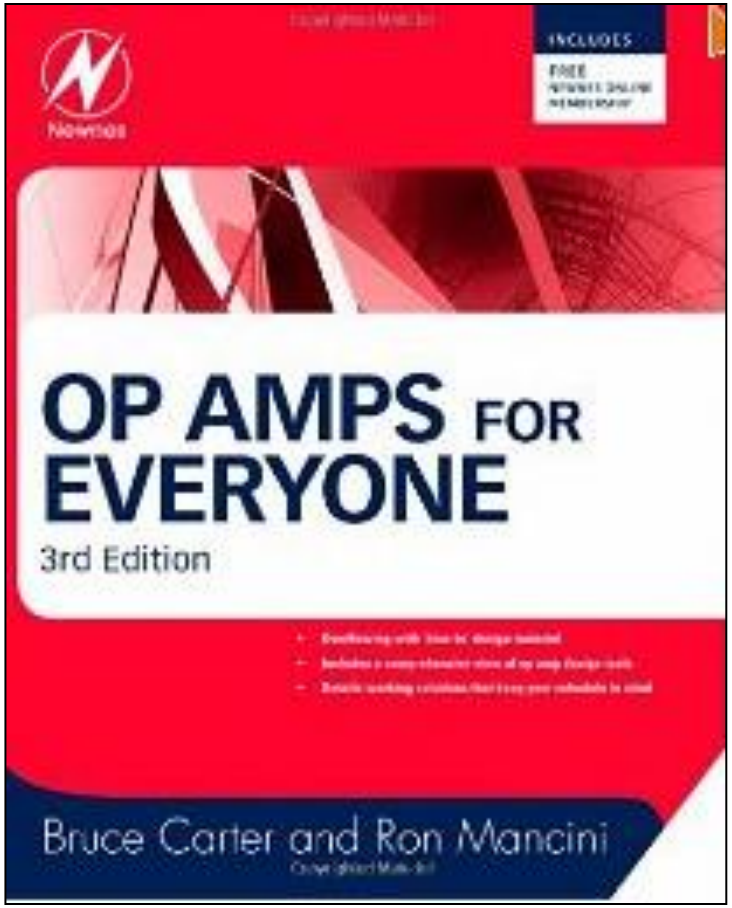
Laboratório 3
Filtros Ativos Passa-Tudo

Referência

[OP AMPs for Everyone](#)
Newnes, 2009



Roteiro Experimental

SEL393 – Laboratório de Instrumentação Eletrônica I
Escola de Engenharia de São Carlos - USP
Departamento de Engenharia Elétrica

Laboratório 3 - Filtros Ativos Passa-Tudo

Implemente em simulação um filtro passa-tudo para gerar um atraso de 2ms em um sinal com espectro de frequência $0 < f < 1$ kHz. Para minimizar a distorção de fase a frequência de corte deve ser maior que 1 kHz.

- Plote em representação cartesiana a fase (Ø) em função da frequência.

- Plote em representação Bode e meça o atraso de grupo não normalizado (T_{gro}) de cada estágio do filtro.

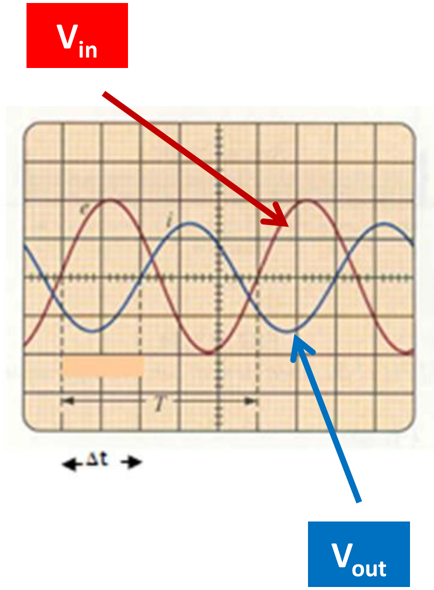
- Compare o valor medido do atraso de grupo não normalizado (T_{gro}) de cada estágio do filtro com o valor teórico.

- Plote em representação Bode e meça o atraso de grupo não normalizado (T_{gro}) do filtro projetado.

- Compare o valor medido do atraso de grupo não normalizado (T_{gro}) do filtro projetado com o valor teórico.

- Verifique que a defasagem muda linearmente com a frequência utilizando para este parâmetro uma escala linear.

Phase Shift



$$\theta = \frac{\Delta t}{T} 360^o = \Delta t f 360^o$$

Δt (delay)varies with the frequency.

To achieve **equal temporal delays** for all the frequencies, we need every frequency to have a different phase shift—namely, a phase shift that results in the same delay for every frequency. More specifically, we need a phase-shift response that *increases* linearly with frequency.

An **ideal linear-phase filter**, then, exhibits phase shift that increases linearly with frequency, and it thereby provides constant temporal delay (this applies primarily to the frequencies within the passband, i.e., the frequencies of interest).

Group delay (t_{gr}) is proportional to the derivative of the phase response with respect to frequency.

The derivative of a linear function is a constant, which explains why a linear phase response is also referred to as constant group delay.

$$t_{gr} = -\frac{d\phi}{d\omega}$$

Now consider a situation in which a filter will see signals composed of various different frequencies that work together. Problems could arise if these different frequencies experience different delays.

1 All-pass filter has a constant gain across the entire frequency range, and a phase response that changes linearly with frequency.

2 All-pass filters are used in circuits referred to as "**phase equalizers**" or "**delay equalizers**." As discussed in Understanding Linear-Phase Filters, it is sometimes important to ensure that all the frequency components in a signal experience **equal temporal delay**.

Audio applications: Frequencies representing different pitches must remain synchronized to ensure proper sound reproduction.

Pitch is an auditory sensation in which a listener assigns musical tones to relative positions on a musical scale based primarily on their perception of the frequency of vibration. Pitch is closely related to frequency, but the two are not equivalent. Frequency is an objective, scientific attribute that can be measured. **Pitch is each person's subjective perception of a sound wave, which cannot be directly measured.** However, this does not necessarily mean that most people won't agree on which notes are higher and lower.

