Syntheses of a PSpice Model of a Titanium-dioxide Memristor and Wien Memristor generator

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***Abstract* — In this paper a PSpice model of the equivalent circuit of the titanium-dioxide memristor's is presented based on the current-voltage relationship. By use of this model a Wien memristor generator is created. The oscillator circuit is analyzed and the basic time diagrams are given. The phase portrait of the system is also presented. The regulation of the output voltage magnitude and of the frequency is realized by changing the memristor states. In the end, some concluding remarks associated with the tolerances of possible changing of memristor parameters with respect to the operation of the Wien memristor are given.**

Keywords—titanium-dioxide memristor; PSpice model; linear drift model; memristor Wien oscillator.

I. INTRODUCTION

The memristor as a fourth basic nonlinear circuit element was predicted in 1971 by Professor Leon Chua [3]. The first physical sample of the memristor was invented in 2008 by Stanley Williams of Helwett-Packard laboratory [11, 12, 15]. That memristor consists of two sub-layers of titanium dioxide, sandwiched between two platinum rims. The main unique property of this element is to memorize the full amount of charge which has passed through it [5, 13]. Many research results and simulations on the memristor analysis have been made in the last few years [1, 2, 4, 6]. The main properties and the principle of operation of the titanium-dioxide memristor have been described. Some physical relationships between the basic electrical quantities of the memristor are accessible [7, 8]. Other important property of the memristor is that its equivalent resistance could be fluently regulated by applying to the element a short current or voltage pulses. Besides this in some parts of its volt-ampere characteristics the memristor has negative differential resistance [9, 10]. The memristor properties described are precondition for its possible application in oscillator schemes [14]. The main purposes of the present paper are to synthesize a PSpice memristor model and its application for analysis of Wien memristor generator scheme in Cadence OrCAD environment.

In Section II an equivalent substituting circuit of the PSpice memristor model is described. The synthesis of memristor Wien oscillator is presented in Section III. The analysis of the scheme mentioned above is given in Section IV. The concluding remarks are presented in Section V.

II. EQUIVALENT CIRCUIT OF A MEMRISTOR PSPICE MODEL WITH LINEAR DRIFT DESIGN

For synthesis of the PSpice memristor schematic a linear ionic drift model is used. The relationship between the memristor current i and its voltage drop u is presented with Eq. (1) [13]:

$$i(t) = \frac{u(t)}{R_{OFF}\sqrt{\left(1 - \dfrac{q(t_0)\mu_v R_{ON}}{D^2}\right)^2 - \dfrac{2\eta\mu_v R_{ON}}{D^2 R_{OFF}}\displaystyle\int u(t)dt}} \quad (1)$$

The PSpice model of the memristor cell, based on Eq. (1) is shown in Fig. 1. The quantity $q(t_0)$ is the initial amount of charge memorized in the memristor cell. The resistance of the memristor in opened state is denoted with R_{OFF}.

