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Research Article

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Features of the Development of the Oscillator with the Wien Bridge

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Abstract The article describes the principle of constructing an autogenerator of sinusoidal oscillations using the *RC* - chain included in the Wien bridge scheme. The possible options for stabilizing the amplitude of the output voltage are considered, and they are compared in terms of the effectiveness of stabilization. The most optimal scheme of the autogenerator was chosen, the method for selecting elements and calculating their parameters was described.

Keywords Autogenerator, Wien Bridge, Operational Amplifier, Feedback, Frequency-dependent circuit, Stabilization of oscillations

Introduction

To supply the modulation winding of a contactless DC meter, a low-frequency (50...1000 *Hz*) source of sinusoidal oscillations with a low level of distortion is required [1]. For low frequencies (less than 10 *kHz*), the use of LC-generators is impractical, since the elements of the oscillating circuit are too large. It is most convenient to implement such a source (also from the point of view of assembly and adjustment) on the basis of RC - an auto-generator on an operational amplifier (OA). In this case, the RC - chain that specifies the generation frequency can be connected both to the inverting input and to the non-inverting input OA. When connecting a RC - chain to the inverting input OA, it must introduce a phase shift with an angle of 180°, which is impractical because it requires a large number of elements (at least 6) in the feedback circuit [2, 3]. Therefore, usually the RC - chain is connected to the non-inverting input OA; at the same time, a positive feedback (PFB) should introduce a zerophase shift at the desired frequency of generation.

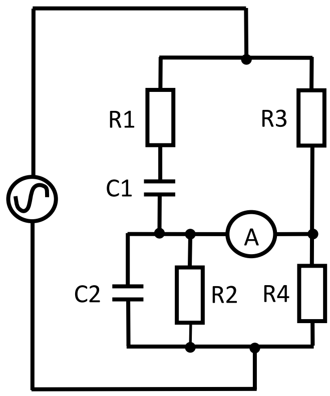

Figure 1: The circuit of Wien bridge

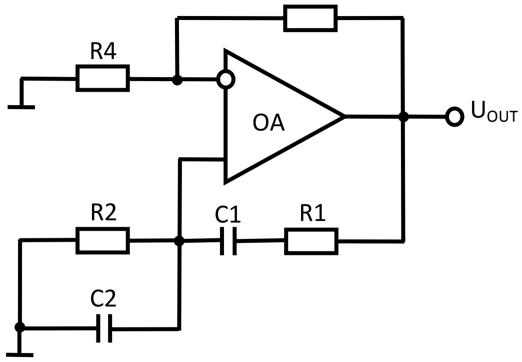

Figure 2: The basic circuit of autogenerator with Wien bridge

Materials and Methods

The above requirements are best implemented in the autogenerators based on the Wien measuring bridge [4, 5]. The advantage of this circuit in autogenerators is a small amount of used parts and good frequency stability. The bridge was designed by Max Wien in 1891 to measure the capacitance of condensers (Fig. 1) [4]. The bridge is powered by sinusoidal voltage and can be balanced, for example, by adjustment $R1$, if the ratio $R3/R4$ corresponds to the ratio of the impedances in the other two arms $C1-R1$, $C2-R2$. At the moment of balance you can find, for example, an unknown value $C1$, if the values of the remaining elements are known. Wien bridge was also used to measure the frequency of the input sinusoidal signal from the known values of the elements of the shoulders at the moment of the bridge balance.

To create a sinusoidal oscillator based on a Wien bridge, an inverting amplifier circuit is used in which the diagonal supply of the bridge is connected to the output terminals OA and the measuring diagonal is connected to the input terminals OA, while the active arms of the bridge form a negative feedback circuit (NFBC), and complex shoulders – the PFB chain (Fig. 2). In this case, the elements of the PFB determine the frequency of generation, and the elements of NFBC - intensification.

In this design, the PFB circuit is a bandpass filter on the elements $R1$, $R2$, $C1$, $C2$ with a central frequency $\omega_0 = 2\pi f_0$. Wien bridge autogenerators are usually used to form harmonic oscillations with frequencies from f_0 *Hz* to 200 *kHz* [2, 3].

