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(71) Applicant *(for all designated States except US)*: **FREESCALE SEMICONDUCTOR, INC.** [US/US]; 6501 William Cannon Drive West, Austin, Texas 78735 (US).

(72) Inventor; and
(71) Applicant *(for US only)*: **LI, Hao** [DE/DE]; Am Römerbrunnen 6, 85586 Poing (DE).

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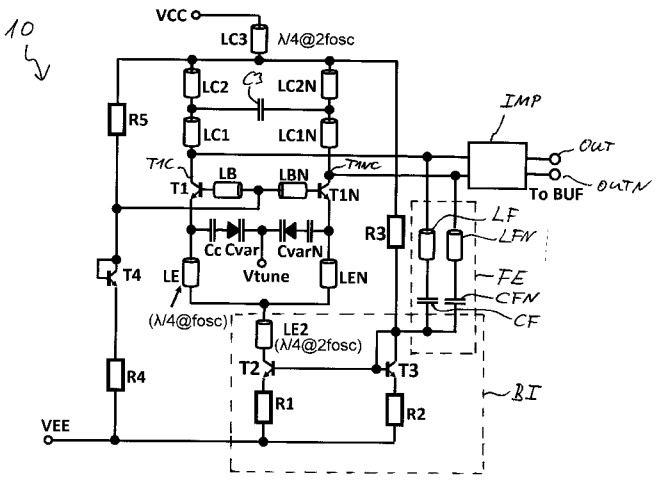
(54) **Title**: VOLTAGE CONTROLLED OSCILLATOR

Fig. 1



(57) **Abstract**: A voltage controlled oscillator (VCO) (10) comprising a first supply node (VCC), a second supply node (VEE), an oscillation transistor (T1), a biasing network (LE2, T2, R1), an output node (T1C) and a feedback network (FE) is described. The VCO is be powered by a supply voltage applied across the first and second supply nodes (VCC, VEE). The oscillation transistor (T1) and the biasing network (BI) are connected in series between the first supply node (VCC) and the second supply node (VEE). The output node (T1C) is connected to the oscillation transistor (T1) so as to deliver an oscillatory output signal. The feedback network (FE) provides an oscillatory feedback signal from the output node (T1C) to the biasing network (BI). The feedback network (FE) comprises a capacitive element (CF) and a transmission line (LF) connected in series for transferring the feedback signal. The VCO may be integrated in a radar device, for example.

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Title : Voltage controlled oscillator

Description

Field of the invention

This invention relates to a voltage controlled oscillator.

Background of the invention

A voltage controlled oscillator (VCO) is an electronic circuit for generating a periodic oscillatory output signal, e.g., an oscillatory voltage or current, the output signal having an oscillation frequency that is adjustable by means of a tuning voltage applied at a varactor in the VCO core. The oscillation frequency (also referred to as the oscillator frequency or VCO frequency) may be varied or modulated by varying this tuning voltage. VCOs may notably be used in high frequency applications such as communication and sensor systems.

One of the most important VCO signal quality parameters is the phase noise. Phase noise is a variable and unpredictable deviation of the phase of the VCO output signal and is usually undesired. Phase noise can limit the performance of an application system, and it can be one of the most critical parameters.

It has been proposed to include a current source in a VCO in order to make the VCO design robust against process and temperature variation, and also to avoid self-biasing in the VCO core. The introduction of a current source in the VCO core may, however, increase the level of VCO phase noise due to noise sources in the current source.

Summary of the invention

The present invention provides a voltage controlled oscillator as described in the accompanying claims.

Specific embodiments of the invention are set forth in the dependent claims.

These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter.

Brief description of the drawings

Further details, aspects and embodiments of the invention will be described, by way of example only, with reference to the drawings. In the drawings, like reference numbers are used to identify like or functionally similar elements. Elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale.

Figure 1 schematically shows an example of an embodiment of a VCO.

Figure 2 shows a plot of a collector current as a function of time for two different VCOs.

Figure 3 schematically shows an example of an embodiment of a VCO.

Detailed description of the preferred embodiments

Because the illustrated embodiments of the present invention may for the most part, be implemented using electronic components and circuits known to those skilled in the art, details will not be explained in any greater extent than that considered necessary as illustrated above, for the understanding and appreciation of the underlying concepts of the present invention and in order not to obfuscate or distract from the teachings of the present invention.

