CURS3

Amplificatoare operaționale liniare

Repetorul de tensiune (caz particular al amplificatorului neinversor $Z_2 = 0, \quad Z_1 \to \infty$), figura 3.1

Calculam amplificarea de tensiune $\mathbf{A_u}$

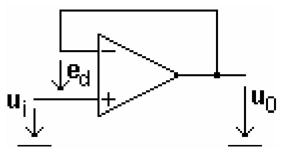

Figura 3.1.

Avem relațiile: $u_0 = -A_0 e_d$ **;** $U_0 = e_d + u_i$ si $u_0 = A_u u_i$ (3.1)

Rezulta: $u_0 (1 + \frac{1}{A_0}) = u_i$ de unde se deduce: $A_u = \frac{A_0}{1 + A_0}$ (3.2)

Calculul impedantei de intrare $\mathbf{Z_{int}}$

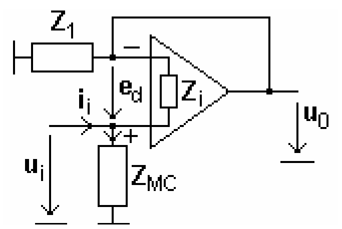

Figura 3.2

(Z1 este de fapt impedanta de mod comun pe borna minus a AO)

Avem: $u_0 = -A_0 e_d$ **;** $u_0 = A_u u_i$

$$\Rightarrow \quad Z_{int} = \frac{u_i}{i_i} \textbf{, dar } i_i = \frac{u_i}{Z_{MC}} - \frac{e_d}{Z_i} = \frac{u_i}{Z_{MC}} + \frac{u_0}{A_0} \cdot \frac{1}{Z_i} = \frac{u_i}{Z_{MC}} + u_i \cdot \frac{\cancel{A_0}}{1 + A_0} \cdot \frac{1}{\cancel{A_0} Z_i}$$

$$\Rightarrow \quad \frac{1}{Z_{int}} = \frac{1}{Z_{MC}} + \frac{1}{Z_i (1 + A_0)} \qquad \Rightarrow \quad Z_{int} = Z_{MC} \| (Z_i (1 + A_0))$$

Repetorul de tensiune realizat cu AOI este caracterizat de urmatorii parametri: $A_u = \frac{A_0}{1 + A_0} |_{A_0 -> \infty} = 1$, $Z_{int} = \infty$, $Z_{ies} = 0$

Amplificatorul diferential (figura 3.3)

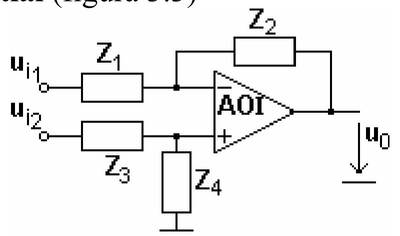

Figura 3.3

$$\begin{cases} u_{id} = u_{i1} - u_{i2} \\ u_{ic} = \dfrac{u_{i1} + u_{i2}}{2} \end{cases} \Rightarrow \begin{cases} u_{i1} = u_{ic} + \dfrac{u_{id}}{2} \\ u_{i2} = u_{ic} - \dfrac{u_{id}}{2} \end{cases}$$

Tinand cont de formulele deduse la amplificatoarele in configuratie de inversor si neinversor, utilizand Teorema Superpoziției deducem :

$$u_0 = -\frac{Z_2}{Z_1}u_{i1} + \frac{Z_4}{Z_3 + Z_4}\cdot\left(1 + \frac{Z_2}{Z_1}\right)\cdot u_{i2} = -\frac{Z_2}{Z_1}\left(u_{ic} + \frac{u_{id}}{2}\right) + \frac{Z_4}{Z_3 + Z_4}\left(1 + \frac{Z_2}{Z_1}\right)\cdot\left(u_{ic} - \frac{u_{id}}{2}\right)$$

(s-au inlocuit u_{i1} și u_{i2}).

