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(54) **Title**: LOW-NOISE OSCILLATOR AMPLITUDE REGULATOR

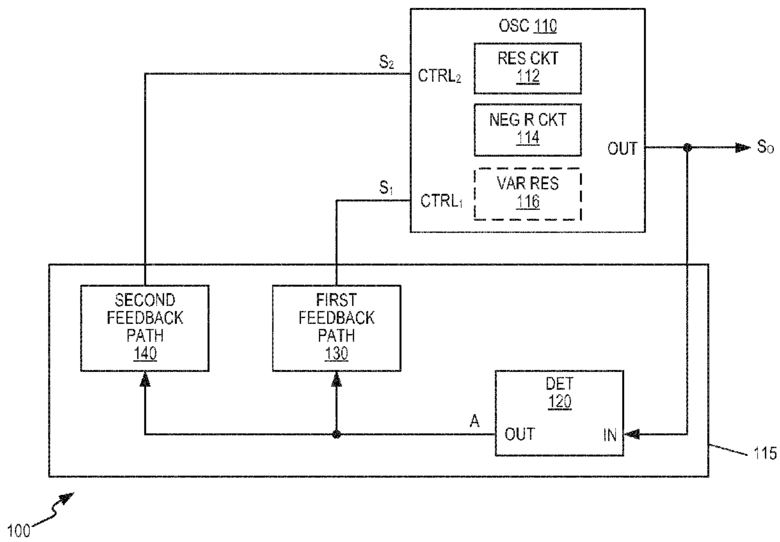

FIG. 1

(57) **Abstract**: A frequency generation solution controls an oscillator amplitude using two feedback paths to generate high frequency signals with lower power consumption and lower noise. A first feedback path provides continuous control of the oscillator amplitude responsive to an amplitude detected at the oscillator output. A second feedback path provides discrete control of the amplitude regulating parameter(s) of the oscillator responsive to the detected oscillator amplitude. Because the second feedback path enables the adjustment of the amplitude regulating parameter(s), the second feedback path enables an amplifier in the first feedback path to operate at a reduced gain, and thus also at a reduced power and a reduced noise, without jeopardizing the performance of the oscillator.

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LOW-NOISE OSCILLATOR AMPLITUDE REGULATOR

TECHNICAL FIELD

The solution presented herein relates generally to frequency generation, and more particularly to reducing phase noise and power consumption of high frequency generation circuits.

BACKGROUND

Oscillators are widely used in various electronic devices, e.g., to provide reference clocks, mixing frequencies for telecommunication signals, etc. A negative resistance-based oscillator represents one type of oscillator architecture typically used for the generation of higher frequency signals, such as used in wireless communication devices. Examples of negative resistance-based oscillators include, but are not limited to crystal oscillators, Surface Acoustic Wave (SAW)-based oscillators, etc. Negative resistance-based oscillators comprise an oscillator core having a resonant circuit operatively connected to a negative resistance circuit. The resonant circuit oscillates at the desired resonant frequency, and the negative resistance circuit cancels the resistive losses of the resonant circuit. In effect, the negative resistance circuit eliminates the natural damping of the resonant circuit, and therefore enables the oscillator core to continuously oscillate at the desired resonant frequency.

The successful operation of electronic devices containing such oscillators requires accurate and reliable amplitude control. In particular, amplitude control is necessary due to the fact that different Q-values, e.g., of different resonant circuits, as well as different PVT (Process, Voltage, and Temperature) conditions for any one oscillator may cause wide amplitude variations. For example, an oscillator having a high-Q resonant circuit will have higher amplitude oscillation than an oscillator having a low-Q resonant circuit. Further, an oscillator running in a linear mode requires continuous regulation of the amplitude to prevent the oscillator amplitude from quickly falling to zero or increasing to a level limited by the non-linear effects, e.g., voltage clipping, of the oscillator. Such voltage clipping can greatly deteriorate oscillator performance, increase the risk of parasitic oscillation, increase the current consumption (depending on circuit topology), and generally make the behavior of the oscillator more unpredictable. Accurate and reliable amplitude control will equalize the amplitude variations across a wide range of Q-values and PVT conditions, as well as ensure good noise performance, provide low current consumption, avoid parasitic oscillation, and possibly prevent damage to active and passive components

A negative feedback loop provides one way to control the amplitude of the oscillator output, where the negative feedback loop senses the amplitude of the oscillator output and then adjusts the amplitude by controlling an operating point of the oscillator core. For example, controlling the current through active transistor devices of the oscillator core controls the transconductance g_m of the oscillator core to control the negative resistance, and thus controls the oscillator amplitude. However, such negative feedback loops may introduce noise into the oscillator core, particularly when the negative feedback loop has a high gain. Further, the nonlinear properties of the oscillator core will convert the input noise to both AM (Amplitude Modulation) and PM (Phase Modulation) noise. While increasing the loop gain of the negative feedback loop will reduce the AM noise, such an increased loop gain will not only increase the power consumption, but will also fail to reduce the PM noise. While reducing the bandwidth of the negative feedback loop will also reduce the noise, such a bandwidth reduction, however, will increase the startup time of the oscillator, and may also undesirably increase the size (consumed chip area) of any filter required to filter the oscillator input signal. Thus, such bandwidth reduction is also not desirable.

As noted above, negative resistance-based oscillators are particularly useful for high frequency applications, and may be particularly important for mmW (millimeter wave) communication. Also, specifically for reference oscillators based on e.g., crystal or SAW resonators, the use of even higher frequencies is anticipated, from todays 10’s of MHz to 100’s of MHz and possibly even frequencies approaching the GHz range. The generation of such higher frequencies generally results in higher power consumption. Further, the generation of such higher frequencies also presents design challenges due to increased tolerances of the resonators, increased noise, increased component sizes, longer startup times, and/or larger impacts from parasitic elements of the circuitry and associated package. Thus, there remains a need for improved higher frequency generation circuits that do not incur higher power consumption, higher noise, and/or longer start-up times.

SUMMARY

The solution presented herein generates high frequency signals with lower power consumption and lower noise by controlling an oscillator amplitude using two feedback paths. A first feedback path provides continuous control of the oscillator amplitude responsive to an amplitude detected at the oscillator output. A second feedback path provides discrete control of the amplitude regulating parameter(s) of the oscillator responsive to the detected oscillator amplitude. Because the second feedback path enables the adjustment of the amplitude regulating parameter(s), the second feedback path enables an amplifier in the first feedback path to operate at a reduced gain, and thus also at a reduced power and a reduced noise, without jeopardizing the performance of the oscillator.

One exemplary embodiment comprises a frequency generation circuit comprising an oscillator, a detector, a first feedback path, and a second feedback path. The oscillator comprises an oscillator output, a first control input, and a second control input. The detector is configured to detect an amplitude of the oscillator output. The first feedback path operatively connects the detector to the first control input, and is configured to provide time-continuous control, responsive to the detected amplitude, of the amplitude of the oscillator output by continuously controlling a first control signal applied to the first control input. The second feedback path operatively connects the detector to the second control input, and is configured to provide time-discrete control, responsive to the detected amplitude, of one or more amplitude regulating parameters of the oscillator by providing time-discrete control of a second control signal applied to the second control input.

Another exemplary embodiment comprises a method of controlling an oscillator comprising an oscillator output, a first control input, and a second control input. The method comprises detecting an amplitude of the oscillator output, and providing time-continuous

control, responsive to the detected amplitude, of the amplitude of the oscillator output by continuously controlling a first control signal applied to the first control input. The method further comprises providing time-discrete control, responsive to the detected amplitude, of one or more amplitude regulating parameters of the oscillator by providing time-discrete control of a second control signal applied to the second control input.

Another exemplary embodiment comprises a computer program product stored in a non-transitory computer readable medium for controlling an oscillator of a frequency generation circuit. The oscillator comprises an oscillator output, a first control input, and a second control input. The computer program product comprises software instructions which, when run on the frequency generation circuit, causes the frequency generation circuit to detect an amplitude of the oscillator output, and provide time-continuous control, responsive to the detected amplitude, of the amplitude of the oscillator output by continuously controlling a first control signal applied to the first control input. The software instructions, when run on the frequency generation circuit, further cause the frequency generation circuit to provide time-discrete control, responsive to the detected amplitude, of one or more amplitude regulating parameters of the oscillator by providing time-discrete control of a second control signal applied to the second control input.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a block diagram of a frequency generation circuit according to one exemplary embodiment.

Figure 2 shows an amplitude control method according to one exemplary embodiment.

Figure 3 shows a block diagram of the first feedback path of the frequency generation circuit of Figure 1 according to one exemplary embodiment.

Figure 4 shows a block diagram of the second feedback path of the frequency generation circuit of Figure 1 according to one exemplary embodiment.

Figure 5 shows another amplitude control method according to one exemplary embodiment.

Figure 6 shows simulation results achievable with only a first feedback path having a high gain.

Figure 7 shows simulation results achievable with only a first feedback path having a low gain.

Figure 8 shows exemplary simulation results achievable with the solution presented herein.

Figure 9 shows exemplary simulation results when the first feedback path has different gains.

Figure 10 shows exemplary simulation results of the noise improvement achievable with the solution presented herein.

DETAILED DESCRIPTION

Figure 1 shows a block diagram of a frequency generation circuit 100 according to one exemplary embodiment. For simplicity, Figure 1 only shows the elements of the frequency generation circuit 100 necessary to facilitate the description provided herein. It will be appreciated by those skilled in the art that the frequency generation circuit 100 may include additional components and/or signal connections not shown in Figure 1.

Frequency generation circuit 100 includes an oscillator 110 coupled to control circuitry 115 that controls the amplitude of the oscillator output. Oscillator 110 includes a first control input ($CTRL_1$), a second control input ($CTRL_2$), and an output (OUT). The oscillator 110 may comprise a crystal oscillator, or any other negative resistance-based oscillator that includes a resonant circuit 112 operatively connected to a negative resistance circuit 114. In one exemplary embodiment, the resonant circuit 112 may comprise a crystal, and the negative resistance circuit 114 may comprise an amplifier (not shown). First and second control signals, S_1 and S_2, applied to the respective first and second control inputs control the amplitude of the signal S_o at the output of the oscillator 110. In particular, the first control signal S_1 provides time-continuous control of the amplitude of S_o, while the second control signal S_2 provides time-discrete control of one or more amplitude regulating parameters of the oscillator 110, as described further below. Exemplary amplitude regulating parameters include, but are not limited to, an oscillator bias current, a number of active oscillator g_m cells, a bias point of one or more of the oscillator g_m cells, and/or a variable resistance connected in parallel with a core of the oscillator 110. Because the second control signal S_2 controls the configuration of the oscillator 110, S_2 enables the relaxation of the requirements that would otherwise be placed on the time-continuous amplitude control provided by the first control signal S_1.

The control circuitry 115 generates the first and second control signals S_1, S_2 responsive to the oscillator output signal S_o according to the exemplary method 200 of Figure 2. More particularly, the control circuitry 115 comprises a detector 120, a first feedback path 130, and a second feedback path 140. The detector 120, which is coupled between the oscillator output and the inputs of the first feedback path 130 and the second feedback path 140, detects an amplitude A of the oscillator output signal S_o (block 210). The first feedback path 130 provides time-continuous control of the amplitude of the oscillator output signal S_o by continuously controlling the first control signal S_1 responsive to the detected amplitude A (block 220). The second feedback path 140 provides time-discrete control of one or more amplitude regulating parameters of the oscillator 110 by controlling, in discrete time, the second control signal S_2 responsive to the detected amplitude A (block 230). For example, the second control signal may provide time-discrete control of the parameter(s) controlling the operation of the negative resistance circuit 114. By controlling the amplitude regulating parameter(s) of the oscillator 110, the second feedback path 140 allows the first feedback path 130 to operate at a lower gain, and therefore at a lower power and with less noise.

Figure 3 shows a block diagram of the first feedback path 130 according to one exemplary embodiment. In this embodiment, the first feedback path 130 includes an amplifier 132 and a filter 134. The detected amplitude A, as well as a reference amplitude

A_{ref}, are input to amplifier 132. Amplifier 132 amplifies the amplitude error A_{err} formed from the difference between the detected amplitude A and the reference amplitude A_{ref}, and filter 134 helps reduce the noise input to the oscillator 110 by low-pass filtering the amplified signal to generate the first control signal S_1. The first control signal S_1 controls the gain of the oscillator core by controlling the gain of the negative resistance circuit 114. In so doing, the first control signal S_1 controls the amplitude of the oscillator output signal S_o.

Amplifier 132 establishes the gain of the first feedback path 130. Because various environmental conditions, oscillator properties, and/or the age of the oscillator 110, may impact the ability of the first control signal S_1 to sufficiently control the amplitude of the oscillator output signal S_o, conventional systems tend to set the gain of amplifier 132 to account for a wide range of conditions, even if some of the more extreme conditions are very rare. For example, higher temperatures may reduce the gain of the oscillator core relative to what that gain would be with the same input control signal at regular operating temperatures. Conventional solutions address this problem by making sure the gain of amplifier 132 is high enough to enable the oscillator core to handle even extreme temperature conditions without dropping the amplitude of the oscillator output S_o below a desired level. Such high gain conditions, however, cause amplifier 132 to consume more power and to insert more noise into the oscillator core than would otherwise be necessary for many operating conditions.

The solution presented herein incorporates the second feedback path 140 into the control circuitry 115 to control the amplitude regulating parameter(s) of the oscillator 110, which allows the first feedback path 130 to be designed and configured for a lower gain. Such gain reduction in the first feedback path 130 will enable the frequency generation circuit 100 to operate at a lower power and will reduce the noise level input to oscillator 110. To that end, the second feedback path 140 controls one or more amplitude regulating parameters responsive to the detected amplitude A of the oscillator output signal S_o. For example, if the detected amplitude A drops too low, indicating that the first control signal is unable to sufficiently amplify the oscillator amplitude, the second feedback path 140 may adjust the amplitude regulating parameters, e.g., by increasing the bias current, increasing the number of active oscillator gm cells, and/or increasing a bias point of one or more of the active gm cells. Alternatively or additionally, the second feedback path 140 may adjust the amplitude regulating parameters by increasing the resistance of a variable resistance connected in parallel with the oscillator core, e.g., using a variable resistor 116 connected across differential outputs of the oscillator 110. In another example, if the detected amplitude A rises too high, indicating the amplitude of the oscillator output signal S_o is too high, the second feedback path 140 may decrease the bias current, decrease the number of active oscillator gm cells, decrease a bias point of one or more of the active gm cells, and/or decrease the resistance of the variable resistor 116 connected in parallel with the core of the oscillator 110. In either case, the second feedback path 140 adjusts the amplitude regulating parameter(s) for the current operating conditions as indicated by the detected amplitude A to enable the oscillator 110 to maintain the desired amplitude at the output without requiring the first feedback path 130 to have a high gain.

