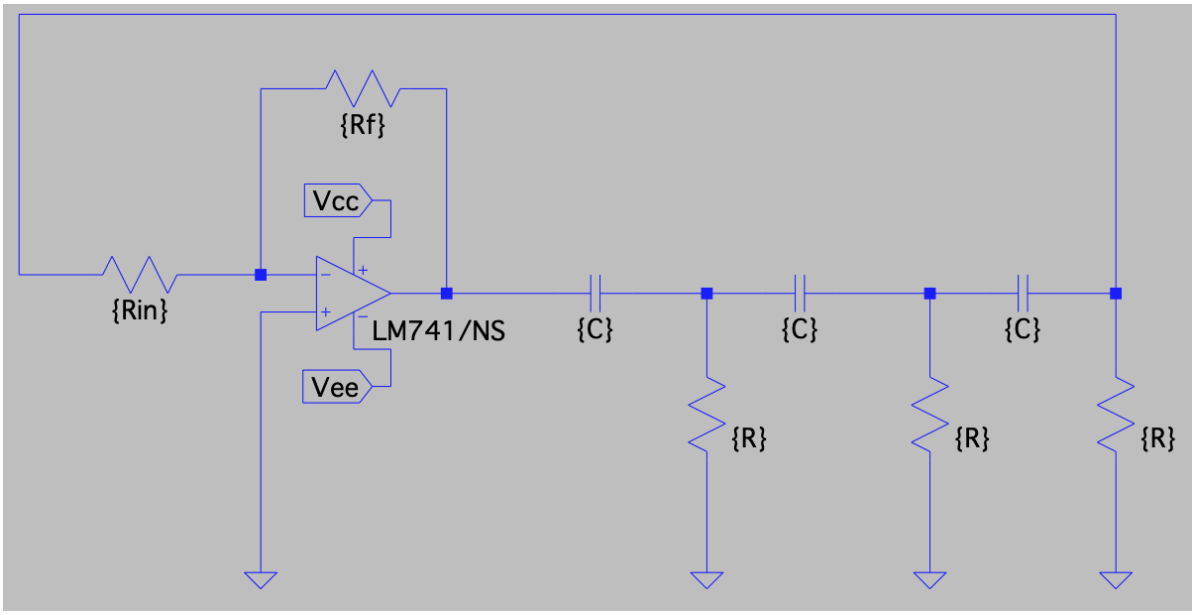
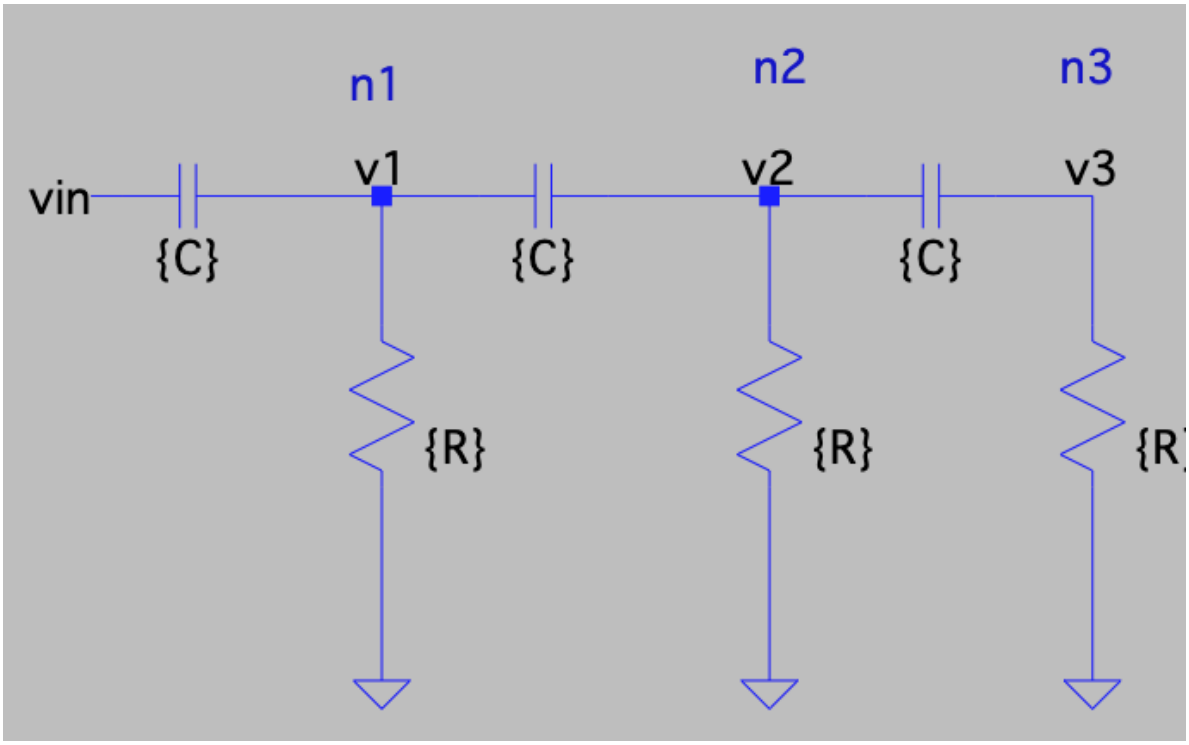
Demonstração da frequencia:

```
clear; clc; clearvars;
syms vin v1 v2 v3 s c r n1 n2 n3 w H f positive
```





Definindo os nos

```
n1 = (v1 - vin)/(1/(s*c)) + v1/r + (v1-v2)/(1/(s*c)) == 0
```

```
n1 =
```

$$\frac{v_1}{r} + c\,s\,(v_1 - v_2) + c\,s\,(v_1 - \mathrm{vin}) = 0$$

```
n2 = (v2 - v1)/(1/(s*c)) + v2/r + (v2-v3)/(1/(s*c)) == 0
```

```
n2 =
```

$$\frac{v_2}{r} - c\,s\,(v_1 - v_2) + c\,s\,(v_2 - v_3) = 0$$

```
n3 = (v3-v2)/(1/(s*c)) + v3/r == 0
```

```
n3 =
```

$$\frac{v_3}{r} - c\,s\,(v_2 - v_3) = 0$$

Isolando v2 a partir do no 3

```
v2 = solve(n3, v2)
```

```
v2 =
```

$$\frac{\frac{v_3}{r} + c\,s\,v_3}{c\,s}$$

Substituindo v2 no no 2

```
n2 = subs(n2)
```

```
n2 =
```

$$\frac{\frac{v_3}{r} + c\,s\,v_3}{c\,r\,s} - c\,s\left(v_3 - \frac{\frac{v_3}{r} + c\,s\,v_3}{c\,s}\right) - c\,s\left(v_1 - \frac{\frac{v_3}{r} + c\,s\,v_3}{c\,s}\right) = 0$$

Substituindo v2 no no 1

```
n1 = subs(n1)
```

```
n1 =
```

$$\frac{v_1}{r} + c\,s\left(v_1 - \frac{\frac{v_3}{r} + c\,s\,v_3}{c\,s}\right) + c\,s\,(v_1 - \mathrm{vin}) = 0$$

Isolando v1 no no 2

```
v1 = solve(n2, v1)
```

v1 =

$$\frac{v_3\,c^2\,r^2\,s^2 + 3\,v_3\,c\,r\,s + v_3}{c^2\,r^2\,s^2}$$

Aplicando v1 no no 1

```
n1 = subs(n1)
```

n1 =

$$\frac{v_3\,c^2\,r^2\,s^2 + 3\,v_3\,c\,r\,s + v_3}{c^2\,r^3\,s^2} - c\,s\,\left(\mathrm{vin} - \sigma_1\right) - c\,s\left(\frac{\frac{v_3}{r} + c\,s\,v_3}{c\,s} - \sigma_1\right) = 0$$

where

$$\sigma_1 = \frac{v_3\,c^2\,r^2\,s^2 + 3\,v_3\,c\,r\,s + v_3}{c^2\,r^2\,s^2}$$

Isolando vin

```
vin = solve(n1, vin)
```

vin =

$$\frac{v_3\,c^3\,r^3\,s^3 + 6\,v_3\,c^2\,r^2\,s^2 + 5\,v_3\,c\,r\,s + v_3}{c^3\,r^3\,s^3}$$

```
  H = simplify(v3/vin)
```

H =

$$\frac{c^3\,r^3\,s^3}{c^3\,r^3\,s^3 + 6\,c^2\,r^2\,s^2 + 5\,c\,r\,s + 1}$$

Fazendo s=jw

```
s = 1i*w;
H = subs(H)
```

H =

$$-\frac{c^3\,r^3\,w^3\,\mathrm{i}}{-c^3\,r^3\,w^3\,\mathrm{i} - 6\,c^2\,r^2\,w^2 + 5\,c\,r\,w\,\mathrm{i} + 1}$$

Como o objetivo ao final 'e defasar 360 graus e 180 por definicao serao defasados pelo ampop, resta encontrarmos uma forma de fazer isso com essa funcao de transferencia. Caso igualamos a parte real do denominador a zero, a funcao de trasnferencia ter'a o angulo desejado de 180 graus.

Para tanto precisamos separar o denominador do numerador de H

```
[numH, denH] = numden(H);
```

Feito isso, substituimos os termos do denominador que sao imaginarios por zero

```
denHreal = subs(denH, 1i, 0);
```

Para atualizar a definicao de H com essa consideracao removemos o termo real do denominador pois este agora vale zero

```
denH = denH - denHreal;
```

Agora, atualizamos H temos

```
H = numH/denH
```

H =

$$-\frac{c^3 r^3 w^3 \mathrm{i}}{5 c r w \mathrm{i} - c^3 r^3 w^3 \mathrm{i}}$$

Igualando o termo real a zero temos

```
denHreal = denHreal == 0
```

denHreal = $6 c^2 r^2 w^2 - 1 = 0$

Extraindo w da igualdade passamos a ter:

```
w = solve(denHreal, w);
w = simplify(w)
```

w =

$$\frac{\sqrt{6}}{6 c r}$$

Como w pode ser escrito em funcao da frequencia f em Hertz, 'e interessante tamb'em definirmos a frequencia dessa forma. Entao:

```
f = w/(2*pi)
```

f =

$$\frac{\sqrt{6}}{12\,c\,r\,\pi}$$

Tendo em vista que o simplificamento feito pelo programa nao mostra a frequencia na forma mais simplificada, uma simplificacao manual desse resultado tanto para f quanto para w daria

$f = \frac{1}{2\,\pi\,\sqrt{6}\;c\,r}$ e tambem $w = \frac{1}{\sqrt{6}\;c\,r}$

Agora, para demonstrar o ganho substituimos a frequencia encontrada na equacao. Dessa forma:

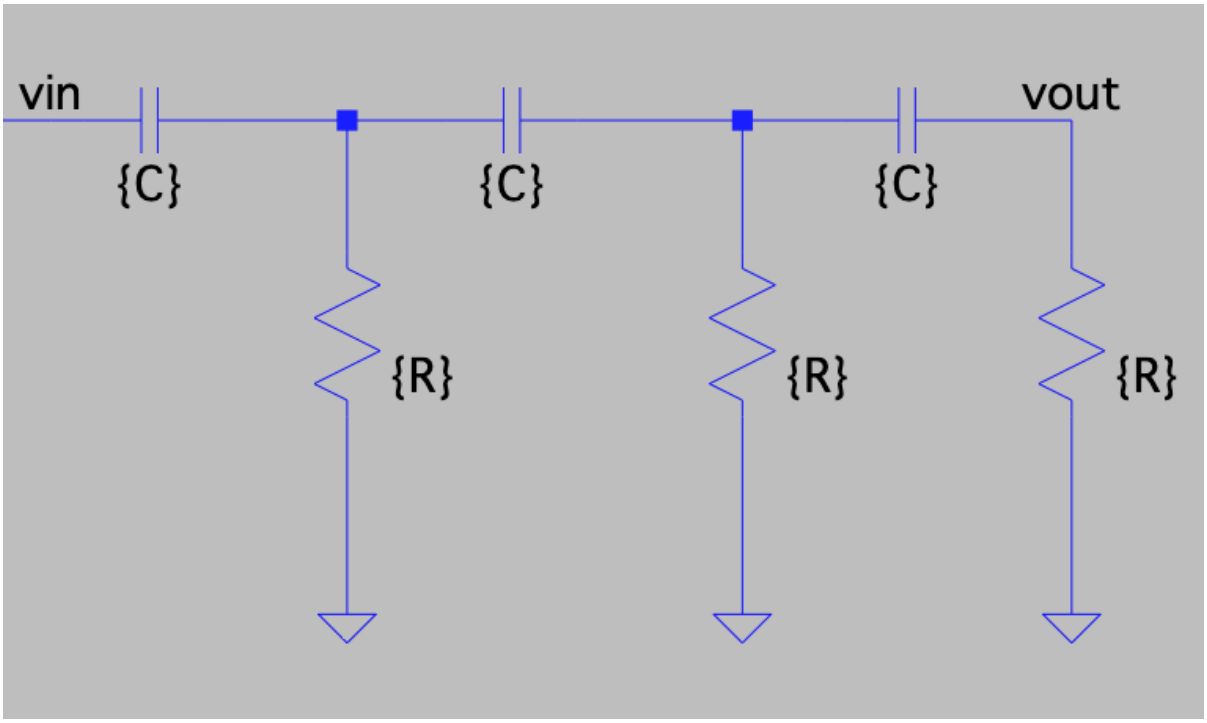
```
A = subs(H)
```

```
A =
```

$$-\frac{1}{29}$$

Impedancia de entrada/saída do bloco B

```
clear; clc; clearvars;
syms r c s w positive
```



Impedancia de entrada rede RC

Comecando pelo terceiro estagio faz-se:

```
zinRC = 1/(s*c) + r
```

zinRC =

$$r+\frac{1}{c\,s}$$

Em seguida fazemos o paralelo do terceiro estagio com o resistor do segundo

```
zinRC = paraleloSym(r,zinRC)
```

zinRC =

$$\frac{1}{\frac{1}{r+\frac{1}{c\,s}}+\frac{1}{r}}$$

Para terminar de computar o segundo estagio, somamos o resultado com o capacitor que ficou de fora

```
zinRC = zinRC + 1/(s*c)
```

zinRC =

$$\frac{1}{\frac{1}{r+\frac{1}{c\,s}}+\frac{1}{r}}+\frac{1}{c\,s}$$

Para o primeiro estagio comecamos fazendo o paralelo do resultado com seu resistor

```
zinRC = paraleloSym(r, zinRC)
```

zinRC =

$$\frac{1}{\frac{1}{\frac{1}{\frac{1}{r+\frac{1}{c\,s}}+\frac{1}{r}}+\frac{1}{c\,s}}+\frac{1}{r}}$$

Em seguida, somamos o resultado com capacitor que ficou de fora

```
zinRC = zinRC + 1/(s*c)
```

zinRC =

$$\frac{1}{c\,s}+\frac{1}{\frac{1}{\frac{1}{\frac{1}{r+\frac{1}{c\,s}}+\frac{1}{r}}+\frac{1}{c\,s}}+\frac{1}{r}}$$

Por fim, para simplificar:

```
s = 1i*w;
zinRC = subs(zinRC);
zinRC = simplify(zinRC)
```

zinRC =

$$\frac{-c^3\,r^3\,w^3+6\,c^2\,r^2\,w^2\,\mathrm{i}+5\,c\,r\,w-\mathrm{i}}{c\,w\,\left(-3\,c^2\,r^2\,w^2+4\,c\,r\,w\,\mathrm{i}+1\right)}$$

```
syms s
```

Impedancia de saida da rede RC

Comecando pelo primeiro estagio temos o paralelo do primeiro resistor e capacitor

```
zoutRC = paraleloSym(r,1/(s*c))
```

zoutRC =

$$\frac{1}{c\,s+\frac{1}{r}}$$

Em seguida temos a soma com o capacitor subsequente

```
zoutRC = zoutRC + 1/(s*c)
```

zoutRC =

$$\frac{1}{c\,s+\frac{1}{r}}+\frac{1}{c\,s}$$

Para completar o segundo estagio, fazemos o paralelo do resultado com o resistor desse estagio

```
zoutRC = paraleloSym(r, zoutRC)
```

zoutRC =

$$\frac{1}{\frac{1}{\frac{1}{c\,s+\frac{1}{r}}+\frac{1}{c\,s}}+\frac{1}{r}}$$

Para o terceiro estagio fazemos o paralelo do resultado com o resistor e o capacitor desse estagio

```
zoutRC = paraleloSym(r, 1/(s*c), zoutRC)
```

zoutRC =

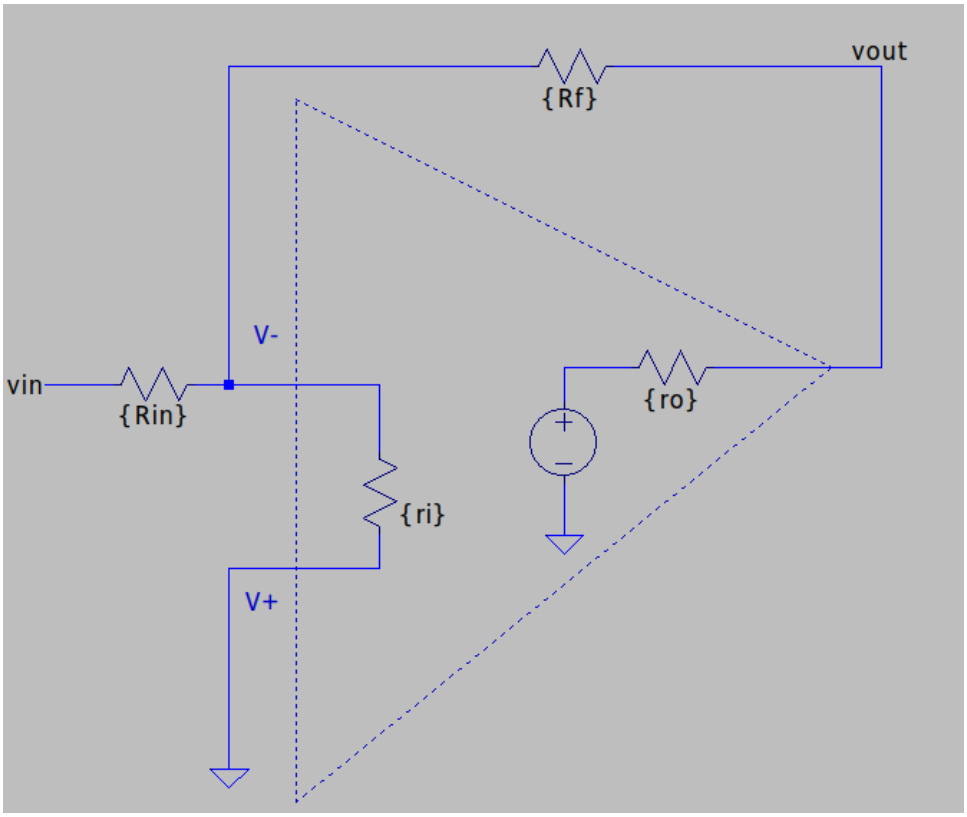
$$\frac{1}{c\,s+\frac{1}{\frac{1}{c\,s+\frac{1}{r}}+\frac{1}{c\,s}}+\frac{2}{r}}$$

```
s = 1i*w;
zoutRC = subs(zoutRC);
zoutRC = simplify(zoutRC)
```

zoutRC =

$$\frac{r\ (2\,c\,r\,w-\mathrm{i})}{3\,c^2\,r^2\,w^2\,\mathrm{i}+6\,c\,r\,w-2\,\mathrm{i}}$$

Impedância de entrada/saída do bloco A



Impedancia de entrada bloco amplificador

```
clc; clear; clearvars;
syms Rin Rf ri ro positive
```

Consideranco o terra virtual, em V- passamos a ter 0V, e assim a impedancia de entrada pode ser escrita como:

```
ZinAmp = Rin
```

ZinAmp = Rin

Impedancia de saida bloco amplificador

Consideranco o terra virtual, em V- tambem, a impedancia de saida pode ser descrita como:

```
ZoutAmp = paraleloSym(ro, Rf);
ZoutAmp = simplify(ZoutAmp)
```

ZoutAmp =

$$\frac{Rf\ ro}{Rf + ro}$$

Projeto dos osciladores

```
clear; clc; clearvars;
syms r c Rin Rf ro ri w f positive
```

Definindo as equações:

```
r = sqrt(6)/(w*c*6)
```

r =

$$\frac{\sqrt{6}}{6\,c\,w}$$

```
ZinAmp = Rin
```

ZinAmp = Rin

```
ZoutAmp = (Rf*ro)/(Rf+ro)
```

ZoutAmp =

$$\frac{\mathrm{Rf}\,\mathrm{ro}}{\mathrm{Rf}+\mathrm{ro}}$$

```
ZinRC = (-c^3*r^3*w^3+6*c^2*r^2*w^2*1i+5*c*r*w-1i)/(c*w*(-3*c^2*r^2*w^2+4*c*r*w*1i+1))
```

ZinRC =

$$\frac{29\,\sqrt{6}}{36\,c\,w\left(\frac{1}{2}+\frac{2\,\sqrt{6}\,\mathrm{i}}{3}\right)}$$

```
ZoutRC = r*(2*c*r*w-1i)/(3*c^2*r^2*w^2*1i+6*c*r*w-2*1i)
```

ZoutRC =

$$\frac{\sqrt{6}\,\left(\frac{\sqrt{6}}{3}-\mathrm{i}\right)}{6\,c\,w\left(\sqrt{6}-\frac{3}{2}\,\mathrm{i}\right)}$$

Considerações

É possivel percebeber que quanto menor o capacitor C maior é o resistor R que se obtém. No entanto aumenta da mesma proporção a impedância de entrada do bloco B, o que seria uma boa coisa se não fosse o fato da impedancia de saida tambem aumentar nessa mesma proporção.

Com isso, é importante encontrar um valor de impedancia de entrada para que a impedancia de saida não seja alta levando em consideracao a impedancia de entrada do bloco A.

Como a impedancia do bloco A é facilmente manipulável foram colocados resistores de maior valor, uma vez que a impedancia de entrada depende só de Rin e a saída apenas de Rin e ro.

