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— *of inventorship (Rule 4.17(iv))*

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[Continued on next page]

(54) Title: OFFSET GENERATIVE RECEIVER

(57) Abstract: A receiver is provided that can be operated at ultra-high frequencies (including terahertz) that are beyond the normal cutoff frequencies of the devices. The receiver can include an offset demodulator that mixes a high frequency input signal received from an antenna with a high local oscillator frequency to output an offset demodulated signal. The offset demodulated signal is input to a regeneration circuit including an amplifier and detector, which outputs a demodulated signal.

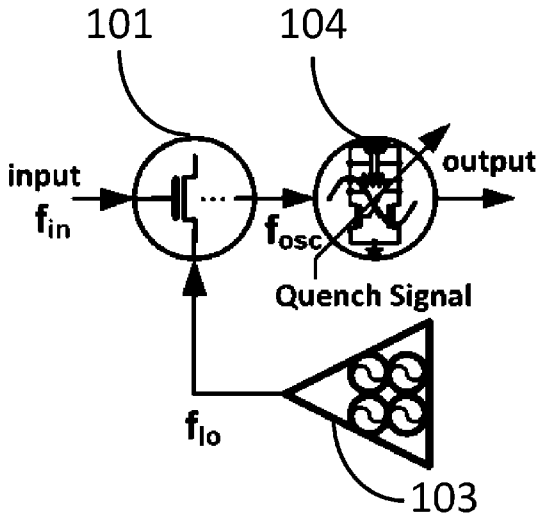


FIG. 1B

WO 2013/074474 A1

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

OFFSET GENERATIVE RECEIVER

BACKGROUND

Receiver operation frequencies are normally limited by device cutoff frequencies. This limitation arises because the receiver circuit cannot provide power or current gain beyond the device cut-off frequencies of the receiver's components. A cutoff frequency is a boundary (at the high or low end) in a system's frequency response at which energy flowing through the system begins to be attenuated rather than passing through – the frequency at which the power output of the circuit has fallen to a given proportion of the power in the passband.

With the expansion of radio-frequency and microwave applications, providing functioning semiconductor-based systems for the millimeter and sub-millimeter wavelength applications continues to be an area of research.

BRIEF SUMMARY

A receiver is disclosed that can, according to certain embodiments, operate at frequencies above the cutoff frequencies of the receiver's components.

Embodiments of the subject receiver utilize an offset generative technique to boost circuit operation frequencies higher than device cut-off frequencies. Such receivers can be referred to as offset generative receivers.

According to one embodiment, an offset generative receiver is provided that includes a front-end offset demodulator that receives a high frequency input signal and a high gain amplifier following the offset demodulator to enable the system to work beyond device cut-off frequencies.

This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used to limit the scope of the claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A shows a diagram of an offset generative circuit with a peripheral input frequency according to one embodiment of the invention.

FIG. 1B shows a diagram of an offset generative circuit with an on-chip frequency f_{LO} according to another embodiment of the invention.

FIG. 2 shows a simulation schematic of an offset generative receiver circuit in accordance with an embodiment of the invention.

FIG. 3A shows a plot of simulated output startup time for a generated 195 GHz frequency signal according to input powers of -20 dBm, -40 dBm, -60 dBm, -80 dBm, and -100 dBm at 1.1014 THz frequency in an offset generative receiver according to an embodiment of the invention.

FIG. 3B shows a simulated plot of converted pulse train according to input power at 1.014 THz frequency in an offset generative receiver according to an embodiment of the invention.

FIG. 3C shows a simulated plot of output pulse width versus input powers of -20 dBm,
-40 dBm, -60 dBm, -80 dBm, and -100 dBm at input frequencies of 195 GHz, 429 GHz, 624 GHz, 819 GHz, and 1.014 THz in an offset generative receiver according to an embodiment of the invention.

FIG. 3D shows a simulated plot of normalized gain at input frequencies of 195 GHz, 429 GHz, 624 GHz, 819 GHz, and 1.014 THz in an offset generative receiver according to an embodiment of the invention.

DETAILED DISCLOSURE

Systems and methods are described herein for operating a receiver at ultra-high frequencies (including terahertz) that are beyond the normal cutoff frequencies of the receiver's components.

Implementations of the subject receiver can be used for applications including, but not limited to imaging, sensing, and communications.

