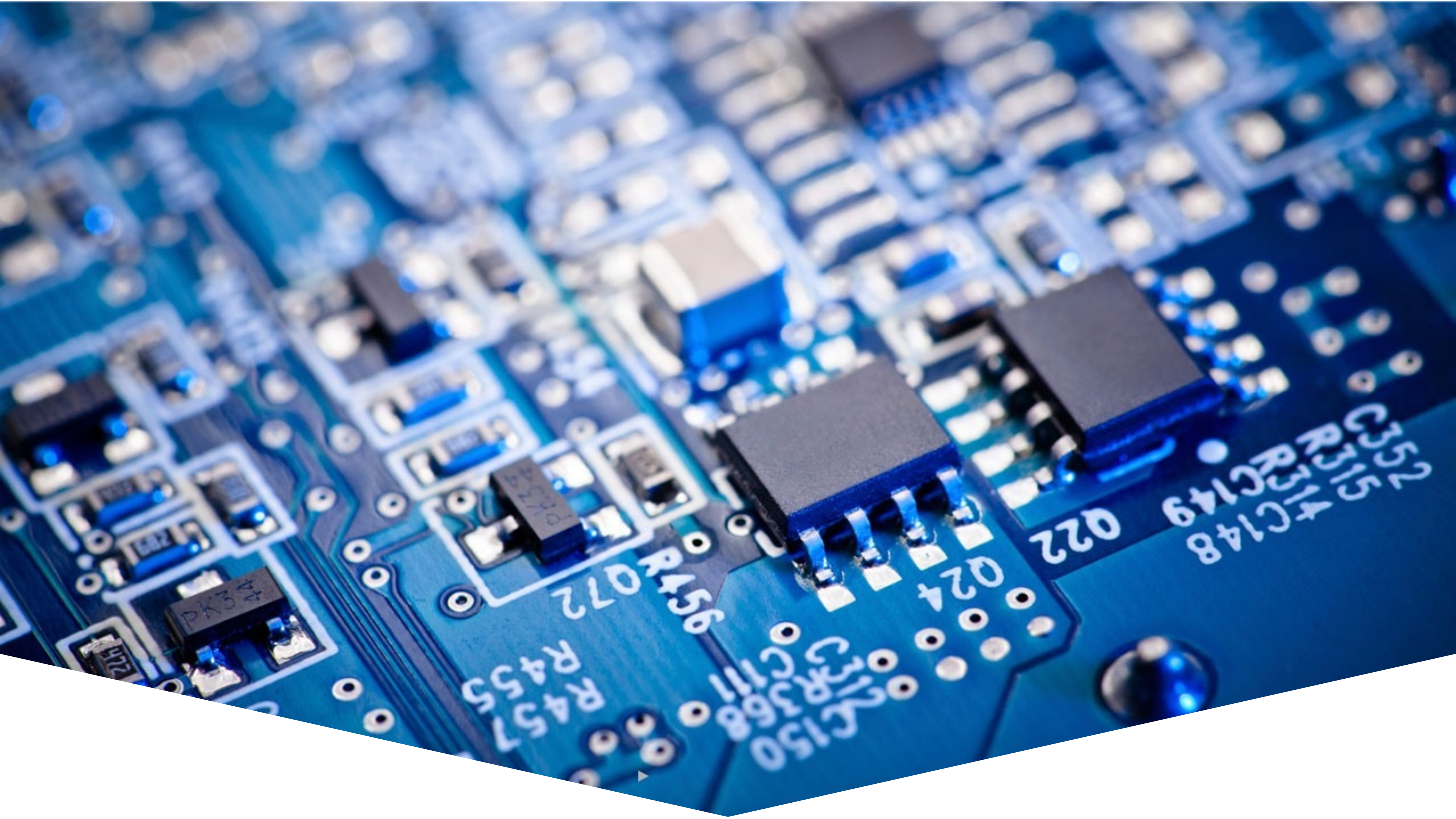


ANALOGE ELEKTRONICA 2

FEEDBACK AND STABILITY

Week 5: Leerdoelen

- Herhaling ANE10:
  - Principe van negatieve feedback
  - Bandwidth extension
  - Feedback topologieën
- Loop Gain
  - Gain and Phase Margin
  - Evaluating loop gain
  - DC-Servo

