International Journal of Communication Networks and Information Security
ISSN: 2073-607X, 2076-0930
*Volume **14** Issue **03 Year 2022** Page **86:98***

Performance Analysis of MEMS Based Oscillator for High Frequency Wireless Communication Systems

[1]Dhifaf Talal Shakir, [2]Hassan Jassim Al-Qureshy, [3]Saad S. Hreshee

[1]Electrical Engineering Department, College of Engineering, University of Babylon, Hilla, Babil, Iraq
dhifaf.zubala.engh301@student.uobabylon.edu.iq
[2]Electrical Engineering Department, College of Engineering, University of Babylon, Hilla, Babil, Iraq
hssn_jasim@yahoo.com
[3]Electrical Engineering Department, College of Engineering, University of Babylon, Hilla, Babil, Iraq
eng.saad.saffah@uobabylon.edu.iq

Article History

Received: 27 July 2022
Revised: 3 October 2022
Accepted: 7 November 2022

Abstract

The frequency oscillator is a basic component found in many electrical, electronic, and communications circuits and systems. Oscillators come in a variety of shapes and sizes, depending on the frequency range employed in a given application. Some applications need oscillators that generate low frequencies and other applications need oscillators that generate extremely high and high frequencies. As a result of the expansion and speed of modern technologies, new oscillators appeared that operating at extremely high frequencies. Most wireless communication systems are constrained in their performance by the accuracy and stability of the reference frequency. Because of its compatibility with silicon, micro-electro-mechanical system (MEMS) is the preferred technology for circuit integration and power reduction. MEMS are a rapidly evolving area of advanced microelectronics. The integration of electrical and mechanical components at the micro size is referred to as a MEMS. MEMS based oscillators have demonstrated tremendous high frequency application potential in recent years. This is owing to their great characteristics such as small size, integration of CMOS IC technology, high frequency-quality factor product, low power consumption, and cheap batch manufacturing cost. This paper's primary objective is to describe the performance of MEMS oscillator technology in high-frequency applications, as well as to discuss the challenges of developing a new MEMS oscillator capable of operating at gigahertz frequencies.

Keywords: MEMS, Oscillator, CMOS OP-AMP, and Wireless Communication

1. Introduction

The expanding use of wireless technology in modern life needs a decrease in power consumption. This is very important nowadays, especially when wireless devices have become more prevalent. During signal transmission and reception, the transceiver frequently requires adequate local oscillators to perform frequency translation. Designing oscillators that meet the strict specifications of different wireless standards is challenging. Oscillators must also be inexpensive, low-power, compact, capable of operating in multiple bands, and silicon compatible. To provide multi-band/mode functionality, this necessitates a wide chip surface and a high-power need [1].

To reduce power consumption in wireless communication applications, MEMS is used as an oscillator. MEMS is an acronym for micro electromechanical system. Microsystems technology (MST) and micro machines are two alternative terms for the same thing. Due to its potential applications in both industrial and consumer areas, it is widely regarded as one of the most fascinating topics. MEMS devices are typically 20 micrometers to a millimeter in size, while MEMS components range in size from 1 to 100 micrometers. [2]

Almost everyone today owns a MEMS device, such as a smartphone, a smart watch, or a fitness tracker. An aeronautic gyroscopic device used in airplane cockpits to detect roll, pitch, and yaw weighed several kilograms and measured several inches in length in the past, but today's MEMS gyroscopes in our smartphones weigh less than a milligram and are the size of a grain of sand. As a result of the smaller size, production costs are lower, and economies of scale are greater. Fig. 1 shows the size of MEMS devices in comparison to the rest of the world. In a nutshell, MEMS attempts to turn existing large mechanical systems into small, better-performing, and mass-producible alternatives, much like integrated circuit and semiconductor technologies have done for electrical and electronic systems. Sensors, actuators, generators, energy sources, and medicinal systems, and oscillators all use MEMS. In this work, MEMS is used as an oscillator. [3, 4]

MEMS as oscillators are a new type of device that has the ability to provide highly integrated and miniaturized system. It has three main advantages that distinguish it from an ordinary oscillator. These advantages are small size, lower power consumption, in addition to a wide bandwidth. In principle, the benefits of replacing quartz technology with MEMS are comparable to those of constructing integrated circuits as opposed to discrete electronic components. These benefits include increased reliability, higher degrees of integration, and lower total costs [5-8].

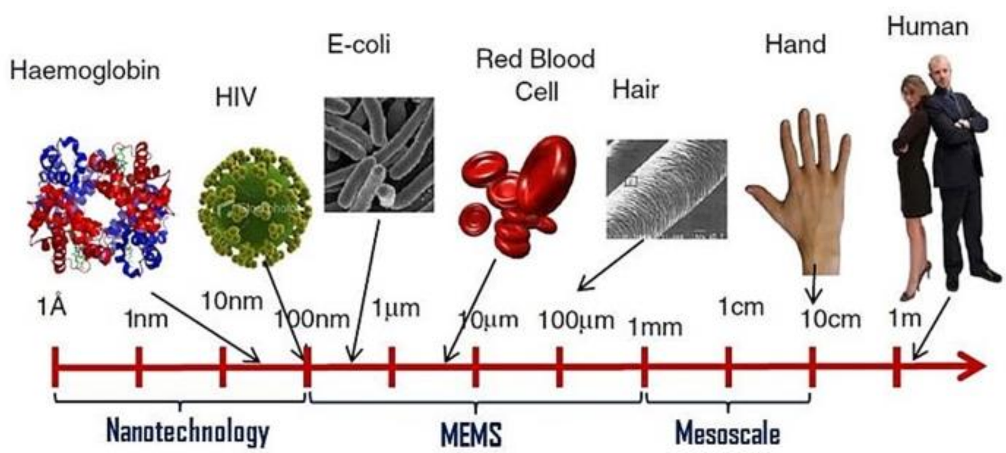

Figure. 1 Scale of Things Representing the Region for Dimensions of MEMS Devices

2. Electrical Oscillator

A frequency oscillator is an electrical oscillator that produces a repeating signal by converting a DC voltage to an AC voltage signal with the appropriate frequency. The oscillator's output signal must be clear in its frequency spectrum and clean, stable, and smooth. The only input signal used to create a pure sinusoidal signal is the dc bias, as shown in Eq. (1). The output of an ideal oscillator is ideal.

$$V_{out} = \mathrm{A}\cos(w_{osc}t) \quad (1)$$

Where: A is the amplitude of the oscillation, w_{osc} is the oscillating frequency and V_{out} is the output voltage.