Digital communications: The sinusoidal harmonic frequencies that constitute a square wave must experience constant delay to avoid distortion of the digital signal.

3 Similar to the low-pass filters, all-pass circuits of higher order consist of cascaded first-order and second-order all-pass stages.

$$A(s) = \frac{\prod_i \left(1 - a_i s + b_i s^2\right)}{\prod_i \left(1 + a_i s + b_i s^2\right)}$$

(a_i and b_i being the coefficients of a partial filter)

4 Group Delay (t_{gr})

It is the time by which the all pass filter delays each frequency within a band.

$$t_{gr} = -\frac{d\phi}{d\omega}$$

5 Normalized Group Delay (T_{gr})

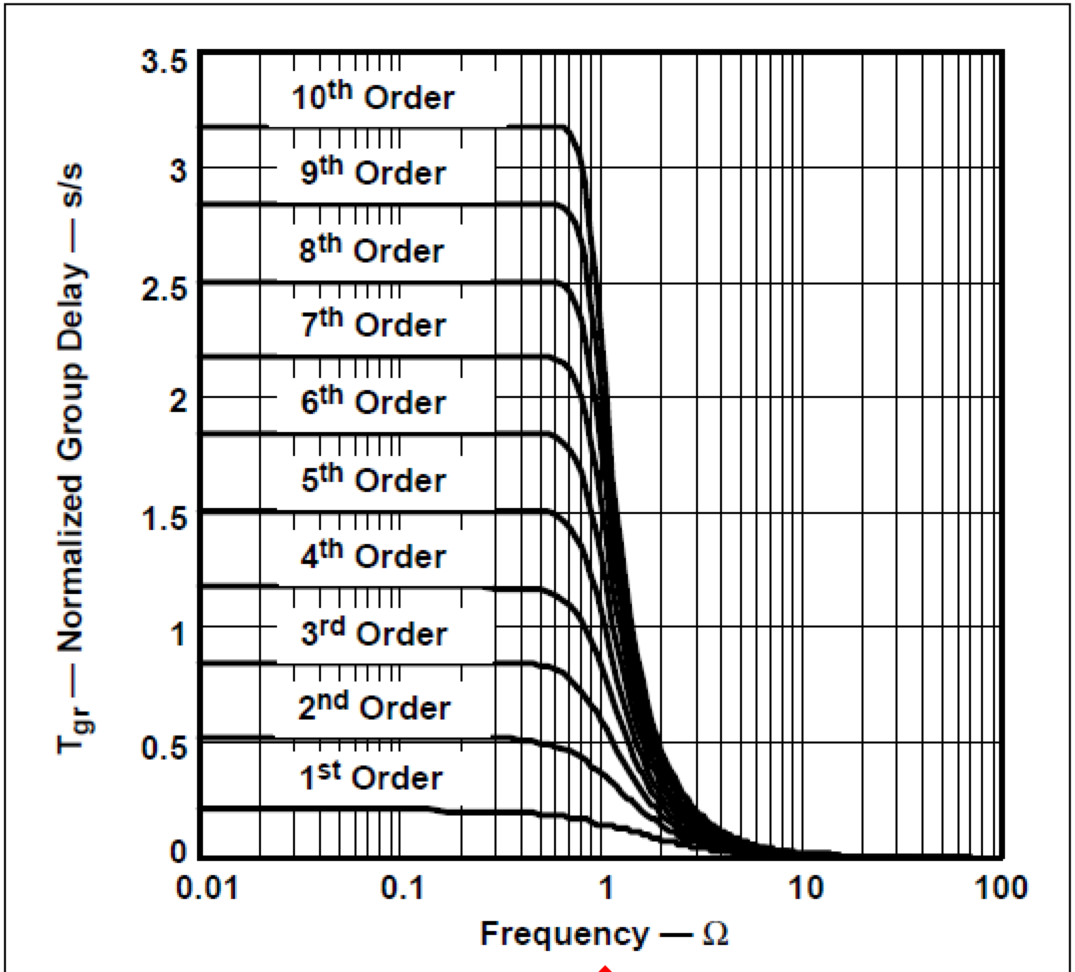
The frequency at which the normalizxed group delay drops to $\frac{1}{\sqrt{2}}$ times its initial value is the corner frequency (f_C) which corresponds to Ω=1.

$$T_{gr} = \frac{t_{gr}}{T_c} = t_{gr} \cdot f_c = t_{gr} \cdot \frac{\omega_c}{2\pi}$$

$$T_{gr} = -\frac{1}{2\pi}\frac{d\emptyset}{d\Omega}$$

$$T_{gr} = -\frac{f_c}{2\pi}\frac{d\emptyset}{df}$$

$$T_{gr} = \frac{1}{\pi}\sum_{i}\frac{a_i\left(1 + b_i\Omega^2\right)}{1 + \left(a_1{}^2 - 2b_1\right)\cdot\Omega^2 + b_1{}^2\Omega^4}$$

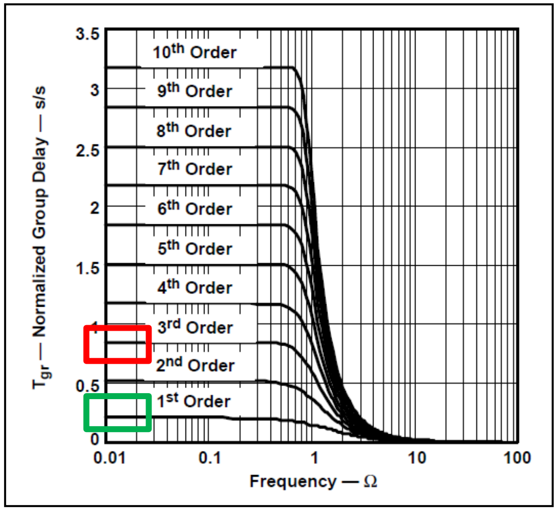


At Ω=1 there is a -3dB decrease in T_{gr} !

