6.002x

CIRCUITS AND ELECTRONICS

Small Signal Circuits

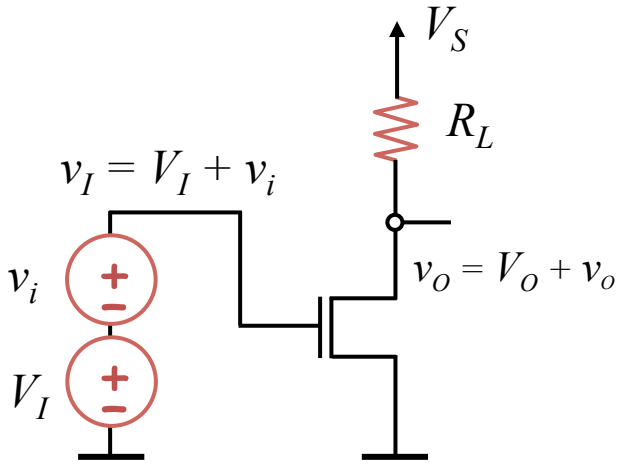


Review:

- Small signal notation

$$v_A = V_A + v_a$$

total — operating point — small signal

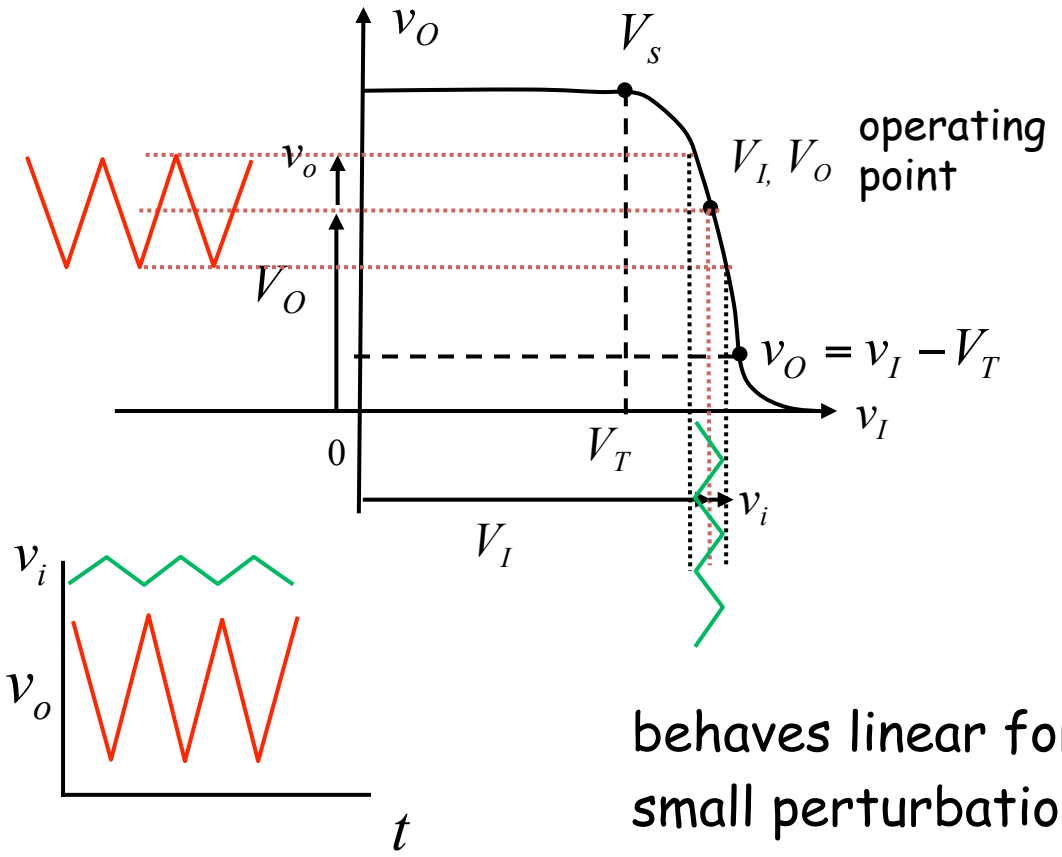


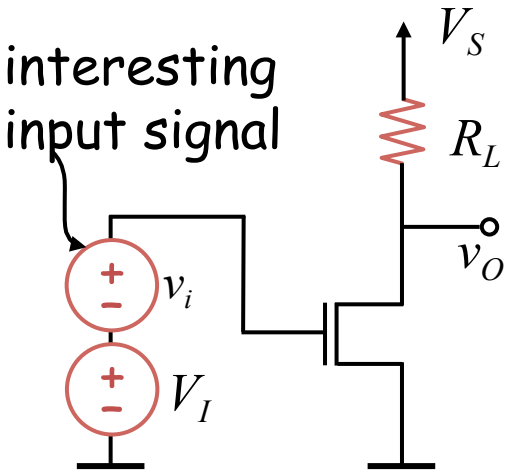
- $$v_{OUT} = f(v_I)$$

$$v_{out} = \frac{d}{dv_I} f(v_I)\Big|_{v_I = V_I} \cdot v_i$$

Review:

