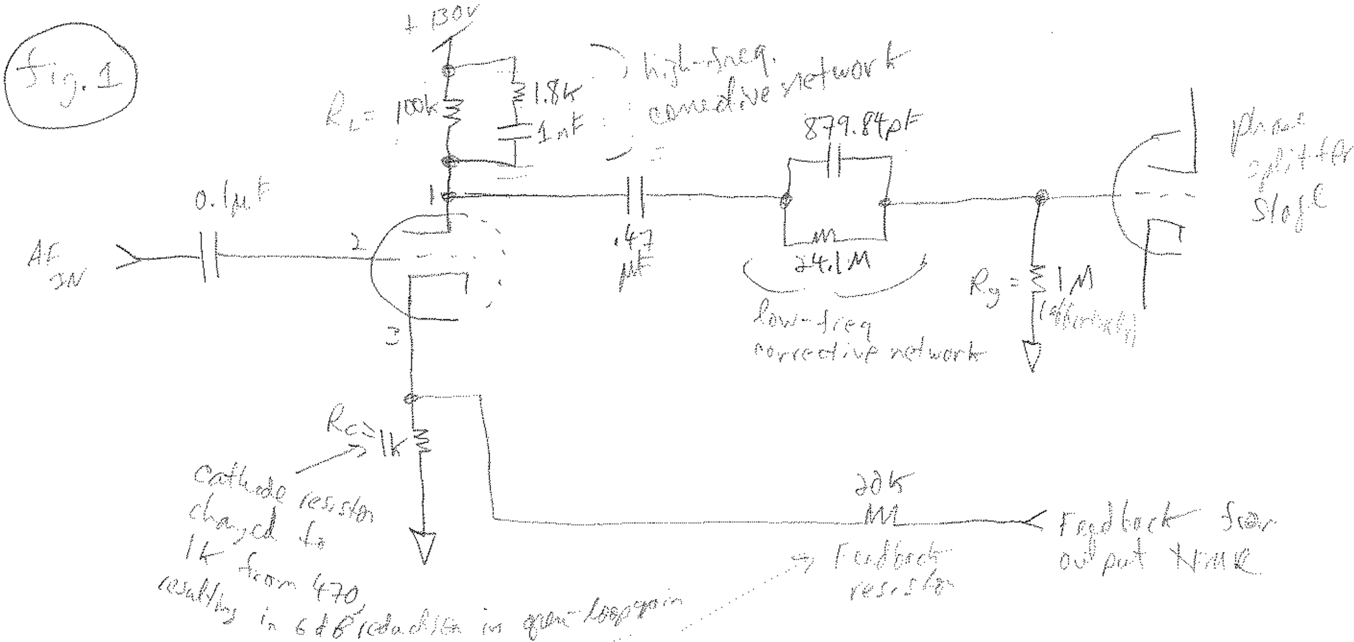
Corrective Networks 4/4/09

- applied to the first stage
- also, increase the cathode resistor on 1st stage to 1k, because the open-loop gain at mid-freq is way too high! (45dB >)
  - this will drop it by 6dB

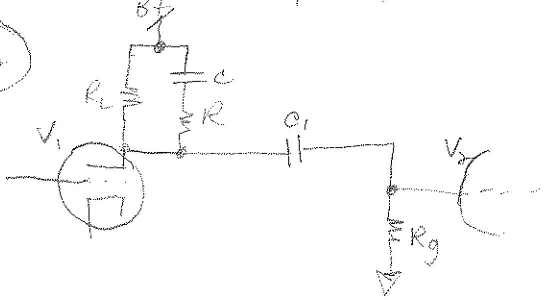
fig. 1



- also, increase the feedback resistor to 10k, we have lots of freq BW and FWD gain might as well use it so that the PA can output max power