6 The T_{gro} is the value of T_{gr} when $\Omega < 0.1$

$$T_{gr0} = \frac{1}{\pi}\sum_i a_i$$

All Pass



n	i	a_i	b_i	f_i / f_C	Q_i	T_{gr0}
1	1	0.6436	0.0000	1.554	—	0.2049
2	1	1.6278	0.8832	1.064	0.58	0.5181
3	1	1.1415	0.0000	0.876	—	0.8437
	2	1.5092	1.0877	0.959	0.69	
4	1	2.3370	1.4878	0.820	0.52	1.1738
	2	1.3506	1.1837	0.919	0.81	
5	1	1.2974	0.0000	0.771	—	1.5060
	2	2.2224	1.5685	0.798	0.56	
	3	1.2116	1.2330	0.901	0.92	
6	1	2.6117	1.7763	0.750	0.51	1.8395
	2	2.0706	1.6015	0.790	0.61	
	3	1.0967	1.2596	0.891	1.02	
7	1	1.3735	0.0000	0.728	—	2.1737
	2	2.5320	1.8169	0.742	0.53	
	3	1.9211	1.6116	0.788	0.66	
	4	1.0023	1.2743	0.886	1.13	
8	1	2.7541	1.9420	0.718	0.51	2.5084
	2	2.4174	1.8300	0.739	0.56	
	3	1.7850	1.6101	0.788	0.71	
	4	0.9239	1.2822	0.883	1.23	
9	1	1.4186	0.0000	0.705	—	2.8434
	2	2.6979	1.9659	0.713	0.52	
	3	2.2940	1.8282	0.740	0.59	
	4	1.6644	1.6027	0.790	0.76	
	5	0.8579	1.2862	0.882	1.32	
10	1	2.8406	2.0490	0.699	0.50	3.1786
	2	2.6120	1.9714	0.712	0.54	
	3	2.1733	1.8184	0.742	0.62	
	4	1.5583	1.5923	0.792	0.81	
	5	0.8018	1.2877	0.881	1.42	

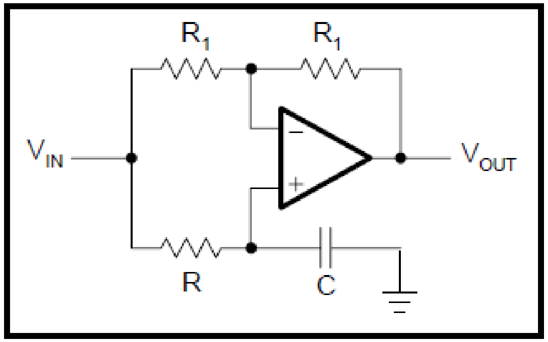
Examples:

n=1 → $$T_{gro} = \frac{1}{\pi}(0{,}6436) = 0{,}2049$$

n=3 → $$T_{gro} = \frac{1}{\pi}(1{,}1415 + 1{,}5092)$$

$$T_{gro} = 0{,}8437$$

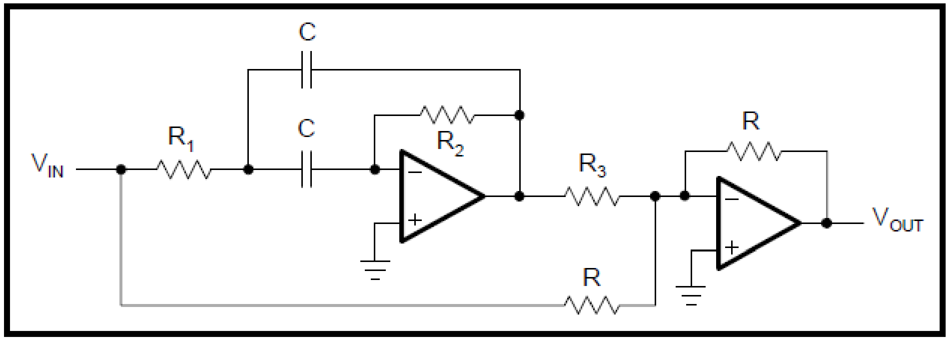
First Order Topology



$T_{gro} = 2RCf_C$

$R_1 = R$

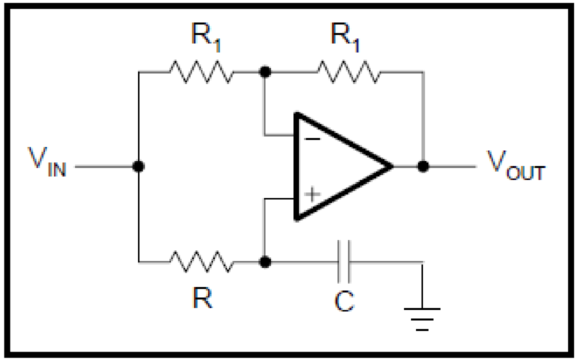
Second Order Topology



$T_{gro} = 4RCf_C$

Designing
All Pass Filters
(First Order Topology)

First Order Topology



$$A(s) = \frac{1 - RC\omega_c \cdot s}{1 + RC\omega_c \cdot s}$$

1 Specify f_C and C

2 Calculate R

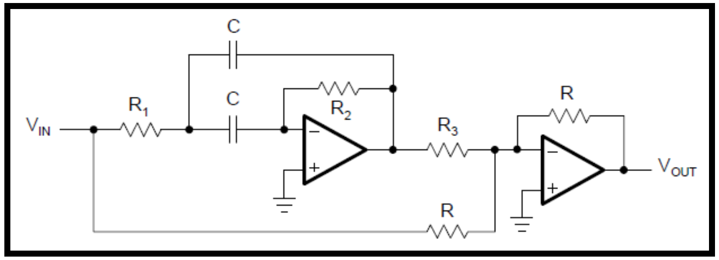
$$R = \frac{a_i}{2\pi f_c \cdot C}$$

3 Delay group

$$T_{gro} = 2RCf_C$$

Designing
All Pass Filters
(Second Order Topology)

