FOREX Publication
Open Access | Rapid and quality publishing

International Journal of Electrical and Electronics Research (IJEER)
Research Article | Volume 12, Issue 3 | Pages 727-733 | e-ISSN: 2347-470X

Design Wien Bridge Oscillator for VLF to VHF Using Practical Op – Amp

Hanan Badeea Ahmed[1], Adham Hadi Saleh[2*], Khalid Awaad Humood[3] and Tahreer Mahmood[4*]

[1]*Department of Electronic Engineering, College of Engineering, University of Diyala, Iraq; hananbadeea79@uodiyala.edu.iq*
[2] *Department of Electronic Engineering, College of Engineering, University of Diyala, Iraq; adham.hadi@yahoo.com*
[3]*Department of Medical Instruments Engineering Techniques, Bilad Alrafidain University College, 32001 Diyala, Iraq; humoodkhalid@gmail.com*
[4]*Department of Electronic Engineering, College of Engineering, University of Diyala, Iraq; tahreer_mahmood_eng@uodiyala.edu.iq*

***Correspondence:** Adham Hadi Saleh; *adham.hadi@yahoo.com*

ABSTRACT- An electronic oscillator is generally a major part of electrical, electronic and communications circuits and systems and it is can be divided into linear and nonlinear families. Wien Bridge is a type of RC phase shift oscillators mostly used for around 1MHz and its design adopts positive feedback technology. In this research, novel look the reasons for the inability to achieve high frequencies was understanding and the ambiguity was removing from the determinants of obtaining a high frequency signal for this type of oscillators, also, new results were obtained with a unique presentation. The output formula for the oscillation resonant frequency was deriving based on the oscillator's theory. The design has beaning successfully achieved by using a practical high-performance op-amp and from the simulation results the frequency bandwidth was 50.7211 MHZ from,VLF (9.83 HZ) to VHF (50.73 MHZ) and. These unique and interesting scientific findings were encouraging.

Keywords: RC, Wien Bridge Oscillator, LF-MF-VHF, OP-AMP.

ARTICLE INFORMATION

Author(s): Hanan Badeea Ahmed, Adham Hadi Saleh, Khalid Awaad Humood and Tahreer Mahmood;

Received: 30/04/2024; **Accepted**: 20/06/2024; **Published**: 20/07/2024;
e-ISSN: 2347-470X;
Paper Id: IJEER 3004-37;
Citation: 10.37391/ijeer.120301
Webpage-link:
https://ijeer.forexjournal.co.in/archive/volume-12/ijeer-120301.html

crossref member CROSSREF.ORG THE CITATION LINKING BACKBONE

Publisher's Note: FOREX Publication stays neutral with regard to Jurisdictional claims in Published maps and institutional affiliations.

1. INTRODUCTION

It is one of basic types of oscillators, which produce sinusoidal signal. Max Wien was accomplishing its basic idea as four arms electrical balance bridge in 1891 for calculating and gauging impedances [1]. It is construct from one operational amplifier and two groups of resistors and capacitors in a way that looks like both types of feedback (FB), *-ve* FB used to get voltage amplification and keep its constant level and the *+ve* FB is connected through RC passive BPF to get desired output oscillation resonance frequency [2-5]. In general, RC phase shift oscillator is used to generate signals typically used for frequencies nearly or equal to about 1 MHz as traditional Wien bridge oscillator. In comparison of 30 years ago [6-9] and recent years with the advent of new high performance of operational amplifier, manufacturers of operational amplifier made it suitable for high frequency applications. This new technology, with modern high-speed op-amp led to introduce high frequency generators based on Wien bridge oscillation theory. These oscillators have butter characteristic such as an improved bandwidth and stability, controlling input and output impedance, decreasing noise and distortion.

The problematic statement in the Wien bridge oscillator design is that in the Wien Bridge oscillator design is that mostly a lot of text books such as [10-20] , also many present journals such as [21-26] state that there is limits of resonance frequency of output signal of Wien bridge oscillator is that these frequency not exceed one megahertz . These and many other references do not clearly mention what these limitations are and how it is can be resolved theoretically or practically.

Successful solutions to the above-mentioned problem were giving in the following sections of this paper.

Which state that the advent of high performance Op-amp & using it as forward open loop for different positive feedback configuration circuit has make the new generation of Wien bridge oscillator, are capable to introduce output signal with high performance characteristic for very low to very high frequency.

2. METHODOLOGY AND MATHEMATICAL MODEL

In this, a Wien bridge oscillator is designing, firstly using theoretical information technology as shown in *figure 1*. It includes a high-performance operational amplifier and an RC positive feedback circuit in the closed loop as shown in *figure 2*. In this work, the used op-amp is non-inverting. In order to get a Phase difference of zero degree and a forward gain mostly a little more than one to satisfy Barkhausen's condition. for the initiation of oscillations in the circuit [27-29]. Secondly, the

International Journal of
Electrical and Electronics Research (IJEER)
Research Article | Volume 12, Issue 3 | Pages 727-733 | e-ISSN: 2347-470X

above design was implemented using simulation software (Multisim12).