To determine the frequency of self-oscillations of the generator and the gain K_U of a non-inverting amplifier necessary for self-excitation, we find the complex transfer coefficient $\dot{\beta}(\omega)$ of the feedback circuit. Consider the general case when the capacitance and resistance of the circuit are different (Fig. 2):

$$\dot{\beta}(\omega) = \frac{U_{PFB}}{U_{OUT}} == \frac{\dfrac{R_2/j\omega C_2}{R_2 + 1/j\omega C_2}}{R_1 + 1/j\omega C_1 + \dfrac{R_2/j\omega C_2}{R_2 + 1/j\omega C_2}} = \frac{1}{1 + \dfrac{R_1}{R_2} + \dfrac{C_2}{C_1} + j\left(\omega R_1 C_2 - \dfrac{1}{\omega R_2 C_1}\right)}. \qquad (1)$$

From (1) it follows that the PFB with the Wien bridge does not introduce a phase shift at any generation frequency if the condition

$$\omega R_1 C_2 - \frac{1}{\omega R_2 C_1} = 0. \qquad (2)$$

The most commonly used symmetric Wien chain is in which $R_1 = R_2 = R$, $C_1 = C_2 = C$. Such a variant of construction provides the possibility of the execution of a RC-generator with a tunable frequency. This is accomplished by using a twin block of identical variable resistances or capacitors and maintains a balance of amplitudes and phases over a wide frequency tuning range. In this case, the generation frequency is determined from (2) by the expression $\omega_0 = 1/RC$, and the transmission coefficient of the PFB circuit $\beta(\omega_0) = \left(1 + \dfrac{R_1}{R_2} + \dfrac{C_2}{C_1}\right)^{-1} = 1/3$. In order to establish stationary harmonic oscillations with frequency ω_0, it is necessary that at this frequency the loop gain of the generator meets the condition $K_U \beta(\omega_0) = 1$, therefore, the threshold of self-excitation of the generator of fig. 2 is equality

$$K_U = 1 + \frac{R_3}{R_4} = 3. \qquad (3)$$

If the value K_U is less than the threshold value, the oscillations fade out. For guaranteed excitation of the oscillator with any fluctuations of OA parameters and the PFB circuit, the loop gain must be slightly larger than one. At the same time, however, the amplitude of the output voltage can increase up to the saturation voltage OA, the shape of the output voltage will differ from the sinusoid, horizontal sections will appear, which will be wider, the larger K_U it exceeds 3. In the limit at high gain, the curve will have a trapezoidal shape approaching a rectangular one. Therefore, after the occurrence of self-oscillations, it is necessary to stabilize their amplitude at such a level that the loop gain is reduced to unity. For this purpose, an automatic adjustment K_U is used by applying as either a $R3$ or $R4$ non-linear or controlled element, which will be automatically adjusted in such a way as to provide the output sinusoid required K_U for a certain value of amplitude. In this case, the applied nonlinear elements must be inertial in order not to react to the instantaneous values of the currents or voltages, and their resistance should be determined only by the average values of the heating. To eliminate distortion, this is significant, since a high-speed FB would distort the generated sine wave, trying to regulate its amplitude within one period.

An example of such elements is a thermistor or a simple low-power low-voltage incandescent lamp, turned on instead of a resistor $R4$ [4]. The resistance R_L of the lamp must meet the threshold value K_U at which the amplitude balance is performed. With an increase in the amplitude of the output signal, the current through the lamp increases, the lamp filament heats up to a higher temperature, as a result of which the resistance of the lamp increases and in formula (3) K_U decreases. In the case of a decrease in the amplitude of the generated oscillations, the opposite occurs. Thus, the incandescent lamp acts here as an automatic amplitude regulator, keeping the mode of self-oscillations near the self-excitation threshold.

The use of a light bulb has certain disadvantages: with regular use of a generator, the life of a light bulb is usually limited to a few months, and its control properties, like a thermistor, depend on the environment temperature.

