ELEC 301 - Real feedback networks

L22 - Oct 30

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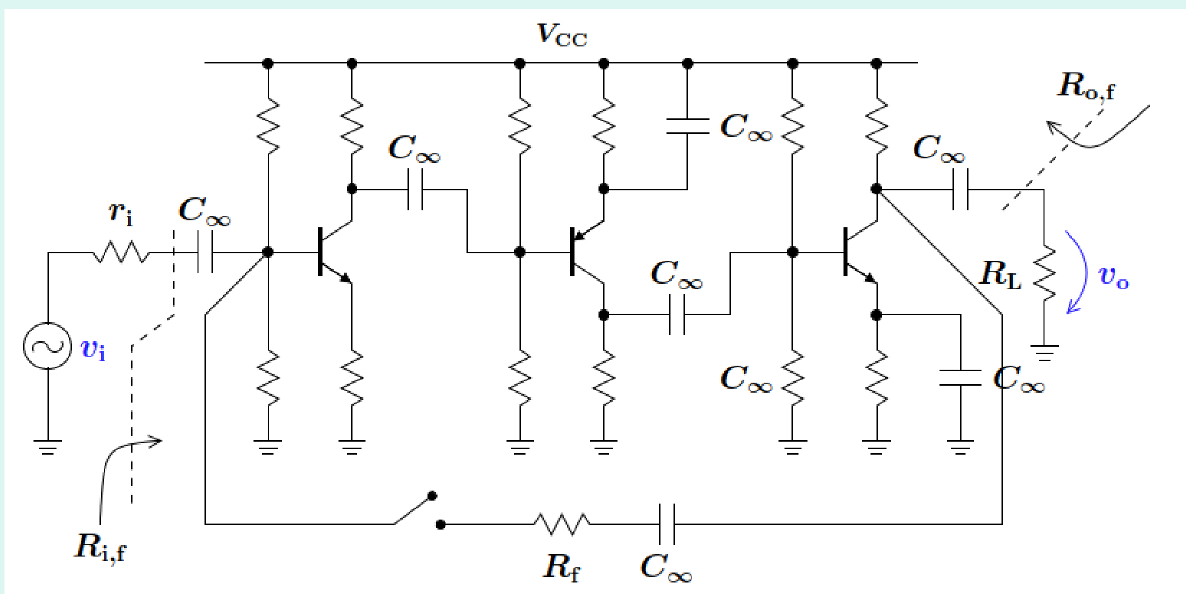
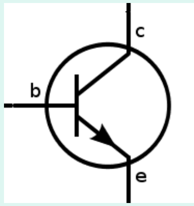
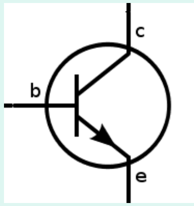




Last time

- From information flow to energy flow: 4 circuit feedback topologies
- The effect of negative feedback on amplifier stages: extends BW, de-sensitivation to amplifier parameter variations, linearization of the transfer function (reduced distortions)



L22 Q01 current amplifier

- What type of feedback topology is suitable for a current amplifier? ($A_i = I_{out}/I_{in}$)

A. series-series

B. series-shunt

C. shunt-series

D. shunt-shunt

L22 Q02 positive feedback

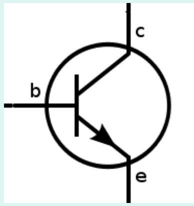
- Assume a voltage amplifier stage with a single pole frequency response (ω_H) has a **slightly positive** feedback network. Which statement is right?

A. The gain and the BW do not change

B. Both the closed-loop gain and the BW increase

C. The closed-loop gain decreases and the BW increases

D. The closed-loop gain increases and the BW decreases



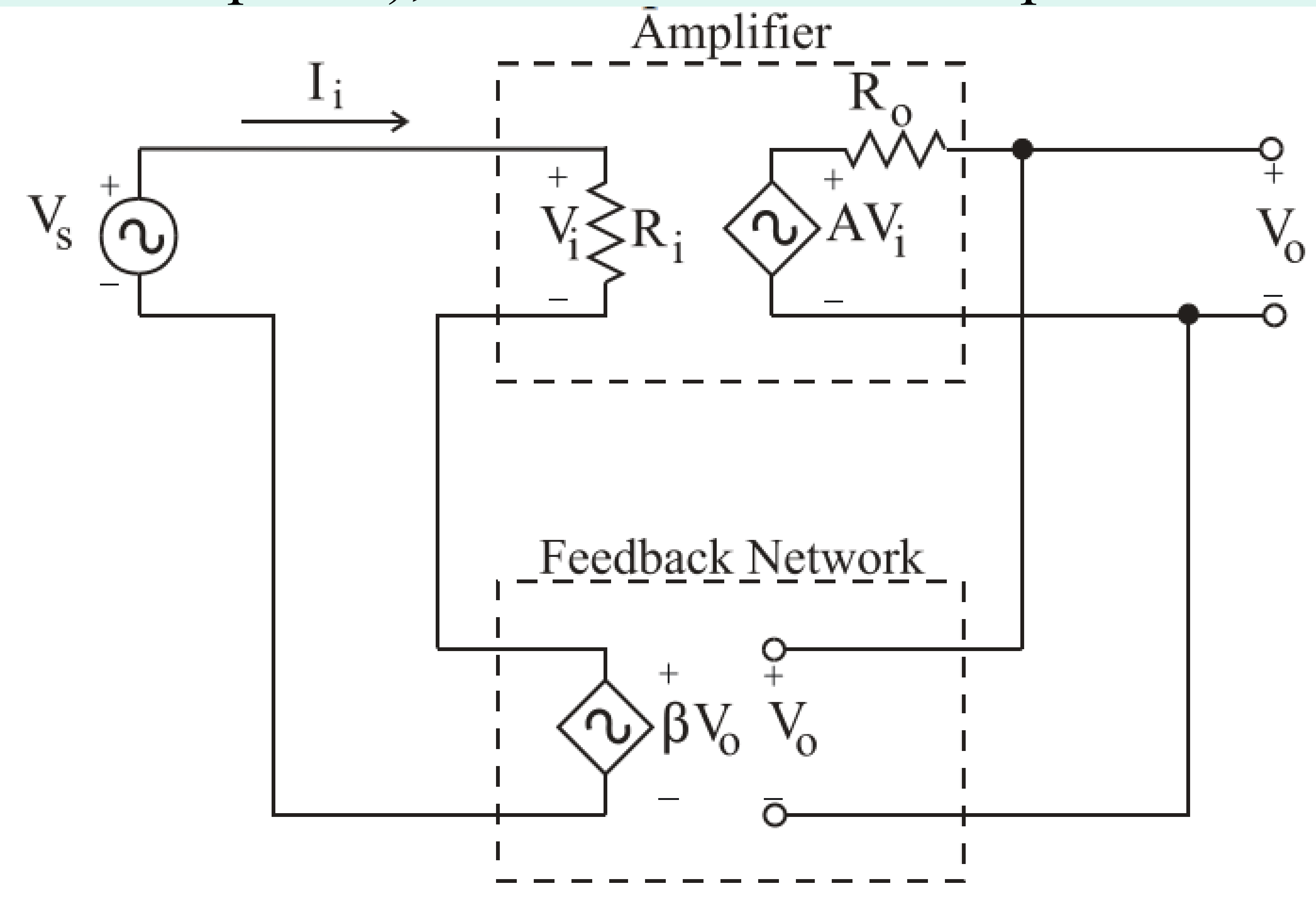
Information flow to energy flow

- signals mapped into voltages/currents => 4 categories of feedback circuit architectures

Input signal x_s	Output signal x_o	Feedback type	Remarks
voltage v_s	voltage v_o	series-shunt	Voltage amplifier A_{vf} (Z_{in} high, Z_{out} low)
current i_s	voltage v_o	shunt-shunt	Transimpedance amplifier Z_f (Z_{in} low, Z_{out} low)
voltage v_s	current i_o	series-series	Transadmittance amplifier Y_f (Z_{in} high, Z_{out} high)
current i_s	current i_o	shunt-series	Current amplifier A_{if} (Z_{in} low, Z_{out} high)