- let's check the math
- according to Radio Designer's Handbook, 4th ed by F. Langford-Smith, p. 371, fig 7.59A,B
  - for a high frequency corrective network:

fig. 2



- the ultimate attenuation of the stage in dB is given by:

$$\text{attn} \simeq 20\log\left(\frac{R_1 + R}{R}\right) \quad ①$$

- when R_1 is given by:

$$R_1 = \frac{R_L R_g}{R_L + R_g} \quad ②$$

- the cut-off freq: $f_1 = \dfrac{1}{2\pi R_1 C}$ ③

- the flattening-out freq: $f_2 \approx \dfrac{1}{2\pi RC}$ ④

continued on p. 2

$V_{in} = 100mV$ (p-p)

f(Hz)	Vout (p-p)	Phase (deg)
1		
2		
3	0.574	27
4	1.08	216
5	1.69	144
6	2.36	172.8
7	3.12	191.52
8	3.96	144
9	4.72	142.56
10	5.55	129.6
20	11.7	79.2
30	15.2	64.8
40	17.10	51.84
50	18.20	36
60	18.35	32.40
70	18.90	32.76
80	19.25	25.92
90	19.4	25.9
100	19.4	18
200	20.2	14.4
300	20.2	8.64
400	20.2	0
500	20.2	0
600	20.2	0
700	20.2	0
800	20.2	0
900	20.20	0
1000	20.15	0
2000	"	"
3000	"	"
4000	20.7	"
5000	"	18
6000	"	21.6
7000	"	25.2
8000	"	23.04
9000	21.35	19.44
10000	21.75	18
20k	20.95	43.2
30k	14.75	25.6
40k	11.6	57.6
50k	14.25	81
60k	12.5	86.4
70k	9.95	100.8
80k	8	115.2
90k	6.85	243
100k	5.85	117.4

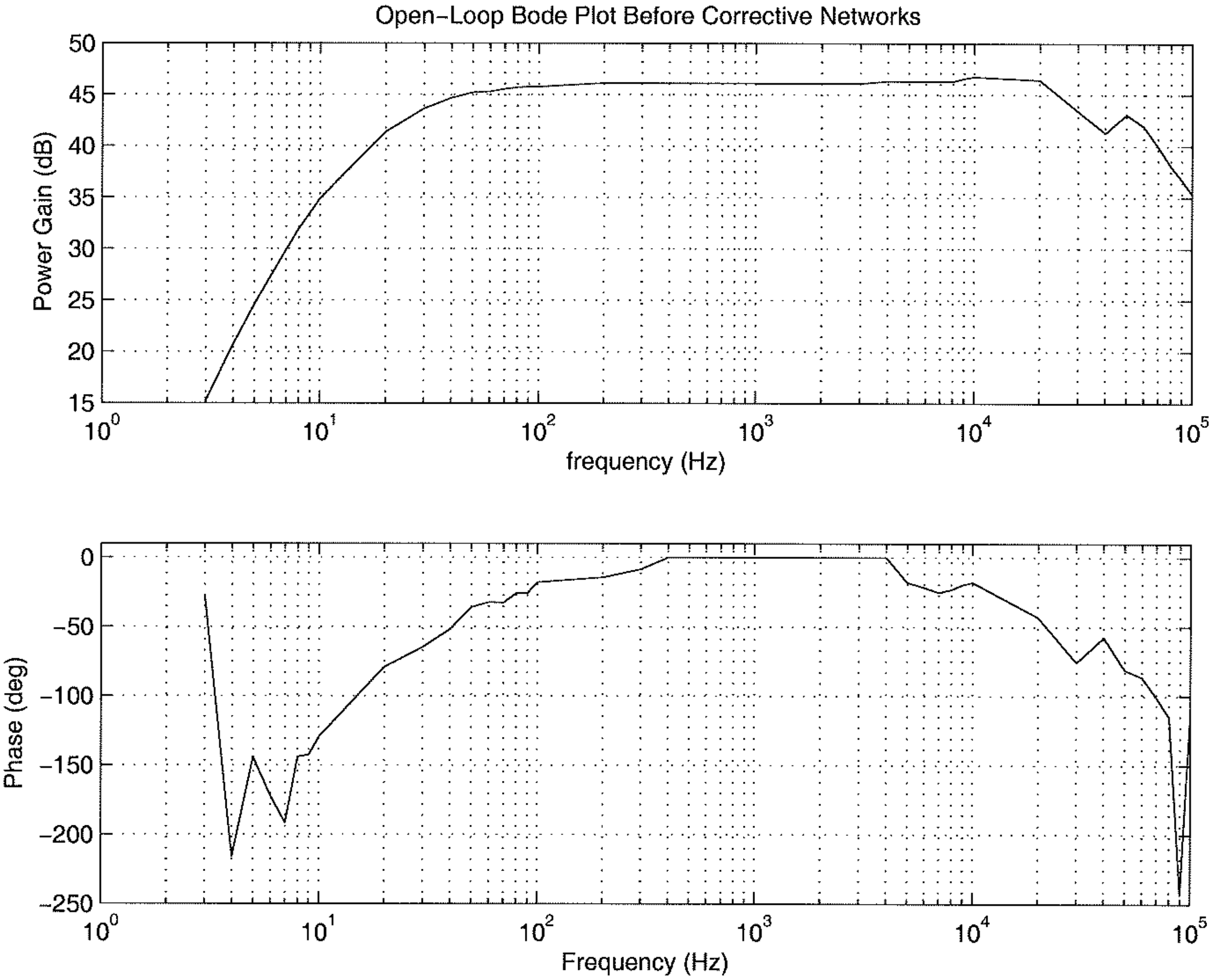
{ ~~[illegible]~~ peak output power measured into an 8Ω load resistor w/a operating in open-loop }

