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Ultra low phase noise and high output power monolithic microwave integrated circuit oscillator for 5G applications

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ABSTRACT

A novel structure of low phase noise and high output power monolithic microwave integrated circuit (MMIC) oscillator is presented in order to use it in 5G applications. The oscillator is based on the ED02AH process which allows us to design a microwave oscillator keeping a minimum size which is impossible to have it using other technologies since microwave oscillators are sensitive components above 20 GHz. The oscillator is studied, designed, and optimized on a GaAs substrate from the OMMIC foundry using the advanced design system (ADS) simulator in order to obtain a miniaturized oscillator (1.1×1.3 mm^2) generating two signals of different frequencies f_{o1}=26 GHz and f_{o2}=30 GHz. The objective is to design an oscillator with high output power and low phase noise while respecting its specifications. The optimization of the proposed microwave oscillator shows satisfying results. Indeed, at 26 GHz and 30 GHz, the output powers are respectively 13.33 dBm and 14.89 dBm. The oscillator produces a sinusoidal signal of 1.5 V and 1.75 V amplitude respectively at 26 GHz and 30 GHz. The oscillator phase noise at f_{o1} and f_{o2} resonance frequencies using the liquid crystal (LC) resonator shows respectively -109 dBc/Hz and -110 dBc/Hz at 10 MHz offset.

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1. INTRODUCTION

A monolithic microwave integrated circuit (MMIC) [1]–[3] is a type of integrated circuit device that are dimensionally small (from around 1 mm² to 10 mm²) and can be mass-produced. MMICs used metal-semiconductor field-effect transistors (MESFETs) as the active device and more recently high electron mobility transistors (HEMTs), pseudomorphic HEMTs and hetero-junction bipolar transistors (HBTs). Indeed, transistors operating in microwaves have become very numerous and can be on different substrates like gallium arsenide (GaAs) and gallium nitride (GaN) in order to use them in the design of power amplifiers PAs, low noise amplifiers LNAs, switching, mixer, filters, and oscillator's circuits.

Recently several studies have been done using the MMIC technology. The first step in the design of a circuit will have to be concerned with the choice of active component, so a technology [4]. Once the choice of the active component is made, it is necessary to have models which describe the performances corresponding to the circuit to be made and this according to the width of the grids for the field-effect transistors (FETs) or the length of the transmitter for the hetero-junction bipolar transistor (HBT) [5]. For instance, in [6], the voltage controlled oscillator (VCO) is based on an liquid crystal (LC) resonator and can be implemented in a single MMIC and itis characterized by low cost, low weight and so low size. However, in [7] and [6], the continuously tunable bandwidth is limited and the phase noise only moderate. In [8], the push-push strategy is applied to coplanar MMIC with InGaPi-GaAs-HBTs, which are known to combine 1/f noise with mm-wave capabilities. Moreover, the wideband, and low noise differential yttrium garnet (YIG) tuned oscillator is presented in [9]. It is based on SiGe MMIC and transmission type YIG resonator. This oscillator with a short transmission line offers oscillator frequencies with a tuning range from 23 to 48.2 GHz. Finally, in [10], the dual band oscillator using single ring resonator employs step impedance (SI) which contains two orthogonal resonant mode and two different frequencies as negative resistance devices.

Indeed, today, thanks to MMIC and 5G technologies, it is possible to integrate on the same substrate any satellite transmission-reception chain that works at very high frequencies [11], [12]. In such systems, the microwave sources consisting of a varied combination of oscillators [13], phase-locked circuits, amplifiers, multipliers [14], [15], occupy a place that is often fundamental. The main element is of course the oscillator. In fact, the microwave oscillator, which is a circuit that changes direct current (DC) power to radio frequency (RF) power, is one of the most important components in microwave systems [16], [17].

For this, the main work of this paper is the study and the design of an oscillator in MMIC technology whose working frequencies are 26 GHz and 30 GHz using pseudomorphic high electron mobility transistor (pHEMT). In fact, satellite earth stations in 26 GHz band are used for receiving earth observation data, for example satellite imagery and climate data, from earth exploration satellite systems. And in 30 GHz they are used for communications satellite systems [18]. The paper is organized as follows. Section 2 describes the procedure and research method of the studied oscillator. Section 3 presents the results found and also performs a comparative study with other recently published works. Finally, a conclusion is made to summarize the whole work.

2. DESIGN PROCEDURE AND RESEARCH METHOD OF MMIC OSCILLATOR

We are facing a challenge whose goal is to design an oscillator capable of generating two different signals at 26 GHz and 30 GHz and characterized by low phase noise and high output power comparing it with previous works. The first step is the choice of the appropriate technology and the size of active element as well as the bias network, and the second one consists of study of stability circuit. In our case, to be able to meet the needs of our specifications and to achieve our goal, we used LC resonator that it contribute generally for having good performances at high frequencies as well as the OMMIC technology, something that will add value to our work in term of phase noise and output power. In what follows, we will detail the design procedure and method followed by the results as well as the discussion. The circuit is designed in MMIC technology in ED02AH process from OMMIC foundry using advanced design system (ADS) software from Agilent. This MMIC oscillator based on LC resonator will be suitable for wireless communication systems of the next generation 5G mm-wave band.

