Transistor Amplifiers:

DC Analysis

ECE 321: Electronics II

Lecture #12:

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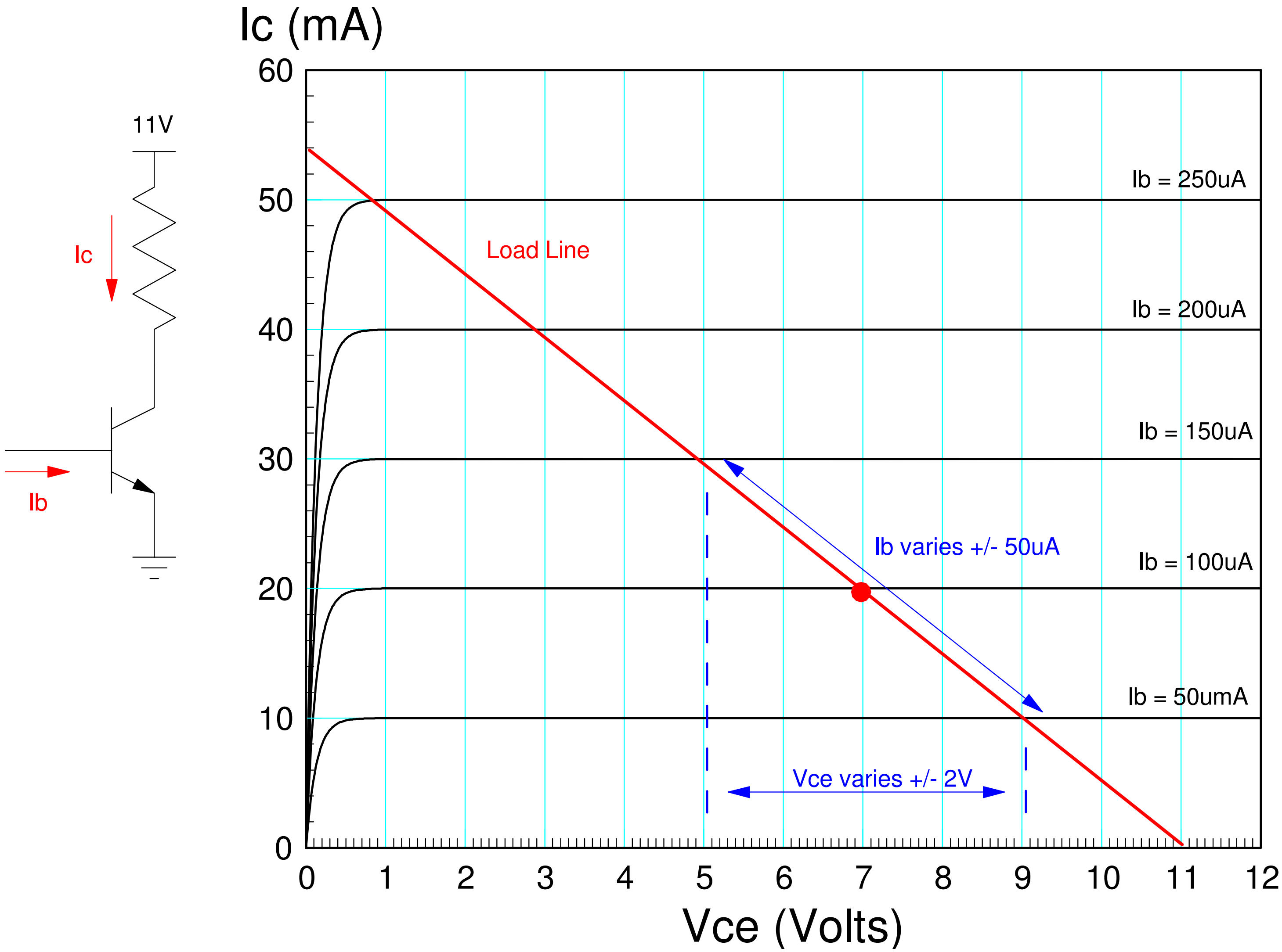
Please visit Bison Academy for corresponding lecture notes, homework sets, and solutions

Background:

Transistor + Resistor gives a load-line

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

Small change in Ib creates large change in Vce



Transistor Amplifiers

Resistors

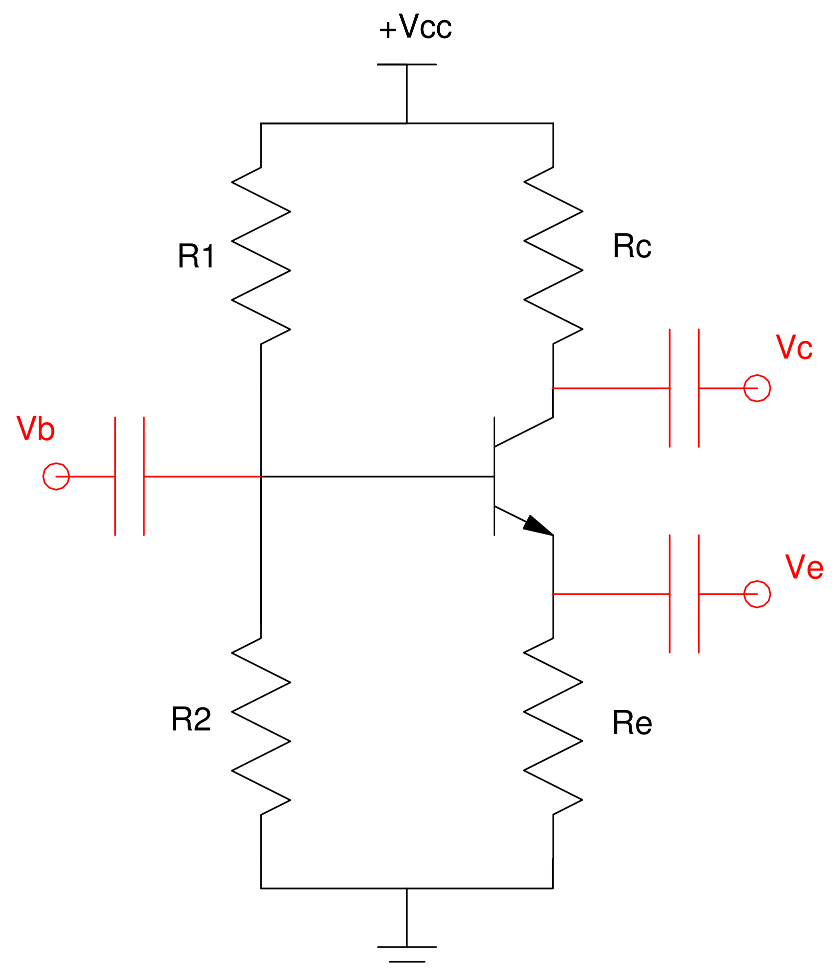
- Rc converts Ic to a voltage
- R1 and R2 bias in the active region
- Re stabilzes the Q-point

Capacitors

- Isolate the circuit at DC

I/O

- Input
- Output
- Ground the third line



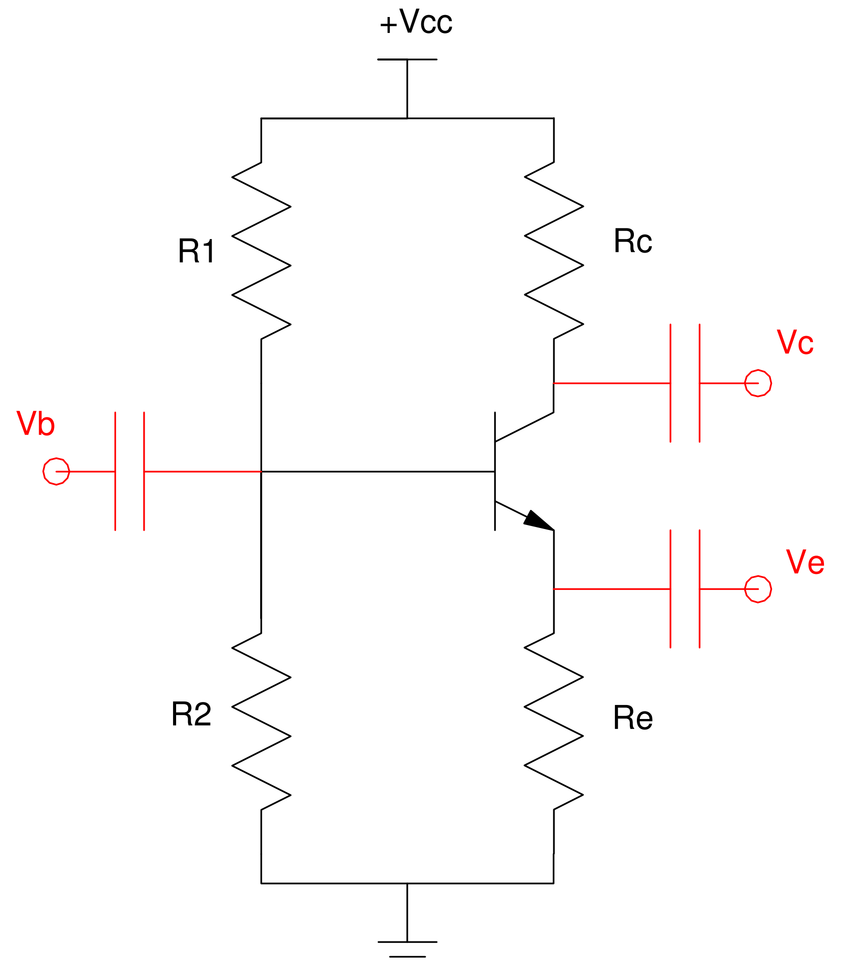
Procedure

DC Analysis (this lecture)

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

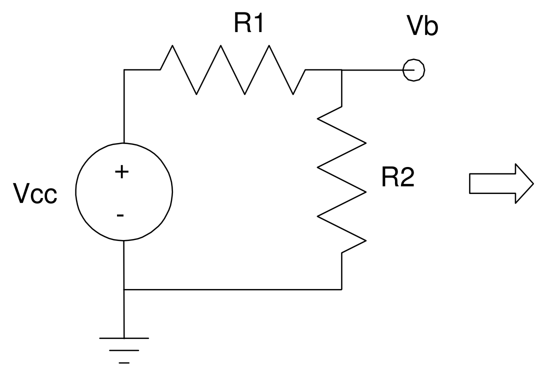
AC Analysis (coming soon)

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

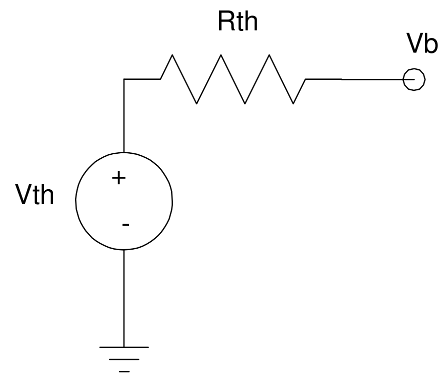


DC Analysis: (Re = 0)