Second Order Topology



$$A(s) = \frac{1 + (2R_1 - \alpha R_2)C\omega_c \cdot s + R_1R_2C^2\omega_c{}^2 \cdot s^2}{1 + 2R_1C\omega_c \cdot s + R_1R_2C^2\omega_c{}^2 \cdot s^2}$$

1 Specify f_C and C

2 Calculate R

$$R = \left|\frac{a_i}{2\pi f_c \cdot C}\right.$$

3 Calculate R_1, R_2, R_3

$$R_1 = \frac{a_1}{4\pi f_c C}$$

$$R_2 = \frac{b_1}{a_1 \pi f_c C}$$

$$R_3 = \frac{R}{\alpha}$$

$$\alpha = \frac{a_1{}^2}{b_1}$$

4 Maximum delay group

$$T_{gro} = 4RCf_C$$

Exemple 2:
Implemente no LTSPice um filtro passa tudo de ordem 1 com frequência de corte de 1KHz. Utilize C=10nF.

1 Specify f_C and C and take a_1

f_C = 1KHz, C=10nF, a_1 = 0,6436

a_1

n	i	a_i	b_i	f_i / f_C	Q_i	T_{gr0}
1	1	0.6436	0.0000	1.554	—	0.2049
2	1	1.6278	0.8832	1.064	0.58	0.5181
3	1	1.1415	0.0000	0.876	—	0.8437

All Pass

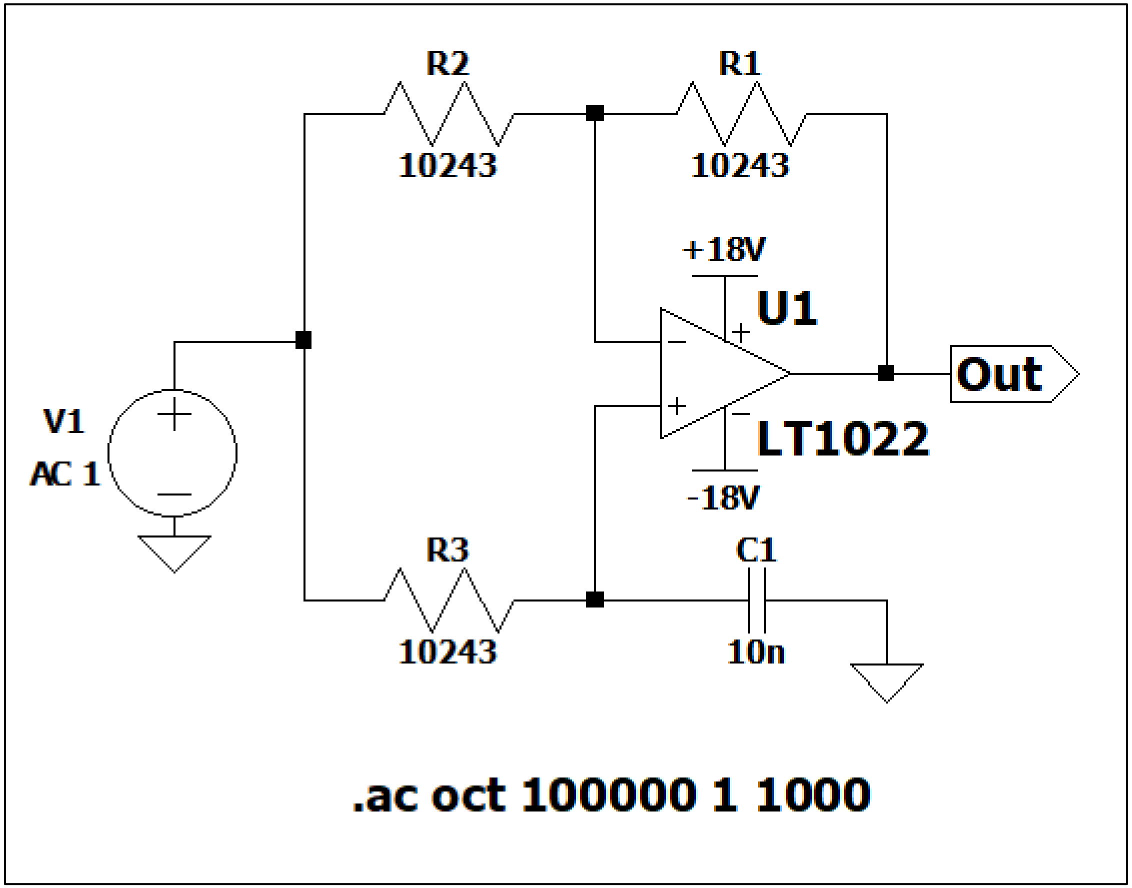
2 Calculate R

$$R = \frac{a_i}{2\pi f_C \cdot C}$$

$$R = \frac{0,6436}{2\pi x 10^3 x 10 x 10^{-9}} = 10243$$

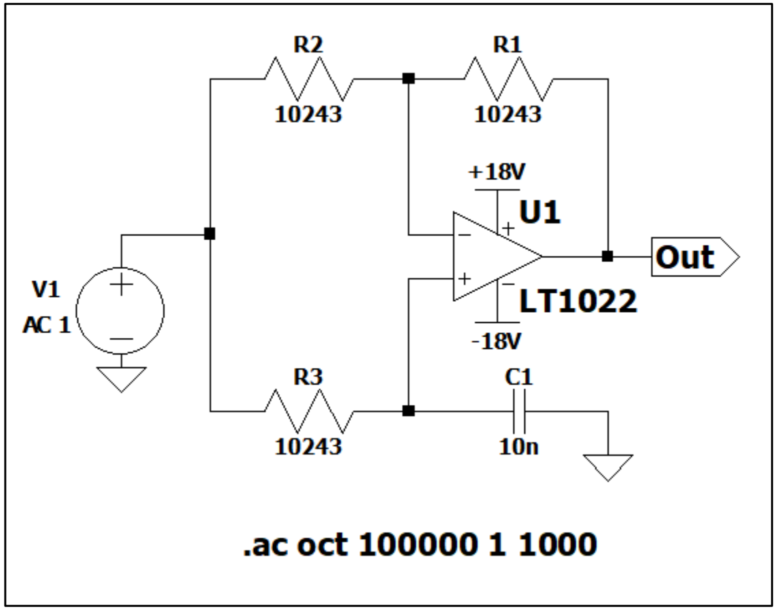
3 Calculate T_{gro}

$$T_{gro} = 2RCf_c \Rightarrow T_{gro} = 2x10243x10x10^{-9}x1000 = 0{,}20486$$



LTSPice Simulation

How to measure Ø and T_{gr} in the LTSPice ???



