

Request for grant of a European patent

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1 Application number:	MKEY	MKEY - EP19183992.7
2 Date of receipt (Rule 35(2) EPC):	DREC	DREC - 02 Jul 2019
3 Date of receipt at EPO (Rule 35(4) EPC):	RENA	
4 Date of filing:		

5 Grant of European patent, and examination of the application under Article 94, are hereby requested, ☒

5.1 The applicant waives his right to be asked whether he wishes to proceed further with the application (Rule 70(2)) ☐

Procedural language:

Description and/or claims filed in:

A translation will be supplied later:

☐

6 Applicant's or representative's reference

P19235 EP3

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14.1 The/Each applicant hereby declares that he is an entity or a natural person under Rule 6(4) EPC. ☐

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A general authorisation has been registered under No.:

632360

Inventor(s)

23

Inventor details filed separately



24

Title of invention

Title of invention:

METHOD OF AND INDUCTOR LAYOUT FOR
REDUCED VCO COUPLING

25

Declaration of priority (Rule 52)

A declaration of priority is hereby made for the following applications:

25.2

The EPO is requested to retrieve a certified copy of the following previous application(s) (priority document(s)) via the WIPO Digital Access Service (DAS) using the indicated access code(s):

25.3

This application is a complete translation of the previous application



25.4

It is not intended to file a (further) declaration of priority



26

Reference to a previously filed application

27

Divisional application



Application number of earlier application:

EP14172888.1

Date of Filing (Art. 80/Rule 40 EPC):

15 February 2005

27.1

This divisional application is of the following generation:



1



2



3



4



5 or subsequent

28

Article 61(1)(b) application



29 Claims

Number of claims:

13

29.1

☒ as attached

29.2

☐ as in the previously filed application (see Section 26.2)

29.3

☐ The claims will be filed later

30 Figures

It is proposed that the abstract be published together with figure No.

2

31 Designation of contracting states

All the contracting states party to the EPC and valid for the parent application at the time of filing of this divisional application are deemed to be designated (see Article 76(2)).

32 Different applicants for different contracting states

33 Extension/Validation

This application is deemed to be a request to extend the effects of the European patent application and the European patent granted in respect of it to all non-contracting states to the EPC with which extension or validation agreements are in force on the date on which the application is filed. However, the request is deemed withdrawn if the extension fee or the validation fee, whichever is applicable, is not paid within the prescribed time limit.

33.1 It is intended to pay the extension fee(s) for the following state(s):

33.2 It is intended to pay the validation fee(s) for the following state(s):

34 Biological material

38 Nucleotide and amino acid sequences

The European patent application contains a sequence listing as part of the description

☐

The sequence listing is attached in computer-readable format in accordance with WIPO Standard ST.25

☐

The sequence listing is attached in PDF format

☐

Further indications

39 Additional copies of the documents cited in the European search report are requested

Number of additional sets of copies:

40 Refund of the search fee under to Article 9 of the Rules relating to Fees is requested

☐

Application or publication number of earlier search report:

42 Payment

Method of payment:

Debit from deposit account

The European Patent Office is hereby authorised, to debit from the deposit account with the EPO any fees and costs indicated on the fees section below.

Currency:

EUR

Deposit account number:

28100100

Account holder:

Ericsson AB

43 Refunds

Any refunds should be made to EPO deposit account:

28100100

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Fees	Factor applied	Fee schedule	Amount to be paid
001 Filing fee – EP direct – online	1	120.00	120.00
002 Fee for a European search - Applications filed on/after 01.07.2005	1	1 300.00	1 300.00
005e Designation fee - For all contracting States designated for applications filed on/after 01.04.2009	1	585.00	585.00
006 Examination fee - For applications filed on/after 01.07.2005	1	1 635.00	1 635.00
033 Renewal fee for the 3rd year	1	470.00	470.00
034 Renewal fee for the 4th year	1	585.00	585.00
035 Renewal fee for the 5th year	1	820.00	820.00
036 Renewal fee for the 6th year	1	1 050.00	1 050.00
037 Renewal fee for the 7th year	1	1 165.00	1 165.00
038 Renewal fee for the 8th year	1	1 280.00	1 280.00
039 Renewal fee for the 9th year	1	1 395.00	1 395.00
040 Renewal fee for the 10th year	1	1 575.00	1 575.00
041 Renewal fee for the 11th year	1	1 575.00	1 575.00
042 Renewal fee for the 12th year	1	1 575.00	1 575.00
043 Renewal fee for the 13th year	1	1 575.00	1 575.00
044 Renewal fee for the 14th year	1	1 575.00	1 575.00
045 Renewal fee for the 15th year	1	1 575.00	1 575.00
552 Additional fee for divisional 2nd generation	1	210.00	210.00
Total:		EUR 20 065.00	

44-A Forms

Details:

System file name:

A-1

Request

as ep-request.pdf

A-2

1. Designation of inventor

1. Inventor

as f1002-1.pdf

44-B Technical documents

Original file name:

System file name:

B-1

Specification

 P19235_EP3_2019-06-17_divisional_text_to_be
_filed.pdf
Description; 13 claims; abstract

B-2

Specification

 P19235_EP3_2019-06-17_divisional_drawings_SPECEPO-2.pdf
to_be_filed.pdf
13 figure(s)

45

General authorisation:

46 Signature(s)

Place: Lund Sweden

Date: 02 July 2019

Signed by: /Ola Andersson/

Association: Ericsson

Representative name: Ericsson

Capacity: (Representative 1)

METHOD OF AND INDUCTOR LAYOUT FOR REDUCED VCO COUPLING

Field of the invention

The present invention relates to voltage-controlled oscillators (VCO) of the type used in
5 radio frequency (RF) transceivers and, in particular, to an improved inductor design in a
VCO.

Background of the invention

Recent advances in wireless communication technology have allowed an entire RF
transceiver to be implemented on a single semiconductor die or chip. However, integrating a
10 complete RF transceiver on a single chip presents a number of challenges. For example, in
wideband code division multiple access (WCDMA) transceivers, a single-chip solution
requires two RF VCOs to be running on the chip at the same time. Such an arrangement may
produce undesired interaction between the two VCOs due to various types of mutual coupling
mechanisms, which may result in spurious receiver responses and unwanted frequencies in the
15 transmit spectrum. The primary mutual coupling mechanism is usually the fundamental
electromagnetic (EM) coupling between the resonators, i.e., the large inductor structures in
the VCOs.

A number of techniques exist for reducing the mutual EM coupling between the VCOs due
to the inductors. One technique involves reduction of EM coupling by careful design of the
20 inductors to provide maximum isolation of the inductors. Another technique calls for
frequency separation by operating the two VCOs at different even harmonics of the desired
frequency. Still another technique involves frequency separation by using a regenerative VCO
concept. The frequency separation methods exploit the filtering properties of the resonator to
reduce interference. However, these solutions require additional circuitry (dividers, mixers,
25 etc.) that may increase current consumption, making them less attractive than other mutual
EM coupling reduction alternatives.

WO 2004/012213 A1 discloses a planar inductance with planar spiral windings, wherein
each winding is in the form of an "eight" with three cross-conductors carrying current in the
same direction and running between two loops.

30 Summary of the invention

An inductor design for reducing mutual EM coupling between VCO resonators and a
method of implementing the same on a single semiconductor chip. A method and system

involve using inductors that are substantially symmetrical about their horizontal and/or their vertical axes and providing current to the inductors in a way so that the resulting magnetic field components tend to cancel each other by virtue of the symmetry. In addition, two such inductors may be placed near each other and oriented in a way so that the induced current in
5 the second inductor due to the magnetic field originating from first inductor is significantly reduced. The inductors may be 8-shaped, four-leaf clover-shaped, single-turn, multi-turn, rotated relative to one another, and/or vertically offset relative to one another.

In general, in one aspect, an inductor having a reduced far field comprises a first loop having a shape that is substantially symmetrical about a first predefined axis, and a second
10 loop having a size and shape substantially identical to a size and shape of the first loop. The second loop is arranged such that a magnetic field emanating therefrom tends to cancel a magnetic field emanating from the first loop.

In general, in another aspect, a method of reducing mutual electromagnetic coupling between two inductors on a semiconductor die comprises the step of forming a first inductor
15 on the semiconductor die having a shape that is substantially symmetrical about a first predefined axis, the shape causing the first inductor to have a reduced far field, at least in some directions. The method further comprises the step of forming a second inductor on the semiconductor die at a predetermined distance from the first inductor, wherein a mutual electromagnetic coupling between the first inductor and the second inductor is reduced as a
20 result of the first inductor having a reduced far field.

In general, in another aspect, an inductor layout having reduced mutual electromagnetic coupling comprises a first inductor having a shape that is substantially symmetrical about a first predefined axis, the shape causing the first inductor to have a reduced electromagnetic field at a certain distance from the first inductor, at least in some directions. The inductor
25 layout further comprises a second inductor positioned at a predetermined distance from the first inductor, wherein a mutual electromagnetic coupling between the first inductor and the second inductor is reduced as a result of the first inductor having a reduced electromagnetic field.

It should be emphasized that the term comprises/comprising, when used in this
30 specification, is taken to specify the presence of stated features, integers, steps, or components, but does not preclude the presence or addition of one or more other features, integers, steps, components, or groups thereof.

Brief description of the drawings

The foregoing and other advantages of the invention will become apparent from the following detailed description and upon reference to the drawings, wherein:

- FIGURE 1 illustrates a prior art O-shaped inductor;
- 5 FIGURE 2 illustrates an 8-shaped inductor;
- FIGURE 3 illustrates a prior art O-shaped inductor arrangement;
- FIGURE 4 illustrates an 8-shaped inductor arrangement;
- FIGURE 5 illustrates an 8-shaped inductor arrangement wherein one inductor is rotated;
- FIGURE 6 illustrates the impact of distance on EM coupling using the 8-shaped inductor
- 10 arrangement;
- FIGURE 7 illustrates an 8-shaped inductor arrangement wherein one inductor is offset from the other inductor;
- FIGURE 8 illustrates the impact of distance on decoupling coefficient using the inductor arrangements;
- 15 FIGURE 9 illustrates a VCO layout wherein symmetry is retained;
- FIGURE 10 illustrates a four-leaf clover shaped inductor;
- FIGURE 11 illustrates a four-leaf clover shaped inductor arrangement;
- FIGURE 12 illustrates the impact of distance on EM coupling using the four-leaf clover shaped inductor arrangement; and
- 20 FIGURE 13 illustrates a two-turn 8-shaped inductor.

Detailed description of illustrative embodiments of the invention

As mentioned above, various embodiments of the invention provide an inductor design and method of implementing the same where mutual EM coupling is reduced. The inductor design and method serve to reduce the EM field at a certain distance from the inductor (i.e., the far

25 field), at least in some directions, by using inductor shapes that are substantially symmetrical. As used herein, the term "symmetrical" refers to symmetry relative to at least one axis. This reduced far field may then be used to reduce the mutual coupling between two inductors. The inductor design and method may also be used to reduce the coupling between an inductor and another on-chip or external structure (e.g., an external power amplifier). This helps reduces

30 the sensitivity of the VCO to interfering signals from other than a second on-chip VCO.

Choosing a substantially symmetrical shape (e.g., a figure-8 or a four-leaf clover shape) for the first inductor helps reduce the EM field at far distances. This will, in turn, reduce mutual EM coupling to the second inductor, regardless of its shape. If the second inductor also has a

similar or substantially identical shape, the tendency of the second inductor to pick up the EM field from the first inductor is also reduced via the same mechanisms. Thus, the overall isolation between the two inductors is further improved. Note, however, that the two inductors need not have the same size or the same shape as long as they have a substantially symmetrical shape. To the extent identical inductor layouts are shown in the figures, it is for illustrative purposes only.