Ideally, the oscillating frequency is where 100% of the signal power is present. Unwanted harmonics accompany real oscillator outputs. A power reduction at the desired frequency results from the distribution of carrier power over the bandwidth and harmonics of the carrier frequency. In addition to harmonics, practical oscillators can encounter phase noise sidebands or jitter in the time domain. A realistic oscillator's output signal can be expressed as phase noise and jitter as described in Eq. 2.

$$V_{out} = \text{A}\cos(w_{osc}t + \theta) \quad (2)$$

where θ is a stochastic variable that represents the phase uncertainty caused by jitter.

Oscillators use feedback systems to create noise-free, pure sinusoidal signals. A typical oscillator block diagram is shown in Fig. 2, which includes a frequency-selective network (j), a positive feedback amplifier Av (j), and the noise input vi.

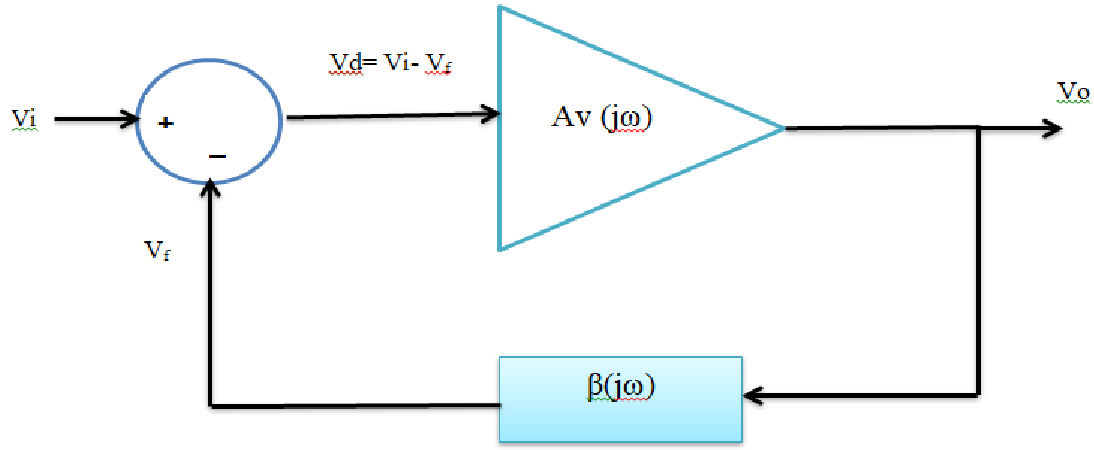

Figure. 2 Block Schematic of the Feedback System

Electrical oscillators are split into two groups according to their frequency-selecting component: LC and RC oscillators. When a resistor is used as a frequency selector rather than an inductor, energy is lost during the oscillation phase, which leads to poor spectral purity. As a result, LC oscillators outperform RC oscillators in terms of noise performance, making them more common in RF transceivers.[9]

The series or parallel placement of the inductor and capacitor in the LC oscillator circuit, can be categorized into numerous topologies. The output will be different for each category. The resonance frequency of a purely parallel LC resonator is given by Eq. (3):

$$f_{osc} = \frac{1}{2\pi\sqrt{L_S C_S}} \quad (3)$$

Capacitive and inductive dividers are the types of dividers that are usually employed in oscillator applications. Their names are the Colpitts and Hartley configurations respectively. The inductor has a Q that is far lower than that of the capacitor, and it consumes a significant amount of space on the chip. As a direct consequence of this, Colpitts is picked instead of Hartley.

The year 2018 marked the centennial anniversary of the invention of Colpitts oscillators, a form of oscillatory circuit. The celebrations took place all around the world. Over the course of the past century and a half, major developments have been made to Colpitts oscillators, and these oscillators have been implemented in a wide variety of technologies, such as vacuum tubes, bipolar circuits, and CMOS technology. There have been very few other electronic circuits that have been around for as long as the Colpitts oscillator and that have had such a significant influence on electronic technology. These days, digital electronics and communication systems both make use of Colpitts oscillators as clock and frequency generators. The uncomplicated vacuum tube oscillator that Colpitts presented in 1918 has given way to the

MEMS oscillators that are utilized in current electronics and that run at high gigahertz frequencies. This is an evolution of the Colpitts oscillator. Because it can include capacitors in the top metal layers—which can be utilized to manufacture accurate capacitors—Colpitts is perfectly suited to contemporary, high-speed CMOS technology. This is because it can be used to make capacitors. It is simple to combine Colpitts with MEMS high Q resonators located outside of a CMOS chip to produce high-quality oscillators. Some examples of these types of resonators are Surface Acoustic Wave (SAW), Bulk Acoustic Wave (BAW), and Film Bulk Acoustic Resonators (FBAR).

