(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 662 870 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
13.11.2013 Bulletin 2013/46

(51) Int Cl.:
H01F 21/12 *(2006.01)*

(21) Application number: **12290160.6**

(22) Date of filing: **09.05.2012**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME

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(54) **Tunable inductive circuits for transceivers**

(57) Presented is a tunable inductive circuit for a transceiver, the circuit having an effective inductance that may be varied. The circuit comprises a primary inductive element and a secondary inductive element spaced apart from the primary inductive element. The secondary inductive element is adapted to be activated/deactivated by a switch so as to modify the effective inductance of the circuit.

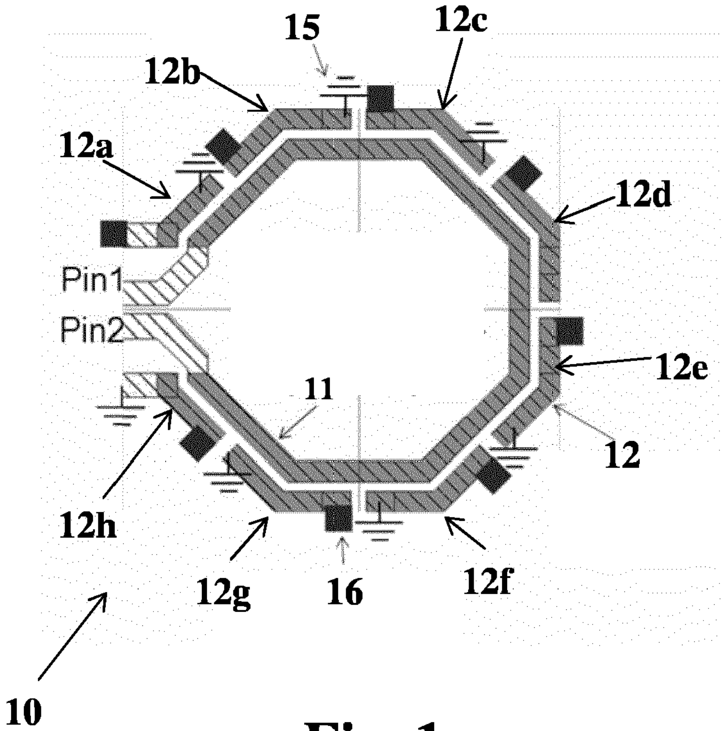

Fig. 1

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Description

[0001] This invention relates to tunable inductive circuits for transceivers.

[0002] Typical transceiver designs used in conventional wireless applications require high performance Voltage Controlled Oscillators (VCOs) with low phase noise in order to generate clean spectral oscillations that are used to modulate or de-modulate signals received or transmitted by an antenna.

[0003] Inductors fabricated on silicon using the back-end available in common CMOS processes are widely used in the design of the LC-tank of a VCO (in general a voltage controlled capacitance (varactor) is used to tune the frequency), but also in filters and other matching networks.

[0004] The realization of high performance VCOs with low phase noise at high frequencies requires large-size varactors and small inductors. The small size of an inductor is advantageous in terms of silicon occupation area, but can be difficult to realise.

[0005] The quality factor (Q-factor) of a spiral inductor is penalized by the proximity of the substrate. Different substrates have different resistivities, but the more common substrates have a resistivity of around 10-20ohm.cm which leads to current dissipation (due to the electromagnetic field generated by a spiral inductor). This dissipation is, in general, decreased by the use of a patterned shield fabricated in bars of lower metal layers (referred to as Metal 1) or polysilicon interconnected by a central bar. Such a patterned shield functions to control current dissipation (due to electric field generation) whilst enabling eddy currents to pass through the shield, thus avoiding the generation of opposite eddy currents that negatively impact the Q factor.

[0006] However, the use of such a patterned shield increases the capacitance of the spiral with the ground (if the shield is connected to ground) and reduces the Self Resonance Frequency (SRF) of the inductor. For this reason, it is known to arrange the shield to be floating (i.e. not connected to the ground) if an increase of the SRF is desired.

[0007] According to an aspect of the invention there is provided a tunable inductive circuit according to the independent claim.

[0008] According to another aspect of the invention there is provided a tunable inductive circuit for a transceiver, the circuit having an effective inductance that may be varied and comprising: a primary inductive element; and a secondary inductive element inductor spaced apart from the primary inductive element; wherein the secondary inductive element is adapted to be activated/deactivated by a switch so as to modify the effective inductance of the circuit.

[0009] Embodiments may therefore provide a high performance VCO that uses a small inductor and large varactors. The tuning of the inductor can be negative (in other words, activation of an increased number of tuning segments decreases the inductor value) which allows the use of higher-sized inductors. In other words, embodiments allow the realization of larger-sized inductors which have a negative variation and are suitable for the design of high performance VCOs.

[0010] The variable inductive arrangements presented may allow the realization of VCOs without varactors which can be replaced by backend capacitors for designs which operate in the RF range. Frequency control can then be realized digitally by the activation/deactivation of one or several secondary spiral inductors. These secondary spiral inductors may be positioned as close as practically possible to the primary inductive element used in a VCO so as to maximise the inductive coupling between the primary inductive element and the secondary spiral inductors.

[0011] The invention may therefore be particularly relevant to circuit design using advanced processes used for analogue and RF applications.

[0012] Embodiments present a primary inductive element having an effective inductance which can be modified by the activation/deactivation of secondary inductive elements coupled by mutual inductance to the primary inductive element. The inductive elements may be spiral inductors obtained as follows:

- The primary inductive spiral may be a conventional octagonal or "8-shaped" spiral inductor formed using a CMOS or BiCMOS process for RF applications.
- The secondary inductive spiral(s) may also be formed from a conventional spiral having a different than that of the primary inductive spiral, wherein the secondary inductive spiral(s) is/are placed as close as possible to the primary inductive spiral so as to maximize mutual coupling.
- The secondary inductive spiral(s) may be divided into several inductive segments, wherein each segment is connected to ground on one side and to a switch on the other side.

[0013] The switch may be a RFMOS switch with the drain connected to the inductive segment and the source connected to ground. The gate can then be used to control (activate/deactivate) the switch and, in tum, the associated inductive segment. In such an arrangement, the series resistance of the transistor in an off-state is very high (several Mega ohms, for example). With this high resistance, the associated inductive segment behaves like it is floating at one side and deactivates the inductive segment and thus removes its influence by mutual inductance to the inner spiral. Further, when the RF transistor is an on-state, the drain-source resistance has a negligible value and both terminals of an inductive segment are connected to ground. This leads to the activation of the inductive segment and thus modification of the effective inductance of the circuit.

[0014] Such modification of the effective inductance can be used to control the frequency of a VCO and, in this manner, enable control of the frequency. A tunable capacitor (varactor) may therefore no longer be required, or the tunable inductor circuit may be used to complement a tunable capacitor. Thus, in a given tuning band, VCO sensitivity (i.e. the step size or resolution of the tuning) could be dual-controlled by the varactor and the inductors, thereby improving frequency control accuracy. The phase noise of oscillators may also be improved for some frequency bands using such improved tuning flexibility (avoiding capacitor non-linearities and a region with an overall lower Q). Moreover, oscillations in different frequency bands may be generated by the use of the outer spirals per frequency band.

[0015] Embodiments may also provide an active shield to be used with the primary inductive element. Such an active shield may be obtained by the use of different elements such as:

- a Standard Shield (SS) with modifications at the central bar level which can transform the shield in several sub-shields; and
- a Spiral in Low Metal (SLM) layers under the primary inductive element.

[0016] These elements may be connected to the ground of the circuit by a RFMOS transistor on at least one side. The series resistance of the RFMOS transistor in off-state is very high (several Mega ohms, for example). With this high resistance, the shield behaves like a floating element. The modification of the shield element's behaviour has an impact on effective inductance which will vary according to whether the transistor is ON or OFF. Thus, when the RF transistor turns on, the effective inductance of is modified in a given frequency range, the initial value being reached again when the transistor is OFF.