Because the gain of amplifier 132 is designed to handle most operating conditions, the control provided by the second feedback path 140 may be implemented in a time-discrete manner. For example, the second feedback path 140 may include a control circuit 142, as shown in Figure 4. Control circuit 142 may control the amplitude regulating parameter(s) of the oscillator in a time-discrete manner by only controlling the amplitude regulating parameter(s) when the detected amplitude A satisfies one or more predetermined conditions, e.g., threshold conditions. For example, the control circuit 142 may control the second control signal S_2 to control the amplitude regulating parameter(s) only when the detected amplitude A exceeds an upper threshold T_U or is lower than a lower threshold T_L. In addition, the control circuit 142 may control the second control signal S_2 to control the amplitude regulating parameter(s) only under certain operating conditions and/or responsive to an event trigger. For example, control circuit 142 may control the second control signal S_2 to allow the amplitude regulating parameter(s) to change when the oscillator 110 powers on and/or when the oscillator 110 is acting in response to some communication event trigger. However, because changing the amplitude regulating parameters during, e.g., active communications, could disrupt the phase and/or frequency of the oscillator 110, the control circuit 142 may control the second control signal S_2 to prevent the amplitude regulating parameter(s) from changing during such periods to prevent this disruption. The control circuit 142 may therefore use, in addition to the threshold conditions, power on/off events and/or communication event triggers to provide additional time-discrete control of the oscillator's amplitude regulating parameter(s).

The exemplary method 250 of Figure 5 provides a more detailed approach for controlling the oscillator 110 at startup. In this exemplary method 250, the oscillator 110 is powered on (block 202), and the process waits until the oscillator 110 stabilizes (block 204). Once the oscillator 110 stabilizes (block 204), the detector 120 detects the amplitude A of the oscillator output signal S_o (block 210). If the detected amplitude A exceeds an upper threshold T_U (block 232) or is less than a lower threshold T_L (block 234), the control circuit 142 in the second feedback path 140 determines the oscillator 110 is unable to maintain a desired amplitude with the current configuration. In response, the control circuit 142 therefore alters one or more amplitude regulating parameters of the oscillator 110 (block 236). Blocks 210, 232, and 234 may be repeated once the oscillator 110 stabilizes again (block 204). This repetition may be indefinite, or may terminate after some predetermined maximum number of iterations.

Figures 6-10 show simulation results to demonstrate the advantages of the solution presented herein. Figures 6 and 7 first show the oscillation amplitude achievable when the control circuitry 115 does not include the second feedback path 140. In this case, the amplitude regulating parameters of the oscillator 110 are fixed and the first feedback path 130 provides the only amplitude control. Figure 6 provides results when amplifier 132 in the first feedback path 130 is configured to operate with a high gain that results in a relatively high loop gain, e.g., greater than 10, versus the results in Figure 7 where the amplifier 132 operates with a lower gain that results in a relatively low loop gain, e.g., less than 5. As shown by Figure 6, the higher loop gain implementation provides a very low amplitude variation, e.g., 50-55% of the full swing. However, the high gain necessary to achieve this low amplitude variation results in high power consumption and high noise levels. The lower loop gain implementation enables lower power consumption and noise levels, but as shown in Figure 7, this lower loop gain implementation has a relatively high amplitude variation, e.g., 48-68% of the full swing.

Figure 8 shows the results when the second feedback path 140 is included with the control circuitry 115 to enable time-discrete adjustment of the amplitude regulating parameter(s) of the oscillator 110. In this simulation, the first feedback path 130 has a low gain and the second feedback path 140 is used to control two extra amplitude regulating parameters, e.g., the bias tail current and/or the number of g_m cells in the oscillator core, as shown by the three curves in Figure 8. As shown by Figure 8, the solution presented herein results in a lower amplitude variation (52-60%), which was previously not achievable when the first feedback path 130 had a lower loop gain. Thus, the solution presented herein provides the lower noise and power consumption benefits more typically associated with lower loop gain implementations while also providing the amplitude control benefits more typically associated with higher loop gain implementations.

Figure 9 shows simulation results demonstrating how the gain of amplifier 132 may be selected to achieve the desired trade-off between amplitude control and noise/power reduction. The results in Figure 9 demonstrate the oscillator amplitude performance for six scenarios, which are qualitatively specified at each point, e.g., “high loop gain,” “low loop gain including second feedback path,” etc. The first four scenarios show the amplitude performance for high/low loop gain and high/low Q scenarios when the second feedback path 140 is not included. The last two scenarios show the amplitude performance for low loop gain and high/low Q scenarios when the second feedback path 140 is included.

Figure 10 shows simulation results demonstrating the noise performance for the same six scenarios as in Figure 9, and thus demonstrates the noise improvement provided by the solution presented herein. In particular, the top two plots show the operation of the frequency generation circuit 100 when the amplitude regulating parameters are fixed and the loop gain of the first feedback path 130 is high. The bottom plot shows the results when the second feedback path 140 is used to modify the bias current and the g_m cells of the oscillator core when the loop gain of the first feedback path 130 is low. The solution presented herein therefore provides a frequency generation circuit having the amplitude control benefits associated with high gain negative feedback and the power and noise benefits associated with low gain negative feedback.

The present invention may, of course, be carried out in other ways than those specifically set forth herein without departing from essential characteristics of the invention. The present embodiments are to be considered in all respects as illustrative and not restrictive, and all changes coming within the meaning and equivalency range of the appended claims are intended to be embraced therein.

CLAIMS

1. A frequency generation circuit (100) comprising:

an oscillator (110) comprising an oscillator output (OUT), a first control input ($CTRL_1$), and a second control input ($CTRL_2$);

a detector (120) configured to detect an amplitude of the oscillator output;

a first feedback path (130) operatively connecting the detector to the first control input ($CTRL_1$),, the first feedback path configured to provide time-continuous control, responsive to the detected amplitude, of the amplitude of the oscillator output by continuously controlling a first control signal (S_1) applied to the first control input; and

a second feedback path (140) operatively connecting the detector to the second control input ($CTRL_2$), the second feedback path configured to provide time-discrete control, responsive to the detected amplitude, of one or more amplitude regulating parameters of the oscillator by providing time-discrete control of a second control signal (S_2) applied to the second control input.

2. The frequency generation circuit of claim 1 wherein the first feedback path (130) is configured to continuously control the oscillator amplitude of the oscillator output (S_0) by continuously controlling a gain of the oscillator (110) responsive to the detected amplitude.

3. The frequency generation circuit of claims 1 or 2 wherein the second feedback path (140) comprises a control circuit (142) operatively connected between a detector output and the second control input ($CTRL_2$),, and wherein the control circuit (142) is configured to provide the time-discrete control of the one or more amplitude regulating parameters by controlling the one or more amplitude regulating parameters when the detector output (A) satisfies one or more predetermined conditions.

4. The frequency generation circuit of claim 3 wherein the control circuit (142) comprises a first comparison circuit configured to compare the detected amplitude to an upper threshold, and wherein the control circuit is configured to provide the time-discrete control of the one or more amplitude regulating parameters by controlling the one or more amplitude regulating parameters when the detected amplitude exceeds the upper threshold.

5. The frequency generation circuit of claims 3 or 4 wherein the control circuit (142) comprises a second comparison circuit configured to compare the detected amplitude to a lower threshold, and wherein the control circuit is configured to provide the time-discrete control the one or more amplitude regulating parameters by controlling the one or more amplitude regulating parameters when the detected amplitude is less than the lower threshold.

6. The frequency generation circuit of any of claims 3-5, wherein the one or more amplitude regulating parameters comprise at least one of an oscillator bias current, a number of oscillator g_m cells, a bias point of one or more of the oscillator g_m cells, and a variable resistance connected in parallel with a core of the oscillator.

7. The frequency generation circuit of any of claims 1-6 wherein the second feedback path further provides time-discrete control of the one or more amplitude regulating parameters by controlling the one or more amplitude regulating parameters responsive to an event trigger.

8. The frequency generation circuit of claim 7 wherein the event trigger comprises at least one of a power event trigger indicating a powering on of the oscillator and a communication event trigger indicating an upcoming radio communication.

9. The frequency generation circuit of claim 8 wherein the communication event comprises an upcoming random access channel transmission event, an upcoming radio transmission event, or an upcoming radio reception event.

10. The frequency generation circuit of any of claims 1-9 wherein the second feedback path (140) prevents changes to the one or more amplitude regulating parameters when the oscillator (110) is being used for wireless communications or when the oscillator has established frequency synchronization with one or more external devices.

11. The frequency generation circuit of any of claims 1-10 further comprising a memory configured to store a current configuration of the oscillator, wherein the current configuration identifies a current status of the one or more amplitude regulating parameters.

12. A method of controlling an oscillator (110) comprising an oscillator output (OUT), a first control input ($CTRL_1$), and a second control input ($CTRL_2$) the method comprising:

detecting (210) an amplitude (A) of the oscillator output (S_0);

providing time-continuous control, responsive to the detected amplitude, of the amplitude of the oscillator output by continuously controlling (220) a first control signal (S_1) applied to the first control input ($CTRL_1$); and

providing time-discrete control, responsive to the detected amplitude, of one or more amplitude regulating parameters of the oscillator by providing time-discrete control (230) of a second control signal (S_2) applied to the second control input ($CTRL_2$).

13. The method of claim 12 wherein continuously controlling the oscillator amplitude of the oscillator output signal comprises continuously controlling a gain of the oscillator (110) responsive to the detected amplitude (A).

14. The method of claims 12 or 13 wherein providing the time-discrete control of the one or more amplitude regulating parameters comprises controlling the one or more amplitude regulating parameters when a detector output satisfies one or more predetermined conditions.

15. The method of claim 14 further comprising comparing the detected amplitude (A) to an upper threshold (232), wherein providing the time-discrete control of the one or more amplitude regulating parameters comprises controlling (236) the one or more amplitude regulating parameters when the detected amplitude exceeds the upper threshold.

16. The method of claims 14 or 15 further comprising comparing the detected amplitude (A) to a lower threshold (234), wherein providing the time-discrete control of the one or more amplitude regulating parameters comprises controlling (236) the one or more amplitude regulating parameters when the detected amplitude is less than the lower threshold.

17. The method of any of claims 14-16 wherein the one or more amplitude regulating parameters comprise at least one of an oscillator bias current, a number of oscillator gm cells, a bias point of one or more of the oscillator gm cells, and a variable resistance (116) connected in parallel with a core of the oscillator.

18. The method of any of claims 12-17 further comprising providing the time-discrete control of the one or more amplitude regulating parameters by controlling the one or more amplitude regulating parameters responsive to an event trigger.

19. The method of claim 18 wherein the event trigger comprises at least one of a power event trigger indicating a powering on of the oscillator and a communication event indicating an upcoming radio communication.

20. The method of claim 19 wherein the communication event comprises an upcoming random access channel transmission event, an upcoming radio transmission event, or an upcoming radio reception event.

21. The method of any of claims 12-20 further comprising controlling the second control signal (S_2) applied to the second control input ($CTRL_2$) to prevent changes to the one or more amplitude regulating parameters when the oscillator is being used for wireless communications or when the oscillator has established frequency synchronization with one or more external devices.

22. The method of any of claims 12-21 further comprising storing a current configuration of the oscillator in memory, wherein the current configuration identifies a current status of the one or more amplitude regulating parameters.

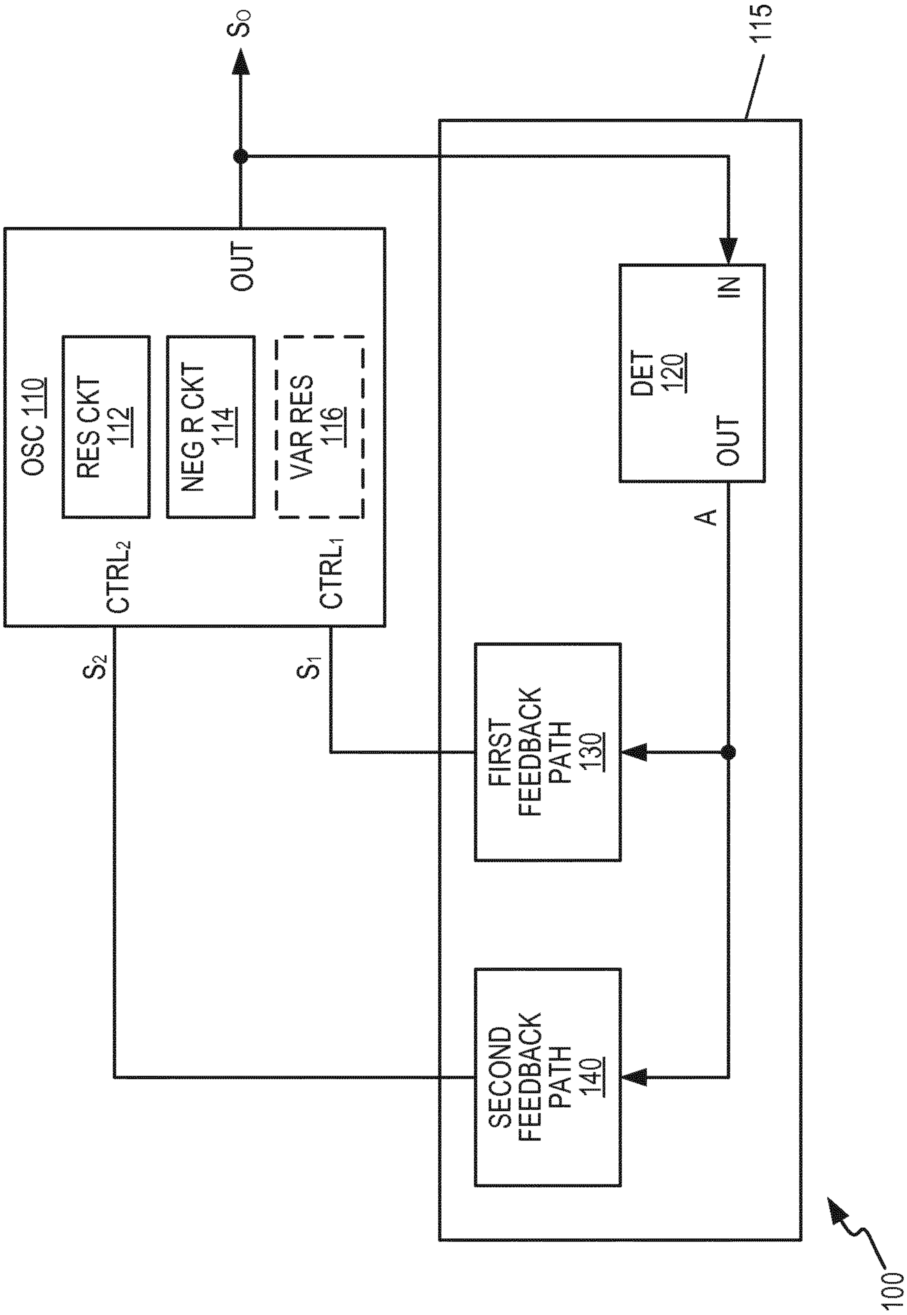
23. A computer program product stored in a non-transitory computer readable medium for controlling an oscillator (110) of a frequency generation circuit (100), the oscillator comprising an oscillator output (OUT), a first control input ($CTRL_1$), and a second control input ($CTRL_2$), the computer program product comprising software instructions which, when run on the frequency generation circuit, causes the frequency generation circuit to:

detect (210) an amplitude (A) of the oscillator output;

provide time-continuous control, responsive to the detected amplitude, of the amplitude of the oscillator output by continuously controlling (220) a first control signal (S_1) applied to the first control input; and

provide time-discrete control, responsive to the detected amplitude, of one or more amplitude regulating parameters of the oscillator by providing time-discrete control (230) of a second control signal (S2) applied to the second control input.

