Lecture 21

BJT

6.2 Single-Stage BJT Amplifiers

Small-Signal Models Analysis

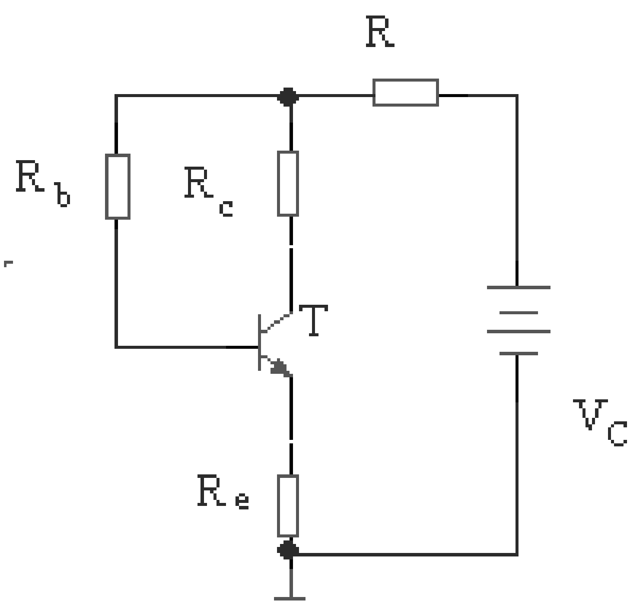
Steps for using small-signal models

1. Determine the DC operating point of the BJT
   — in particular, the collector current
2. Calculate small-signal model parameters: r_{be}
3. Eliminate DC sources
   – replace voltage sources with short circuits and current sources with open circuits
4. Replace BJT with equivalent small-signal models
5. Analysis

