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Introduction to Electronics

An introduction to electronic components and a study of circuits containing such devices.

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Week 7: BJTs

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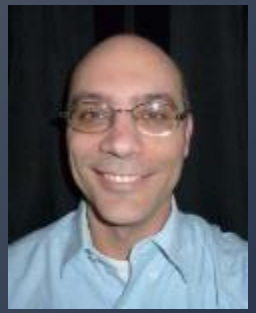

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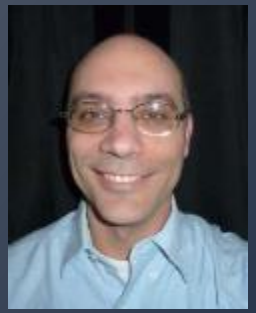

Bipolar Junction Transistor Introduction

Dr. Allen Robinson
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Introduce the bipolar junction transistor

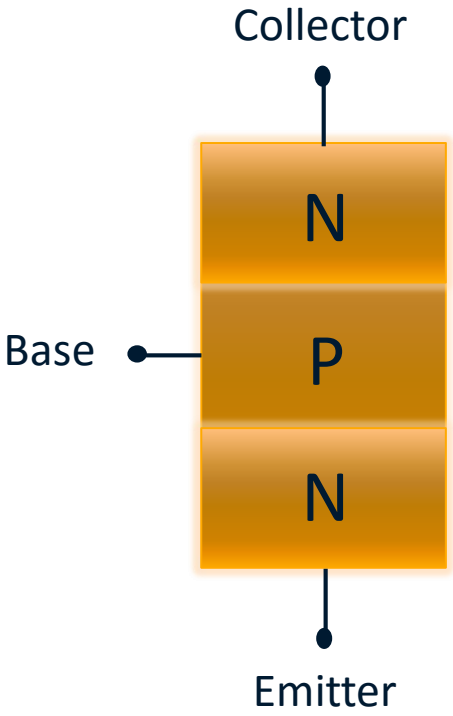
Previous Lesson

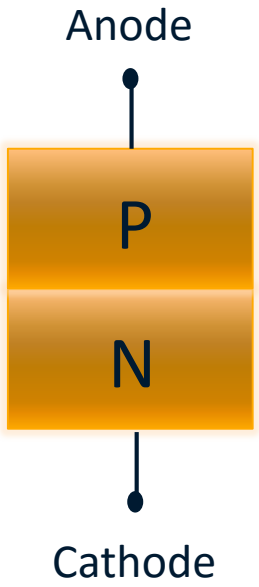
- Examined common source amplifier

Lesson Objectives

- Introduce bipolar junction transistor

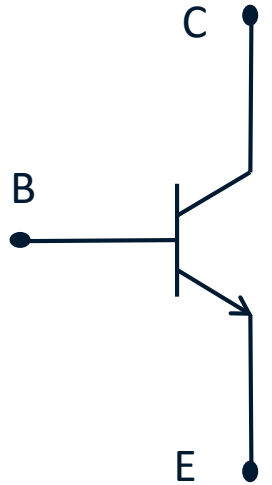
NPN BJT Structure

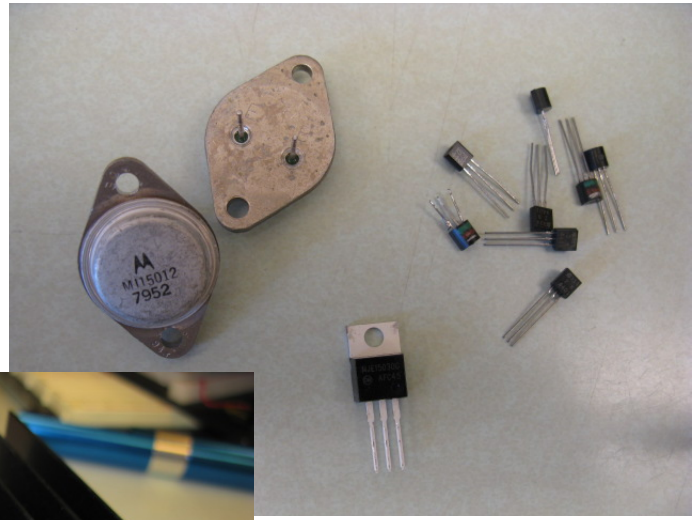


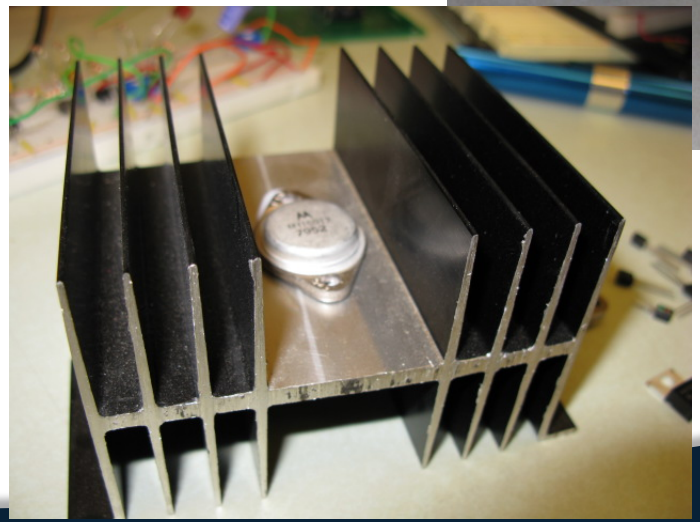


Diode Structure

Symbol and Packages







Regions of Operation

Region	Collector-Base Junction	Base-Emitter Junction
Cutoff	Reverse	Reverse
Saturation	Forward	Forward
Active	Reverse	Forward
Reverse Active	Forward	Reverse

Summary

- Introduced bipolar junction transistor (BJT)
- Examined BJT symbol, structure, and uses

Next Lesson

- BJT terminal characteristics

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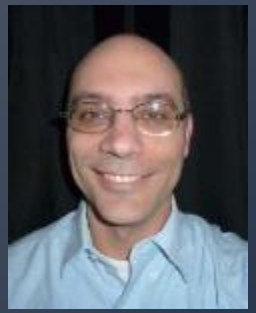

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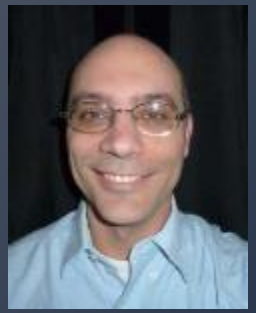

BJT Terminal Characteristics

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School of Electrical and Computer Engineering