24. A wireless communication device comprising the frequency generation circuit (100) of any of claims 1-11.



S_O
115
OSC 110
RES CKT 112
NEG R CKT 114
VAR RES 116
OUT
$CTRL_2$
$CTRL_1$
DET 120
IN
OUT
A
S_2
S_1
FIRST FEEDBACK PATH 130
SECOND FEEDBACK PATH 140
100

FIG. 1

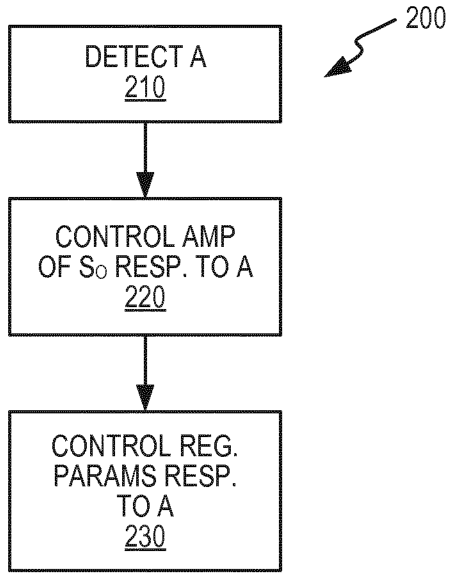


FIG. 2

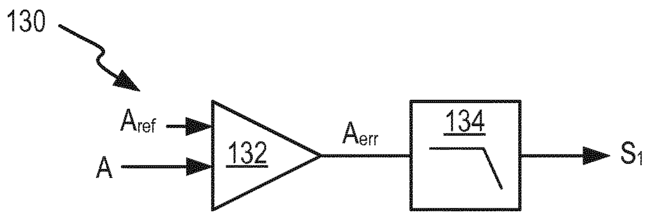


FIG. 3

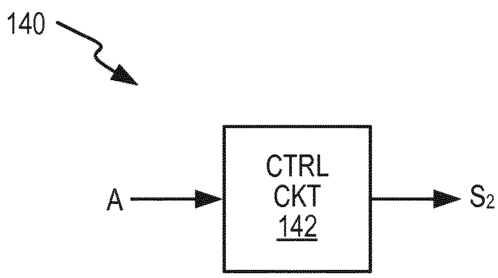
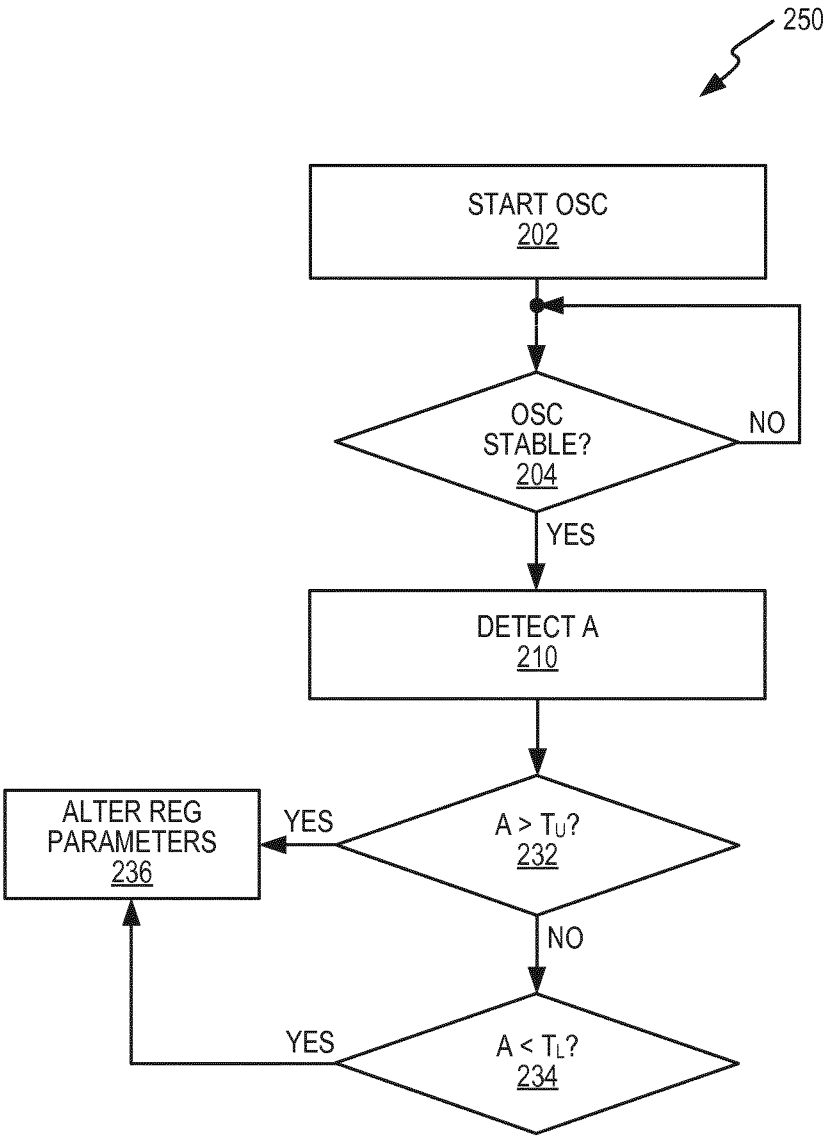


FIG. 4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OSC
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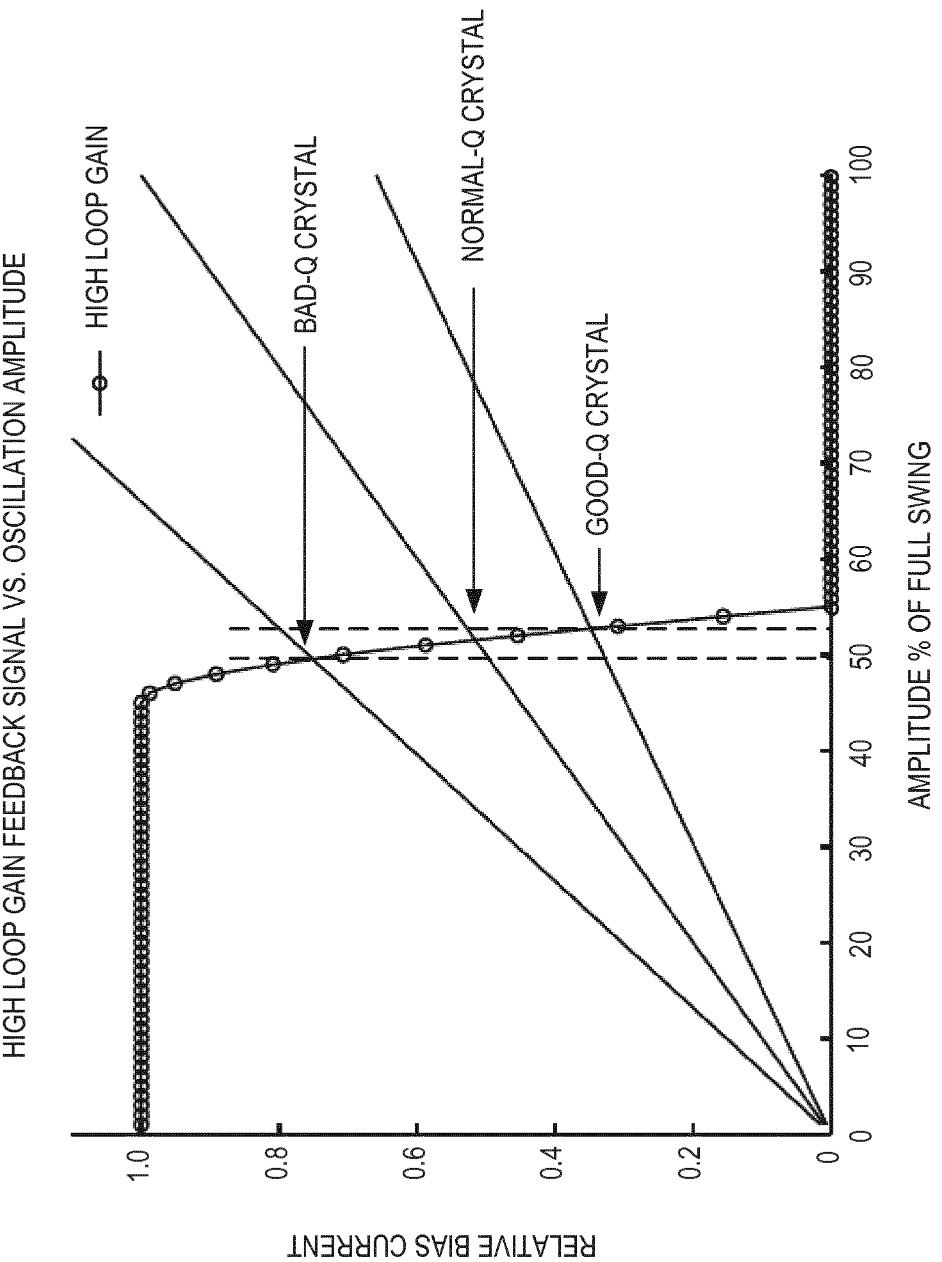
234

FIG. 5


HIGH LOOP GAIN FEEDBACK SIGNAL VS. OSCILLATION AMPLITUDE
HIGH LOOP GAIN
BAD-Q CRYSTAL
NORMAL-Q CRYSTAL
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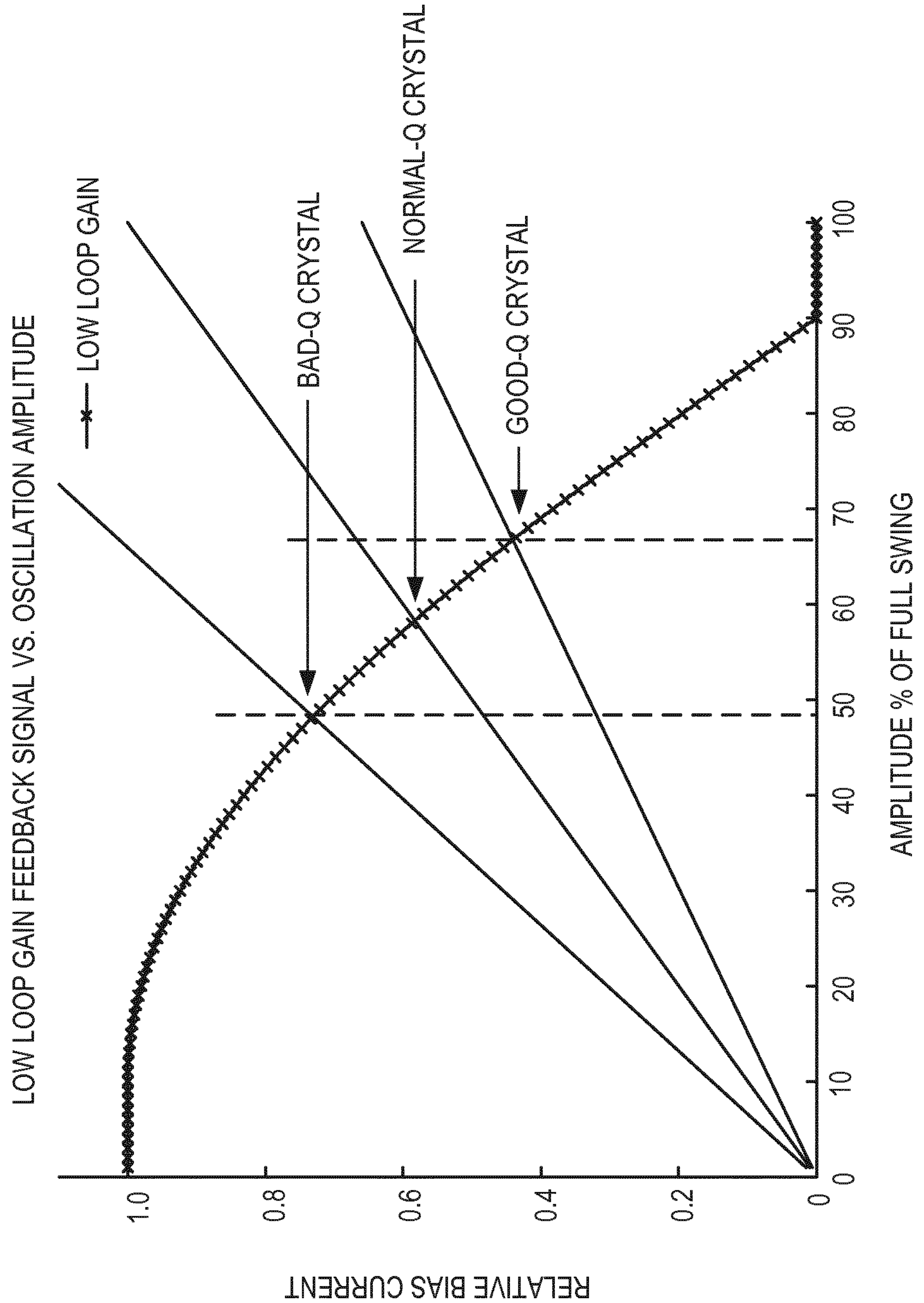
RELATIVE BIAS CURRENT
1.0
0.8
0.6
0.4
0.2
0
0
10
20
30
40
50
60
70
80
90
100
AMPLITUDE % OF FULL SWING