6.2 Single-Stage BJT Amplifiers

Small-Signal Models Analysis

Example 1



$$V_C = (I_B + I_C)R + I_B R_b + V_{BE} + I_E R_e$$

$$\rightarrow I_B = \frac{V_C - V_{BE}}{R_b + (1+\beta)(R + R_e)}$$

$$I_C \approx \beta I_B,$$

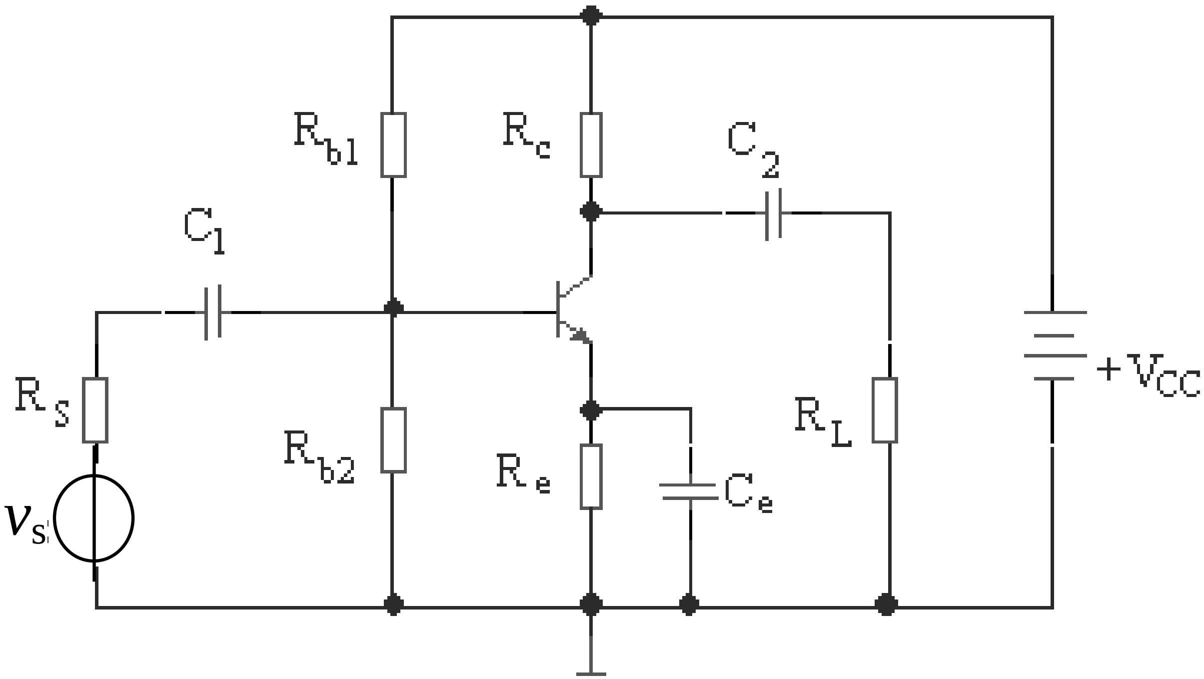
$$I_E = I_C + I_B = (1+\beta) I_B$$

$$V_{CE} = V_C - I_C R_C - I_E (R + R_e)$$

6.2 Single-Stage BJT Amplifiers

Small-Signal Models Analysis

Example 2



$$V_B = \frac{R_{b2}}{R_{b1} + R_{b2}} V_{CC}$$

$$I_C \approx I_E = \frac{V_B - V_{BE}}{R_e} \approx V_B / R_e$$

$$I_B = \frac{I_C}{\beta}$$

$$V_{CE} = V_{CC} - I_C(R_C + R_e)$$

6.2 Single-Stage BJT Amplifiers

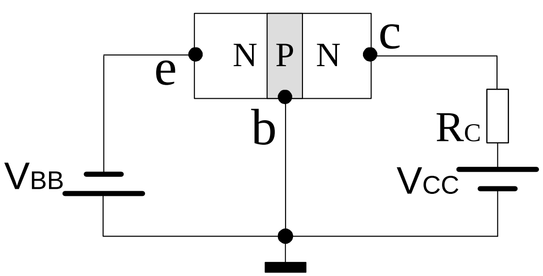
Small-Signal Models Analysis

There are three basic configurations for single-stage BJT amplifiers:

– Common-Emitter

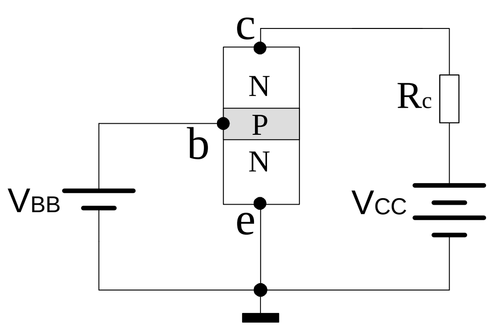
– Common-Base

– Common-Collector



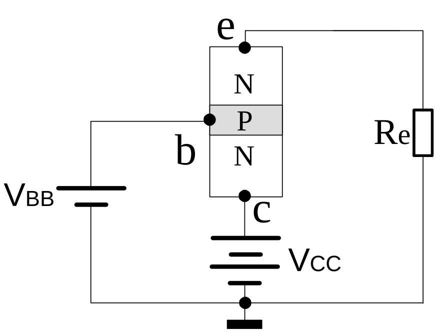
(a)

$$V_E < V_B < V_C$$



(b)

$$V_E < V_B < V_C$$

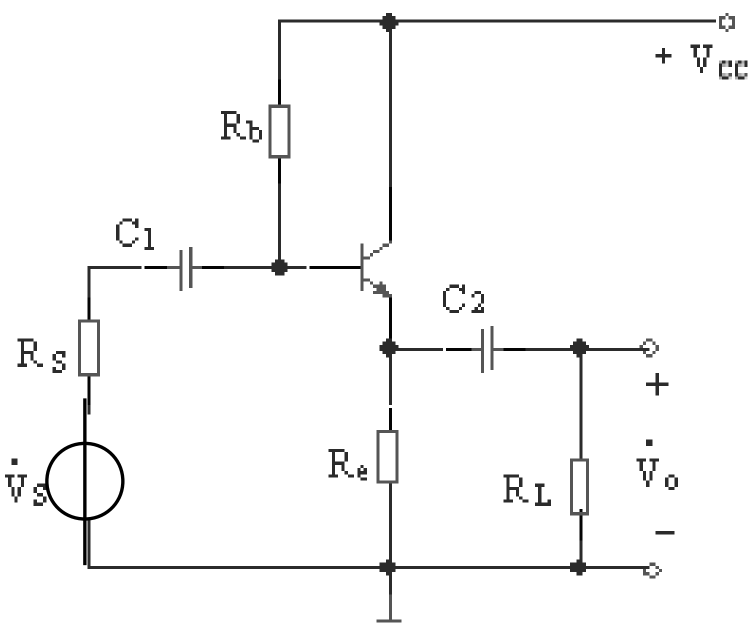


(c)

