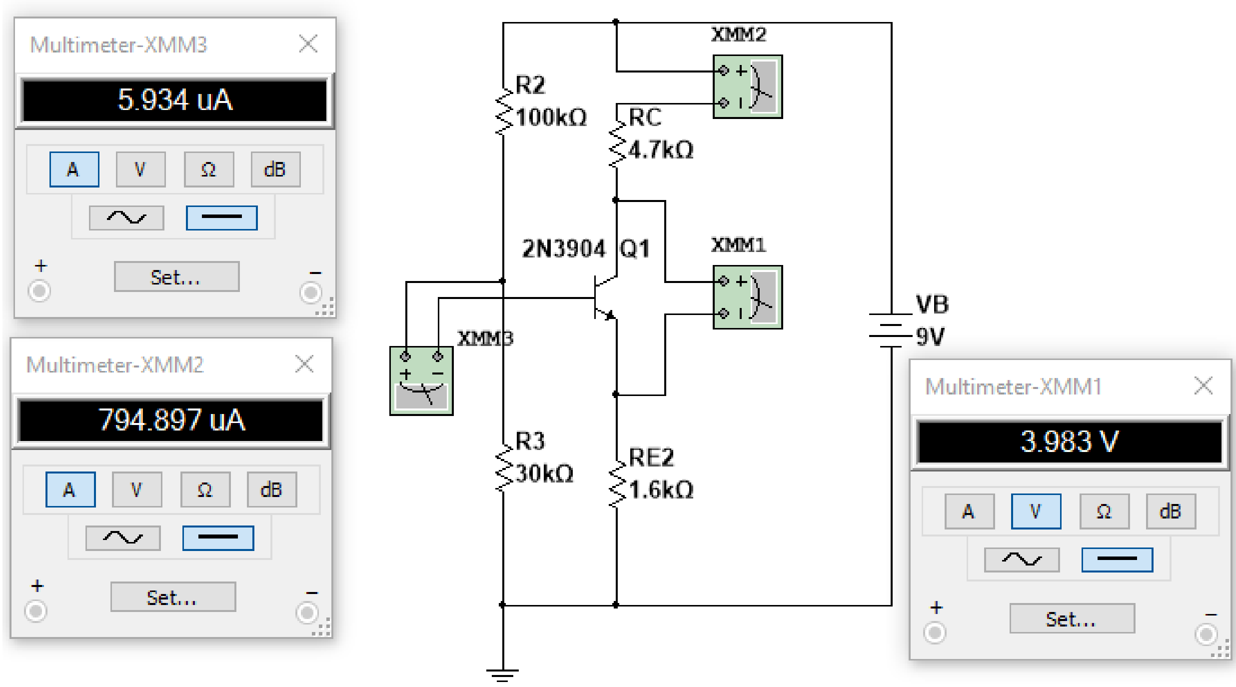
Chapter 3

Common Collector and Common Drain Configurations

1. DC Equivalents and Analysis of these Amplifiers

1.1BJT



Theoretically there is no need to perform the DC analysis since the circuit was kept similar from the DC point of view to the one presented in the case of the common-emitter amplifier