FIG. 6



LOW LOOP GAIN FEEDBACK SIGNAL VS. OSCILLATION AMPLITUDE
LOW LOOP GAIN
BAD-Q CRYSTAL
NORMAL-Q CRYSTAL
GOOD-Q CRYSTAL
RELATIVE BIAS CURRENT
1.0
0.8
0.6
0.4
0.2
0
0
10
20
30
40
50
60
70
80
90
100
AMPLITUDE % OF FULL SWING

FIG. 7

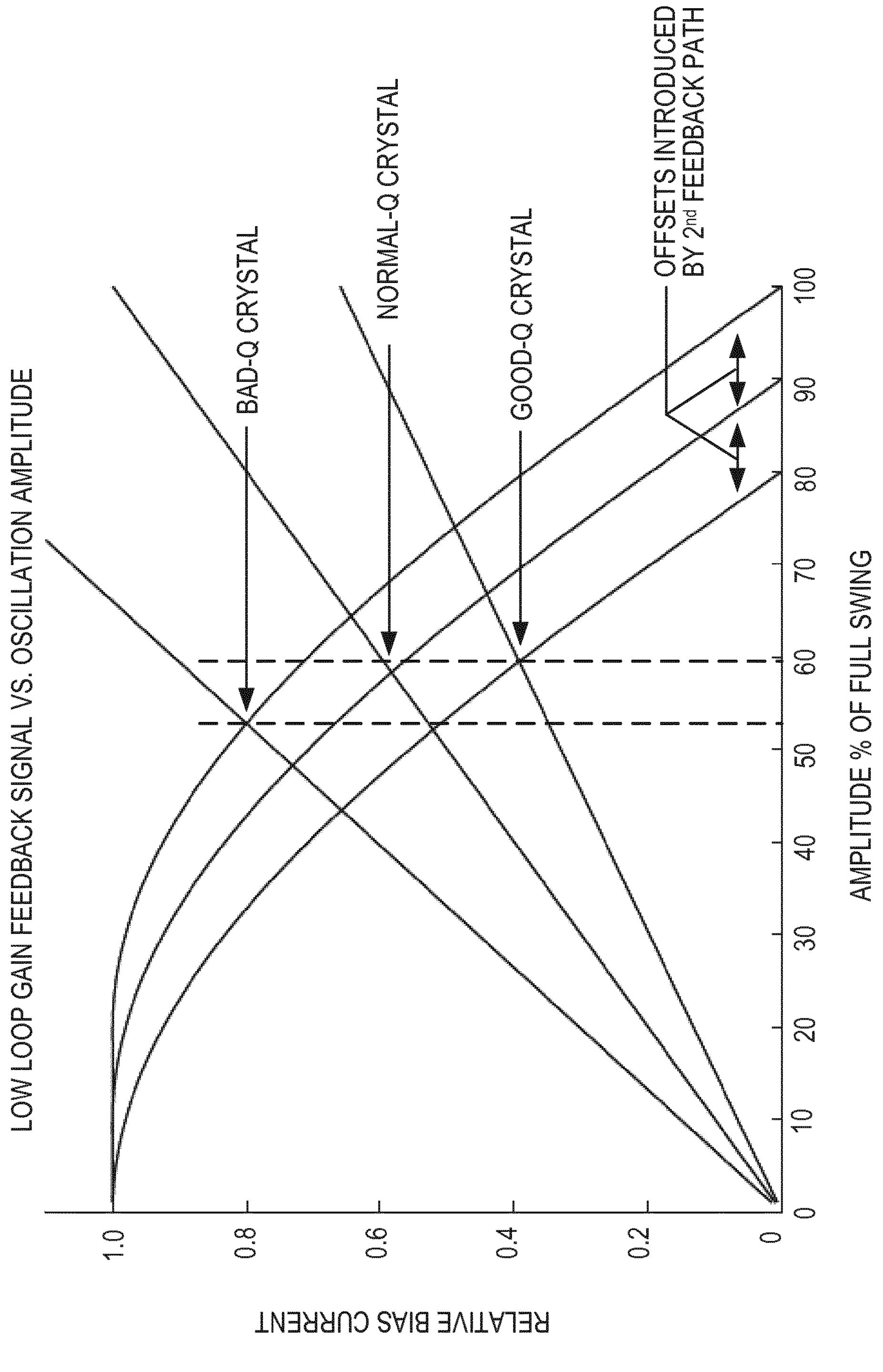
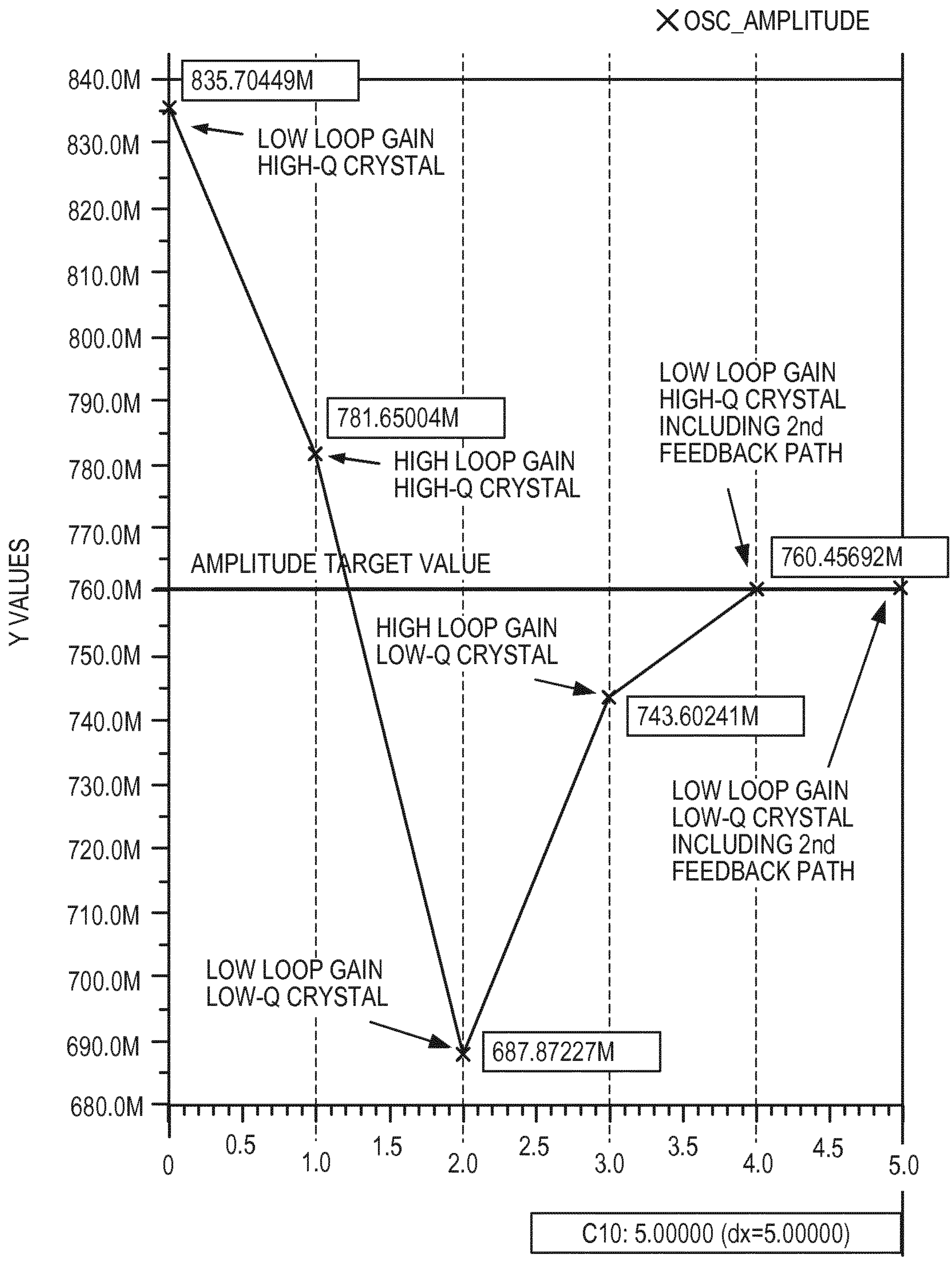
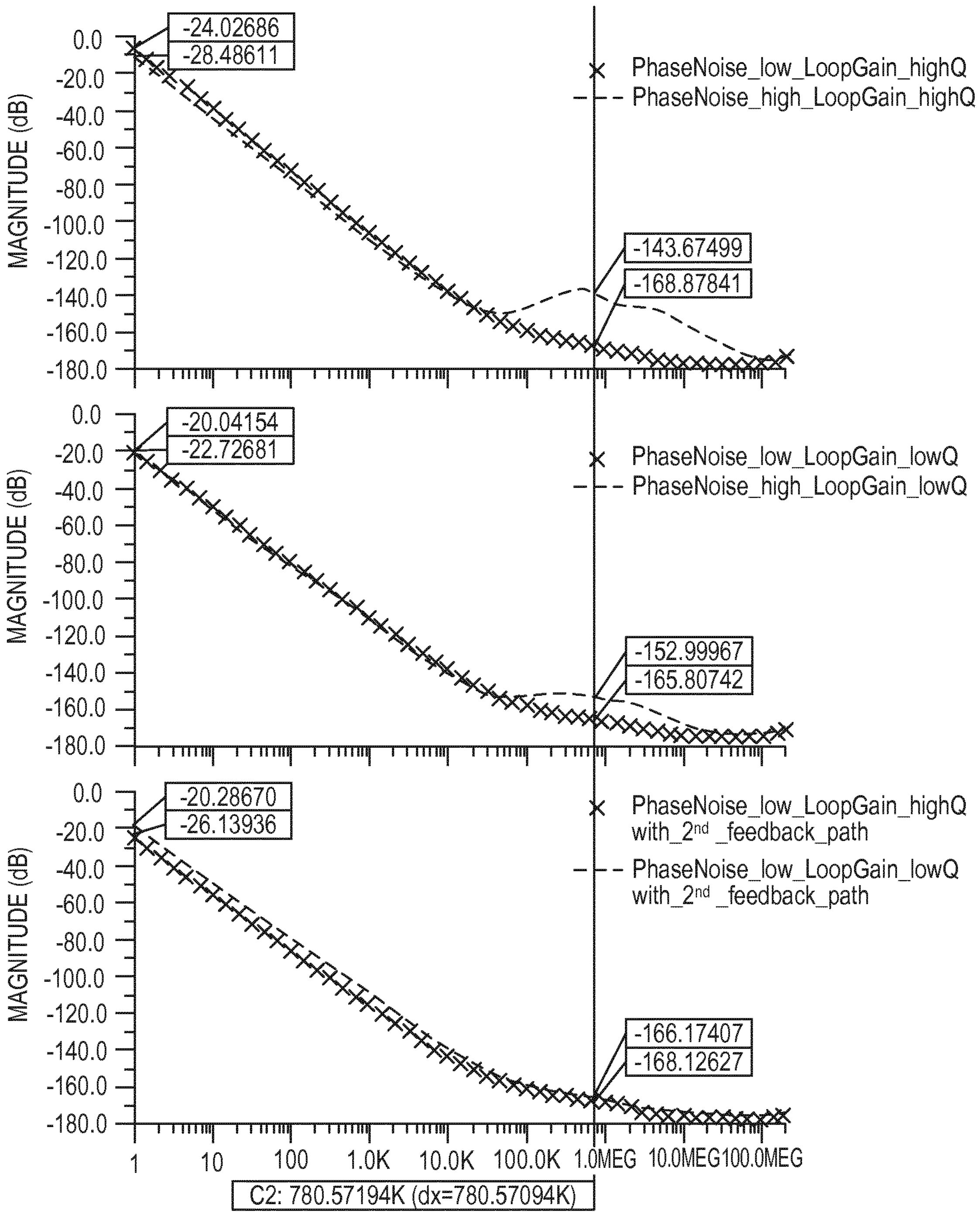

LOW LOOP GAIN FEEDBACK SIGNAL VS. OSCILLATION AMPLITUDE
BAD-Q CRYSTAL
NORMAL-Q CRYSTAL
GOOD-Q CRYSTAL
OFFSETS INTRODUCED BY 2nd FEEDBACK PATH
RELATIVE BIAS CURRENT
1.0
0.8
0.6
0.4
0.2
0
0
10
20
30
40
50
60
70
80
90
100
AMPLITUDE % OF FULL SWING

FIG. 8



OSC_AMPLITUDE
Y VALUES
840.0M
830.0M
820.0M
810.0M
800.0M
790.0M
780.0M
770.0M
760.0M
750.0M
740.0M
730.0M
720.0M
710.0M
700.0M
690.0M
680.0M
835.70449M
LOW LOOP GAIN
HIGH-Q CRYSTAL
781.65004M
HIGH LOOP GAIN
HIGH-Q CRYSTAL
LOW LOOP GAIN
HIGH-Q CRYSTAL
INCLUDING 2nd
FEEDBACK PATH
AMPLITUDE TARGET VALUE
760.45692M
HIGH LOOP GAIN
LOW-Q CRYSTAL
743.60241M
LOW LOOP GAIN
LOW-Q CRYSTAL
INCLUDING 2nd
FEEDBACK PATH
LOW LOOP GAIN
LOW-Q CRYSTAL
687.87227M
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
C10: 5.00000 (dx=5.00000)

FIG. 9



MAGNITUDE (dB)
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
-120.0
-140.0
-160.0
-180.0
-24.02686
-28.48611
-143.67499
-168.87841
PhaseNoise_low_LoopGain_highQ
PhaseNoise_high_LoopGain_highQ
-20.04154
-22.72681
-152.99967
-165.80742
PhaseNoise_low_LoopGain_lowQ
PhaseNoise_high_LoopGain_lowQ
-20.28670
-26.13936
-166.17407
-168.12627
PhaseNoise_low_LoopGain_highQ with_2nd _feedback_path
PhaseNoise_low_LoopGain_lowQ with_2nd _feedback_path
1
10
100
1.0K
10.0K
100.0K
1.0MEG
10.0MEG
100.0MEG
C2: 780.57194K (dx=780.57094K)