Fase (Ø)

Ø=arctan(Im(V(out))/Re(V(out)))

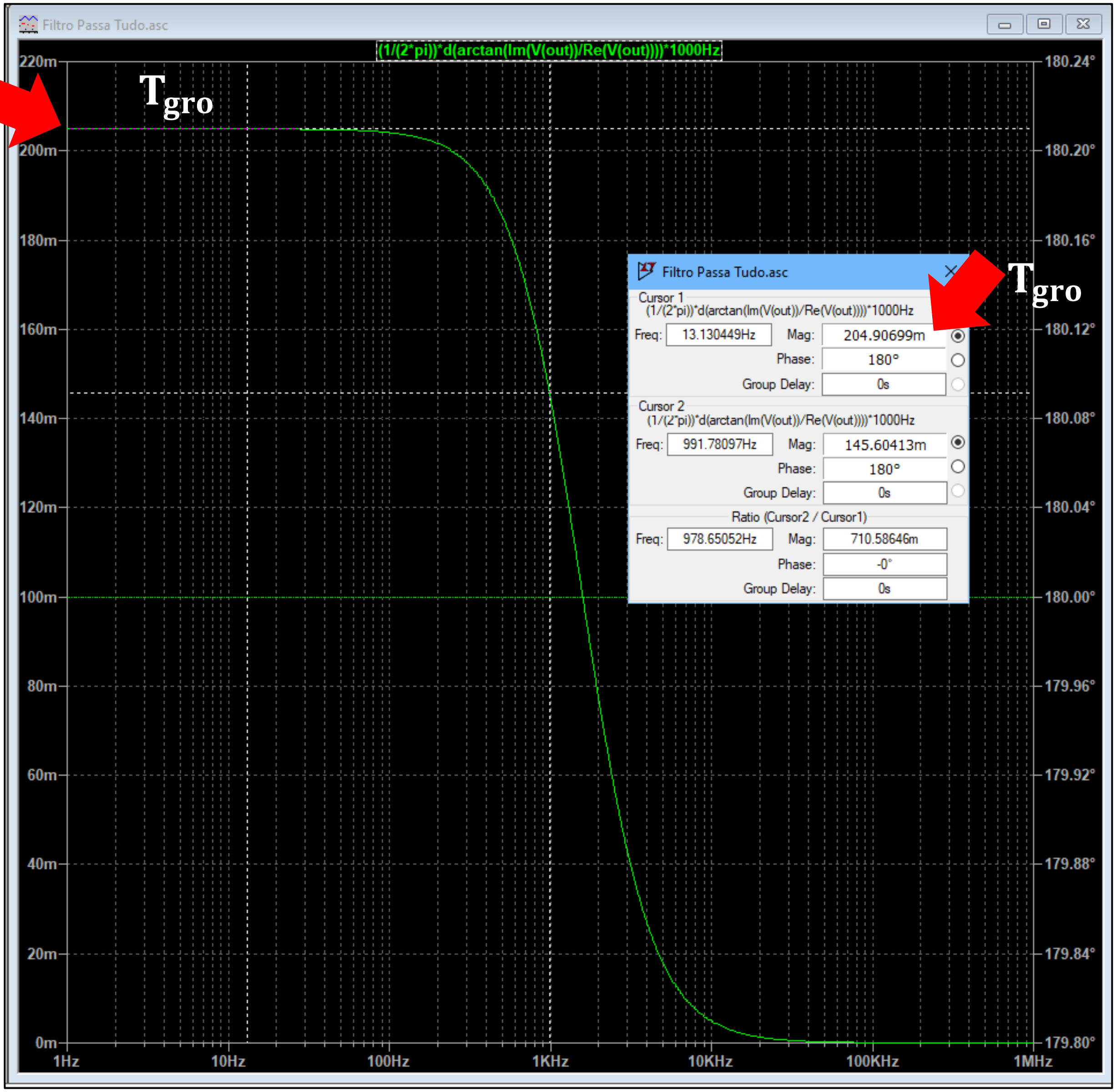
Normalized Delay group (T_{gr})

