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Design of MMIC oscillators using GaAs 0.2 µm PHEMT technology

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Abstract: We propose a feedback type oscillator and two negative resistance oscillators. These microwave oscillators have been designed in the S band frequency. A relatively symmetric resonator is used in the feedback type oscillator. The first negative resistance oscillator uses a simple lumped element resonator which is substituted by a microstrip resonator in the second oscillator to improve results. The negative resistance oscillator produces 4.207 dBm and 7.124 dBm output power with the lumped element resonator and microstrip resonator respectively, and the feedback type oscillator produces −10.707 dBm output power. The feedback type oscillator operates at 3 GHz with phase noise levels at −83.30 dBc/Hz and −103.3 dBc/Hz at 100 kHz and 1 MHz offset frequencies respectively. The phase noise levels of the negative resistance oscillator with the lumped element resonator are −94.64 dBc/Hz and −116 dBc/Hz at 100 kHz and 1 MHz offset frequencies respectively, at an oscillation frequency of 3.053 GHz. With the microstrip resonator the phase noise levels are −99.49 dBc/Hz and −119.641 dBc/Hz at 100 kHz and 1 MHz offset frequencies respectively, at an oscillation frequency of 3.072 GHz. The results showed that both the output power and the phase noise of the negative resistance oscillators were better than those of the feedback type oscillator.

Key words: Microwave oscillator, Feedback type, Negative resistance, Resonator, Advanced design system software
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1 Introduction

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 (Gonzalez, 1997). In fact, it is used to produce the carrier in any communication system that transmits and receives data on a high frequency carrier. The two main parts of the oscillator are an active, nonlinear element that provides gain, and a frequency selective circuit. An oscillator makes an output at the frequency of interest with only a DC signal input and an active part; for example, a transistor makes a sinusoidal steady-state RF signal from a DC source. The oscillation is triggered by noise or a transient signal; as the power is generated, the oscillator's amplitude will be restricted and becomes stable based on nonlinearities of the active device. The stable oscillation state maintains a particular frequency and output power. A resonator is the central part of the oscillator because it is the frequency selective device. At resonance, the transition phase and loss of the network are zero. Phase noise has an important effect on the oscillator's output signal. If the frequency of another signal is near to the signal of interest of the oscillator, both signals mix together and both desired and undesired signals are distributed because, in comparison with the main frequency, the oscillator has finite power at small frequency offsets. Therefore, the interfering signal overlaps the signal of interest and if the undesired signal is larger, a major problem can arise. Two important parameters for controlling the phase noise are the resonator half bandwidth and the flicker corner frequency. Low flicker noise devices and a high Q frequency resonator for reducing the oscillator half bandwidth can be helpful for cleaning up the oscillator spectrum and decreasing the phase noise in communication systems (Chenakin, 2009). In 1966 Leeson showed that maximizing the resonator loaded Q factor can decrease the oscillator phase noise, and Everard proved in 1985 that the maximum phase noise of an oscillator occurs when the ratio of the loaded quality factor (Q_L) to the unloaded quality factor (Q_0) of the resonator is 2/3 (Ain *et al.*, 2001).

Also, the output power requirement of oscillators is determined by the desired application. Feedback type oscillators and negative resistance oscillators are two basic configurations. Here, we present and compare the phase noise levels and output powers of these oscillators (Collin, 1992).

2 Feedback oscillators

A feedback oscillator has three main parts: an amplifier which operates at the desired frequency, a resonator for selecting the frequency, and an output load. Fig. 1 shows the feedback oscillator model. If we consider $V_o(\omega)$ and $V_i(\omega)$ as an output voltage of load and an input voltage respectively of a feedback network, and A and B as an open loop gain and the feedback factor respectively, then

$$V_o(\omega)=A\cdot V_i(\omega)+A\cdot B\cdot V_o(\omega). \tag{1}$$

The oscillator loop gain is achieved by finding $V_o(\omega)$ from Eq. (1). The gain after feedback is shown by A_f:

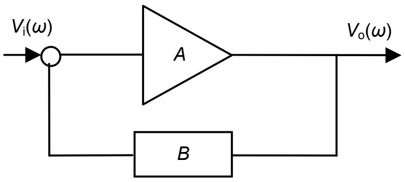


Fig. 1 Closed-loop oscillator model

$$A_f=\frac{A}{1-AB}. \tag{2}$$

We will have a non-zero output with a zero input when $1-AB=0$ and the phase shift is 2π rad.

At the frequency of interest, the phase difference around the feedback loop must be equal to an integral multiple of 2π rad or zero, and the open loop small signal gain must reach a maximum and become greater than unity (Pozar, 1993).