Feedback effect on impedances

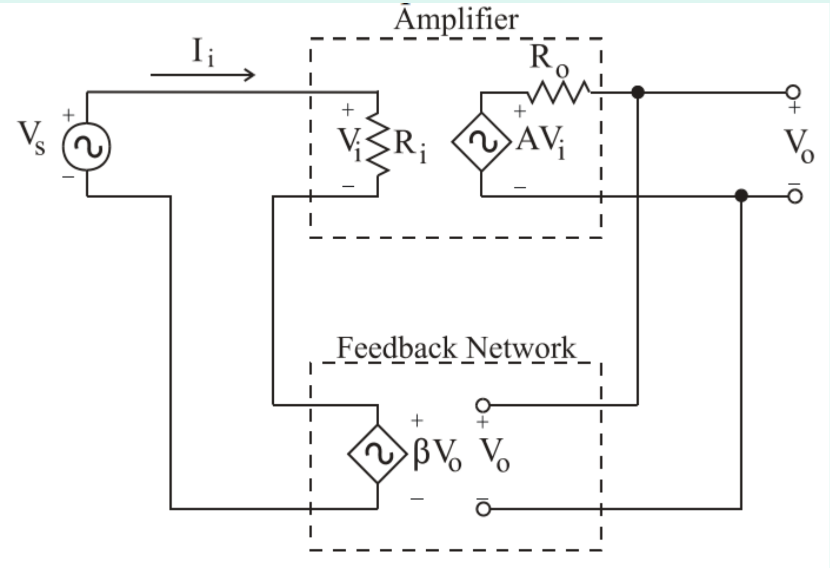
- Consider the series-shunt feedback amplifier (voltage amplifier), with ideal feedback diport

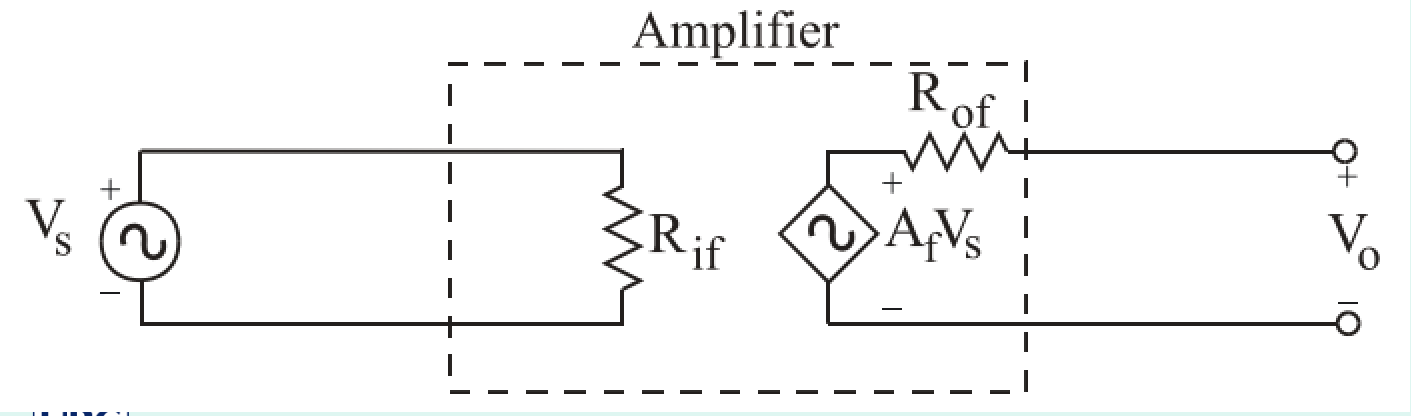


$$A_{vf} = \frac{V_o}{V_s} = \frac{A}{1 + A\beta}$$

Voltage amplifier

- equivalent diport model

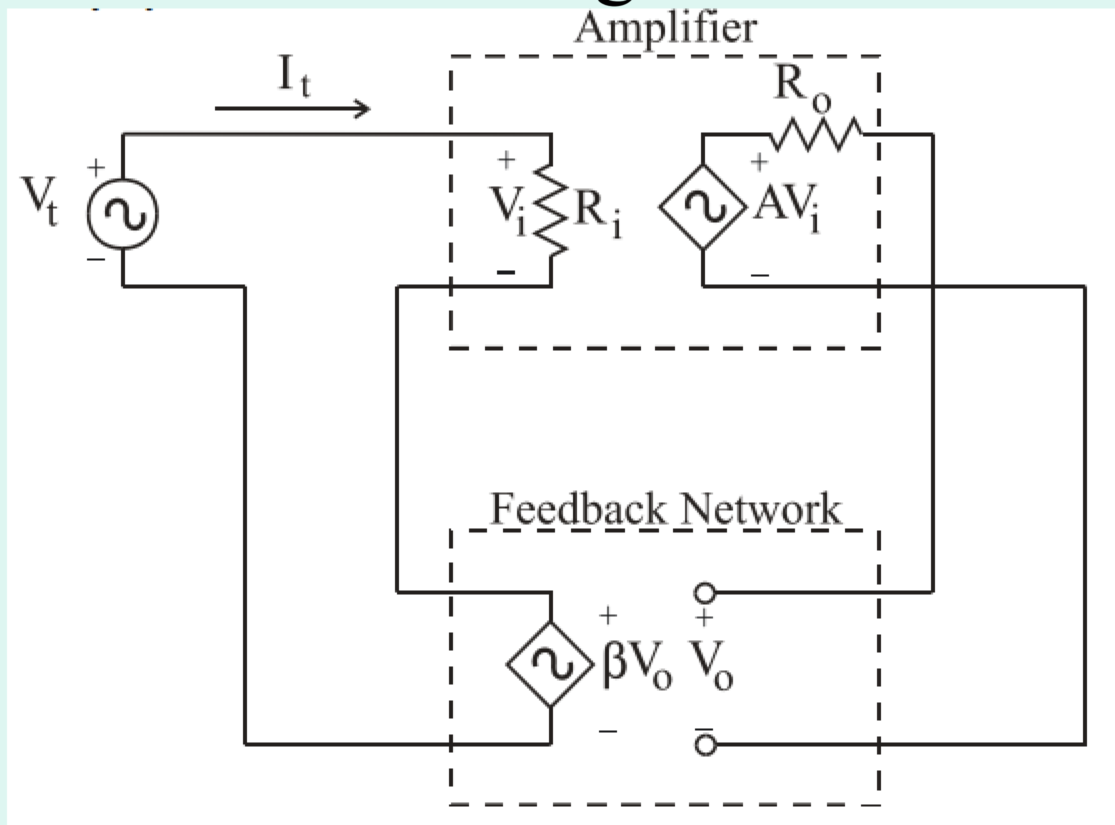




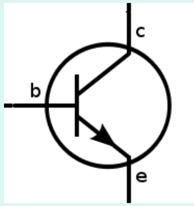
$R_{if}, R_{of} = ?$

Finding R_{if}

- Replace source with a test voltage source

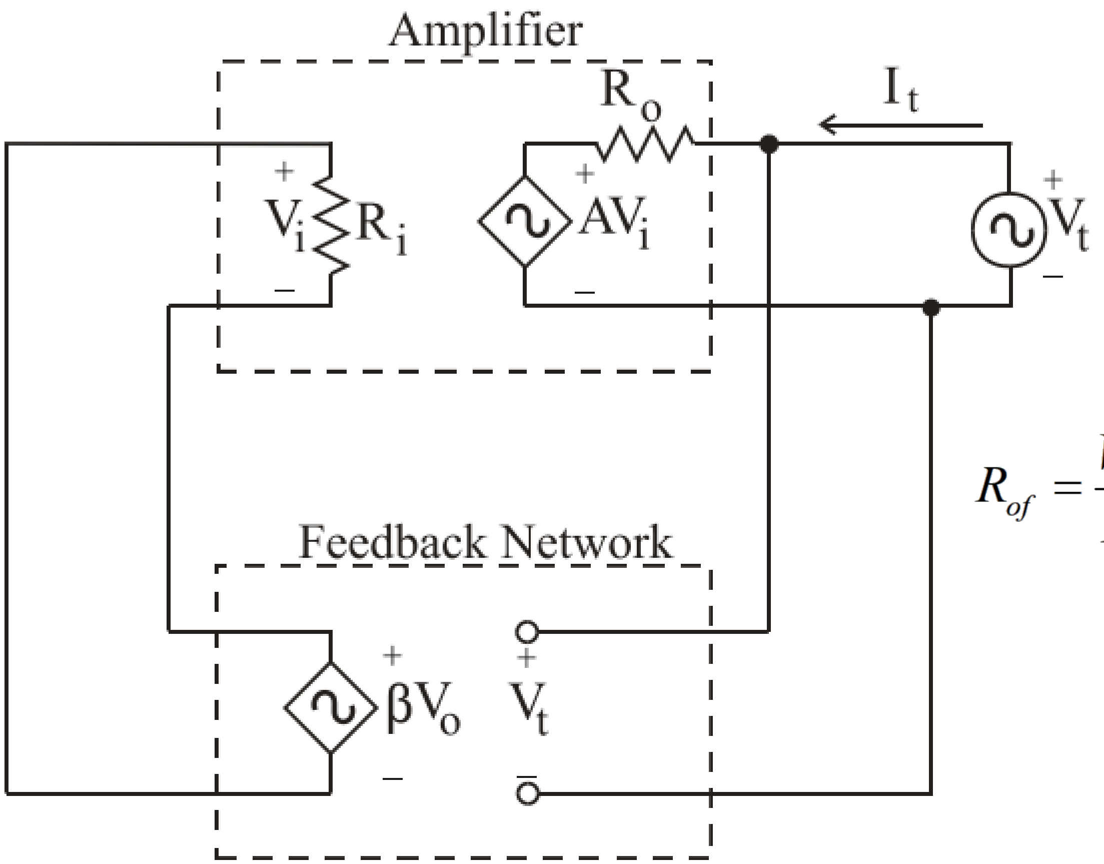


$$R_{if} = \frac{V_t}{I_t} = \frac{V_t}{\frac{V_i}{R_i}} = R_i \frac{V_i + \beta V_o}{V_i} = R_i\left(1 + A\beta\right)$$