$R_L = 9.6\ \Omega$ $\Rightarrow P_{peak} = 453.75\ W$
$V_{peak} = 66\ V$

- all of this data was plotted in tube_bode_plots.m

- open-loop gain before corrective networks

This is OPEN-LOOP Bode plot Data



Open-Loop Bode Plot Before Corrective Networks

1c

- looking at eq ① solve for R, so we can work towards the proper attenuation

$$\text{attn} = 20 \log\left(\frac{R_1 + R}{R}\right)$$

$$\frac{\text{attn}}{20} = \log\left(\frac{R_1 + R}{R}\right)$$

$$10^{(\text{attn}/20)} = \frac{R_1 + R}{R}$$

$$10^{(\text{attn}/20)} = \frac{R_1}{R} + 1$$

$$10^{(\text{attn}/20)} - 1 = \frac{R_1}{R}$$

$$\Rightarrow R = \frac{R_1}{10^{(\text{attn}/20)} - 1} \quad ⑤$$

- solve for C using eq ④

$$f_2 = \frac{1}{2\pi RC} \Rightarrow C = \frac{1}{2\pi R f_2} \quad ⑥$$

- estimate f_2 off of the bode plot using data from Pala
  - ↳ f_2 is the high freq where the phase hits 180°, on the upper, higher freq, portion of the plot

$f_2 \approx 85\ kHz$

$\text{attn} \approx 37.4 - \overset{\text{due to increased cathode resistor in first stage}}{6} = 31.4\ dB + \text{gain margin} = 3dB$ in this case

- eq's 5, 6, 2, 3, and 4 were coded up into tube-bode-plot.m with the values above and with the values in (fig 1) (actual schematic),

⟹ the results for the high-freq corrective network are:

$f_1 = 1.651\ kHz$ $\quad$ $\text{attn} = 34.4\ dB$

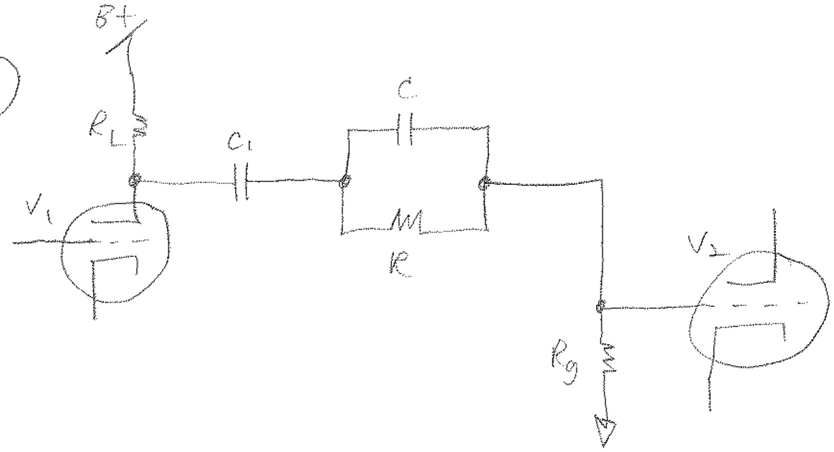
$f_2 = 85\ kHz$ $\quad$ $R = 1.7659\ k$

$C = 1060\ pF$

↳ these results are applied to fig 1

- for a low freq. corrective network:

fig.3



- the ultimate attenuation of the step in dB is

$$attn \approx 20 \log\left(\frac{R + R_g}{R_g}\right) \quad ⑦$$

- the cut-off freq: $f_1 = \dfrac{1}{2\pi C(R_L + R_g)}$ ⑧

- the flattening-out freq: $f_2 \approx \dfrac{1}{2\pi R C}$ ⑨

- using eq ⑦, solve for R

$$attn = 20 \log\left(\frac{R + R_g}{R_g}\right)$$

$$\frac{attn}{20} = \log\left(\frac{R + R_g}{R_g}\right)$$

$$10^{(attn/20)} = \frac{R + R_g}{R_g}$$

$$10^{(attn/20)} = \frac{R}{R_g} + 1$$

$$10^{(attn/20)} - 1 = \frac{R}{R_g}$$

$$\Rightarrow R = R_g\left[10^{(attn/20)} - 1\right] \quad ⑩$$

– using eq. ⑨ solve for C

$$f_2 = \frac{1}{2\pi RC} \Longrightarrow C = \frac{1}{2\pi R f_2} \quad ⑪$$

– estimate f_2, where the lower end of the bode plot (from data on p. 1a) hits 180°

$f_2 \approx 7.5\ Hz$ due to increased cathode resistor on 1st stage

$att_n = 31 - 6 = 25 + \underset{\uparrow}{3} = 28$

gain margin of 3 dB

– eq's 10, 11, 8, and 9 were coded up in to MATLAB, file name tube_bode_plots.m, f_2 and att_n were inputted, resulting in:

$f_1 = 164.5\ Hz$ $\quad$ $att_n = 28\ dB$

$f_2 = 7.5\ Hz$ $\quad$ $R = 24.1\ M$

$C = 879.84\ pF$

↳ these results are applied to fig 1

- another option is to reduce the grid resistor in the 2nd stage and try to achieve more conservative R, C values for the corrective networks
  - let $R_g = 100k$
  - and, let the cathode resistor in the 1st stage, R_c, be $470 = R_c$