After applying the electrical circuit theories to the proposed design circuit shown in *figure 1*, *Zp* and *Zs* were calculating as in *equations 1, 2* respectively

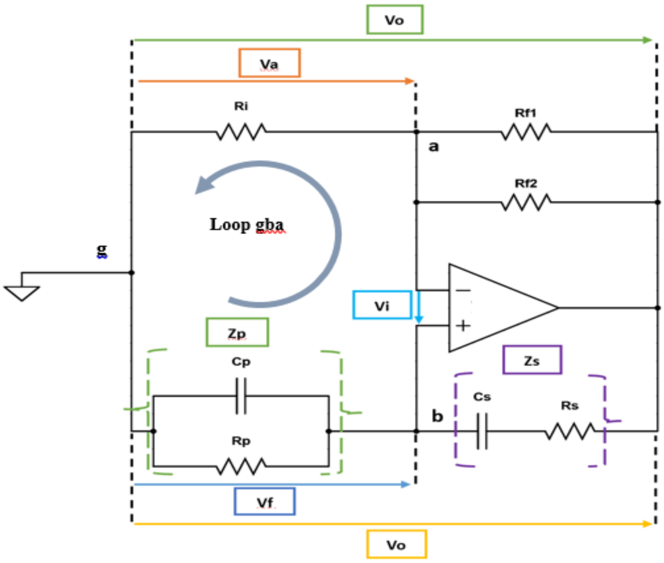


Figure 1. Suggested circuit design scheme

$$Zp = \frac{Rp}{1 + jwCpRp} \tag{1}$$

$$Zs = Rs + \frac{1}{jwCs} \tag{2}$$

$$Vf = \frac{Vo}{Zs + Zp} * Zp \tag{3}$$

$$Va = \frac{Vo}{Rf + Ri} * Ri \tag{4}$$

By applying KVL on the closed loop *gba* of circuit, diagram of *figure1*

$$Vf - Vi - Va = 0 \tag{5}$$

Depending on the c/s of ideal op-amp and oscillation theory. The voltage Vi can be taken a zero value so that;

$$Vf - Va = 0$$

Substitute the values of V_f & V_a from *equations (3) & (4)* into *equation (5)* getting that:

$$\frac{Rs}{(Rs+Rp) + \frac{CpRp}{Cp} + j(wCpRsRp - \frac{1}{wCs})} = \frac{Ri}{Rf + Ri} \tag{6}$$

From these above equations of the proposal design, the circuit works at oscillation frequency satisfies the Barkhausen condition, which state that $|AB| = 1$, and $\angle AB = 0$. (Unity loop & zero phase shift degree) [28-34]. To derive the maximum output frequency signal which is called resonant frequency that happen at resonance the imaginary part of *equation (6)* above equal to zero, therefore:

$$wCpRsRp = \frac{1}{wCs}, \quad w^2 = \frac{1}{RsRpCsCp}, \quad fr = \frac{1}{2\pi\sqrt{RsRpCsCp}} \tag{7}$$

Also, *equation (6)* after taken imaginary part at zero & Rs= Rp=R & Cs=Cp =C, *equation (6)* become as follows

$$\frac{Rp}{Rs + Rp + \frac{CpRs}{Cs}} = \frac{Ri}{Rf + Ri}$$

$$\frac{R}{R + R + R} = \frac{Ri}{Rf + Ri}$$

$$\frac{1}{3} = \frac{Ri}{Rf + Ri} \qquad Rf = Rf1 // Rf2 = 2Ri$$

3. BARKHAUSEN MODIFIED CRITERIA & MAXIMUM FREQUENCY LIMITATION INVESTIGATIONS

The modification of the Barkhausen conditions for oscillators was used to securing the oscillation of the oscillators when the linear oscillator circuit becomes unstable. Due to shift the position of poles to the right side of the frequency plane. In order for the oscillations to start, continuing and stability, these poles must be on conjugate complex pair form and on the imaginary axis of the frequency plane. Hence, we can understand the FB circuit as a prerequisite for the occurrence of oscillations. It is a new look at the role of this property in the presence of existing oscillations so this modification is called the modified Barkhausen criterion. [35-43] Factors determining the ability to achieve high resonant frequencies of the oscillator signal were investigated. These factors that are identified, understood, and studied are unit gain bandwidth (f_T), turn rate (slew rate SR), and output voltage of the device (Vo = Vin Av) as shown in *equations 8, 9, 10, 11*. [42-46] Thus, the ambiguity has been removed from the parameters of obtaining a high frequency signal for this type of oscillator.