Examine bipolar junction transistor terminal characteristics

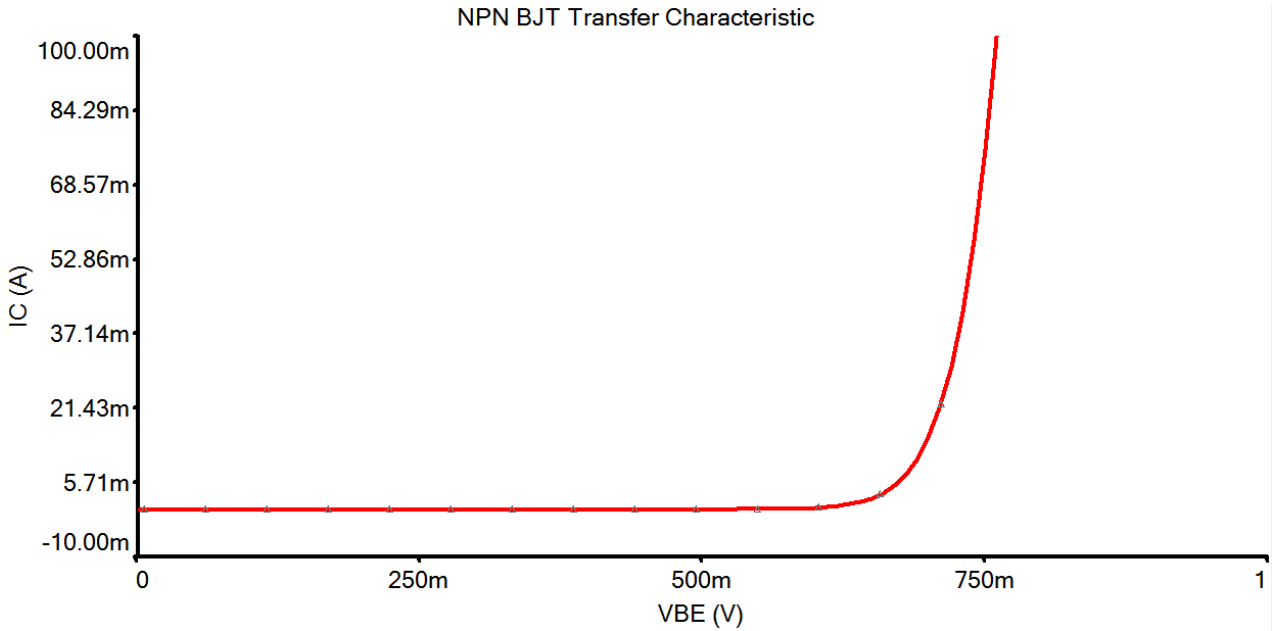
Previous Lesson

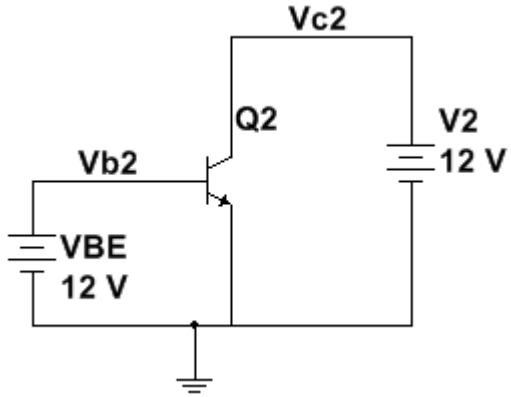
- Introduced the Bipolar Junction Transistor (BJT)

Lesson Objectives

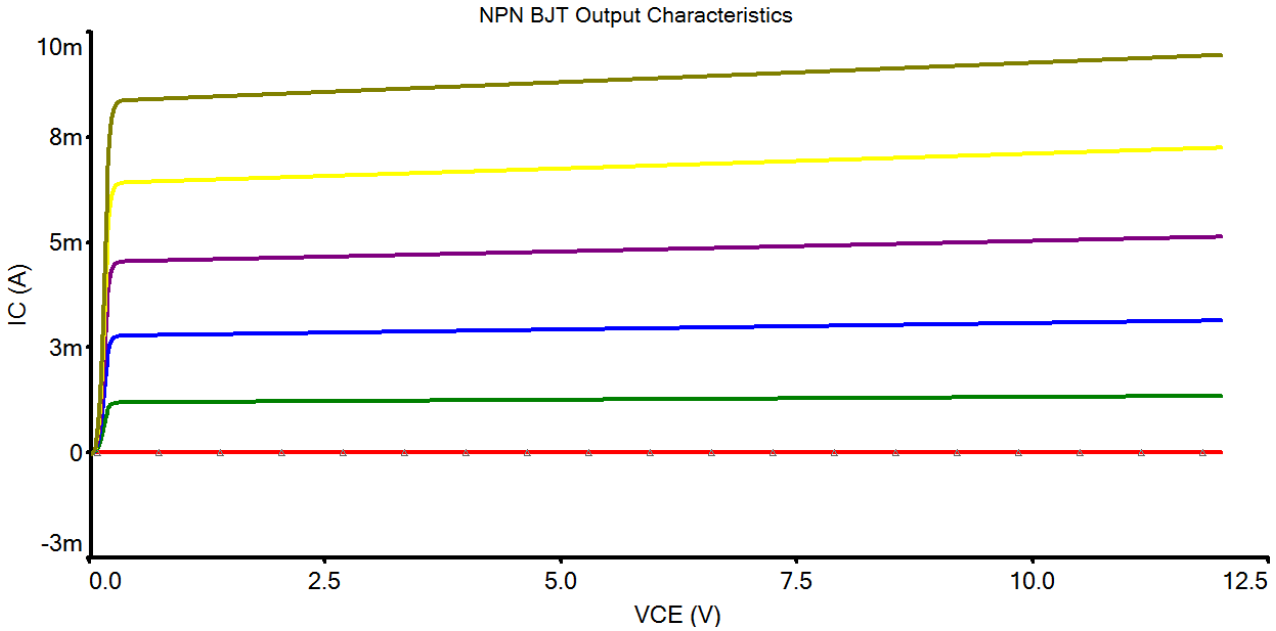
- Examine BJT terminal characteristics

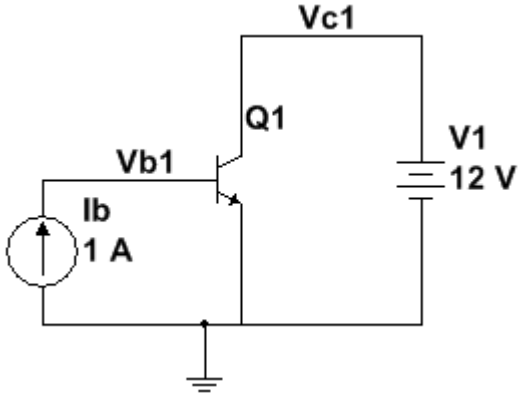
Characteristic Curves





Characteristic Curves





Regions of Operation

Cutoff Region

$V_{BE} \lesssim 0.5\,\mathrm{V}$

$I_B = I_C = I_E = 0$

Active Region

$V_{BE} \approx 0.7\,\mathrm{V}$

$V_{CE} \gtrsim 0.2\,\mathrm{V}$

$I_B > 0$

$I_C = \beta I_B = \alpha I_E$

Saturation Region

$V_{BE} \approx 0.7\,\mathrm{V}$

$V_{CE} \approx 0.2\,\mathrm{V}$

$I_B > 0$

$I_C < \beta I_B$

β = Base to collector current gain. Typical value = 100.

α = Emitter to collector current gain. Typical value = 0.99.

Active Region

$$I_C = I_S e^{V_{BE}/V_T} \qquad I_C = \beta I_B = \alpha I_E$$

$$\beta = \beta_0 \left(1 + \frac{V_{CE}}{V_A}\right)$$

$$I_S = I_{S0} \left(1 + \frac{V_{CE}}{V_A}\right)$$

$$V_T = \frac{kT}{q} = 0.0259\,\mathrm{V} \quad (T = 300\,\mathrm{K})$$

I_{S0} = Zero bias saturation current. Typical value = 1E-15 A.

β_0 = Zero bias base to collector current gain. Typical value = 100.

α = Emitter to collector current gain = $\beta/(\beta+1)$. Typical value = 0.99.

V_A = Early Voltage. Typical value = 150.

Summary

- Examined BJT terminal characteristics

Next Lesson

- BJT parameters

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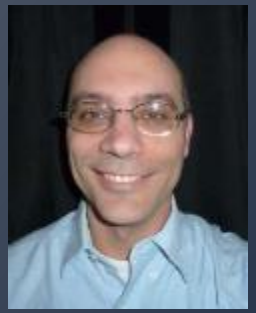

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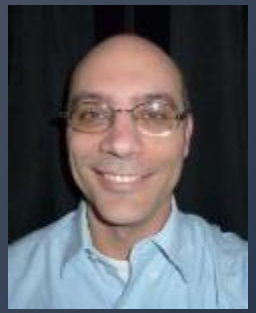


Bipolar Junction Transistor Parameters

Dr. Allen Robinson
Academic Professional
School of Electrical and Computer Engineering

