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Single Commercially Available IC: LT1228 Based Sinusoidal Oscillator

***Abstract**. A sinusoidal oscillator using a single commercially available IC with gain control of the oscillation frequency is proposed in this paper. The proposed sinusoidal oscillator has a single commercially available IC, three resistors and two grounded capacitors. The LT1228, available from Linear Technology Corporation, has been used in this circuit. The oscillation condition is configured by the transconductance gain and the values of the resistors. Also, the oscillation frequency is freely adjusted by the gain of a voltage amplifier without affecting the oscillation condition. The theoretical analysis is verified by the satisfactory experimental results.*

Streszczenie.** Opisano gnerator z możliwością strojenia wykorzystujący proste dostępne na rynku ikłady scalone. Układ składa się z trzech oporników, dwóch kondensatorów I układu LT1228. Warunki generacji są kontriolowane za pośrednictwem wzmocniania transkonduktancyjnego. **Prosty obwódgeneratora sinuspoidalnego bazujący na układzie LT1228

Keywords: LT1228, Sinusoidal Oscillator, Gain control.
Słowa kluczowe:generator sinusoidalny, układ scalony LT1228.

Introduction

The sinusoidal oscillator is extremely useful in communication systems, electronic power systems, and instrumentation/measurement systems [1-3]. Furthermore, a sinusoidal signal is a key part of training students in the laboratory [3-5] to become skilled electrical and electronic engineering.

Today, sinusoidal oscillators are frequently used in research and a large number of results have now been published [1-22]. They employ different high performance active building blocks and exhibit several advantages such as: their condition and frequency of oscillation can be orthogonally or independently adjusted with the transconductance gains [3-9, 15-17, 20-22] or the parasitic resistances [2-4, 13, 16, 18] or voltage gains [1, 10, 12, 14]. The sinusoidal signal provides only voltage-mode [1-2, 7, 10-14, 19-20] or current-mode [3, 6, 8-9, 15, 18, 22]. Also, some circuits provide voltage and current-mode simultaneously [4-5, 16-17]. However, there are some drawbacks as it has been found that (i) there are many active devices [10-11, 13-14, 18-19] (ii) there are requirements for an extension or copy terminal of active devices [3-4, 7, 9, 15, 17] (iii) the use of floating capacitors may cause parasitic effects [8, 19, 21] (iv) the output-impedance of voltage signal does not have low-impedance which is required for a voltage buffer [2, 5, 7, 10, 13-14, 17] (v) the active devices in [2, 4-5, 9, 11, 13-16, 18-20, 22] are not commercially available with IC, (vi) the results of oscillator circuits in [2, 4-5, 9, 11, 13-16, 18-20, 22] are only presented by computer simulation without an experimental implementation. A comparison of the proposed sinusoidal oscillator and recent research is shown in Table 1.

This paper proposes a synthesis of the voltage-mode sinusoidal oscillator with gain control of the oscillation frequency. The proposed sinusoidal circuit enjoys several advantages such as (i) construction of a circuit is very simple employing a single active device with commercially available IC (ii) use of grounded capacitors (iii) low-impedances of output voltage signal (iv) availability of adjustment of the oscillation frequency and (v) low sensitivity of active and passive devices.

Table 1 A comparison of the proposed sinusoidal circuit and recent research

Ref.	Active element	No. of Active elements	Technology	No. of C+R	Extension ports/terminals	Non-effect control of frequency and condition of oscillation	Low output-impedance
1	DVB+VGA+ECCII	4	Discrete	2+2	No	Yes	No
2	CCCDBA	2	CMOS	2+1	No	Yes	Yes
5	VDTA	2	CMOS	2+0	No	Yes	No
7	MO-CCCCTA	2	CMOS/ Discrete	2+0	Yes	Yes	No
10	ECCII	4	Discrete	2+2	Yes	Yes	No
11	DVCC	4	CMOS	2+4	No	Yes	No
12	CG-CFBA+ CG-CIBA	2	Discrete	2+3	No	Yes	Yes
13	CCCII	4	CMOS	3+1	Yes	Yes	No
14	CCII	3	CMOS	2+2	No	Yes	No
16	CCCTA	1	Bi-CMOS	2+0	Yes	Yes	No
19	OTRA	3	CMOS	3+4	No	Yes	Yes
20	BDTA	1	Discrete	3+2	No	Yes	Yes
Prop.	LT1228	1	Discrete	2+3	No	Yes	Yes

The proposed sinusoidal oscillator

The proposed sinusoidal oscillator can be explained in terms of the characteristics of LT1228, the details of the proposed circuit, a sensitivity analysis and a non-ideal analysis.