Where the upper limits of its resonant frequency was restricted with the elements, product of gain bandwidth (f_T), slew rate which did help determine the maximum input frequency and amplitude of the output signal from the oscillator so that the output is not distorted too much, also voltage gain (Av) & peak voltage (V_m) of sinusoidal output voltage as following.

$$Vo\ (t) = Vm\ Sinwt \tag{8}$$

$$SR = (dVo(t))/dt = (d(Vm\ Sinwt))/dt = Vm.W\ .Coswt \tag{9}$$

$$SR = 2\pi fm.Vm \tag{10}$$

$$fmo = (\ SR)/(2\pi Vm) \tag{11}$$

Where:

f_{mo}: Maximum frequency of oscillation; SR: Slew rate of op amp; and $|V_m|$: Absolute peak value of output voltage (V_o).

FOREX Publication
Open Access | Rapid and quality publishing

International Journal of
Electrical and Electronics Research (IJEER)
Research Article | Volume 12, Issue 3 | Pages 727-733 | e-ISSN: 2347-470X

Thus, it becomes necessary to check the data sheet for of the device before using it for high frequency applications. The type of op amp is LM171AIN was used in this design.

The two parallel diodes D1 and D2 in the above design serves as an excellent circuit for regulating the control required of the output of op amp voltage. This is in order to keep the BJTs operating point of Op-amp working in an active region away from saturation and lower cutoff regions so that D1 & D2 is considered as an automatic control of the output voltage. As mentioned above, the value of the maximum frequency fluctuation (f_{mo}) for this proposed design is approximately equal to or slightly smaller than the value indicated in *equation (11)*.

4. SIMULATION RESULTS

Figure 2 shows the sub final circuit of the simulated design for VLF to VHF output signals. This circuit of the design was implemented using software Multisim program, which is a powerful electronic simulation program mostly used to design, implement and simulate electronic circuits and systems. The frequency values required to be obtained for the signal generated in the designed circuit depend on choosing the values of capacitances and resistors (Rs, Rp, Cs & Cp) as shown in *equation (7)*.

Mathematical calculations such as bandwidth was 249.99999 Mhz of VLF (10hz) to VHF (250Mhz) obtained from the application of this *equation*, and *figures 1, 2, and 3*.

The simulation results of the measured frequency bandwidth was 50.7211 MHZ from, VLF (9.83 HZ) to VHF (50.73 MHZ) and other important parameters with related *figure 4(A)-4(L)* were presented in *table 1*. Where the above equation depends on the following elements Rs, Rp, Cs, & Cp. After relying on statistical theories in the principle of right and wrong, and verifying the results of the frequencies in the above equation in terms of signal stability. According to stability considerations and linear stability, the results are better if the values of (Rs & Rp) are reduced to the least possible without prejudice to conditions stability. Therefore, Rs = Rp = 520 Ω was chosen, and accordingly *equation 10* was deduced from *equation 7* after substitution Rs & Rp with its above chosen values.

$$fr = \frac{0.1923}{200\pi\sqrt{CsCp}} \tag{12}$$

Table (1) shows calculations parameters values & signals measurements and the time taken to start oscillation of the final simulation scheme circuit shown in *figure 3*.

