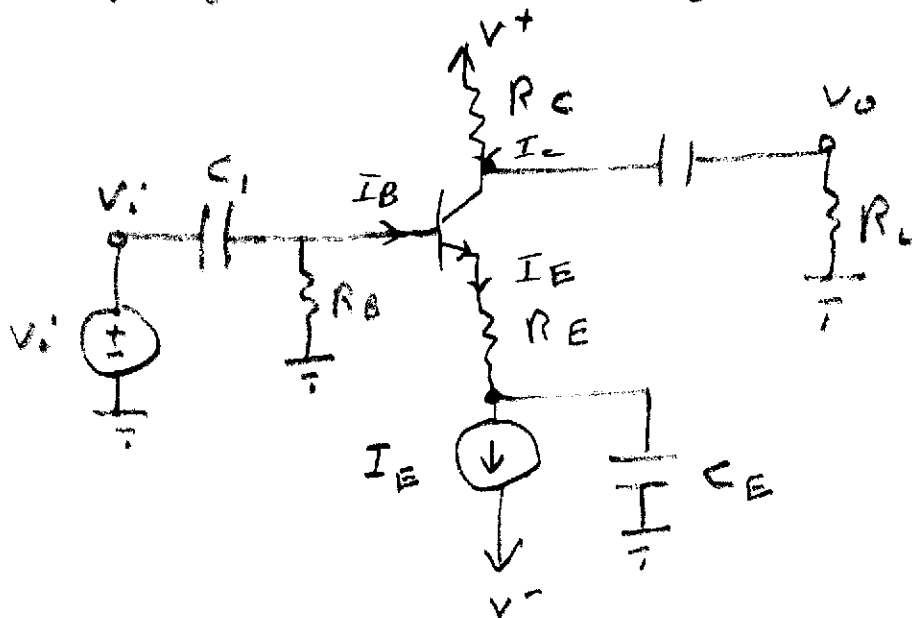


Single Stage Common Emitter Amplifier Biased By a Current Source

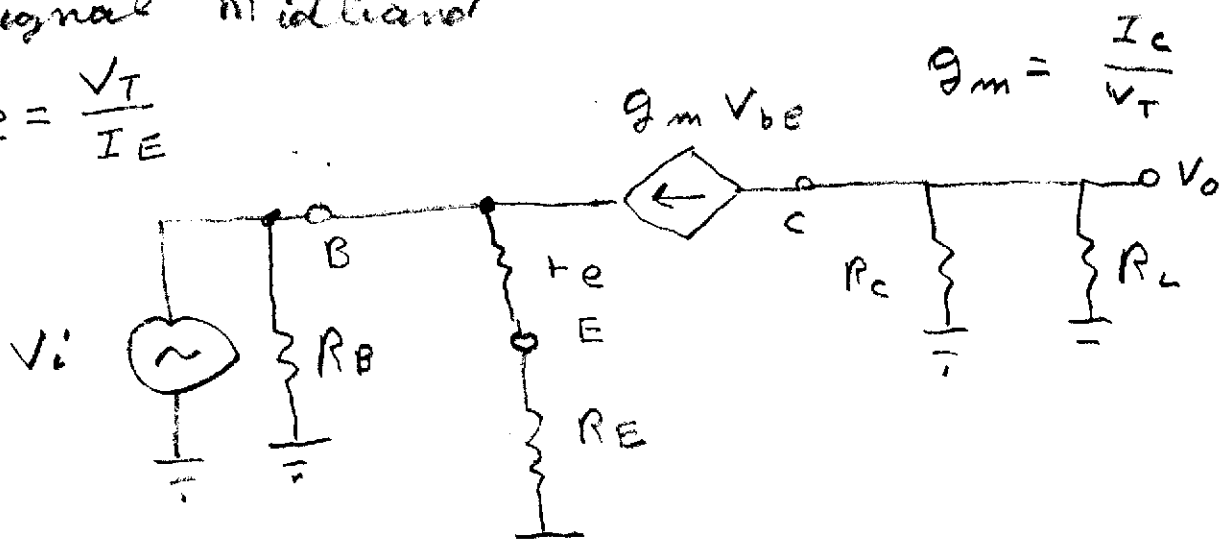


DC $I_E = I_E$ $I_C = \alpha I_E$ $I_B = \frac{I_C}{\beta}$

$V_C = V^+ - I_C R_C$, $V_B = -I_B R_B$ $V_E = V_B - V_{BE}$

AC Use Simplified T Model Small Signal Model

$r_e = \frac{V_T}{I_E}$



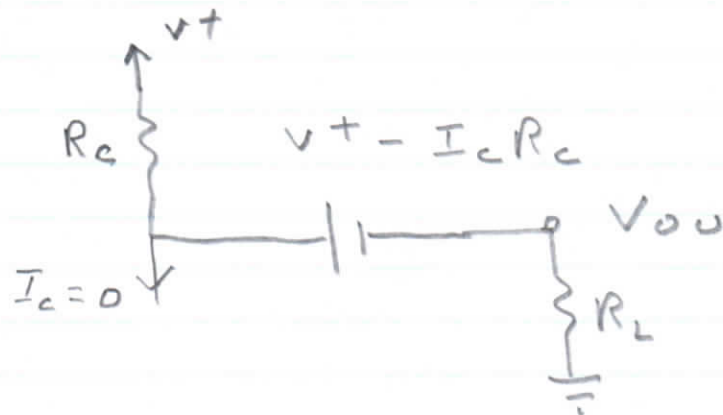
$T(\omega) = \frac{V_O}{V_i} = -\alpha \frac{R_C \parallel R_L}{r_e + R_E}$

$\alpha = \frac{\beta}{\beta + 1}$

Clipping

Upper Clipping V_{ou}

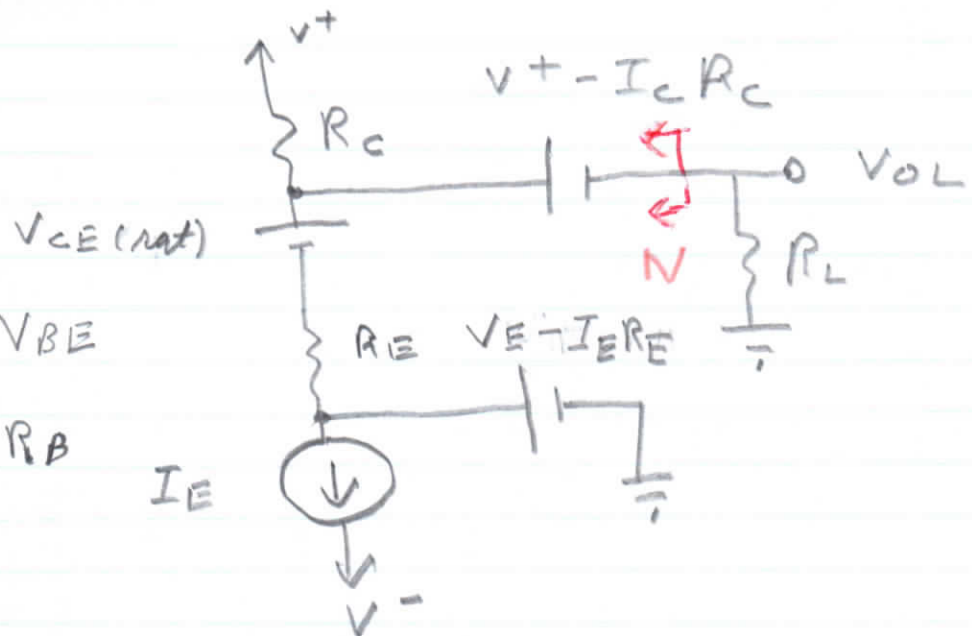
Input goes low enough transistor is cut off $i_c = 0$, model with caps as batteries equal to DC voltages across



$$V_{ou} = v^+ \frac{R_L}{R_c + R_L} - (v^+ - I_c R_c) \frac{R_L}{R_c + R_L} = I_c R_c \parallel R_L$$

Lower Clipping V_{ol}

Input goes high enough transistor is saturated $V_{CE} = V_{CE(sat)}$

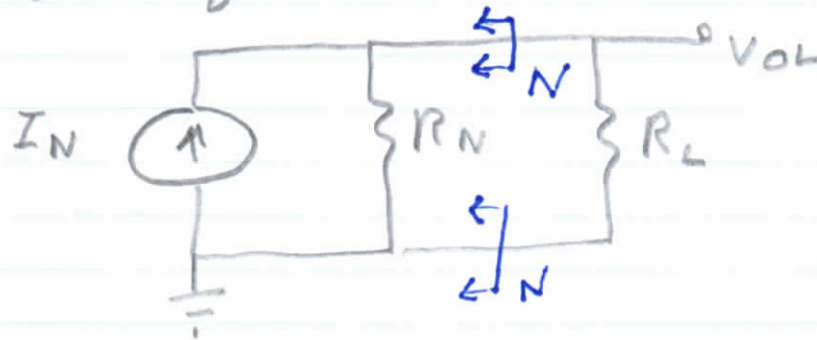


$$V_E = V_B - V_{BE}$$

$$V_B = -I_B R_B$$

 I_E


To expedite determining V_{OL} find Norton Equivalent w/rt R_L



$$R_N = R_C \parallel R_E$$

$$I_N = \frac{V^+}{R_C} - \frac{V^+ - I_C R_C}{R_C \parallel R_E} + \frac{V_{CE(sat)}}{R_E} + \frac{V_E - I_E R_E}{R_E}$$