F = 250Hz

Antes de tudo definamos os parâmetros do ampop. Nesse caso o ampop utilizado foi o LM741.

```
riDatasheet = 2e6;
roDatasheet = 75;
Rin250 = 1e3;
Rf250 = Rin250 * 29;
```

Definindo a frequencia de projeto e o capacitor:

```
w250 = 2*pi*250;
c250 = 820e-9;
```

Obtendo R

```
r250 = subs(r,{c,w},{c250,w250});
double(r250)
```

```
ans = 316.9499
```

Com R e C podemos obter as impedancias de entrada/saida da rede RC

```
ZinRC250 = subs(ZinRC,{c,r,w},{c250,r250,w250});
abs(double(ZinRC250))
```

```
ans = 897.0032
```

```
ZoutRC250 = subs(ZoutRC,{c,r,w},{c250,r250,w250});
abs(double(ZoutRC250))
```

```
ans = 142.4584
```

Por fim, definimos ri, ro e as resistencias Rin e Rf sendo Rf == 29Rin de maneira a obtermos as impedancias de entrada/saida do bloco de amplificação

```
ZinAmp250 = subs(ZinAmp, {Rin, Rf, ri, ro}, {Rin250, Rf250, riDatasheet, roDatasheet})
```

$$\mathrm{ZinAmp250} = 1000$$

```
ZoutAmp250 = subs(ZoutAmp, {Rin, Rf, ri, ro}, {Rin250, Rf250, riDatasheet, roDatasheet
double(ZoutAmp250)
```

```
ans = 74.8065
```

Relação de componentes usados/medidos

$\mathrm{Rin} : 1k\Omega - 986\Omega$

$\mathrm{R}f : 30k\Omega \ - 29,5k\Omega$

$C(1) : 820\mathrm{nF} - 781\mathrm{nF}$

$C(2) : 820\mathrm{nF} - 759,1\mathrm{nF}$

$C(3) : 820\mathrm{nF} - 796,4\mathrm{nF}$

$\mathrm{R}(1) : 330\Omega - 304\Omega$

$\mathrm{R}(2) : 330\Omega - 305\Omega$

$\mathrm{R}(3) : 330\Omega - 301\Omega$

$\mathrm{Pot} : 50k\Omega - 3,8k\Omega$

F = 4,5kHz

Antes de tudo definamos os parâmetros do ampop. Nesse caso o ampop utilizado foi o LM741.

```
Rin4500 = 1e3;
Rf4500 = Rin4500 * 29;
```

Definindo a frequencia de projeto e o capacitor:

```
w4500 = 2*pi*4.5e3;
c4500 = 47e-9;
```

Obtendo R

```
r4500 = subs(r,{c,w},{c4500,w4500});
double(r4500)
```

```
ans = 307.2091
```

Com R e C podemos obter as impedancias de entrada/saida da rede RC

```
ZinRC4500 = subs(ZinRC,{c,r,w},{c4500,r4500,w4500});
abs(double(ZinRC4500))
```

```
ans = 869.4357
```

```
ZoutRC4500 = subs(ZoutRC,{c,r,w},{c4500,r4500,w4500});
abs(double(ZoutRC4500))
```

```
ans = 138.0802
```

Por fim, definimos ri, ro e as resistencias Rin e Rf sendo Rf == 29Rin de maneira a obtermos as impedancias de entrada/saida do bloco de amplificação

```
ZinAmp4500 = subs(ZinAmp, {Rin, Rf, ri, ro}, {Rin4500, Rf4500, riDatasheet, roDatasheet
```

```
ZinAmp4500 = 1000
```

```
ZoutAmp4500 = subs(ZoutAmp, {Rin, Rf, ri, ro}, {Rin4500, Rf4500, riDatasheet, roDatashe
double(ZoutAmp4500)
```

```
ans = 74.8065
```

Relação de componentes usados/medidos

$\mathrm{Rin} : 1k\Omega - 976\Omega$

$\mathrm{R}f : 30k\Omega \ - 27,1k\Omega$

$C(1) : 47\mathrm{nF} - 47,85\mathrm{nF}$

$C(2) : 47\mathrm{nF} - 46,93\mathrm{nF}$

$C(3) : 47\mathrm{nF} - 45,37\mathrm{nF}$

$\mathrm{R}(1) : 300\Omega - 300\Omega$

$\mathrm{R}(2) : 300\Omega - 305\Omega$

$\mathrm{R}(3) : 300\Omega - 301\Omega$

$\mathrm{Pot} : 100k\Omega - 23,5k\Omega$

F = 65kHz

Antes de tudo definamos os parâmetros do ampop. Nesse caso o ampop utilizado foi o LM741.

```
Rin65k = 1e3;
Rf65k = Rin65k * 29;
```

Definindo a frequencia de projeto e o capacitor:

```
w65k = 2*pi*65e3;
c65k = 3.3e-9;
```

Obtendo R

```
r65k = subs(r,{c,w},{c65k,w65k});
double(r65k)
```

```
ans = 302.9125
```

Com R e C podemos obter as impedancias de entrada/saida da rede RC

```
ZinRC65k = subs(ZinRC,{c,r,w},{c65k,r65k,w65k});
abs(double(ZinRC65k))
```

```
ans = 857.2758
```

```
ZoutRC65k = subs(ZoutRC,{c,r,w},{c65k,r65k,w65k});
abs(double(ZoutRC65k))
```

```
ans = 136.1490
```

Por fim, definimos ri, ro e as resistencias Rin e Rf sendo Rf == 29Rin de maneira a obtermos as impedancias de entrada/saida do bloco de amplificação

```
ZinAmp65k = subs(ZinAmp, {Rin, Rf, ri, ro}, {Rin65k, Rf65k, riDatasheet, roDatasheet})
```

```
ZinAmp65k = 1000
```

```
ZoutAmp65k = subs(ZoutAmp, {Rin, Rf, ri, ro}, {Rin65k, Rf65k, riDatasheet, roDatasheet
double(ZoutAmp65k)
```

```
ans = 74.8065
```

Relação de componentes usados/medidos

$\mathrm{Rin} : 1k\Omega - 993\Omega$

$\mathrm{R}f : 30k\Omega \ - 29,4k\Omega$

$C(1) : 3,3\mathrm{nF} - 3,153\mathrm{nF}$

$C(2) : 3,3\mathrm{nF} - 3,174\mathrm{nF}$

$C(3) : 3,3\mathrm{nF} - 3,200\mathrm{nF}$

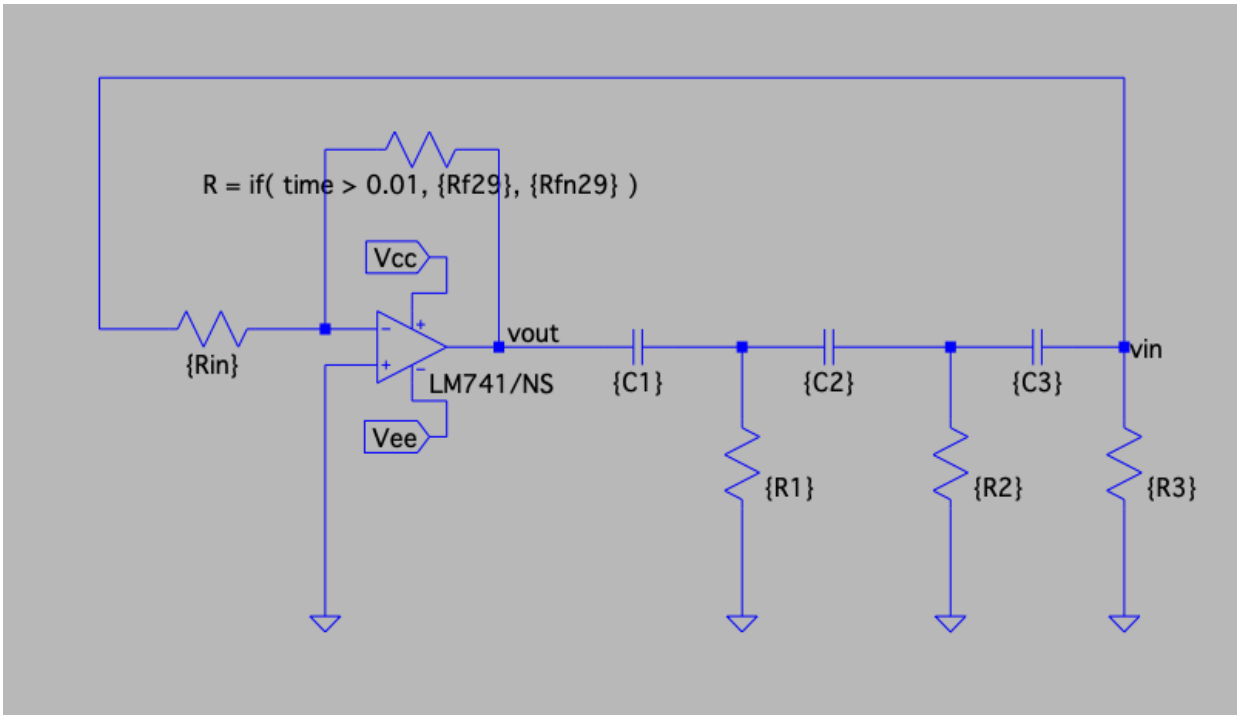
$\mathrm{R}(1) : 300\Omega - 330\Omega$

$\mathrm{R}(2) : 300\Omega - 327\Omega$

$\mathrm{R}(3) : 300\Omega - 329\Omega$

250Hz

Topologia completa



Indice:

Diretivas spice

Teórico

```
.meas tran time_period trig V(vout)=0 rise=1 targ V(vout)=0 rise=2
.meas frequency param 1/time_period
.meas tran time_delay trig V(vin)=0 rise=1 targ V(vout)=0 rise=1
.meas phase param 360*(time_delay / time_period)
.meas TRAN vin_meas FIND V(vin) WHEN V(vout)=10
.meas gain param 10/vin_meas
.meas max_vin max V(vin)
.meas min_vin min V(vin)
.meas max_vout max V(vout)
.meas min_vout min V(vout)

.lib ../../../../libs/LM741.lib
.param Rin=1k C=820n R=316.9499
.param Rf29={30k +3.8k} Rfn29=100k

.tran 0 {2+2/250} 2
tstep tstop tstart
```

Prático

```
.meas tran time_period trig V(vout)=0 rise=1 targ V(vout)=0 rise=2
.meas frequency param 1/time_period
.meas tran time_delay trig V(vin)=0 rise=1 targ V(vout)=0 rise=1
.meas phase param 360*(time_delay / time_period)
.meas TRAN vin_meas FIND V(vin) WHEN V(vout)=10
.meas gain param 10/vin_meas
.meas max_vin max V(vin)
.meas min_vin min V(vin)
.meas max_vout max V(vout)
.meas min_vout min V(vout)

.lib ../../../../libs/LM741.lib

.tran 0 {2+2/250} 2
tstep tstop tstart

.param Rf29={29.5k +3.8k} Rfn29=100k

.param Rin=986
.param C1=781n C2=759.1n C3=796.4n
.param R1=304 R2=305 R3=301
```

Medições

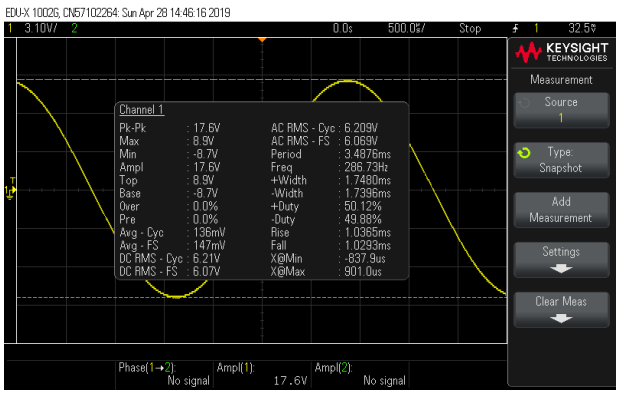
Teórico - simulação

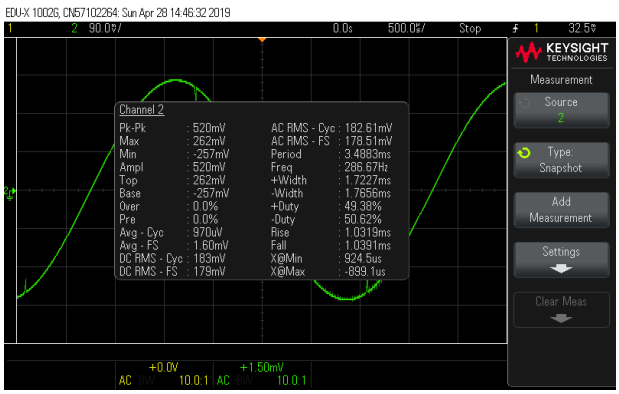
```
Direct Newton iteration for .op point succeeded.
Heightened Def Con from 1.04197 to 1.04197

time_period=0.00379758 FROM 0.000779724 TO 0.00457731
frequency: 1/time_period=263.325
time_delay=-0.00189117 FROM 0.0026709 TO 0.000779724
phase: 360*(time_delay / time_period)=-179.278
vin_meas: v(vin)=-0.296035 at 0.0014646
gain: 10/vin_meas=-33.7798
max_vin: MAX(v(vin))=0.396462 FROM 0 TO 0.008
min_vin: MIN(v(vin))=-0.414685 FROM 0 TO 0.008
max_vout: MAX(v(vout))=10.822 FROM 0 TO 0.008
min_vout: MIN(v(vout))=-10.8189 FROM 0 TO 0.008


Date: Wed May  1 21:19:45 2019
Total elapsed time: 2.706 seconds.

tnom = 27
temp = 27
method = modified trap
totiter = 229966
traniter = 229955
tranpoints = 77306
accept = 53560
rejected = 23747
matrix size = 39
fillins = 33
solver = Alternate
Matrix Compiler1: 4278 object code size  1.3/1.0/[0.5]
Matrix Compiler2: off
```

Prático - simulação

```
Direct Newton iteration for .op point succeeded.
Heightened Def Con from 0.48699 to 0.48699

time_period=0.00346761 FROM 0.00292505 TO 0.00639266
frequency: 1/time_period=288.383
time_delay=0.00174135 FROM 0.0011837 TO 0.00292505
phase: 360*(time_delay / time_period)=180.783
vin_meas: v(vin)=-0.296347 at 8.7757e-05
gain: 10/vin_meas=-33.7442
max_vin: MAX(v(vin))=0.386324 FROM 0 TO 0.008
min_vin: MIN(v(vin))=-0.40632 FROM 0 TO 0.008
max_vout: MAX(v(vout))=10.8147 FROM 0 TO 0.008
min_vout: MIN(v(vout))=-10.8105 FROM 0 TO 0.008


Date: Wed May  1 21:44:56 2019
Total elapsed time: 2.743 seconds.

tnom = 27
temp = 27
method = modified trap
totiter = 243538
traniter = 243527
tranpoints = 81059
accept = 56482
rejected = 24578
matrix size = 39
fillins = 33
solver = Alternate
Matrix Compiler1: 4278 object code size  1.2/0.8/[0.6]
Matrix Compiler2: off
```

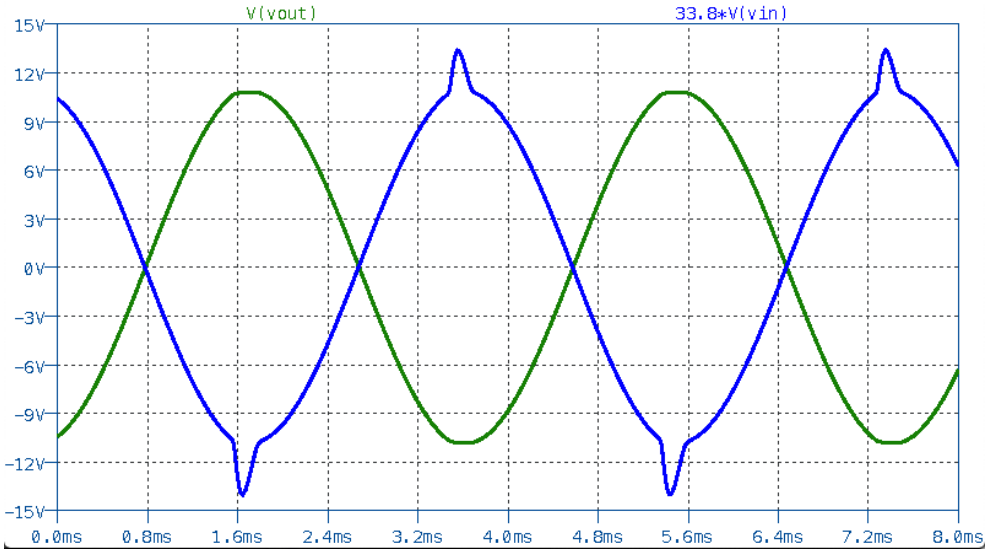
Prático



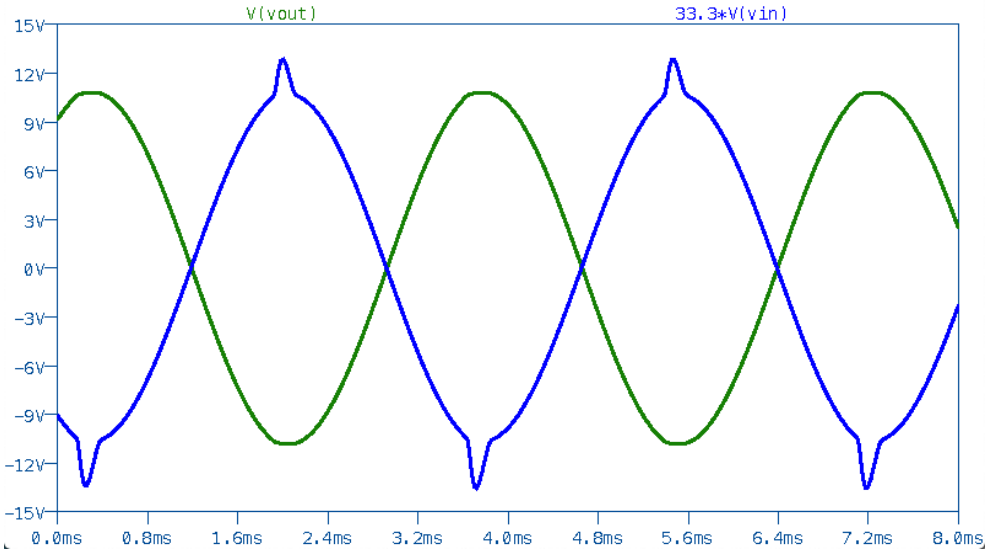


Formas de onda

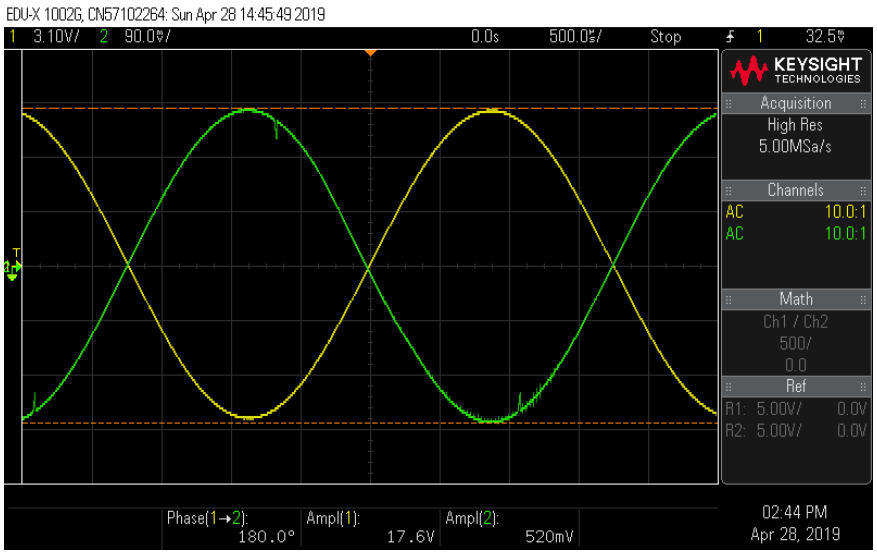
Teórico - simulação



Prático - simulação

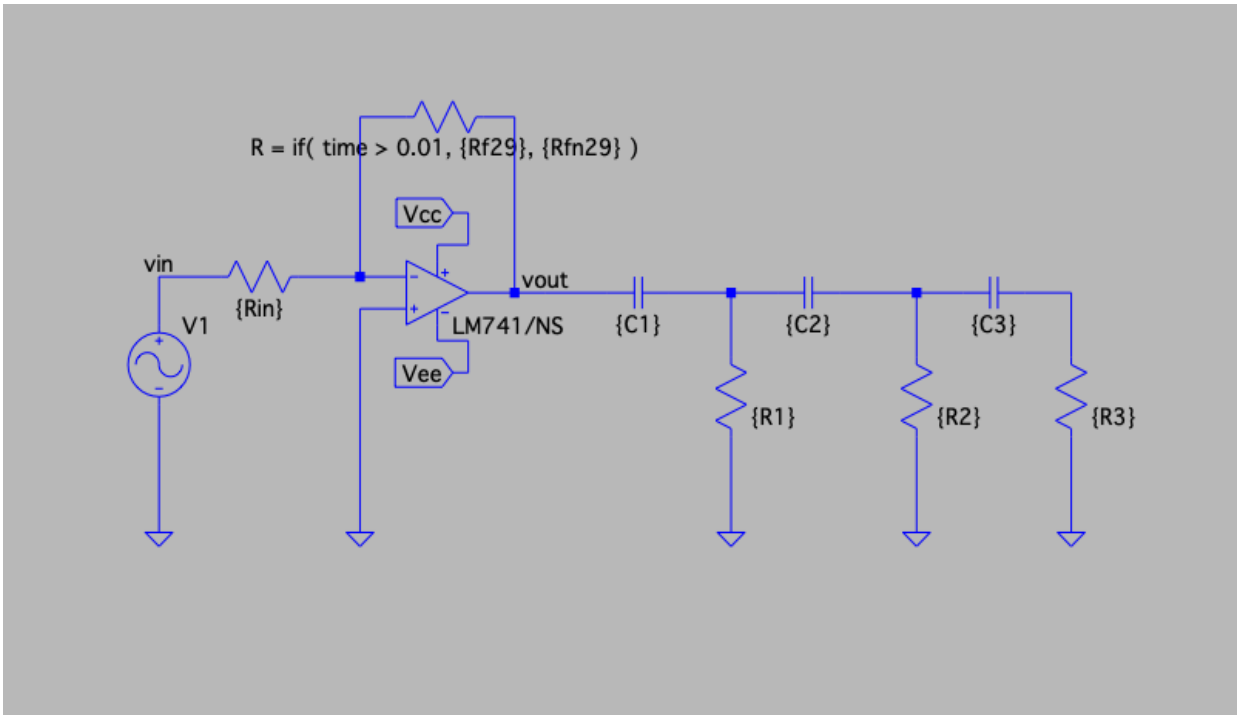


Prático



250Hz

Topologia aberta: Debug A



Indice:

Diretivas spice - com carga

Teórico

```
.meas tran time_period trig V(vout)=0 rise=1 targ V(vout)=0 rise=2
.meas frequency param 1/time_period
.meas tran time_delay trig V(vin)=0 rise=1 targ V(vout)=0 rise=1
.meas phase param 360*(time_delay / time_period)
.meas TRAN vin_meas FIND V(vin) WHEN V(vout)=10
.meas gain param 10/vin_meas
.meas max_vin max V(vin)
.meas min_vin min V(vin)
.meas max_vout max V(vout)
.meas min_vout min V(vout)

.lib ../../../libs/LM741.lib
.param Rin=1k C=820n R=316.9499
.param Rf29={30k +3.8k} Rfn29=100k

.tran 0 {2+2/250} 2
tstep tstop tstart
```

Prático

```
.meas tran time_period trig V(vout)=0 rise=1 targ V(vout)=0 rise=2
.meas frequency param 1/time_period
.meas tran time_delay trig V(vin)=0 rise=1 targ V(vout)=0 rise=1
.meas phase param 360*(time_delay / time_period)
.meas TRAN vin_meas FIND V(vin) WHEN V(vout)=10
.meas gain param 10/vin_meas
.meas max_vin max V(vin)
.meas min_vin min V(vin)
.meas max_vout max V(vout)
.meas min_vout min V(vout)

.lib ../../../../libs/LM741.lib

.param Rf29={29.5k +3.8k} Rfn29=100k

.param Rin=986
.param C1=781n C2=759.1n C3=796.4n
.param R1=304 R2=305 R3=301

.tran 0 {2+2/250} 2
tstep tstop tstart
```

Medições - com carga

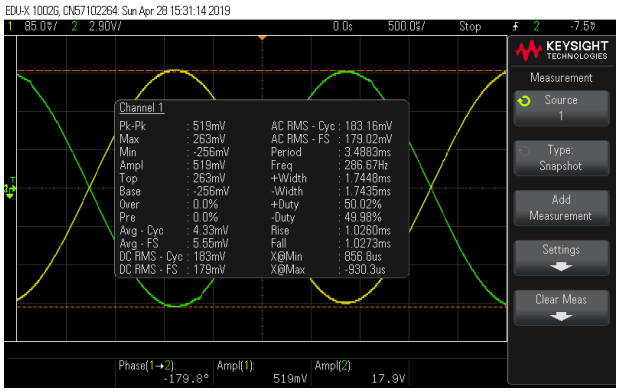
Teórico - simulação

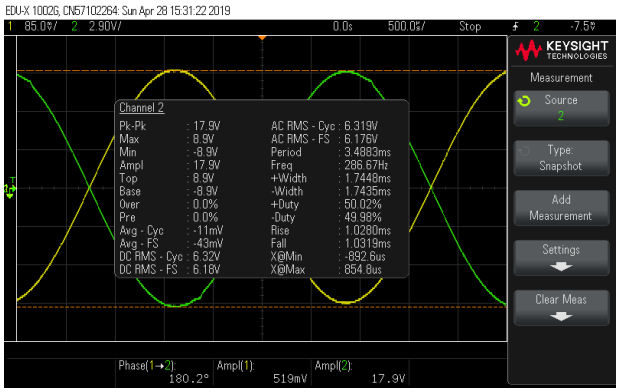
```
Direct Newton iteration for .op point succeeded.

time_period=0.00379865 FROM 3.91938e-06 TO 0.00380257
frequency: 1/time_period=263.251
time_delay=-0.0018954 FROM 0.00189932 TO 3.91938e-06
phase: 360*(time_delay / time_period)=-179.628
vin_meas: v(vin)=-0.297262 at 0.000513918
gain: 10/vin_meas=-33.6404
max_vin: MAX(v(vin))=0.395622 FROM 0 TO 0.008
min_vin: MIN(v(vin))=-0.395711 FROM 0 TO 0.008
max_vout: MAX(v(vout))=10.8845 FROM 0 TO 0.008
min_vout: MIN(v(vout))=-10.8828 FROM 0 TO 0.008


Date: Wed May  1 21:12:23 2019
Total elapsed time: 2.374 seconds.

tnom = 27
temp = 27
method = modified trap
totiter = 211599
traniter = 211588
tranpoints = 51970
accept = 36047
rejected = 15923
matrix size = 41
fillins = 29
solver = Alternate
Matrix Compiler1: 4024 object code size  1.1/0.9/[0.6]
Matrix Compiler2: off
```

Prático - simulação

```
Direct Newton iteration for .op point succeeded.

time_period=0.00346761 FROM 0.00254924 TO 0.00601685
frequency: 1/time_period=288.383
time_delay=0.00173782 FROM 0.000811423 TO 0.00254924
phase: 360*(time_delay / time_period)=180.416
vin_meas: v(vin)=-0.29213 at 0.000337508
gain: 10/vin_meas=-34.2313
max_vin: MAX(v(vin))=0.385628 FROM 0 TO 0.008
min_vin: MIN(v(vin))=-0.385665 FROM 0 TO 0.008
max_vout: MAX(v(vout))=10.8753 FROM 0 TO 0.008
min_vout: MIN(v(vout))=-10.8735 FROM 0 TO 0.008


Date: Wed May  1 21:51:14 2019
Total elapsed time: 2.671 seconds.

tnom = 27
temp = 27
method = modified trap
totiter = 232729
traniter = 232718
tranpoints = 56925
accept = 39226
rejected = 17699
matrix size = 41
fillins = 29
solver = Alternate
Matrix Compiler1: 4024 object code size  1.1/0.8/[0.6]
Matrix Compiler2: off
```