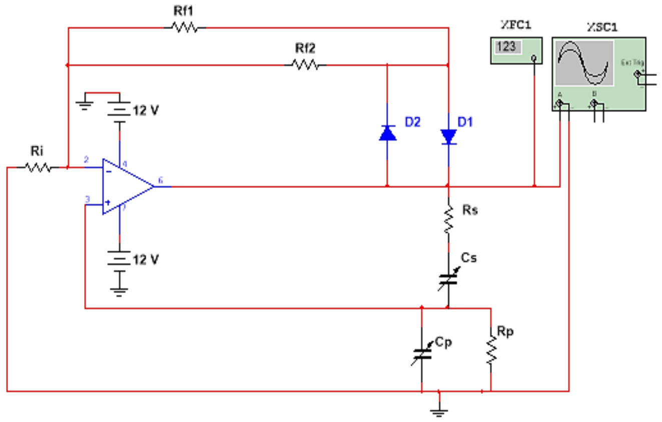


Figure 2. sub final circuit of the design

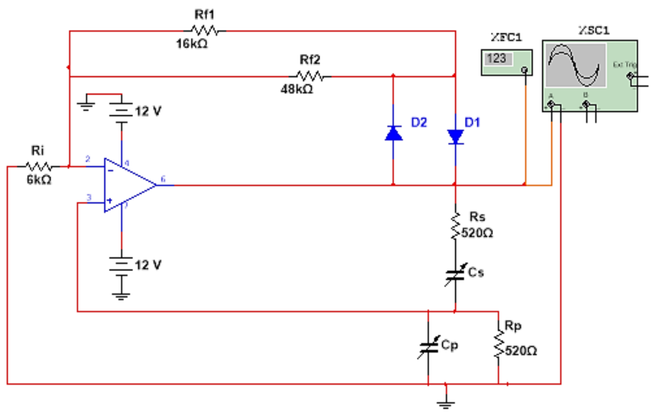


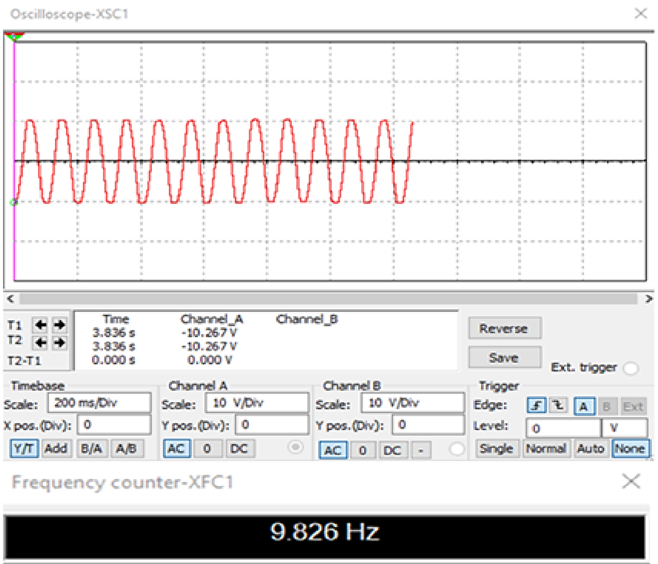
Figure 3. Final simulation scheme circuit

Table 1: Calculations parameters values & signals measurements

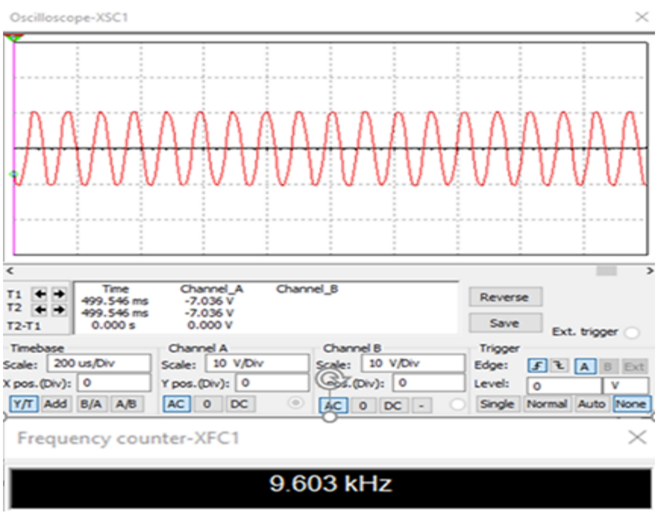
Feedback Parameters		Resonance Frequency (f_r)		Time Taken to Start Oscillation	Proposal Circuit with Output Signal Shape
$R_S = R_P$	$C_S = C_P$	Theoretically Calculation	Measurement Simulation		
520 Ω	159.155 µF	10 Hz	9.826 Hz	30 second	Figure 4-A
520 Ω	3.0606 µF	100 Hz	98.263 Hz	4.5 second	-
520 Ω	612.1 nF	500 Hz	491.255 Hz	< 2 second	-
520 Ω	306.606 nF	1000 Hz	982.203 Hz	< 1 second	-
520 Ω	30.606 nF	10 KHz	9.603 KHz	< 1 second	Figure 4-B
520 Ω	3.0606 pF	100 KHz	93.564 KHz	1 second	-
520 Ω	0.6 pF	500 KHz	475.455 KHz	3 second	Figure 4-C
520 Ω	382.58 pF	800 KHz	750 KHz	8 second	-
520 Ω	306 pF	1.0 MHz	955 KHz	20 second	Figure 4-D
520 Ω	218.62 pF	1.4 MHz	1.351 MHz	1 minute &40 sec	-
520 Ω	102.02 pF	3.0 MHz	3.02 MHz	22 minute &38 sec	-

International Journal of
Electrical and Electronics Research (IJEER)
Research Article | Volume 12, Issue 3 | Pages 727-733 | e-ISSN: 2347-470X