$$\Rightarrow \quad u_0 = \left[-\frac{Z_2}{Z_1} - \frac{Z_4}{Z_3 + Z_4}\left(1 + \frac{Z_2}{Z_1}\right)\right]\cdot\frac{u_{id}}{2} + \left[-\frac{Z_2}{Z_1} + \frac{Z_4}{Z_3 + Z_4}\left(1 + \frac{Z_2}{Z_1}\right)\right]\cdot u_{ic}$$

in cazul in care se pune conditia ca amplificarea de mod comun sa fie zero se deduc relatiile:

$$\left[-\frac{Z_2}{Z_1} + \frac{Z_4}{Z_3 + Z_4}\left(1 + \frac{Z_2}{Z_1}\right)\right] \to 0$$

$$Z_2 = \frac{Z_4(Z_1 + Z_2)}{Z_3 + Z_4} \quad \equiv \quad Z_2 Z_3 = Z_1 Z_4 \quad \equiv \quad \frac{Z_2}{Z_1} = \frac{Z_4}{Z_3}$$

$$\Rightarrow \quad A_u = -\frac{Z_2}{Z_1}\left(u_{i1} - u_{i2}\right)$$

Impedanțele de intrare trebuie să fie egale $Z_{\text{int}1} = Z_{\text{int}2}$

$$\left.\begin{aligned} Z_{\text{int}1} &= Z_1 + \underbrace{Z_i \left\| \frac{Z_2}{1 + A_0} \right.}_{0} \approx Z_1 \\ Z_{\text{int}2} &= Z_3 + Z_4 \end{aligned}\right\} \Rightarrow \quad Z_1 = Z_3 + Z_4$$

Aceasta conditie poate fi realizata cu schema din figura 3.4

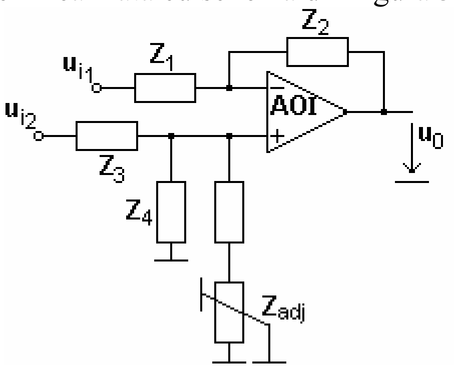

Figura 3.4

<u>reglaj dificil</u> + bandă de trecere limitată $\Rightarrow$ Se poate utiliza schema din figura 3.5

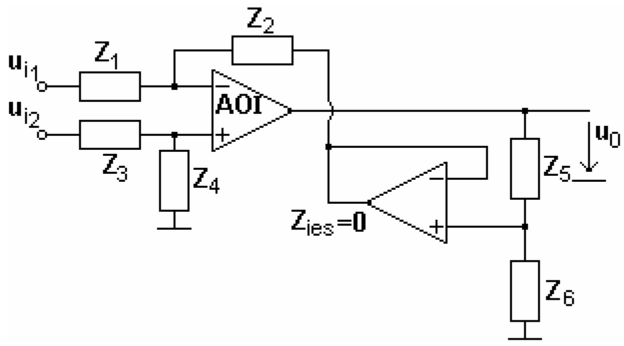

Figura 3.5

$$u_0 = u_{id}\left(-\frac{Z_2}{Z_1}\right)\cdot\frac{Z_5+Z_6}{Z_6}$$

Observatie: Conditia de amplificator diferential poate fi indeplinita usor ($\frac{Z_2}{Z_1}=\frac{Z_4}{Z_3}$), reglajul amplificarii realizandu-se din Z_5 şi Z_6.