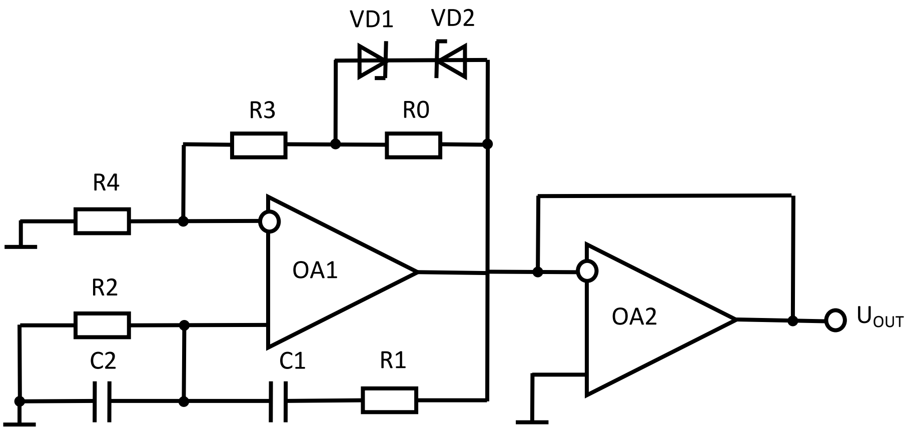

Figure 3: The scheme of amplitude stabilization of output sinusoid by using stabilitron

In [5], automatic adjustment K_U is carried out using a chain consisting of counter-connected stabilitrons (Zener diodes) VD1, VD2 and a resistor $R0$ (Fig. 3).

At small values of the voltage U_{OUT}, the voltage U_D on the diodes is less than the stabilization voltage U_{ST}, the resistance $R0$ is not bypassed by the diodes. The resistances $R0$, $R3$, $R4$ are chosen so that they occur $K_U = 1 + \frac{R_0 + R_3}{R_4} > 3$, as a result of which the amplitude of the voltage U_{OUT} and the voltage U_D proportional to it increases. When the voltage U_D reaches an amplitude value equal to the stabilization voltage U_{ST}, one or another stabilitron opens, their pair shunts the resistance $R0$. The gain becomes $K_U = 1 + \frac{R_3}{R_4} < 3$, therefore, U_{OUT} will change, but already in the opposite direction, increasing (in magnitude) to the amplitude value of another sign. The amplitude value of the current of the NFB circuit at the moment of switching

$$I_m = \frac{U_{OUTm}}{R_0 + R_3 + R_4} = \frac{U_{ST}}{R_0},$$

therefore, oscillations are set with amplitude

$$U_{OUTm} = \frac{U_{ST}\left(R_0 + R_3 + R_4\right)}{R_0}.$$

On the second OA, a buffer amplifier is built, isolating the Wien chain from the influence of an external load. The disadvantage of the circuit is Fig. 3 is that, due to the possible variation in the parameters of the stabilitrons, the fronts of the sinusoid at the output turn out to be asymmetric.

More effective is the stabilization of the amplitude of the output voltage of the generator using conventional high-speed diodes in the NFB circuit (Fig. 4) [6, 7]. In this case, stabilization is carried out by changing the dynamic resistance r_D of the diode with a change in current I_D (instantaneous value) flowing through the diode. The dynamic resistance of the diode is determined by the formula $r_D = U_T / I_D$, where U_T is the temperature potential of the $p-n$ junction, which is equal to 25.5 *mV* at room temperature. With an increase in the amplitude of the output signal, the current through the diode increases, its dynamic resistance decreases, which is connected in series with $R3$, which leads to a K_U decrease in the amplitude of oscillations. If the amplitude decreases, then a decrease in the current through the diode leads to an increase in the dynamic resistance of the diode; the coefficient K_U and signal amplitude increase.

The voltage drop across the $p-n$ junction of ordinary diodes does not exceed 0,7 *V* (in the case of silicon diodes), therefore, in the circuit in fig. 4, the generator output voltage is about 2,5 *V*. To increase the output voltage, it is possible to turn on several diodes in series instead of one, but this makes the generator more dependent on the external temperature. Moreover, the time required to stabilize the oscillations increases, and the amplitude of the output signal decreases. For this reason, it is advisable to use a single diode and amplify the output voltage, using for this purpose an OA Buffer amplifier.