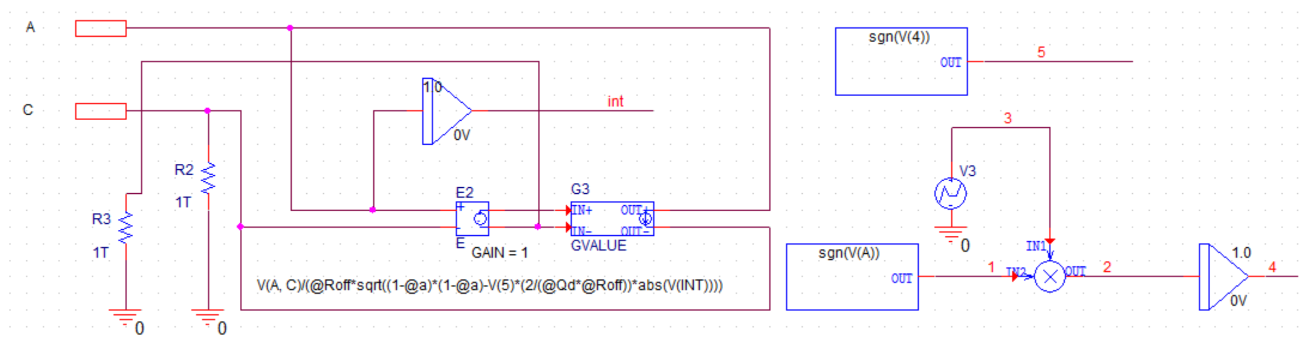

Fig. 1. Equivalent circuit of the PSpice model created

The quantity η represents the polarization of the memristor with respect of the initial sign of the voltage drop over it. When the memristor is forward biased the positive potential is applied to the anode of the memristor and the coefficient η is equal to 1. When the element is reverse biased the negative potential is applied to the anode of the memristor and the coefficient η is equal to -1. The quantity D represents the length of the memristor, μ_v is the ionic mobility of the oxygen vacancies and R_{ON} is the resistance of the memristor in closed state. The coefficient η is settled on without human intervention in the beginning of the simulation. For this reason a short positive impulse is used and it is multiplied by the sign of the initial memristor voltage drop. After integration and determining the sign of the signal it is equalized to the coefficient η.

III. SYNTHESIS OF A MEMRISTOR WIEN GENERATOR

The electrical circuit of the memristor Wien generator constructed is presented in Fig. 2. It is obtained by modifying the classical scheme of the oscillator with Wien Bridge by substituting some of the resistors with memristors. The operational amplifier used here works as a master nonlinear unit. The resistance of the memristor cells used in the circuit could be managed by external current or voltage sources. The variation of the resistances of the memristors M_1 and M_2 is used for regulating the frequency of the output signal of the oscillator. With changing the equivalent resistance of the memristors M_3 and M_4 we can regulate the magnitude of the output signal in a determined interval.

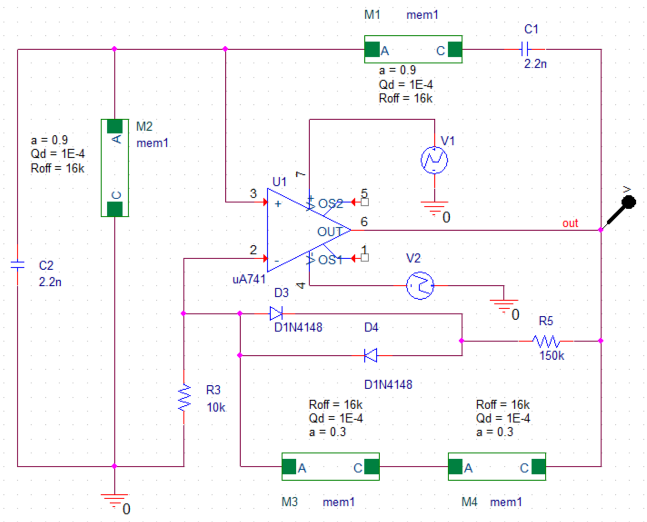

Fig. 2. Memristor Wien generator

IV. ANALYSIS OF THE MEMRISTOIR WIEN GENERATOR

The Wien bridge consists of two equally at value capacitors $C_1 = C_2 = 2{,}2\ nF$ and of two equally at parameters memristors M_1 and M_2. At every moment the resistances of the memristors M_1 and M_2 must be equal one to another. Theoretically the frequency of the output voltage generated is determined with Eq. (2):

$$f_0 = \frac{1}{2\pi R_{eqM1} C_1} \tag{2}$$

The power supply voltages of the operational amplifier increase not instantly but almost linearly for 0 to 15 V for a short time interval. That is the initial actuating impulse for creating of the further oscillations in the Wien generator. Theoretically the oscillations could be actuated in different way - by short external current or voltage pulse or by preliminarily charging some of the capacitors in the circuit investigated.

The initial normalized charge of a titanium dioxide memristor is denoted with $a = q(t0)/Q_d$. Let us adjust the initial normalized charge of the memristors so that we have $a_{M1} = a_{M2} = 0{,}05$ and $a_{M3} = a_{M4} = 0{,}4$. In this case the time diagram of the output voltage is presented in Fig. 3.