In a typical receiver, an input signal is mixed with a local oscillator signal at a carrier frequency (down-converted) and demodulated to recover the transmitted information. In digital communications, the incoming signal (often at RF) is down-converted to an intermediate frequency (IF) and demodulated. For the demodulation, a carrier frequency and symbol clock recovery is performed. Then, signal decomposition, via a demodulator operating at IF, to I and Q components occurs, followed by slicing, decoding and de-interleaving before expansion to the original bit stream.

In accordance with certain embodiments of the invention, a receiver is provided where an input signal from an antenna is modulated down (e.g., demodulated) and the offset output of the modulation stage is provided to a regenerative circuit. The regenerative circuit portion provides a feedback loop where the loop is coupled to the incoming signal source (output from the modulation stage) and the desired frequencies are coupled out of the loop to a subsequent amplification stage. The regenerative circuit functions as a combination of an oscillator and mixer which converts the modulation directly to the desired frequencies.

According to embodiments, an offset demodulator followed by a high gain amplifier that receives the offset output from the offset demodulator is used to enable operations of the receiver at frequencies above the cutoff frequencies of the receiver.

The offset demodulation can be accomplished via a signal multiplier (working in this context as a mixer) that down-converts the input signal by mixing two input signals (the input signal being one of the two input signals) and outputting the sum frequency and the difference frequency of the two signals. By incorporating a local oscillator as one of the two input signals, the input signal frequency can be demodulated. In accordance with certain embodiments of the invention, the offset demodulator is implemented as a down-conversion mixer, where the mixer is working with frequencies higher than the device cut-off frequency for the mixer. In particular, the mixer is receiving input signals at frequencies higher than its device cut-off frequencies.

The high gain amplification can be accomplished via a regenerative amplifier circuit. It should be understood that the meaning of "high gain" in the context of a high gain amplifier or high gain amplification is system related and dependent on the particular circuit design of the amplifier as well as the type of input signals being amplified; and that a non-inconsequential amplification of the input signal is sought. In general, the gain of an amplifier is a ratio of output to input power, voltage, or current.

In one embodiment, an amplifier and power detector can be used as the regenerative amplifier circuit. A quench signal is used to control the gain and amplification time of the regenerative amplifier circuit.

In many systems, a maximum frequency handled by the system is the unit power gain frequency (or maximum oscillation frequency) fMAX. Embodiments of the invention enable higher than fMAX operating frequencies by utilizing an offset demodulator and regenerative circuit amplifier. In accordance with certain embodiments of the invention, an input signal fIN is down-converted (modulated down), via the offset demodulator (using a frequency

fLO), to an oscillation frequency fOSC. The offset demodulator output fOSC = fIN – fLO, where fIN > fMAX and fLO > fMAX.

In one embodiment as shown in Figure 1A, the offset demodulator **101** receives the high frequency fLO signal from a peripheral input **102**. In another embodiment, as shown in Figure 1B, an on-chip high frequency generator **103** (or local oscillator) can be used to provide the high frequency fLO signal. The output of the offset demodulator **101** is input to a regenerative circuit **104** before providing the signal for use in a system.

The offset output at frequency fOSC is equivalent to the self-resonant frequency of the regenerative circuit, and can be small due to attenuation from higher than device cut-off frequency operation. The frequency fOSC is input into a high gain regenerative amplifier to detect the input signal with the frequency higher than device cut-off frequencies.

Since the incoming signal frequency to the offset demodulator is different from the local regenerative frequency of the regenerative amplifier, the receiver can be referred to as "offset generative". To enable systems to work beyond fMAX, embodiments of the invention employ an offset generative circuit as described with respect to Figures 1A and 1B.

Simulations were performed using the schematic illustrated in Figure 2 for a 65 nm CMOS implementation and device cutoff frequency fT of about 200 GHz. It should be understood that embodiments of the subject offset generative receiver are not limited to CMOS or the 65 nm technology node and can be implemented in any technology or technology node.

