(a) Passband: $f_c = 20MHz$ $R_p < 0.2dB$
Stopband: $f_s = 35MHz$ $R_s < 65dB$

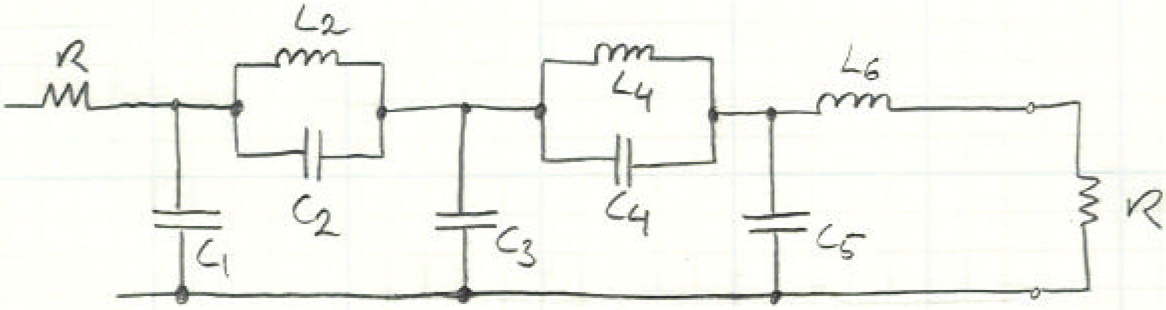
Using Matlab "ellipord":

$\boxed{N = 6}$ $\omega_n = 2\pi \cdot 20 \, Mrad/s$

(b) Reflection coeff: $\rho = \sqrt{1 - 10^{-0.1 R_p}} = 21.2\%$
$\cong \underline{\underline{20\%}}$

Steepness Factor: $\Omega_s = \frac{f_s}{f_c} = 1.75$

Prototype: Williams p. 11.87



$\Omega_s = 1.756$, $A_{min} = 67.8dB \overset{\checkmark}{>} 65dB$

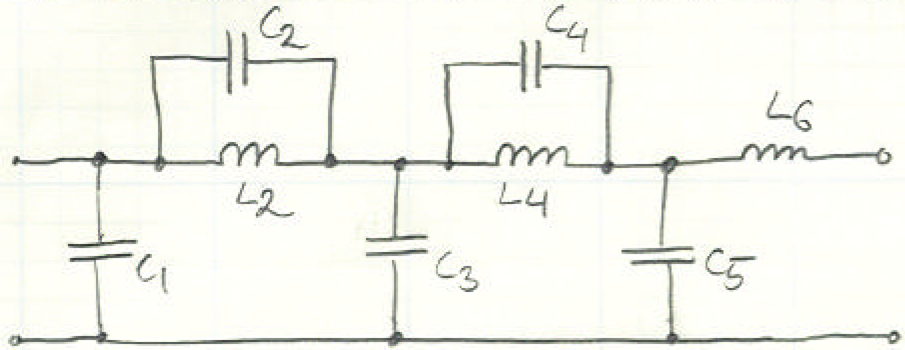
$\Rightarrow$ $C_1 = 1.040$ $C_4 = 0.2063$
$C_2 = 0.1206$ $L_4 = 1.477$
$L_2 = 1.369$ $C_5 = 1.374$
$C_3 = 1.585$ $L_6 = 1.153$

Using Matlab:

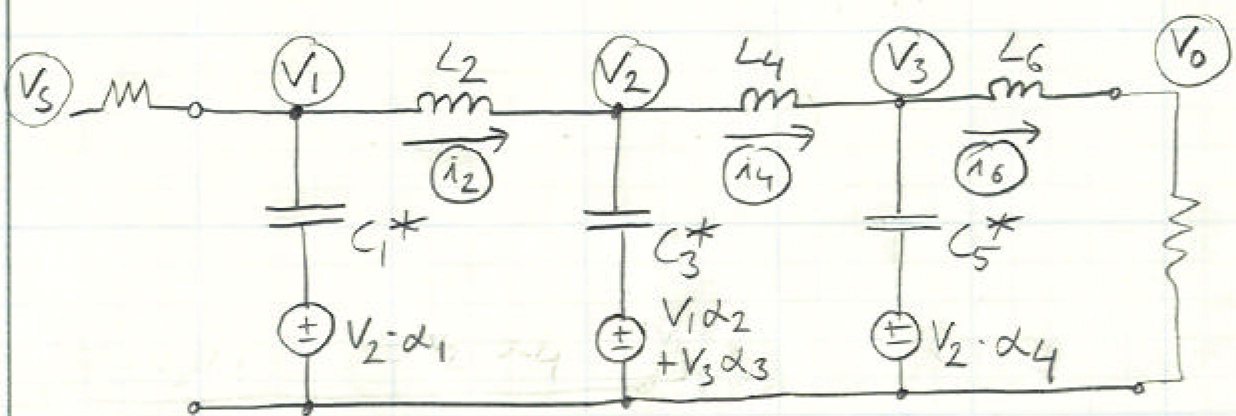
Iterate R until denormaliztion yields reasonable capacitor values:

```
R = 10000

using:
-------
Lr=R/Wn
Cr=1/(R*Wn)
C1=C1n*Cr
C2=C2n*Cr
C3=C3n*Cr
C4=C4n*Cr
C5=C5n*Cr
L3=L3n*Lr
L4=L4n*Lr
L6=L6n*Lr

Lr = 7.9577e-005
Cr = 7.9577e-013

denormalized component values:
------------------------------

C1 = 8.2761e-013
C2 = 9.5970e-014
C3 = 1.2613e-012
C4 = 1.6417e-013
C5 = 1.0934e-012

L3 = 1.0894e-004
L4 = 1.1754e-004
L6 = 9.1753e-005
```

(c)