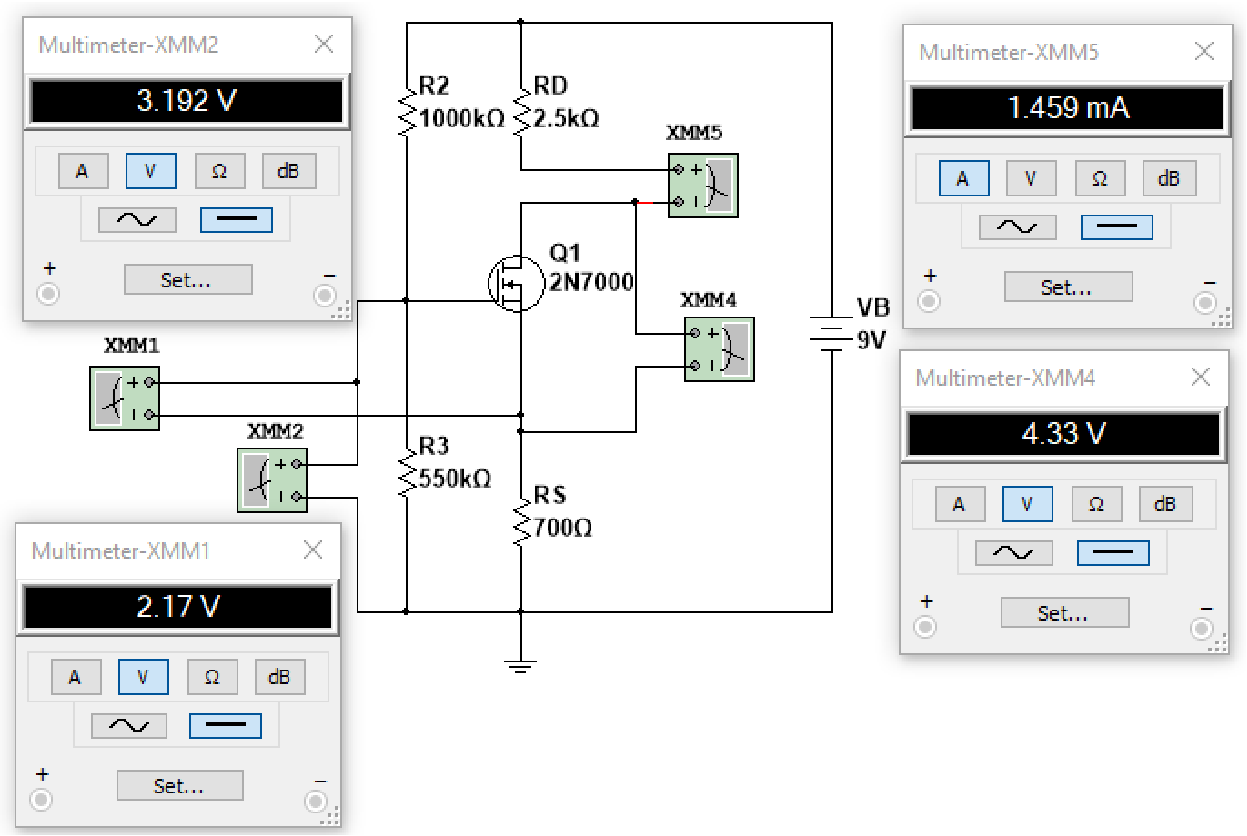
```
R2=100e3; R3=30e3; RB=1/(1/R2+1/R3);
Vbeq=0.7; RC=4.7e3; RE=1.6e3;
beta=136; VB=9; Vbb=R3/(R2+R3) *VB;
A= [RB/beta+RE,0; RC+RE,1];
B= [Vbb-Vbeq; VB];
X=A\B
VCEQ=VB-(RC+RE) *X
```

$I_{CQ} = 778\mu A$

$V_{CEQ} = 4.1V$

These numbers are close to the simulated values even though the ratio of the collector current to the base current is approximately 134. We again see how important some parameters are since a small variation of beta (less than 2 %) in a very minor variation of the Q-point. However, if we are facing a 4-fold increase of the beta ratio, there will be noticeable variations of the Q-point if it were not for the presence of R_C.

2.1 MOSFET



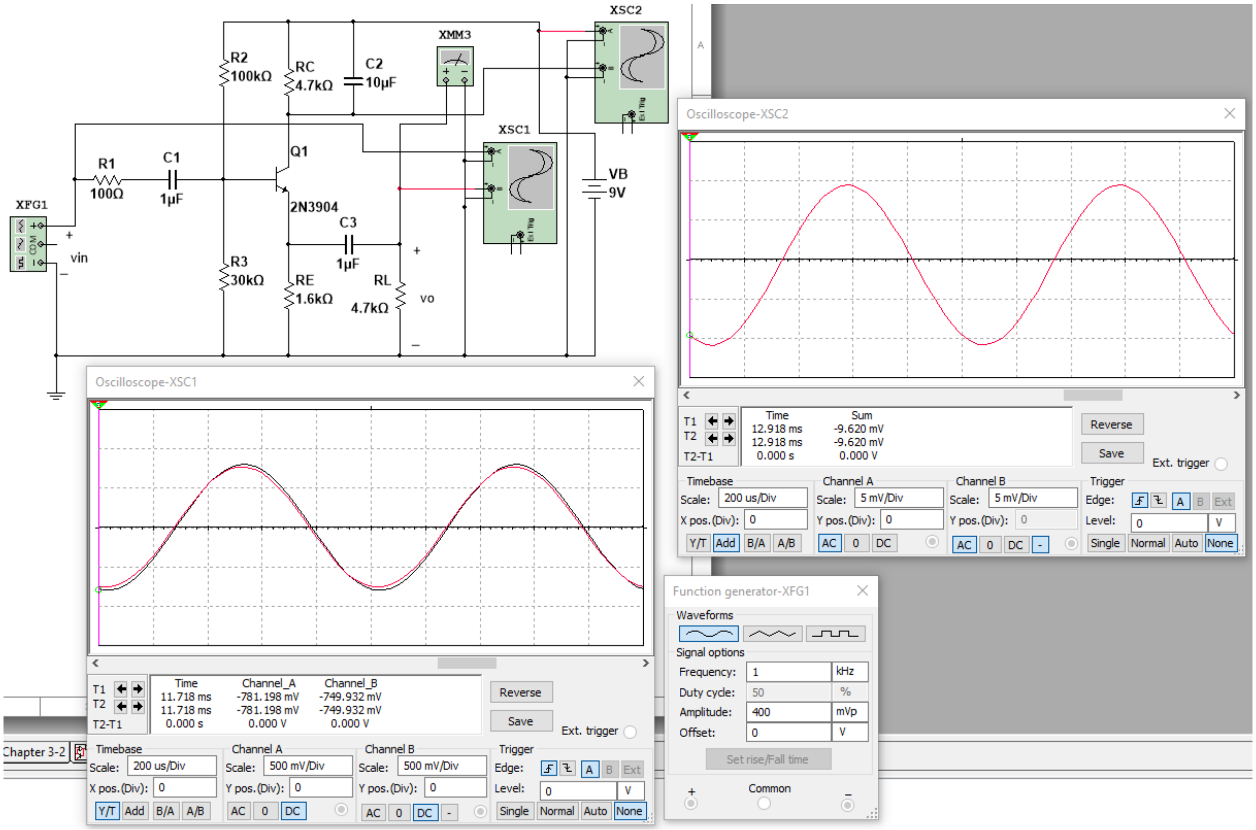
Even though it may not be an optimum choice of the Components values, and the location of the Q-point, we chose the same circuit that was presented as a common-emitter amplifier. Of course, the output will be accessible through the emitter rather than the collector, and the AC performance will be different, but from a DC point of view, the circuit will have the same characteristics. Hence,

