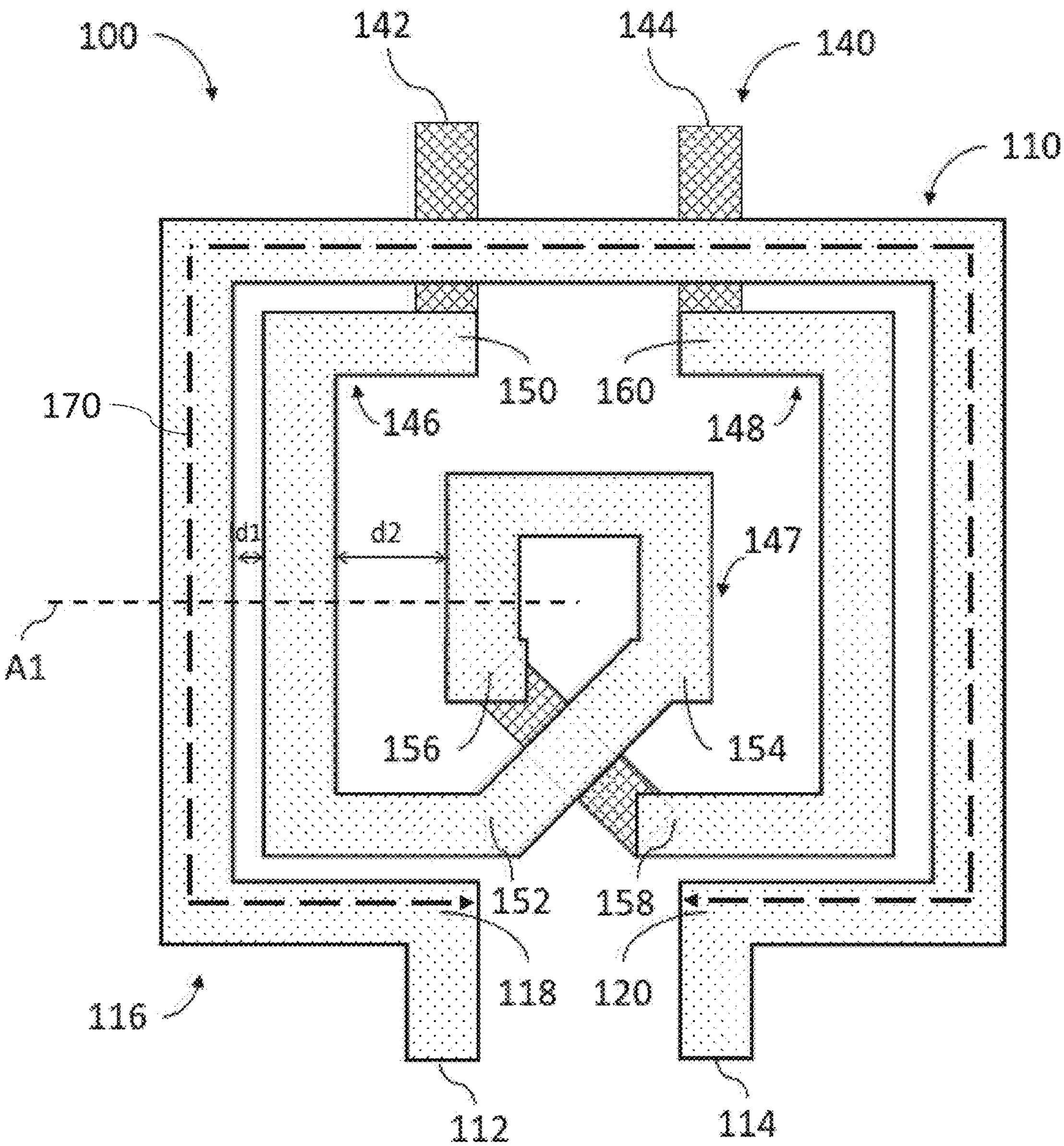

100
142
144
140
110
170
150
160
146
148
147
d1
d2
A1
156
154
152
158
118
120
116
112
114

FIG 1

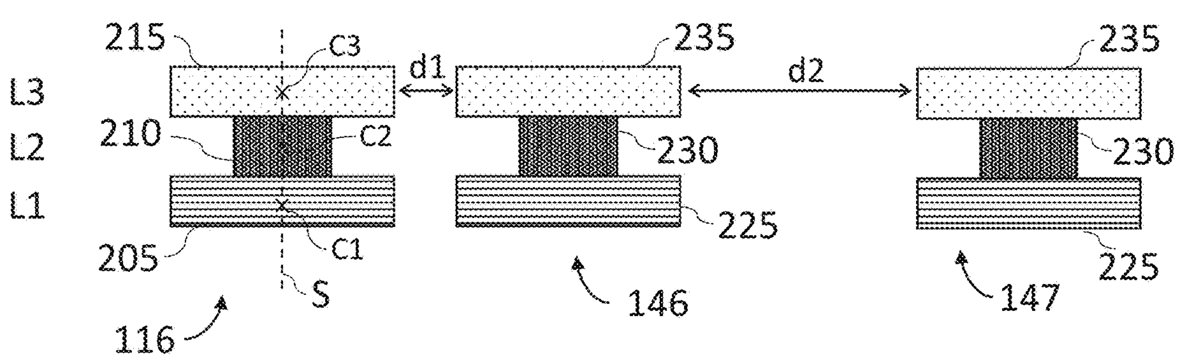

215
C3
d1
235
d2
235
L3
L2
L1
210
C2
230
230
225
225
205
C1
S
146
147
116

FIG 2

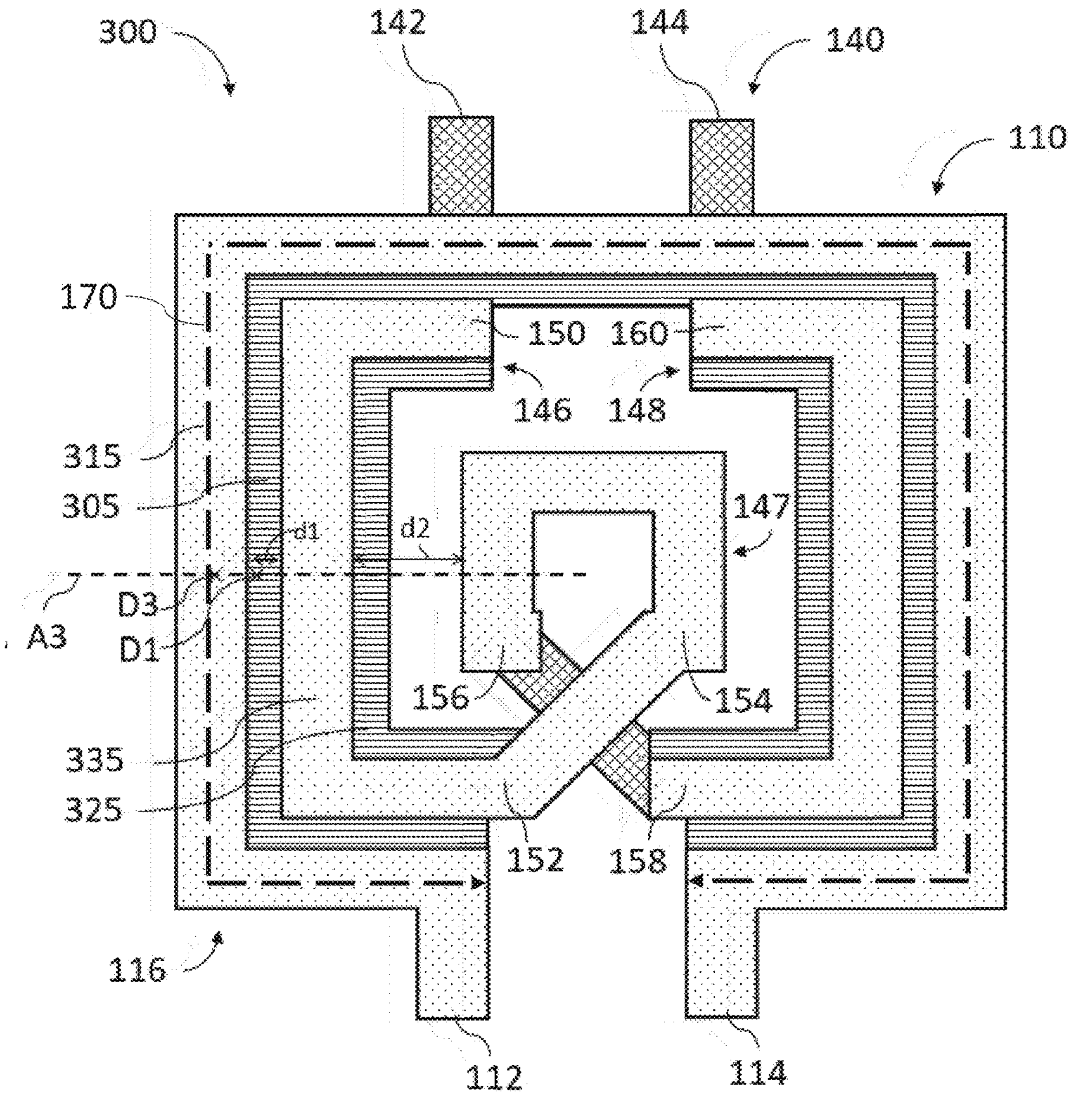

300
142
144
140
110
170
150
160
146
148
315
305
147
d1
d2
D3
A3
D1
156
154
335
325
152
158
116
112
114