2.1. Choice of active element

The most important part of the active component is the choice of transistor to be used with the adequate size. The transistor plays a vital role in the power output and the amount of phase noise in the final oscillator; therefore, the choice of transistor needs careful consideration. In this respect, the selected process in this work is developed by OMMIC foundry and we choice ED02OH pHEMT process with gate length equal to 0.18 μm and total size is nxw as shown in Figure 1, and it is based on a GaAs technology.

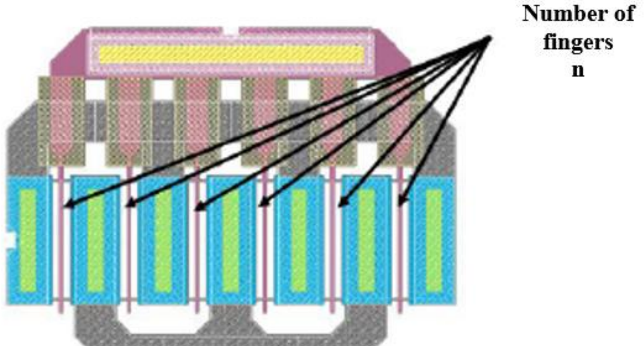


Figure 1. Layout of fED02ONl transistor for ED02OH process (6×15 μm)

2.2. Design of LC resonator

LC oscillator is a type of oscillator where an inductor-capacitor resonant circuit is used for giving the required positive feedback for sustaining the oscillations as shown in Figure 2. Moreover, according to the Barkhausen criterion for sustained oscillations, a circuit will sustain stable oscillations only for frequencies at which the loop gain of the system is equal to or greater than 1 and the phase shift between input and output is 0 or an integral multiple of 2 πn. LC oscillators can be realized using bipolar junction transistor (BJT), field effect transistor (FET), metal oxide semiconductor field effect transistor (MOSFET), and metal-semiconductor field effect transistor (MESFET). In our case, we will use ED02OH pHEMT as mentioned in the previous part.

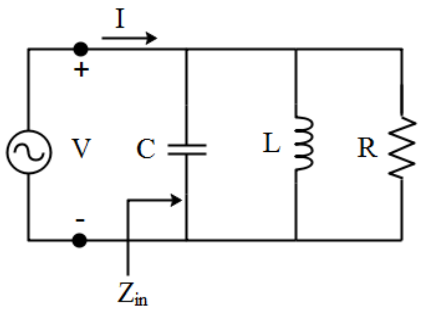


Figure 2. Resistor, inductor, and capacitor (RLC) resonator circuit

Furthermore, this type of oscillators is commonly used at very high frequencies comparing it with the lumped elements. They are not suitable for use as very low frequency because the inductors and the capacitors would be large in size, heavy and costly to manufacture. The input impedance Zin of the resonator can be written using RLC network components:

$$Z_{in} = \frac{s\frac{1}{C}}{s^2+s(\frac{1}{CR})+(\frac{1}{LC})} \tag{1}$$

The resonance and quality factor are calculated by determining the poles of the expression (1) where w_0 is the resonance frequency and Q is the quality factor of the resonator.

$$\frac{w_0}{Q} = \frac{1}{CR} \tag{2}$$

$$w_0 = \frac{1}{\sqrt{LC}} \tag{3}$$

$$Q = \frac{R}{w_0 L} = w_0 RC \tag{4}$$

To sum up, the quality factor can be considered as a measure of the energy storage efficiency of the LC circuit. The equations from (1) to (4) describe the fundamental response of parallel RLC circuit. The power dissipated in the circuit is the result of losses in the resonator due to the non-ideality of the circuit elements. To overcome them, an applied energy must be introduced. This can be done by the negative resistance resulting from the transconductance (gm) of an amplifier in order to maintain the oscillations. Table 1 shows the values of ideal elements of LC resonator using the equations mentioned above at 26 GHz and 30 GHz. Typical applications of LC oscillators include RF signal generators, frequency mixers, tuners, sine wave generators, and RF modulators.

Table 1. Value of ideal elements of LC resonator

	26 (GHz)	30 (GHz)
Q	500	500
R (Ω)	725	260
L (pH)	8.87	9.19
C (pF)	4.22	10.20

2.3. Study of circuit stability

The S-parameter formulation was introduced by Ohira *et al*. [11] which states that for absolute stability, two conditions must apply:

$$\mathrm{K} < 1 \text{ and } \mathrm{B} < 0 \quad (5)$$

K and B are respectively the stability factor and measurement stability, in practice K<1 is taken by the vast microwave community as the condition for absolute stability [19], [20].

