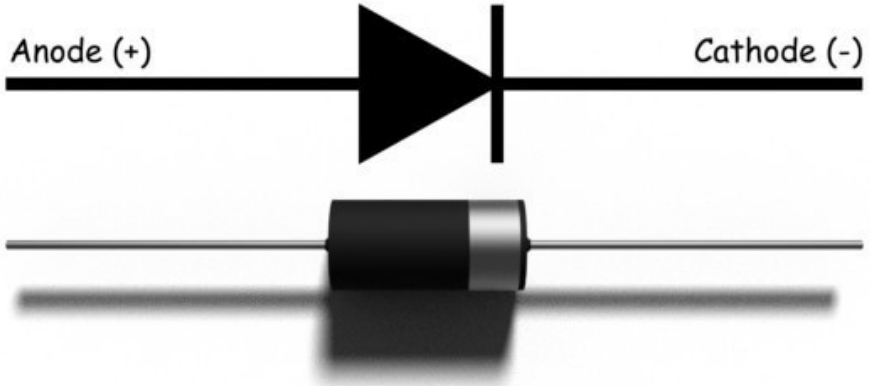
電子電路入門導論

雙極性電晶體 -BJT

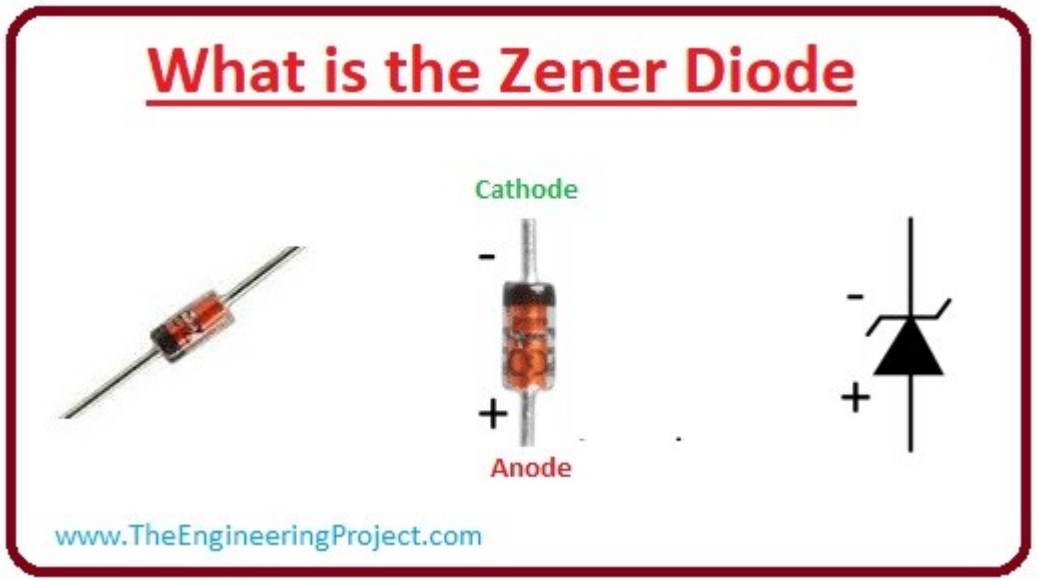
蘇文鈺
成功大學資訊工程系

本投影片之圖片取自網路

二極體 Diode

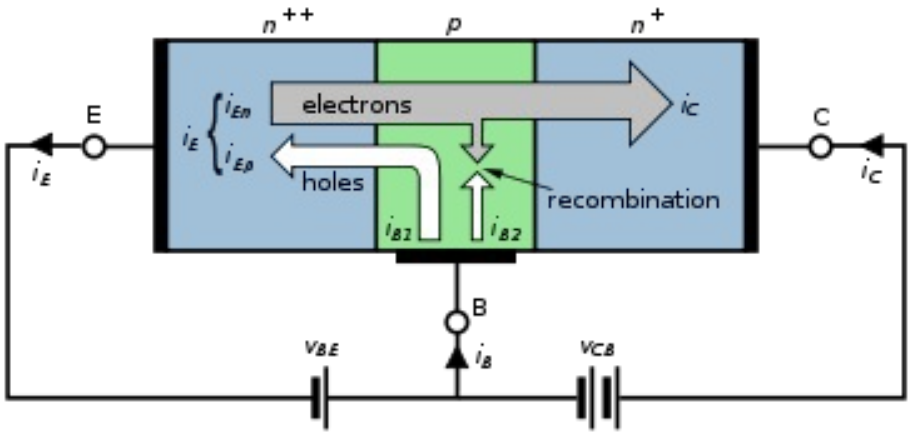


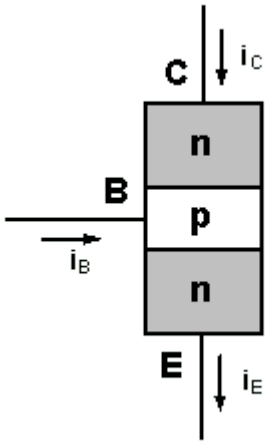
由 P(Anode) 到 N(Cathode) 單向導通

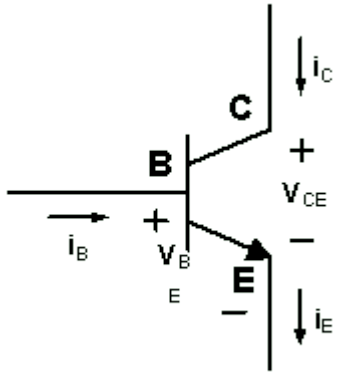


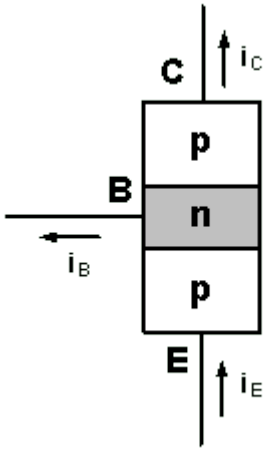
- 由 P(Anode) 到 N(Cathode) 單向導通
- 但是通常反過來用，反向施加電壓時二極體崩潰後產生固定的導通電壓
  - 可以做為穩壓使用
  - 可以做為參考電壓使用

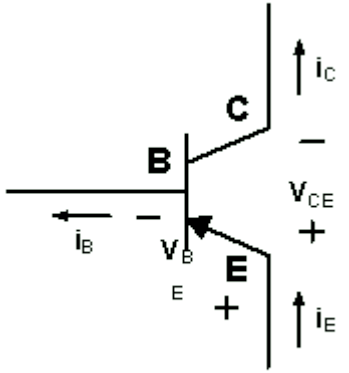
雙極性電晶體， Bipolar Junction Transistor

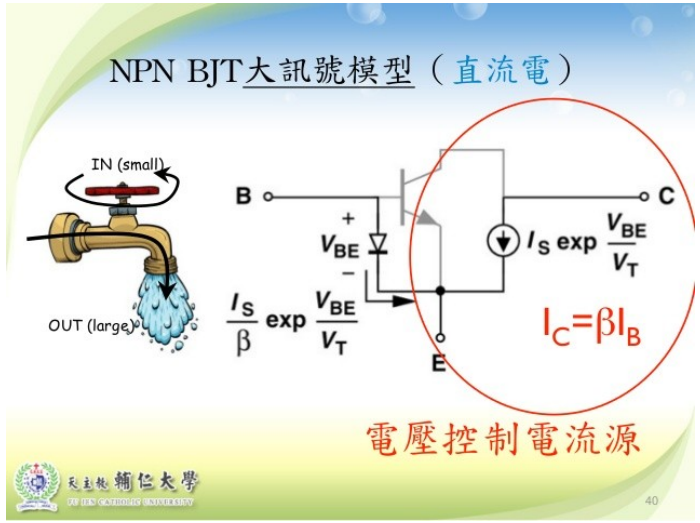












雙極性電晶體的規格範例

Micro Commercial Components
20736 Marilla Street Chatsworth
CA 91311
Phone: (818) 701-4933
Fax: (818) 701-4939

