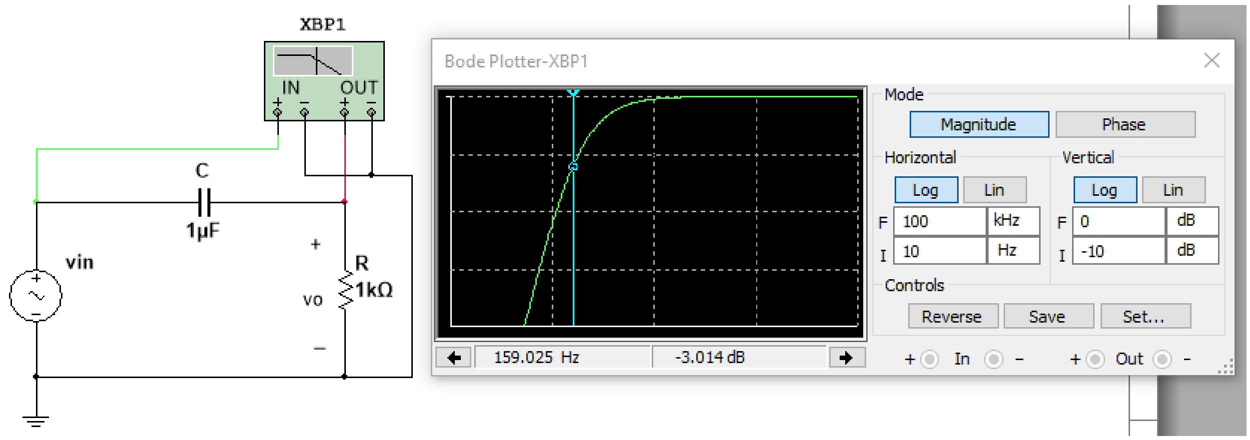
Chapter 5

Common Emitter and Common Source Low Frequency Response

1. Simple RC First Order System



We can see that for this simple RC source-driven system,

$$\frac{v_0(j\omega)}{v_{in}(j\omega)} = \frac{R}{R + \dfrac{1}{jC\omega}}$$

$$= \frac{jRC\omega}{1 + jRC\omega}$$

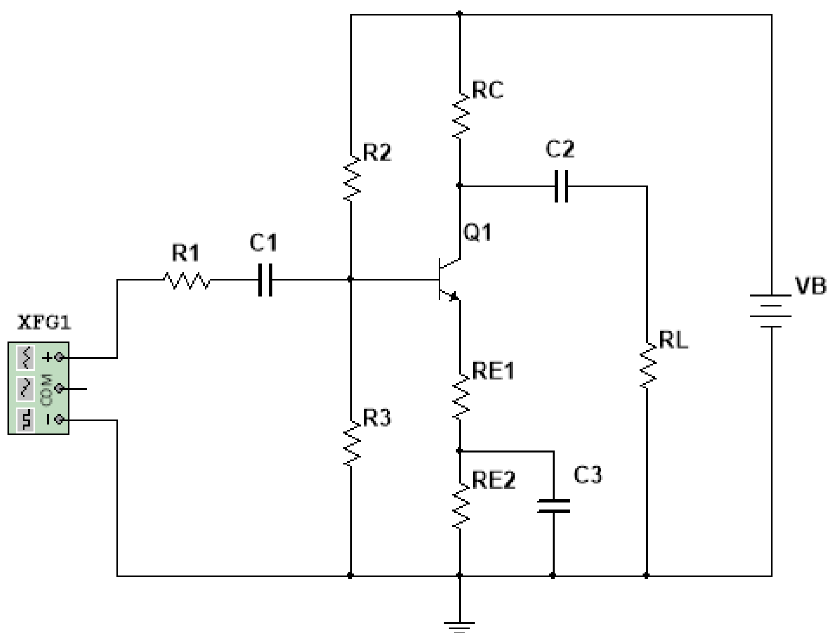
$$= \frac{jRC\omega}{1 + j\dfrac{\omega}{\dfrac{1}{RC}}}$$

$$= \frac{jRC\omega}{1 + j\dfrac{\omega}{\omega_c}}, \text{ where } \omega_c = \frac{1}{RC} \text{ is the 3-dB cutoff frequency}$$