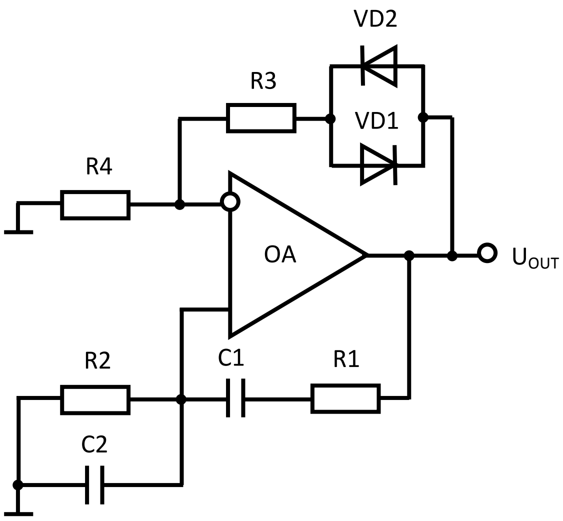

Figure 4: The circuit of amplitude stabilization of output sinusoid by using diods

There is also known a method of stabilizing the amplitude of the output sinusoid generator by using LEDs in the NFB circuit [7]. Their use is caused by the magnitude of the voltage drop, which usually lies in the range of 1.2...1.5 *V*, which allows to obtain a sufficiently high value of the output voltage and adjust it in the range of about 5...10 *V*. However, the circuit is somewhat complicated, it is necessary to pass through LEDs are a significant current (about 5 *mA*), so that they are in the optimal mode, besides the LEDs have the disadvantages listed above for stabilitrons.

Results

Qualitatively, the best results can be achieved by using automatic gain control (AGC), which, compared with the diode version, can provide greater amplitude of output oscillations and less distortion of the sinusoid [6, 8-10].

In the circuit of the oscillator shown in Fig. 5, the active element of the AGC is a field-effect transistor VT1 connected in parallel with the resistor $R0$. The transistor operates in a variable resistor mode and provides excellent control of the amplitude of oscillations due to the wide range of drain-source resistance, which depends on the voltage across the gate. The transistor is controlled by a peak detector made on the elements of VD1, $R6$, $C3$ and having a substantially large time constant. At the gate of the transistor is applied rectified and smoothed voltage from the output of the generator.

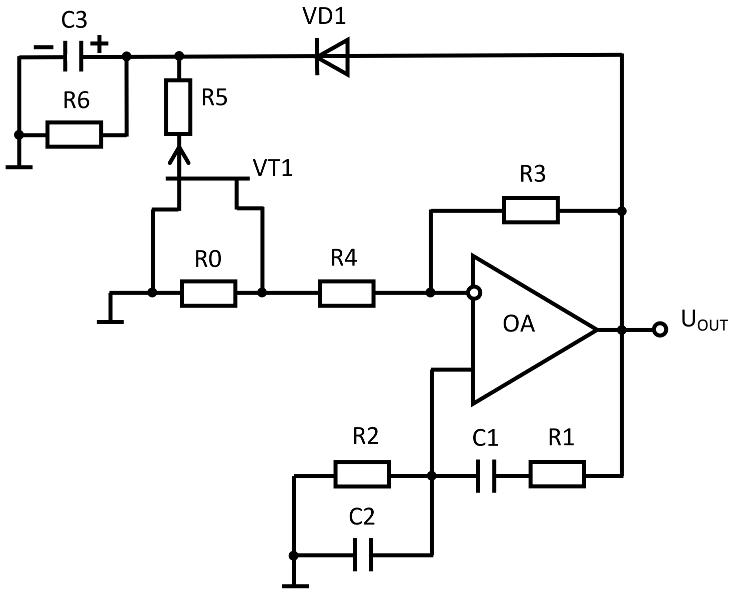

Figure 5: The scheme of amplitude stabilization of output sinusoid with the help of field-effect transistor

When the circuit is turned on, the capacitor $C3$ is discharged, at the gate of VT1 there is a zero voltage, the drain-source channel is open, the transistor completely shunts the section of the resistor $R0$, therefore, K_U is maximum, and the circuit starts up confidently. The capacitor $C3$ starts charging through the diode VD1 positive half-wave output sine wave. As the channel $C3$ is charged, the channel is locked, K_U reduced, the circuit finds the same balance at which $K_U = 3$, and the generator produces an undistorted sinusoid. With such regulation, the distortion of the sinusoid is negligible [9].