Negatieve Feedback

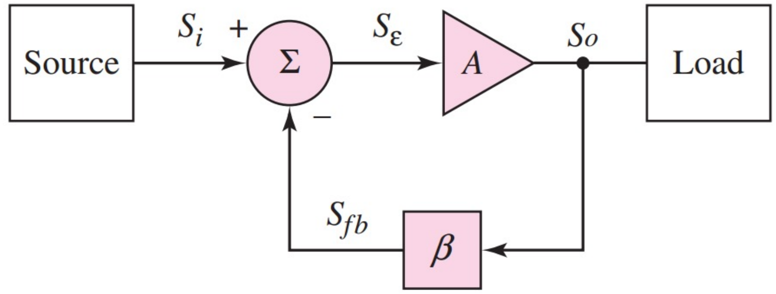


Figure 12.1 Basic configuration of a feedback amplifier

- **Voordelen:**
  1. Stabiliseren van versterking
  2. Verbeteren van frequentieresponsie
  3. Reductie van (niet-lineaire) verstoringen
  4. Verbeteren van ingangs- en uitgangsimpedanties

- **Nadeel:**
  1. Overall versterking wordt minder
  2. Systeem kan instabiel worden voor hogere frequenties

Negatieve Feedback - Principe

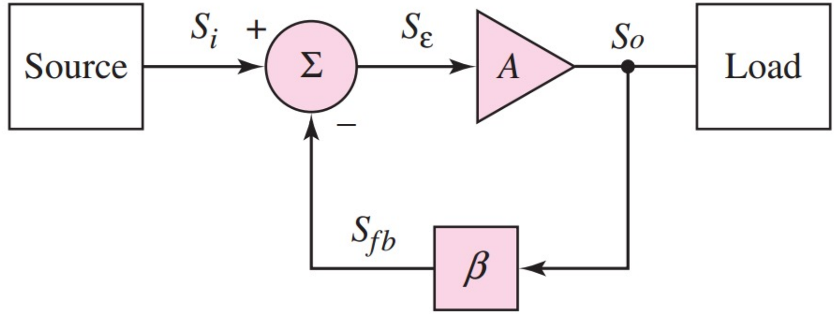


Figure 12.1 Basic configuration of a feedback amplifier

- **Definities:**

  A Open-loop gain (zonder feedback)

  β Loop gain (versterking in de feedback lus)

  A_f Closed-loop gain (versterking met feedback)

Relaties:

$$S_0 = A\,S_\varepsilon\,, \qquad S_{fb} = \beta\,S_0\,, \qquad S_\varepsilon = S_i - S_{fb}\,; \qquad \text{Gain: } A_f = \frac{S_o}{S_i}$$

of in matrix notatie:

$$\begin{pmatrix} 1 & -A & 0 \\ \beta & 0 & -1 \\ 0 & 1 & 1 \end{pmatrix} \begin{pmatrix} S_o \\ S_\varepsilon \\ S_{fb} \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ S_i \end{pmatrix}$$

Negatieve Feedback

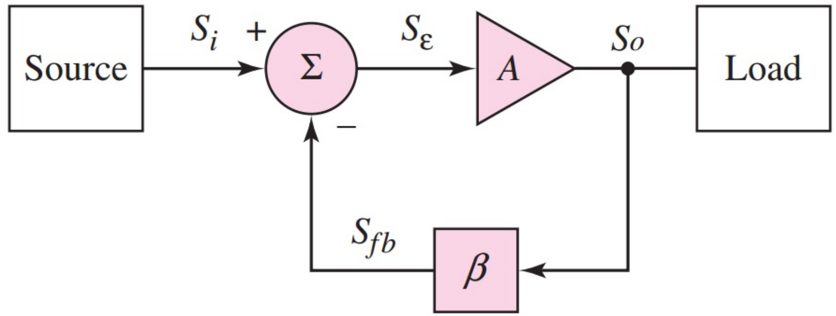


Figure 12.1 Basic configuration of a feedback amplifier

- **Cramer's regel:**

$$S_0 = \frac{D_1}{D} \;;$$

$$D = \begin{vmatrix} 1 & -A & 0 \\ \beta & 0 & -1 \\ 0 & 1 & 1 \end{vmatrix} = 1 + \beta A \,,$$