$$or \;\; f_c = \frac{1}{2\pi RC}, \text{ and in this case, } f_c = 159.16\,Hz$$

2. Midband Short-Circuit Time-Constant Method
BJT-Based Common Emitter Amplifier with Emitter Degeneration

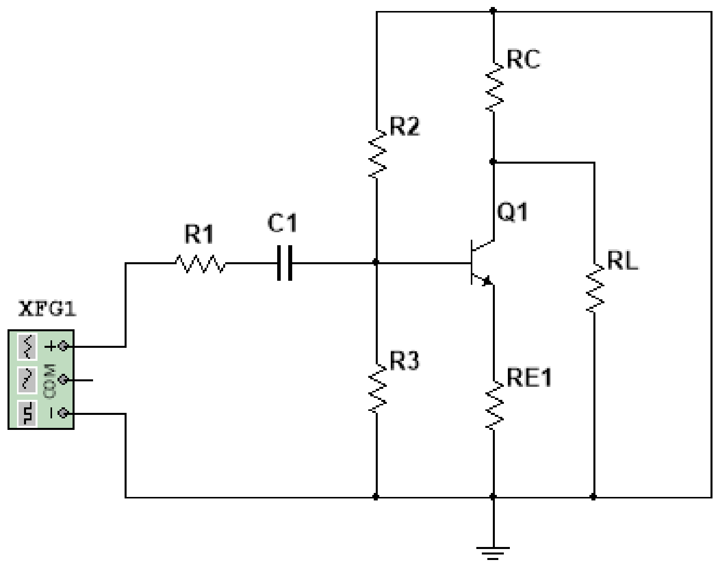
In this section, we are going to assume that each capacitor is a short circuit ($C \longrightarrow \infty$) except the one under consideration. From a practical point of view, we will assume that the impedance of any capacitor at midband frequencies will be negligible compared to the resistor connected to its terminals.



2.1 Choice of C_1

Let V_B, C_2 and C_3 be replaced by shorts.

Since the Thevenin equivalent of the circuit to the right of C_1 is just a resistor whose resistance is equal to the input resistance seen from the base, then the RC circuit is made of the input source, C_1, and the series combination of R_1 and R_{inb} such that
$R_{inb} = R_2//R_3//((r\pi + (\beta_0+1)R_{E1})$
Since we want the impedance of the capacitor at midband to be negligible compared to the resistance R_1+R_{inb}



$$\frac{1}{C_1\omega_{midband}} \ll (R_1 + R_{inb})$$

$$C_1 \gg \frac{1}{(R_1 + R_{inb})\omega_{midband}}, \text{hence}$$

$$C_1 = \frac{10}{R_{FC1}\omega_{midband}}, \text{where we use 10 fold as much larger}$$

$$\text{and } R_{FC1} = R_1 + R_2 // R_3 //(r_\pi + (\beta_0 + 1)R_{E1})$$

2.2 Choice of C_2

The analysis of C_2 is similar to the analysis of the effect of C_1 on the circuit.

2.3 Choice of C_2

Similarly, C_2 will see the series combination of R_L with the parallel combination of R_C and the output resistance seen from the collector, as obtained before for a common-emitter amplifier with emitter degeneration

$$R_{FC2} = R_L + R_C // r_0 \left(1 + \frac{\beta_0 R_{E1}}{R_{th} + r_\pi + R_{E1}}\right)$$

$$R_{th} = R_B // R_1 \qquad R_B = R_2 // R_3$$

$$\frac{1}{C_2\omega_{midband}} \ll R_{FC2}$$

$$C_2 \gg \frac{1}{R_{FC2}\omega_{midband}}, \text{hence}$$

$$C_2 = \frac{10}{R_{FC2}\omega_{midband}}, \text{where we use 10 fold as much larger}$$

2.4 Choice of C_3

The resistance seen by C_3 is R_{E2} in parallel with the series combination of R_{E1} and the output resistance seen from the emitter of the transistor
$R_{FC3} = R_{E2}//(R_{E1} + (1/g_m + R_{th}/\beta_0))$
$R_{th} = R_1//R_B$
$R_B = R_2//R_3$

$$\frac{1}{C_3\omega_{midband}} \ll R_{FC3}$$

$$C_3 \gg \frac{1}{R_{FC3}\omega_{midband}}, \text{hence}$$

$$C_3 = \frac{10}{R_{FC3}\omega_{midband}}, \text{where we use 10 fold as much larger}$$