$$\mathrm{k} = \frac{1-|S_{11}|^2-|S_{22}|^2+|S_{11}S_{22}-S_{12}*S_{21}|}{2|S_{12}S_{21}|} > 1 \quad (6)$$

$$\mathrm{B} = 1 + |S_{11}|^2 - |S_{22}|^2 - |\Delta|^2 \quad (7)$$

Where

$$\Delta = S22S11 - S12\,S21 \quad (8)$$

2.4. Phase noise

All the components of an oscillator produce noise and more precisely it comes from the active component. Therefore, the sources combine to form amplitude and phase modulation noise. Generally, phase noise is the most considered because it directly affects the stability of the oscillation frequency. The phase noise performance described in Leeson's formula [21]:

$$\mathrm{L}(\Delta \mathrm{w})\ \alpha\ \mathrm{F}\ \frac{4\mathrm{KTR}_{\mathrm{tank}}}{\mathrm{v}_0^2}\ \left(\frac{\mathrm{w}_0}{2\Delta \mathrm{w} \mathrm{Q}_{\mathrm{tank}}}\right) \quad (9)$$

where F is noise factor. K is boltzman constant. T is temperature. v_0 is signal amplitude. w_0 is Center frequency. $Q_{tank}$is load quality factor.

3. RESULTS AND DISCUSSION

In order to verify the MMIC oscillator performance in terms of stability factor, oscillator frequency, phase noise and output power, a set of simulations are performed in harmonic balance simulator using ADS software from Agilent. The oscillator proposed in Figure 3 is mounted on a GaAs substrate with a thickness of 100 µm. The size (nxw) of the fED02ONL transistor in GaAs-pHEMT technology is determined so as to have a minimum stability factor. The advantage of using this type of transistor is to have a low phase noise oscillator. The drain-to-source voltage of the transistor is V_{ds}=3.4 V and the DC power consumption is about 340 mW.

From Figure 4(a), we observe that the stability factor decreases by adding the number of fingers. Therefore, the optimal number of fingers is n_{opt}=8. And by setting n to 8, the width of the transistor is varied. As shown in Figure 4(b), the results show that the optimal value of w is 30 µm. It should be noted that the optimal value is chosen in such a way as to obtain a minimum stability factor and of very small dimensions. Therefore, the size of the studied transistor fED02ONl pHEMT is: n_{opt}xw=8x30 µm.

The ideal localized elements of the resonators RiLiCi are replaced by real elements supplied by the OMMIC foundry. Resistors, capacitors, and inductors are successively of the NiCr type (tRwED2AH), lumped MIM Si3N4 capacitors model (CbetaED2) and spiral inductor model (indED02EH). The resonant frequency of R1L1C1 is 26 GHz while the resonant frequency of R2L2C2 is 30 GHz. The optimized values of these elements are shown in the Table 2.

In order to generate an RF signal to the load, the oscillator must be unstable. However, the use of the inductance in series with source of the transistor allowed us to create a conditionally stable circuit at a narrow frequency. For this, we had to add a capacity Csi in parallel with the inductance Lsi to have an unstable circuit. In Figures 5(a) and (b), the results show that the previous condition of stability is satisfied (K<1 and B<0) at both of studied frequencies (26 GHz and 30 GHz).

It remains to verify the oscillation condition in relation to the reflection coefficients for the two input and output ports for the two blocks. The Figure 6 shows that the reflection coefficients S11 and S22 for the two blocks at both frequencies 26 GHz and 30 GHz at port 1 and port 2 are greater than unity, which satisfies the maintenance of the oscillation at these two studied frequencies. From this study we can see that all the oscillation conditions are satisfied to generate two RF signals at the two ports P1 and P2 of respective frequencies 26 and 30 GHz.