Referring to Figure 2, a modulated signal (fIN) is input to the first building block **210** through the pin "IN." The first building block represents a demodulator and a LO generator, which provides a local oscillator frequency input signal (fLO) to be mixed with the modulated signal input to the first building block **210**. For the first building block schematic, VDDDEM is the supply of the demodulator, VBNDEM is the bias for the detector, VSSI is the ground, and VCOT, VCOP, VCON, and VCOB are voltages at different nodes in the circuit. The output (fOSC) of the first building block **210** is input to the second building block **220**. The second building block **220** represents an amplifier and power detector, which provide a regenerative amplifier and envelope detector. For the second building block schematic, QUEN is the quench signal, IBARR is the current bias for the regenerative amplifier, VC is the frequency control bit, and OP1, ON1, VCORRP, and VCORRN are voltages at different nodes in the circuit. The second building block **220** outputs a demodulated base band signal at the pin "OUT." In certain embodiments, a bandpass filter

associated with the detector can be part of the second building block **220** or provided at the output of the second building block **220**.

For the simulations shown in Figures 3A and 3B, the front end offset demodulator generates a 195 GHz signal through the mixing of the incoming *f*IN of 1.014 THz (195 GHz * frequency index of 5.2) with *f*LO of 0.819 THz (195 GHz * frequency index of 4.2). The small 195 GHz signal (as shown in Figure 3A) from the offset demodulator then injects into the subsequent regenerative amplifier and envelope detector to realize input power to pulse duty cycle mapping as shown in Figure 3B. As illustrated by the simulations, the offset generative amplifier allows higher than device *f*MAX input, as long as it satisfies that *f*OSC= *f*IN-*f*LO.

Figure 3A shows a plot of simulated output startup time for the example CMOS implementation with an input frequency *f*IN of 1.014 THz at various input signal powers. As shown in Figure 3A, the offset generative amplifier oscillation startup time for the generated 195 GHz frequency signal varies with the input signal powers of -20 dBm, -40 dBm, -60 dBm, -80 dBm, and -100 dBm. In particular, the -20 dBm input signal power for the 1.014 THz *f*IN has a longest startup time, with improved startup times occurring as the input signal power becomes more negative.

Figure 3B shows a simulated plot of the converted pulse train for the example CMOS implementation. As can be seen from the plot in Figure 3B of the envelope output, the pulse width decreases as the input signal power becomes more negative (i.e., pulse width increases with input power).

Figure 3C shows a simulated plot of output pulse width versus input powers of -20 dBm, -40 dBm, -60 dBm, -80 dBm, and -100 dBm at input frequencies of 195 GHz, 429 GHz, 624 GHz, 819 GHz, and 1.014 THz in an offset generative receiver according to an embodiment of the invention. These input frequencies can be considered the local regenerative frequencies (e.g., *f*OSC).

Figure 3D shows a simulated plot of normalized gain at input frequencies of 195 GHz, 429 GHz, 624 GHz, 819 GHz, and 1.014 THz in an offset generative receiver according to an embodiment of the invention. Referring to Figure 3D the normalized gains for the simulated offset generative amplifier oscillation duty cycle verses input power curves at different frequency indexes are shown. The normalized regenerative receiver gain is about 1 (for the 195 GHz input frequency). As the input frequency increases beyond the device

*f*MAX (of about 240 GHz), the offset generative response works to maintain a functional gain.

The results show that the offset generative gain decreases by a small amount versus *f*IN when *f*IN is higher than device *f*MAX (about 240 GHz), but with a larger gap to the fundamental frequency regenerative operation. It is because the front offset demodulator gain does not drop much by increasing *f*IN when it is higher than device *f*MAX. Compared with harmonic mixing, this method provides higher gain profile due to direct demodulation and avoids or minimizes undesired harmonic interferences. Moreover, a high gain regenerative amplifier not only amplifies the signal with negligible flicker noise effect, but also serves as a sharp filter to remove out-of-band interferences.

According to one embodiment, by using the two stage technique illustrated in Figures 1A and 1B, an efficient design for both power and area can be accomplished while enabling higher than device cutoff frequency operations.

Any reference in this specification to "one embodiment," "an embodiment," "example embodiment," etc., means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the invention. The appearances of such phrases in various places in the specification are not necessarily all referring to the same embodiment. In addition, any elements or limitations of any invention or embodiment thereof disclosed herein can be combined with any and/or all other elements or limitations (individually or in any combination) or any other invention or embodiment thereof disclosed herein, and all such combinations are contemplated with the scope of the invention without limitation thereto.

It should be understood that the examples and embodiments described herein are for illustrative purposes only and that various modifications or changes in light thereof will be suggested to persons skilled in the art and are to be included within the spirit and purview of this application.