I Graphical View





behaves linear for small perturbations

Review: II Mathematical view

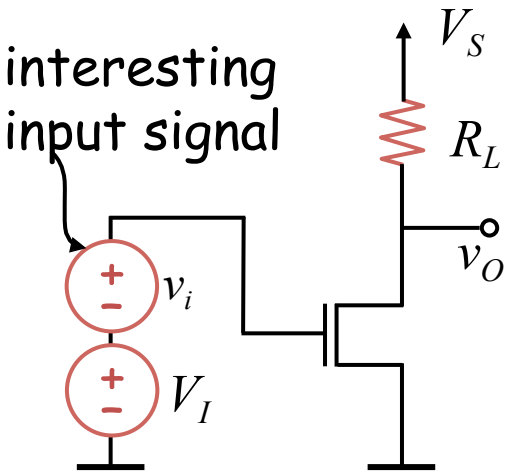
$$v_O = V_S - \frac{K(v_I - V_T)^2}{2} R_L$$

$$v_o = \frac{d}{dv_I}\left[V_S - \frac{K}{2}(v_I - V_T)^2 R_L\right]\Bigg|_{v_I = V_I} \cdot v_i$$

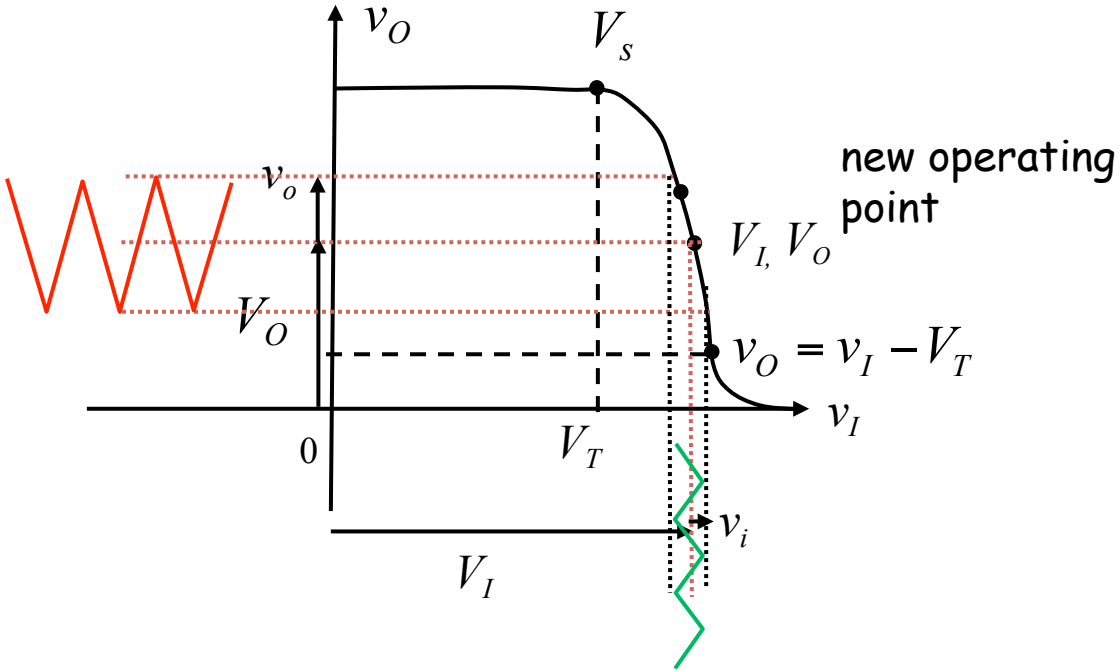
$$v_o = -\underbrace{K(V_I - V_T)}_{g_m} R_L \cdot v_i$$