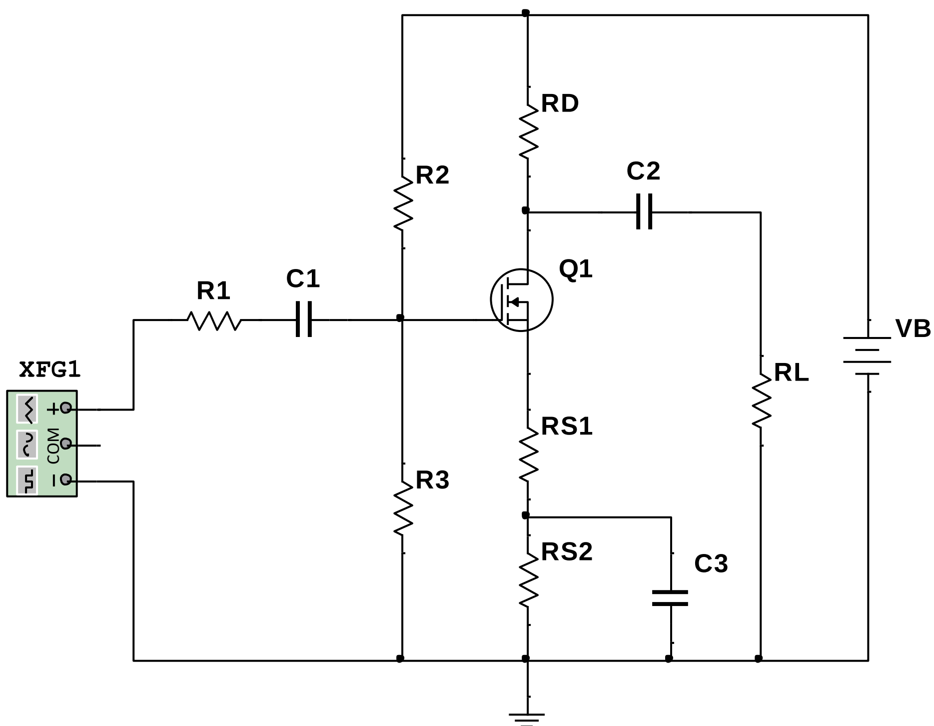
3. Midband Short-Circuit Time-Constant Method
MOSFET-Based Common Source Amplifier with Source Degeneration

The same reasons apply to a MOSFET amplifier as shown below. As long as we remember that a MOSFET is equivalent to a BJT with $r_\pi = \infty$, $\beta_0 = \infty$, but β_0/r_π is still g_m, we have the following expressions for the coupling capacitors and the bypass capacitor so that they have negligible impedance in midband, and hence can be approximated by short circuits.

$$C_1 = \frac{10}{R_{FC1}\omega_{midband}}, \qquad R_{FC1} = R_1 + R_2 // R_3$$

$$C_2 = \frac{10}{R_{FC2}\omega_{midband}}, \qquad R_{FC2} = R_L + R_D // r_0 \left(1 + g_m R_{S1}\right)$$

$$C_3 = \frac{10}{R_{FC3}\omega_{midband}}, \qquad R_{FC3} = R_{S2} // \left(R_{S1} + \frac{1}{g_m} \right)$$