[0017] Such modification of the inductance can be used to control the inductance value of inductors used in VCOs and, in this manner, control the frequency.

[0018] A tunable capacitor (varactor) may therefore no longer be required, or the tunable inductor element may be used complementary to a tuning capacitor. Thus, in a given tuning band, VCO sensitivity (i.e. the size of a tuning step) could be dual-controlled by a varactor and inductor(s), thereby enabling accurate frequency control. The phase noise of oscillators may also be improved for some frequency bands by this improved tuning flexibility (for example, by avoiding capacitor non-linearities and a region with an overall lower Q). Moreover, oscillations in different frequency bands can be generated by the use of the shield elements and use of a variable inductor per frequency band.

[0019] Control of the shield may also have an impact on SRF (e.g. modification of inductance induces a modification of the SRF). This effect can be advantageous for applications which require a modification of SRF.

[0020] Examples of the invention will now be described in detail with reference to the accompanying drawings, in which:

Figure 1 shows a tunable inductive circuit according to an embodiment of the invention;
Figure 2 is an equivalent circuit diagram of a tunable inductive circuit according to an embodiment of the invention;
Figure 3 is an equivalent circuit diagram of a VCO employing the tunable inductive circuit of Figure 1;
Figure 4 illustrates an alternative embodiment of a tunable inductive circuit;
Figure 5A is a graph showing the variation of effective inductance with the number of activated outer spiral inductor segments for the embodiment of Figure 4;
Figure 5B is a graph showing the variation of the Q factor with the number of activated outer spiral inductor segments for the embodiment of Figure 4;
Figure 6 illustrates a tunable inductive circuit according to another embodiment of the invention;
Figure 7 illustrates yet another embodiment wherein the spiral inductor segments are each combined with a MIM capacitor;
Figure 8 show a shield part of a tunable inductive circuit according to another embodiment of the invention;
Figure 9 illustrates a tunable inductive circuit according to the invention, wherein the shield of Figure 8 is provided in the lowermost metal layer L;
Figure 10 is an equivalent circuit of a VCO employing the variable inductive circuit of Figure 9
Figure 11A illustrates yet another embodiment of the invention;
Figure 11B is a graph showing the variation of the effective inductance with the number of activated quarter bars for the embodiment of Figure 11A;
Figure 12A-12C illustrate alternative embodiments of a secondary spiral inductor according to the invention;
Figures 13A and 13B show simulation results of yet another embodiment of the invention; and
Figure 14 shows a modification of the invention employing '8'-shaped inductors.

[0021] A tunable inductive circuit 10 according to first embodiment is shown in Figure 1. The inductive circuit comprises a primary inductive element 11 having an effective inductance which can be modified by the activation/deactivation of a secondary inductive element 12 which is coupled by mutual inductance to the primary inductive element 11. The primary inductive element 11 is a conventional octagonal-shaped spiral inductor formed using a CMOS or BiCMOS process for RF applications. The secondary inductive element 12 is also formed from a spiral inductor and has a larger inner diameter than the outer diameter of the primary inductive element 11. Here, the outer secondary inductive element 12 is placed as close as possible to (but spaced apart from) the primary inductive element 11 so as to maximize mutual coupling.

[0022] The secondary inductive element 12 is divided into eight (8) segments 12a-12h, wherein each segment is connected to ground 15 (i.e. zero (0) volts) at one end and to a switch 16 at the other end. Here, each switch is a RFMOS switch 16 with its drain connected to the respective segment 12a and its source connected to ground. The gate of the RFMOS switch 16 can thus be used to control (activate/deactivate) the switch 16 and, in turn, the associated segment.

[0023] In this arrangement, the series resistance of the RFMOS switch 16 in an off-state is very high (several Mega ohms, for example). With this high resistance, the associated segment 12a behaves like it is floating at one side and deactivates the associated segment 12a, thereby removing its influence by mutual inductance to the primary inductive element 11.

[0024] When the RFMOS switch 16 is an on-state, the drain-source resistance has a negligible value and both ends/terminals of the associated segment 12a are connected to ground. This leads to the activation of the segment 12 and modification of effective inductance of the tunable inductive element 10. In other words, the mutual inductance between the primary inductive element 11 and a segment 12a of the secondary inductive element 12 defines the inductance variation. Thus, it will be appreciated that activation/deactivation of the RFMOS switches can modify the effective inductance of the tunable inductive circuit 10.

[0025] By way of example only, use of such a tunable inductive circuit in a VCO can enable control of the frequency of the VCO. Thus, embodiments of the tunable indcutive circuit presented herein may allow the realization of VCOs without varactors which can be replaced by backend capacitors for designs in RF range. In such embodiments, the control of frequency may be employed by the activation/deactivation of one or several outer spiral segments.

[0026] From the above description, it will be understood that activation of a segment of the secondary inductive element 12 is realized by an RF switch (for example, a nMOSFET transistor) which connects an end terminal of the segment to the ground, wherein the other end terminal of the segment is permanently connected to the ground.

[0027] Different numbers of segments can be employed. For example, because the mutual inductance between the primary inductive element 11 and a segment 12a of the secondary inductive element 12 defines the inductance variation, the number of segment may be increased beyond eight to enable smaller variations in effective inductance to be realised. In other words, the number of segments of the secondary inductive element 12 can be increased to allow finer modification of the effective inductance.

[0028] An equivalent circuit of an embodiment is shown in Figure 2, wherein: Li is the inductance of the primary inductive element; Lo_x is the inductance of a single segment of the secondary inductive element; and Mx is the mutual inductance between the primary inductive element and a single segment of the secondary inductive element.

[0029] Accordingly, the effective inductance Leff seen at pins of the primary inductive element 12 may be represented by the following equation (i):

$$Leff - Li - \sum_{0}^{N} \frac{Mx^2}{Lo_x}\Big|_{activated} \qquad \text{(i)}$$

[0030] Thus, different numbers of activated segments will generate different values of Leff. With one of the terminals of segments of the secondary inductive element permanently grounded, the activation of a segment is realized when the second terminal is also connected to the ground (using an MOSFET switch for example).

[0031] It will be appreciated that an embodiment may employ only one segment for the secondary inductive element (i.e. a single spiral inductor). In such an embodiment, two effective inductance Leff values are obtainable.

[0032] A greater number of segments can be obtained through division of the secondary inductive element.

[0033] By way of example, Figure 3 is an equivalent circuit of a VCO 17 employing the tunable inductive circuit of Figure 1. Thus, the number N of The secondary inductive element segments in this example equals eight (8).

[0034] An alternative embodiment of a tunable inductive circuit comprising four secondary inductive element segments 12 is shown in Figure 4. This embodiment was simulated using an EM simulator.

[0035] To mimic the activation of segments, a ground connection was designed around the inductive elements and interconnections to the ground defined. The tunable inductive circuit was first simulated with each segment of the secondary inductive element 12 having only one terminal connected to the ground, then each second terminal of each segment have been grounded. A simulation with port1 and port2 defined on primary inductive element 11 pins was made for each segment interconnection. The simulations therefore gave the behaviour of the variable inductive circuit in the following states:

i. Effective inductance and Q factor when all segments of the secondary inductive element 12 are floating;
ii. Effective inductance and Q factor with one segment of the secondary inductive element 12 activated (connected to the ground at both extremities);
iii. Effective inductance and Q factor with two segments of the secondary inductive element 12 activated;
iv. Effective inductance and Q factor with three segments of the secondary inductive element 12 activated; and
v. Effective inductance and Q factor with all four segments of the secondary inductive element 12 activated.

[0036] The simulation results were taken at 11 GHz for differential inductance and quality factor.