Further, although various embodiments of the invention are described herein mainly with respect to VCO-related isolation issues, RF amplifiers and mixers with tuned LC loads or inductive degeneration may also couple to each other or to a VCO and create interference problems. Thus, a person having ordinary skill in the art will appreciate that the inductor design and method may be used to reduce coupling between two functional blocks of any type so long as each contains one or more inductors.

In order to reduce EM coupling between two inductors, it is typically necessary to reduce the far field generated by the inductor coils. Unfortunately, this is not a simple task because there are many topological constraints on a planar integrated inductor. For example, a typical inductor design uses two or more stacked metal layers. Normally the top layer is much thicker (i.e., has lower resistance) than the other layers. It is therefore desirable to mainly use this layer in order to achieve a maximum Q-factor. Where the wires are crossing, thinner metal layers are usually used and careful design of the crossings is needed to combine high Q-factor with minimum coupling. Further, negative electromagnetic coupling between parallel wire segments close to each other should be avoided so that the inductance per wire length unit is maximized. However, by exploiting the symmetry of the inductor in one or more dimensions together with controlling the EM field components emanating from different parts of the inductor coil, the far field may be reduced in some directions due to canceling effects.

Existing VCO inductor designs are optimized for maximum Q-factor given the constraints regarding silicon area, wire width, and the like. FIGURE 1 shows an example of an existing inductor 100 commonly used in RF VCOs. The inductor 100 is a differential 1.25 nH inductor with an inductor coil 102 having two terminals 104. As can be seen, the positions of the terminals 104a and 104b have been optimized for connection to the rest of the VCO, including any varactors and MOS switches (not shown) that may be present, but little attention was paid to mutual EM coupling apart from keeping a certain minimum distance from other metal wires in the vicinity.

FIGURE 2 shows an example of an inductor 200. The inductor 200 has an inductor coil 202 and terminals 204a and 204b, and has been designed so that it is substantially

symmetrical about a horizontal axis X. In the present example, the inductor coil 202 is in the form of a single-turn 8-shaped structure with an upper loop 206a and a lower loop 206b. By virtue of the figure-8 shape, current in the upper loop 206a travels in a direction (e.g., counterclockwise, see arrows) that is opposite to current in the lower loop 206b (e.g., clockwise). As a result, the EM field components emanating at a certain distance from the two substantially symmetrical loops 206a and 206b also have opposite directions and tend to counteract each other. The directions of the EM field components are indicated by conventional notation in the middle of each loop 206a and 206b. Consequently, the inductor 200 has been found to have a significantly reduced far field at a certain distance from the inductor coil 202. Thus, by making the two loops 206a and 206b substantially symmetrical, cancellation of a significant amount of far field on either side of the horizontal symmetry axis X may be achieved. It should be noted, however, that perfect symmetry between the two loops 206a and 206b may be difficult to achieve given the presence of the terminals 204a and 204b.

In addition, the positioning of the terminals 204a and 204b may help minimize the far field. For example, positioning the two terminals 204a and 204b as close to each other as possible helps make the field contributions from the two parts of the inductor 200 identical. It is also desirable to minimize the additional loop external to the inductor 200 created by the connections to the varactors and switches. This extra loop may compromise the symmetry of the inductor itself to some extent and may reduce the canceling effect. In theory, it should be possible to modify the geometry of the inductor (e.g., make the upper loop slightly larger) to compensate for this effect. The symmetry of the inductor 200 with respect to a center vertical axis is also important for minimizing the generation of common-mode signal components.

Other considerations may include basic layout parameters, such as the width and height of the inductor coil 202 together with the width and spacing of the surrounding metal wires.

These parameters, however, are mainly determined by requirements on inductance, Q-factor, chip area, and process layout rules and have only minor influence on mutual coupling characteristics as long as symmetry of the inductor coil is maintained.

FIGURE 3 illustrates a prior art inductor arrangement of two O-shaped inductors 300 and 302. The two inductors 300 and 302 are placed side-by-side and have O-shaped inductor coils 304 and 306. The inductors coils 304 and 306 in this embodiment are substantially the same size as the 8-shaped inductor coil (e.g., 350 x 350 μm) of FIGURE 2 and are symmetrical relative to their vertical axes Y. The terminals for the two inductor coils 304 and 306 are labeled as 308a & 308b and 310a & 310b, respectively. Because each O-shaped inductor 300

and 302 provides little or no EM reduction individually, the arrangement as a whole provides little or no mutual EM coupling reduction.

On the other hand, an inductor arrangement involving two 8-shaped inductors like the one in FIGURE 2 may provide further reduced mutual EM coupling. This is illustrated in FIGURE 4, where an inductor arrangement similar to the arrangement in FIGURE 3 is shown, except the two inductors 400 and 402 have 8-shaped inductor coils 404 and 406 instead of O-shaped inductor coils. The terminals for the inductor coils 404 and 406 are labeled as 408a & 408b and 410a & 410b, respectively. Each individual inductor 400 and 402 has a reduced far field by virtue of the 8-shaped inductor coil 404 and 406, as explained above with respect to FIGURE 2. In addition, there is also a reduction in the mutual coupling between the two inductors 400 and 402. This is because the same mechanism that causes the radiated EM field from the first inductor to be reduced also causes the "EM field receive sensitivity" of the second inductor to be reduced. Thus, the combined effect of the two inductors upon each other provides the desired coupling reduction.

Note that it is not necessary for the two inductors 400 and 402 to have the same size. All that is needed for mutual EM coupling reduction is for them to have similar EM reducing shapes. Further, a combination of an O-shaped inductor and an 8-shaped inductor may still result in mutual coupling reduction. However, since such an arrangement only uses the EM canceling effect of one inductor (the O-shaped inductor has little or no EM cancellation), the total isolation between the two inductors is less. In some embodiments, it has been found that even greater isolation may be achieved by rotating one of the inductor coils, as shown in FIGURE 5. Here, two inductors 500 and 502 having nearly identical 8-shaped inductor coils 504 and 506 have again been placed side-by-side. Their terminals are again labeled as 508a & 508b and 510a & 510b, respectively. However, one of the inductor coils, say, the inductor coil 504 on the left, has been rotated by 90 degrees to further reduce mutual EM coupling.

In addition to the above designs, other more complex inductor designs that are symmetrical in more than one dimension, for example, a four-leaf clover shape, may also be used. These complex inductor designs are useful because higher inductance values typically need to have more than one turn in order not to consume too much chip area. In addition, such complex inductor designs are often less sensitive to sub-optimal placement and orientation.

To determine the effectiveness of the above inductor designs in reducing mutual EM coupling, simulations were performed using the Momentum 2D EM Simulator™ from Agilent Technologies, with some simulations also repeated in FastHenry™ from the Computational Prototyping Group to verify the results. The simulations used a simple

semiconductor substrate model that described the metal and dielectric layers on top of a typical semiconductor substrate. The four terminals of the two mutually coupled inductors were defined as the ports of a linear 4-port network (see FIGURE 4). The interaction between the inductors in such a network may often be expressed using an s-parameter matrix. Those having ordinary skill in the art understand that s-parameter theory is a general technique used to describe how signals are reflected and transmitted in a network. The below s-parameter matrix S gives a substantially complete description of the network's behavior when it is connected to the surrounding components.

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix} \quad (1)$$

However, the mutual coupling between the two inductors is often difficult to extract directly from the s-parameters where, as here, the network has four single-ended ports. For this type of analysis, it is sometimes more convenient to treat the two inductors as a differential 2-port network by transforming the single-ended s-parameter matrix into a mixed-mode s-parameter matrix S^{mm} .

$$S^{mm} = M \cdot S \cdot M^T \quad (2)$$

where M is the transformation of voltages and currents at the four single-ended ports to differential and common-mode voltages and currents at the two differential ports, and is given by:

$$M = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & -1 & 0 & 0 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 \end{bmatrix} \quad (3)$$

and M^T is the transposed version of the original matrix M (i.e., with the rows and columns exchanged). For more information regarding this transformation, the reader is referred to David E Bockelman et al., Combined Differential and Common-Mode Scattering Parameters: Theory and Simulation, IEEE Trans. on Microwave Theory and Techniques, vol. MTT-43, pp. 1530-1539, July 1995. The results of the transformation is:

$$S^{mm} = \begin{bmatrix} \begin{bmatrix} S_{d1d1} & S_{d1d2} \\ S_{d2d1} & S_{d2d2} \end{bmatrix} & \begin{bmatrix} S_{d1c1} & S_{d1c2} \\ S_{d2c1} & S_{d2c2} \end{bmatrix} \\ \begin{bmatrix} S_{c1d1} & S_{c1d2} \\ S_{c2d1} & S_{c2d2} \end{bmatrix} & \begin{bmatrix} S_{c1c1} & S_{c1c2} \\ S_{c2c1} & S_{c2c2} \end{bmatrix} \end{bmatrix} \quad (4)$$

As can be seen, the upper left 2-by-2 sub-matrix contains the purely differential 2-port s-parameters, while the other sub-matrices contain the common-mode behavior. The voltage transfer gain G_{vdd} was then calculated using standard 2-port s-parameter formulas, for example:

$$G_{vdd} = \text{real} \left(\frac{s_{d2d1}}{1 + s_{d1d1}} \right) \quad (5)$$

This theoretical gain parameter G_{vdd} extracted from the 4-port s-parameter simulation results was then used to compare the mutual coupling between different combinations of inductor layouts.

Using the above mixed-mode s-parameters, the differential voltage gain G_{vdd} from the ports of the first inductor to the ports of the second inductor was calculated at 3.7 GHz. The corresponding coupling coefficient was then estimated based on s-parameter simulations on a test circuit with two coupled inductors. Table 1 shows a summary of the simulation results for the mutual coupling between different coil shapes and orientations for two inductors at a center distance of 1 mm. In Table 1, the “notation 8_shape_90” represents a figure-8 shaped inductor that has been rotated 90 degrees and the notation “8_shape_-90” represents a figure-8 shaped inductor that has been rotated by -90 degrees, “Q1” is the Q-factor for the Inductor 1, “Att” is the attenuation of the mutual EM coupling between the two inductors, and k is the estimated coupling coefficient.

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Inductor 1	Inductor 2	L1 [nH]	Q1	Gvdd [dB]	Att [dB]	K
O-shape	O-shape	0.841	16.93	-54.0	reference	0.002077
8-shape	O-shape	1.216	15.20	-75.6	21.6	0.000173
8-shape_90	O-shape	1.218	15.63	-74.9	20.9	0.000187
8-shape	8-shape	1.216	15.84	-86.5	32.5	0.000049
8-shape_90	8-shape	1.216	15.19	-89.7	35.7	0.000034
8-shape_90	8-shape_-90	1.216	15.69	-92.8	38.8	0.000024

Table 1

As can be seen, making one of the inductors 8-shaped was shown to reduce the mutual coupling by up to 20 dB. Making both of them 8-shaped was shown to improve the isolation by up to 30 dB. Making both connectors 8-shaped and rotating them by 90 degrees in opposite directions was shown to improve the isolation nearly 40 dB.