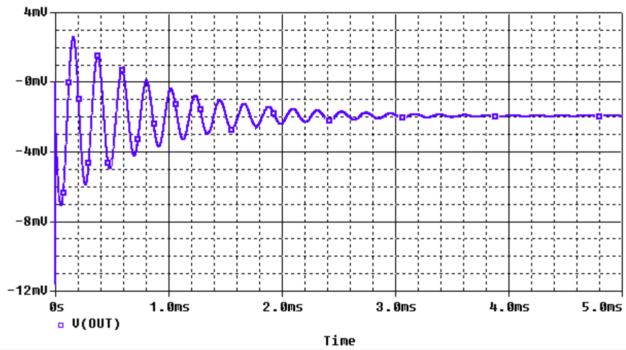

Fig. 3. Time diagram of output voltage of the generator at $a_{M3} = 0{,}4$

The process of oscillations is pseudo-periodic and the output voltage generations attenuate for about 4 *ms*. This is due to the relatively small value of the equivalent resistance of the memristors M_3 and M_4 which theoretically must not be smaller than 21,1 $k\Omega$.

The time diagram of output voltage at $a_{M3} = a_{M4} = 0{,}4$ is presented in Fig. 4. In the beginning the magnitude of the voltage generated is increasing. The duration of the initial transient process is about 7 *ms*. After this process the output voltage has stable magnitude and frequency.

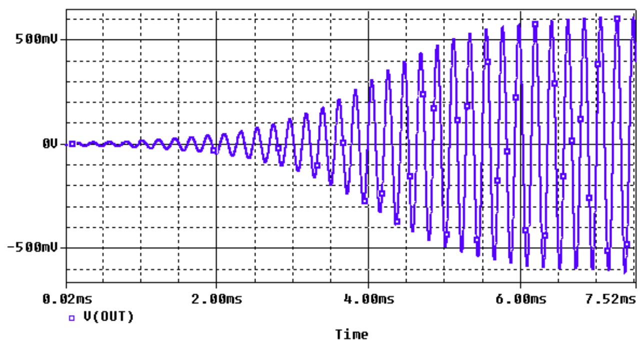

Fig. 4. Time diagram of output voltage of the generator at $a_{M3} = 0{,}35$

The spectral structure of the output voltage generated is given in Fig. 5. The signal has only the basic first harmonic. The magnitude of the output voltage is about 600 mV. The magnitude of the signal generated is relatively small with respect to the value of the power supply voltage of the controlling element of the generator. But in this case we have almost ideal sinusoidal output signal generated. The nonlinearity of the memristors does not affect the shape of the output signal.

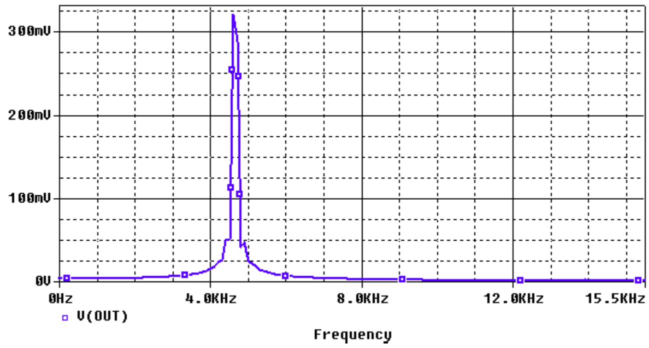

Fig. 5. Spectral structure of output voltage at $a_{M3} = 0{,}35$

The process of oscillating when $a_{M3} = a_{M4} = 0{,}05$ is presented by the time diagram in Fig. 6. It is obvious that the transient process in the scheme is about 0,8 *ms*. In the present case the length of the transient process is about 9 times shorter than the duration of the initial process described above. The output voltage is limited almost to the value of the power supply because of the saturation of the operational amplifier. The output signal is highly distorted and is almost similar to trapezoidal impulse sequence.

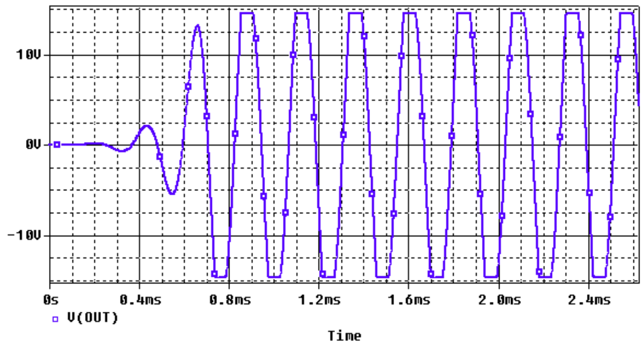

Fig. 6. Time diagram of output voltage of the generator at $a_{M3} = 0{,}05$

The spectral composition of the output signal described is presented in Fig. 7. It is obvious that the second, third and fourth harmonics of the output voltage have significant magnitudes. Because of that reason in this case the Wien generator could not be used as sinusoidal oscillator but it could be utilized as impulse generator. If we want to use the scheme as a sine wave generator a narrow band filter is needed.