CLAIMS

What is claimed is:

1. An offset generative receiver, comprising:

an offset demodulator for receiving an input signal from an antenna, mixing the input signal with a local oscillator frequency, and outputting an offset demodulated signal;

an amplifier for receiving the offset demodulated signal and amplifying the offset demodulated signal according to a quench signal; and

a power detector for receiving the offset demodulated signal at an output of the amplifier and outputting a demodulated signal.

2. The offset generative receiver according to claim 1, wherein the local oscillator frequency is greater than the maximum oscillation frequency of a system having the offset generative receiver.

3. The offset generative receiver according to claim 1, wherein the offset demodulator comprises a down-conversion mixer, wherein the local oscillator frequency is higher than a device cutoff frequency of the down-conversion mixer.

4. An imaging system comprising the offset generative receiver according to any of claims 1-3.

5. A sensing system comprising the offset generative receiver according to any of claims 1-3.

6. A communications system comprising the offset generative receiver according to any of claims 1-3.

7. An offset regenerative receiver, comprising:

an offset demodulator receiving for receiving an input signal (fin) and mixing the input signal (fin) with a local oscillator frequency signal (flo) to output an offset oscillating frequency signal (fosc); and

a regenerative amplifier and envelope detector receiving the offset oscillating frequency signal (fosc) to output a demodulated baseband signal.

8. The offset generative receiver according to claim 7, wherein the local oscillator frequency signal (flo) is at a frequency greater than a maximum oscillation frequency of a system having the offset generative receiver.

9. The offset generative receiver according to claim 8, wherein the offset demodulator comprises a down-conversion mixer, wherein the frequency of the local oscillator frequency signal is higher than a device cutoff frequency of the down-conversion mixer.