The characteristics of LT1228

LT1228 is produced by Linear Technology Corporation [23]. It includes an operational transconductance amplifier (OTA) and a current feedback amplifier (CFA) in an 8-pin package. The details of LT1228 are shown in Fig. 1. The V_{+}, and V_{-} terminals (Pins 2 and 3) have different input voltages which have high-impedances. The *z* terminal (Pin 1) is the output current that also has a high-impedance. In addition, the *x* and *w* terminals (Pins 5 and 7) are the output voltage which have a low-impedance and can be directed to drive load or to connect with the next stage. The electrical characteristics of LT1228 can be represented by the following mathematical function:

$$\begin{vmatrix} I_{V+} \\ I_{V-} \\ I_z \\ V_x \\ V_w \end{vmatrix} = \begin{vmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ g_m & -g_m & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & R_T & 0 \end{vmatrix} \begin{vmatrix} V_+ \\ V_- \\ V_z \\ I_x \\ I_w \end{vmatrix}, \tag{1}$$

when R_T is the transresistance gain that has very high values for typically standard or infinite value for ideal. g_m is transconductance gain that is set/adjusted by the external DC bias current into Pin 5 (I_{SET}). It can be seen that g_m is directly adjusted with an external DC bias current as follows:

$$g_m = 10 I_{SET}\,. \tag{2}$$

Proposed sinusoidal oscillator

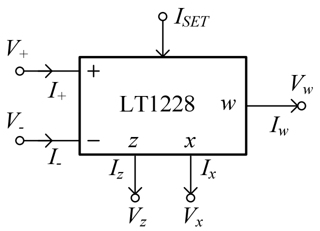
The proposed oscillator in Fig. 2 is implemented by a single LT1228, two grounded capacitors and three resistors. It is convenient and appropriate to use this oscillator as it is an off-the-shelf design. The characteristic equation of circuit can be analyzed in the following equation as:

$$R_1C_1C_2s^2 + \left(C_2 - C_1R_1g_m\right)s + g_m(B-1) = 0\,, \tag{3}$$

where the sinusoidal circuit is ready to generate the sinusoidal signal when it is set

$$C_2 \approx C_1R_1g_m\,. \tag{4}$$

a)



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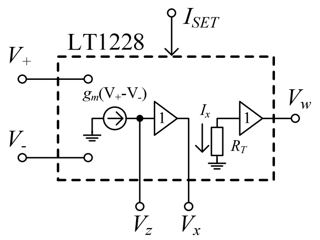


c)

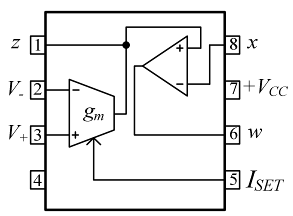


Fig.1. Detail of LT1228 (a) electrical symbol (b) equivalent circuit (c) pin configuration

This is also known as the oscillation condition. It can evidently be configured by the transconductance gain g_m and the value of resistor R_1. The oscillation frequency of the proposed oscillator will be expressed as

$$\omega_{osc} = \sqrt{\frac{g_m\left(B-1\right)}{R_1C_1C_2}}\,. \tag{5}$$

The oscillation frequency can be adjusted by the voltage gain *B*. This gain can easily be configured by adjusting the values of resistors R_{f1} and R_{f1} or both. It can also be expressed as $B = 1 + R_{f1}/R_{f2}$. Therefore, this oscillator circuit can be appropriately used for practice in the electronic/electrical engineering laboratory. Furthermore, the output sinusoidal signal can be simply used for connecting to the load because this terminal has a low-impedance.