Figures 1 and 3 illustrate a first and second example of a VCO 10, respectively. The VCO 10 has a voltage controlled oscillator frequency. The VCO 10 may notably comprise a first supply node VCC, a second supply node VEE, an oscillation transistor T1, a biasing network BI, an output node T1C~~C1~~, and a feedback network FE. The VCO 10 may be of the Colpitts type.

In the shown example, the VCO 10 may comprise a first group of components and a second group of components that are arranged symmetrically with respect to each other to produce a differential output signal, e.g., the voltage between nodes T1C and T1NC. Each component of the first group may have a counterpart component in the second group. In the shown example, the first group notably comprises the components LC2, LC1, T1, LB, Cvar, LE, LF, and CF, while the second group comprises the corresponding counterpart components LC2N, LC1N, T1N, LBN, CvarN, LEN, LFN, and CFN.

The VCO 10 may be arranged to be powered by a supply voltage applied across the first and second supply nodes VCC and VEE. The supply voltage may be a direct current (DC) voltage.

The oscillation transistor T1 or the pair of transistors T1, T1N and the biasing network BI may be connected in series between the first supply node VCC and the second supply node VEE. In the shown example, the oscillation transistor T1 is a bipolar transistor. In an alternative example (not shown), the oscillation transistor T1 may be a field effect transistor. The output node may, for example, be the collector TC1 of the oscillation transistor T1 (in the case of a bipolar transistor) or the source of the oscillation transistor (in the case of a field effect transistor). In the shown example, a counterpart output node is provided by the collector T1NC of the transistor T1N that is the counterpart of the first oscillation transistor T1, and the output signal may be the voltage between the output nodes T1C and T1NC. In an alternative example, the VCO 10 may be of an asymmetrical or non-differential design. The output signal may then be the voltage between the output node T1C and a ground node. The ground node may, for example, be provided by one of the two supply nodes VCC and VEE. More generally, the output node (T1C in the present example) may be connected to the oscillation transistor T1 so as to deliver an oscillatory output signal that has the oscillator frequency. The output signal may be a voltage or a current. The oscillator frequency may be above 1 gigahertz or even above 10 gigahertz. The oscillator frequency may, for example, be 77 gigahertz, a frequency commonly used in automotive radar devices.

The feedback network FE may provide an oscillatory feedback signal from, e.g., the output node T1C to the biasing network BI. The feedback network FE may comprise a capacitive element CF and a transmission line LF connected in series for transferring the feedback signal to the biasing network BI. The feedback signal may thus be synchronized with the VCO output signal to achieve a fast switching on and off of the oscillation transistor T1 (in a non-differential design) or

the pair of oscillation transistors T1 and T1N (in a differential design). The turn on and off time of the oscillation transistors of T1 and T1N may thus be reduced. A contribution of T1 and T1N ~~to~~ shot noise to ~~of~~ the VCO phase noise may hence be reduced accordingly. A noise contribution of other components of the VCO 10 may also decrease.

The VCO 10 may, for example, have an oscillation frequency of 38.5 GHz, the capacitive element CF may have a capacitance of, e.g., about 1.5 pF and the transmission line LF may have a length of, e.g., about 1900 micrometers (um). The VCO 10 may, for example, be connected to a frequency doubler circuit (not shown) to generate a frequency-doubled signal having a frequency of, e.g., 77 GHz. The frequency-doubled signal may be used in a 77 GHz radar application, for example.

The capacitive element CF may be implemented on chip, e.g., using Metal-Isolation-Metal (MIM) or metal–oxide–semiconductor (MOS) capacitors. The transmission line LF in the feedback network may behave as an inductance and may be implemented on chip using, e.g., a single metal wire over a ground plane, a pair of metal wires over a ground plane, a coplanar transmission line, or, in a certain GHz range, one or more spiral inductors.

In the examples of Figures 1 and 3, the oscillation transistors T1 and T1N may have their bases interconnected via transmission lines LB and LBN, and their emitters interconnected via one or more capacitive elements, e.g., capacitive elements CC, CCN, Cvar, CvarN. The capacitive elements Cvar and CvarN may be varactors having a voltage controlled capacitance. The oscillator frequency may thus be controlled by varying the capacitance of the varactors Cvar and CvarN by means of the control voltage Vtune. The network of components LB, T1, CC, Cvar, and their counterparts LBN, T1N CCN, and CvarN may be considered the core of the VCO 10. The feedback signal that is fed back to the VCO core may notably reduce the phase noise contributions of the various components of the VCO core and notably the contributions of the transmission lines LB and LBN and of Cvar and CvarN. The incorporation of the feedback network FE in VCO 10 may also increase the oscillation amplitude which may further reduce the phase noise.