FIG 3

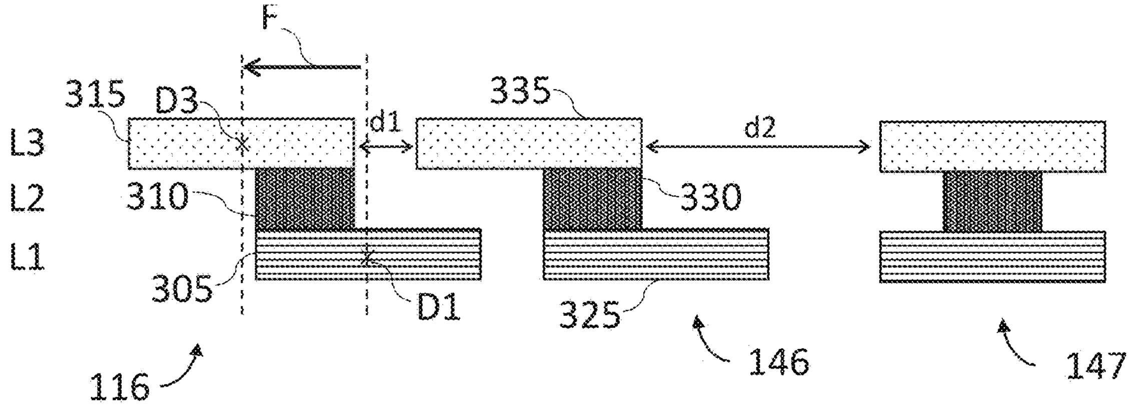

F
315
D3
d1
335
d2
L3
L2
310
330
L1
305
D1
325
116
146
147

FIG 4

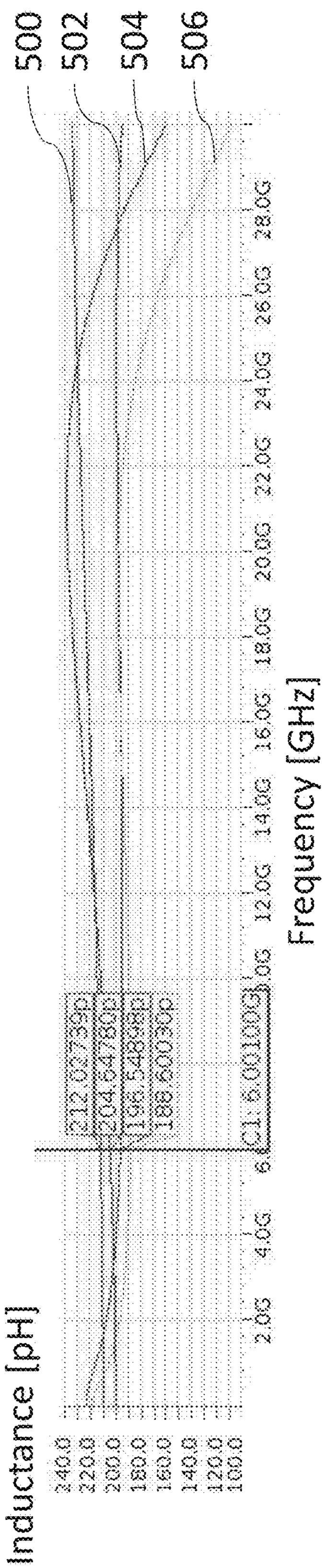


FIG 5A

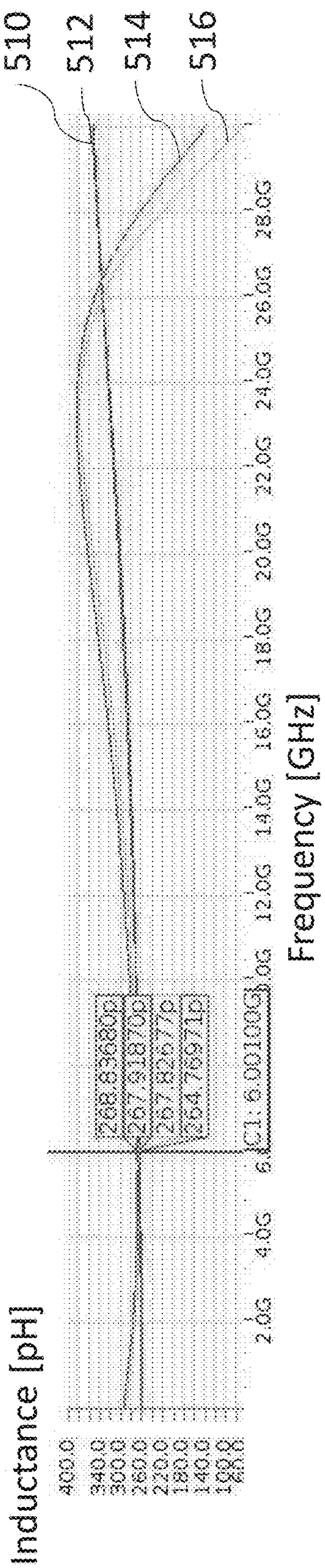


FIG 5B

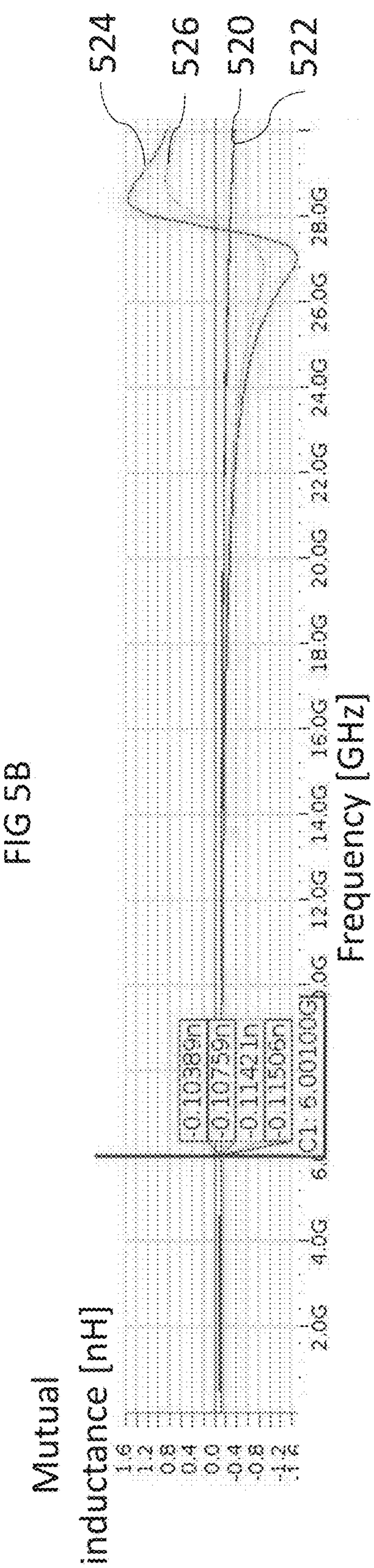


FIG 5C

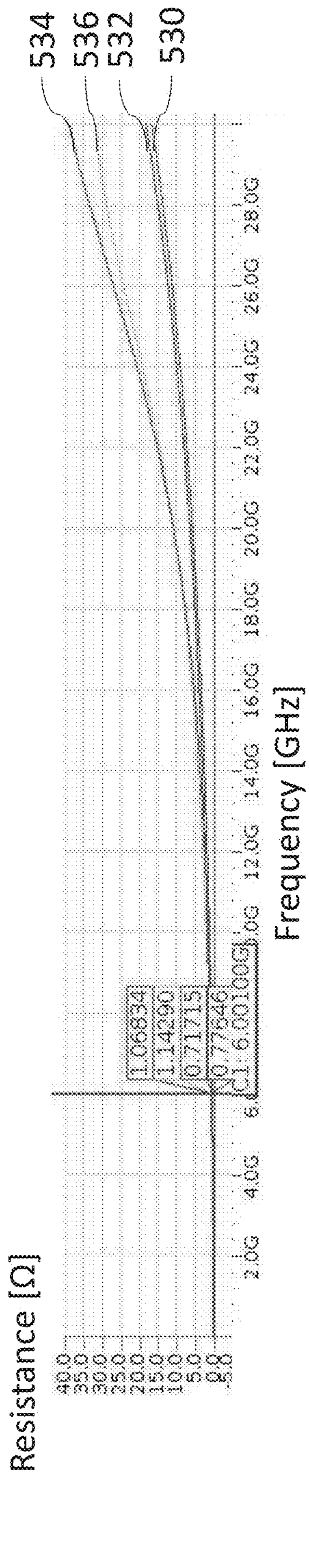

534
536
532
530
Resistance [Ω]
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
-5.0
2.0G
4.0G
12.0G
14.0G
16.0G
18.0G
20.0G
22.0G
24.0G
26.0G
28.0G
1.06834
1.14290
0.71715
0.77646
C1 6.00100G
Frequency [GHz]

FIG 5D

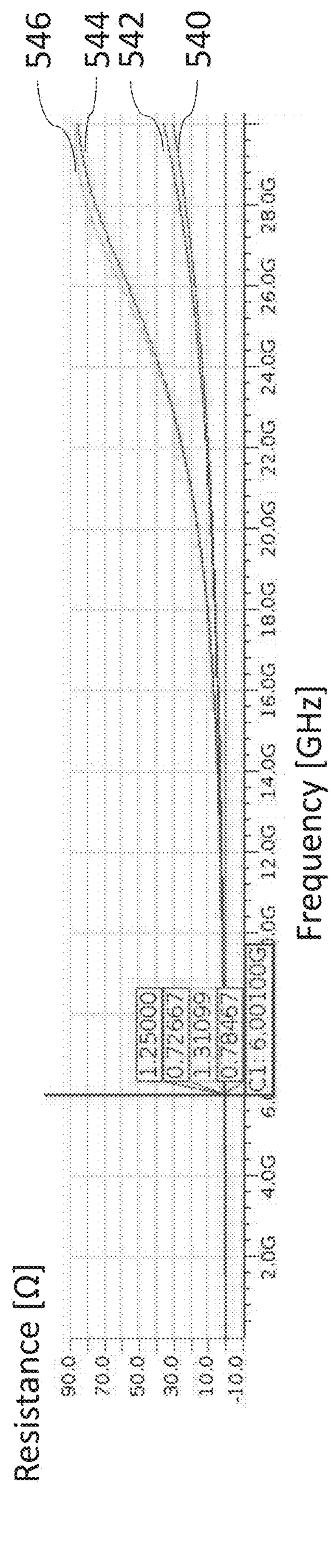

546
544
542
540
Resistance [Ω]
90.0
70.0
50.0
30.0
10.0
-10.0
2.0G
4.0G
12.0G
14.0G
16.0G
18.0G
20.0G
22.0G
24.0G
26.0G
28.0G
1.25000
0.72667
1.31099
0.78467
C1 6.00100G
Frequency [GHz]

FIG 5E

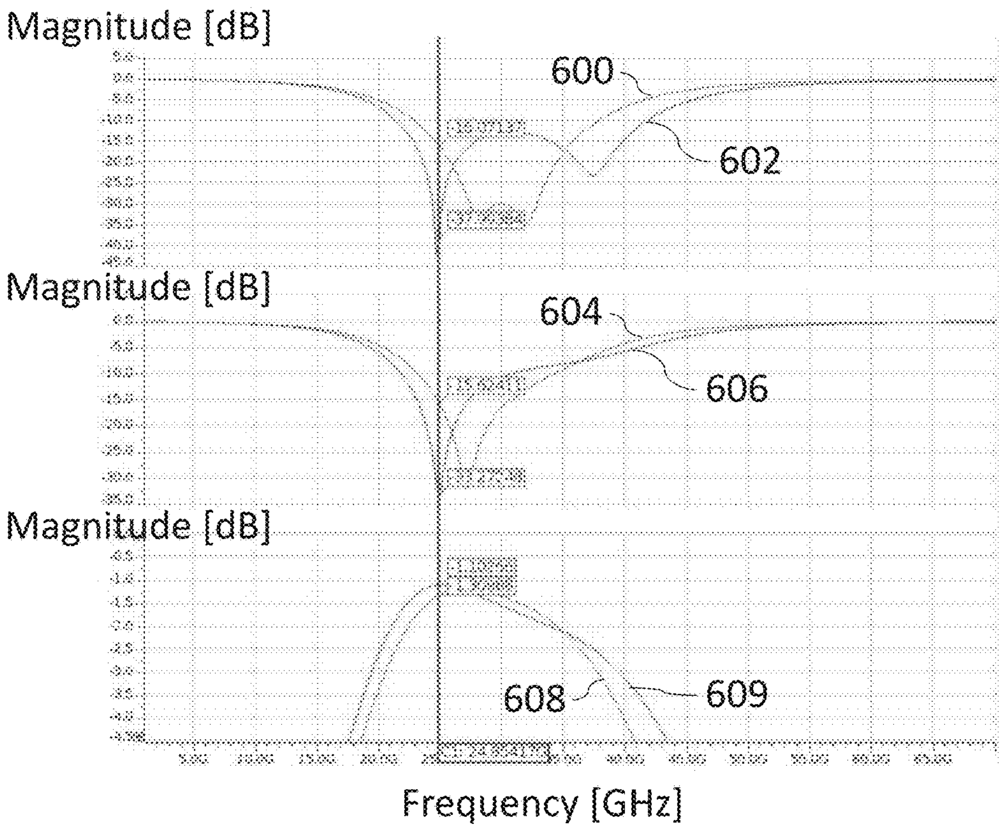

Magnitude [dB]
600
602
Magnitude [dB]
604
606
Magnitude [dB]
608
609
Frequency [GHz]

FIG 6A

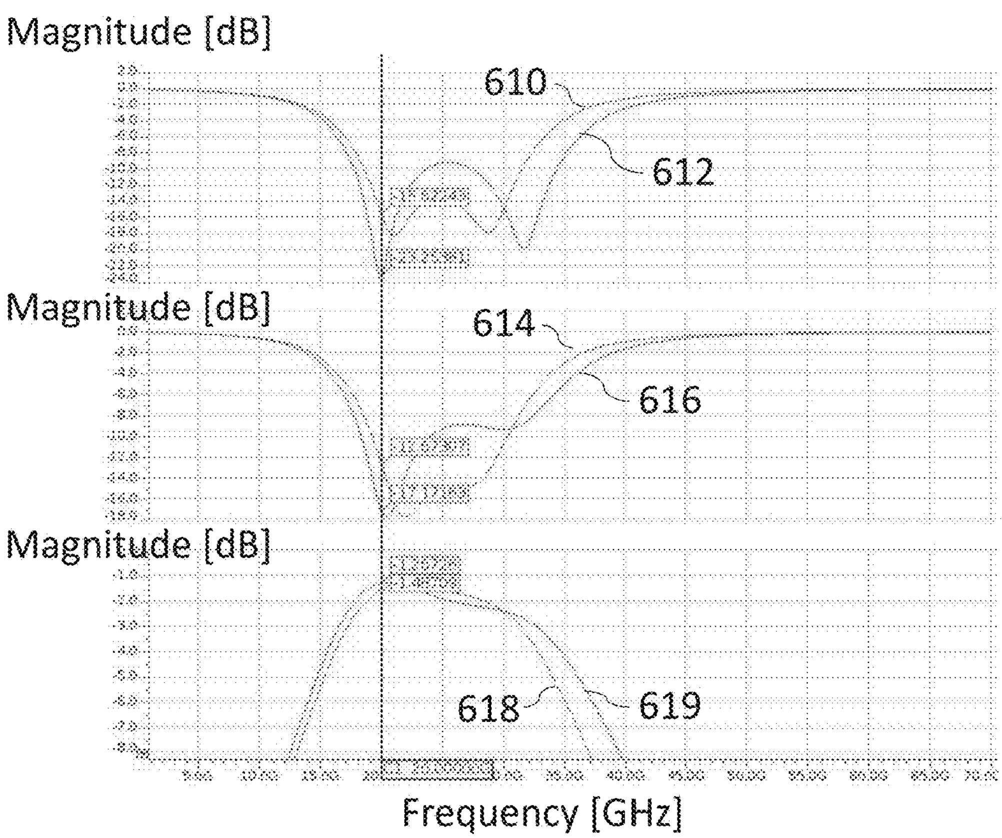

Magnitude [dB]
610
612
Magnitude [dB]
614
616
Magnitude [dB]
618
619
Frequency [GHz]