Methods of designing an oscillator

When designing an oscillator with a Wien bridge, for example, according to the scheme of fig. 5, it is necessary that the selected OA can provide the current required for generation, have sufficient frequency bandwidth, have large input and small output resistances, and also a sufficiently large admissible value of the input current. In this case, the higher the generation frequency, the higher quality the OA should be. At low frequencies up to about $f = 10$ *kHz*, you can use any OA from the types K140UD7, K153UD1B, LM324, TL062, TL072, TDA2320. At high frequencies of the order of up to $f = 100$ *kHz*, OA types of the AD8597, AD8599, OP27, NE5532, LM833, LF355 manifest themselves well.

The accuracy of the generation frequency depends on the accuracy of the elements of the frequency-dependent circuit. And in this case, it is important not only the accuracy of the fitting of the nominal element, but also the stability of the characteristics with temperature. With this in mind, it is advisable to choose high-precision metal-metal resistors of type C5-61 as resistors $R_1 = R_2 = R$ [11]. They are produced only with a power of 0.25 *W*, a minimum deviation $\pm 0,005\%$ from the nominal resistance and a minimum value of the temperature coefficient of resistance (TCR) $\alpha_t = \pm 10 \cdot 10^{-6}\ {}^0C^{-1}$. The intermediate values of the nominal resistances of these resistors correspond to the series E192 according to GOST 28884-90 [12]. As capacitors $C_1 = C_2 = C$, it is advisable to use multilayer ceramic capacitors (MLCC) of the 1-st class, which have high stability, low level of losses, minimum nominal error ($\pm 2\%$), minimal capacitance dependence on temperature ($TCC = \pm 30 \cdot 10^{-6} /^{o} C$), have small dimensions and are great for placement on printed circuit boards [13].

The resistance values of the resistors R and the capacitance of the capacitors C are interconnected by the condition (2), at the generation frequency their resistance must be equal to each other:

$$R = 1/\omega_0 C = X_C \ . \tag{4}$$

The resistance R must be chosen in such a way as not to overload the shelter OA by the input current; after that, by the values ω_0 and R is calculated C by the formula (4).

As VT1, it is desirable to use a silicon diffusion-planar field-effect transistor with a gate based on p-n junction (J-FET) and p-type or n-type channel. When using n-channel J-FET is necessary in the diagram in fig. 5 change the polarity (flip) VD1 and $C3$. It should be noted that the amplitude of the generated signal will directly depend on the threshold voltage VT1. If the output amplitude is insufficient, then it is quite possible to use the second (buffer) OA for a small amplification of the signal amplitude. Resistances $R0$, $R3$, $R4$ are selected so as to ensure the condition

$$\frac{R_3}{R_0 + R_4} > 2 \ . \tag{5}$$

When the channel is closed, the drain-source of the transistor VT1 is the amplitude value of the current of the NFB circuit

$$I_m = \frac{U_{OUTm}}{R_3 + R_4 + R_0} = \frac{U_{FS}}{R_0} \ ,$$

where U_{FS} is the value of the voltage of the flow-source channel when the voltage at the gate relative to the source is less than the threshold value, therefore, the oscillations are set with amplitude

$$U_{OUTm} = \frac{U_{FS} R_0}{R_3 + R_4 + R_0} \ . \tag{6}$$

For given values U_{OUTm} and U_{FS} , $R0$, $R3$, $R4$ values are calculated using equations (5) and (6), Considering also the need to ensure the condition $R_3 + R_4 + R_0 > R_{OUTOA}$, Resistance $R5$, $R6$, $C3$ was determined by the values of the parameters of the selected type VT1 and voltage setpoint U_{OUTm} .

Conclusions

Of all the circuit solutions of the auto-generator of sinusoidal oscillations using the Wien bridge, it is preferable to use automatic gain control (Fig. 5), which allows for greater amplitude of the output oscillations and less distortion of the sinusoid. Such an autogenerator was manufactured and tested for five different generation frequency values ranging from 50 to 1000 *Hz*. The installation of the required frequencies was made by the appropriate choice of nominal values R and C according to formula (4). Tests have shown that the generator produces an almost pure sinusoid, the distortions of which do not exceed 0.15%.

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