Examine bipolar junction transistor parameters

Previous Lesson

- Introduced bipolar junction transistor

Lesson Objective

- Relate BJT parameters to characteristic curves

Active Region

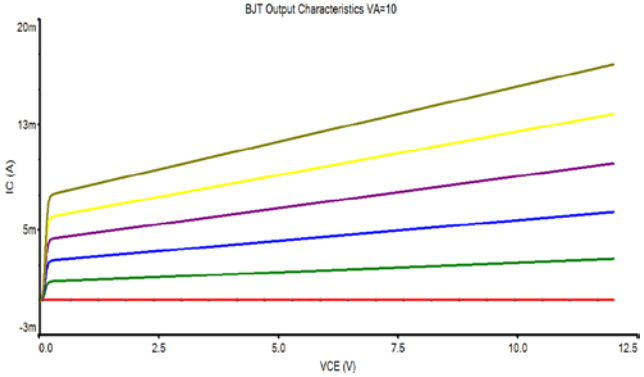
$$I_C = I_S e^{V_{BE}/V_T} \qquad I_C = \beta I_B = \alpha I_E$$

$$\beta = \beta_0 \left(1 + \frac{V_{CE}}{V_A}\right)$$

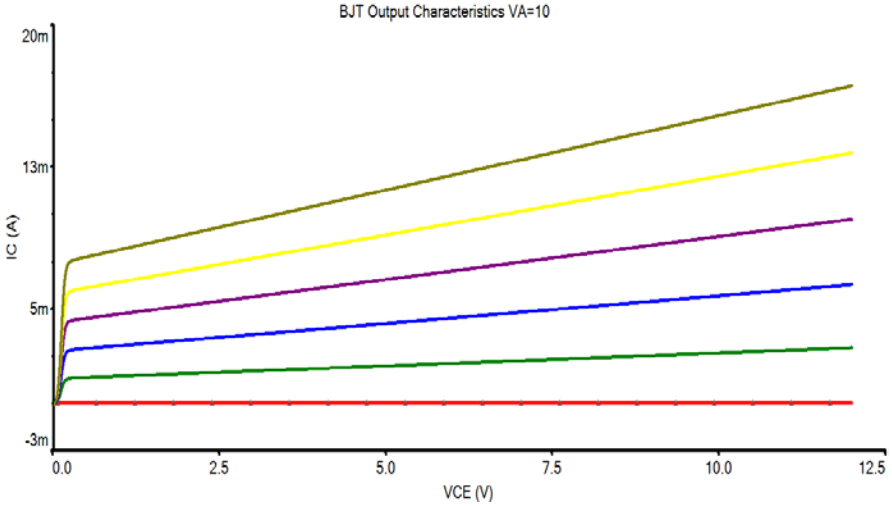
$$I_S = I_{S0} \left(1 + \frac{V_{CE}}{V_A}\right)$$

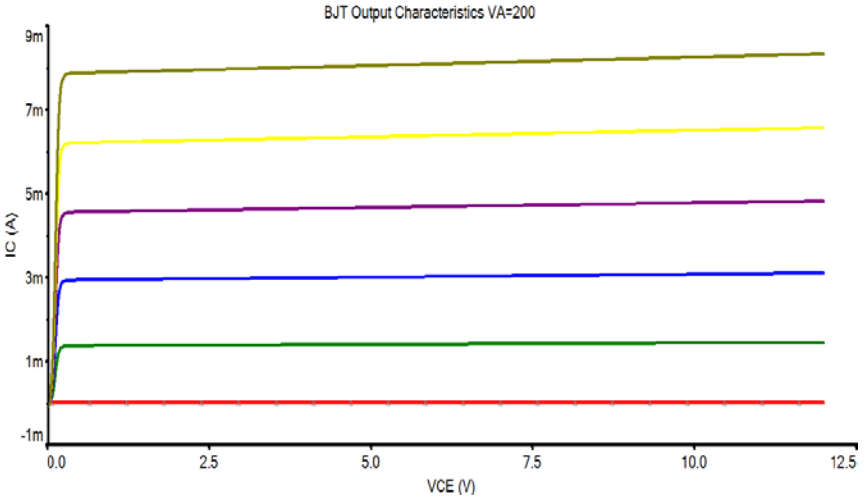
$$V_T = \frac{kT}{q} = 0.0259\,\mathrm{V}$$

$$(T = 300\,\mathrm{K})$$

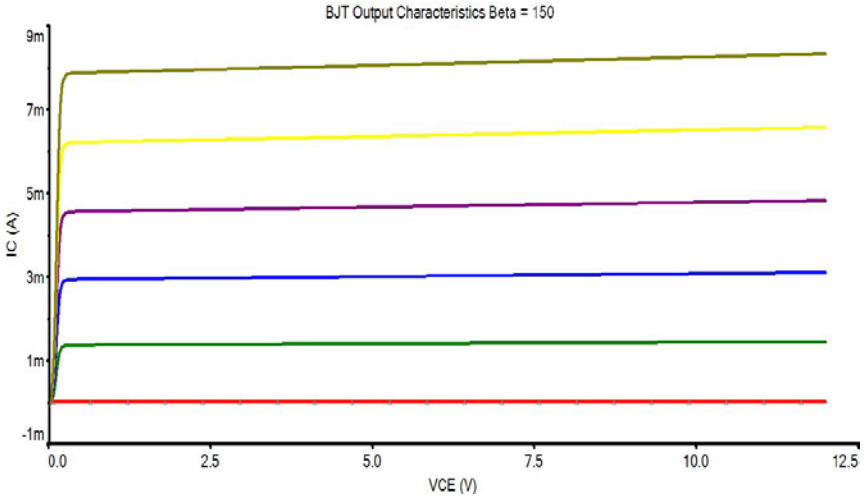


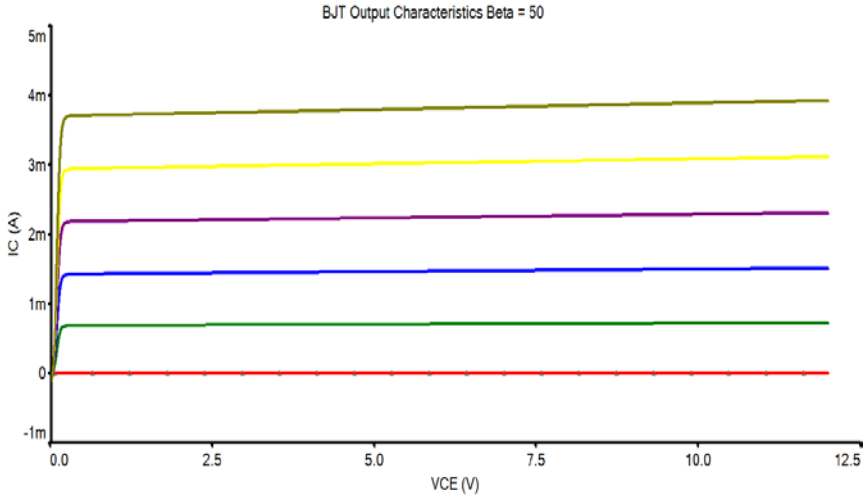
Changing Early Voltage



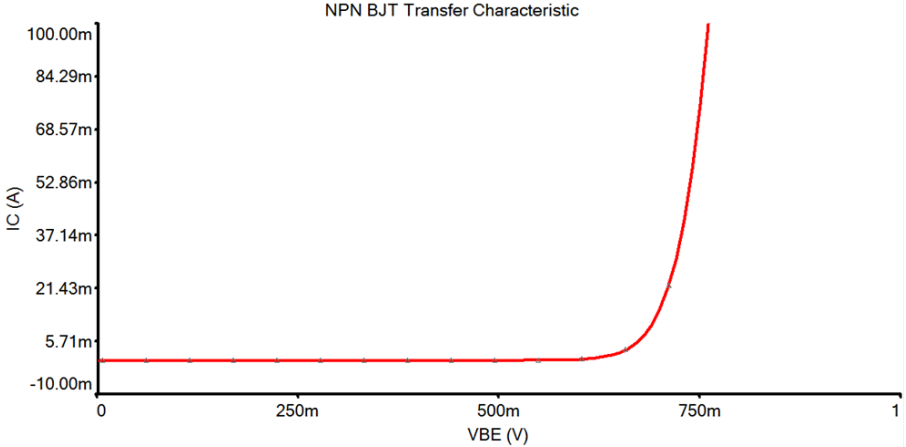


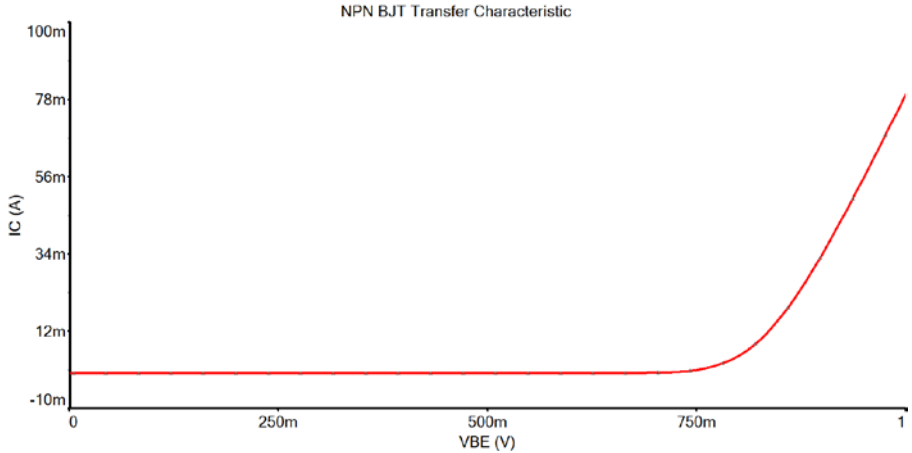
Changing Beta





Changing Saturation Current I_S





Summary

- Determined how BJT parameters affect characteristics

Next Lesson

- BJT Curve Tracer Measurements

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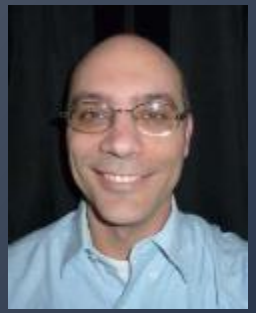