FIG 6B

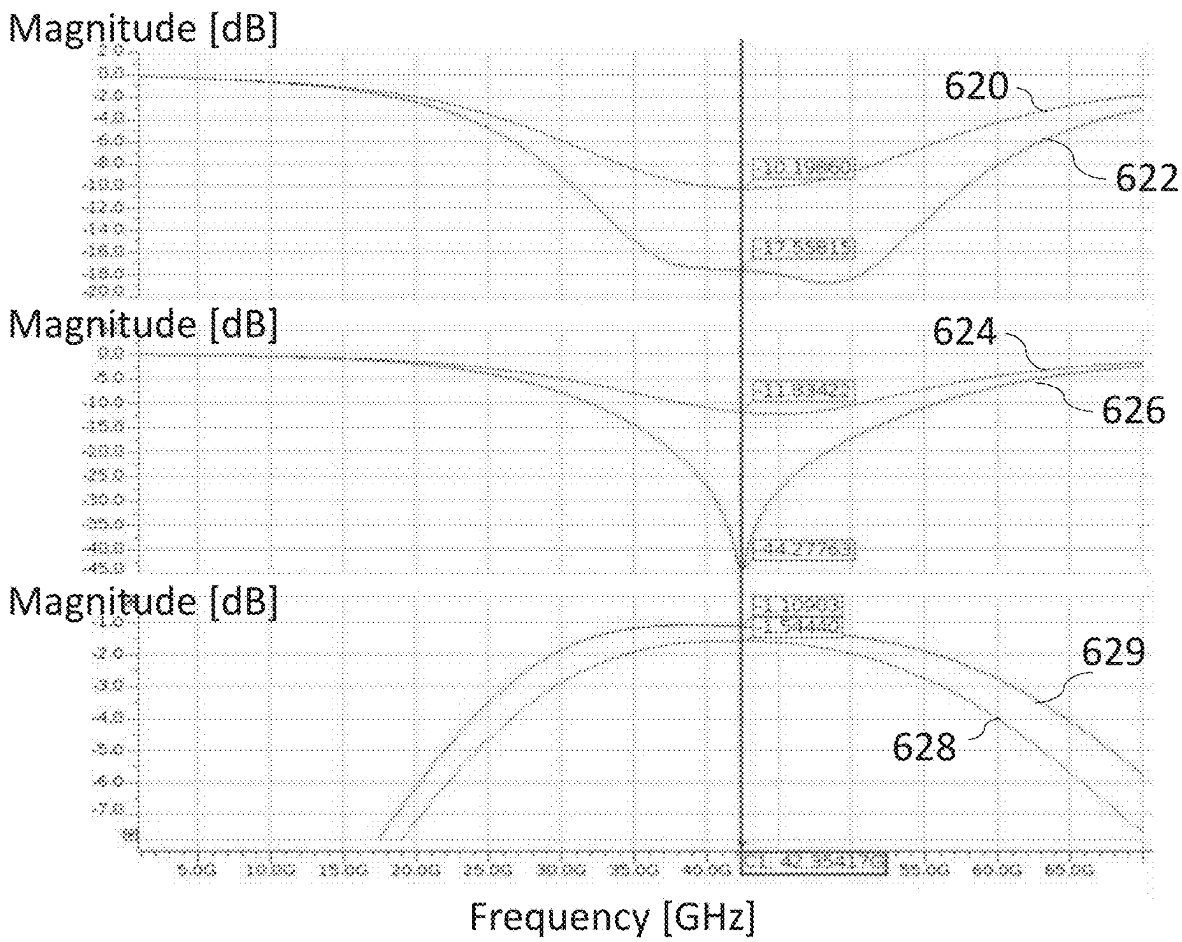

Magnitude [dB]
620
622
Magnitude [dB]
624
626
Magnitude [dB]
629
628
Frequency [GHz]

FIG 6C

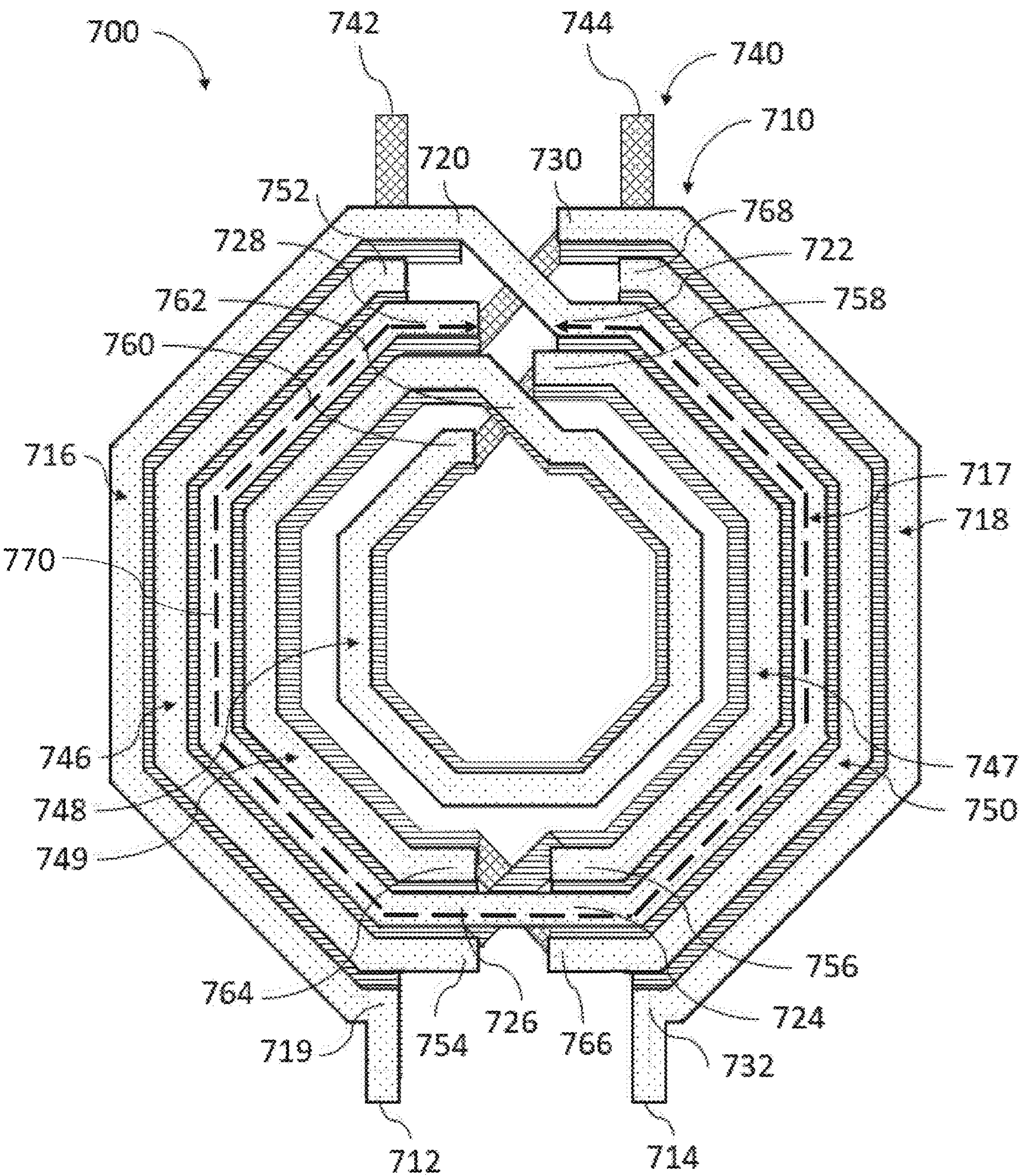

700
742
744
740
710
720
730
752
768
728
722
762
758
760
716
717
718
770
746
747
748
750
749
756
764
724
719
754
726
766
732
712
714