2N3904

NPN General Purpose Amplifier

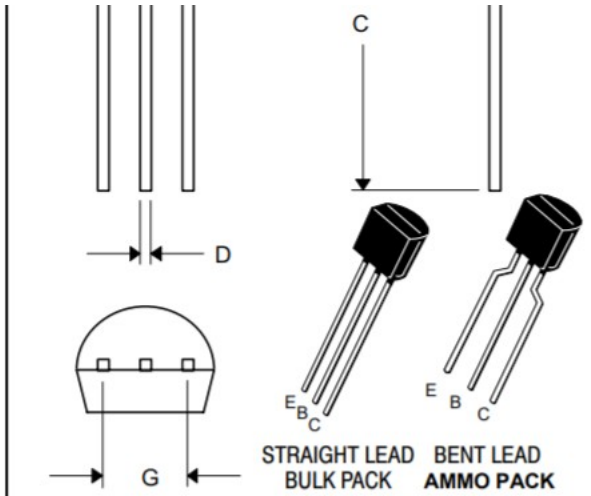
Features

- Lead Free Finish/RoHS Compliant ("P" Suffix designates RoHS Compliant. See ordering information)
- Capable of 625mW of Power Disspation and 200mA Ic
- Epoxy meets UL 94 V-0 flammability rating
- Moisure Sensitivity Level 1
- Through Hole Package
- Halogen free available upon request by adding suffix "-HF"
- Operating Temperature: -55°C to +150°C
- Storage Temperature: -55°C to +150°C

Electrical Characteristics @ 25°C Unless Otherwise Specified

Symbol	Parameter	Min	Max	Units
OFF CHARACTERISTICS				
$V_{(BR)CEO}$	Collector-Emitter Breakdown Voltage* (I_C=1.0mAdc, I_B=0)	40		Vdc
$V_{(BR)CBO}$	Collector-Base Breakdown Voltage (I_C=10μAdc, I_E=0)	60		Vdc
$V_{(BR)EBO}$	Emitter-Base Breakdown Voltage (I_E=10μAdc, I_C=0)	6.0		Vdc
I_{BL}	Base Cutoff Current (V_{CE}=30Vdc, V_{BE}=3.0Vdc)		50	nAdc
I_{CEX}	Collector Cutoff Current (V_{CE}=30Vdc, V_{BE}=3.0Vdc)		50	nAdc
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
SMALL-SIGNAL CHARACTERISTICS				
f_T	Current Gain-Bandwidth Product (I_C=10mAdc, V_{CE}=20Vdc, f=100MHz)	250		MHz
C_{obo}	Output Capacitance (V_{CB}=5.0Vdec, I_E=0, f=1.0MHz)		4.0	pF
C_{ibo}	Input Capacitance (V_{BE}=0.5Vdc, I_C=0, f=1.0MHz)		8.0	pF
NF	Noise Figure (I_C=100μAdc, V_{CE}=5.0Vdc, R_S=1.0kΩ f=10Hz to 15.7kHz)		5.0	dB
SWITCHING CHARACTERISTICS				
t_d	Delay Time	(V_{CC}=3.0Vdc, V_{BE}=0.5Vdc	35	ns
t_r	Rise Time	I_C=10mAdc, I_{B1}=1.0mAdc)	35	ns
t_s	Storage Time	(V_{CC}=3.0Vdc, I_C=10mAdc	200	ns
t_f	Fall Time	I_{B1}=I_{B2}=1.0mAdc)	50	ns

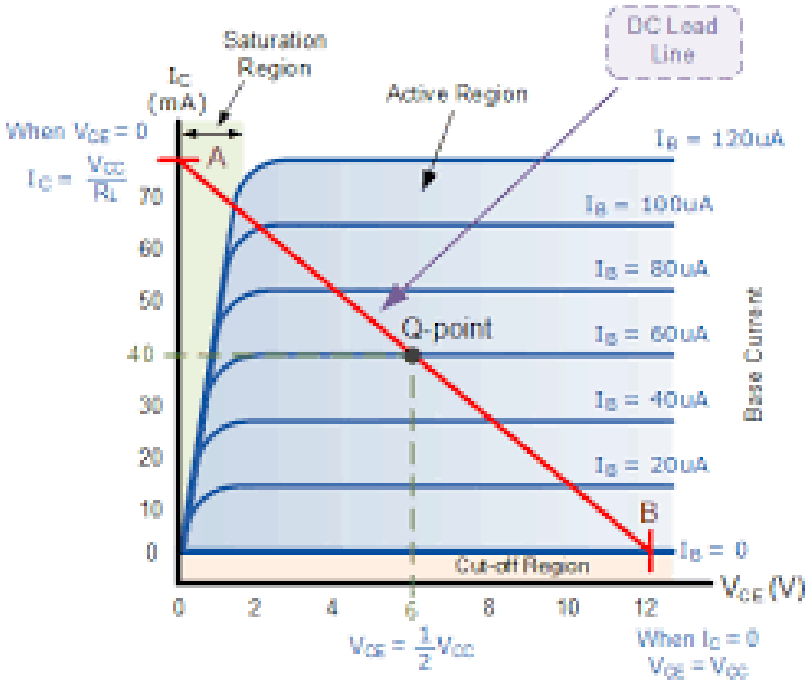
*Pulse Width ≤ 300μs, Duty Cycle ≤ 2.0%



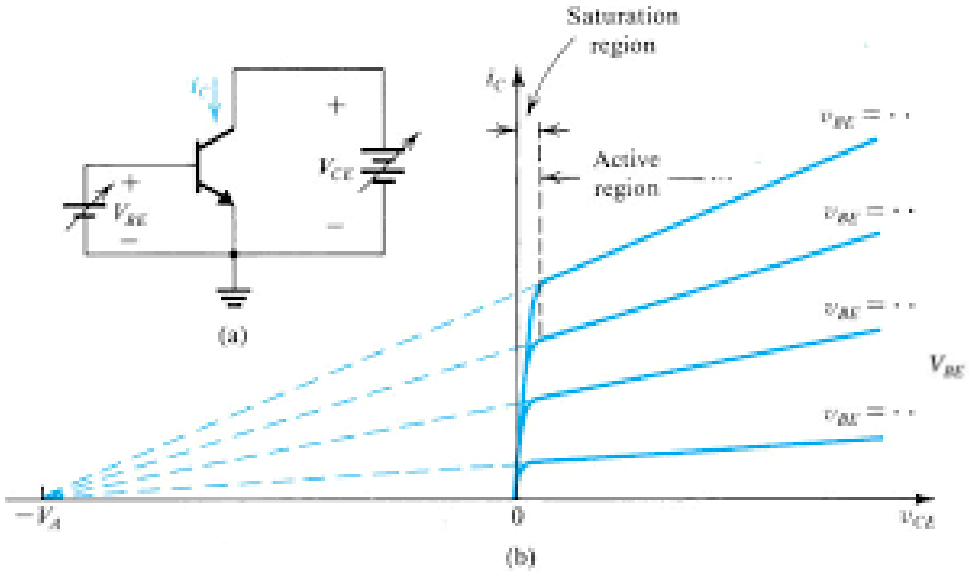
DIMENSIONS					
	INCHES		MM		
DIM	MIN	MAX	MIN	MAX	NOTE
A	.175	.185	4.45	4.70	
B	.175	.185	4.45	4.70	
C	.500	---	12.70	---	
D	.016	.020	0.41	0.63	
E	.135	.145	3.43	3.68	
G	.095	.105	2.42	2.67	Straight Lead
	.173	.220	4.40	5.60	Bent Lead

* For ammo packing detailed specification, click here to visit our website of product packaging for details.