Alte scheme de amplificatoare diferențiale

A) Schemă utilizând doua amplificatoare in configuratie inversoare (anticipez amplificatorul sumator), figura 3.6

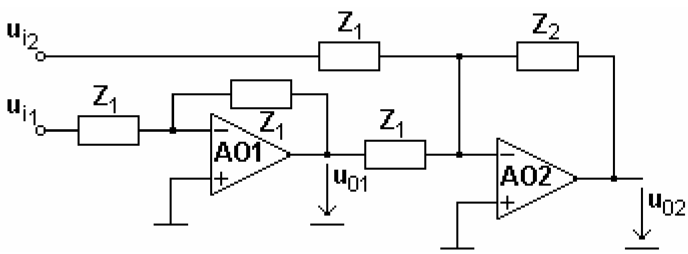

Figura 3.6

$$u_{01} = -\frac{Z_1}{Z_1}\cdot u_{i1} = -u_{i1}$$

Aplicand KI la borna inversoare la AO2 rezulta

$$\Rightarrow \quad \frac{u_{i2}}{Z_1}+\frac{u_{01}}{Z_1}+\frac{u_{02}}{Z_2}=0 \quad \Rightarrow \quad u_{02}=(u_{i2}-u_{i1})\cdot\left(-\frac{Z_2}{Z_1}\right)$$

La aceasta configuratie impedanțele de intrare sunt egale $\approx R_1$

B) Schema utilizând doua amplificatoare in configuratie neinversoare, figura 3.7

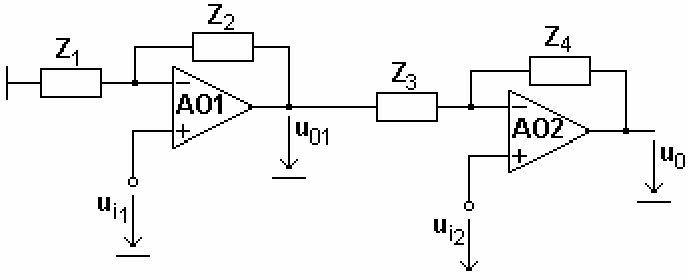

Figura 3.7

$$u_{02}=\left(1+\frac{Z_4}{Z_3}\right)\cdot u_{i2}-\frac{Z_4}{Z_3}\cdot u_{i1}\cdot\left(1+\frac{Z_2}{Z_1}\right)$$

$$A_{MC}=0 \quad\Rightarrow\quad 1+\frac{Z_4}{Z_3}=\frac{Z_4}{Z_3}\cdot\left(1+\frac{Z_2}{Z_1}\right) \quad\Rightarrow\quad Z_1\left(\cancel{Z_4}+Z_3\right)=Z_4\left(\cancel{Z_1}+Z_2\right)$$

$$\Rightarrow\quad \frac{Z_1}{Z_2}=\frac{Z_4}{Z_3} \qquad Z_{\text{int}1,2}\to\infty$$

Creşterea Z_{int} se poate realiza şi utilizând un AO diferențial clasic cu două repetoare de tensiune, figura 3.8

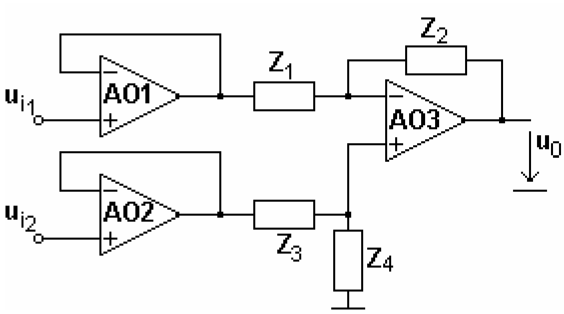

Figura 3.8

$Z_{\text{int}}\to\infty$ (AO1 şi AO2 trebuie să aibă CMR f. mare)

Observatie: Schema anterioara păstrează totuşi faptul că trebuie să fac două reglaje pentru AO3

C) Schema cu trei AO la care reglajul amplificarii este independent de AO3, figura 3.9