I_{DS} = 1.46mA
V_{DS} = 4.34 V
V_{GS} = 2.17V
Since $V_{DS} > V_{GS} - V_{TN} > 0$, the assumption of a saturation region is valid.
These values verify the results obtained in the simulation.

2. AC Analysis

2.1 BJT

The circuit shown below is a common-collector configuration where the output is taken from the emitter, and the input is injected in the path of the base, hence sharing the collector.



Oscilloscope-XSC1

	Time	Channel_A	Channel_B
T1	11.718 ms	-781.198 mV	-749.932 mV
T2	11.718 ms	-781.198 mV	-749.932 mV
T2-T1	0.000 s	0.000 V	0.000 V

Timebase: Scale: 200 us/Div; X pos.(Div): 0; Y/T
Channel A: Scale: 500 mV/Div; Y pos.(Div): 0; DC
Channel B: Scale: 500 mV/Div; Y pos.(Div): 0; DC
Trigger: Edge: A; Level: 0 V; None

Oscilloscope-XSC2

	Time	Sum
T1	12.918 ms	-9.620 mV
T2	12.918 ms	-9.620 mV
T2-T1	0.000 s	0.000 V

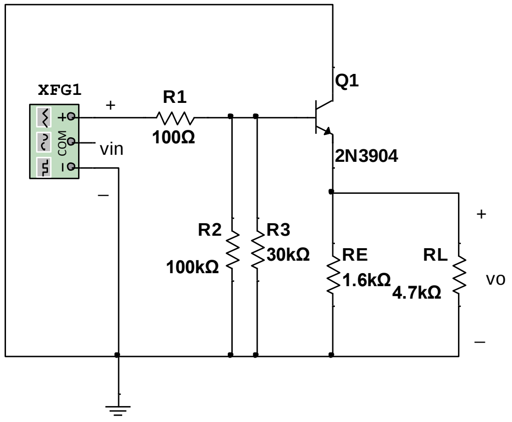
Timebase: Scale: 200 us/Div; X pos.(Div): 0; Add
Channel A: Scale: 5 mV/Div; Y pos.(Div): 0; AC
Channel B: Scale: 5 mV/Div; Y pos.(Div): 0; AC; -
Trigger: Edge: A; Level: 0 V; None

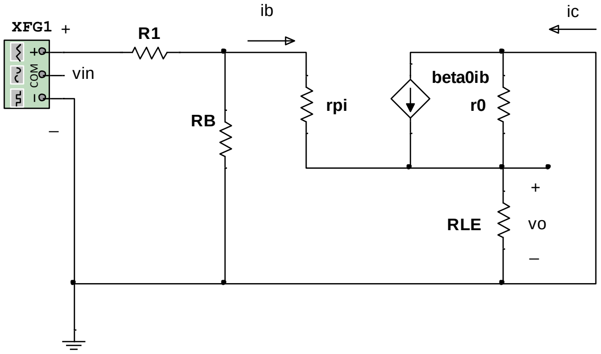
Function generator-XFG1

Signal options
Frequency: 1 kHz
Duty cycle: 50 %
Amplitude: 400 mVp
Offset: 0 V

Let us assume again that the capacitors have zero impedance at all frequencies except DC. In addition, all the large capacitors in the power supplies will render the DC power supplies into short circuits from an AC point of view.