[0037] Figures 5A and 5B illustrate the obtained simulation results. More specifically, Figure 5A shows the variation of the effective inductance with the number of activated segments of the secondary inductive element 12, and Figure 5B shows the variation of the Q factor with the number of activated segments of the secondary inductive element 12.

[0038] From the simulation results, it can be seen that activation of one more segment of the secondary inductive element 12 provides a decrease in effective inductance of between 3 and 8% compared to the previous state. Also, the Q factor exhibits a degradation of close to 35% when all the segments are activated. It therefore appears that when all the segments are activated, the variable inductive circuit is somehow "suffocated". It may therefore be recommended to use segments activated in only side of the secondary inductive element 12 if the Quality factor is an issue.

[0039] A primary inductive element with more than one turn can be employed in alternative embodiments to allow an increase of the mutual inductance between the primary inductive element and the secondary inductive element (segments).

[0040] Turning to Figure 6, yet another embodiment is shown, wherein the primary inductive element has secondary inductive element segments 22 positioned inside and outside of the approximate circle that it defines. In other words, an outer spiral inductor is provided outside of the spiral forming the primary inductive element 11, and an inner spiral inductor is provided inside the spiral forming the primary inductive element 11, wherein both the inner and outer spirals each comprise a plurality of mutually separated segments 22. Further, the outer spiral inductor has a larger inner diameter than the outer diameter of the primary inductive element 11, and the inner spiral inductor has a smaller outer diameter than the inner diameter of primary inductive element 11.

[0041] Placing spiral inductor segments 22 either side of the primary inductive element 11 allows an increase in the number of spiral inductor segments and an increase in the mutual inductance to be grounded. Here, fifteen (15) spiral inductor segments 22 are shown, but it will be appreciated that that number of segments can be modified in order to meet circuit requirements (such as maintaining an exploitable mutual inductance Mx and keeping the Quality factor within an acceptable range). Also, the size of length of the spiral inductor segments can be made different depending on the effective inductance variation steps required.

[0042] Figure 7 illustrates yet another embodiment wherein the spiral inductor segments are each combined with a MIM capacitor 24. In this case the effective inductance Leff of the variable inductor may be represented by the following equation (2):

$$Leff = Li + \sum \frac{[illegible]}{[illegible]} [illegible] \quad (2),$$

wherein C_{mim} is the capacitance of the MIM capacitor 24.

[0043] The use of MIM capacitors for some segments can provide more flexibility in inductance step control to allow fine tuning.

[0044] Referring to Figure 8, there is shown a shield 100 part of a tunable inductive circuit according to another embodiment of the invention. The shield 100 employs a standard shield element which is divided into four (4) parts 102a-102d. A central bar 105 connects shield slot members 110, the shield slot members 110 being arranged in a parallel spaced apart formation and perpendicular to the central bar 105. The central bar 105 is divided into four (4) separate bars (or quarter bars) 105a-105d, each bar being connected to a quarter of the shield slot members 110. Each quarter bar 105a-105d is connected to ground 115 via a switch 120 (such as a RFMOS).

[0045] Turning now to Figure 9, there is illustrated a tunable inductive circuit 122 according to the invention, wherein the shield 100 is provided in the lowermost metal layer L. The layer L used for shield can be metal or polysilicon.

[0046] Above the shield 100, there is provided a secondary spiral inductor 125 in a lower metal layer L+1 (i.e. in a layer labelled metal 2 if the shield is made in the layer labelled metal 1, or in metal 1 if the shield is in polysilicon).

[0047] Above the secondary spiral inductor 125 is a primary spiral inductor 130. The spiral inductor 125 in the lower metal layer L+1 is connected to the ground 115 at one end and at the other end is connected to ground 115 via a RFMOS transistor 135.

[0048] The secondary spiral inductor 125 in the lower metal layer L+1 may be obtained by designing a spiral similar to primary spiral inductor 130. The sizes (e.g. the inner diameter and width) of the secondary spiral inductor 125 in the lower metal layer L+1 may be similar to primary spiral inductor, wherein the sizes are chosen in view of a desired mutual inductance to be created between spirals 125 and 130.

[0049] A compromise may be made between the quality factor of the tunable inductive circuit and its capacity to be tuned when the secondary spiral inductor 125 is designed. For example, the proximity of the spirals 125 and 130 may generate crowding currents which degrade the quality factor. This degradation is typically more important when the mutual inductance between the spirals 125 and 130 is higher. Accordingly, the following two parameters may be important for mutual inductance calculation:

(i) the width of secondary spiral inductor 125 (which may be different from the width of the primary spiral inductor 130); and

(ii) and the layer used to realize the spiral inductor 125 - a layer closer to the layer used for the primary spiral inductor 130 will typically provide higher mutual inductance.

[0050] Thus, when the secondary spiral inductor 125 is designed, a calculation of mutual inductance between spirals 125 and 130 can be made.

[0051] However, the tuning of the variable inductive circuit 122 will be reduced to two states depending on whether the RFMOS transistor 135 is ON or OFF.

[0052] When the transistor 135 is in an ON state, the secondary spiral inductor 125 is connected to the ground at both sides and generates a short circuit of the primary spiral inductor 130 through the mutual inductance that exists between spiral inductors 125 and 130. When the transistor 135 is in the OFF state, only the parasitic capacitance between spirals has an impact on overall behaviour of spiral inductors 125 and 130.

[0053] A RF module that treats/generates RF signals (such as a VCO, for example) and uses inductors can generate perturbations on silicon ground. For non-ideal silicon grounds (i.e. those affected by perturbations), electromagnetic (EM) shield elements can be used to mitigate the impact of generated perturbations.

[0054] Thus, when the EM shield elements are active (i.e, switches 120 are on), the shield 100 is at ground and the amplitude of perturbations induced in the silicon ground are increased. This is due to the coupling that exists between the spiral inductors 125 and 130 and the shield 100. When shield elements are inactive (i.e. when switches 120 are off), the shield 100 is left floating and a smaller ratio of the perturbations is coupled into the silicon ground.

[0055] In other words, switching ON or OFF of the quarter bars 105a-105d of the shield 100 generates a shift of the SRF frequency due to modification of the capacitance between the shield 100 and the secondary spiral inductor 125 under the primary spiral inductor 130. This modification may therefore be used to tune the effective inductance of the variable inductive circuit 122.

[0056] Figure 10 is an equivalent circuit of a VCO 150 employing the variable inductive circuit of Figure 9.

[0057] An embodiment comprising a primary spiral inductor having two turns with an inner diameter of 100μm, 10μm width and 3μm spacing (as shown in Figure 11A) has been simulated with a commercial EM simulator. Figure 11B illustrates the obtained simulation results. More specifically, Figure 11B shows the variation of the effective inductance with the number of activated quarter bars 105a-105d of the shield 100.

[0058] To improve the number of tuning steps, alternative embodiments of the secondary spiral inductor may be proposed as illustrated in Figures 12A-12C

[0059] Figure 12A illustrates an embodiment of a variable inductive circuit 122a where: the primary spiral inductor 130 is formed in the sixth metal layer (i.e. metal 6, M6); the secondary spiral inductor 125a is formed in the second metal layer (i.e. metal 2, M2); and the shield 100a is formed in the first metal layer (i.e. metal 1, M1) and left floating. The secondary spiral inductor 125a is connected to ground via a MOSFET switch 135a and so switching the MOSFET 135a between ON and OFF states switches the effective inductance of the variable inductive circuit 122a between two respective values.