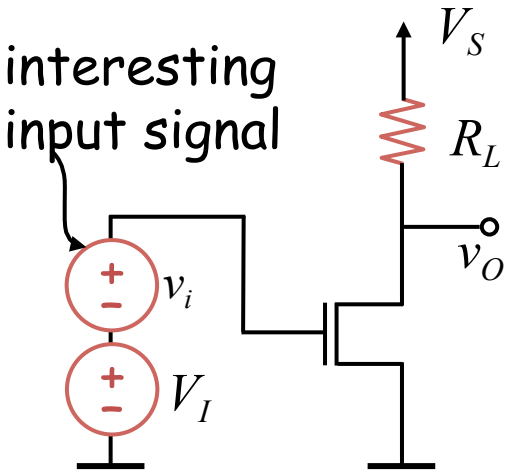
related to V_I

constant for fixed DC bias



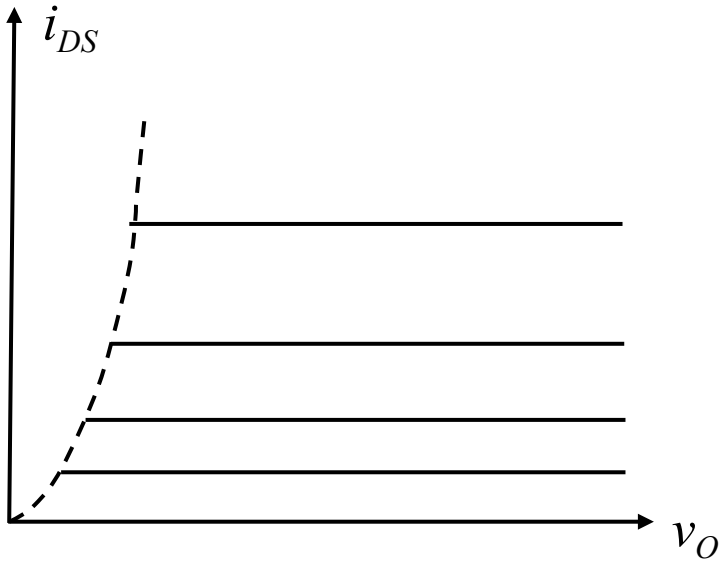
How to choose the bias point aka operating point





How to choose the bias point

$$v_o = -\underbrace{K(V_I - V_T)}_{g_m} R_L \cdot v_i$$

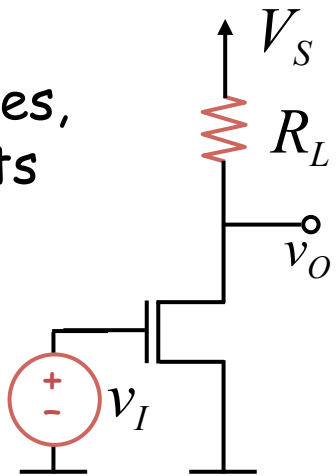


Demo

III The Small Signal Circuit View

We can derive small circuit equivalent models for our devices, and thereby conduct small signal analysis directly on circuits

e.g. large signal circuit model for amp



We can replace large signal element models with small signal element models in the same circuit topology