$$T_{gr} = -\frac{f_c}{2\pi}\frac{d\text{Ø}}{df}$$

T_{gr} =(1/(2∗pi))∗d(arctan(Im(V(out))/Re(V(out))))*1000Hz

$$\frac{d\text{Ø}}{df}$$

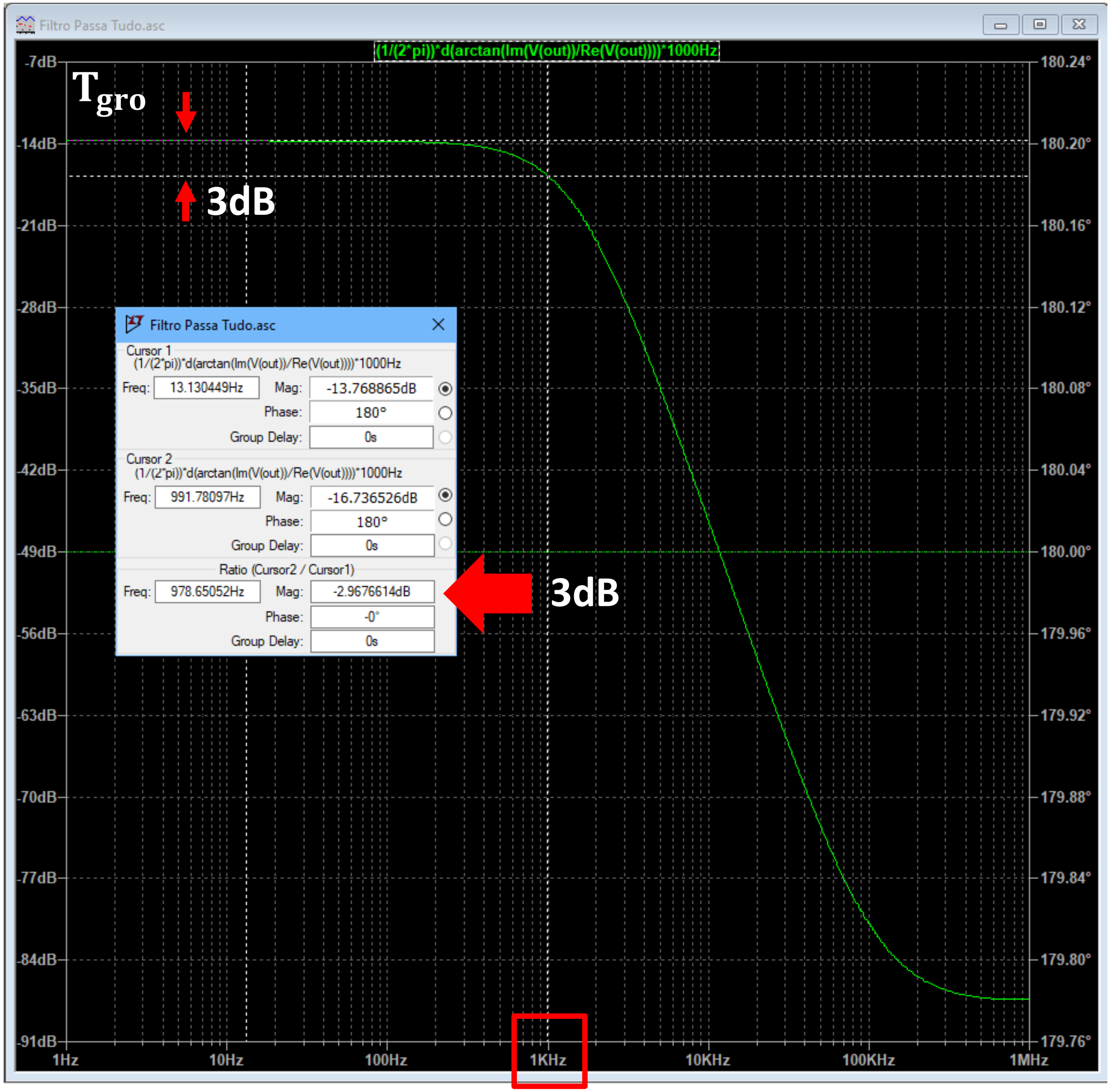
Normalized delay group (T_{gr}) $\rightarrow$ T_{gr} =(1/(2*pi))*d(arctan(Im(V(out))/Re(V(out))))*1000Hz



Medida do T_{gro}

Normalized delay group (T_{gr}) $T_{gr} = (1/(2*pi))*d(arctan(Im(V(out))/Re(V(out))))*1000Hz$