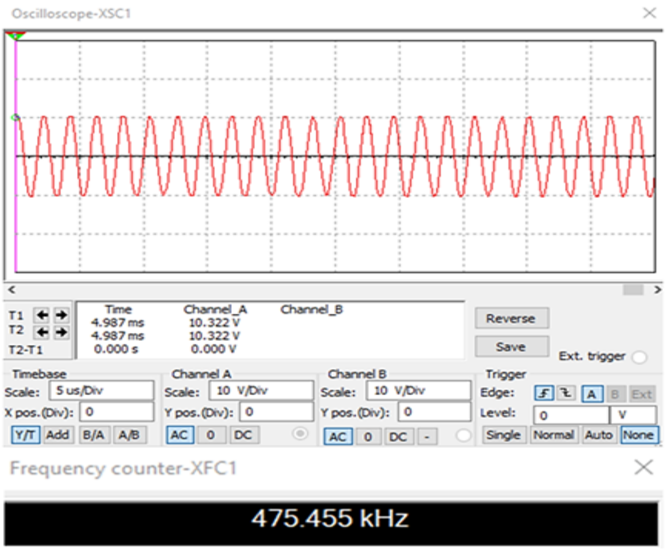
520 Ω	61.21 pF	5.0 MHz	5.225 MHz	30 minutes	Figure 4-E
520 Ω	43.73 pF	7.0 MHz	7.494 MHz	29 minutes	-
520 Ω	30.08 pF	10.0 MHz	10.837 MHz	16 minutes	-
520 Ω	20.4 pF	15.0 MHz	15.148 MHz	12.5 minute	Figure 4-F
520 Ω	15.3 pF	20.0 MHz	18.915 MHz	12 minutes	-
520 Ω	12.24 pF	25.0 MHz	21.527 MHz	11 minutes	-
520 Ω	10.2 pF	30.0 MHz	23.986 MHz	13 minutes	Figure 4-G
520 Ω	7.65 pF	40.0 MHz	27.847 MHz	12 minutes	
520 Ω	5.1 pF	60.0 MHz	33.344 MHz	15.18 minute	Figure 4-H
520 Ω	3.06 pF	100.0 MHz	40.194 MHz	30 minutes	-
520 Ω	2.509 pF	122.0 MHz	42.869 MHz	37 minutes	-
520 Ω	2 pF	153.0 MHz	45.651 MHz	35 minutes	Figure 4-I
520 Ω	1.913 pF	160 MHz	46.282 MHz	39 minutes	Figure 4-J
520 Ω	1.7 pF	180 MHz	47.648 MHz	43 minutes	-
520 Ω	1.531 pF	200 MHz	48.764 MHz	53 minute & 30sec	Figure 4-K
520 Ω	1.22488 pF	250 MHz	50.73 MHz	75minute& 30 sec	Figure 4-L