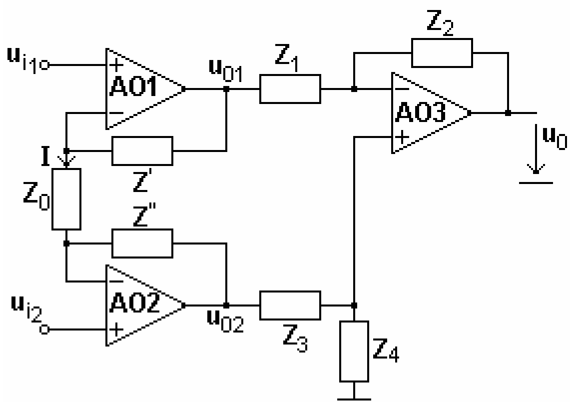

Figura 3.9

$$I=\frac{u_{01}-u_{02}}{Z'+Z_0+Z''}=\frac{u_{i1}-u_{i2}}{Z_0}$$ cu condiția : $\frac{Z_1}{Z_2}=\frac{Z_3}{Z_4}$ pentru AO3 rezulta:

$$u_0=-\frac{Z_2}{Z_1}\cdot\left(u_{01}-u_{02}\right)=-\frac{Z_2}{Z_1}\left(Z'+Z_0+Z''\right)\cdot\frac{1}{Z_0}\cdot\left(u_{i1}-u_{i2}\right).$$

Pot calcula şi altfel si anume cu Teorema Superpoziției :

$$u_{01}=u_{i1}\left(1+\frac{Z'}{Z_0}\right)-u_{i2}\frac{Z'}{Z_0};$$

$$u_{02}=-u_{i1}\frac{Z''}{Z_0}+u_{i2}\cdot\left(1+\frac{Z''}{Z_0}\right);$$

$$u_0 = -\frac{Z_2}{Z_1}\cdot(u_{01} - u_{02}) = -\frac{Z_2}{Z_1}\cdot\left(1+\frac{Z'+Z''}{Z_0}\right).$$

Amplificatoare cu câştig reglabil

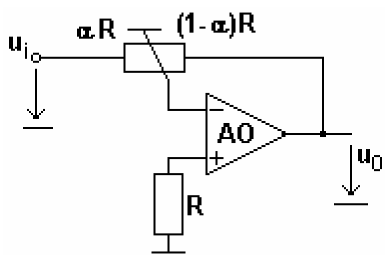

Figura 3.10

$A_u = -\frac{1-\alpha}{\alpha}$**;** $0 < \alpha < 1$**;** $\alpha \to 0 \;\Rightarrow\; Z_{int} \to 0$**;** $\alpha \to 1 \;\Rightarrow$ AO debitează curent mare.

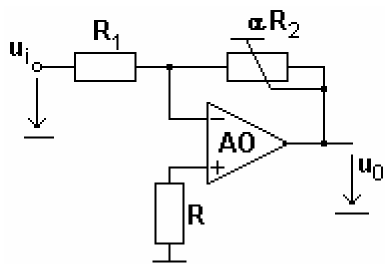

Figura 3.11

$A_u = -\frac{\alpha R_2}{R_1}$**;** $0 < \alpha < 1$**;** $Z_{int} = R_1$ (fixă)**;** $A_u \in \left(-\frac{R_2}{R_1}, 0\right)$**.**

Observatie: Se poate modifica amplificare şi prin reglajul rezistentei R_1**.**

Amplificator cu reglaj pe ieşire

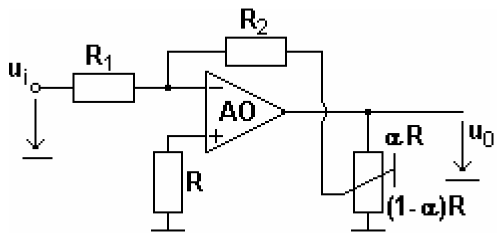

Figura 3.12

Echivalez schema :