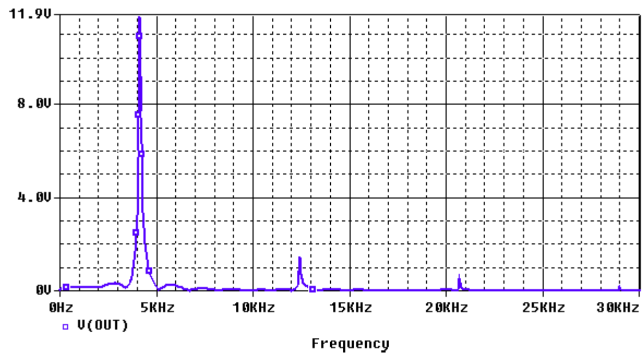

Fig. 7. Spectral structure of output voltage at $a_{M3} = 0{,}05$

The time diagram of the voltage drop across the memristor M_1 is presented in Fig. 8. The magnitude of the voltage is very high. The voltage drop is non-sinusoidal. The time diagram of the memristor current is presented in Fig. 9. The shapes of the voltage and the current are similar. That is due to the high frequency of the signal generated, which is about 4 *kHz*. In this mode the behaviour of the memristors is like this of a linear resistor.

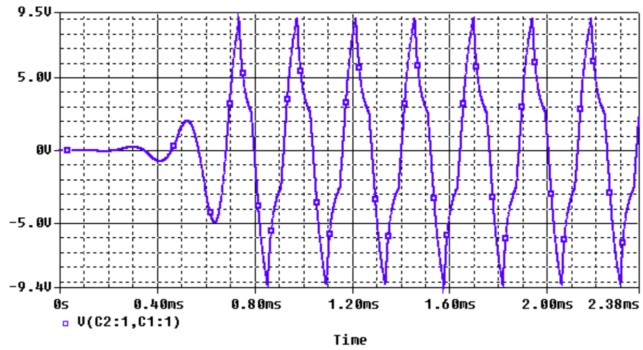

Fig. 8. Time diagram of the voltage drop across M_1

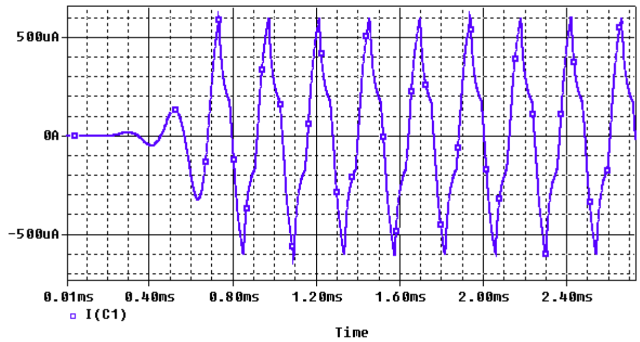

Fig. 9. Time diagram of the current through M_1

The time diagram of the output voltage at parameter values $a_{M3} = a_{M4} = 0{,}05$ and $a_{M1} = a_{M2} = 0{,}05$ is presented in Fig. 10. The frequency of the signal generated is 5 *kHz*. When we change the parameters so that $a_{M3} = a_{M4} = 0{,}3$ and $a_{M1} = a_{M2} = 0{,}90$ then we ontain the time diagram of the output voltage presented in Fig. 11.