FIG. 10

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/060873

A. CLASSIFICATION OF SUBJECT MATTER
INV. H03L5/00 H03B5/12
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)
H03L H03B

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 practicable, 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.
X	US 2014/035684 A1 (NA YOO SAM [KR] ET AL) 6 February 2014 (2014-02-06) paragraph [0039] - paragraph [0041]; figure 1 paragraph [0050] - paragraph [0061]; figures 3,4 paragraph [0076] - paragraph [0081]; figure 8 -----	1-24
X	US 2008/266011 A1 (KUOSMANEN VILI P [FI]) 30 October 2008 (2008-10-30) paragraph [0031] - paragraph [0035]; figure 2 paragraph [0038] paragraph [0040] - paragraph [0043] -----	1,3-5, 7-12, 14-16, 18-24
	-/--	

[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 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 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
12 July 2016	20/07/2016

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

1

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2015/109064 A1 (MIN QING [CN] ET AL) 23 April 2015 (2015-04-23) paragraph [0037] - paragraph [0053]; figures 1,2 -----	1-24
A	US 2011/304407 A1 (CHIANG MEEI-LING [US] ET AL) 15 December 2011 (2011-12-15) paragraph [0025] - paragraph [0041]; figures 2,3,4 -----	1-24
A	US 2007/096841 A1 (CONNELL LAWRENCE E [US] ET AL) 3 May 2007 (2007-05-03) paragraph [0013] - paragraph [0034]; figures 1-5 -----	1-24

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2016/060873

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		US 2014035684 A1	06-02-2014
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		US 2007096841 A1	03-05-2007
		WO 2007070166 A1	21-06-2007

(19)中华人民共和国国家知识产权局

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2017.12.05
(86)PCT国际申请的申请数据
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(87)PCT国际申请的公布数据
WO2016/192962 EN 2016.12.08
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(51)Int.Cl.
H03L 5/00(2006.01)
H03B 5/12(2006.01)

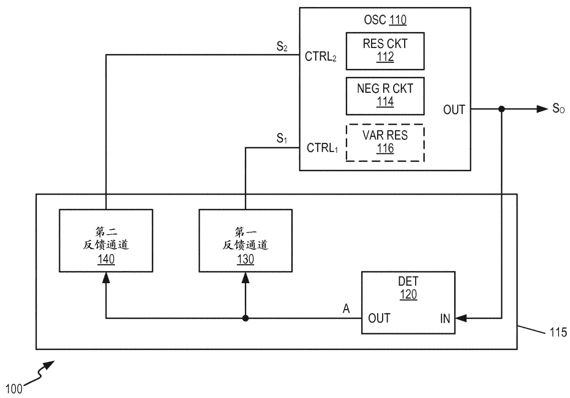
权利要求书3页 说明书5页 附图8页

(54)发明名称

低噪声振荡器振幅调节器

(57)摘要

频率生成解决方案使用两个反馈通道来控制振荡器振幅,以便生成具有更低功率消耗和更低噪声的高频率信号。第一反馈通道提供响应于在振荡器输出所检测的振幅对振荡器振幅的连续控制。第二反馈通道提供响应于所检测的振荡器振幅对振荡器的振幅调节参数的离散控制。因为第二反馈通道能够实现对振幅调节参数的调整,故第二反馈通道使第一反馈通道中的放大器能够按照降低的增益并且因而还按照降低的功率以及降低的噪声进行操作,而不危及振荡器的性能。



CN 107683568 A

1.一种频率生成电路(100),包括:

振荡器(110),其包括振荡器输出(OUT)、第一控制输入($CTRL_1$)和第二控制输入($CTRL_2$);

检测器(120),配置成检测所述振荡器输出的振幅;

第一反馈通道(130),其可操作地将所述检测器连接到所述第一控制输入($CTRL_1$),所述第一反馈通道配置成通过连续控制施加到所述第一控制输入的第一控制信号(S_1)来提供响应于所检测的振幅对所述振荡器输出的所述振幅的时间连续控制;以及

第二反馈通道(140),其可操作地将所述检测器连接到所述第二控制输入($CTRL_2$),所述第二反馈通道配置成通过提供对施加到所述第二控制输入的第二控制信号(S_2)的时间离散控制来提供响应于所检测的振幅对所述振荡器的一个或多个振幅调节参数的时间离散控制。

2.如权利要求1所述的频率生成电路,其中,所述第一反馈通道(130)配置成通过响应于所检测的振幅连续控制所述振荡器(110)的增益,来连续控制所述振荡器输出(S_o)的所述振荡器振幅。

3.如权利要求1或2所述的频率生成电路,其中,所述第二反馈通道(140)包括可操作地连接在检测器输出与所述第二控制输入($CTRL_2$)之间的控制电路(142),并且其中所述控制电路(142)配置成通过在所述检测器输出(A)满足一个或多个预定条件时控制所述一个或多个振幅调节参数,来提供对所述一个或多个振幅调节参数的所述时间离散控制。

4.如权利要求3所述的频率生成电路,其中,所述控制电路(142)包括配置成将所检测的振幅与上阈值进行比较的第一比较电路,并且其中所述控制电路配置成通过在所检测的振幅超过所述上阈值时控制所述一个或多个振幅调节参数,来提供对所述一个或多个振幅调节参数的所述时间离散控制。

5.如权利要求3或4所述的频率生成电路,其中,所述控制电路(142)包括配置成将所检测的振幅与下阈值进行比较的第二比较电路,并且其中所述控制电路配置成通过在所检测的振幅低于所述下阈值时控制所述一个或多个振幅调节参数,来提供对所述一个或多个振幅调节参数的所述时间离散控制。

6.如权利要求3-5中任一项所述的频率生成电路,其中,所述一个或多个振幅调节参数包括如下参数中的至少一个:振荡器偏置电流、振荡器g_m单元的数量、所述振荡器g_m单元中的一个或多个振荡器g_m单元的偏置点、以及与所述振荡器的核心并联连接的可变电阻。

7.如权利要求1-6中任一项所述的频率生成电路,其中,所述第二反馈通道还通过响应于事件触发控制所述一个或多个振幅调节参数,来提供对所述一个或多个振幅调节参数的时间离散控制。

8.如权利要求7所述的频率生成电路,其中,所述事件触发包括指示所述振荡器的加电的功率事件触发以及指示即将到来的无线电通信的通信事件触发中的至少一个。

9.如权利要求8所述的频率生成电路,其中,所述通信事件包括即将到来的随机访问信道传送事件、即将到来的无线电传送事件、或者即将到来的无线电接收事件。

10.如权利要求1-9中任一项所述的频率生成电路,其中,所述第二反馈通道(140)防止在所述振荡器(110)正被用于无线通信时或者在所述振荡器已经建立与一个或多个外部装置的频率同步时对所述一个或多个振幅调节参数的改变。

11.如权利要求1-10中任一项所述的频率生成电路,还包括配置成存储所述振荡器的当前配置的存储器,其中所述当前配置标识所述一个或多个振幅调节参数的当前状态。

12.一种控制包括振荡器输出(OUT)、第一控制输入($CTRL_1$)和第二控制输入($CTRL_2$)的振荡器(110)的方法,所述方法包括:

检测(210)所述振荡器输出(S_o)的振幅(A);

通过连续控制(220)施加到所述第一控制输入($CTRL_1$)的第一控制信号(S_1)来提供响应于所检测的振幅对所述振荡器输出的所述振幅的时间连续控制;以及

通过提供对施加到所述第二控制输入($CTRL_2$)的第二控制信号(S_2)的时间离散控制(230)来提供响应于所检测的振幅对所述振荡器的一个或多个振幅调节参数的时间离散控制。

13.如权利要求12所述的方法,其中,连续控制所述振荡器输出信号的所述振荡器振幅包括响应于所检测的振幅(A)而连续控制所述振荡器(110)的增益。

14.如权利要求12或13所述的方法,其中,提供对所述一个或多个振幅调节参数的所述时间离散控制包括当检测器输出满足一个或多个预定条件时控制所述一个或多个振幅调节参数。

15.如权利要求14所述的方法,还包括将所检测的振幅(A)与上阈值进行比较(232),其中提供对所述一个或多个振幅调节参数的所述时间离散控制包括当所检测的振幅超过所述上阈值时控制(236)所述一个或多个振幅调节参数。

16.如权利要求14或15所述的方法,还包括将所检测的振幅(A)与下阈值进行比较(234),其中提供对所述一个或多个振幅调节参数的所述时间离散控制包括当所检测的振幅低于所述下阈值时控制(236)所述一个或多个振幅调节参数。

17.如权利要求14-16中任一项所述的方法,其中,所述一个或多个振幅调节参数包括如下参数中的至少一个:振荡器偏置电流、振荡器g_m单元的数量、所述振荡器g_m单元中的一个或多个振荡器g_m单元的偏置点、以及与所述振荡器的核心并联连接的可变电阻(116)。

18.如权利要求12-17中任一项所述的方法,还包括通过响应于事件触发控制所述一个或多个振幅调节参数,来提供对所述一个或多个振幅调节参数的所述时间离散控制。

19.如权利要求18所述的方法,其中,所述事件触发包括指示所述振荡器的加电的功率事件触发以及指示即将到来的无线电通信的通信事件中的至少一个。

20.如权利要求19所述的方法,其中,所述通信事件包括即将到来的随机访问信道传送事件、即将到来的无线电传送事件、或者即将到来的无线电接收事件。

21.如权利要求12-20中任一项所述的方法,还包括控制施加到所述第二控制输入($CTRL_2$)的所述第二控制信号(S_2),以防止在所述振荡器正被用于无线通信时或者在所述振荡器已经建立与一个或多个外部装置的频率同步时对所述一个或多个振幅调节参数的改变。

22.如权利要求12-21中任一项所述的方法,还包括在存储器中存储所述振荡器的当前配置,其中所述当前配置标识所述一个或多个振幅调节参数的当前状态。

23.一种存储在非暂态计算机可读介质中用于控制频率生成电路(100)的振荡器(110)的计算机程序产品,所述振荡器包括振荡器输出(OUT)、第一控制输入($CTRL_1$)和第二控制输入($CTRL_2$),所述计算机程序产品包括软件指令,所述软件指令在运行于所述频率生成电

路之上时使所述频率生成电路：

检测(210)所述振荡器输出的振幅(A)；

通过连续控制(220)施加到所述第一控制输入的第一控制信号(S_1)来提供响应于所检测的振幅对所述振荡器输出的所述振幅的时间连续控制;以及

通过提供对施加到所述第二控制输入的第二控制信号(S_2)的时间离散控制(230)来提供响应于所检测的振幅对所述振荡器的一个或多个振幅调节参数的时间离散控制。

24.一种包括权利要求1-11中任一项所述的频率生成电路(100)的无线通信装置。

低噪声振荡器振幅调节器

技术领域

[0001] 本文所呈现的解决方案一般涉及频率生成，且更具体来说涉及降低高频率生成电路的相位噪声和功率消耗。

背景技术

[0002] 振荡器广泛用于各种电子装置中，例如用来提供参考时钟、电信信号的频率混合等。基于负电阻的振荡器表示通常用于生成更高频率信号(诸如用于无线通信装置中)的一种振荡器架构类型。基于负电阻的振荡器的示例包括但不限于晶体振荡器、基于表面声波(SAW)的振荡器等。基于负电阻的振荡器包括振荡器核心，其具有可操作地连接到负电阻电路的谐振电路。谐振电路在期望的谐振频率处振荡，且负电阻电路抵消谐振电路的电阻性损耗。实际上，负电阻电路消除谐振电路的自然阻尼，并且因此使振荡器核心能够在期望的谐振频率处连续振荡。

[0003] 包含这类振荡器的电子装置的成功操作要求准确且可靠的振幅控制。具体来说，振幅控制由于如下事实而是必要的：例如不同谐振电路的不同Q值以及任一个振荡器的不同PVT (过程、电压和温度)条件可引起广泛的振幅变化。例如，与具有低Q谐振电路的振荡器相比，具有高Q谐振电路的振荡器将具有更高的振幅振荡。此外，按照线性模式运行的振荡器要求振幅的连续调节，以防止振荡器振幅快速下降到零或者增加到振荡器的非线性效应(例如电压削波)所限制的水平。这种电压削波能够使振荡器性能极大地退化，增加寄生振荡的风险，增加电流消耗(取决于电路拓扑)，并且一般使振荡器的行为更加不可预测。准确且可靠的振幅控制将均衡跨大范围的Q值和PVT条件的振幅变化，以及确保良好噪声性能，提供低电流消耗，避免寄生振荡，并且可能防止对有源和无源组件的损坏。

[0004] 负反馈环路提供用来控制振荡器输出的振幅的一种方式，其中负反馈环路感测振荡器输出的振幅，并且然后通过控制振荡器核心的操作点来调整振幅。例如，控制经过振荡器核心的有源晶体管装置的电流来控制振荡器核心的跨导g_m，以控制负电阻，并且因而控制振荡器振幅。但是，这类负反馈环路可将噪声引入振荡器核心，特别是在负反馈环路具有高增益时。此外，振荡器核心的非线性性质将会把输入噪声转换成AM (振幅调制)和PM (相位调制)噪声二者。虽然增加负反馈环路的环路增益将降低AM噪声，但是这种增加的环路增益不仅将增加功率消耗，而且还将无法降低PM噪声。虽然降低负反馈环路的带宽也将降低噪声，但是这种带宽降低将增加振荡器的启动时间，并且还可不合乎期望地增加对振荡器输入信号进行滤波所要求的任何滤波器的大小(消耗芯片面积)。因此，这种带宽降低也不是合乎期望的。

[0005] 如以上所指出的，基于负电阻的振荡器对高频率应用是特别有用的，并且对mmW(毫米波)通信可以是特别重要的。而且，具体对于基于例如晶体或SAW谐振器的参考振荡器而言，甚至更高频率(从当今数十MHz到数百MHz以及甚至可能接近GHz范围的频率)的使用是被预期的。这类更高频率的生成一般引起更高功率消耗。此外，这类更高频率的生成还由于谐振器的增加的容差、增加的噪声、增加的组件大小、更长的启动时间、和/或来自电路和