FIG 7A

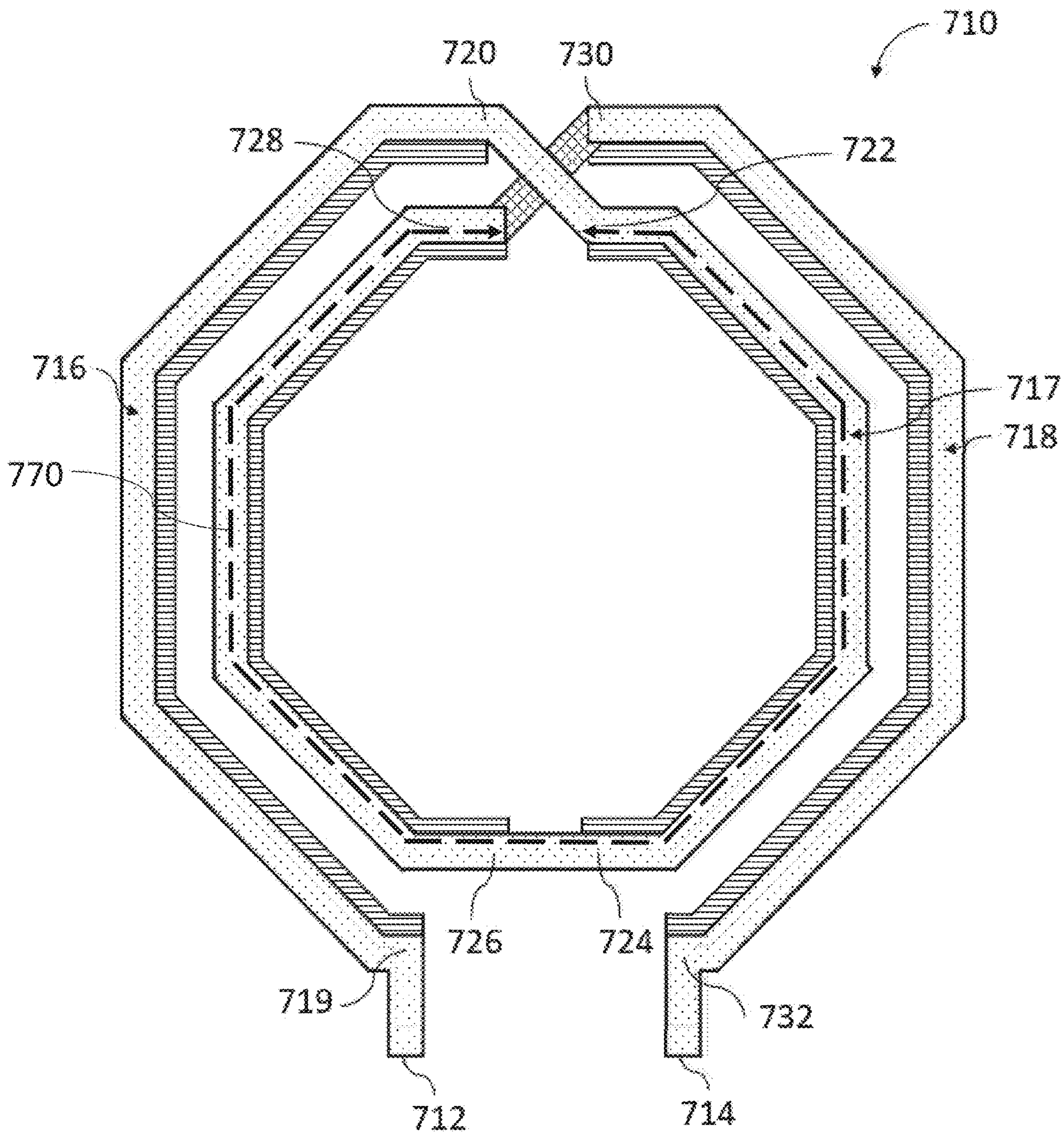


FIG 7B

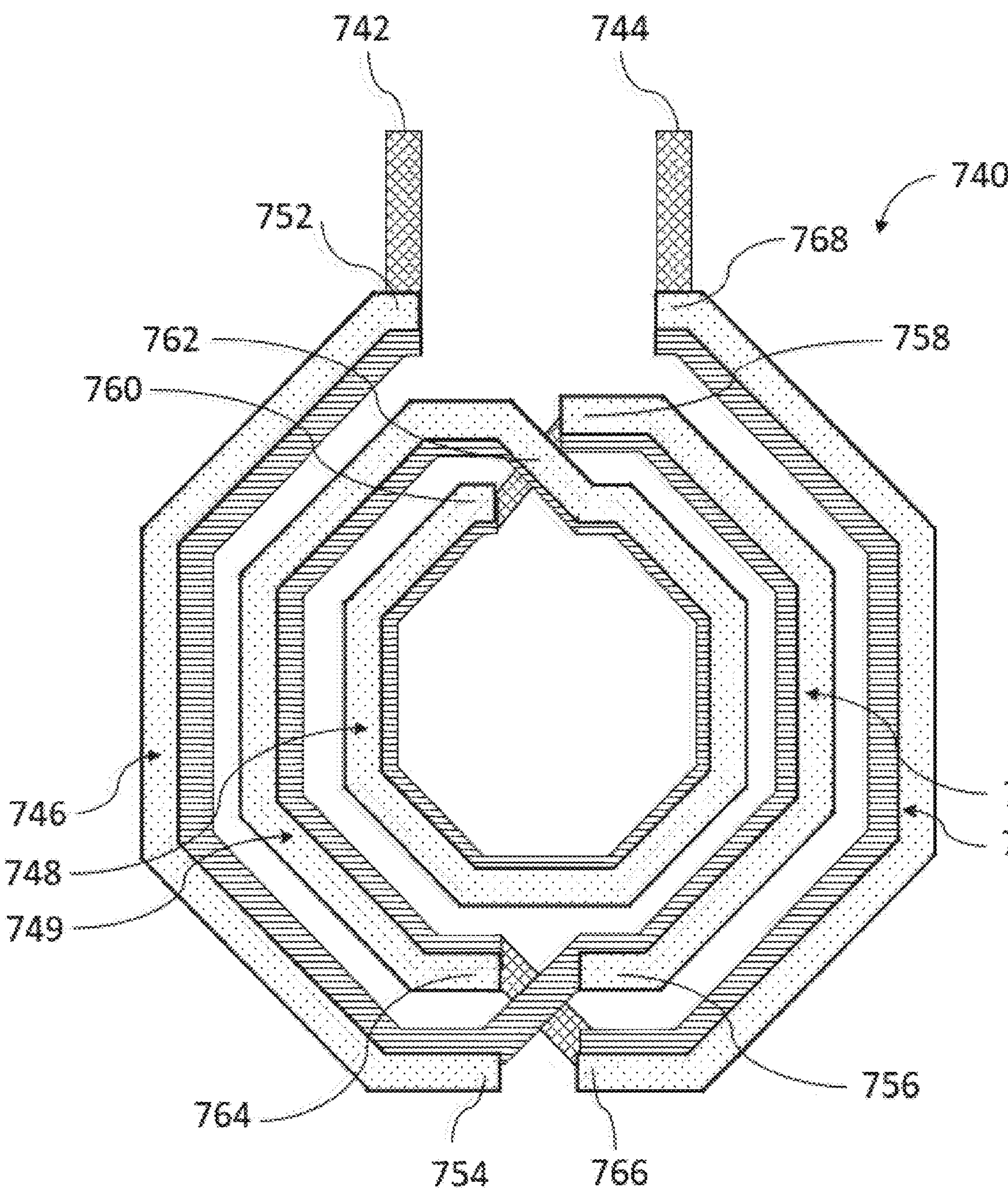

742
744
740
752
768
762
758
760
747
746
750
748
749
756
764
754
766

FIG 7C

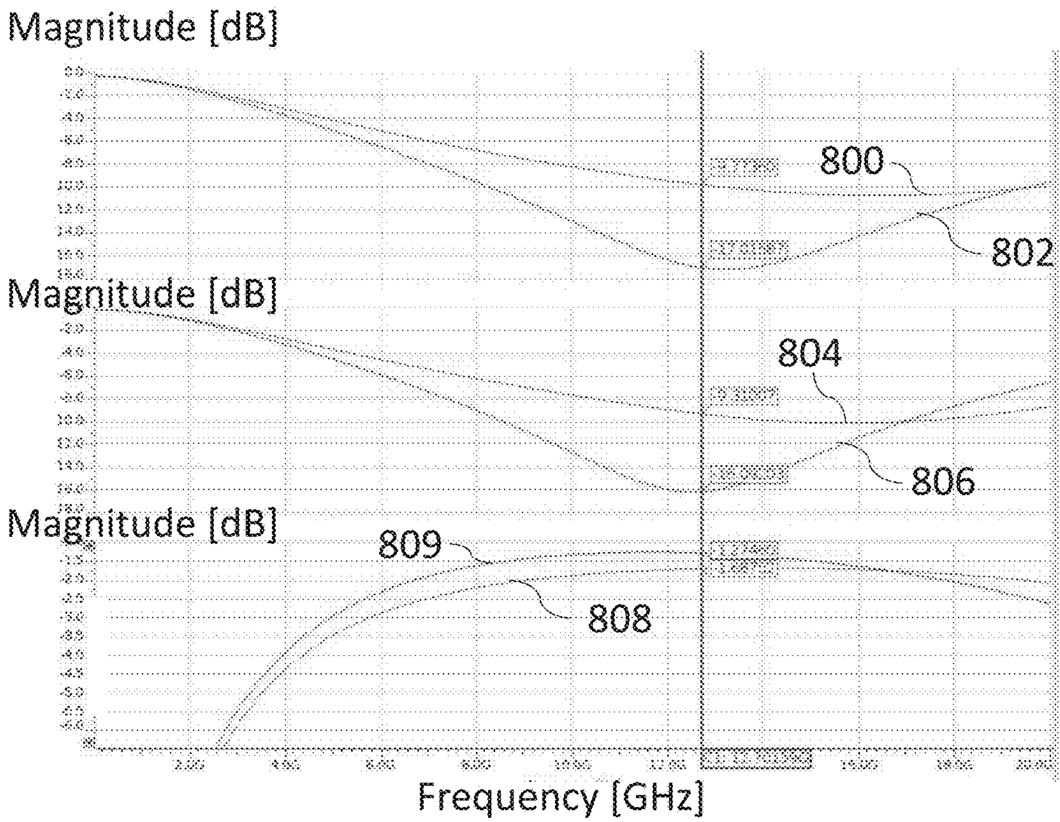

Magnitude [dB]
800
802
Magnitude [dB]
804
806
Magnitude [dB]
809
808
Frequency [GHz]

FIG 8A

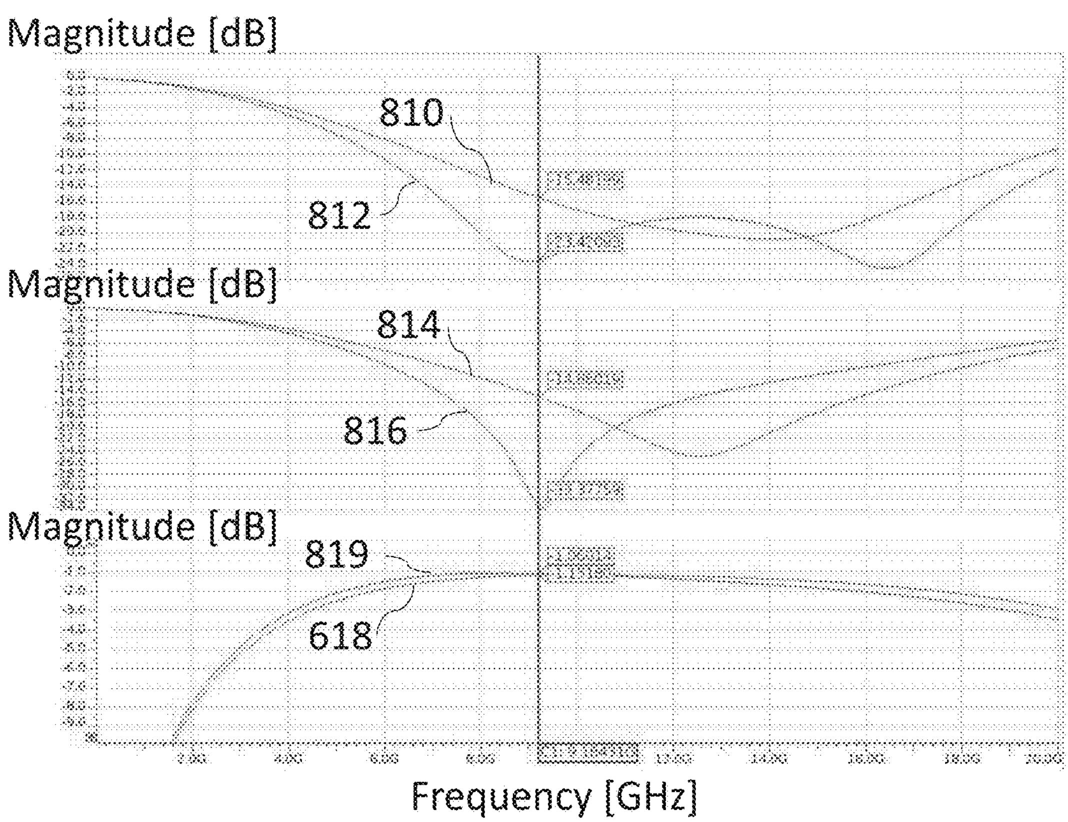

Magnitude [dB]
810
812
Magnitude [dB]
814
816
Magnitude [dB]
819
618
Frequency [GHz]

FIG 8B

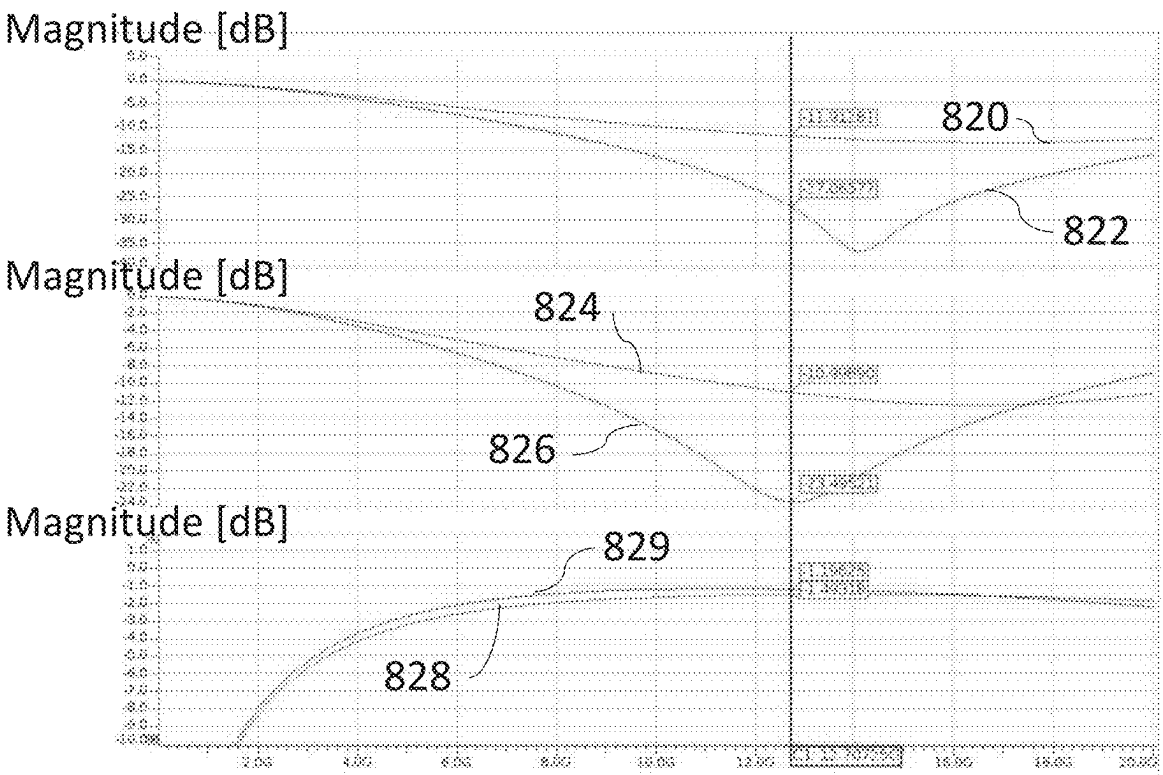


FIG 8C
Frequency [GHz]

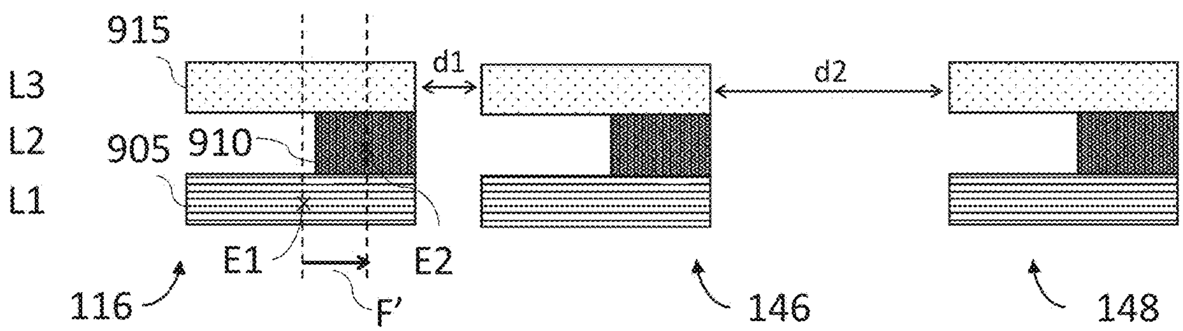


FIG 9

TRANSFORMER STRUCTURE

CROSS REFERENCE TO RELATED APPLICATION(S)

[0001] This application claims the priority benefit of French patent application number FR2401615, filed on Feb. 19, 2024, entitled "Structure d'un Transformateur", which is hereby incorporated by reference to the maximum extent allowable by law.

TECHNICAL FIELD

[0002] The present disclosure generally concerns transformers and transformer manufacturing methods.

BACKGROUND

[0003] A transformer generally comprises two magnetically-coupled inductors, and transfers power from one inductor to the other. Transformers can be used for a variety of applications, such as to perform power adaptation or convert differential signals to common mode and vice versa, as the name suggests, with a balun ("balanced-unbalanced"). In particular, an impedance transformer is an electronic component aiming at modifying the impedance between two terminals of an electronic circuit. There exists a need for transformers with a higher performance and/or operational over a wider frequency range and/or with better capacitive coupling between inductances.

BRIEF SUMMARY

[0004] An embodiment provides a transformer comprising, in a laminated structure, a first inductor and a second inductor, the first inductor comprising:

- [0005] a first loop comprising a first conductive track in a first level of the structure and a second conductive track in a second level of the structure, the first and second conductive tracks being adapted to being electrically connected to each other directly, or by an intermediate conductive track, over at least half the length of the first loop;

wherein, over at least half the length of the first loop, the first and second conductive tracks are arranged so that, in a cross-section view perpendicular to the length of the first loop, the center of mass of the first conductive track is laterally offset from the center of mass of the second conductive track in the cross-section plane, and in a direction parallel to the plane formed by the first level.