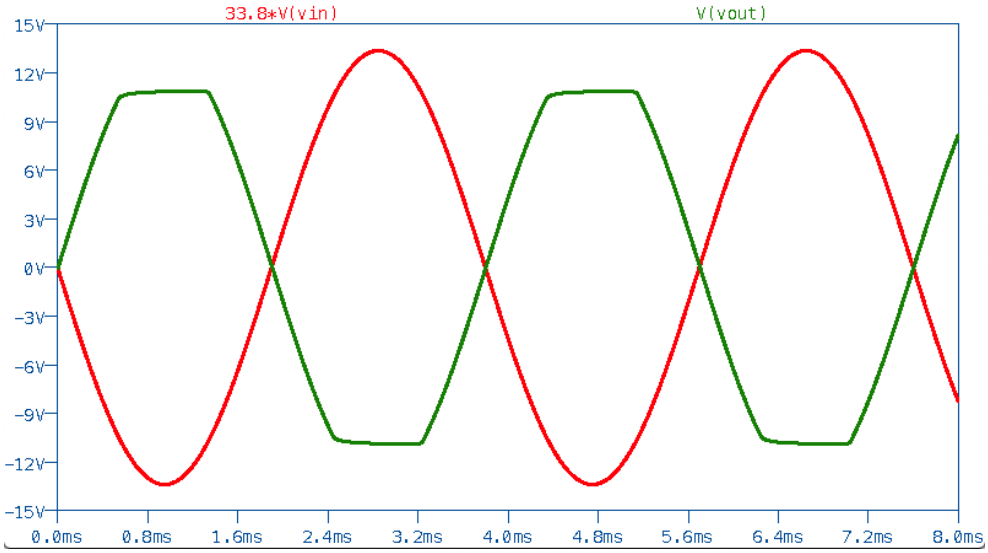
Prático



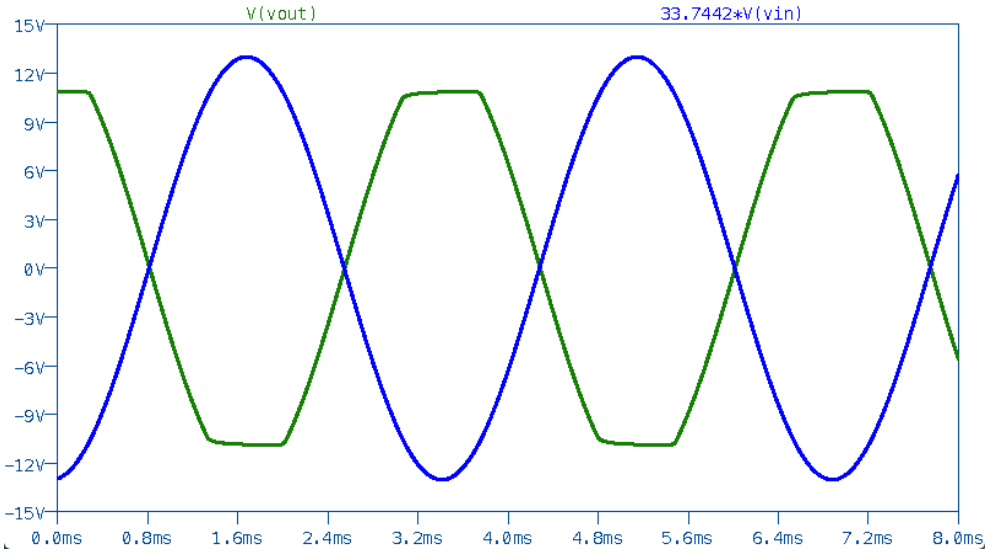


Formas de onda - com carga

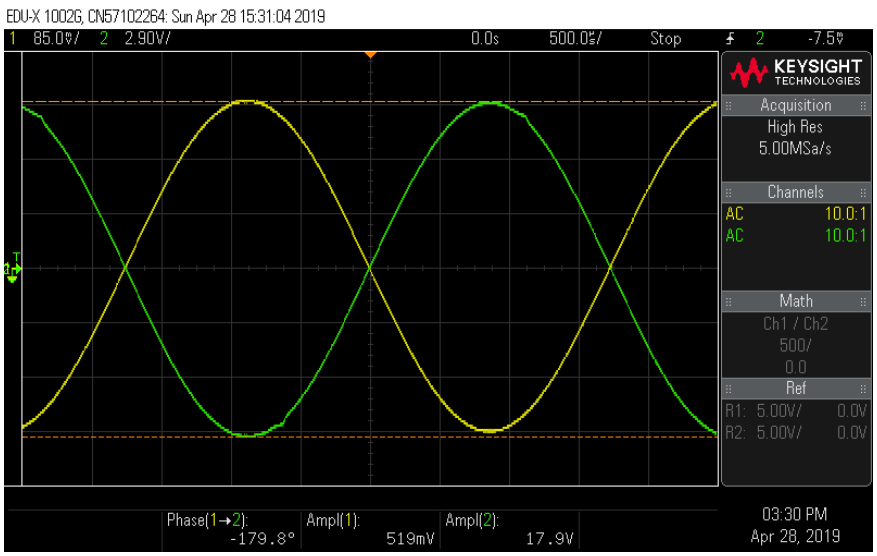
Teórico - simulação



Prático - simulação



Prático



Medições - sem carga

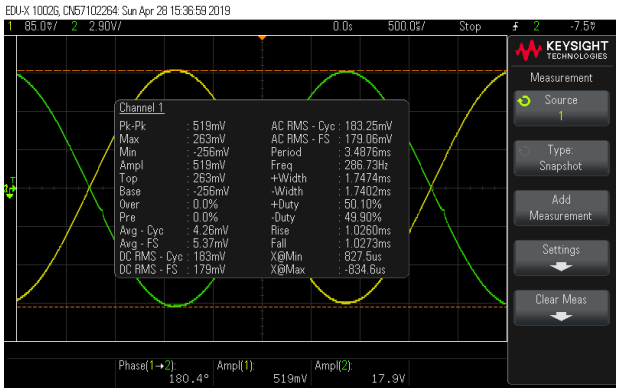
Teórico - simulação

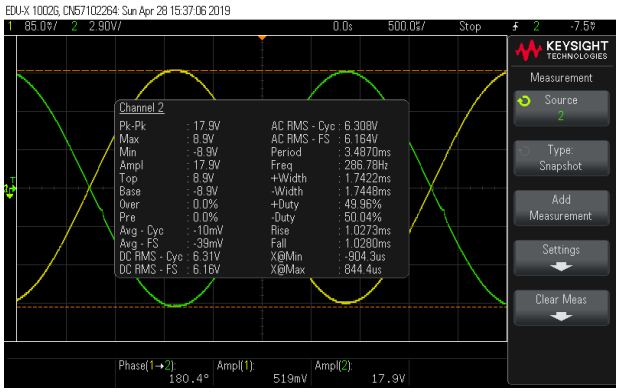
```
Direct Newton iteration for .op point succeeded.

time_period=0.00379865 FROM 3.89379e-06 TO 0.00380254
frequency: 1/time_period=263.252
time_delay=-0.00189545 FROM 0.00189934 TO 3.89379e-06
phase: 360*(time_delay / time_period)=-179.633
vin_meas: v(vin)=-0.297212 at 0.000513765
gain: 10/vin_meas=-33.646
max_vin: MAX(v(vin))=0.395686 FROM 0 TO 0.008
min_vin: MIN(v(vin))=-0.395701 FROM 0 TO 0.008
max_vout: MAX(v(vout))=10.9783 FROM 0 TO 0.008
min_vout: MIN(v(vout))=-10.978 FROM 0 TO 0.008


Date: Wed May  1 21:10:51 2019
Total elapsed time: 1.862 seconds.

tnom = 27
temp = 27
method = modified trap
totiter = 172068
traniter = 172057
tranpoints = 45205
accept = 30646
rejected = 14559
matrix size = 38
fillins = 29
solver = Alternate
Matrix Compiler1: 3826 object code size  0.9/0.8/[0.5]
Matrix Compiler2: off
```

Prático - simulação

```
Direct Newton iteration for .op point succeeded.

time_period=0.00346763 FROM 0.00254917 TO 0.0060168
frequency: 1/time_period=288.382
time_delay=0.00173774 FROM 0.000811433 TO 0.00254917
phase: 360*(time_delay / time_period)=180.408
vin_meas: v(vin)=-0.292519 at 0.000335917
gain: 10/vin_meas=-34.1858
max_vin: MAX(v(vin))=0.385668 FROM 0 TO 0.008
min_vin: MIN(v(vin))=-0.385657 FROM 0 TO 0.008
max_vout: MAX(v(vout))=10.9762 FROM 0 TO 0.008
min_vout: MIN(v(vout))=-10.9758 FROM 0 TO 0.008


Date: Wed May  1 21:53:53 2019
Total elapsed time: 1.993 seconds.

tnom = 27
temp = 27
method = modified trap
totiter = 182253
traniter = 182242
tranpoints = 49510
accept = 33460
rejected = 16050
matrix size = 38
fillins = 29
solver = Alternate
Matrix Compiler1: 3826 object code size  1.1/0.7/[0.6]
Matrix Compiler2: off
```

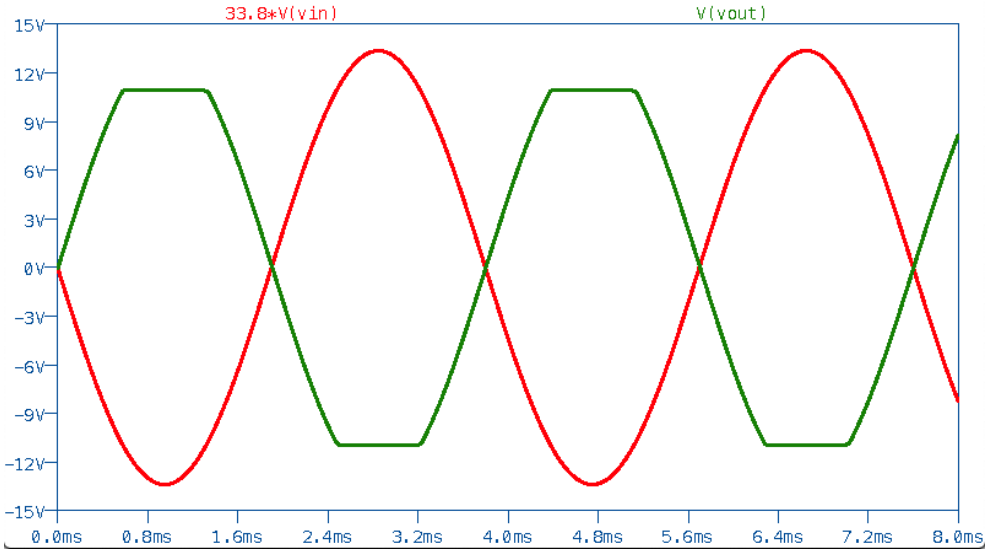
Prático



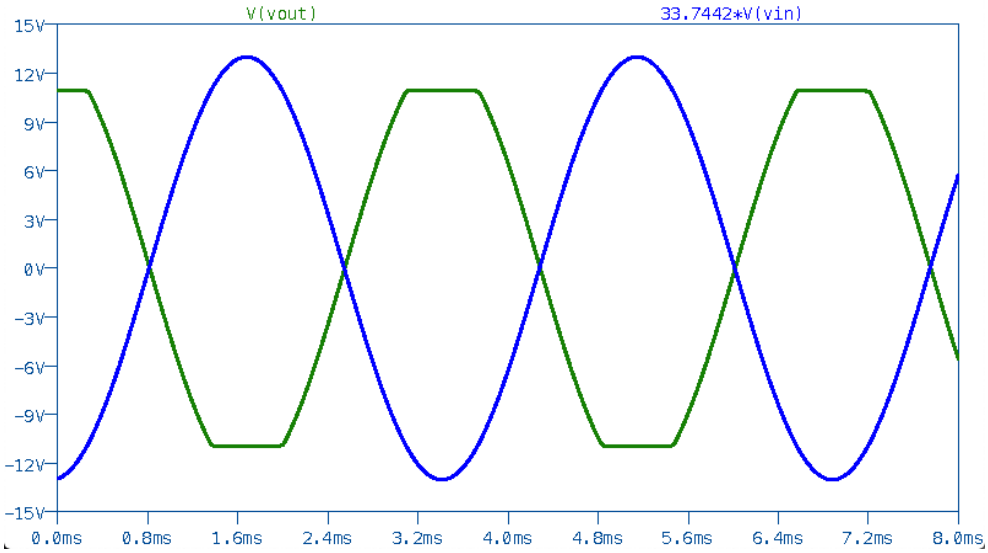


Formas de onda - sem carga

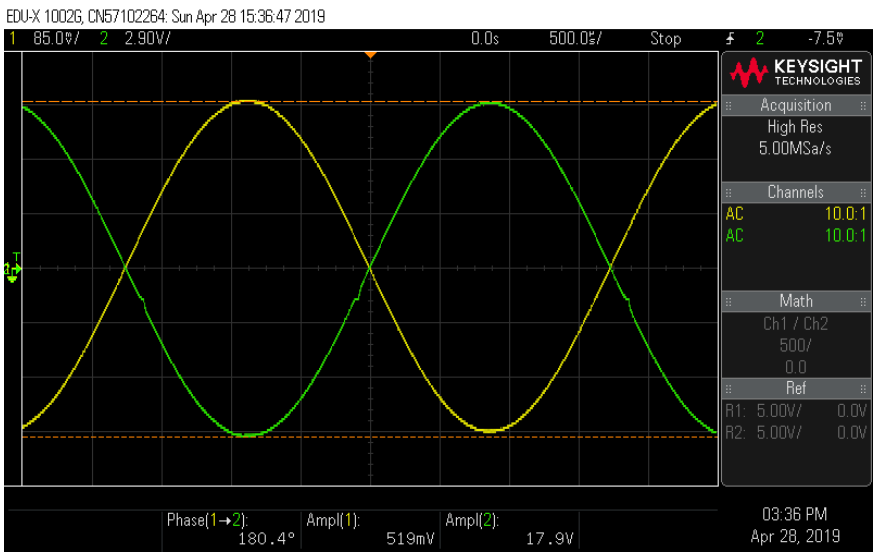
Teórico - simulação



Prático - simulação

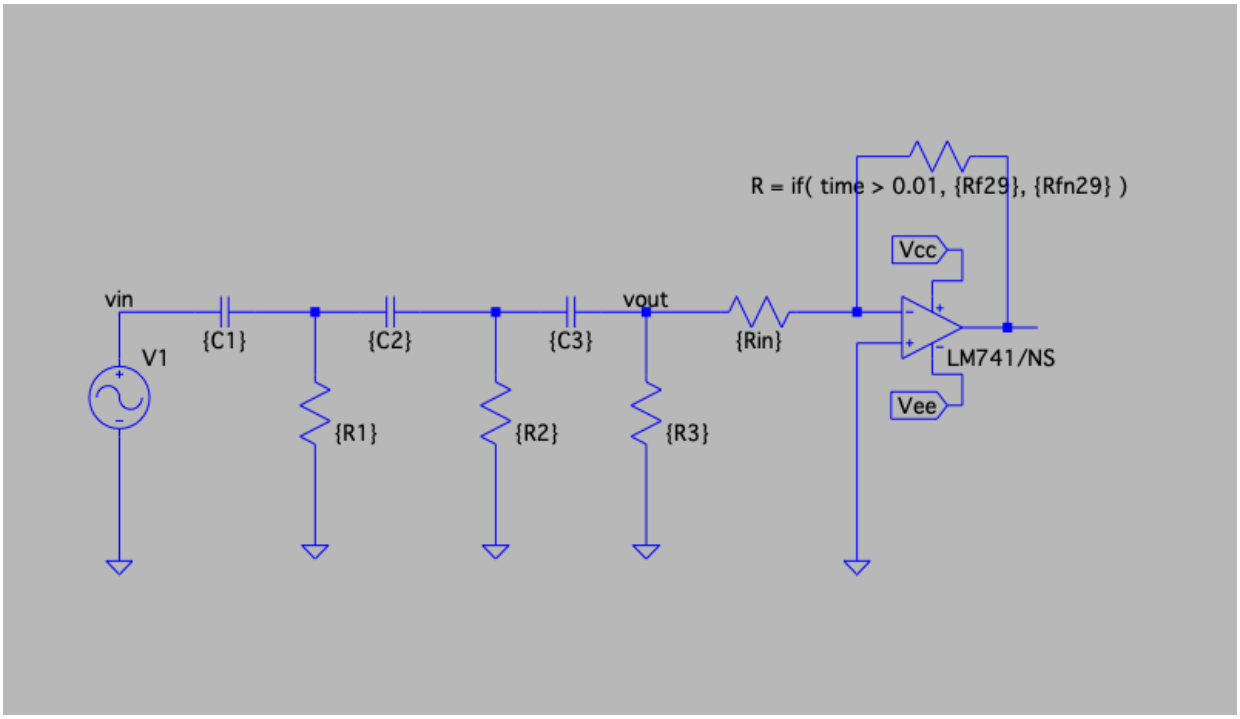


Prático



250Hz

Topologia aberta: Debug B



Indice:

Diretivas spice - com carga

Teórico

```
.meas tran time_period trig V(vout)=0 rise=1 targ V(vout)=0 rise=2
.meas frequency param 1/time_period
.meas tran time_delay trig V(vin)=0 rise=1 targ V(vout)=0 rise=1
.meas phase param 360*(time_delay / time_period)
.meas TRAN vout_meas FIND V(vout) WHEN V(vin)=10
.meas gain param 10/vout_meas
.meas max_vin max V(vin)
.meas min_vin min V(vin)
.meas max_vout max V(vout)
.meas min_vout min V(vout)

.lib ../../../../libs/LM741.lib
.param Rin=1k C=820n R=316.9499
.param Rf29={30k +3.8k} Rfn29=100k

.tran 0 {2+2/250} 2
 tstep tstop tstart
```

Prático

```
.meas tran time_period trig V(vout)=0 rise=1 targ V(vout)=0 rise=2
.meas frequency param 1/time_period
.meas tran time_delay trig V(vin)=0 rise=1 targ V(vout)=0 rise=1
.meas phase param 360*(time_delay / time_period)
.meas TRAN vout_meas FIND V(vout) WHEN V(vin)=10
.meas gain param 10/vout_meas
.meas max_vin max V(vin)
.meas min_vin min V(vin)
.meas max_vout max V(vout)
.meas min_vout min V(vout)

.lib ../../../../libs/LM741.lib

.param Rf29={29.5k +3.8k} Rfn29=100k

.param Rin=986
.param C1=781n C2=759.1n C3=796.4n
.param R1=304 R2=305 R3=301

.tran 0 {2+2/250} 2
 tstep tstop tstart
```

Medições - com carga

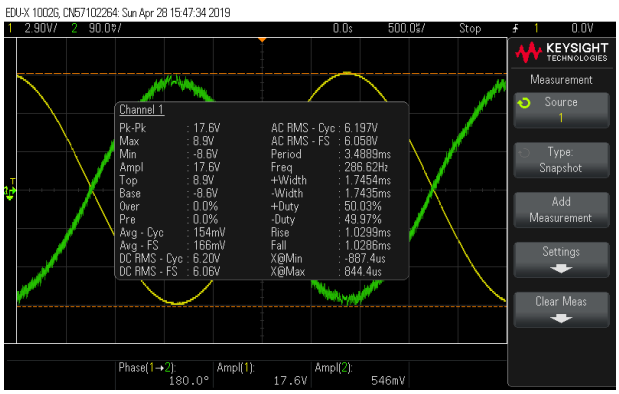
Teórico - simulação

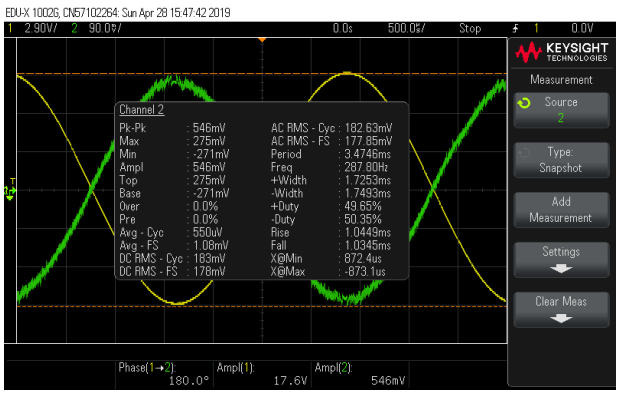
```
Direct Newton iteration for .op point succeeded.
Heightened Def Con from 0.0197405 to 0.0197405

time_period=0.00379759 FROM 0.00321925 TO 0.00701684
frequency: 1/time_period=263.325
time_delay=0.00189011 FROM 0.00132915 TO 0.00321925
phase: 360*(time_delay / time_period)=179.177
vout_meas: v(vout)=-0.305703 at 0.00204371
gain: 10/vout_meas=-32.7115
max_vin: MAX(v(vin))=10.8115 FROM 0 TO 0.008
min_vin: MIN(v(vin))=-10.8138 FROM 0 TO 0.008
max_vout: MAX(v(vout))=0.3307 FROM 0 TO 0.008
min_vout: MIN(v(vout))=-0.329662 FROM 0 TO 0.008


Date: Wed May  1 22:17:27 2019
Total elapsed time: 2.386 seconds.

tnom = 27
temp = 27
method = modified trap
totiter = 196380
traniter = 196369
tranpoints = 66610
accept = 46029
rejected = 20582
matrix size = 41
fillins = 29
solver = Alternate
Matrix Compiler1: 4024 object code size  1.1/1.0/[0.4]
Matrix Compiler2: off
```

Prático - simulação

```
Circuit: * /Users/Igor/eln3-osc/invFase/simulation/250hz/practical/debugB_practical.asc

Direct Newton iteration for .op point succeeded.
Heightened Def Con from 0.0131691 to 0.0131691
Heightened Def Con from 0.988964 to 0.988964

time_period=0.00346758 FROM 0.00253722 TO 0.0060048
frequency: 1/time_period=288.386
time_delay=0.00172579 FROM 0.000811431 TO 0.00253722
phase: 360*(time_delay / time_period)=179.169
vout_meas: v(vout)=-0.30502 at 0.00146643
gain: 10/vout_meas=-32.7847
max_vin: MAX(v(vin))=10.8014 FROM 0 TO 0.008
min_vin: MIN(v(vin))=-10.8001 FROM 0 TO 0.008
max_vout: MAX(v(vout))=0.328859 FROM 0 TO 0.008
min_vout: MIN(v(vout))=-0.328373 FROM 0 TO 0.008


Date: Wed May  1 22:12:43 2019
Total elapsed time: 2.547 seconds.

tnom = 27
temp = 27
method = modified trap
totiter = 216899
traniter = 216888
tranpoints = 73146
accept = 49945
rejected = 23203
matrix size = 41
fillins = 29
solver = Alternate
```