4. Numerical Evaluations of the Required Capacitors

Let us assume that f = 800Hz is representative of midband.

```
ICQ=778e-6;VCEQ=4.1;VA=74.03;beta=136;
gm=40*ICQ;r0=(VA+VCEQ)/ICQ;rpi=beta/gm;fm=800;
R1=100;R2=100e3;R3=30e3;RC=4.7e3;RE1=600;RE2=1e3;RL=4.7e3;
RB=1/(1/R2+1/R3);Rth=1/(1/R1+1/RB);
RFC1=R1+RB;RFC2=RL+1/(1/RC+1/(r0*(1+beta*RE1/(Rth+rpi+RE1))));
RFC3=1/(1/RE2+1/(RE1+1/gm+Rth/beta));
C1=10/(RFC1*2*pi*fm);C2=10/(RFC2*2*pi*fm);C3=10/(RFC3*2*pi*fm);
disp('For the BJT configuration')
disp(['Capacitor C1 is equal to ',num2str(C1*1e9),' nF'])
```

```
disp(['Capacitor C2 is equal to ',num2str(C2*1e9),' nF'])
disp(['Capacitor C3 is equal to ',num2str(C3*1e6),' uF'])

fLB=1/(2*pi)*(1/(RFC1*C1)+1/(RFC2*C2)+1/(RFC3*C3));
disp(['The 3-dB cutoff frequency for a BJT-based common-emitter amplifier using the SCTC is ',num2str(fLB),' Hz'])

IDSQ=1.46e-3;VDSQ=4.33;Kn=0.1;lambda=1/50;
R1=100;R2=1000e3;R3=550e3;RD=2.5e3;RL=4.7e3;RS1=200;RS2=500;
gm=sqrt(2*Kn*IDSQ);r0=(1/lambda+VDSQ)/IDSQ;fm=800;
RG=1/(1/R2+1/R3);
RFC1=R1+RG;RFC2=RL+1/(1/RD+1/(r0*(1+gm*RS1)));
RFC3=1/(1/RS2+1/(RS1+1/gm));
C1=10/(RFC1*2*pi*fm);C2=10/(RFC2*2*pi*fm);C3=10/(RFC3*2*pi*fm);
disp(' ')
disp('For the MOSFET configuration')
disp(['Capacitor C1 is equal to ',num2str(C1*1e9),' nF'])
disp(['Capacitor C2 is equal to ',num2str(C2*1e9),' nF'])
disp(['Capacitor C3 is equal to ',num2str(C3*1e6),' uF'])

fLM=1/(2*pi)*(1/(RFC1*C1)+1/(RFC2*C2)+1/(RFC3*C3));
disp(['The 3-dB cutoff frequency for a MOSFET-based common-source amplifier using the SCTC is ',num2str(fLM),' Hz'])
```

For the BJT configuration

Capacitor C1 is equal to 85.837 nF

Capacitor C2 is equal to 211.9315 nF

Capacitor C3 is equal to 5.133 uF

The 3-dB cutoff frequency for a BJT-based common-emitter amplifier using the SCTC is 240 Hz