10. An imaging system comprising the offset generative receiver according to any of claims 7-9.

11. A sensing system comprising the offset generative receiver according to any of claims 7-9.

12. A communications system comprising the offset generative receiver according to any of claims 7-9.

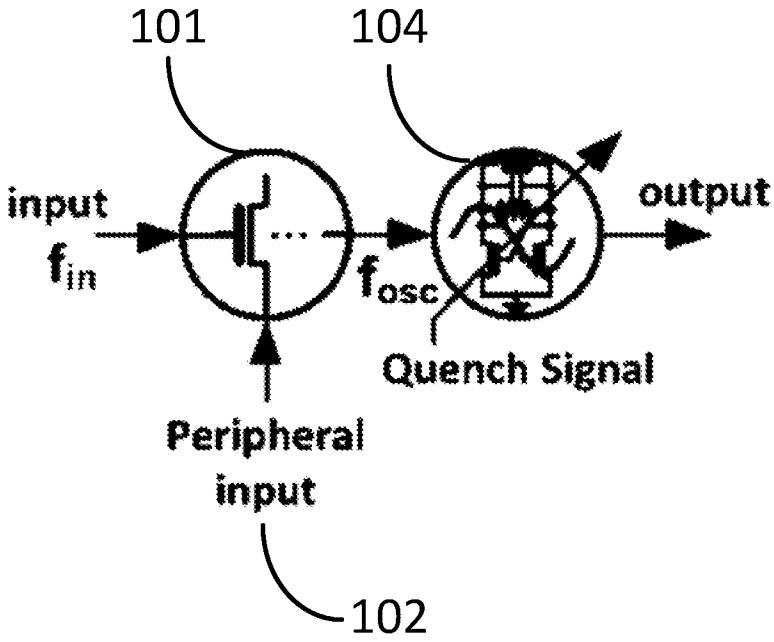

101
104
input
f_{in}
f_{osc}
output
Quench Signal
Peripheral
input
102

FIG. 1A