Additionally, Colpitts oscillators have good compatibility with the integrated circuit (IC) technology that is used in modern high-speed electronics. It is already possible for several semiconductor foundries to construct integrated circuits with high-speed transistors that have transition frequencies (ft) of up to 300 GHz. This makes it possible to create incredibly rapid gain stages. A few of these foundries also produce high precision capacitors that are constructed with a variety of metal layers that are connected to one another. Because it only needs a gain stage and two capacitors for its feedback, the Colpitts oscillator is easily producible in modern integrated circuits (ICs) due to the fact that its only need. Realizing a single inductor for use in feedback may also be accomplished through the use of metal layers or an external microprocessor. Alternately, you may replace the inductors with modern, premium MEMS-based resonators such as BAW, SAW resonators, or FBARs. This would be still another alternative. By utilizing MEMS resonators, it is possible to construct oscillators of a high quality that have outstanding frequency stability, very minimal phase noise, and perhaps lower overall power usage. [10]

The resonance tank circuit for the Colpitts Oscillator, which produces sinusoidal oscillations, is created by connecting two center-tapped capacitors in series with a parallel inductor. This creates the circuit for the resonance tank. The Colpitts oscillator circuit is shown here in Figure 3.

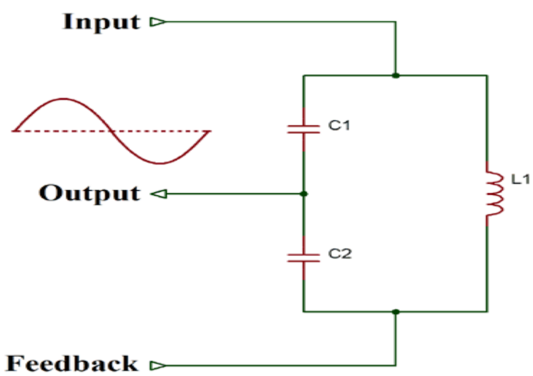

Figure. 3 Colpitts Oscillator

The frequency of oscillations is determined, which is given. in Eq. (4)

as $f_{r=\frac{1}{2\pi\sqrt{LC_T}}}$ (4)

The derivation of the Colpitts oscillator is the Pierce oscillator, and it is named after George W. Pierce, its inventor. Because the Pierce type uses only a few elements: a quartz crystal that serves as a highly selective filter element. The Pierce oscillator is shown in Fig. 4.

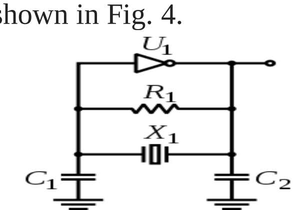

Figure.4 Pierce Oscillator

3. Challenges In High Frequency Design Of MEMS As Oscillator

Oscillators in the gigahertz frequency range are essential components in communications systems. When using MEMS as oscillators at millimeter Wave frequencies, some basic challenges arise. One issue in operation at gigahertz frequencies is maintaining high frequency stability and compactness. Another issue in constructing MEMS as an oscillator in the Gigahertz frequency range is reducing phase noise. Phase noise is one of the most significant measurements for oscillators. By looking at the phase noise plot, an expert engineer can tell a lot about the quality of an oscillator and if it is suitable for the application.
The amplifier nonlinearity, which is crucial in mm Wave communication at high frequencies, is an example of an impaired hardware effect. The behavior of a circuit, specifically an amplifier, in which the signal strength output is proportional to the signal strength is known as non-linearity. In a non-linear device, the output-to-input (gain) amplitude ratio is determined by the signal input strength. Further studies will concentrate on design optimization to enhance the resonator's linearity in order to reduce frequency instability and phase noise.

4. MEMS As Oscillator

The demand for wireless products that are portable, light weight, require less power, and are simple to use has fuelled development into a completely integrated transceiver. Mechanical oscillators can be miniaturized to micro sizes using MEMS technology. These MEMS-based oscillators offer a viable alternative for applications that require a high level of integration and small size. As devices become smaller and more integrated on a single chip, the amount of power consumed will drop. The work on MEMS as oscillator are shown in tables 1, 2 and 3 for years 2010-2014, 2015-2017 and 2018-2021 respectively.

Table 1. Performance Parameters of MEMS as Oscillator for Years 2010-2014

Ref. No.	Year of publication	Frequency	Type of oscillator	Gain	Application
[11]	2010	52 MHz	piezoresistive	_	time-keeping and frequency reference applications
[12]	2010	1.05-GHz	Pierce oscillator	_	_
[13]	2010	32.768 kHz	_	_	Time control applications
[14]	2011	1.006GHz	_	76 dB	_
[15]	2012	_	ring oscillator	_	_
[16]	2012	48MHz	_	99 dB	_
[17]	2012	20-MHz	_	_	_
[18]	2013	20 MHz	reference oscillator	112.5dB	_
[19]	2013	20MHz	Pierce oscillator	_	_
[20]	2013	10MHz	_	_	_
[21]	2013	1.16 GHz	Colpitts oscillators	_	_
[22]	2013	11-MHz	Pierce oscillator		sensing system
[23]	2014	168.1 MHz	_	_	_

The range of frequencies used in table 1 from 32.768 kHz to1.7 GHz and it shows gain range of 76 dB to 112.5 dB. LC oscillator such as Colpitts and Pierce oscillator is used in applications that need high frequencies while RC oscillator is used in applications that need low frequencies.

Table 2. Performance Parameters of MEMS as Oscillator for Years 2015_2017

Ref. No.	Year of publication	Frequency	Type of oscillator	Gain	Application
[24]	2015	32 kHz	_	_	_
[25]	2015	17.22 MHz	_	122 dB	clock generation
[26]	2016	110KHz	Pierce oscillator	_	_
[27]	2016	7.22MHz	reference oscillator	122dB	biomedical electronic applications
[28]	2016	_	Sinewave oscillator	_	_
[29]	2016	1.2 MHz	_	_	_
[30]	2017	61-MHz	Pierce oscillator	_	GSM
[31]	2017	214 MHz	_	80 dB	_
[32]	2017	3.73MHz	Differential	_	_
[33]	2017	1.396GHz	_	31dB	_
[34]	2017	1.3 GHz	Pierce oscillator	_	_
[35]	2017	150 MHz	Colpitts Oscillator	_	_
[36]	2017	256 MHz	Reference Oscillator	_	_
[37]	2017	3.2MHz	_	_	_
[38]	2017	24-MHz	_	132 dB	_

In table 2, for years from 2015 to 2017, the range of frequencies from 32 kHz to 1.396GHz. The gain is reversely proportional with frequency when the frequency is increased the gain is reduced. Very important thing in designing high frequency oscillators is achieving acceptable range of gain.