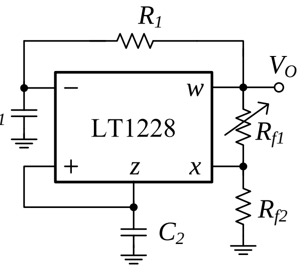


Fig.2. Proposed sinusoidal oscillator

The sensitivity analysis

The sensitivity analysis is used for explaining the performance criteria of the oscillator circuits. The active and passive values can be used to show the relation between the sensitivities of the oscillation frequency and the deviation that is

$$S_{R_1}^{\omega_{osc}} = -\frac{1}{2}, S_{C_1}^{\omega_{osc}} = -\frac{1}{2}, S_{C_2}^{\omega_{osc}} = -\frac{1}{2} \text{ and } S_{g_m}^{\omega_{osc}} = \frac{1}{2}, \tag{6}$$

From (6) it is clear that the sensitivities are low since the absolute values of the sensitivities are less than unity.

Non-ideal Analysis

Practically, LT1228 has parasitic elements at all terminals/pins. They are resistors and capacitors connected to ground at high-impedance terminals V_+, V_- and *z* terminals. These parasitic elements can be defined as R_+, C_+, R_-, C_-, R_z and C_z, respectively. x and w terminals appear in the series resistors R_x and R_w, respectively, since these terminals have low-impedance. The transresistance gain R_T is paralleled by C_T. These parasitic elements have an effect on the performance of the proposed oscillator. In this case, if the operation frequency (f_{op}) is determined as $f_{op} << 1/R_TC_T$, the equation for the characteristics of the proposed oscillator becomes:

$$\begin{gathered} C_1^{'}C_2^{'}s^2 + \left(G_1C_2^{'} + G_{\_}C_2^{'} + G_2C_1^{'} - g_mC_1^{'}\right)s + \\ G_1G_2 + G_{\_}G_2 + g_m(G_1B - G_1 - G_{\_}) = 0 \end{gathered}. \tag{7}$$

From (7) the oscillation condition becomes

$$G_1C_2^{'} + G_{\_}C_2^{'} + G_2C_1^{'} \approx g_mC_1^{'}\,. \tag{8}$$

The oscillation frequency is modified to

$$\omega_{osc} = \sqrt{\frac{G_1G_2 + G_{\_}G_2 + g_m(G_1B - G_1 - G_{\_})}{C_1^{'}C_2^{'}}}\,. \tag{9}$$

Where, $C_1^{'} = C_1 + C_{\_}$, $C_2^{'} = C_2 + C_z + C_+$, $G_{\_} = 1/R_{\_}$, $G_+ = 1/R_+$, $G_z = 1/R_z$, $G_1 = 1/R_1$ $G_2 = G_z + G_+$, $B = \dfrac{G_w + G_{Rf1} + G_{Rf2}}{G_wG_{Rf1}}$, $G_w = 1/R_w$, $G_{Rf1} = 1/R_{f1}$ and $G_{Rf2} = 1/R_{f2}$.

Thus, it can be seen that the parasitic elements of LT1228 have been degraded to the performances of the proposed sinusoidal oscillator.

Fig.3. The prototype circuit board

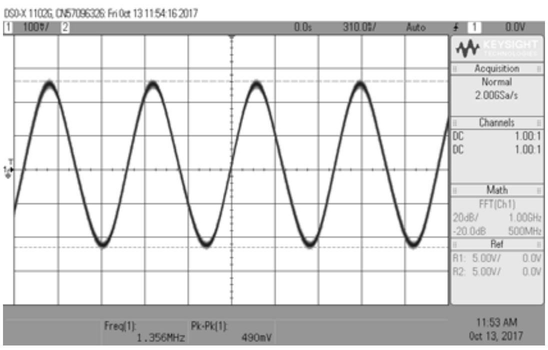
Table 2 The parasitic elements of LT1228 [23]

	TYP	UNITS
Transconductance amplifier (OTA)		
Input resistance (V+, V-) Input capacitances (V+, V-) Output resistance (z) Output capacitances* (z)	1000 3 8 6	MΩ pF MΩ pF
Current feedback amplifier (CFA)		
Input resistance (z) Input capacitances* (z)	25 6	MΩ pF
* This includes the input capacitance of the CFA and the output capacitance of the OTA		