The VCO 10 may further comprise a network of inductive and capacitive elements LC1, LC1N, LC2, LC2N, and C3 with a high side connected to the first supply node VCC and a second side connected to the oscillation transistors T1 and T1N. A quarter wavelength transmission line LC3 may be connected between the first supply node VCC and the rest of the circuit. Furthermore, resistive elements R1, R2, R3, R4, and R5 and transistors T2, T3 and T4 may be provided for setting various voltage levels at various nodes within the circuit. For example, the resistive elements R4 and R5 may be arranged to provide a voltage divider between the first supply node VCC and the second supply node VEE so as to provide a bias voltage to the control terminals (e.g., basis terminals or gate terminals) of the oscillation transistors T1 and T1N. The voltage divider may further comprise a diode T4 connected in series with the resistive elements R4 and R5. The diode T4 may be provided in the form of a bipolar transistor having its based shorted to its collector.

The VCO 10 may further comprise an impedance transformer IMP connected between, e.g., the differential output T1C, T1NC of the oscillation transistors T1 and T1N and a differential output terminal OUT, OUTN of the VCO 10. The differential output terminal OUT, OUTN may, for

example, be connected to a buffer (not shown). The impedance transformer may be designed such that it has a high input impedance, i.e., loading of the tank, so as to avoid degrading the tank quality factor. The tank quality factor may be determined mainly by a quality factor of the varactor and the transmission line in the VCO 10 and also by the base resistance of the oscillation transistors T1 and T1N. In the example of Figure 3, the biasing network BI does not comprise any current source. In the example of Figure 1, in contrast, the biasing network BI may comprise a transistor T2 and a transistor T3 acting as a first current source and a second current source, respectively. The VCO 10 may further comprise one or more transmission lines. The transmission lines may notably comprise transmission lines LC3, LE, LEN, LB, LBN, LE2, LF, and LFN. The electrical length of each transmission line may be chosen to achieve a desired oscillation frequency, the lowest phase noise and optimum phase shift between its respective ends.

It is thus proposed to introduce a LC feedback network in a VCO. A fast switching on and off of the oscillation transistors may thus be achieved. The turn on and turn off times of the oscillation transistors may be significantly reduced, and the signal amplitude in the VCO core may become large. Shot noise contribution to phase noise may thereby be reduced. Furthermore, the large oscillation amplitude may also reduce the VCO phase noise. The feedback network may comprise the transmission line LF and the capacitive element CF in a non-differential design, or a pair of transmission lines LF, LFN and a pair of capacitive elements CF, CFN in a differential design. The capacitance of the capacitive element or the electrical length of the transmission line may be optimized to achieve a high input impedance and a correct, i.e., synchronized, phase relationship between the original signal, i.e., the VCO output signal, and the feedback signal.

Referring now to Figure 2, the collector current of the oscillation transistor T1 (or equivalently of the second oscillation transistor T1N) is plotted as a function of time T. The time T is given in picoseconds (ps). The current is given in amperes. Graph A refers to a VCO identical to the one described above in reference to Figure 1, but lacking the feedback network FE. Graph B refers to the VCO 10 described above in reference to Figure 1. The feedback network FE in the VCO 10 was found to yield a reduction of the noise contribution of the oscillation transistors, an increase of the oscillation amplitude in the VCO core and a reduction of the noise contribution of the transmission lines LB and LBN and of the varactors Cvar and CvarN. A total phase noise reduction of approximately two decibels has been observed.

In the foregoing specification, the invention has been described with reference to specific examples of embodiments of the invention. It will, however, be evident that various modifications and changes may be made therein without departing from the broader spirit and scope of the invention as set forth in the appended claims.

Although specific conductivity types or polarity of potentials have been described in the examples, it will be appreciated that conductivity types and polarities of potentials may be reversed.

Also for example, the examples, or portions thereof, may implemented as soft or code representations of physical circuitry or of logical representations convertible into physical circuitry, such as in a hardware description language of any appropriate type.