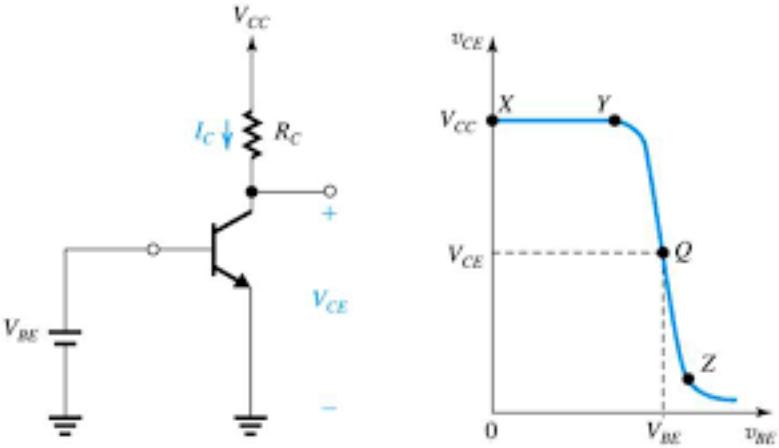
特性曲線



較為理想的

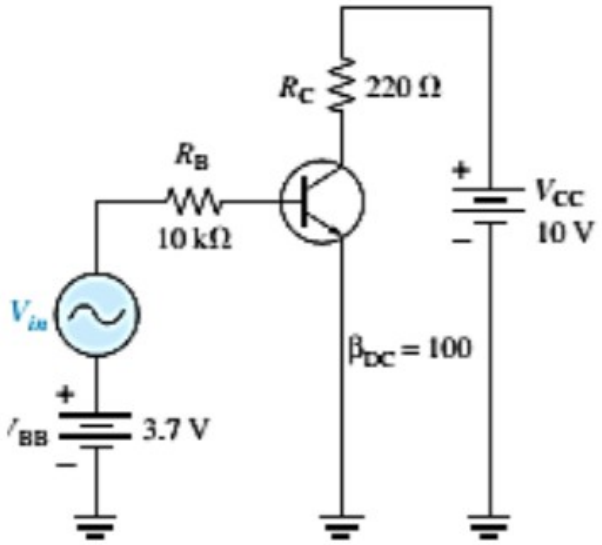


稍微誇張一點的，但是比較
可以清楚看出其輸出內部阻抗



把第一章圖轉個角度來看
Q 為此電晶體的操作點

偏壓電路 (Biasing)



$$I_{BQ} = \frac{V_{BB} - 0.7\,\text{V}}{R_B} = \frac{3.7\,\text{V} - 0.7\,\text{V}}{10\,\text{k}\Omega} = 300\,\mu\text{A}$$

$$I_{CQ} = \beta_{DC} I_{BQ} = (100)(300\,\mu\text{A}) = 30\,\text{mA}$$

$$V_{CEQ} = V_{CC} - I_{CQ} R_C = 10\,\text{V} - (30\,\text{mA})(220\,\Omega) = 3.4\,\text{V}$$

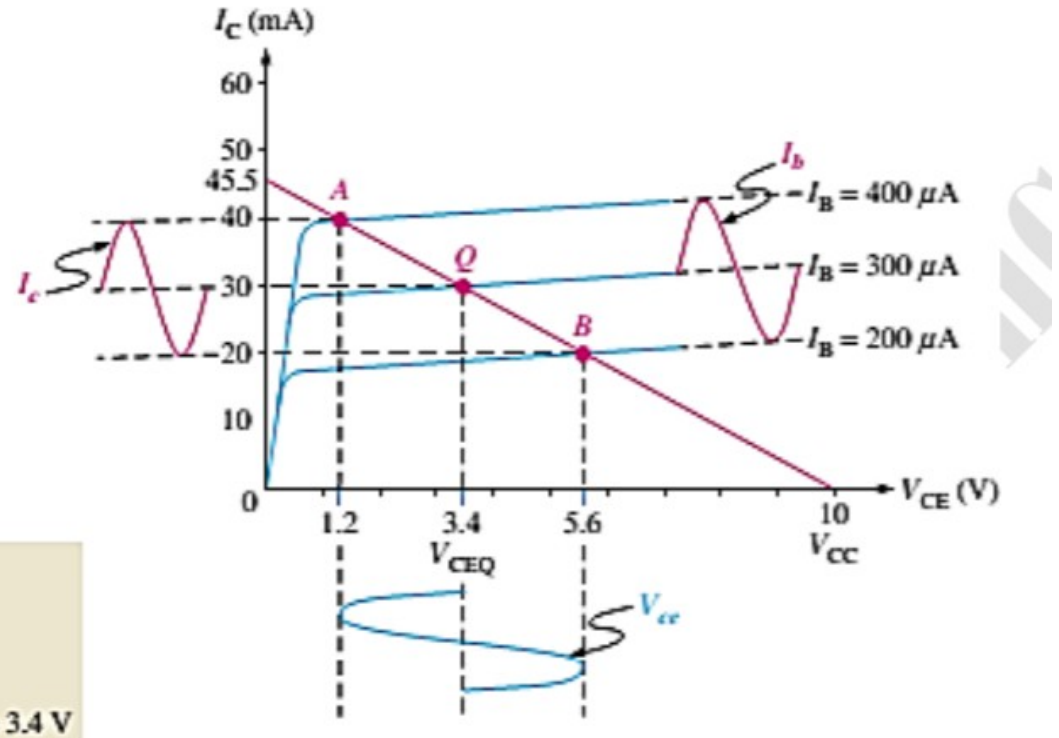
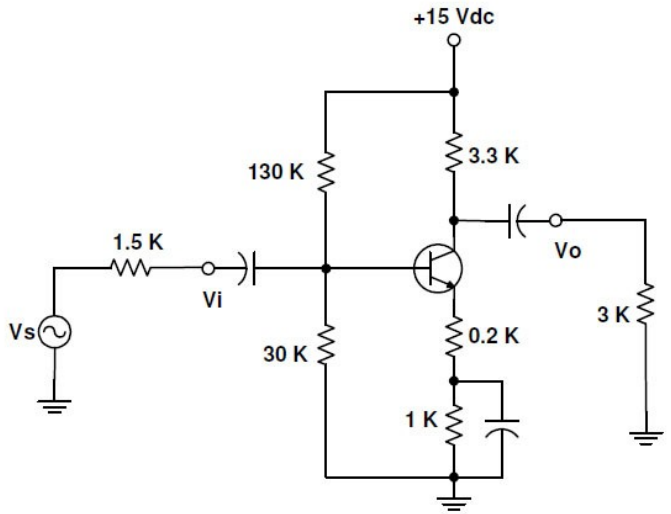


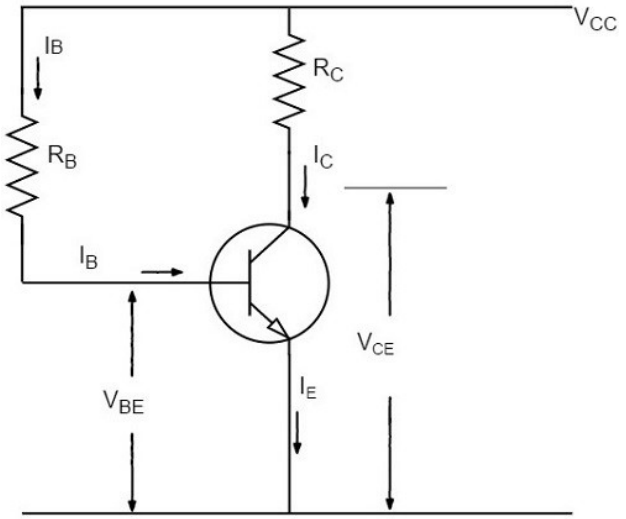
Figure 14: Variations in I_C and V_{CE} as a result of a variation in base current.