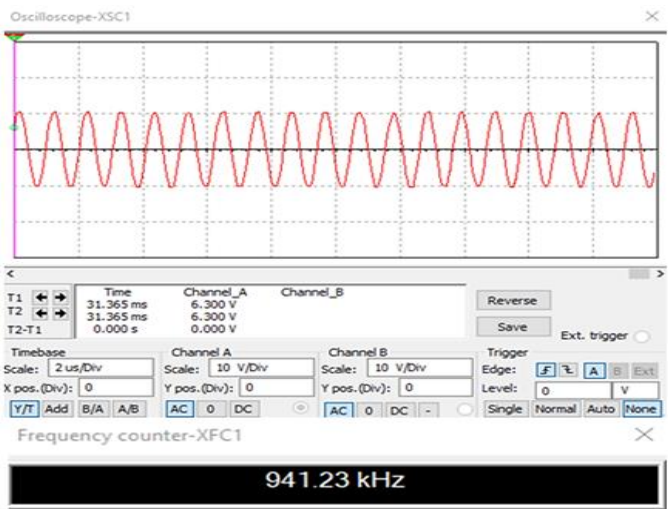
(a) Foc = 10 Hz



(b) Foc = 10 KHz

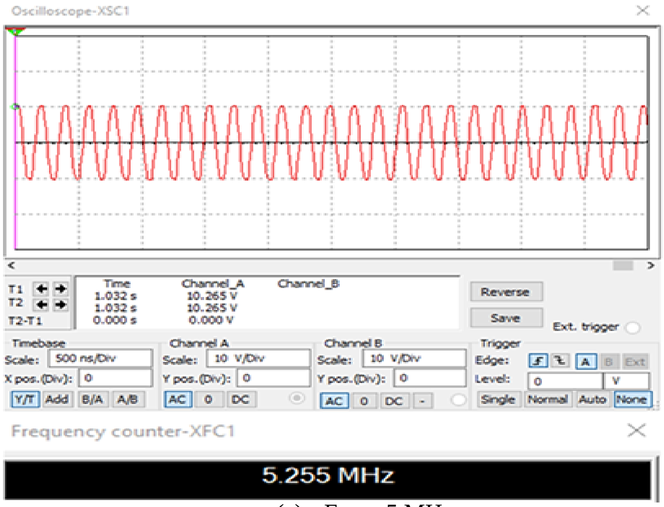


(c) Foc = 500 KHz

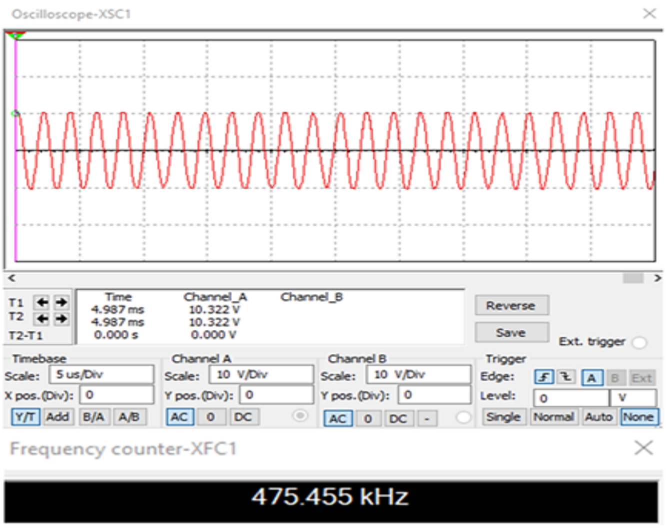


(d) Foc = 1 MHz

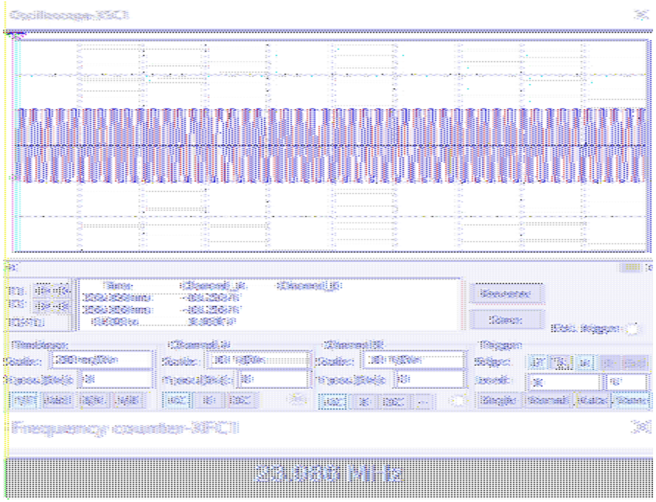
FOREX Publication
Open Access | Rapid and quality publishing
International Journal of
Electrical and Electronics Research (IJEER)
Research Article | Volume 12, Issue 3 | Pages 727-733 | e-ISSN: 2347-470X



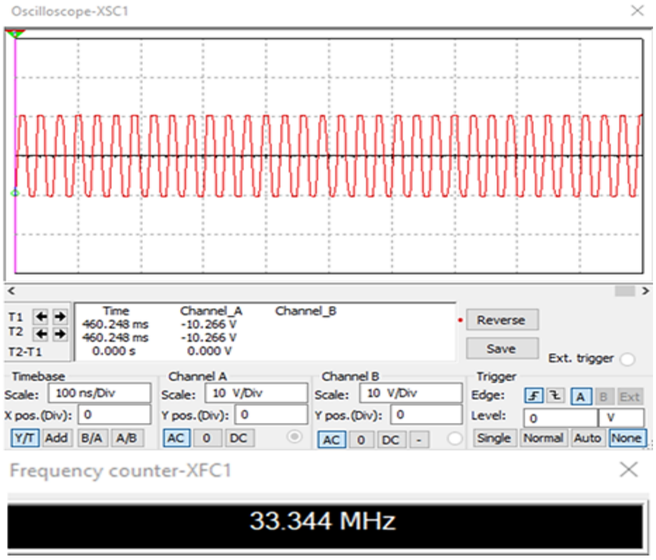
(e) Foc = 5 MHz



(f) Foc = 15 MHz



(g) Foc= 30 MHz



(h) Foc = 60 MHz

5. CONCLUSION

The sematic diagram of designed circuit is comprised from operational amplifier has absolute gain equal three. This operation amplifier has a unique c/s, such as high slew rate and very large input impedance accordingly, it became possible to be more appropriate and more effective in building and designing systems with high characteristics and performance when they are part of signal generation systems and circuits, including oscillators.

The measurement signals generated by the designed circuit disappear when the gain of the loop (AB) is less than one, and this signal is unstable when the gain of the loop (AB) is greater than one.

While the signal has a constant amplitude and a constant frequency when |AB|=1.X (X=0.001,0.002 to 0.009) and according to values of capacitances and resistances (Rs, Rp, Cs and Cp) that are chosen and compensated for the purpose of finding the resonant frequency as in *equation (7)*. This is can only be achieved after Barkhausen's oscillation condition is satisfied. Among the results recorded in Table -1- regarding the values of the measured signal frequencies for the designed circuit. By comparing these measured signal frequencies with the theoretically calculated frequencies according to *equation (7)* for the same values of the designed circuit elements. After observing the values of these frequencies, as we mentioned above, there are some differences between the values of high frequencies above 40 MHz of the measured signal and those calculated theoretically as shown in *table 1*.

Based on the presentation and interpretation in this research and through the analysis of these results (based on *equation 11* and *table 1*), it becomes clear that the main reason for these differences has become clear, which is the amount of RS (slew rate) as well as the output voltage Vm, according to *equation (11)*.