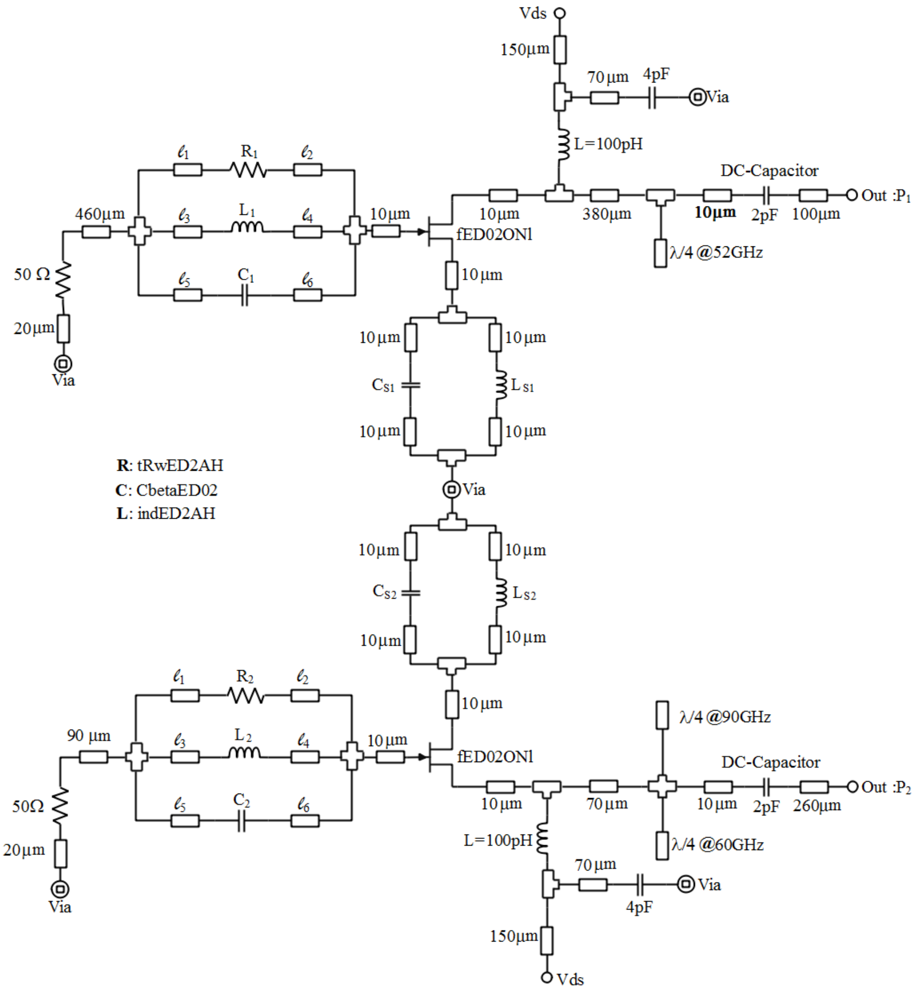
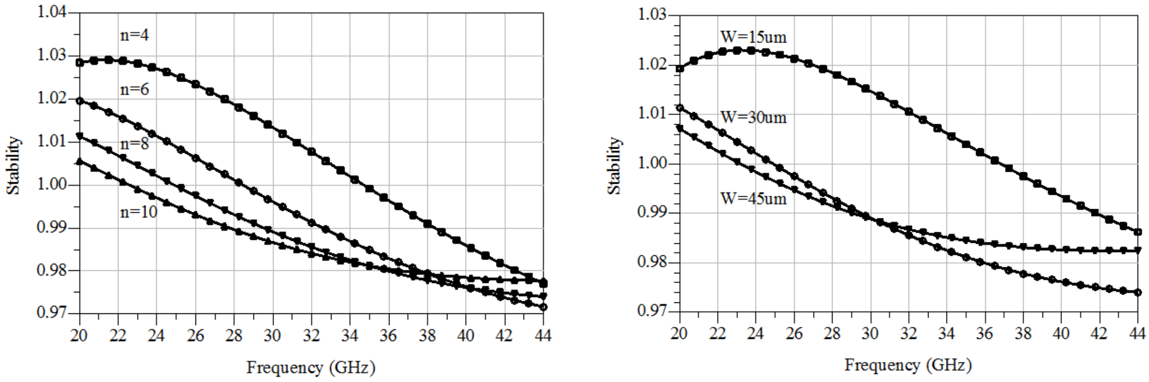


Figure 3. RLC resonator circuit



(a) (b)

Figure 4. Transistor stability factor for different values of (a) number of fingers and (b) length of fingers

Table 2. Values of real elements of RLC resonators (li in µm)

26 GHz						30 GHz					
$R_1(\Omega)$		L_1(pH)		C_1(pF)		$R_2(\Omega)$		L_2(pH)		C_2(pF)	
725		220		8		260		130		2.8	
ℓ_1	ℓ_2	ℓ_3	ℓ_4	ℓ_5	ℓ_6	ℓ_1	ℓ_2	ℓ_3	ℓ_4	ℓ_5	ℓ_6
272	950	272	950	500	500	272	950	272	950	500	500

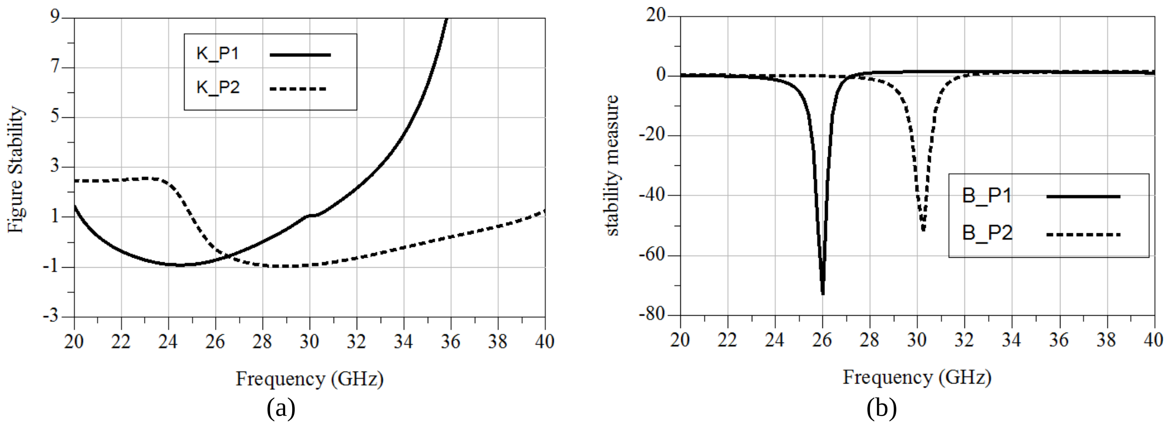


Figure 5. Evolution of (a) stability factor K and (b) stability measurement B

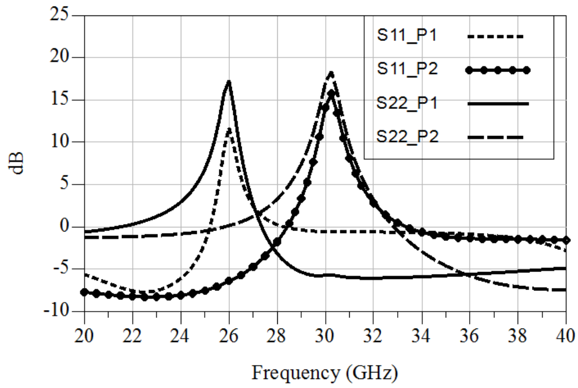


Figure 6. S_{11} and S_{22} simulated characteristics of the proposed MMIC oscillator