⇓ EQUIVALENT



$$\alpha_1 = \frac{C_2}{C_1 + C_2}$$

$$C_1^* = C_1 + C_2$$

$$\alpha_2 = \frac{C_2}{C_3^*} \qquad C_3^* = C_2 + C_3 + C_4$$

$$\alpha_3 = \frac{C_4}{C_3^*}$$

$$\alpha_4 = \frac{C_4}{C_4 + C_5}$$

$$C_5^* = C_4 + C_5$$

c)

$$V_1 = \frac{1}{sC_1^*}\left[\frac{V_s - V_1}{R} - I_2\right] + \alpha_1 V_2 \qquad (1)$$

$$I_2 = \frac{1}{sL_2}\left[V_1 - V_2\right]$$

$$V_{I2} = I_2 \cdot R^* = \frac{R^{*2}}{sL_2}\left[\frac{V_1}{R_*} - \frac{V_2}{R^*}\right] \qquad (2)$$

$$V_2 = \frac{1}{sC_3^*}\left[I_2 - I_4\right] + \alpha_2 V_1 + \alpha_3 V_3 \qquad (3)$$

$$I_4 = \frac{1}{sL_4}\left[V_2 - V_3\right]$$

$$V_{I4} = I_4 \cdot R^* = \frac{R^{*2}}{sL_4}\left[\frac{V_2}{R^*} - \frac{V_3}{R^*}\right] \qquad (4)$$

$$V_3 = \frac{1}{sC_5^*}\left[I_4 - I_6\right] + \alpha_4 V_2 \qquad (5)$$

$$I_6 = \frac{1}{sL_6}\left[V_3 - V_0\right]$$

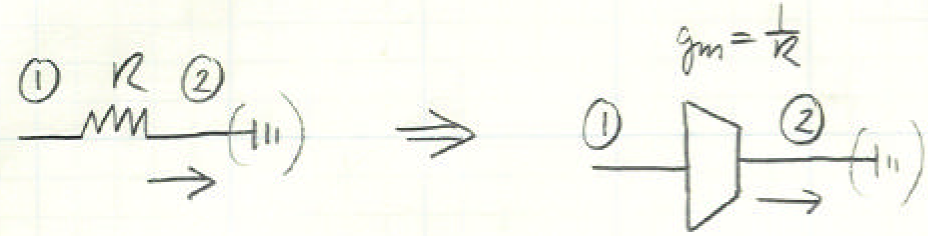
$$V_{I6} = I_6 \cdot R^* = \frac{R^{*2}}{sL_6}\left[\frac{V_3}{R^*} - \frac{V_0}{R^*}\right] \qquad (6)$$

with: $I_2 = \frac{V_{I2}}{R^*}$ $\qquad V_0 = I_6 \cdot R$

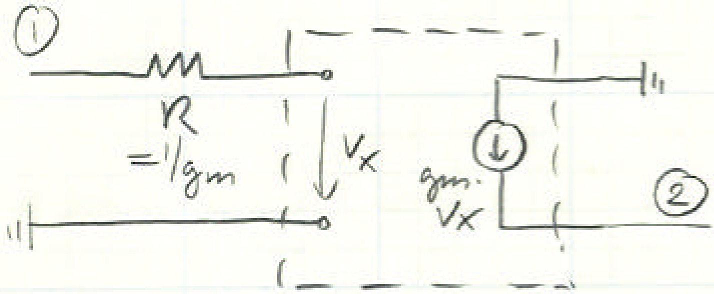
$I_4 = \frac{V_{I4}}{R^*}$ $\qquad = V_{I6}\frac{R}{R^*}$

$I_6 = \frac{V_{I6}}{R^*}$

(c)



noise modelling:



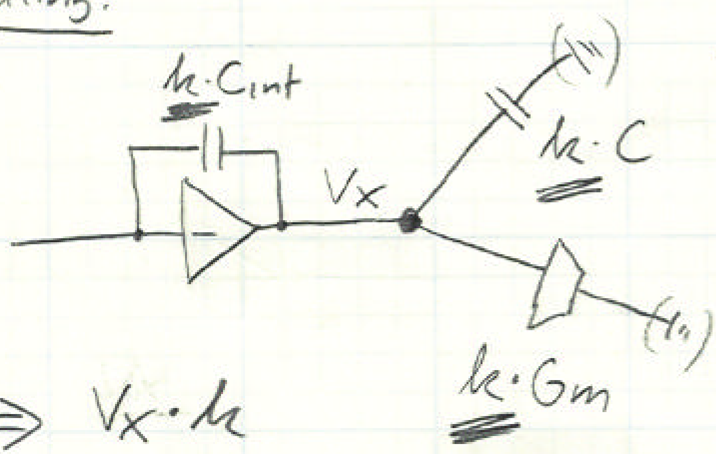
SPICE G-Element

→ See attached schematic

$G_m = \frac{1}{R}$

$G_m^* = \frac{1}{R^*}$

(d) gain scaling:



⇒ $V_x \cdot k$

scaling

→ peak gain of unity from each integrator

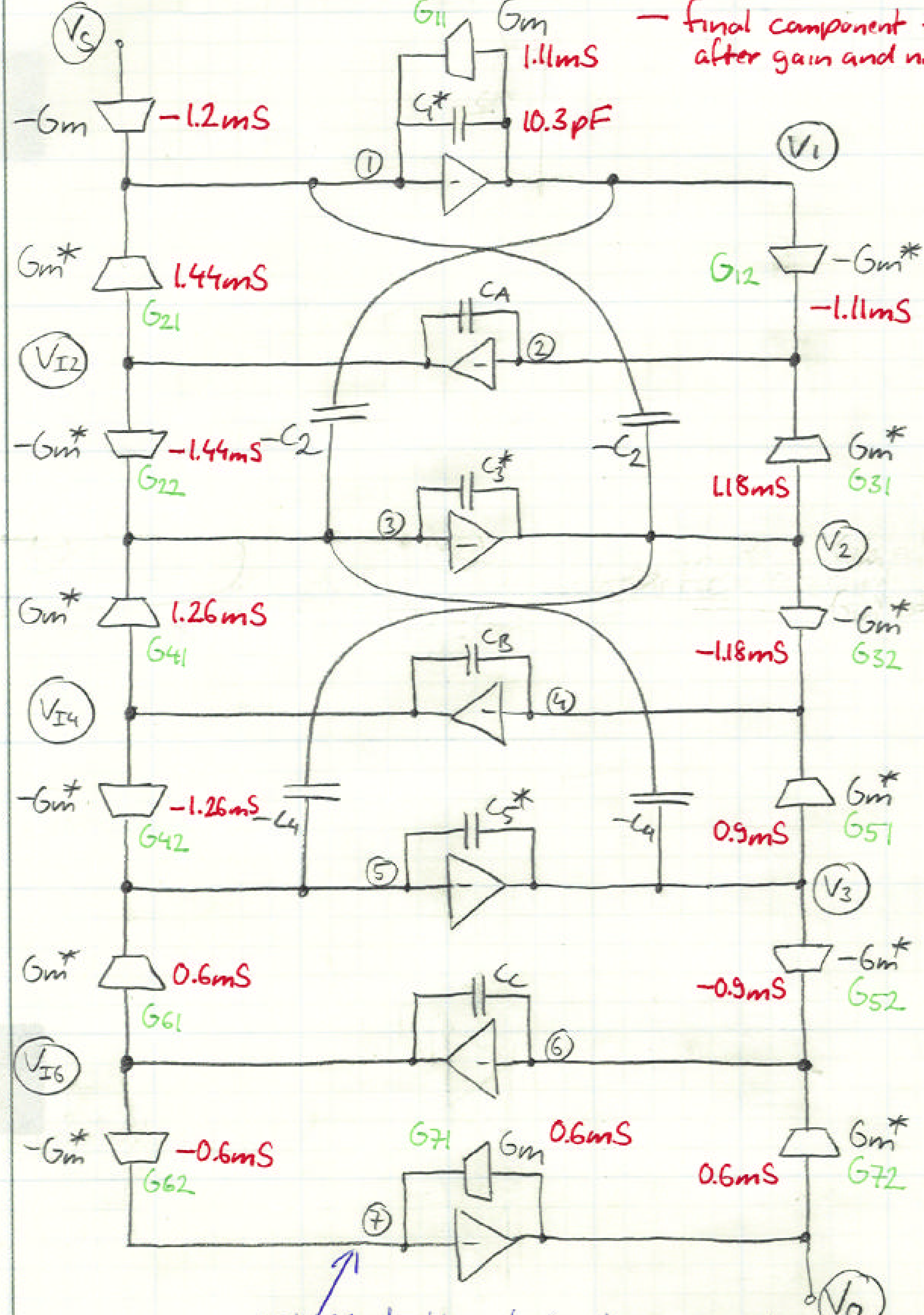
→ See attached Plot ①

Gm-C Implementation

$G_m = \frac{1}{R}$

$G_m^* = \frac{1}{R^*}$

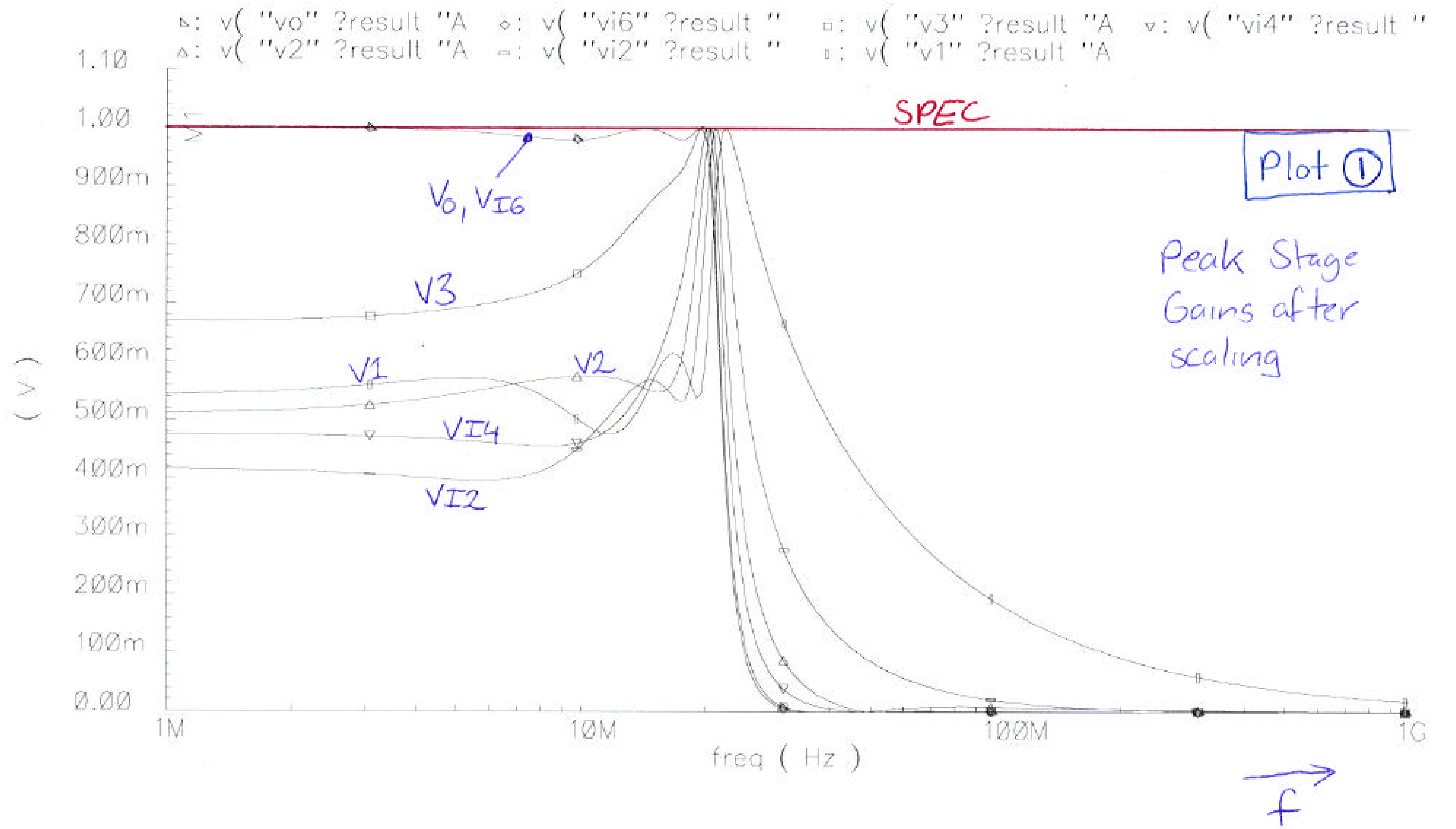
— final component values after gain and noise scaling