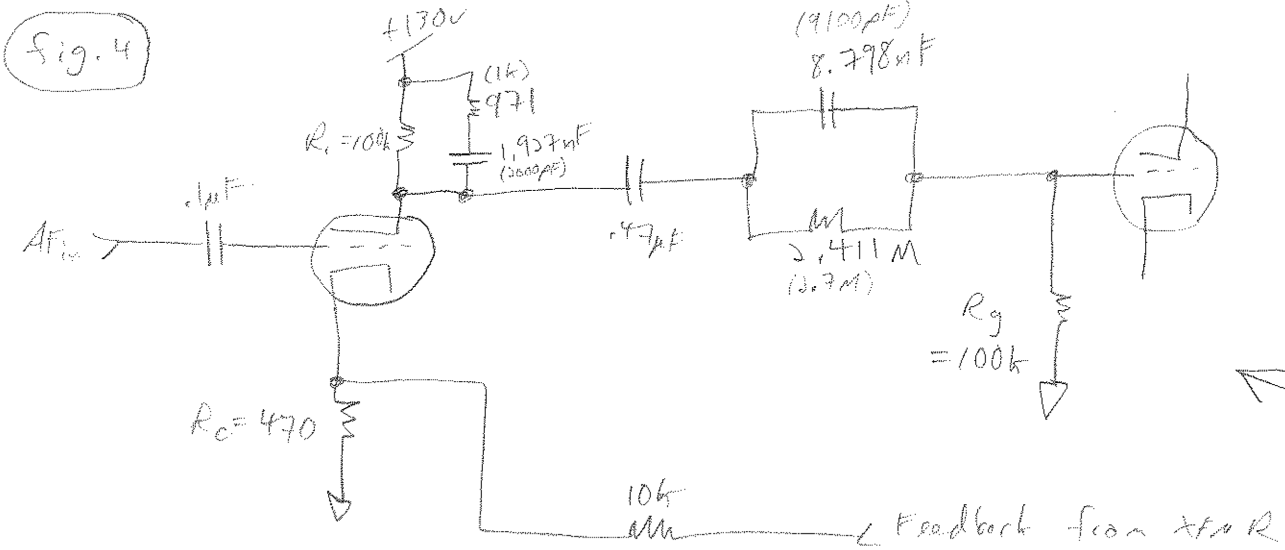
$\Rightarrow$ 3 dB lower fwd loop gain (same as if $R_c = 1k$)

$\Rightarrow$ reduce the feedback resistor to 10k

- re-draw here

(actual values)

fig. 4



- apply the new value of R_g to the .m file, resulting in:

High-Freq Network:
$f_1 = 1.651$ kHz
$f_2 = 85$ kHz
$R = 0.971$ k
$C = 1.927$ nF

Low-Freq Network:
$f_1 = 90.44$ Hz
$f_2 = 7.5$ Hz
$R = 2.4119$ MΩ
$C = 8.7984$ nF

apply these to fig. 4

$V_{in} = 100\,mV$ (p-p)

f (Hz)	Vout (p-p)	Phase (deg)
3	—	—
4	0.365	−158
5	0.272	−162
6	0.375	−151.2
7	0.494	−138.6
8	0.624	−144
9	0.760	−145.8
10	0.932	−126
20	2.67	−117
30	4.55	−94.5
40	6.28	−86.4
50	7.78	−81
60	8.9	−70.2
70	10	−63
80	10.92	−57.6
90	11.68	−48.6
100	12.12	−45
200	14.68	−21.6
300	15.24	−10.8
400	15.34	0
500	15.34	+4.5
600	14.98	+10.8
700	14.84	+15.12
800	14.56	21.6
900	14.26	24.3
1E3	13.82	+27
2E3	10.72	+46.8
3E3	8.24	+54
4E3	6.66	+72
5E3	5.42	+72
6E3	4.63	+75.6
7E3	4.01	+75.6
8E3	3.53	+79.2
9E3	3.145	+81
10E3	2.845	+81
20E3	1.465	+90
30E3	0.858	+108
40E3	0.533	+72
50E3	0.613	+90
60E3	0.538	+97.2
70E3	0.433	+107.1
80E3	0.356	+115.2
90E3	0.300	+113.4
100E3	0.249	+117
200E3	62E-3	+122.4
300E3	33.7E-3	+108
400E3	23.1E-3	+168
500E3	146.5E-3	+72
600E3	171.5E-3	+75.6
700E3	159E-3	+75.6
800E3	146E-3	+72
900E3	148E-3	+81
1E6	165E-3	+72

V_{in} changed to 300 mV (p-p)

V_{in} changed to 800 mV (p-p)

Bode plot data
- open-loop gain
- after correction networks from fig 4. were installed