The transistor fED0ONl is a nonlinear element which is capable to generate harmonics which affect the output signal causing it a possible distortion as seen in Figure 7 which shows us the spectrum of the output with the $2f_0$ and $3f_0$ harmonics at Figure 7(a) and time domain output signal of the studies oscillator of the two ports at Figure 7(b). For this, resonators of $\lambda/_4$ length are added to the output of the two ports in order to suppress these unwanted harmonics. Table 3 shows the results of factor stability K and measured stability B of studied oscillator at both of 26 GHz and 30 GHz and Table 4 shows the length of resonators.

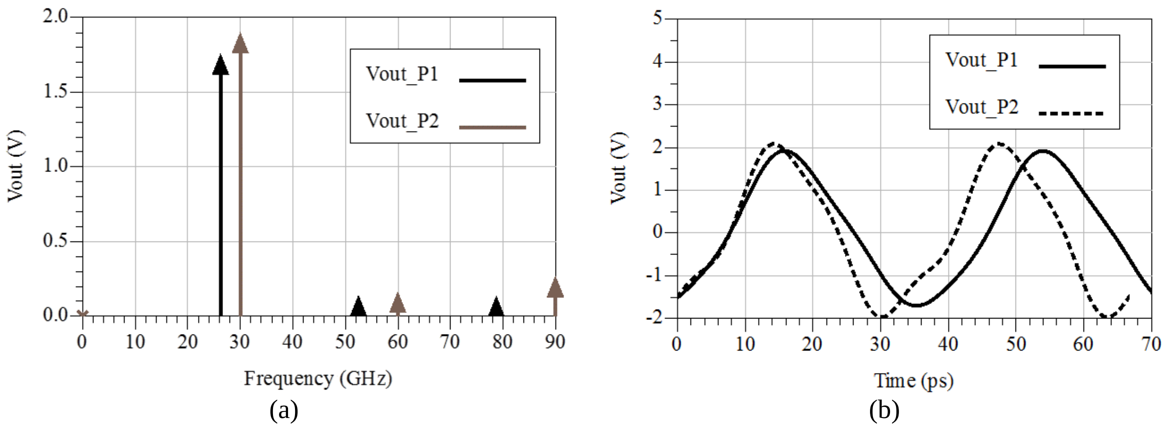


Figure 7. Output signal of proposed MMIC oscillator (a) signal spectrum and (b) time domain

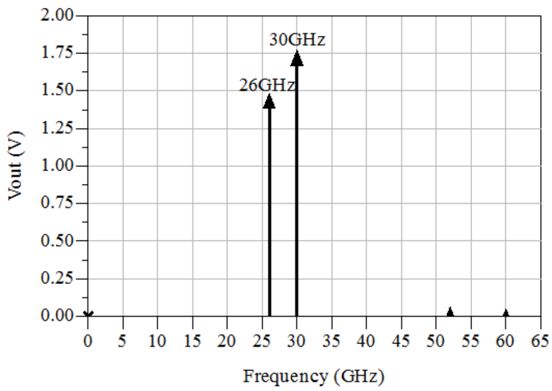
Table 3. Factor stability and measured stability at 26 GHz and 30 GHz

Stability@ 26 GHz (L_{S1}=123 pH and C_{S1}=0.75 pF)		Stability@ 30 GHz (L_{S2}=118 pH and C_{S2}=0.5 pF)	
K_1	B_1	K_2	B_2
-0.919	-74	-0.95	-53

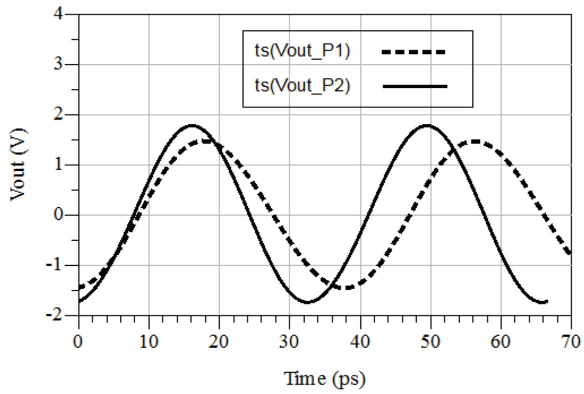
Table 4. Length of $\lambda/4$ resonators

$L_{\lambda/4}$@ 52 GHz	$L_{\lambda/4}$@ 60 GHz	$L_{\lambda/4}$@ 90 GHz
400 µm	300 µm	141 µm