Finding R_{of}

- Apply a test voltage source at the output

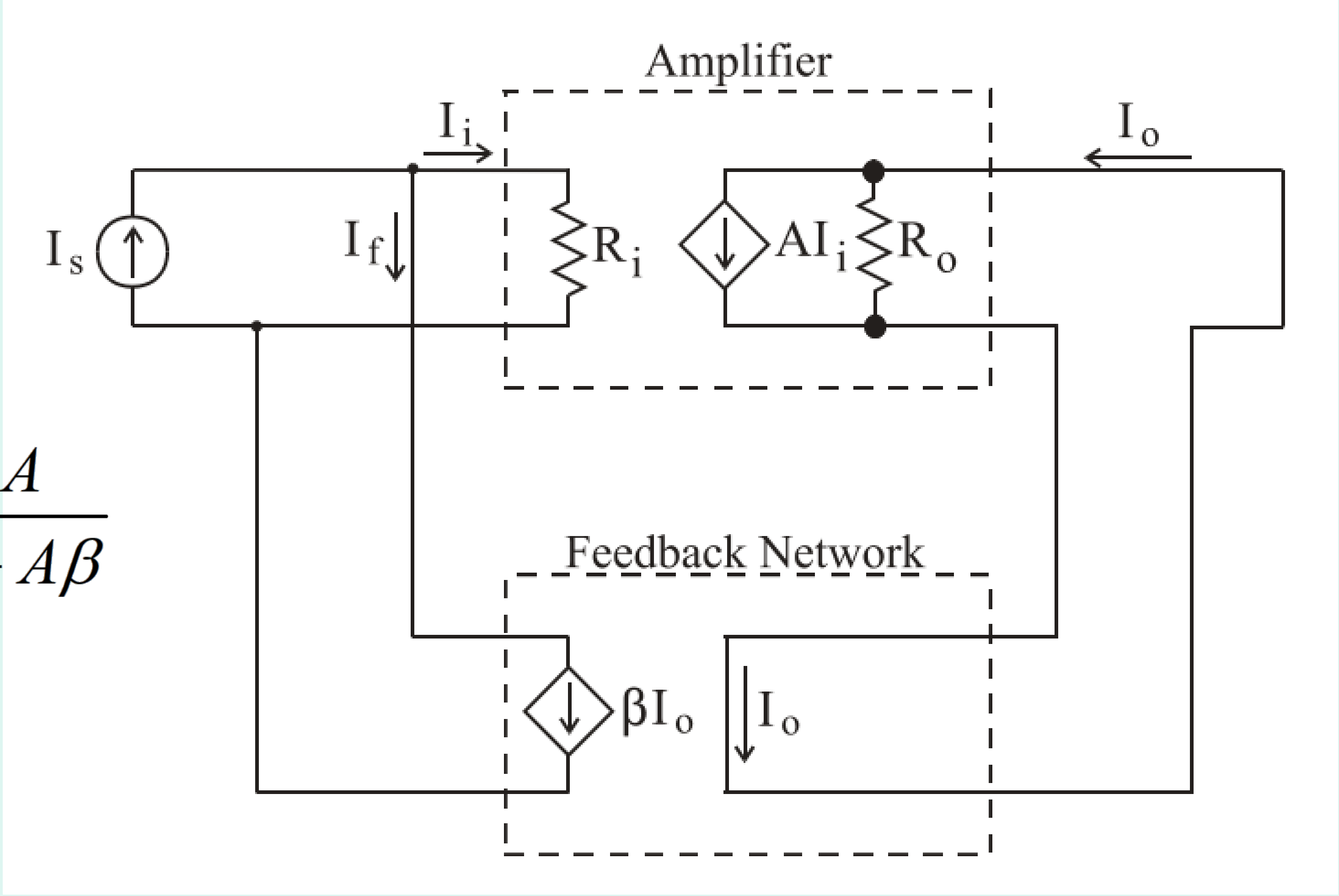


$$R_{of} = \frac{V_t}{I_t} = \frac{V_t}{\dfrac{V_t - AV_i}{R_o}} = R_o \frac{V_t}{V_t + A\beta V_t} = \frac{R_o}{1 + A\beta}$$

Concl: negative feedback brings the diport closer to an ideal diport (voltage amplifier)