[0060] Figure 12B illustrates another embodiment of a variable inductive circuit 122b where: the primary spiral inductor 130b is formed in the sixth metal layer (i.e. metal 6, M6); the secondary spiral inductor 125b is formed in the second metal layer (i.e. metal 2, M2); and the shield 100b is formed in the first metal layer (i.e. metal 1) and left floating. Here, the secondary spiral inductor 125b is split into two spiral segments $125b_1$ and $125b_2$, each of which are connected to ground via an associated MOSFET switch $135b_1$ and $135b_2$. Switching the MOSFET switches $135b_1$ and $135b_2$ between ON and OFF states in various combinations therefore enables switching of the effective inductance of the variable inductive circuit 122b between four respective values.

[0061] Figure 12C illustrates yet another embodiment of a variable inductive circuit 122c where: the primary spiral inductor 130c is formed in the sixth metal layer (i.e. metal 6); the secondary spiral inductor 125c is formed in the second and third metal layers (i.e. metal 2 and metal 3); and the shield 100c is formed in the first metal layer (i.e, metal 1) and left floating. Here, the secondary spiral inductor 125c is split into three spiral segments $125c_1$,$125c_2$ and $125c_3$, each of which are connected to ground via an associated MOSFET switch $135c_1$, $135c_2$ and $135c_3$. More specifically, two spiral segments $125c_1$ and $125c_2$ are formed in the second metal layer (metal 2), whereas the third spiral segment $125c_3$ is formed in the third metal layer (metal 3). Switching the MOSFET switches $135c_1$, $135c_2$ and $135c_3$ between ON and OFF states in various combinations therefore enables switching of the effective inductance of the variable inductive circuit 122b between eight respective values.

[0062] It will be understood that similar arrangements can be made without a shield or employing a polysilicon shield.

[0063] Investigations have shown that embodiments can provide a variation of inductance up to 5% at 15GHz for a SRF frequency higher than 25GHz in differential mode.

[0064] Simulation results of an embodiment of the invention are shown in the graphs of Figure 13A and 13B. The simulated embodiment employed a primary spiral inductor having a single turn an inner diameter of 100μm and 10μm width. The secondary spiral inductor was formed in the second metal layer (i.e. metal 2) and had a width of 20μm. A shield was employed in the first metal layer (i.e. metal 1). The variation of the inductance and quality factor was measured versus frequency for when the RFMOS connecting the secondary spiral inductor to ground is in ON and OFF states. As can be seen from the graph of Figure 13A, the variation of the inductance is higher than 25% at 5GHz when the RFMOS switch between ON and OFF states.

[0065] Various modifications will be apparent to those skilled in the art.

[0066] For example, a modified embodiment employing '8'-shaped inductors is shown in Figure 14. Here, the secondary 8-shaped inductor 140 is formed in the first metal layer (i.e. metal 1) using two octagonal spiral inductors 140a and 140b. The '8'-shaped inductor is connected to ground via transistors 145 placed at the top and bottom of the '8'-shape.

Claims

1. A tunable inductive circuit (10) for a transceiver, the circuit having an effective inductance that may be varied and comprising:

   a primary inductive element (11); and
   a secondary inductive element (12) spaced apart from the primary inductive element so as to be coupled by mutual inductance to the primary inductive element;
   wherein the secondary inductive element is connected to a reference voltage (15) via a switch (16), such that the switch is adapted to modify the effective inductance of the circuit when switched between first and second operating states.

2. The tunable inductive circuit of claim 1, wherein the secondary inductive element (12) is divided into a plurality of inductive segments (12a-12h), and wherein at least one the plurality of inductive segments (12a-12h) is connected to the reference voltage (15) at one end and connected at the other end to the reference voltage via the switch (16).

3. The tunable inductive circuit of claim 1 or 2, wherein the switch is a MOS switch having its drain connected to the secondary inductive element (12) and its source connected to the reference voltage (15) such that the gate is adapted control the operating state of the MOS switch.

4. The tunable inductive circuit of any preceding claim, wherein at least one of the primary (11) and secondary (12) inductive elements is a spiral inductor.

5. The tunable inductive circuit of claim 4, wherein the at least one of the primary (11) and secondary (12) inductive elements is formed from an octagonal or '8'-shaped spiral.

6. The tunable inductive circuit of any preceding claim, wherein the size of primary inductive element (11) is different from the size of the secondary inductive element (12) in at least one dimension.

7. The tunable inductive circuit of any preceding claim, further comprising an electromagnetic, EM, shield (100) spaced apart from the primary inductive element so as to be coupled by mutual inductance to the primary inductive element, wherein the EM shield is connected to a shield reference voltage (115) via a second switch (120), such that the second switch is adapted to modify the effective inductance of the circuit when switched between first and second operating states.

8. The tunable inductive circuit of claim 7, wherein the EM shield (100) is formed in a first layer and the primary inductive element (11) is formed in a second layer, the second layer being above the first layer.

9. The tunable inductive circuit of claim 7 or claim 8, wherein the EM shield (100) is divided into a plurality of shield segments (102a-102d), and wherein at least one the plurality of shield segments is connected to the shield reference voltage (115) at one end and connected at the other end to the shield reference voltage via the second switch (120).

