Bias Lecture

Go over each of the following circuits. Discuss the function of each component: $R_l, R_s, R_1, R_2, Q1, M1, C_c$

Figure 1: Single resistor biasing of the emitter degenerated common emitter amplifier

In particular, describe the use of the Regenerating resistor to stabilize the circuit against thermally induced drift. Make the point that this is the first practical use of negative feedback that they have encountered.

Describe the need for the bias circuit - without it the amplifier won’t “turn on” until $V_{in}$ gets above 0.7 volts. This isn’t suitable for amplifying small signals. Also, Describe the fact that you can “center” the amplifier in its range (i.e., make $V_o = V_{dd}/2$, for example). This gives maximum “dynamic range.

For circuit 1, you begin by choosing $R_l$. Take it to be, say 5000Ω. Also, take $V_{dd}$ to be 5 volts. We are also free to choose $R_s$. It should be small (why?) Make it 100Ω. To center the output in “quiescence” (i.e., when the input signal is zero), $V_o$ must be 2.5V and $I_c$ must be 0.5mA. Thus, $I_b$ must be $I_c/\beta$ If $\beta$ is 100, $I_b$ is 5μA. So the question becomes: how do we choose $R_1$ to make the base drive current 5 microamps?
Figure 2: H-Bias scheme for the emitter degenerated common emitter

Figure 3: H-bias scheme for the source degenerated common source amplifier
We do this by writing the Kirchoff voltage law as:

\[ I_b R_1 + 0.7 + R_s(I_b + I_c) = I_b R_1 + 0.7 + R_s(I_b + 100I_b) = V_{cc} \]  

(1)

This allows you to solve for \( R_1 \), since \( I_b \), \( R_l \) and \( R_s \) are known:

\[ R_1 = \frac{V_{cc} - 0.7}{I_b} + 101R_s \]  

(2)

or \( R_1 = 870,000\Omega \).

You can solve circuit 2 the same way. Only you replace the H-bias resistors (\( R_1, R_2 \) and the \( V_{cc} \) source by their Thevenin equivalent. Here:

\[ V_{th} = \frac{R_2}{R_1 + R_2} V_{cc} \]  

(3)

and:

\[ R_{th} = \frac{R_1 R_2}{R_1 + R_2} \]  

(4)

You are free to choose either \( R_1 \) or \( R_2 \), but not both!

For circuit three, requiring that the output is “centered in quiescence” determines \( I_{ds} \). If \( R_l \) is 5000\( \Omega \) again, \( I_{ds} \) is .5 mA (again). So you now “engineer” a bias network (\( R_1, R_2 \) to create a \( V_{gs} \) to supply that \( I_{ds} \). Begin by noting that \( V_s \) is \( I_{ds} R_s \). If \( R_s \) is, again 100\( \Omega \), \( V_s \) is 50mV. So all we need is to get a \( V_g \) to do the job.

Of course, you make the going in assumption that the transistor is operating in saturation:

\[ I_{ds} = \frac{k_m}{2} (V_{gs} - V_{th})^2 \]  

(5)

Knowing \( k_m \) and \( V_{th} \) allow you to solve for \( I_{ds} \). But what’s \( V_{th} \)? Well, its just the manufacturer’s increased by body effect! But as the source reverse bias is small (50mV) the body effect threshold increase is similarly small.

Let’s take the \( k_m/2 \) factor in eq. 5 to be 1mS (= 10\(^{-3}\)). The question is what gate voltage is necessary to get the 0.5mA needed to get the output to sit at \( V_{dd}/2 = 2.5V \)?

Let’s take \( V_{th} \) as given and equal to 1V. We simply solve:

\[ .5 \times 10^{-3} = 10^{-3} (V_g - 0.05 - 1)^2 \]  

(6)

which is simply eq.5 (with what we know filled in). This solves for \( V_g = 1.76V \). Is this enough to put the transistor into saturation (the necessary condition for eq. 5 to hold)? Well \( V_g - V_s = 1.7V \), bigger than a threshold. So the transistor is on. \( V_d \) is the output voltage (2.5V), and \( V_d - V_g = 2.5 - 1.76 = 0.75V \), which is less than a threshold. Thus the inversion is pinched off on the drain side, and the transistor is in saturation.
To get the bias resistor values, realize that:

\[ V_g = rV_{dd} \]  \hspace{1cm} (7)

where \( r \) is the divider ratio:

\[ r = \frac{R_2}{R_1 + R_2} \]  \hspace{1cm} (8)

For the case at hand, \( r \) must be \( 1.76/5 = 0.35 \). ANY combination of resistors with this \( r \) will do!