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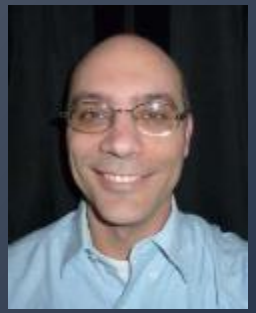

Bipolar Junction Transistor Curve Tracer

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Determine BJT parameters from curve tracer measurements

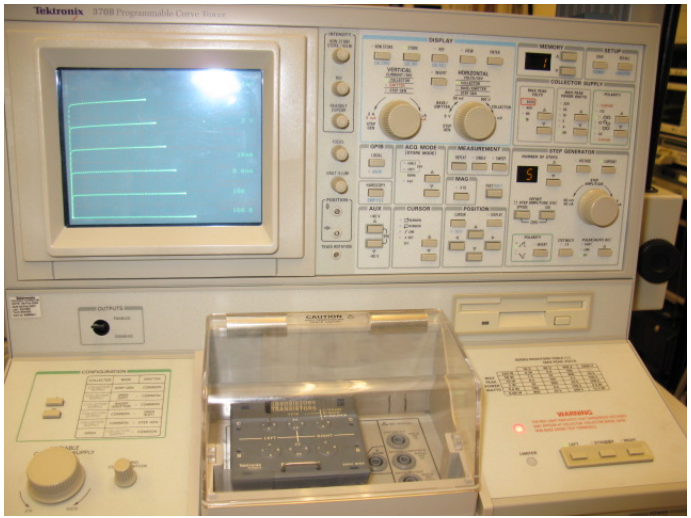
Previous Lesson

- Introduced bipolar junction transistor parameters

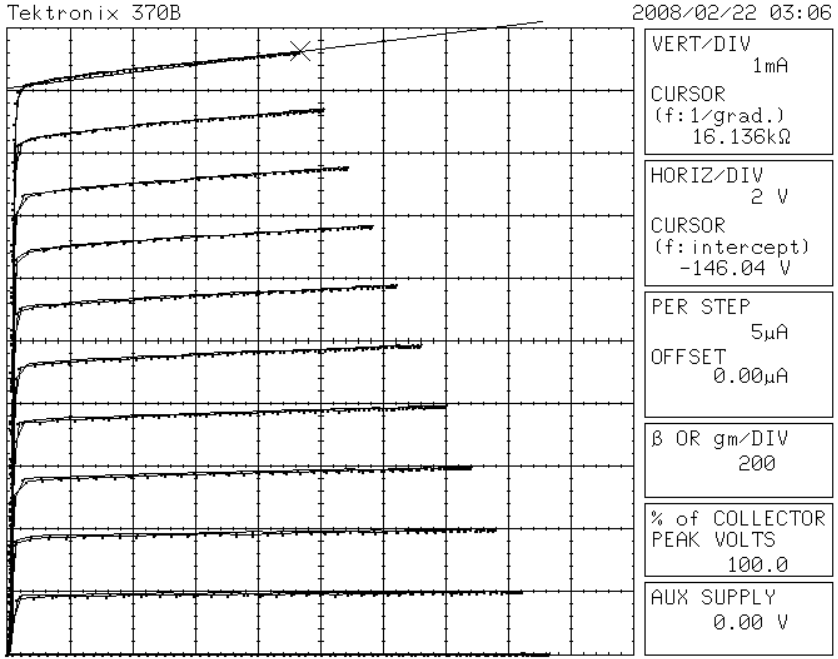
Lesson Objectives

- Introduce the curve tracer
- Solve for parameters from measured data

Curve Tracer



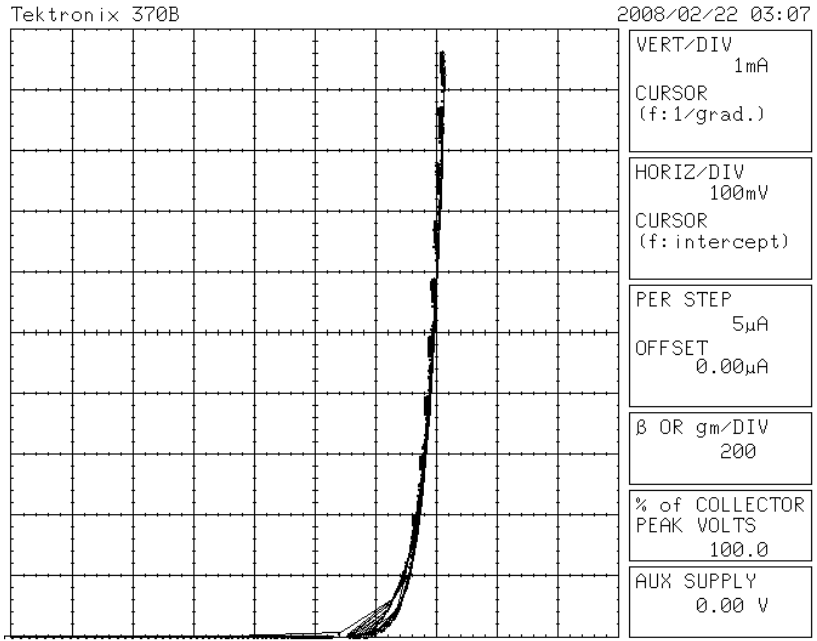
Measured Output Characteristics



$$V_A = \frac{I_C}{m} - V_{CE}$$

$$\beta_0 = \frac{I_C/I_B}{1 + \frac{V_{CE}}{V_A}}$$

Measured Transfer Characteristics



$$I_C = I_S e^{V_{BE}/V_T} \qquad I_{S0} = I_C \frac{e^{-V_{BE}/V_T}}{1 + \frac{V_{CE}}{V_A}}$$

Summary

- Determined BJT parameters from measured data

Next Lesson

- BJT Switch

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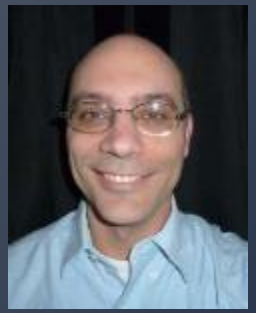

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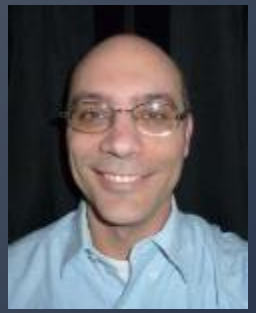
Bipolar Junction Transistor Switch



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Introduce bipolar junction transistor switch