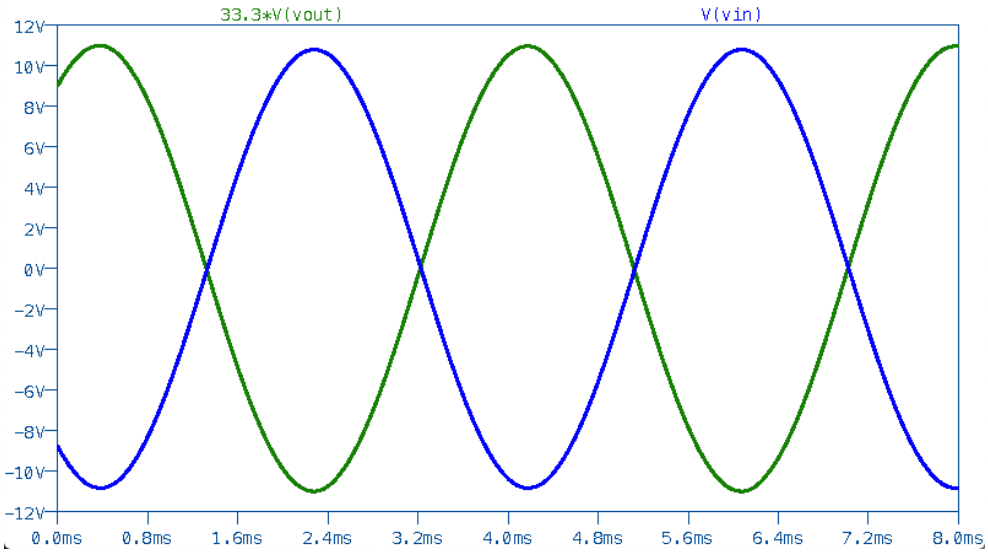
Prático



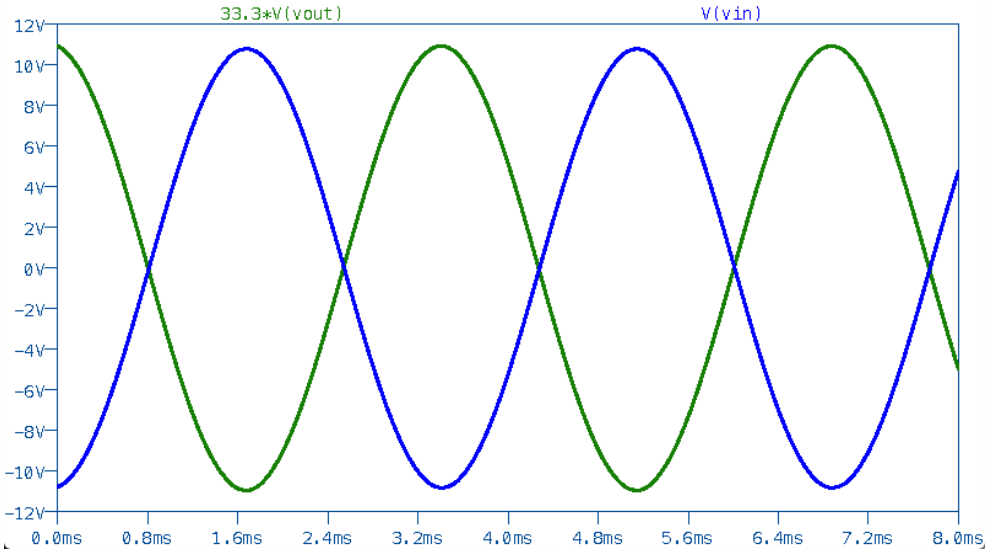


Formas de onda - com carga

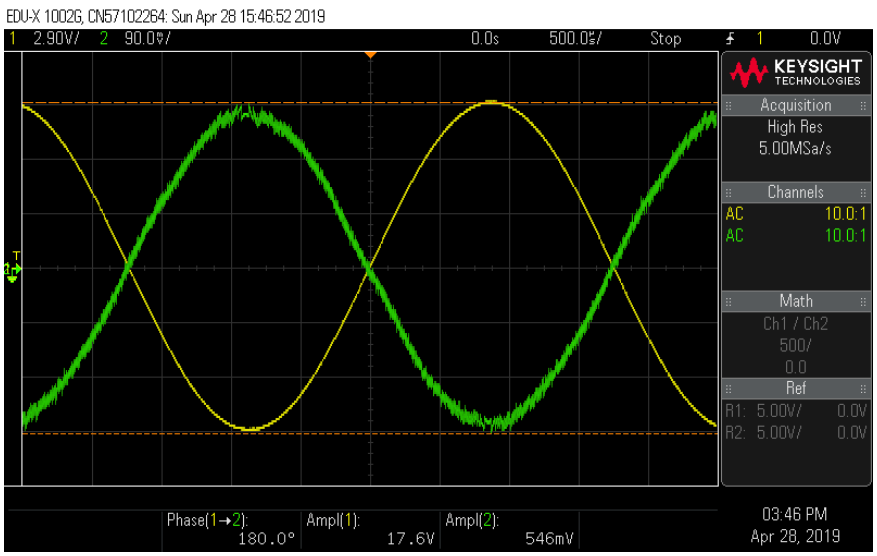
Teórico - simulação



Prático - simulação



Prático



Medições - sem carga

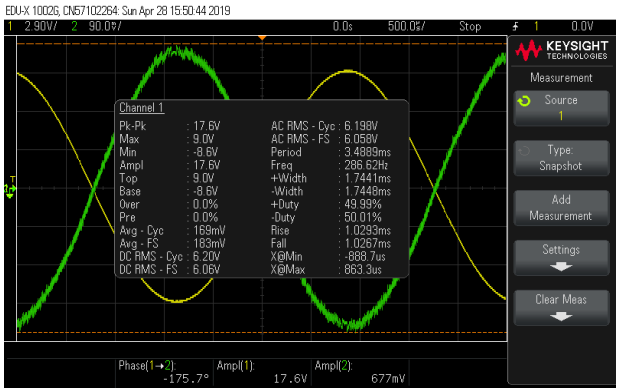
Teórico - simulação

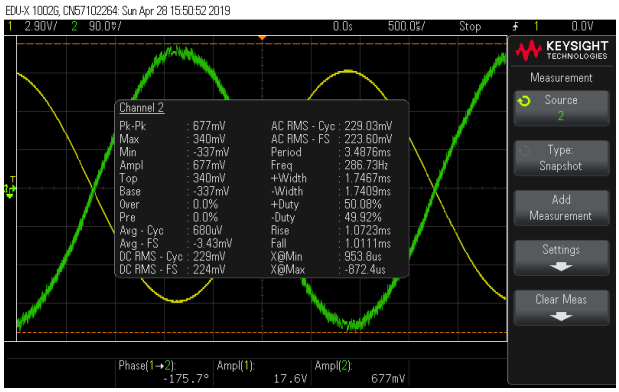
```
Circuit: * /Users/Igor/eln3-osc/invFase/simulation/250hz/theorical/debugB_theorical.asc

WARNING: Less than two connections to node VEE.  This node is used by V2.
WARNING: Less than two connections to node VCC.  This node is used by V3.
Direct Newton iteration for .op point succeeded.

time_period=0.00379753 FROM 0.00326008 TO 0.00705761
frequency: 1/time_period=263.329
time_delay=0.00193093 FROM 0.00132915 TO 0.00326008
phase: 360*(time_delay / time_period)=183.049
vout_meas: v(vout)=-0.374868 at 0.00204315
gain: 10/vout_meas=-26.6761
max_vin: MAX(v(vin))=10.8122 FROM 0 TO 0.008
min_vin: MIN(v(vin))=-10.8138 FROM 0 TO 0.008
max_vout: MAX(v(vout))=0.418818 FROM 0 TO 0.008
min_vout: MIN(v(vout))=-0.4148 FROM 0 TO 0.008


Date: Wed May  1 22:18:28 2019
Total elapsed time: 0.125 seconds.

tnom = 27
temp = 27
method = modified trap
totiter = 39167
traniter = 39164
tranpoints = 19583
accept = 13089
rejected = 6494
matrix size = 9
fillins = 0
solver = Alternate
```

Prático - simulação

```
Circuit: * /Users/Igor/eln3-osc/invFase/simulation/250hz/practical/debugB_practical.asc

WARNING: Less than two connections to node VEE.  This node is used by V2.
WARNING: Less than two connections to node VCC.  This node is used by V3.
Direct Newton iteration for .op point succeeded.

time_period=0.00346749 FROM 0.00257343 TO 0.00604092
frequency: 1/time_period=288.393
time_delay=0.00176201 FROM 0.000811415 TO 0.00257343
phase: 360*(time_delay / time_period)=182.935
vout_meas: v(vout)=-0.371415 at 0.00146571
gain: 10/vout_meas=-26.924
max_vin: MAX(v(vin))=10.7938 FROM 0 TO 0.008
min_vin: MIN(v(vin))=-10.7975 FROM 0 TO 0.008
max_vout: MAX(v(vout))=0.416461 FROM 0 TO 0.008
min_vout: MIN(v(vout))=-0.410128 FROM 0 TO 0.008


Date: Wed May  1 22:14:28 2019
Total elapsed time: 0.135 seconds.

tnom = 27
temp = 27
method = modified trap
totiter = 41321
traniter = 41318
tranpoints = 20660
accept = 14176
rejected = 6484
matrix size = 9
fillins = 0
solver = Alternate
```

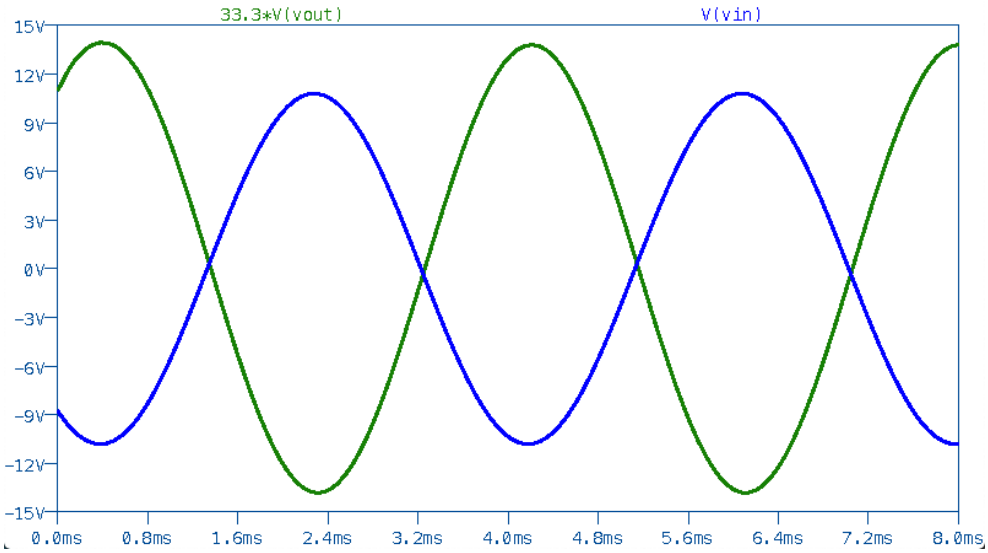
Prático



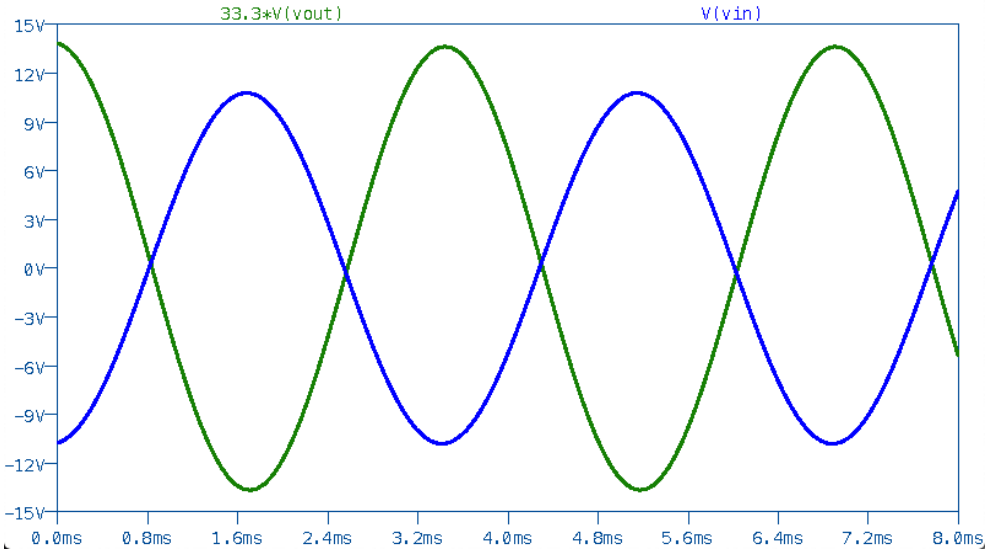


Formas de onda - sem carga

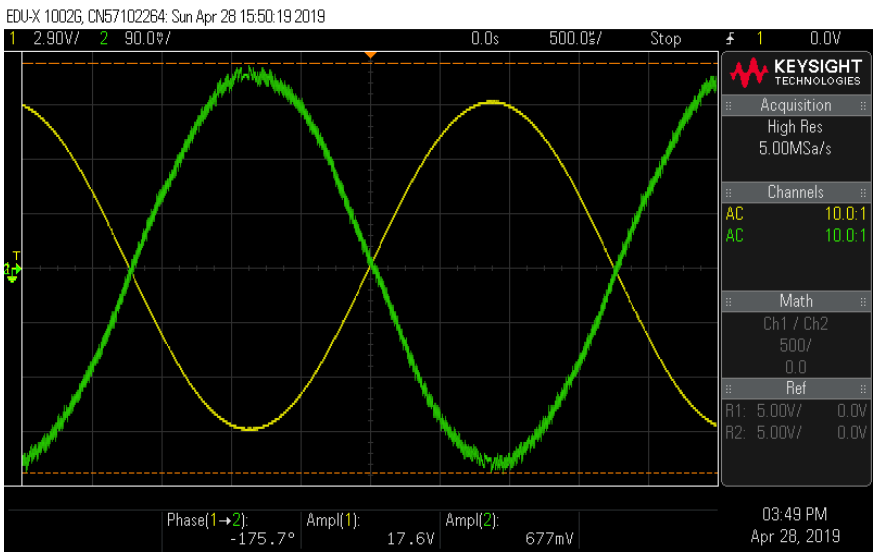
Teórico - simulação



Prático - simulação

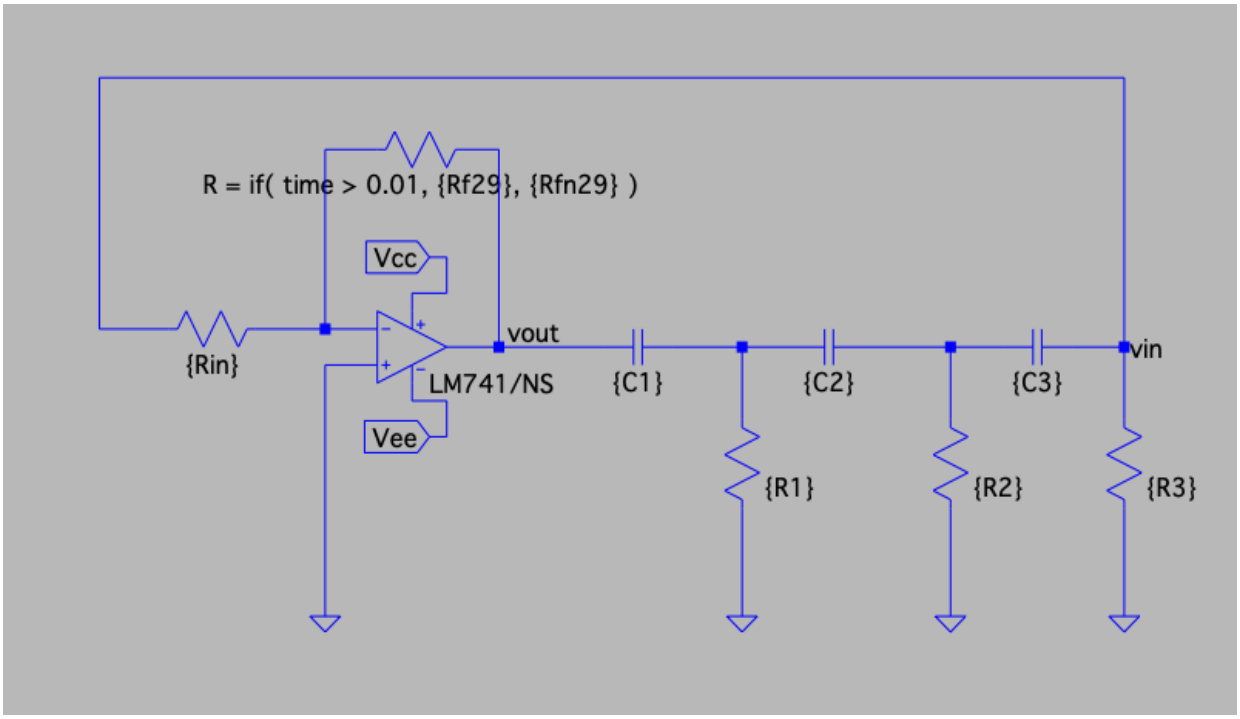


Prático



4.5kHz

Topologia completa



Indice:

Diretivas spice

Teórico

```
.meas tran time_period trig V(vout)=0 rise=1 targ V(vout)=0 rise=2
.meas frequency param 1/time_period
.meas tran time_delay trig V(vin)=0 rise=1 targ V(vout)=0 rise=1
.meas phase param 360*(time_delay / time_period)
.meas TRAN vin_meas FIND V(vin) WHEN V(vout)=10
.meas gain param 10/vin_meas
.meas max_vin max V(vin)
.meas min_vin min V(vin)
.meas max_vout max V(vout)
.meas min_vout min V(vout)

.lib ../../../../libs/LM741.lib
.param Rin=1k C=47n R=307.2
.param Rf29=50k Rfn29=150k

.tran 0 {0.1+2/4500} 0.1
 tstep tstop tstart
```

Prático

```
.meas tran time_period trig V(vout)=0 rise=1 targ V(vout)=0 rise=2
.meas frequency param 1/time_period
.meas tran time_delay trig V(vin)=0 rise=1 targ V(vout)=0 rise=1
.meas phase param 360*(time_delay / time_period)
.meas TRAN vin_meas FIND V(vin) WHEN V(vout)=10
.meas gain param 10/vin_meas
.meas max_vin max V(vin)
.meas min_vin min V(vin)
.meas max_vout max V(vout)
.meas min_vout min V(vout)

.lib ../../../../libs/LM741.lib

.param Rf29=50k Rfn29=150k

.param Rin=976
.param C1=47.85n C2=46.93n C3=45.37n
.param R1=300 R2=305 R3=301

.tran 0 {0.11+2/4500} 0.11
 tstep tstop tstart
```

Medições

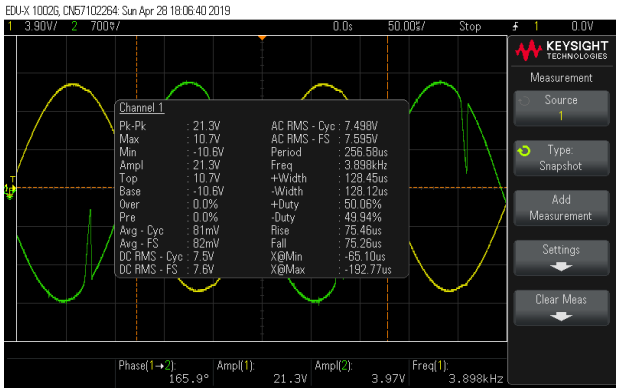
Teórico - simulação

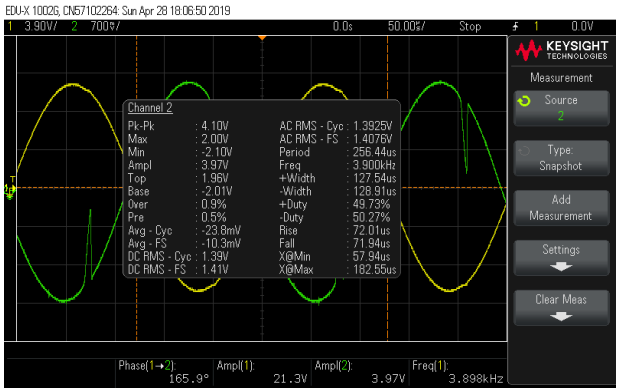
```
Direct Newton iteration for .op point succeeded.

time_period=0.000256735 FROM 0.00014878 TO 0.000405515
frequency: 1/time_period=3895.07
time_delay=0.000139206 FROM 9.57396e-06 TO 0.00014878
phase: 360*(time_delay / time_period)=195.198
vin_meas: v(vin)=-0.214368 at 0.000197719
gain: 10/vin_meas=-46.6488
max_vin: MAX(v(vin))=0.218233 FROM 0 TO 0.000444444
min_vin: MIN(v(vin))=-0.21921 FROM 0 TO 0.000444444
max_vout: MAX(v(vout))=10.7829 FROM 0 TO 0.000444444
min_vout: MIN(v(vout))=-10.6995 FROM 0 TO 0.000444444


Date: Wed May  1 22:25:44 2019
Total elapsed time: 0.992 seconds.

tnom = 27
temp = 27
method = modified trap
totiter = 82329
traniter = 82318
tranpoints = 22292
accept = 16186
rejected = 6106
matrix size = 39
fillins = 33
solver = Alternate
Matrix Compiler1: 4278 object code size  1.2/0.9/[0.7]
Matrix Compiler2: off
```

Prático - simulação

```
Direct Newton iteration for .op point succeeded.

time_period=0.000252596 FROM 0.000159878 TO 0.000412474
frequency: 1/time_period=3958.89
time_delay=0.000137836 FROM 2.20423e-05 TO 0.000159878
phase: 360*(time_delay / time_period)=196.444
vin_meas: v(vin)=-0.211324 at 0.000207068
gain: 10/vin_meas=-47.3207
max_vin: MAX(v(vin))=0.222528 FROM 0 TO 0.000444444
min_vin: MIN(v(vin))=-0.24538 FROM 0 TO 0.000444444
max_vout: MAX(v(vout))=10.8278 FROM 0 TO 0.000444444
min_vout: MIN(v(vout))=-10.8001 FROM 0 TO 0.000444444


Date: Wed May  1 22:53:42 2019
Total elapsed time: 1.391 seconds.

tnom = 27
temp = 27
method = modified trap
totiter = 123704
traniter = 123693
tranpoints = 33870
accept = 23694
rejected = 10176
matrix size = 39
fillins = 33
solver = Alternate
Matrix Compiler1: 4278 object code size  1.2/0.9/[0.7]
Matrix Compiler2: off
```

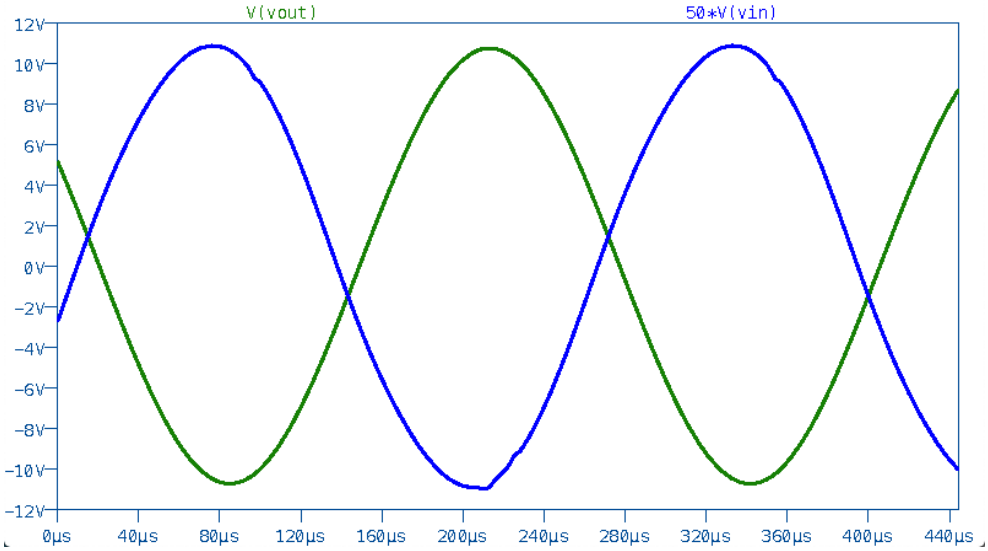
Prático



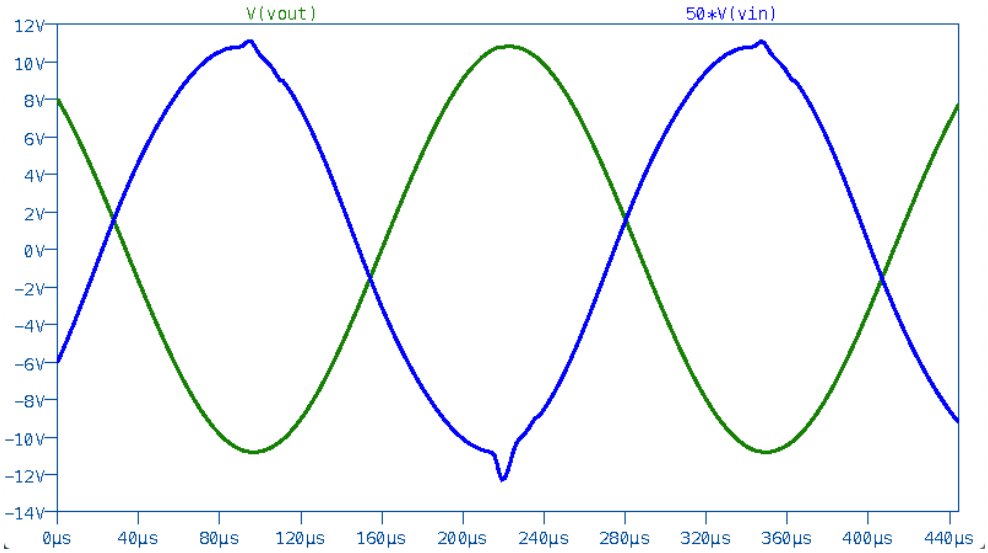


Formas de onda

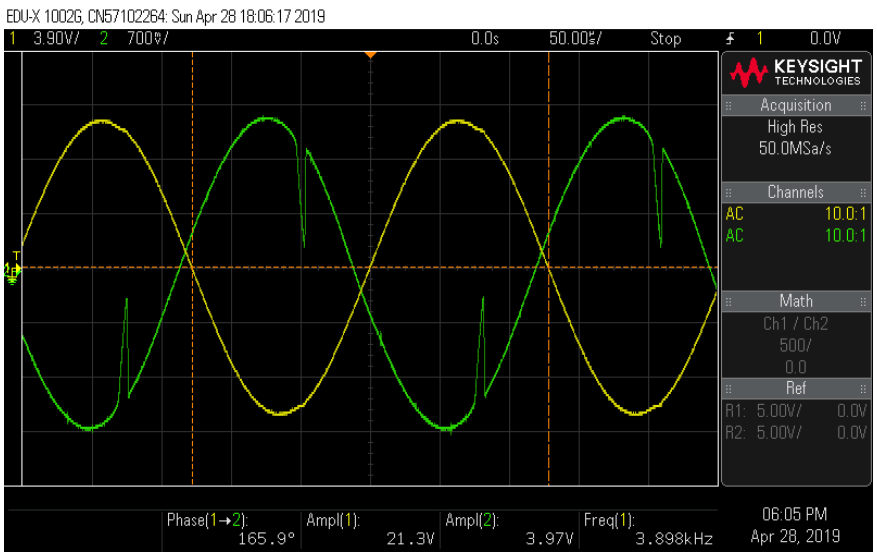
Teórico - simulação



Prático - simulação

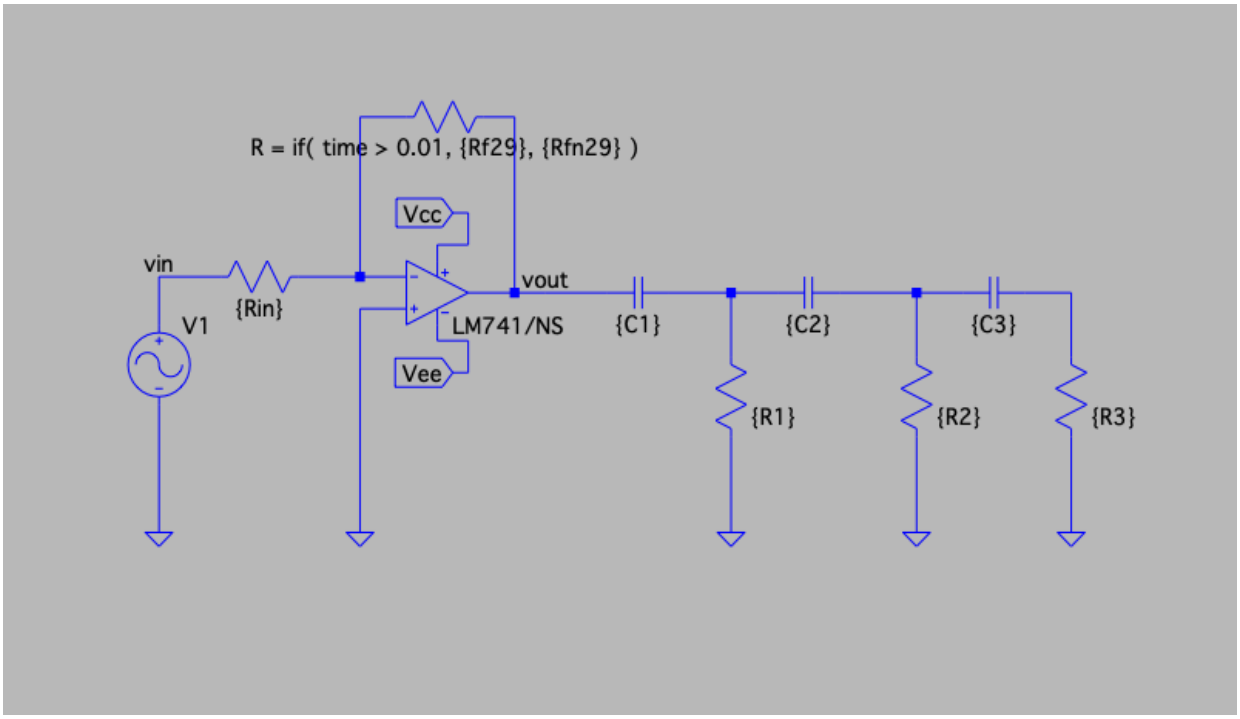


Prático



4.5kHz

Topologia aberta: Debug A



Indice:

Diretivas spice - com carga

Teórico

```
.meas tran time_period trig V(vout)=0 rise=1 targ V(vout)=0 rise=2
.meas frequency param 1/time_period
.meas tran time_delay trig V(vin)=0 rise=1 targ V(vout)=0 rise=1
.meas phase param 360*(time_delay / time_period)
.meas TRAN vin_meas FIND V(vin) WHEN V(vout)=10
.meas gain param 10/vin_meas
.meas max_vin max V(vin)
.meas min_vin min V(vin)
.meas max_vout max V(vout)
.meas min_vout min V(vout)

.lib ../../../../libs/LM741.lib
.param Rin=1k C=47n R=307.2
.param Rf29=50k Rfn29=150k

.tran 0 {0.1+2/4500} 0.1
 tstep tstop tstart
```

Prático

```
.meas tran time_period trig V(vout)=0 rise=1 targ V(vout)=0 rise=2
.meas frequency param 1/time_period
.meas tran time_delay trig V(vin)=0 rise=1 targ V(vout)=0 rise=1
.meas phase param 360*(time_delay / time_period)
.meas TRAN vin_meas FIND V(vin) WHEN V(vout)=10
.meas gain param 10/vin_meas
.meas max_vin max V(vin)
.meas min_vin min V(vin)
.meas max_vout max V(vout)
.meas min_vout min V(vout)

.lib ../../../../libs/LM741.lib

.param Rf29=50k Rfn29=150k

.param Rin=976
.param C1=47.85n C2=46.93n C3=45.37n
.param R1=300 R2=305 R3=301

.tran 0 {0.11+2/4500} 0.11
 tstep tstop tstart
```

Medições - com carga

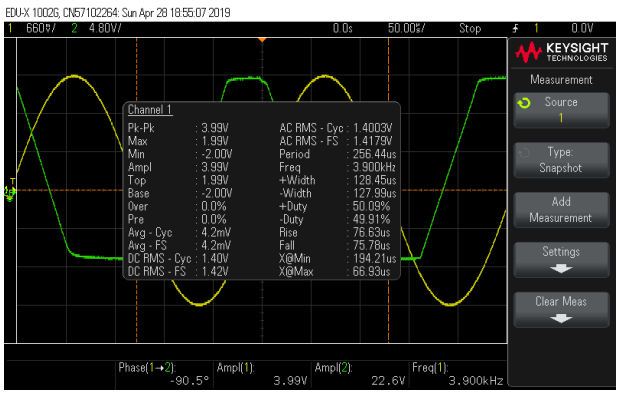
Teórico - simulação

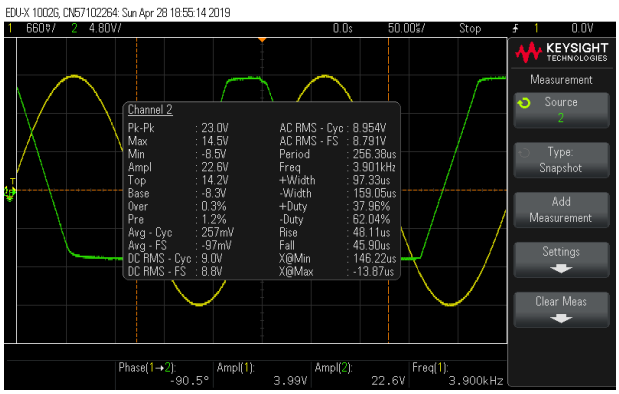
```
Direct Newton iteration for .op point succeeded.

time_period=0.000256321 FROM 8.89392e-06 TO 0.000265215
frequency: 1/time_period=3901.35
time_delay=-0.000117676 FROM 0.00012657 TO 8.89392e-06
phase: 360*(time_delay / time_period)=-165.275
vin_meas: v(vin)=-0.215375 at 5.60871e-05
gain: 10/vin_meas=-46.4307
max_vin: MAX(v(vin))=0.21813 FROM 0 TO 0.000444444
min_vin: MIN(v(vin))=-0.218127 FROM 0 TO 0.000444444
max_vout: MAX(v(vout))=10.7527 FROM 0 TO 0.000444444
min_vout: MIN(v(vout))=-10.6703 FROM 0 TO 0.000444444


Date: Wed May  1 22:34:22 2019
Total elapsed time: 1.336 seconds.

tnom = 27
temp = 27
method = modified trap
totiter = 114304
traniter = 114293
tranpoints = 21396
accept = 14795
rejected = 6601
matrix size = 41
fillins = 29
solver = Alternate
Matrix Compiler1: 4024 object code size  1.2/0.8/[0.5]
Matrix Compiler2: off
```

Prático - simulação

```
Direct Newton iteration for .op point succeeded.

time_period=0.000252588 FROM 1.65034e-05 TO 0.000269091
frequency: 1/time_period=3959.02
time_delay=-0.000115377 FROM 0.00013188 TO 1.65034e-05
phase: 360*(time_delay / time_period)=-164.441
vin_meas: v(vin)=-0.216875 at 5.97821e-05
gain: 10/vin_meas=-46.1095
max_vin: MAX(v(vin))=0.22235 FROM 0 TO 0.000444444
min_vin: MIN(v(vin))=-0.222388 FROM 0 TO 0.000444444
max_vout: MAX(v(vout))=10.8096 FROM 0 TO 0.000444444
min_vout: MIN(v(vout))=-10.7991 FROM 0 TO 0.000444444


Date: Wed May  1 22:57:50 2019
Total elapsed time: 1.622 seconds.

tnom = 27
temp = 27
method = modified trap
totiter = 140587
traniter = 140576
tranpoints = 32181
accept = 21442
rejected = 10739
matrix size = 41
fillins = 29
solver = Alternate
Matrix Compiler1: 4024 object code size  1.2/0.8/[0.6]
Matrix Compiler2: off
```

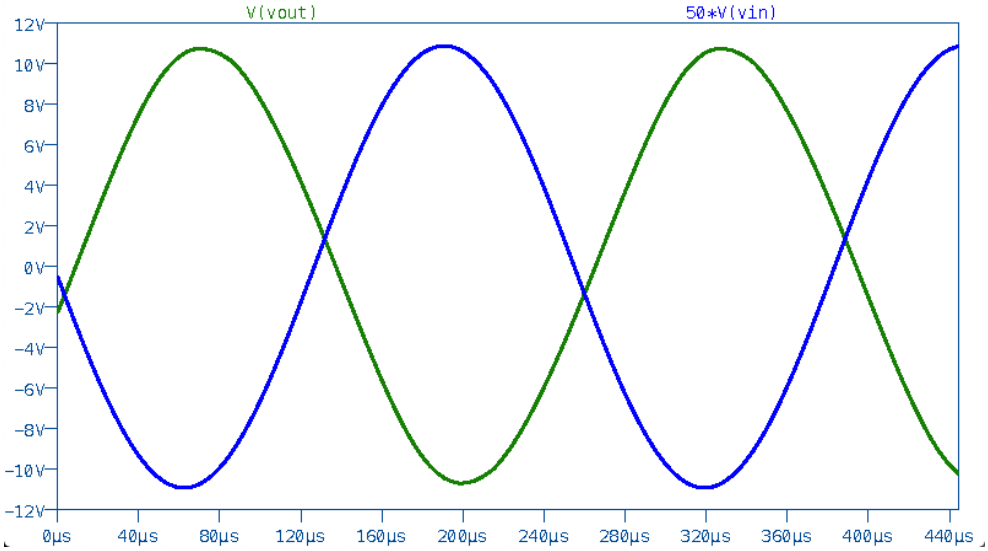
Prático



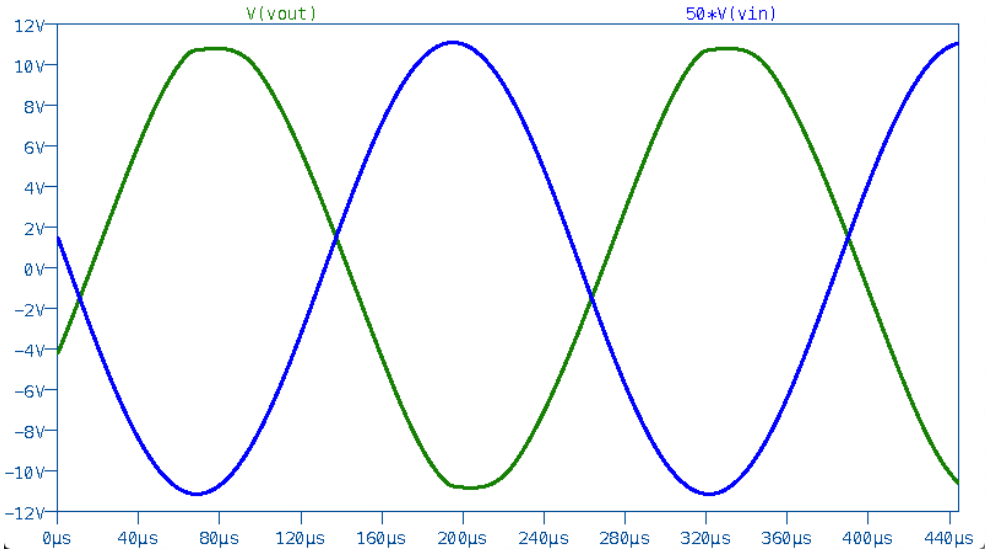


Formas de onda - com carga

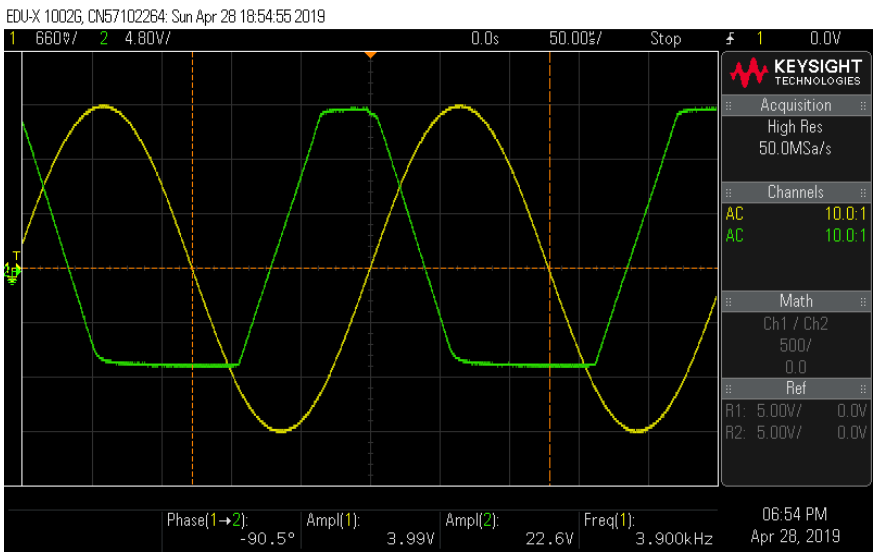
Teórico - simulação



Prático - simulação



Prático



Medições - sem carga

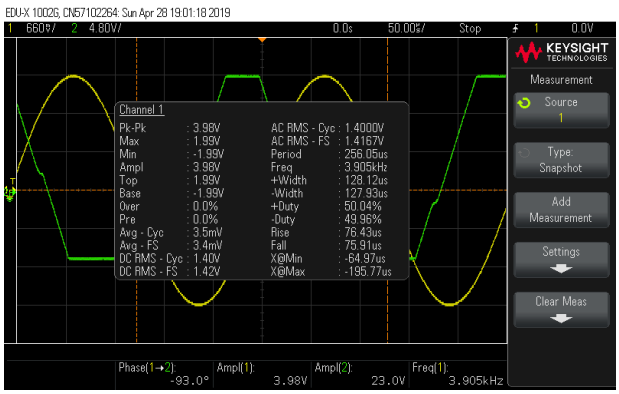
Teórico - simulação

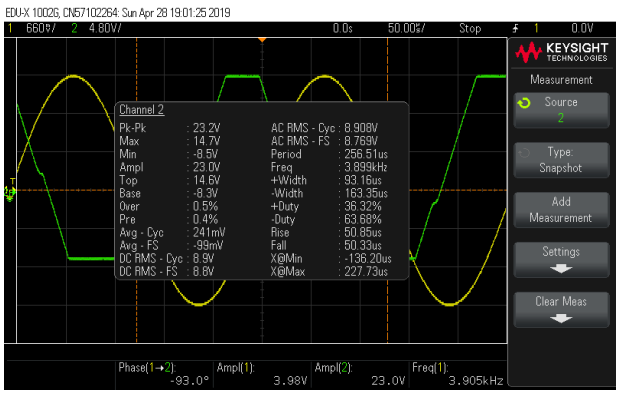
```
Direct Newton iteration for .op point succeeded.

time_period=0.000256501 FROM 8.49308e-06 TO 0.000264994
frequency: 1/time_period=3898.62
time_delay=-0.000118078 FROM 0.000126571 TO 8.49308e-06
phase: 360*(time_delay / time_period)=-165.722
vin_meas: v(vin)=-0.215573 at 5.66897e-05
gain: 10/vin_meas=-46.3879
max_vin: MAX(v(vin))=0.218004 FROM 0 TO 0.000444444
min_vin: MIN(v(vin))=-0.218062 FROM 0 TO 0.000444444
max_vout: MAX(v(vout))=10.7263 FROM 0 TO 0.000444444
min_vout: MIN(v(vout))=-10.6147 FROM 0 TO 0.000444444


Date: Wed May  1 22:36:05 2019
Total elapsed time: 0.762 seconds.

tnom = 27
temp = 27
method = modified trap
totiter = 66125
traniter = 66114
tranpoints = 15342
accept = 10982
rejected = 4360
matrix size = 38
fillins = 29
solver = Alternate
Matrix Compiler1: 3826 object code size  1.1/0.8/[0.7]
Matrix Compiler2: off
```

Prático - simulação

```
Direct Newton iteration for .op point succeeded.

time_period=0.000252567 FROM 1.62551e-05 TO 0.000268822
frequency: 1/time_period=3959.35
time_delay=-0.000115627 FROM 0.000131882 TO 1.62551e-05
phase: 360*(time_delay / time_period)=-164.81
vin_meas: v(vin)=-0.217128 at 6.01997e-05
gain: 10/vin_meas=-46.0558
max_vin: MAX(v(vin))=0.222363 FROM 0 TO 0.000444444
min_vin: MIN(v(vin))=-0.22237 FROM 0 TO 0.000444444
max_vout: MAX(v(vout))=10.9464 FROM 0 TO 0.000444444
min_vout: MIN(v(vout))=-10.9345 FROM 0 TO 0.000444444


Date: Wed May  1 22:59:06 2019
Total elapsed time: 1.081 seconds.

tnom = 27
temp = 27
method = modified trap
totiter = 97212
traniter = 97201
tranpoints = 23499
accept = 15234
rejected = 8265
matrix size = 38
fillins = 29
solver = Alternate
Matrix Compiler1: 3826 object code size  1.1/0.9/[0.4]
Matrix Compiler2: off
```

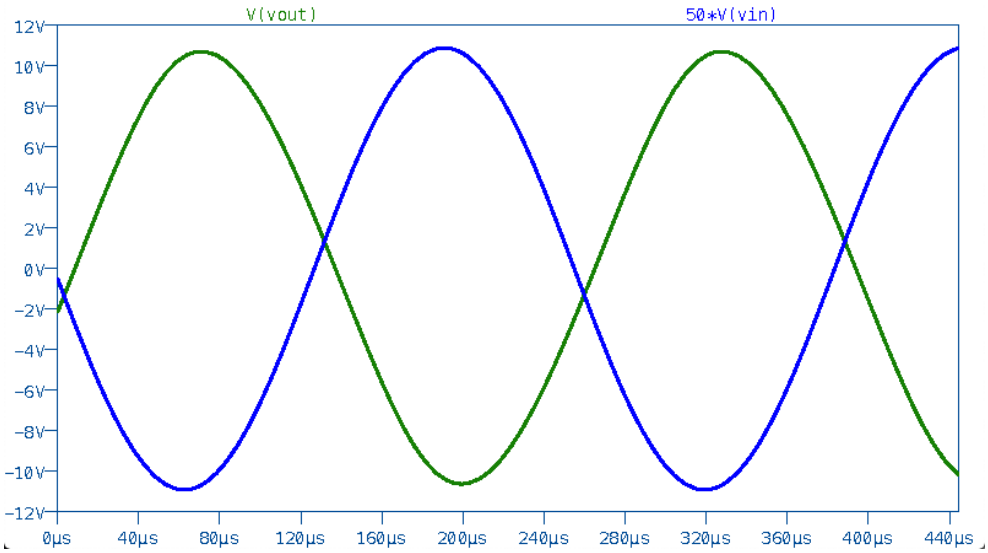
Prático



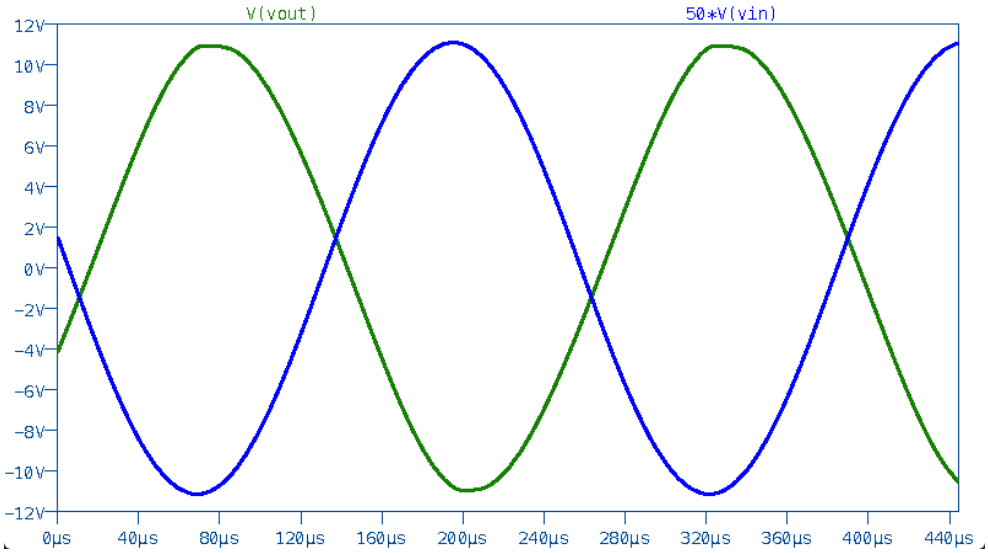


Formas de onda - sem carga

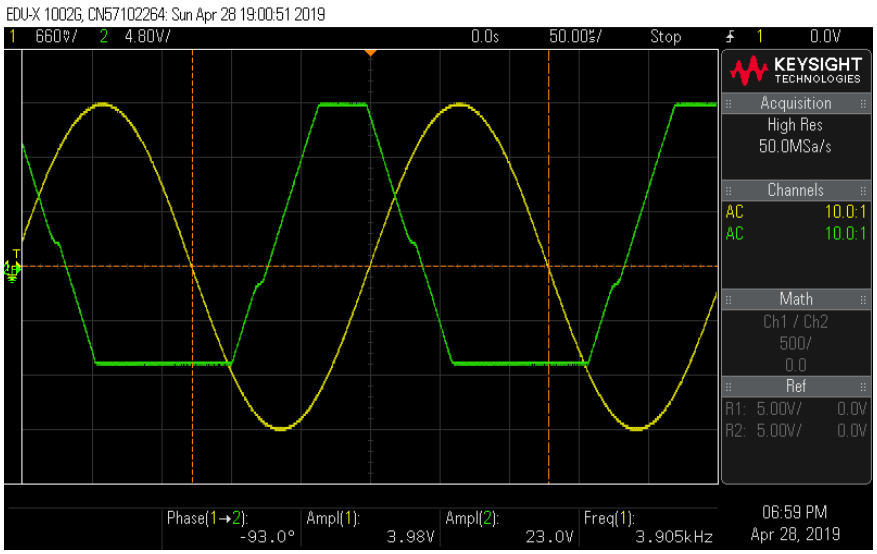
Teórico - simulação



Prático - simulação

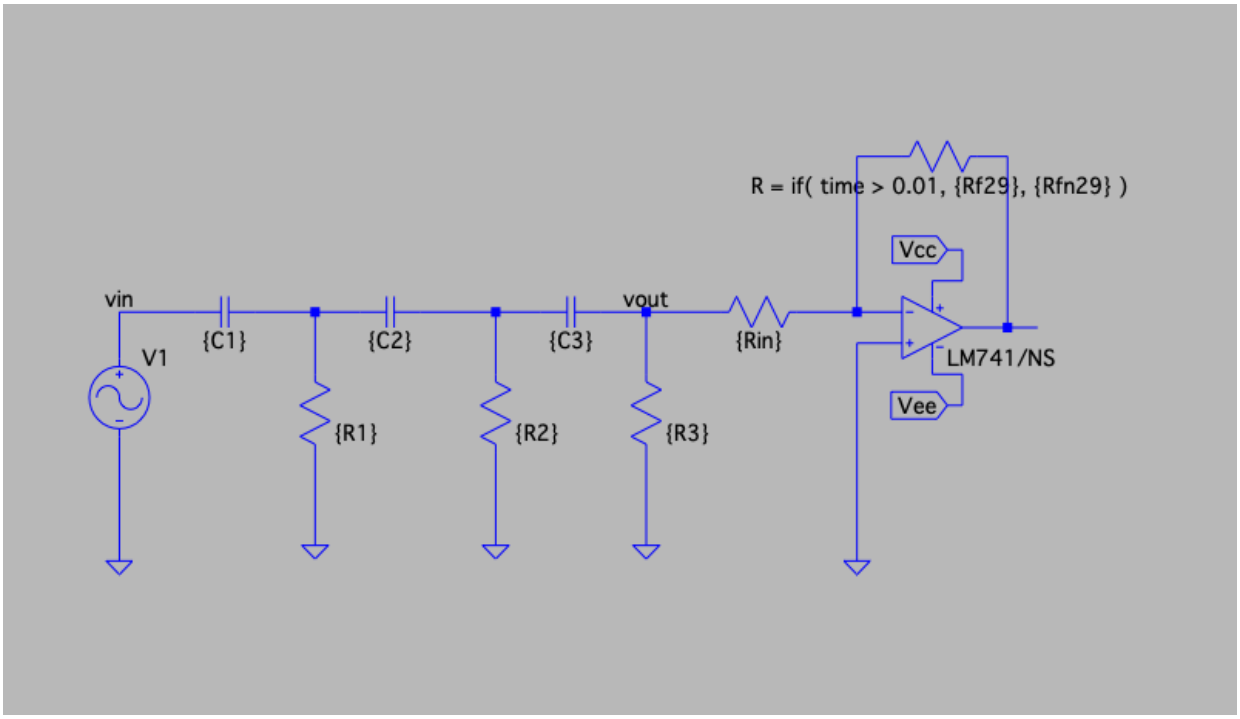


Prático



4.5kHz

Topologia aberta: Debug B



Indice:

Diretivas spice - com carga

Teórico

```
.meas tran time_period trig V(vout)=0 rise=1 targ V(vout)=0 rise=2
.meas frequency param 1/time_period
.meas tran time_delay trig V(vin)=0 rise=1 targ V(vout)=0 rise=1
.meas phase param 360*(time_delay / time_period)
.meas TRAN vout_meas FIND V(vout) WHEN V(vin)=10
.meas gain param 10/vout_meas
.meas max_vin max V(vin)
.meas min_vin min V(vin)
.meas max_vout max V(vout)
.meas min_vout min V(vout)

.lib ../../../../libs/LM741.lib
.param Rin=1k C=47n R=307.2
.param Rf29=50k Rfn29=150k

.tran 0 {0.11+2/4500} 0.11
 tstep tstop tstart
```

Prático

```
.meas tran time_period trig V(vout)=0 rise=1 targ V(vout)=0 rise=2
.meas frequency param 1/time_period
.meas tran time_delay trig V(vin)=0 rise=1 targ V(vout)=0 rise=1
.meas phase param 360*(time_delay / time_period)
.meas TRAN vout_meas FIND V(vout) WHEN V(vin)=10
.meas gain param 10/vout_meas
.meas max_vin max V(vin)
.meas min_vin min V(vin)
.meas max_vout max V(vout)
.meas min_vout min V(vout)

.lib ../../../../libs/LM741.lib

.param Rf29=50k Rfn29=150k

.param Rin=976
.param C1=47.85n C2=46.93n C3=45.37n
.param R1=300 R2=305 R3=301

.tran 0 {0.115+2/4500} 0.115
 tstep tstop tstart
```