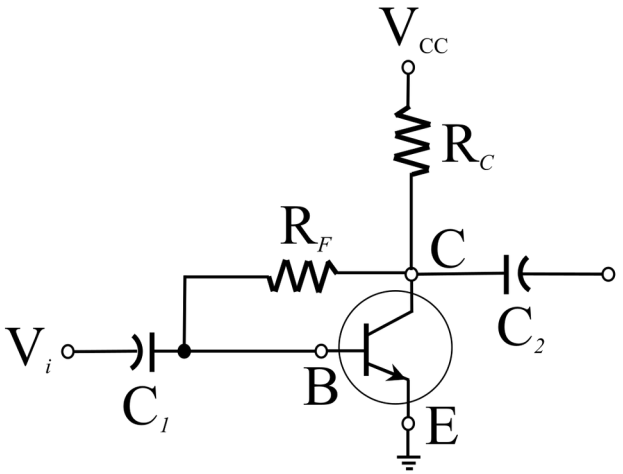
幾種較為實際的偏壓方式



Voltage divider

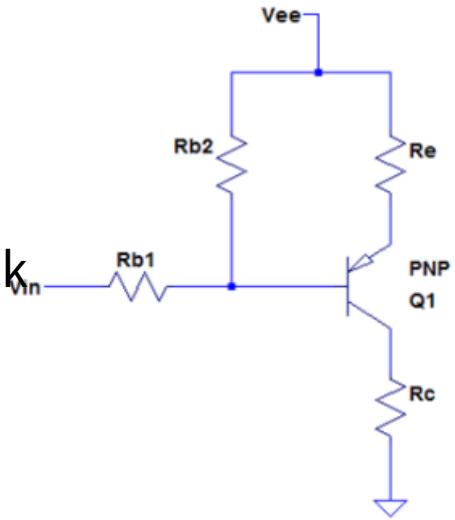
Base



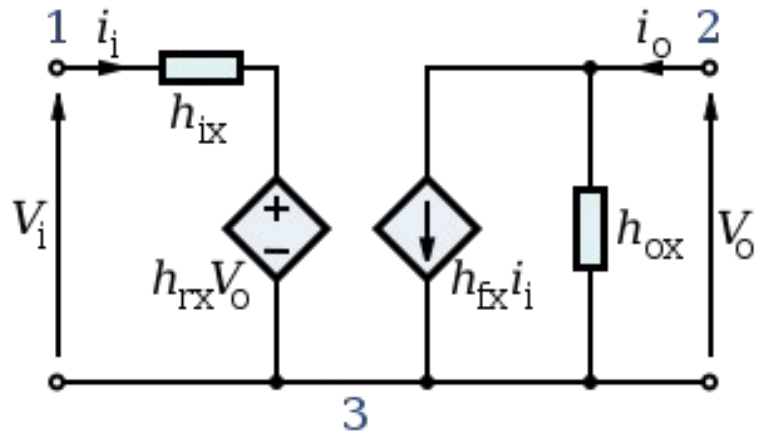


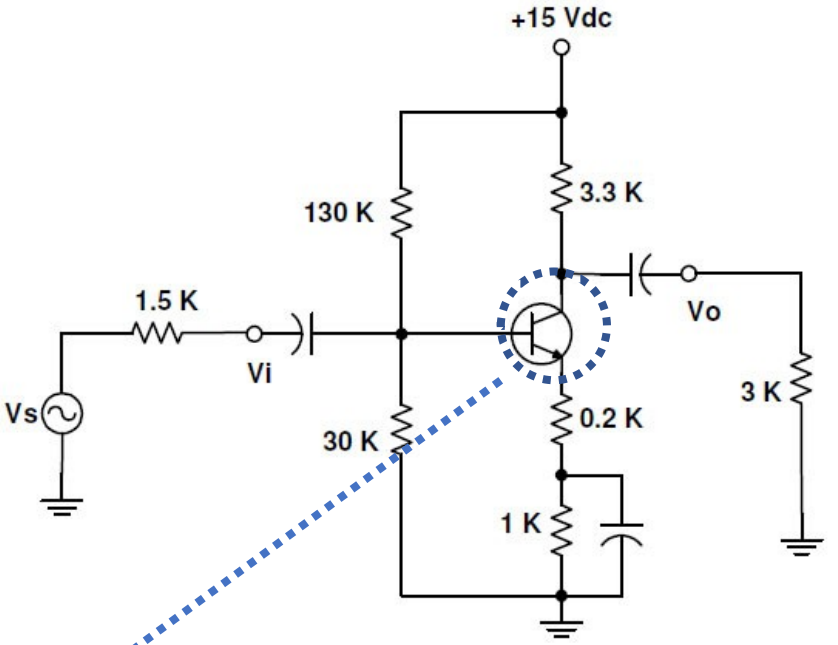
Base + Collector Feedback

Base + Emitter feedback



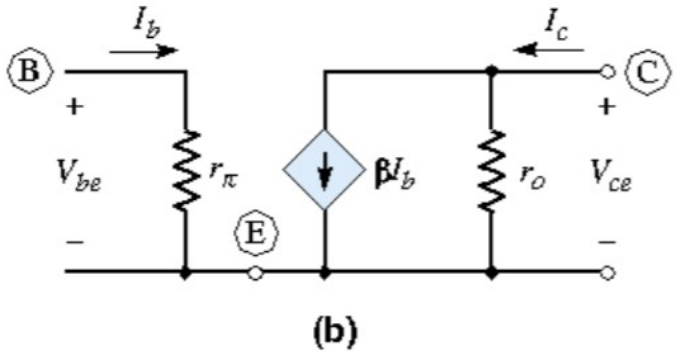
小訊號等效模型 (Equivalent Model)