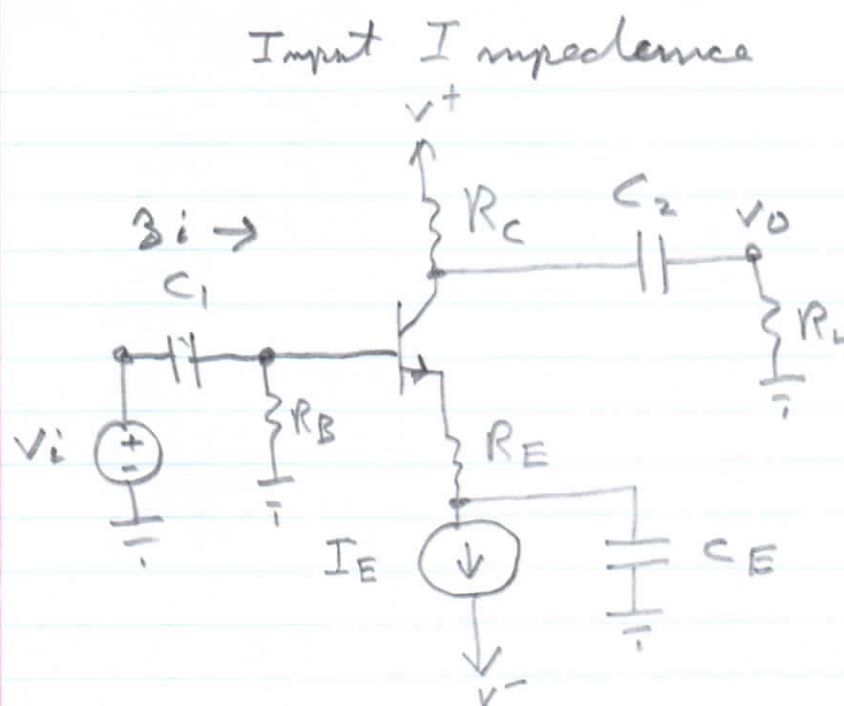
$$V_{OL} = I_N R_N \parallel R_L =$$

$$\left[\frac{V^+}{R_C} - \frac{V^+ - I_C R_C}{R_C \parallel R_E} + \frac{V_{CE(sat)}}{R_E} + \frac{V_E - I_E R_E}{R_E} \right] R_C \parallel R_E \parallel R_L$$

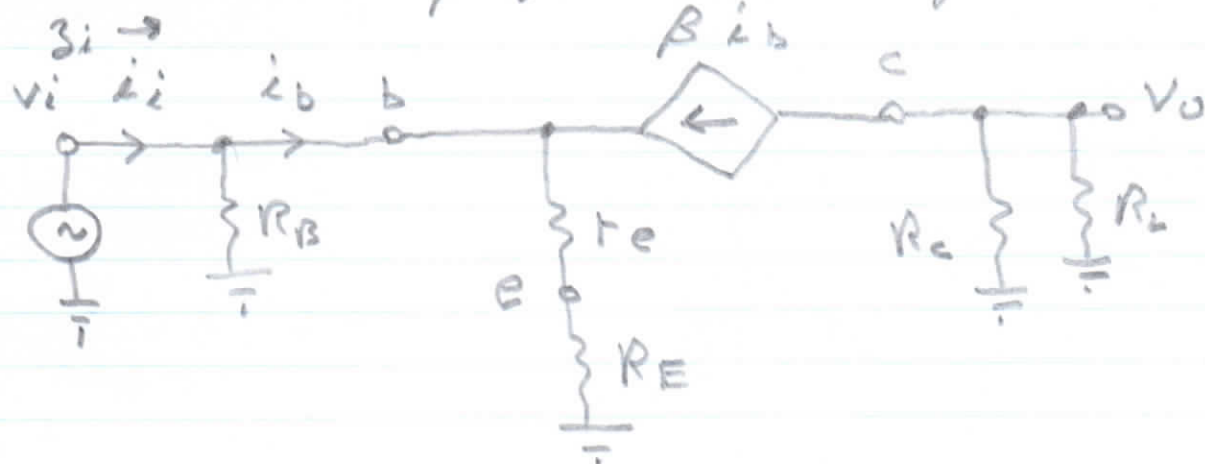
$$V_{OL} = - \left[V^+ + V_{BE} - V_{CE(sat)} + I_C \left(\frac{R_B + R_E}{\beta} - R_C \right) \right] \frac{R_C \parallel R_L}{R_E + R_C \parallel R_L}$$

For Symmetric Clipping $V_{OH} = -V_{OL} \Rightarrow$

$$I_C = \frac{V^+ + V_{BE} - V_{CE(sat)}}{R_C + R_E + R_C \parallel R_L} - \frac{R_B + R_E}{\beta}$$



Midband Simplified Small Signal T Model

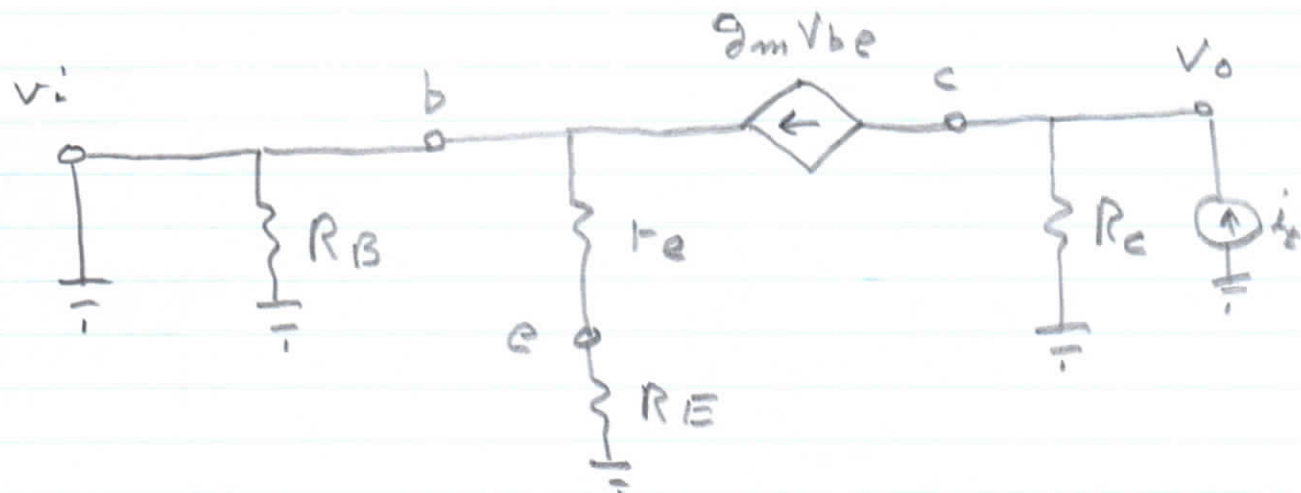


$$V_b = (\beta + 1) i_b [r_e + R_E]$$

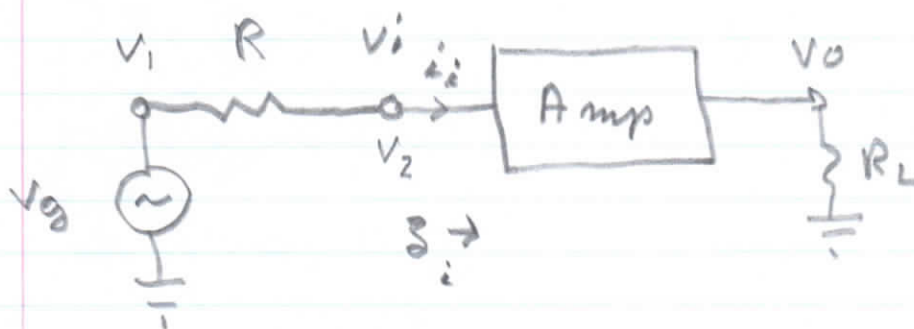
$$\frac{V_b}{i_b} = (\beta + 1) [r_e + R_E]$$

$$Z_i = \frac{V_i}{i_i} = R_B \parallel [(\beta + 1)(r_e + R_E)]$$

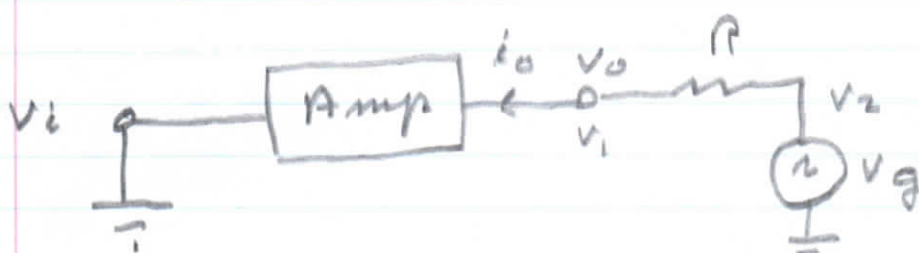
Output Impedance



$$Z_o = \frac{V_o}{i_x} = R_C$$

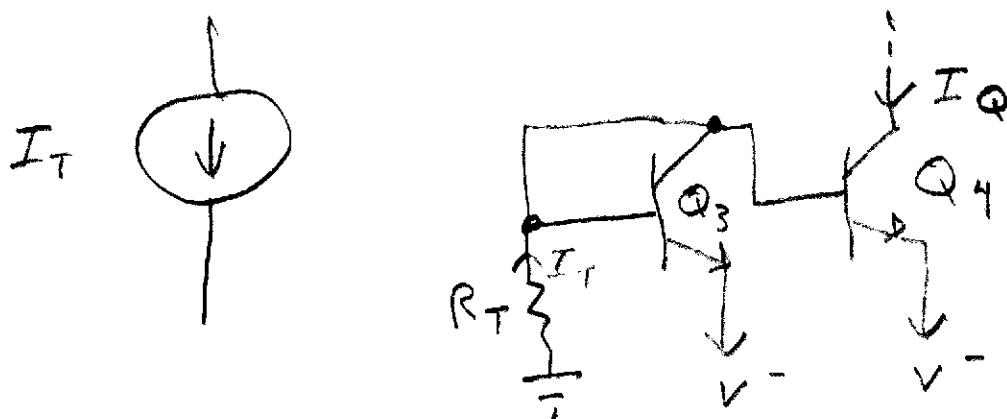
To Measure Z_i 

$$Z_i = \frac{V_i}{i_i} = \frac{V_2}{\frac{V_1 - V_2}{R}} = R \frac{1}{\frac{V_1}{V_2} - 1}$$