10. A varactor comprising a tunable inductive circuit according to any preceding claim.

11. A voltage controlled oscillator comprising a tunable inductive circuit according to any preceding claim.

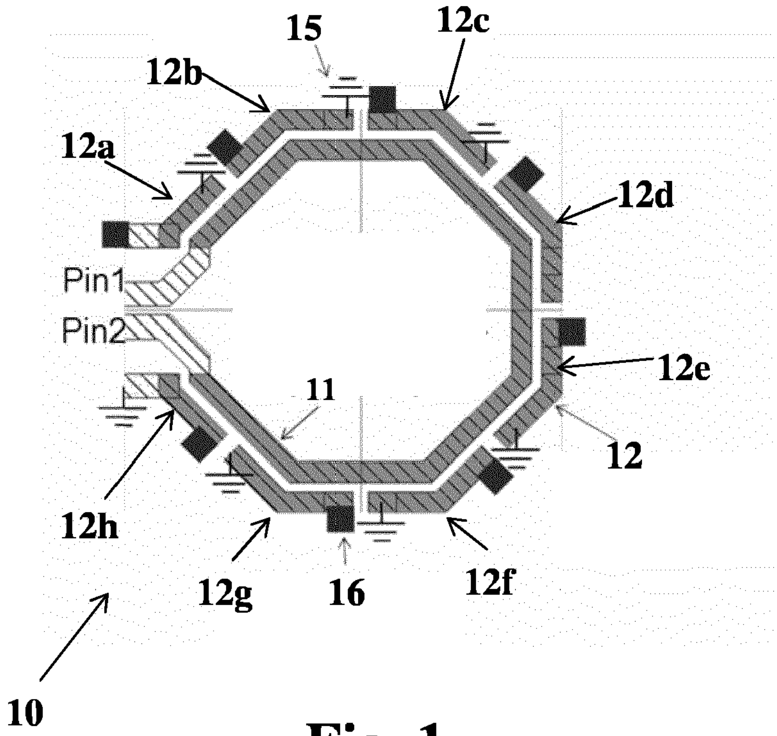


Fig. 1

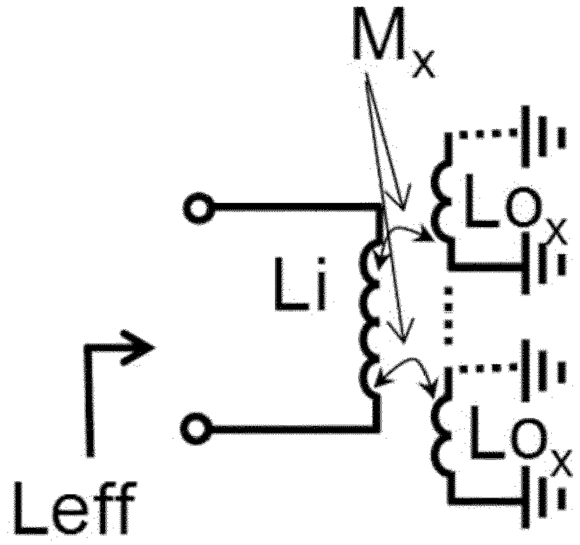


Fig. 2

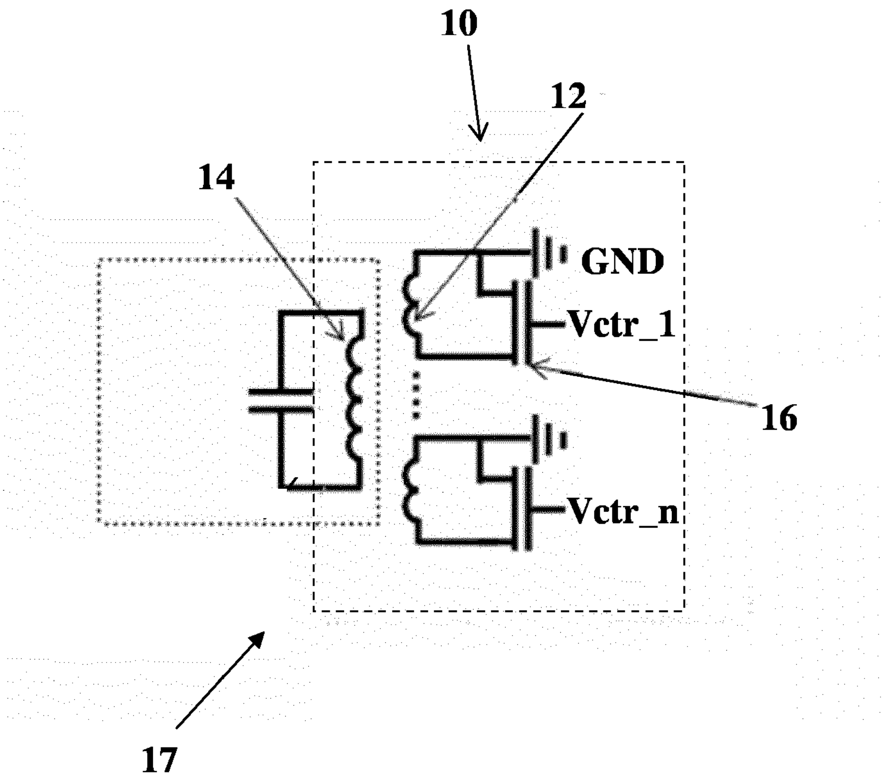


Fig. 3

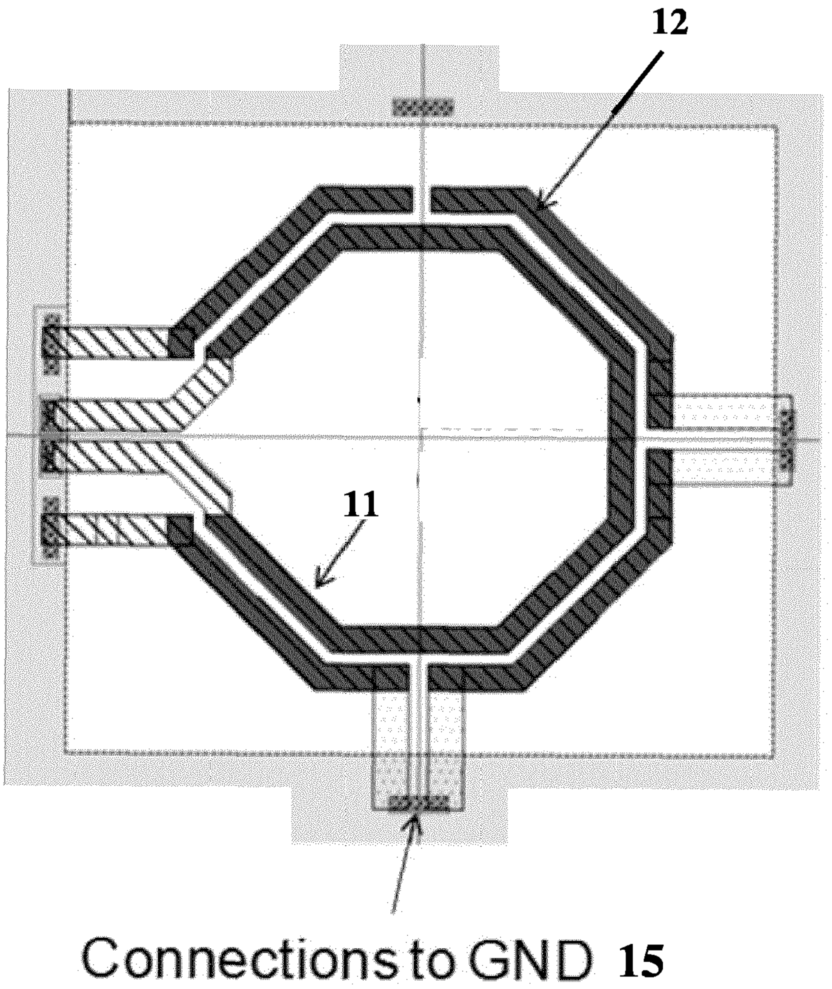


Fig. 4

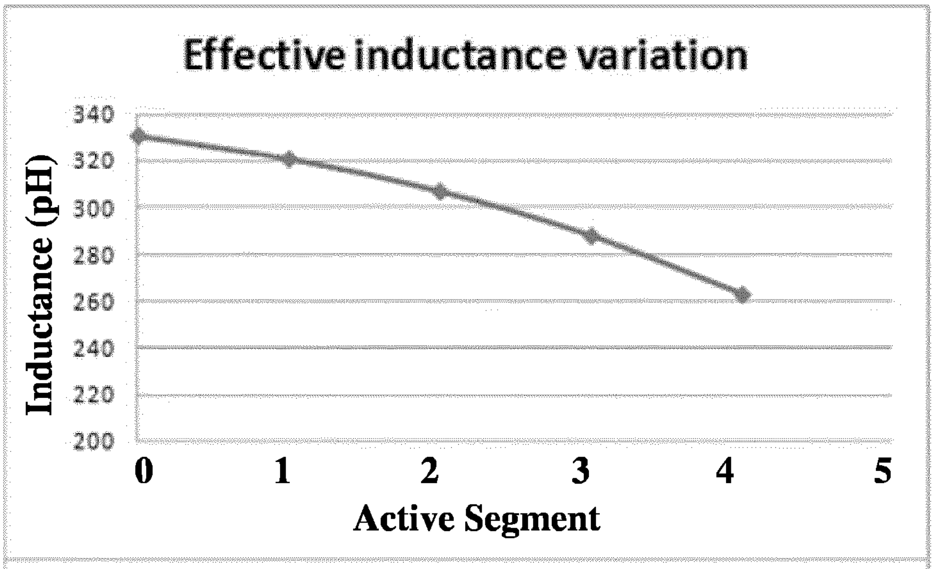

Effective inductance variation
Inductance (pH)
340
320
300
280
260
240
220
200
0
1
2
3
4
5
Active Segment