Current amplifier case

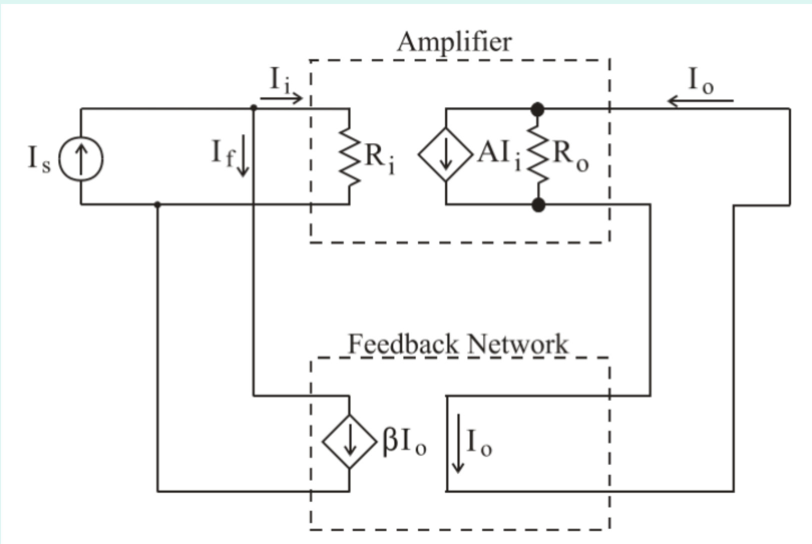
- Shunt-series feedback topology

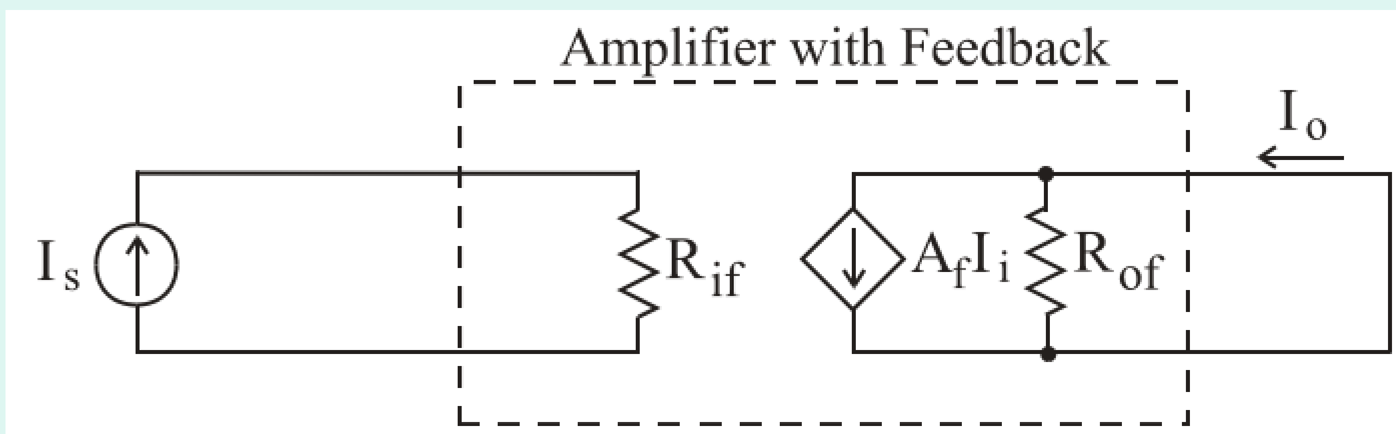


$$A_{if} = \frac{I_o}{I_s} = \frac{A}{1 + A\beta}$$

Current amplifier diport model

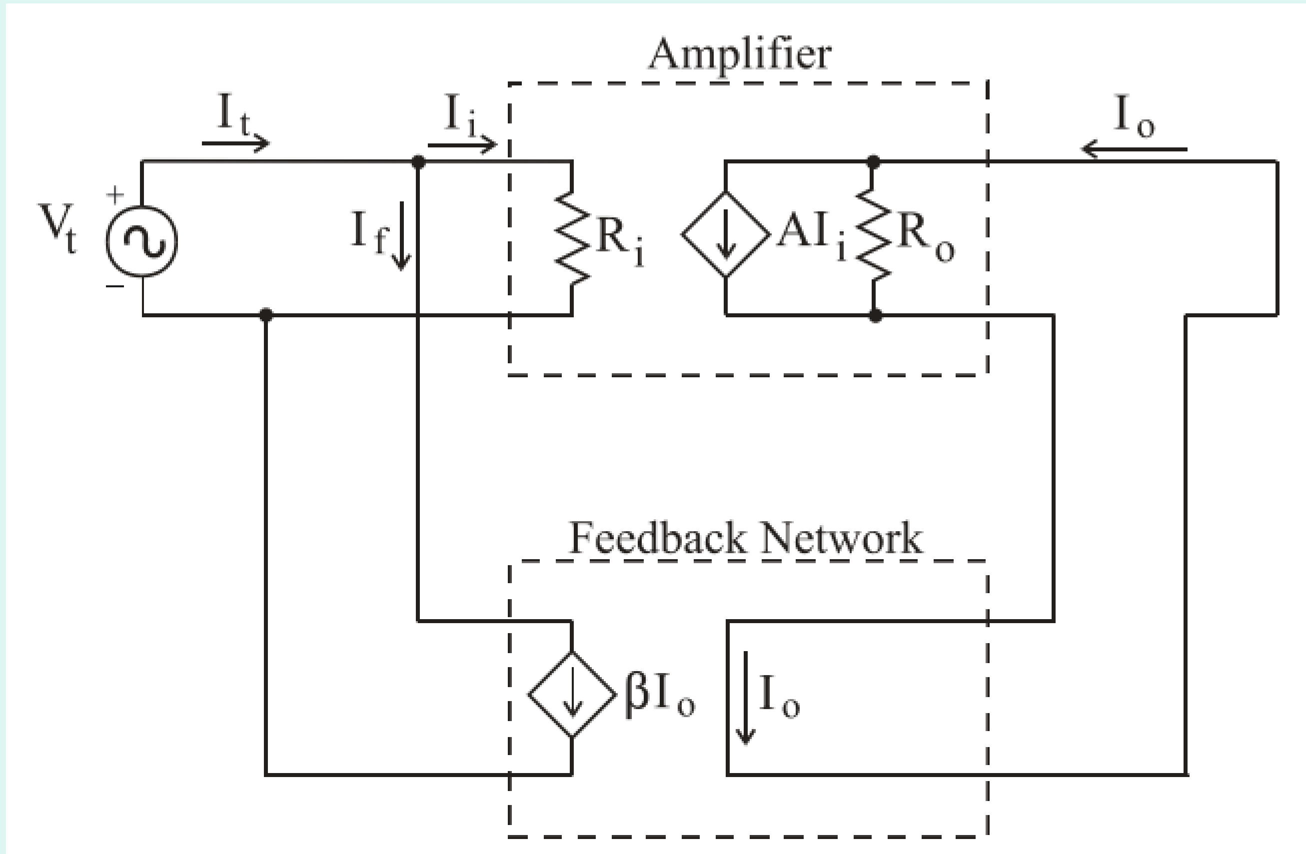
- Equivalent circuit model





Current amplifier - input impedance

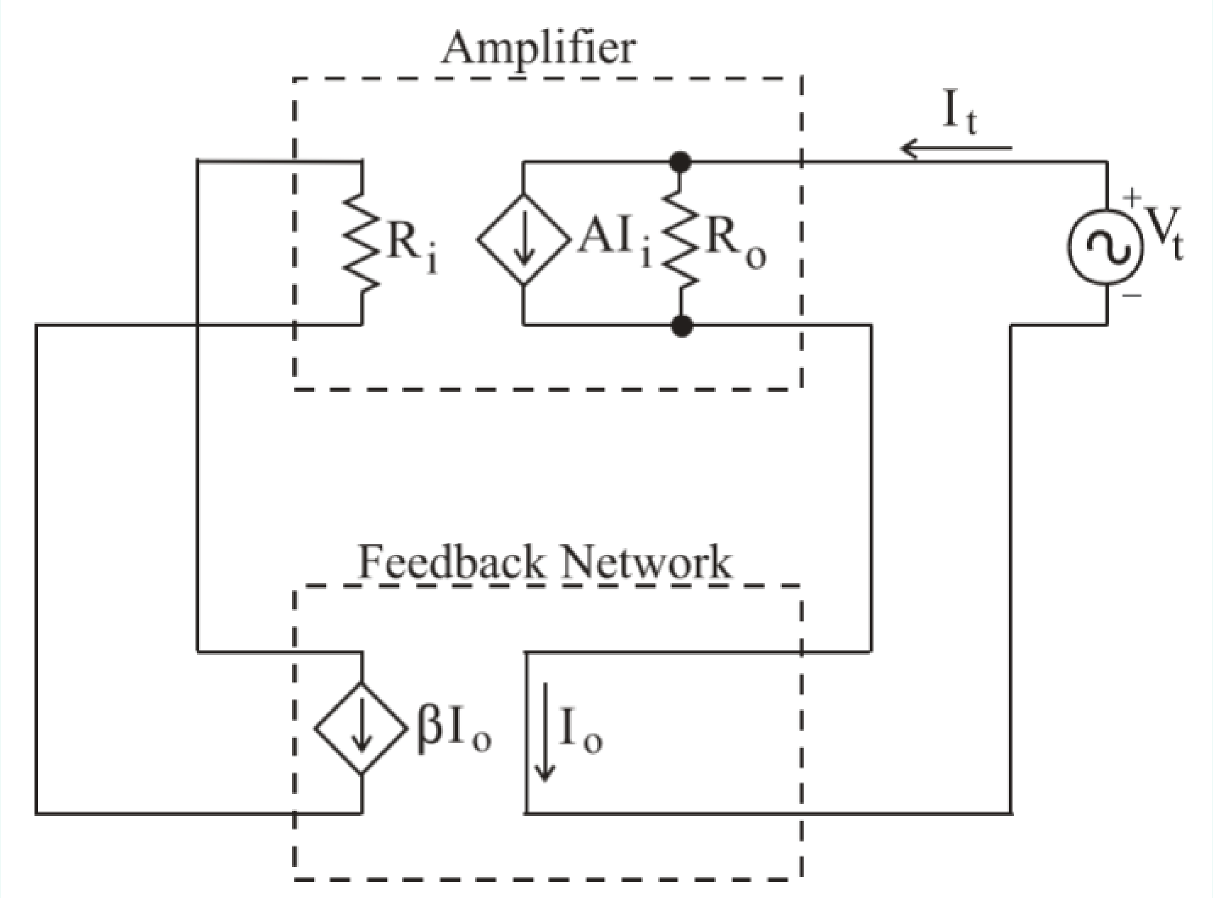
- Replace the input current source with a test voltage source V_t



$$R_{if} = \frac{V_t}{I_t} = \frac{V_t}{\frac{V_t}{R_i} + \beta I_o} = \frac{V_t}{\frac{V_t}{R_i} + A\beta I_i} = \frac{R_i}{1 + A\beta}$$

Current amplifier - output impedance

- Cancel input independent current source, apply test voltage source at output

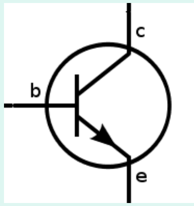


$$R_{of} = \frac{V_t}{I_t} = \frac{(I_t - AI_i)R_o}{I_t} = R_o \frac{I_t - A(-\beta I_t)}{I_t} = R_o(1 + A\beta)$$