After adding the $\lambda/4$ resonators, the result becomes as shown in Figure 8. The Figure 8(a) shows the spectrum of output signal while Figure 8(b) shows the time domain output signal for the two ports at both studied frequencies 26 GHz and 30 GHz. As shown in Figure 9, the proposed circuit achieves an ultra-low phase noise (PN) in the two ports P_1 and P_2. The PN at P_1 for f_{o1}=26 GHz is -88 dBc/Hz, -109 dBc/Hz and -129 dBc/Hz respectively at 100 KHz, 1 MHz and 10 MHz. However, for f_{o2}=30 GHz at the port P_2, the PN is -98.08 dBc/Hz, -110 dBc/Hz and -130 dBc/Hz at the same frequencies.



(a)



(b)

Figure 8. Final output signal of proposed MMIC oscillator (a) signal spectrum and (b) time domain

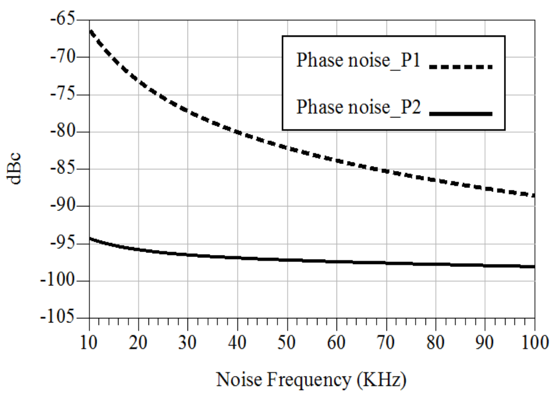


Figure 9. Phase noise of proposed MMIC oscillator

For sum up, as seen in Table 5, if we compare this work with others like [22]–[26], we find that our oscillator meets our needs and specifications; it's more relevant with regard to phase noise (-88 dBc/Hz, -109 dBc/Hz and -129 dBc/Hz for 26 GHz and -98.08 dBc/Hz, -110 dBc/Hz and -130 dBc/Hz for 30 GHz respectively at 100 KHz, 1 MHz and 100 MHz) and output supplied P_{out} (13.33 dBm for 26 GHz and 14.89 dBm for 30 GHz). Indeed, we observe a significant difference of its values by comparing it with previous works. As well as for example, the work [27] is based on the same technology that we used in this MMIC oscillator, however, it got a very low achieved power at the output compared to our work.

Finally, Figure 10 shows the layout of the proposed ultra-low phase noise dual band MMIC oscillator which is characterized by its miniature size compared to other works which only support a single oscillation frequency, on the other hand in our work, the studied oscillator is designed for the generation of two RF signals at 26 GHz and at 30 GHz keeping a miniature size which is 1.43 mm^2. It is to highlight that the realization of this type of oscillators can only be done exclusively through the OMMIC foundry.

Table 5. Performance comparison of different oscillators

	Techno (um)	Freq (GHz) F0 res	Dissipated power (mW)	Pout (dBm)	Size mm^2	Phase noise dBc/Hz		
						@100 KHz	@1 MHz	@10 MHz
[21]	28 nm-CMOS	27.3	11.58		0.15	-83	-106	-126
		31.2	13.5	NA		-80	-104	-125
[22]	65 nm-CMOS	27.5	23	~ -8	1.2x1	-72	-100	-126
[23]	0.25 µm-GaN HEMT	15.05	63	-6	2 x 1	-106	-133	NA
[24]	0.13 µm-SiGe	29.6	18			NA	-100	NA
	BiCMOS	35.5	20	NA	0.1	NA	-90	NA
[25]	0.13 µm-SiGe HBT	36.3	132	NA	0.1x0.12	NA	-75	NA
[26]	0.15 µm-GaAs pHEMT	37.608 ~ 38.06	129.9	10.46	NA	-82.2	-112	NA
This	0.18 µm-GaAs	26	183	13.33		-88	-109	-129
work	pHEMT	30	171	14.89	1.1x1.3	-98.08	-110	-130

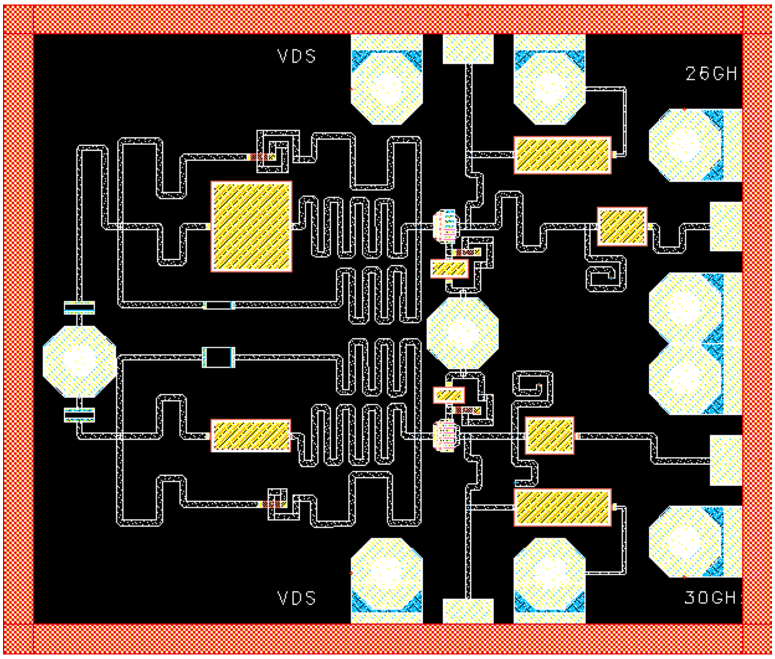


Figure 10. Layout of the proposed ultra-low phase noise dual band MMIC oscillator (1.1×1.3 mm^2)