Medições - com carga

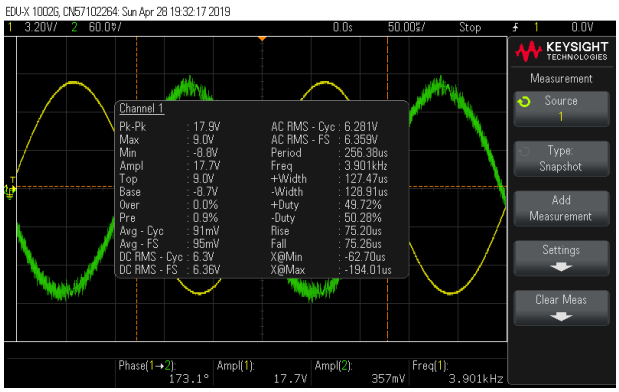
Teórico - simulação

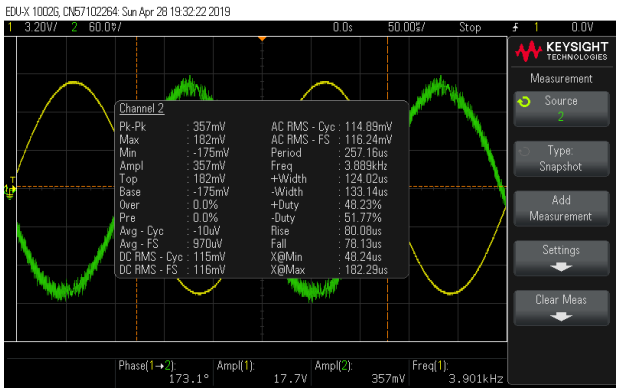
```
Direct Newton iteration for .op point succeeded.

time_period=0.00025661 FROM 8.06624e-07 TO 0.000257416
frequency: 1/time_period=3896.97
time_delay=-0.000138421 FROM 0.000139227 TO 8.06624e-07
phase: 360*(time_delay / time_period)=-194.191
vout_meas: v(vout)=-0.217834 at 0.000187977
gain: 10/vout_meas=-45.9065
max_vin: MAX(v(vin))=10.776 FROM 0 TO 0.000444444
min_vin: MIN(v(vin))=-10.7764 FROM 0 TO 0.000444444
max_vout: MAX(v(vout))=0.220545 FROM 0 TO 0.000444444
min_vout: MIN(v(vout))=-0.219829 FROM 0 TO 0.000444444


Date: Wed May  1 22:41:47 2019
Total elapsed time: 1.010 seconds.

tnom = 27
temp = 27
method = modified trap
totiter = 87915
traniter = 87904
tranpoints = 21619
accept = 14856
rejected = 6763
matrix size = 41
fillins = 29
solver = Alternate
Matrix Compiler1: 4024 object code size  1.1/0.9/[0.6]
Matrix Compiler2: off
```

Prático - simulação

```
Direct Newton iteration for .op point succeeded.

time_period=0.000252637 FROM 4.69295e-05 TO 0.000299567
frequency: 1/time_period=3958.25
time_delay=-0.000136872 FROM 0.000183801 TO 4.69295e-05
phase: 360*(time_delay / time_period)=-195.038
vout_meas: v(vout)=-0.174909 at 9.93719e-06
gain: 10/vout_meas=-57.1726
max_vin: MAX(v(vin))=10.8243 FROM 0 TO 0.000444444
min_vin: MIN(v(vin))=-10.8216 FROM 0 TO 0.000444444
max_vout: MAX(v(vout))=0.218495 FROM 0 TO 0.000444444
min_vout: MIN(v(vout))=-0.217854 FROM 0 TO 0.000444444


Date: Wed May  1 23:07:13 2019
Total elapsed time: 1.153 seconds.

tnom = 27
temp = 27
method = modified trap
totiter = 101536
traniter = 101525
tranpoints = 25474
accept = 17564
rejected = 7910
matrix size = 41
fillins = 29
solver = Alternate
Matrix Compiler1: 4024 object code size  1.1/0.7/[0.4]
Matrix Compiler2: off
```

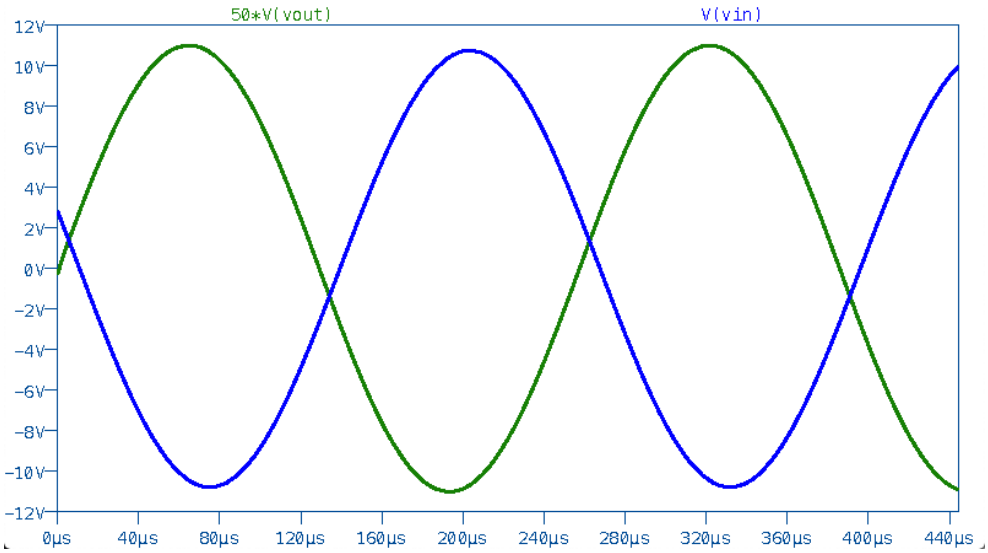
Prático



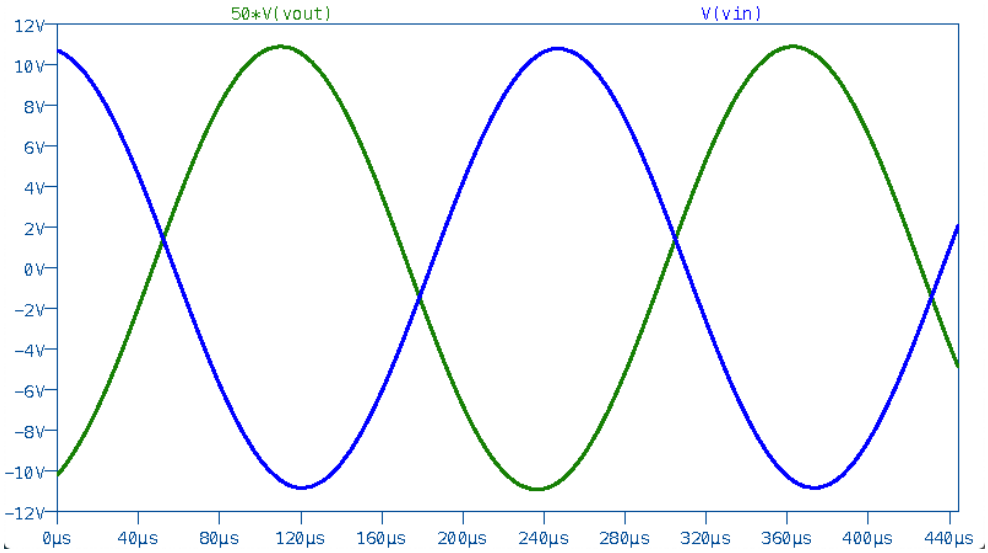


Formas de onda - com carga

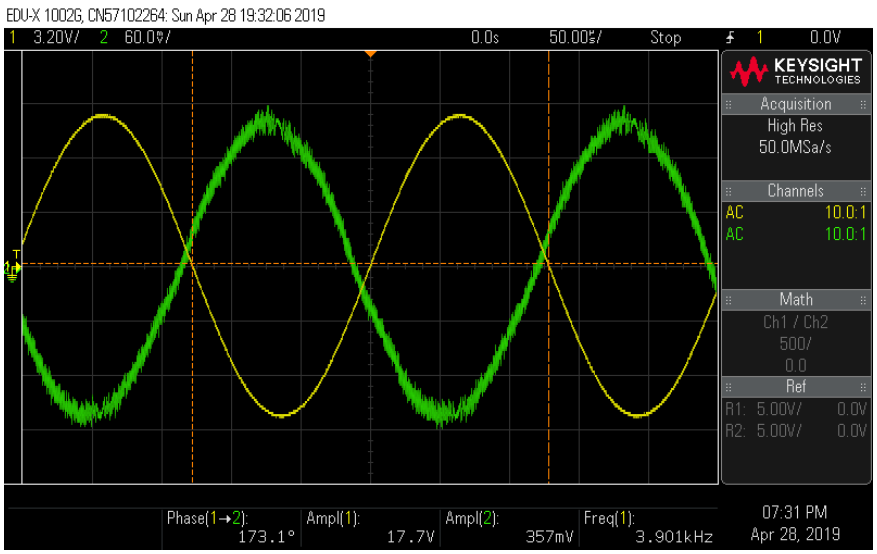
Teórico - simulação



Prático - simulação



Prático



Medições - sem carga

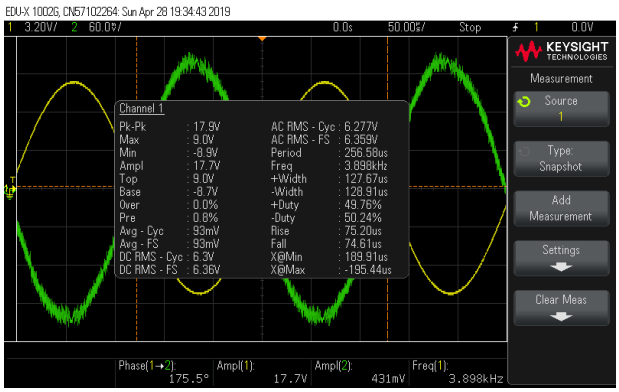
Teórico - simulação

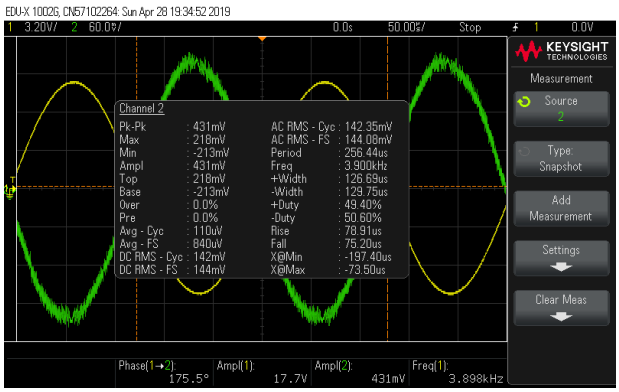
```
WARNING: Less than two connections to node VCC.  This node is used by V3.
Direct Newton iteration for .op point succeeded.

time_period=0.000257199 FROM 4.4941e-06 TO 0.000261693
frequency: 1/time_period=3888.05
time_delay=-0.000134734 FROM 0.000139228 TO 4.4941e-06
phase: 360*(time_delay / time_period)=-188.586
vout_meas: v(vout)=-0.26537 at 0.000187962
gain: 10/vout_meas=-37.6833
max_vin: MAX(v(vin))=10.7755 FROM 0 TO 0.000444444
min_vin: MIN(v(vin))=-10.7771 FROM 0 TO 0.000444444
max_vout: MAX(v(vout))=0.273679 FROM 0 TO 0.000444444
min_vout: MIN(v(vout))=-0.273231 FROM 0 TO 0.000444444


Date: Wed May  1 22:43:30 2019
Total elapsed time: 0.111 seconds.

tnom = 27
temp = 27
method = modified trap
totiter = 32627
traniter = 32624
tranpoints = 16313
accept = 10804
rejected = 5509
matrix size = 9
fillins = 0
solver = Alternate
Matrix Compiler1: off  [0.0]/0.1/0.1
Matrix Compiler2: off
```

Prático - simulação

```
Circuit: * /Users/Igor/eln3-osc/invFase/simulation/4.5khz/practical/debugB_practical.asc

WARNING: Less than two connections to node VEE.  This node is used by V2.
WARNING: Less than two connections to node VCC.  This node is used by V3.
Direct Newton iteration for .op point succeeded.

time_period=0.00025262 FROM 5.12096e-05 TO 0.00030383
frequency: 1/time_period=3958.51
time_delay=-0.000132592 FROM 0.000183802 TO 5.12096e-05
phase: 360*(time_delay / time_period)=-188.953
vout_meas: v(vout)=-0.233117 at 1.00171e-05
gain: 10/vout_meas=-42.8969
max_vin: MAX(v(vin))=10.8166 FROM 0 TO 0.000444444
min_vin: MIN(v(vin))=-10.8173 FROM 0 TO 0.000444444
max_vout: MAX(v(vout))=0.271178 FROM 0 TO 0.000444444
min_vout: MIN(v(vout))=-0.27102 FROM 0 TO 0.000444444


Date: Wed May  1 23:08:24 2019
Total elapsed time: 0.118 seconds.

tnom = 27
temp = 27
method = modified trap
totiter = 34257
traniter = 34254
tranpoints = 17128
accept = 11432
rejected = 5696
matrix size = 9
fillins = 0
solver = Alternate
```

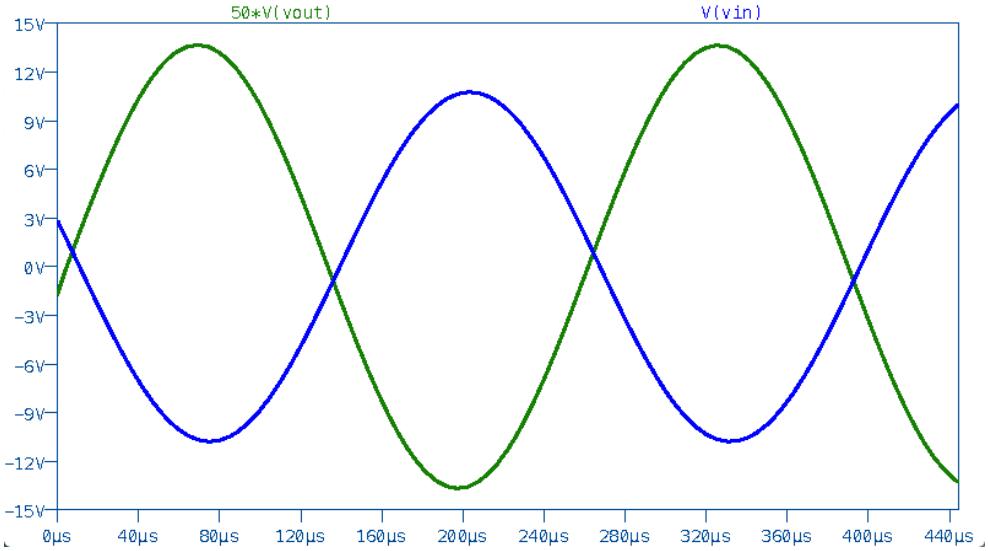
Prático



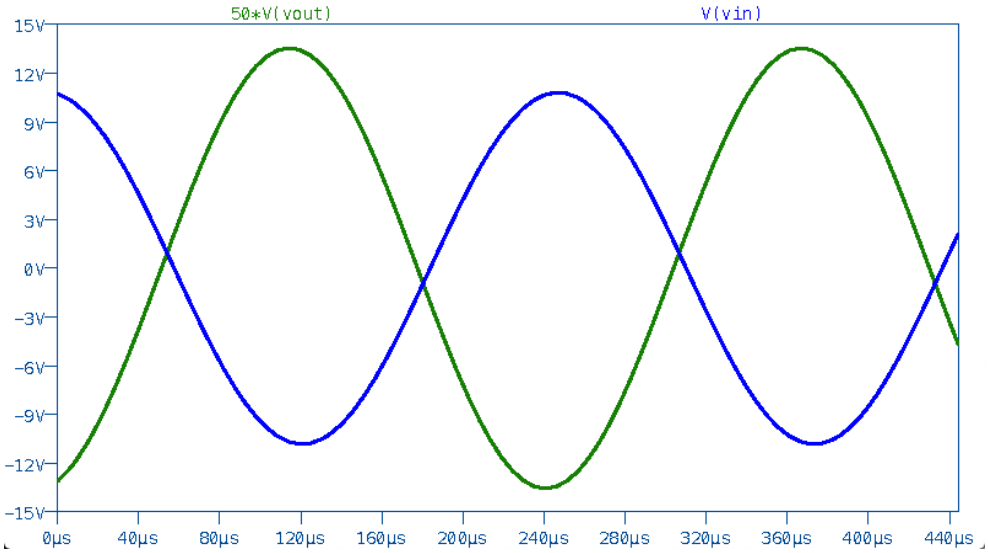


Formas de onda - sem carga

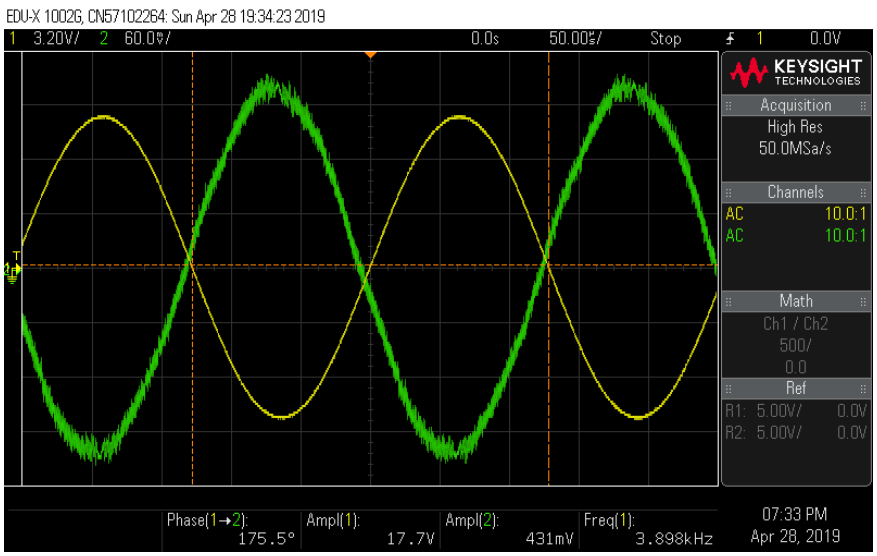
Teórico - simulação



Prático - simulação

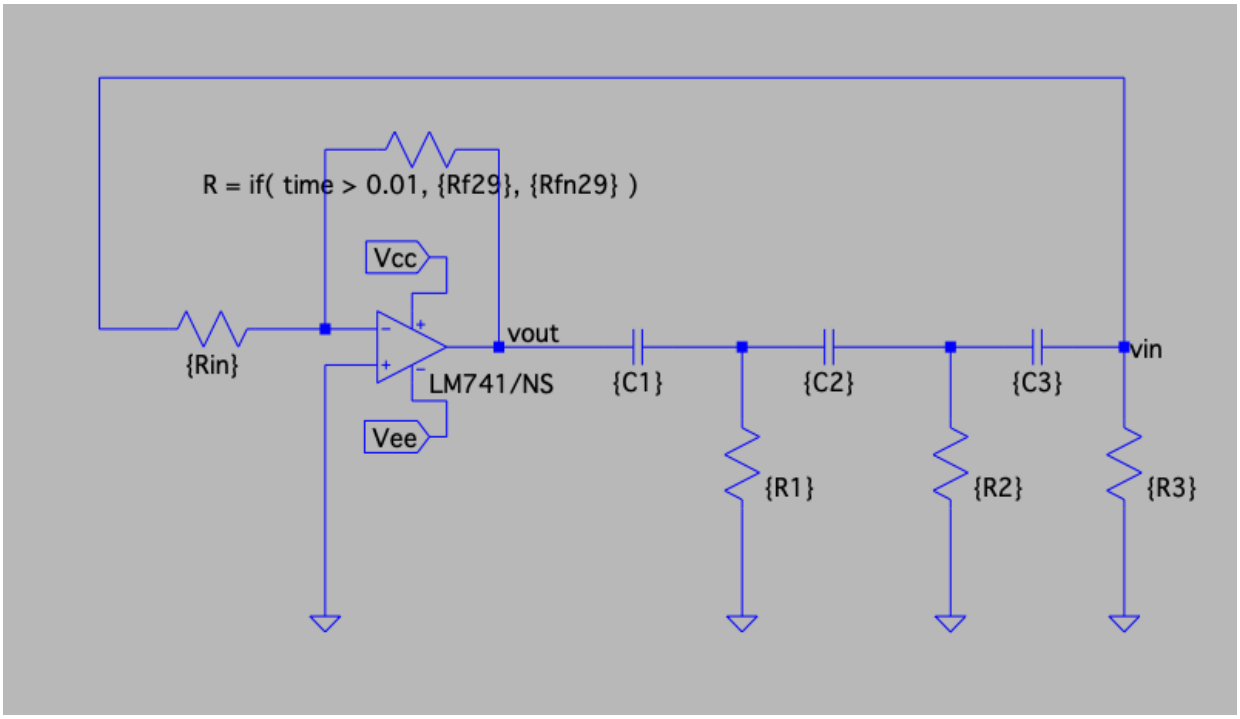


Prático



65kHz

Topologia completa



Indice:

Diretivas spice

Teórico

```
.meas tran time_period trig V(vout)=0 rise=1 targ V(vout)=0 rise=2
.meas frequency param 1/time_period
.meas tran time_delay trig V(vin)=0 rise=1 targ V(vout)=0 rise=1
.meas phase param 360*(time_delay / time_period)
.meas TRAN vin_meas FIND V(vin) WHEN V(vout)=10
.meas gain param 10/vin_meas
.meas max_vin max V(vin)
.meas min_vin min V(vin)
.meas max_vout max V(vout)
.meas min_vout min V(vout)

.lib ../../../../libs/LM741.lib
.param Rin=1k C=3.3n R=302.9
.param Rf29=60k Rfn29=200k

.tran 0 {1+2/65000} 1
 tstep tstop tstart
```

Prático

```
.meas tran time_period trig V(vout)=0 rise=1 targ V(vout)=0 rise=2
.meas frequency param 1/time_period
.meas tran time_delay trig V(vin)=0 rise=1 targ V(vout)=0 rise=1
.meas phase param 360*(time_delay / time_period)
.meas TRAN vin_meas FIND V(vin) WHEN V(vout)=10
.meas gain param 10/vin_meas
.meas max_vin max V(vin)
.meas min_vin min V(vin)
.meas max_vout max V(vout)
.meas min_vout min V(vout)

.lib ../../../../libs/LM741.lib
.param Rf29={29.4k + 30k} Rfn29=150k
.param Rin=993
.param C1=3.153n C2=3.174n C3=3.2n
.param R1=330 R2=327 R3=329

.tran 0 {0.1+2/65000} 0.1
 tstep tstop tstart
```

Medições

Teórico - simulação

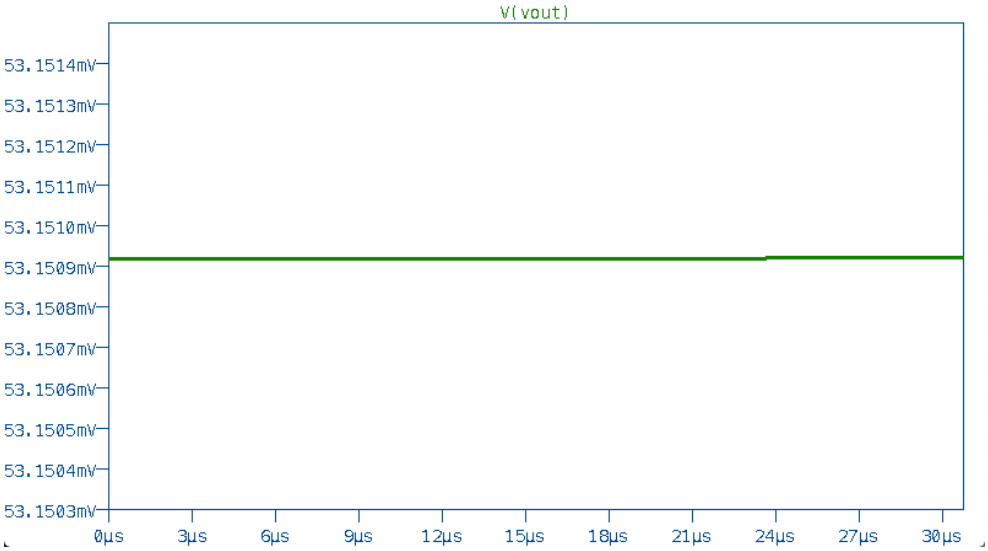
```
Circuit: * /Users/Igor/eln3-osc/invFase/simulation/65khz/theorical/complete_theorical.asc

Direct Newton iteration for .op point succeeded.


Measurement "time_period" FAIL'ed

Measurement "frequency" FAIL'ed

Measurement "time_delay" FAIL'ed

Measurement "phase" FAIL'ed

Measurement "vin_meas" FAIL'ed

Measurement "gain" FAIL'ed
max_vin: MAX(v(vin))=0.000232423 FROM 0 TO 3.07692e-05
min_vin: MIN(v(vin))=0.000232416 FROM 0 TO 3.07692e-05
max_vout: MAX(v(vout))=0.0531509 FROM 0 TO 3.07692e-05
min_vout: MIN(v(vout))=0.0531509 FROM 0 TO 3.07692e-05


Date: Thu May  2 00:03:21 2019
Total elapsed time: 0.091 seconds.

tnom = 27
temp = 27
method = modified trap
totiter = 2667
traniter = 2656
tranpoints = 1329
accept = 1306
```