关联封装的寄生元件的更大影响而呈现设计挑战。因此,仍然存在对于不引起更高功率消耗、更高噪声、和/或更长启动时间的改进的更高频率生成电路的需要。

发明内容

[0006] 本文所呈现的解决方案通过使用两个反馈通道控制振荡器振幅,来生成具有更低功率消耗和更低噪声的高频率信号。第一反馈通道提供响应于在振荡器输出所检测的振幅对振荡器振幅的连续控制。第二反馈通道提供响应于所检测的振荡器振幅对振荡器的振幅调节参数的离散控制。因为第二反馈通道能够实现对振幅调节参数的调整,故第二反馈通道使第一反馈通道中的放大器能够按照降低的增益并且因而还按照降低的功率和降低的噪声进行操作,而不危及振荡器的性能。

[0007] 一个示范实施例包括频率生成电路,其包括振荡器、检测器、第一反馈通道和第二反馈通道。振荡器包括振荡器输出、第一控制输入和第二控制输入。检测器配置成检测振荡器输出的振幅。第一反馈通道可操作地将检测器连接到第一控制输入,并且配置成通过连续控制施加到第一控制输入的第一控制信号来提供响应于所检测的振幅对振荡器输出的振幅的时间连续控制。第二反馈通道可操作地将检测器连接到第二控制输入,并且配置成通过提供对施加到第二控制输入的第二控制信号的时间离散控制来提供响应于所检测的振幅对振荡器的一个或多个振幅调节参数的时间离散控制。

[0008] 另一个示范实施例包括一种控制含有振荡器输出、第一控制输入和第二控制输入的振荡器的方法。该方法包括检测振荡器输出的振幅,以及通过连续控制施加到第一控制输入的第一控制信号来提供响应于所检测的振幅对振荡器输出的振幅的时间连续控制。该方法还包括通过提供对施加到第二控制输入的第二控制信号的时间离散控制来提供响应于所检测的振幅对振荡器的一个或多个振幅调节参数的时间离散控制。

[0009] 另一个示范实施例包括一种计算机程序产品,其被存储在非暂态计算机可读介质中,以用于控制频率生成电路的振荡器。振荡器包括振荡器输出、第一控制输入和第二控制输入。该计算机程序产品包括软件指令,所述软件指令在运行于频率生成电路之上时使频率生成电路检测振荡器输出的振幅,以及通过连续控制施加到第一控制输入的第一控制信号来提供响应于所检测的振幅对振荡器输出的振幅的时间连续控制。所述软件指令在运行于频率生成电路之上时还使频率生成电路通过提供对施加到第二控制输入的第二控制信号的时间离散控制来提供响应于所检测的振幅对振荡器的一个或多个振幅调节参数的时间离散控制。

附图说明

[0010] 图1示出按照一个示范实施例的频率生成电路的框图。

[0011] 图2示出按照一个示范实施例的振幅控制方法。

[0012] 图3示出按照一个示范实施例、图1的频率生成电路的第一反馈通道的框图。

[0013] 图4示出按照一个示范实施例、图1的频率生成电路的第二反馈通道的框图。

[0014] 图5示出按照一个示范实施例的另一种振幅控制方法。

[0015] 图6示出仅采用具有高增益的第一反馈通道可取得的模拟结果。

[0016] 图7示出仅采用具有低增益的第一反馈通道可取得的模拟结果。

[0017] 图8示出采用本文所呈现的解决方案可取得的示范模拟结果。

[0018] 图9示出当第一反馈通道具有不同增益时的示范模拟结果。

[0019] 图10示出采用本文所呈现的解决方案可取得的噪声改进的示范模拟结果。

具体实施方式

[0020] 图1示出按照一个示范实施例的频率生成电路100的框图。为了简洁起见，图1仅示出促进本文所提供的描述所必需的频率生成电路100的元件。本领域的技术人员将领会到的是，频率生成电路100可包括在图1未示出的附加组件和/或信号连接。

频率生成电路100包括耦合到控制电路115(其控制振荡器输出的振幅)的振荡器110。振荡器110包括第一控制输入($CTRL_1$)、第二控制输入($CTRL_2$)和输出(OUT)。振荡器110可包括晶体振荡器或者任何其他基于负电阻的振荡器(其包括可操作地连接到负电阻电路114的谐振电路112)。在一个示范实施例中，谐振电路112可包括晶体，以及负电阻电路114可包括放大器(未示出)。施加到相应第一和第二控制输入的第一和第二控制信号S_1和S_2控制在振荡器110的输出处的信号S_o的振幅。具体来说，如下面所进一步描述的，第一控制信号S_1提供对S_0的振幅的时间连续控制，而第二控制信号S_2提供对振荡器110的一个或多个振幅调节参数的时间离散控制。示范振幅调节参数包括但不限于振荡器偏置电流、有源振荡器g_m单元的数量、振荡器g_m单元其中的一个或多个振荡器g_m单元的偏置点、和/或与振荡器110的核心并联连接的可变电阻。因为第二控制信号S_2控制振荡器110的配置，所以S_2能够实现将以其他方式对由第一控制信号S_1提供的时间连续振幅控制所施加的要求的放宽。

[0021] 控制电路115按照图2的示范方法200，响应振荡器输出信号S_o而生成第一和第二控制信号S_1、S_2。更具体来说，控制电路115包括检测器120、第一反馈通道130和第二反馈通道140。检测器120(其耦合在振荡器输出与第一反馈通道130和第二反馈通道140的输入之间)检测振荡器输出信号S_o的振幅A (框210)。第一反馈通道130响应于所检测的振幅A，通过连续控制第一控制信号S_1来提供对振荡器输出信号S_o的振幅的时间连续控制(框220)。第二反馈通道140响应于所检测的振幅A，通过在离散时间中控制第二控制信号S_2来提供对振荡器110的一个或多个振幅调节参数的时间离散控制(框230)。例如，第二控制信号可提供对控制负电阻电路114的操作的参数的时间离散控制。通过控制振荡器110的振幅调节参数，第二反馈通道140允许第一反馈通道130按照更低增益并且因此按照更低功率和采用更少噪声来进行操作。

[0022] 图3示出按照一个示范实施例的第一反馈通道130的框图。在这个实施例中，第一反馈通道130包括放大器132和滤波器134。所检测振幅A以及参考振幅A_{ref}被输入到放大器132。放大器132放大从所检测振幅A与参考振幅A_{ref}之间的差所形成的振幅误差A_{err}，以及滤波器134通过对放大的信号进行低通滤波来帮助降低输入到振荡器110的噪声，以生成第一控制信号S_1。第一控制信号S_1通过控制负电阻电路114的增益来控制振荡器核心的增益。这样做时，第一控制信号S_1控制振荡器输出信号S_o的振幅。

[0023] 放大器132建立第一反馈通道130的增益。因为各种环境条件、振荡器性质、和/或振荡器110的使用年限可影响第一控制信号S_1充分控制振荡器输出信号S_o的振幅的能力，所以传统系统趋向于将放大器132的增益设置成计及大范围的条件，即使一些更极端条件是很罕见的。例如，相对于在常规操作温度采用相同输入控制信号的情况下振荡器核心的增

益将达到的程度而言，更高温度可降低该增益。传统解决方案通过确保放大器132的增益足够高以使振荡器核心能够应付甚至极端的温度条件而不使振荡器输出S_o的振幅下降到低于期望水平来解决这个问题。但是，这类高增益条件使放大器132消耗更多功率，并且插入比将以其他方式对于许多操作条件必要的噪声更多的噪声到振荡器核心中。

[0024] 本文所呈现的解决方案将第二反馈通道140结合到控制电路115中，以控制振荡器110的振幅调节参数，这允许第一反馈通道130被设计和配置成用于更低增益。第一反馈通道130中的这种增益降低将使频率生成电路100能够操作在更低功率，并且将降低输入到振荡器110的噪声级别。为此，第二反馈通道140响应于振荡器输出信号S_o的所检测振幅A而控制一个或多个振幅调节参数。例如，如果所检测振幅A下降得过低，从而指示第一控制信号不能充分放大振荡器振幅，则第二反馈通道140可例如通过增加偏置电流、增加有源振荡器gm单元的数量、和/或增加有源gm单元其中的一个或多个有源gm单元的偏置点来调整振幅调节参数。备选或另外地，第二反馈通道140可通过例如使用跨振荡器110的差分输出连接的可变电阻器116增加与振荡器核心并联连接的可变电阻的电阻来调整振幅调节参数。在另一个示例中，如果所检测振幅A上升得过高，从而指示振荡器输出信号S_o的振幅过高，则第二反馈通道140可减小偏置电流，减小有源振荡器gm单元的数量，减小有源gm单元中的一个或多个有源gm单元的偏置点，和/或减小与振荡器110的核心并联连接的可变电阻器116的电阻。在任一种情况下，第二反馈通道140调整如由所检测振幅A指示的对于当前操作条件的振幅调节参数，以便使振荡器110能够保持输出处的期望振幅，而不要求第一反馈通道130具有高的增益。

[0025] 因为放大器132的增益设计成应付大多数操作条件，所以第二反馈通道140所提供的控制可按照时间离散方式来实现。例如，第二反馈通道140可包括控制电路142，如图4中所示。控制电路142可通过在所检测振幅A满足一个或多个预定条件(例如阈值条件)时仅控制振幅调节参数来按照时间离散方式控制振荡器的振幅调节参数。例如，控制电路142可控制第二控制信号S_2，以便仅当所检测振幅A超过上阈值T_U或者低于下阈值T_L时来控制振幅调节参数。另外，控制电路142可控制第二控制信号S_2，以便仅在某些操作条件下和/或响应于事件触发来控制振幅调节参数。例如，控制电路142可控制第二控制信号S_2，以便当振荡器110加电时和/或当振荡器110正响应于某个通信事件触发而做出行动时允许振幅调节参数发生改变。但是，因为在例如有源通信期间改变振幅调节参数能够扰乱振荡器110的相位和/或频率，所以控制电路142可控制第二控制信号S_2，以防止振幅调节参数在此类时期期间发生改变，从而防止这个扰乱。因此，控制电路142可除了阈值条件之外还使用加电/断电事件和/或通信事件触发来提供对振荡器的振幅调节参数的附加时间离散控制。

[0026] 图5的示范方法250提供用于在启动时控制振荡器110的更详细途径。在该示范方法250中，振荡器110被加电(框202)，并且该过程一直等到振荡器110稳定为止(框204)。一旦振荡器110稳定(框204)，检测器120检测振荡器输出信号S_o的振幅A (框210)。如果所检测振幅A超过上阈值T_U (框232)或者低于下阈值T_L (框234)，则第二反馈通道140中的控制电路142确定振荡器110采用当前配置不能够保持期望振幅。作为响应，控制电路142因此变更振荡器110的一个或多个振幅调节参数(框236)。一旦振荡器110再次稳定(框204)，则可重复进行框210、232和234。这个重复进行可以是无限的，或者可在某个预定的最大迭代次数之后终止。

[0027] 图6-10示出用来展示本文所呈现的解决方案的优点的模拟结果。图6和图7首先示出当控制电路115没有包括第二反馈通道140时可取得的振荡振幅。在这种情况下，振荡器110的振幅调节参数是固定的，并且第一反馈通道130提供唯一振幅控制。图6提供当第一反馈通道130中的放大器132配置成采用引起例如大于10的相对高的环路增益的高增益进行操作时的结果与图7中的结果的对比，其中在图7的结果中，放大器132采用引起例如小于5的相对低的环路增益的较低增益进行操作。如图6所示，较高环路增益实现提供例如全摆幅的50-55%的很低的振幅变化。但是，取得此低振幅变化所必需的高增益引起高功率消耗和高噪声级别。较低环路增益实现能够实现较低功率消耗和功率级别，但是如图7中所示，此较低环路增益实现具有例如全摆幅的48-68%的相对高的振幅变化。

[0028] 图8示出当控制电路115包含有第二反馈通道140用来能够实现对振荡器110的振幅调节参数的时间离散调整时的结果。在这个模拟中，第一反馈通道130具有低增益，并且第二反馈通道140被用来控制两个额外振幅调节参数，例如偏置尾电流和/或振荡器核心中的g_m单元的数量，如图8中的三条曲线所示。如图8所示，本文所呈现的解决方案引起更低振幅变化(52-60%)，这是先前当第一反馈通道130具有较低环路增益时所不可取得的。因此，本文所呈现的解决方案提供与较低环路增益实现更加通常关联的更低噪声和功率消耗有益效果，同时还提供与较高环路增益实现更加通常关联的振幅控制有益效果。

[0029] 图9示出模拟结果，其展现了放大器132的增益可如何被选择以取得振幅控制和噪声/功率降低之间的期望的折衷。图9中的结果展现针对六种情形(其在每个点处被定性地指定，例如“高环路增益”、“包含第二反馈通道的低环路增益”等)的振荡器振幅表现。前四种情形示出当没有包含第二反馈通道140时针对高/低环路增益和高/低Q情形的振幅表现。后两种情形示出当包含第二反馈通道140时针对低环路增益和高/低Q情形的振幅表现。

[0030] 图10示出模拟结果，其展现对于与图9中相同的六种情形的噪声性能，并且因而展现由本文所呈现的解决方案所提供的噪声改进。具体来说，顶部两个图示出当振幅调节参数被固定并且第一反馈通道130的环路增益为高时的频率生成电路100的操作。底部图示出当第二反馈通道140被用来修改偏置电流以及振荡器核心的g_m单元(当第一反馈通道130的环路增益为低时)时的结果。因此，本文所呈现的解决方案提供一种频率生成电路，其具有与高增益负反馈关联的振幅控制有益效果以及与低增益负反馈关联的功率和噪声有益效果。

[0031] 在不偏离本发明的本质特性的情况下，本发明当然可通过不同于本文中所具体阐述的方式的其他方式来被执行。所呈现的实施例在所有方面要被认为是说明性而不是限制性的，并且在随附权利要求的含意和等效范围之内出现的所有改变都预期被涵盖在其中。

