RC OSCILLATORS WITH TWO OPERATIONAL AMPLIFIERS WITH PRECISION PHASE SHIFT BETWEEN TWO OUTPUTS

Pavel HORSKÝ
Dept. of Radioelectronics
Technical University of Brno
Purkyňova 118, CZ - 612 00 BRNO
E-mail: horskyp@urel.fee.vutbr.cz

Abstract

In some instruments oscillator with precision 90° phase shift of output signals is needed. In this article a new type of RC oscillators with precision 90° phase shift between two low impedance output signals is described. This phase shift does not depend on tolerances of RC networks used.

1. Introduction

Using two operational amplifiers and simple RC networks RC oscillators with two low impedance outputs can be made. By those oscillators the phase shift or magnitude voltage ratio of output signals can be set. Some of them have precision 90° phase shift of output signals independent on time constants of RC networks used.

As a typical example the simple phase standard for phasemeter calibration can be considered. There are phase calibrators, which allow to set phase shift, frequency and amplitude of output signals. Phase calibrators are expensive devices and so high performance and range from 0° to 360° are often not needed.

The above mentioned oscillators can be used as a simple phase standard with fixed 90° phase shift or in some instruments where oscillators are needed with precision 90° phase shift of output signals.

2. Oscillator circuits

Several types of RC oscillators with two operational amplifiers with different features are described in [1]. The oscillators with advantageous features for constructing oscillators with precision phase shift are selected. The oscillator with adjustable phase shift can be designed [1], but the phase shift precision is dependent on precision of time constants of used RC networks (τ_1 and τ_2). It means that accuracy of components R_1, R_2, C_1 and C_2 has influence on the total precision. These oscillators will not be discussed here.

Oscillators in Fig. 1 and Fig. 2 have precision ± 90° phase shift and an opportunity to adjust magnitude voltage ratio. The first output signal v_1 is taken from operational amplifier OA_1 output and the second output signal v_2 is taken from operational amplifier OA_2 output. The following symbols are used:

$$A = \frac{R_b}{R_a}, \quad \tau_1 = R_1 \cdot C_1, \quad \tau_2 = R_2 \cdot C_2.$$

For use as a phase standard it is always set $\tau_1 = \tau_2$; consequently output voltages have the same magnitude and the amplitude stabilization has no interaction with oscillation frequency.

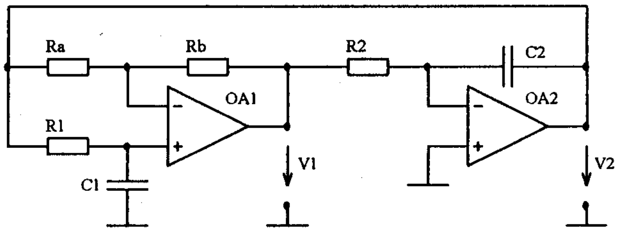

Fig.1 Oscillator circuit 1

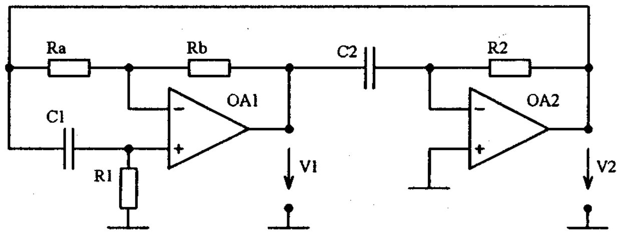

Fig.2 Oscillator circuit 2

3. Error sources

Regarding the above mentioned equations, if the ideal operational amplifiers are considered, the values of used components have no influence on phase shift.

When the influence of *capacitors dissipation factor tg δ* is tested, the capacitors C_1 and C_2 are bridged over with resistors R_{C1} and R_{C2}. The whole symbolic solution of phase shift for oscillator in Fig. 2 is

Table 1 Characteristic equation, oscillation condition and frequency and output voltages ratio

Character. Equation	$p^2+\frac{\tau_2-A\tau_1}{\tau_1\tau_2}p+\frac{1}{\tau_1\tau_2}=0$		
	General	for $\tau_1=\tau_2$	for $A=1$
Oscillation Condition	$\tau_2-A\tau_1=0$	$A=1$	$\tau_1=\tau_2$
Rising osc. Condition	$\tau_2-A\tau_1<0$	$A>1$	$\tau_1<\tau_2$
ω_0	$\frac{1}{\sqrt{\tau_1\tau_2}}$	$\frac{1}{\tau}$	$\frac{1}{\sqrt{\tau_1\tau_2}}$
$\frac{V_2}{V_1}$ Fig. 1	$\sqrt{\frac{\tau_1}{\tau_2}}\cdot e^{j\cdot 90^\circ}$	$1\cdot e^{j\cdot 90^\circ}$	$1\cdot e^{j\cdot 90^\circ}$
$\frac{V_2}{V_1}$ Fig. 2	$\sqrt{\frac{\tau_1}{\tau_2}}\cdot e^{-j\cdot 90^\circ}$	$1\cdot e^{-j\cdot 90^\circ}$	$1\cdot e^{-j\cdot 90^\circ}$

$$\varphi_{\mathrm{tg}\delta}=\mathrm{arctg}\left[\frac{R_{C2}}{R_2}\sqrt{1+\frac{R_1}{R_{C1}}-\frac{R_2}{R_{C2}}-\left(\frac{R_2}{R_{C2}}\right)^2}\right]-\pi\cdot \tag{1}$$