Fig. 5A

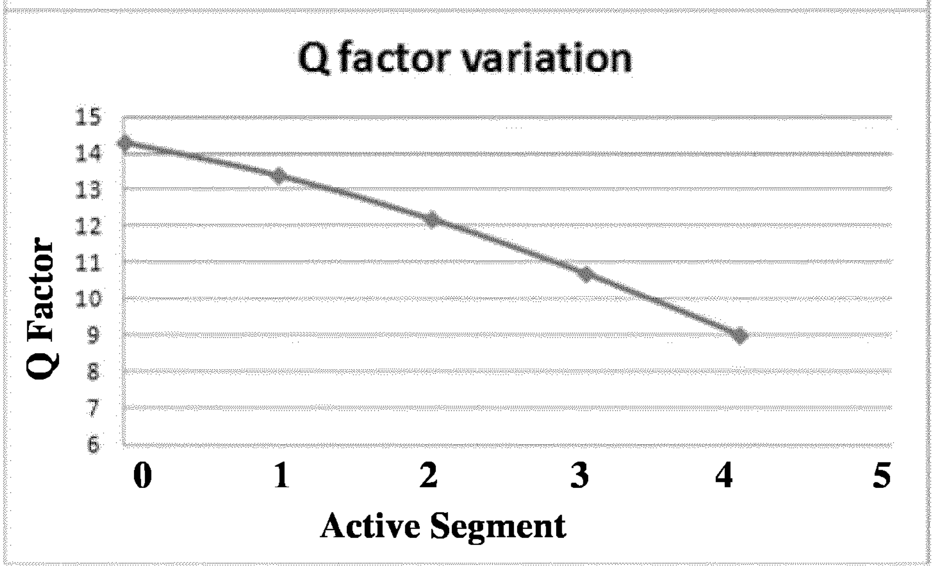

Q factor variation
Q Factor
15
14
13
12
11
10
9
8
7
6
0
1
2
3
4
5
Active Segment

Fig. 5B

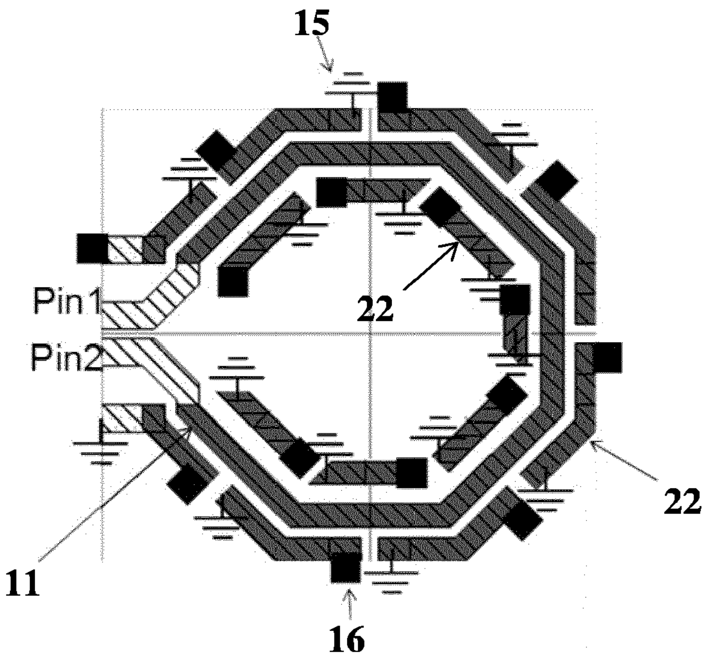


Fig. 6

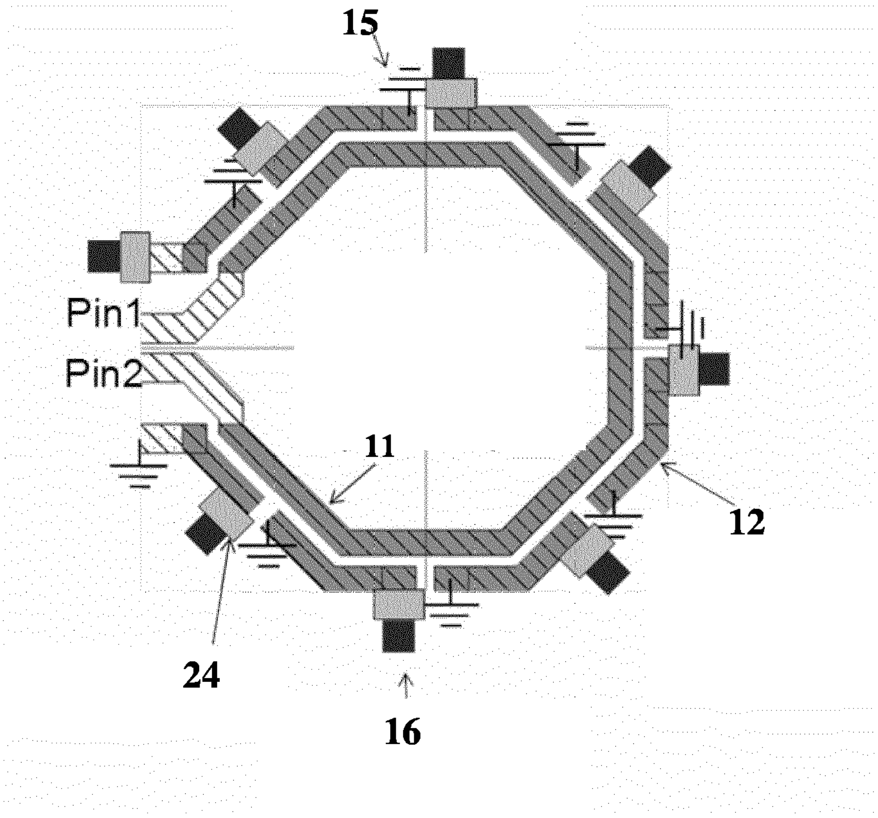
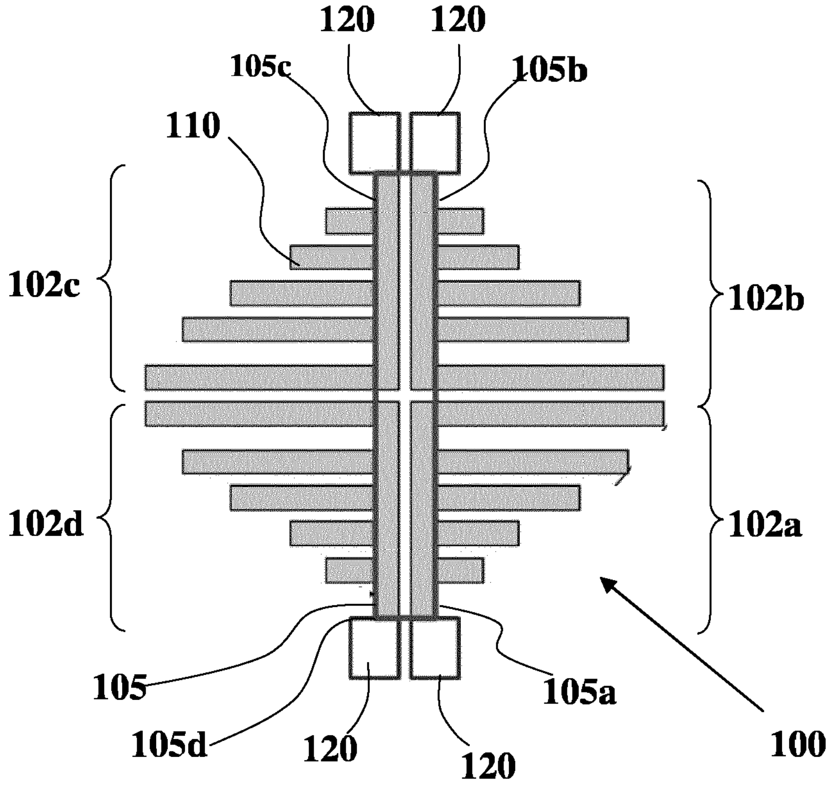


Fig. 7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120
105c
105b
110
102c
102b
102d
102a
105
105a
105d
120
120
100