However, other modifications, variations and alternatives are also possible. The specifications and drawings are, accordingly, to be regarded in an illustrative rather than in a restrictive sense.

In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. The word ‘comprising’ does not exclude the presence of other elements or steps then those listed in a claim. Furthermore, the terms “a” or “an,” as used herein, are defined as one or more than one. Also, the use of introductory phrases such as “at least one” and “one or more” in the claims should not be construed to imply that the introduction of another claim element by the indefinite articles "a" or "an" limits any particular claim containing such introduced claim element to inventions containing only one such element, even when the same claim includes the introductory phrases "one or more" or "at least one" and indefinite articles such as "a" or "an." The same holds true for the use of definite articles. Unless stated otherwise, terms such as “first” and “second” are used to arbitrarily distinguish between the elements such terms describe. Thus, these terms are not necessarily intended to indicate temporal or other prioritization of such elements. The mere fact that certain measures are recited in mutually different claims does not indicate that a combination of these measures cannot be used to advantage.

Claims

1. A voltage-controlled oscillator (VCO) (10) having a voltage controlled oscillator frequency,

wherein the VCO comprises a first supply node (VCC), a second supply node (VEE), an oscillation transistor (T1), a biasing network (BI), an output node (T1C), and a feedback network (FE);

the VCO is arranged to be powered by a supply voltage applied across the first and second supply nodes (VCC, VEE);

the oscillation transistor (T1) and the biasing network (BI) are connected in series between the first supply node (VCC) and the second supply node (VEE);

the output node (T1C) is connected to the oscillation transistor (T1) so as to provide an oscillatory output signal which has said oscillator frequency;

the feedback network (FE) is arranged to provide an oscillatory feedback signal from the output node (T1C) to the biasing network (BI); and

the feedback network (FE) comprises a capacitive element (CF) and a transmission line (LF) connected in series for transferring the feedback signal.

2. The VCO of claim 1, wherein the biasing network (BI) comprises a current source.

3. The VCO of claim 1 or 2, wherein the current source comprises a transistor (T2) connected between the second supply node (VEE) and the oscillation transistor (T1).

4. The VCO of one of the preceding claims, wherein the VCO is of the Colpitts type.

5. The VCO of one of the preceding claims, wherein the oscillation transistor (T1) is a bipolar transistor having a collector (T1C) connected to the first supply node (VCC) and an emitter connected to the bias network (BI).

6. The VCO of claim 5, comprising a first transmission line (LE) and a second transmission line (LE2) connected in series, the first transmission line (LE) having an electrical length of one quarter wavelength for the oscillator frequency, the second transmission line (LE2) having an electrical length of one quarter wavelength for twice the oscillator frequency, the first transmission line (LE) being connected to the emitter of the oscillation transistor (T1), the second transmission line (LE2) being connected between the first transmission line (LE) and the biasing network (BI).

7. The VCO of one of the preceding claims, comprising a first group of components (T1, LE) and a second group of components (T1N, LEN), wherein the first group and the second group are arranged symmetrically with respect to each other, each component of the first group having a counterpart component in the second group, the first group of components comprising said oscillation transistor (T1) as a first oscillation transistor, said second group of components

comprising a second oscillation transistor (T2) as the counterpart component of the first oscillation transistor (T1).

8. The VCO of one of the preceding claims, wherein the feedback signal is synchronized with said output signal to achieve a fast switching on and off of the oscillation transistor (T1).