Note that this last stage can be eliminated! ⇒ finite broadband noise

Component values for active circuit:

```
-----------------------------------

using     R* = 10k      and noise multiplier     knoise = 12.04


Gm  = 1.204000000000000e-003
G1  = 1.112579160000000e-003
G2 =  1.442499820000000e-003
G3 =  1.180008200000000e-003
G4 =  1.264294500000000e-003
G5 =  9.018634100000001e-004
G6 =  6.020450000000001e-004
G7 =  6.020450000000001e-004

Cint1 = 1.027551560209852e-011
Cint2 = 1.571481785937049e-011
Cint3 = 1.795313656436392e-011
Cint4 = 1.486000241283849e-011
Cint5 = 1.134149859621723e-011
Cint6 = 5.523932934198271e-012
```



▷: v("vo" ?result "A
◇: v("vi6" ?result "
□: v("v3" ?result "A
▽: v("vi4" ?result "
△: v("v2" ?result "A
▭: v("vi2" ?result "
▯: v("v1" ?result "A
1.10
1.00
900m
800m
700m
600m
500m
400m
300m
200m
100m
0.00
(V)
1M
10M
100M
1G
freq (Hz)
SPEC
Plot ①
Peak Stage Gains after scaling
V_0, V_{I6}
V3
V1
V2
VI4
VI2
f

(d) ctd:

Noise: $\sim\sqrt{\frac{kT}{C}}$

all C↑ to reduce noise,

all Gm↑ to keep same xfer function

before scaling $\sqrt{\int_0^{100meg} \overline{v_{on}^2}\, df} = 347\mu V_{rms}$

⇒ introduce noise scaling factor

$k_{noise} = (3.47)^2$ to get

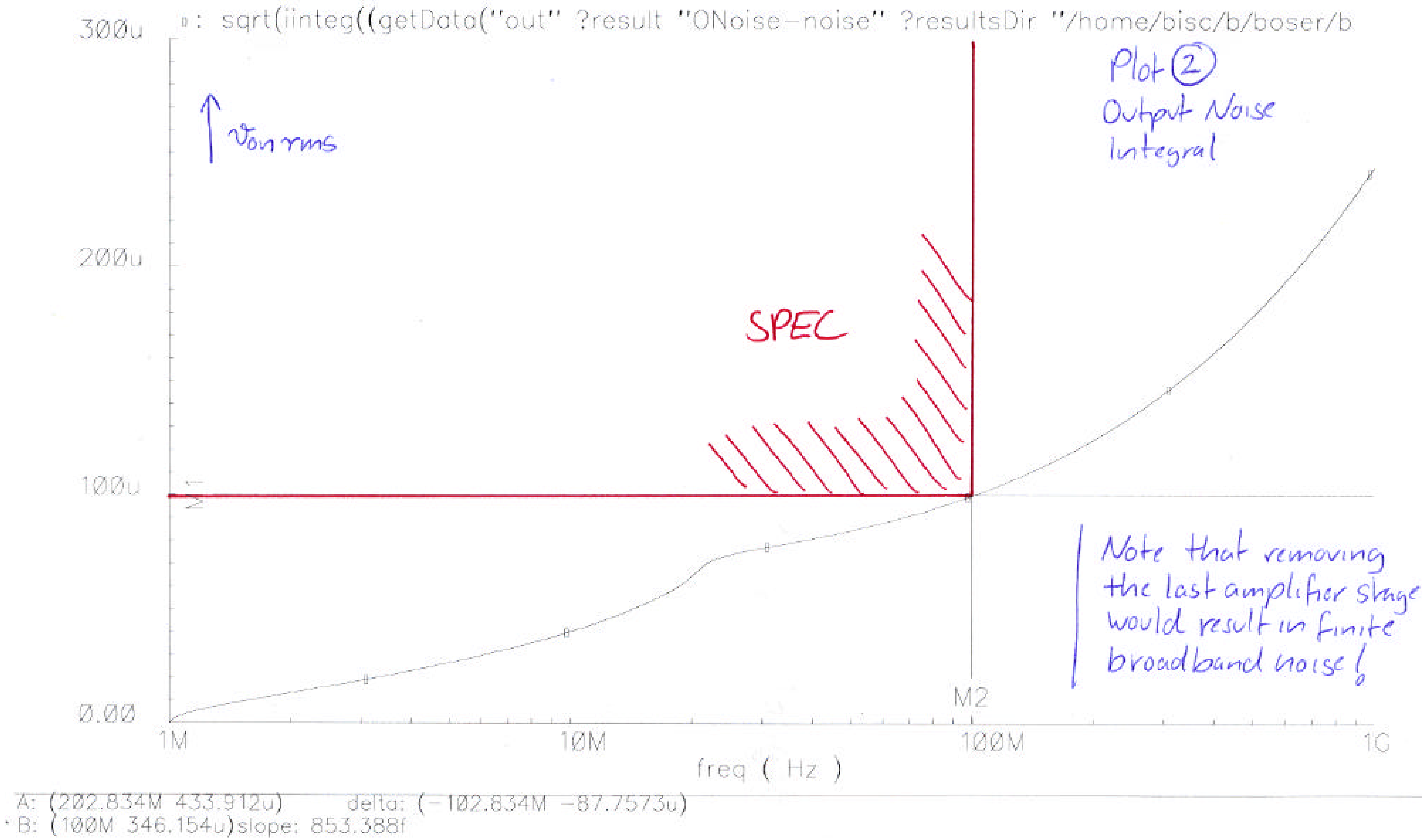
$\sqrt{\int \overline{v_{on}^2}\, df} \overset{!}{=} 100\mu V_{rms}$