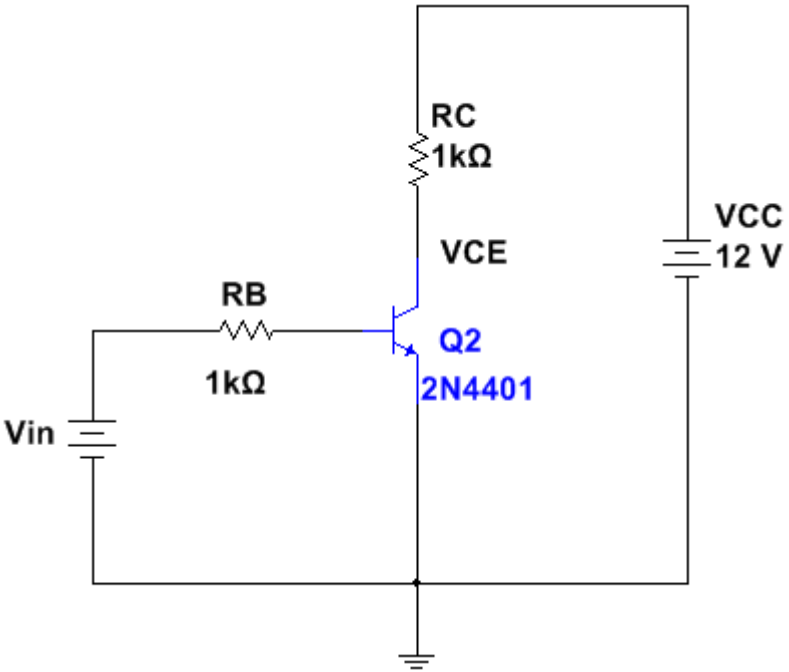
Previous Lesson

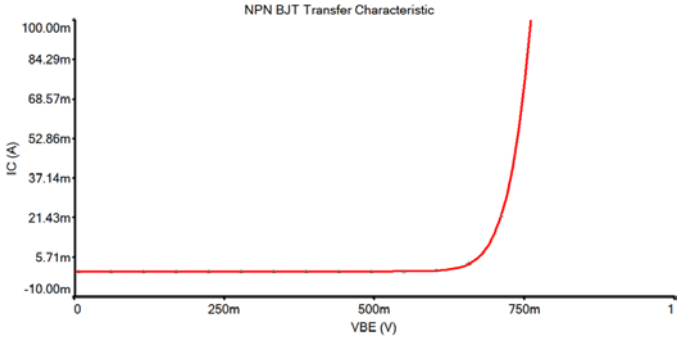
- Examined BJT parameters

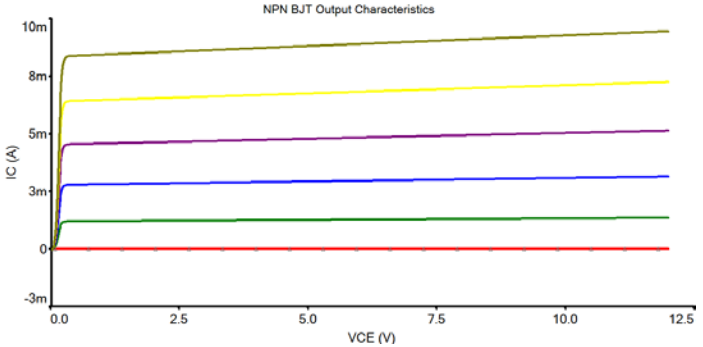
Lesson Objectives

- Introduce BJT switch

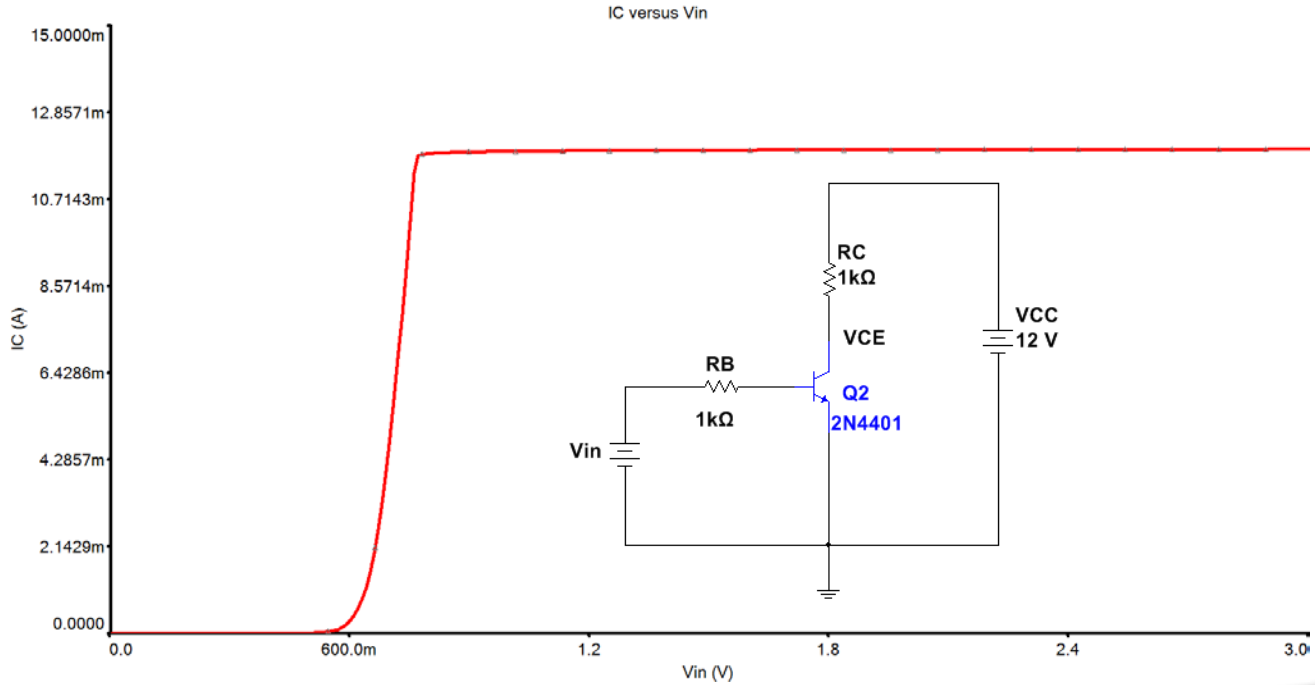
Schematic


RC
1kΩ
VCE
VCC
12 V
RB
1kΩ
Q2
2N4401
Vin

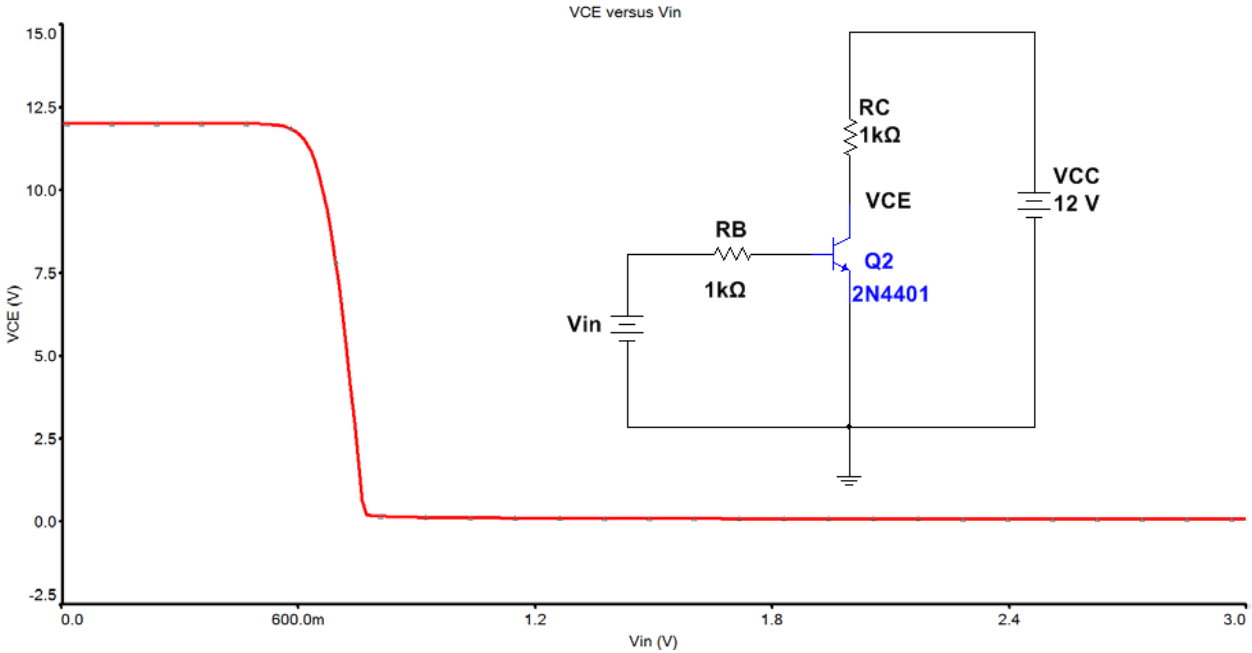

NPN BJT Transfer Characteristic
100.00m
84.29m
68.57m
52.86m
37.14m
21.43m
5.71m
-10.00m
IC (A)
0
250m
500m
750m
1
VBE (V)


NPN BJT Output Characteristics
10m
8m
5m
3m
0
-3m
IC (A)
0.0
2.5
5.0
7.5
10.0
12.5
VCE (V)