9. The VCO of one of the preceding claims, where the oscillator frequency is above 1 GHz.

10. A radar device comprising a voltage-controlled oscillator (10) as set forth in one of the preceding claims.

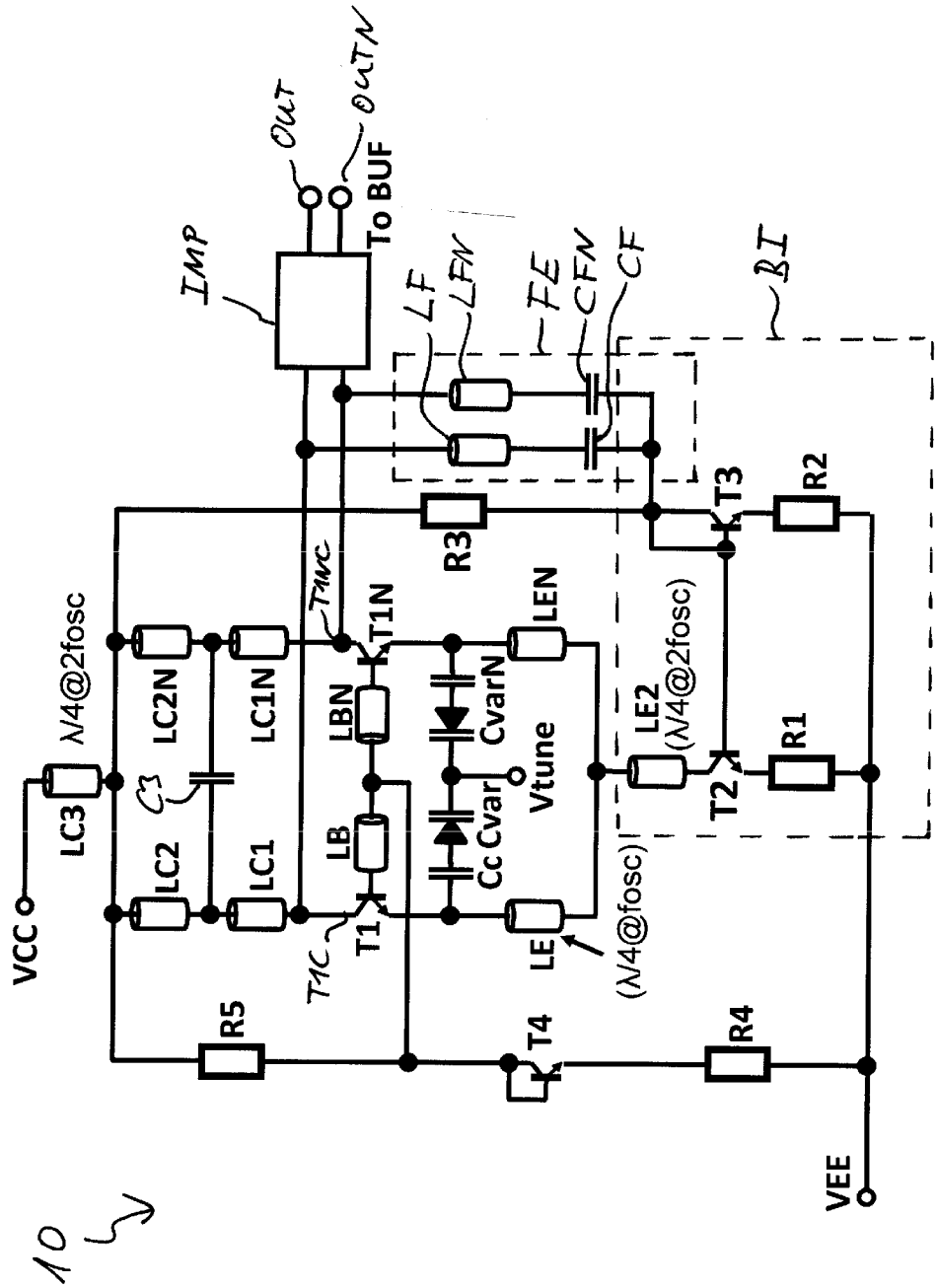
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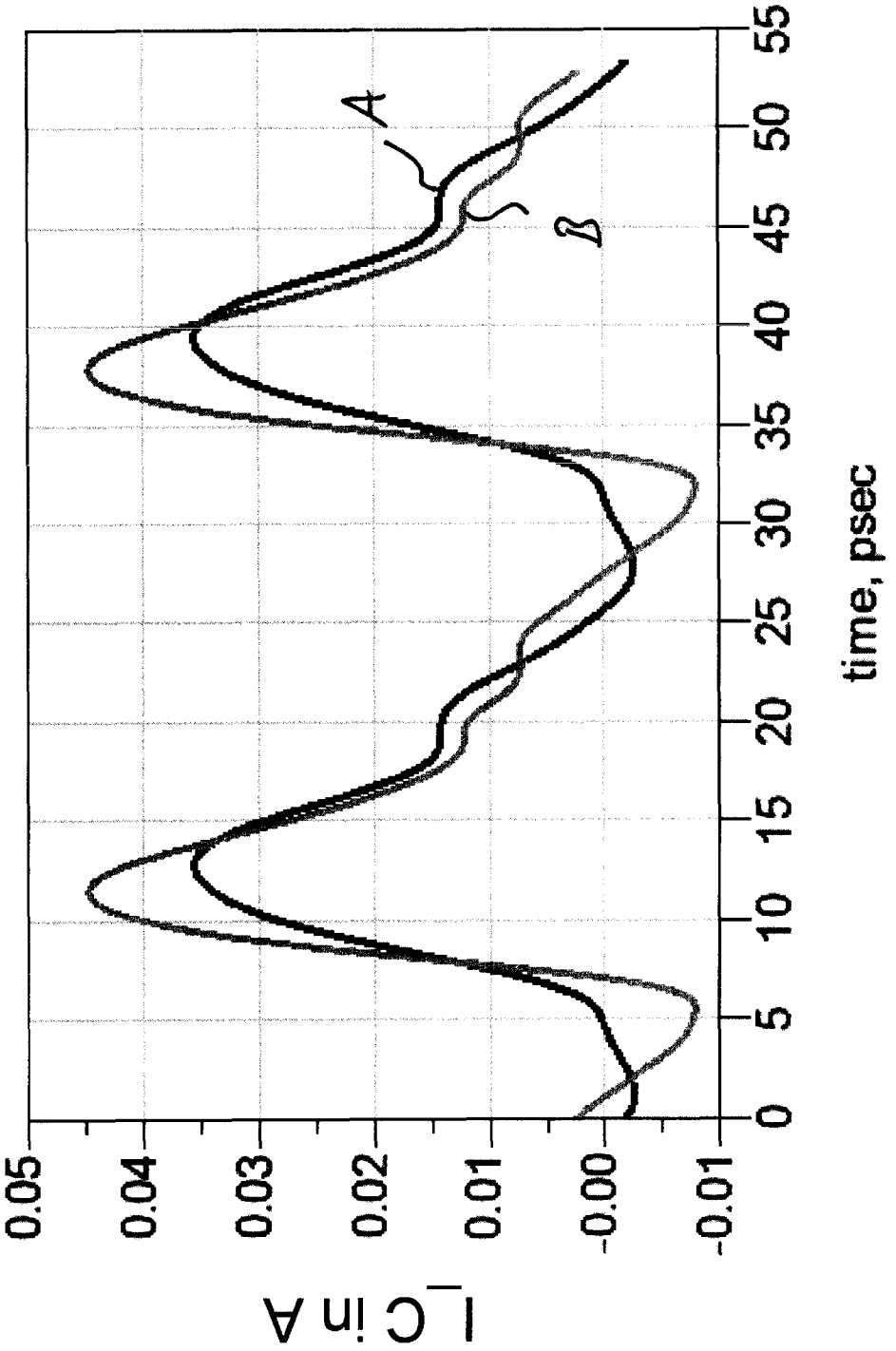
Fig. 1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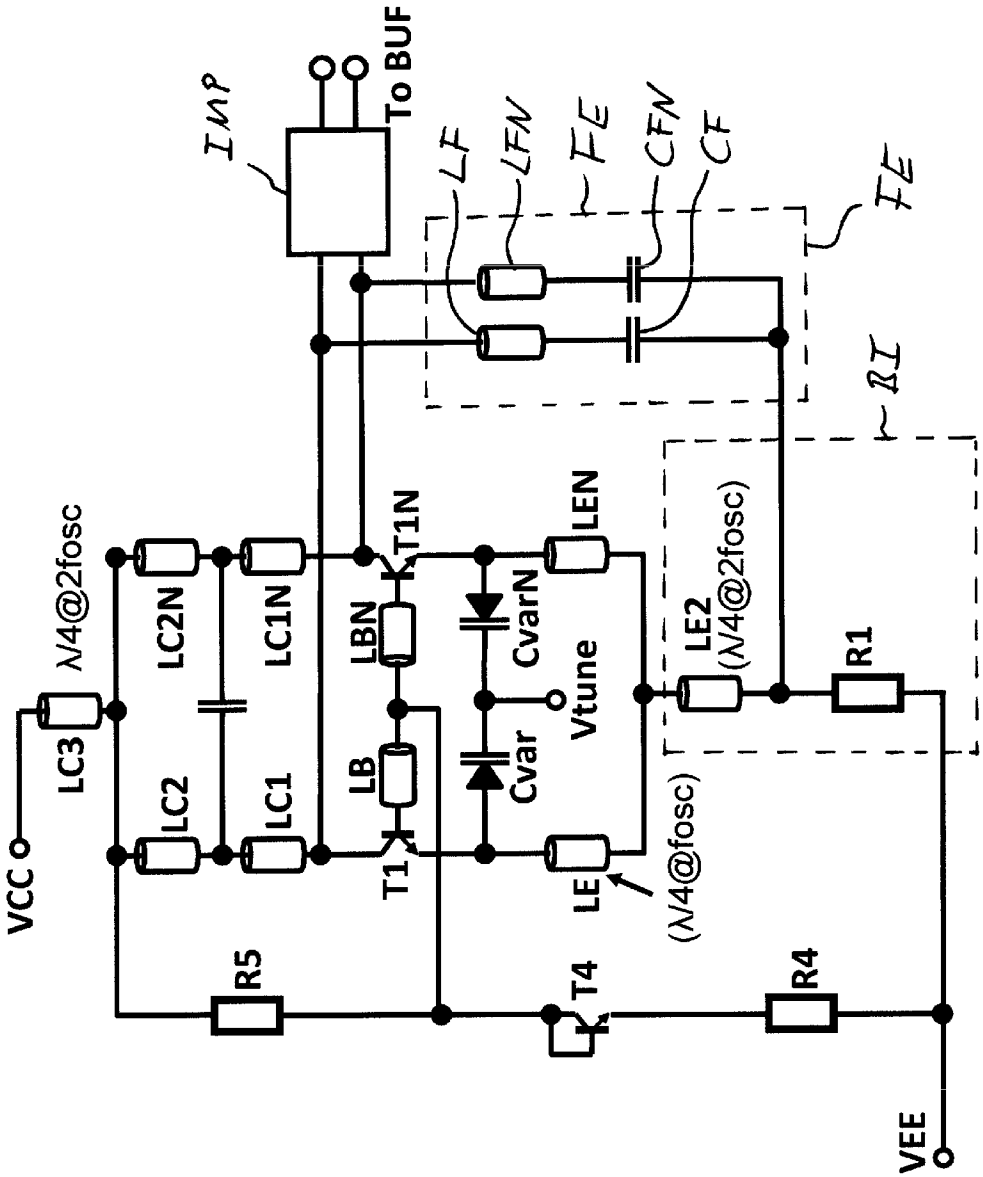
B