→ Noise Integral Plot see attached (2)

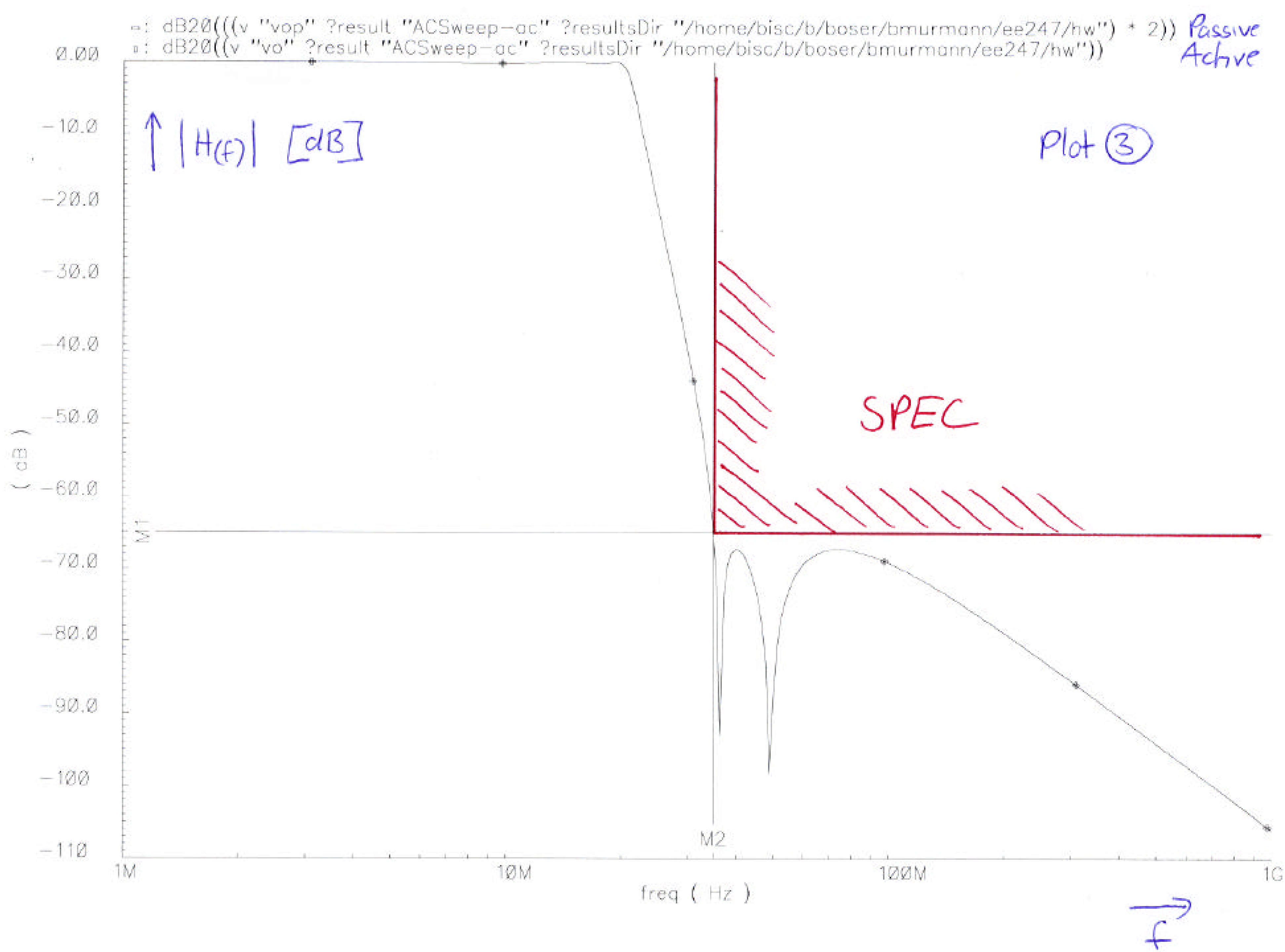
→ Frequency response see attached plots (3), (4)

⇒ exact match with ✓
2x transfer function of passive LC ckt.

