

Design a Class-A power amplifier operating from a 2 V supply with output power  $P_{out}=20$  dBm or 150mW at  $f_o=1$  GHz and determine the following parameters.

- Output power ( $P_{out}$  dBm).
- Power added efficiency (PAE %).
- 1 dB compression point (P1dB).
- Third order intercept (IP3).

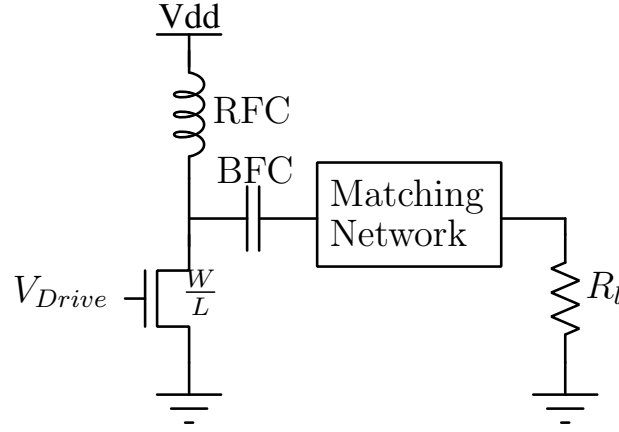


Figure 1: Typical schematic of a CMOS Class-A power amplifier.

$$P_{max} = \frac{V_{dd}^2}{2R_l} \quad (1)$$

Given  $V_{dd}=2$  V and  $R_l=50 \Omega$  we achieve a  $P_{out}=40$ mW ?? 4 times lower than the required 150mW.

Use a matching network to transform the load impedance from  $R_l=50 \Omega$  to required from  $P_{max}$  relation.

Use the following equations for low-pass matching network.

$$Q = \sqrt{\frac{R_l}{R_{in}} - 1} \quad (2)$$

$$C_1 = \frac{Q}{\omega R_l} \quad (3)$$

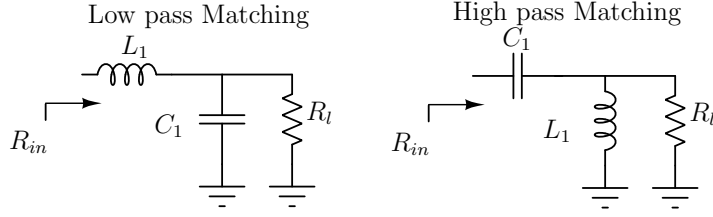


Figure 2: L-match configuration.

$$L_1 = \frac{1}{\omega^2 C_1} \frac{Q^2}{1 + Q^2} \quad (4)$$

and the following for high-pass matching network.

$$Q = \sqrt{\frac{R_l}{R_{in}} - 1} \quad (5)$$

$$L_1 = \frac{R_l}{\omega Q} \quad (6)$$

$$C_1 = \frac{1}{\omega^2 L_1} \left(1 + \frac{1}{Q^2}\right) \quad (7)$$

Design guideline,

- Always transform the load impedance to a value lower than computed, to account for various losses.
- Choose a high-pass or a low-pass matching network with either a parallel or a series resonator.
- Size the width of NMOS transistor for an effective  $R_{on} \approx 0.3 \Omega$ , .
- RFC impedance needs to be atleast 10 times the transformed load impedance  $\omega L_{RFC} \approx 10 * R_{in}$ , compute  $L_{RFC}$  at  $\omega$ .
- The NMOS is biased in saturation mode, initial point of reference is  $\frac{V_{dd}}{2}$ .

Perform HB analysis setup with reference to the below screenshots.

**Edit Object Properties**

Apply To:

Show: ☐ system ☒ user ☒ CDF

| Property      | Value     | Display                            |
|---------------|-----------|------------------------------------|
| Library Name  | analogLib | <input type="button" value="off"/> |
| Cell Name     | port      | <input type="button" value="off"/> |
| View Name     | symbol    | <input type="button" value="off"/> |
| Instance Name | PORT2     | <input type="button" value="off"/> |

| User Property | Master Value | Local Value | Display                            |
|---------------|--------------|-------------|------------------------------------|
| Ivignore      | TRUE         |             | <input type="button" value="off"/> |

| CDF Parameter               | Value                    | Display                            |
|-----------------------------|--------------------------|------------------------------------|
| Resistance                  | 50 Ohms                  | <input type="button" value="off"/> |
| Reactance                   |                          | <input type="button" value="off"/> |
| Port number                 |                          | <input type="button" value="off"/> |
| DC voltage                  | BIAS V                   | <input type="button" value="off"/> |
| Source type                 | sine                     | <input type="button" value="off"/> |
| Frequency name 1            | IN                       | <input type="button" value="off"/> |
| Frequency 1                 | 1G Hz                    | <input type="button" value="off"/> |
| Amplitude 1 (Vpk)           |                          | <input type="button" value="off"/> |
| Amplitude 1 (dBm)           | IN_A                     | <input type="button" value="off"/> |
| Phase for Sinusoid 1        |                          | <input type="button" value="off"/> |
| Sine DC level               |                          | <input type="button" value="off"/> |
| Delay time                  |                          | <input type="button" value="off"/> |
| Display second sinusoid     | <input type="checkbox"/> | <input type="button" value="off"/> |
| Display multi sinusoid      | <input type="checkbox"/> | <input type="button" value="off"/> |
| Display modulation params   | <input type="checkbox"/> | <input type="button" value="off"/> |
| Display small signal params | <input type="checkbox"/> | <input type="button" value="off"/> |
| Display temperature params  | <input type="checkbox"/> | <input type="button" value="off"/> |
| Display noise parameters    | <input type="checkbox"/> | <input type="button" value="off"/> |
| Multiplier                  |                          | <input type="button" value="off"/> |

Figure 3: Set the input port parameters as shown.