It turns out that RS has the most prominent role in determining the maximum output frequency (fmo) resulting from the design according to *equation (11)*. Given the successive and tremendous development in the industry of high-performance integrated circuits, it will soon be easy to obtain an operational amplifier that will make the design of this type of oscillators with very high frequency specifications possible, available and applicable. Due to successful solutions to the limitations of the problem as explained in the sections 2 & 3 of this paper. The amount of RS (slew rate) > 400 V/µs for LM171AIN was used in this design as well as the output voltage Vm can be adjusted to suitable value. It turns out that RS & Vm has the most prominent role in determining the maximum output frequency (fmo) resulting from the design according to *equation (11)*.

These results beside of the unique c/s of Wien bridge can make the Wien bridge oscillator, are capable of introducing output signal with high performance characteristic for very low to very high frequency so that a Wien bridge is chosen for achieving a wider frequency range.

REFERENCES

[1] Tomas L. Zapf, "Calibration of Inductance Standard in the Maxwell –Wien Bridge Circuit," Journal of Research of the National Bureau of standards-C. Engineering and Instrumentation Vol. 65C, No.3, July –Sep.1961.

[2] E.L. Ginzton; L.M. Hollingsworth, "Phase-Shift Oscillators", Proceedings of the IRE (Volume: 29, Issue: 2, February 1941).

[3] Kenneth. Clarke, Associate, IRE,"Wien Bridge Oscillator Design", Proceedings of the I.R.E. February ,1953.

[4] Zack D. Reynoids, San Jose," Adjustable Frequency Wien-Bridge", United States Patent Office Patented Jan. 11, 1966 3,229,228.

[5] M. A. Reddy; "Operational amplifier circuits for the Wien-Bridge oscillator". IEEE Trans. on Circuits and Systems, Vol. CAS-23, No. 6, pp 384-389, June 1976 1040.

[6] A. Budak and K. Nay, "Operational amplifier circuits for the Wien Bridge oscillator." IEEE Trans. Circuits Syst., Vol. CAS-28, pp. 930- 934, Sept. 1981.

[7] M. Filanovsky, "A Wien bridge RC oscillator with fast amplitude control", INT. J. Electronics, 1985, vol. 58, No.5, 817-826.

[8] A. Carlosena, P. Martinez. & S. Porta, "An improved Wien Bridge Oscillator", IEEE Transactions on circuits & systems, Vol. 37, No. 4, April 1990.

[9] Erik Lindberg, IEEE Life member, "The Wien Bridge Oscillator Family" Lindberg, E. (2006), In Proceedings of the ICSES-06 (pp. 189-192).

[10] Millman, J., & Grabel, A. (1987). Microelectronics (2nd ed., p. 661). New York: McGraw-Hill.

[11] A.S. Sedra and K.C. Smith, Microelectronic Circuits 4th Ed, Oxford University Press, 1998.

[12] Malvino, A. P. (1999). Electronic principles (6th ed., p. 857). New York: Glencoe/McGraw-Hill.

[13] Walter G. Jung Editor,"OP AMP Applications", Copyright © 2002 By Analog Devices, Inc. Printed in the United States of America, ISBN 0-916550-26-5.

[14] Sedra, A. S., & Smith, K. C. (2004). Microelectronic circuits (5th ed., pp. 1168–1169). New York: Oxford University Press.

[15] B. L. Theraja, A. K. Theraja, "A Textbook of electrical Technology, Vol. 1 Basic Electrical Engineering", S. Chand & company Ltd, First Multicolor Edition, New Delhi-India, 2005.

[16] Robert L. Boylested & Louis Nashelsky "Electronic Devices and Circuit Theory"International Edition, Ninth Edition, Copyright 2006 by Pearson Education.

[17] Guillermo Gonzalez, "Foundations of Oscillator Circuit Design", Artech House, Inc. 2007.

[18] Johan Huijsing, "Operational Amplifiers Theory and Design", 2nd Edition Springer Science+ Business Media B.V. 2011.

[19] Seedra and Kenneth C.Smith "Micro Electronic" New York Oxford , Oxford University Press Copyright 2015.

[20] Thomas F. Schubert, Jr. and Ernest M. Kim, "Fundamentals of Electronics: Book 4 Oscillator and Advanced Electronics Topics". 2016, copyright© 2016 by Margan & Claypool Adel S.

[21] A. Rodriguez-Vazquez, J. L. Huertas, and B. Perez-Verdu, "High-Frequency Design of the Wien-Bridge Oscillator Using Composite Amplifiers", IEEE Transactions. on Circuits & systems, Vol. CAS-34, No. 4, April 1987.

[22] J. V. Vosper. "The Wien bridge oscillator incorporating an op-amp as the active element." Int. J. Elect. Enging Educ., Vol. 25, pp. 125-139. Manchester U.P., 1988. Printed in Great Britain.

[23] Carlosena, A., et al., "Wien Bridge oscillators using active compensated VCVS.", In: Proceedings of the 33rd Midwest Symposium on Circuits and Systems, pp. 1038–1041. IEEE, Calgary, 12 August 1990.