Experimental results

The proposed sinusoidal oscillator was used for the prototype circuit board as shown in Fig. 3. The LT1228 was set at a supply voltage of $\pm 5V$. The passive elements of the proposed oscillator are C_1 = C_2 = 100pF. The proposed oscillator generates a sinusoidal signal by setting up the condition of oscillation with a DC bias current $I_{SET} = 100\mu A$ and the values of resistor R_1 = $1k\Omega$. The resistors R_{f1} and R_{f2} are simultaneously configured as 470Ω for the gain B of 2. From the above passive elements and bias current, the oscillation frequency can be calculated as a sinusoidal signal with 1.59MHz. The sinusoidal waveform is displayed on an oscilloscope model DX1102G of Keysight Technologies in Fig. 4 (a) that shows the steady-state response of the sinusoidal output signal at a frequency of 1.35MHz. The signal analyzer CSX N9000A from Agilent Technologies is convenient to use to examine the frequency spectrum and harmonics of the output signal. They are illustrated together in Fig. 4 (b). The harmonics of the output signal are used to calculate the %THD which is about 2.37%. It can be seen that the theoretical and experimental oscillation frequency has an error of about 15.0%. The error may be caused by the parasitic elements of LT1228 that are described in last section. These parasitic elements are known as resistors and capacitors at the terminals of LT1228 that are also summarized in Table 2. Furthermore, the passive elements of the prototype circuit board have some tolerance errors. The tolerance errors are about 20% for the both of the passive capacitors and 3% for the three of the passive resistors. However, the error of frequency can easily be compensated for by adjusting the gain B.

a)



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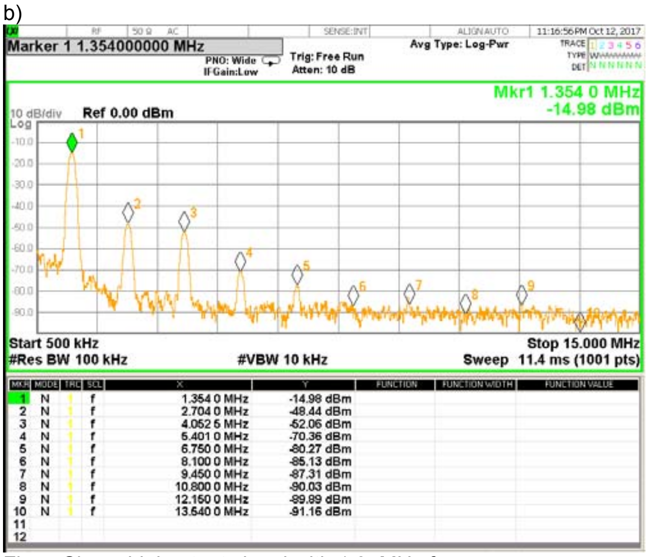


Fig.4. Sinusoidal output signal with 1.35MHz frequency
(a) sinusoidal waveform (b) frequency spectrum and harmonics

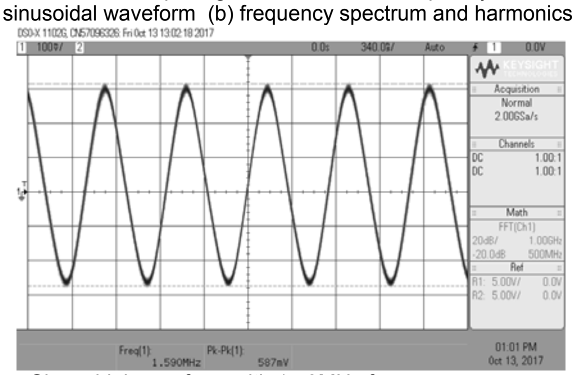


Fig.5. Sinusoidal waveform with 1.59MHz frequency

The experiment in Fig. 5 shows that when the gain B is slightly adjusted to 2.52, the oscillation frequency is archived with 1.59MHz frequency. The adjustment of gain B for varying the oscillation frequency is demonstrated by changing the gain B from 2 to 5.25 when the resistor R_{f1} is adjusted from 470Ω to $2k\Omega$ and remains at $R_{f2} = 470\Omega$. The results of the frequency of oscillation vary from 1.35MHz to 2.01MHz. These experimental results can be plotted to show the relative oscillation frequency and the gain B as shown in Fig. 6. This confirms that the frequency of oscillation can be adjusted without affecting the oscillation condition. Moreover the oscillation frequency is proportional to the gain B.