For practical use for both oscillators with sufficient precision is

$$\left|\Delta\varphi_{\mathrm{tg}\delta}\right|\approx\frac{\pi}{2}-\mathrm{arctg}\frac{R_{C2}}{R_2}. \tag{2}$$

The phase accuracy is influenced more by the dissipation factor of capacitor C_2 than by the dissipation factor of capacitor C_1. When capacitors with low tg δ (polystyrene dielectric) are used, the influence of capacitors tg δ is not considered.

The *frequency characteristic of used operational amplifiers* (above all the transient frequency) has the primary influence on phase precision. If the theoretically calculated oscillation frequency f_0 (for ideal operational amplifiers) approaches operational amplifiers transient frequency f_t then the oscillation frequency f, the oscillation condition and the phase shift φ of output signals change. For simplification both operational amplifiers are replaced by ideal integrators with the same time constant τ_t and the time constants of both RC networks are the same ($\tau_1=\tau_2=\tau$). The following coefficients ξ, k are used: $f=\xi f_0$ and $f_t=k\cdot f_0$. The characteristic equation of such circuit is the fourth order and after simplification is:

$$\begin{aligned}&-j(A+1)\xi^4-(2+2k+2A+Ak)\xi^3+\\&+j(1+3k+Ak+k^2+A)\xi^2+(k+k^2-Ak^2)\xi-jk^2=0.\end{aligned} \tag{3}$$

The real and imaginary part of equation (3) are solved separately. The coefficient ξ is calculated as root of equation

$$\xi^6+\left(2+k+k^2\right)\xi^4+\left(1+k+3\cdot k^2+k^3\right)\xi^2-k^3=0 \tag{4}$$

and then the oscillation frequency f is $f=\xi f_0$. The symbolic solution of equation (4) is possible, but the results are very large and the numeric solution is preferred. The oscillation condition is

$$A=\frac{-2(k+1)\xi^2+k+k^2}{(k+2)\xi^2+k^2}. \tag{5}$$

The frequency ratio of real oscillation frequency and oscillation frequency for ideal operational amplifiers f/f_0 dependence on frequency ratio of operational amplifiers transient frequency and oscillation frequency for ideal operational amplifiers f_t/f_0 is shown in Fig. 3.

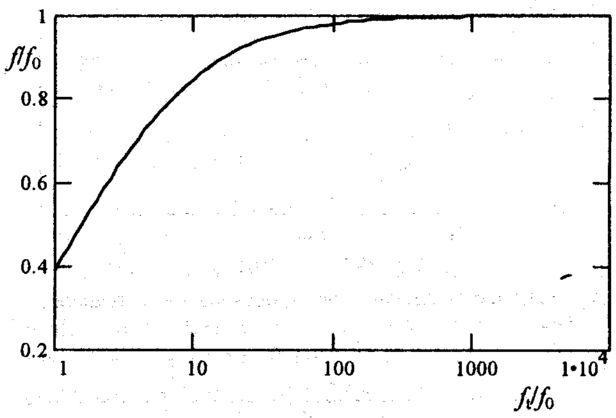

Fig.3a The frequency ratio f/f_0 (linear scale) dependence on frequency ratio f_t/f_0

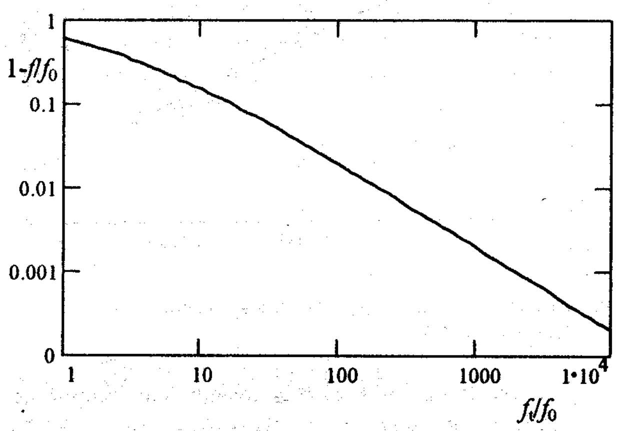

Fig.3b The frequency ratio f/f_0 (logarithmic scale) dependence on frequency ratio f_t/f_0

The phase error is calculated from voltage ratio and is

$$\left|\Delta\varphi_f\right|=\mathrm{arctg}\frac{f}{f_t+f_0}=\mathrm{arctg}\frac{\xi}{k+1}. \tag{6}$$

The phase error $\Delta\varphi_f$ dependence on frequency ratio of operational amplifiers transient frequency and oscillation frequency for ideal operational amplifiers f_t/f_0 is shown in Fig. 4.