4. CONCLUSION

The MMIC technique in oscillator applications is used for a low cost and low phase noise performance. For this, in this paper we studied and designed a novel miniaturized oscillator with MMIC technology for 5G applications in order to generate two RF signals at 26 and 30 GHz using Agilent ADS. The results obtained during the study satisfied all the oscillation conditions necessary at these two frequencies and are satisfactory with regard to phase noise, output spectrum and output time domain signal. Indeed, to conclude, we can say that we were able to realize an oscillator capable of generating two sinusoidal RF signals while keeping a minimal surface by comparing it with the old works and which is

1.43 mm^2. In addition, this MMIC oscillator is characterized by maximum output power equal to 13.33 dBm for 26 GHz and 14.89 dBm for 30 GHz which is seen as an added value to this work.

REFERENCES

[1] J. O. Plouchart, H. Wang, C. Pinatel, M. Riet, P. Berdaguer, and C. Dubon-Chevallier, "HBT MMICs for L band mobile radiocommunications," in *Proceedings of 1994 IEEE Microwave and Millimeter-Wave Monolithic Circuits Symposium*, 1994, pp. 233–236, doi: 10.1109/MCS.1994.332096.

[2] H. Blanck *et al.*, "Fully monolithic Ku and Ka-band GaInP/GaAs HBT wideband VCOs," in *1994 IEEE MTT-S International Microwave Symposium Digest (Cat. No.94CH3389-4)*, pp. 127–130, doi: 10.1109/MWSYM.1994.335349.

[3] K. J. Anderson and D. L. Allen, "A miniature integrated monolithic VCO module," in *IEEE MTT-S International Microwave Symposium Digest*, 1988, pp. 495–498, doi: 10.1109/MWSYM.1988.22082.

[4] J. Portilla, M. Campovecchio, R. Quéré, and J. Obregon, "A new coherent extraction method of FET and HEMT models for MMIC applications," in *GaAs'94-European Gallium Arsenide Applications Symposium*, 1994, pp. 377–380.

[5] E. Reese and J. M. Beall, "Optimized X and Ku band GaAs MMIC varactor tuned FET oscillators," in *IEEE MTT-S International Microwave Symposium Digest*, 1988, pp. 487–490, doi: 10.1109/MWSYM.1988.22080.

[6] M. Van Delden, N. Pohl, and T. Musch, "An ultra-wideband fast frequency ramp synthesizer at 60 GHz with low noise using a new loop gain compensation technique," *IEEE Transactions on Microwave Theory and Techniques*, vol. 66, no. 9, pp. 3937–3946, Sep. 2018, doi: 10.1109/TMTT.2018.2851991.

[7] T. N. T. Do *et al.*, "7–13 GHz MMIC GaN HEMT voltage-controlled-oscillators (VCOs) for satellite applications," in *2017 12th European Microwave Integrated Circuits Conference (EuMIC)*, Oct. 2017, pp. 220–223, doi: 10.23919/EuMIC.2017.8230699.

[8] A. Schott, H. Kuhnert, F. Lenk, J. Hilsenbeck, J. Wurfl, and W. Heinrich, "38 GHz push-push GaAs-HBT MMIC oscillator," in *IEEE MTT-S International Microwave Symposium Digest (Cat. No.02CH37278)*, 2002, pp. 839–842, doi: 10.1109/MWSYM.2002.1011761.

[9] M. van Delden, N. Pohl, K. Aufinger, C. Baer, and T. Musch, "A low-noise transmission-type yttrium iron garnet tuned oscillator based on a SiGe MMIC and bond-coupling operating up to 48 GHz," *IEEE Transactions on Microwave Theory and Techniques*, vol. 67, no. 10, pp. 3973–3982, Oct. 2019, doi: 10.1109/TMTT.2019.2926293.

[10] B. Li, Y. Liu, C. Yu, and Y. Wu, "A novel concurrent dual-band oscillator based on a single ring resonator," *IEEE Microwave and Wireless Components Letters*, vol. 26, no. 8, pp. 607–609, Aug. 2016, doi: 10.1109/LMWC.2016.2585567.

[11] T. Ohira, T. Tokumitsu, T. Hiraoka, Y. Kihata, K. Araki, and H. Kato, "Development of key monolithic circuits to ka-band full MMIC receivers," in *Microwave and Millimeter-Wave Monolithic Circuits*, vol. 87, pp. 69–74, doi: 10.1109/MCS.1987.1114518.