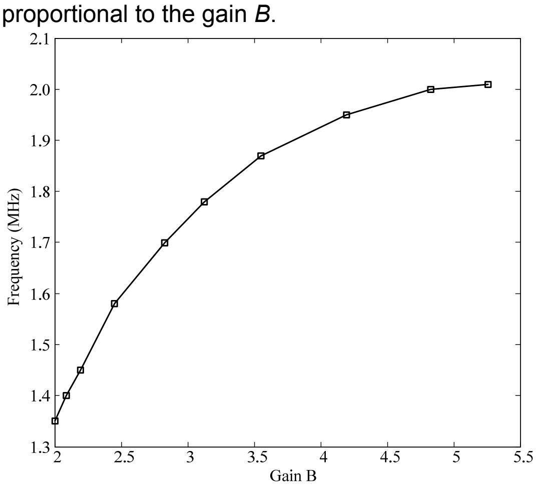
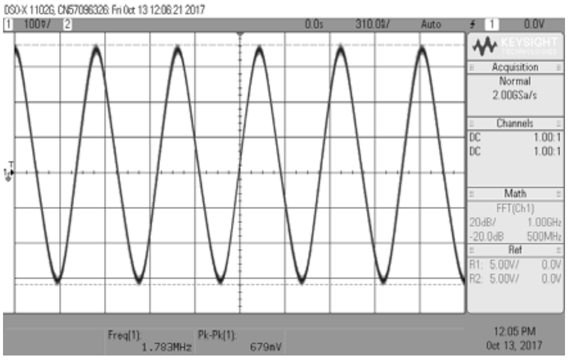


Fig.6. Oscillation Frequency when varying gain B

The example of the sinusoidal signals in Figs. 7 and 8 are show the sinusoidal waveform, the frequency spectrum and the harmonics when gain B is set to 3.12 and 5.25, respectively. The oscillation frequency is 1.78MHz and 2.01MHz, respectively.

a)



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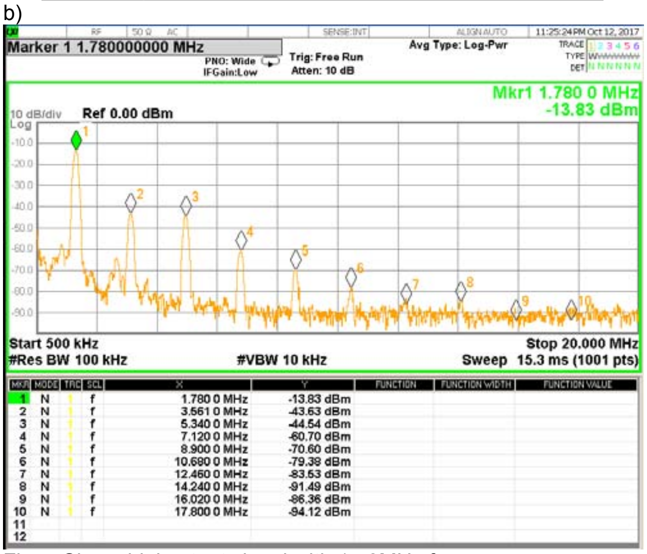
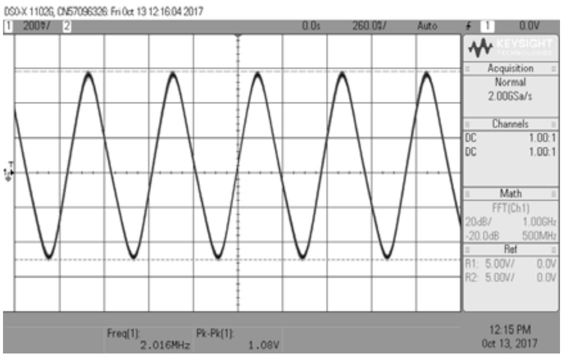


Fig.7. Sinusoidal output signal with 1.78MHz frequency
(a) sinusoidal waveform (b) frequency spectrum and harmonics

In addition, the oscillation frequency can be adjusted by changing the values of capacitors C_1 and C_2 that simultaneously change to 47pF and kept to be gain B of 3.12. It was found that the oscillation frequency varies directly to 2.91MHz. The sinusoidal waveform, the frequency spectrum and the harmonics are shown in Fig. 9, respectively. Clearly, these experimetal results conform to the theoretical analysis in (5). The proposed sinusoidal oscillator is also suitable for practice in the electronics/electrical laboratory since the IC is also commercially available and can easily be adjusted to the oscillation frequency by varying the gain B.