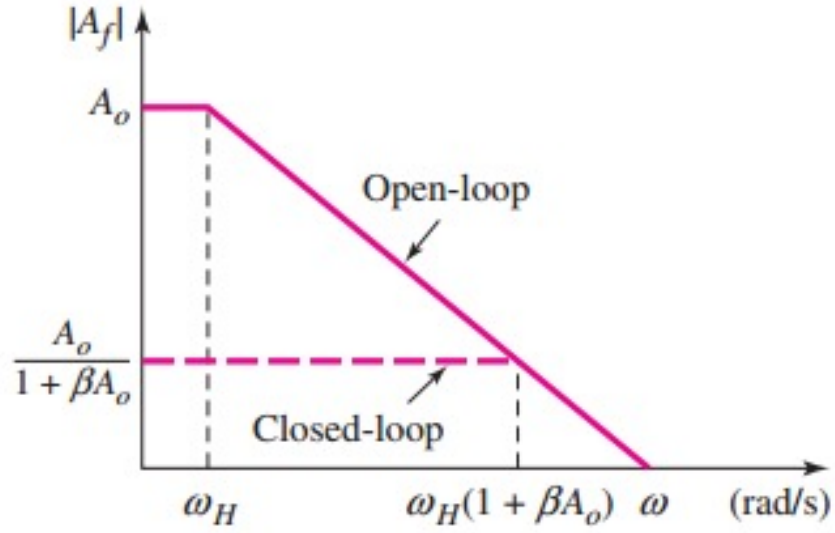
$$A_f = \frac{S_o}{S_i} = \frac{D_1}{S_i\, D} \;;$$

$$D_1 = \begin{vmatrix} 0 & -A & 0 \\ 0 & 0 & -1 \\ S_i & 1 & 1 \end{vmatrix} = A\, S_i$$

- **Dus de closed-loop gain:**

$$A_f = \frac{A}{1 + \beta A} = \frac{1}{\beta + \frac{1}{A}}$$

Bandwidth extension



- Frequentie responsie 1e orde amplifier:

$$A(s) = \frac{A_0}{1+\frac{s}{\omega_h}}$$

Midband gain

Kantelfrequentie

- De closed-loop gain:

$$A_f(s) = \frac{A(s)}{1+\beta A(s)} = \frac{\frac{A_0}{1+\frac{s}{\omega_h}}}{1+\beta.\frac{A_0}{1+\frac{s}{\omega_h}}} = \frac{A_0}{1+\frac{s}{\omega_h}+\beta.A_0} = \frac{A_0}{1+\beta.A_0}\cdot\frac{1}{1+\frac{s}{\omega_h(1+\beta\, A_0)}}$$

- Conclusie:
  - Closed-loop gain is factor $1+\beta A_0$ kleiner geworden
  - Kantelpunt is factor $1+\beta A_0$ groter geworden: $\omega_{fh} = \omega_h\,(1+\beta A_0)$

HOGESCHOOL ROTTERDAM

Negatieve Feedback

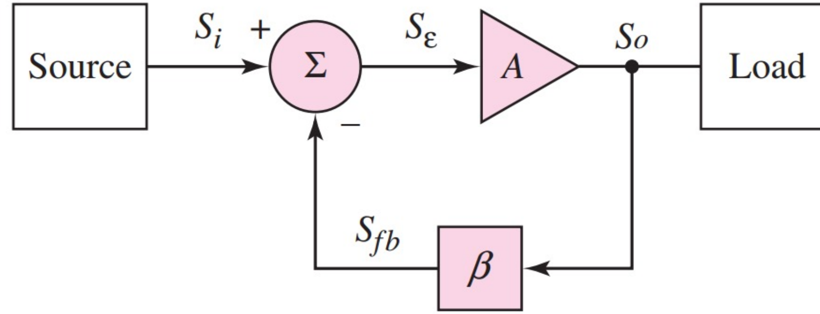


Figure 12.1 Basic configuration of a feedback amplifier

Open-loop gain: A

Transfer functie: β

Loop gain: $T = \beta\ A$

Closed-loop gain: A_f

$$A_f = \frac{A}{1+T} = \frac{A}{1+\beta A}$$

Open-loop kantelpunt: f_H

Closed-loop kantelpunt: f_{fH}

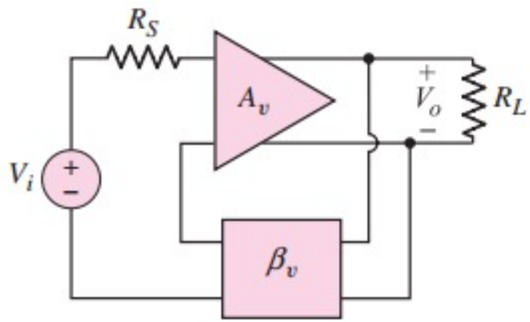
Bandwidth extension:

$$f_{fH} = (1+\beta A) f_H$$

$$A_f\ f_{fH} = A\ f_H$$

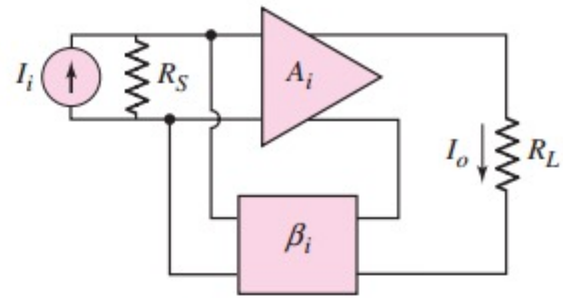
Feedback topologieën

$$A_{vf} = \frac{V_o}{V_i}$$



(a) Series–shunt

Voltage amplifier

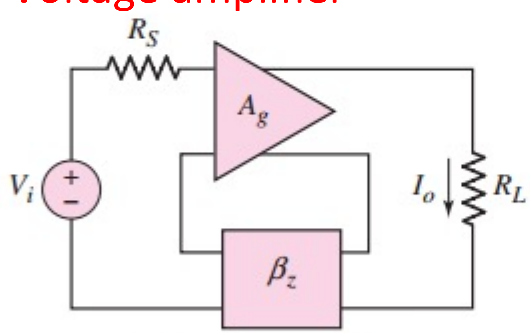


(b) Shunt–series

Current amplifier

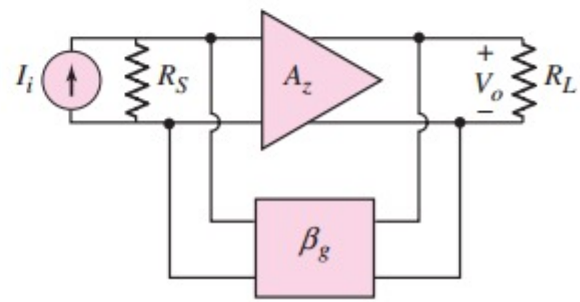
$$A_{if} = \frac{I_o}{I_i}$$

$$Y_f = \frac{I_o}{V_i}$$



(c) Series–series

Transconductance amplifier



(d) Shunt–shunt

Transresistance amplifier

$$Z_f = \frac{V_o}{I_i}$$

Series-shunt topologie

Dit is een voorbeeld van een feedback systeem:

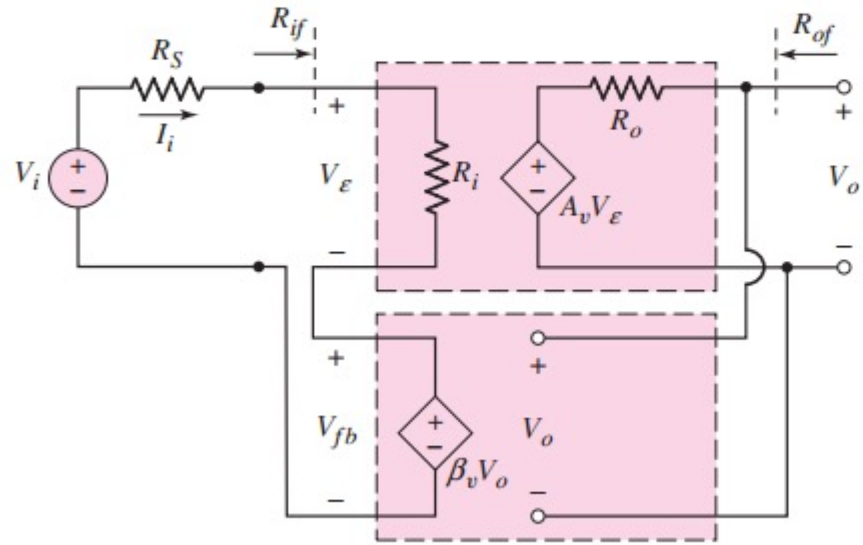


Figure 12.6 Ideal series–shunt feedback topology

$$\begin{pmatrix} 1 & -A_v & 0 \\ \beta_v & 0 & -1 \\ 0 & 1 & 1 \end{pmatrix} \begin{pmatrix} V_o \\ V_\varepsilon \\ V_{fb} \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ V_i \end{pmatrix}$$