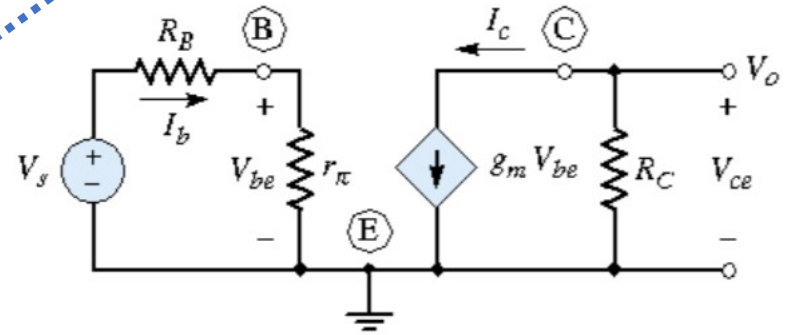




Common Emitter
共射級

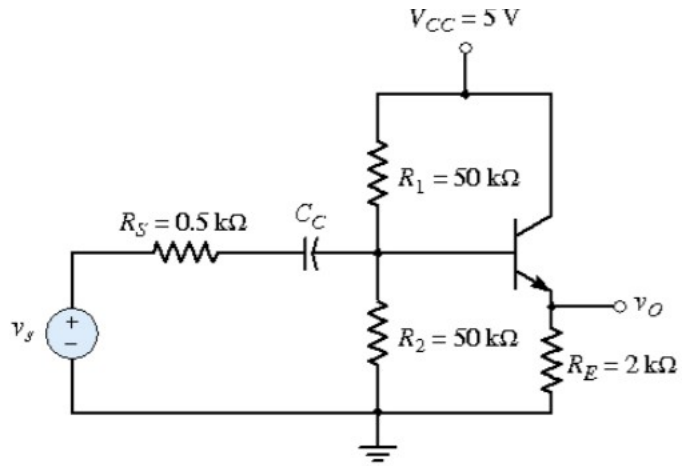
或

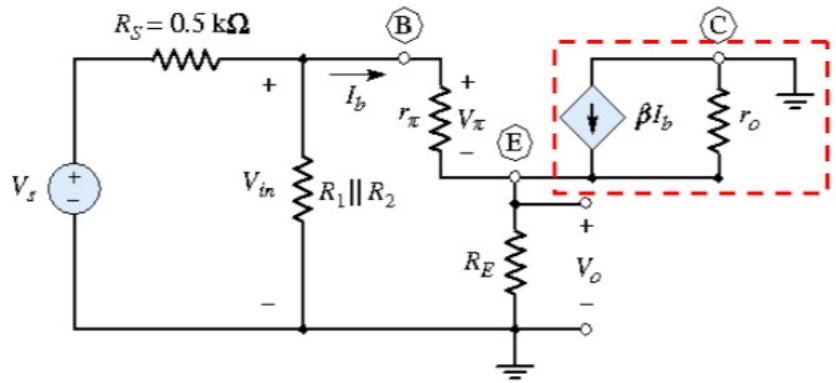




Common Emitter
共射級小訊號模型

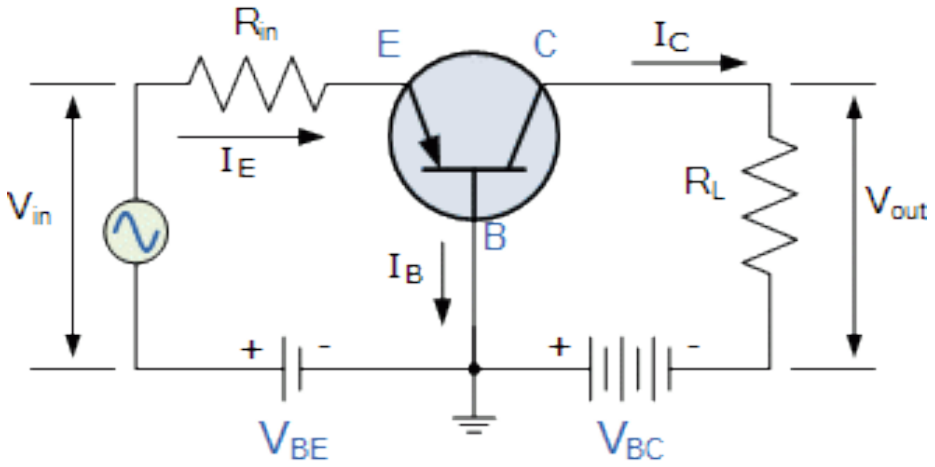
共集級 (Common Collector)

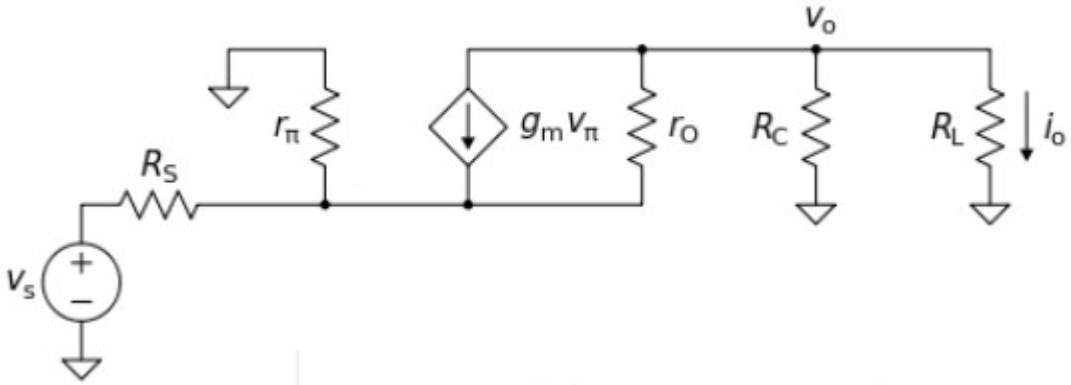


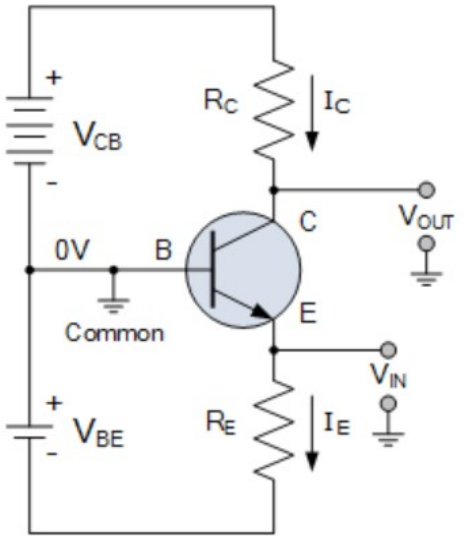


共基級 (Common Base)

https://www.electronics-tutorials.ws/amplifier/common-base-amplifier.html



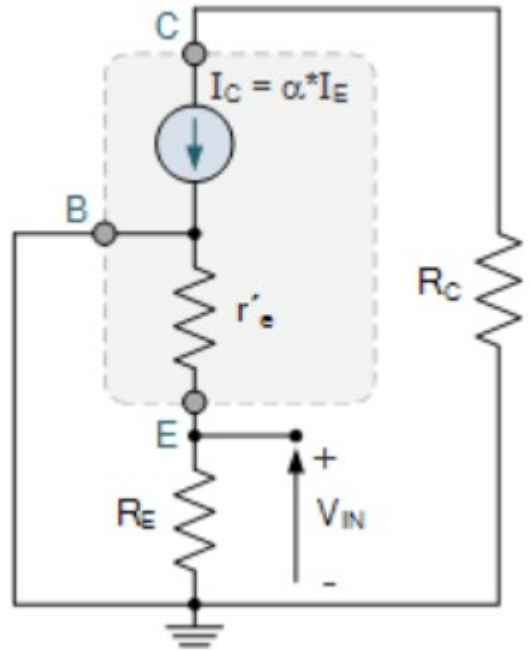




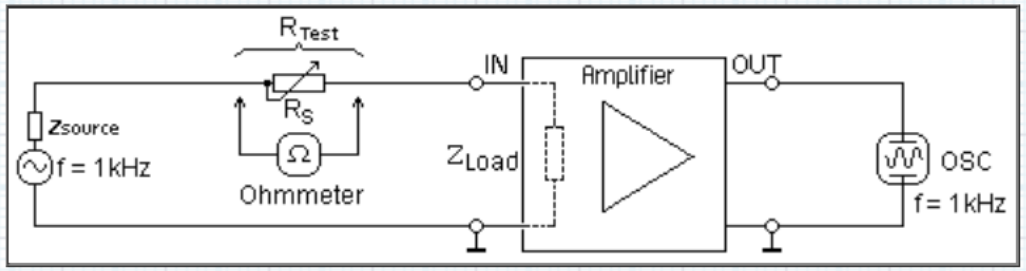
電壓放大倍率
= 電流放大倍率 X(Rc/(re||RE))

Re 稱為動態內部射級電阻
=.025V/IE

特色 :
1. 因為 re 很小，放大倍率極大
2. 輸出阻抗 (Rc) 很大

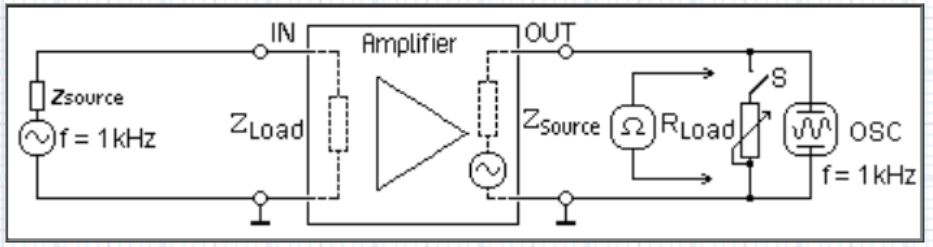


輸出與輸入阻抗的測量與計算



Generator signal V_1	2.0	volts
Series resistance R_{test}	1000	ohms
Signal after resistor V_2	1.0	volts
Reset ↓ Calculate		
Input impedance Z_{load}		ohms