Table 3. Performance Parameters of MEMS as Oscillator for Years 2018_2021

Ref. No.	Year of publication	Frequency	Type of oscillator	Gain	Application
[39]	2018	2.4GHz	Pierce oscillator	33 dB	Bluetooth technology and GSM
[40]	2018	175 MHz	_	_	_
[41]	2018	150.5 MHz	_	_	timing applications
[42]	2018	1.23-MHz	_	_	_
[43]	2018	750MHz and 1900MHz	RF local oscillator	_	down-conversion mixer
		100MHz up to several GHz	reference oscillator	_	synthesizer generating frequencies
[44]	2019	28-MHz		_	4G/GPS applications
[45]	2019	16MHz	Colpitts oscillators	_	_
[46]	2019	600 MHz	_	_	_
[47]	2019	18-MHz	_	98-dB	_
[48]	2020	33.14kHz	pulse-driven oscillator	_	low-power timekeeper
[49]	2020	12.9-GHz	Pierce oscillator	_	5G communications

[50]	2020	8.6 GHz	_	_	5G communications
[51]	2020	30 GHz	_	_	_
[52]	2020	2.14MHz	Colpitts oscillators	_	_
[53]	2020	300 _500 MHz	_	_	_
[54]	2021	8.6-GHz	Modified Pierce oscillator	_	
[55]	2021	6.89-MHz	_	118dB	_
[56]	2021	50MHz	_	112dB	_

As shown in tables (1, 2 and 3), the maximum frequency used is 30GHz. Future research should develop this oscillator technology to mm Wave frequencies (30GHz-300GHz).

5. MEMS As Oscillator At GHZ Frequencies

In order to create a micro electromechanical system (MEMS) oscillator that operates at 1.05 GHz, Zuo et al. used piezoelectric AlN contour mode resonators that were subjected to lateral-field excitation (LFE) in [12]. This was done in order to design MEMS as an oscillator that operates at GHz frequencies. Figure 5 depicts the MEMS resonator operating at 1.05 GHz frequency. The phase noise floor of the oscillator is 146 dBc/Hz, which is sufficient to meet the standards set out by GSM. Additionally, the oscillator's phase noise at a 1-kHz offset frequency is 81 dBc/Hz. The total device performance has the best FoM when compared to other gigahertz oscillators that are based on FBAR, SAW, and CMOS LC technologies.

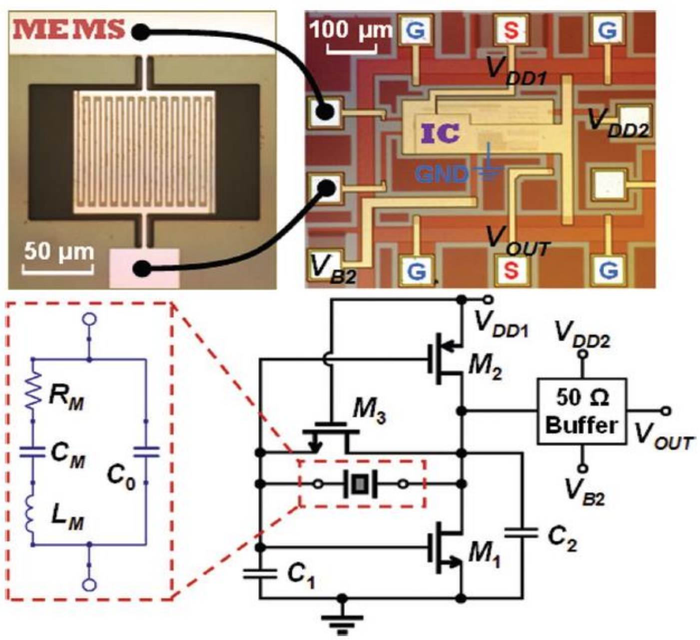

Figure. 5. CMOS IC Chip Wire-Bonding and the MEMS Resonator's Micrographs and Circuit Diagrams

Lavasani and colleagues developed a high-gain adjustable transimpedance amplifier (TIA) for use in gigahertz oscillators with significant motional resistance and shunt parasitic capacitance and published their findings in reference 14. The input current is amplified by a low-power broadband current pre-amplifier and voltage conversion stage before it is sent on to the TIA's feedback voltage amplifiers for further amplification. Using this approach, the TIA is capable of producing a gain that is continuous up to 1.7 GHz and is 76 dB-Ohm. Resonators belonging to the family of high-order laterally stimulated bulk resonators were utilized in this investigation (LBAR). The electrical model of the resonator and the TIA circuits that were employed for this work are depicted in Figures 6 and 7.