Current amplifier - conclusions

- Ideal current amplifier - zero R_{in}, infinite R_{out}
- The shunt-series feedback drives a current amplifier closer to the ideal corresponding diport

$$\begin{cases} R_{if} = \dfrac{R_i}{1 + A\beta} \\ R_{of} = R_o\left(1 + A\beta\right) \end{cases}$$



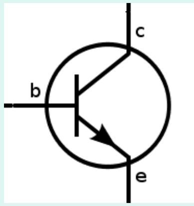
Remaining amplifier types

- Transimpedance amplifier - shunt-shunt feedback topology:

$$\text{Transimpedance } (i \rightarrow u): \begin{cases} A_{zf} = \dfrac{V_o}{I_s} = \dfrac{A}{1+A\beta} \\ R_{if} = \dfrac{R_i}{1+A\beta} \\ R_{of} = \dfrac{R_o}{1+A\beta} \end{cases}$$

Transadmittance amplifier - series-series feedback topology:

$$\text{Transadmitance } (u \rightarrow i): \begin{cases} A_{yf} = \dfrac{I_o}{V_s} = \dfrac{A}{1+A\beta} \\ R_{if} = R_i(1+A\beta) \\ R_{of} = R_o(1+A\beta) \end{cases}$$



Four feedback topologies

- Summary of closed-loop parameters

Topology	Closed-Loop Gain A_f	Input Resistance R_{if}	Output Resistance R_{of}
Voltage-Sampling Series-Mixing	$A/(1+A\beta)$	$R_i(1+A\beta)$	$R_o/(1+A\beta)$
Current-Sampling Series-Mixing	$A/(1+A\beta)$	$R_i(1+A\beta)$	$R_o(1+A\beta)$
Voltage-Sampling Shunt-Mixing	$A/(1+A\beta)$	$R_i/(1+A\beta)$	$R_o/(1+A\beta)$
Current-Sampling Shunt-Mixing	$A/(1+A\beta)$	$R_i/(1+A\beta)$	$R_o(1+A\beta)$

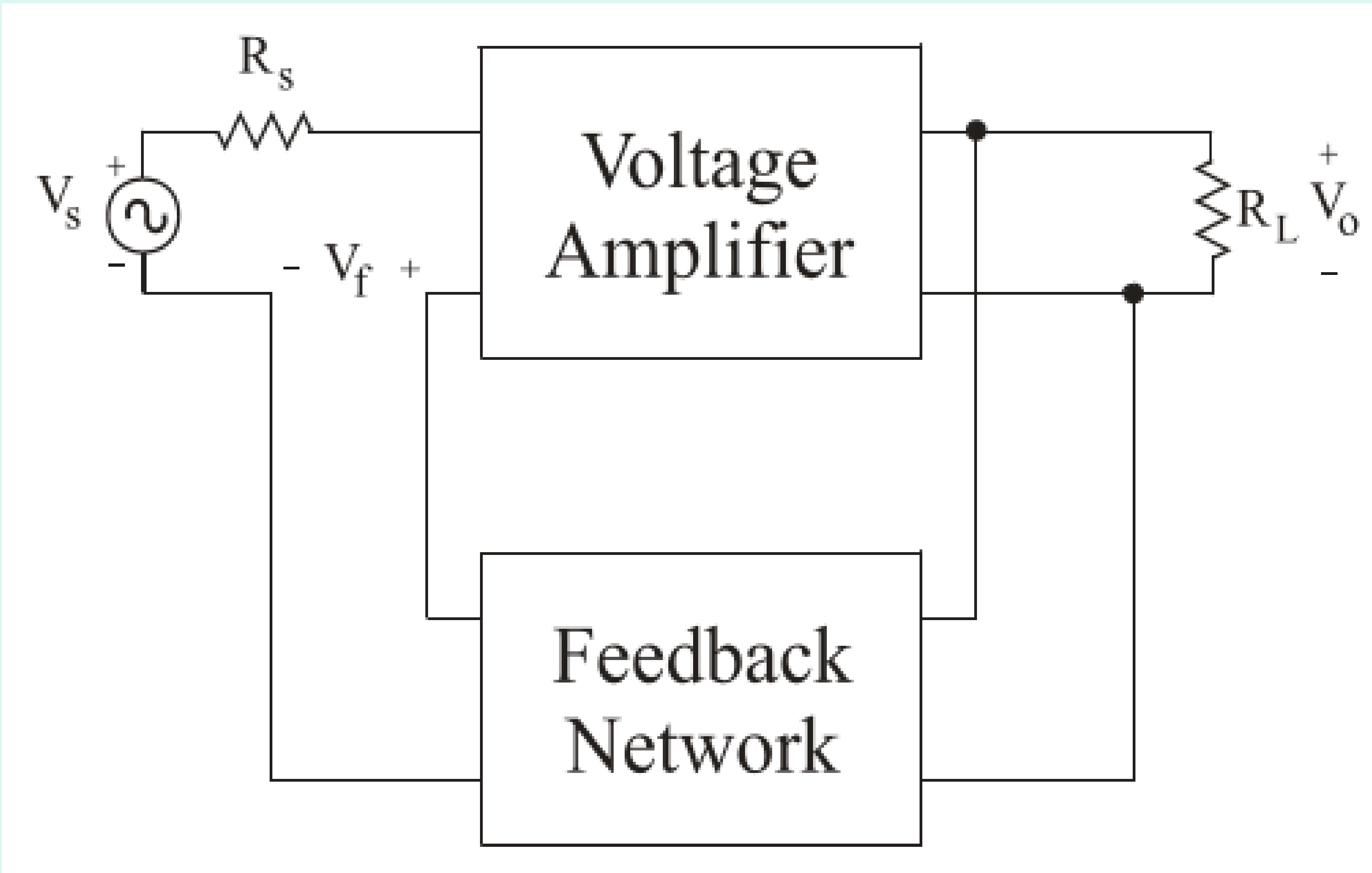
Source: Roberts+Sedra [1997]Spice, 2^{nd} ed.

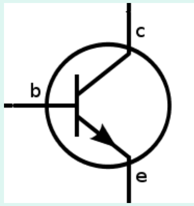
Non-ideal feedback networks

- So far we used an implicit assumption: the feedback network is ideal: it does not load the amplifier (it does not change the open-loop gain)+ there is no forward feed through
- Reality: a feedback network will affect A, R_i and R_o