$$V_E < V_B < V_C$$

6.2 Single-Stage BJT Amplifiers

Common-Collector Amplifier



$$V_{CC} = I_B R_b + V_{BE} + I_E R_e = I_B R_b + V_{BE} + (1+\beta) I_B R_e$$

$$I_B = \frac{V_{CC} - V_{BE}}{R_b + (1+\beta)R_e} \approx \frac{V_{CC}}{R_b + (1+\beta)R_e}$$

$$I_C = \beta I_B$$

$$V_{CC} = V_{CE} + I_E R_e \approx V_{CE} + I_C R_e$$

$$V_{CE} \approx V_{CC} - I_C R_e$$

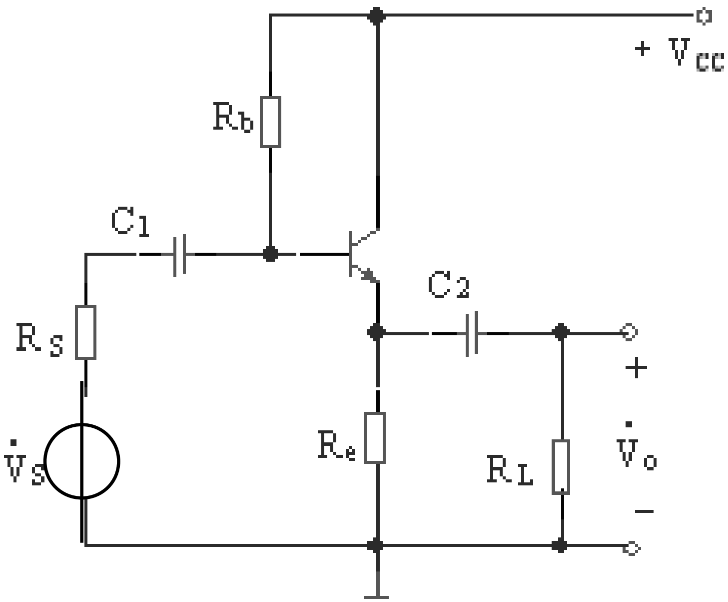
Note : $\dot{V}_o$ is slightly less than $\dot{V}_i$ due to the voltage drop introduced by V_{BE}

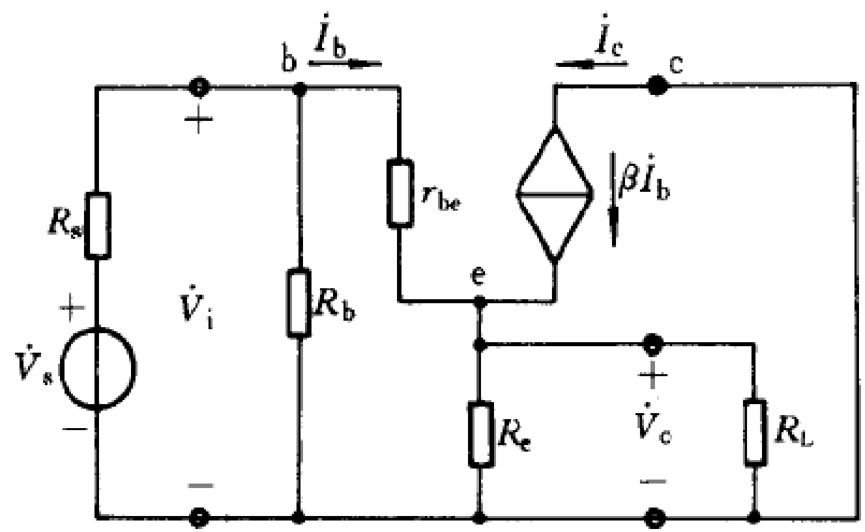
$$A_V \cong 1$$

6.2 Single-Stage BJT Amplifiers

Common-Collector Amplifier

The last basic configuration is to tie the collector to a fixed voltage, drive an input signal into the base and observe the output at the emitter.