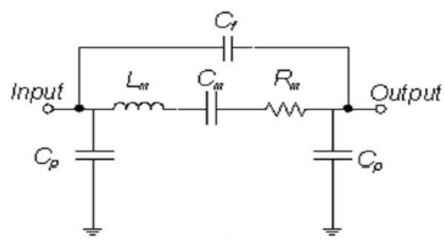

Figure.6 the LBAR's Equivalent Lumped Electrical Model

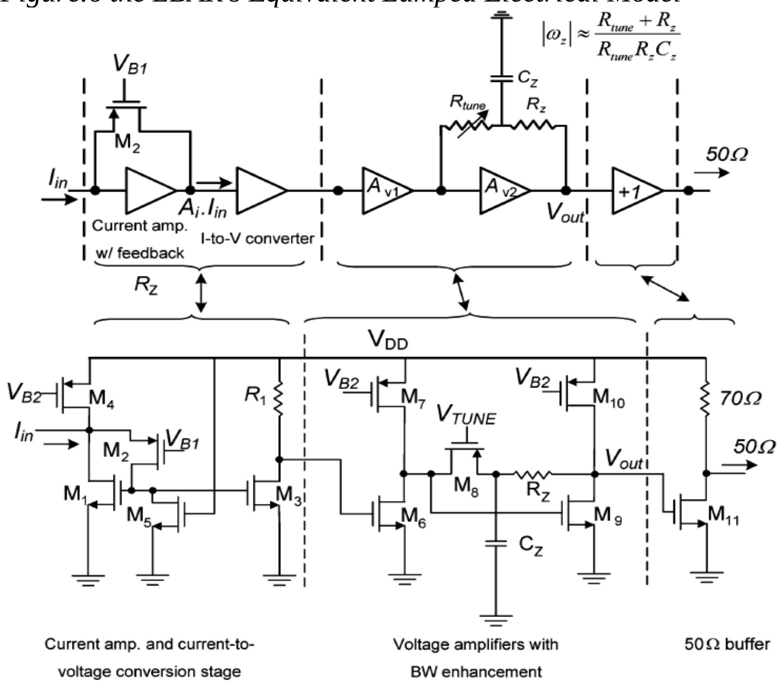

Figure. 7 Diagrammatic Representations of the Tia Showing the Active Pre-Amplification

A differential Colpitts oscillator made of 0.13 um CMOS-designed micromachined Aluminum Nitride (AlN) MEMS Contour-Mode-Resonators was introduced by J. Koo et al. in [21]. At a supply voltage of 1 V, the oscillator uses 4.2 mW total and operates at 1.16 GHz. The resonator in this investigation is a piezoelectric plate that is 4 m thick. The IDT electrodes layer, which is formed of a 100 nm thick Al thin film that is directly deposited on the silicon substrate, covers it. The resonator plate measures 52 by 122 um2. The differential Colpitts oscillator was constructed to use this AlN CMR, as shown in Fig. 8.

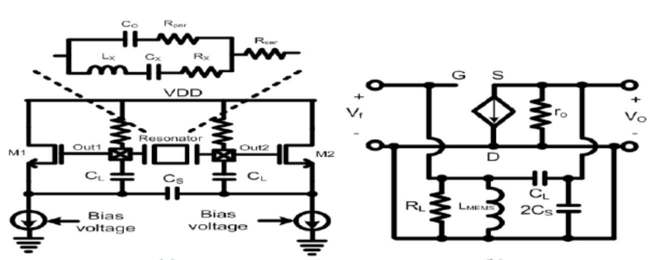

Figure.8 (A) Colpitts Oscillator (B) Its Tiny Signal Model

A transimpedance amplifier (TIA) and the TIA circuit associated with the MEMS SAW resonator depicted in Fig. 9 were employed as an oscillator in [33] by Kamarudin, et al. With 31dB gain and a 176° phase shift, the transimpedance amplifier offers a 16.531GHz bandwidth. The resulting gain is sufficient to offset the resonator's losses. the oscillation that was created at 1.396GHz following near loop gain. Phase noise was achieved using the oscillator at -133.97dBc/Hz of 10 kHz.

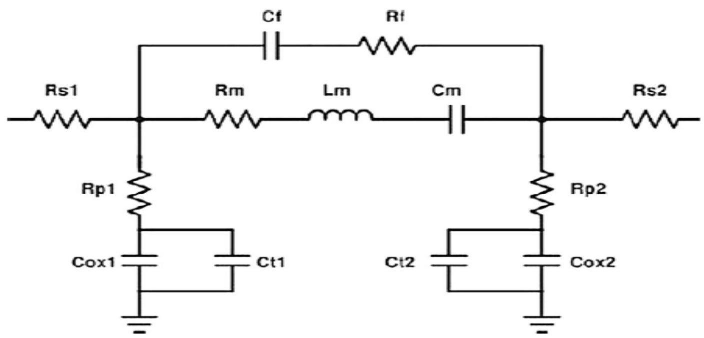

Figure.9. SAW Resonator Circuit

A boosted Pierce oscillator circuit was designed by Hamzah et al. in [34]. The two, three-stage cascade amplifiers in the boosted piercing design offer enough gain to make up for the SAW resonator's significant insertion losses of -65 dB at 1.3 GHz. Fig. 10 depicts the boosted piercing oscillator circuit that was employed in this paper

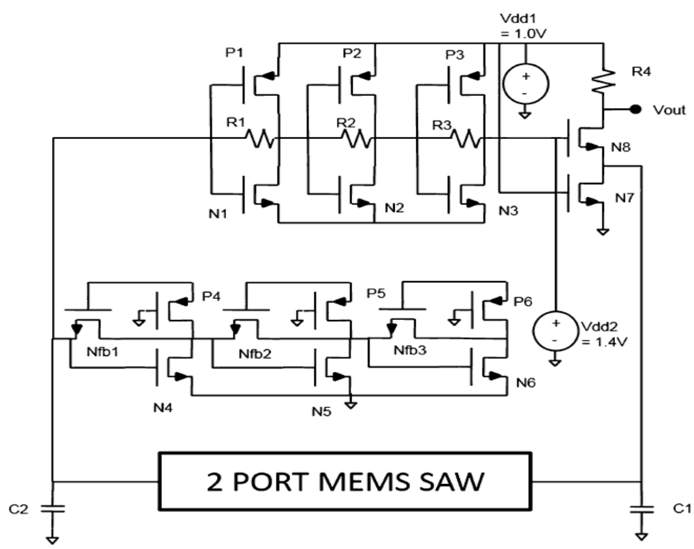

Figure. 10. Boosted Pierce Oscillator Circuit

A lithium niobate (LiNbO3) resonator housing three more antisymmetric overtones in a silicon germanium (SiGe) Pierce oscillator operating at 12.9 GHz was described by Kourani et al. in [49] in 2020 for 5G communications. MEMS oscillator developed in this paper has thus far achieved a greater oscillation frequency. The shown performance highlights the high potential for 5G frequency synthesis of microwave acoustic oscillators. In compact form factors, this paper enables low power 5G transceivers with high speed, high sensitivity, and good selectivity. The Pierce oscillator shown in Fig. 11 is used to excite the third overtone of the resonator at a frequency of 13 GHz.