Foundations: Section 8.2.1, and also at the end of this lecture sequence

Small Signal Circuit Analysis

1. Find operating point using DC bias inputs using large signal model.

2. Develop small signal (linearized) models for elements.

3. Replace original elements with small signal models to get the small signal circuit

Analyze resulting linearized circuit…

Key: Can use superposition and other linear circuit tools with linearized circuit!

Small Signal Circuit Analysis

1. Find operating point using DC bias inputs using large signal model.

2. How to develop small signal (linearized) models for each of the elements around the operating point.

Large signal element model

Small signal

② Voltage Sources and DC Supply V_S

Large signal

Small signal

DC voltage source behaves as short to small signals.

DC current source behaves as open to small signals.

② Similarly, R

large
signal

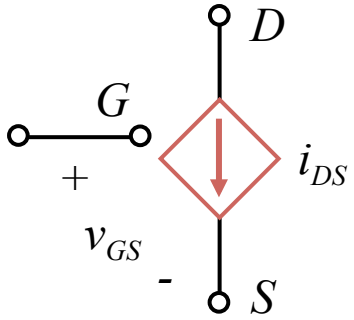
small
signal

② MOSFET

Large signal

② MOSFET

large signal



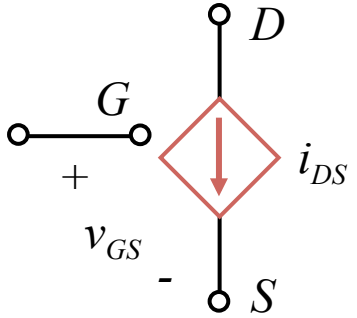
$$i_{DS} = \frac{K}{2}\left(v_{GS} - V_T\right)^2$$

② MOSFET

Small signal

$$i_{DS} = \frac{K}{2}(v_{GS} - V_T)^2$$

large signal

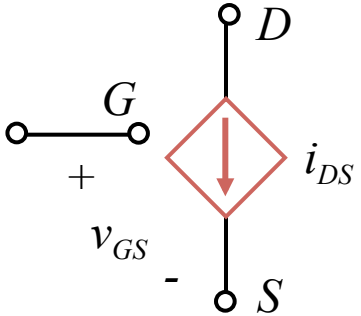


$$i_{DS} = \frac{K}{2}(v_{GS} - V_T)^2$$

② MOSFET

$$i_{ds} = K\left(V_{GS} - V_T\right)v_{gs}$$

Large signal

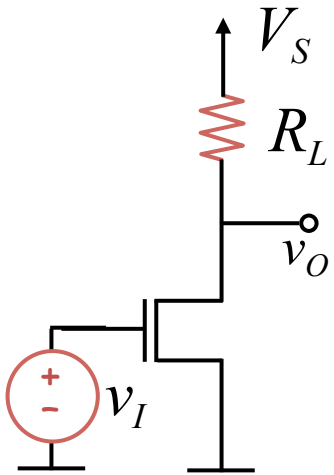


$$i_{DS} = \frac{K}{2}\left(v_{GS} - V_T\right)^2$$

small signal

Amplifier example

Let us perform a small signal analysis of our MOSFET amplifier using the small signal circuit method