In the feedback type oscillator design, the significant part is a relatively symmetric lumped element resonator in the feedback (Fig. 2).

The following equation represents the computing of the frequency of interest (Ain *et al.*, 2001):

$$f=\frac{1}{2\pi\sqrt{L_3\left(\frac{C_2C_5}{C_2+C_5}+C_4\right)}}. \tag{3}$$

Simulation was carried out with an Agilent ADS harmonic balance simulator using GaAs 0.2 μm PHEMT technology. The process of designing the

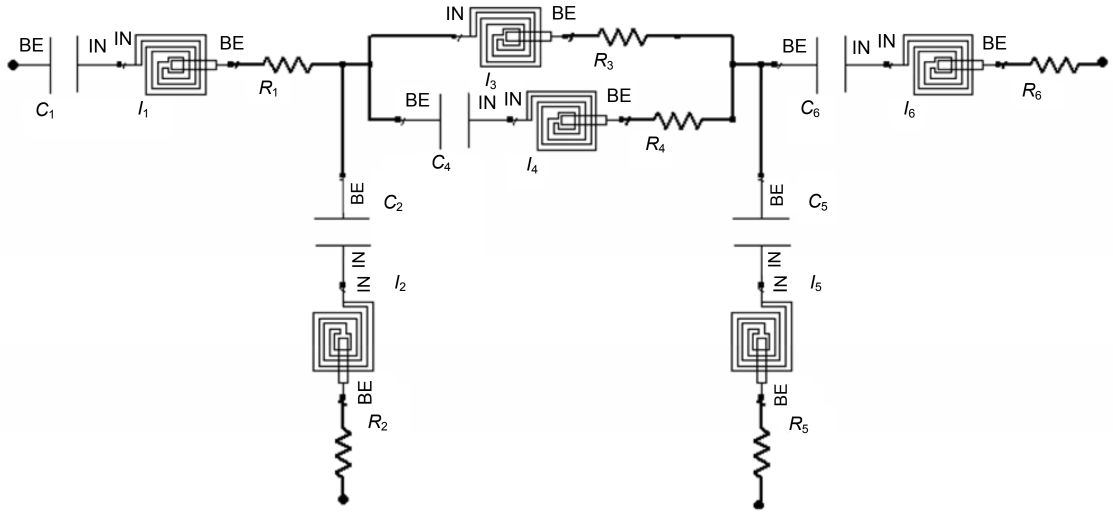
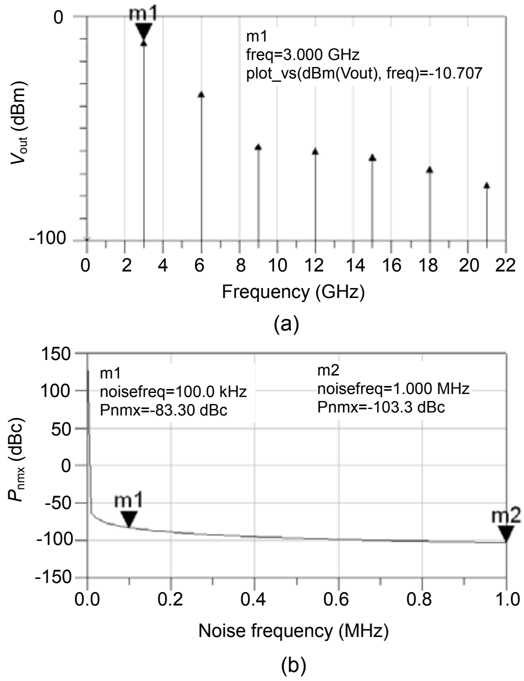


Fig. 2 Lumped element resonator

circuits was as follows. First, we determined the proper bias circuit. Then, by analyzing that circuit, we identified a good work point. After adding the resonator, we analyzed the open loop circuit with consideration of the conditions mentioned previously in the description of the open loop circuit (Mahyuddin *et al.*, 2006; Ramarajn *et al.*, 2011).

We selected the work point V_{DS}=2 V, I_{DS}=20 mA with V_{GS}=0 V when using a field-effect transistor (FET) transistor. The simulated loaded quality factor of the resonator (Q_{L}) was 20 and Q_{L}/Q_0 was 0.88. The open loop small signal mag(S(2, 1)) was 2.69 at zero phase, and the stability factor (k) of this oscillator was −0.0939.

The output power was −10.70 dBm at 3 GHz. The frequency and phase noise of the oscillator at 100 kHz and 1 MHz offsets were −83.30 dBc/Hz and −103.3 dBc/Hz, respectively (Fig. 3).