A second series of simulations was performed where the center distance between the coils was varied from 0.5 mm up to 2.0 mm for two 8-shaped inductors compared to two O-shaped inductors. The results are plotted in FIGURE 6, where the vertical axis represents the differential transfer gain G_{vdd} and the horizontal axis represents the distance between the centers of the two inductors in millimeters (mm). As can be seen, the 8-shaped inductors (plot 600) resulted in much lower mutual coupling relative to the O-shaped inductors (plot 602). In addition, the 8-shaped inductors show a degree of resonant behavior where the mutual coupling is very low at a certain distance (depending on the frequency). The “average” isolation improvement for the second series (ignoring the sharp minima near 2.0 mm) is between 30 and 40 dB.

Positioning of the inductors relative to each other may also affect the amount of mutual coupling. In order to get an understanding of how much the positioning of the inductors affects mutual coupling, additional simulations were done where one of the inductor coils was offset from the ideal symmetry axis by a varying amount. This is illustrated in FIGURE 7, where two inductors 700 and 702 having nearly identical 8-shaped inductor coils 704 and 706 are shown. As can be seen, however, the connector coil 704 on the left has been offset vertically from the ideal symmetry axis X by a certain distance Z to a new axis X'. The details of the simulation are shown in Table 2 below, where Deg is the degradation in dB. With this arrangement, some degradation of the inductor isolation was observed, but even at a 1 mm offset, which corresponds to an orientation of 45 degrees, an improvement of about 30 dB in mutual coupling reduction is achieved for the 8-shaped inductor.

Offset [mm]	L1 [nH]	Q1	Gvdd [dB]	Att [dB]	Deg [dB]	k estim
0.0	1.216	15.19	-89.7	35.7	reference	0.000034
0.1	1.216	15.19	-85.3	31.3	4.4	0.000057
0.2	1.216	15.19	-82.5	28.5	7.2	0.000078
0.3	1.216	15.19	-81.0	27.0	8.7	0.000093
0.5	1.216	15.19	-81.8	27.8	7.9	0.000085
0.7	1.216	15.19	-85.8	31.8	3.9	0.000053
1.0	1.216	15.19	-103.4	49.4	-13.7	0.000007

Table 2

To investigate the relationship between differential voltage gain G_{vdd} and coupling coefficient k , s-parameter simulations of the two inductors were performed in Spectre™. Thereafter, an estimated coupling coefficient k was able to be calculated from Momentum 2D EM Simulator™ results and included in Table 1 and Table 2.

5 To verify the results of the coupling coefficient estimation, an alternative tool FastHenry™ was used to calculate k . The simulated results are plotted in FIGURE 8. In FIGURE 8 the horizontal axis again represents the distance between the centers of the inductors in mm, but the vertical axis now represents the coupling coefficient k , the bottom plot 800 represents the FastHenry™ results, and the top plot 802 represents the Momentum 2D EM Simulator™ results. The agreement between the two sets of results appears quite good for distances up to 1.5 mm, but some discrepancy may be noted at 2 mm. The most likely explanation for the discrepancy is that the Momentum 2D EM Simulator™ results are more reliable.

From the foregoing, it can be clearly seen that mutual coupling reduction is closely related to the symmetry of the inductor. Therefore, the layout of the rest of the VCO should be
15 designed to minimize any additional inductor loops that may be created when the inductor is connected to the VCO components (e.g., varicaps and capacitive switches), since the magnetic field from this additional loop will affect the balance between the up field components of opposite signs and reduce any canceling effect.

FIGURE 9 shows an exemplary layout for a typical 4 GHz VCO 900 with an 8-shaped
20 inductor 902 that may be used to minimize any additional inductor loops. As can be seen, the layout for the resonator (e.g., switches, varactor) and active parts is substantially symmetrical around the vertical axis Y. The supply voltage (e.g., bias and decoupling) is also applied symmetrically, with the wires routed on top of each other so that they will not create an additional loop. Preferably, all capacitive resonator components are fully differential and have
25 a symmetrical layout.

As alluded to above, more complex inductor designs that are symmetrical in more than one dimension, for example, a four-leaf clover shape design, may also be used. In general, by increasing the number of loops from two to four, the canceling effect may be improved further in some directions and for some distances. This is because, in general (and at least for
30 the 8-shaped inductors), the isolation between inductors is dependent on the relative placement of the coils. FIGURE 10 illustrates an example of a four-leaf clover-shaped inductor 1000. The four loops 1002, 1004, 1006, and 1008 of the inductor 1000 are connected in such a way that the magnetic field emanating from any two adjacent loops have opposite directions and tend to cancel one another. Thus, the cancellation of the different magnetic

field components is less dependent, for example, on the direction of the second inductor coil where two four-leaf clover-shaped inductors are present on the same chip.

Furthermore, as shown in FIGURE 12, a configuration where one of the inductors (e.g., inductor 1100) is rotated 45 degrees relative to the other inductor (e.g., inductor 1102) has been observed to have even lower EM coupling between the two inductors 1100 and 1102.

The differential transfer gain G_{vdd} is plotted in FIGURE 12 for two four-leaf clover shaped inductor arrangement (plot 1200) as a function of center distance together with the performance of two 8-shaped inductors (plot 1202) and two O-shaped inductors (plot 1204). One of the four-leaf clover shaped inductors has been rotated by about 45 degrees (indicated by the “r”) and likewise one of the 8-shaped inductors has been rotated by about 90 degrees (again indicated by the “r”). The vertical axis of the chart represents the differential transfer gain G_{vdd} and the horizontal axis represents the center distance. As can be seen, the isolation for the two four-leaf clover shaped inductor arrangement is nearly 10 dB better than the 8-shaped inductor arrangement for distances below 1 mm and show no resonant behavior at larger distances.

The improvement in the directional behavior of the four-leaf clover shaped inductor arrangement is shown in Table 3. As can be seen, there is no degradation in isolation when moving away from the symmetry axis, only a smaller improvement due to the increasing distance. However, due to the more complex wire layout, resulting in less inductance per length of wire, the Q-factor is slightly lower compared to the 8-shaped inductor arrangement.

Offset [mm]	L1 [nH]	Q1	Gvdd [dB]	Att [dB]	Deg [dB]	k estim
0.0	1.300	13.09	-92.5	38.5	reference	0.000025
0.1	1.300	13.09	-92.9	38.9	-0.4	0.000024
0.2	1.300	13.09	-92.9	38.9	-0.4	0.000024
0.3	1.300	13.09	-93.4	39.4	-0.9	0.000022
0.5	1.300	13.09	-94.1	40.1	-1.6	0.000021
0.7	1.300	13.09	-94.9	40.9	-2.4	0.000019
1.0	1.300	13.09	-97.1	43.1	-4.6	0.000015

Table 3

In applications where higher inductance values are needed, it is possible to use inductor coils with more than one turn, since single turn designs tend to take up too much chip area.

An example of a two-turn 8-shaped inductor 1300 is shown in FIGURE 13. As can be seen, the two-turn 8-shaped inductor 1300 is essentially similar to the 8-shaped inductor 200 of FIGURE 2, except that the two outer loops 1302 and 1304 of the inductor 1300 each turn into an inner loop 1306 and 1308, respectively. The terminals 1310a and 1310b of the inductor 1300 are then connected to the lower inner loop 1308. Such a two-turn inductor 1300 may provide a higher inductance value without taking up too much chip area, while also reducing the Q-factor. In the embodiment shown here, the Q-factor may be reduced from approximately 15 to 12.5 at 4 GHz.

Although a two-turn 8-shaped inductor has been shown, those of ordinary skill and they are will understand that other configurations may also be used, such as a two-turn four-leaf clover shaped inductor, provided that near symmetry can be maintained given the crossing of the inner and outer loops and positioning requirements of the terminals. Other symmetrical shapes besides those described thus far may also show the same or even better coupling reduction if a satisfactory balance between parameters such as Q-factor, coil size, and coupling coefficient can be reached.

For completeness, the subject matter of the claims of the root parent application (application number 05715341.3) as filed is provided in the below list of examples as a part of this detailed description.

EXAMPLES:

1. An inductor layout having reduced mutual electromagnetic coupling, comprising:
a first inductor having a shape that is substantially symmetrical about a first predefined axis, said shape causing said first inductor to have a reduced electromagnetic field at a certain distance from said first inductor, at least in some directions; and
a second inductor positioned at a predetermined distance from said first inductor, wherein a mutual electromagnetic coupling between said first inductor and said second inductor is reduced as a result of said first inductor having a reduced electromagnetic field.
2. The inductor layout according to example 1, wherein said first inductor and said second inductor are formed on a single semiconductor die.
3. The inductor layout according to example 1, wherein said first inductor and said second inductor are oriented in a same direction.

4. The inductor layout according to example 1, wherein said first inductor and said second inductor are oriented in different directions.

5. The inductor layout according to example 1, wherein said first inductor and said second inductor share a common axis.

6. The inductor layout according to example 1, wherein said first inductor and said second inductor share no common axis.

7. The inductor layout according to example 1, wherein said first inductor and said second inductor are substantially 8-shaped.

8. The inductor layout according to example 7, further comprising an inner loop within each outer loop of said substantially 8-shaped first and second inductors.

15

9. The inductor layout according to example 1, wherein said first inductor and said second inductor are substantially four-leaf clover-shaped.

10. The inductor layout according to example 1, wherein said first inductor and said second inductor are symmetrical about a second predefined axis.

11. A method of reducing mutual electromagnetic coupling between two inductors on a semiconductor die, comprising:

forming a first inductor on said semiconductor die having a shape that is substantially symmetrical about a first predefined axis, said shape causing said first inductor to have a reduced far field, at least in some directions; and

forming a second inductor on said semiconductor die at a predetermined distance from said first inductor, wherein a mutual electromagnetic coupling between said first inductor and said second inductor is reduced as a result of said first inductor having a reduced far field.

30

12. The method according to example 11, wherein said second inductor has a shape that is substantially identical to said shape of said first inductor.

13. The method according to example 11, further comprising orienting said first inductor and said second inductor in a same direction.

14. The method according to example 11, further comprising orienting said first inductor 5 and said second inductor in different directions.

15. The method according to example 11, further comprising placing said first inductor and said second inductor on a common axis that is shared by said first inductor and said second inductor.

10

16. The method according to example 11, further comprising placing said first inductor and said second inductor so that they share no common axis.

17. The method according to example 11, wherein said steps of forming said first and 15 second inductors include forming said first and second inductors in a substantially 8 shape.

18. The method according to example 17, further comprising forming an inner loop within each outer loop of said substantially 8-shaped first and second inductors.

20 19. The method according to example 11, wherein said steps of forming said first and second inductors include forming said first and second inductors in a substantially fourleaf clover shape.

20. The method according to example 11, wherein said first inductor and said second 25 inductor are symmetrical about a second predefined axis.

21. An inductor having a reduced far field, comprising:

a first loop having a shape that is substantially symmetrical about a first predefined axis; and

30 a second loop having a size and shape substantially identical to a size and shape of said first loop, said second loop arranged such that a magnetic field emanating therefrom tends to cancel a magnetic field emanating from said first loop.

22. The inductor according to example 21, wherein said first loop and said second loop are substantially symmetrical about a second predefined axis.

23. The inductor according to example 21, further comprising:

- 5 a third loop in said inductor having a size and shape substantially identical to said size and shape of said first loop, said third loop arranged such that a magnetic field emanating therefrom tends to cancel a magnetic field emanating from said first loop; and
- a fourth loop in said inductor having a size and shape substantially identical to a size and shape of said second loop, said fourth loop arranged such that a magnetic field emanating
- 10 therefrom tends to cancel a magnetic field emanating from said second loop.

24. The inductor according to example 23, wherein said third loop is inside said first loop and said fourth loop is inside said second loop.