**Choosing Analyses -- ADE L (1)**

☐ qpxf   ☐ qpss   ☒ hb   ☐ hbac  
☐ hbnoise

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Harmonic Balance Analysis

Transient-Aided Options

Run transient?

Detect Steady State ☐ Stop Time(tstab) 100n

Save Initial Transient Results (saveinit) ☐ no ☐ yes

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Tones ☐ Frequencies ☒ Names

Tones

| # | Name | Expr | Value | Mchan | Ovsap | Tstab | SrcId |
|---|------|------|-------|-------|-------|-------|-------|
| 2 | IN   | 1G   | 1G    | 20    | 2     | no    | PORT2 |

Freqdivide Ratio for tone with Tstab

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Harmonics

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Accuracy Defaults (errpreset)

☐ conservative   ☒ moderate   ☐ liberal

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Oscillator ☐

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Sweep  ☒

Variable

Frequency Variable? ☒ no ☐ yes

Variable Name

Sweep Range

☒ Start-Stop   Start  Stop   
☐ Center-Span

Sweep Type

☒ Linear   ☐ Step Size   
☐ Logarithmic   ☒ Number of Steps

Add Specific Points ☐

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Enabled ☒

Figure 4: HB setup sweeping the input power from -40dBm to 10 dBm to compute P1dB compression point and IP3.

**Direct Plot Form**

Plotting Mode **Append**

**Analysis**

☒ hb

**Function**

☐ Voltage ☐ Current  
☒ Power ☐ Voltage Gain  
☐ Current Gain ☐ Power Gain  
☐ Transconductance ☐ Transimpedance  
☐ Compression Point ☐ IPN Curves  
☐ Power Contours ☐ Reflection Contours  
☐ Harmonic Frequency ☐ Power Added Eff.  
☐ Power Gain Vs Pout ☐ Comp. Vs Pout  
☐ Node Complex Imp. ☐ THD

Select **Port ( fixed R(port) )**

**Sweep**

☐ spectrum ☒ variable

**Modifier**

☐ Magnitude ☐ dB10 ☒ dBm

Output Harmonic

|   |    |
|---|----|
| 0 | 0  |
| 1 | 1G |
| 2 | 2G |
| 3 | 3G |
| 4 | 4G |
| 5 | 5G |
| - | -  |

Loadpull Contour ☐

Add To Outputs ☐

> Select Port on schematic...

**OK** Cancel Help

Figure 5: HB form window to plot  $P_{out}$ , PAE %, P1dB and IPN .

**Direct Plot Form**

Plotting Mode **Append**

**Analysis**

☒ hb

**Function**

☐ Voltage ☐ Current  
☐ Power ☐ Voltage Gain  
☐ Current Gain ☐ Power Gain  
☐ Transconductance ☐ Transimpedance  
☒ Compression Point ☐ IPN Curves  
☐ Power Contours ☐ Reflection Contours  
☐ Harmonic Frequency ☐ Power Added Eff.  
☐ Power Gain Vs Pout ☐ Comp. Vs Pout  
☐ Node Complex Imp. ☐ THD

Select **Port ( fixed R(port) )**

Format **Output Power**

Compression Point/Curve **Input-referred**

Gain Compression (dB) **1**

"IN\_A" ranges from -40 to 10  
 Input Power Extrapolation Point (dBm)   
 (Defaults to -40)

**Input Referred 1dB Compression**

1st Order Harmonic

|   |    |
|---|----|
| 0 | 0  |
| 1 | 1G |
| 2 | 2G |
| 3 | 3G |
| 4 | 4G |
| 5 | 5G |
| - | -  |

Loadpull Contour ☐

Add To Outputs ☐ **Replot**

> Select Port on schematic...

**OK** Cancel Help

Figure 6: P1dB 1dB compression point.

**Direct Plot Form**

Plotting Mode: Append

**Analysis**

☒ hb

**Function**

☐ Voltage ☐ Current  
☐ Power ☐ Voltage Gain  
☐ Current Gain ☐ Power Gain  
☐ Transconductance ☐ Transimpedance  
☐ Compression Point ☒ IPN Curves  
☐ Power Contours ☐ Reflection Contours  
☐ Harmonic Frequency ☐ Power Added Eff.  
☐ Power Gain Vs Pout ☐ Comp. Vs Pout  
☐ Node Complex Imp. ☐ THD

Select: Port ( fixed R(port) )

Circuit Input Power: ☐ Single Point ☒ Variable Sweep ("IN\_A")

"IN\_A" ranges from -40 to 10  
 Input Power Extrapolation Point (dBm) (Defaults to -40)

Input Referred IP3: ☐ Carrier ☒ 3rd

| 3rd Order Harmonic |    | 1st Order Harmonic |    |
|--------------------|----|--------------------|----|
| 0                  | 0  | 0                  | 0  |
| 1                  | 1G | 1                  | 1G |
| 2                  | 2G | 2                  | 2G |
| 3                  | 3G | 3                  | 3G |
| 4                  | 4G | 4                  | 4G |
| 5                  | 5G | 5                  | 5G |

Add To Outputs ☐ Replot

> Select Port on schematic...

OK Cancel Help

Figure 7: IP3, input power level at which the fundamental and third harmonic have the same power level.