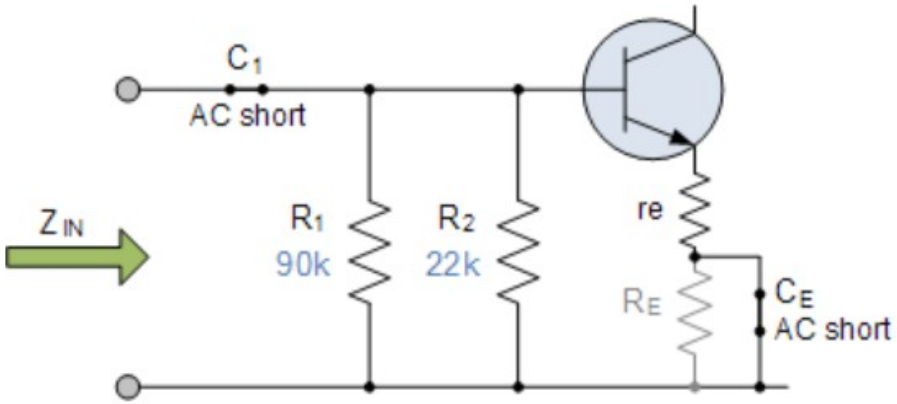
Input impedance	$Z_{Load} = R_{Test} \times \left(\frac{V_2}{V_1 - V_2} \right)$

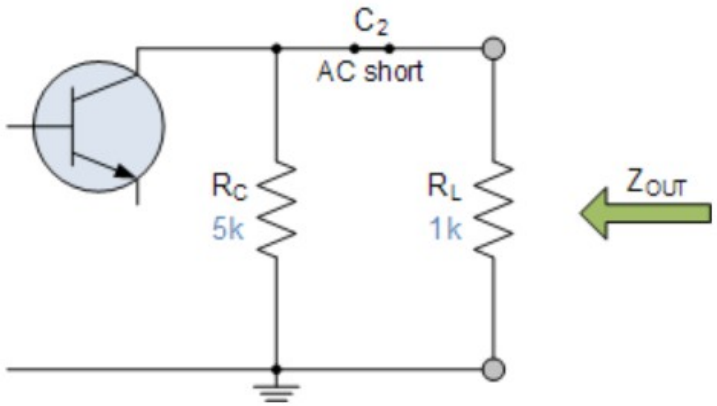


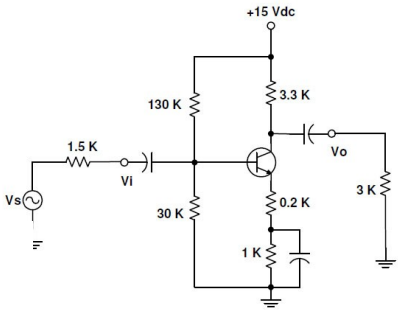
Open-circuit voltage V_1	2.0	volts
Load resistance R_{load}	10	ohms
Loaded circuit voltage V_2	1.5	volts
Reset ↓ Calculate		
Output Impedance Z_{source}		ohms

Output impedance	$Z_{Source} = R_{Load} \times \left(\frac{V_1}{V_2} - 1 \right)$

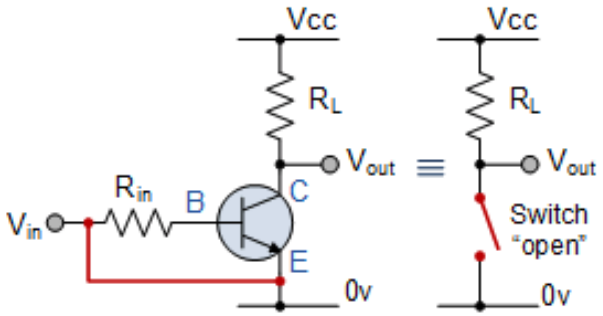
Common Emitter Input/output impedance



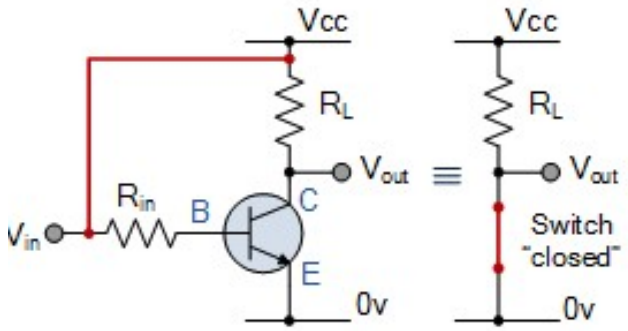




電晶體可以當作一個開關使用



- The input and Base are grounded (0v)
- Base-Emitter voltage V_{BE} < 0.7v
- Base-Emitter junction is reverse biased
- Base-Collector junction is reverse biased
- Transistor is "fully-OFF" (Cut-off region)
- No Collector current flows ($I_C = 0$)
- $V_{OUT} = V_{CE} = V_{CC}$ = "1"
- Transistor operates as an "open switch"

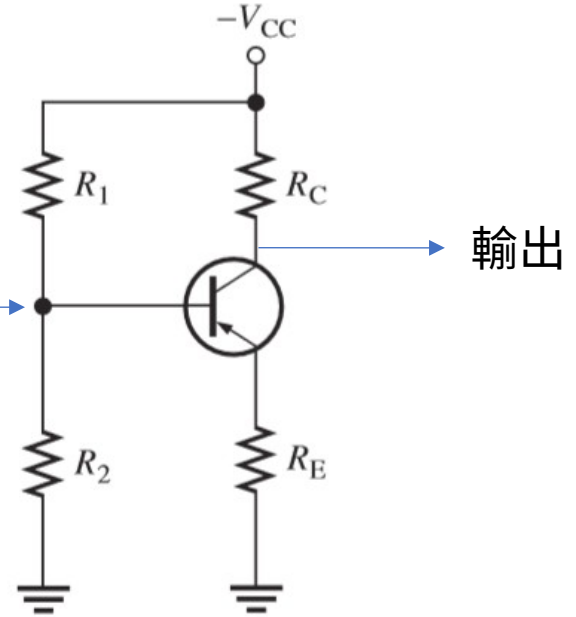


- The input and Base are connected to V_{CC}
- Base-Emitter voltage V_{BE} > 0.7v
- Base-Emitter junction is forward biased
- Base-Collector junction is forward biased
- Transistor is "fully-ON" (saturation region)
- Max Collector current flows ($I_C = Vcc/R_L$)
- $V_{CE} = 0$ (ideal saturation)
- $V_{OUT} = V_{CE}$ = "0"
- Transistor operates as a "closed switch"