Max V_{pp} @ 1kHz = 67.6 V

$R_L = 9.6\ \Omega$

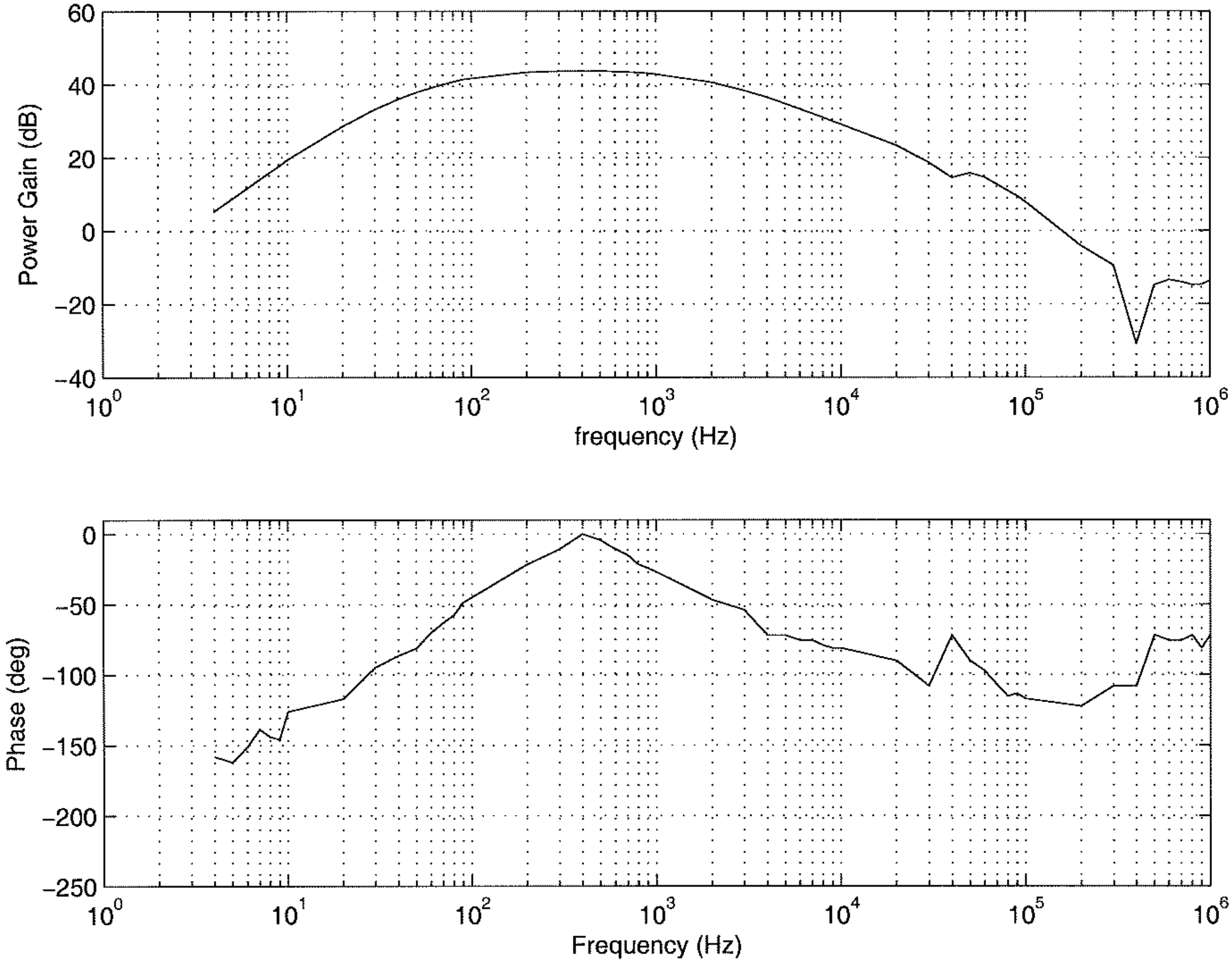
$\Rightarrow P_{peak} = 4.76$ W

<u>as observed:</u>

(+) ⇒ output is leading input

(−) ⇒ output is lagging input

Open-Loop Bode Plot After Corrective Networks



- Closed - loop data, $V_{in(p-p)}$ = 400mV,

$R_{feedback}$ = 10k

f(Hz)	$V_{out(p-p)}$	Phase (deg)
5	0,990	-135
6	1,37	-129.6
7	1,715	-126
8	2.65	-115.2
9	2.42	-113.4
10	2.81	-108
20	6,12	-79.2
30	7.86	-54
40	8.78	-43,2
50	9,34	-36
60	9,56	-32.4
70	9.70	-25,2
80	9,82	-21,6
90	9,9	-19,44
100	9,9	-18
200	10,1	-7,2
300	10.1	-5,4
400	10.1	0
500	10.1	0
600	10,1	0
700	10,1	0
800	10,1	0
900	10.14	0
1E3	10.1	10.3
2E3	10,06	7.2
3E3	9.82	13,5
4E3	9.62	21.6
5E3	9.30	27
6E3	9.02	30,4
7E3	8.66	31.5
8E3	8,32	36
9E3	8,0	40.5
10E3	7.76	45
20E3	5,11	72
30E3	3.3	86.4
40E3	2,3	72
50E3	2,53	81
60E3	2,24	97,2
70E3	1,805	100.8
80E3	1.505	115.2
90E3	1,248	113.4
100E3	1.054	113.4
200E3	0,251	108
300E3	0.135	108
400E3		
500E3		
600E3		
700E3		
800E3		
900E3		
1M		