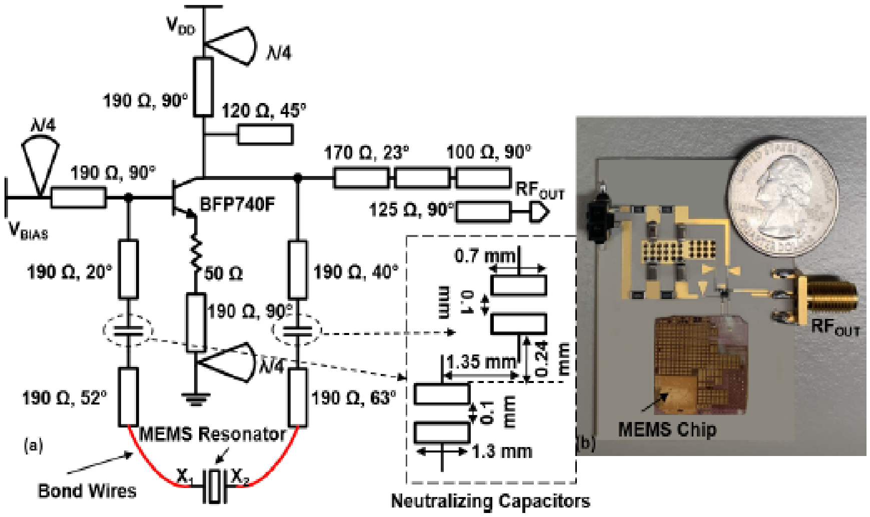

Figure. 11. (A) the RF Section of the 13-Ghz Oscillator in A Simplified Design. (B) Oscillator PCB.

In [51], Srivastava et al. constructed and computer-simulated a 14 nm Global Foundry (GF) 30 GHz oscillator with a 10,000 Q factor MEMS resonator. With the use of a high-Q on-chip MEMS resonator, they were able to achieve the basic phase noise restrictions in a millimeter Wave oscillator circuit utilizing the circuit depicted in Fig. 12.

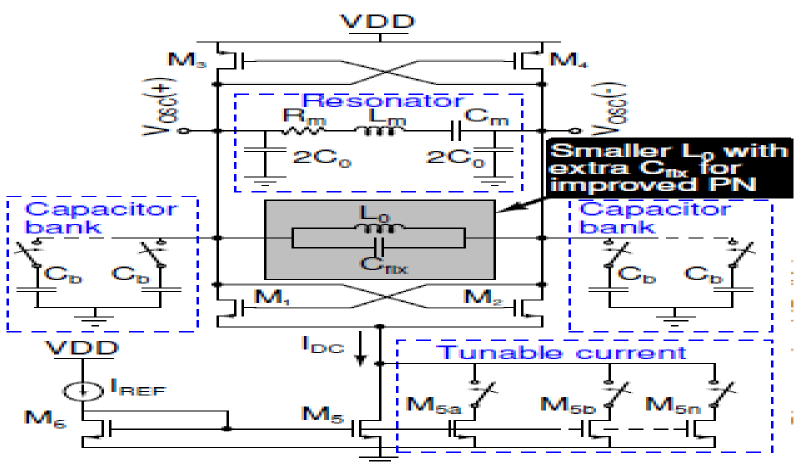

Figure. 12 Schematic for A MEMS Resonator on a 30 GHZ Oscillator

6. Conclusion

MEMS technology has a lot of promise to be a part of the forthcoming miniaturization revolution. Micro electromechanical systems have shown to be useful in a variety of commercial and government applications. Micro machines with tiny dimensions, low power consumption, and exquisite performance can only be developed with the help of MEMS. Due to their little size and capacity for fabricating using a standard CMOS process, oscillators based on MEMS are frequently employed in electrical systems to produce the reference frequency, allowing for new single-chip wireless communication systems with higher frequencies. In this paper the MEMS technology is used as high-performance oscillator. The performance of MEMS as an oscillator has been extensively studied and analyzed. There are many types of oscillators that can be used but the studies show that the LC oscillator is the best choice for the oscillator based on MEMS in extremely high frequencies.

References

[1] J. Karim, A. Alam, and A. Nordin" MEMS-BASED OSCILLATORS: A REVIEW", IIUM Engineering Journal, Vol. 15, No. 1, 2014.

[2] M. Mishra, V. Dubey, P. Mishra and I. Khan," MEMS Technology: A Review", *Journal of Engineering Research and Reports, 2019.*

[3] Q. Al-Gayem, S. Hreshee, and H. Jaafar, "Simulation and Test of Nano-Electro-Mechanical Switch for Low Power Logic Operations", European Journal of Scientific Research, Vol. 130 No 1, pp.169 – 177, March 2015.

[4] T. Mohammed, Q. Al-Gayem, and S. Hreshee. "Design and Simulation of High-Frequency Actuator and Sensor Based on NEMS Resonator." In *Research in Intelligent and Computing in Engineering*, pp. 501-513. Springer, Singapore, 2021.

[5] S. Srivastav, P. Bhardwaj and Summit," Fabrication, Sensing & Application of MEMS/NEMS Technology", IJCEM International Journal of Computational Engineering & Management, Vol. 12, April 2011.

[6] N. Hussain, N. Divyashree and S. Kumar," MEMS Sensors in IoT Applications", Journal of Control & Instrumentation, Volume 12, Issue 1, April 2021.

[7] D. Budanov, D. Morozov and M. Pilipko," MEMS Technologies: Theory and Practice", Computing, Telecommunications and Control, Vol. 14, No. 2, 2021.