For the MOSFET configuration

Capacitor C1 is equal to 5.605 nF

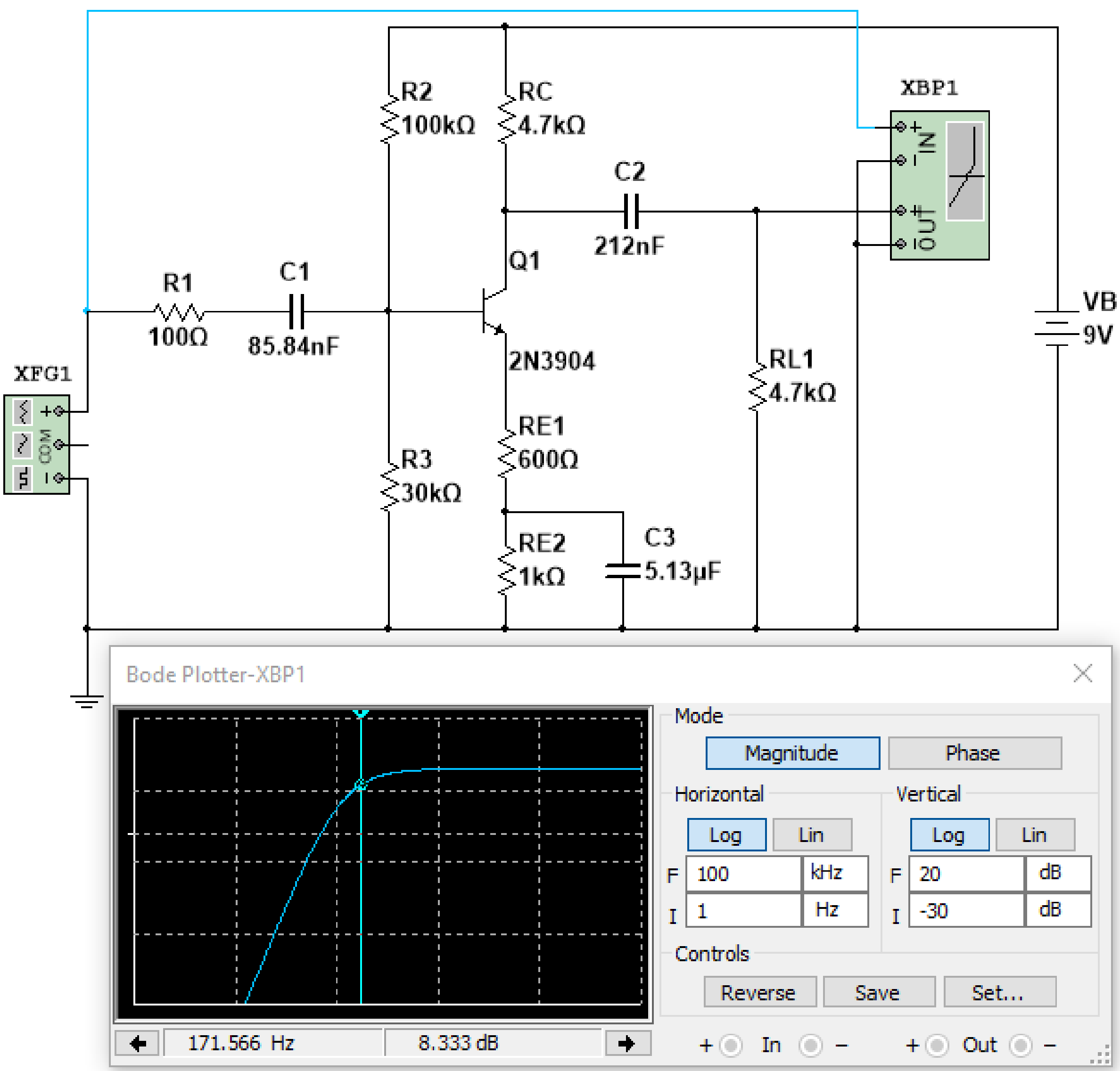
Capacitor C2 is equal to 277.7554 nF

Capacitor C3 is equal to 11.6743 uF

The 3-dB cutoff frequency for a MOSFET-based common-source amplifier using the SCTC is 240 Hz

Though this is just an example, note that the bypass capacitor C_3 will always be the larger of the three capacitors because RFC3 is the smaller of the three resistances involved in the calculations.