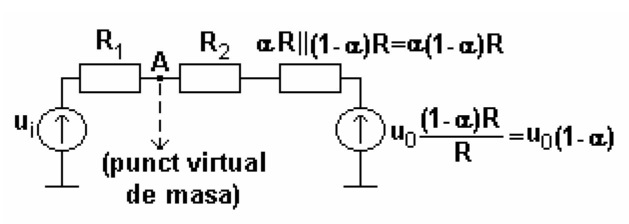

Figura 3.13

KI in **A** : $\Rightarrow$ $\frac{u_i}{R_1} = -\frac{u_0 \cdot (1-\alpha)}{R_2 + \alpha(1-\alpha)R}$;

$$A = \frac{u_0}{u_i} = -\frac{R_2 + \alpha(1-\alpha)R}{R_1(1-\alpha)} = -\left(\frac{R_2}{R_1} \cdot \frac{1}{1-\alpha} + \alpha \frac{R}{R_1}\right);$$

$$0 < \alpha < 1; \qquad A_u \in \left(-\frac{R_2}{R_1}, -\infty\right).$$

$$Z_{\text{int}} = R_1 + Z_i \left\| \frac{R_2 + \alpha(1-\alpha)R}{1 + A_0(1-\alpha)} \right. .$$

Reglarea amplificării in intervalul (-1,+1)

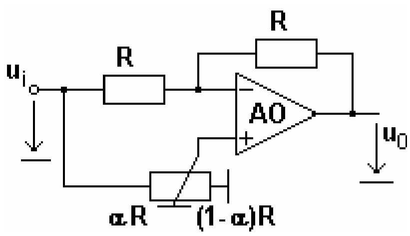

Figura 3.14

$$u_0 = -\frac{R}{R} \cdot u_i + \left(1 + \frac{R}{R}\right) \cdot \frac{(1-\alpha) u_i R}{R} = u_i (1 - \alpha \cdot 2); \qquad 0 < \alpha < 1; \qquad A \in (-1, +1).$$

Aplicatii:

- Extinderea domeniuli de masura la un ADC după polaritatea semnalului;
- Măsurarea temperaturii cu punte activă.

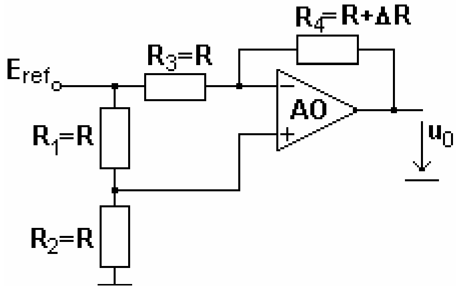

Figura 3.15

$$u_0 = E_{ref}\left[-\frac{R + \Delta R}{R} + \left(1 + \frac{R + \Delta R}{R}\right) \cdot \frac{R}{2R}\right] = \frac{E_{ref}}{2R}(-2R - 2\Delta R + R + R + \Delta R) = \frac{E_{ref}}{2R}(-\Delta R);$$

De obicei $R + \Delta R = R_0(1 + \alpha T)$, (termorezistență).

Amplificatorul (inversor / neinversor) sumator

Sumator inversor:

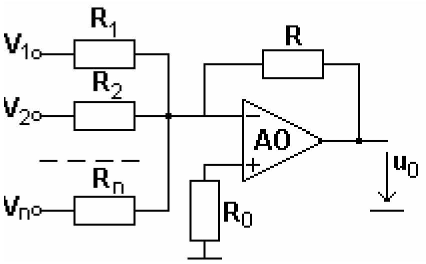

Figura 3.16

Schema echivalentă:

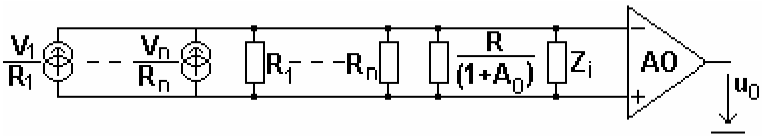

FIG 3.17

$e_d = I_{echiv} R_{echiv}$, unde $I_{echiv} = \sum_{i=1}^{n} \frac{u_i}{R_i}$ şi $\frac{1}{R_{echiv}} = \sum_{i=1}^{n} \frac{1}{R_i} + \frac{1+A_0}{R} + \frac{1}{Z_i}$.

