

A new harmonic oscillator: The GIC Resonator

Circuit description

The generalized impedance converter structure (GIC) introduced by Antoniou [1] is a very versatile two-opamp block for realizing active filter circuits applying the concept of impedance simulation. If compared with other two-amplifier configurations it can be considered as an „optimum configuration“ [2]. It is, therefore, promising to also adapt this concept to sinusoidal RC oscillators.

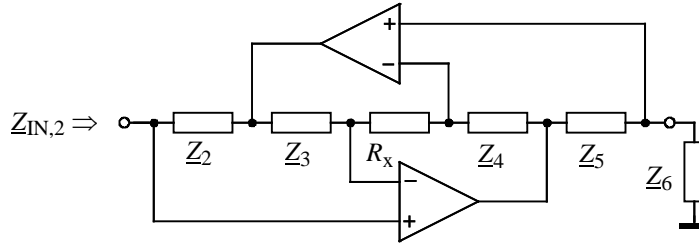


Fig. 1 GIC topology (Antoniou) with additional resistor R_X

Consider the circuit in Fig. 1. Note that in case $R_X=0$ this circuit represents Antoniou's classical GIC structure. For idealized opamps the input impedance measured into the element Z_2 can be calculated:

$$Z_{IN,2} = \frac{Z_2 Z_4 Z_6}{Z_3 Z_5} - R_X \frac{Z_2}{Z_3} . \quad (1)$$

It is well known that the first part of $Z_{IN,2}$ can represent a grounded inductance (Z_3 or Z_5 capacitive) or a frequency-dependent negative resistor (FDNR) with two capacitive numerator elements. While both alternatives can be used for oscillator applications only the preferred method based on inductor simulation is described in the following.

Selecting $Z_5 = 1/j\omega C_5$ the input impedance is

$$Z_{IN,2} = j\omega C_5 \frac{R_2 R_4 R_6}{R_3} - R_X \frac{R_2}{R_3} . \quad (2)$$

The real part of $Z_{IN,2}$ is a negative resistance which will be used for for a safe start-up of oscillations thereby compensating losses caused by parts parasitics and amplifier imperfections. With regard to other design constraints (parts values, amplitude control) it is convenient to choose $R_X R_2 / R_3$ larger than necessary and to use an additional external resistor R_1 for balancing both resistive parts, see Fig. 2.

Now looking into R_1 the input impedance $Z_{IN,1}$ represents a grounded inductance L_1 in series with a resistive part R_N

$$Z_{IN,1} = j\omega C_5 \frac{R_2 R_4 R_6}{R_3} + \left(R_1 - R_X \frac{R_2}{R_3} \right) = j\omega L_1 + R_N$$

After setting $R_2 = R_3 = R_4 = R$ we get

$$L_1 = C_5 R R_6 \text{ and } R_N = R_1 - R_X . \quad (3)$$

Shunting this active circuit with a capacitor C_1 a tank circuit is realized (see Fig. 2) that is able to oscillate if parasitic losses and amplifier imperfections are compensated by choosing $R_N < 0$. In practice, a value $R_N = R_1 - R_X \approx -(10 \dots 50) \Omega$ is sufficient to ensure a safe start of the oscillations.

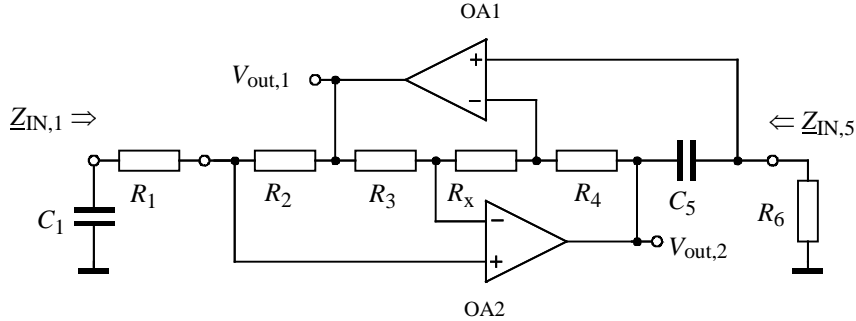


Fig. 2 GIC Resonator

Using eqn. (3) the oscillation frequency of the tank circuit is

$$f_0 = \frac{1}{2\pi\sqrt{L_1 C_1}} = \frac{1}{2\pi\sqrt{R R_6 C_1 C_5}} \xrightarrow{C_1=C_5=C} \frac{1}{2\pi C \sqrt{R R_6}}.$$

Note the frequency tuning capability of the circuit by variation of a single resistor (R_6) – independent on the oscillation condition set by $R_N < 0$. Because the tuning resistor R_6 is grounded it can be replaced by a FET to enable electronic frequency control.

It turns out that – without additional circuitry for amplitude limiting – the rising oscillation signal drives at first opamp OA1 into saturation. Thus, $V_{out,1}$ is a sinusoidal signal with clipped amplitudes, see Fig. 3. Owing to the Q -factor of the tank circuit a bandpass filtered version of $V_{out,1}$ is available at the output $V_{out,2}$ with a signal quality (THD) that strongly depends on the Q -factor:

$$Q = \frac{\omega_0 L_1}{|R_N|} = \frac{C_5 R R_6}{|R_N| \sqrt{C_1 C_5 R R_6}} \xrightarrow[\substack{C_1=C_5=C \\ R_N=R_1-R_X}]{\substack{C_1=C_5=C \\ R_N=R_1-R_X}} \frac{\sqrt{R R_6}}{|R_1 - R_X|}. \quad (4)$$

For a good signal quality a value of $Q_{min}=50$ should be implemented (35 dB attenuation of the 3rd harmonic). The signal quality of the signal $V_{out,2}$ can be further improved by limiting the voltage across R_X using two anti-parallel diodes. In this case, the value of R_X should be selected in the range (0.2...2) k Ω .