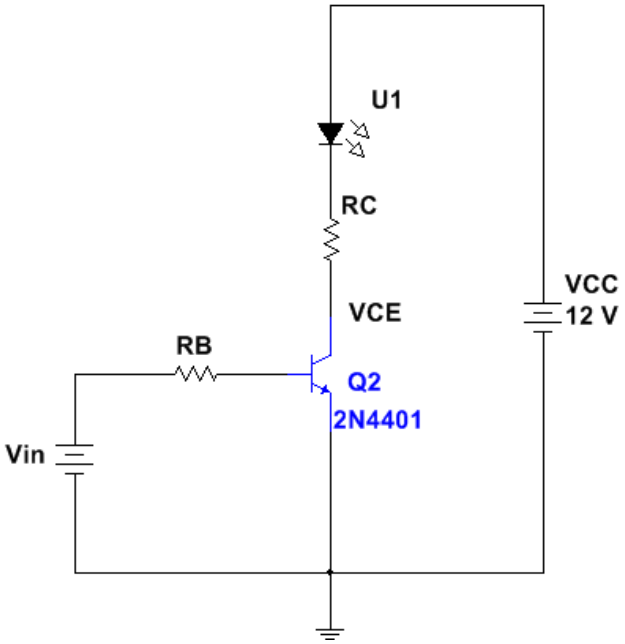
I_C versus V_{in}



V_{CE} versus V_{in}



Example LED Load



Summary

- Introduced BJT switch
- Examined BJT switch characteristics

Next Lesson

- BJT Common Emitter Amplifier

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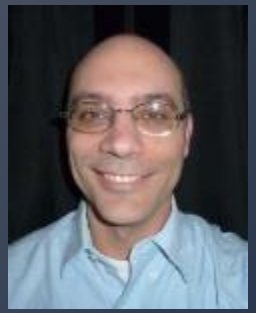

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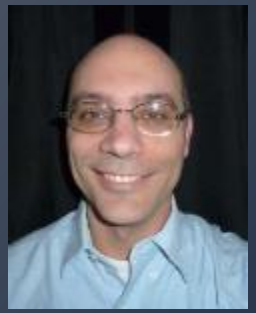

BJT Common Emitter Amplifier

Dr. Allen Robinson
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School of Electrical and Computer Engineering

Introduce bipolar junction transistor common emitter amplifier

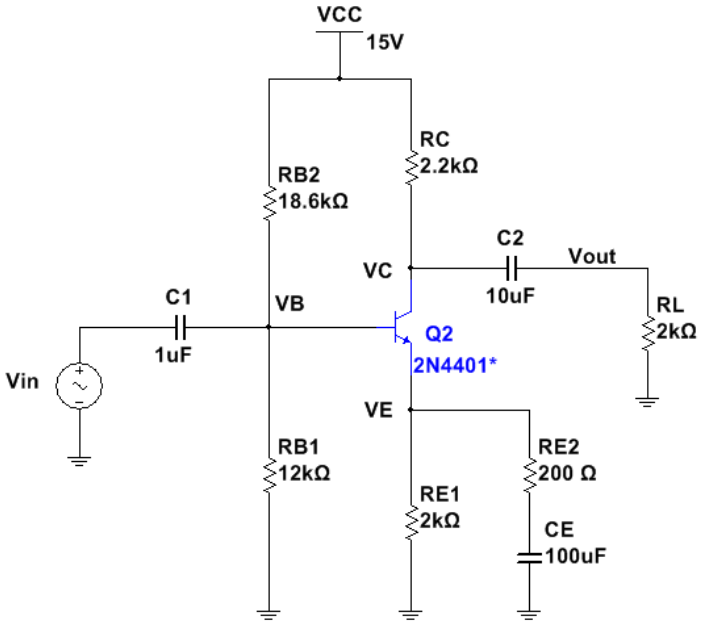
Previous Lesson

- Examined BJT switch

Lesson Objectives

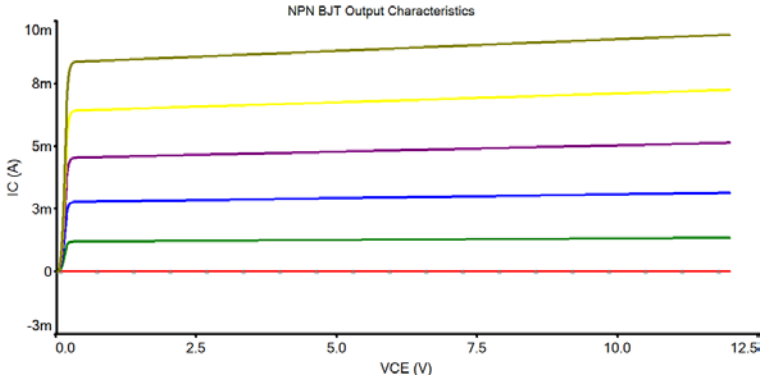
- Introduce BJT common emitter (CE) amplifier
- Examine biasing of the CE amplifier

Common Emitter Circuit Schematic

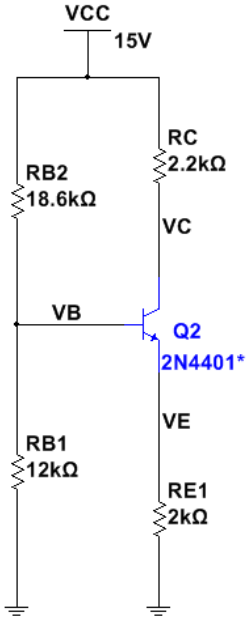


Regions of Operation

Region	Collector-Base Junction	Base-Emitter Junction
Cutoff	Reverse	Reverse
Saturation	Forward	Forward
Active	Reverse	Forward
Reverse Active	Forward	Reverse



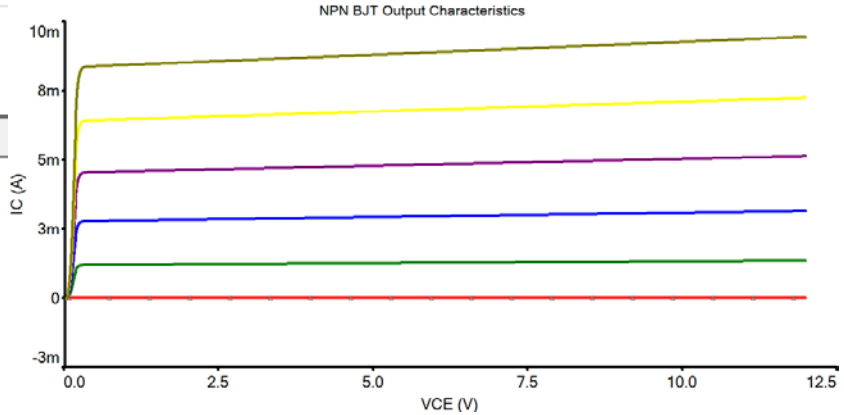
DC Bias Circuit



Bias Values

bjt ce
DC Operating Point

	DC Operating Point	
1	@qq2[ic]	2.43276 m
2	@qq2[ib]	40.48994 u
3	@qq2[ie]	-2.47325 m
4	V(vc)	9.66069
5	V(vb)	5.58764
6	V(ve)	4.93473



Summary

- Introduced BJT CE Amplifier
- Solved CE biasing example

Next Lesson

- BJT Common Emitter Amplifier AC Analysis

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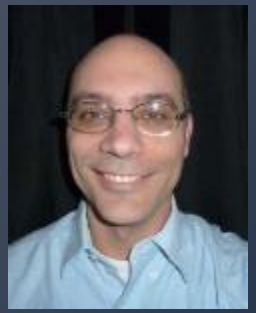

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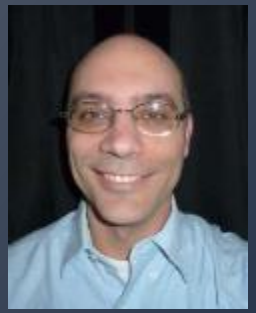


BJT Common Emitter Amplifier AC Behavior

Dr. Allen Robinson
Academic Professional
School of Electrical and Computer Engineering