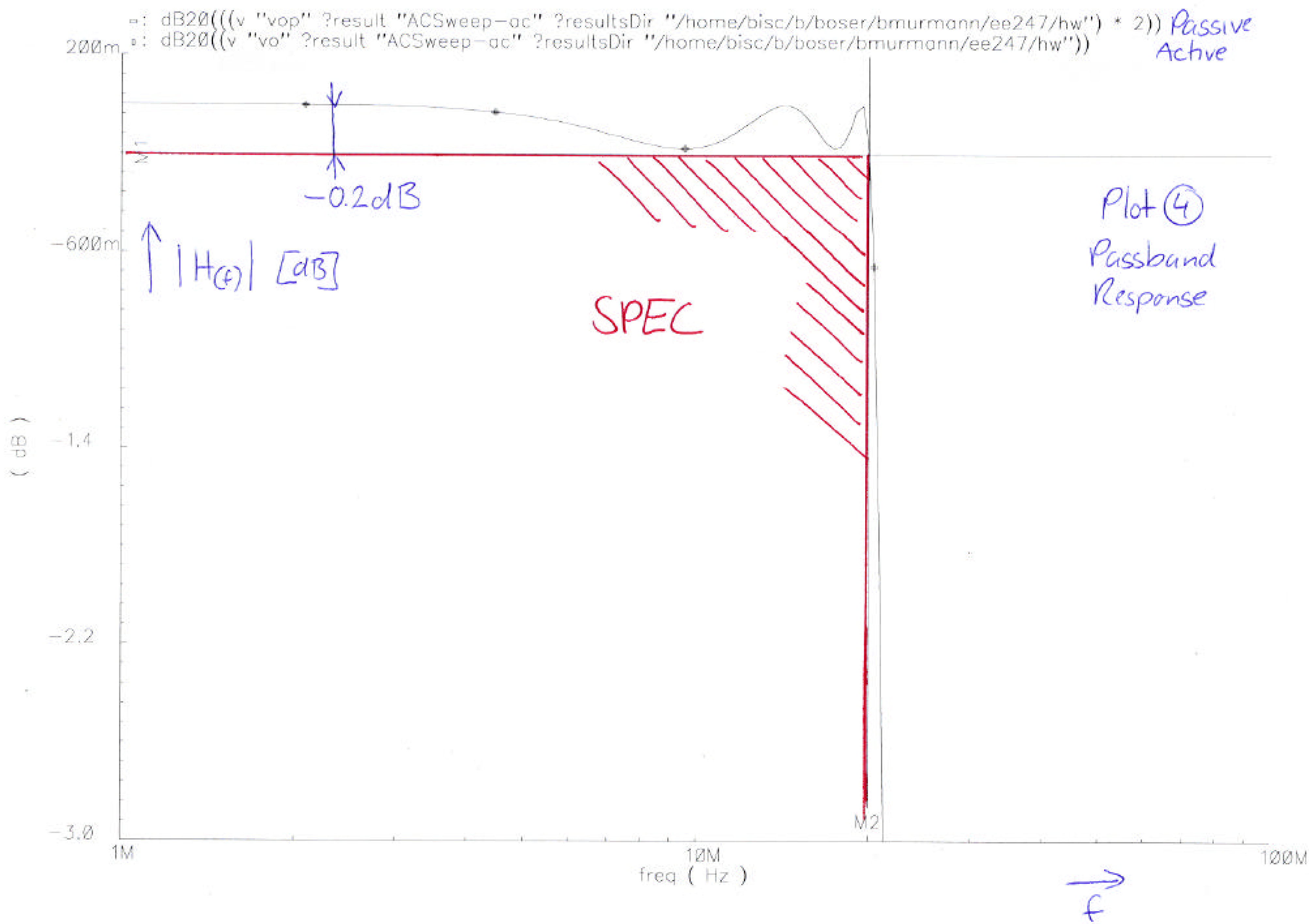
→ scaled component values see above schematic



▫: sqrt(iinteg((getData("out" ?result "ONoise-noise" ?resultsDir "/home/bisc/b/boser/b
300u
200u
100u
0.00
1M
10M
100M
1G
freq (Hz)
M1
M2
von rms
SPEC
Plot 2
Output Noise Integral
Note that removing the last amplifier stage would result in finite broadband noise!
A: (202.834M 433.912u) delta: (-102.834M -87.7573u)
B: (100M 346.154u)slope: 853.388f

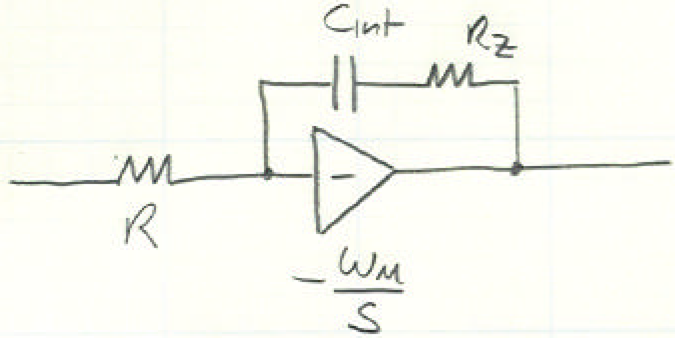


dB20(((v "vop" ?result "ACSweep-ac" ?resultsDir "/home/bisc/b/boser/bmurmann/ee247/hw") * 2)) Passive
dB20((v "vo" ?result "ACSweep-ac" ?resultsDir "/home/bisc/b/boser/bmurmann/ee247/hw")) Active
|H(f)| [dB]
Plot ③
SPEC
0.00
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
-90.0
-100
-110
(dB)
M1
M2
1M
10M
100M
1G
freq (Hz)
f



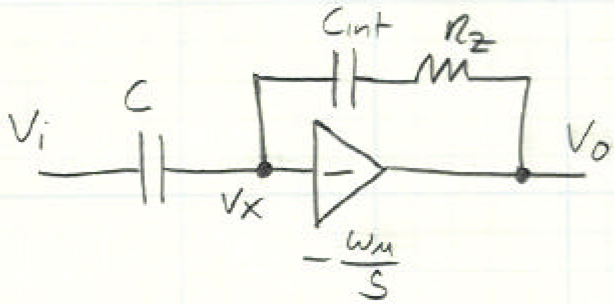
▫: dB20(((v "vop" ?result "ACSweep-ac" ?resultsDir "/home/bisc/b/boser/bmurmann/ee247/hw") * 2)) Passive
▫: dB20((v "vo" ?result "ACSweep-ac" ?resultsDir "/home/bisc/b/boser/bmurmann/ee247/hw")) Active
200m
-600m
-1.4
-2.2
-3.0
(dB)
M1
M2
-0.2dB
|H(f)| [dB]
SPEC
Plot (4)
Passband
Response
1M
10M
100M
freq (Hz)
f

(e)



$$\boxed{R_Z = \frac{1}{\omega_M C_{int}}}$$

cancels parasitic pole in the above ckt.