15

While the present invention has been described with reference to one or more particular illustrative embodiments, those skilled in the art will recognize that many changes may be made thereto without departing from the scope of the present invention. For example, although only reduction in electro-magnetic coupling has been described in the foregoing,

20 other coupling mechanisms via the substrate or supply lines as well as the effects of components placed between the two VCOs can have an important influence on the maximum achievable isolation. Therefore, each of the foregoing embodiments and variations thereof is contemplated as falling within the scope of the claimed invention, which is set forth in the following claims.

25

CLAIMS

1. A radio-frequency transceiver, comprising:
a first inductor (200, 1300), which is substantially symmetric about a symmetry axis, the
first inductor (200, 1300) comprising terminals (204a, 204b; 1310a, 1310b), a first loop
5 (206a), and a second loop (206b), wherein the first loop (206a; 1004) and the second loop
(206b) are arranged such that current in the first loop (206a) travels in a direction that is
opposite to current in the second loop (206b) such that electromagnetic field components
emanating from the first loop (206a) and the second loop (206b) also have opposite directions
and tend to counteract each other; and wherein the terminals (204a, 204b; 1310a, 1310b) are
10 connected to the second loop (206b).
2. The radio-frequency transceiver according to claim 1, wherein the terminals (204a,
204b; 1310a, 1310b) are positioned at a side of the second loop (206b) that is opposite to the
first loop (206a).
15
3. The radio-frequency transceiver according to claim 1 or 2, wherein the terminals (204a,
204b) are positioned closely.
- 20 4. The radio-frequency transceiver according to any preceding claim, wherein the first
inductor (200) has more than one turn.
5. The radio-frequency transceiver according to any preceding claim, wherein the first
inductor (200) is figure-8 shaped.
25
6. The semiconductor die according to any of the claims 1-4, wherein the first inductor has
four loops.
7. The radio-frequency transceiver according to claim 6, wherein the first inductor is four-
30 leaf clover shaped.
8. The radio-frequency transceiver according to any preceding claim, comprising a
voltage-controlled oscillator comprising the first inductor.

9. The radio-frequency transceiver according to any preceding claim, wherein the first inductor is integrated on a semiconductor chip.

10. The radio-frequency transceiver according to claim 9, wherein the semiconductor chip
5 comprises a second inductor.

11. The radio-frequency transceiver according to claim 10, wherein
the second inductor (200, 1300) is substantially symmetric about a symmetry axis and
comprises terminals (204a, 204b; 1310a, 1310b), a first loop (206a), and a second loop
10 (206b), wherein the first loop (206a; 1004) and the second loop (206b) of the second inductor
are arranged such that current in the first loop (206a) of the second inductor travels in a
direction that is opposite to current in the second loop (206b) of the second inductor such that
electromagnetic field components emanating from the first loop (206a) of the second inductor
and the second loop (206b) of the second inductor also have opposite directions and tend to
15 counteract each other; and wherein the terminals (204a, 204b; 1310a, 1310b) of the second
inductor are connected to the second loop (206b) of the second inductor.

12. The radio-frequency transceiver according to any one of the claims 9-11, wherein the
radio-frequency transceiver is integrated on the semiconductor chip.
20

13. A semiconductor chip comprising the radio-frequency transceiver according to claim
12.

1/6

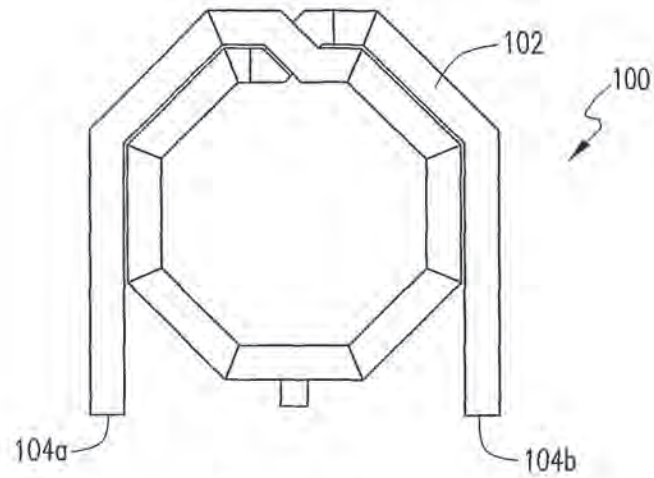


FIG. 1
(PRIOR ART)

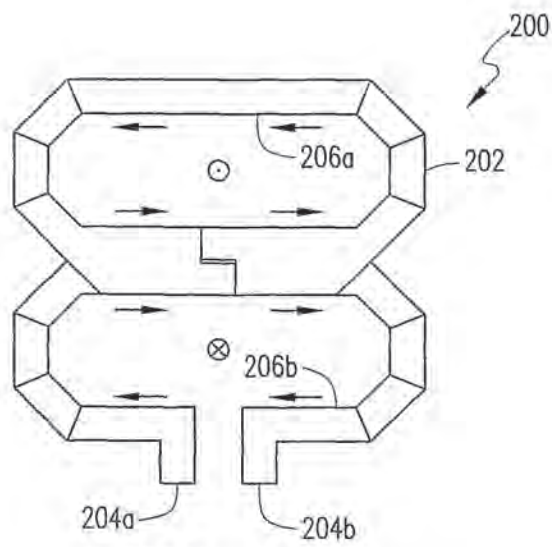
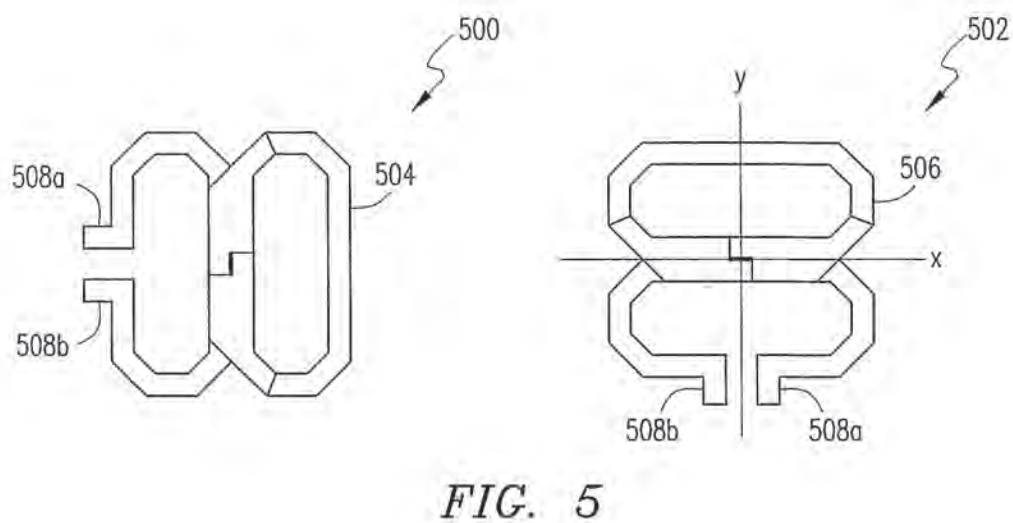
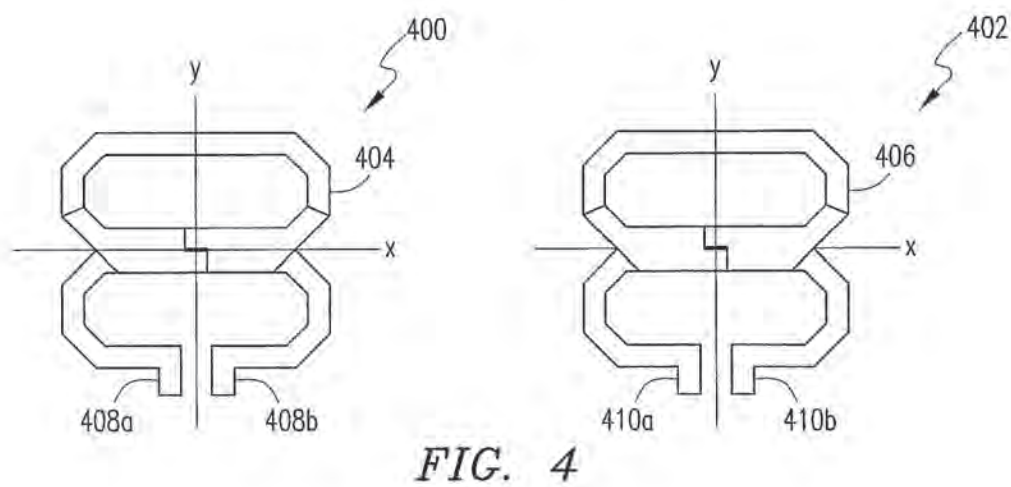
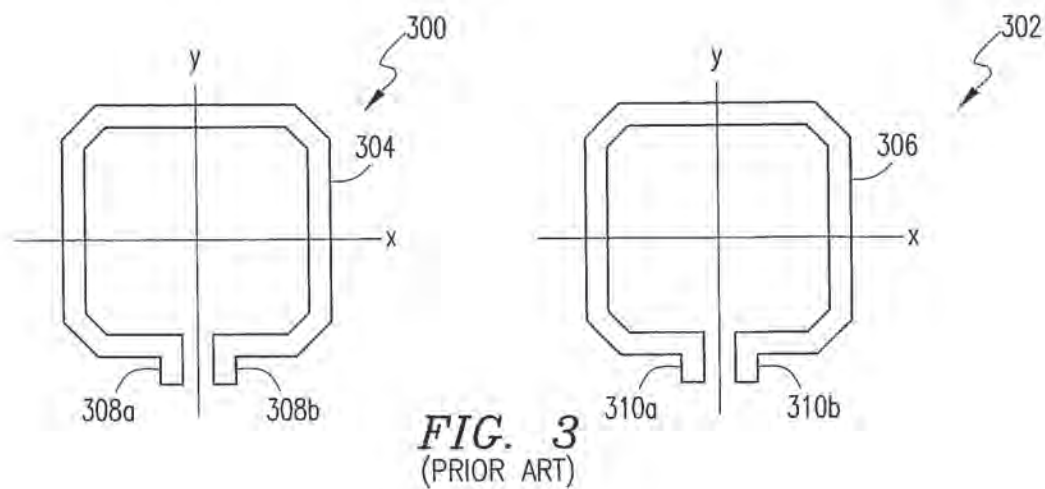