Examine ac behavior of CE amplifier

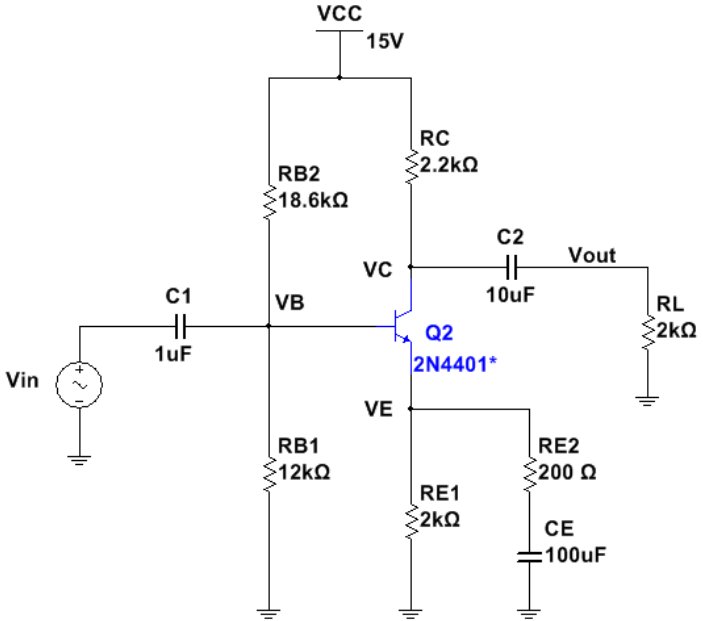
Previous Lesson

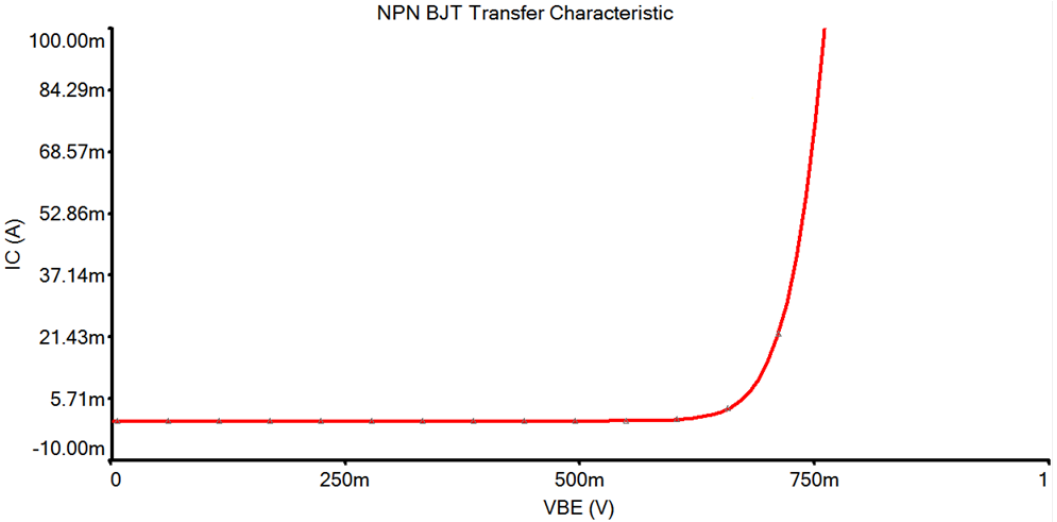
- Introduced CE amplifier
- Examined dc biasing of the amplifier

Lesson Objectives

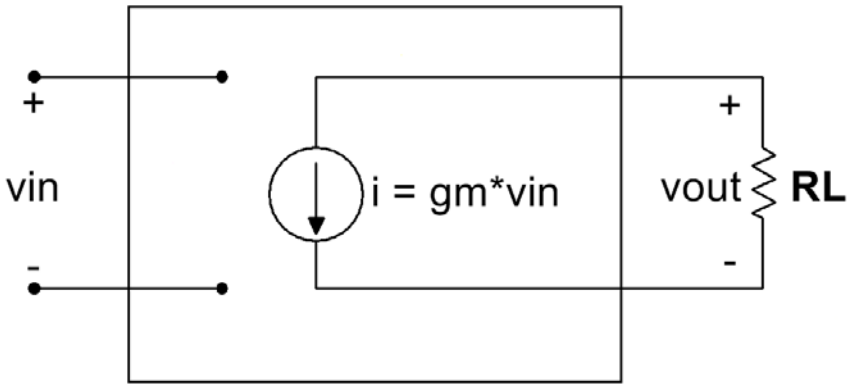
- Examine ac behavior of the CE amplifier