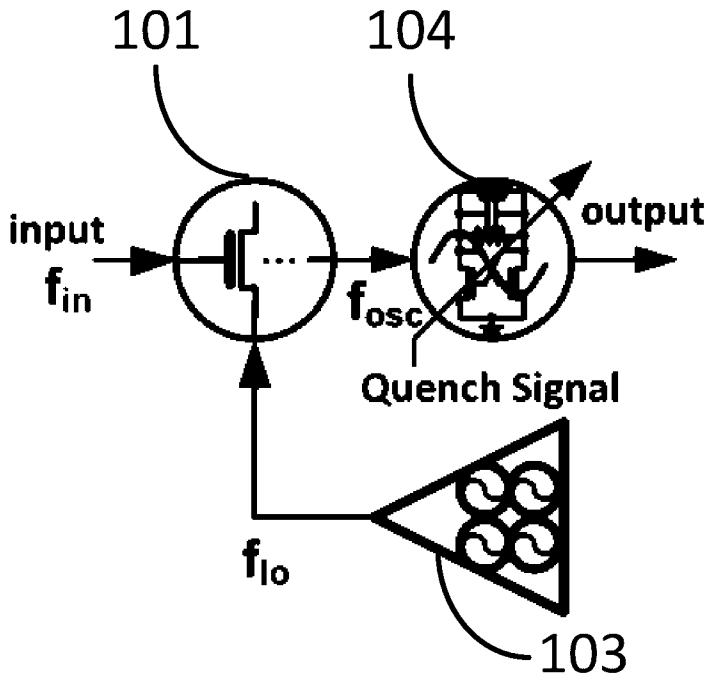

101
104
input
f_{in}
f_{osc}
output
Quench Signal
f_{lo}
103

FIG. 1B

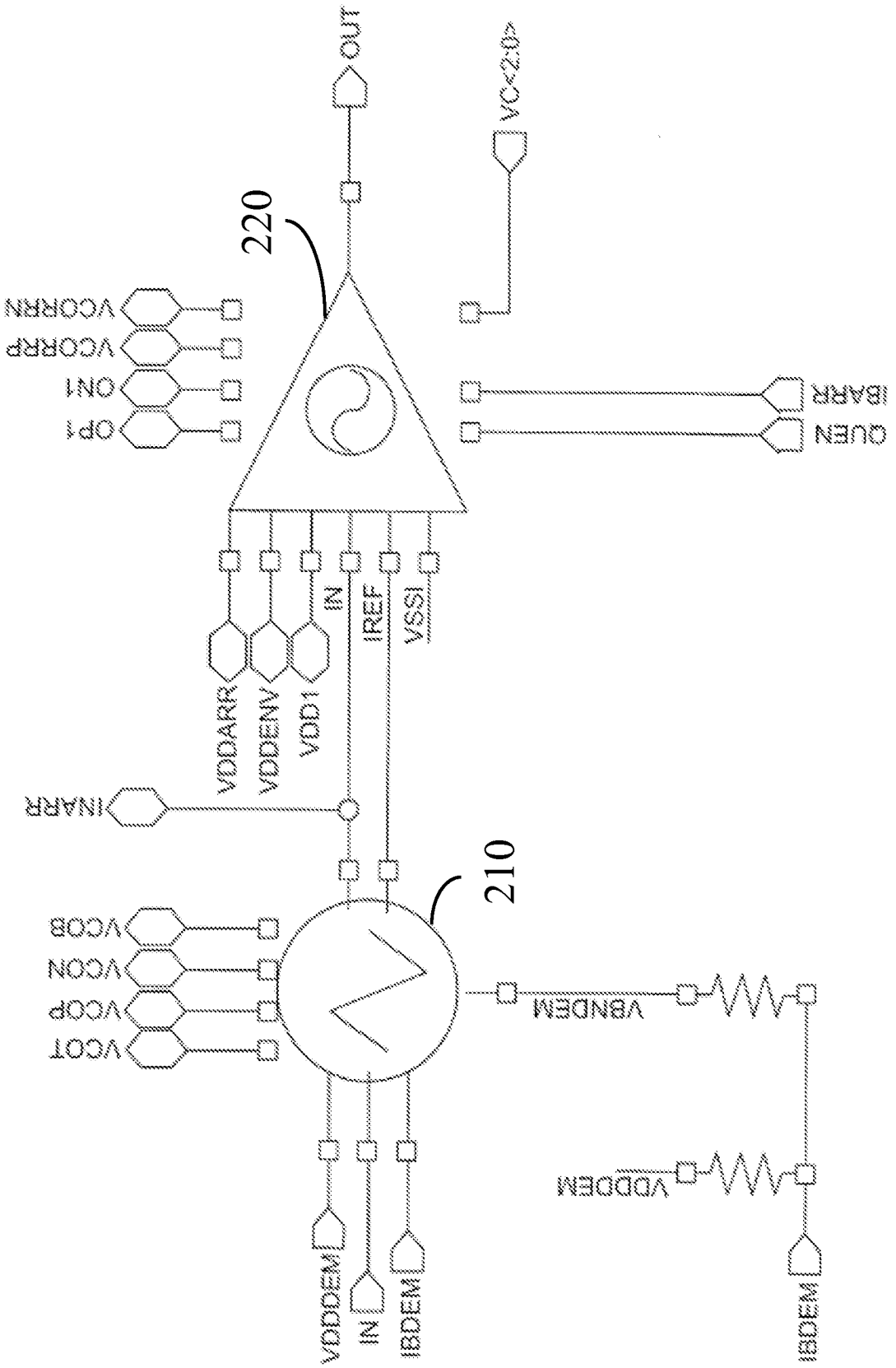

OUT
VC<2:0>
220
VCORRN
VCORRP
ON1
OP1
IBARR
QUEN
VDDARR
VDDEMV
VDD1
IN
IREF
VSSI
INARR
210
VCOB
VCON
VCOP
VCOT
VBNDEM
VDDDEM
VDDDEM
IN
IBDEM
IBDEM

FIG. 2

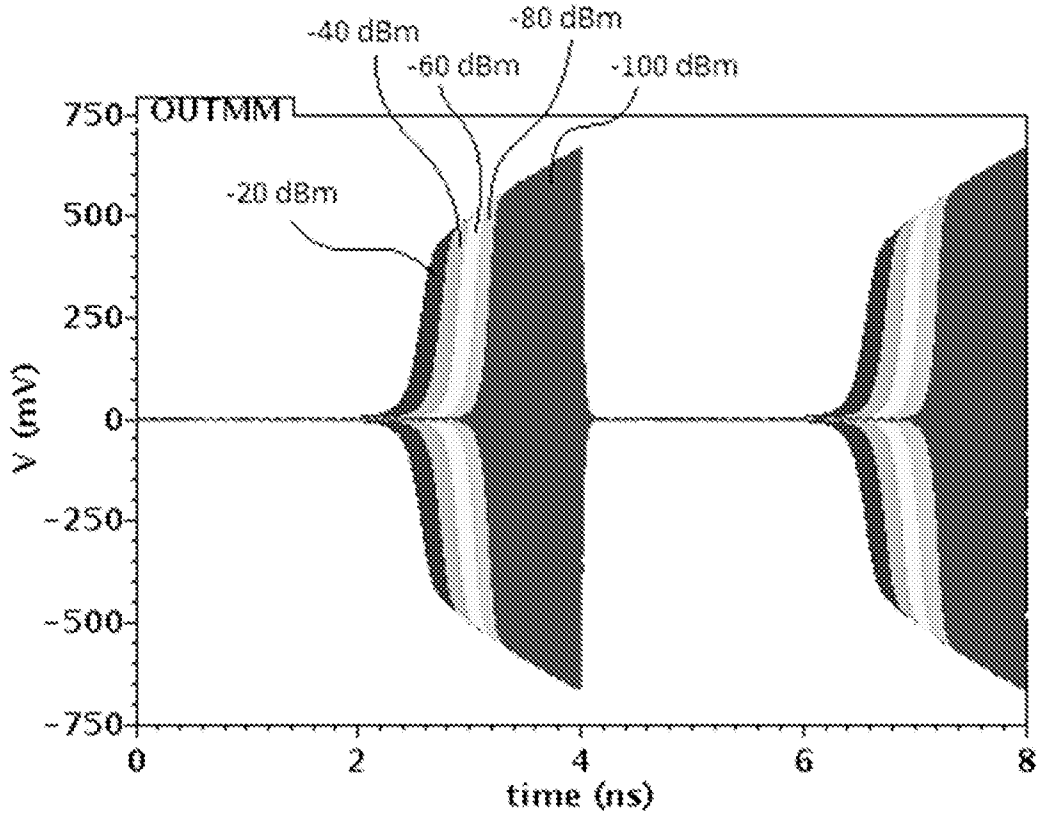

-40 dBm
-80 dBm
-60 dBm
-100 dBm
OUTMM
-20 dBm
750
500
250
0
-250
-500
-750
V (mV)
0
2
4
6
8
time (ns)