To Measure Z_o 

$$Z_o = \frac{V_o}{i_o} = \frac{V_1}{\frac{V_1 - V_2}{R}} = R \frac{1}{1 - \frac{V_2}{V_1}}$$

DC Current Sources



Assume Q_3 & Q_4 have perfectly matched characteristics, viz identical SPICE parameters.

$$I_C = I_{S0} \left[1 + \frac{V_{CE}}{V_A} \right] e^{\frac{V_{BE}}{V_T}}$$

zero bias I_{S0} saturation current V_T thermal voltage
 V_A Early Voltage

$$I_B \quad V_A \gg V_{CE}$$

$$I_{C3} \approx I_{C4} \quad \text{Assume } \beta = \infty \quad I_B = 0$$

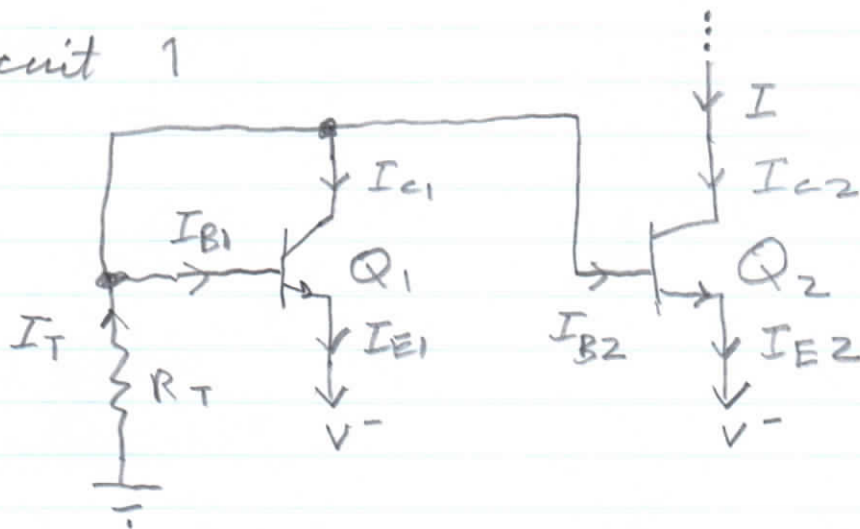
$$I_{C3} = I_T = I_{C4} = I_Q$$

$$I_T = \frac{-V^- - V_{BE}}{R_T}$$

$$I_T R_T + V_{BE} + V^- = 0$$

Electronic Current Sources

Circuit 1



Identical Transistors

$$V_{B1} = V_{B2} \quad V_{E1} = V_{E2} = V^- \Rightarrow$$

$$I_{C1} = I_{C2} = I, \quad I_T = I_{B1} + I_{C1} + I_{B2}$$

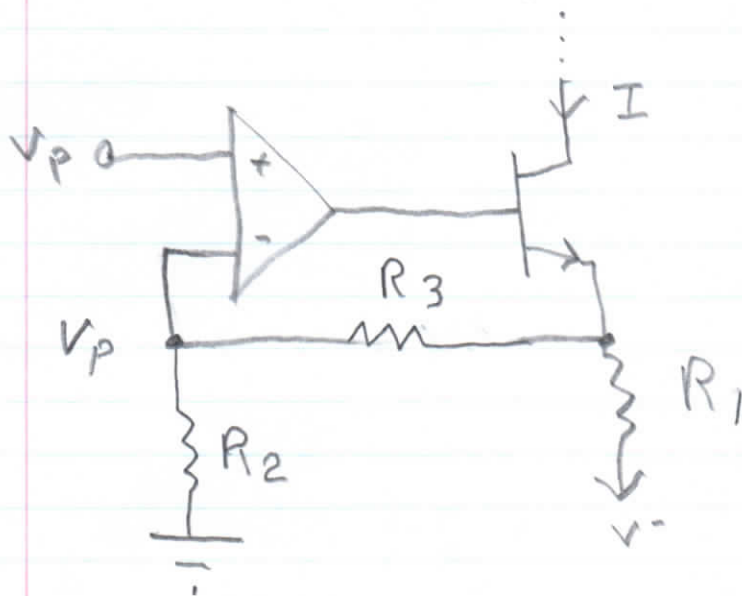
$$I_T = I \left[1 + \frac{2}{\beta} \right], \quad I_T R_T = -V_{BE} - V^-$$

$$R_T = \frac{-V_{BE} - V^-}{I \left[1 + \frac{2}{\beta} \right]}$$

Remember $V^- < 0$

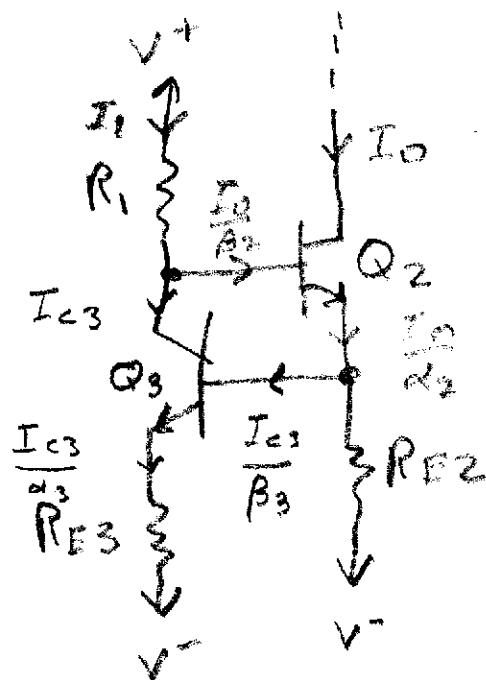
Current Source

Circuit 2 Op Amp

Negative Feedback $\Rightarrow$ Virtual Short

$$V_p = \frac{I}{\alpha} \frac{R_1}{R_2 + R_3 + R_1} R_2 + V^- \frac{R_2}{R_1 + R_2 + R_3}$$

Since $V^- < 0$, $V_p < 0$

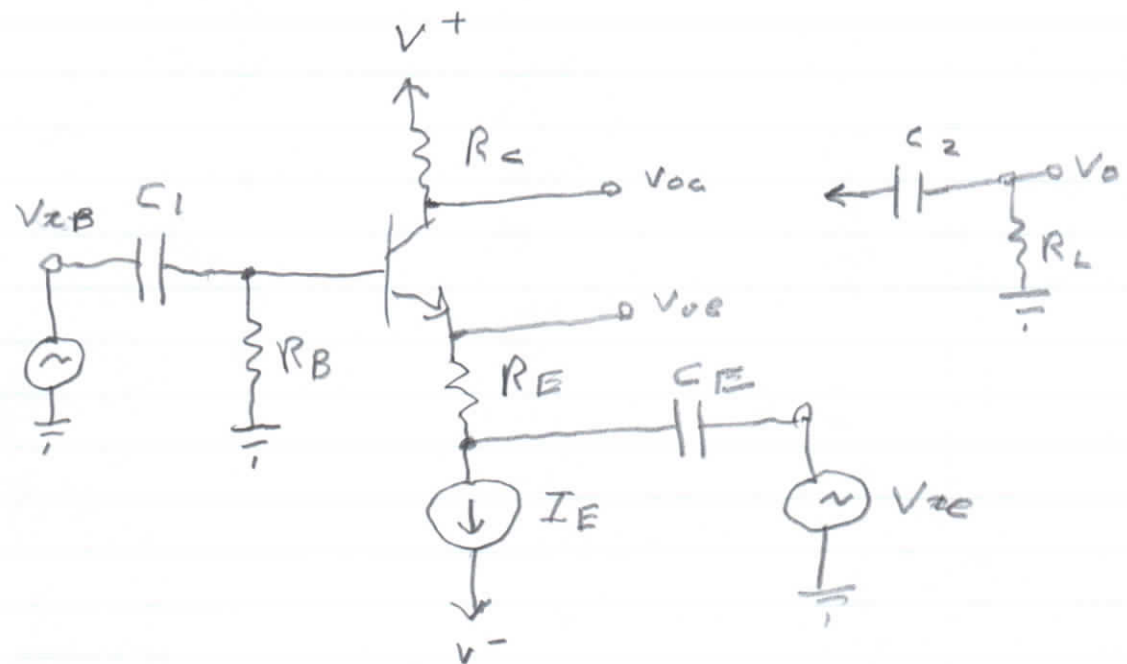


Circuit 3

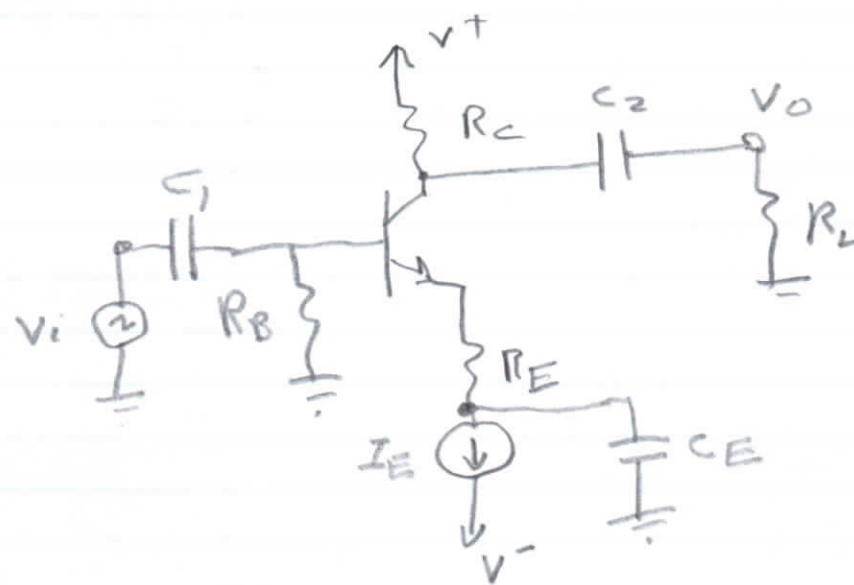
$$R_1 = \frac{V^+ - V^- - (V_{BE3} + V_{BE2}) - \left(I_1 - \frac{I_O}{\beta_2} \right) \frac{R_{E2}}{\alpha_3}}{I_1}$$

$$R_{E2} = \frac{V_{BE3} + \frac{I_{C3}}{\alpha_3} R_{E3}}{\frac{I_O}{\alpha_2} - \frac{I_{C3}}{\beta_3}}$$