Common Emitter Circuit Schematic



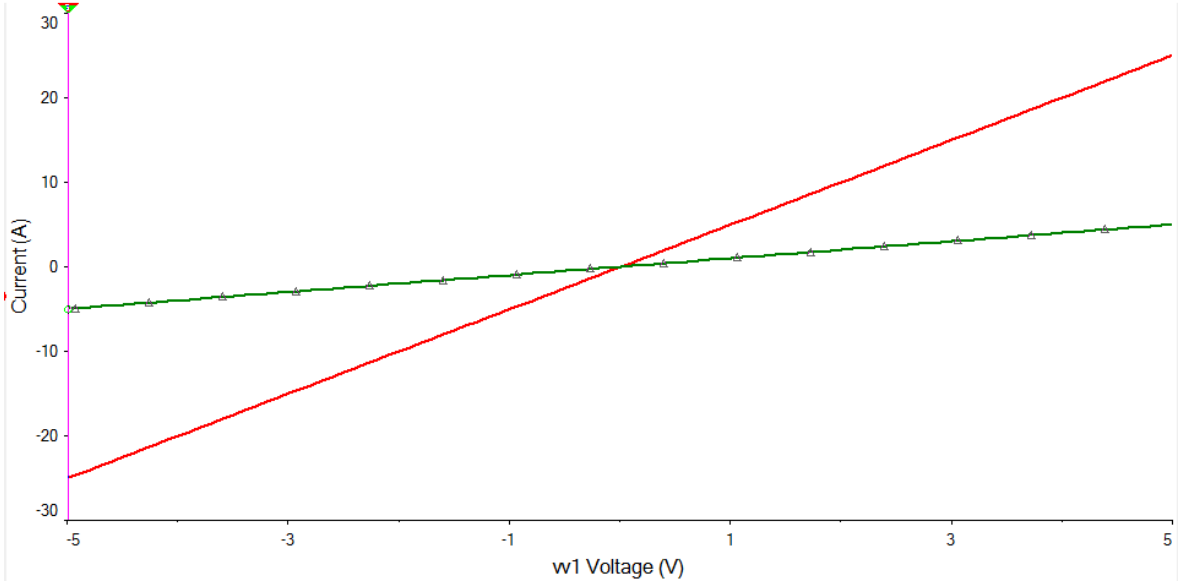


Amplifier Model



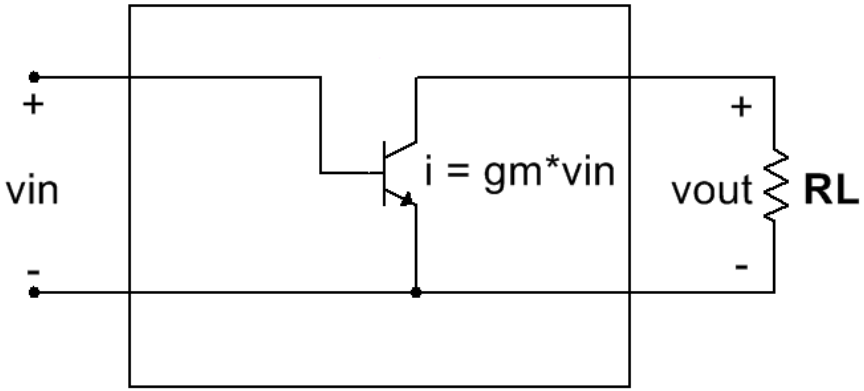
gm = transconductance

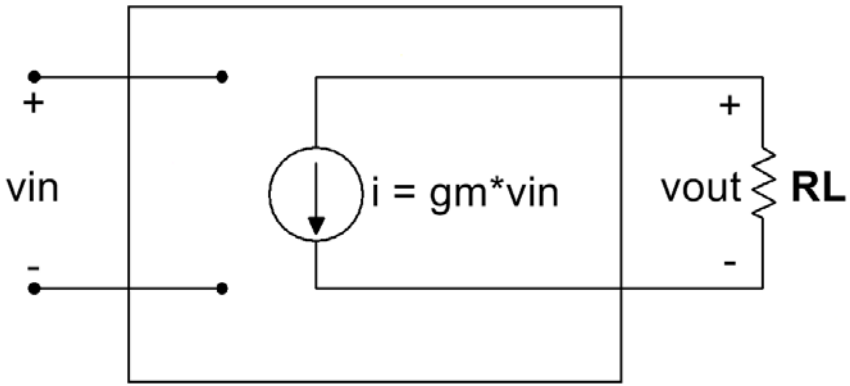
I-V Characteristic



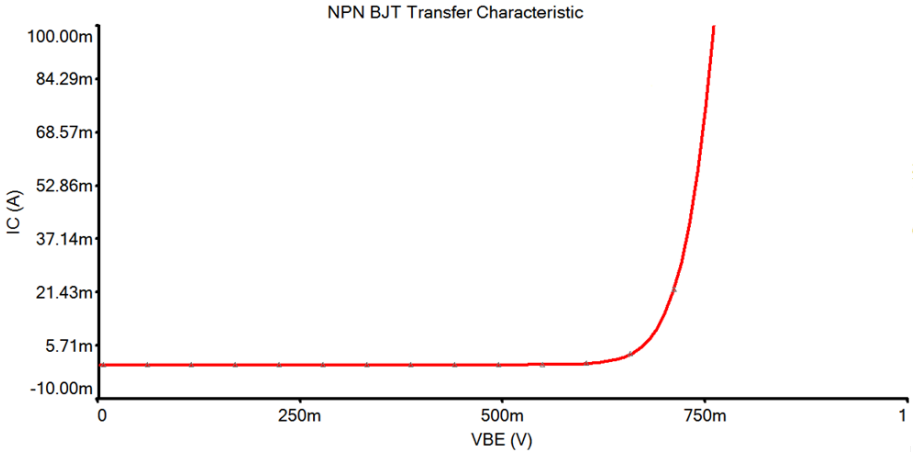
i = gm*vin

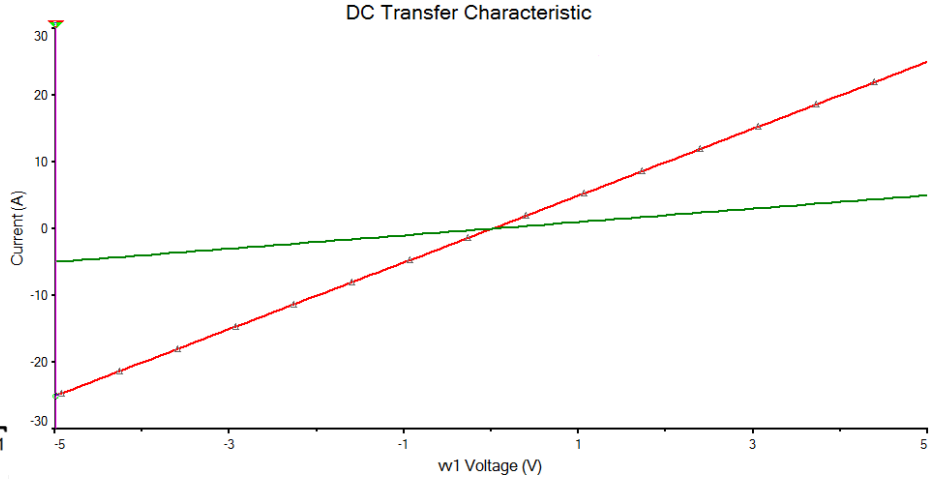
CE Amplifier





I-V Characteristics

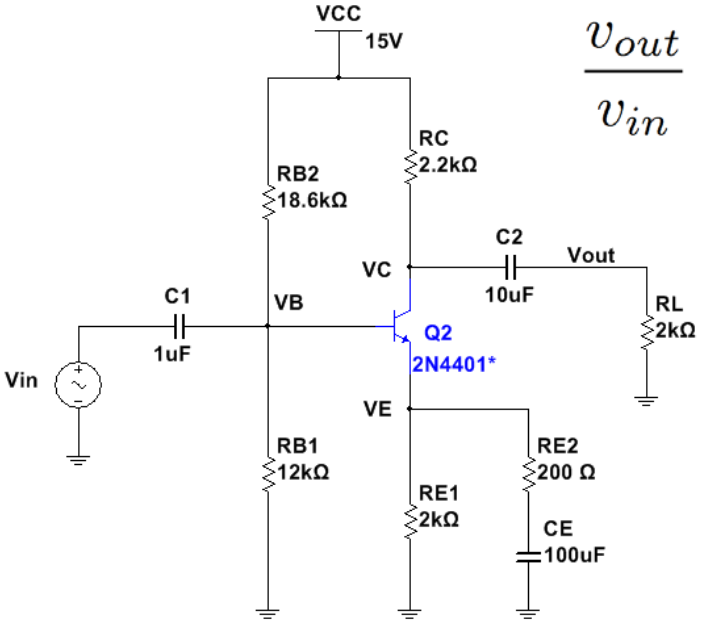




$g_m = I_C/V_T$

$V_T = 0.0259V$

Gain Equation



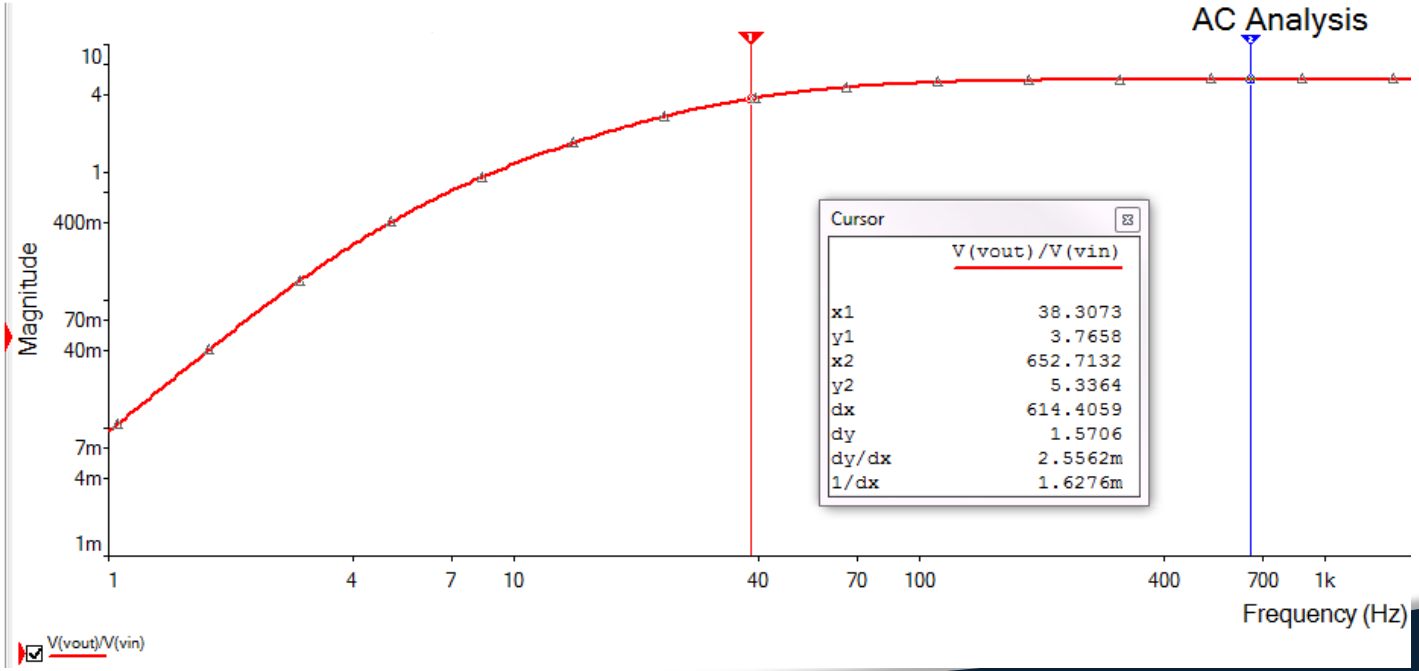
$$\frac{v_{out}}{v_{in}} = -\alpha \frac{R_C || R_L}{r_e + R_{E1} || R_{E2}} \qquad \frac{v_{out}}{v_{in}} = -g_m R_L$$

$$r_e = \frac{\alpha}{g_m}$$

$$\alpha = \frac{\beta}{\beta + 1}$$

$$g_m = \frac{I_C}{V_T}$$

AC Analysis


AC Analysis
10
4
1
400m
70m
40m
7m
4m
1m
Magnitude
1
4
7
10
40
70
100
400
700
1k
Frequency (Hz)
Cursor
V(vout)/V(vin)
x1 38.3073
y1 3.7658
x2 652.7132
y2 5.3364
dx 614.4059
dy 1.5706
dy/dx 2.5562m
1/dx 1.6276m
V(vout)/V(vin)

Summary

- Examined ac behavior of the CE amplifier