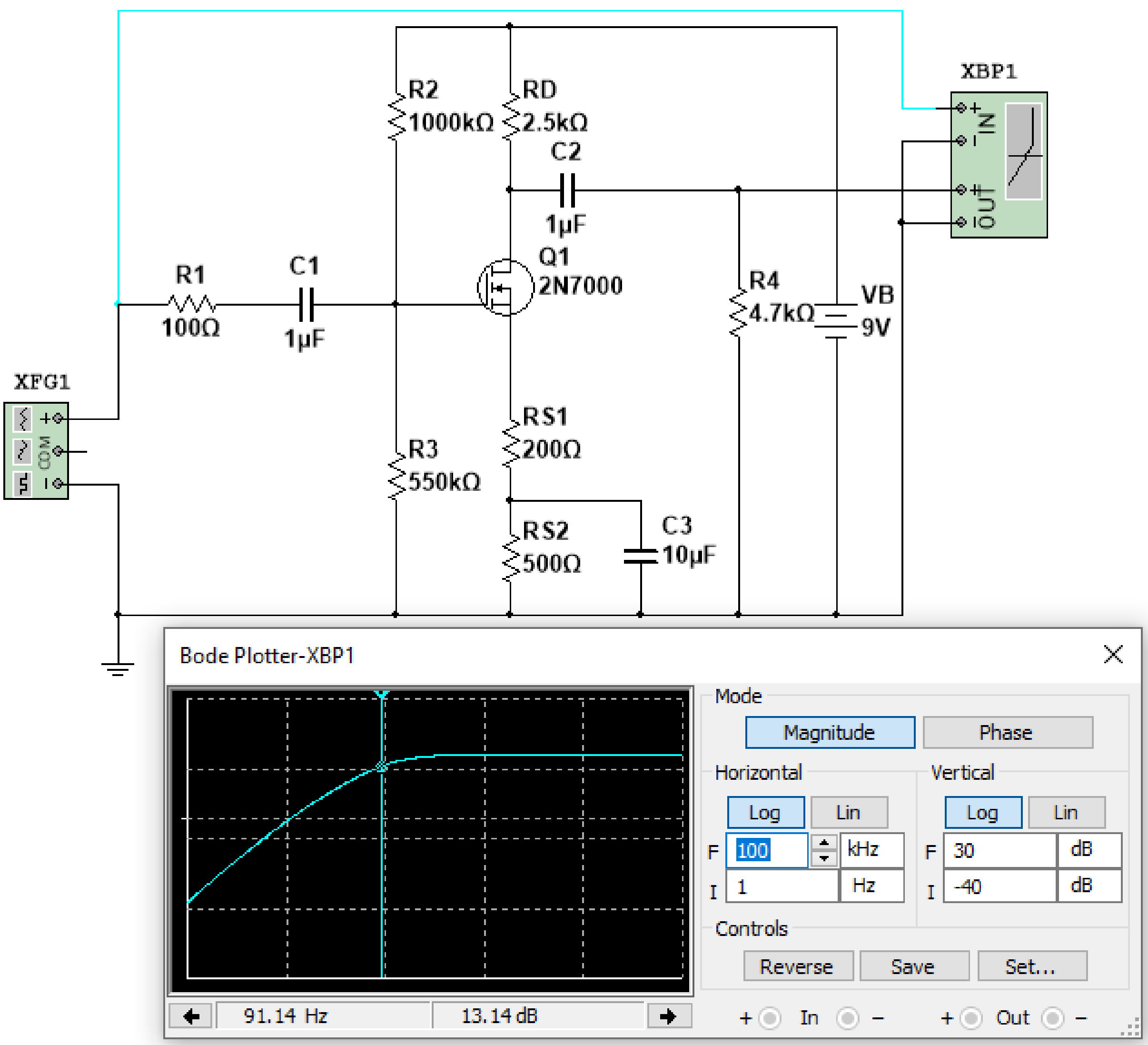
4.1 Frequency Response - BJT



In the kHz range, the gain is about 11.27dB, though at 800 Hz, the gain is only 11.13dB. The 3 dB cutoff frequency located at a gain equal to 8.27dB (we chose 8.33dB in Multisim) is 171.6 Hz. We will comment more on this frequency after we discuss the short-circuit time-constant method.

4.2 Frequency response – MOSFET

In the kHz range, the gain is about 15.7dB, though at 800 Hz, the gain is only 15.58dB (not much of a variation). The 3 dB cutoff frequency located at a gain equal to 12.7dB (we chose 12.71dB in Multisim) is 151.18 Hz. We again will comment more on this frequency after we discuss the short-circuit time-constant method.



5. Short-Circuit Time Constant Method

An acceptable approximation to the 3-dB cutoff frequency can be obtained as the sum of the inverse of the time constants $R_{FCi}C_i$, where R_{FCi} is the resistance seen by C_i when all the other capacitors are replaced by short circuits.

Since we have 3 capacitors (2 coupling and one bypass),

$$\omega_L \cong \frac{1}{R_{FC1}C_1} + \frac{1}{R_{FC2}C_2} + \frac{1}{R_{FC3}C_3}$$

However, since we chose the capacitors to satisfy

$$C_i = \frac{10}{R_{FCi}\omega_{midband}}$$

$$\omega_L \cong \frac{1}{R_{FC1}C_1} + \frac{1}{R_{FC2}C_2} + \frac{1}{R_{FC3}C_3}$$

$$\omega_L \cong \frac{1}{\frac{10}{\omega_{midband}}} + \frac{1}{\frac{10}{\omega_{midband}}} + \frac{1}{\frac{10}{\omega_{midband}}}$$

$$\omega_L \cong 3\frac{\omega_{midband}}{10}$$

Since $f_{midband}$ = 800 Hz,

F_L = 3*800/10 = 240 Hz for both BJT and MOSFET in this case

However, the 3-dB cutoff frequencies obtained through the Bode plotter in Multisim give us

BJT: f_L = 171.6 Hz approximately (31.7% variation)

MOSFET f_L = 151.2 Hz approximately (58.7% variation)

We can see that the evaluation of the approximation to the 3-dB cutoff frequency is not stellar, but in both cases, the practical cutoff frequency is smaller than the one evaluated through the SCTC (Short-Circuit Time-Constant Method). The approximation looks more like an upper bound; therefore, the amplifier performs better than the approximation would let us believe.