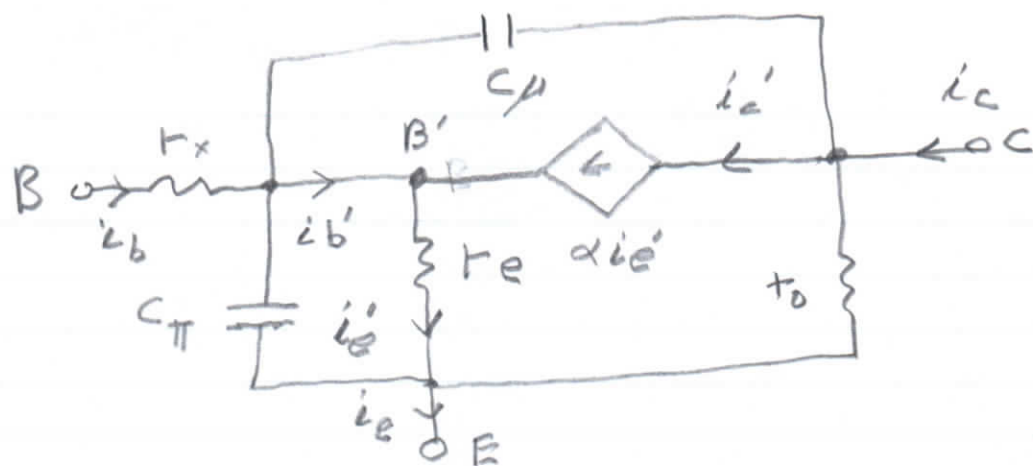
Single BJT Amplifier



Common Emitter



Want small signal midband voltage gain. At midband $C_1, C_2, \& C_E$ are shorts. $V^+ = V^- = 0, I_E = 0$. Use T model for BJT

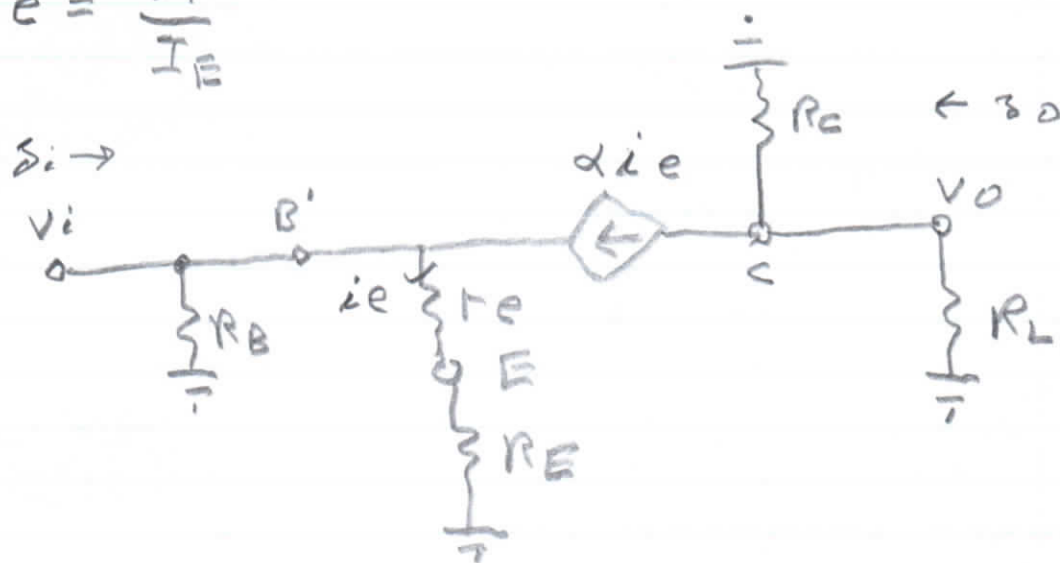


At midband C_{π} & C_{μ} are open circuits
Neglect $r_x \equiv$ base spreading resistance

$$r_o = \frac{V_A}{I_C}$$

$V_A \equiv$ Early Voltage
Assume to be infinite

$$r_e = \frac{V_T}{I_E}$$



$$i_e = \frac{v_i}{r_e + R_E}$$

$$v_o = -\alpha i_e R_C \parallel R_L$$

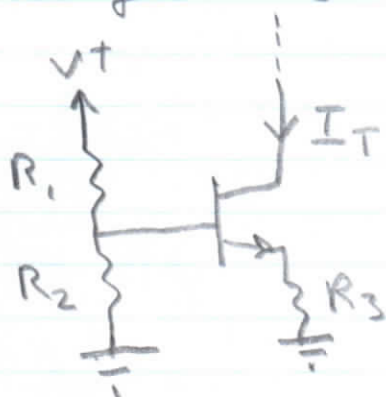
$$T = \frac{v_o}{v_i} = -\alpha \frac{R_C \parallel R_L}{r_e + R_E}$$

$$Z_i = R_B \parallel [(\beta+1)(r_e + R_E)] \quad Z_o = R_C$$

Current Sources



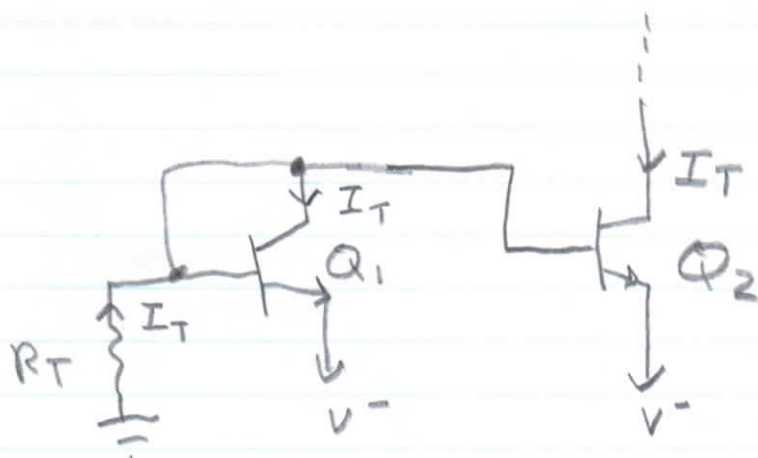
Single BJT



$$\beta = \infty$$

$$I_T = \frac{\frac{R_2}{R_1 + R_2} V^+ - V_{BE}}{R_3}$$

Two BJT

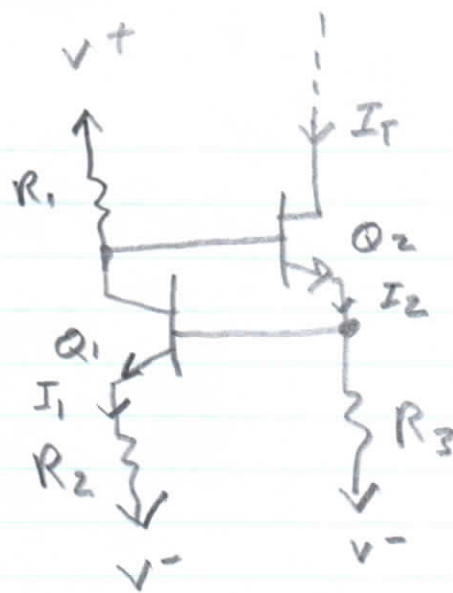


$$\beta = \infty$$

$$V_{BE1} = V_{BE2} \Rightarrow I_1 = I_2 = I_T$$

$$I_T R_T + V_{BE1} + V^- = 0$$

$$R_T = \frac{-V^- - V_{BE1}}{I_T} = - \frac{V^- + V_{BE}}{I_T}$$



$$\beta = \infty$$

$$I_T = I_2$$

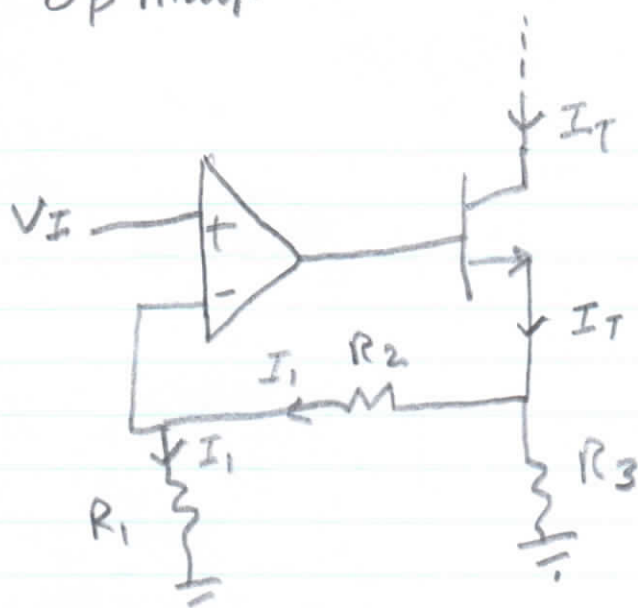
$$\begin{cases} I_2 R_3 = V_{BE} + I_1 R_2 \\ V^+ - I_1 R_1 - V_{BE} - V_{BE} - I_1 R_2 = V^- \end{cases}$$

$$I_1 = \frac{V^+ - V^- - 2V_{BE}}{R_1 + R_2}$$

$$I_T R_3 = V_{BE} + \frac{R_2}{R_1 + R_2} [V^+ - V^- - 2V_{BE}]$$

$$R_3 = \frac{V_{BE}}{I_T} + \frac{R_2}{R_1 + R_2} \frac{V^+ - V^- - 2V_{BE}}{I_T}$$