(a)

(b)

Fig. 3 Simulated frequency spectrum (a) and phase noise (b) of the feedback type oscillator

3 Negative resistance oscillators

A negative resistance oscillator also uses feedback, but it makes negative impedance at an input load. We can divide this type of oscillator into three main parts: an active device, a resonator, and output matching (Fig. 4).

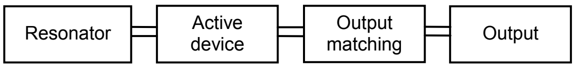


Fig. 4 Oscillator block diagram

The active device and the resonator must compensate the parasitic resistance of the resonator and the imaginary impedance of the active device at the desired oscillation frequency (Ellinger, 2008).

The negative resistor removes loss from the resonator and can be made using a three-terminal active device with true feedback (Fig. 5).

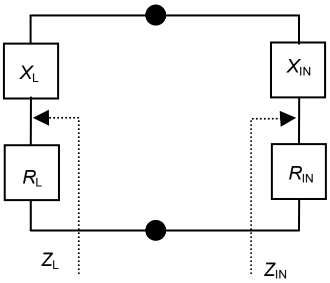


Fig. 5 Negative resistance oscillator model

For the negative resistance design, the circuit must be unstable and the following conditions must be satisfied:

$$R_{\mathrm{IN}}+Z_{\mathrm{L}}<0. \tag{4}$$

With the above condition, oscillation occurs. When the amplitude of the current reaches the value of interest, R_{L} should decrease. When R_{IN} equals R_{L}, a stable oscillation occurs; therefore, we have two other conditions as follows (Razavi, 1989; Greennikov, 1999; Tony, 2001; Gilmore and Besser, 2003; Gonzalez-Posadas *et al.*, 2011):

$$R_{\mathrm{IN}}+R_{\mathrm{L}}=0, \quad X_{\mathrm{IN}}+X_{\mathrm{L}}=0. \tag{5}$$

Based on the theory above, a negative resistance oscillator with a simple resonator consisting of an inductor and a capacitor can be designed and simulated using an Agilent ADS harmonic balance simulator with GaAs 0.2 μm PHEMT technology (Fig. 6).

A DC bias circuit and work point were chosen as a feedback oscillator. The magnitudes of S(1, 1) and S(2, 2) and the stability factor for this transistor were calculated as 2.135, 1.051, and 0.35, respectively, which satisfied the necessary condition for oscillation. Results in Fig. 7 show the oscillation frequency at 3.053 GHz and 4.2 dBm output power, and the phase