4. Experimental results

The main features of projected generators have been experimentally tested. The operational amplifiers MAA 741 with transient frequency about 650 kHz (measured value for used operational amplifiers) are chosen because so the errors due to low transient frequency can be tested easily.

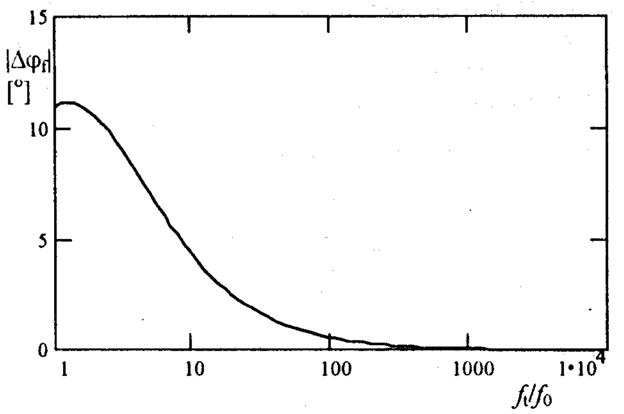

Fig.4a The phase error $\Delta\varphi_f$ (linear scale) dependence on frequency ratio f_t/f_0

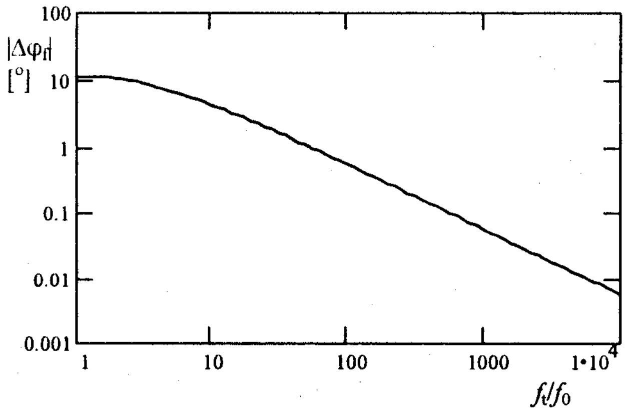

Fig.4b The phase error $\Delta\varphi_f$ (logarithmic scale) dependence on frequency ratio f_t/f_0

The oscillator in Fig 2 is tested. The amplitude stabilization is provided with thermistor in series to resistor R_b. The values of used components are: $R_1 = R_2 = R_a = 11\ \text{k}\Omega$, $R_b = 9\ \text{k}\Omega$, $C_1 = C_2 = 10\ \text{nF}$ $(f / f_t = 444)$ in the first experiment and $C_1 = C_2 = 150\ \text{pF}$ $(f / f_t = 7.1)$ in the second experiment. The theoretical results are calculated from measured values of components used. The output signals have those parameters:

The precision phasemeter Krohn Hitte 6600 with phase error less than $\pm 0.1^\circ$ is used for phase shift measurement. The measured phase shift for the first experiment is -90.1° and for the second experiment is -97°. The theoretically calculated values -90.13° and -95.6° with good precision correspond with the measured values. The changing of DC power supplies voltages from 10 V to 18 V (both simultaneously or each separately) has no measurable influence on phase shift. Capacitor C_2 magnification from 10 nF to 11.5 nF causes the change of phase shift up to -90.3°. Poor tg δ of used capacitors is simulated with resistor 100 kΩ parallel-connected to capacitor. Phase shift for C_1 with poor tg δ is -90.2° and for C_2 with poor tg δ is -97°. (theoretically -96.3°)

Table 2 The measured and calculated values

	Experimental results				Theoret. Results	
C_1, C_2	10 nF		150 pF		10 nF	150 pF
Frequency [Hz]	1454		72600		1457	73200
Phase shift [°]	-90.1		-97		-90.13	-95.6
Output	v_1	v_2	v_1	v_2		
RMS volt. [V]	4.13	4.24	0.34	0.36		
THD [%]	0.407	0.132	0.9	0.25		

5. Conclusion

New type of RC oscillator with precision 90° phase shift between two low impedance outputs is described. The main advantage of this network is fixed phase shift of 90° independent on used component values (the ideal operational amplifiers are considered). The main influence on phase precision has the operational amplifiers transient frequency. In applications, where a very high phase precision (better than 0.01°) is needed, operational amplifiers with transient frequency higher than 1000 times oscillation frequency are required. The experimental results with good precision verify the theoretical relations.

References

[1] HORSKÝ, P.: RC oscillators with two operational amplifiers. In. Proc. of "Radioelektronika 96", TU Brno, 1996, pp. 358-361.

About Author ...

Pavel HORSKÝ was born in Brno, in 1970. At present, he is the PhD Student at TU Brno, Institute of Radioelectronics. His research interests include circuit theory and applications, computer-aided analysis and metrology.