Op Amp



$$\beta = \infty$$

$$I_1 = \frac{V_I}{R_1}$$

$$I_1 = I_T \frac{R_3}{R_1 + R_2 + R_3}$$

$$\frac{V_I}{R_1} = I_T \frac{R_3}{R_1 + R_2 + R_3}$$

JFET



$$V_S - I_T R_S = V^-$$

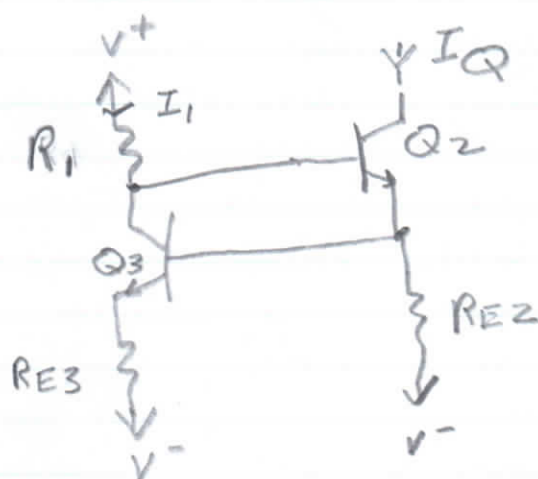
$$I_T = \beta [V_{GS} - V_T]^2$$

$$I_T = \beta [V^- - V^- + I_T R_S]^2$$

$$I_T = \beta I_T^2 R_S^2$$

$$R_S = \frac{1}{\sqrt{\beta I_T}}$$

Current Source Design



For simplicity
 let $\beta_2 = \beta_3 = \infty$
 For the calculation

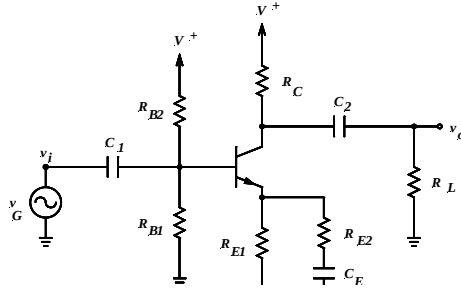
$$I_1 = \frac{V^+ - V^- - 2 V_{BE}}{R_1 + R_{E3}}$$

$$I_Q = \frac{V_{BE} + I_1 R_{E3}}{R_{E2}}$$

Pick values for R_1 & R_{E3}
 that will result in a I_1 of
 a few mA. Compute

$$R_{E2} = \frac{V_{BE} + I_1 R_{E3}}{I_Q}$$

to the desired I_Q .



Common Emitter

$$\begin{aligned}
 r_x &:= 10\Omega & R_C &:= 6.8\text{k}\Omega & R_L &:= 22\text{k}\Omega & R_{E1} &:= 2\text{k}\Omega \\
 \beta &:= 200 & V_{BE} &:= 0.65\text{V} & A_V &:= 25 & V_{\text{plus}} &:= 15\text{V} \\
 R_p(A, B) &:= \frac{A \cdot B}{A + B} & \alpha &:= \frac{\beta}{\beta + 1} & R_{te} &:= \frac{\alpha \cdot R_p(R_C, R_L)}{A_V} & R_{E2} &:= \frac{1}{\frac{1}{R_{te}} - \frac{1}{R_{E1}}} \\
 R_{tc} &:= R_p(R_C, R_L) & V_{CEsat} &:= 0.3\text{V} & I_C &:= \frac{V_{\text{plus}} - V_{CEsat}}{R_{tc} + R_C + \frac{(R_{E1} + R_{te})}{\alpha}} & I_C &= 1.034 \cdot \text{mA} \\
 R_{E2} &= 230.58\Omega & I_B &:= \frac{I_C}{\beta} & I_E &:= \frac{I_C}{\alpha} & V_C &:= V_{\text{plus}} - I_C \cdot R_C & V_E &:= I_E \cdot R_{E1} & V_B &:= V_E + V_{BE}
 \end{aligned}$$

For Symmetric Clipping

$$I_B = 5.172 \cdot \mu\text{A} \quad I_E = 1.039 \cdot \text{mA} \quad V_C = 7.967 \text{ V} \quad V_E = 2.079 \text{ V} \quad V_B = 2.729 \text{ V}$$

$$I_{B1} := 10 \cdot I_B \quad I_{B2} := I_{B1} + I_B \quad R_{B1} := \frac{V_B}{I_{B1}} \quad R_{B2} := \frac{V_{\text{plus}} - V_B}{I_{B2}} \quad V_A := 74.03\text{V}$$

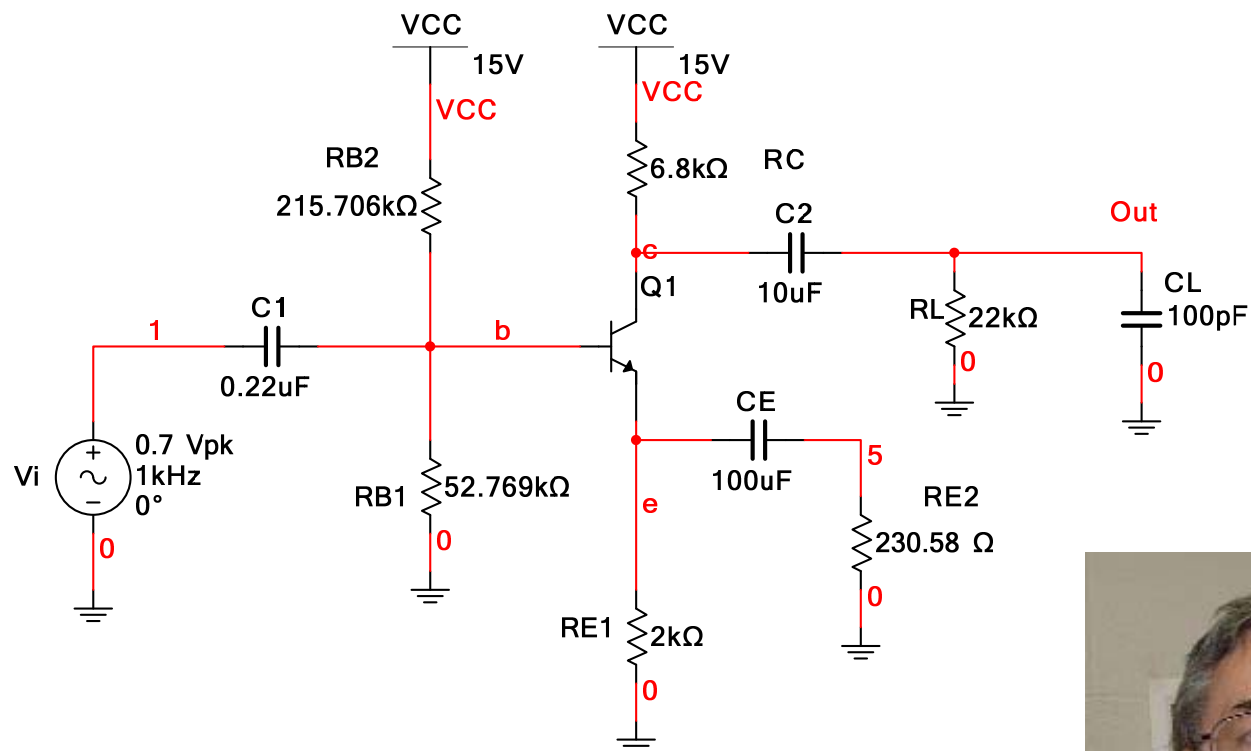
$$R_{B1} = 52.769 \cdot \text{k}\Omega \quad R_{B2} = 215.706 \cdot \text{k}\Omega \quad V_T := 25.9\text{mV} \quad r_e := \frac{V_T}{I_E}$$

$$r_{ie} := \frac{r_x}{1 + \beta} + r_e \quad V_{CB} := V_C - V_B \quad r_o := \frac{V_A + V_{CB}}{I_C} \quad r_o = 76.637 \cdot \text{k}\Omega$$

$$r_{ic} := \frac{r_o + R_p(r_{ie}, R_{te})}{1 - \alpha \cdot \frac{R_{te}}{r_{ie} + R_{te}}} \quad A_V := -\alpha \cdot \frac{R_p(r_{ic}, R_{tc})}{r_{ie} + R_{te}} \quad A_V = -22.138$$

$$v_{\text{oplus}} := I_C \cdot R_{tc} \quad v_{\text{ominus}} := -[V_{\text{plus}} - I_C \cdot (R_C + R_{E1})] \cdot \frac{R_{tc}}{R_{tc} + R_{te}}$$

$$v_{\text{oplus}} = 5.373 \text{ V} \quad v_{\text{ominus}} = -5.672 \text{ V}$$



Title: Common Emitter				
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Date: 2013-08-25	Sheet 1 of 1			

Common Emitter

DC Operating Point

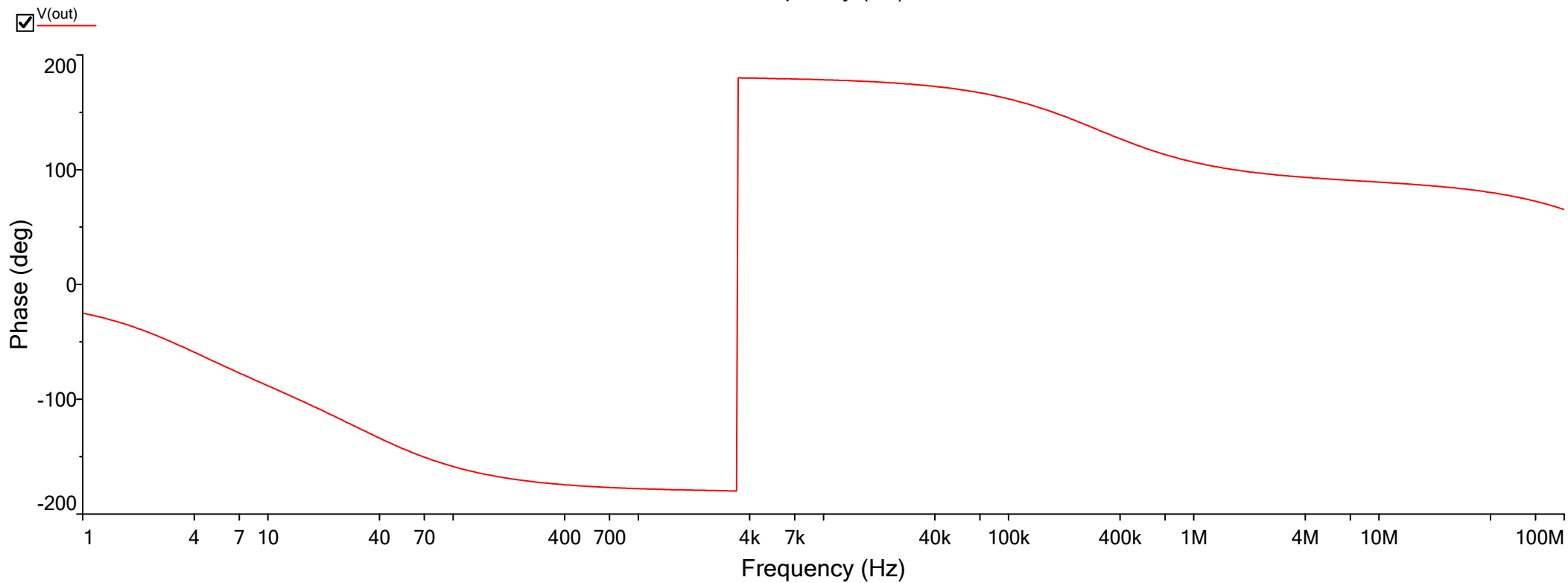
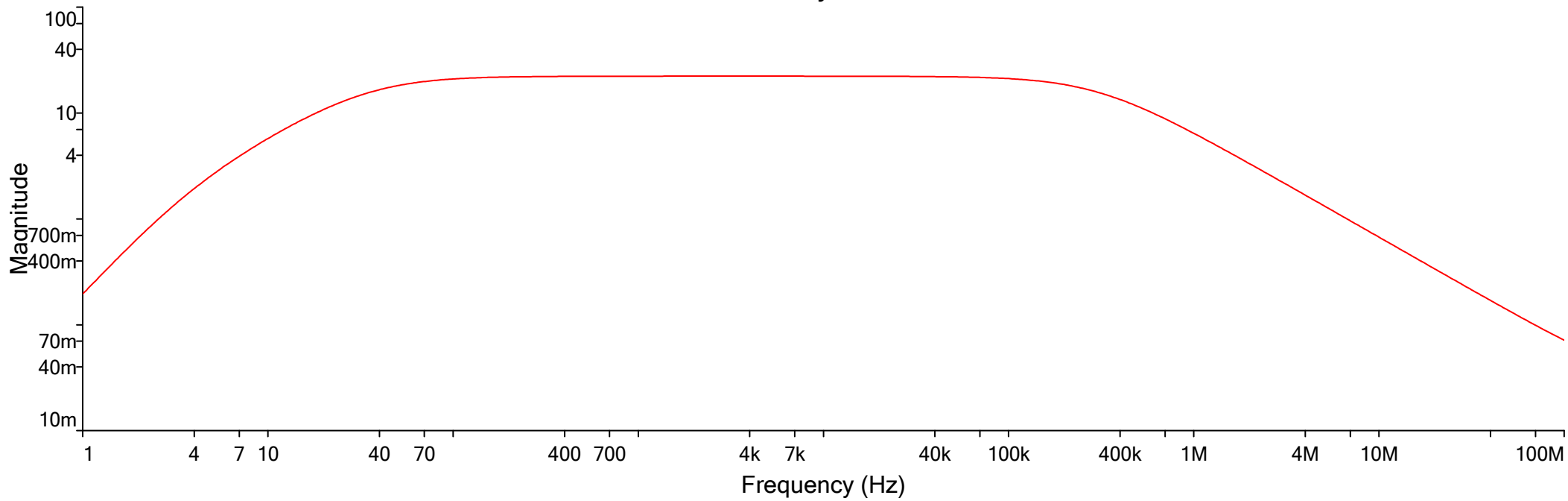
Printing Time: Sunday, August 25, 2013, 1:15:47 PM

	DC Operating Point	
1	V(c)	7.90770
2	V(e)	2.09609
3	@qq1[ic]	1.04570 m
4	V(b)	2.73369

Common Emitter

Printing Time: Sunday, August 25, 2013, 1:17:04 PM

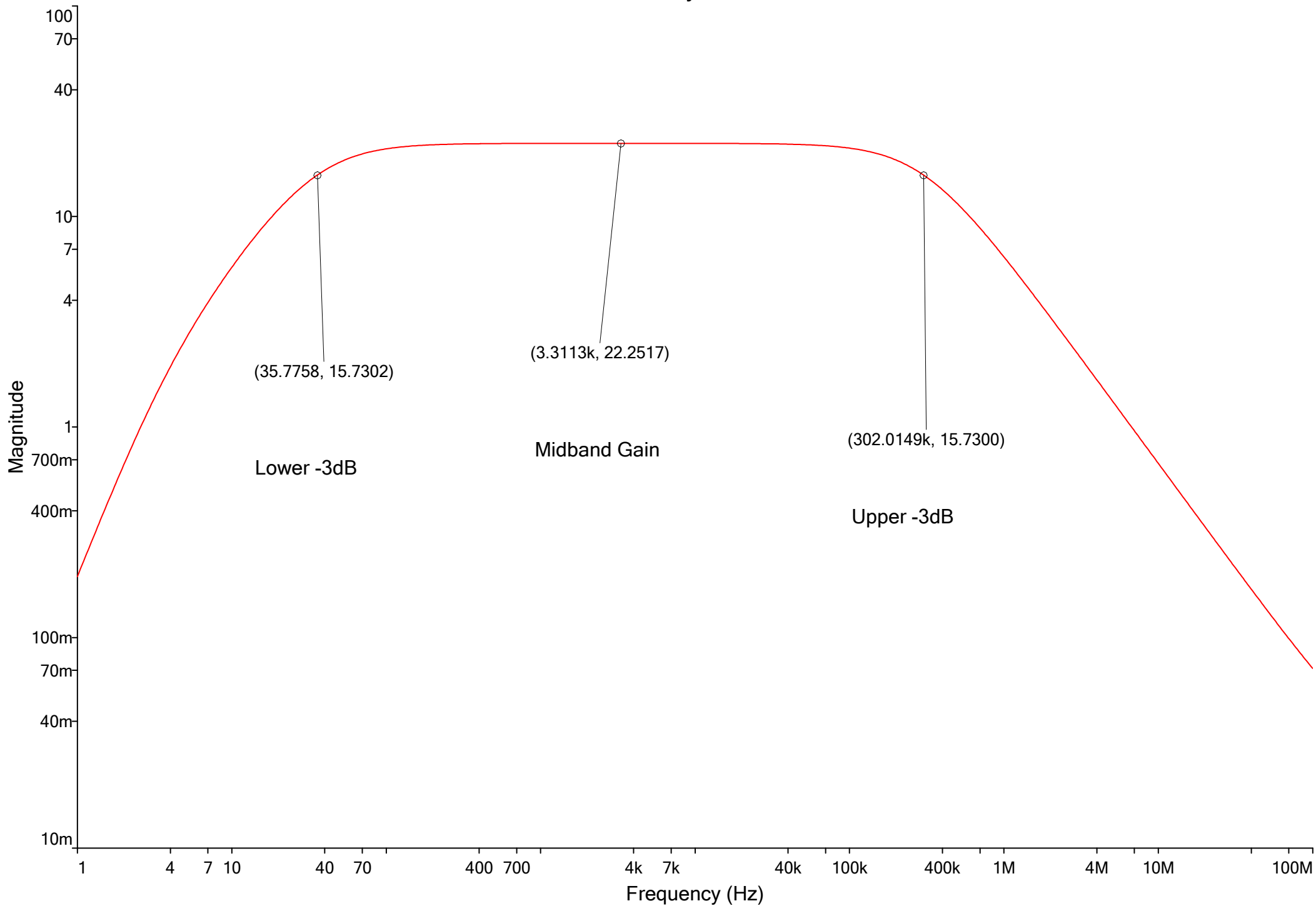
AC Analysis



Common Emitter

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AC Analysis

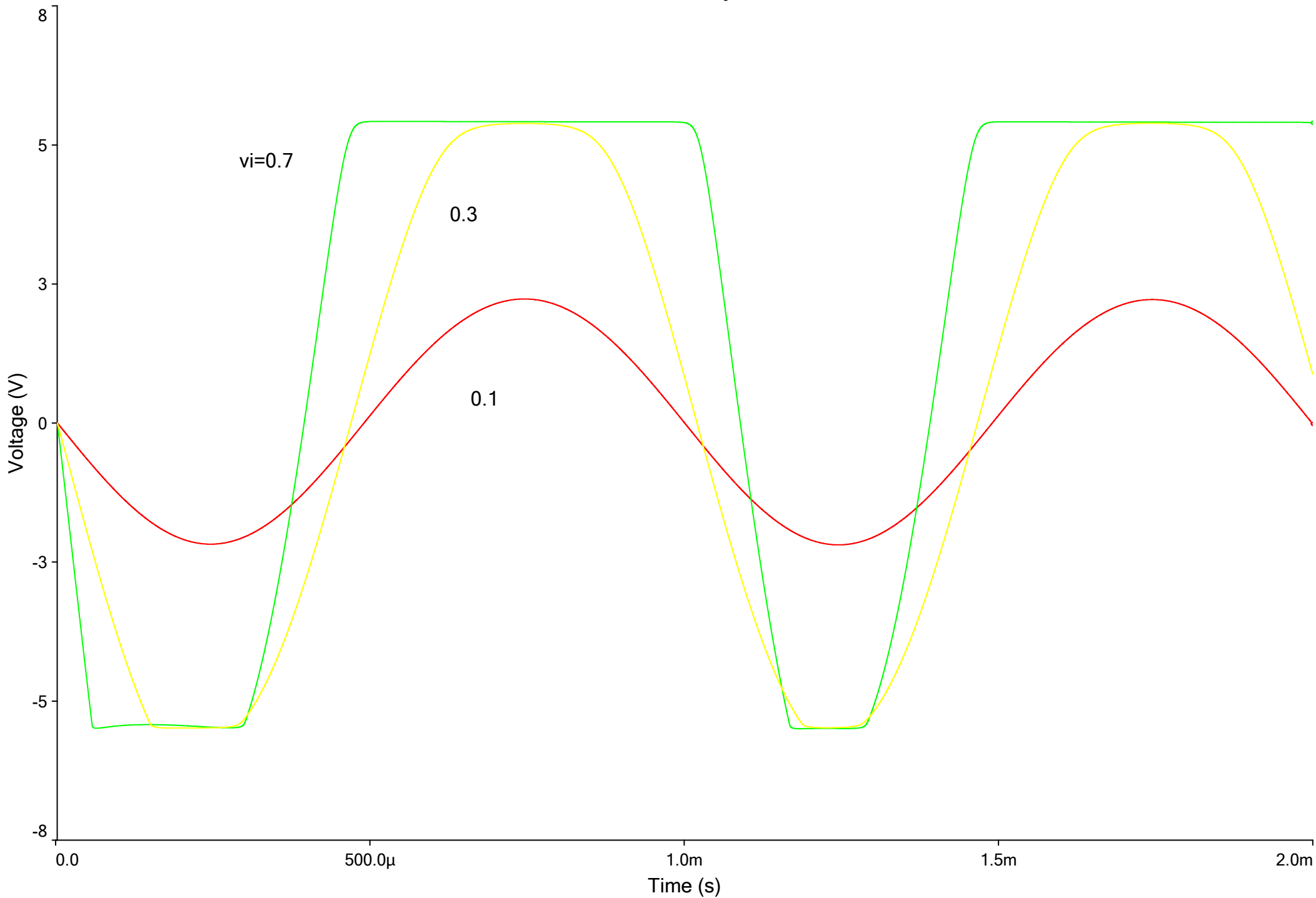


V(out)

Transient Analysis(Merged_1)(Merged_1)

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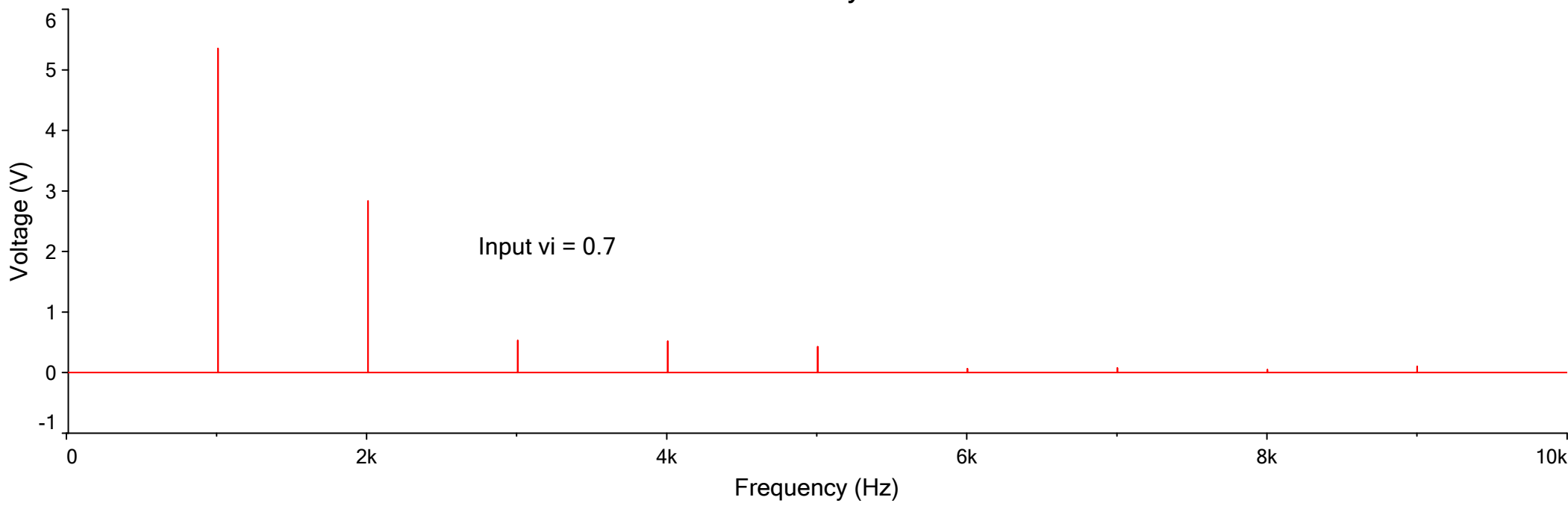
Transient Analysis



Common Emitter

1	Fourier analysis for					
2	DC component:	2.1819				
3	No. Harmonics:	9				
4	THD:	55.3119 %				
5	Grid size:	256				
6	Interpolation Degree 1					
7	:					
8	Harmonic	Frequency	Magnitude	Phase	Norm. Mag	Norm. Phase
9	1	1000	5.35346	-175.99	1	0
10	2	2000	2.83153	98.6467	0.528915	274.64
11	3	3000	0.528752	20.6445	0.0987681	196.638
12	4	4000	0.515847	96.7866	0.0963576	272.78
13	5	5000	0.427744	16.0483	0.0799005	192.041
14	6	6000	0.0606975	-37.868	0.011338	138.125
15	7	7000	0.0762513	-7.8517	0.0142434	168.141
16	8	8000	0.04855	156.595	0.00906889	332.588
17	9	9000	0.100448	44.6129	0.0187633	220.606
18						

Fourier Analysis

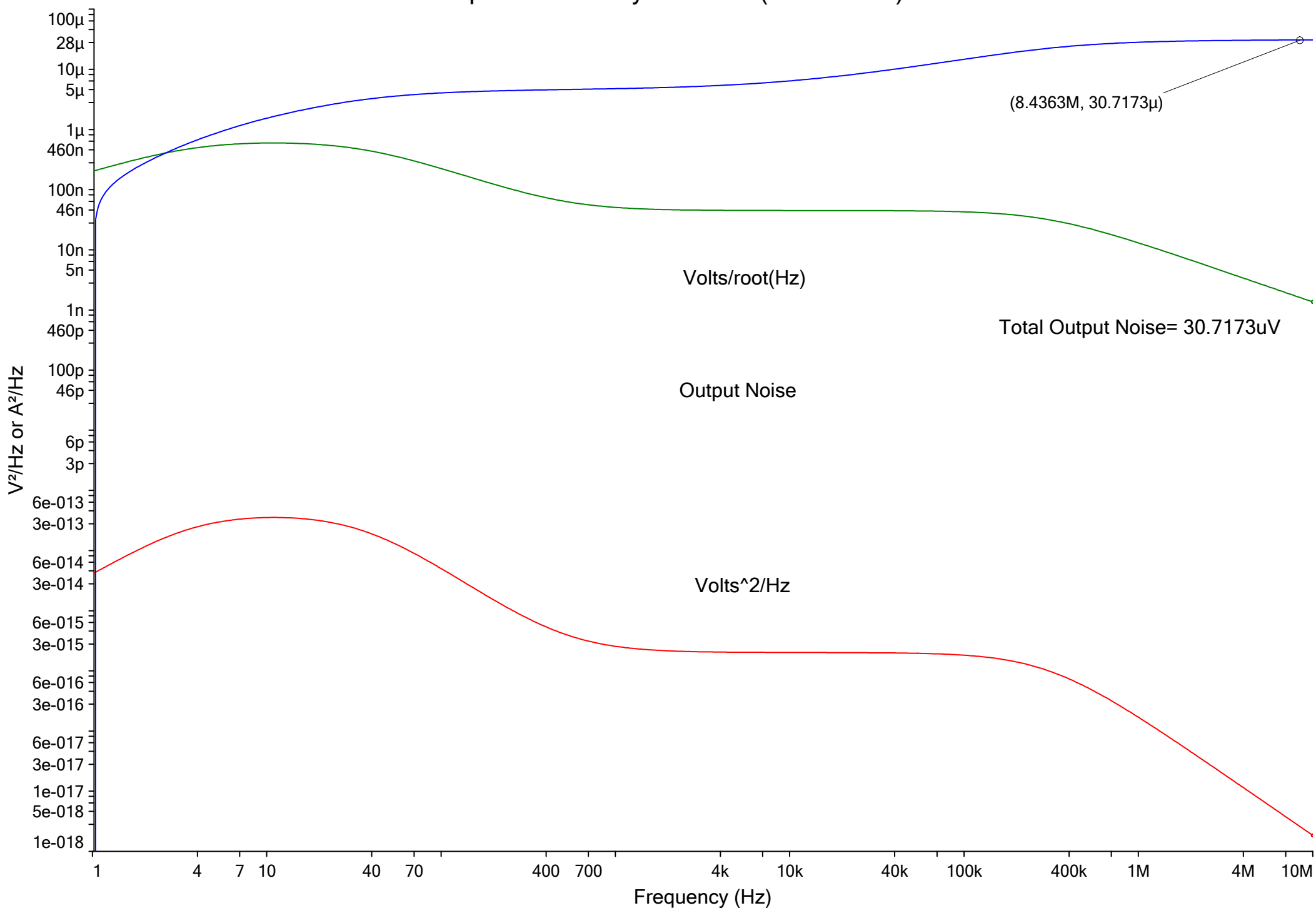


☒ V(out)

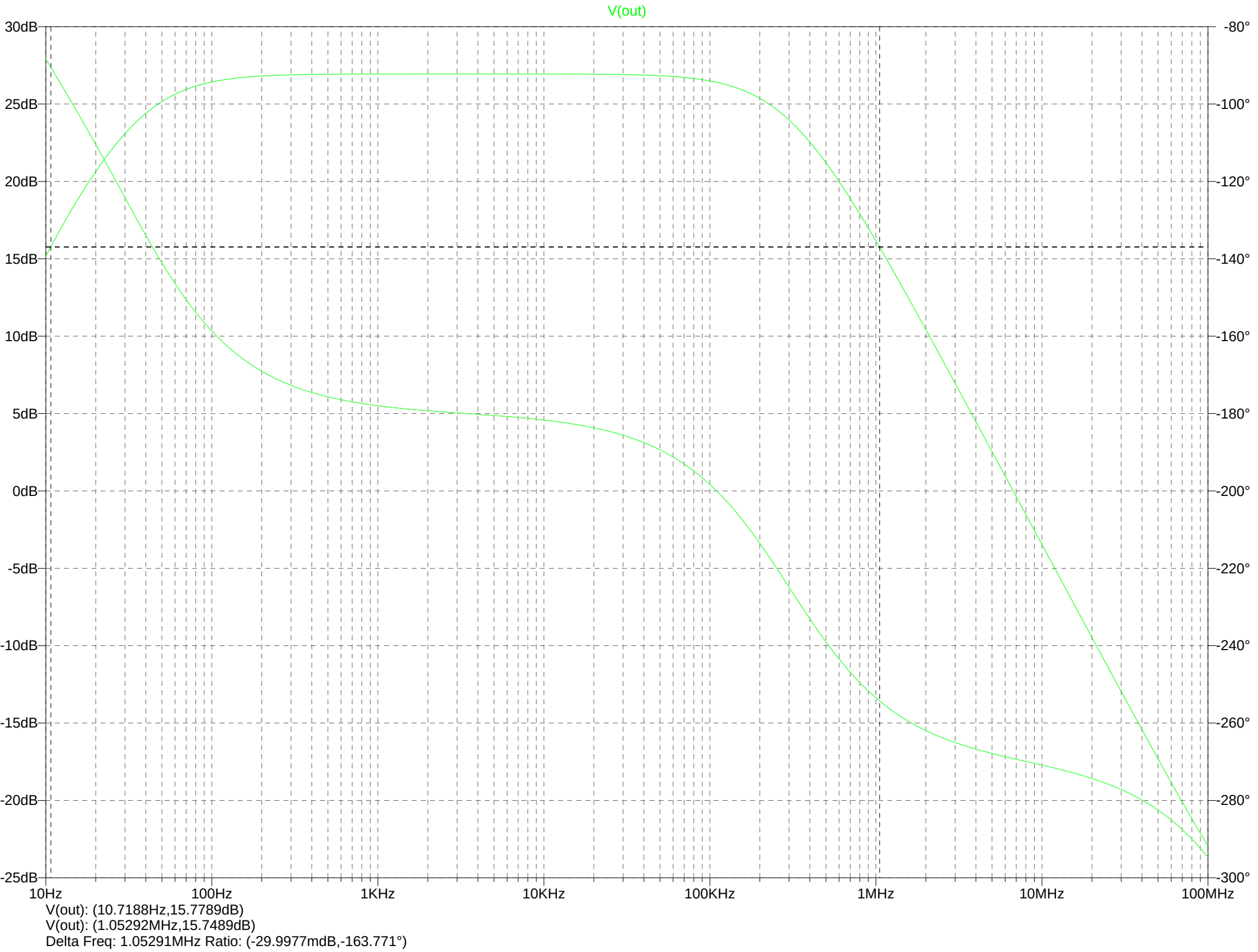
Common Emitter

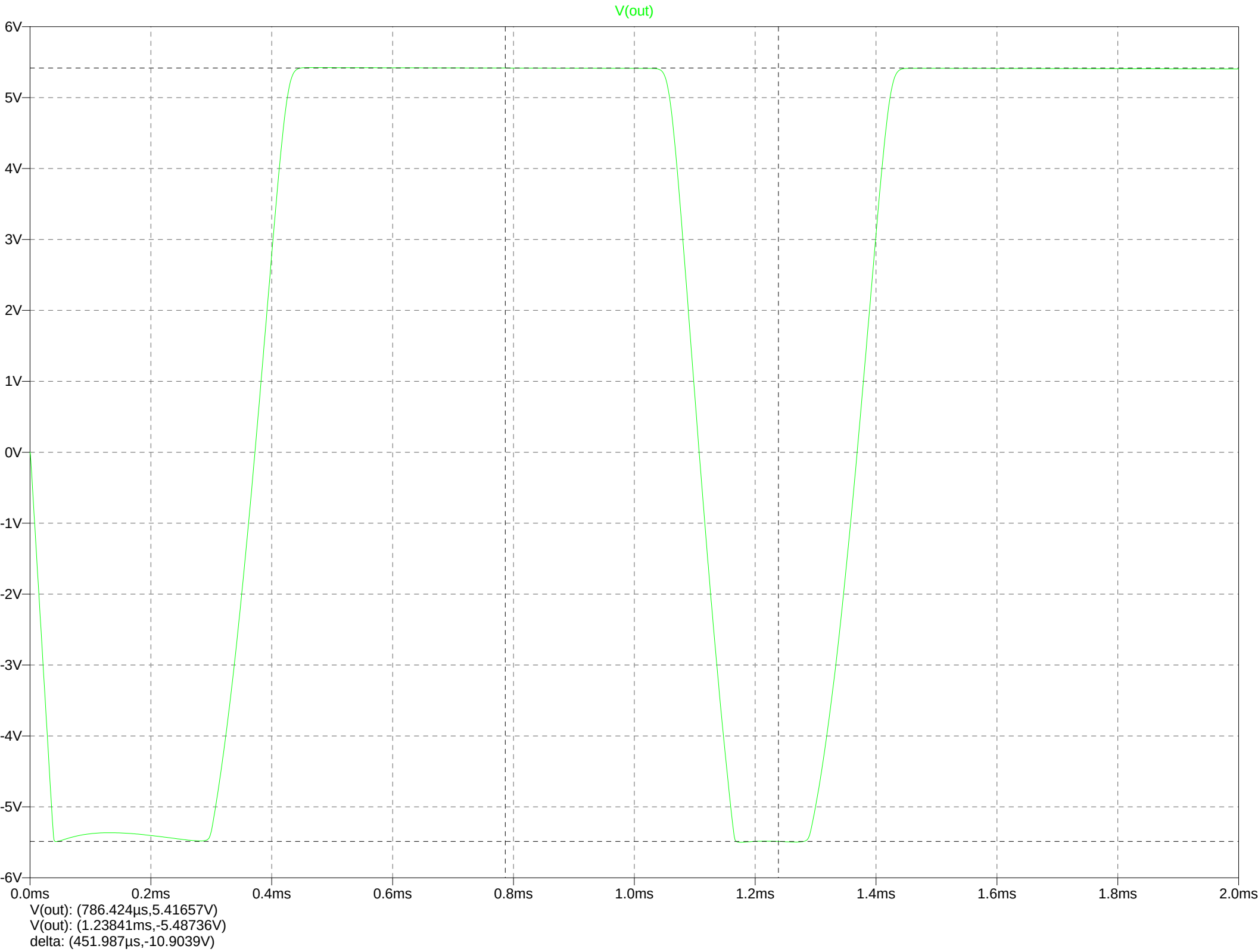
Printing Time: Sunday, August 25, 2013, 1:38:47 PM

Noise Spectral Density Curves - (V^2 or A^2)/Hz



```
COMMON EMITTER AMPLIFIER
VI 1 0 AC 1 SIN(0 1 1K)
C1 1 B 0.22U
VCC 3 0 DC 15
RB2 3 B 215.706K
RB1 B 0 52.769K
RC 3 C 6.8K
Q C B E BREW
.MODEL BREW NPN(IS=20F BF=200 VA=170 RB=10 CJC=3.6P TF=300P)
RE1 E 0 2K
CE E 5 100U
RE2 5 0 230.58
C2 C OUT 10U
RL OUT 0 22K
CL OUT 0 100P
.OP
.AC DEC 1000 10 100MEG
.TRAN 0 20M
.FOUR 1K V(OUT)
.NOISE V(OUT) VI DEC 1000 1 100MEG
.END
```







V(out): (999.036Hz,3.42558V)
V(out): (2.00527KHz,1.95918V)
Delta Freq: 1.00623KHz Ratio: (571.926m,-73.2939°)

--- Z:\Z_Red_Ruby\brewdoclece4043hww\TutorialSuper\Exp01CE\CE.fft ---