a)



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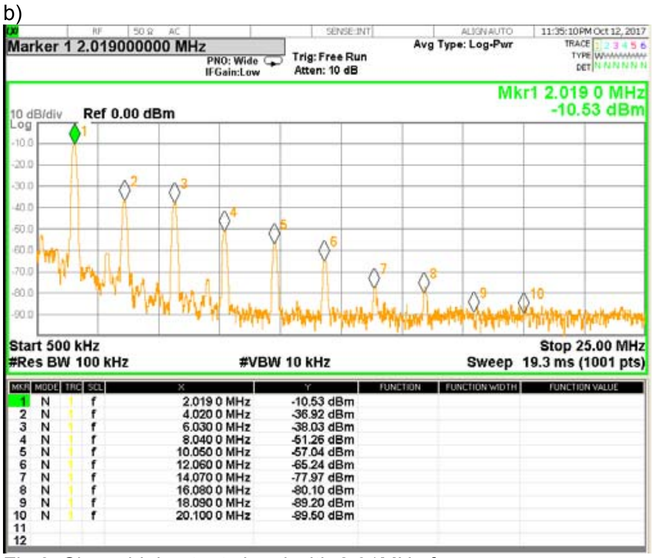
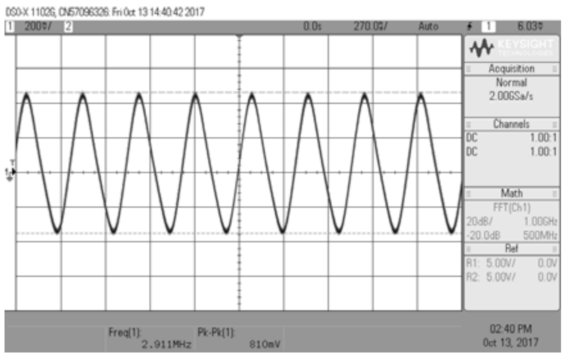


Fig.8. Sinusoidal output signal with 2.01MHz frequency
(a) sinusoidal waveform (b) frequency spectrum and harmonics

a)



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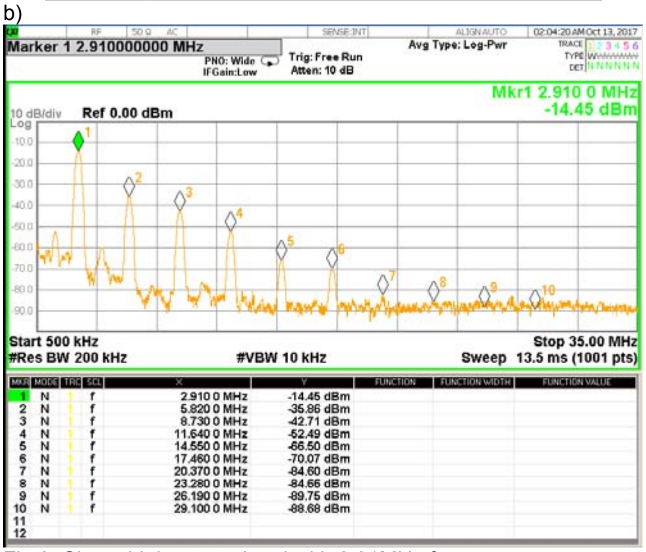

Fig.9. Sinusoidal output signal with 2.91MHz frequency
(a) sinusoidal waveform (b) frequency spectrum and harmonics

Conclusion

The sinusoidal oscillator presented in this paper is an LT1228 from Linear Technology Corporation. The proposed sinusoidal oscillator is constructed of a single LT1228, three resistors and two grounded capacitors. In addition, the oscillation frequency can be freely adjusted by the gain B without affecting the oscillation condition. The voltage of the sinusoidal output has a low output-impedance terminal and can be suitably connected for loading without a voltage buffer or impedance matching. The experiment is simple and low cost as well as convenient to use as it is an off-the-shelf design. The experimental results show that the proposed sinusoidal oscillator is useful for practice in the laboratory for the training of electronic and electrical engineers.

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