Replace R1 and R2 with their Thevenin equivalent



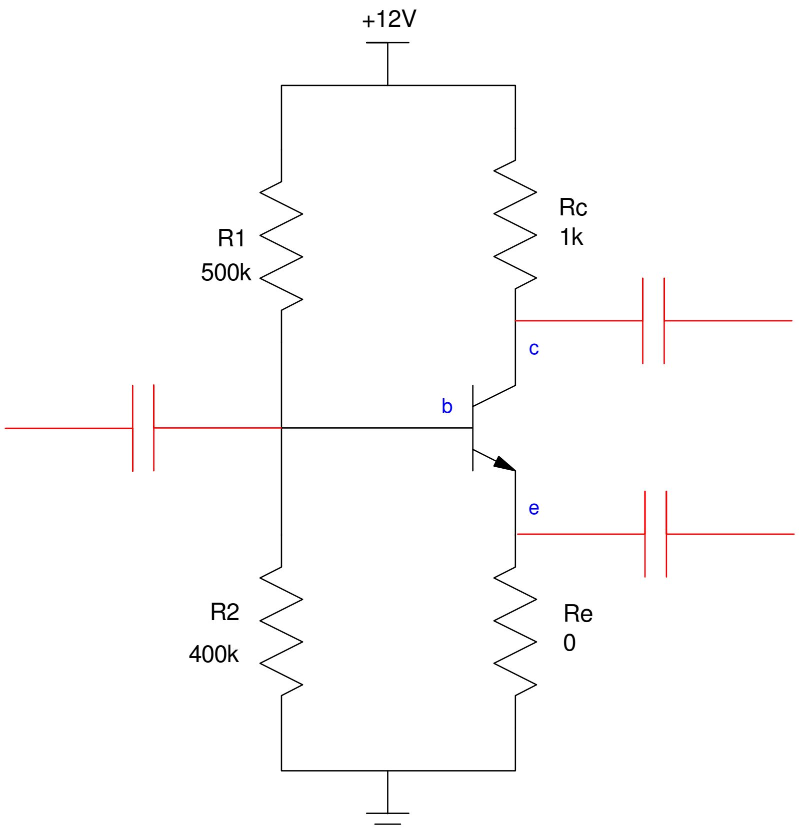
Actual Circuit



Thevenin Equivalent

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

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

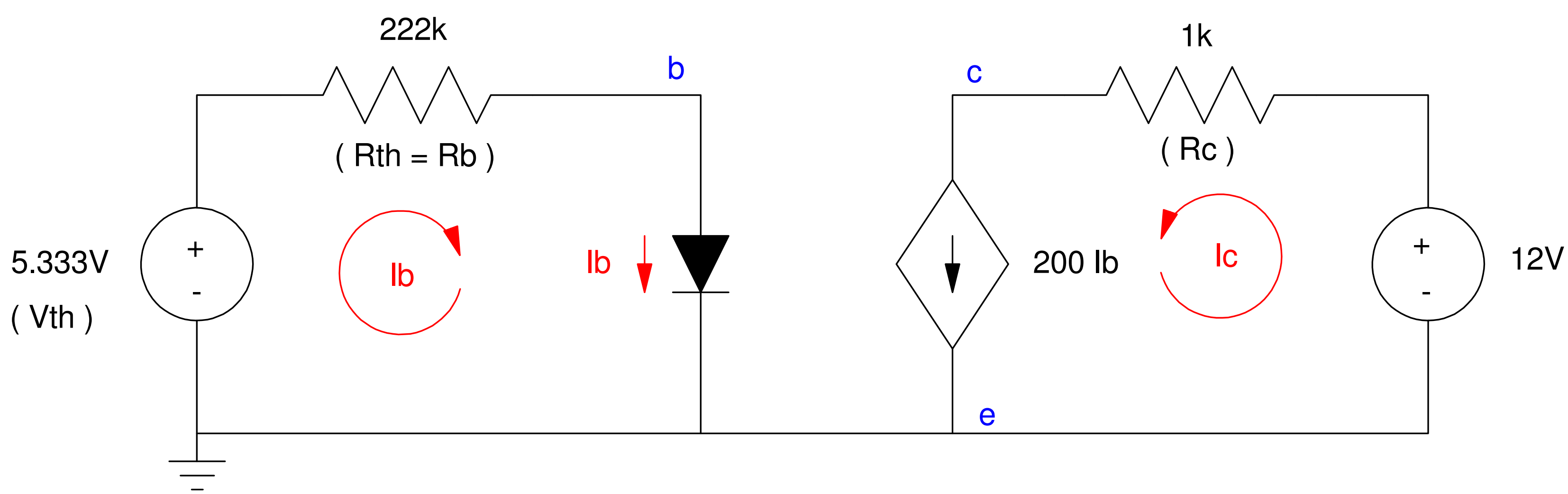


Redraw the circuit: Assume Re = 0

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

$$I_c = 200 I_b = 4.170 mA$$

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



DC Analysis: Re > 0