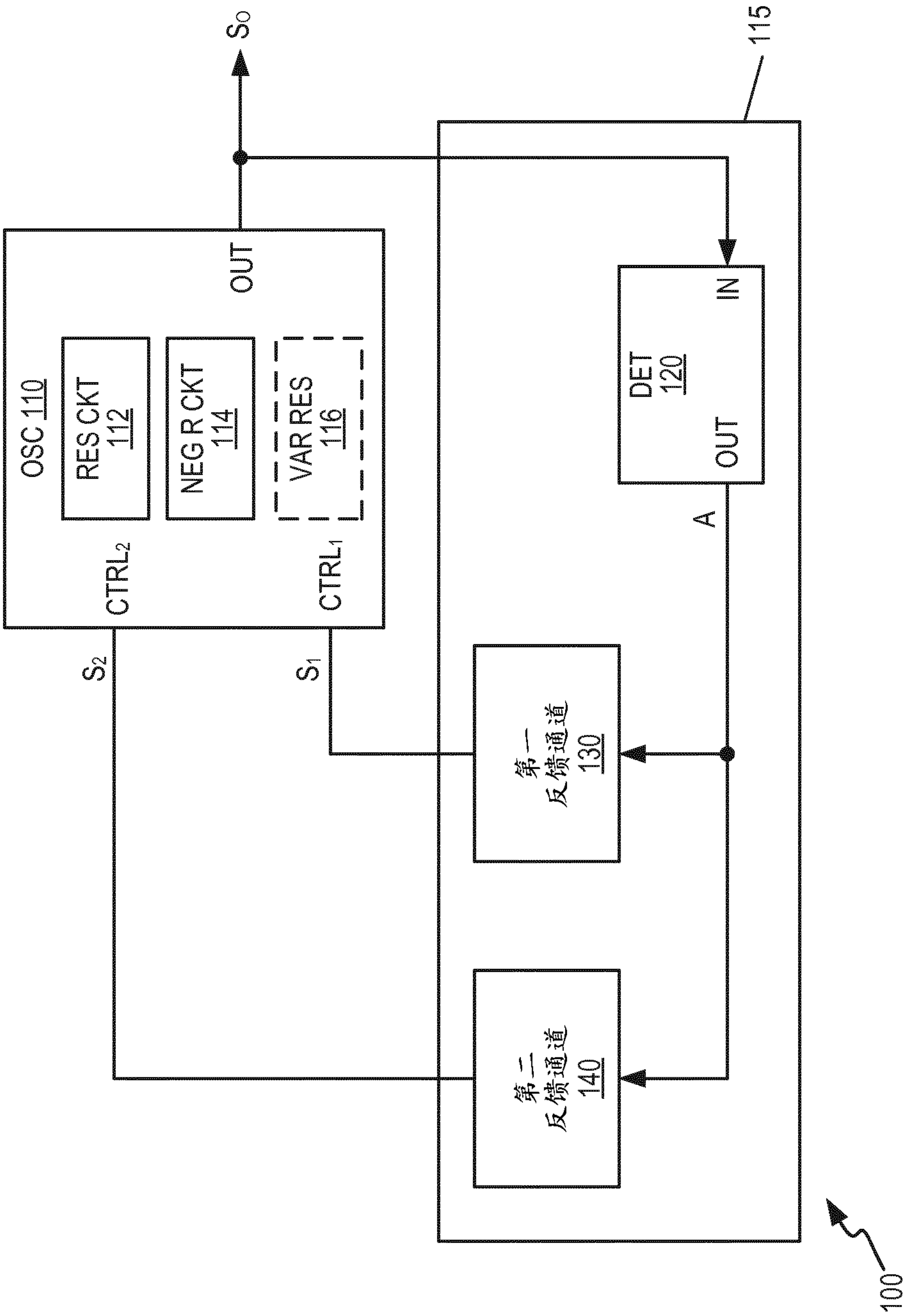

S_O
115
OUT
OSC 110
RES CKT 112
NEG R CKT 114
VAR RES 116
CTRL2
CTRL1
IN
DET 120
OUT
A
S2
S1
第一反馈通道 130
第二反馈通道 140
100

图 1

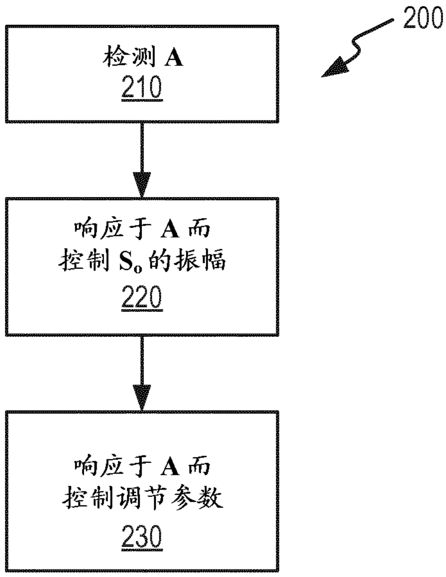

200
检测 A
210
响应于 A 而
控制 S_o 的振幅
220
响应于 A 而
控制调节参数
230

图 2

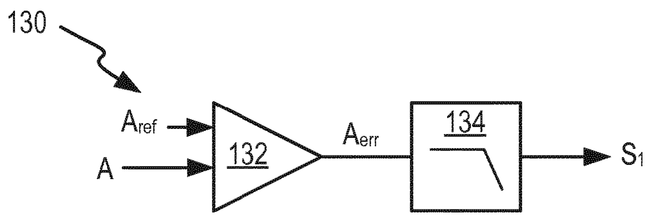

130
A_{ref}
A
132
A_{err}
134
S_1

图 3

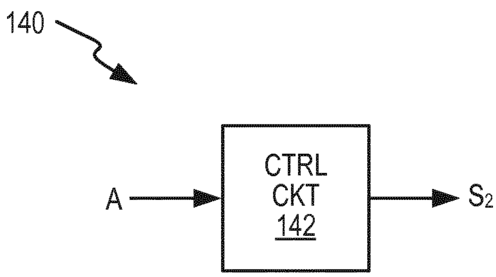

140
A
CTRL
CKT
142
S_2

图 4

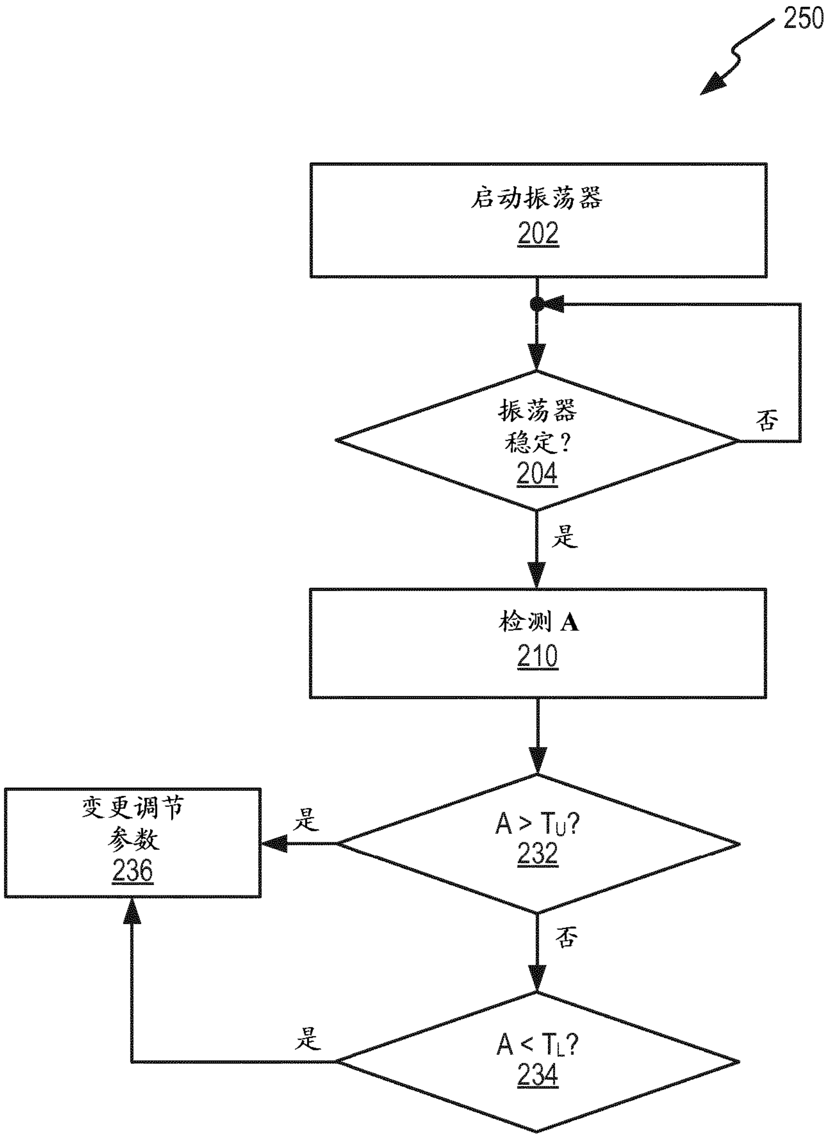
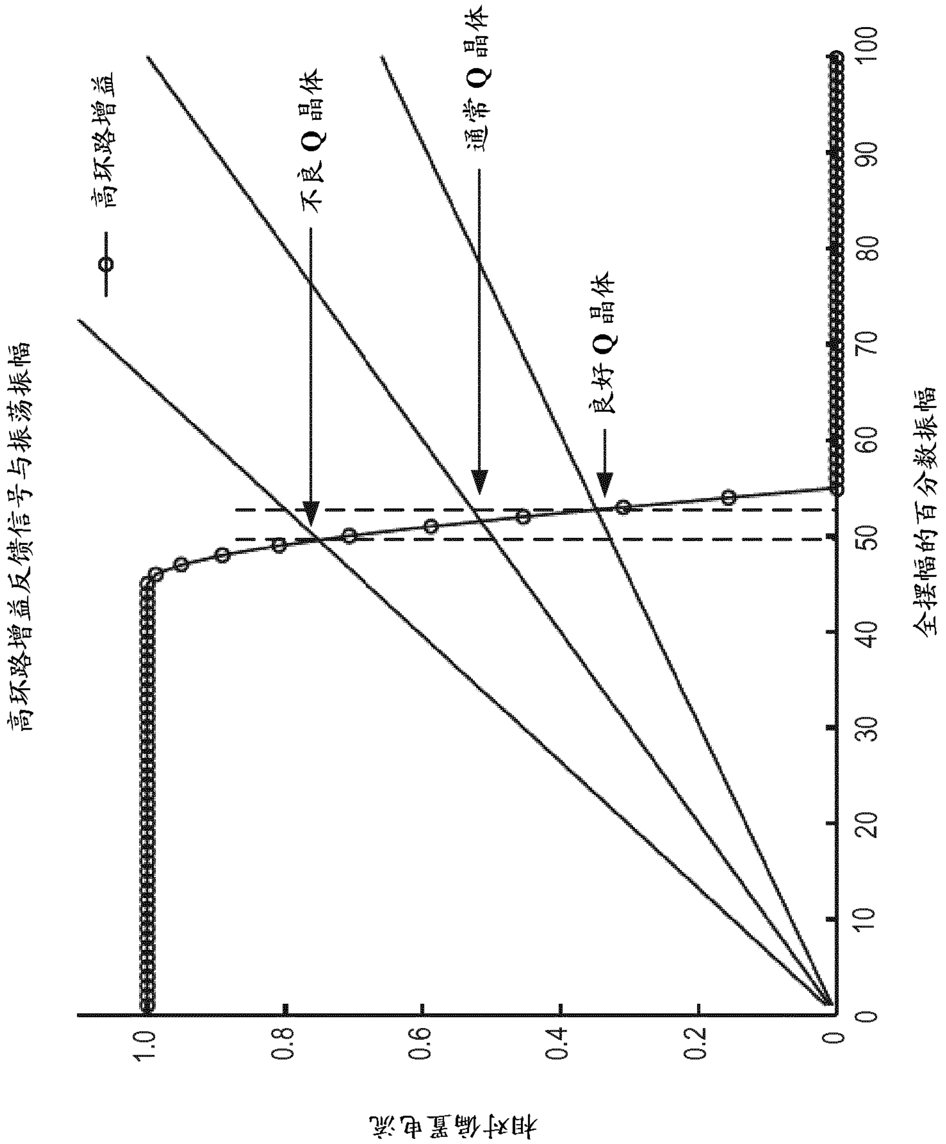

250
启动振荡器
202
振荡器
稳定?
204
否
是
检测 A
210
变更调节
参数
236
是
A > TU?
232
否
是
A < TL?
234

图 5



高环路增益反馈信号与振荡振幅
高环路增益
不良Q晶体
通常Q晶体
良好Q晶体
全摆幅的百分数振幅
相对偏置电流
0
10
20
30
40
50
60
70
80
90
100
0
0.2
0.4
0.6
0.8
1.0

图 6

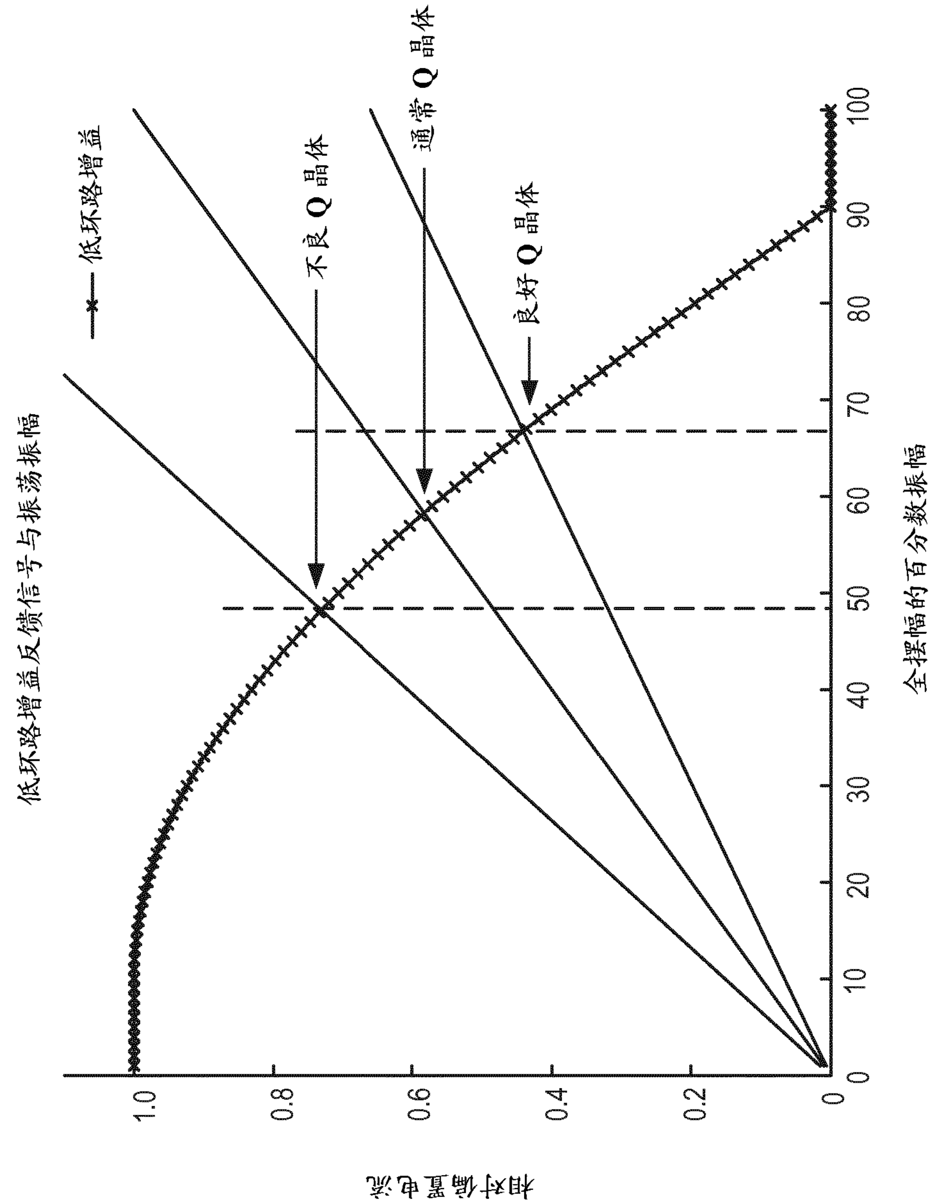

低环路增益反馈信号与振荡振幅
低环路增益
不良Q晶体
通常Q晶体
良好Q晶体
全摆幅的百分数振幅
相对偏置电流
0
10
20
30
40
50
60
70
80
90
100
0
0.2
0.4
0.6
0.8
1.0