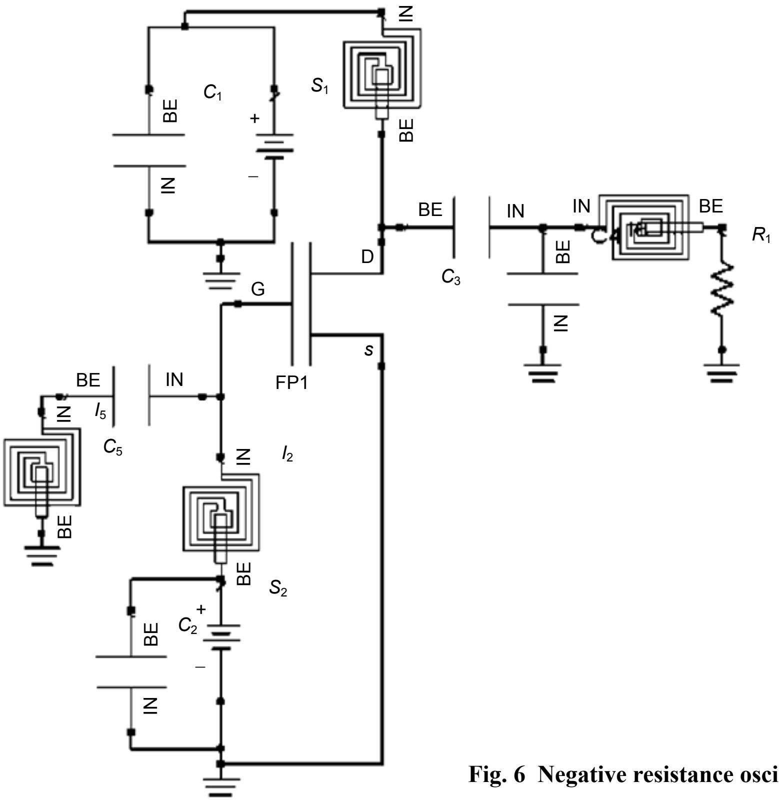


Fig. 6 Negative resistance oscillator circuit

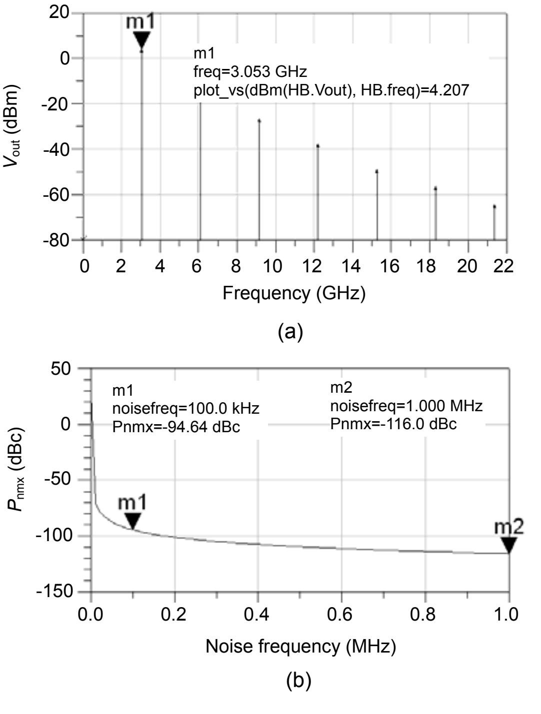


Fig. 7 Simulated frequency spectrum (a) and phase noise (b) of a negative resistance oscillator with a lumped element resonator

noise at −94.64 dBc/Hz and −116 dBc/Hz at 100 kHz and 1 MHz offsets, respectively.

After reaching a proper oscillation, the lumped element resonator was replaced by microstrip lines in the circuit (Krowne, 2006).

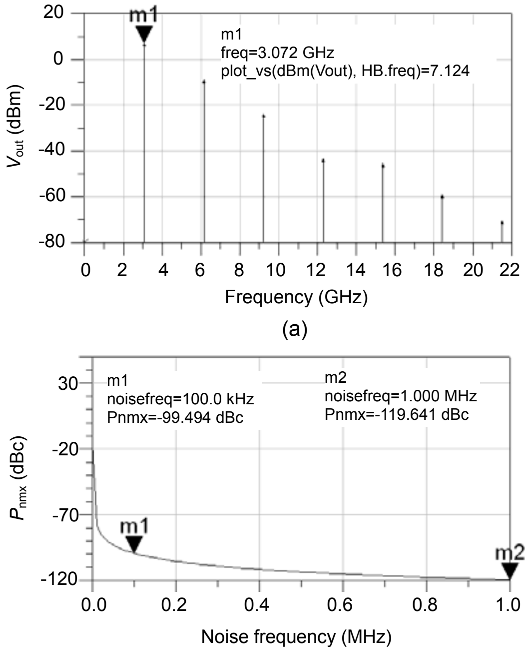
The widths and lengths of the microstrip lines were 0.75 mm and 1.25 mm respectively for the capacitor and 0.27 mm and 1.25 mm respectively for the inductor.

This oscillator showed better results (Fig. 8). The output power of the oscillator was 7.124 dBm at 3.072 GHz, and the phase noise levels were −99.49 dBc/Hz and −119.641 dBc/Hz at 100 kHz and 1 MHz offsets, respectively.

The phase noise levels and output power values of the lumped element and microstrip resonator oscillators are summarized in Table 1.

Table 1 Results of negative resistance oscillators

Output power (dBm)	Phase noise (dBc/Hz)		Type
	100 kHz	1 MHz	
4.207	−94.64	−116	First resonator
7.124	−99.49	−119.641	Microstrip resonator



(a)

(b)

Fig. 8 Simulated frequency spectrum (a) and phase noise (b) of a negative resistance oscillator with a microstrip resonator

4 Summary

In this paper, three oscillators were designed using feedback and negative resistance methods. These oscillators were simulated using an Agilent ADS harmonic balance simulator with GaAs 0.2 μm PHEMT technology. Two of the oscillators were negative resistance types but with different resonators. The microstrip resonator oscillator showed better results than the lumped element resonator oscillator. Fig. 9 presents the oscillatory states of the feedback type and microstrip negative resistance oscillators.

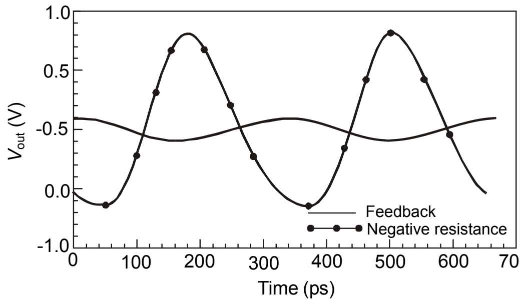


Fig. 9 Output of a feedback type and a negative resistance oscillator with a microstrip resonator

The output power and phase noise of both negative resistance oscillators were better than those of the feedback type oscillator. The performances of the negative resistance oscillators were compared with those from other studies in the S band frequency (Table 2).