[8] J. Zhu, X. Liu, Q. Shi, T. He, Z. Sun, X. Guo, W. Liu, O. Sulaiman, B. Dong and C. Lee," Development Trends and Perspectives of Future Sensors and MEMS/NEMS", Micromachines 2020.

[9] K. Humood, O. Imran and A. 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.

[10] M. Azadmehr, I. Paprotny, and L. Marchetti," 100 Years of Colpitts Oscillators: Ontology Review of Common Oscillator Circuit Topologies", IEEE CIRCUITS AND SYSTEMS MAGAZINE, 2020.

[11] J. Bontemps, Design of a MEMS-based 52 MHz oscillator, PHD thesis, Eindhoven University of Technology, 2010.

[12] C. Zuo, J. Spiegel and G. Piazza," 1.05-GHz CMOS oscillator based on lateral- field-excited piezoelectric AlN contour- mode MEMS resonators," IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, vol. 57, no. 1, January 2010.

[13] A. Pomarico, A. Morea, P. Flora, G. Roselli and E. Lasalandra," Vertical MEMS Resonators for Real-Time Clock Applications", Journal of Sensors Volume 2010, Article ID 362439, 5 pages.

[14] H. Lavasani, W. Pan, B. Harrington, R. Abdolvand and F. Ayazi," A 76 dBΩ 1.7 GHz 0.18 μm CMOS tunable TIA using broadband current pre-amplifier for high frequency lateral MEMS oscillators," IEEE J. Solid-State Circuits, vol. 46, no. 1, pp. 224–235, 2011.

[15] J. Gamarra, N. Barniol and J. Juillard," Analysis of a MEMS-based ring oscillator", May 2012.

[16] M. Li, C. Li, L. Hou, Y. Liu, and S. Li," A 1.57mW 99dBΩ CMOS Transimpedance Amplifier for VHF Micromechanical Reference Oscillators," in 2012 IEEE International Symposium on Circuits and Systems, 2012, pp. 209–212.

[17] S. Seth, S. Wang, T. Kenny, and B. Murmann," A −131-dBc/Hz, 20-MHz MEMS Oscillator with a 6.9-mW, 69-kΩ, Gain-Tunable CMOS TIA", 2012 IEEE.

[18] R. Mekky, P. Cicek and M. El-Gamal," Ultra low-power low-noise transimpedance amplifier for MEMS-based reference oscillators", IEEE, December 2013.

[19] A. Zainuddin, J. Karim, A. Nordin, M. Pandian and S. Khan," Design and Simulation of 20MHz Oscillator using CMOS-MEMS Beam Resonators", 2013IEEE.

[20] M. Taufik, A. Zainuddin, A. Nordin and M. Pandian," Design and simulation of two-stage CMOS amplifier for MEMS resonator," *ICCAS 2013 - 2013 IEEE Int. Conf. Circuits. Syst. "Advanced Circuits Syst. Sustain.*, no. 2, pp. 135–139, 2013.
[21] J. Koo, A. Tazzoli, J. Fernandez, G. Piazza, and B. Otis," A -173 dBc/Hz @ 1 MHz offset Colpitts Oscillator using AlN Contour-Mode MEMS Resonator", 2013 IEEE.
[22] J. Verd, A. Uranga, J. Segura and N. Barniol," A 3V CMOS-MEMS OSCILLATOR IN 0.35UM CMOS TECHNOLOGY", 2013 IEEE.
[23] Y. Hui and N. Sun," High Resolution Magnetometer Based on a High Frequency Magnetoelectric MEMS-CMOS Oscillator", journal of microelectromechanical systems, 2014 IEEE.
[24] S. Zaliasl, J. Salvia, G. Hill, L. Chen, K. Joo, R. Palwai, N. Arumugam, M. Phadke, S. Mukherjee, H. Lee, C. Grosjean, P. Hagelin, S. Pamarti, T. Fiez, K. Makinwa, A. Partridge, and V. Menon," A 3 ppm 1.5 × 0.8 mm2 1.0 μA 32.768 kHz MEMS-Based Oscillator", IEEE JOURNAL OF SOLID-STATE CIRCUITS, VOL. 50, NO. 1, JANUARY 2015.
[25] S. Roy, H. Ramiah, and A. Reza," Designing a new high gain CMOS amplifier towards a 17.22 MHz MEMS based Si oscillator for a cost-effective clock generator IC", IEICE Electronics Express, Vol.12, No.10, 1–8, 2015.
[26] C. Do, A. Erbes, J. Yan and A. Seshia," Design and implementation of a low-power hybrid capacitive MEMS oscillator", Microelectronics Journal, 2016.
[27] S. Roy, H. Ramiah, A. Reza, C. Lim and E. Ferrer," Design of a MEMS-Based Oscillator Using 180nm CMOS Technology", PLOS ONE | DOI: 10.1371/journal.pone.0158954 July 8, 2016.
[28] A. Brenes, J. Juillard and F. Vinci dos Santos," Impact of the closed-loop phase shift on the frequency stability of capacitive MEMS oscillators", 2016 IEEE.
[29] M. Li, K. Tseng, C. Liu, C. Chen, and S. Li," An 8V 50μW 1.2MHz CMOS-MEMS Oscillator", 2016 IEEE.
[30] T. L. Naing, Capacitive-Gap MEMS Resonator-Based Oscillator Systems for Low-Power Signal Processing, Electrical Engineering and Computer Sciences University of California at Berkeley, May 1, 2017, PHD thesis.
[31] A. BOUCHAMI, "MODELING AND IMPLEMENTATION OF HIGH-PERFORMANCE MEMS-BASED OSCILLATOR", MSC thesis, AUGUST 2017.
[32] A. Uranga, G. Sobreviela, M. Riverola, F. Torres, and N. Barniol," Phase-Noise Reduction in a CMOS-MEMS Oscillator under Nonlinear MEMS Operation," *IEEE Trans. Circuits Syst. I Regul. Pap.*, vol. 64, no. 12, pp. 3047–3055, 2017.
[33] N. Kamarudin, J. Karim, and H. Hussin," Transimpedance Amplifier for MEMS SAW Oscillator in 1.4GHz", International Conference on Applied Electronic and Engineering 2017 (ICAEE2017).
[34] M. Hamzah, J. Karim, A. Ralib and A. Nordin," Design and analysis of a boosted pierce oscillator using MEMS SAW resonators", Microsystem Technologies, Springer, 2017.
[35] A. Kourani, Y. Song, B. Arakawa, R. Lu, J. Guan, A. Gao and S. Gong," A 150 MHz Voltage Controlled Oscillator using Lithium Niobate RF-MEMS Resonator", 2017 IEEE.
[36] J. Stegner, U. Stehr, C. Tu, J. Lee and M. Hein," Very-Low Phase Noise RF-MEMS Reference Oscillator Using AlN-on-Si Resonators Achieved by Accurate Co-Simulation", 2017 IEEE.
[37] A. Uranga, G. Sobreviela, M. Riverola, F. Torres, and N. Barniol," Phase-Noise Reduction in a CMOS-MEMS Oscillator Under Nonlinear MEMS Operation", IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS–I: REGULAR PAPERS, VOL. 64, NO. 12, DECEMBER 2017.
[38] G. Sobreviela, M. Riverola, F. Torres, A. Uranga and N. Barniol," Optimization of the close-to-carrier Phase Noise in a CMOS-MEMS oscillator using a Phase Tunable Sustaining-Amplifier", IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, 2017.
[39] F. Lut, N. Kamarudin and J. Karim," Current Reference Pierce Oscillator Circuit Topology for Low Phase Noise MEMS SAW Oscillator", INTERNATIONAL JOURNAL OF ELECTRICAL AND ELECTRONIC SYSTEMS RESEARCH, 2018.