Exm: voltage amplifier with feedback

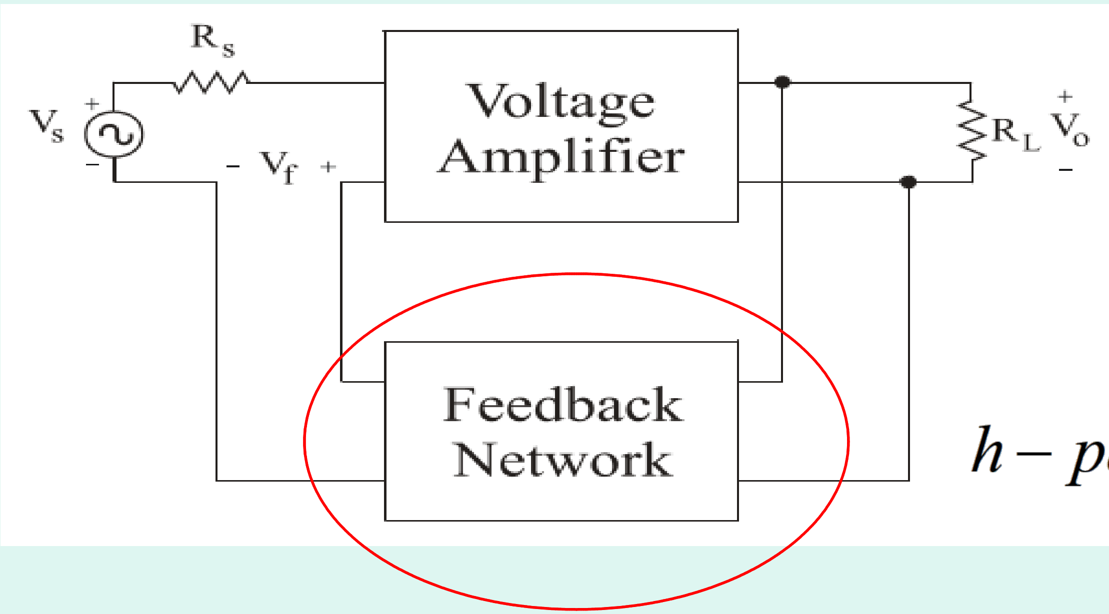
- Series-shunt feedback topology





Series-shunt feedback network

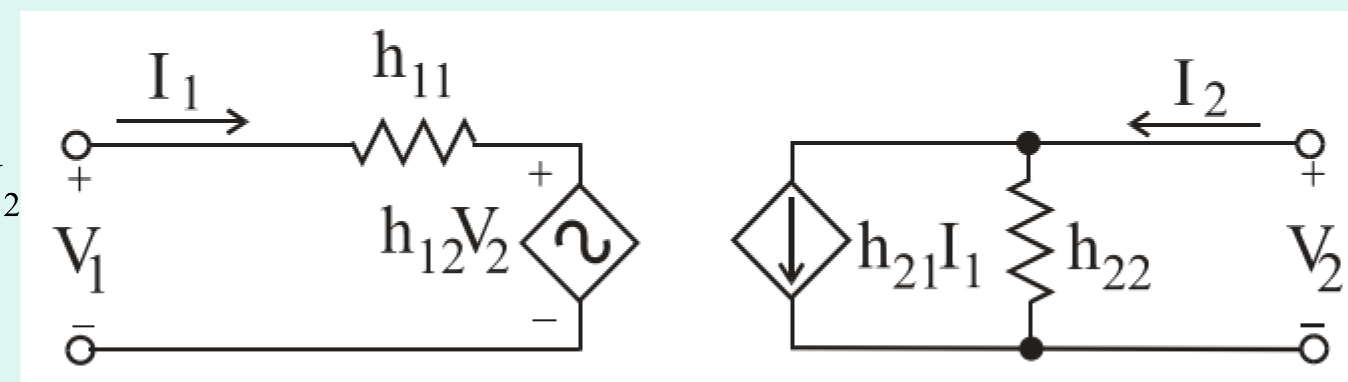
- General diport representation: the **h-parameter network**

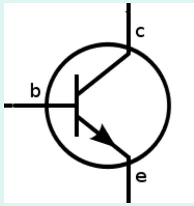


$$h-parameters:\begin{cases} V_1 = h_{11}I_1 + h_{12}V_2 \\ I_2 = h_{21}I_1 + h_{22}V_2 \end{cases}$$

Independent var: I_1, V_2

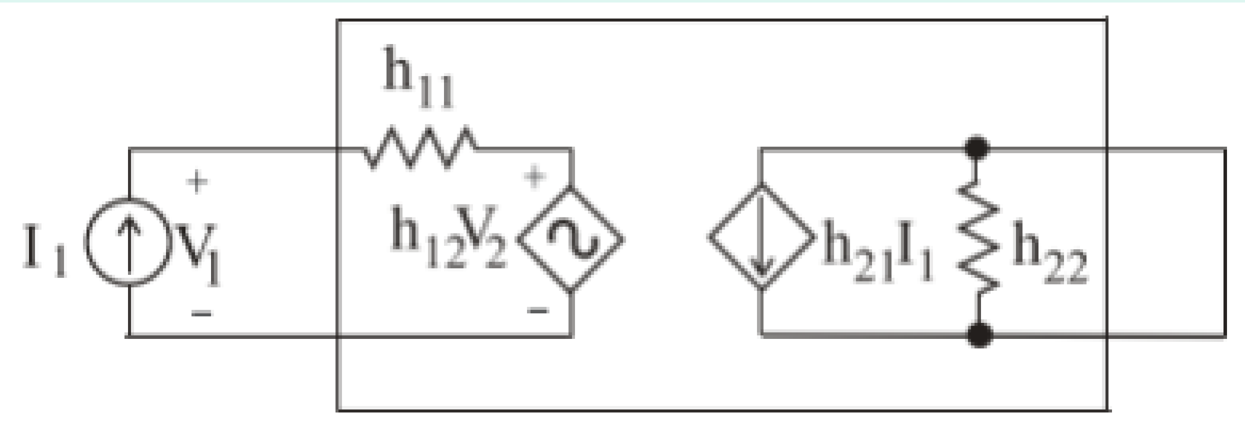
Dependent var: V_1, I_2



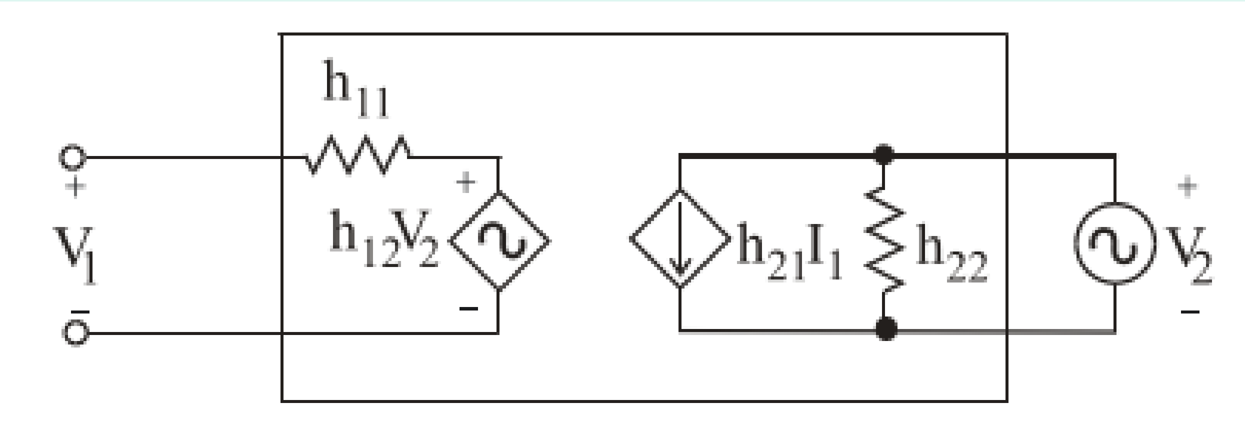


Measuring the h-parameters

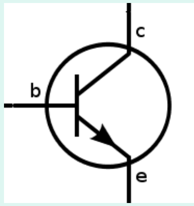
- Equations result directly from the linear diport description



$$h_{11} = \left.\frac{V_1}{I_1}\right|_{V_2=0}$$



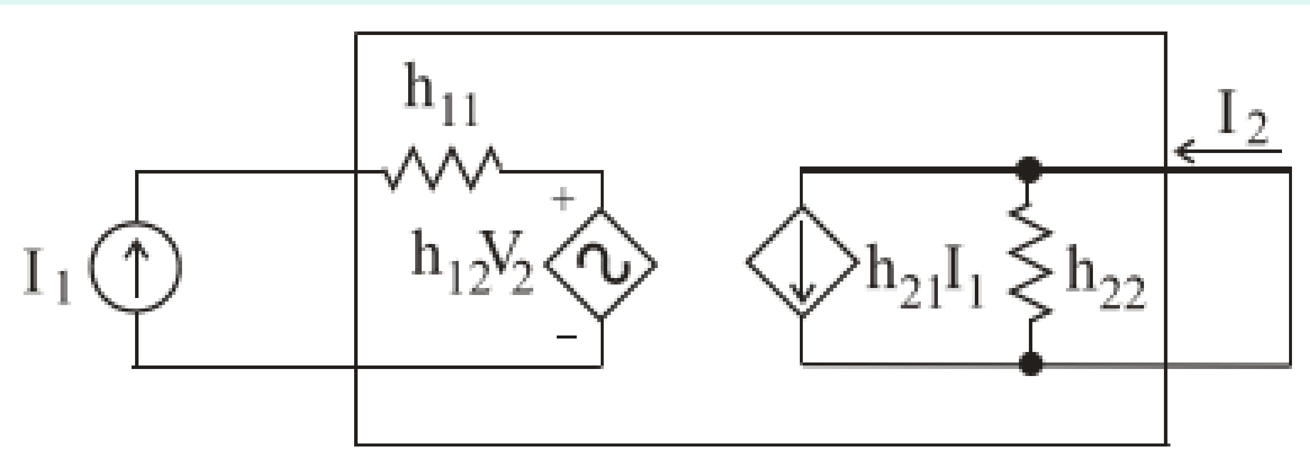
$$h_{12} = \left.\frac{V_1}{V_2}\right|_{I_1=0}$$