$$V_0 = \frac{D_1}{D} = \frac{\begin{vmatrix} 0 & -A_v & 0 \\ 0 & 0 & -1 \\ V_i & 1 & 1 \end{vmatrix}}{\begin{vmatrix} 1 & -A_v & 0 \\ \beta_v & 0 & -1 \\ 0 & 1 & 1 \end{vmatrix}} = \frac{V_i A_v}{1 + \beta_v\, A_v}$$

$$A_{vf} = \frac{V_o}{V_i} = \frac{A_v}{1 + \beta_v\, A_v}$$

Series-shunt topologie - ingangsimpedantie

Ingangsimpedantie met feedback R_{if}:

$$R_{if} = \frac{V_i}{I_i} \;, \qquad I_i = \frac{V_\varepsilon}{R_i}$$

$$\begin{pmatrix} 1 & -A_v & 0 \\ \beta_v & 0 & -1 \\ 0 & 1 & 1 \end{pmatrix} \begin{pmatrix} V_o \\ V_\varepsilon \\ V_{fb} \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ V_i \end{pmatrix}$$

$$V_\varepsilon = \frac{D_2}{D} = \frac{\begin{vmatrix} 1 & 0 & 0 \\ \beta_v & 0 & -1 \\ 0 & V_i & 1 \end{vmatrix}}{\begin{vmatrix} 1 & -A_v & 0 \\ \beta_v & 0 & -1 \\ 0 & 1 & 1 \end{vmatrix}} = \frac{V_i}{1 + \beta_v\, A_v} \,,$$

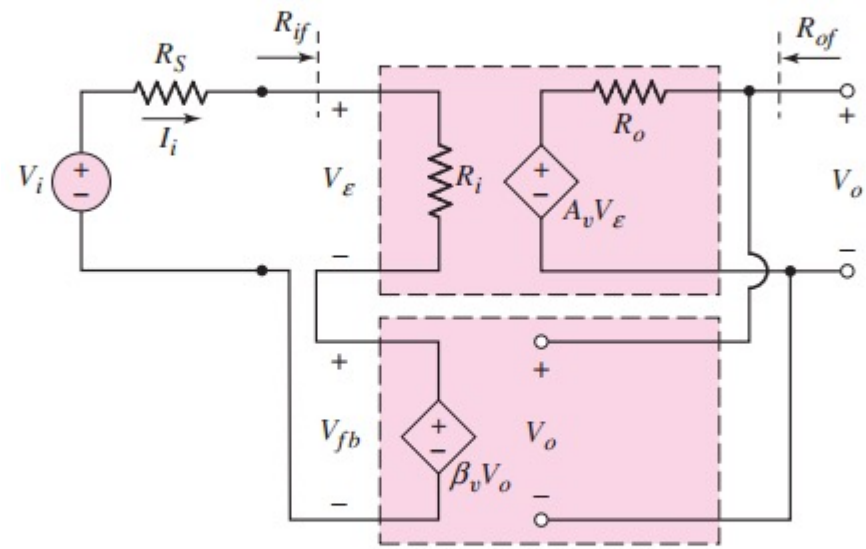


Figure 12.6 Ideal series–shunt feedback topology

$$R_{if} = \frac{V_i}{I_i} = (1 + \beta_v\, A_v) R_i$$

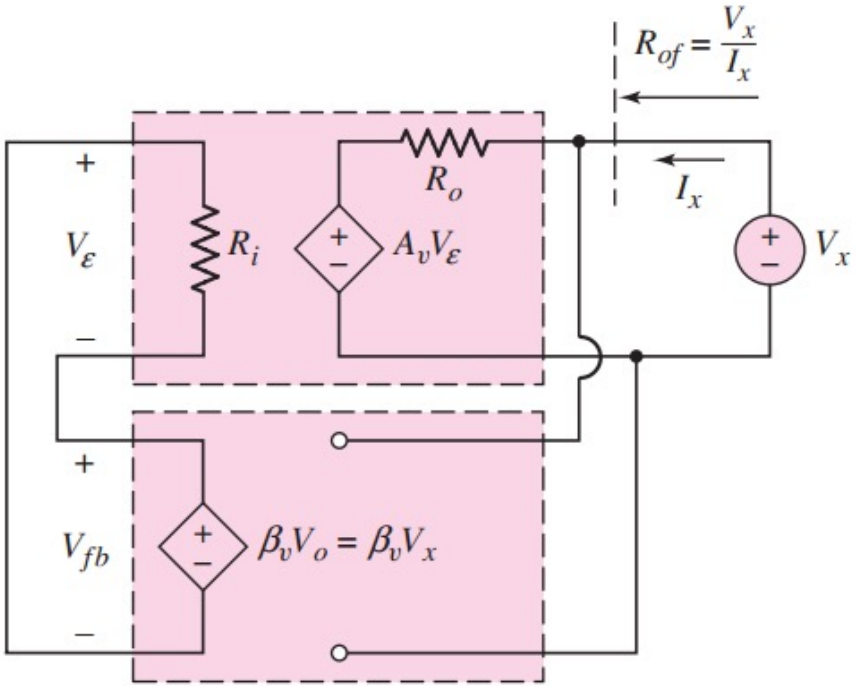
Series-Shunt topologie - uitgangsimpedantie