图 7

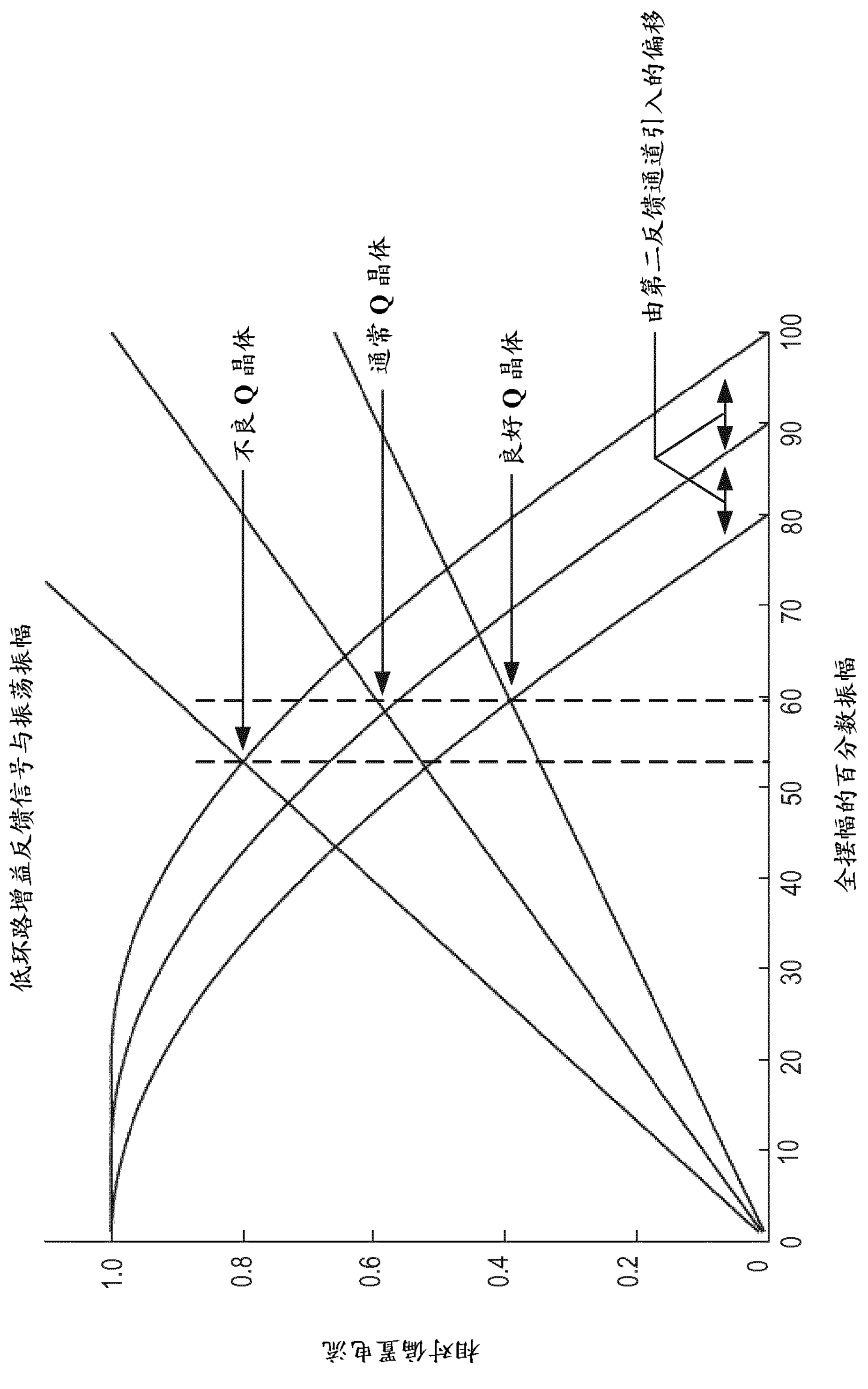
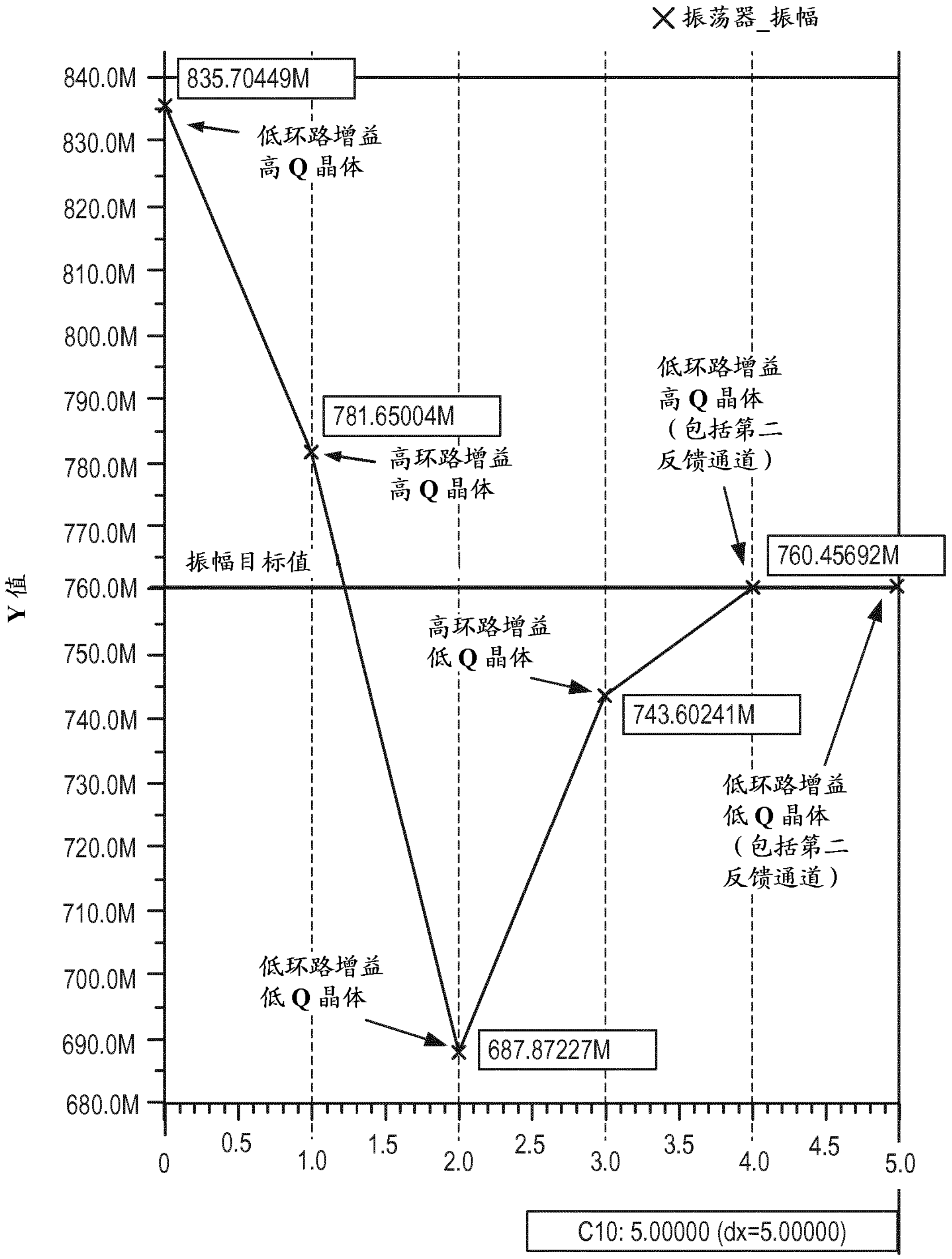
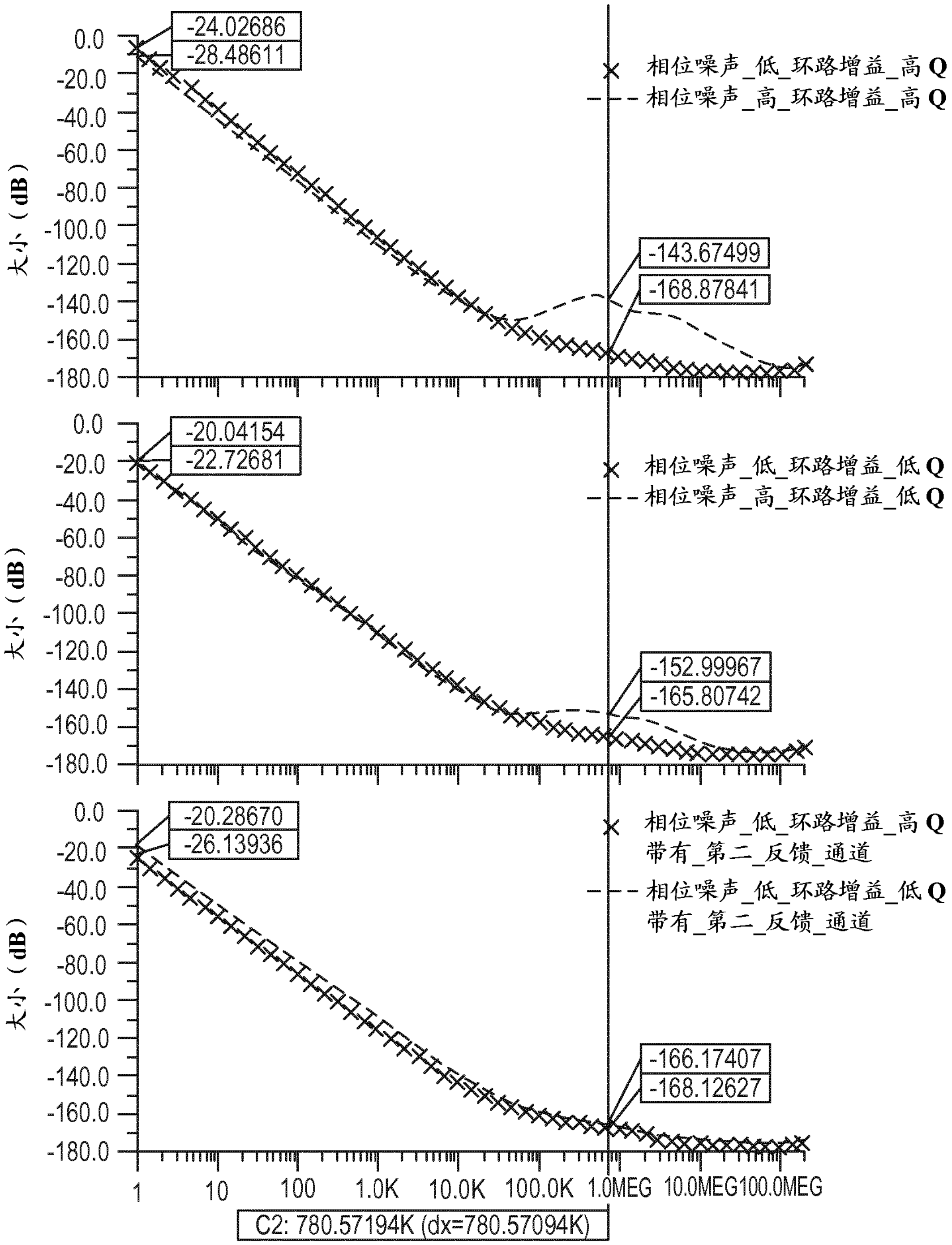

低环路增益反馈信号与振荡振幅
不良Q晶体
通常Q晶体
良好Q晶体
由第二反馈通道引入的偏移
1.0
0.8
0.6
0.4
0.2
0
相对偏置电流
0
10
20
30
40
50
60
70
80
90
100
全摆幅的百分数振幅

图 8



振荡器_振幅
840.0M
830.0M
820.0M
810.0M
800.0M
790.0M
780.0M
770.0M
760.0M
750.0M
740.0M
730.0M
720.0M
710.0M
700.0M
690.0M
680.0M
Y值
835.70449M
低环路增益
高Q晶体
781.65004M
高环路增益
高Q晶体
振幅目标值
低环路增益
低Q晶体
687.87227M
高环路增益
低Q晶体
743.60241M
低环路增益
高Q晶体
（包括第二
反馈通道）
760.45692M
低环路增益
低Q晶体
（包括第二
反馈通道）
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
C10: 5.00000 (dx=5.00000)

图 9



0.0
-20.0
-40.0
-60.0
-80.0
-100.0
-120.0
-140.0
-160.0
-180.0
大小（dB）
-24.02686
-28.48611
-143.67499
-168.87841
相位噪声_低_环路增益_高 Q
相位噪声_高_环路增益_高 Q
-20.04154
-22.72681
-152.99967
-165.80742
相位噪声_低_环路增益_低 Q
相位噪声_高_环路增益_低 Q
-20.28670
-26.13936
-166.17407
-168.12627
相位噪声_低_环路增益_高 Q 带有_第二_反馈_通道
相位噪声_低_环路增益_低 Q 带有_第二_反馈_通道
1
10
100
1.0K
10.0K
100.0K
1.0MEG
10.0MEG
100.0MEG
C2: 780.57194K (dx=780.57094K)

图 10