# Transistor Amplifiers:
## DC Analysis
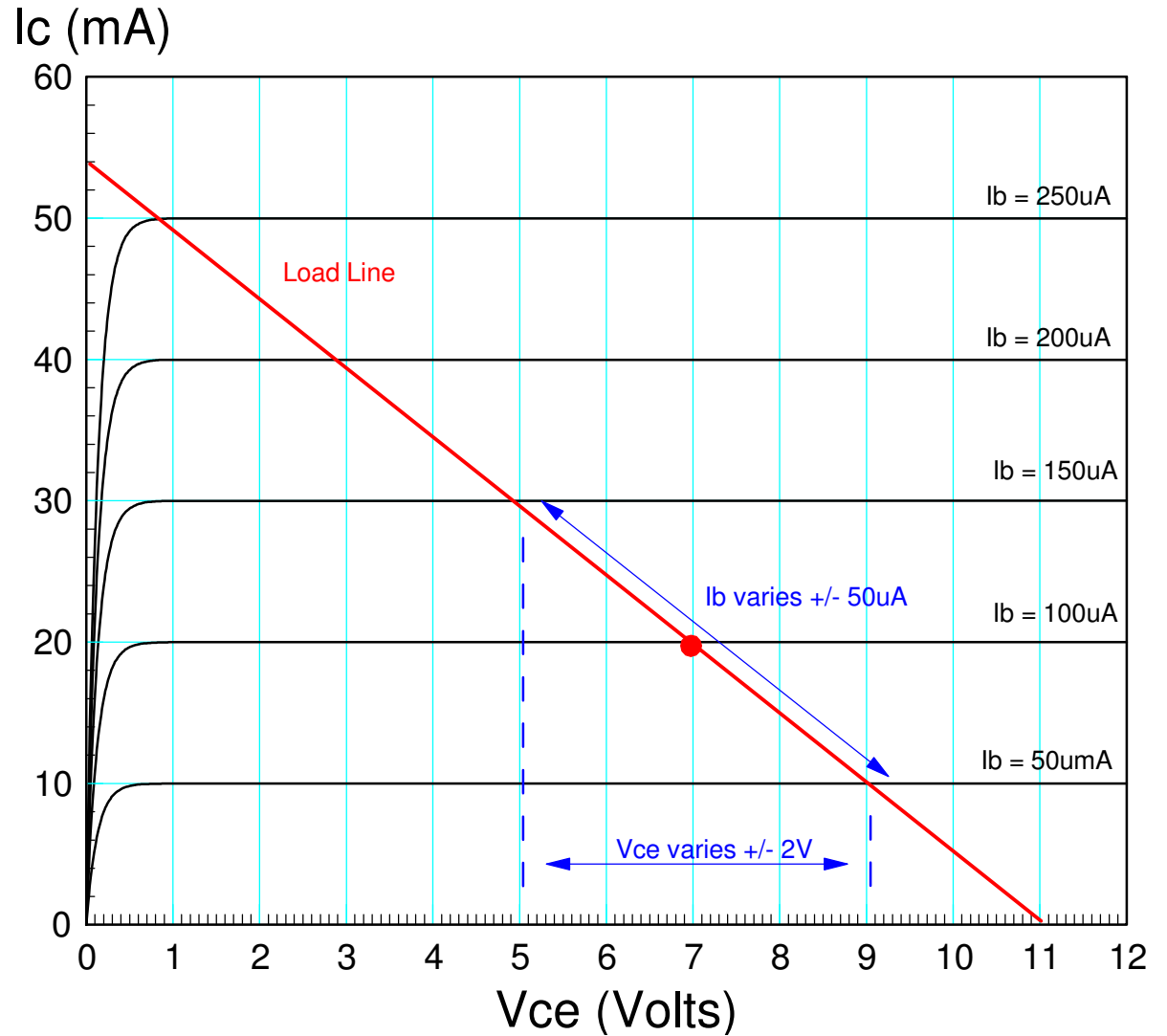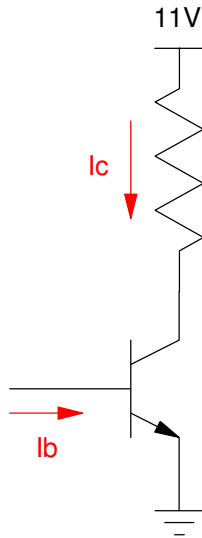## ECE 321: Electronics II
## Lecture #12:
## Jake Glower

Please visit Bison Academy for corresponding
lecture notes, homework sets, and solutions

# Background:

Transistor + Resistor gives a load-line

For +/- operation (AC) bias in the active region

Small change in Ib creates large change in Vce



Ic (mA)

11V

Ic

Ib

Ib = 250uA

Load Line

Ib = 200uA

Ib = 150uA

Ib varies +/- 50uA

Ib = 100uA

Ib = 50umA

Vce varies +/- 2V

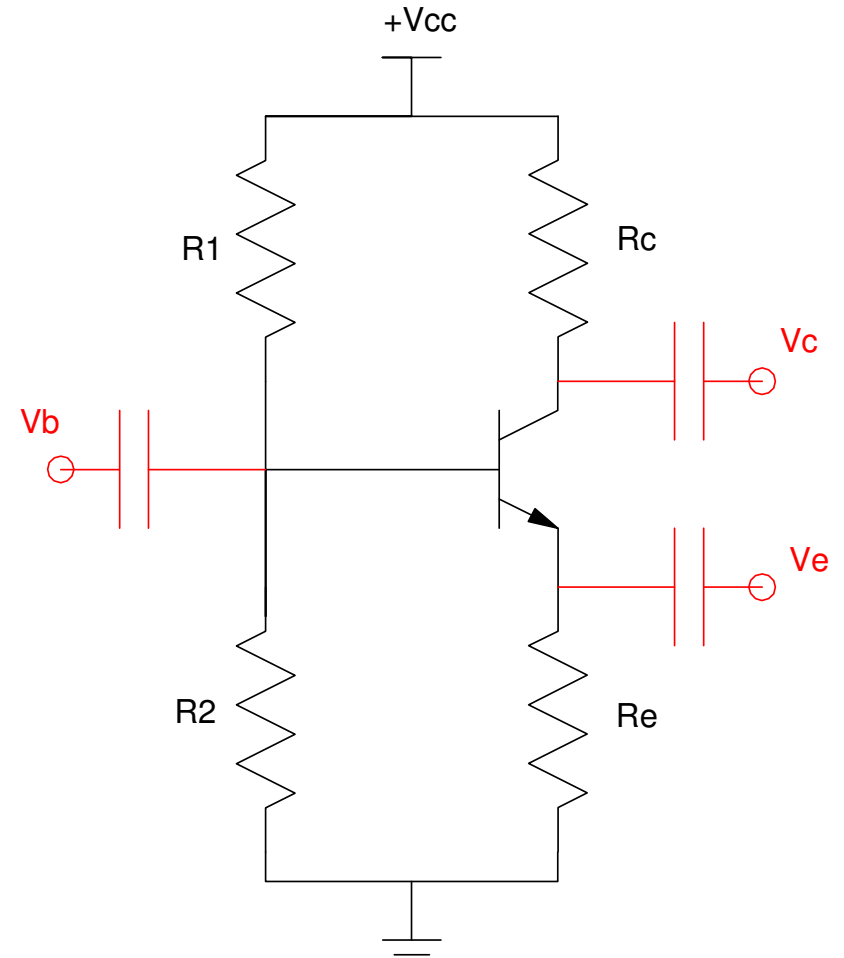Vce (Volts)