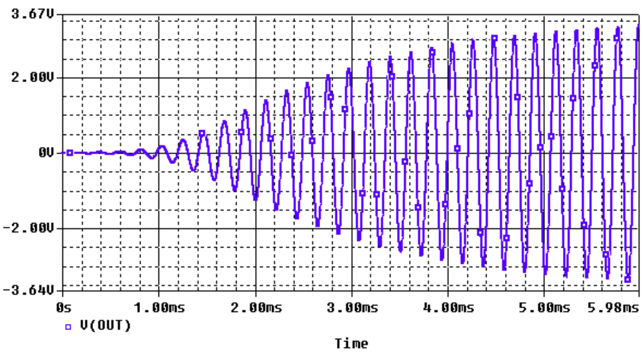

Fig. 10. Diagram of output voltage, $a_{M3} = a_{M4} = 0{,}3$ and $a_{M1} = a_{M2} = 0{,}05$

It is obvious that the signal generated has a frequency many times higher than 4 *kHz*. That is due to the different adjustment of the Wien bridge. The frequency's accurate value is 36,7 *kHz*.

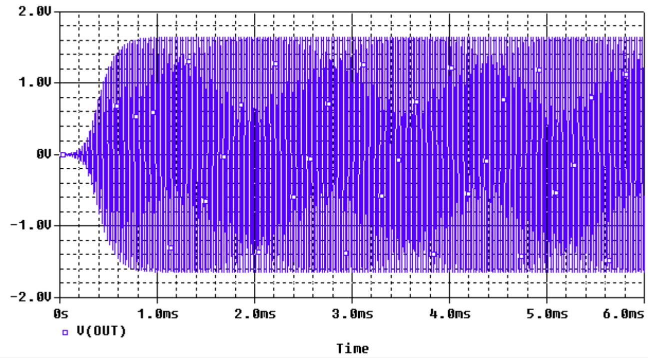

Fig. 11. Diagram of output voltage at $a_{M3} = a_{M4} = 0{,}3$ and $a_{M1} = a_{M2} = 0{,}90$

Theoretically we could find the maximal to minimal frequencies ratio using Eq. (2):

$$\frac{f_{0\max}}{f_{0\min}} = \frac{1}{2\pi R_{eqM1\min} C_1} : \frac{1}{2\pi R_{eqM1\max} C_1} = \\ = \frac{R_{eqM1\max}}{R_{eqM1\min}} = \frac{R_{OFF}}{R_{ON}} = \frac{16000}{100} = 160 \qquad (2)$$

This ratio is relatively high and it could be proved that a similar memristor Wien generator may almost cover the audio frequency range.

The phase portrait of the generator investigated is presented in Fig. 12. It is obtained using the current-voltage relationship of the capacitor C_2.

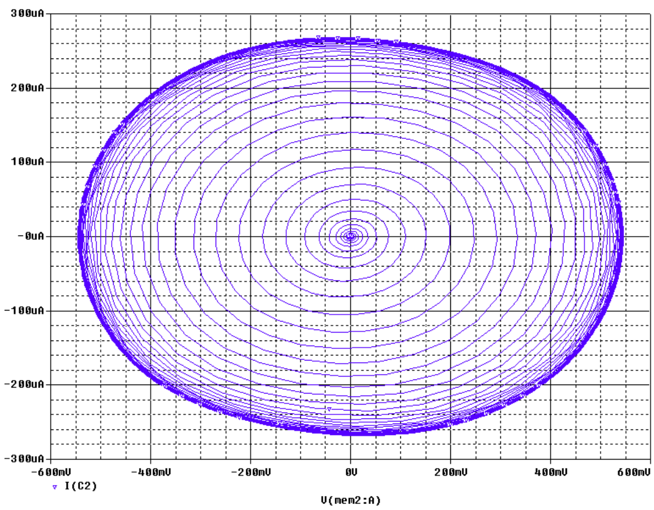

Fig. 12. Phase portrait of the system at $a_{M3} = a_{M4} = 0{,}3$, $a_{M1} = a_{M2} = 0{,}90$

V. CONCLUSIONS

From the results presented above it is clear that memristor elements could be used in oscillator circuits. The memristor cells can replace some of the resistors in the Wien generator scheme. Especially the memristors could be used in the frequency-determining circuits like the Wien bridge and the circuit for balancing the scheme. The convenience of using memristor cells is its easy and fine adjusting by applying of external voltage or current sources. In spite of memristor's non-linearity it has been specified that at appropriate mode it does not introduce nonlinear distortions in the signal generated. It has also been determined that at very high frequencies the memristor cells may operate with high voltage signals without appearance of breakthrough or other destructive defects. With altering the memristors charge we can tune the frequency of the signal generated in relatively wide range.

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