Fig. 8

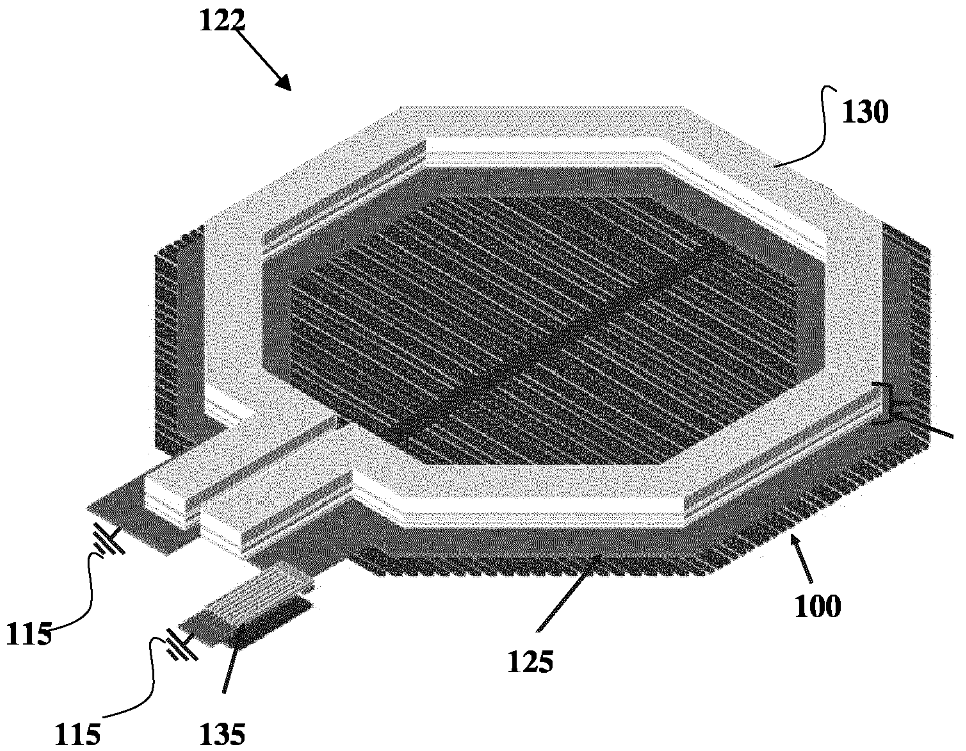

Fig.9

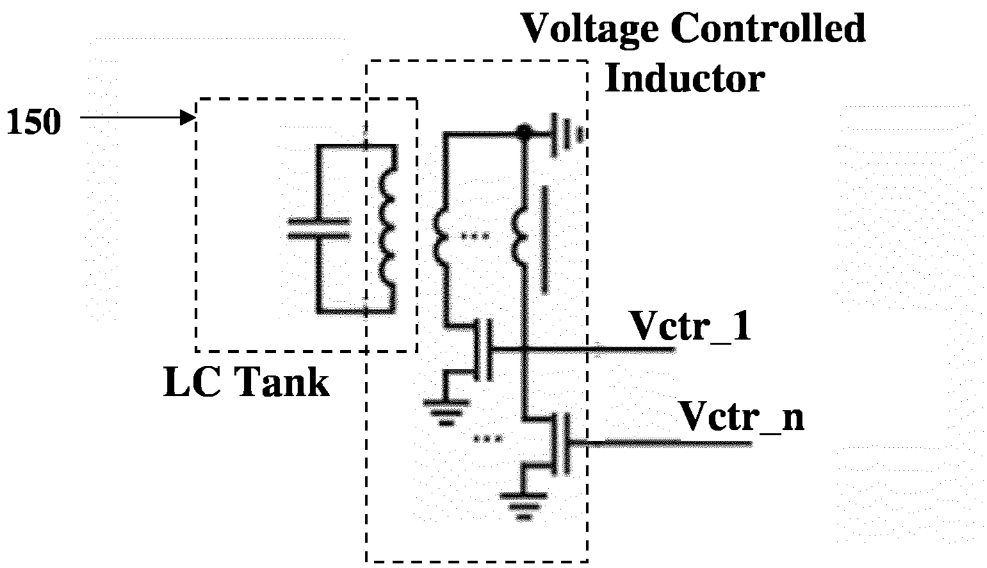

Fig.10

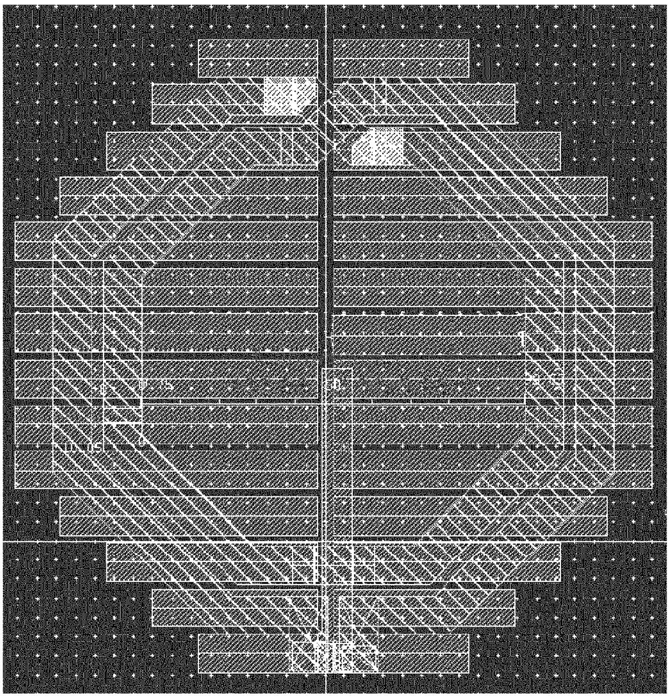

Fig.11A

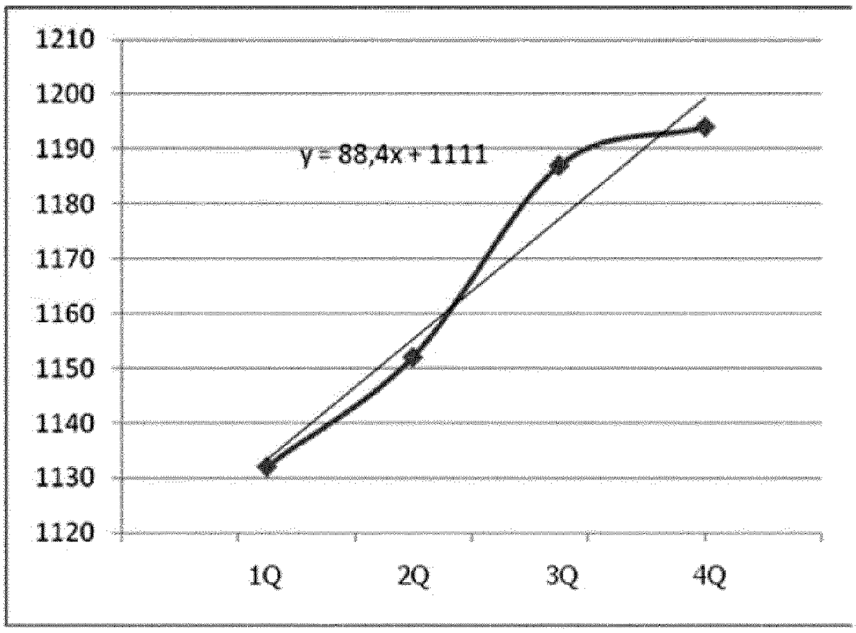

Fig.11B

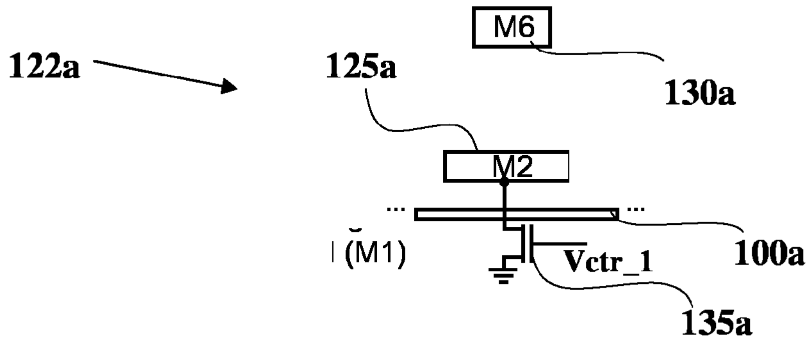

Fig.12A

Vctr_1

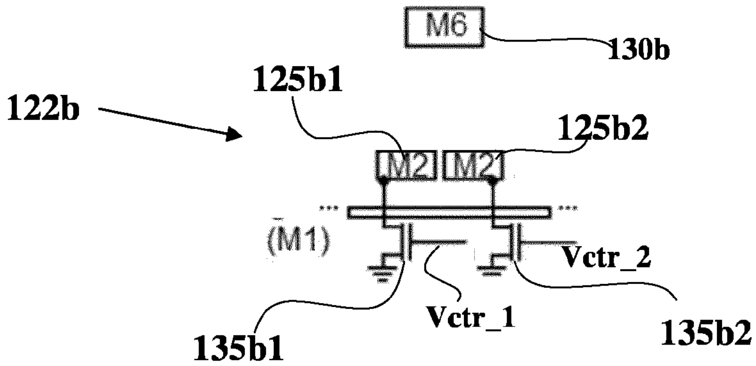

Fig.12B

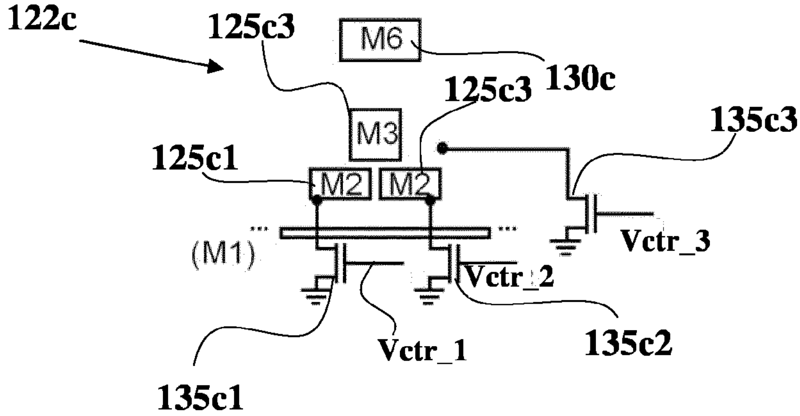

Fig.12C

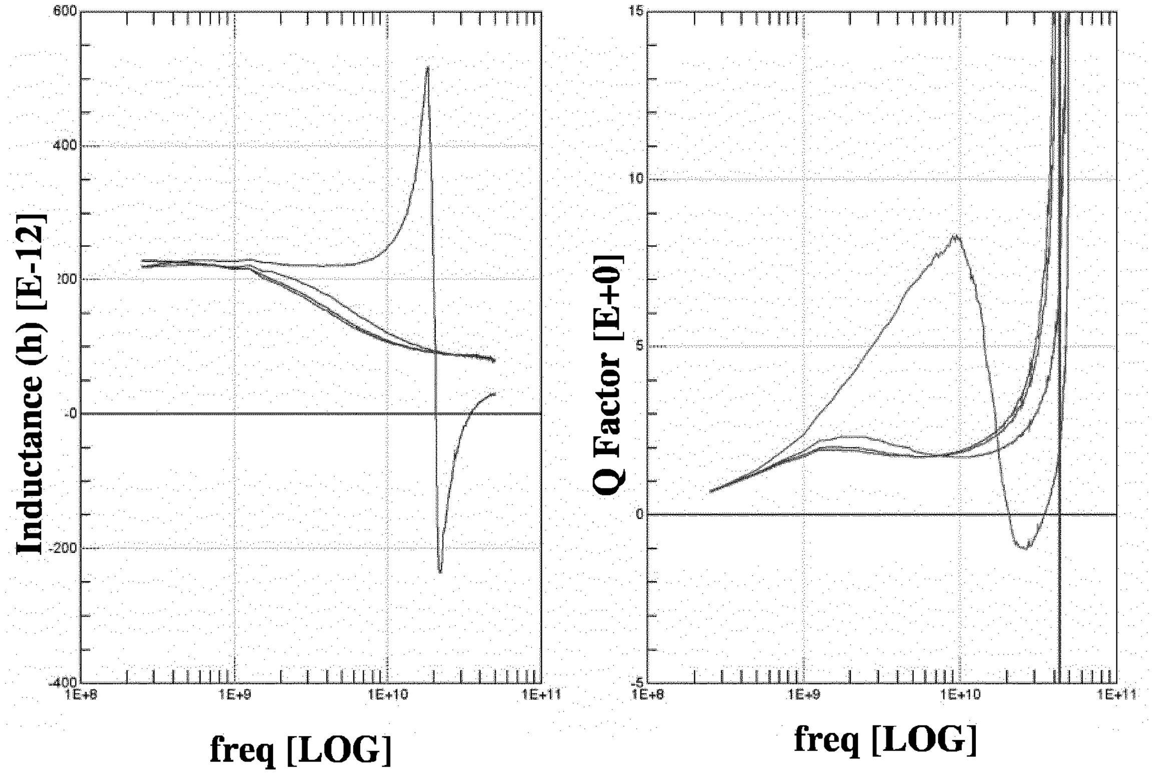
600
400
200
0
-200
-400
Inductance (h) [E-12]
1E+8
1E+9
1E+10
1E+11
freq [LOG]
15
10
5
0
-5
Q Factor [E+0]
1E+8
1E+9
1E+10
1E+11
freq [LOG]

Fig.13

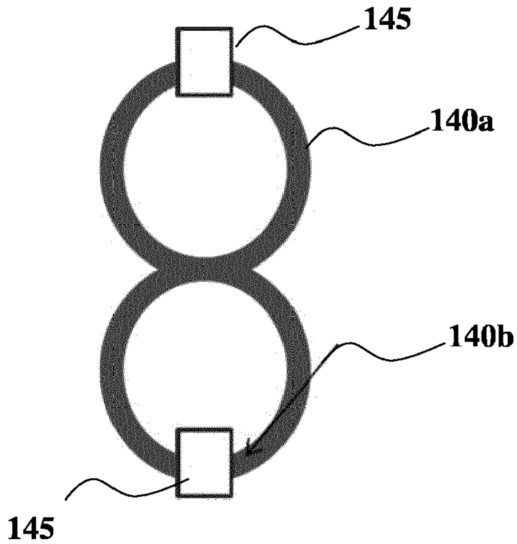

Fig.14

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EUROPEAN SEARCH REPORT

Application Number
EP 12 29 0160

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 7 298 238 B1 (EATON DERAN S [US] ET AL) 20 November 2007 (2007-11-20) * abstract * * column 4, line 1 - line 60; claim 1; figures 1,2 * -----	1-11	INV. H01F21/12
X	US 2005/068146 A1 (JESSIE DARRYL [US]) 31 March 2005 (2005-03-31) * abstract * * paragraph [0038] - paragraph [0043]; figures 3A-3C * * paragraph [0079] - paragraph [0087]; figures 10-11 * -----	1-11	
X	US 2007/085649 A1 (PARK BOOK SUNG [KR]) 19 April 2007 (2007-04-19) * abstract * * paragraph [0028] - paragraph [0039]; figures 2,3,10-13 * * paragraph [0051] - paragraph [0055] * -----	1-11	
X	US 2008/136572 A1 (AYAZI FARROKH [US] ET AL) 12 June 2008 (2008-06-12) * abstract * * claims 1,2 * -----	1-6	TECHNICAL FIELDS SEARCHED (IPC) H01F

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	26 September 2012	Warneck, Nicolas

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26-09-2012

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