Example: Simulation results, see Fig. 3.

- Operational amplifiers: LT1022, powered with +/- 12 volts.
- $C_1=C_5=0.1 \mu\text{F}$, $R_2=R_3=R_4=R=1 \text{ k}\Omega$, $R_X=500 \Omega$, $R_1=f(f_0)$
- By variation of R_6 in the range (0.1...10) k Ω the frequency was tuned over a 10:1 range (nominal frequencies in brackets):

$$R_6=10.132 \text{ k}\Omega, R_1=470 \Omega: f_0=499.9 \text{ Hz (500 Hz)}, V_{out,2,peak}=9.8 \text{ V, THD}=0.7\%$$

$$R_6=2.533 \text{ k}\Omega, R_1=485 \Omega: f_0=999.8 \text{ Hz (1 kHz)}, V_{out,2,peak}=9.1 \text{ V, THD}=0.6\%$$

$$R_6=101.32 \Omega, R_1=495 \Omega: f_0=4.985 \text{ kHz (5 kHz)}, V_{out,2,peak}=7.1 \text{ V, THD}=0.8\%$$

Remark: In order to guarantee for all three cases a quality factor $Q > 50$ the resistor R_1 was slightly increased according to eqn. (4).

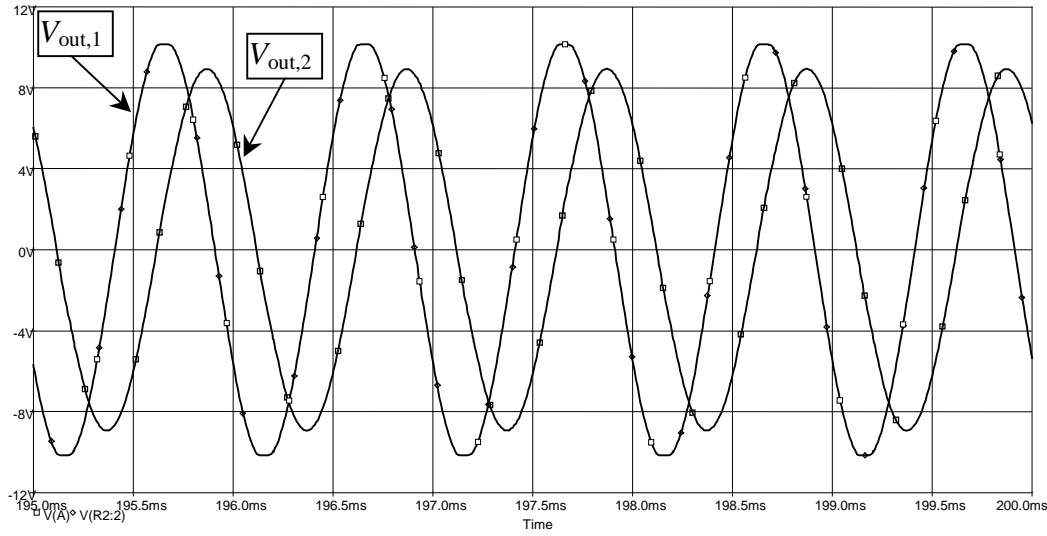


Fig. 3 Output voltages $V_{out,1}$ and $V_{out,2}$ ($R_6=2.533 \text{ k}\Omega$)

Circuit modification:

In order to start and maintain oscillations the GIC resonator in Fig. 2 contains a resistor R_X , which generates - in combination with R_1 - a relatively small negative resistance R_N in series to the active inductance L_1 . The same effect can be achieved with a negative resistor R_P in parallel to L_1 . For this purpose – with $R_1=R_X=0$ – a relatively large resistor R_P is placed between the common node of both inverting opamp inputs and ground.

In this case, the conversion from a series to a parallel loss resistor

$$R_P = \frac{(\omega_0 L_1)^2}{|R_N|}$$

leads to

$$Q = \frac{R_P}{\sqrt{RR_6}}.$$

Alternative interpretation

Interestingly, the function of the oscillator in Fig. 2 can also be described looking into the circuit from the right side. If we set again

$$C_1=C_5=C \text{ and } R_2=R_3=R_4=R$$

the input impedance is

$$Z_{IN,5} = -\frac{1}{\omega^2 RC^2} - \frac{R_X - R_1}{j\omega RC}.$$

This expression represents the impedance of a frequency-dependent negative resistor (FDNR) in series with the impedance of a negative capacitance ($R_X > R_1$). Shunting the FDNR with a (positive) resistor R_6 forms again a resonant circuit. The function of the negative capacitance is readily explained applying the rules of the inverse impedance transformation (*Bruton*, [3]):

$$-1/sC \Rightarrow -R, \quad R \Rightarrow sL, \quad 1/(s^2 RC^2) \Rightarrow 1/sC.$$

References:

- [1] Antoniou, A.: Realization of gyrators using operational amplifiers and their use in RC-active network synthesis, IEE Proc. 1969, 116 (11), pp. 1838-1850.
- [2] Sedra, A.S. and Espinoza, J.L.: Sensitivity and frequency limitations of biquadratic active filters, IEEE Trans. 1975, CAS-22 (2), pp. 122-130.
- [3] Bruton, L.T.: Network transfer functions using the concept of frequency-dependent negative resistance, IEEE Trans. Circuit Theory CT-16, pp. 406-408.