[0006] According to an embodiment, the first and second conductive tracks are connected together by the intermediate conductive track, the intermediate conductive track comprising one or a plurality of vias.

[0007] According to an embodiment, the first loop further comprises a third conductive track electrically connected to the second conductive track over at least half the length of the first loop, wherein the second conductive track comprises one or a plurality of vias coupling the first conductive track to the third conductive track.

[0008] According to an embodiment, the second inductor comprises a first loop comprising a fourth conductive track in the first level of the structure and a fifth conductive track in the second level of the structure.

[0009] According to an embodiment, the first conductive track of the first loop of the first inductor in the first level at least partially faces the fifth track of the first loop of the second inductor in the second level.

[0010] Another embodiment provides a method of manufacturing a transformer comprising, in a laminated structure, a first inductor and a second inductor, the method comprising:

- [0011] the forming, in a first level of the structure, of a first conductive track of a first loop of a first inductor;
- [0012] the forming, in a second level of the structure, of a second conductive track of the first loop, the first and second conductive tracks being adapted to being electrically connected to each other directly, or via an intermediate conductive track, over at least half the length of the first loop;

wherein, over at least half the length of the first loop, the first and second conductive tracks are arranged in such a way that, in a cross-section view perpendicular to the length of the first loop, the center of mass of the first conductive track is laterally offset from the center of mass of the second conductive track in the cross-section plane, and in a direction parallel to the plane formed by the first level.

[0013] According to an embodiment, the first and second conductive tracks to each are connected other by the intermediate conductive track, the method further comprising, after the forming of the first conductive track and before the forming of the second conductive track, the forming of at least one via forming the intermediate conductive track on the first conductive track, the second conductive track being formed on the at least one via so that the first and second conductive tracks are electrically connected to each other via the at least one via.

[0014] According to an embodiment, the second conductive track comprises one or a plurality of vias, the method further comprising, after the forming of the second conductive track, the forming of a third conductive track on the second conductive track, the third conductive track being electrically connected to the second conductive track over at least half the length of the first loop.

[0015] According to an embodiment, the method further comprises:

- [0016] the forming, in the first level of the structure, of a fourth conductive track of a first loop of the second inductor;
- [0017] the forming, in the second level of the structure, of a fifth conductive track of the first loop of the second inductor.

[0018] According to an embodiment, the fifth track of the first loop in the second level is shaped so that the first conductive track of the first loop in the first level at least partially faces the fifth track of the first loop in the second level.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] The foregoing features and advantages, as well as others, will be described in detail in the rest of the disclosure of specific embodiments given as an illustration and not limitation with reference to the accompanying drawings, in which:

[0020] FIG. **1** is a top view of a transformer comprising two inductors;

[0021] FIG. **2** is a partial cross-section view of the transformer of FIG. **1**;

[0022] FIG. **3** is a top view of a transformer according to an embodiment of the present disclosure;

[0023] FIG. **4** is a partial cross-section view of the transformer of FIG. **3**, according to an embodiment of the present disclosure;

[0024] FIG. **5**A is a graph showing the value of the first inductor of the transformer of FIGS. **1** and **3** as a function of the operating frequency of the transformer;

[0025] FIG. **5**B is a graph showing the value of the second inductance of the transformer of FIGS. **1** and **3** as a function of the operating frequency of the transformer;

[0026] FIG. **5**C is a graph showing the value of the mutual coupling parameter between the two inductances s of the transformer of FIGS. **1** and **3** as a function of the operating frequency of the transformer;

[0027] FIG. **5**D is a graph showing the series resistance of the first inductance of the transformer of FIGS. **1** and **3** as a function of the operating frequency of the transformer;

[0028] FIG. **5**E is a graph showing the series resistance of the second inductance of the transformer of FIGS. **1** and **3** as a function of the operating frequency of the transformer;

[0029] FIG. **6**A is a graph showing scattering parameters for the input, output, and transmission adaptation of the signal by the transformers of FIGS. **1** and **3** at a 25-GHz frequency;

[0030] FIG. **6**B is a graph showing scattering parameters for the signal input, output, and transmission adaptation by the transformers of FIGS. **1** and **3** at a 20-GHz frequency;

[0031] FIG. **6**C is a graph showing scattering parameters for the input, output, and transmission adaptation of the signal by the transformers of FIGS. **1** and **3** at a 42-GHz frequency;

[0032] FIG. **7**A is a top view of an example of a transformer according to an embodiment of the present disclosure;

[0033] FIG. **7**B and FIG. **7**C are top views of a first and of a second inductor of the transformer of FIG. **7**A;

[0034] FIG. **8**A is a graph showing scattering parameters for the input, output, and transmission adaptation of the signal by the transformers of FIGS. **1** and **3** at a 12-GHz frequency;

[0035] FIG. **8**B is a graph showing scattering parameters for the input, output, and transmission of the signal by the transformers of FIGS. **1** and **3** at a 9-GHz frequency;

[0036] FIG. **8**C is a graph showing scattering parameters for the input, output, and transmission adaptation of the signal by the transformers of FIGS. **1** and **3** at a 13-GHz frequency; and

[0037] FIG. **9** is a partial cross-section view of the transformer of FIG. **1**, according to another example than that of FIG. **2** and according to an embodiment of the present disclosure.

DETAILED DESCRIPTION

[0038] Like features have been designated by like references in the various figures. In particular, the structural and/or functional features that are common among the various embodiments may have the same references and may dispose identical structural, dimensional and material properties.

[0039] For clarity, only those steps and elements which are useful to the understanding of the described embodiments have been shown and are described in detail.

[0040] Unless indicated otherwise, when reference is made to two elements connected together, this signifies a direct connection without any intermediate elements other than conductors, and when reference is made to two elements coupled together, this signifies that these two elements can be connected or they can be coupled via one or more other elements.

[0041] In the following description, where reference is made to absolute position qualifiers, such as "front", "back", "top", "bottom", "left", "right", etc., or relative position qualifiers, such as "top", "bottom", "upper", "lower", etc., or orientation qualifiers, such as "horizontal", "vertical", etc., reference is made unless otherwise specified to the orientation of the drawings.

[0042] Unless specified otherwise, the expressions "about", "approximately", "substantially", and "in the order of" signify plus or minus 10%, preferably of plus or minus 5%.

[0043] In the rest of the disclosure, transformers formed in a laminated structure are considered. By "laminated structure", there is meant a stack of insulating and conductive levels coating a substrate. There is here called "conductive level" a set of conductive tracks defined in a same layer of a conductive material, for example a metal, for example copper.

[0044] FIG. **1** is a top view of an example of a transformer **100** comprising two inductors **110**, **140**. For example, transformer **100** is used as a balun and power adapter: a common-mode signal is for example transformed into a differential-mode signal, the input impedance is for example adapted to 50 Ohms, the output impedance is for example adapted to 100 Ohms.

[0045] According to an embodiment, the first inductor **110** is connected to a first external electronic circuit (not shown in FIG. **1**) and the second inductor **140** is connected to a second external electronic circuit (also not shown in FIG. **1**).

[0046] Inductor **110** comprises two connection terminals, for example an input/output terminal **112** and an input/output terminal **114**. Inductor **110**, as shown in the example of FIG. **1**, comprises a loop **116**, that is, one or a plurality of conductive tracks coupled together and comprising a full circle, coupling a first end **118** to a second end **120**. The first end **118** is for example coupled to connection terminal **112**, and the second end **120** is for example coupled to connection terminal **114**.

[0047] Inductor **140** comprises two connection terminals, for example an input/output terminal **142** and an input/output terminal **144**. Inductor **140**, as shown in the example in FIG. **1**, comprises two loops: a first loop formed by the two half-loops **146** and **148**, and a second loop **147**. The first half-loop **146** of the first loop couples an end **150** to an end **152**. End **150** is for example coupled to connection terminal **142**. The second loop **147** couples an end **154** to an end **156**. End **154** is for example coupled to end **152** via one or a plurality of conductive tracks. The second half-loop **148** of the first loop couples an end **158** to an end **160**. End **158** is for example coupled to end **156** via one or a plurality of conductive tracks and/or one or a plurality of vias. End **160** is for example coupled to connection terminal **144**.

[0048] In the example of FIG. **1**, loops **116** and **147** and the loop formed by the assembly of half-loops **146** and **148**, have a substantially rectangular shape. In other embodiments, the loops are, for example, other than rectangular in shape, such as octagonal, circular, etc.

[0049] The loop **116** of the first inductor **110**, the two half-loops **146**, **148** of the second inductor **140**, and the second loop **147** of the second inductor **140** are formed by a stack of three conductive tracks, each being in a separate level, as will be described in relation to FIG. **2**. Even if the loop **116** is formed by a stack of three conductive tracks, it is one single loop because the tracks are connected in parallel with each other and are connected together along at least half of their length. The loop **116** generates an electromagnetic field that is different from an electromagnetic field that would be generated by two or three loops connected in series via their extremities and stacked.

[0050] In the example of FIG. **1**, the loop **116** has a length **170**, illustrated by a double-headed arrow.

[0051] FIG. **2** schematically shows a partial cross-section view of the transformer **100** of FIG. **1** along an axis A**1** shown in FIG. **1**, running through loop **116**, half-loop **146**, and loop **147**.

[0052] The loops of the inductors **110** and **140** of the transformer **100** of FIG. **1** each comprise, for example, conductive tracks in levels L1, L2, L3, so that level L2 is intermediate to levels L1 and L3. Levels L1 and L3 are, for example, metallization levels and level L2 is, for example, an insulating level in which vias may be formed to couple conductive tracks of the metallization levels. Conductive tracks formed in level L2 are, for example, vias.

[0053] Loop **116** comprises a conductive track **205** in level L1, a conductive track **210** in level L2, and a conductive track **215** in level L3.

[0054] Half-loop **146** comprises a conductive track **225** in level L1, a conductive track **230** in level L2, and a conductive track **235** in level L3.

[0055] A distance d**1** separates loop **116** and half-loop **146** at axis A**1**, and a distance d**2** separates half-loop **146** and loop **147** at axis A**1**, these distances d**1** and d**2** also being shown in FIG. **1**. In the example of FIGS. **1** and **2**, distance d**2** is greater than distance d**1**.

[0056] In the cross-section view of FIG. **2**, the conductive tracks **205**, **210**, and **215** of each loop are centered on a same axis S, that is, their cross-sections have their centers of mass, C**1**, C**2**, and C**3** respectively, aligned along axis S. Axis S is in the cross-section plane of FIG. **2** and perpendicularly intersects levels L1, L2, and L3. For the definition of the center of mass, it is considered that each of conductive tracks **205**, **210**, and **215** has a uniform density.

[0057] Referring once again to FIG. **1**, loop **116**, each of half-loops **146**, **148**, and loop **147** comprise conductive tracks in levels L1, L2, and L3 coupled to each other over the entire length of the loop. The conductive tracks coupling ends **156** and **158**, end **150** to connection terminal **142** and end **160** to connection terminal **144** comprise, for example, a single conductive track formed in a single level which is, for example, a level other than levels L1, L2, and L3. Generally speaking, each of the inductor loops comprises at least two conductive tracks coupled together over at least half the length of the loop.

[0058] FIG. **3** is a top view of an example of a transformer **300** according to an embodiment of the present disclosure. For example, transformer **300** is an impedance transformer.

[0059] Some of the elements of FIG. **3** correspond to elements of FIG. **1** or of FIG. **2**. These elements are designated with a same reference and are not described again in detail.

[0060] The transformer **300** of FIG. **3** corresponds to the transformer **100** of FIG. **1**, in which a conductive track **305** of the layer L1 of loop **116** is offset from a conductive track **315** of the layer L3 of loop **116**.

[0061] In particular, conductive track **305** is 1 laterally offset so that, for any point of loop **116**, in a cross-section view, the center of mass D1 of conductive track **305** is laterally offset from the center of mass D3 of conductive track **315**, in the cross-section plane, in a direction parallel to the plane formed by the first conductive level L1. In the example of FIG. **3**, conductive track **305** is offset towards the inside of loop **116**. According to an alternative embodiment, conductive track **305** is offset towards the outside of loop **116**.

[0062] In the example of FIG. **3**, a conductive track **325** of the layer L1 of half-loops **146** and **148** is also offset similarly to the conductive track **305** of loop **116**.

[0063] In the example of FIG. **3**, none of the conductive tracks of loop **147** is offset.

[0064] In FIG. **3**, in top view, the tracks of level L3 are fully visible, and those of level L1 are partially visible, when they are not covered by tracks of higher levels. The tracks of level L2 are, in the example of FIG. **3**, fully covered by the tracks of level L3 and are not visible. The tracks coupling connection terminals **142** and **144** to ends **150** and **160** respectively, and the tracks coupling ends **156** and **158** are for example formed in a conductive level separate from levels L1, L2, and L3.

[0065] FIG. **4** is a partial cross-section view, along an axis A**3** of FIG. **3** crossing the loop **116**, the half-loop **146**, and the loop **147** of the transformer **300** of FIG. **3**, according to an embodiment of the present disclosure.