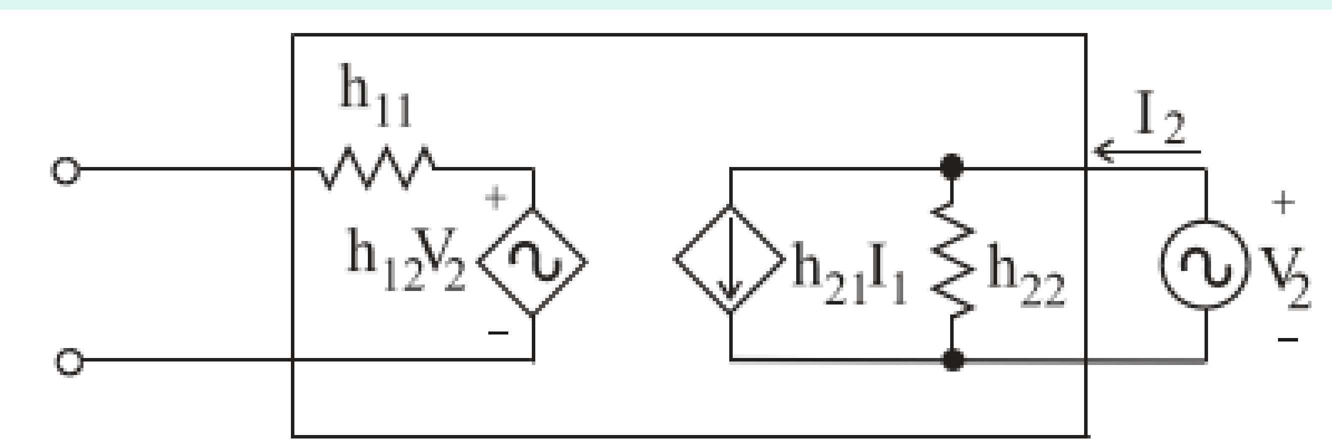
Measuring h-parameters (2)

- Linear diport → superposition of effects
- h_{21} = forward transmission

$$\begin{cases} V_1 = h_{11}I_1 + h_{12}V_2 \\ I_2 = h_{21}I_1 + h_{22}V_2 \end{cases}$$



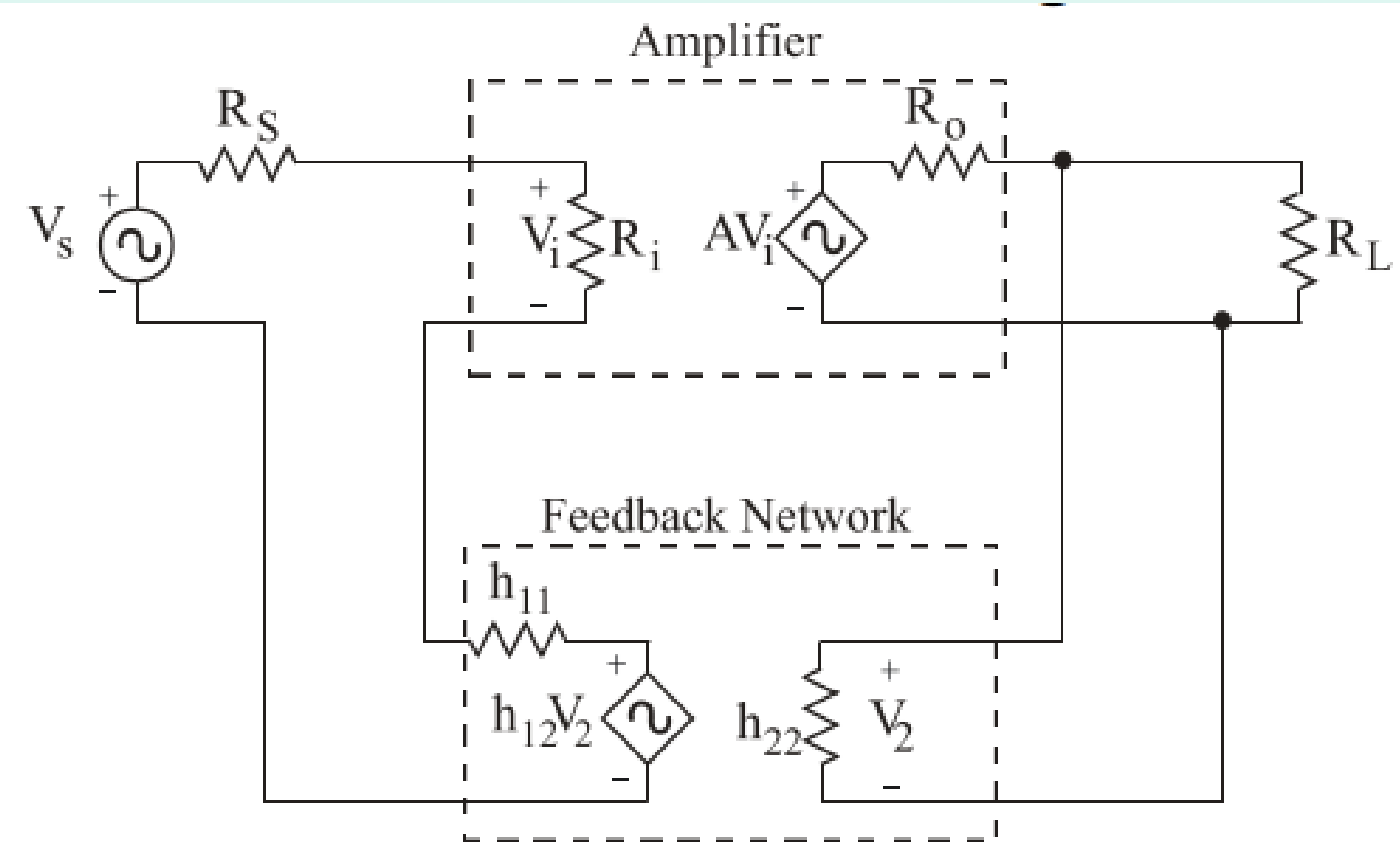
$$h_{21} = \left.\frac{I_2}{I_1}\right|_{V_2=0}$$