Prático - simulação

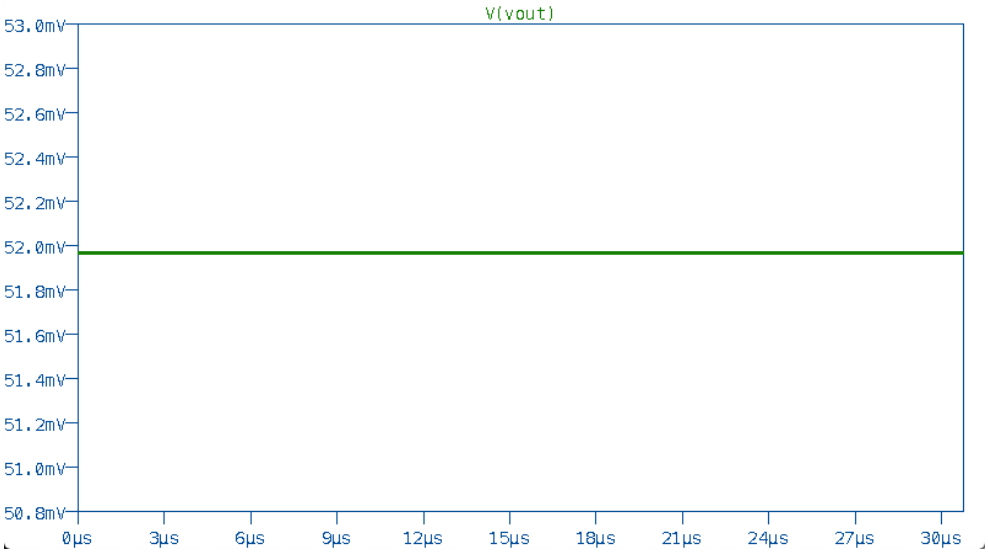
```
Circuit: * /Users/Igor/eln3-osc/invFase/simulation/65khz/practical/complete_practical.asc

Direct Newton iteration for .op point succeeded.


Measurement "time_period" FAIL'ed

Measurement "frequency" FAIL'ed

Measurement "time_delay" FAIL'ed

Measurement "phase" FAIL'ed

Measurement "vin_meas" FAIL'ed

Measurement "gain" FAIL'ed
max_vin: MAX(v(vin))=0.000248804 FROM 0 TO 3.07692e-05
min_vin: MIN(v(vin))=0.000248804 FROM 0 TO 3.07692e-05
max_vout: MAX(v(vout))=0.0519712 FROM 0 TO 3.07692e-05
min_vout: MIN(v(vout))=0.0519712 FROM 0 TO 3.07692e-05


Date: Thu May  2 07:31:09 2019
Total elapsed time: 0.118 seconds.

tnom = 27
temp = 27
method = Gear
totiter = 2686
traniter = 2675
tranpoints = 1337
accept = 1314
```

Formas de onda

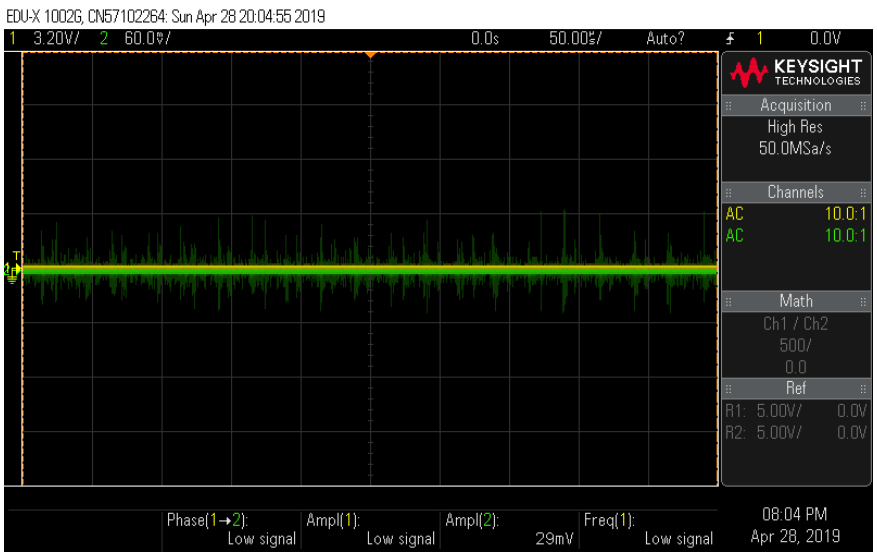
Teórico - simulação



Prático - simulação

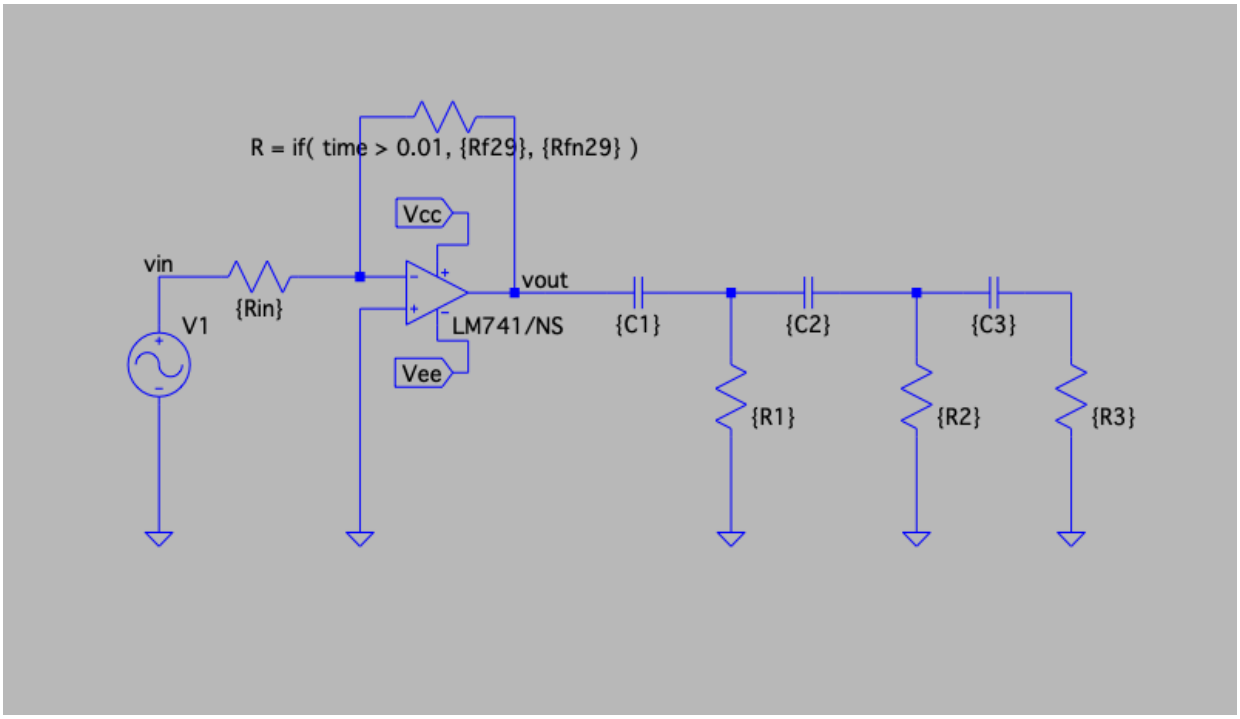


Prático



65kHz

Topologia aberta: Debug A



Indice:

Diretivas spice - com carga

Teórico

```
.meas tran time_period trig V(vout)=0 rise=1 targ V(vout)=0 rise=2
.meas frequency param 1/time_period
.meas tran time_delay trig V(vin)=0 rise=1 targ V(vout)=0 rise=1
.meas phase param 360*(time_delay / time_period)
.meas TRAN vin_meas FIND V(vin) WHEN V(vout)=1
.meas gain param 1/vin_meas
.meas max_vin max V(vin)
.meas min_vin min V(vin)
.meas max_vout max V(vout)
.meas min_vout min V(vout)

.lib ../../../../libs/LM741.lib
.param Rin=1k C=3.3n R=302.9
.param Rf29=60k Rfn29=200k

.tran 0 {0.1+2/65000} 0.1
 tstep tstop tstart
```

Prático

```
.meas tran time_period trig V(vout)=0 rise=1 targ V(vout)=0 rise=2
.meas frequency param 1/time_period
.meas tran time_delay trig V(vin)=0 rise=1 targ V(vout)=0 rise=1
.meas phase param 360*(time_delay / time_period)
.meas TRAN vin_meas FIND V(vin) WHEN V(vout)=1
.meas gain param 1/vin_meas
.meas max_vin max V(vin)
.meas min_vin min V(vin)
.meas max_vout max V(vout)
.meas min_vout min V(vout)

.lib ../../../../libs/LM741.lib
.param Rf29={29.4k + 30k} Rfn29=150k

.param Rin=993
.param C1=3.153n C2=3.174n C3=3.2n
.param R1=330 R2=327 R3=329

.tran 0 {0.1+2/65000} 0.1
 tstep tstop tstart
```

Medições - com carga

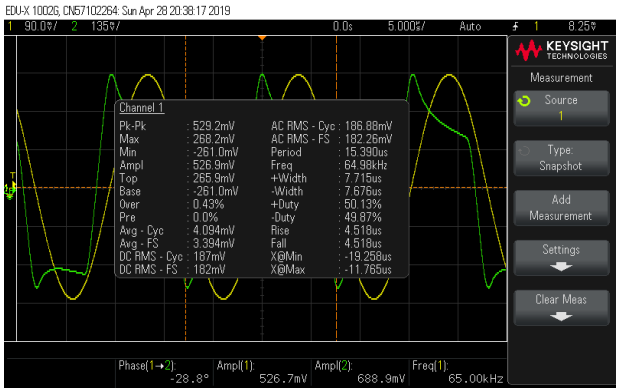
Teórico - simulação

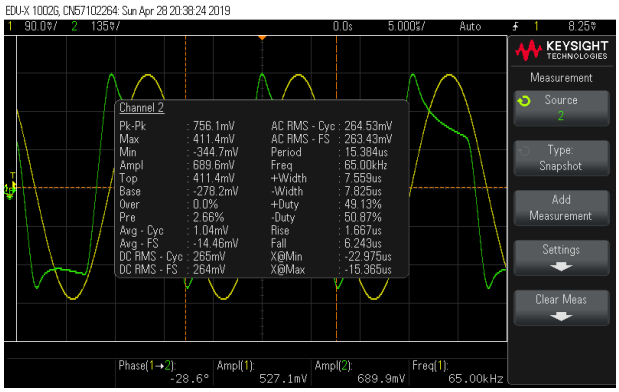
```
Direct Newton iteration for .op point succeeded.

time_period=1.53816e-05 FROM 1.14937e-05 TO 2.68753e-05
frequency: 1/time_period=65012.8
time_delay=1.14937e-05 FROM 3.89903e-18 TO 1.14937e-05
phase: 360*(time_delay / time_period)=269.006
vin_meas: v(vin)=0.0780266 at 8.96295e-07
gain: 1/vin_meas=12.8161
max_vin: MAX(v(vin))=0.218215 FROM 0 TO 3.07692e-05
min_vin: MIN(v(vin))=-0.218225 FROM 0 TO 3.07692e-05
max_vout: MAX(v(vout))=1.11016 FROM 0 TO 3.07692e-05
min_vout: MIN(v(vout))=-0.984024 FROM 0 TO 3.07692e-05


Date: Thu May  2 07:07:08 2019
Total elapsed time: 16.598 seconds.

tnom = 27
temp = 27
method = Gear
totiter = 1428496
traniter = 1428485
tranpoints = 507387
accept = 345917
rejected = 161470
matrix size = 41
fillins = 29
solver = Alternate
Matrix Compiler1: 4024 object code size  1.3/0.8/[0.4]
Matrix Compiler2: off
```

Prático - simulação

```
Direct Newton iteration for .op point succeeded.

time_period=1.53818e-05 FROM 1.15038e-05 TO 2.68856e-05
frequency: 1/time_period=65011.9
time_delay=1.15038e-05 FROM 3.89905e-18 TO 1.15038e-05
phase: 360*(time_delay / time_period)=269.237
vin_meas: v(vin)=0.090952 at 9.36134e-07
gain: 1/vin_meas=10.9948
max_vin: MAX(v(vin))=0.243754 FROM 0 TO 3.07692e-05
min_vin: MIN(v(vin))=-0.243756 FROM 0 TO 3.07692e-05
max_vout: MAX(v(vout))=1.12403 FROM 0 TO 3.07692e-05
min_vout: MIN(v(vout))=-0.998653 FROM 0 TO 3.07692e-05


Date: Thu May  2 07:43:06 2019
Total elapsed time: 16.665 seconds.

tnom = 27
temp = 27
method = Gear
totiter = 1433749
traniter = 1433738
tranpoints = 509205
accept = 351289
rejected = 157916
matrix size = 41
fillins = 29
solver = Alternate
Matrix Compiler1: 4024 object code size  1.3/0.8/[0.5]
Matrix Compiler2: off
```

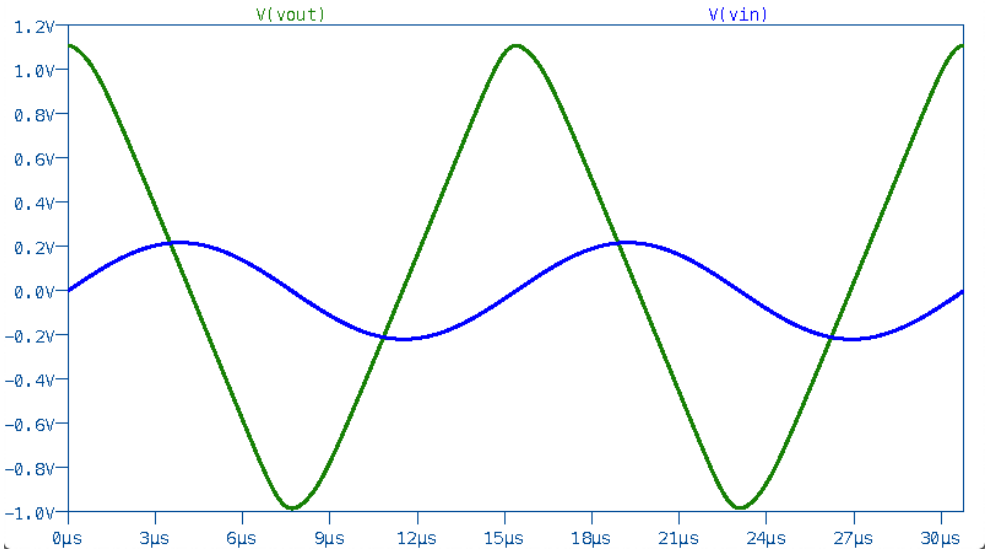
Prático



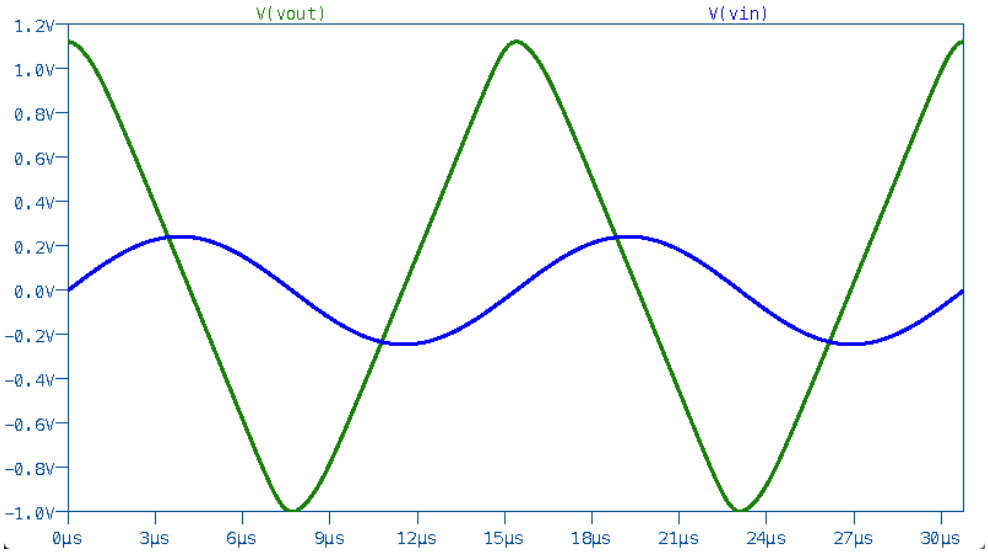


Formas de onda - com carga

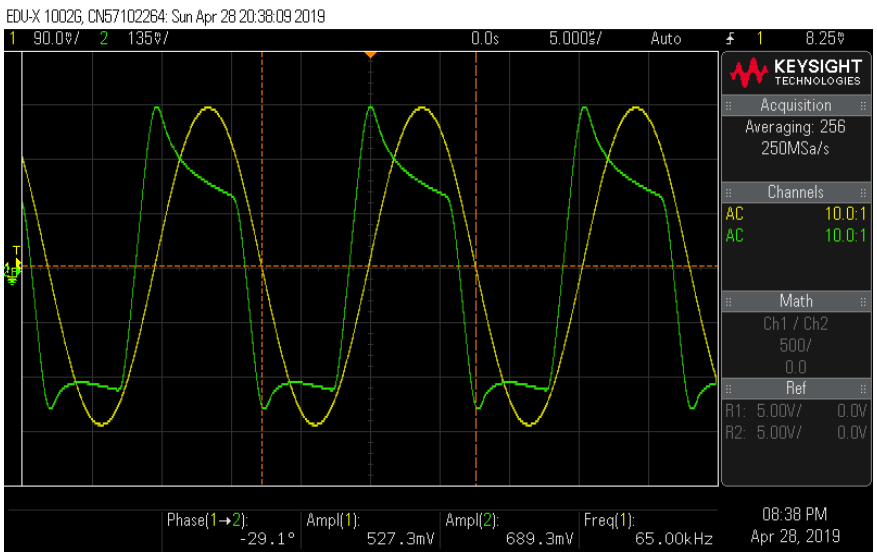
Teórico - simulação



Prático - simulação



Prático



Medições - sem carga

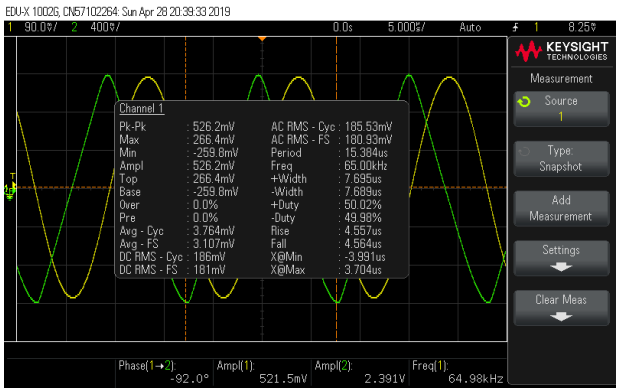
Teórico - simulação

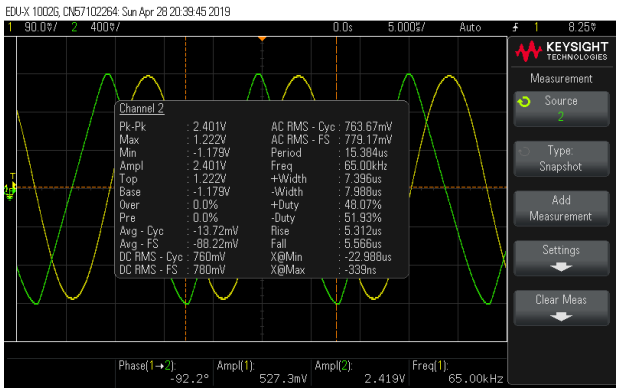
```
Circuit: * /Users/Igor/eln3-osc/invFase/simulation/65khz/theorical/debugA_theorical.asc

Direct Newton iteration for .op point succeeded.

time_period=1.53802e-05 FROM 1.12288e-05 TO 2.6609e-05
frequency: 1/time_period=65018.6
time_delay=1.12288e-05 FROM 3.8816e-18 TO 1.12288e-05
phase: 360*(time_delay / time_period)=262.829
vin_meas: v(vin)=0.0685105 at 7.82326e-07
gain: 1/vin_meas=14.5963
max_vin: MAX(v(vin))=0.218194 FROM 0 TO 3.07692e-05
min_vin: MIN(v(vin))=-0.218103 FROM 0 TO 3.07692e-05
max_vout: MAX(v(vout))=1.1696 FROM 0 TO 3.07692e-05
min_vout: MIN(v(vout))=-1.04714 FROM 0 TO 3.07692e-05


Date: Thu May  2 07:09:11 2019
Total elapsed time: 12.515 seconds.

tnom = 27
temp = 27
method = Gear
totiter = 1112018
traniter = 1112007
tranpoints = 480494
accept = 315964
rejected = 164530
matrix size = 38
fillins = 29
solver = Alternate
Matrix Compiler1: 3826 object code size  1.0/0.8/[0.6]
Matrix Compiler2: off
```

Prático - simulação

```
Direct Newton iteration for .op point succeeded.

time_period=1.53814e-05 FROM 1.12436e-05 TO 2.6625e-05
frequency: 1/time_period=65013.6
time_delay=1.12436e-05 FROM 3.87644e-18 TO 1.12436e-05
phase: 360*(time_delay / time_period)=263.156
vin_meas: v(vin)=0.0798893 at 8.18332e-07
gain: 1/vin_meas=12.5173
max_vin: MAX(v(vin))=0.243504 FROM 0 TO 3.07692e-05
min_vin: MIN(v(vin))=-0.243514 FROM 0 TO 3.07692e-05
max_vout: MAX(v(vout))=1.18408 FROM 0 TO 3.07692e-05
min_vout: MIN(v(vout))=-1.0603 FROM 0 TO 3.07692e-05


Date: Thu May  2 07:44:24 2019
Total elapsed time: 12.460 seconds.

tnom = 27
temp = 27
method = Gear
totiter = 1100545
traniter = 1100534
tranpoints = 482000
accept = 325285
rejected = 156715
matrix size = 38
fillins = 29
solver = Alternate
Matrix Compiler1: 3826 object code size  1.1/0.7/[0.4]
Matrix Compiler2: off
```