$\Rightarrow$ R_Z does **not** cancel f_{p2} for capacitive input branches!

$$0 = (V_i - V_x)sC + (V_o - V_x) \cdot \frac{1}{R_Z + \frac{1}{sC_{int}}}$$

$$V_x = -\frac{sV_o}{\omega_M}$$

$$0 = V_i sC + V_o \left(\frac{1 + \frac{s}{\omega_M}}{R_Z + \frac{1}{sC_{int}}} + \frac{s^2}{\omega_M} \right)$$

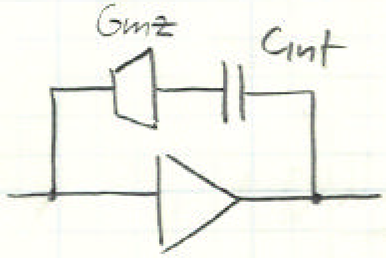
$$\frac{V_o}{V_i} = -\frac{sC}{\frac{1 + \frac{s}{\omega_M}}{R_Z + \frac{1}{sC_{int}}} + \frac{s^2}{\omega_M}}$$

$$\frac{V_o}{V_i} = - \frac{\frac{1}{sC_{int}}\left(1 + sC_{int}R_z\right)}{s^2 \frac{RC^2}{\omega_\mu} + \frac{s}{\omega_\mu} + \left(1 + \frac{C}{C_{int}}\right)}$$ //

⇒ not possible to cancel the two parasitic poles in $D(s)$

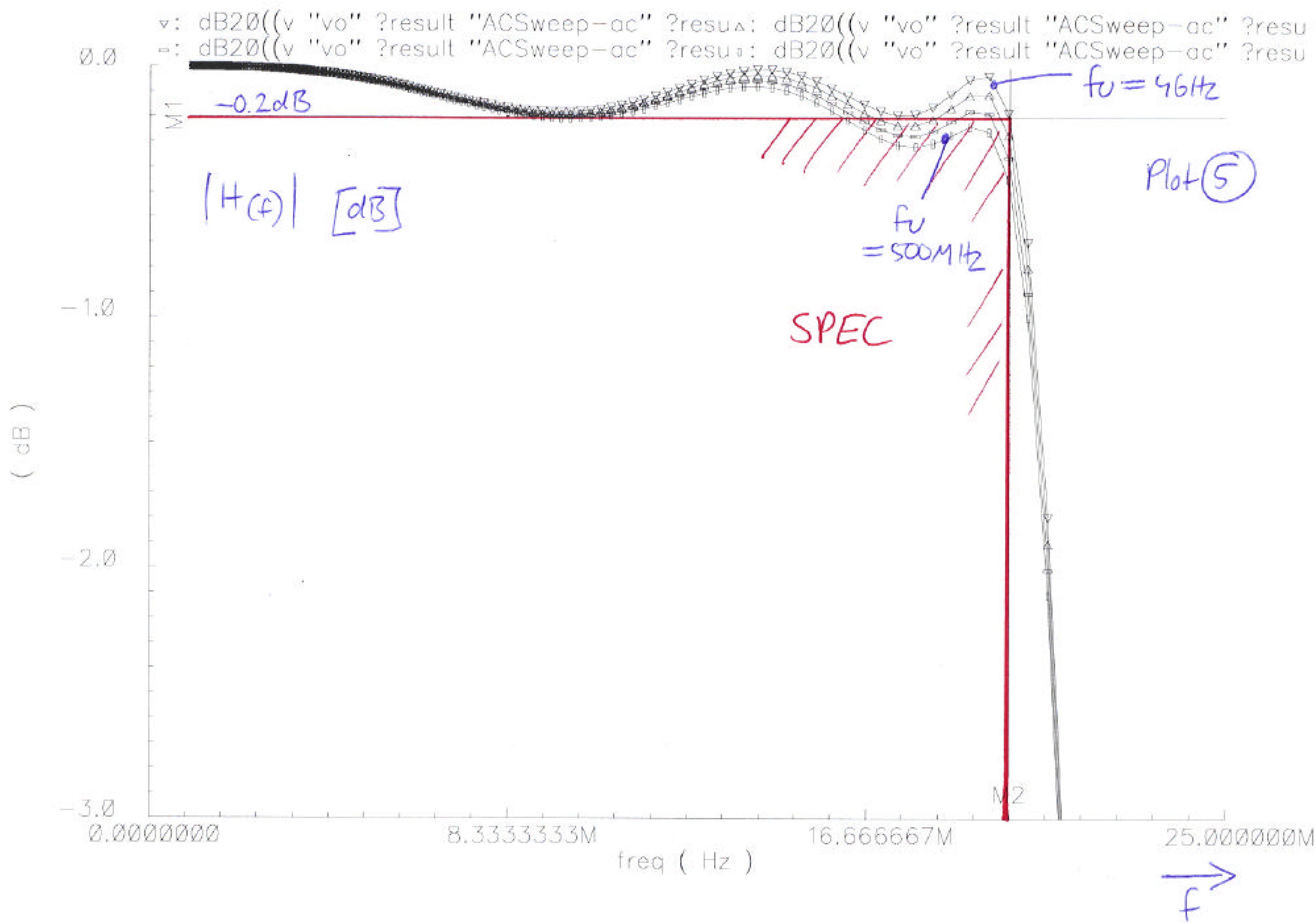
⇒ Can not cancel completely in stages 1,3,5