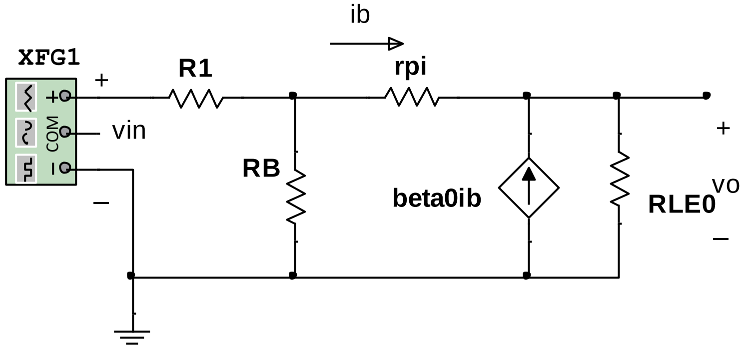
The two versions of the AC equivalent are shown below:





2.1.1 Voltage Gain

Let us redraw the last circuit for simpler analysis.



Note that $R_B = R_2//R_3$, $R_{LE0} = R_L//R_E//r_0$

$$i_b + \beta_0 i_b = \frac{v_0}{R_{LE0}}$$

$$v_b = r_\pi i_b + R_{LE0}(\beta_0 + 1) i_b$$

$$i_b = \frac{v_0}{(\beta_0 + 1) R_{LE0}}$$

$$v_b = (r_\pi + R_{LE0}(\beta_0 + 1)) \frac{v_0}{(\beta_0 + 1) R_{LE0}}$$

$$\frac{v_0}{v_b} = \frac{(\beta_0 + 1) R_{LE0}}{r_\pi + (\beta_0 + 1) R_{LE0}}$$

Since

$$R_{inb} = \frac{v_b}{i_b} = r_\pi + R_{LE0}(\beta_0 + 1)$$

$$\frac{v_b}{v_{in}} = \frac{R_B // R_{inb}}{R_1 + R_B // R_{inb}}$$

$$\frac{v_0}{v_{in}} = \frac{R_B // R_{inb}}{R_1 + R_B // R_{inb}} \frac{(\beta_0 + 1) R_{LE0}}{r_\pi + (\beta_0 + 1) R_{LE0}}$$

Note that the voltage gain is a positive number always less than one. The output signal is in phase with the input signal. This is not an amplifier that amplifies the voltage, however, the current is amplified and therefore there is power amplification. The advantage to using this configuration in the design of a voltage amplifier will be known when we derive the output resistance of a common-collector configuration.

2.1.2 Input Resistance

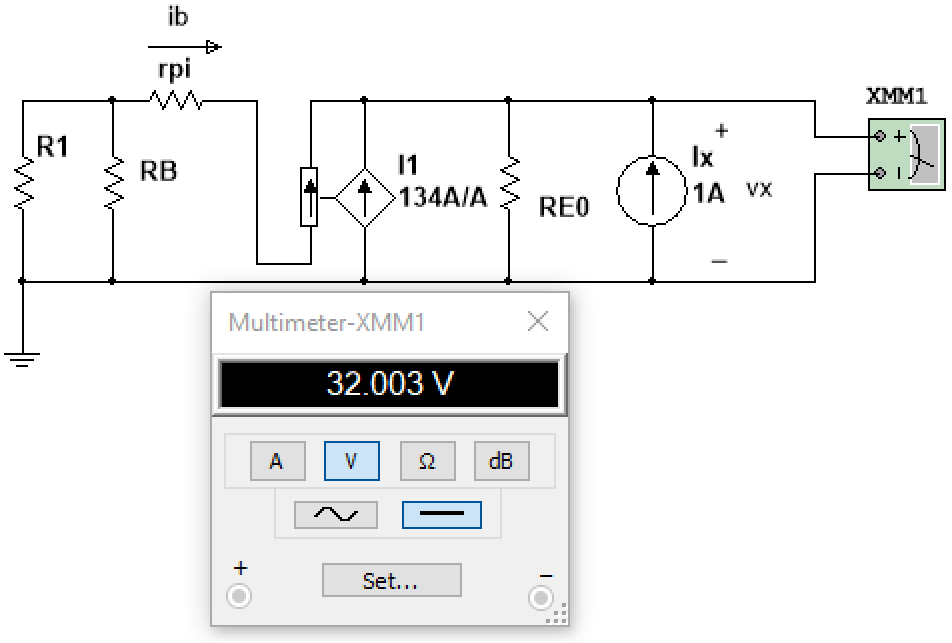
We have already seen that the input resistance is given by

$$R_{inb} = \frac{v_b}{i_b} = r_\pi + R_{LE0}(\beta_0 + 1)$$

The input resistance is very large.

