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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
27 October 2011 (27.10.2011)

PCT

(10) International Publication Number
WO 2011/131237 A1

(51) International Patent Classification:
H03B 21/01 (2006.01)

(21) International Application Number:
PCT/EP2010/055259

(22) International Filing Date:
21 April 2010 (21.04.2010)

(25) Filing Language: English

(26) Publication Language: English

(71) Applicant *(for all designated States except US)*: **TELEFONAKTIEBOLAGET LM ERICSSON (publ)** [SE/SE]; S-164 83 Stockholm (SE).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **BAO, Mingquan** [SE/SE]; Citrusgatan 27, S-426 54 Västra Frölunda (SE). **ZIRATH, Herbert** [SE/SE]; Ö. Brovaktaregatan 48, S-431 36 Mölndal (SE).

(74) Agent: **SCHLOSSMAN, Ulf**; Patentor KB, Flöjelbergsgatan 8B, S-431 37 Mölndal (SE).

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

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

Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

Published:

— *with international search report (Art. 21(3))*

(54) **Title**: A DIRECT ANALOG FREQUENCY SYNTHESIZER

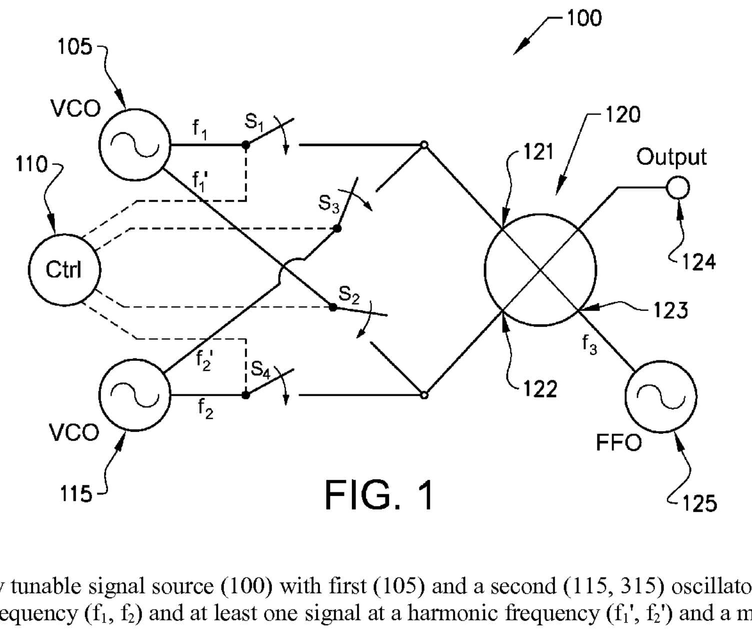

FIG. 1

(57) **Abstract**: A frequency tunable signal source (100) with first (105) and a second (115, 315) oscillators, each of which outputs a signal at a fundamental frequency (f_1, f_2) and at least one signal at a harmonic frequency (f_1', f_2') and a mixer (120) with first (121) and second (122) input ports and an output port (124), and a control unit (110) which controls switches (S_1, S_2, S_3, S_4), by means of which two of said signals (f_1, f_2, f_1', f_2') are switchably connected to the first input port. The other two signals are switchably to the other input port, with one switch (S_1, S_2, S_3, S_4) for each signal (f_1, f_2, f_1', f_2'). There is also comprised a third oscillator (125), with an output signal connected to a third input port (123) of the mixer (120). At least one of the oscillators (105, 115, 315, 125) is a VCO, a Voltage Controlled Oscillator.

WO 2011/131237 A1

A DIRECT ANALOG FREQUENCY SYNTHESIZER

TECHNICAL FIELD

The present invention discloses an improved tunable signal source.

BACKGROUND

The demand for tunable signal sources with low phase noise and a wide tuning range is growing, particularly tunable signal sources which can be used in higher frequency ranges, e.g. at 60 GHZ and above. Such a signal source can be used in a variety of technical fields such as, for example, radars and telecommunications.

One commonly used approach to obtain a high frequency signal source is to design a low frequency VCO, Voltage Controlled Oscillator, and to then apply frequency multipliers to up-convert the frequency of the VCO. Although it in this way is relatively easy to obtain an improvement in phase noise performance compared to a high frequency VCO, the phase noise degrades by 6dB at every doubling of the oscillation frequency. This phase noise degradation, which accompanies an increase in frequency, can be alleviated by using a mixer and a fixed frequency oscillator in order to up-convert the frequency. Unfortunately, this approach has the drawback of having a relatively small tuning range, since the absolute tuning range determined by the low frequency VCO is unchanged in the frequency up-conversion.

SUMMARY

As explained above, there is a need for a high frequency signal source which has improved properties with respect to phase noise and tuning range compared to previously known such signal sources.

A purpose of the present invention is to offer such a high frequency signal source. This purpose is met by the present invention in that it discloses a frequency tunable signal source which comprises a first and a second oscillator, each of which has as its output a signal at a fundamental frequency and at least one signal at a harmonic frequency of the fundamental frequency.

The frequency tunable signal source of the invention also comprises a mixer with a first and a second input port as well as an output port, and further comprises a control unit which controls ON/OFF switches, by means of which switches two of said signals are switchably connected to the first input port and the other two signals are switchably to the other input port, with one switch for each signal.

In addition, the frequency tunable signal source also comprises a third oscillator which produces an output signal which is connected to a third input port of the mixer, and at least one of the first, second and third oscillators is a VCO, a Voltage Controlled Oscillator.

By means of the invention, as will be explained in the detailed description given in this text, a frequency tunable signal source with low phase noise is obtained, which can be used at high frequencies.

In one embodiment of the frequency tunable signal source of the invention, the third oscillator is a fixed frequency oscillator, an FFO.

In one embodiment of the frequency tunable signal source of the invention, at least one of the first and second oscillators is a VCO.

In one embodiment of the frequency tunable signal source of the invention, one of the first and second oscillators is an FFO.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described in more detail in the following, with reference to the appended drawings, in which

Fig 1 shows a first embodiment of the invention, and
Fig 2 shows states of the embodiment of fig 1, and
Fig 3 shows a second embodiment of the invention, and
Fig 4 shows states of the embodiment of fig 3, and
Fig 5 shows a circuit diagram of a component in the invention.

DETAILED DESCRIPTION

The invention will be described in detail below, and the terms “fundamental frequency” and “harmonic frequency” will be used. These terms can briefly be defined as follows: A periodic signal can be expressed by means of, for example, a Fourier series with the components $N*f_0$, where f_0 is the signal’s fundamental frequency and N is an integer. Thus:

N=1 gives us the signal’s fundamental frequency, also known as the first harmonic, and
N=2 gives us the signal’s second harmonic, and
N=3 gives us the signal’s third harmonic, etcetera.

Fig 1 shows a first embodiment 100 of a tunable signal source of the invention. In this embodiment, the tunable signal source comprises a first 105 and a second 115 Voltage Controlled Oscillator, VCO. Each of the VCOs 105, 115, has two output signals, a first output signal at a fundamental frequency of the VCO, shown in fig 1 as f_1 and f_2, respectively, and a second output signal at a harmonic frequency of the fundamental frequency, where the harmonic frequencies can, in principle, be any harmonic of the fundamental frequency, and which will from now on merely be referred to as "harmonic frequencies". The output signals at the harmonic frequencies of the first 105 and second 115 VCO are shown as f_1' and f_2' respectively in fig 1. In principle any harmonic frequency of the fundamental frequency can be used, e.g. 2nd, 3rd, etc, as well as the 1st, i.e. the fundamental frequency. In addition, there is no need to use the same harmonic from both oscillators, i.e. the 2nd harmonic from one oscillator and the 3rd harmonic from the other oscillator can be used. However, the invention will be described below with reference to an embodiment in which the second harmonic from both oscillators is used.

The embodiment 100 also comprises a mixer 120 with a first 121 and a second 122 input port as well as an output port 124. The output signals from the two VCOs 105, 115 are connected pair-wise to the input ports 121, 122 of the mixer via ON/OFF switches shown as S_1-S_4 in fig 1, with one switch being used for each signal. The switches S_1-S_4 are controlled by a control unit 110, and are suitably controlled so that only one signal at a time reaches each of the input ports 121, 122, i.e. only one of S_1/S_3 and one of S_4/S_2 should be closed at the same time.

As those skilled in the field will understand, which of the four output signals that are connected to which input port (via an ON/OFF switch) depends on which results that are desired as output signals from the mixer 120. In principle, any of the signals f_1, f_2, f_1', f_2', can be input to either one of the input ports 121, 122, or in fact to of both the input ports 121, 122 of the mixer.

However, in the example given in fig 1, the connections (via the ON/OFF switches S_1-S_4) from the VCOs 105, 115 to the input ports 121,122 of the mixer 120 are as follows:

The signal at the fundamental frequency f_1 of the first VCO 105 and the signal at the fundamental frequency f_2 of the second VCO 115 are connected to the first input port 121 and the second input port 122 of the mixer 120 respectively via the switches S_1 and S_4 respectively; the signal at the second harmonic frequency f_1' of the first VCO 105 and the signal at the second harmonic frequency f_2' of the second VCO 115 are connected to the mixer's second input port 122 and first input port 121 respectively via the switches S_2 and S_3, respectively.

As is also shown in fig 1, the mixer 120 of the tunable signal source 100 is a so called three-input-port mixer, i.e. a mixer which has a third input port 123 in addition to the first 121 and second 122 input ports. The tunable signal source 100 also comprises a third oscillator 125, which in this example of an embodiment is a so called Fixed Frequency Oscillator, an FFO, although the third oscillator can also be a VCO. Suitably, the third oscillator 125 should have a similar phase noise performance to the first and second oscillators, i.e. in this case the VCOs 105, 115. As will be realized, an available signal frequency at the output port 124 of the mixer 120 is the sum of all three input frequencies. For this reason the two VCOs 105, 115, can be used to generate a relatively low-frequency signal, which is then shifted “upwards” by means of the signal from the FFO 125. The frequency of the signal from the FFO 125 will from now on also be referred to as f_3 in this text as well as in the appended drawings. Naturally, as one skilled in the art will realize, with three signals as the input to the mixer 120, a multitude of frequencies will be available at the output port 123 of the mixer 120, all of which can be accessed if so desired. Suitably, the desired frequency component is accessed by means of a filter (not shown) at the output port 124 of the mixer 123.

In addition, although the FFO 125 is used in this embodiment to obtain a shift upwards in frequency, the FFO 125 can of course also be used to obtain virtually any other shift, such as, for example a shift downwards in frequency.

The control unit 110 operates to cause the switches S_1-S_4 to be in the ON or OFF position depending on which frequency it is desired to have as the output frequency of the mixer 120. Fig 2 is a table which shows the frequency of the output signal at the output port 124 of the mixer 120 as a function of the position of the switches S_1-S_4, where ON is indicated as “1” and OFF is indicated as “0”. In this example, it is assumed that, as described above, the frequencies of the signals from the VCOs 105, 115 which are connected to the input ports of the mixer 120 are as follows:

- S_1 and S_4 connect the fundamental frequencies of the two VCOs to the first input port 121 and the second input port 122, respectively.
- S_2 and S_3 connect the second harmonic frequencies of the two VCOs to the first input port 121 and the second input port 122, respectively.

In addition, the table of fig 2 does not show all of the possible combinations of settings of the switches S_1-S_4, since the table is merely intended to illustrate an example, and shows how to obtain four frequency combinations which are of interest, i.e. $2f_1$, $2f_2$ and $f_1 \pm f_2$. These combinations are shown in the table of fig 2 without the frequency from the FFO 125, i.e. f_3.

As those skilled in the art will realize, a vast number of combinations are possible with a tunable signal source of the invention, depending on how the frequency ranges of the VCOs 105 and 115 are chosen and how the VCOs are set (i.e. controlled by means of a tuning voltage) within their respective ranges, in combination with how the FFO 125 is chosen, as well as how the switches S_1-S_4 are set.

However, suitably, the frequency ranges of the two VCOs 105 and 115 are chosen so that the frequency combinations shown in the table in fig 2 cover a wide frequency range in a “seamless” fashion. In one example, the fundamental frequency f_1 of the first VCO 105 is chosen to be tunable in the range of 9-11 GHz, and the fundamental frequency f_2 of the second VCO 115 is chosen to be tunable in the range of 7-8 GHz. If this is the case, the combinations of f_1 and f_2 in the table of fig 2 will be as follows:

- $2f_2$: 14-16 GHz
- f_1+f_2:16-19GHZ
- $2f_1$: 18-22 GHz

Thus, with the values exemplified above of the ranges of f_1 and f_2, a frequency range of 14-22 GHz can be covered “seamlessly”. An additional “upwards shift” can then be obtained by means of the frequency f_3 of the FFO 125. As can be seen, the invention offers a tunable signal source with a wide tuning range.

It should be pointed out that the invention can be varied in a wide variety of ways with respect to the kinds of oscillators used: in the embodiment 100 of fig 1, there are two VCOs and one FFO. This can be varied in a large number of ways, with each of the three oscillators being chosen freely as either a VCO or an FFO.

In an alternative embodiment 300 of the invention shown in shown in fig 3, there are two FFOs and one VCO. Components which are also present in the embodiment 100 of fig 1 have retained their reference numbers in the embodiment 300 of fig 3, meaning that the second FFO which is introduced in fig 3 has been given the reference number 315.

The fundamental frequency f_2 as well as the second harmonic f_2' of the FFO 315 are both connected to the second input port 122 of the mixer 120 via respective ON/OFF switches S_2 and S_4, and the fundamental frequency f_1 as well as the second harmonic f_1' of the VCO 105 are both connected to the first input port 121 of the mixer 120 via respective ON/OFF switches S_1 and S_3. All of the ON/OFF switches are controlled by the control unit 110 in order to obtain the desired output frequency at the output port 124 of the mixer 120. Again, in similarity to the embodiment 100 of fig 1, which two of the signals f_1, f_1', f_2, f_2' that are connected to one and the same input port of the mixer 120 via ON/OFF switches is a design issue – in principle, all combinations are possible.

If, as an example, the tuning range of the VCO 105 is chosen to be in the range of 8-10 GHZ and the FFO 315 has a fundamental frequency of 6 GHz, the following combinations are among those that can be obtained by means of the switches S_1-S_4:

- f_1 : 8-10 GHz
- f_2 : 6 GHz
- $2f_1$: 16-20 GHz
- $2f_2$: 12 GHz
- $2f_1$-f_2 : 10-14 GHz
- f_1+f_2 : 14-16 GHz
- f_1+$2f_2$: 20-22 GHz

As can be seen, the frequency combinations f_1, $2f_1$-f_2, f_1+f_2, $2f_1$, f_1+$2f_2$, cover the whole frequency region of 8~22 GHz. Those frequency bands and the settings of the switches S_1-S_4 which are necessary to obtain them are shown in the table of fig 4. As with the example of fig 1, the frequency range covered by means of the VCO 105 and FFO 315 can then be shifted additionally by means of the FFO 125. For example, the FFO 125 can be chosen to be one which operates at 67 GHz in order to generate an E-band signal at the output from the mixer 120, or to be one which operates at 42 GHz in order to generate a 60 GHz-band signal. Due to the wide band at lower frequencies (8-22 GHz) the up-shifted signal will have a good tuning range.

Turning now to the issue of the phase noise performance of the tunable signal source of the invention, one requirement is that the oscillator which is used to up-shift the signal (such as the FFO 125 in fig 3), this oscillator should have a phase noise performance which is comparable to that of the other two oscillators used, and should of course be as low as possible.

The three input-port mixer denoted as 120 in the embodiments shown in figs 1 and 3 is also an important component in a tunable signal source of the invention. A conventional mixer is usually designed to mix only two input signals, as opposed to the three input-port mixer used in the present invention. One general way of obtaining a three input-port mixer is to cascade two two-port mixers. However, this would result in a large DC power consumption and a large chip area. Moreover, an impedance matching network would be needed between two mixers.

Thus, in a preferred embodiment, the invention uses a single mixer with three input ports. One example 500 of such a mixer is shown in fig 5: the mixer 500 comprises four emitter-coupled pairs of bipolar transistors, shown in fig 5 as 503 which comprises transistors Q1 and Q2, 504 which comprises transistors Q3 and Q4, 501 which comprises transistors Q5and Q6 and 502 which comprises transistors Q7 and Q8. The emitters of the pair Q5-Q6 are also connected to the collectors of the pair Q1-Q2, and the emitters of the pair Q7-Q6 are connected to the collectors of the pair Q3-Q4. The collector of Q5 is connected to the collector of Q7, and the collector of Q6 is connected to the collector of Q8.

The differential input signal of a first oscillator at frequency f_1 is input at the bases of the emitter coupled pairs, Q_5 with Q_6 and Q_7 with Q_8, while the input signals at frequencies f_2 from a second of the other two oscillators is input to the bases of one transistor in each of the pairs Q1-Q2 and Q3-Q4, with the differential signal at frequency f_3 from the third oscillator being input at the base of the other transistor in these pairs. It should be pointed out that the input-ports for the signal at frequency f_1 and the signal at f_3 can be exchanged.

The invention is not limited to the examples of embodiments described above and shown in the drawings, but may be freely varied within the scope of the appended claims.

CLAIMS

1. A frequency tunable signal source (100) comprising a first (105) and a second (115, 315) oscillator, each of which has as its output a signal at a fundamental frequency (f_1, f_2) and at least one signal at a harmonic frequency (f_1', f_2') of the fundamental frequency, and a mixer (120) with a first (121) and a second (122) input port as well as an output port (124), the frequency tunable signal source (100) being characterized in that it also comprises a control unit (110) which controls ON/OFF switches (S_1, S_2, S_3, S_4), by means of which switches two of said signals (f_1, f_2, f_1', f_2') are switchably connected to the first input port and the other two signals are switchably to the other input port, with one switch (S_1, S_2, S_3, S_4) for each signal (f_1, f_2, f_1', f_2'), the frequency tunable signal source being further characterized in that it also comprises a third oscillator (125), which produces an output signal which is connected to a third input port (123) of the mixer (120) and in that at least one of the oscillators (105, 115, 315, 125) is a VCO, a Voltage Controlled Oscillator.

2. The frequency tunable signal source (100) of claim 1, in which the third oscillator (125) is a fixed frequency oscillator, an FFO.

3. The frequency tunable signal source (100) of claim 1 or 2, in which at least one of the first (105) and second (115, 315) oscillators is a VCO.

4. The frequency tunable signal source (100) of any of claims 1-3, in which one of the first (105) and second oscillators (115, 315) is an FFO.

5. The frequency tunable signal source (100) of any of claims 1-3, in which both the first (105) and the second (115, 315) oscillators are VCOs with tuning ranges which do not have an overlap.

6. The frequency tunable signal source (100) of any of claims 1-5, in which the harmonic frequency of the oscillators’ fundamental frequency is the second harmonic frequency.

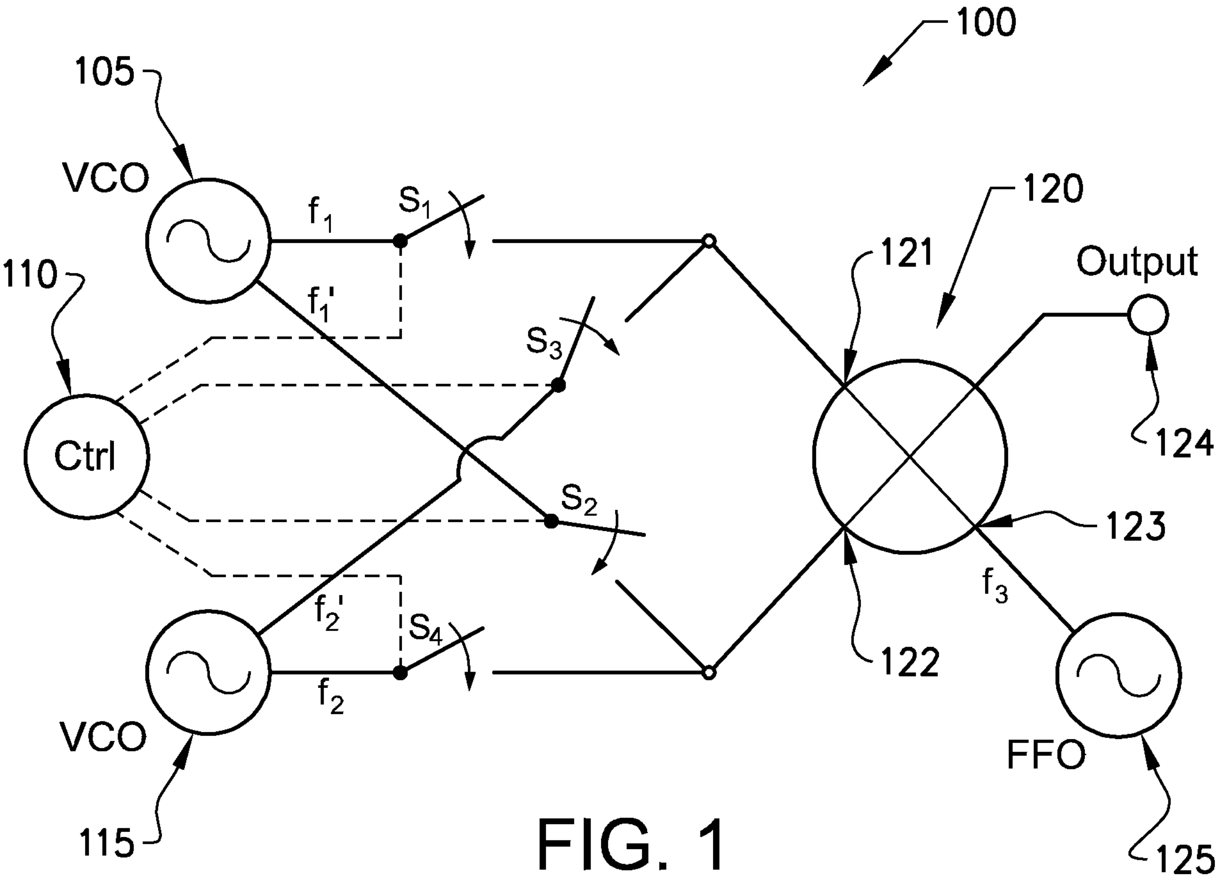

FIG. 1

S_1	0	0	1
S_2	1	0	0
S_3	0	1	0
S_4	0	0	1
Frequency	$2f_1$	$2f_2$	f_1+f_2; f_1-f_2

FIG. 2

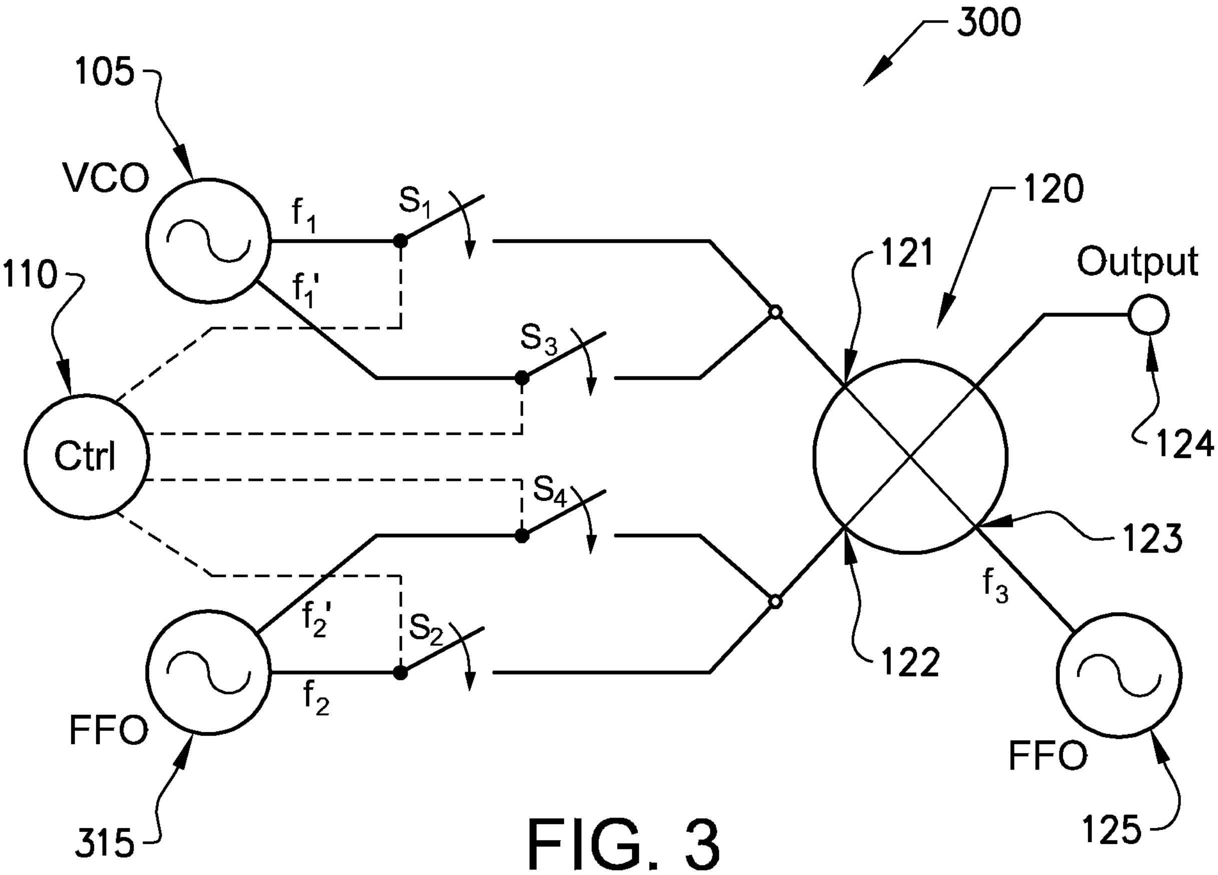

FIG. 3

	S_1	S_2	S_3	S_4
f_1	1	0	0	0
$2f_1-f_2$	0	1	1	0
f_1+f_2	1	1	0	0
$2f_1$	0	0	1	0
f_1+2f_2	1	0	0	1

FIG. 4

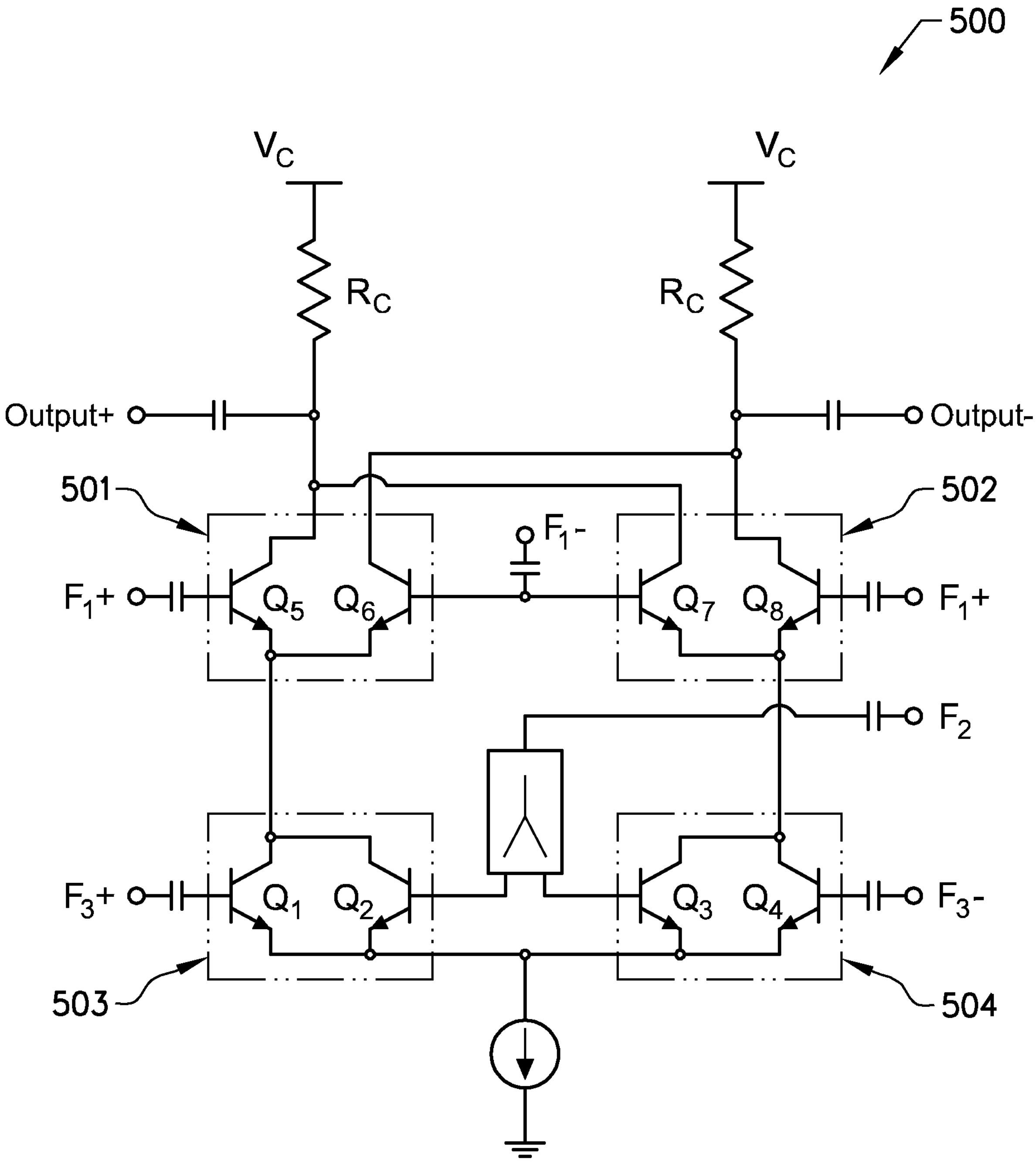
500
V_C
V_C
R_C
R_C
Output+
Output-
501
502
F_1-
F_1+
Q_5
Q_6
Q_7
Q_8
F_1+
F_2
F_3+
Q_1
Q_2
Q_3
Q_4
F_3-
503
504

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2010/055259

A. CLASSIFICATION OF SUBJECT MATTER
INV. H03B21/01
ADD.

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 H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	BUDREAU A J ET AL: "A Review of SAW-Based Direct Frequency Synthesizers", IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 30, no. 5, 1 May 1982 (1982-05-01), pages 686-693, XP011243853, ISSN: 0018-9480 *section II. Switched SAW Filterbank Synthesizer*figure 2 -----	1-6

-/--

[X] Further documents are listed in the continuation of Box C.

[X] 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 document 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 another 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
31 January 2011	04/02/2011

Name and mailing address of the ISA/
European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer
Aouichi, Mohamed

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2010/055259

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	PENGBEI ZHANG ET AL: "A new RF front-end and frequency synthesizer architecture for 3.1-10.6 GHz MB-OFDM UWB receivers", CIRCUITS AND SYSTEMS, 2005. 48TH MIDWEST SYMPOSIUM ON CINICINNATI, OHIO AUGUST 7-10, 2005, PISCATAWAY, US, 7 August 2005 (2005-08-07), pages 1119-1122, XP010895338, DOI: DOI:10.1109/MWSCAS.2005.1594302 ISBN: 978-0-7803-9197-0 *Section IV. Frequency Synthesizer Architecture*figure 4 -----	1-6
A	GB 2 136 238 A (VARIAN ASSOCIATES) 12 September 1984 (1984-09-12) page 1, line 69 - page 2, line 6; figures 1,2 -----	1-6

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2010/055259

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
GB 2136238 A	12-09-1984	US 4570079 A	11-02-1986