FIG. 2

2/6



3/6

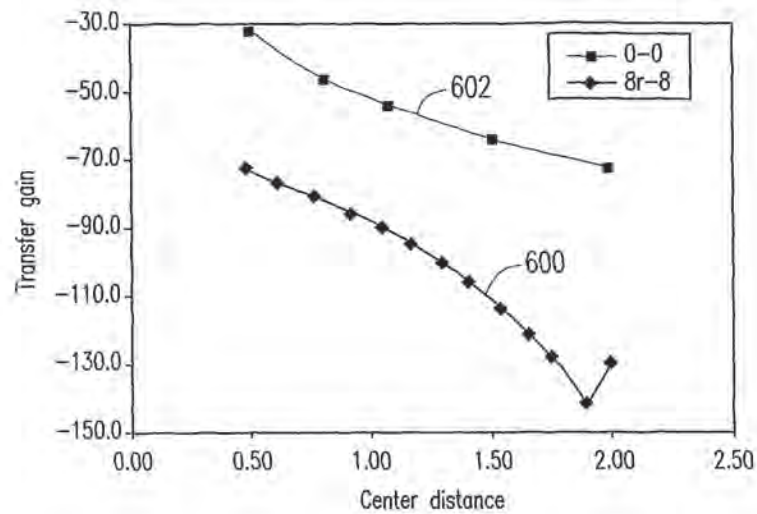


FIG. 6

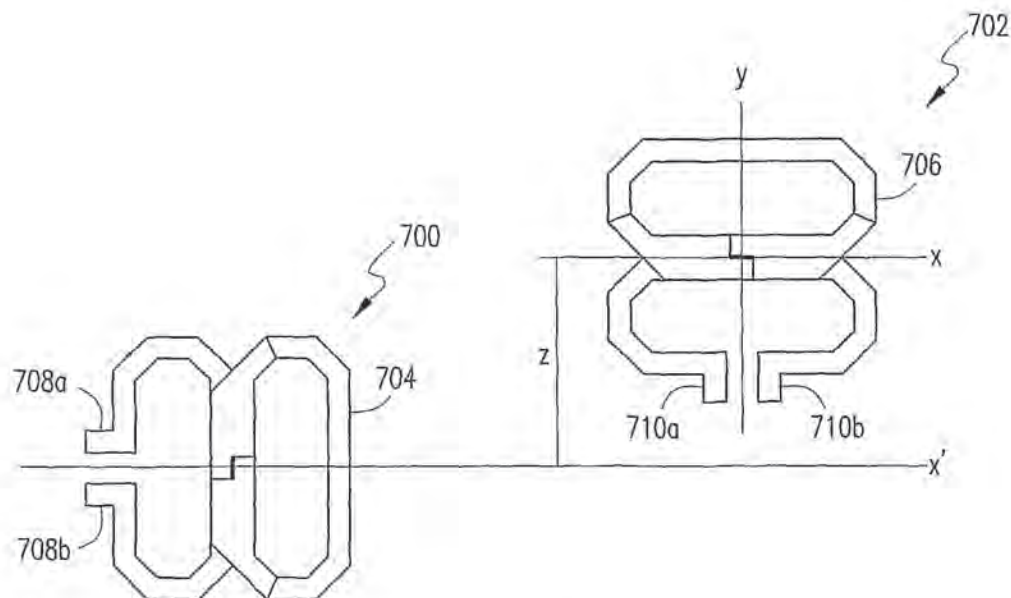


FIG. 7

4/6

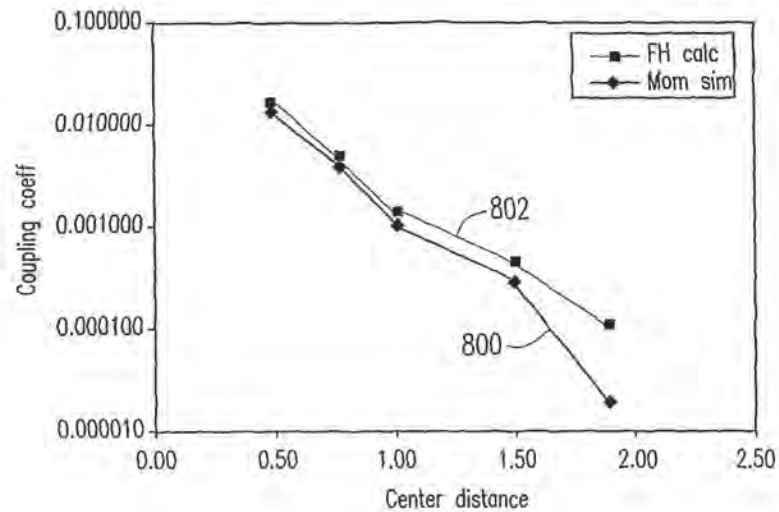


FIG. 8

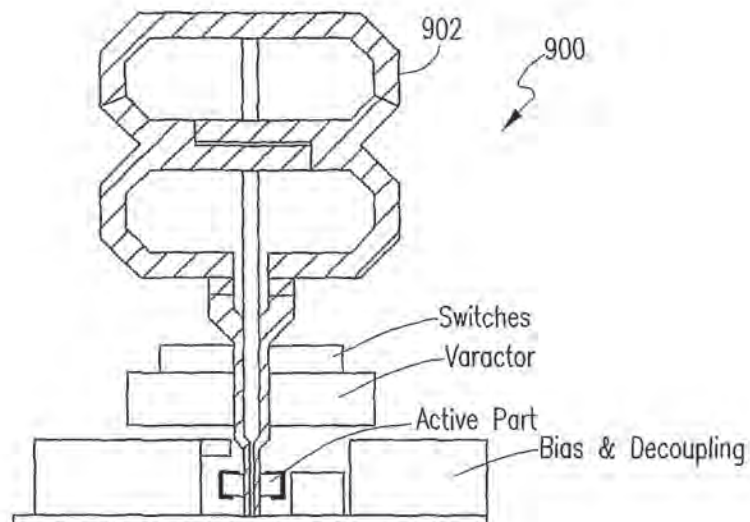
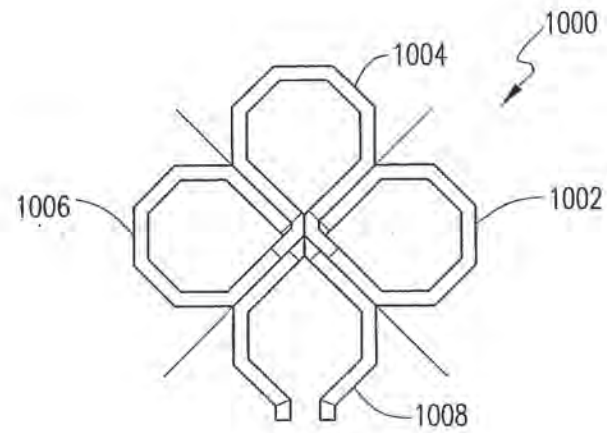
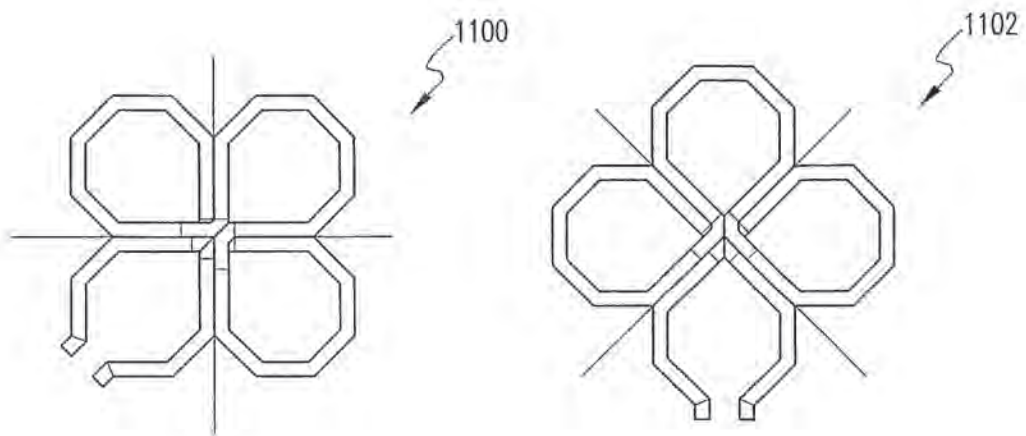


FIG. 9

5/6

*FIG. 10**FIG. 11*

6/6

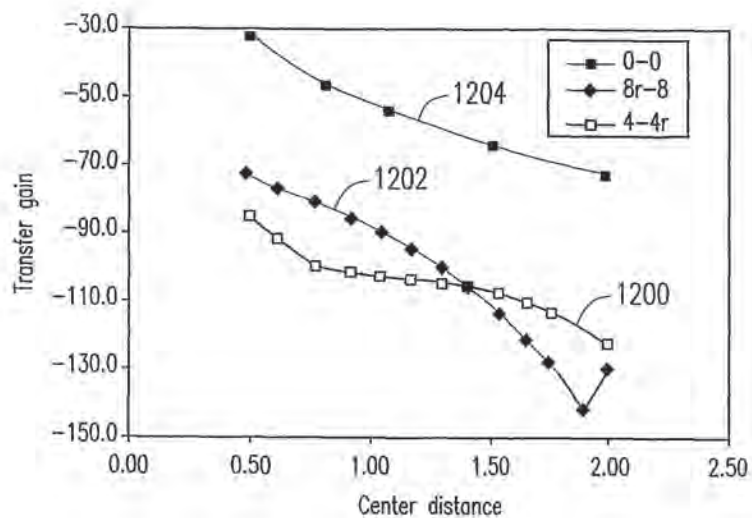


FIG. 12

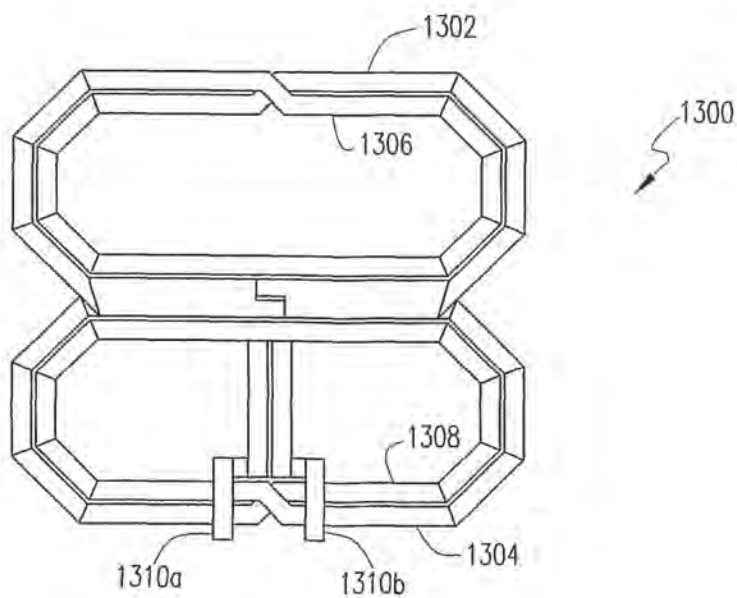


FIG. 13



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Application No. 19 183 992.7 - 1201	Ref. P19235 EP3	Date 13.03.2020
Applicant Telefonaktiebolaget LM Ericsson (publ)		

Communication pursuant to Article 94(3) EPC

The examination of the above-identified application has revealed that it does not meet the requirements of the European Patent Convention for the reasons enclosed herewith. If the deficiencies indicated are not rectified the application may be refused pursuant to Article 97(2) EPC.

You are invited to file your observations and insofar as the deficiencies are such as to be rectifiable, to correct the indicated deficiencies within a period

of 4 months

from the notification of this communication, this period being computed in accordance with Rules 126(2) and 131(2) and (4) EPC. One set of amendments to the description, claims and drawings is to be filed within the said period on separate sheets (R. 50(1) EPC).

If filing amendments, you must identify them and indicate the basis for them in the application as filed. Failure to meet either requirement may lead to a communication from the Examining Division requesting that you correct this deficiency (R. 137(4) EPC).

In case you withdraw the application within the above-mentioned period, the examination fee will be refunded at a rate of 50% (Art. 11 (b) RFees).

Failure to comply with this invitation in due time will result in the application being deemed to be withdrawn (Art. 94(4) EPC).

Registered letter

EPO Form 2001 11.16T/1



Marti Almeda, Rafael
Primary Examiner
For the Examining Division

Enclosure(s): 3 page/s reasons (Form 2906)
FR-2805618-A1, WO-9805048-A1

The examination is being carried out on the **following application documents**

Description, Pages

1-15 as originally filed

Claims, Numbers

1-13 as originally filed

Drawings, Sheets

1/6-6/6 as originally filed

The following document is cited by the Examiner. A copy of the document is annexed to the communication and the numbering will be adhered to in the rest of the procedure.