2.1.3 Output Resistance

This is the circuit used to evaluate the output resistance seen by the load resistor R_L, where $R_B = R_2 // R_3$, $R_{E0} = R_E // r_0$, and let $R_{th} = R_1 // R_B$.



32.003 V

$$v_x = -(R_{th} + r_\pi) i_b$$

$$v_x = R_{E0}((\beta_0 + 1) i_b + i_x)$$

$$= R_{E0}\left(-(\beta_0 + 1)\frac{v_x}{(R_{th} + r_\pi)} + i_x \right)$$

$$v_x\left(1 + \frac{(\beta_0 + 1)R_{E0}}{(R_{th} + r_\pi)} \right) = R_{E0} i_x$$

$$R_{out} = \frac{v_x}{i_x} = \frac{R_{E0}}{1 + \frac{(\beta_0 + 1)R_{E0}}{(R_{th} + r_\pi)}}$$

If R_{E0} approaches infinity (equivalent to looking directly into the emitter)

$$R_{out} = \frac{R_{th} + r_\pi}{\beta_0 + 1}$$

$$\text{and if } \beta_0 \gg 1$$

$$R_{out} = \frac{R_{th} + r_\pi}{\beta_0}$$

$$R_{out} = \frac{1}{g_m} + \frac{R_{th}}{\beta_0}$$

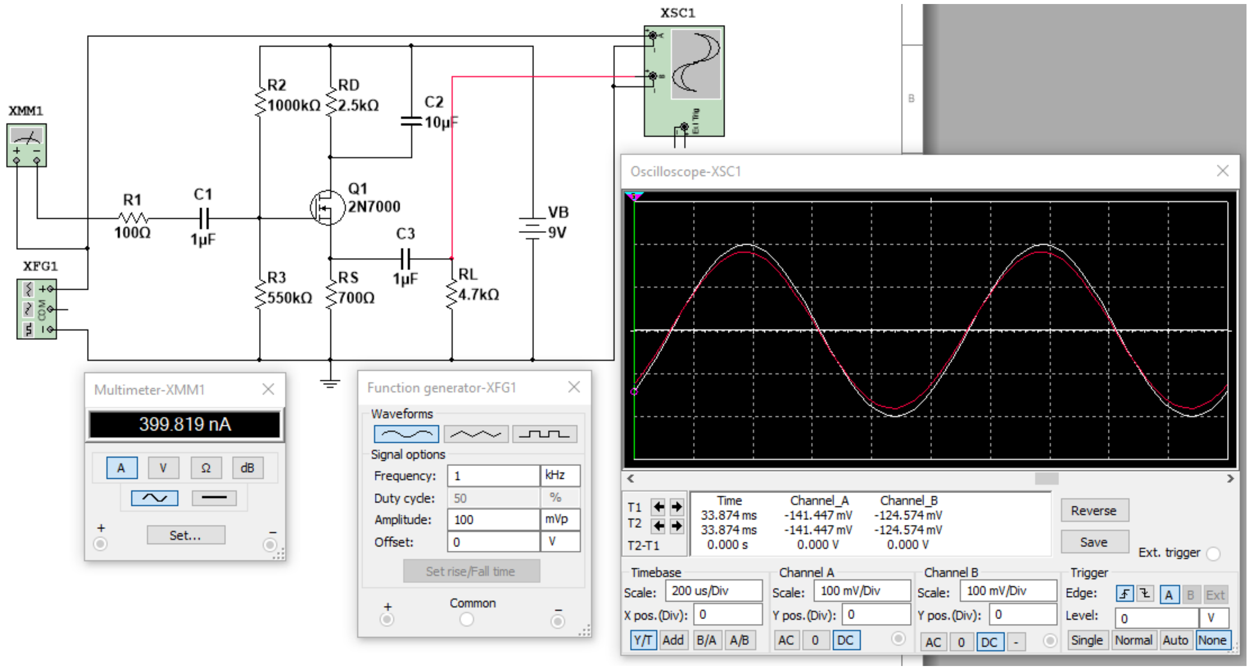
```
R1=100;R2=100e3;R3=30e3;RC=4.7e3;RL=4.7e3;RE=1.6e3;
RB=1/(1/R2+1/R3);RLE=1/(1/RL+1/RE);beta=134;
VB=9;VBB=R3/(R2+R3)*VB;Rth=1/(1/R1+1/RB);
ICQ=778e-6;VCEQ=4.1;VA=74.03;
gm=40*ICQ; rpi=beta/gm; r0=(VA+VCEQ)/ICQ;
RLE0=1/(1/RL+1/RE+1/r0);
Rinb=rpi+RLE0*(1+beta);
RinbB=1/(1/RB+1/Rinb);
Gain=RLE0*(1+beta)/(rpi+RLE0*(1+beta))*RinbB/(R1+RinbB);
Rin=R1+RinbB;
Rout=(Rth+rpi)/(beta+1);
disp(['The exact voltage gain is ',num2str(Gain)])
%disp(['The voltage gain (first approximation) is ',num2str(Gain1)])
disp(['The input resistance is ',num2str(Rin/1000),' kOhms'])
disp(['The output resistance seen by RL is ',num2str(Rout),' Ohms'])
```

```
The exact voltage gain is 0.96888
The input resistance is 20.3235 kOhms
The output resistance seen by RL is 32.6332 Ohms
```