Cancel using:



$$G_{mz} = \frac{1}{R_z} = \omega_\mu \cdot C_{int}$$

Using Spice, found $f_U > 4\,GHz$ to meet Specs. → See plot ⑤ (Passband Ripple critical to meet w/ finite BW)



▽: dB20((v "vo" ?result "ACSweep-ac" ?resu △: dB20((v "vo" ?result "ACSweep-ac" ?resu
□: dB20((v "vo" ?result "ACSweep-ac" ?resu ◇: dB20((v "vo" ?result "ACSweep-ac" ?resu
0.0
-1.0
-2.0
-3.0
(dB)
M1
-0.2dB
|H(f)| [dB]
fu = 4GHz
Plot 5
fu = 500MHz
SPEC
M2
0.0000000
8.3333333M
16.666667M
25.000000M
freq (Hz)
f

```
* EE247 Homework#3 - Spectre Input - Boris Murmann

********** Circuit Desription *************
simulator lang=spectre
parameters
+ R  = 10k             //*** Passive Network Components
+ C1 = 8.2761e-013
+ C2 = 9.5970e-014
+ C3 = 1.2613e-012
+ C4 = 1.6417e-013
+ C5 = 1.0934e-012
+ L2 = 1.0894e-004
+ L4 = 1.1754e-004
+ L6 = 9.1753e-005
+ knoise=3.47**2       //*** Noise Scaling Factor
+ k1=0.924             //*** Stage Amplitude Scaling Factors
+ k2=1.198
+ k3=0.98
+ k4=1.05
+ k5=0.749
+ k6=0.5
+ k7=0.5
+ Rx =  10k            //*** Active Network Components
+ Gm =  knoise*1/R
+ Gmx = knoise*1/Rx
+ C1x = knoise*(C1+C2)
+ C2x = knoise*C2
+ Ca =  knoise*L2/Rx**2
+ C3x = knoise*(C2+C3+C4)
+ C4x = knoise*C4
+ Cb =  knoise*L4/Rx**2
+ C5x = knoise*(C4+C5)
+ Cc =  knoise*L6/Rx**2
+ G11 = k1*Gm
+ G12 = k1*Gmx
+ G2 =  k2*Gmx
+ G3 =  k3*Gmx
+ G4 =  k4*Gmx
+ G5 =  k5*Gmx
+ G6 =  k6*Gmx
+ G7 =  k7*Gmx
+ wu =  6.28*4Gig   //*** Amplifier Unity Gain Frequency

*** Passive Ladder
Rs        (vs n1)       resistor  r=R
C_1       (n1  0)       capacitor c=C1
L_2       (n1 n2)       inductor  l=L2
C_2       (n1 n2)       capacitor c=C2
C_3       (n2  0)       capacitor c=C3
L_4       (n2 n3)       inductor  l=L4
C_4       (n2 n3)       capacitor c=C4
C_5       (n3  0)       capacitor c=C5
L_6       (n3 vop)      inductor  l=L6
Ro        (vop 0)       resistor  r=R

*** Active Network
v_s       (vs  0)       vsource   type=sine ampl=1 freq=1Meg mag=1
gin       (vs  1)       xcon      g=-Gm
```

```
****
int1      (1  v1)        integz     Cint=k1*C1x wux=wu
g11       (v1  1)        xcon       g=G11
g21       (vi2 1)        xcon       g=G2
c21       (1  v2)        capacitor c=-k3*C2x
c22       (3  v1)        capacitor c=-k1*C2x
****
int2      (2 vi2)        integz     Cint=k2*Ca wux=wu
g12       (v1  2)        xcon       g=-G12
g31       (v2  2)        xcon       g=G3
****
int3      (3  v2)        integz     Cint=k3*C3x wux=wu
g22       (vi2 3)        xcon       g=-G2
g41       (vi4 3)        xcon       g=G4
c41       (5  v2)        capacitor c=-k3*C4x
c42       (3  v3)        capacitor c=-k5*C4x
****
int4      (4 vi4)        integz     Cint=k4*Cb wux=wu
g32       (v2  4)        xcon       g=-G3
g51       (v3  4)        xcon       g=G5
****
int5      (5  v3)        integz     Cint=k5*C5x wux=wu
g42       (vi4 5)        xcon       g=-G4
g61       (vi6 5)        xcon       g=G6
****
int6      (6 vi6)        integz     Cint=k6*Cc wux=wu
g52       (v3  6)        xcon       g=-G5
g72       (vo  6)        xcon       g=G7
****
amp7      (vo 0 7 0)     vcvs       gain=-1e6
g62       (vi6 7)        xcon       g=-G6
g71       (vo  7)        xcon       g=G7

subckt integz (vi vo)
  parameters Cint wux
  c1 (vo n1)      capacitor  c=Cint
  Rz (n1 vi)      resistor   r=1/(wux*Cint)
  k1 (vo 0 vi 0) svcvs gain=-1 numer=[wux] denom=[0 1]
ends integz
subckt xcon  (vi io)
  parameters g
  rn (vi vix)     resistor r=1/g
  k1 (0 io vix 0) vccs gm=g
ends xcon

********** Control Statements *************
SimOptions options
+        rawfmt=   psfbin
+        gmin=     1E-12
+        reltol=   1E-03
+        vabstol=  1E-06
+        iabstol=  1E-12
+        temp=     27
**+        currents= all

ACSweep    ac       start=1Meg stop=1Gig dec=100
ONoise     (vo 0)  noise start=1Meg stop=1Gig dec=100
```