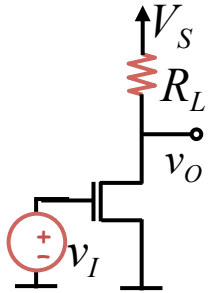


Amplifier example: Step 1

Find operating point
from large signal model

Large signal model

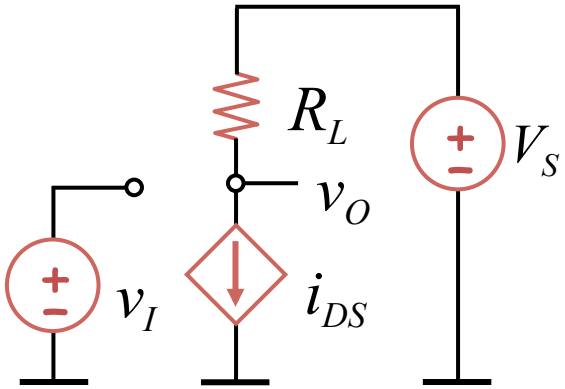
Small signal model



Amplifier example: Step 2

Find small signal models for elements

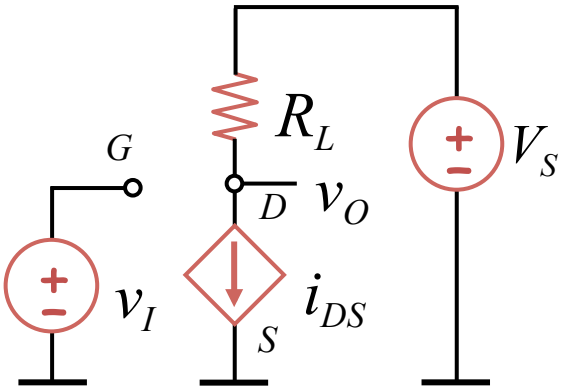
Large signal model



$$i_{DS} = \frac{K}{2}(v_I - V_T)^2$$

$$v_O = V_S - \frac{K}{2}(v_I - V_T)^2 R_L$$

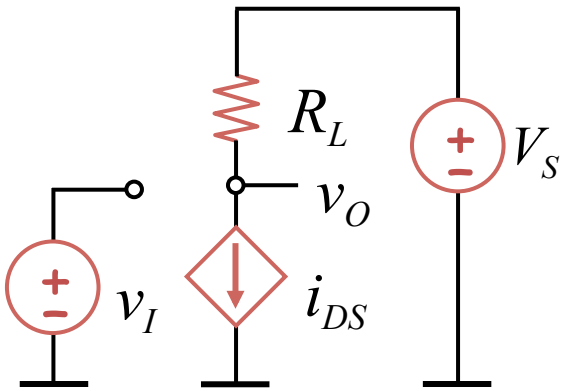
Developing the small signal model



Amplifier example: Step 3

Replace elements in original circuit with small signal models

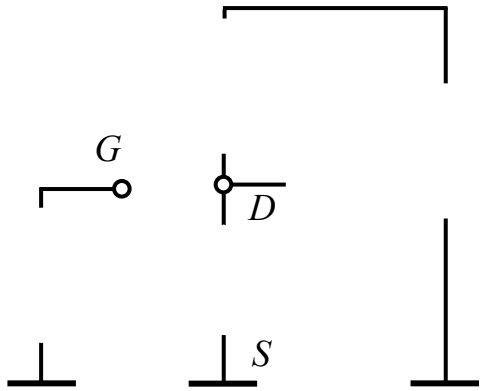
Large signal model



$$i_{DS} = \frac{K}{2}(v_I - V_T)^2$$

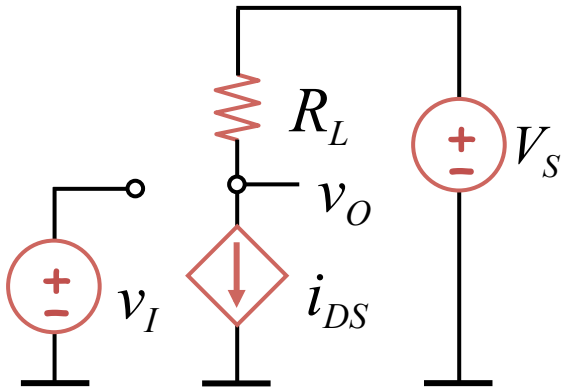
$$v_O = V_S - \frac{K}{2}(v_I - V_T)^2 R_L$$