The input resistance could be increased by increasing R_2 and R_3 while maintaining the same Q-point. Note that there is also less AC power dissipation by using a capacitor across R_C while limiting the frequency response.

	Calculated	Simulated	Error %
Voltage Gain	0.969	0.958	0.64
R_{in}	20.324kΩ	354.46kΩ*	0.14
R_{iE}	164.7kΩ	164.69kΩ	0.006
R_{out}	32.63Ω	32.003Ω	0

2.2 MOSFET



Multimeter-XMM1

399.819 nA

Function generator-XFG1

Waveforms

Signal options

Frequency: 1 kHz

Duty cycle: 50 %

Amplitude: 100 mVp

Offset: 0 V

Oscilloscope-XSC1

	Time	Channel_A	Channel_B
T1	33.874 ms	-141.447 mV	-124.574 mV
T2	33.874 ms	-141.447 mV	-124.574 mV
T2-T1	0.000 s	0.000 V	0.000 V

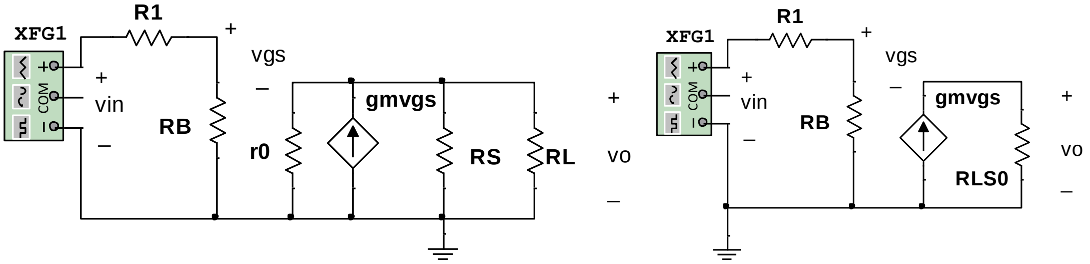
Timebase Scale: 200 us/Div; X pos.(Div): 0

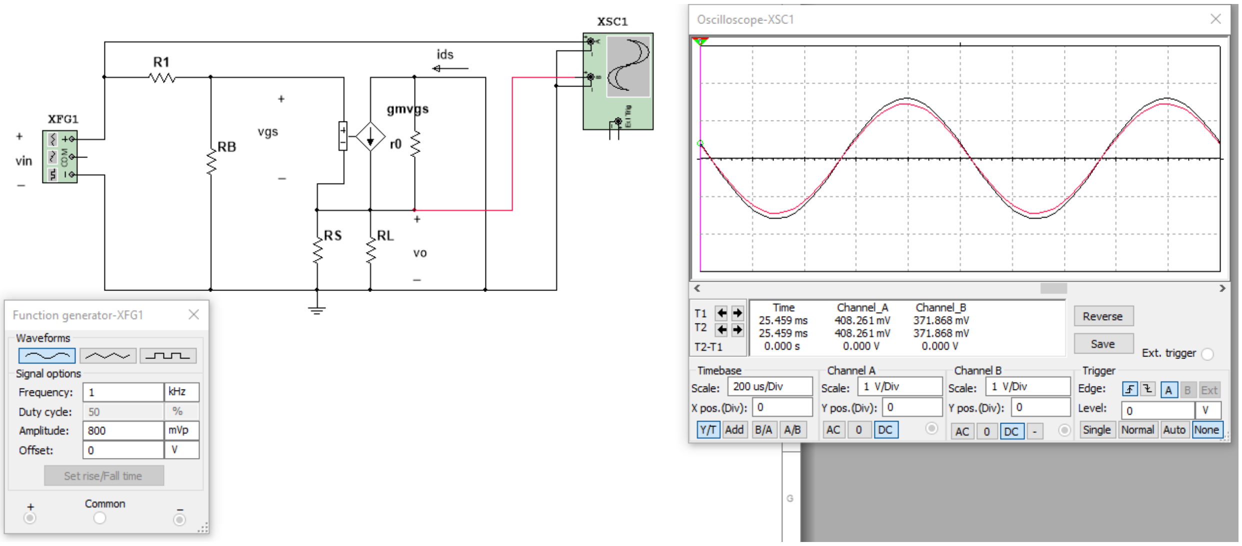
Channel A Scale: 100 mV/Div; Y pos.(Div): 0