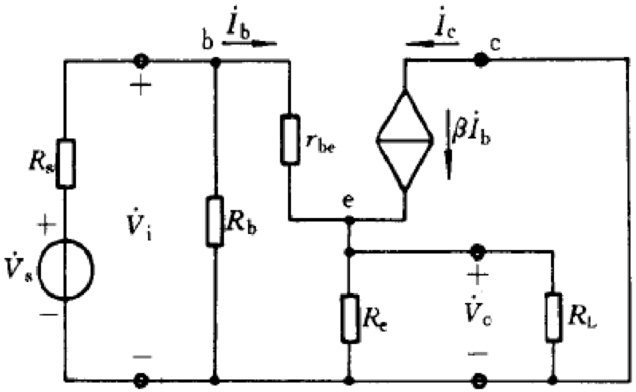




6.2 Single-Stage BJT Amplifiers

Common-Collector Amplifier

Let's find A_v, A_i:



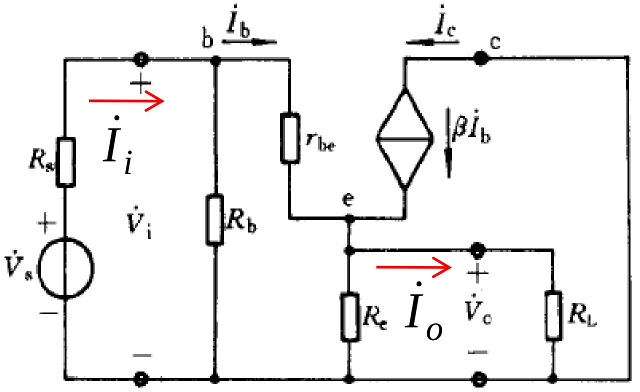
$$\dot{V}_o = I_e(R_e // R_L) = \dot{I}_b(1+\beta)(R_e // R_L)$$

$$\dot{V}_i = \dot{I}_b[r_{be} + (1+\beta)(R_e // R_L)] = I_b r_{be} + I_e(R_e // R_L)$$

$$\therefore A_V = \frac{\dot{V}_O}{\dot{V}_i} = \frac{(1+\beta)(R_e // R_L)}{r_{be} + (1+\beta)(R_e // R_L)} \approx \frac{\beta(R_e // R_L)}{r_{be} + (1+\beta)(R_e // R_L)} < 1$$

6.2 Single-Stage BJT Amplifiers

Common-Collector Amplifier



Let's find A_v, A_i:

$$I_o R_L = I_e(R_e // R_L) = (1+\beta)I_b(R_e // R_L)$$

$$I_o = I_b \frac{(1+\beta)(R_e // R_L)}{R_L}$$

$$I_b(r_{be} + (1+\beta)(R_e // R_L)) = (I_i - I_b)R_b$$

$$I_i = I_b \frac{r_{be} + (1+\beta)(R_e // R_L) + R_b}{R_b} \approx I_b \frac{(1+\beta)(R_e // R_L) + R_b}{R_b}$$

$$A_i = \frac{(1+\beta)(R_e // R_L)}{R_L} \times \frac{R_b}{(1+\beta)(R_e // R_L) + R_b} \approx \frac{(1+\beta)(R_e // R_L)}{R_L}$$

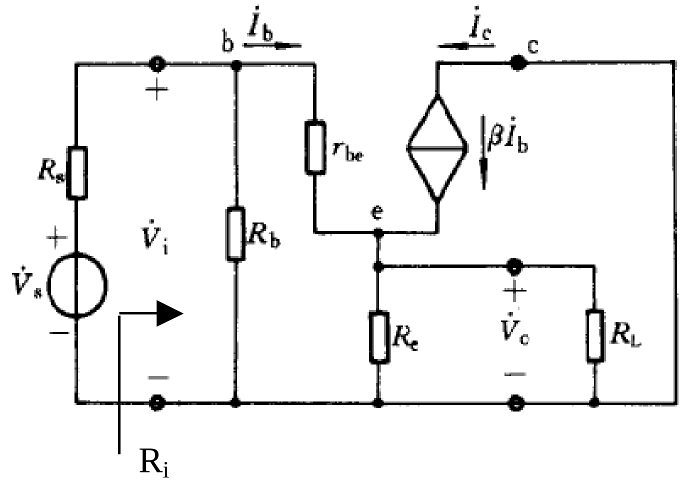
$(1+\beta)(R_e // R_L) << R_b$

$$A_i \approx \frac{(1+\beta)(R_e // R_L)}{R_L} >> 1$$

6.2 Single-Stage BJT Amplifiers

Common-Collector Amplifier

Let’s find R_i:



$$v_i = i_b r_{be} + i_e (R_e // R_L) = i_b \left[r_{be} + (1+\beta)(R_e // R_L) \right]$$