[0066] Certain elements of FIG. **4** correspond to elements of FIGS. **1** to **3**. These elements are designated with the same reference and are not described again in detail.

[0067] In the cross-section view of FIG. **4**, the center of mass D3 of the conductive track **315** of loop **116** is laterally offset from the center of mass D1 of the conductive track **305** of loop **116**, in the cross-section plane, in a direction parallel to the plane formed by first conductor L1. The lateral displacement of conductive track **315** relative to conductive track **305** is indicated by an arrow F. This displacement F is for example selected so that conductive tracks **305** and **315** remain at least partially opposite each other, to enable an intermediate conductive track **310**, in layer L2, to electrically couple conductive tracks **305** and **315**.

[0068] Although an offset of an upper track with respect to a lower track is described in the example of FIGS. **3** and **4**, in other embodiments, an offset of the lower track with respect to the upper track is for example performed.

[0069] Similarly, the conductive track **335** of level L3 of half-loop **146** is offset by the lateral displacement F with respect to the conductive track **325** of level L1 of half-loop **146**.

[0070] The tracks of loop **147** are for example not offset.

[0071] The track **310** of level L2 of loop **116** is for example offset to ensure the connection between conductive tracks **305** and **315**. Similarly, a track **330** of level L2 of half-loop **146** is for example offset to ensure the connection between conductive tracks **325** and **335**.

[0072] As described in relation with FIG. **1**, distance d**1** separates the conductive tracks of level L3 of loop **116** and of half-loop **146** at axis A**3**, and distance d**2** separates the conductive tracks of level L3 of half-loop **146** and of loop **147** at axis A**3**. In the example of FIG. **4**, the lateral displacement F with respect to distance d**1** is such that conductive tracks **305** and **335** partially face each other.

[0073] More generally, according to the distance separating two adjacent loops and the width of the conductive tracks forming the loops, a conductive track of the first conductive level of one loop does or not partially face a track of the second conductive level of another adjacent loop. An advantage of providing partially opposite conductive tracks is that this improves, according to cases, the compactness of the transformer and/or the magnetic coupling between inductors.

[0074] Although in the example of FIGS. **3** and **4**, the conductive tracks of loop **116** and of each of half-loops **146** and **148** are laterally offset, in other embodiments, it would be possible to offset the conductive tracks of only one of the half-loops or of half of one of the loops. The applied offset is for example selected according to the desired effect on the output parameters.

[0075] FIG. **5**A is a graph showing the value ("Inductance [pH]") of the first inductance **110** of the transformer **100**, **300** of FIGS. **1** and **3** as a function of the operating frequency ("Frequency [GHz]") of the transformer.

[0076] A first curve **500** represents the value of the inductance **110** of the transformer **100** of FIG. **1**, such as modeled according to a model using an equivalent diagram of transformer **100** by using a small-signal approximation.

[0077] A second curve **502** represents the value of the inductance **110** of the transformer **100** of FIG. **1**, obtained by performing a digital or electromagnetic simulation enabling to obtain at the output of the simulation the scattering parameters of the transformer.

[0078] For the ensuing comparison in the drawing, a digital simulation is for example carried out, assuming that the first inductor **110** is connected in parallel with a power generator, for example having a 50-Ohm characteristic impedance, and that the second inductor **140** is connected in parallel with a power generator, for example having a 50-Ohm characteristic impedance. The simulation enables to obtain the scattering parameters of the transformer, from which is extracted one of the parameters among the value of inductance **110**, the value of the mutual coupling parameter between inductances **110** and **140**, and the series resistance of inductance **110**. The other two parameters are obtained by using the equivalent diagram of transformer **100**, for which the small-signal parameters characteristic of the considered transformer are extracted from this same simulation. The same digital simulation is replicated for the other transformers considered in this comparison.

[0079] A third curve **504** represents the value of the inductance **110** of the transformer **300** of FIG. **3**, such as modeled according to the model using an equivalent diagram of transformer **100** by using a small-signal approximation.

[0080] A fourth curve **506** represents the value of the inductance **110** of the transformer **300** of FIG. **3**, obtained by performing the digital simulation.

[0081] Over a frequency range, for example between 2 and 22 GHz, the value **500** of the inductance **110** of transformer **100** and the value **504** of the inductance **110** of transformer **300** such as modeled are similar to within 10%.

[0082] Over a frequency range, for example between 2 and 22 GHz, the value **502** of the inductance **110** of transformer **100** and the value **506** of the inductance **110** of transformer **300** such as digitally simulated are similar to within 10%.

[0083] Over a frequency range, the value of the first inductance **110** varies little when a conductive track is offset with the offset described in relation with FIGS. **3** and **4**.

[0084] FIG. **5**B is a graph showing the value ("Inductance [pH]") of the second inductance **140** of the transformer **100**, **300** of FIGS. **1** and **3** as a function of the operating frequency ("Frequency [GHz]") of the impedance transformer.

[0085] A first curve **510** represents the value of the inductance **140** of the transformer **100** of FIG. **1**, such as modeled according to a model using an equivalent diagram of transformer **100** by using the small-signal approximation.

[0086] A second curve **512** represents the value of the inductance **140** of the transformer **100** of FIG. **1**, obtained by performing the digital simulation described in relation with FIG. **5**A.

[0087] A third curve **514** represents the value of the inductance **140** of the transformer **300** of FIG. **3**, such as modeled according to a model using an equivalent diagram of transformer **100** by using the small-signal approximation.

[0088] A fourth curve **516** represents the value of the inductance **140** of the transformer **300** of FIG. **3**, obtained by performing the digital simulation described in relation with FIG. **5**A.

[0089] Over a frequency range, for example between 4 and 10 GHz, the value **510** of the inductance **140** of transformer **100** and the value **514** of the inductance **140** of transformer **300** such as modeled are similar to within 10%.

[0090] Over a frequency range, for example between 4 and 10 GHz, the value **512** of the inductance **140** of transformer **100** and the value **516** of the inductance **140** of transformer **300** such as digitally simulated are similar to within 10%.

[0091] Over a frequency range, the value of the second inductance **140** varies little when conductive tracks are offset according to the offset described in relation with FIGS. **3** and **4**.

[0092] FIG. **5**C is a graph showing the value of the mutual coupling parameter ("Mutual inductance [nH]") between the two inductances **110**, **140** of the transformer **100**, **300** of FIGS. **1** and **3** as a function of the operating frequency ("Frequency [GHz]") of the impedance transformer.

[0093] A first curve **520** represents the value of the mutual coupling parameter between the two inductances **110** and **140** of the transformer **100** of FIG. **1**, such as modeled according to a model using an equivalent diagram of the transformer **100** by using the small-signal approximation.

[0094] A second curve **522** represents the value of the mutual coupling parameter between the two inductances **110** and **140** of the transformer **100** of FIG. **1**, obtained by performing the digital simulation described in relation to FIG. **5**A.

[0095] A third curve **524** represents the value of the mutual coupling parameter between the two inductances **110** and **140** of the transformer **300** of FIG. **3**, such as modeled according to a model using an equivalent diagram of transformer **100** by using the small-signal approximation.

[0096] A fourth curve **526** represents the value of the mutual coupling parameter between the two inductances **110** and **140** of the transformer **300** of FIG. **3**, obtained by performing the digital simulation described in relation with FIG. **5**A.

[0097] Over a frequency range, for example between a few MHz and 20 GHz, according to the model, the value of the mutual coupling parameter **524** of transformer **300** having offset conductive tracks is greater, in absolute value, than the value of the mutual coupling parameter **520** of transformer **100** having no offset conductive tracks. For example, for a 6-GHz frequency, the mutual coupling parameter increases by approximately 7% when conductive tracks are offset.

[0098] Over a frequency range, for example between a few MHZ and 20 GHz, according to the digital simulation, the value of the mutual coupling parameter **526** of transformer **300** having offset conductive tracks is greater, in absolute value, than the value of the mutual coupling parameter **522** of transformer **100** having no offset conductive tracks. For example, at a 6-GHz frequency, the mutual by coupling parameter increases approximately 10% when conductive tracks are offset.

[0099] Over a frequency range, the value of the mutual coupling parameter increases when conductive tracks are offset with the offset described in relation with FIGS. **3** and **4**.

[0100] FIG. **5**D is a graph showing the series resistance ("Resistance [Ω]") of the first inductor **110** of the transformer **100**, **300** of FIGS. **1** and **3** as a function of the operating frequency ("Frequency [GHz]") of the impedance transformer. The resistor in series with the inductors of an impedance transformer causes losses in the system and impacts the adaptation performance, whereby it is desirable to minimize this value.

[0101] A first curve **530** represents the series resistance of the inductor **110** of the transformer **100** of FIG. **1**, such as modeled according to a model using an equivalent diagram of transformer **100** by using the small-signal approximation.

[0102] A second curve **532** represents the series resistance of the inductor **110** of the transformer **100** of FIG. **1**, obtained by performing the digital simulation described in relation with FIG. **5**A.

[0103] A third curve **534** represents the series resistance of the inductor **110** of the transformer **300** of FIG. **3**, such as modeled according to a model using an equivalent diagram of transformer **100** using the small-signal approximation.

[0104] A fourth curve **536** represents the series resistance of the inductor **110** of the transformer **300** of FIG. **3**, obtained by performing the digital simulation described in relation with FIG. **5**A.

[0105] Over a frequency range, for example between a few MHz and 10 GHZ, according to the model, the series resistance **534** of the inductor **110** of transformer **300** is greater than the value **530** of the inductance **110** of transformer **100**. For example, at a 6-GHz frequency, the resistance is approximately 7% higher when conductive tracks are offset.

[0106] Over a frequency range, for example between a few MHz and 10 GHz, according to the model, the series resistance **536** of the inductor **110** of transformer **300** is higher than the value **532** of the inductor **110** of transformer **100**. For example, for a 6-GHz frequency, the resistance is around 8% higher when conductive tracks are offset.

[0107] Over a frequency range, the series resistance of the first inductor **110** increases slightly and is very little modified when a conductive track is offset with the offset described in relation with FIGS. **3** and **4**.

[0108] FIG. **5**E is a graph showing the series resistance ("Resistance [Ω]") of the second inductor **140** of the transformer **100**, **300** of FIGS. **1** and **3** as a function of the operating frequency ("Frequency [GHz]") of the impedance transformer.

[0109] A first curve **540** represents the series resistance of the inductor **140** of the transformer **100** of FIG. **1**, such as modeled according to a model using an equivalent diagram of transformer **100** by using the small-signal approximation.

[0110] A second curve **542** represents the series resistance of the inductor **140** of the transformer **100** of FIG. **1**, obtained by performing the digital simulation described in relation with FIG. **5**A.

[0111] A third curve **544** represents the series resistance of the inductor **140** of the transformer **300** of FIG. **3**, such as modeled according to a model using an equivalent diagram of the transformer **100** by using the small-signal approximation.

[0112] A fourth curve **546** represents the series resistance of the inductor **140** of the transformer **300** of FIG. **3**, obtained by performing the digital simulation described in relation with FIG. **5**A.

[0113] Over a frequency range, for example between a few MHz and 10 GHz, according to the model, the series resistance **544** of the inductor **140** of transformer **300** is higher than the value **540** of the inductor **140** of transformer **100**. For example, at a 6-GHz frequency, the series resistance is around 5% higher when conductive tracks are offset.

[0114] Over a frequency range, for example between a few MHZ and 10 GHZ, according to the model, the series resistance **546** of the inductor **140** of impedance transformer **300** is higher than the value **542** of the inductor **140** of impedance transformer **100**. For example, for a 6-GHz frequency, the series resistance is around 8% higher when conductive tracks are offset.

[0115] Over a frequency range, the value of the series resistance of the second inductor **140** is very little modified when a conductive track is offset according to the offset described in relation with FIGS. **3** and **4**.

[0116] In addition to the results described in FIGS. **5**A to **5**E resulting from the offset of conductive tracks in a transformer, the capacitive coupling between the two inductors **110** and **140** of the transformer **300** of FIG. **3** is approximately 100% greater than the capacitive coupling of the transformer **100** of FIG. **1**.

[0117] FIGS. **6**A to **6**C are graphs obtained by means of the digital simulation described in relation with FIG. **5**A with the transformer **100** of FIG. **1** and with the transformer **300** of FIG. **3**. A first capacitive element and a second capacitive element are added in parallel with each of the inductors **110** and **140** of transformer **300**. A first capacitive element and a second capacitive element having the same values are added in parallel with each of the inductors **110** and **140** of transformer **100**. The values of the first and second capacitive elements used in the simulation are adjusted according to the operating frequency of the transformer to optimize the power adaptation of the considered transformer. FIGS. **6**A to **6**C show reflection coefficients S11 of the primary circuit of the transformer comprising the first capacitive element and inductor **110**, and S22 of the secondary circuit of the transformer comprising the second capacitive element and inductor **140**, characterizing the proportion of power reflected between the considered circuit and what is connected thereto. On design of a transformer, it is desirable for the parameters S11 and S22 to be relatively low, which means that the power reflected at the transformer is relatively low and preferably minimal. A third parameter, S21, is shown in FIGS. **6**A to **6**C. It is the power gain or loss of the considered transformer **100**, **300**. On design of a transformer, it is desirable for S21 to be either close to 1, or close to 0 dB, which indicates that the losses relative to the transformer in the considered environment are low and that the power transmitted through the transformer is increased.