[40] A. Kourani, R. Lu, T. Manzaneque, Y. Yang, A. Gao, and S. Gong," A 175 MHz 72 μW Voltage Controlled Oscillator with 1.4% Tuning Range based on Lithium Niobate MEMS Resonator and 65 nm CMOS", 2018 IEEE/MTT-S International Microwave Symposium.
[41] J. Zhao, Q. Yuan, H. Sun, J. Yang, and L. Sun," A high-performance oscillator based on RF MEMS resonator and low-noise sustaining circuit for timing applications", IEICE Electronics Express, Vol.15, No.10, 1–9,2018.
[42] M. Li, C. Chen, and S. Li," A Study on the Design Parameters for MEMS Oscillators Incorporating Nonlinearities", IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS,2018.
[43] J. Stegner, M. Fischer, S.Gropp, U. Stehr, J. Muller, M. Hoffmann, and M. Hein," A Multi-Frequency MEMS-Based RF Oscillator Covering the Range from 11.7MHz to 1.9GHz", 2018 IEEE/MTT-S International Microwave Symposium.
[44] G. Mussi, M. Carrara, G. Langfelder, G. Gattere," Polysilicon MEMS Resonator for 28-MHz Oscillators", 2019 IEEE.
[45] S. Habermehl, N. Bajaj, S. Shah · D. Quinn,D. Weinstein and J. Rhoads," Synchronization in a network of coupled MEMS-Colpitts Oscillators", Springer, 2019.
[46] J. Stegner, M.Fischer, S. Gropp, U. Stehr, and M. Hein," MEMS-Based RF Oscillators Using SiCer Technology", October 2019, IEEE microwave magazine.
[47] A. Bouchami, M. Elsayed and F. Nabki," A Sub-mW 18-MHz MEMS Oscillator Based on a 98-dBΩ Adjustable Bandwidth Transimpedance Amplifier and a Lamé-Mode Resonator", Sensors 2019.
[48] S. Seok, G. Cristiano and T. Jang," Design of Ultra-Low Power Pulse-Driven MEMS Oscillator", 2020 IEEE.
[49] A. Kourani , Y. Yang and S. Gong. ," A *Ku*-Band Oscillator Utilizing Overtone Lithium Niobate RF-MEMS Resonator for 5G", IEEE MICROWAVE AND WIRELESS COMPONENTS LETTERS, VOL. 30, NO. 7, JULY 2020.
[50] A. Kourani, Y. Yang, and S. Gong," An X-Band Oscillator Utilizing Overtone Lithium Niobate MEMS Resonator and 65-nm CMOS", 2020 IEEE.
[51] A. Srivastava, B. Chatterjee, U. Rawat, Y. He, D. Weinstein and S. Sen," Analysis and Design Considerations for Achieving the Fundamental Limits of Phase Noise in mm Wave Oscillators with On-Chip MEMS Resonator", 2020 IEEE.
[52] F. Nawaz1a, M. Sulaiman, U. Jamil and R. Shakoor," System Model Extraction of MEMS Beam Resonator for Colpitts Crystal Oscillator", February 2020.
[53] A. Kourani, R. Lu and S. Gong," A Wideband Oscillator Exploiting Multiple Resonances in Lithium Niobate MEMS Resonator", IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, Volume: 67, Issue: 9, Sept. 2020.
[54] A. Kourani, Y. Yang and S. Gong," L- and X-Band Dual-Frequency Synthesizer Utilizing Lithium Niobate RF-MEMS and Open-Loop Frequency Dividers" IEEE Transactions on Ultrasonics, Ferroelectrics, And Frequency Control, Vol. 68, No. 5, May 2021.
[55] A. Kira, M. Elsayed , K. Allidina , V. Chodavarapu and M. El-Gamal," A 6.89-MHz 143-nW MEMS Oscillator Based on a 118-dBΩ Tuneable Gain and Duty-Cycle CMOS TIA", Electronics 2021.
[56] R. Perelló-Roig, J. Verd, S. Bota and J. Segura," A Tuneable-Gain Transimpedance Amplifier for CMOS-MEMS Resonators Characterization", Micromachines 2021.