Fig. 2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LC3
LC2
LC1
LC2N
LC1N
LB
LBN
T1
T1N
Cvar
CvarN
Vtune
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LEN
LE2
(λ/4@2fosc)
R1
R5
T4
R4
VEE

Fig. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2013/050194

A. CLASSIFICATION OF SUBJECT MATTER

H03B 5/18(2006.01)i, H01P 7/08(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H03B 5/18; H01P 7/04; H03B 5/04; H03B 5/12; H03L 7/08; H01P 7/10; H03B 5/08; H01P 7/08

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords:VCO, node, transistor, collector, emitter, feedback network, biasing network, transmission line, wavelength

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6326854 B1 (NICHOLLS et al.) 04 December 2001 See column 6,line 31-column 8,line 36, column 11,lines 1-64, and figures 1-6.	1-10
A	KR 10-2007-0061233 A (ELECTRONICS AND TELECOMMUNICATIONS RESEARCH INSTITUTE) 13 June 2007 See abstract, pages 3-7 and figures 1-5.	1-10
A	JP 2012-039574 A (NIPPON DEMPA KOGYO CO., LTD.) 23 February 2012 See abstract, paragraphs [0022]-[0045], and figures 1-7.	1-10
A	US 2011-0018597 A1 (LEE et al.) 27 January 2011 See abstract, paragraphs [0035]-[0050], and figures 1-6.	1-10
A	US 5821820 A (SNIDER et al.) 13 October 1998 See abstract, column 2, line 54 - column 6, line 51, and figures 1-6.	1-10

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 August 2013 (27.08.2013)	**27 August 2013 (27.08.2013)**

Name and mailing address of the ISA/KR
Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon Metropolitan City, 302-701, Republic of Korea
Facsimile No. +82-42-472-7140

Authorized officer
KIM Sung Gon
Telephone No. +82-42-481-8746

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/IB2013/050194

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