Om de uitgangsimpedantie $R_{of} = \frac{V_x}{I_x}$ te bereken:

- sluit ingang kort
- zet een testspanning V_x op de uitgang

$$\begin{pmatrix} 0 & 1 & 1 \\ -\beta_v & 0 & 1 \\ 1 & -A_v & 0 \end{pmatrix} \begin{pmatrix} V_x \\ V_\varepsilon \\ V_{fb} \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ I_x R_o \end{pmatrix}$$

$$V_x = \frac{D_1}{D} = \frac{\begin{vmatrix} 0 & 1 & 1 \\ 0 & 0 & 1 \\ I_x R_o & -A_v & 0 \end{vmatrix}}{\begin{vmatrix} 0 & 1 & 1 \\ -\beta_v & 0 & 1 \\ 1 & -A_v & 0 \end{vmatrix}} = \frac{I_x R_o}{1 + \beta_v\, A_v}$$



$$R_{of} = \frac{V_x}{I_x} = \frac{R_o}{1 + \beta_v\, A_v}$$

Series-shunt topologie - samenvatting

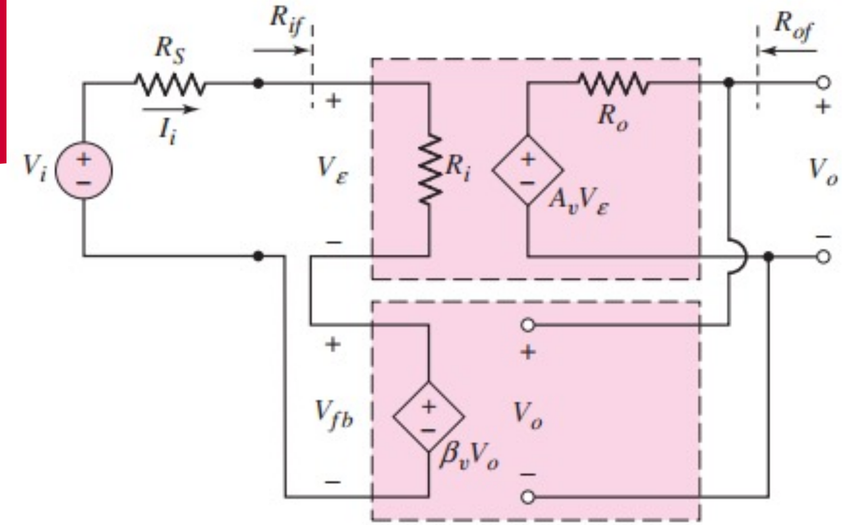


Figure 12.6 Ideal series–shunt feedback topology

- Series-shunt = voltage amplifier:
  - Source-signal: voltage
  - Output-signal: voltage

- Versterking:
  - wordt stabieler (gewenst!)

$$A_{vf} = \frac{V_o}{V_i} = \frac{A_v}{1 + \beta_v A_v}$$

- Ingangsimpedantie:
  - wordt groter (gewenst!)

$$R_{if} = \frac{V_i}{I_i} = R_i\,(1 + \beta_v A_v)$$

- Uitgangsimpedantie:
  - wordt lager (gewenst!)