FIG. 3A

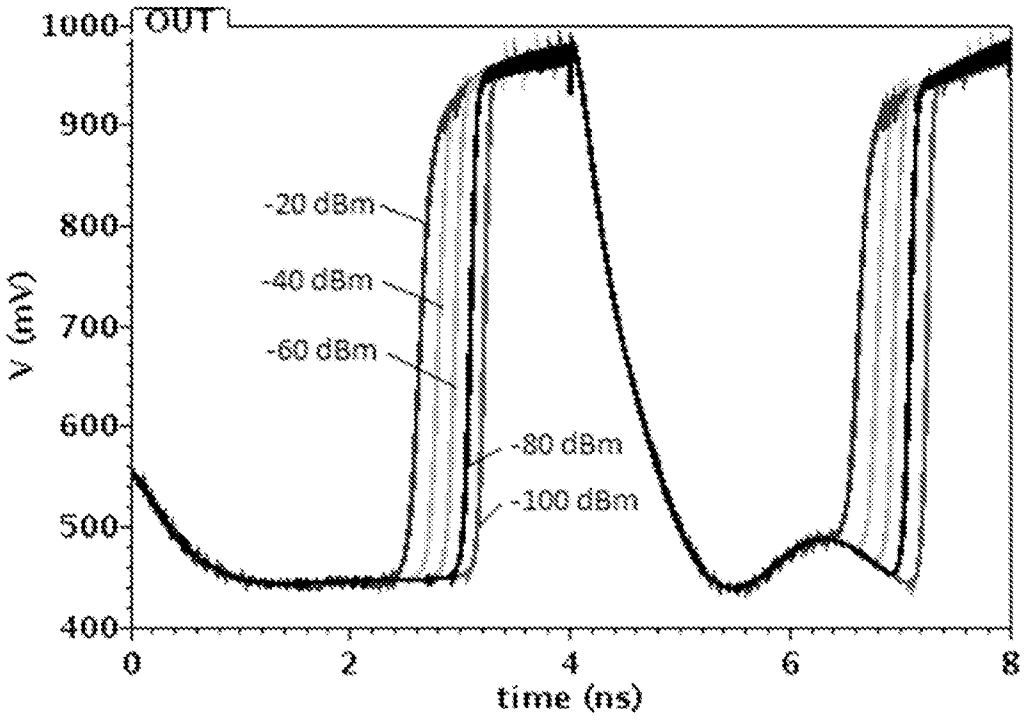

OUT
1000
900
800
700
600
500
400
V (mV)
-20 dBm
-40 dBm
-60 dBm
-80 dBm
-100 dBm
0
2
4
6
8
time (ns)

FIG. 3B

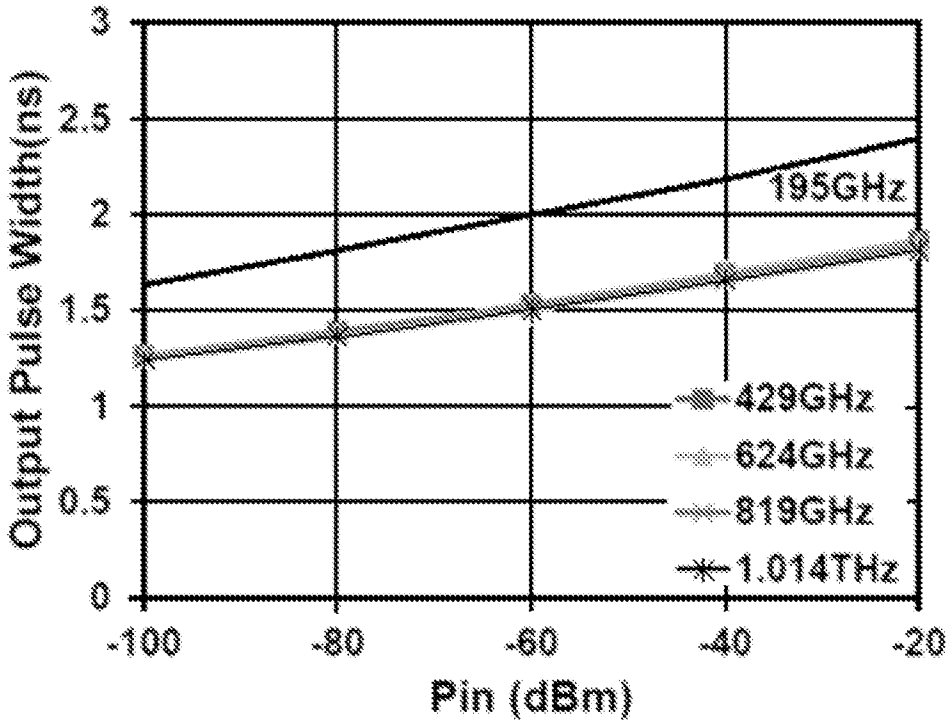

Output Pulse Width(ns)
3
2.5
2
1.5
1
0.5
0
-100
-80
-60
-40
-20
Pin (dBm)
195GHz
429GHz
624GHz
819GHz
1.014THz