Developing the small signal model



Amplifier example: Analyze resulting SS circuit

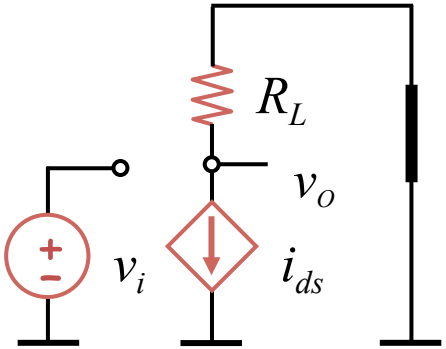
Large signal model



$$i_{DS} = \frac{K}{2}(v_I - V_T)^2$$

$$v_O = V_S - \frac{K}{2}(v_I - V_T)^2 R_L$$

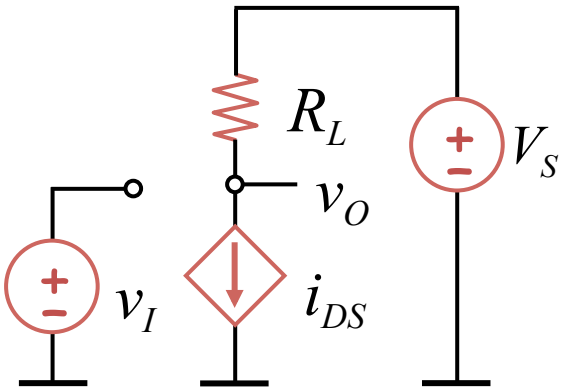
Small signal model



$$i_{ds} = K(V_I - V_T)\cdot v_i$$

Amplifier example: Analyze resulting SS circuit

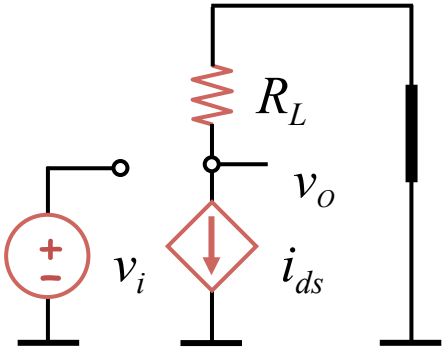
Large signal model



$$i_{DS} = \frac{K}{2}(v_I - V_T)^2$$

$$v_O = V_S - \frac{K}{2}(v_I - V_T)^2 R_L$$

Small signal model



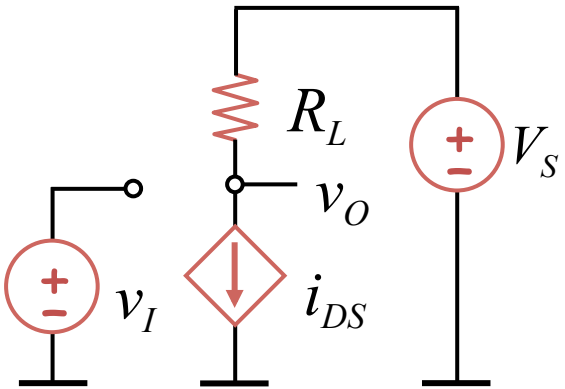
$$i_{ds} = K(V_I - V_T)\cdot v_i$$

Node method:

Since small signal models are linear, our linear tools will now apply…

Amplifier example: Analyze resulting SS circuit

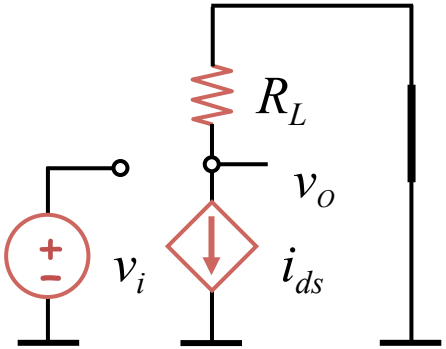
Large signal model



$$i_{DS} = \frac{K}{2}(v_I - V_T)^2$$

$$v_O = V_S - \frac{K}{2}(v_I - V_T)^2 R_L$$

Small signal model



$$i_{ds} = K(V_I - V_T)\cdot v_i$$

$$v_o = -K(V_I - V_T)R_L \cdot v_i$$

Notice, first we need to find operating point voltages and currents.
Get these from large signal analysis

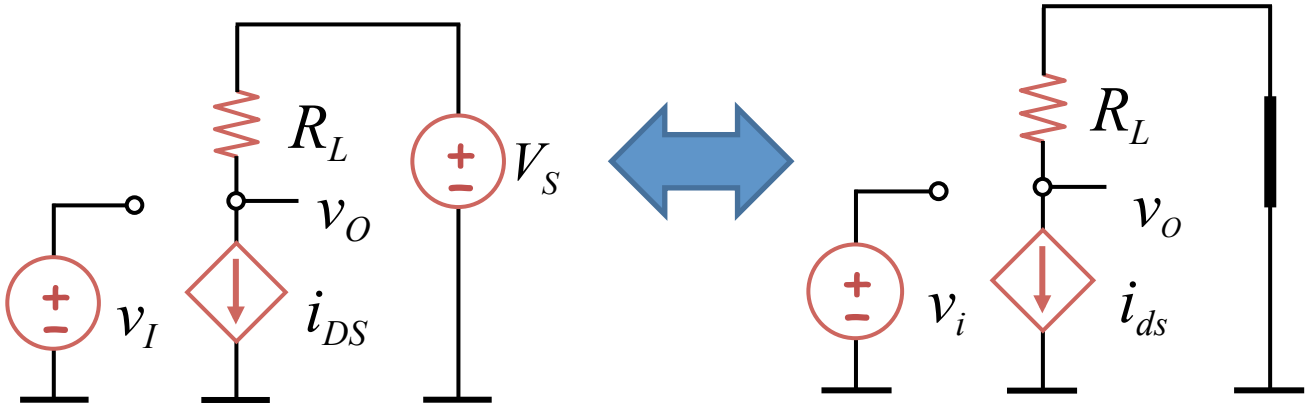
But, note that we can obtain insight into small-signal behavior directly from the small-signal circuit, without having to do a large signal analysis

The Small Signal Circuit View – A Perspective

To find relationship between small signal parameters of circuit:

(1) we replaced large signal device models with corresponding small signal device models in the original circuit

(2) then analyzed the resulting small signal circuit.

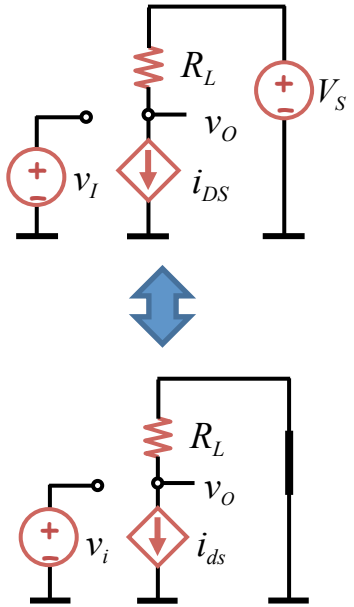


Why was this possible?

Also see section 8.2.1 of A&L

The Small Signal Circuit View – Foundations

- KVL, KCL applied to some circuit C yields:



- Replace total variables with operating point variables plus small signal variables

- Operating point variables themselves satisfy the same KVL, KCL equations

- so, we can cancel them out, leaving

- But is the same equation as with small signal variables replacing total variables, so must reflect same typology as in C, except that small signal models are used.

Caution: