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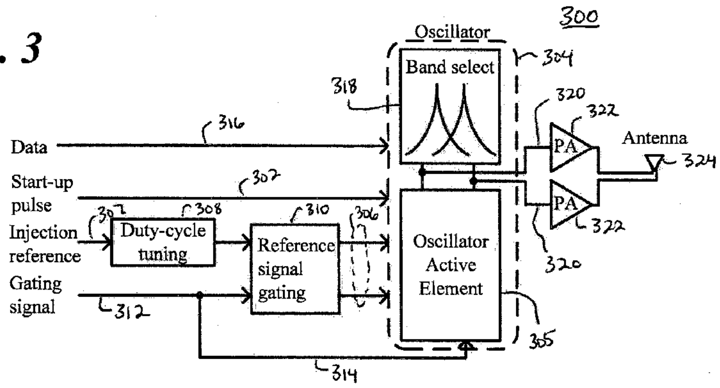
(54) **Title**: METHOD AND APPARATUS FOR A DUTY-CYCLED HARMONIC INJECTION LOCKED OSCILLATOR

FIG. 3



(57) **Abstract**: A method and an apparatus for a duty-cycled injection locked oscillator is provided for frequency shift keyed (FSK) signal transmissions. The oscillator includes a resonance LC tank and a first switching device. The first switching device is coupled to the resonance LC tank and injects an initial current pulse with a predetermined pulse magnitude into the resonance LC tank. The initial current pulse also fixes an initial phase of the duty-cycled injection locked free-running oscillator in response to the predetermined magnitude of the initial current pulse to enable fast settling of injection locking and high data rate operation of the duty-cycled injection locked oscillator. The oscillator also includes a second switching device, such as a differential pair of switching devices. The second switching device is coupled to the LC resonance tank for injecting a gated periodic reference signal having a duty cycle modified to reduce power of the reference signal by approximately seventy-five per cent.

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METHOD AND APPARATUS FOR A DUTY-CYCLED HARMONIC INJECTION LOCKED OSCILLATOR

FIELD OF THE INVENTION

[0001] The present invention generally relates to ultra low power, wideband oscillators and more particularly relates to oscillators for low-power frequency shift-keying (FSK) transmitters.

BACKGROUND OF THE DISCLOSURE

[0002] In biomedical applications, tethering wires impose significant restrictions on the subject under investigation and limits the free movement. Therefore, a wireless transmitter is usually preferred to send out electro-biophysiological signals. For example, in the neural signal recording of a free-moving live subject, the recorded signal could substantially differ from that of a movement-restricted subject. In order to have concurrent access to multi-channel information in neural signal recording applications, the required transmission data rate is approximately 100 Mbps with 100 channels, even when on-the-fly signal processing and time-domain multiplexing techniques are applied.

[0003] Power consumption is also a key constraint to wireless transmitters in biomedical applications, especially when the transmitter is implanted. When powered by a battery or by wireless telemetry, the transmitter is designed to consume low power to avoid frequent battery replacement or excessive exposure of live subjects to electromagnetic waves. However, high data rate communications is difficult to realize in a limited power budget environment. For example phase-locked loop based oscillators typically are limited to generation of low data rate signals and require high power consumption. In conventional transmitters for low power biomedical applications, power consumption may be reduced by employing open-loop frequency synthesis techniques, such as open-loop voltage controlled oscillators. Such techniques, though, result in the generated frequency being inaccurate and unstable over process, voltage, and temperature variations, making demodulation at the receiver side more difficult.

[0004] Low power yet accurate frequency synthesis can be obtained through known injection locking techniques. For example, a free-running oscillator will lock to the fundamental or harmonics of an injected reference signal under the condition that the targeted harmonic is within the locking range of the oscillator. The major benefits of injection lock LC oscillators include low phase noise and low power consumption. However, the use of injection lock LC oscillators is limited to low data rate communications, even though LC oscillators are preferred for better phase noise performance. One major problem with injection lock oscillators is the variable locking time, which could be as long as three microseconds.

[0005] In biomedical applications, frequency-shift keying (FSK) modulation schemes are preferred due to their inherent superior performance in bit-error rate (BER) and interference rejection. The problem of indefinite locking time, however, still exists. For FSK modulation, conventionally the reference signal is generated by hopping from one frequency to another.

[0006] Thus, what is needed is a method and apparatus for low-power transmission of signals at a high data rate. Furthermore, other desirable features and characteristics will become apparent from the subsequent detailed description and the appended claims, taken in conjunction with the accompanying drawings and this background of the disclosure.

SUMMARY OF THE INVENTION

[0007] According to the Detailed Description, a method for fixing the initial phase of a free-running oscillator is provided for low power high data rate frequency shift-keying (FSK) communications. The method includes injecting an initial current pulse into the resonant LC tank of the free-running oscillator. The initial current pulse has a predetermined magnitude. The method also includes locking the free-running oscillator in response to a relationship between the predetermined magnitude of the initial current pulse and a phase of the free-running oscillator.

[0008] In addition, a method for signal generation as target harmonics of the free running LC oscillator for injection lock is provided. The method includes injecting a gated reference current signal into a resonance LC tank of the free running oscillator. The method further includes varying a duty cycle of the gated reference current signal to reduce power of the gated reference signal while maintaining substantially equivalent strength of injected harmonics.

[0009] Further, a duty-cycled injection locked oscillator is provided for frequency shift keyed (FSK) signal transmission. The oscillator includes a resonance LC tank and a first switching device. The first switching device is coupled to the resonance LC tank and injects an initial current pulse with a predetermined pulse magnitude into the resonance LC tank. The initial current pulse also fixes an initial phase of the free-running oscillator in response to the predetermined magnitude of the initial current pulse to enable fast settling of injection locking and high data rate operation of the duty-cycled injection locked oscillator. -

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The accompanying figures, where like reference numerals refer to identical or functionally similar elements throughout the separate views and which together with the detailed description below are incorporated in and form part of the specification, serve to illustrate various embodiments and to explain various principles and advantages in accordance with the present invention.

[0011] FIG. 1 is a circuit diagram of a conventional differential complementary cross-coupled LC oscillator;

[0012] FIG. 2 is a signaling diagram of a duty-cycled transmitter output for frequency shift-keyed (FSK) transmissions in accordance with the present embodiment;

[0013] FIG. 3 is a block diagram of an injection-locked transmitter for burst mode FSK transmission in accordance with the present embodiment;

[0014] FIG. 4 is a circuit diagram of a duty-cycled harmonic injection-locked differential oscillator in accordance with the present embodiment;

[0015] FIG. 5 is a circuit diagram of a single-ended representation for the differential oscillator of FIG. 4;

[0016] FIG. 6 is depicts timing diagrams for operation of the duty-cycled injection locked oscillator of FIG. 4 in accordance with the present embodiment; and

[0017] FIG. 7 is a graph depicting the relationship between the initial phase of a free-running oscillator and the logarithm of the magnitude of the initial current pulse of the oscillator of FIG. 4 in accordance with the present embodiment.

[0018] Skilled artisans will appreciate that elements in the figures are illustrated for simplicity and clarity and do not necessarily include any non-essential elements of the transmitter. For example, the power amplifier and antenna of the present embodiments are only depicted in the block diagram of FIG. 3 and omitted in other figures. Those skilled in the art with the information disclosed herein will understand that the remaining circuitry can be designed in accordance with any of a number of conventional schemes.

DETAILED DESCRIPTION

[0019] The following detailed description is merely exemplary in nature and is not intended to limit the invention or the application and uses of the invention. Furthermore, there is no intention to be bound by any theory presented in the preceding background of the invention or the following detailed description of the invention.

[0020] Open-loop free-running oscillators are typically used to reduce power consumption in transmitters for biomedical applications. Referring to FIG. 1, a circuit diagram of a conventional complementary cross-coupled LC oscillator 100 is depicted. Such oscillators are typically used in biomedical transmitters because of its advantages of low power consumption and low phase noise. The LC oscillator includes coil L 102 and tunable capacitor banks 2C 104. Without locking to any reference signal, the oscillator 100 can run at a desired frequency by tuning the capacitor banks 2C 104 in response to signal V_{DATA} on line 106. In biomedical applications, a frequency shift-keying (FSK) transmission scheme is usually adopted as the modulation scheme for the oscillator 100 because of the excellent bit-error rate (BER) performance and interference rejection, and the FSK modulation is realized by tuning the capacitor banks 2C 104. The resonance tank of the coil L 102 and the capacitor banks 2C 104 is accomplished by cross coupling transistor pair MN0 (108) and MN1 (110) and cross coupling transistor pair MP0 (112) and MP1 (114), while the LC oscillator is biased by current source I_b 116.

[0021] While low power consumption could be achieved by the oscillator 100, it has a major disadvantage. Due to variations of process, voltage, and temperature, the oscillation frequency drifts over time. The frequency inaccuracy and instability makes demodulation difficult at the receiver side and increases the burden of the receiver.

[0022] The present embodiment provides a promising candidate for low power yet accurate frequency synthesis utilizing the injection locking technique. The major benefits of injection lock oscillators include low phase noise and low power consumption. And a free-running oscillator will lock to the fundamental or harmonics of an injected reference signal when the targeted harmonic is within the locking range of the oscillator. Referring to FIG. 2, a signaling diagram 200 of a duty-cycled transmitter output for frequency shift-keying (FSK) transmissions in accordance with the present embodiment is depicted. The signaling diagram 200 depicts burst-mode operation of an FSK transmitter where the burst-mode output signal 202, 204 for each data element 206, 208 occupies only a fraction of the bit period 210. With the output pulse width of T_p 212 and bit period of T_f 210, the duty cycle of the transmitter output can be calculated as

$$\eta = T_p / T_f \times 100\% \qquad [1]$$

[0023] Referring to FIG. 3, a block diagram illustrates an injection-locked transmitter 300 for burst mode FSK transmission in accordance with the present embodiment. The transmitter 300 operates in burst mode to save power. An initial start-up pulse on line 302 quickly starts up an oscillator 304 and fixes the phase of the free-running oscillator 304, including active oscillator elements 305. With the knowledge of the phase of the free-running oscillator 304, a reference current signal can be injected on line 306 at the optimum timing to achieve fast locking. The optimum timing is accomplished by providing an injection reference signal 307 to a duty-cycle tuning block 308.

[0024] The output of the duty-cycle tuning block 308 is provided to a reference signal gating block 310 which generates the reference current signals for injection on lines 306 into the oscillator active elements 305 at optimal times. Meanwhile, a gating signal is provided to the reference signal gating block 310 on line 312. In accordance with the present embodiment, the reference signal has a duty cycle of 33.33% instead of a conventional 50% duty cycle. The modified duty cycle of the reference signal reduces the required power of the reference signal and produces balanced output power. The gating signal is also applied on line 314 to the oscillator active elements 305 and turns the oscillator 304 on and off to realize the burst mode operation.

[0025] In order to achieve FSK modulation, the data on line 316 sets a frequency band of the free running frequency in band select block 318 of the oscillator 304 close to one of two harmonics of the reference signal such that one of the harmonics always falls into the locking range of the free-running oscillator 304. The signals produced by the oscillator V_{out} on lines 320 are amplified and sent to power amplifiers 322 and an antenna 324 for transmission. One major contribution to the advantageous operation of the FSK transmitter 300 in accordance with the present embodiment is that an initial current pulse is applied to fix the initial phase of the free-running oscillator. This current pulse also serves the purpose of enabling quick start-up of the oscillator and, with the known initial phase of the free-running oscillator, the injection reference signal has a target to quickly lock to. Therefore, the variable settling time in prior art solutions can be avoided and high data rate can be achieved. In addition, the adjusted duty cycle of the injection reference signal obtains two-fold benefits. One benefit is the power of the injected reference signal is reduced by approximately 75% with low orders of harmonics. And the other benefit is that harmonics of equal power can be obtained such that the transmitter 300 has the same locking condition and balanced power levels at the two different harmonic frequencies.

[0026] A circuit diagram of a duty-cycled harmonic injection-locked oscillator 400 in accordance with the present embodiment is shown in FIG. 4. The oscillator 400 is a differential implementation of the injection lock oscillator for the FSK transmitter where both the oscillator 400 and the injection reference signal 402 are in differential modes to minimize the effect of power supply variations. The burst mode is realized by the signal *Rst*, which turns the oscillator and injection signal on and off by turning on and off switching devices 404, 406, and 418. When there is a data bit to be transmitted, the *Rst* signal is set to low and the tail current I_b is supplied to start up the oscillator. The data bit also selects a proper capacitor bank 408 for FSK operation as is well-known to those skilled in the art of conventional open-loop oscillators for FSK transmission. The switching device 406 is set to open to allow oscillation to build up in the oscillator 400. When the burst mode data transmission is completed, the signal *Rst* is set to high. In response thereto, tail current I_b is cut off and the oscillator differential output terminals V_{outp} and V_{outm} are shorted to speed up the turning off of the oscillator 400.

[0027] The free-running frequency of the oscillator 400 is set by the capacitor banks 408 to ensure the 4th and 5th harmonics of the reference signal are always within the locking range of the oscillator 400. The strength of the initial current pulse is set by the current source $I_{b,init}$ 410 and operated by a switching device 412, while the strength of the injection reference signal is determined by the current source $I_{b,inj}$ 402 and injected in a differential mode by the cooperative operation of a switching device 414 and a switching device 416. The differential injection signal V_{injp} and V_{injm} to the respective switching device 414 and 416 each has a duty cycle of 33.33%, instead of 50%. The start up of the oscillator 400 is speed up by the initial current pulse supplied through the switching device 412 and the phase of the oscillator 400 during free running is determined by the magnitude of the initial current pulse. The initial current pulse extends operation of the oscillator 400 to high data rate applications.

[0028] Referring to FIG. 5, a circuit diagram of a single-ended representation 500 for the differential duty-cycled injection locked oscillator 400 is depicted with an LC tank 502 for oscillating the signal and a switching device 504 for injecting the current pulse 402. The switching device 404 and the switching device 412 operate similarly to that described above.

[0029] Signal timing diagrams for the single-ended alternate of embodiment 400 for burst mode injection lock oscillation is shown in FIG. 6. Taking the desired operating frequency as the fourth harmonic of the reference signal as an example, in accordance with the present embodiment, the data sets the capacitor bank such that the fourth harmonic 600 of the injection reference signal 612 is within the locking range of the oscillator 400. At time t_A 602, the signal *Rst* 604 is disabled such that the oscillator starts to build up oscillations by noises in the circuit, the noises being on the order of nano-volts. At time t_B 606, a current pulse 608 is injected into the oscillator with magnitude of $I_{b,init}$ 610. As the injected current pulse has a magnitude many orders of magnitude higher than the noise, the state of the oscillator is over-written. When the oscillator reaches steady state, the phase of the free-running oscillation is linearly related to the logarithm of $I_{b,init}$, as shown in a graph 700 in FIG. 7. The graph 700 depicts the relationship 702 between the initial phase of a free-running oscillator (plotted on the x-axis 704) and the logarithm of the magnitude of the initial current pulse of the oscillator 400, 500 (plotted on the y-axis 706) in accordance with the present embodiment.

[0030] Referring back to FIG. 6 and utilizing conventional fast-locking oscillation techniques, with the phase of the free-running oscillator fixed by $I_{b,init}$, one can inject a reference signal V_{inj} 612 at an optimum timing 614 to for fast locking the oscillator 400, 500. The gated periodic injection signal V_{inj} with a duty cycle of η' and period T_{inj} can be decomposed into a one-sided exponential Fourier series as

$$V_{inj} = \sum_{n=0}^{\infty} c_n e^{jn\frac{2\pi}{T_{inj}}t} \qquad [2]$$

where c_n is the exponential Fourier series coefficients.

[0031] In conventional injection lock oscillators, the duty cycle of the injection reference signal is 50% and, in order to have frequency separation of approximately 100 MHz and operating frequencies of 400 MHz to 600 MHz for FSK operation, the ninth and eleventh harmonics of a fundamental 54.24 MHz can be used, resulting in harmonic coefficients of magnitude 0.1415 and 0.1157 respectively. In accordance with the present embodiment, the duty cycle of the injected reference signal is adjusted to 33.33%, nearly doubling the harmonic coefficients. This in turn reduces the injection signal power by approximately 75% while maintaining the same harmonic strength of the injection reference signal. More importantly, as the power of the injected harmonic directly adds into the oscillator, the equal power levels of the fourth and the fifth harmonics make the power levels of the oscillator output equal at the fourth and fifth harmonics. Subsequently, the transmitted output power levels are the same at the fourth and fifth harmonics of the reference signal, relieving the receiver for demodulation. At time t_C 614, the reference signal is injected for fast locking. Subsequently, the oscillator is locked to the fourth harmonic of the reference signal. Finally at time t_D 616, the signal *Rst* 604 is enabled and the oscillator is turned off.

[0032] In accordance with the present embodiment, a duty-cycled harmonic injection locked oscillator 400, 500 for low-power high-data rate burst-mode FSK transmission is provided which advantageously achieves constantly fast locking instead of variable locking time. As seen in the description hereinabove, an initial current pulse is injected to fix the initial phase of the free-running oscillator. The initial phase of a free-running oscillator in steady- state is linearly related to the logarithm of the magnitude of the current pulse. With the initial phase of the free-running oscillator fixed, constantly fast locking time is always achieved, leading to high data rate transmission.

[0033] Another major advantage of oscillator 400, 500 in accordance with the present embodiment is that the power of the injection reference is reduced by approximately 75% and equal-power output of FSK transmissions is achieved by modifying the duty cycle of the injection reference signal.

[0034] Thus it can be seen that a burst-mode injection-locked *LC* oscillator has been provided for FSK transmission in neural signal recording applications. Injection locking is used to provide accurate and stable output frequencies. An initial current pulse is injected to the oscillator to quickly start up the oscillator and to fix the initial phase of the free-running oscillator. Oscillation frequency of the free-running oscillator is tuned by a capacitor array, and with the knowledge of the initial phase and free-running frequency, a reference signal is injected at the optimum timing for fast locking. The duty-cycle of the reference signal is tuned to 33.33% to reduce its power by 75% and to provide harmonics of equal power thereby enabling the FSK transmitter 400, 500 in accordance with the present embodiment to achieve a high data rate of 54.24 Mbps with measured bit energy efficiency of 62 pJ/bit.

[0035] While at least one exemplary embodiment has been presented in the foregoing detailed description of the invention, it should be appreciated that a vast number of variations exist. It should further be appreciated that the exemplary embodiments are only examples, and are not intended to limit the scope, applicability, dimensions, or configuration of the invention in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing an exemplary embodiment of the invention, it being understood that various changes may be made in the steps for fabrication and elements of the apparatus described in the exemplary embodiments without departing from the scope of the invention as set forth in the appended claims.

CLAIMS

What is claimed is:

1. A method for fixing the initial phase of a free-running oscillator comprising:

injecting an initial current pulse into the resonant LC tank of the free-running oscillator, wherein the initial current pulse has a predetermined magnitude; and

locking the free-running oscillator in response to a relationship between the predetermined magnitude of the initial current pulse and a phase of the free-running oscillator.

2. The method in accordance with Claim 1 wherein the step of locking the free-running oscillator comprises:

determining the relationship between the predetermined magnitude of the initial current pulse and the phase of the free-running oscillator; and

locking the free-running oscillator in response to the determination.

3. The method in accordance with any of Claims 1 and 2 wherein the initial current pulse has both a predetermined magnitude and a predetermined pulse width.

4. The method in accordance with any of Claims 1 to 3 wherein the free-running oscillator is a differential oscillator and wherein the resonant LC tank has a first side and a second side, and wherein the step of injecting the initial current pulse into the

resonant LC tank comprises the step of injecting the initial current pulse into either the first side or the second side of the resonant LC tank.

5. A method for signal generation as target harmonics of the free running LC oscillator for injection locking, the method comprising:

injecting a gated reference current signal into a resonance LC tank of the injection-locked free running oscillator;

varying a duty cycle of the gated reference current signal to reduce power of the gated reference signal while maintaining substantially equivalent strength of injected harmonics.

6. The method in accordance with Claim 5 wherein the step of varying the duty cycle of the gated reference current signal comprises varying the duty cycle of the gated reference current signal to produce equal-power harmonics for the injection-locked free running LC oscillator to lock to.

7. The method in accordance with any of Claims 5 or 6 wherein the step of varying the duty cycle of the gated reference current signal comprises varying the duty cycle of the gated reference current signal to change coefficients of low level harmonics thereof.

8. The method in accordance with any of Claims 5 to 7 further comprising:

injecting an initial current pulse into the resonance LC tank of the injection-locked free running oscillator, wherein the initial current pulse has a predetermined magnitude; and

locking the injection-locked free running oscillator in response to a relationship between the predetermined magnitude of the initial current pulse and a phase of the injection-locked free running oscillator.

9. The method in accordance with Claim 8 wherein the initial current pulse has both a predetermined magnitude and a predetermined pulse width.

10. The method in accordance with any of Claims 5 to 9 wherein the free-running oscillator is a differential oscillator and wherein the resonance LC tank has a first side and a second side, and wherein the step of injecting the initial current pulse into the resonance LC tank comprises the step of injecting the initial current pulse into either the first side or the second side of the resonance LC tank.

11. A duty-cycled injection locked oscillator for frequency shift keyed (FSK) signal transmission comprising:

a resonance LC tank for generating an oscillation transmission signal; and

a first switching device coupled to the resonance LC tank for injecting an initial current pulse thereinto, wherein the initial current pulse has a predetermined pulse magnitude, and wherein the initial current pulse fixes an initial phase of the free-running oscillator in response to the predetermined magnitude of the initial current pulse to enable fast settling of injection locking and high data rate operation of the duty-cycled injection locked oscillator.

12. The oscillator in accordance with Claim 11 wherein the initial current pulse has both a predetermined magnitude and a predetermined pulse width.

13. The oscillator in accordance with any of Claims 11 or 12 further comprising a second switching device coupled to the LC resonance tank for injecting a gated periodic reference signal, wherein a duty cycle of the gated periodic reference signal is modified to reduce power of the gated periodic reference signal by approximately seventy-five per cent.

14. The oscillator in accordance with Claim 13 wherein the second switching device is a differential pair of switching devices.

15. The oscillator in accordance with any of Claims 11 to 14 wherein the first switching device and/or the second switching device each comprise a PMOS devices.

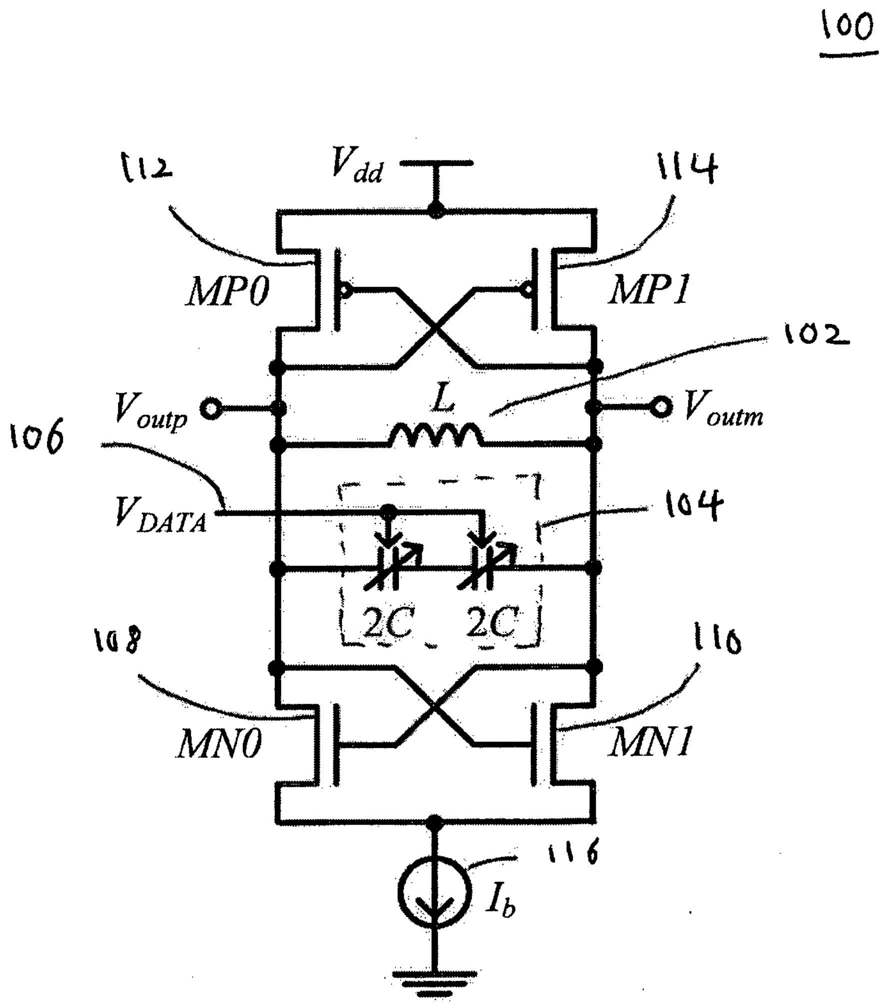
16. The oscillator in accordance with any of Claims 11 to 14 wherein the first switching device and the second switching device each comprise a NMOS devices.

17. The oscillator in accordance with Claim 14 wherein each of the differential pair of switching devices are either PMOS devices or NMOS devices.

18. The oscillator in accordance with Claim 13 wherein the duty cycle of the gated periodic reference signal is also modified to provide equal power harmonics for the oscillator to lock to.

19. The oscillator in accordance with any of Claims 14 to 17 wherein the duty-cycled injection locked oscillator is a differential oscillator and wherein the resonance LC tank has a first side and a second side, and wherein the first switching device is coupled to the first side of the resonance LC tank for injecting the initial current pulse into the first side of the resonance LC tank.

20. The oscillator in accordance with any of Claims 14 to 17 wherein the duty-cycled injection locked oscillator is a differential oscillator and wherein the resonance LC tank has a first side and a second side, and wherein the first switching device is coupled to the second side of the resonance LC tank for injecting the initial current pulse into the second side of the resonance LC tank.



PRIOR ART

FIG. 1

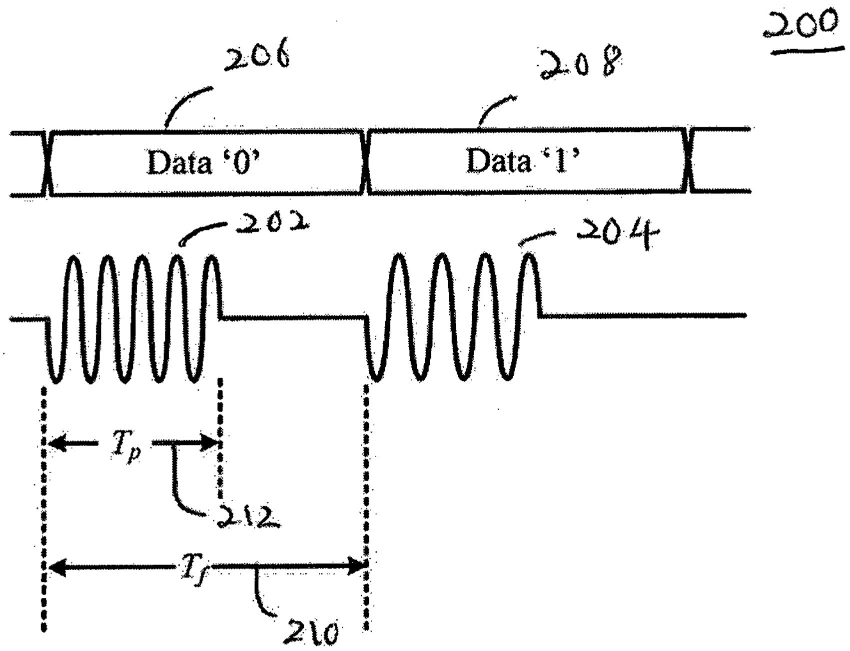
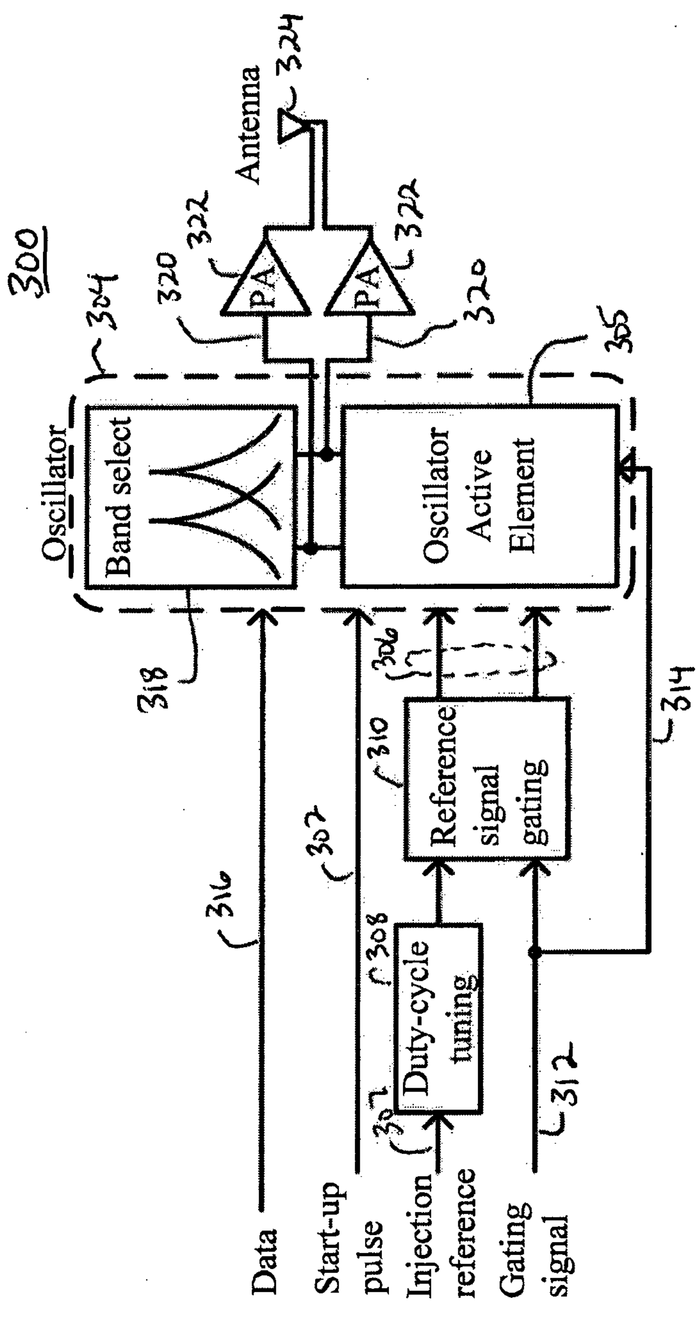


FIG. 2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PA
Antenna
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304
305
318
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302
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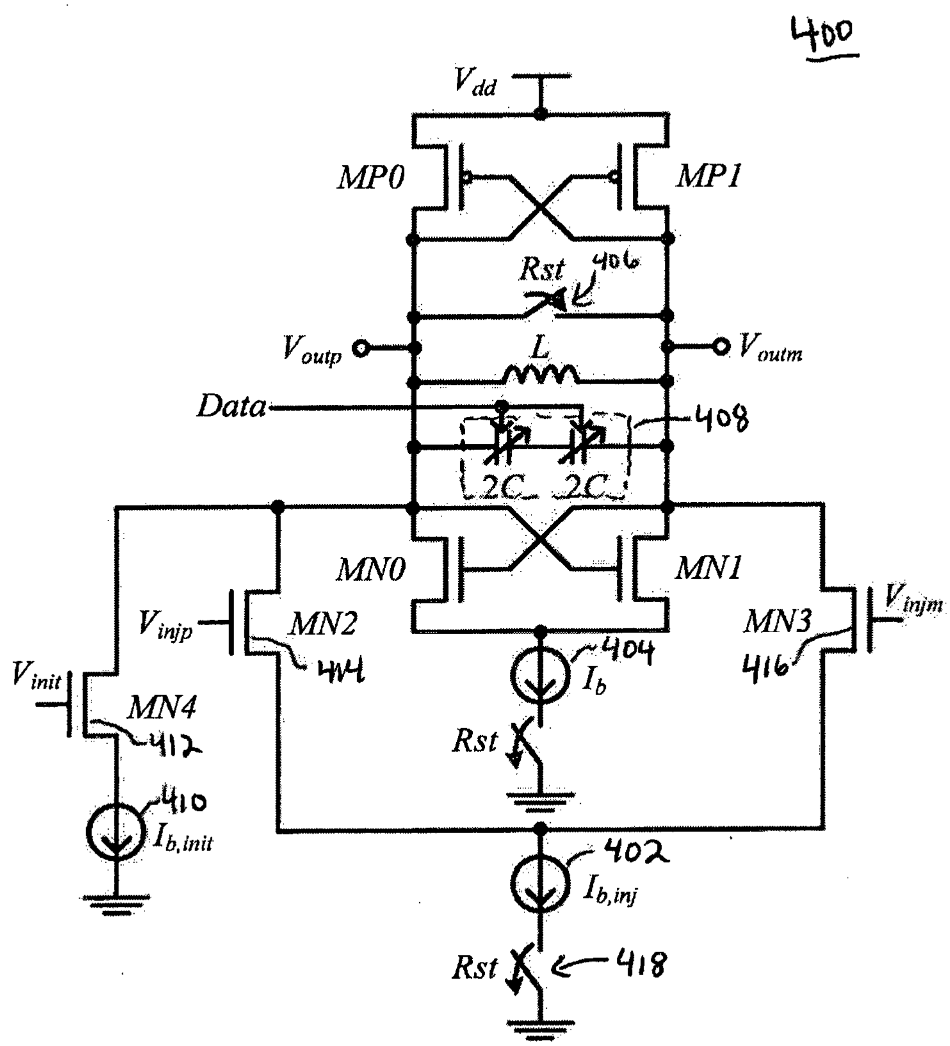
310
314
308
307
312
Reference signal gating
Duty-cycle tuning
Data
Start-up pulse
Injection reference
Gating signal

FIG. 3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MN2
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MN3
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Rst
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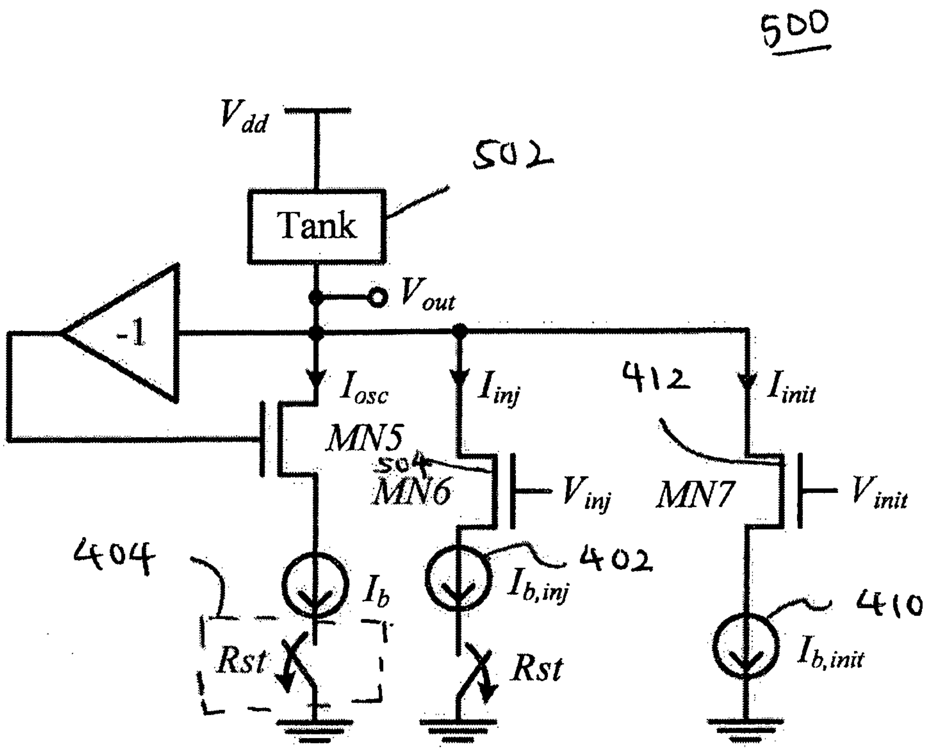
FIG. 4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504
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V_{inj}
MN7
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404
402
I_b
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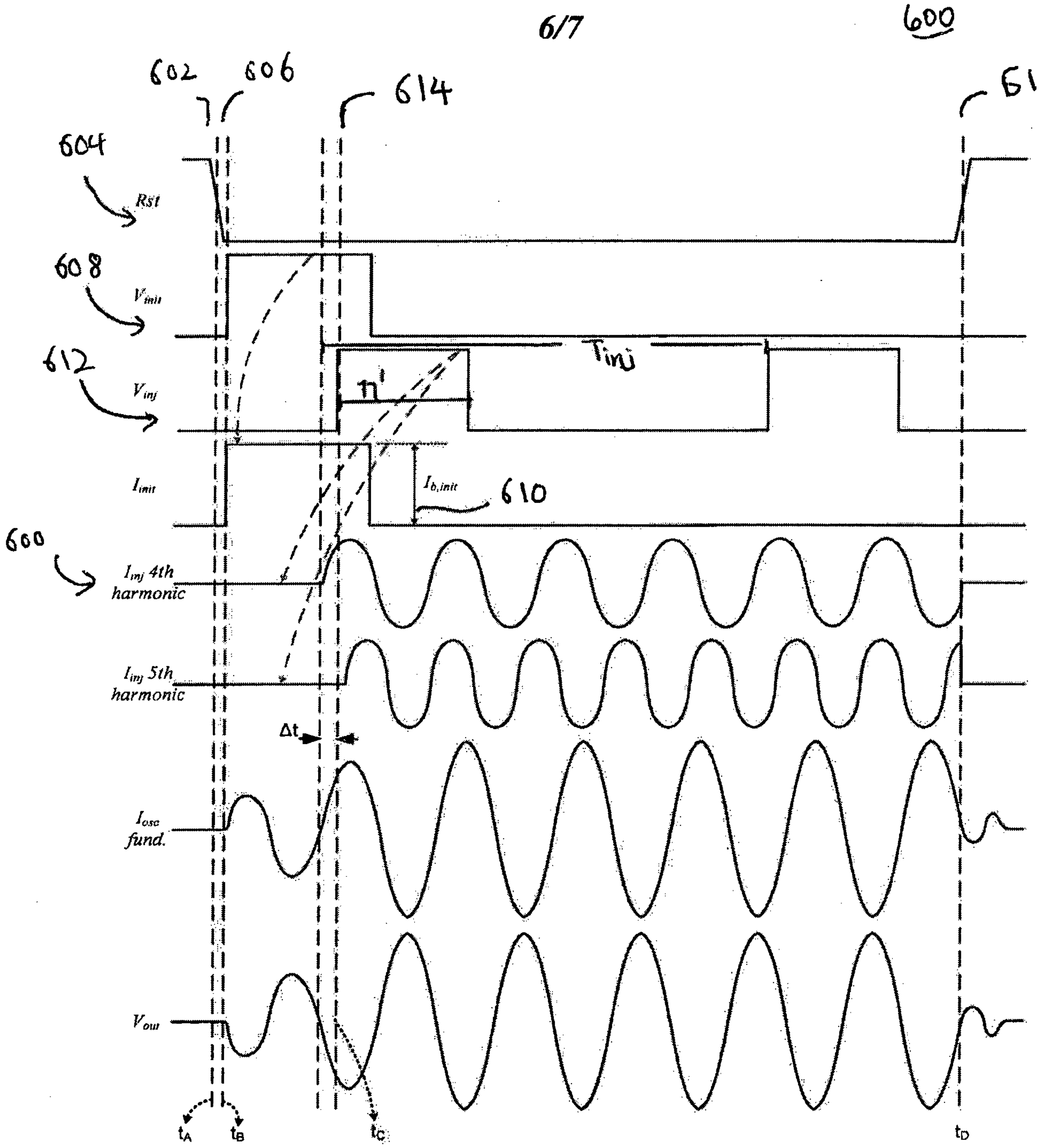
410
$I_{b,init}$
Rst
Rst

FIG. 5



600
602
606
614
616
604
Rst
608
V_{init}
612
V_{inj}
T_{inj}
T_1'
I_{init}
$I_{b,init}$
610
600
I_{inj} 4th harmonic
I_{inj} 5th harmonic
Δt
I_{osc} fund.
V_{out}
t_A
t_B
t_C
t_D

FIG. 6

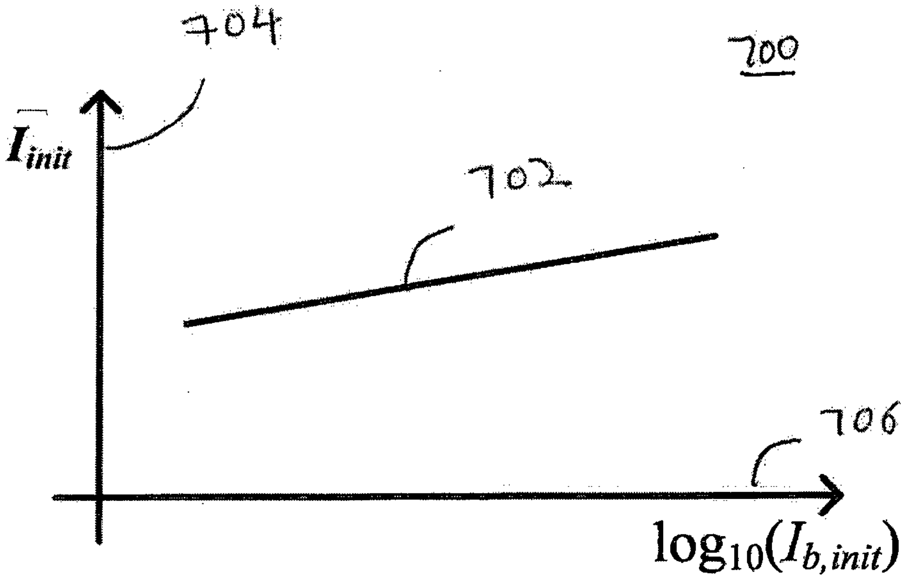


FIG. 7

INTERNATIONAL SEARCH REPORT	International application No. PCT/SG2011/000125

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.

H03B 5/08 (2006.01) ***H03L 7/06*** (2006.01) ***H04B 1/38*** (2006.01)

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)

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

Full Text and INTERNET: LC tank, harmonics, duty cycle, current pulse, square wave, CMOS, PMOS, NMOS, oscillator, FSK, differential, injection locking, power, resonant and other terms and phrases.

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	Bhansali, P.; Roychowdhury, J.; , "Gen-Adler: The generalized Adler's equation for injection locking analysis in oscillators," *Design Automation Conference, 2009. ASP-DAC 2009. Asia and South Pacific* , vol., no., pp.522-527, 19-22 Jan. 2009 page 524 – see section B – *Ring Oscillator* and *Sinusoidal Injection Current* , equations 29-42	1-4
X	Monaco, E.; Pozzoni, M.; Svelto, F.; Mazzanti, A.; , "Injection-Locked CMOS Frequency Doublers for μ-Wave and mm-Wave Applications," *Solid-State Circuits, IEEE Journal of* , vol.45, no.8, pp.1565-1574, Aug. 2010 Figures 3, 4, 6, 7 & 10 and Section III-IV	1 and 4
X	Helal, B.M.; Chun-Ming Hsu; Johnson, K.; Perrott, M.H.; , "A Low Jitter Programmable Clock Multiplier Based on a Pulse Injection-Locked Oscillator With a Highly-Digital Tuning Loop," *Solid-State Circuits, IEEE Journal of* , vol.44, no.5, pp.1391-1400, May 2009 Figures 1-8, 10-13, page 1396 , left hand column, third paragraph & section IV,	5-10
X	Verma, S.; Rategh, H.R.; Lee, T.H.; , "A unified model for injection-locked frequency dividers," *Solid-State Circuits, IEEE Journal of* , vol.38, no.6, pp. 1015- 1027, June 2003 Figure 22, page 1025 – section VII, sections II – VI	11-20

[X] 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	"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
"E"	earlier application or patent but published on or after the international filing date	"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
"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)	"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
"O"	document referring to an oral disclosure, use, exhibition or other means	"&"	document member of the same patent family
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search	Date of mailing of the international search report
16 June 2011	24 JUN 2011
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. +61 2 6283 7999	Authorized officer **AMBARISH NATU** AUSTRALIAN PATENT OFFICE (ISO 9001 Quality Certified Service) Telephone No : +61 2 6283 2414

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Pandey, J.; Jianlei Shi; Otis, B.; , "A 120μW MICS/ISM-band FSK receiver with a 44μW low-power mode based on injection-locking and 9x frequency multiplication," *Solid-State Circuits Conference Digest of Technical Papers (ISSCC), 2011 IEEE International* , pp.460-462, 20-24 February 2011 Whole document	
A	Pandey, J.; Otis, B.; , "A 90μW MICS/ISM band transmitter with 22% global efficiency," *Radio Frequency Integrated Circuits Symposium (RFIC), 2010 IEEE*, pp.285-288, 23-25 May 2010 Whole document	

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SG2011/000125

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
   because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
   because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See Supplemental Box I

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☒ No protest accompanied the payment of additional search fees.

Supplemental Box I
(To be used when the space in any of Boxes I to IV is not sufficient)

Continuation of Box No: III

This International Application does not comply with the requirements of unity of invention because it does not relate to one invention or to a group of inventions so linked as to form a single general inventive concept.

In assessing whether there is more than one invention claimed, I have given consideration to those features which can be considered to potentially distinguish the claimed combination of features from the prior art. Where different claims have different distinguishing features they define different inventions.

This International Searching Authority has found that there are different inventions as follows:

- Claims 1-4 are directed to a method for fixing the initial phase of a free running oscillator. It is considered that such a method comprising injecting an initial current pulse into a resonant LC tank of the free running oscillator, wherein the initial current pulse has a predetermined magnitude; and locking the oscillator in response to a relationship between the predetermined magnitude of the initial current pulse and a phase of the free running oscillator comprises a first distinguishing feature.

- Claims 5-10 are directed to a method of signal generation as target harmonics of the free running LC oscillator for injection locking. It is considered that such a method comprising injecting a gated reference current signal into a resonance LC tank of the injection locked free running oscillator and varying a duty cycle of the gated reference current signal to reduce power of gated reference signal while maintaining substantially equivalent strength of injected harmonics comprises a second distinguishing feature.

- Claims 11-20 are directed to a duty cycled injection locked oscillator for frequency shift keyed signal transmission. It is considered that such an oscillator comprising a resonance LC tank for generating an oscillation transmission signal and a first switching device coupled to the resonance LC tank for injecting an initial current pulse wherein the initial current pulse has a predetermined pulse magnitude and wherein the initial current pulse fixes an initial phase of the free running oscillator in response to the predetermined magnitude of the initial current pulse to enable fast settling of injection locking and high data rate operation of duty cycled injection locked oscillator comprises a third distinguishing feature.

PCT Rule 13.2, first sentence, states that unity of invention is only fulfilled when there is a technical relationship among the claimed inventions involving one or more of the same or corresponding special technical features. PCT Rule 13.2, second sentence, defines a special technical feature as a feature which makes a contribution over the prior art.

The only feature common to all of the claims is a resonant LC tank circuit. However this concept is not novel in light of:

1. US 2008 / 0309435 A1 (WU) 18 December 2008
2. US 2010 / 0277207 A1 (MAHDAVI) 04 November 2010

This means that the common feature can not constitute a special technical feature within the meaning of PCT Rule 13.2, second sentence, since it makes no contribution over the prior art.

Because the common feature does not satisfy the requirement for being a special technical feature it follows that it cannot provide the necessary technical relationship between the identified inventions. Therefore the claims do not satisfy the requirement of unity of invention *a posteriori*.