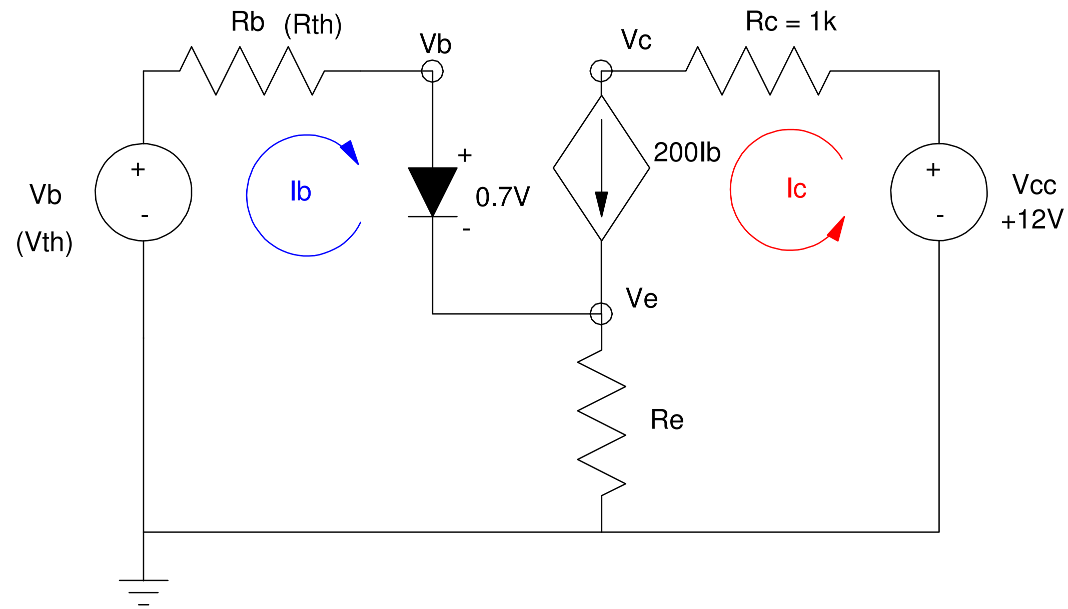
Redraw the circuit

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

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

$$I_c = \beta I_b$$

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

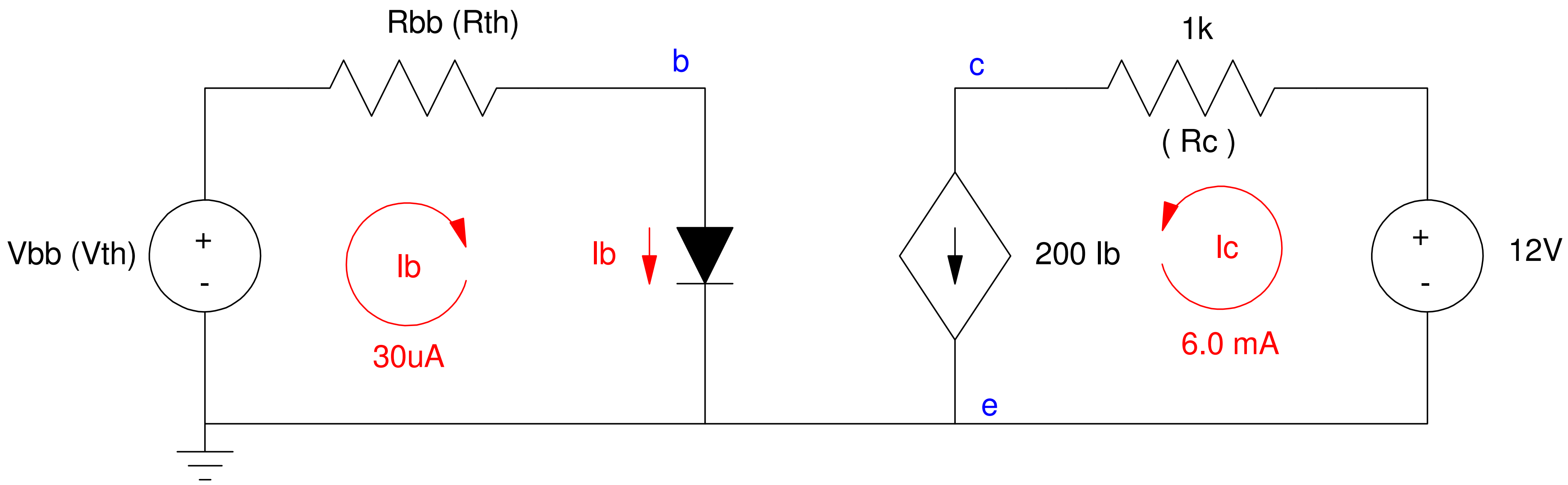


DC Design

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

$$V_b = 12V$$

$$R_b = 377k\Omega$$

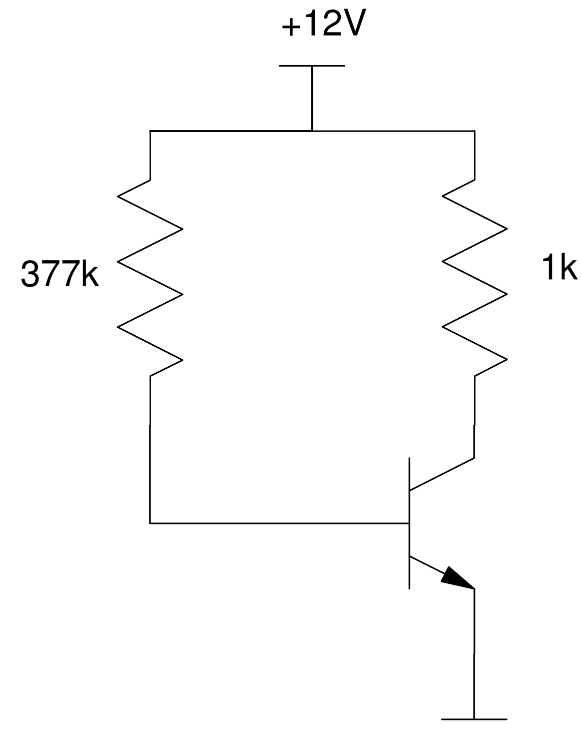
Converting back to R1 and R2:

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

$$R_2 = \infty$$

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

$$R_1 = 377k\Omega$$

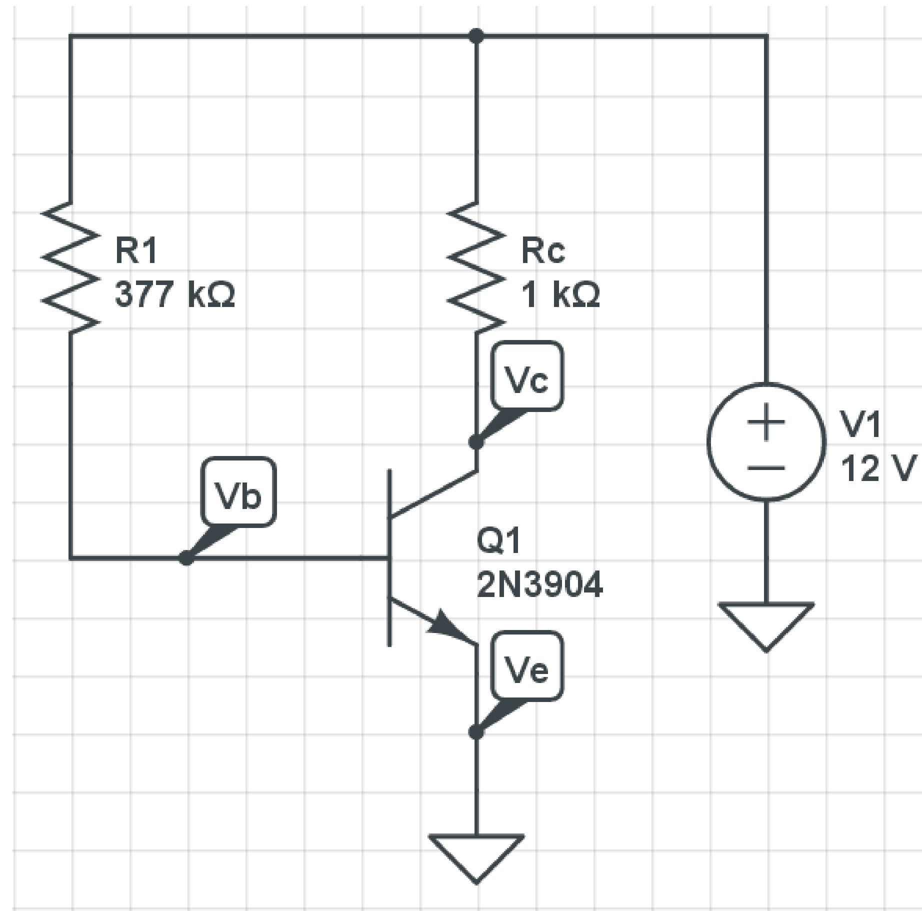


CircuitLab Simulation

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

- Vce = 7.385V (vs. 6.00V)
- $\beta = Ic / Ib = 153.8$ (vs. 200)



Variations in β:

h_{fe} (β) varies with each transistor

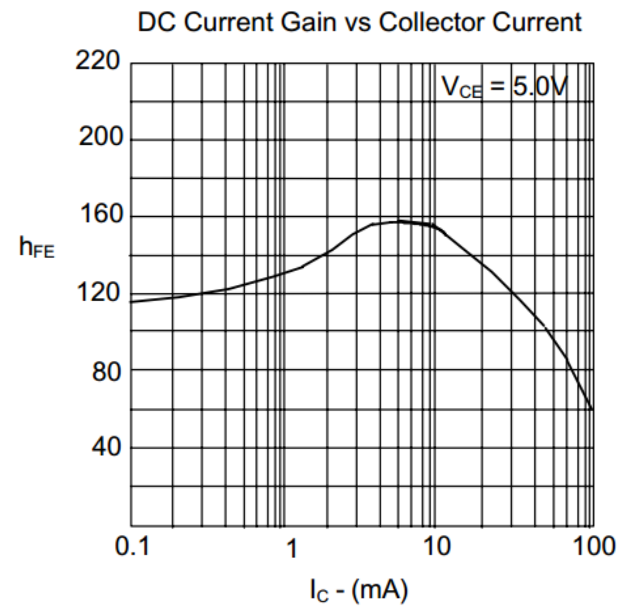
- 2n222: $100 < h_{fe} < 300$
- LM3904: $100 < h_{fe} < 300$
- TIP112: $300 < h_{fe}$