$$h_{22} = \left.\frac{I_2}{V_2}\right|_{I_1=0}$$

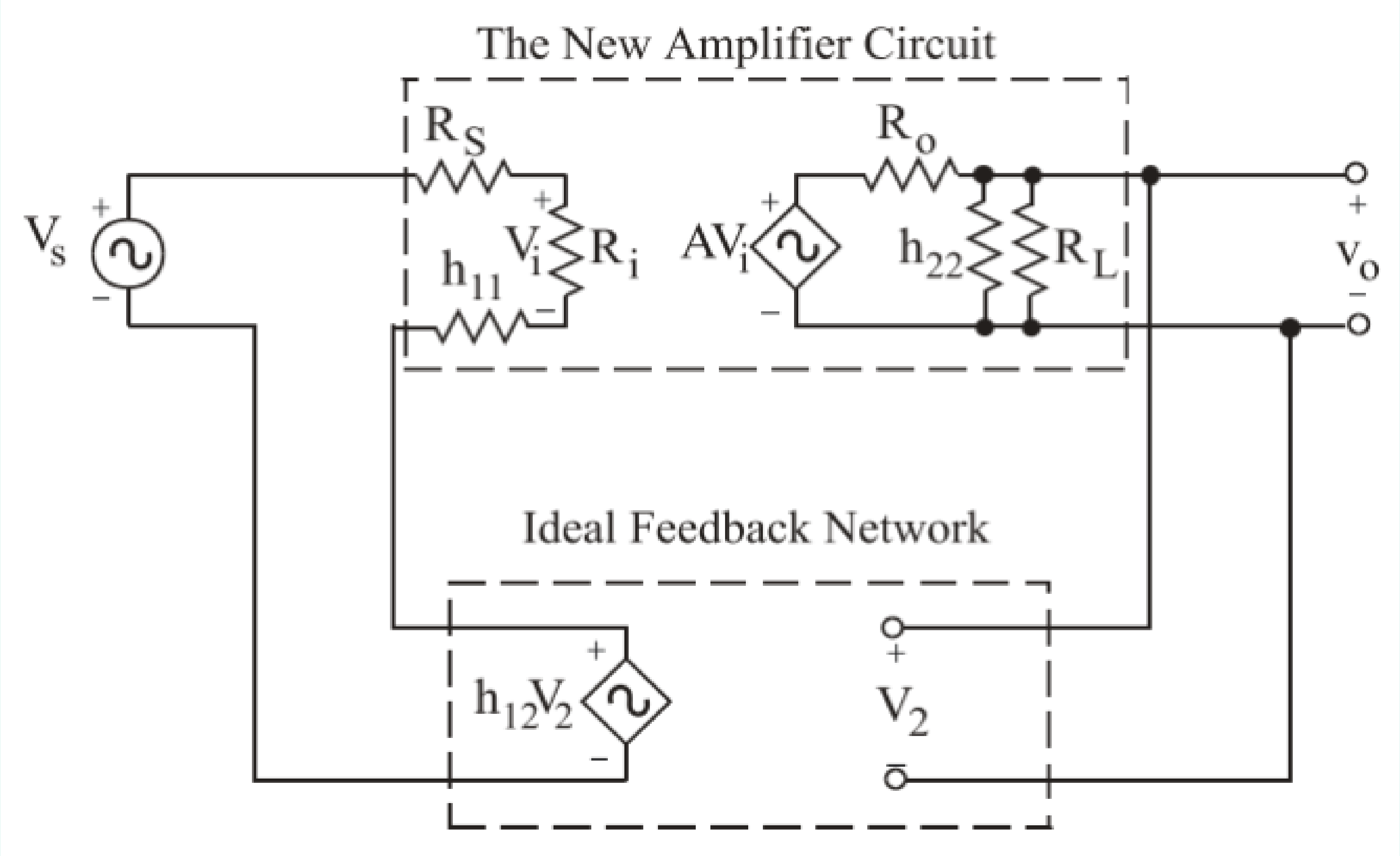
Voltage amplifier with a real β-network

- The series-shunt feedback case



Real β-network → Ideal β-network

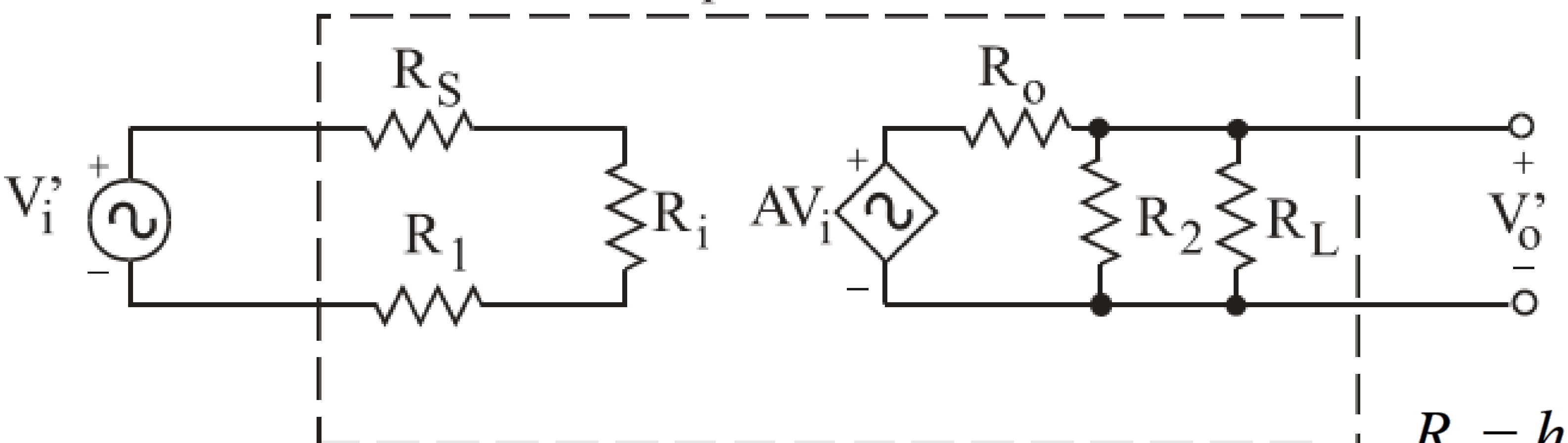
- Absorb the non-ideal terms in the β-network as part of the forward amplifier, to reduce to the ideal feedback case => we can apply the formulas from the ideal case



Modified diports: back to ideal feedback

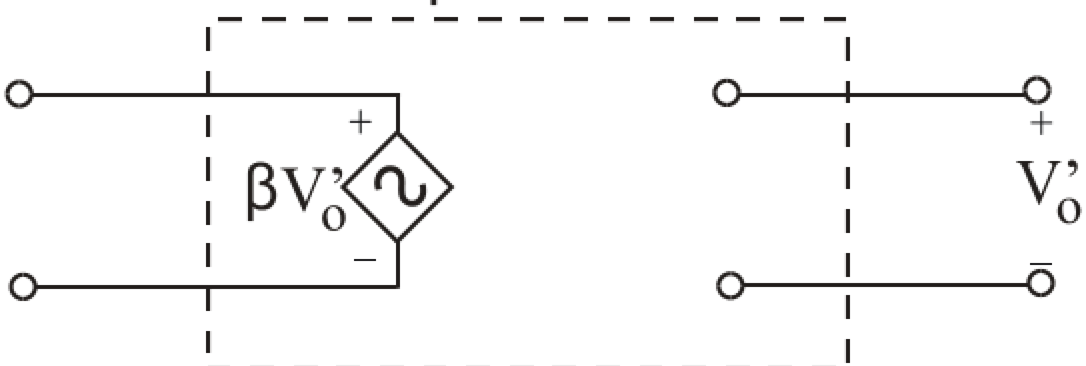
- Circuit transformation: modified amplifier + ideal feedback diport

The Amplifier Circuit



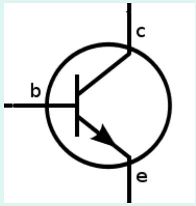
$$R_1 = h_{11} = \left.\frac{V_1}{I_1}\right|_{V_2=0}$$

β Network



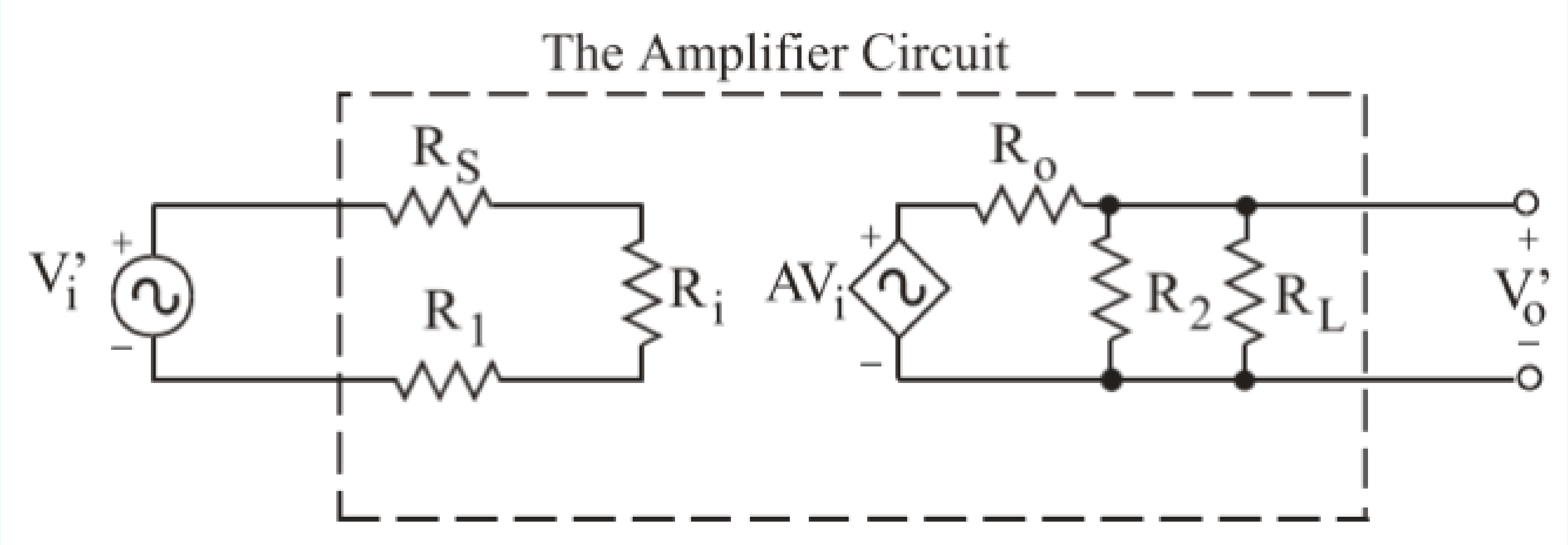
$$\beta = h_{12} = \left.\frac{V_1}{V_2}\right|_{I_1=0}$$

$$R_2 = \frac{1}{h_{22}}, \ h_{22} = \left.\frac{I_2}{V_2}\right|_{I_1=0}$$



Series-shunt feedback

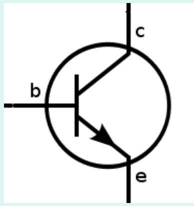
- We can apply the feedback formulas for the modified amplifier+ideal feedback case



$$A' = \frac{V_o'}{V_i'} \Rightarrow A_f = \frac{A'}{1+\beta A'}$$

$$R_{if} = R_i'\left(1+\beta A'\right)$$

$$R_{of} = \frac{R_o'}{1+\beta A'}$$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