Verificação da queda de 3dB em f_c 1KHz

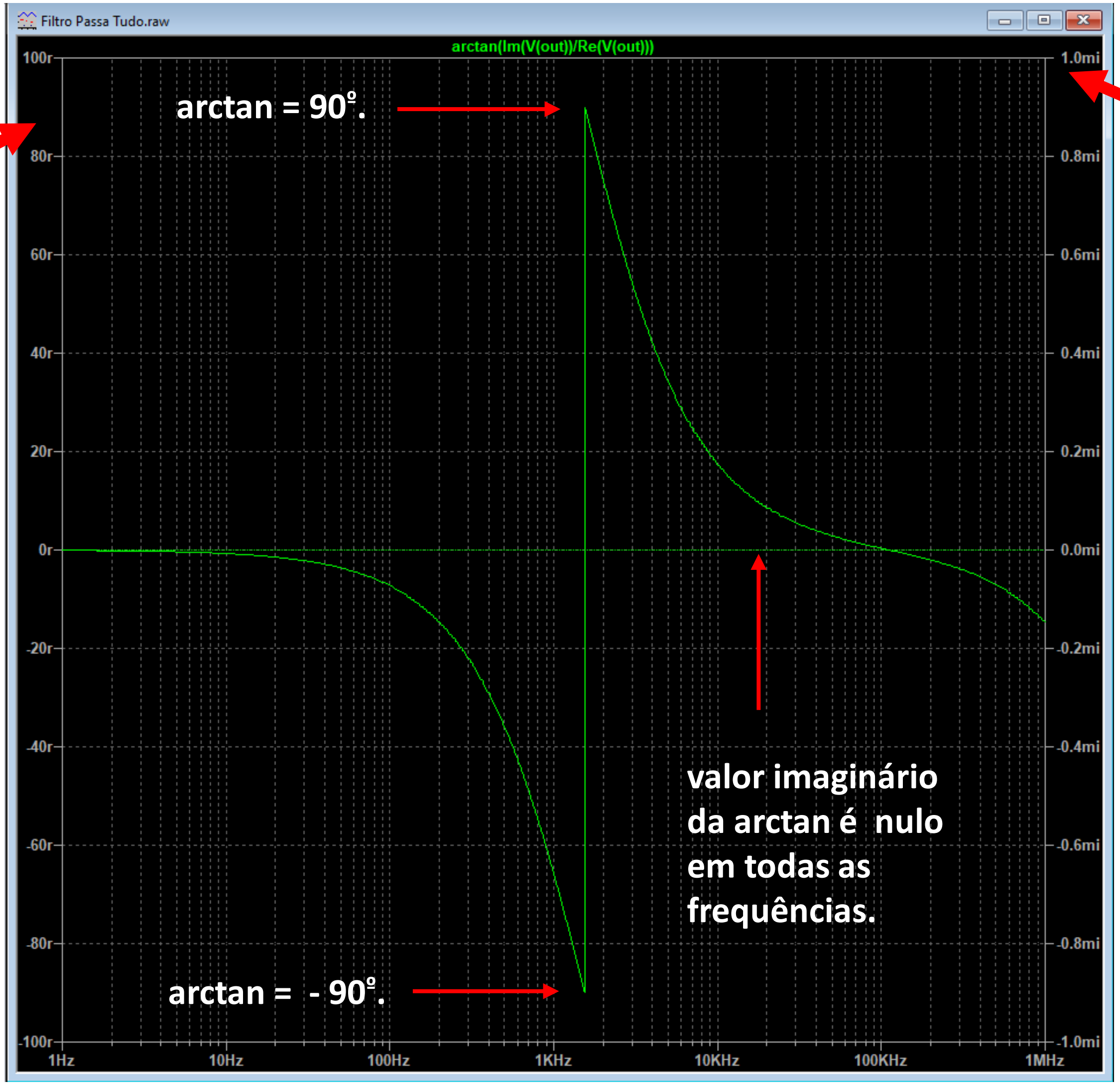


Fase (Ø) → Ø=arctan(Im(V(out))/Re(V(out)))

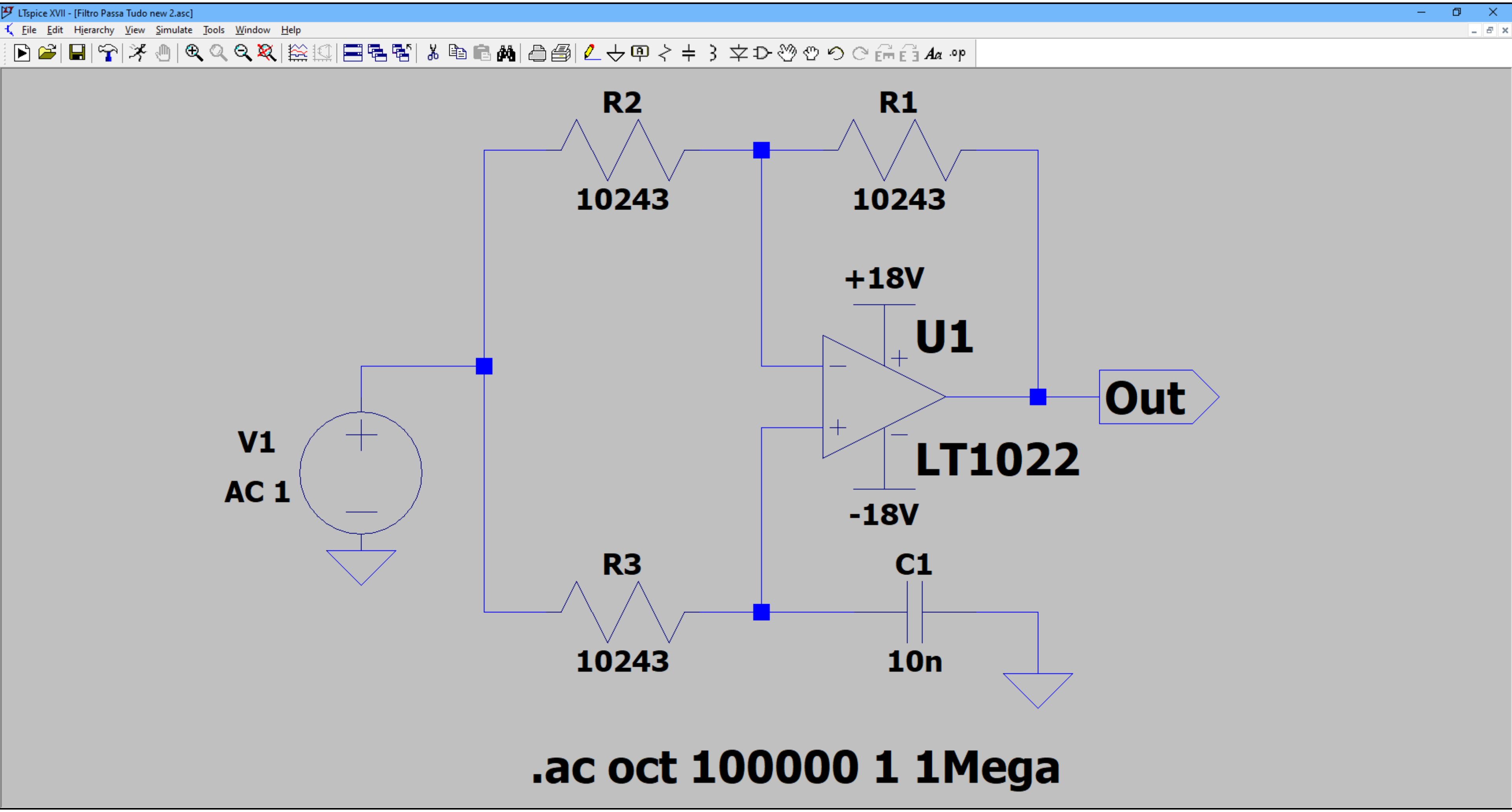
Ø x f (utilizando representação cartesiana no LTSPice)

Eixo vertical esquerdo: valor real (r) do arctan em função da frequência

O valor de arctan varia de 90º à - 90º.



Eixo vertical direito: valor imaginário (i) do arctan que tem ser nulo em todas as frequências porque arctan é um número real.