ON CHARACTERISTICS

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

h_{fe} (β) varies with the operating point

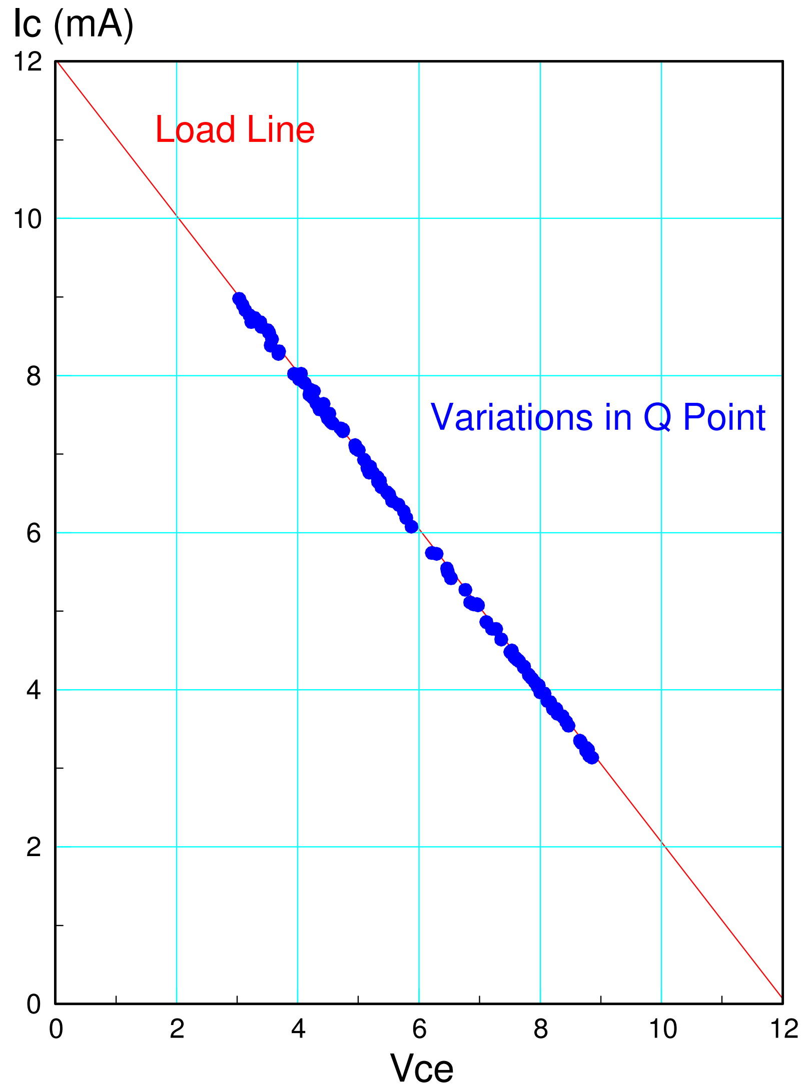
- 115 @ Ic = 0.1mA
- 155 @ Ic = 10mA
- 60 @ Ic = 100mA



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, '.');
```

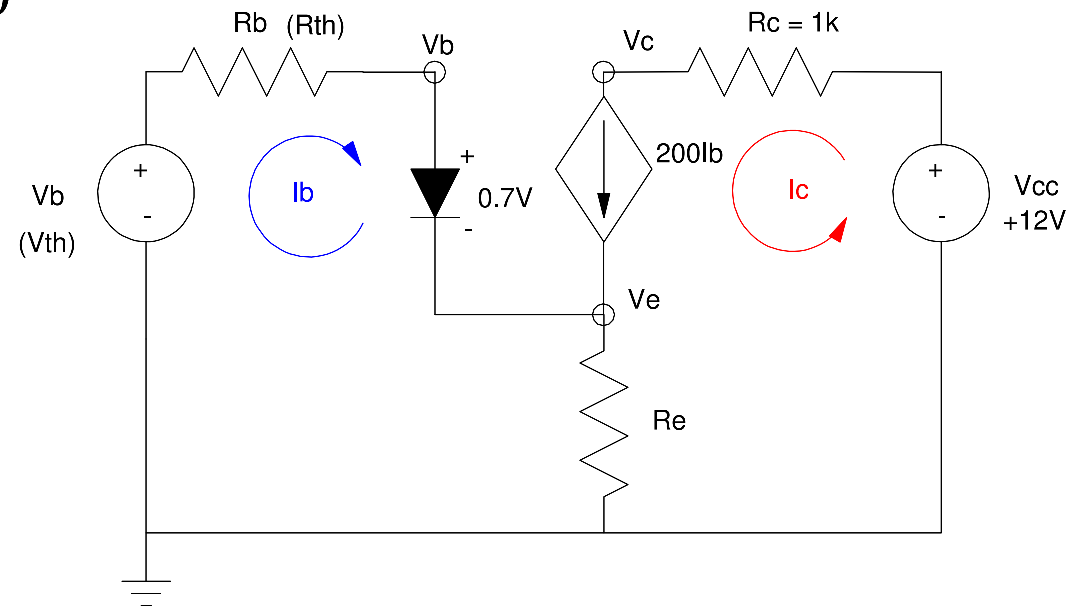


To compensate for variations in β, add Re.

$$I_c = \beta I_b$$

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

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



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

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

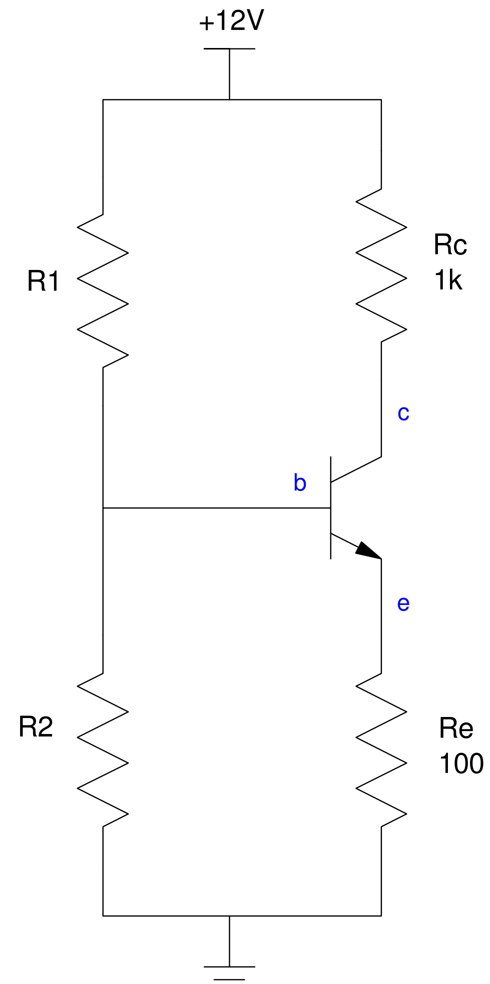
$$V_c \approx V_{cc} - \left(\frac{\beta R_c}{(1+\beta)R_e}\right)(V_b - 0.7)$$

To stabilize the Q point, pick Re such that

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

Design (take 2)

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



Pick Re > 0

$$R_e = 100\Omega$$

To stabize the Q point

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

$$20,100\Omega >> R_b$$

$$R_b = 2k\Omega$$