$$u_0 = -A_0 e_d = -A_0 \cdot \sum_{i=1}^{n} \frac{u_i}{R_i} \cdot \frac{1}{\sum_{i=1}^{n} \frac{1}{R_i} + \frac{1+A_0}{R} + \frac{1}{Z_i}}.$$

Dacă $R_i = R$ pentru $i = (1, n)$ $\Rightarrow$

$$\Rightarrow \quad u_0 = \frac{-A_0 \cdot \frac{1}{R} \cdot \sum_{i=1}^{n} u_i}{\frac{n}{R} + \frac{1+A_0}{R} + \frac{1}{Z_i}} = -\sum_{i=1}^{n} u_i \cdot \frac{1}{\frac{n}{A_0} + \frac{1}{A_0} + 1 + \frac{R}{Z_i A_0}} = -\frac{\sum_{i=1}^{n} u_i}{1+\varepsilon};$$

unde $\frac{n}{A_0}$ este eroarea datorată numărului de intrări ; $\frac{1}{A_0}$ este eroarea AO ; $\frac{R}{Z_i A_0}$ este eroarea lui Z_i.

$\Rightarrow \quad \frac{n}{A_0} + \frac{1}{A_0} + \frac{R}{Z_i A_0} = \varepsilon$, o eroare.

$\Rightarrow \quad n \downarrow \; ; \; A_0 \uparrow \; ; \; Z_i \uparrow \; ; \; R \downarrow$.

Sumator neinversor:

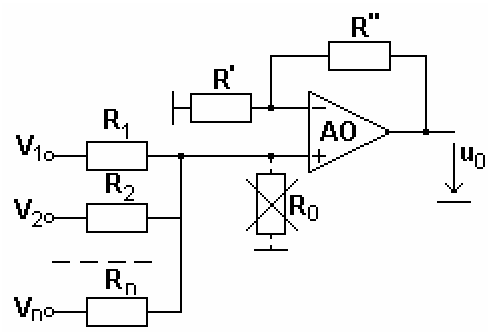

Figura 3.18

Schema echivalentă:

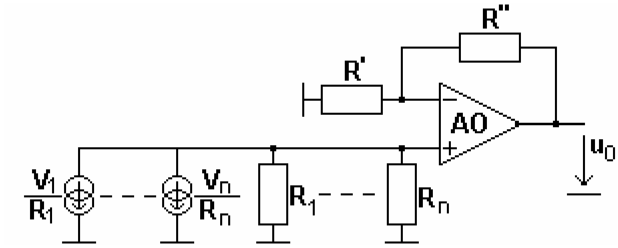

FIG 3.19

$$u_0 = V_+\left(1+\frac{R''}{R'}\right); \qquad V_+ = \left(\sum I_k\right)\cdot R_{echiv} = \frac{\sum_{i=1}^{n}\frac{u_i}{R_i}}{\sum_{i=1}^{n}\frac{1}{R_i}};$$

Pentru $R_i = R, \quad i=\overline{1,n}$ $\Rightarrow$ $$u_0 = \left(1+\frac{R''}{R'}\right)\cdot\frac{\frac{1}{R}\cdot\sum_{i=1}^{n}u_i}{\frac{n}{R}} = \frac{\left(1+\frac{R''}{R'}\right)}{n}\cdot\left(\sum_{i=1}^{n}u_i\right).$$

Dacă $\frac{\left(1+\frac{R''}{R'}\right)}{n}=1$ $\Rightarrow$ $u_0 = \sum_{i=1}^{n}u_i$.

Aplicatie:

→ convertor numeric – analogic

$$R_1 = \frac{R}{2^0}; \quad R_2 = \frac{R}{2^1}; \quad \ldots \quad R_n = \frac{R}{2^{n-1}}; \qquad u_i = \begin{cases}"0" & \rightarrow \; GND \\ "1" & \rightarrow \; +Vcc\end{cases} \qquad i=\overline{1,n}.$$