[12] T. Ohira, H. Kato, K. Araki, and F. Ishitsuka, "A compact full MMIC module for Ku-band phase-locked oscillators," *IEEE Transactions on Microwave Theory and Techniques*, vol. 37, no. 4, pp. 723–728, Apr. 1989, doi: 10.1109/22.18845.

[13] S. B. Moghe and T. J. Holden, "High-performance GaAs MMIC oscillators," *IEEE Transactions on Microwave Theory and Techniques*, vol. 35, no. 12, pp. 1283–1287, Dec. 1987, doi: 10.1109/TMTT.1987.1133849.

[14] A. Adar and R. Ramachandran, "An HBT MMIC wideband VCO," in *1991 IEEE MTT-S International Microwave Symposium Digest*, pp. 247–250, doi: 10.1109/MWSYM.1991.146974.

[15] G. Dietz, R. Becker, R. Haubenstricker, S. Moghe, and G. Giacomino, "A 10-14 GHz quenchable MMIC oscillator," in *IEEE 1991 Microwave and Millimeter-Wave Monolithic Circuits Symposium. Digest of Papers*, pp. 23–26, doi: 10.1109/MCS.1991.148079.

[16] N. Kazemy Najafabadi, S. Nemati, and M. Dousti, "Design of MMIC oscillators using GaAs 0.2 μm PHEMT technology," *Journal of Zhejiang University Science C*, vol. 13, no. 10, pp. 793–798, Oct. 2012, doi: 10.1631/jzus.C1200013.

[17] S. Ramesh, M. Nithin, and H. M. Kittur, "Design of millimeter wave LC oscillators for 5G applications," in *2019 International Conference on Communication and Signal Processing (ICCSP)*, Apr. 2019, pp. 0935–0939, doi: 10.1109/ICCSP.2019.8697905.

[18] G. Anzic and D. J. Connolly, "20 and 30 GHz MMIC technology for future space communication antenna systems." NASA Technical Memorandum 83745, 1985.

[19] H. Sutcliffe, "Broadband feedback amplifiers," *Electronics and Power*, vol. 29, no. 1, Art. no. 99, 1983, doi: 10.1049/ep.1983.0052.

[20] A. Platzker and W. Struble, "Rigorous determination of the stability of linear n-node circuits from network determinants and the appropriate role of the stability factor K of their reduced two-ports," in *Third International Workshop on Integrated Nonlinear Microwave and Millimeterwave Circuits*, pp. 93–107, doi: 10.1109/INMMC.1994.512515.

[21] D. B. Leeson, "A simple model of feedback oscillator noise spectrum," *Proceedings of the IEEE*, vol. 54, no. 2, pp. 329–330, 1966, doi: 10.1109/PROC.1966.4682.

[22] Y. Hu, T. Siriburanon, and R. B. Staszewski, "A 30-GHz class-F23 oscillator in 28nm CMOS using harmonic extraction and achieving 120 kHz 1/f 3 corner," in *ESSCIRC 2017-43rd IEEE European Solid State Circuits Conference*, Sep. 2017, pp. 87–90, doi: 10.1109/ESSCIRC.2017.8094532.

[23] T. Siriburanon *et al.*, "A 28-GHz fractional-N frequency synthesizer with reference and frequency doublers for 5G cellular," in *ESSCIRC Conference 2015-41st European Solid-State Circuits Conference (ESSCIRC)*, Sep. 2015, pp. 76–79, doi: 10.1109/ESSCIRC.2015.7313832.

[24] M. Horberg and D. Kuylenstierna, "Low phase noise power-efficient MMIC GaN-HEMT oscillator at 15 GHz based on a quasi-lumped on-chip resonator," in *2015 IEEE MTT-S International Microwave Symposium*, May 2015, pp. 1–4, doi: 10.1109/MWSYM.2015.7166767.

[25] M. Kucharski, F. Herzel, H. J. Ng, and D. Kissinger, "A Ka-band BiCMOS LC-VCO with wide tuning range and low phase noise using switched coupled inductors," in *2016 11th European Microwave Integrated Circuits Conference (EuMIC)*, Oct. 2016, pp. 201–204, doi: 10.1109/EuMIC.2016.7777525.

[26] A. Dyskin, S. Wagner, and I. Kallfass, "A compact resistive quadrature low noise Ka-Band VCO SiGe HBT MMIC," in *2019 12th German Microwave Conference (GeMiC)*, Mar. 2019, pp. 95–98, doi: 10.23919/GEMIC.2019.8698169.

[27] C.-L. Chang, C.-H. Tseng, and H.-Y. Chang, "A new monolithic Ka-Band filter-based voltage-controlled oscillator using 0.15 μm GaAs pHEMT technology," *IEEE Microwave and Wireless Components Letters*, vol. 24, no. 2, pp. 111–113, Feb. 2014, doi: 10.1109/LMWC.2013.2290224.

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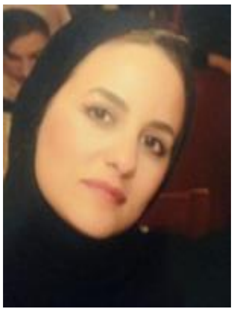

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