Load Resistor $R_L = 9.6\Omega$

$V_{pp(max)}$ = 68.2 at 1kHz

$V_{pp(max)}$ = 63.4 at 50 Hz

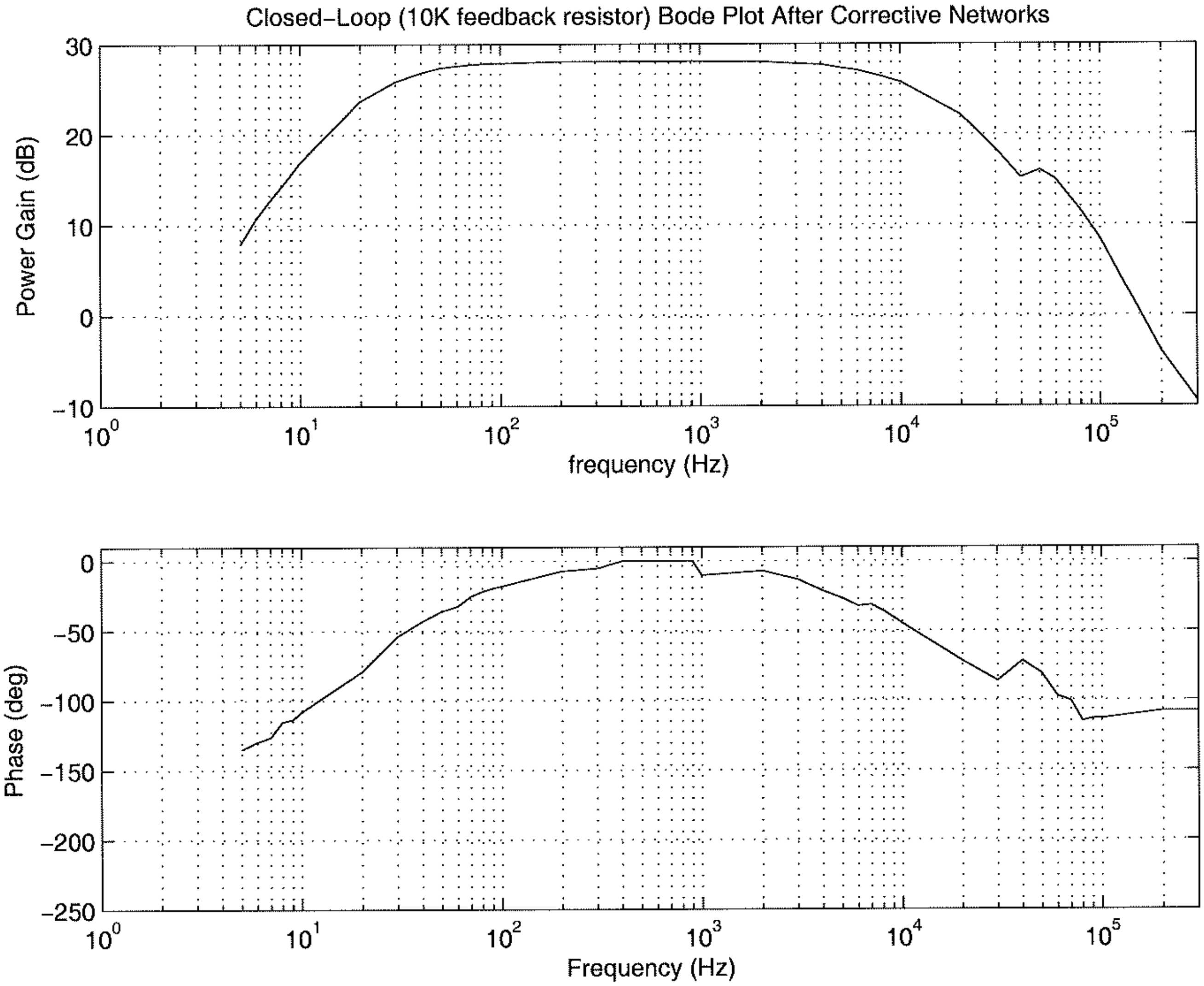
$V_{pp(max)}$ = 73.0 at 10kHz

$V_{pp(max)}$ = 58.2 at 15kHz

$V_{pp(max)}$ = 47.2 at 10 Hz

$V_{pp(max)}$ = 64.2 at 20Hz

$R_{feedback}$ = 10k


Closed-Loop (10K feedback resistor) Bode Plot After Corrective Networks

→ closed-loop data, $V_{in}(p-p)$ = 400 mV, $R_{feedback}$ = 4.7k

f(Hz)	V_{out}(p-p)	Phase (deg)
5	0.880	−135
6	1.08	−108
7	1.33	−113.4
8	1.56	−100.8
9	1.8	−97.2
10	2.03	−90
20	3.76	−57.6
30	4.53	−43.2
40	4.91	−36
50	5.13	−27
60	5.23	−21.6
70	5.30	−20.16
80	5.35	−20.16
90	5.38	−16.2
100	5.41	−14.4
200	5.44	−7.2
300	5.44	−5.4
400	5.44	−2.88
500	5.44	0
600	5.44	0
700	5.44	0
800	5.44	0
900	5.44	0
1E3	5.43	0
2E3	5.43	7.2
3E3	5.43	10.8
4E3	5.34	14.4
5E3	5.32	16.2
6E3	5.25	19.44
7E3	5.19	22.68
8E3	5.13	25.92
9E3	5.03	29.16
10E3	4.94	28.8
20E3	3.99	50.4
30E3	2.93	70.2
40E3	2.30	50.4
50E3	2.575	63
60E3	2.27	86.4
70E3	1.89	100.8
80E3	1.58	100.8
90E3	1.308	110.16
100E3	1.10	117
200E3	0.253	115.2
300E3	0.139	108
400E3		
500E3		
600E3		
700E3		
800E3		
900E3		
1M		

Load
Resistor
= 9.6 Ω

f(Hz)	Max Power Out V_{pp}(Peak)
10	37.7
20	61.3
50	62.1
1E3	66.7
10E3	73.1
15E3	57.0

Closed–Loop (4.7K feedback resistor) Bode Plot After Corrective Networks