$$R_{of} = \frac{V_x}{I_x} = \frac{R_o}{1 + \beta_v A_v}$$

Loop Gain

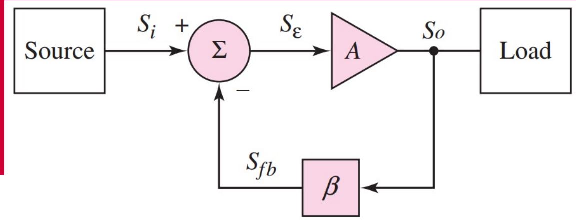
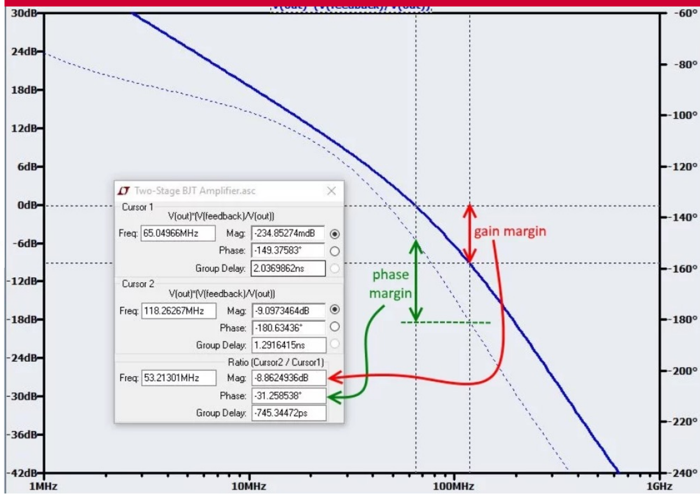
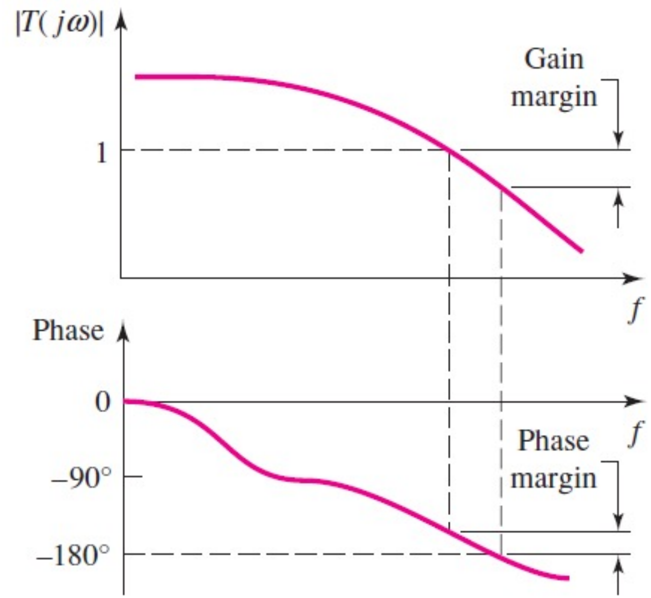


Figure 12.1 Basic configuration of a feedback amplifier

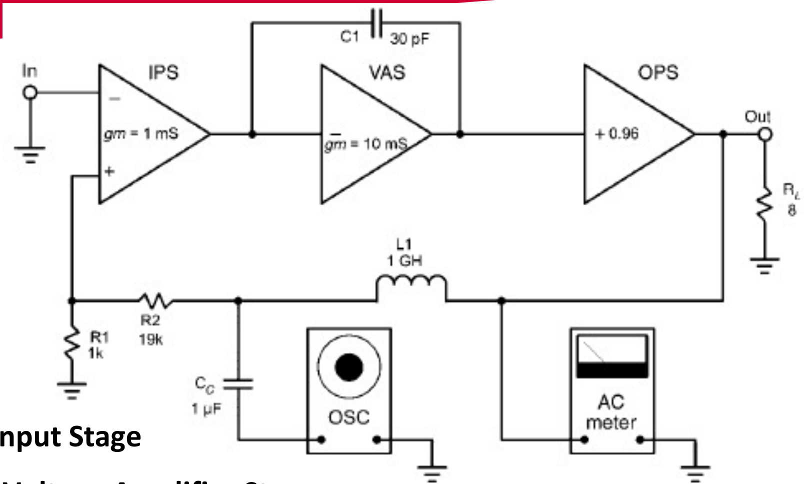


- Loop gain: $T = \beta\, A$
  - Bepaalt stabiliteit van systeem
  - Te bepalen door systeem ‘open te knippen’
- Meting:
  - Cursor 1: bij loop-gain van 1 (0 dB)
  - Cursor 2: bij fase van -180°
- Gain Margin:
  - Verschil in dB tussen beide cursors
  - Minimaal 6 dB voor power-amps nodig
- Phase Margin:
  - Verschil in fase tussen beide cursors
  - Minimaal 45° voor power amps nodig