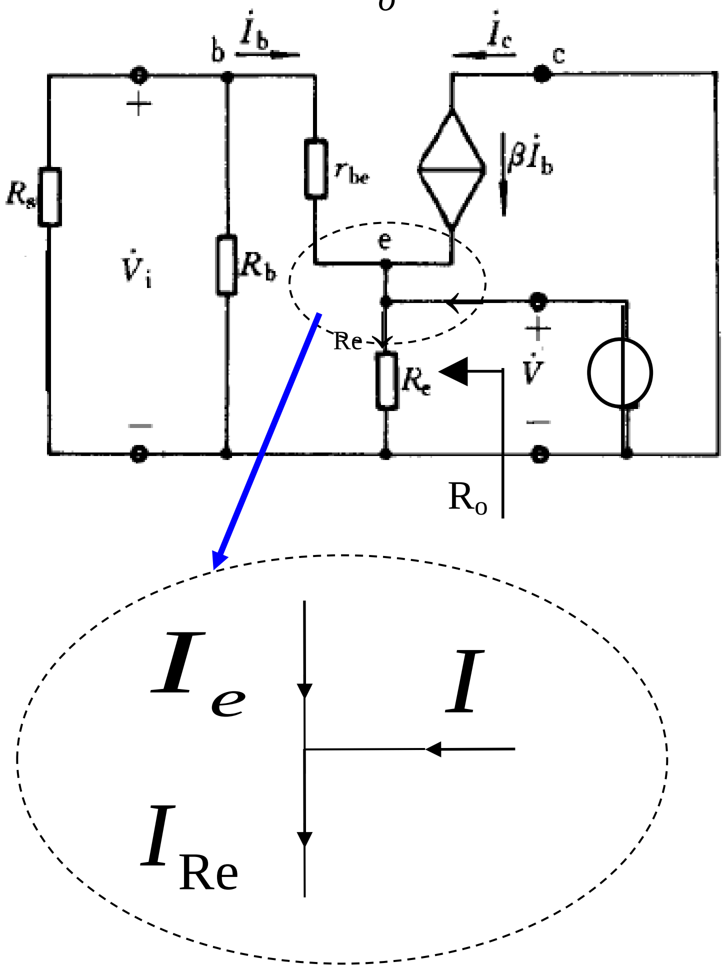
$$R_i' = \frac{v_i}{i_b} = r_{be} + (1+\beta)(R_e // R_L)$$

$$R_i = R_i' // R_b = [r_{be} + (1+\beta)(R_e // R_L)] // R_b \approx R_b // \beta(R_e // R_L)$$

6.2 Single-Stage BJT Amplifiers

Common-Collector Amplifier

Let's find R_o:



$$I_{Re} = I + I_e \qquad I = I_{Re} - I_e$$

$$I = I_{Re} - I_e = I_{Re} - (1+\beta) I_b$$

$$I = I_{\mathrm{Re}} - I_b - \beta I_b$$

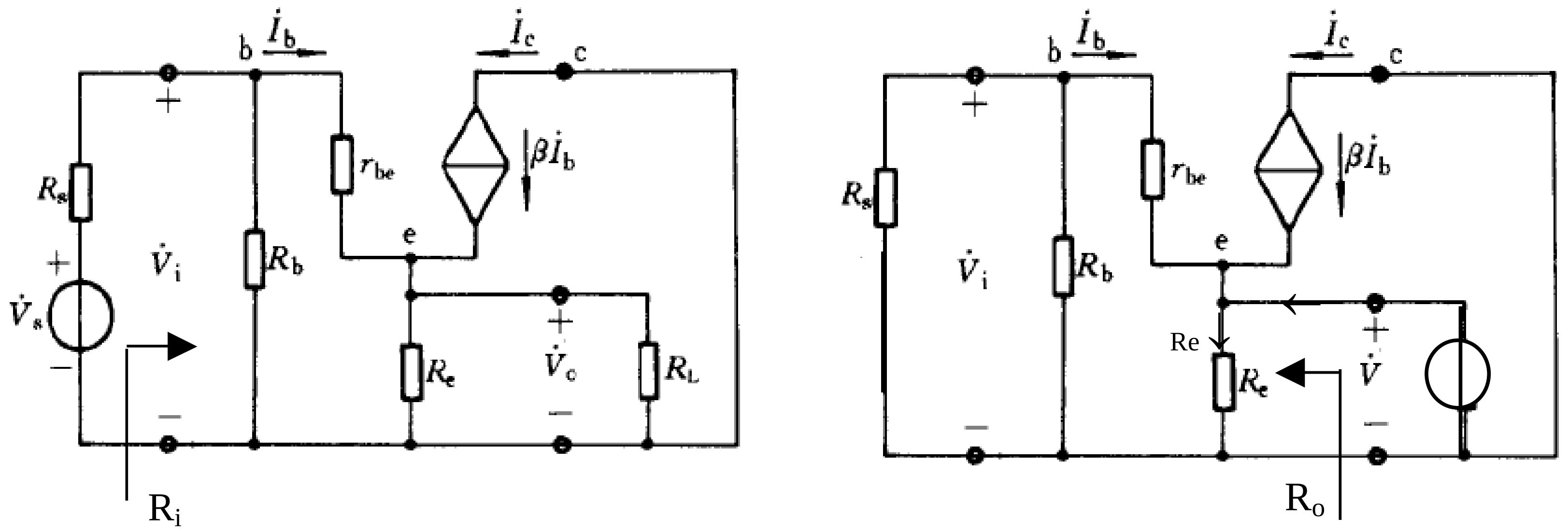
$$= \frac{v}{R_e} + (1+\beta)\frac{v}{r_{be} + R_s // R_b}$$

$$R_o = \frac{v}{i} = \frac{1}{\dfrac{1}{R_e} + \dfrac{1}{(r_{be} + R_s // R_b)/(1+\beta)}}$$

$$= R_e // \frac{(r_{be} + R_s // R_b)}{1+\beta}$$

6.2 Single-Stage BJT Amplifiers

Common-Collector Amplifier

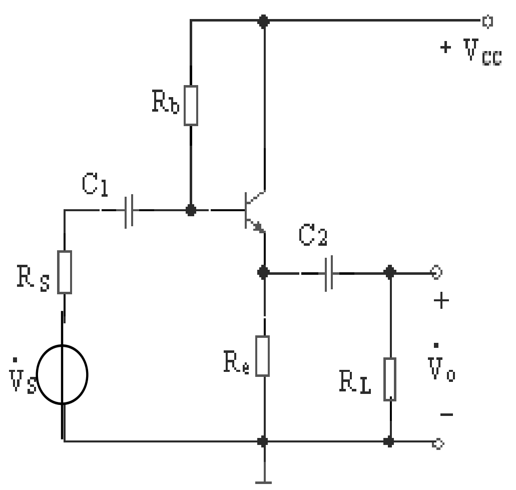


$$R_i = [r_{be} + (1+\beta)(R_e // R_L)] // R_b$$

$$R_o = R_e // \frac{(r_{be} + R_s // R_b)}{1+\beta}$$

6.2 Single-Stage BJT Amplifiers

Common-Collector Amplifier



$$A_V = \frac{\dot{V}_O}{\dot{V}_i} \approx \frac{\beta(R_e // R_L)}{r_{be} + (1+\beta)(R_e // R_L)} \approx 1$$

$$A_i \approx \frac{(1+\beta)(R_e // R_L)}{R_L} >> 1$$

$$R_i = [r_{be} + (1+\beta)(R_e // R_L)] // R_b$$

$$R_o = R_e // \frac{(r_{be} + R_s // R_b)}{1+\beta}$$

C-C amp characteristics:

- Voltage gain is less than unity, but close (to unity) since β is large and r_{be} is small.
- Also called an emitter follower since the emitter follows the input signal.
- Input resistance is higher, output resistance is lower.
  - Used for connecting a source with a large R_s to a load with low resistance.