[24] Carlosena, A., Martinez, P., & Porta, S. (1991). Wien-bridge oscillators with op amp independent oscillation frequency. IEEE Transactions of Instrumentation and Measurement, 40, 644–646.

[25] Khalid Awaad Humood, Adham Hadi Saleh, Wurod Qasim Mohamed "Design and Simulation of OP- AMP-RC Sine Wave Oscillator", Mechanical Engineering Faculty, Technical University-Sofia, Bulgarian Journal for Engineering Design, issue 24, October 2014.

[26] Khalid Awaad Humood, Adham Hadi Saleh, Wurod Qasim Mohamed, "Design & Implementation of OP-AMP-RC Sine Wave Oscillator", Diyala Journal of Engineering Sciences, ISSN 1999-8716, Vol. 08, No. 01, pp. 89-901, March 2015.

[27] H. Barkhausen," Lehrbuch der Elektronen-Rhren und ihrer technischen Anwendungen: Rckkopplung", 3rd ed. Leipzig: Hirzel, 1935.

[28] Ali Ümit Keskin, "Wien Bridge Oscillator Performances Using Current &Voltage Feedback Amplifires", IJCI Proceedings of International Conference on Signal Processing, ISSN 1304-2386, Vol. 1, No. 2, September 2003.

[29] E. Lindberg, ''Oscillators - An Approach for a Better Understanding'', Proceedings of the 2003 European Conference on Circuit Theory and Design, Krakow, Poland, 2003.

[30] Erik Lindberg, IEEE Life member, "The Wien Bridge Oscillator Family" Lindberg, E. (2006), In Proceedings of the ICSES-06 (pp. 189-192).

[31] Lindberg: The Barkhausen Criterion (Observation?) 18th IEEE Workshop on Nonlinear Dynamics of Electronic Systems (NDES 2010), May 26-28, 2010, Dresden, Germany.

[32] Selim S. Awad, member, IEEE, "Extending the Frequency Range of a Wien-Bridge Oscillator Using Composite Operational Amplifiers ", IEEE Transactions on Instrumentation and Measurement. Vol .38, No. 3. June 1989.

[33] Erik Lindberg, IEEE Life member, "The Wien Bridge Oscillator Family" Lindberg, E. (2006). In Proceedings of the ICSES-06 (pp. 189-192)

[34] Erik Lindberg, IEEE Life member, "Oscillators and Operational Amplifiers", Authorized licensed use limited to: Denmark's Tekniske Information center. Downloaded on December 2, 2009 at 04:46 from IEEE Xplore.

[35] Khalid A. Humood, Omar A. Imran, Adnan M. Taha, "Design and Simulation of High Frequency Colpitts Oscillator Based on BJT Amplifier" International Journal of Electrical and Computer Engineering (IJECE), Vol. 10, No. 1, February 2020, pp. 160-170.

[36] Khalid Awaad Humood, Tahreer Mahmood, Qahtan Khalaf Omran & Hayder Khaleel AL-Qaysi, "Design LC oscillator for MF, HF& VHF using both ideal and practical operation amplifier", Periodicals of Engineering and Natural Sciences Vol. 10, No. 1, January 2022, pp.164-177.

[37] Vimal Singh,"A note on determination of oscillation startup condition", Analog Integr Circ Sig Process (2006) 48:251–255 .

[38] Vimal Singh,"Failure of Barkhausen oscillation building up criterion: Further evidence" Analog Integr Circ Sig Process (2007) 50:127–132.

[39] Fan He. Raymond Ribas, Cyril Lahuec. Michel Je´ze´quel, Discussion on the general oscillation startup condition and the Barkhausen criterion, Analog Integr Circ Sig Process (2009) 59:215–221.

[40] Vimal Singh, "Discussion on Barkhausen and Nyquist stability criteria", Analog Integr Circ Sig Process (2010) 62:327–332.

[41] Lutz von Wangenheim, "On the Barkhausen and Nyquist stability criteria", Analog Integr Circ Sig Process (2011) 66:139–141.

[42] Jim Williams, "Slew Rate Verification for Wideband Amplifiers", Application Note 94May 2003.

[43] B.N. Biswas, S. Pal, S. Chatterjee, "Movement of Poles in Oscillator", Proceeding of E2NC 2011, pp. 155- 161, Jan. 2011.

[44] Herminio Martı´nez-Garcı´a, "On modified Wien-bridge oscillator and a stable oscillator", Analog Integr Circ Sig Process (2013) 75:179–194.

[45] Chia-Wei Lin1, Yen-Ting Chen, Ying-Chen Chen, Chung-Cheng Chen, "Improvement of the Barkhausen criterion and the implementation of an intelligent function generator", J Eng., 2017, Vol. 2017, Issue. 4, pp. 126–138.

[46] Chung-Cheng Chen and Yen-Ting Chen, Correction of traditional incorrect oscillation formula for the Wien-Bridge Oscillator, IET Circuits, Devices & Systems, Volume 16, Issue 3, May 2022 Pages 201-299.