Evaluating Loop Gain

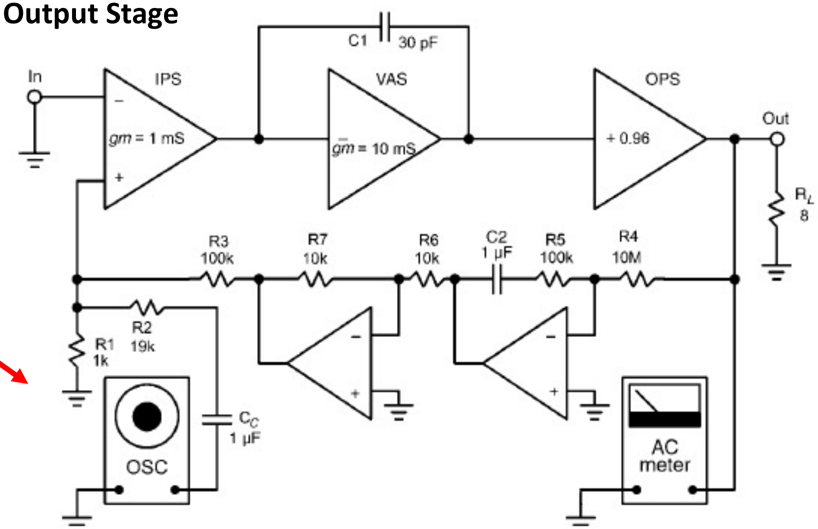
- Breaking the loop
  - Signaal toevoegen op input van loop
  - Frequentie en fase meten op uitgang van loop
- Probleem:
  - DC-niveaus / bias moet wel gelijk blijven
  - Moeilijk door hoge open-loop gain
- Hoe op te lossen:
  - LT-Spice: 1 GH spoel in loop plaatsen
  - Praktijk: DC-Servo toevoegen



IPS: Input Stage

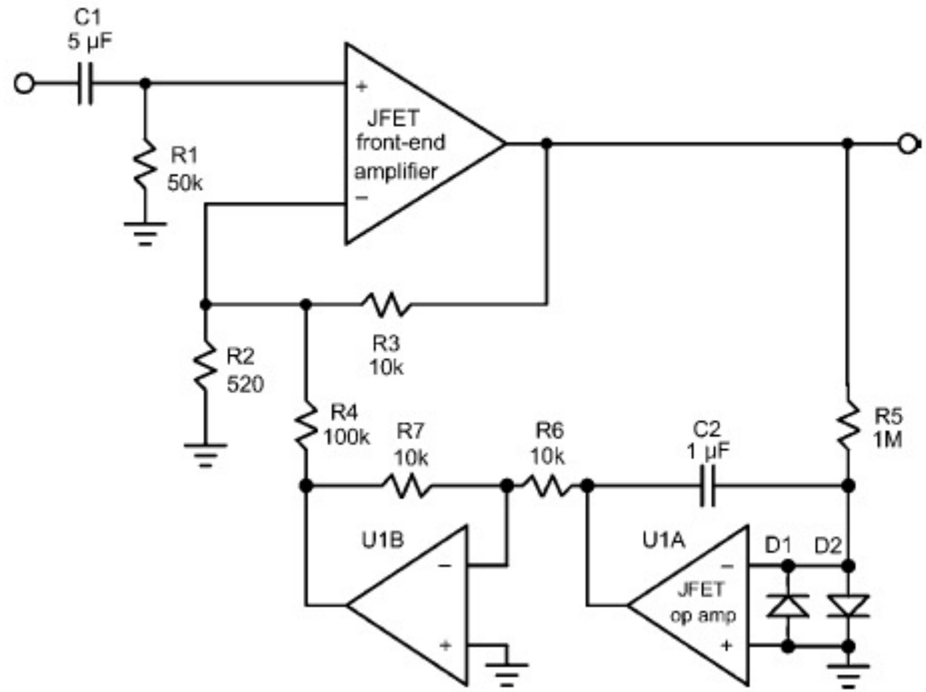
VAS: Voltage Amplifier Stage

OPS: Output Stage



DC-Servo Basics

- DC-Servo concept:
  - DC op output gefilterd door lowpass-filter
  - Teruggekoppeld naar feedback-loop
  - DC op output wordt hiermee kleiner
- Praktijk:
  - Integrator (U1A) voor lowpass-filter en gain
  - Inverterende versterker nodig voor juiste fase
  - Zonder DC-Servo: DC-level is ±100 mV
  - Met DC-Servo: DC-level < 10 mV



Nazorg

Behandeld is:

- Feedback & Stability
- Loop-gain & meting
- DC-Servo's