Channel B Scale: 100 mV/Div; Y pos.(Div): 0

Trigger Level: 0 V

The two circuits shown below are the AC equivalent of the MOSFET-based circuit.





Function generator-XFG1

Waveforms

Signal options

Frequency: 1 kHz

Duty cycle: 50 %

Amplitude: 800 mVp

Offset: 0 V

Oscilloscope-XSC1

	Time	Channel_A	Channel_B
T1	25.459 ms	408.261 mV	371.868 mV
T2	25.459 ms	408.261 mV	371.868 mV
T2-T1	0.000 s	0.000 V	0.000 V

Timebase Scale: 200 us/Div; X pos.(Div): 0

Channel A Scale: 1 V/Div; Y pos.(Div): 0

Channel B Scale: 1 V/Div; Y pos.(Div): 0

Trigger Level: 0 V

Note that $R_B = R_2//R_3$, $R_{LS0} = R_L//R_S//r_0$

2.2.1 Voltage Gain

$$-v_g + v_{gs} + v_o = 0$$

$$v_o = g_m v_{gs} R_{LS0}$$

$$-v_g + \frac{v_o}{g_m R_{LS0}} + v_o = 0$$

$$\frac{v_o}{v_g} = \frac{g_m R_{LS0}}{1 + g_m R_{LS0}}$$

Since

$$\frac{v_g}{v_{in}} = \frac{R_B}{R_1 + R_B}$$

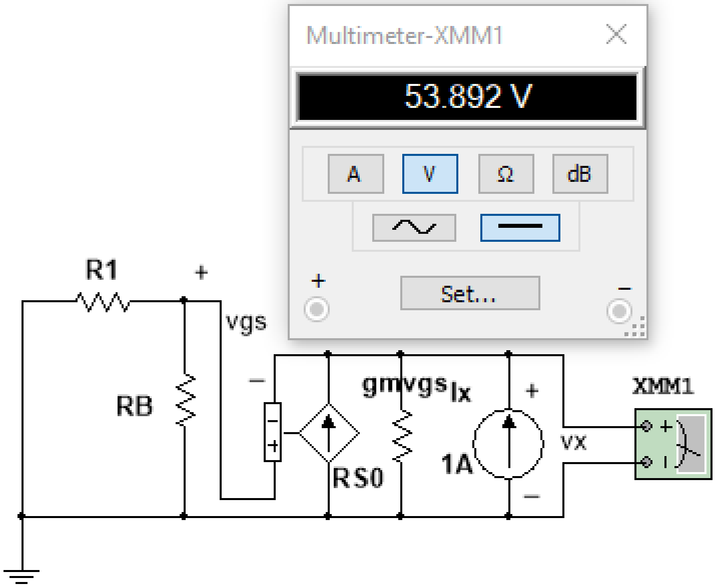
$$\frac{v_o}{v_{in}} = \frac{R_B}{R_1 + R_B} \frac{g_m R_{LS0}}{1 + g_m R_{LS0}}$$

2.2.2 Input Resistance

The input resistance seen by the voltage source v_{in} is
$R_{in} = R_1 + R_B$

2.2.3 Output Resistance

The output resistance seen by R_L is derived as follows:



Multimeter-XMM1

53.892 V

$$+v_{gs} + v_x = 0$$

$$v_x = (i_x + g_m v_{gs}) R_{s0}$$

$$v_x = (i_x - g_m v_x) R_{s0}$$

$$v_x (1 + g_m R_{s0}) = i_x \, R_{s0}$$

$$R_{out} = \frac{v_x}{i_x} = \frac{R_{s0}}{(1 + g_m R_{s0})}$$

$$R_{out} = \frac{1}{g_m} // R_{s0}$$

$$R_{iS} = \frac{1}{g_m} \text{, resistance seen looking into the source}$$

```
R1=100;R2=1000e3;R3=550e3;RD=2.5e3;RL=4.7e3;RS=700;Kn=0.1;
RG=1/(1/R2+1/R3);
VB=9;VG=R3/(R2+R3)*VB;Rth=1/(1/R1+1/RG);
IDSQ=1.46E-3;VDSQ=4.34;lambda=1/50;
gm=sqrt(2*Kn*IDSQ); r0=(1/lambda+VDSQ)/IDSQ;
RiS=1/gm; RS0=1/(1/RS+1/r0);RLS0=1/(1/RS0+1/RL);
Gain=gm*RLS0/(1+gm*RLS0);
Rin=R1+RG;
Rout=1/(1/RS0+1/RiS);
disp(['The exact voltage gain is ',num2str(Gain)])
disp(['The input resistance is ',num2str(Rin/1000),' kOhms'])
disp(['The output resistance seen from the emitter is ',num2str(RiS),' Ohms'])
disp(['The output resistance seen by RL is ',num2str(Rout),' Ohms'])
```

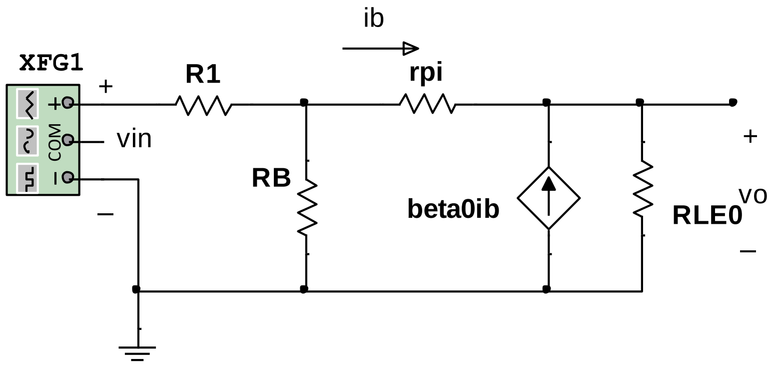
```
The exact voltage gain is 0.91106
The input resistance is 354.9387 kOhms
The output resistance seen from the emitter is 58.5206 Ohms
The output resistance seen by RL is 53.9274 Ohms
```

	Calculated	Simulated	Error %
Voltage Gain	0.91106	0.911	0
R_{in}	354.94kΩ	354.94kΩ	0
R_{iS}	58.52Ω	58.48Ω	0.07
R_{out}	53.93Ω	53.9Ω	0.06

Note that the simulation showed that even a 1.6 Vp input sinewave exhibited no distortion visible to the naked eye, verifying that a MOSFET has a much wider input signal range. Its much wider signal range makes it a stage required to process the amplified version of a signal without distortion.

The output resistance is much lower than the output resistance of a common-source amplifier, making it the desired last stage needed to design a voltage amplifier.

3. Input Signal Range
   3.1 BJT



$$v_b = r_\pi i_b + (\beta_0 + 1) i_b R_{LE0}$$

$$\text{Sin}\,ce\, r_\pi i_b = v_{be}$$

$$v_b = v_{be} + (\beta_0 + 1)\frac{v_{be}}{r_\pi} R_{LE0}$$

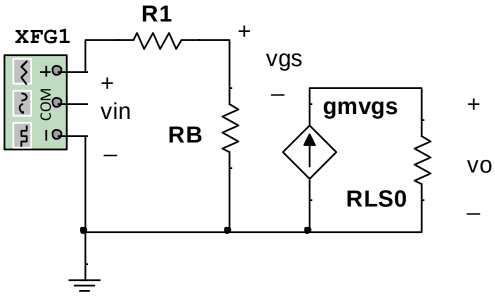
$$v_b = v_{be}(1 + \frac{\beta_0 + 1}{r_\pi}) R_{LE0}$$

$$v_b \leq 0.005(1 + \frac{\beta_0 + 1}{r_\pi}) R_{LE0}$$

$$and\ if\ \beta_0 \gg 1$$

$$v_b \le 0.005(1+g_m)R_{LE0}$$

3.2 MOSFET



$$v_g = v_{gs} + g_m v_{gs} R_{LS0}$$

$$v_g = v_{gs}(1+g_m R_{LS0})$$

$$v_g \le 0.2(V_{GS} - V_{TN})(1+g_m R_{LS0})$$

We see now that the two most important advantages of having an emitter or a source resistor, aside from a better control over the Q-point, are an increased input resistance, and an increased input signal range.