# Transistor Amplifiers

## Resistors

- Rc converts Ic to a voltage
- R1 and R2 bias in the active region
- Re stabilzes the Q-point

## Capacitors

- Isolate the circuit at DC
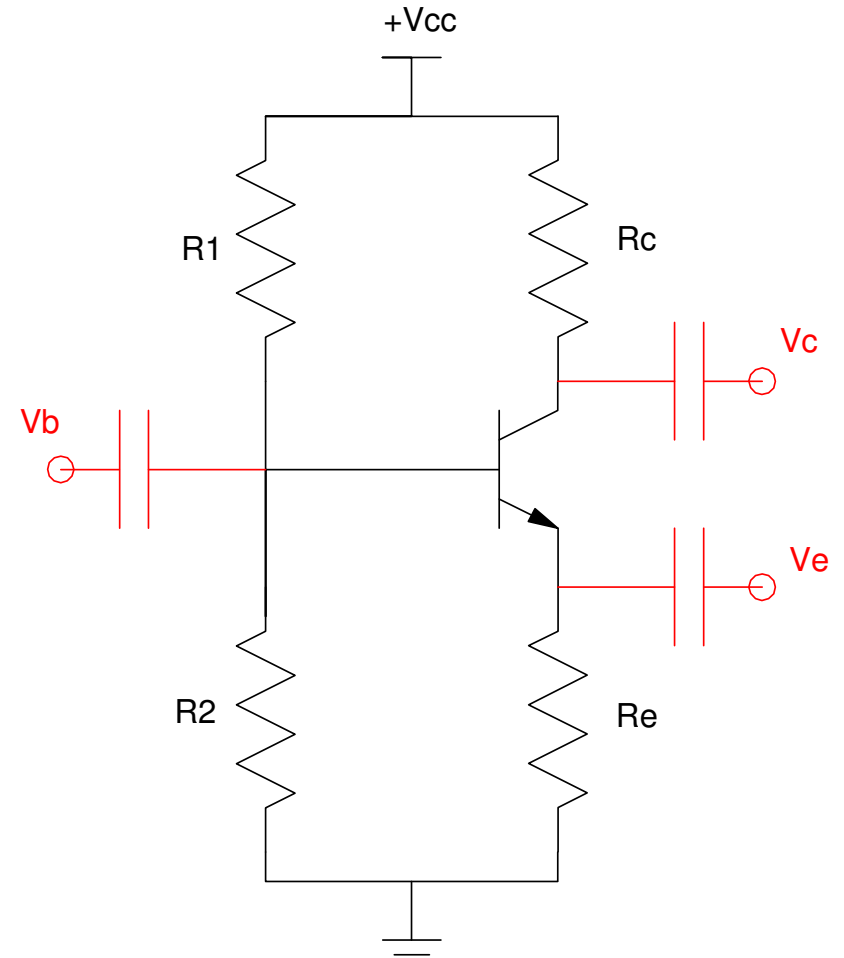
## I/O

- Input
- Output
- Ground the third line

# Procedure

DC Analysis (this lecture)

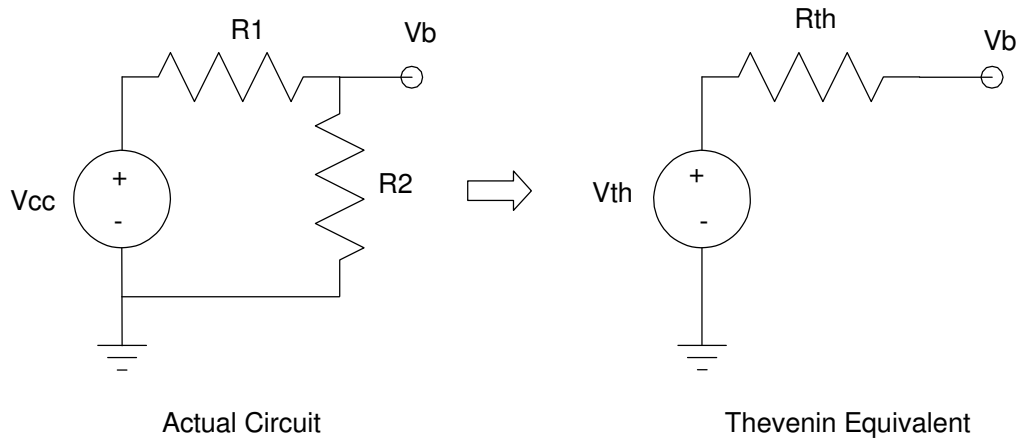- Find R1, R2, and Re to set the DC operating point

AC Analysis (coming soon)

- Apply a small signal to one C
- Model the AC behaviour
  - Common Emitter (emitter gounded)
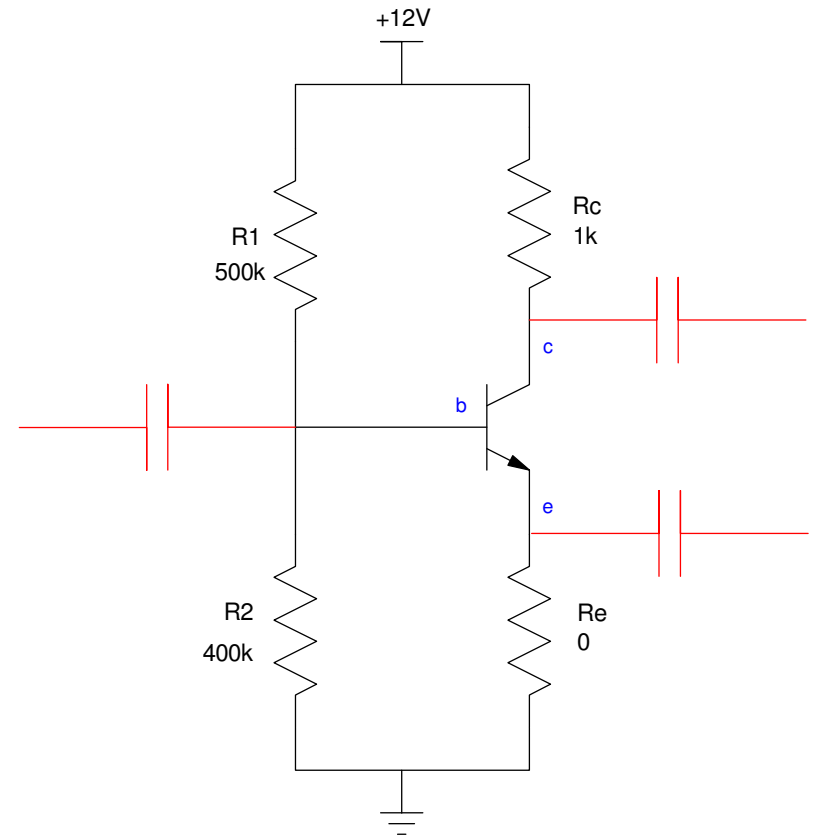  - Common Base (base grounded)
  - Common Collector (collector grounded)

# DC Analysis:  (Re = 0)

Replace R1 and R2 with their Thevenin equivalent



Actual Circuit

Thevenin Equivalent

$$R_{th} = R_1 || R_2 = 222k$$

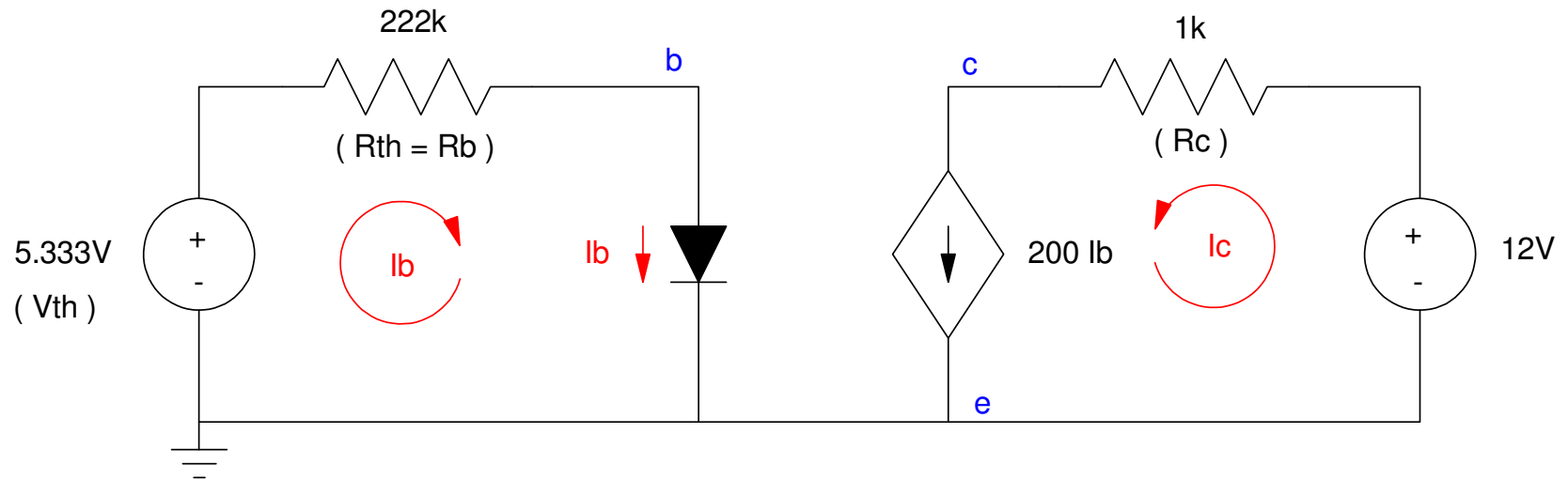$$V_{th} = \left(\frac{R_2}{R_1 + R_2}\right) V_{cc} = 5.33V$$

# Redraw the circuit:  Assume Re = 0

$$I_b = \left( \frac{5.333 - 0.7}{222k} \right) = 20.85\mu A$$

$$I_c = 200 I_b = 4.170 mA$$

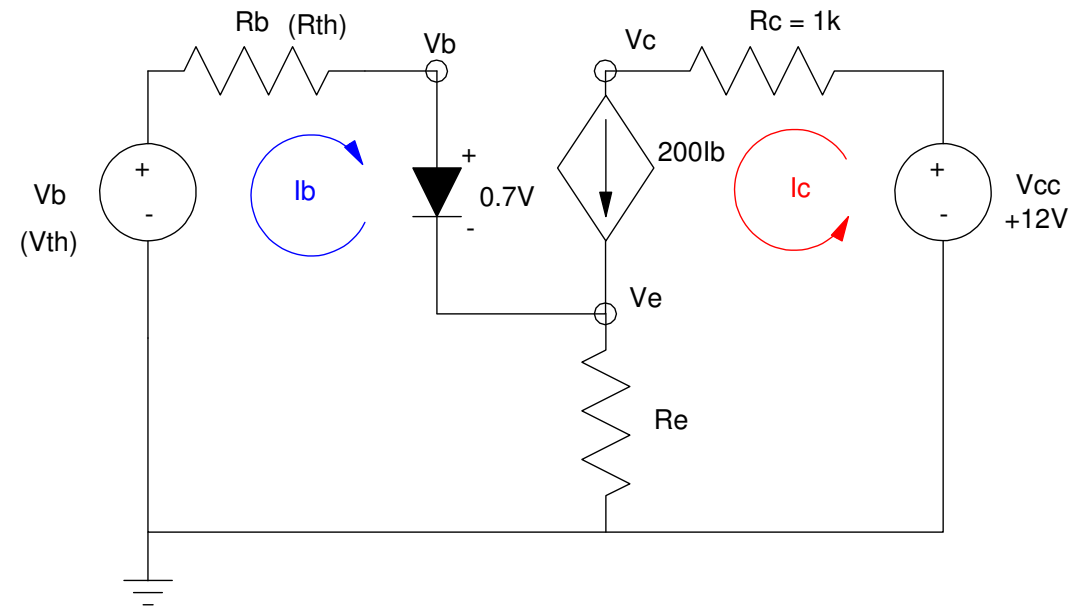$$V_{ce} = 12 - 1000 I_c = 7.83V$$

# DC Analysis: Re > 0

Redraw the circuit

$$V_{bb} = R_{bb}I_b + 0.7 + R_e(I_b + \beta I_b)$$

$$I_b = \left( \frac{V_{bb} - 0.7}{R_{bb} + (1+\beta)R_e} \right)$$

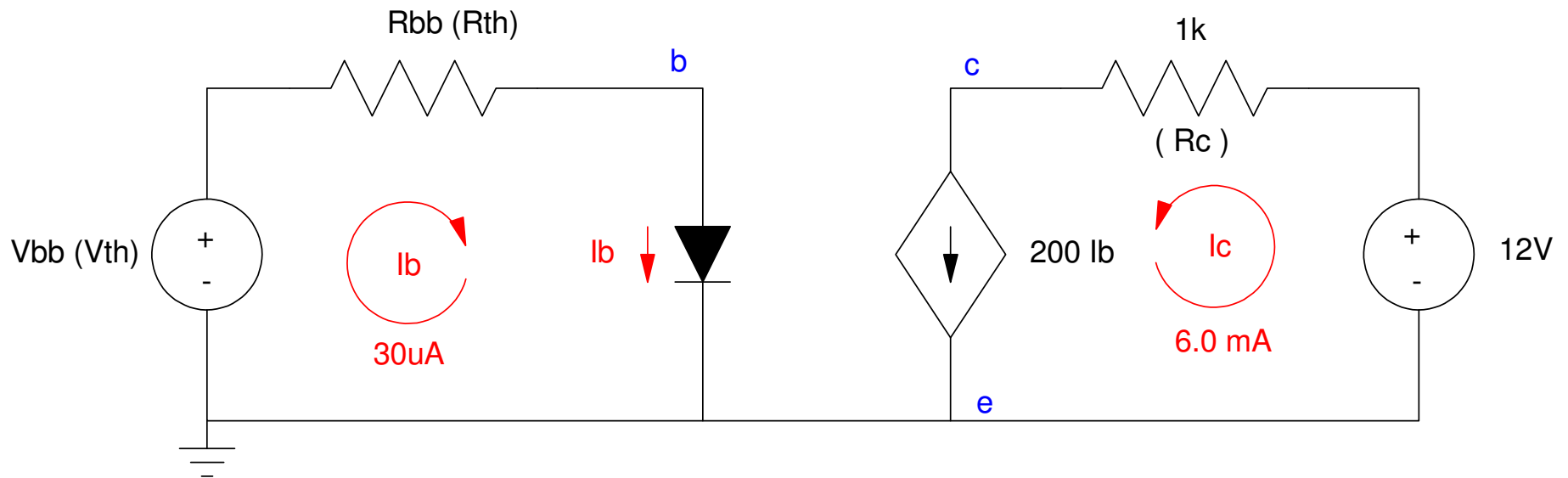$$I_c = \beta I_b$$

$$V_{ce} = 12 - R_c I_c - R_e(I_b + I_c)$$

# DC Design

Find Rth and Vth to set the Q-point to 6.00V

$$I_c = \left( \frac{12V - 6V}{1k} \right) = 6mA$$

$$I_b = \left( \frac{I_c}{200} \right) = 30\mu A$$
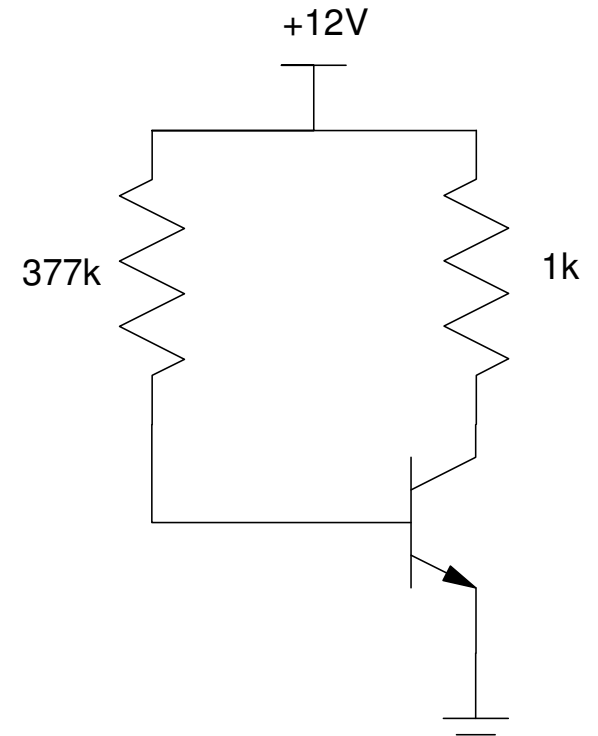
Let Vb = +12V

$$V_b = 12V$$

$$R_b = 377k\Omega$$

Converting back to R1 and R2:

$$V_b = \left(\frac{R_2}{R_1+R_2}\right)12V = 12V$$

$$R_2 = \infty$$

$$R_b = R_1 \| R_2 = 377k\Omega$$

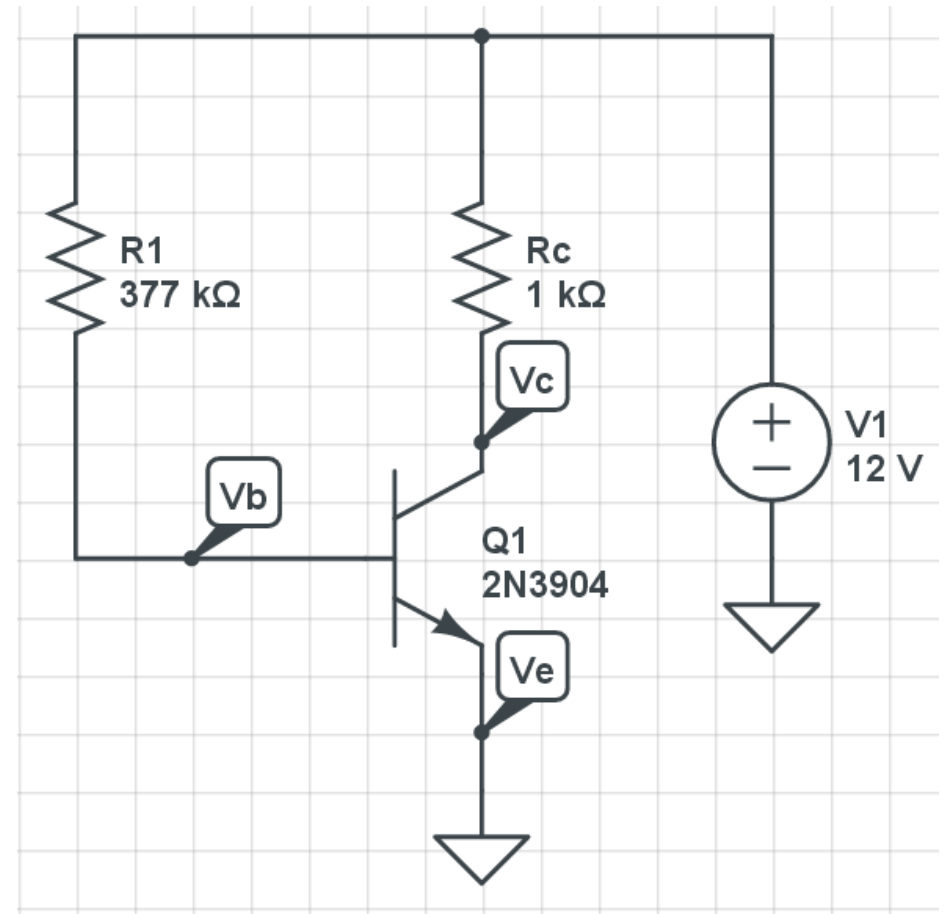$$R_1 = 377k\Omega$$

# CircuitLab Simulation

| DC | |
|---|---|
| V(Vb) | 698.1 mV |
| V(Vc) | 7.385 V |
| V(Ve) | 0.000 V |
| I(Q1.nB) | 29.98 µA |
| I(Q1.nC) | 4.615 mA |

- $V_{ce} = 7.385V$  (vs. 6.00V)
- $\beta = I_c / I_b = 153.8$ (vs. 200)

# Variations in $\beta$:

$h_{fe}$ ( $\beta$ ) varies with each transistor
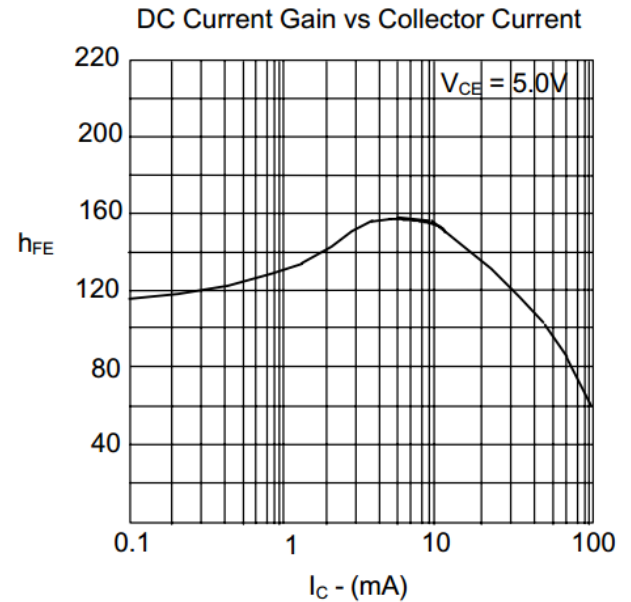
- 2n222:  $100 < h_{fe} < 300$
- LM3904:  $100 < h_{fe} < 300$
- TIP112:   $300 < h_{fe}$

$h_{fe}$ ( $\beta$ ) varies with the operating point

- 115 @ Ic = 0.1mA
- 155 @ Ic = 10mA
- 60 @ Ic = 100mA

**ON CHARACTERISTICS**

| $h_{FE}$ | DC Current Gain* | | | |
|---|---|---|---|---|
| | ($I_C$=0.1mAdc, $V_{CE}$=1.0Vdc) | 40 | | |
| | ($I_C$=1.0mAdc, $V_{CE}$=1.0Vdc) | 70 | | |
| | ($I_C$=10mAdc, $V_{CE}$=1.0Vdc) | 100 | 300 | |
| | ($I_C$=50mAdc, $V_{CE}$=1.0Vdc) | 60 | | |
| | ($I_C$=100mAdc, $V_{CE}$=1.0Vdc) | 30 | | |
| $V_{CE(sat)}$ | Collector-Emitter Saturation Voltage | | | |
| | ($I_C$=10mAdc, $I_B$=1.0mAdc) | | 0.2 | Vdc |
| | ($I_C$=50mAdc, $I_B$=5.0mAdc) | | 0.4 | |
| $V_{BE(sat)}$ | Base-Emitter Saturation Voltage | | | |
| | ($I_C$=10mAdc, $I_B$=1.0mAdc) | 0.65 | 0.85 | Vdc |
| | ($I_C$=50mAdc, $I_B$=5.0mAdc) | | 0.95 | |



DC Current Gain vs Collector Current

# This affects the Q-point

- Monte Carlo simulation

```
V = [];
I = [];
for i=1:100
    Rb = 377000 * (1 + (rand()*2-1)*0.01);
    Rc = 1000 * (1 + (rand()*2-1)*0.01);
    Beta = 200 + 100*(rand()*2-1);
    Ib = (12-0.7)/Rb;
    Ic = Beta*Ib;
    Vc = 12-Ic*Rc;
    V = [V ; Vc];
    I = [I ; Ic];
    end
plot(V, I, '.');
```
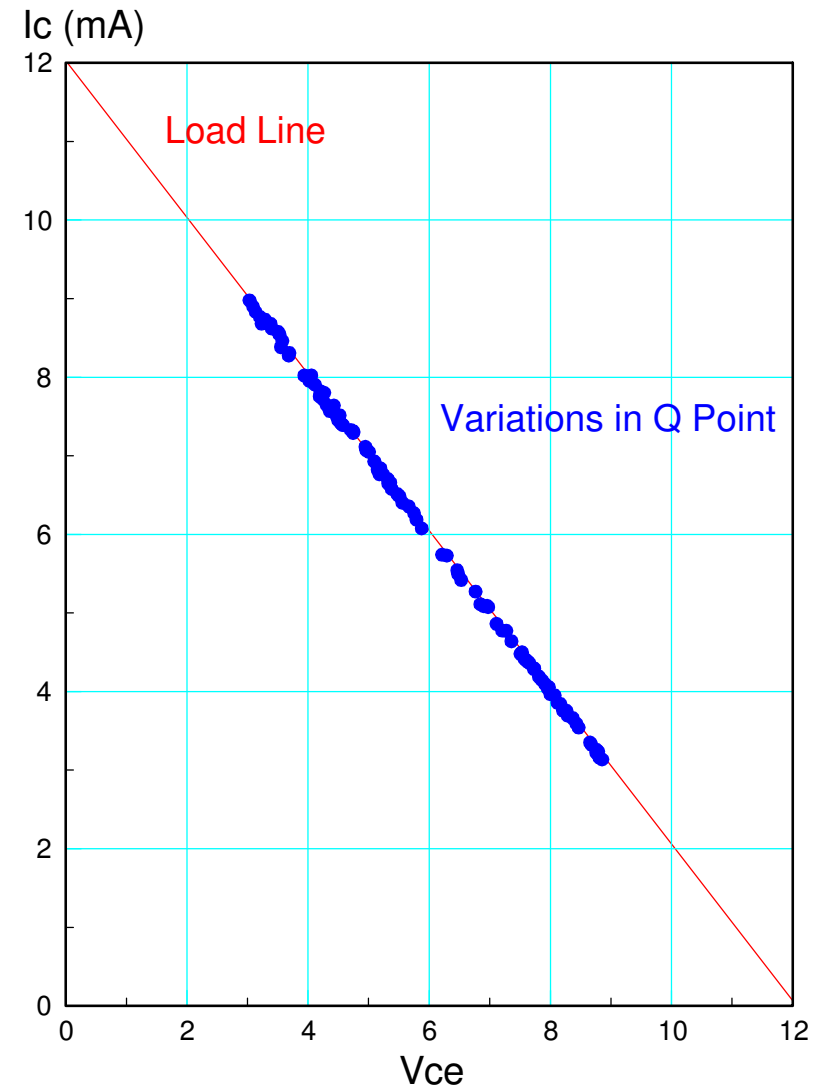
To compensate for variations in β, add Re.

$$I_c = \beta I_b$$

$$-V_b + R_b I_b + 0.7 + R_e(I_b + I_c) = 0$$

$$I_b = \left(\frac{V_b - 0.7}{R_b + (1+\beta)R_e}\right)$$
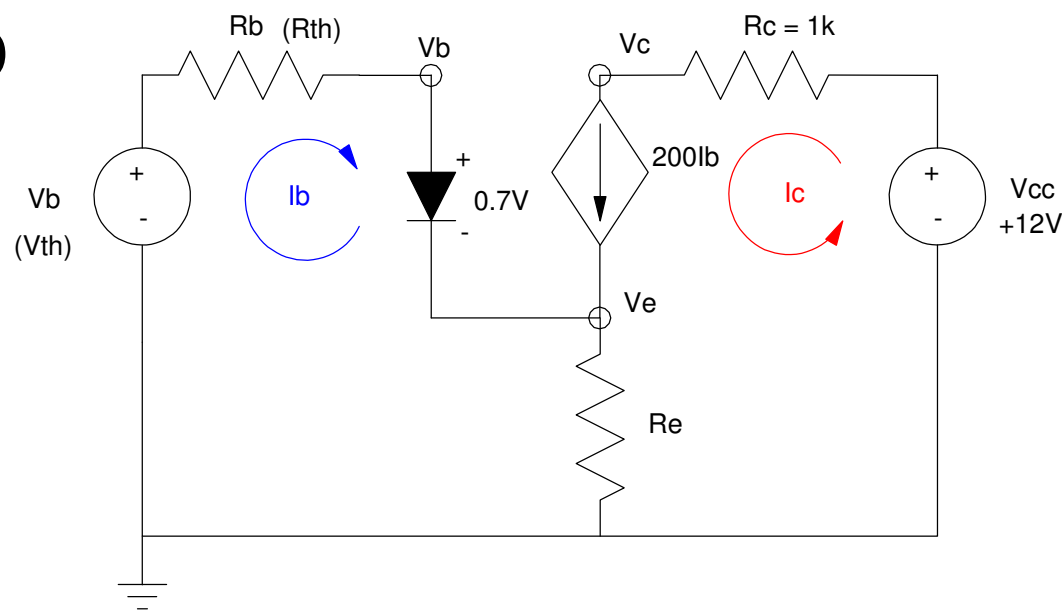
To stabilze the voltage at Vc:

$$V_c = V_{cc} - R_c I_c$$

$$V_c = V_{cc} - \left(\frac{\beta R_c}{R_b + (1+\beta)R_e}\right)(V_b - 0.7)$$

If

$$(1+\beta)R_e >> R_b$$

$$V_c \approx V_{cc} - \left(\frac{\beta R_c}{(1+\beta)R_e}\right)(V_b - 0.7)$$

To stabilize the Q point, pick Re such that

$$(1+\beta)R_e \gg R_b$$



Design (take 2)

- Vce = 6V
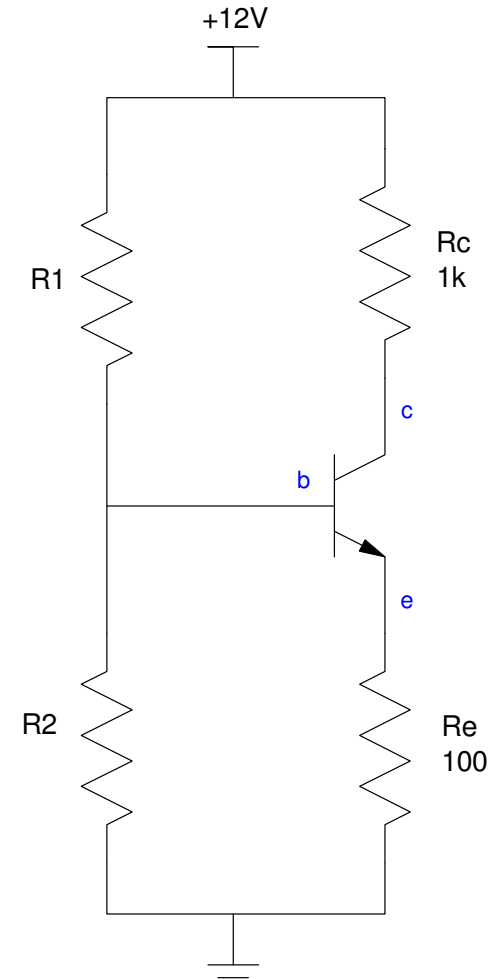
- Stabilize Q-point for variations in β

Pick Re > 0

$$R_e = 100\Omega$$

To stabize the Q point

$$(1+\beta)R_e \gg R_b$$

$$20,100\Omega \gg R_b$$

$$R_b = 2k\Omega$$

From before,

$$I_c = 6mA$$

$$I_b = 30\mu A$$

so

$$I_b = \left(\frac{V_b - 0.7}{R_b + (1+\beta)R_e}\right) = 30\mu A$$

$$V_b = 1.363V$$

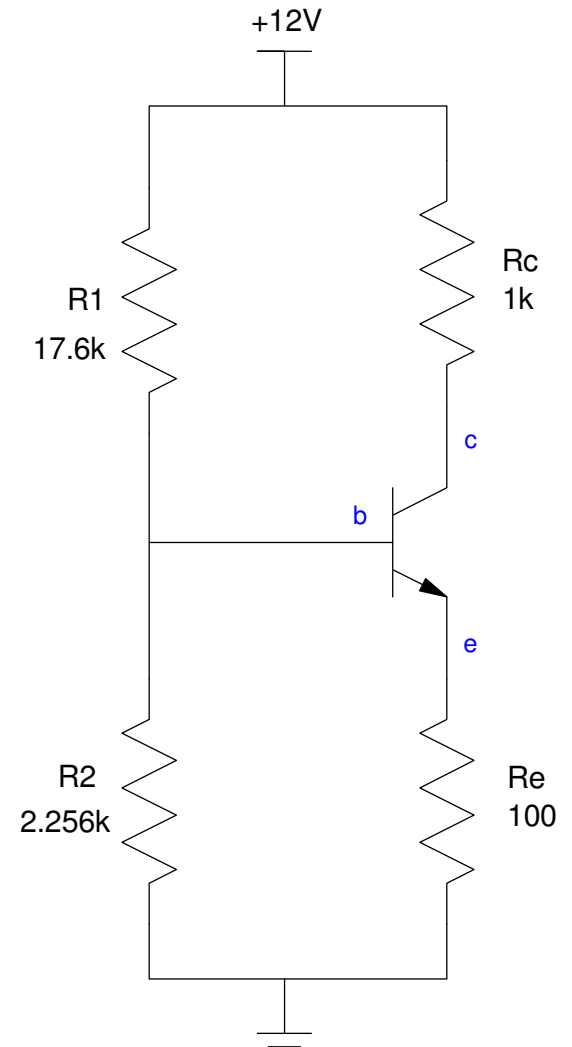This corresponds to R1 and R2 being:

$$\left(\frac{R_1 R_2}{R_1 + R_2}\right) = 2000$$
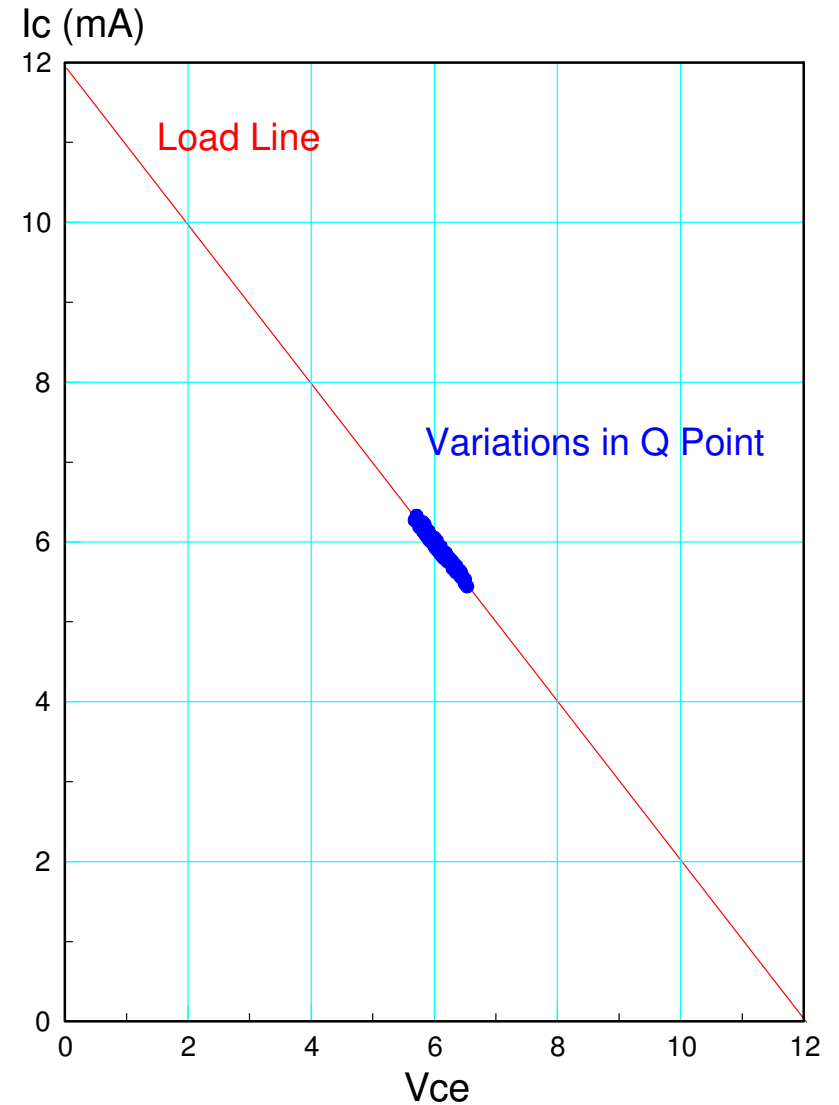
$$\left(\frac{R_2}{R_1 + R_2}\right)12V = 1.363V$$

$$R_1 = 17.6k\Omega$$

$$R_2 = 2256\Omega$$

# Monte-Carlo Simulation

```
V = [];
I = [];
for i=1:100
    R1 = 17600 * (1 + (rand()*2-1)*0.01);
    R2 = 2256 * (1 + (rand()*2-1)*0.01);
    Rc = 1000 * (1 + (rand()*2-1)*0.01);
    Re = 100 * (1 + (rand()*2-1)*0.01);
    Beta = 200 + 100*(rand()*2-1);
    Vb = 12*(R2 / (R1+R2));
    Rb = 1/(1/R1 + 1/R2);
    Ib = (Vb-0.7) / (Rb + (1+Beta)*Re);
    Ic = Beta*Ib;
    Vc = 12 - Rc*Ic;
    V = [V ; Vc];
    I = [I ; Ic];
    end
plot(V,I*1000,'.');
```

# CircuitLab Simulation

- Vce = 5.635V  (vs. 6.00V)

- Ib = 38.39 uA  (vs. 30.0uA)

- Ic = 5.783mA (vs. 6.00mA)

- $\beta = \frac{I_c}{I_b} = 150.6$  (vs. 200)

- Re helped stabilize the Q-point in spite of the differnce in β
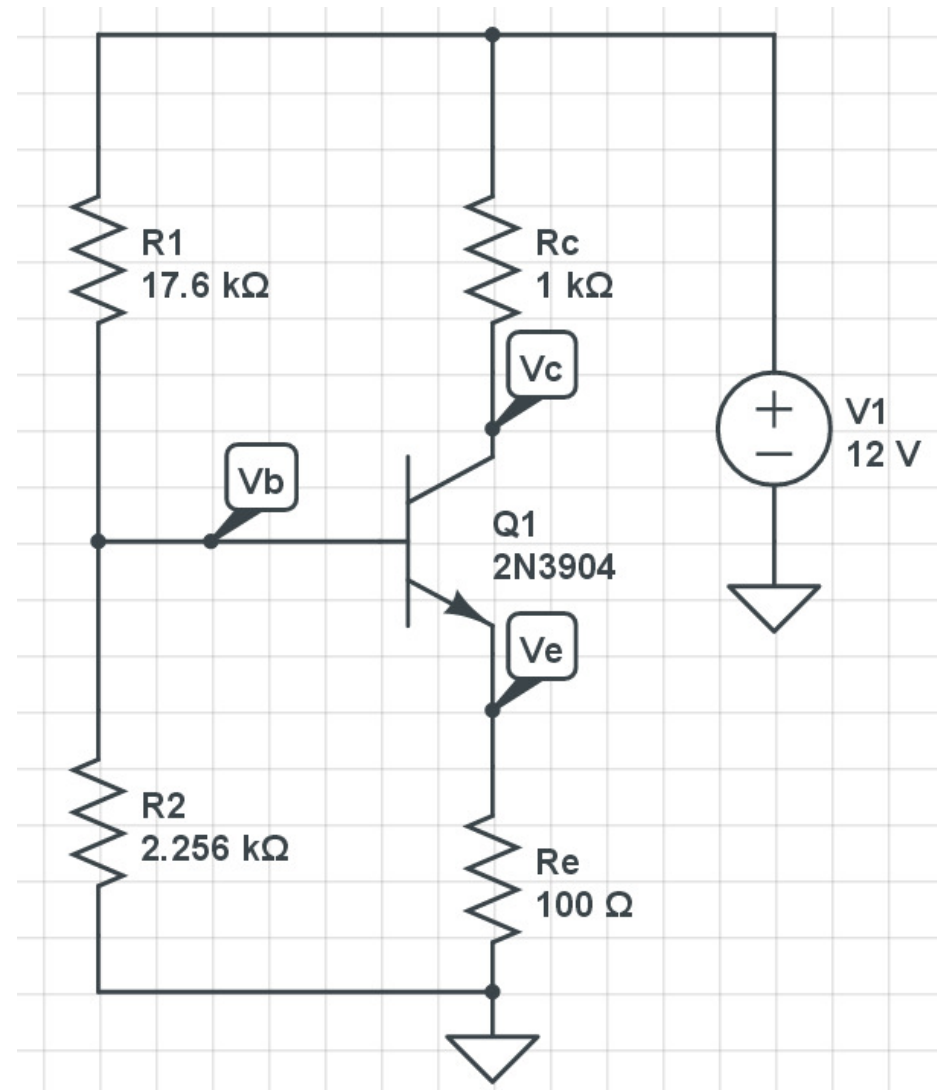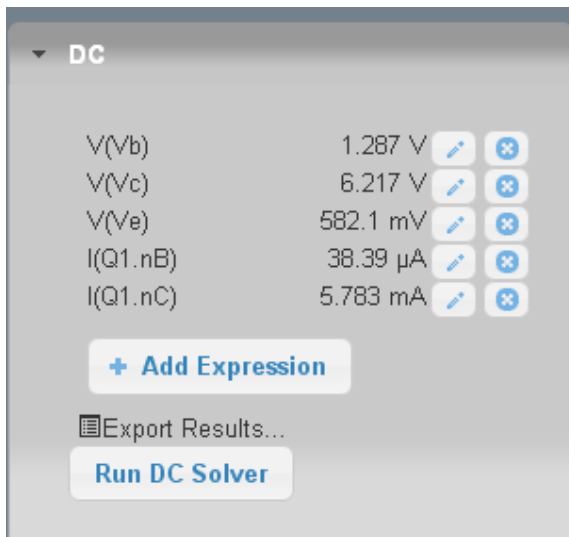
# Summary:

- In order to use a transistor as a Class-A amplifier, you need to bias it in the active region.

- Re serves to stabilize the Q-point for variations in β

- R1 and R2 serve to set the Q-point

- The capacitors isolate the circuit at DC

The following lectures will look at AC analysis of this circuit