From before,

$$I_c = 6mA$$

$$I_b = 30\mu A$$

so

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

$$V_b = 1.363V$$

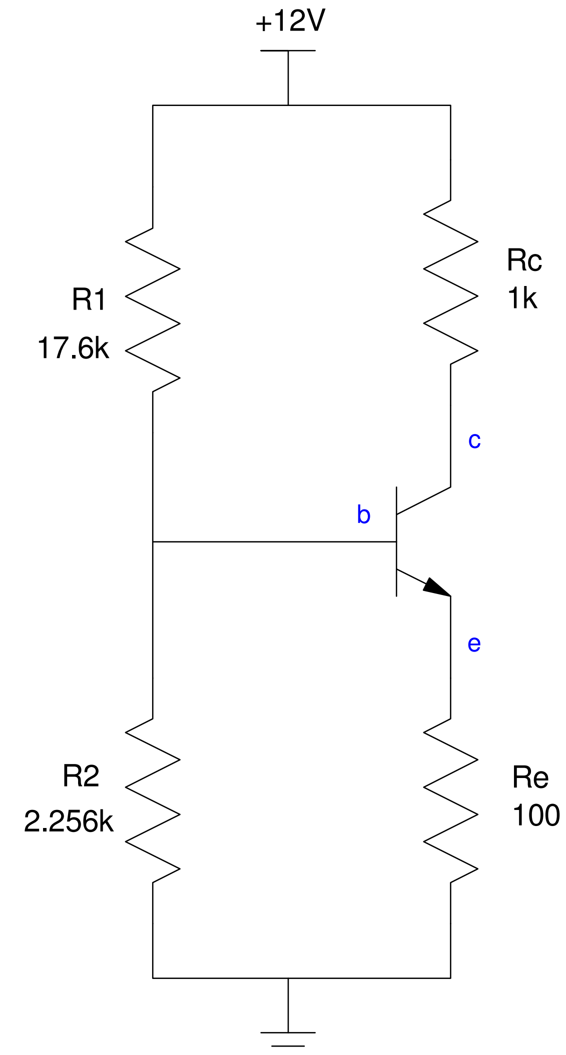
This corresponds to R1 and R2 being:

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

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

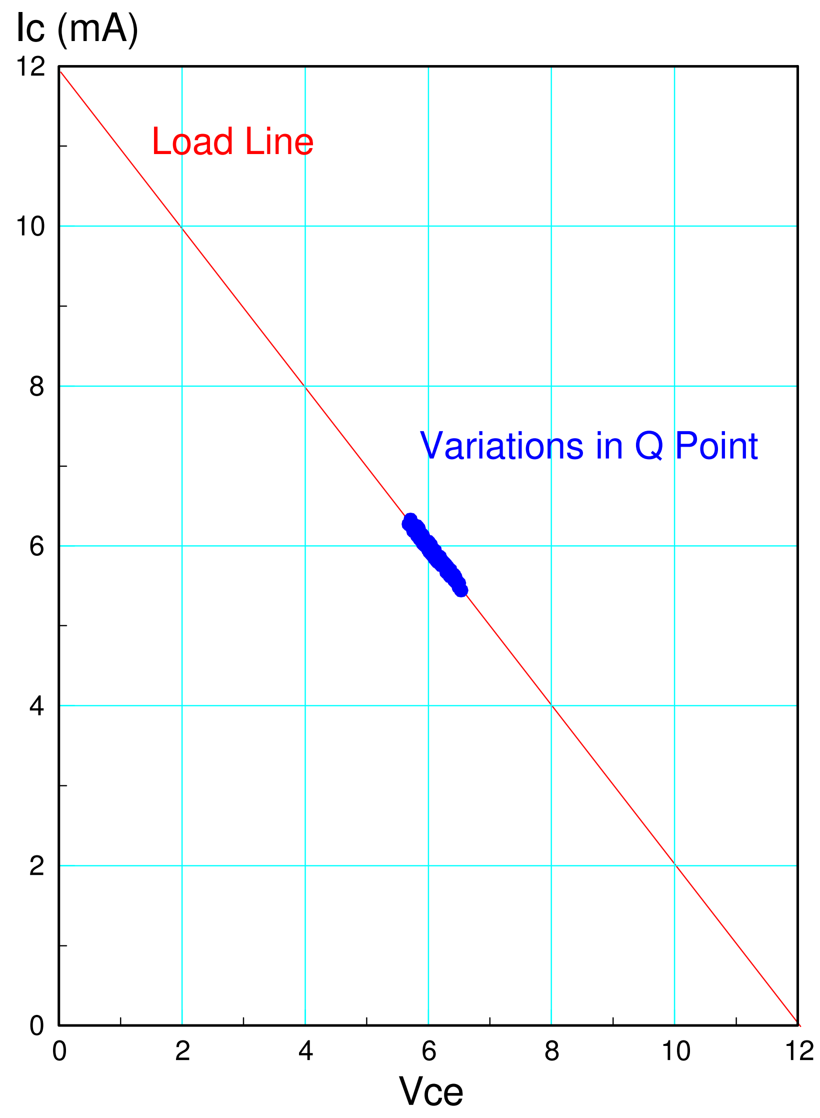
$$R_1 = 17.6k\Omega$$

$$R_2 = 2256\Omega$$



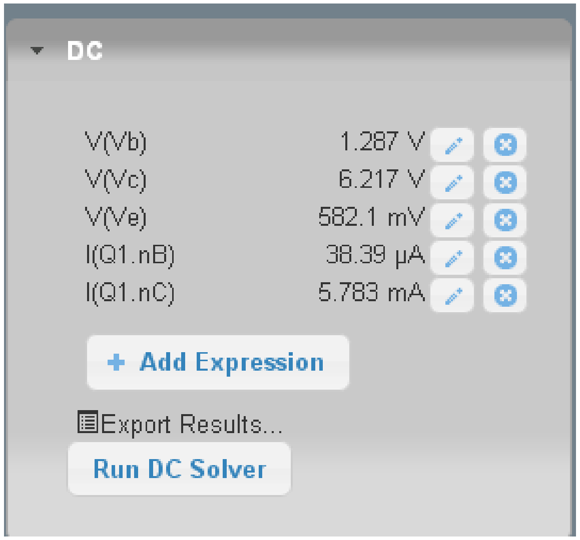
Monte-Carlo Simulation

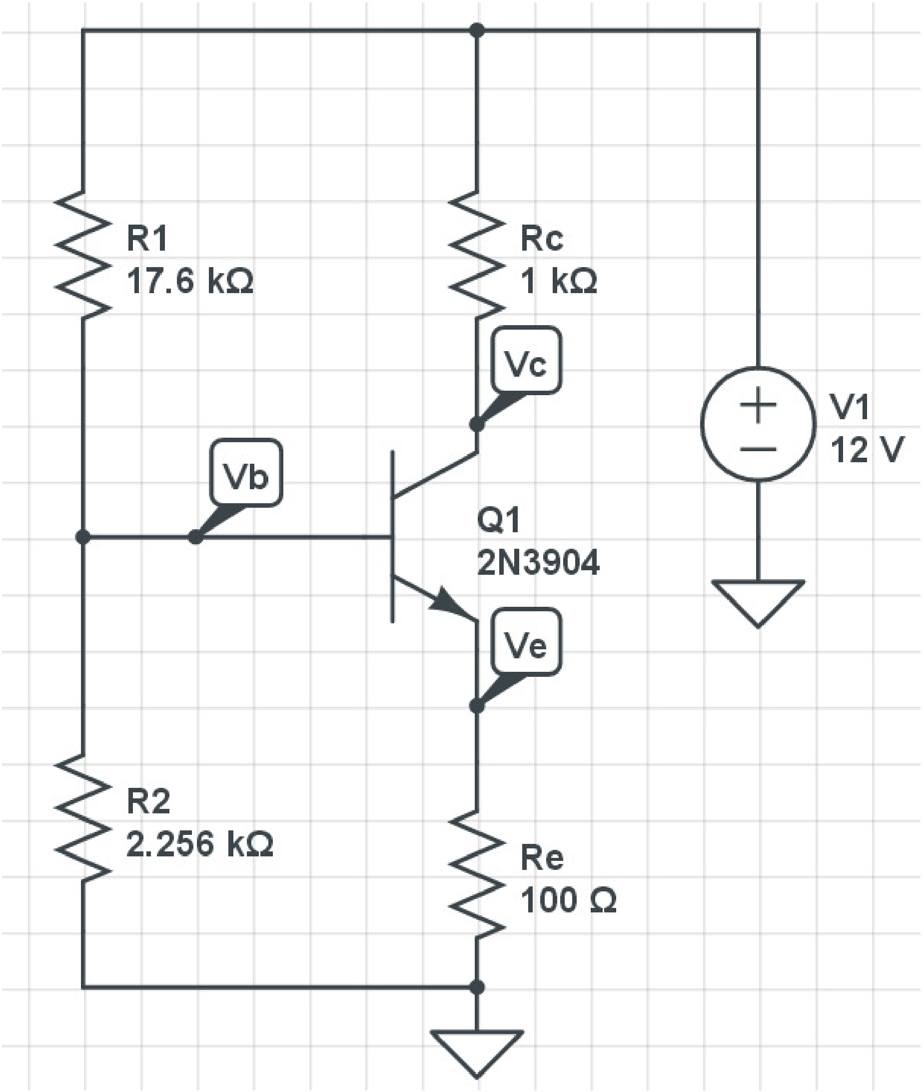
```
V = [];
I = [];
for i=1:100
   R1 = 17600 * (1 + (rand()*2-1)*0.01);
   R2 = 2256 * (1 + (rand()*2-1)*0.01);
   Rc = 1000 * (1 + (rand()*2-1)*0.01);
   Re = 100 * (1 + (rand()*2-1)*0.01);
   Beta = 200 + 100*(rand()*2-1);
   Vb = 12*(R2 / (R1+R2));
   Rb = 1/(1/R1 + 1/R2);
   Ib = (Vb-0.7) / (Rb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