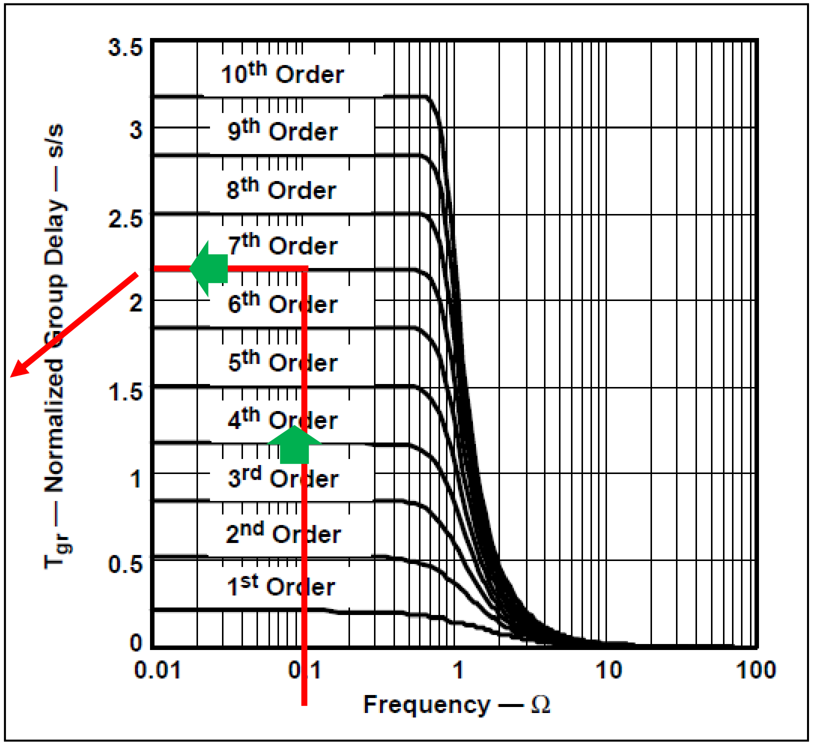

LTspice XVII - [Filtro Passa Tudo new 2.asc]
File Edit Hierarchy View Simulate Tools Window Help
R2
10243
R1
10243
+18V
U1
V1
AC 1
Out
LT1022
-18V
R3
10243
C1
10n
.ac oct 100000 1 1Mega

Exemple 1:

A signal with the frequency spectrum, 0 < f < 1 kHz needs to be delayed by 2 ms. To keep the phase distortions at a minimum, the corner frequency of the all-pass filter must be $f_C \geq 1$ kHz. Design a 2-ms delay all-pass filter.

1 The figure below shows a seventh-order all-pass is needed to accomplish the desired delay.

$T_{gro} = 2.1737$



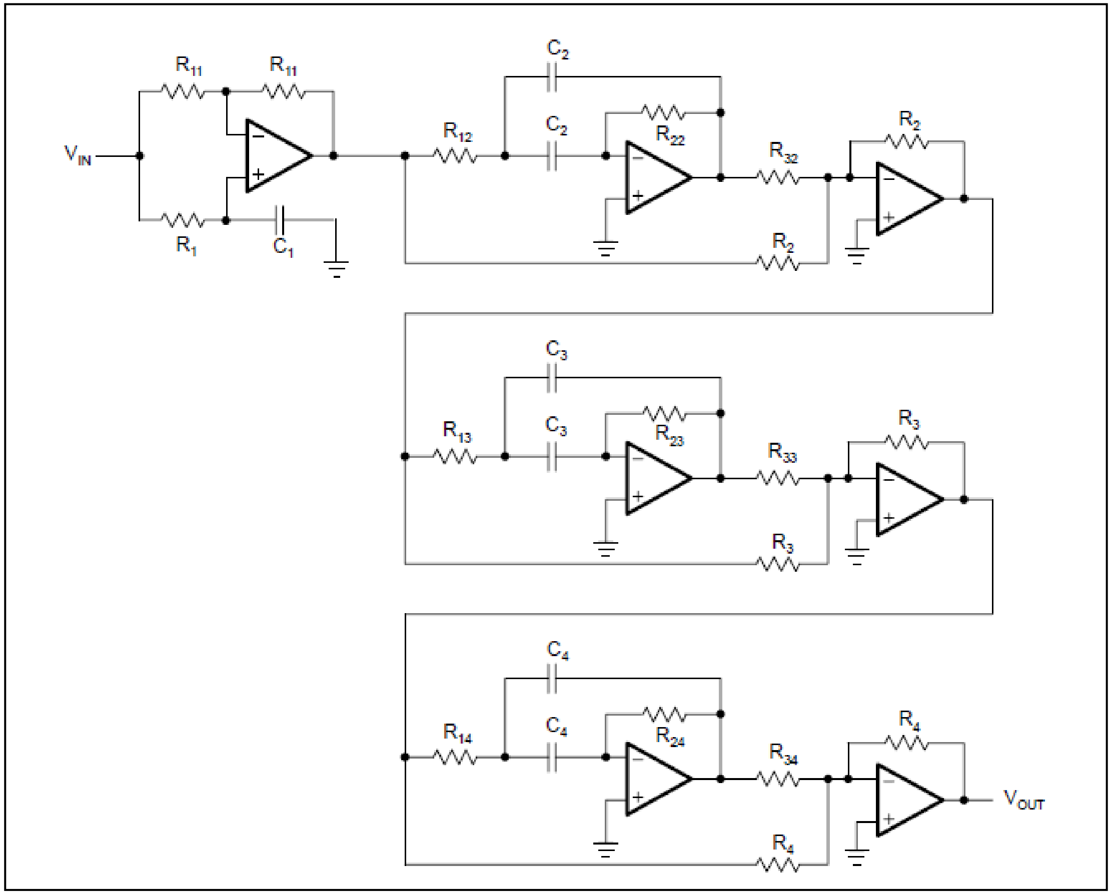
O filtro de ordem 6 tem Tgro=2. Sendo tgr=2ms resulta que a frequência de corte é f_c = 1KHz. No entanto $f_C \geq 1$ kHz e, portanto, o filtro escolhido deverá ter ordem 7.

$T_{gr0} = 2.1737$

tgr=2ms

$$f_C = \frac{T_{gr0}}{t_{gr0}} = 1.087 \text{ kHz}$$

All Pass Filter – 7th Order



All Pass Filter – 7th Order