D1 FR 2 805 618 A1 (COMMISSARIAT ENERGIE ATOMIQUE [FR]) 31 August 2001 (2001-08-31)

Reference is made to the following document; the numbering will be adhered to in the rest of the procedure.

D2 WO 2004/012213 A (PHILIPS INTELLECTUAL PROPERTY & STANDARDS GMBH; KONINKLIJKE PHILIPS EL) 5 February 2004 (2004-02-05)

The following document is cited by the Examiner. A copy of the document is annexed to the communication and the numbering will be adhered to in the rest of the procedure.

D3 WO 98/05048 A1 (MOTOROLA INC [US]) 5 February 1998 (1998-02-05)

1 The present application does not meet the requirements of Article 52(1) EPC because the subject-matter of claim 1 is not new within the meaning of Article 54(1) and (2) EPC.

1.1 D1 (fig. 4; page 12, lines 10-25) discloses explicit:

A transceiver, comprising:

a first inductor (32), which is substantially symmetric about a symmetry axis,

the first inductor (32) comprising:

terminals,

a first loop, and

a second loop,

wherein the first loop and the second loop are arranged

such that current in the first loop travels in a direction that is opposite to current in the second loop

such that electromagnetic field components emanating from the first loop and the second loop also have opposite directions and tend to counteract each other; and

wherein the terminals are connected to the second loop.

D1 also discloses that inductor (32) actuates as a reception antenna (32) of an alternative magnetic field of 70 Hz emitted by inductor (30). Electromagnetic fields between 30 and 300 Hz produce wavelengths of super low frequency of the radio spectrum. Therefore, D1 also discloses implicit the feature of claim 1

"radio-frequency transceiver"

The subject-matter of claim 1 is therefore not new (Article 54(1) and (2) EPC).

2 Dependent claims 2-6, 8 and 9 does not appear to contain any additional features which, in combination with the features of any claim to which it refers, meet the requirements of the EPC with respect to novelty or inventive step.

2.1 D1 also discloses the features of dependent claims 2, 3 and 5. The subject-matter of these claims is therefore not new.

- 2.2 The features of dependent claims 4, 8 and 9 have already been employed for the same purpose in the similar transceiver of D2. It would therefore be obvious to the person skilled in the art to apply these features with corresponding effect to a transceiver according to D1, thus arriving at a transceiver according to claims 4, 8 and 9.
- 2.3 The features of dependent claim 6 have already been employed for the same purpose in the similar transceiver of D3. It would therefore be obvious to the person skilled in the art to apply these features with corresponding effect to a transceiver according to D1, thus arriving at a transceiver according to claims 6.
- 3 The applicant is invited to file a new claims which takes account of the above comments.



Letter accompanying subsequently filed items

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The document(s) listed below is (are) subsequently filed documents pertaining to the following application:

Application number and/or EP publication number:

EP19183992.7

Reference:

P19235 EP3

Procedural phase:

Examination

Name of represented party:

Telefonaktiebolaget LM Ericsson (publ)

	Description of document	Original file name	Assigned file name
1	Reply to examination report	P19235_EP3_2020-06-11_Resp_94(3)_EPC_to_be_filed.pdf	EXRE3-1.pdf
2	Amended claims (clean copy)	P19235_EP3_2020-06-11_amended_claims_clean_to_be_filed.pdf	CLMS-1.pdf
3	Amended claims with annotations	P19235_EP3_2020-06-11_amended_claims_marked_to_be_filed.pdf	CLMS-HWA-1.pdf

Signature 1

Place: Lund Sweden
Date: 12 June 2020
Signed by: /Ola Andersson/
Association: Ericsson
Capacity: Representative 1

Smart card certificate 1

Common name: Stefan Gippert 9209
EPO ID: 9209
Issued by: European Patent Office CA G2

Attending to this matter

Ola Andersson +46107165662

European Patent Office

Via CMS (epoline Case Management System)

80298 Munich
GERMANY**Response to communication pursuant to Article 94(3) EPC**

Application Number: 19183992.7
Application Date: 2019-07-02
Applicant: Telefonaktiebolaget LM Ericsson (publ)
Our Reference: P19235 EP3

Enclosure(s):

Description: None

Claims: Amended claims with and without marked-up amendments

Dear Sirs,

This is in response to the communication pursuant to Article 94(3) EPC dated 13.03.2020.

The claims have been amended by including the subject matter of claims 9 and 10 into claim 1. Consequently, claims 9 and 10 have been deleted. The other claims have been renumbered and claim dependencies have been adapted accordingly. Furthermore, the subject of claim 6 has been corrected to "radio frequency transceiver" to conform with the claims on which it depends.

In the communication, claims 1-6 and 8-9 were objected to with reference to lack of novelty or inventive step. No objection was set forth relating to claim 10. Since new claim 1 corresponds to previous claim 10, the application is believed to be in a condition ready for grant. Hence, a communication under Rule 71(3) EPC is respectfully requested. Should the Examining Division disagree, it is requested that the reasons therefore be set forth in a written communication pursuant to Art 94(3) EPC. Purely as a precaution, oral proceedings are requested in case the Examining Division should consider refusing the application.

/Ola Andersson/

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Reg No: 556056-6258

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CLAIMS

1. A radio-frequency transceiver, comprising:
a first inductor (200, 1300), which is substantially symmetric about a symmetry axis, the
first inductor (200, 1300) comprising terminals (204a, 204b; 1310a, 1310b), a first loop
5 (206a), and a second loop (206b), wherein the first loop (206a; 1004) and the second loop
(206b) are arranged such that current in the first loop (206a) travels in a direction that is
opposite to current in the second loop (206b) such that electromagnetic field components
emanating from the first loop (206a) and the second loop (206b) also have opposite directions
and tend to counteract each other; and wherein the terminals (204a, 204b; 1310a, 1310b) are
10 connected to the second loop (206b);
wherein the first inductor is integrated on a semiconductor chip; and
wherein the semiconductor chip comprises a second inductor.
2. The radio-frequency transceiver according to claim 1, wherein the terminals (204a,
15 204b; 1310a, 1310b) are positioned at a side of the second loop (206b) that is opposite to the
first loop (206a).
3. The radio-frequency transceiver according to claim 1 or 2, wherein the terminals (204a,
204b) are positioned closely.
- 20 4. The radio-frequency transceiver according to any preceding claim, wherein the first
inductor (200) has more than one turn.
5. The radio-frequency transceiver according to any preceding claim, wherein the first
25 inductor (200) is figure-8 shaped.
6. The radio-frequency transceiver according to any of the claims 1-4, wherein the first
inductor has four loops.
- 30 7. The radio-frequency transceiver according to claim 6, wherein the first inductor is four-
leaf clover shaped.
8. The radio-frequency transceiver according to any preceding claim, comprising a
voltage-controlled oscillator comprising the first inductor.

9. The radio-frequency transceiver according to any preceding claim, wherein
the second inductor (200, 1300) is substantially symmetric about a symmetry axis and
comprises terminals (204a, 204b; 1310a, 1310b), a first loop (206a), and a second loop
5 (206b), wherein the first loop (206a; 1004) and the second loop (206b) of the second inductor
are arranged such that current in the first loop (206a) of the second inductor travels in a
direction that is opposite to current in the second loop (206b) of the second inductor such that
electromagnetic field components emanating from the first loop (206a) of the second inductor
and the second loop (206b) of the second inductor also have opposite directions and tend to
10 counteract each other; and wherein the terminals (204a, 204b; 1310a, 1310b) of the second
inductor are connected to the second loop (206b) of the second inductor.

10. The radio-frequency transceiver according to any preceding claim, wherein the radio-
frequency transceiver is integrated on the semiconductor chip.

15

11. A semiconductor chip comprising the radio-frequency transceiver according to claim
10.

CLAIMS

1. A radio-frequency transceiver, comprising:
a first inductor (200, 1300), which is substantially symmetric about a symmetry axis, the
first inductor (200, 1300) comprising terminals (204a, 204b; 1310a, 1310b), a first loop
5 (206a), and a second loop (206b), wherein the first loop (206a; 1004) and the second loop
(206b) are arranged such that current in the first loop (206a) travels in a direction that is
opposite to current in the second loop (206b) such that electromagnetic field components
emanating from the first loop (206a) and the second loop (206b) also have opposite directions
and tend to counteract each other; and wherein the terminals (204a, 204b; 1310a, 1310b) are
10 connected to the second loop (206b);
wherein the first inductor is integrated on a semiconductor chip; and
wherein the semiconductor chip comprises a second inductor.
2. The radio-frequency transceiver according to claim 1, wherein the terminals (204a,
15 204b; 1310a, 1310b) are positioned at a side of the second loop (206b) that is opposite to the
first loop (206a).
3. The radio-frequency transceiver according to claim 1 or 2, wherein the terminals (204a,
204b) are positioned closely.
- 20 4. The radio-frequency transceiver according to any preceding claim, wherein the first
inductor (200) has more than one turn.
5. The radio-frequency transceiver according to any preceding claim, wherein the first
25 inductor (200) is figure-8 shaped.
6. ~~The semiconductor die~~radio-frequency transceiver according to any of the claims 1-4,
wherein the first inductor has four loops.
- 30 7. The radio-frequency transceiver according to claim 6, wherein the first inductor is four-
leaf clover shaped.
8. The radio-frequency transceiver according to any preceding claim, comprising a
voltage-controlled oscillator comprising the first inductor.

~~9. The radio-frequency transceiver according to any preceding claim, wherein the first inductor is integrated on a semiconductor chip.~~

5 ~~10. The radio-frequency transceiver according to claim 9, wherein the semiconductor chip comprises a second inductor.~~

~~11. The radio-frequency transceiver according to any preceding claim ~~10~~, wherein the second inductor (200, 1300) is substantially symmetric about a symmetry axis and~~
 10 ~~comprises terminals (204a, 204b; 1310a, 1310b), a first loop (206a), and a second loop (206b), wherein the first loop (206a; 1004) and the second loop (206b) of the second inductor are arranged such that current in the first loop (206a) of the second inductor travels in a direction that is opposite to current in the second loop (206b) of the second inductor such that electromagnetic field components emanating from the first loop (206a) of the second inductor~~
 15 ~~and the second loop (206b) of the second inductor also have opposite directions and tend to counteract each other; and wherein the terminals (204a, 204b; 1310a, 1310b) of the second inductor are connected to the second loop (206b) of the second inductor.~~

~~12. The radio-frequency transceiver according to any ~~one of the claims 9-11~~ preceding claim, wherein the radio-frequency transceiver is integrated on the semiconductor chip.~~

~~13. A semiconductor chip comprising the radio-frequency transceiver according to claim ~~12~~ 10.~~



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Application No. 19 183 992.7 - 1201	Ref. P19235 EP3	Date 19.06.2020
Applicant Telefonaktiebolaget LM Ericsson (publ)		

Communication pursuant to Article 94(3) EPC

The examination of the above-identified application has revealed that it does not meet the requirements of the European Patent Convention for the reasons enclosed herewith. If the deficiencies indicated are not rectified the application may be refused pursuant to Article 97(2) EPC.

You are invited to file your observations and insofar as the deficiencies are such as to be rectifiable, to correct the indicated deficiencies within a period

of 4 months

from the notification of this communication, this period being computed in accordance with Rules 126(2) and 131(2) and (4) EPC. One set of amendments to the description, claims and drawings is to be filed within the said period on separate sheets (R. 50(1) EPC).