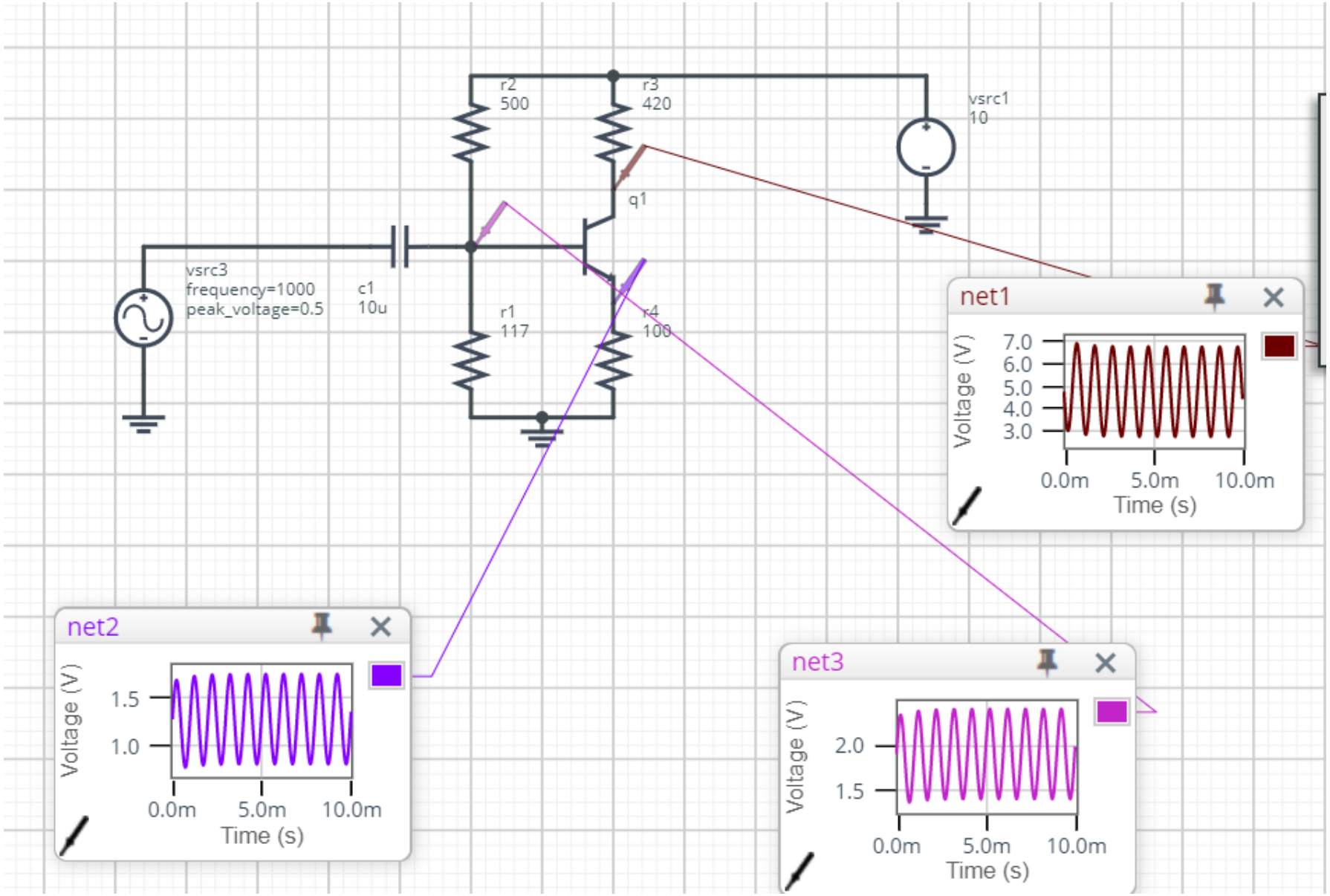
https://www.electronics-tutorials.ws/transistor/tran_4.html

BC337(npn) 與 BC327(pnp)

- 請用 Voltage Divider 的方式，設計一個共射級的放大器。
  - 規格
    - 集級電流為 5~20mA
    - 放大倍率約為 4 倍
    - 輸入電壓 10V
    - BC337 datasheet:
      - https://www.mouser.tw/datasheet/2/308/BC337-D1802338.
  - 請問
    - 四個電阻值各為多少？
    - 輸出阻抗為多少？
    - 當輸入訊號為 0 時，集級電壓為幾伏特？
    - 輸入阻抗為幾 Ohm?
    - 在失真極低時，訊號最大擺幅約為幾伏特？



http://www.sengpielaudio.com/calculator-InputOutputImpedance.htm


r2
500
r3
420
vsrc1
10
q1
vsrc3
frequency=1000
peak_voltage=0.5
c1
10u
r1
117
r4
100
net1
Voltage (V)
7.0
6.0
5.0
4.0
3.0
0.0m
5.0m
10.0m
Time (s)
net2
Voltage (V)
1.5
1.0
0.0m
5.0m
10.0m
Time (s)
net3
Voltage (V)
2.0
1.5
0.0m
5.0m
10.0m
Time (s)

Quiz(下周)

- 出題方向
  - BC337 或 BC327
  - 共射極
  - 其他的偏壓方式
  - 電壓仍保持 10V
  - 放大倍率改變
  - 集級電流改變
  - 請計算出前一頁的五個問題

實做 (下下周)

- 請備妥材料
  - 2N2904 若干顆
  - 可變電阻四個
    - 以你認為適當的數值為準
  - 麵包板一片
    - 請買有附導線者
  - 鱷魚夾連接線兩包
  - 杜邦連接線 (公的)
- 驗收
  - 達到 p.11 的要求
  - 測量四個電阻的阻值為多少？
    - 與先前計算出的誤差為多少？

