EE142 Problem Set 9

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1 Review of Important Concepts

Assume a memoryless distortion circuit is modeled by $I_{out} = a_0 + a_1 V_{in} + a_2 V_{in}^2 + a_3 V_{in}^3$ and the input DC bias voltage is $V_{in,0}$.

(a) Derive IIP3, OIP3, IP_{1dB}, and IP_{3dB}

We begin by driving the circuit with a two-tone input with equal amplitude A and frequencies ω_1 and ω_2:

$$S_i = A\cos(\omega_1 t) + A\cos(\omega_2 t)$$

Now the full expanded form of the output can be derived:

$$\begin{aligned} S_o = \frac{9a_3}{4}A^3\cos(\omega_1 t) + \frac{A^3 a_3}{4}\cos(3\omega_1 t) + \frac{9a_3}{4}A^3\cos(\omega_2 t) + \frac{A^3 a_3}{4}\cos(3\omega_2 t) \\ + \frac{3a_3}{4}A^3\cos(2\omega_1 t + \omega_2 t) + \frac{A^2 a_2}{2}\cos(2\omega_1 t) + \frac{A^2 a_2}{2}\cos(2\omega_2 t) + \\ A^2 a_2\cos(\omega_1 t - \omega_2 t) + A^2 a_2\cos(\omega_1 t + \omega_2 t) + A^2 a_2 + Aa_1\cos(\omega_1 t) + Aa_1\cos(\omega_2 t) \end{aligned}$$

We define $IM3$ as $\frac{\text{Amplitude of one 3rd order IM product}}{\text{Amplitude of Fundamental}}$

$$\begin{aligned} IM3 &= \frac{3a_3/4 \cdot A^3}{Aa_1} \\ &= \frac{3}{4}\frac{a_3}{a_1}A^2 \end{aligned}$$

To find IIP3, set $|IM3| = 1$ and solve for A. OIP3 is just the IIP3 power referenced to the output.

$$\begin{aligned} IIP3 &= \sqrt{\frac{4}{3}\left|\frac{a_1}{a_3}\right|} \\ OIP3 &= IIP3 \cdot a_1 \end{aligned}$$

IP_{1dB} is defined by using a single-tone input and checking at what input power level the circuit's apparent gain has dropped by 1dB.

$$S_o = \frac{3a_3}{4}A^3\cos(\omega_1 t) + \frac{A^3 a_3}{4}\cos(3\omega_1 t) + \frac{A^2 a_2}{2}\cos(2\omega_1 t) + \frac{A^2 a_2}{2} + Aa_1\cos(\omega_1 t)$$

$$\text{Apparent Gain} = \frac{a_1 A + \frac{3}{4}a_3 A^3}{A}$$

$$= a_1(1 + \frac{3}{4}\frac{a_3}{a_1}A^2)$$

$$20\log(1 + \frac{3}{4}\frac{a_3}{a_1}A^2) = -1dB$$

$$IP_{1dB} = \sqrt{\frac{4}{3}|\frac{a_1}{a_3}|}\cdot\sqrt{0.11}$$

$$IP_{3dB} = \sqrt{\frac{4}{3}|\frac{a_1}{a_3}|}\cdot\sqrt{0.085}$$

(b) If IIP3 is 10V, what is the input-blocker level that degrades the small-signal gain of the desired signal by 2dB?

We model an input signal $S_i = A\cos(\omega_1 t) + B\cos(\omega_2 t)$, where ω_1 is the blocker, ω_2 is the desired tone, and A and B are their magnitudes with $A >> B$.

We want to look at the cubic terms in S_o, the output signal.

$$S_o \text{ contains } \frac{3a_3}{2}A^2 B\cos(\omega_2 t)$$

$$\text{Apparent Gain} = \frac{a_1 B + a_3\frac{3}{2}A^2 B}{B}$$

$$= a_1(1 + \frac{3}{2}\frac{a_3}{a_1}A^2)$$

$$= a_1(1 + \frac{2}{IIP3^2}A^2)$$

$$20\log(1 + \frac{2}{IIP3^2}A^2) = -2dB$$

$$V_{blocker,max} = 2.188 \text{ V}$$

(c) Following part (b), what will be the tolerable blocker levels for a two-tone blocker?

We consider the following input signal: $A\cos(\omega_d t) + B\cos(\omega_{b1} t) + B\cos(\omega_{b2} t)$

Looking at the terms that contribute to ω_d, we find the blocker term:

$$S_o \text{ contains } = 3AB^2 a_3$$

this is just as expected since with two blocker tones, they will each contribute a blocking term to the desired signal. So, $V_{blocker,max} = 1.094$ V

(d) If IIP3 is 10V, what are the IP_{1dB} for two-tone and three-tone input signals?

$$IP_{1dB,one-tone} = \sqrt{\frac{4}{3}|\frac{a_1}{a_3}|} \cdot \sqrt{0.11} = 3.32 \text{ V}$$

$$IP_{1dB,two-tone} = \sqrt{\frac{4}{9}|\frac{a_1}{a_3}|} \cdot \sqrt{0.11} = 1.9 \text{ V}$$

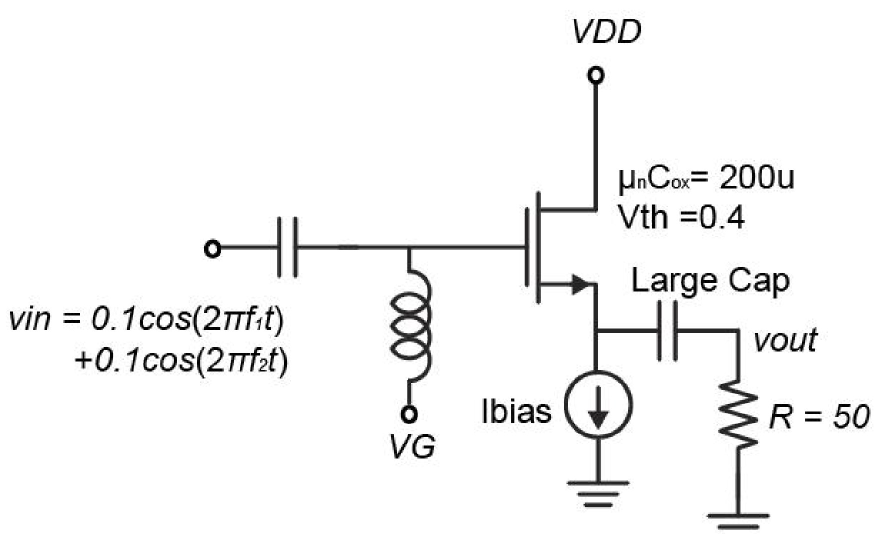
$$IP_{1dB,three-tone} = \sqrt{\frac{4}{15}|\frac{a_1}{a_3}|} \cdot \sqrt{0.11} = 1.48 \text{ V}$$

(e) If the modeled circuit is a BJT with $I_{out} = I_s \exp(V_{be}/V_T)$, use a math tool to find the actual output third-harmonic current as a function of the input magnitude. Compare the actual values to the estimated values via the power series.

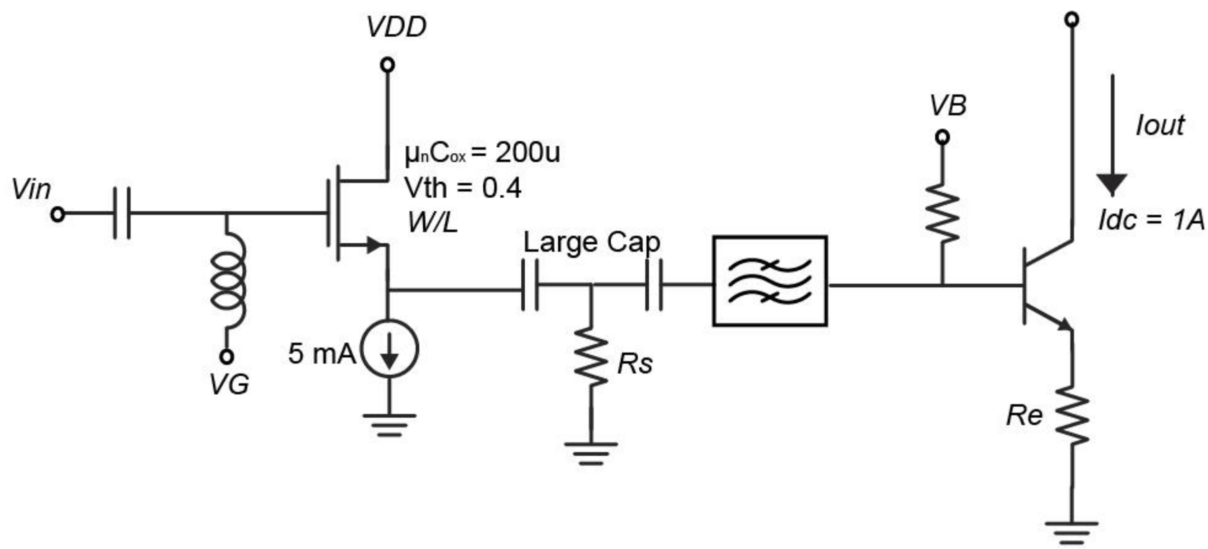
2 Distortion of a Source Follower

For the source follower shown below, calculate the required bias current (I_{bias} and W/L for the long-channel transistor to drive the load with a swing of 100 mV (at both f_1 and f_2), with IM3 equal to -50 dBc.

Correction: vout= 0.1cos(2pi*f1*t)+0.1cos(2pi*f2*t) vin magnitude is not specified



3 Pre-distortion and Source-degeneration Linearizer



(a) For the above schematic, what are the OIP3 of the BJT stage for $R_e = 0\Omega$ and $R_e = 0.02\Omega$?

(b) What are the two possible R_e for the BJT stage to have an OIP3 of 10A?