If filing amendments, you must identify them and indicate the basis for them in the application as filed. Failure to meet either requirement may lead to a communication from the Examining Division requesting that you correct this deficiency (R. 137(4) EPC).

Failure to comply with this invitation in due time will result in the application being deemed to be withdrawn (Art. 94(4) EPC).

Registered letter

EPO Form 2001 11.16Tdt



Marti Almeda, Rafael
Primary Examiner
For the Examining Division

Enclosure(s): 2 page/s reasons (Form 2906)

The examination is being carried out on the **following application documents**

Description, Pages

1-15 as originally filed

Claims, Numbers

1-11 filed in electronic form on 12-06-2020

Drawings, Sheets

1/6-6/6 as originally filed

After further examination, the following objection has been found:

- 1 The present application does not meet the requirements of Article 52(1) EPC because the subject-matter of claim 1 does not involve an inventive step within the meaning of Article 56 EPC.
- 1.1 The subject-matter of claim 1 differs from the known transceiver of D1 in that:
"wherein the first inductor is integrated on a semiconductor chip; and
wherein the semiconductor chip comprises a second inductor".
- 1.2 The solution proposed in claim 1 of the present application cannot be considered to involve an inventive step (Articles 52(1) and 56 EPC) for the following reasons:
 - 1.2.1 The problem to be solved by these differing features is not defined. Therefore, these features are considered merely one of several straightforward possibilities which the skilled person would select without exercising inventive skill.

- 1.2.2 The originally filed description (see page 5, line 30-page 6, line 2; fig. 3) discloses these differing features being part of the prior art as providing the same advantages as in the present application.

The skilled person would therefore regard it as a normal design to include these differing features in the transceiver described in D1.

- 2 It is not at present apparent which part of the application could serve as a basis for a new, allowable claim. Should the applicant nevertheless regard some particular matter as patentable, an independent claim should be filed taking account of Rule 43(1) EPC. The applicant should also indicate how the subject-matter of the new claim differs from the state of the art and the significance thereof.

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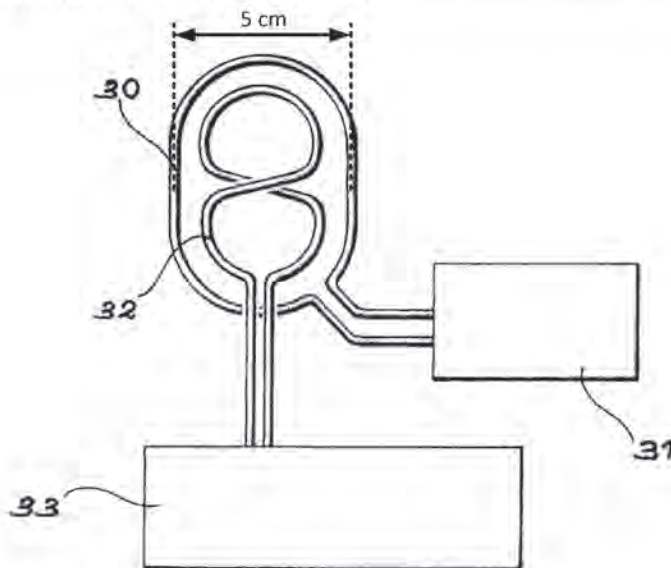
Response to Communication pursuant to Article 94(3) EPC

Application Number: 19183992.7
Application Date: July 02, 2019
Applicant: Telefonaktiebolaget LM Ericsson (publ)
Our Reference: P019235EP03

Dear EPO,

This is in response to the communication pursuant to Article 94(3) EPC dated 19.06.2020.
Further processing is requested and the corresponding fee is paid.

An annotated version of Fig. 4 is shown below indicating the size of the element 30 as given in the description of D1 (FR2805618A1).



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Element 32 in D1 is an antenna. The antenna 32 has a certain size dictated by its intended use. Based on the above-indicated size of element 30, it can be concluded that the size of the antenna 32 is more than 3 cm in the horizontal direction (at the widest place) and more than 10 cm in the vertical direction. Hence, the antenna 32 is several orders of magnitude larger than what is feasible to integrate on semiconductor chip. At least for this reason, the skilled person would not consider modifying the detection device ("dispositif de détection") of D1 to arrive at something falling within the terms of claim 1.

In view of the above, the application is believed to be in a condition ready for grant. Hence, a communication under Rule 71(3) EPC is respectfully requested. Should the Examining Division disagree, it is requested that the reasons therefore be set forth in a written communication pursuant to Art 94(3) EPC.

/Ola Andersson/

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Questions about this communication?
Contact Customer Services at
www.epo.com/contact

Primary Examiner
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Application No. 19 183 992.7 - 1201	Ref. P19235 EP3	Date 22.03.2022
Applicant Telefonaktiebolaget LM Ericsson (publ)		

Communication pursuant to Article 94(3) EPC

The examination of the above-identified application has revealed that it does not meet the requirements of the European Patent Convention for the reasons enclosed herewith. If the deficiencies indicated are not rectified the application may be refused pursuant to Article 97(2) EPC.

You are invited to file your observations and insofar as the deficiencies are such as to be rectifiable, to correct the indicated deficiencies within a period

of 4 months

from the notification of this communication, this period being computed in accordance with Rules 126(2) and 131(2) and (4) EPC. One set of amendments to the description, claims and drawings is to be filed within the said period on separate sheets (R. 50(1) EPC).

If filing amendments, you must identify them and indicate the basis for them in the application as filed. Failure to meet either requirement may lead to a communication from the Examining Division requesting that you correct this deficiency (R. 137(4) EPC).

Failure to comply with this invitation in due time will result in the application being deemed to be withdrawn (Art. 94(4) EPC).

Registered Letter

EPO Form 2001 11.16AUWF (17.03.2022)



Hermann, Robert
Primary Examiner
For the Examining Division

Enclosure(s): 3 page/s reasons (EPO Form 2906)

The examination is being carried out on the **following application documents**

Description, Pages

1-15 as originally filed

Claims, Numbers

1-11 filed in electronic form on 12-06-2020

Drawings, Sheets

1/6-6/6 as originally filed

1 Reference is made to the following documents:

- D1 FR 2 805 618 A1 (COMMISSARIAT ENERGIE ATOMIQUE [FR]) 31 August 2001 (2001-08-31)
- D2 WO 2004/012213 A (PHILIPS INTELLECTUAL PROPERTY & STANDARDS GMBH; KONINKLIJKE PHILIPS EL) 5 February 2004 (2004-02-05)
- D3 WO 98/05048 A1 (MOTOROLA INC [US]) 5 February 1998 (1998-02-05)

2 Summary

- 2.1 For administrative reasons a new first examiner had to be assigned for the present application.
- 2.2 The procedure, the communications of the examining division and the letters and amendments of the applicant have been carefully reviewed. In the course of this review it was however detected that the present divisional application does not comply with the requirements of Art. 76(1) EPC. The reasons are provided below. Since, this objection is of a very fundamental nature at this stage no further arguments or evidence is provided with respect to the question of novelty and inventive step. The applicant is invited to provide a new set of claims defining subject-matter which does not extend beyond the content of the earlier application as filed.

3 Divisional application (Art. 76 EPC)

- 3.1 The present application is a divisional application in the sense of Article 76 EPC of the earlier European patent application No. 14 172 888.1. Which in turn was a divisional application of the earlier European patent application No. 05 715 341.3.

Present divisional application introduces subject-matter which extends beyond the content of the earlier applications as filed, contrary to Article 76(1) EPC (see also the decision of the Enlarged Board of Appeal G1/06). The amendments concerned are the following:

A) The present claims are directed to a radio-frequency transceiver (see claims 1- 12) and a semiconductor chip comprising such a radio-frequency transceiver. The only parts of the content as filed of the application 05 715 341.3 which could provide any base for claiming a radio-frequency transceiver can be found in page 1 of this application in the passage defining the field of the invention and the background of the invention, see page 1 lines 9 - 24. This has however no direct and unambiguous disclosure for a radio-frequency transceiver comprising the first and second inductor as defined in the present independent claim 1. It appears in view of the overall content of the earlier applications that this disclosure concerns inductors and possibly a voltage-controlled oscillator comprising such inductors.

B) Two inductors as presently claimed are only disclosed in a specific arrangement which reduces the mutual coupling between them, see the claims as originally filed for the application 05 715 341.3 or see in the description of this application page 2 last paragraph to page 3 first paragraph and page 4 line 11 - page 5 line 19. No base exists for the unspecific arrangement of the two inductors on a semiconductor chip as presently claimed.

C) For first inductor the present independent claim 1 merely defines that this inductor is 'substantially symmetric', and comprises a first loop and a second loop. The claim fails however to define that the first loop is also substantially symmetrical about a first predefined axis and that the second loop has size and shape substantially identical to the first loop, see the application 05 715 341.3 claims 21 and 22 and page 2 lines 18 - 22. No disclosure is provided which would allow to not claim these additional symmetry features, in particular since the reduced far field aimed for is a direct consequence of these features.

D) For the first and second loop defined in the present independent claim 1 it is defined that they *"are arranged such that current in the first loop (206a) travels in a direction that is opposite to current in the second loop (206b) such that electromagnetic field components emanating from the first loop (206a) and the*

second loop (206b) also have opposite directions and tend to counteract each other". This feature is disclosed in the earlier applications only for a specific arrangement of the two loops, see the application 05 715 341.3 figure 2, page 5 line 28 - page 6 line 14 - the shape is defined as 'figure-8 shaped'. No other arrangement for achieving this current and electromagnetic field flow is disclosed.

4 Procedure

4.1 The applicant is invited to file new claims which take account of the above comments.

4.2 In order to comply with the requirements of Rule 137(4) EPC, the applicant should clearly identify the amendments made, irrespective of whether they concern amendments by addition, replacement or deletion, and indicate the passages of the application as filed on which these amendments are based (see Guidelines H III, 2.1).

If the applicant considers it appropriate, these indications could be submitted in handwritten form on a copy of the relevant parts of the application as filed or in documents with tracked changes.

4.3 Amendments should be made by filing replacement pages. Unnecessary recasting of the description should be avoided. An amended abstract is not required. The applicant should also take account of the requirements of Rule 50(1) EPC. According to Rule 50(1) in conjunction with Rule 49(8) EPC, amendments shall be typed or printed. Handwritten amendments may only be made in documents other than those replacing application documents (Rule 50(2) EPC); they may, for example, be used to fulfil the requirements of Rule 137(4) EPC (identifying amendments and indicating basis for them).