FIG. 3C

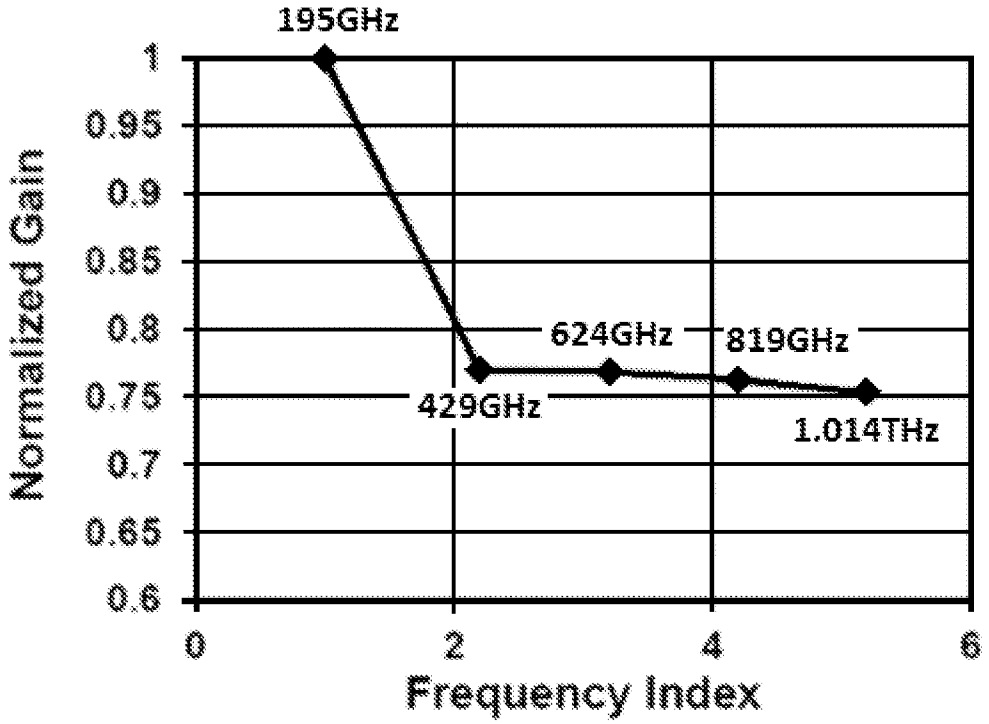

Normalized Gain
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0
2
4
6
Frequency Index
195GHz
624GHz
819GHz
429GHz
1.014THz

FIG. 3D

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2012/064749

A. CLASSIFICATION OF SUBJECT MATTER

H04B 1/16(2006.01)i, H04L 27/00(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04B 1/16; G01S 13/76; H03D 7/16; G08B 1/08; H04L 27/06; H04B 1/06; H04B 1/26; G01S 7/28; H04Q 5/22; H04L 27/00

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

Korean utility models and applications for utility models
Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & keywords: offset oscillating frequency, demodulation, local oscillator, receiver

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	US 2005-0258999 A1 (ALAN PETER JENKINS et al.) 24 November 2005 See paragraphs [0005]-[0008],[0013],[0014] and figure 3.	1-12
A	US 2006-0066444 A1 (WAYNE E. STEEVES) 30 March 2006 See paragraphs [0070],[0071],[0074] and figure 4.	1-12
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A	US 2005-0107062 A1 (HIROSHI MIYAGI) 19 May 2005 See paragraphs [0021]-[0024] and figure 1.	1-12

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

☒ See patent family annex.

* Special categories of cited documents:

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 MARCH 2013 (22.03.2013)	**25 MARCH 2013 (25.03.2013)**

Name and mailing address of the ISA/KR

Facsimile No. 82-42-472-7140

Authorized officer

KIM, Byoung Sung

Telephone No. 82-42-481-8403

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/US2012/064749

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