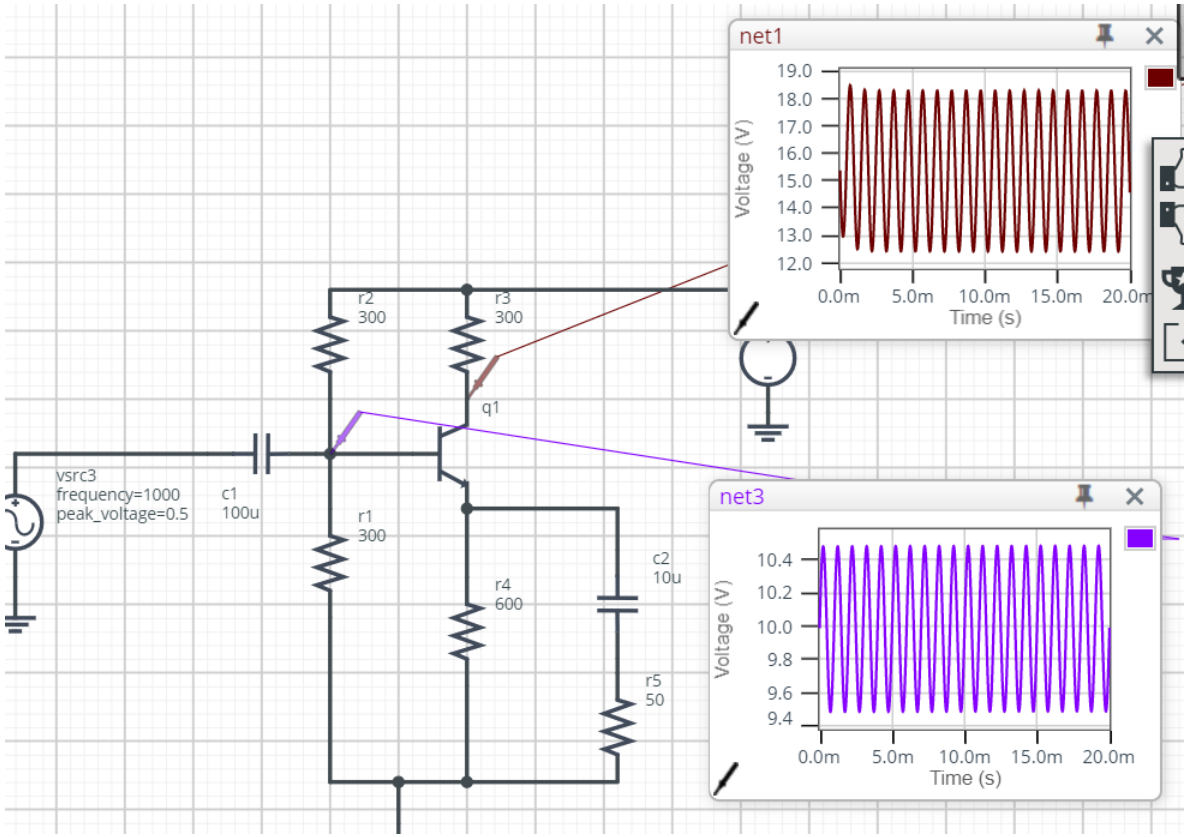
測驗（下下週）

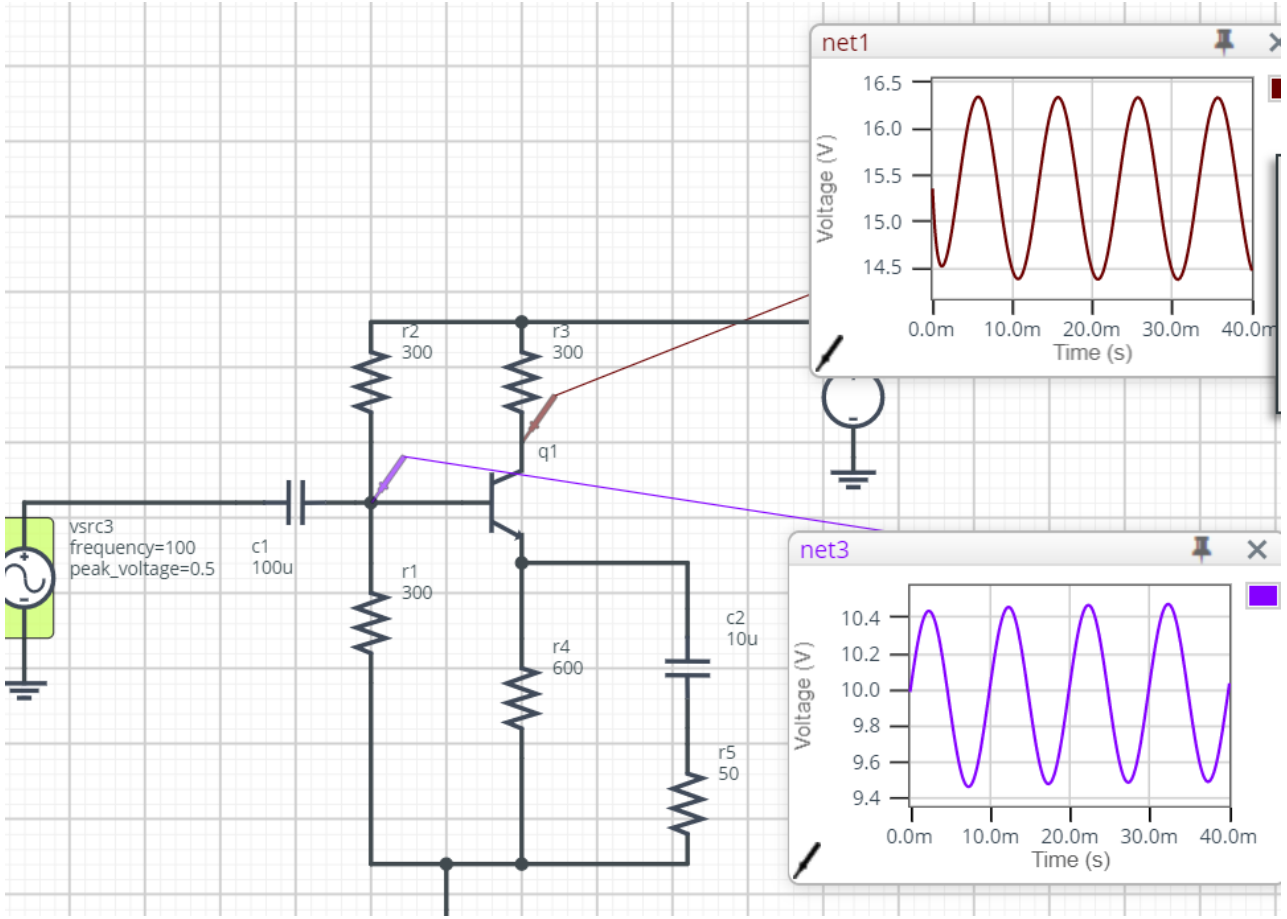
- 基於 Quiz 更為深入的計算問題

實做組準備材料

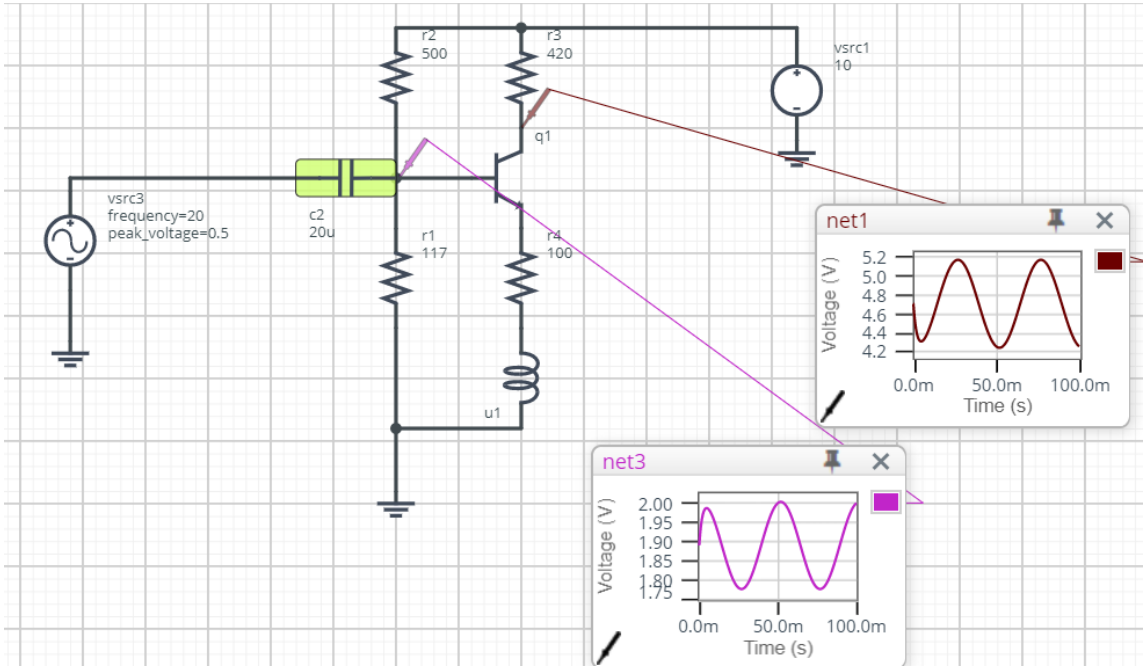
- BC337 若干顆
- 電阻 (依據本周小考所計算的數值，請多準備其他可能會用到的)
- 麵包版
- 三種線材
- 夾子
- 5~10uf 電容兩個

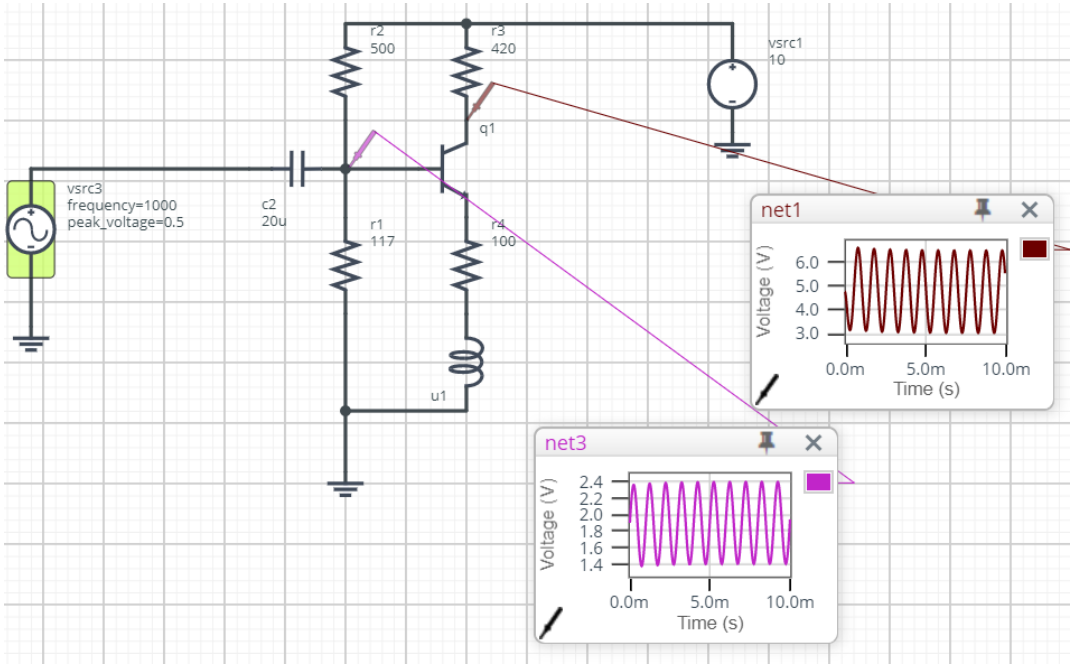
如果在射級電阻旁邊加一個電容呢？





如果在射級上加一個電感呢？





網路參考資料

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