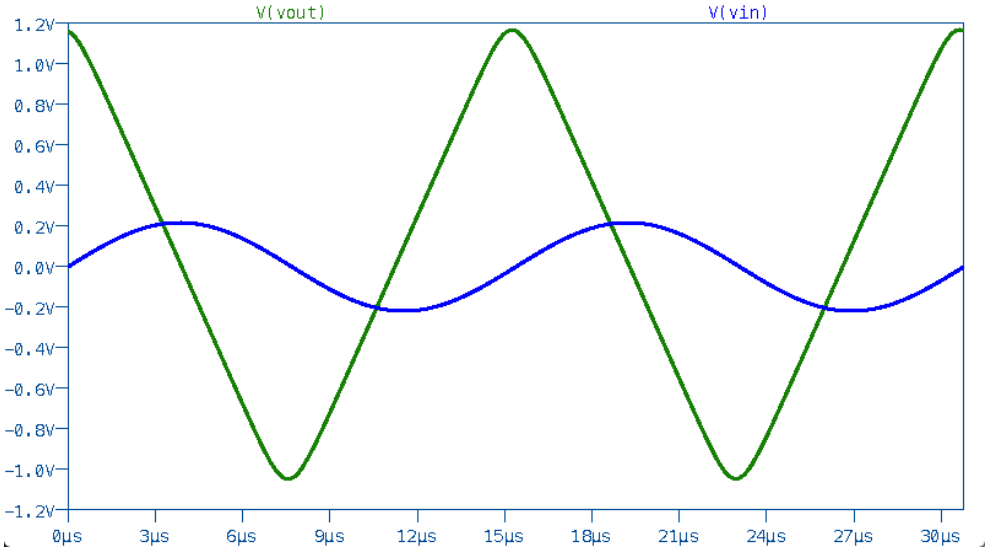
Prático



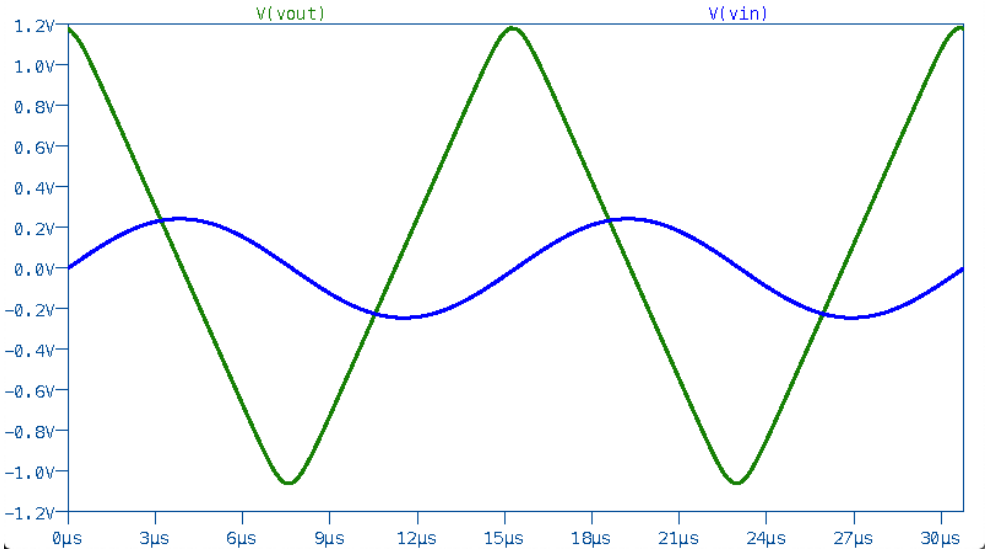


Formas de onda - sem carga

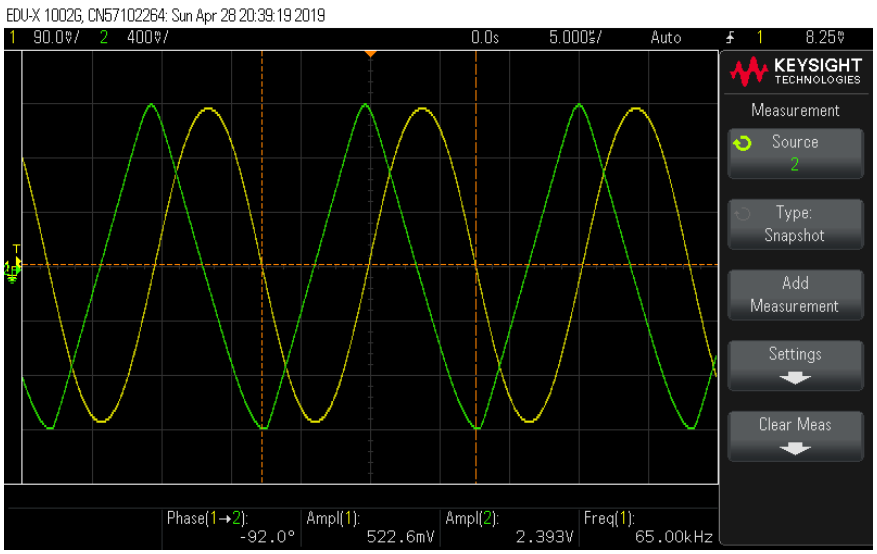
Teórico - simulação



Prático - simulação

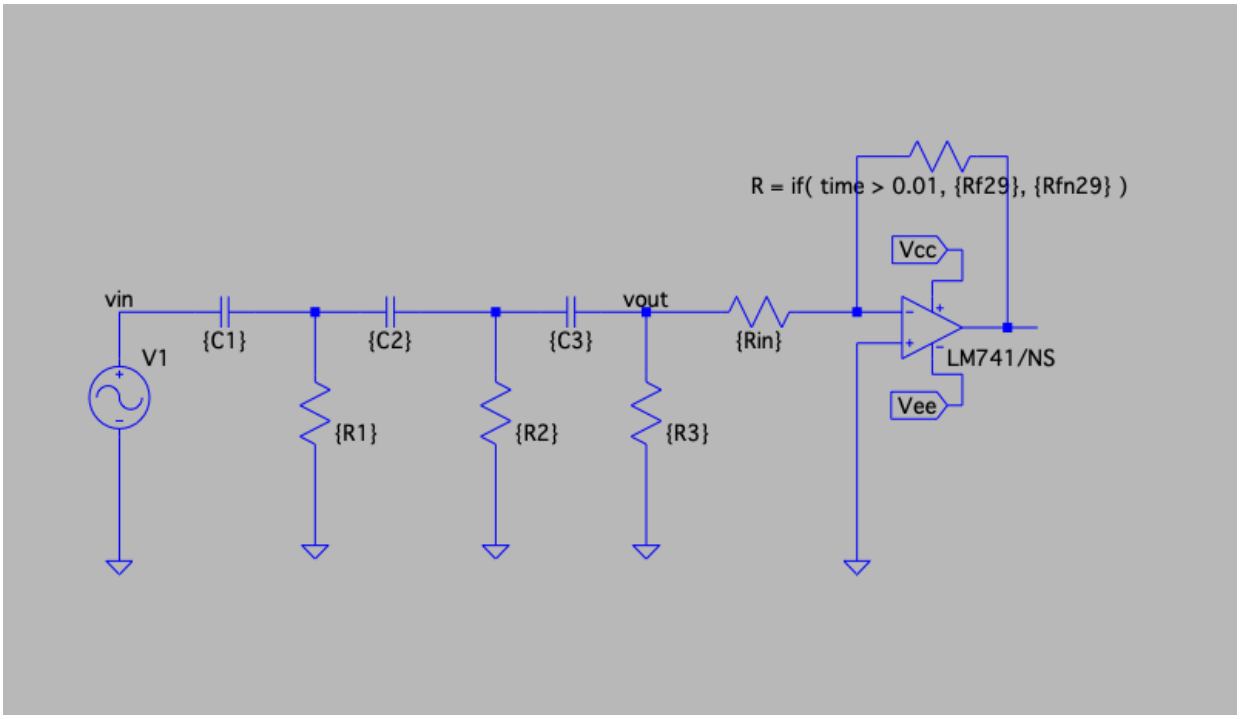


Prático



65kHz

Topologia aberta: Debug B



Indice:

Diretivas spice - com carga

Teórico

```
.meas tran time_period trig V(vout)=0 rise=1 targ V(vout)=0 rise=2
.meas frequency param 1/time_period
.meas tran time_delay trig V(vin)=0 rise=1 targ V(vout)=0 rise=1
.meas phase param 360*(time_delay / time_period)
.meas TRAN vout_meas FIND V(vout) WHEN V(vin)=10
.meas gain param 10/vout_meas
.meas max_vin max V(vin)
.meas min_vin min V(vin)
.meas max_vout max V(vout)
.meas min_vout min V(vout)

.lib ../../../../libs/LM741.lib
.param Rin=1k C=3.3n R=302.9
.param Rf29=60k Rfn29=200k

.tran 0 {0.1+2/65000} 0.1
 tstep tstop tstart
```

Prático

```
.meas tran time_period trig V(vout)=0 rise=1 targ V(vout)=0 rise=2
.meas frequency param 1/time_period
.meas tran time_delay trig V(vin)=0 rise=1 targ V(vout)=0 rise=1
.meas phase param 360*(time_delay / time_period)
.meas TRAN vout_meas FIND V(vout) WHEN V(vin)=10
.meas gain param 10/vout_meas
.meas max_vin max V(vin)
.meas min_vin min V(vin)
.meas max_vout max V(vout)
.meas min_vout min V(vout)

.lib ../../../../libs/LM741.lib
.param Rf29={29.4k + 30k} Rfn29=150k
.param Rin=993
.param C1=3.153n C2=3.174n C3=3.2n
.param R1=330 R2=327 R3=329

.tran 0 {0.1+2/65000} 0.1
 tstep tstop tstart
```

Medições - com carga

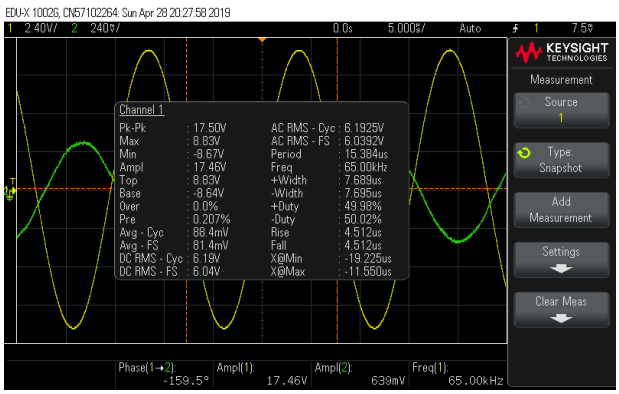
Teórico - simulação

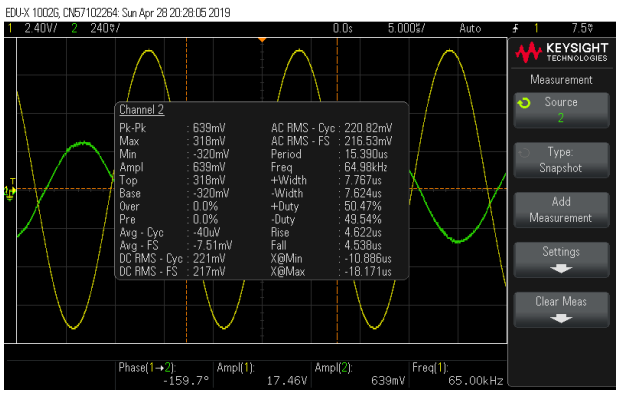
```
Direct Newton iteration for .op point succeeded.
Heightened Def Con from 0.01 to 0.01

time_period=1.53835e-05 FROM 7.65998e-06 TO 2.30435e-05
frequency: 1/time_period=65004.7
time_delay=7.65998e-06 FROM 3.89828e-18 TO 7.65998e-06
phase: 360*(time_delay / time_period)=179.257
vout_meas: v(vout)=-0.346878 at 2.88387e-06
gain: 10/vout_meas=-28.8286
max_vin: MAX(v(vin))=10.8253 FROM 0 TO 3.07692e-05
min_vin: MIN(v(vin))=-10.8254 FROM 0 TO 3.07692e-05
max_vout: MAX(v(vout))=0.373447 FROM 0 TO 3.07692e-05
min_vout: MIN(v(vout))=-0.373504 FROM 0 TO 3.07692e-05


Date: Thu May  2 07:18:29 2019
Total elapsed time: 13.822 seconds.

tnom = 27
temp = 27
method = Gear
totiter = 1156528
traniter = 1156517
tranpoints = 506736
accept = 348980
rejected = 157757
matrix size = 41
fillins = 29
solver = Alternate
Matrix Compiler1: 4024 object code size  1.1/0.9/[0.7]
Matrix Compiler2: off
```

Prático - simulação

```
Direct Newton iteration for .op point succeeded.
Heightened Def Con from 0.01 to 0.01

time_period=1.53839e-05 FROM 7.77069e-06 TO 2.31545e-05
frequency: 1/time_period=65003.2
time_delay=7.77069e-06 FROM 3.8983e-18 TO 7.77069e-06
phase: 360*(time_delay / time_period)=181.843
vout_meas: v(vout)=-0.371108 at 2.88407e-06
gain: 10/vout_meas=-26.9463
max_vin: MAX(v(vin))=10.8232 FROM 0 TO 3.07692e-05
min_vin: MIN(v(vin))=-10.8233 FROM 0 TO 3.07692e-05
max_vout: MAX(v(vout))=0.407195 FROM 0 TO 3.07692e-05
min_vout: MIN(v(vout))=-0.407591 FROM 0 TO 3.07692e-05


Date: Thu May  2 07:51:55 2019
Total elapsed time: 14.668 seconds.

tnom = 27
temp = 27
method = Gear
totiter = 1209309
traniter = 1209298
tranpoints = 533374
accept = 364342
rejected = 169033
matrix size = 41
fillins = 29
solver = Alternate
Matrix Compiler1: 4024 object code size  1.2/0.9/[0.5]
Matrix Compiler2: off
```

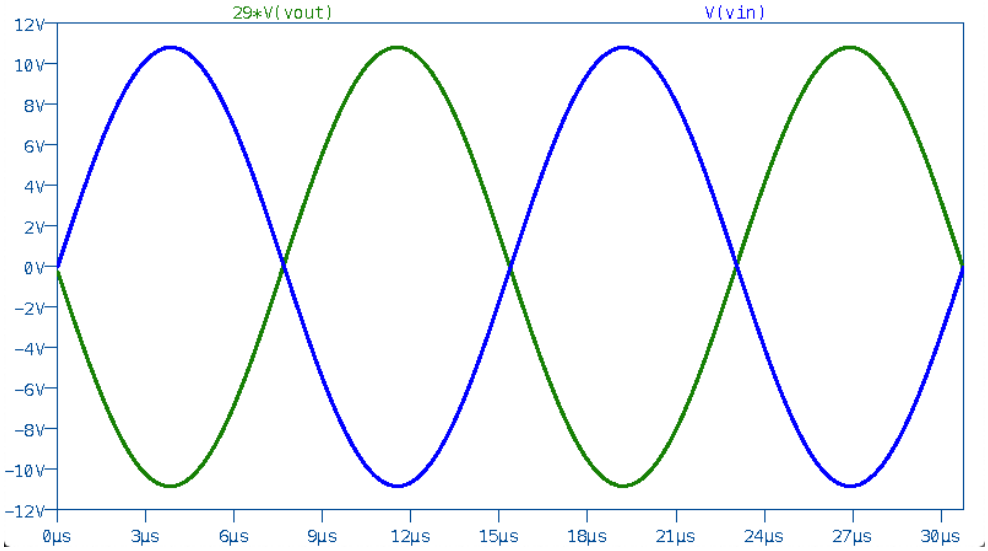
Prático



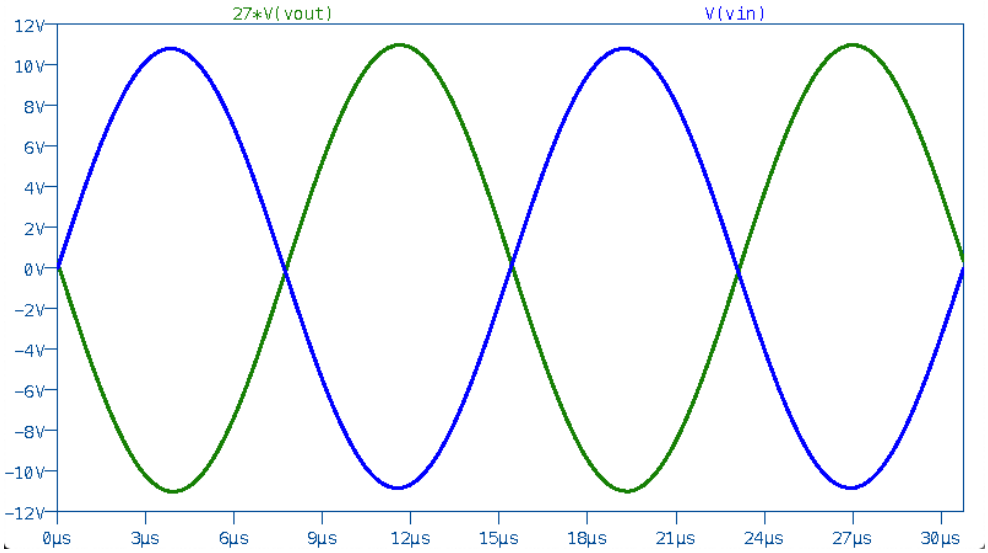


Formas de onda - com carga

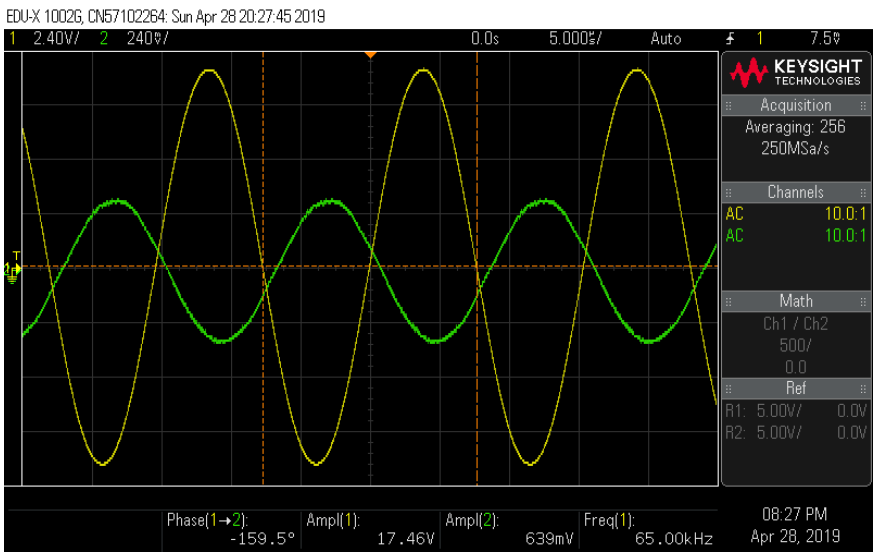
Teórico - simulação



Prático - simulação



Prático



Medições - sem carga

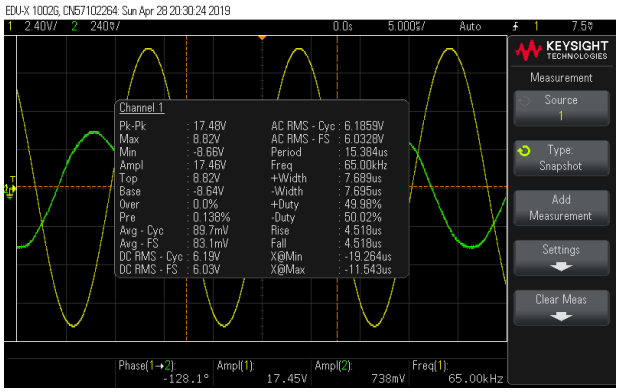
Teórico - simulação

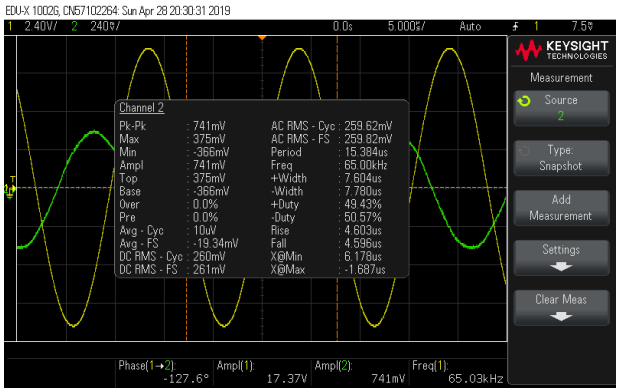
```
Circuit: * /Users/Igor/eln3-osc/invFase/simulation/65khz/theorical/debugB_theorical.asc

WARNING: Less than two connections to node VEE.  This node is used by V2.
WARNING: Less than two connections to node VCC.  This node is used by V3.
Direct Newton iteration for .op point succeeded.

time_period=1.5383e-05 FROM 7.69604e-06 TO 2.30791e-05
frequency: 1/time_period=65006.8
time_delay=7.69604e-06 FROM 3.89883e-18 TO 7.69604e-06
phase: 360*(time_delay / time_period)=180.106
vout_meas: v(vout)=-0.347163 at 2.88392e-06
gain: 10/vout_meas=-28.8049
max_vin: MAX(v(vin))=10.8251 FROM 0 TO 3.07692e-05
min_vin: MIN(v(vin))=-10.8278 FROM 0 TO 3.07692e-05
max_vout: MAX(v(vout))=0.373913 FROM 0 TO 3.07692e-05
min_vout: MIN(v(vout))=-0.37506 FROM 0 TO 3.07692e-05


Date: Thu May  2 07:21:20 2019
Total elapsed time: 1.203 seconds.

tnom = 27
temp = 27
method = Gear
totiter = 624545
traniter = 624542
tranpoints = 312272
accept = 195274
rejected = 116998
matrix size = 9
fillins = 0
solver = Alternate
```

Prático - simulação

```
Circuit: * /Users/Igor/eln3-osc/invFase/simulation/65khz/practical/debugB_practical.asc

WARNING: Less than two connections to node VEE.  This node is used by V2.
WARNING: Less than two connections to node VCC.  This node is used by V3.
Direct Newton iteration for .op point succeeded.

time_period=1.53829e-05 FROM 7.80744e-06 TO 2.31903e-05
frequency: 1/time_period=65007.2
time_delay=7.80744e-06 FROM 3.89881e-18 TO 7.80744e-06
phase: 360*(time_delay / time_period)=182.714
vout_meas: v(vout)=-0.371226 at 2.88969e-06
gain: 10/vout_meas=-26.9378
max_vin: MAX(v(vin))=10.8252 FROM 0 TO 3.07692e-05
min_vin: MIN(v(vin))=-10.8277 FROM 0 TO 3.07692e-05
max_vout: MAX(v(vout))=0.407971 FROM 0 TO 3.07692e-05
min_vout: MIN(v(vout))=-0.409104 FROM 0 TO 3.07692e-05


Date: Thu May  2 07:53:18 2019
Total elapsed time: 1.184 seconds.

tnom = 27
temp = 27
method = Gear
totiter = 598547
traniter = 598544
tranpoints = 299273
accept = 195274
rejected = 103999
matrix size = 9
fillins = 0
solver = Alternate
```

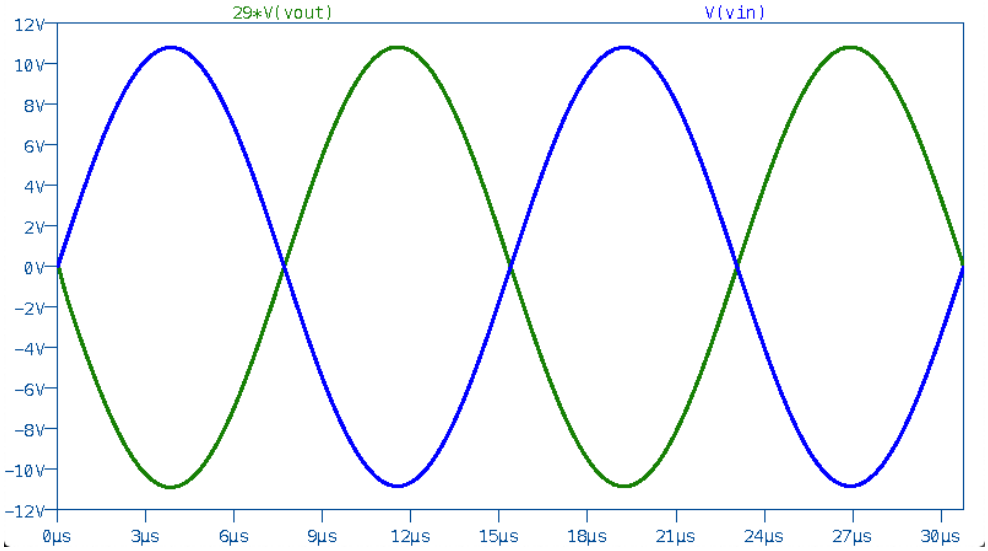
Prático



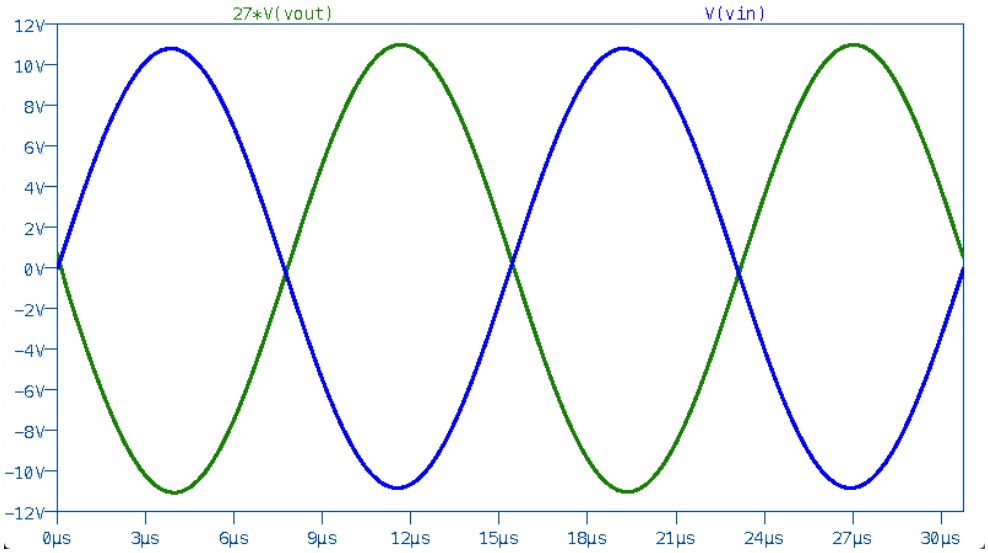


Formas de onda - sem carga

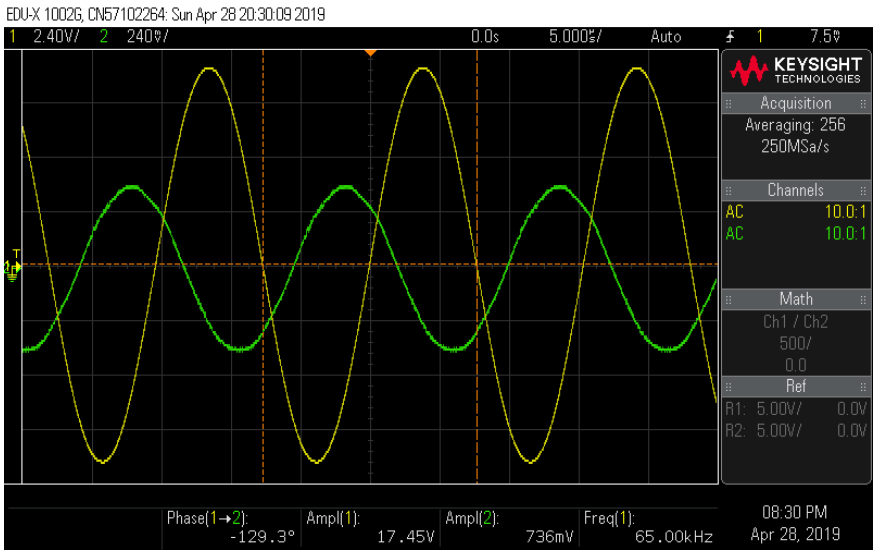
Teórico - simulação



Prático - simulação



Prático



Considerações

A impedância de entrada/saída do bloco amplificador pode ser facilmente manipulada, vez que depende fortemente de Rin e Rf.

No projeto a escolha de 1k e 30k se deve ao fato do simulador de circuitos trabalhar melhor com esses valores, mas se fossem escolhidos valores como 10k e 290k ou 100k e 2,9Meg uma frequencia de oscilação mais próxima a da projetada seria encontrada.

Assim sendo, numa implementação prática onde se desejasse obter um resultado melhor esse seria o primeiro ponto de melhoria

Um outro ponto de melhoria seria a construção desse circuito em uma placa de circuito impresso dedicada, eliminando assim o fator Protoboard que no circuito de 4.5kHz já começa a pesar.