[0118] Figure a graph showing 6A is the scattering parameters: S11, S22, and S21 of signal transmission by the impedance transformers **100**, **300** of FIGS. **1** and **3** at a 25-GHz frequency.

[0119] In the example of FIG. **6**A, the first and second capacitive elements used for the digital simulation have value 150 fF and 120 fF.

[0120] Curve **600** shows the amplitude ("Magnitude [dB]") of coefficient S11 in decibels of the transformer **100** of FIG. **1** as a function of the operating frequency ("Frequency [GHz]").

[0121] Curve **602** shows the amplitude ("Magnitude [dB]") of coefficient S11 in decibels of the transformer **300** of FIG. **3** as a function of the operating frequency ("Frequency [GHz]").

[0122] Curve **604** shows the amplitude ("Magnitude [dB]") of coefficient S22 in decibels of the transformer **100** of FIG. **1** as a function of the operating frequency ("Frequency [GHz]").

[0123] Curve **606** shows the amplitude ("Magnitude [dB]") of coefficient S22 in decibels of the transformer **300** of FIG. **3** as a function of the operating frequency ("Frequency [GHz]").

[0124] Curve **608** shows the amplitude ("Magnitude [dB]") of coefficient S21 in decibels of the transformer **100** of FIG. **1** as a function of the operating frequency ("Frequency [GHz]").

[0125] Curve **609** shows the amplitude ("Magnitude [dB]") of coefficient S21 in decibels of the transformer **300** of FIG. **3** as a function of the operating frequency ("Frequency [GHz]").

[0126] For a 25-GHZ frequency, coefficient S11 is approximately −38 dB for transformer **300**, to be compared with −16 dB for transformer **100**.

[0127] For a 25-GHZ frequency, coefficient S22 is approximately −33 dB for transformer **300**, to be compared with −16 dB for transformer **100**.

[0128] For a 25-GHZ frequency, coefficient S21 is approximately −1.1 dB for transformer **300**, to be compared with −1.3 dB for transformer **100**.

[0129] For a 25-GHZ frequency, for the transformer **300** comprising offset conductive tracks as described in relation with FIGS. **3** and **4**, coefficients S11 and S22 are lower and the coefficient S21 is closer to 0 than for the transformer **100** of FIG. **1**.

[0130] FIG. **6**B is a graph showing the scattering parameters: S11, S22, and S21 of signal transmission by the impedance transformers **100**, **300** of FIGS. **1** and **3** at a 20-GHz frequency.

[0131] In the example of FIG. **6**B, the first and second capacitive elements used for the digital simulation have value 245 fF and 169 fF.

[0132] Curve **610** shows the amplitude ("Magnitude [dB]") of coefficient S11 in decibels of the transformer **100** of FIG. **1** as a function of the operating frequency ("Frequency [GHz]").

[0133] Curve **612** shows the amplitude ("Magnitude [dB]") of coefficient S11 in decibels of the transformer **300** of FIG. **3** as a function of the operating frequency ("Frequency [GHz]").

[0134] Curve **614** shows the amplitude ("Magnitude [dB]") of coefficient S22 in decibels of the transformer **100** of FIG. **1** as a function of the operating frequency ("Frequency [GHz]").

[0135] Curve **616** shows the amplitude ("Magnitude [dB]") of coefficient S22 in decibels of the transformer **300** of FIG. **3** as a function of the operating frequency ("Frequency [GHz]").

[0136] Curve **618** shows the amplitude ("Magnitude [dB]") of coefficient S21 in decibels of the transformer **100** of FIG. **1** as a function of the operating frequency ("Frequency [GHz]").

[0137] Curve **619** shows the amplitude ("Magnitude [dB]") of coefficient S21 in decibels of the transformer **300** of FIG. **3** as a function of the operating frequency ("Frequency [GHz]").

[0138] For a 20-GHZ frequency, coefficient S11 is approximately −23 dB for transformer **300**, to be compared with −16 dB for transformer **100**.

[0139] For a 20-GHZ frequency, coefficient S22 is approximately −17 dB for transformer **300**, to be compared with −13 dB for transformer **100**.

[0140] At a 20-GHz frequency, coefficient S21 is approximately −1.3 dB for transformer **300**, to be compared with −1.5 dB for transformer **100**.

[0141] For a 20-GHz frequency, for the transformer **300** comprising offset conductive tracks as described in relation with FIGS. **3** and **4**, coefficients S11 and S22 are lower and coefficient S21 is closer to 0 than for the transformer **100** of FIG. **1**.

[0142] FIG. **6**C is a graph showing the scattering parameters: S11, S22, and S21 of signal transmission by the impedance transformers **100**, **300** of FIGS. **1** and **3** at a 42-GHz frequency.

[0143] The first and second capacities used for the digital simulation have value 80 fF and 40 fF.

[0144] Curve **620** shows the amplitude ("Magnitude [dB]") of coefficient S11 in decibels of the transformer **100** of FIG. **1** as a function of the operating frequency ("Frequency [GHz]").

[0145] Curve **622** shows the amplitude ("Magnitude [dB]") of coefficient S11 in decibels of the transformer **300** of FIG. **3** as a function of the operating frequency ("Frequency [GHz]").

[0146] Curve **624** shows the amplitude ("Magnitude [dB]") of coefficient S22 in decibels of the transformer **100** of FIG. **1** as a function of the operating frequency ("Frequency [GHz]").

[0147] Curve **626** shows the amplitude ("Magnitude [dB]") of coefficient S22 in decibels of the transformer **300** of FIG. **3** as a function of the operating frequency ("Frequency [GHz]").

[0148] Curve **628** shows the amplitude ("Magnitude [dB]") of coefficient S21 in decibels of the transformer **100** of FIG. **1** as a function of the operating frequency ("Frequency [GHz]").

[0149] Curve **629** shows the amplitude ("Magnitude [dB]") of coefficient S21 in decibels of the transformer **300** of FIG. **3** as a function of the operating frequency ("Frequency [GHz]").

[0150] For a frequency, coefficient S11 is 42-GHz approximately −18 dB for transformer **300**, to be compared with −10 dB for transformer **100**.

[0151] For a 42-GHz frequency, coefficient S22 is approximately −44 dB for transformer **300**, to be compared with −12 dB for transformer **100**.

[0152] For a 42-GHz frequency, coefficient S21 is approximately −1.1 dB for transformer **300**, to be compared with −1.5 dB for transformer **100**.

[0153] For a 42-GHz frequency, for the transformer **300** comprising offset conductive tracks as described in relation to FIGS. **3** and **4**, the coefficients S11 and S22 are lower and the coefficient S21 is closer to 0 than for the transformer **100** of FIG. **1**.

[0154] FIG. **7**A is a top view of an example of transformer **700** according to an embodiment of the present disclosure. For example, transformer **700** is an impedance transformer.

[0155] FIG. **7**B and FIG. **7**C are top views of a first inductor **710** and of a second inductor **740** of the transformer **700** of FIG. **7**A.

[0156] According to an embodiment, the first inductor **710** is connected to a first external electronic circuit (not shown in FIGS. **7**A to **7**C) and the second inductor **740** is connected to a second external electronic circuit (not shown in FIGS. **7**A to **7**C).

[0157] Transformer **700** comprises the first external inductor **710**. Inductor **710** comprises two connection terminals, for example an input/output terminal **712** and an input/output terminal **714**. Inductor **710**, as shown in the example of FIG. **7**A and of FIG. **7**B, comprises two loops: a first loop formed of a first half-loop **716** and of a second half-loop **718**, and a second loop **717**, so that an electric current flowing through inductor **710** from its terminal **712** to its terminal **714** flows, in the order, through half-loop **716**, then loop **717**, and then half-loop **718**. The first half-loop **716** couples an end **719** to an end **720**. End **719** is for example coupled to connection terminal **712** by one or a plurality of conductive tracks. The second one **717** couples an end **722** to an end **728**. End **722** is for example coupled to end **720** by one or a plurality of conductive tracks. The second half-loop **718** couples an end **730** to an end **732**. End **730** is for example coupled to end **728** by one or a plurality of conductive tracks and/or one or a plurality of vias. End **732** is for example coupled to connection terminal **714** by one or a plurality of conductive tracks.

[0158] Transformer **700** comprises the second internal inductor **740**. Inductor **740** comprises two connection terminals, for example an input/output terminal **742** and an input/output terminal **744**. Inductor **740**, as shown in the example of FIG. **7**A and of FIG. **7**C, comprises three loops: a first loop formed of a first half-loop **746** and of a second half-loop **750**, a second loop formed of a first half-loop **747** and of a second half-loop **749**, and a third loop **748**. An electric current flowing through inductor **740** from its terminal **742** to its terminal **744** flows, in the order, through half-loop **746**, then half-loop **747**, then loop **748**, then half-loop **749**, then half-loop **750**.

[0159] The first half-loop **746** of the first loop couples an end **752** to an end **754**. End **752** is for example coupled to connection terminal **742** by one or a plurality of conductive tracks and/or one or a plurality of vias. The first half-loop **747** of the second loop couples an end **756** to an end **758**. End **756** is for example coupled to end **754** by one or a plurality of conductive tracks and/or one or a plurality of vias. The third loop **748** couples an end **760** to an end **762**. End **760** is for example coupled to end **758** by one or a plurality of conductive tracks and/or one or a plurality of vias. End **762** is for example the junction between half-loops **748** and **749**. The second half-loop **749** of the second loop couples an end **762** to an end **764**. The second half-loop **750** of the first loop couples an end **766** to an end **768**. End **766** is for example coupled to end **764** by one or a plurality of conductive tracks and/or one or a plurality of vias. End **768** is for example coupled to connection terminal **744** by one or a plurality of conductive tracks and/or one or a plurality of vias.

[0160] As compared with the examples of FIGS. **1** and **3**, in the example of FIG. **7**A, the loops are substantially octagonal in shape instead of being substantially rectangular. In other embodiments, other loop shapes are possible.

[0161] In the example of the transformer **700** of FIG. **7**A, the loops of inductors **710** and **740** are each formed of a stack of three conductive tracks distributed in levels L1, L2, and L3 according to the arrangement described in relation with FIG. **4**. In particular, loop **717**, loop **748**, and each of half-loops **716**, **718**, **746**, **747**, **749**, and **750** comprise conductive tracks in levels L1, L2, and L3 coupled together along the entire length of the loop. The conductive tracks coupling ends **758** and **760**, **764** and **766**, end **752** to connection terminal **742**, and end **768** to connection terminal **744** comprise, for example, a single conductive track formed in a single level which is, for example, a level other than levels L1, L2, and L3. The conductive tracks coupling ends **754** and **756** comprise, for example, a single conductive track formed in a single level which is, for example, level L1. Generally, each of the inductor loops comprises at least two conductive tracks coupled together over at least half the loop length. For example, the loop **117** has a length **770**, illustrated in FIG. **7**A by a double-headed arrow.

[0162] The transformer **300** of FIG. **3** corresponds to the transformer **100** of FIG. **1**, in which the conductive track **205** of loop **116** is offset from the conductive track **215** of loop **116**.

[0163] Still referring to the example of transformer **700**, the conductive tracks of level L1 of loop **717**, loop **748**, and each of half-loops **716**, **718**, **746**, **747**, **749**, and **750** are laterally offset so that, at any point, in a cross-section view, the centers of mass of the conductive tracks of level L3 are laterally offset from the centers of mass of the conductive tracks of level L1, in the cross-section plane, in a direction parallel to the plane formed by the first conductive level L1. In this example, the conductive tracks of level L3 are offset towards the outside of inductors **710**, **740**. According to an alternative embodiment, the conductive tracks of level L3 are offset towards the inside of inductors **710**, **740**. The offset direction is selected according to the desired performance.

[0164] In FIGS. **7**A to **7**C, in top view, the tracks of level L3 are fully visible, and those of level L1 are partially visible, when they are not covered by tracks of higher levels. The tracks of level L2 are, in the example shown in FIGS. **7**A to **7**C, totally covered by the tracks of level L3 and are not visible.

[0165] FIGS. **8**A to **8**C are graphs obtained by means of the digital simulation described in relation with FIG. **5**A with the transformer **700** of FIG. **7**A and with a second transformer similar to transformer **700** but exhibiting no offset between conductive tracks of a same loop. In the example of FIG. **8**A, the capacitive elements are removed from the circuit used for the simulation. In the example of FIGS. **8**B and **8**C, the values of the first and second capacitive elements used in the simulation are adjusted as a function of the operating frequency of the transformer to optimize the power adaptation and the power transfer of the considered transformer. FIGS. **8**A to **8**C show reflection coefficients S11 exhibited by the primary circuit of the transformer comprising the first capacitive element and inductor **110**, and S22 exhibited by the secondary circuit of the transformer comprising the second capacitive element and inductor **140**, characterizing the proportion of power reflected between the considered circuit and what is connected thereto. On design of a transformer, it is desirable for parameters S11 and S22 to be as low as possible, which means that the power reflected at the transformer is decreased, preferably to a minimum. A third parameter, S21, is shown in FIGS. **8**A to **8**C. It is the power gain or loss of the considered transformer. On design of a transformer, it is desirable for S21 to be as close to 1 as possible, or as close to 0 dB as possible, which indicates that losses relative to the transformer in the considered environment are low, and the power transmitted through the transformer is increased.