Letter accompanying subsequently filed items

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The document(s) listed below is (are) subsequently filed documents pertaining to the following application:

Application number:

EP19183992.7

Applicant's or representative's reference

P019235EP03

Name of represented party

Telefonaktiebolaget LM Ericsson (publ)

	Description of document	Original file name	Assigned file name
1	Reply to examination report	P019235EP03_2022-12-20_Response_to_Art_94-3_Communication.pdf	EXRE3-1.pdf
2	Amended claims (clean copy)	P019235EP03_2022-12-20_amended_claims_clean.pdf	CLMS-1.pdf
3	Amended claims with annotations	P019235EP03_2022-12-20_amended_claims_marked.pdf	CLMS-HWA-1.pdf

	Fees	Factor applied	Fee schedule	Amount to be paid
15-1	122 Fee for further processing (non fee related cases)	1	275.00	275.00
	Total:		EUR	275.00

	Payment	
1	Mode of payment	Debit from deposit account
	Currency:	EUR
	The European Patent Office is hereby authorised, to debit from the deposit account with the EPO any fees and costs indicated on the fees page.	
	Deposit account number:	28100100
	Account holder:	Ericsson AB
2	Refund/Reimbursement	
	Reimbursement (if any) to be made to EPO deposit account:	28100100
	Account holder:	Ericsson AB

Signatures

Place:	
Date:	20 December 2022
Signed by:	/Ola Andersson/
Capacity:	Representative
Function of person signing:	Representative

CLAIMS

1. A semiconductor die having formed thereon:
 - a first inductor (200, 1300), which is substantially symmetric about a first symmetry axis,
 - the first inductor (200, 1300) comprising terminals (204a, 204b; 1310a, 1310b), and a figure-8
 - 5 shaped coil having
 - a first loop (206a) having a size and shape that is substantially symmetric about a second symmetry axis, perpendicular to the first symmetry axis; and
 - a second loop (206b) having a size and shape substantially identical to a size and shape of the first loop;
 - 10 wherein the first loop (206a; 1004) and the second loop (206b) are arranged such that current in the first loop (206a) travels in a direction that is opposite to current in the second loop (206b) such that electromagnetic field components emanating from the first loop (206a) and the second loop (206b) also have opposite directions and tend to counteract each other; and wherein the terminals (204a, 204b; 1310a, 1310b) are connected to the second loop
 - 15 (206b); and
 - a second inductor.
2. The semiconductor die according to claim 1, wherein the terminals (204a, 204b; 1310a, 1310b) are positioned at a side of the second loop (206b) that is opposite to the first loop
- 20 (206a).
3. The semiconductor die according to claim 1 or 2, wherein the terminals (204a, 204b) are positioned closely
- 25 4. The semiconductor die according to any preceding claim, wherein the first inductor (200) has more than one turn.
5. The semiconductor die according to any preceding claim, comprising a voltage-controlled oscillator comprising the first inductor.
- 30 6. The semiconductor die according to any preceding claim, wherein the second inductor (200, 1300) is substantially symmetric about a third symmetry axis, which is either equal to, parallel with, or perpendicular to the first symmetry axis, and comprises terminals (204a, 204b; 1310a, 1310b), and a figure-8 shaped coil having

- a first loop (206a) having a size and shape that is substantially symmetric about a fourth symmetry axis, perpendicular to the third symmetry axis; and
- a second loop (206b) having a size and shape substantially identical to a size and shape of the first loop (206a) of the second inductor;

5 wherein the first loop (206a; 1004) and the second loop (206b) of the second inductor are arranged such that current in the first loop (206a) of the second inductor travels in a direction that is opposite to current in the second loop (206b) of the second inductor such that electromagnetic field components emanating from the first loop (206a) of the second inductor and the second loop (206b) of the second inductor also have opposite directions and tend to
10 counteract each other; and wherein the terminals (204a, 204b; 1310a, 1310b) of the second inductor are connected to the second loop (206b) of the second inductor.

7. The semiconductor die according to claim 6, wherein the second inductor is rotated 90 degrees relative to the first inductor.

CLAIMS

1. ~~A radio-frequency transceiver, comprising~~semiconductor die having formed thereon:
a first inductor (200, 1300), which is substantially symmetric about a first symmetry axis,
the first inductor (200, 1300) comprising terminals (204a, 204b; 1310a, 1310b), and a figure-8
5 shaped coil having
- a first loop (206a) having a size and shape that is substantially symmetric about a second
symmetry axis, perpendicular to the first symmetry axis; and
- a second loop (206b) having a size and shape substantially identical to a size and shape of
the first loop;
10 wherein the first loop (206a; 1004) and the second loop (206b) are arranged such that
current in the first loop (206a) travels in a direction that is opposite to current in the second
loop (206b) such that electromagnetic field components emanating from the first loop (206a)
and the second loop (206b) also have opposite directions and tend to counteract each other;
and wherein the terminals (204a, 204b; 1310a, 1310b) are connected to the second loop
15 (206b); and
wherein ~~the first inductor is integrated on a semiconductor chip; and~~
wherein ~~the semiconductor chip comprises a second inductor.~~
2. ~~The radio-frequency transceiver~~semiconductor die according to claim 1, wherein the
20 terminals (204a, 204b; 1310a, 1310b) are positioned at a side of the second loop (206b) that is
opposite to the first loop (206a).
3. ~~The radio-frequency transceiver~~semiconductor die according to claim 1 or 2, wherein
the terminals (204a, 204b) are positioned closely.
25
4. ~~The radio-frequency transceiver~~semiconductor die according to any preceding claim,
wherein the first inductor (200) has more than one turn.
5. ~~The radio-frequency transceiver~~ according to any preceding claim, wherein the first
30 inductor (200) ~~is figure-8 shaped.~~
6. ~~The radio-frequency transceiver~~ according to any of the claims 1-4, wherein the first
inductor has four loops.

~~7. The radio-frequency transceiver according to claim 6, wherein the first inductor is four-leaf clover shaped.~~

~~85. The radio-frequency transceiver semiconductor die according to any preceding claim,~~
5 comprising a voltage-controlled oscillator comprising the first inductor.

~~96. The radio-frequency transceiver semiconductor die according to any preceding claim,~~
wherein

the second inductor (200, 1300) is substantially symmetric about a third symmetry axis,
10 which is either equal to, parallel with, or perpendicular to the first symmetry axis, and
comprises terminals (204a, 204b; 1310a, 1310b), and a figure-8 shaped coil having
- a first loop (206a) having a size and shape that is substantially symmetric about a fourth
symmetry axis, perpendicular to the third symmetry axis; and
- a second loop (206b) having a size and shape substantially identical to a size and shape of
15 the first loop (206a) of the second inductor;

wherein the first loop (206a; 1004) and the second loop (206b) of the second inductor are
arranged such that current in the first loop (206a) of the second inductor travels in a direction
that is opposite to current in the second loop (206b) of the second inductor such that
electromagnetic field components emanating from the first loop (206a) of the second inductor
20 and the second loop (206b) of the second inductor also have opposite directions and tend to
counteract each other; and wherein the terminals (204a, 204b; 1310a, 1310b) of the second
inductor are connected to the second loop (206b) of the second inductor.

~~10. The radio-frequency transceiver according to any preceding claim, wherein the radio-~~
25 ~~frequency transceiver is integrated on the semiconductor chip.~~

~~11. A semiconductor chip comprising the radio-frequency transceiver according to claim~~
40.

30 7. The semiconductor die according to claim 6, wherein the second inductor is rotated 90
degrees relative to the first inductor.



Our Reference: P019235EP03
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Response to Communication pursuant to Article 94(3) EPC

Application Number: 19183992.7
Application Date: February 15, 2005
Applicant: Telefonaktiebolaget LM Ericsson (publ)
Our Reference: P019235EP03

Encl:

Amended claims with and without marked-up amendments

Dear EPO,

This is in response to the communication pursuant to Article 94(3) EPC dated 22.03.2022.
Further processing is hereby requested and the corresponding fee is paid.

In the communication, the Examiner has made four objections labeled A, B, C, and D with reference to A 76(1) EPC. These are referred to below as item A, item B, item C, and item D, respectively.

References to passages in the description are made below with reference to the original PCT application published as WO 2005/096328 A1 (i.e. the root parent application 05715341.3 as filed). Corresponding passages are present in each application in the chain of divisional applications. It should also be noted that the text of the claims of the root parent application as filed is included at the end of the description of each of the divisional applications as filed (i.e. both the present application 19183992.7 and its immediate parent application 14172888.1).

The following amendments and arguments are made with respect to the enclosed amended claims. The applicant reserves the right to reinstate, and/or file one or more divisional applications, based on any excised subject matter

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Item A

The applicant respectfully disagrees with the Examiner's opinion that the "radio frequency transceiver" lacks support in the earlier applications as filed. However, in the interest of expediting the examination procedure, the claims have been amended to be directed towards "a semiconductor die" having the first and second inductor formed thereon. Support for the first and second inductors formed on the same semiconductor die, or chip, can e.g. be found in the description on page 2, line 23 - page 3, line 2 and claims 2 and 11 of the root parent application as filed.

Item B

The applicant respectfully disagrees with the Examiner's assessment under item B. The reduction of electromagnetic coupling between the first and the second inductor (compared with two O-shaped inductors) is a technical effect of the shape of the first inductor. Although the distance between the inductors has an influence on the total amount of coupling (see e.g. Fig. 6), it is still significantly reduced compared with two O-shaped inductors at the same distance. Hence, no particular distance between the two inductors is mandated in the description. Furthermore, it is clear from the description that the two inductors may be rotated and/or offset relative to one another, see e.g. page 2, lines 16-17, and tables 1-3. Hence, it is submitted that the root parent application as filed does not mandate any particular distance or relative orientation of the two inductors. (The same goes for the two divisional applications).

Item C

The applicant respectfully disagrees with the Examiner's assessment under item C. For example, according to the description, page 4, lines 15-16, the term "symmetrical" refers to symmetry relative to at least one axis. Furthermore, original claim 1 of the root parent application provides support for not including the features indicated by the Examiner under item C.

However, in the interest of expediting the examination procedure, claim 1 has been amended as suggested by the Examiner under item C. The symmetry axes of the first inductor have been labeled "first symmetry axis" and "second symmetry axis", respectively. Furthermore, it has been defined that these axes are perpendicular. The first symmetry axis corresponds to the "horizontal axis X" referred to throughout the description. The second symmetry axis corresponds to the "vertical axis Y" referred to throughout the description. The horizontal axis X and the vertical axis Y are perpendicular.

Item D

The applicant respectfully disagrees with the Examiner's assessment under item D. For instance, it is submitted that also the four-leaf clover-shaped inductors disclosed in the application also have loops arranged in such a manner, see e.g. page 13, lines 2-4.

However, in the interest of expediting the examination procedure, claim 1 has been amended by defining that the first inductor has a figure-8 shaped coil, which is supported e.g. by the embodiments described in the context of Fig. 2, 4, 5, 7, 9, and 13.



Further amendments

Previous claims 5-7 have been deleted and the other claims have been renumbered accordingly.

In claim 6 (previous claim 9), the definition of the second inductor has been amended in the same way as the definition of the first inductor in claim 1. The symmetry axes of the second inductor have been labeled third symmetry axis and fourth symmetry axis, respectively. Furthermore, it is defined that the third symmetry axis is either equal to the first symmetry axis (corresponding to the case where the first and second inductor are oriented in the same direction and share the same "X axis", e.g. as in Fig. 4), parallel to the first symmetry axis (corresponding to the case where the two inductors are oriented in the same direction but "vertically" offset relative to one another), or perpendicular to the first symmetry axis (corresponding to the cases where the inductors are rotated 90 degrees relative to one another, e.g. as in Figs. 5 and 7).

A new claim 7 has been introduced, defining that the second inductor is rotated 90 degrees relative to the first inductor. This is e.g. supported in the description on page 8, lines 3-4.

Requests

It is respectfully submitted that the items raised in the communication have been fully addressed and we request that a communication under R 71(3) be issued based on the enclosed amended claims.

Should the Examining Division consider further editorial amendments necessary before issuing a communication under Rule 71(3) EPC, we respectfully suggest contacting the undersigned per phone to bring the present examination procedure to an efficient conclusion.

Purely as a precaution, oral proceedings are requested in case the Examining Division should consider refusing the application.

/Ola Andersson/

Ola Andersson
European Patent Attorney

Association Ericsson (Registration number 643)