Table 2 Comparison with published results in the S-band frequency

Parameter	Value/Description				
	This study	Yoo *et al.* (2010)	Choi *et al.* (2009)	Hauspie *et al.* (2007)	
Technology	GaAs ED02AH 0.2 μm	GaAs HBT	CMOS 0.18 μm	CMOS 0.13 μm	CMOS 0.13 μm
V_{dc} (V)	2.0	2.9	1.8	1.2	1.2
I_{dc} (mA)	20	30		7.7	5.2
P_{dc} (mW)	40		7.2		
f (GHz)	3.072	3.583	2.594	3.1	3.8
Phase noise (dBc/Hz)					
100 kHz	−99.49	−96.7			
600 kHz	−115.2				
1 MHz	−119.641	−118.5		−119	−117
3 MHz	−129.2		−119		
P_{out} (dBm)	7.124	3.65	−12		

We can conclude that our proposed oscillator has reasonable phase noise and output power.

References

Ain, M.F., Lancaster, M.J., Gardner, P., 2001. Design of L-Band Microwave Oscillators. 6th IEEE High Frequency Postgraduate Student Colloquium, p.19-24.

Chenakin, A., 2009. Phase noise reduction in microwave oscillators. *Microw. J.*, **52**:124-140.

Choi, S., Yu, H., Kim, Y., 2009. A 2.4/5.2-GHz dual band CMOS VCO using bias matching network. *J. Semicond. Technol. Sci.*, **9**(4):192-197. [doi:10.5573/JSTS.2009.9.4.192]

Collin, R.E., 1992. Fundamentals of Microwave Engineering (2nd Ed.). McGraw-Hill, NY.

Ellinger, F., 2008. Radio Frequency Integrated Circuits and Technologies (2nd Ed.). Springer Verlag Berlin Heidelberg. [doi:10.1007/978-3-540-69325-3]

Gilmore, R., Besser, L., 2003. Practical RF Circuit Design for Modern Wireless Systems. Vol. 2, Artech House, London.

Gonzalez, G., 1997. Microwave Transistor Amplifiers: Analysis and Design (2nd Ed.). Prentice-Hall, Inc., New Jersey.

Gonzalez-Posadas, V., Jimenez-Martin, J.L., Parra-Cerrada, A., Segovia-Vargas, D., Garcia-Munoz, L.E., 2011. Oscillator accurate linear analysis and design classic linear methods review and comments. *Progr. Electromagn. Res.*, **118**:89-116. [doi:10.2528/PIER11041403]

Greennikov, A.V., 1999. Stability of negative resistance oscillator circuits. *Int. J. Electr. Eng. Educ.*, **36**:242-254.

Hauspie, D., Park, E., Craninckx, J., 2007. Wide-band VCO with simultaneous switching of frequency band, active core, and varactor size. *IEEE J. Solid-State Circ.*, **42**(7):1472-1480. [doi:10.1109/JSSC.2007.899105]

Krowne, C.M., 2006. Network analaysis of microwave oscillators using microstrip transmission lines. *IEEE Electron. Lett.*, **13**(4):115-117. [doi:10.1049/el:19770081]

Mahyuddin, N.M., Ain, M.F., Hassan, S., 2006. Modeling of a 10GHz Dielectric Resonator Oscillator in ADS. Int. RF and Microwave Conf., p.106-110. [doi:10.1109/RFM.2006.331048]

Pozar, D.M., 1993. Microwave Engineering. Addison-Wesley, USA.

Ramarajn, B., Sreekanth, S., Kumari, D.L., 2011. Design and development of X-band oscillator for FM telemetry transmitter. *Int. J. Eng. Sci. Technol.*, **3**(5):4003-4013.

Razavi, B., 1989. RF Microelectronics. Prentice Hall, New Jersey.

Tony, C.H., 2001. The Design of 2.4 GHz Bipolar Oscillator by Using the Method of Negative Resistance. Microwave Laboratory, Department of Electronic Engineering, The Chinese University of Hong Kong, Hong Kong, China.

Yoo, H., Maharjan, R.K., Kim, N., 2010. An X-band InGaP/GaAs hetero-junction bipolar transistor based microwave integrated circuit differential voltage controlled oscillator for satellite communications. *IETE J.*, **56**:340-345.