[0166] FIG. **8**A is a graph showing the scattering parameters: S11, S22, and S21 of signal transmission by the transformer **700** of FIG. **7**A and the quality parameters S11, S22, and S21 of the second transformer at a 12-GHz frequency.

[0167] Curve **800** shows the amplitude ("Magnitude [dB] ") of the coefficient S11 in decibels of the second transformer as a function of the operating frequency ("Frequency [GHz]").

[0168] Curve **802** shows the amplitude ("Magnitude [dB] ") of the coefficient S11 in decibels of the transformer **700** of FIG. **7**A as a function of operating frequency ("Frequency [GHz]").

[0169] Curve **804** shows the amplitude ("Magnitude [dB] ") of the coefficient S22 in decibels of the second transformer as a function of the operating frequency ("Frequency [GHz]").

[0170] Curve **806** shows the amplitude ("Magnitude [dB] ") of the coefficient S22 in decibels of the transformer **700** of FIG. **7**A as a function of the operating frequency ("Frequency [GHz]").

[0171] Curve **808** shows the amplitude ("Magnitude [dB] ") of the coefficient S21 in decibels of the second transformer as a function of the operating frequency ("Frequency [GHz]").

[0172] Curve **809** shows the amplitude ("Magnitude [dB] ") of the coefficient S21 in decibels of the transformer **700** of FIG. **7**A as a function of the operating frequency ("Frequency [GHz]").

[0173] For a 12-GHz frequency, without using capacitive elements external to the impedance transformers during the simulation, coefficient S11 is approximately −17 dB for transformer **700**, to be compared with −10 dB for the second transformer.

[0174] Coefficient S22 is approximately −16 dB for transformer **700**, to be compared with −9 dB for the second transformer.

[0175] Coefficient S21 is approximately −1.3 dB for transformer **700**, to be compared with −1.7 dB for the second transformer.

[0176] For a 12-GHz frequency, for transformer **700** comprising offset conductive tracks as described in relation with FIGS. **3** and **4**, coefficients S11 and S22 are lower and coefficient S21 is closer to 0 than for the second transformer.

[0177] FIG. **8**B is a graph showing the scattering parameters: S11, S22, and S21 of the signal transmission by the transformer **700** of FIG. **7**A and the quality parameters S11, S22, and S21 of the second transformer at a 9-GHz frequency.

[0178] In the example of FIG. **6**B, the first and second capacitances used for the digital simulation are 140 fF and 60 fF.

[0179] Curve **810** shows the amplitude ("Magnitude [dB] ") of the coefficient S11 in decibels of the second transformer as a function of the operating frequency ("Frequency [GHz]").

[0180] Curve **812** shows the amplitude ("Magnitude [dB] ") of the coefficient S11 in decibels of the transformer **700** of FIG. **7**A as a function of the operating frequency ("Frequency [GHz]").

[0181] Curve **814** shows the amplitude ("Magnitude [dB] ") of the coefficient S22 in decibels of the second transformer as a function of the operating frequency ("Frequency [GHz]").

[0182] Curve **816** shows the amplitude ("Magnitude [dB] ") of the coefficient S22 in decibels of the transformer **700** of FIG. **7**A as a function of the operating frequency ("Frequency [GHz]").

[0183] Curve **818** shows the amplitude ("Magnitude [dB] ") of the coefficient S21 in decibels of the second transformer as a function of the operating frequency ("Frequency [GHz]").

[0184] Curve **819** shows the amplitude ("Magnitude [dB] ") of the coefficient S21 in decibels of the transformer **700** of FIG. **7**A as a function of the operating frequency ("Frequency [GHz]").

[0185] For a 9-GHZ frequency, coefficient S11 is approximately −23 dB for transformer **700**, to be compared with −15 dB for the second transformer.

[0186] Coefficient S22 is approximately −33 dB for transformer **700**, to be compared with −15 dB for the second transformer.

[0187] Coefficient S21 is approximately −1.3 dB for transformer **700**, to be compared with −1.2 dB for the second impedance transformer.

[0188] For a 9-GHz frequency, for transformer **700** comprising offset conductive tracks as described in relation with FIGS. **3** and **4**, coefficients S11 and S22 are lower and coefficient S21 is closer to 0 than for the second transformer.

[0189] FIG. **8**C is a graph showing the scattering parameters: S11, S22, and S21 of signal transmission by the transformer **700** of FIG. **7**A and the quality parameters S11, S22, and S21 of the second transformer at a 13-GHz frequency.

[0190] The first capacitive element used for the digital simulation has a 60-fF value, and the second capacitive element is not connected.

[0191] Curve **820** shows the amplitude ("Magnitude [dB] ") of the coefficient S11 in decibels of the second transformer as a function of the operating frequency ("Frequency [GHz]").

[0192] Curve **822** shows the amplitude ("Magnitude [dB] ") of the coefficient S11 in decibels of the transformer **700** of FIG. **7**A as a function of the operating frequency ("Frequency [GHz]").

[0193] Curve **824** shows the amplitude ("Magnitude [dB]") of the coefficient S22 in decibels of the second transformer as a function of the operating frequency ("Frequency [GHz]").

[0194] Curve **826** shows the amplitude ("Magnitude [dB]") of the coefficient S22 in decibels of the transformer **700** of FIG. **7**A as a function of the operating frequency ("Frequency [GHz]").

[0195] Curve **828** shows the amplitude ("Magnitude [dB]") of the coefficient S21 in decibels of the second transformer as a function of the operating frequency ("Frequency [GHz]").

[0196] Curve **829** shows the amplitude ("Magnitude [dB]") of the coefficient S21 in decibels of the transformer **700** of FIG. **7**A as a function of the operating frequency ("Frequency [GHz]").

[0197] For a 12.7-GHz frequency, coefficient S11 is approximately −27 dB for transformer **700**, to be compared with −12 dB for the second impedance transformer.

[0198] Coefficient S22 is approximately −44 dB for transformer **700**, to be compared with −12 dB for the second impedance transformer.

[0199] Coefficient S21 is approximately −1.1 dB for transformer **700**, to be compared with −1.5 dB for the second transformer.

[0200] For a 12.7-GHZ for transformer frequency, **700** comprising offset conductive tracks as described in relation with FIGS. **3** and **4**, coefficients S11 and S22 are lower and coefficient S21 is closer to 0 than for the second transformer.

[0201] FIG. **9** is a partial cross-section view of the transformer of FIG. **1**, according to another example than that of FIG. **2** and according to an embodiment of the present disclosure.

[0202] Certain elements of FIG. **9** correspond to elements of FIGS. **1** to **4**. These elements are designated with a same reference and are not described again in detail.

[0203] FIG. **9** shows an alternative to FIG. **2**. Instead of an offset between the conductive tracks **305** of the layer L1 and **315** of the layer L3 of transformer **300** as described in relation with FIGS. **3** and **4**, in the example of FIG. **9**, the offset is, for example, achieved between the conductive tracks **905** of the layer L1 and **910** of the layer L2 of loop **116**.

[0204] Conductive track **910**, for example formed by one or a plurality of conductive vias, is laterally offset so that, for any point of loop **116**, in a cross-section view, the center of mass E2 of conductive track **910** is laterally offset from the center of mass E1 of conductive track **905**, in the cross-section plane, in a direction parallel to the plane formed by the first conductive level L1. The offset is represented by an arrow F'.

[0205] An example of a manufacturing method is detailed hereafter for the transformer **100** of FIGS. **1** and **9**. Similar methods are used, for example, to manufacture the transformer **300** of FIG. **3** and **700** of FIG. **7**A.

[0206] The method comprises, for example:

- **[0207]** a step of forming, in a first level L1 of a structure, the conductive track **905** of loop **116**, of inductor **110**,
- **[0208]** a step of forming, in a second level L2 of the structure, one or a plurality of vias forming the conductive track **910** of loop **116**;
- **[0209]** a step of forming, in a third level L3 of the structure, the conductive track **915** of loop **116**, conductive tracks **905**, **910**, and **915** being electrically connected together directly over at least half, or approximately half, the length of loop **116**. Over at least half, or approximately half, the length of loop **116**, conductive tracks **905** and **910** are arranged so that, in a cross-section view perpendicular to the length of loop **116**, the center of mass E1 of conductive track **905** is laterally offset from the center of mass E2 of conductive track **910** in the cross-section plane, and in a direction parallel to the plane formed by level L1.

[0210] In other embodiments, for the transformer **300** of FIGS. **3** and **4**, over at least half the length of loop **116**, conductive tracks **305** and **315** are arranged so that, in a cross-section view perpendicular to the length of loop **116**, the center of mass D1 of conductive track **305** is laterally offset from the center of mass D3 of conductive track **315** in the cross-section plane, and in a direction parallel to the plane formed by level L1.

[0211] According to the described embodiments, the offset between two conductive tracks of a loop of an inductor of a transformer increases the mutual coupling between inductors as well as the capacitive coupling and enables to improve the reflection and transmission gain coefficients of the transformer. The increase of the capacitive coupling enables to decrease the value of or to remove capacitive elements external to the transformer in the concerned electronic circuits. This improves the compactness of the transformer.

[0212] Having a transformer comprising one loop having a first conductive track and a second conductive track electrically connected over at least half the length of the loop has the advantage of lowering the series resistance of the loop and increasing the quality factor of the transformer.

[0213] Various embodiments and variants have been described. Those skilled in the art will understand that certain features of these various embodiments and variants may be combined, and other variants will occur to those skilled in the art. In particular, examples of configurations of impedance transformers **300**, **700** have been disclosed, but the inductors and loops may have other shapes and arrangements. A lateral offset of a track **205** towards the outside of loop **116** has been illustrated, but an offset towards the inside of the loop is also possible. The loops of the shown impedance transformers **100**, **300**, **700** comprise three conductive tracks connected over the length of the loop or over at least half the length of the loop. According to some embodiments, the loops of the impedance transformers **100**, **300**, **700** comprise conductive tracks connected to each other discontinuously such that, by adding the length of the connections, the conductive tracks are connected to each other at least half the length of the loop. A greater number of conductive tracks is also possible.

1. A transformer comprising, in a laminated structure, a first inductor and a second inductor, wherein the first inductor comprises:

a first loop comprising a first conductive track in a first level of the structure and a second conductive track in a second level of the structure, the first and second conductive tracks being adapted to being electrically connected to each other directly, or via an intermediate conductive track, over at least half a length of the first loop; and

wherein, over at least half the length of the first loop, the first and second conductive tracks are arranged so that, in a cross-section plane perpendicular to the length of the first loop, a center of mass of the first conductive track is laterally offset from the center of mass of the second conductive track in the cross-section plane, and in a direction parallel to the plane formed by the first level.

2. The transformer of claim **1**, wherein the first and second conductive tracks are connected to each other by the intermediate conductive track, the intermediate conductive track comprising one or a plurality of vias.

3. The transformer of claim **1**, the first loop further comprising a third conductive track electrically connected to the second conductive track over at least half the length of the first loop, wherein the second conductive track comprises one or a plurality of vias coupling the first conductive track to the third conductive track.

4. The transformer of claim **1**, wherein the second inductor comprises a first loop comprising a fourth conductive track in the first level of the structure and a fifth conductive track in the second level of the structure.

5. The transformer of claim **4**, wherein the first conductive track of the first loop of the first inductor in the first level at least partially faces the fifth track of the first loop of the second inductor in the second level.

6. A method of manufacturing a transformer comprising, in a laminated structure, a first inductor and a second inductor, the method comprising:

forming, in a first level of the structure, of a first conductive track of a first loop of a first inductor;

forming, in a second level of the structure, of a second conductive track of the first loop, the first and second conductive tracks being adapted to being electrically connected to each other directly, or via an intermediate conductive track, over at least half a length of the first loop; and

wherein, over at least half the length of the first loop, the first and second conductive tracks are arranged so that, in a cross-section plane perpendicular to the length of the first loop, a center of mass of the first conductive track is laterally offset from the center of mass of the second conductive track in the cross-section plane, and in a direction parallel to the plane formed by the first level.

7. The method of claim **6**, wherein the first and second conductive tracks are connected to each other by the intermediate conductive track, the method further comprising, after the forming of the first conductive track and before the forming of the second conductive track, the forming of at least one via forming the intermediate conductive track on the first conductive track, the second conductive track being formed on the at least one via so that the first and second conductive tracks are electrically connected to each other via the at least one via.

8. The method of claim **6**, wherein the second conductive track comprises one or a plurality of vias, the method further comprising, after the forming of the second conductive track, the forming of a third conductive track on the second conductive track, the third conductive track being electrically connected to the second conductive track over at least half the length of the first loop.

9. The method of claim **6**, further comprising:

forming, in the first level of the structure, of a fourth conductive track of a first loop of the second inductor; and

forming, in the second level of the structure, of a fifth conductive track of the first loop of the second inductor.

10. The method of claim **9**, wherein the fifth track of the first loop in the second level is formed in such a way that the first conductive track of the first loop in the first level at least partially faces the fifth track of the first loop in the second level.

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