

CURS 5

Amplificatoare de curent alternativ Integrator:

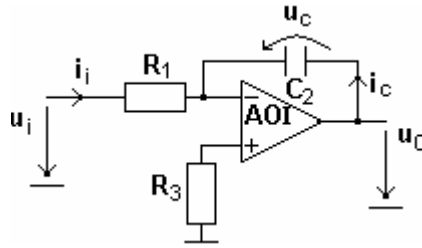


Figura 5.1

$$R_1 \cong R_3;$$

$$i_i = -i_c; \quad u_0 = u_c; \quad i_i = \frac{u_i}{R_1}; \quad i_c = C_2 \frac{du_c}{dt} \Rightarrow u_0 = -\frac{1}{R_1 C_2} \int_0^t u_i dt + Const$$

Cu condiția inițială $t=0 \Rightarrow$

$$Const = u_0(0) = u_c(0)$$

Se notează:

$$\tau = R_1 C$$

$$[\text{sec}] = [\Omega] \cdot [F]$$

Reamintesc

$$[\text{sec}] = \frac{[H]}{[\Omega]}$$

$$H(s) = \frac{u_0(s)}{u_i(s)} = -\frac{Z_2}{Z_1} = -\frac{1}{sC_2 R_1} = -\frac{1}{R_1 C_2 s} = -\frac{1}{\tau s}$$

(amplificator inversor)

$$H(s)|_{s=j\omega} = -\frac{1}{j\omega R_1 C_2} = \frac{j}{\omega R_1 C_2}$$

$$A_u = \|H(j\omega)\| = \sqrt{\left(\frac{1}{\omega R_1 C_2}\right)^2} = \frac{1}{\omega R_1 C_2} \quad \phi = \arctg \frac{\text{Im } H}{\text{Re } H} = \frac{\pi}{2}$$

Circuitul are o comportare de filtru trece jos (figura5.2)

$$[\text{num}] = [-1];$$

$$[\text{den}] = [0.5 \ 0];$$

$$a = 0;$$

$$b = 4;$$

$$x = \text{logspace}(a,b,1000);$$

$$\text{bode}(\text{num},\text{den},x);$$

$$\text{grid}$$

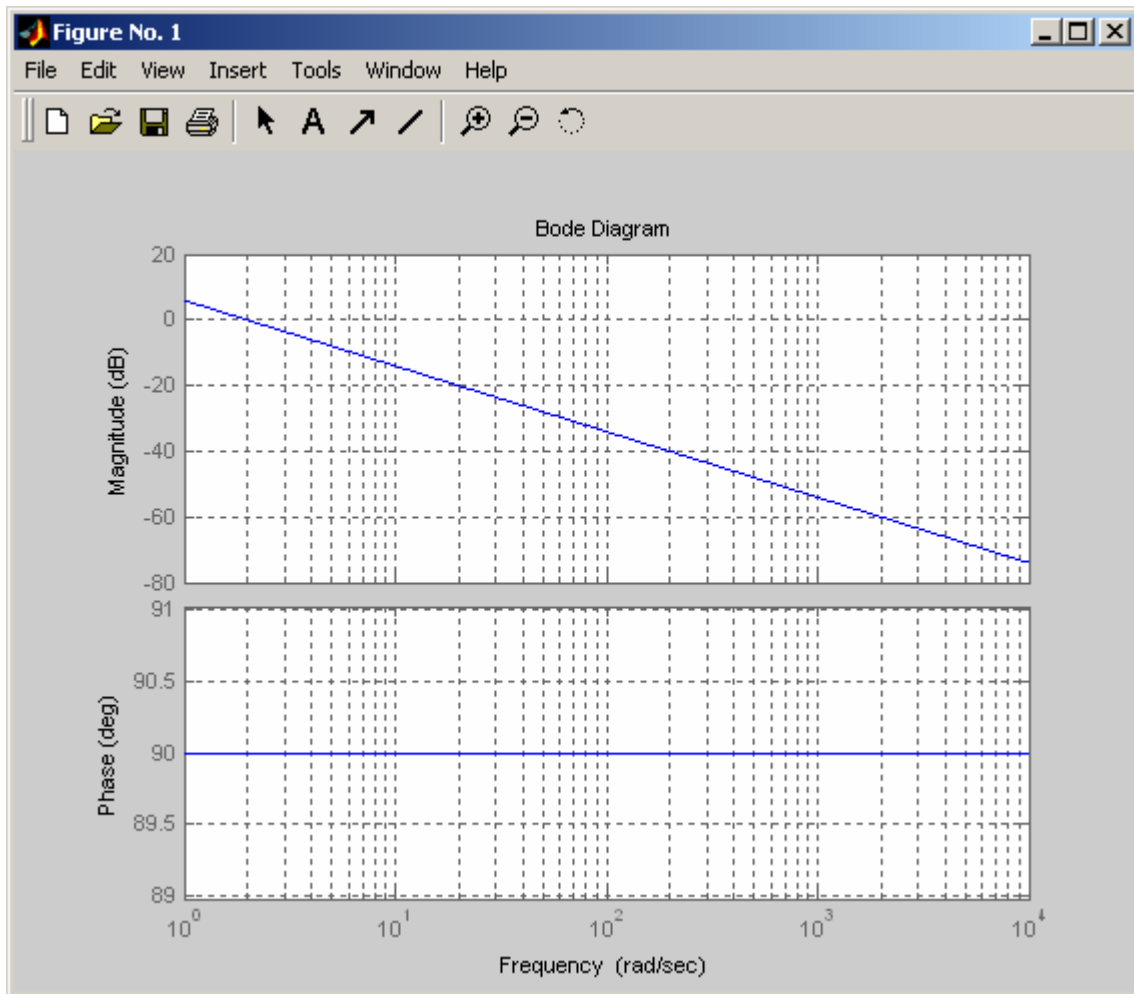


Figura 5.2

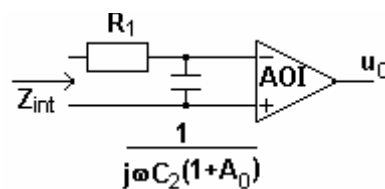


Figura 5.3

capacitatea se multiplică prin efect Miller.

$$\Rightarrow \tau = R_1 C_2 (1 + A_0) \uparrow$$

Diferențiator (derivator):

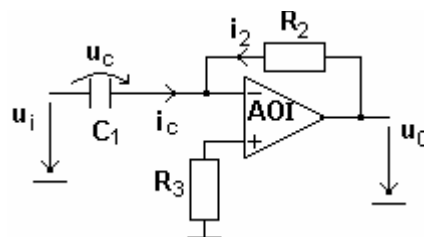


Figura 5.4

$$i_c = C_1 \frac{du_i}{dt} = -\frac{u_0}{R_2} \quad \Rightarrow \quad u_0 = -C_1 R_2 \frac{du_i}{dt}$$

Notite

Pe de altă parte :

$$H(j\omega) = -\frac{Z_2}{Z_1} = -\frac{R_2}{\frac{1}{j\omega C_1}} = -j\omega C_1 R_2; \quad A_u = \|H(j\omega)\| = \omega C_1 R_2$$

Caracteristica este prezentata in figura 5.5

```
[num] = [-0.5 0];  
[den] = [1];  
a = 0;  
b = 4;  
x = logspace(a,b,1000);  
bode(num,den,x);  
grid
```

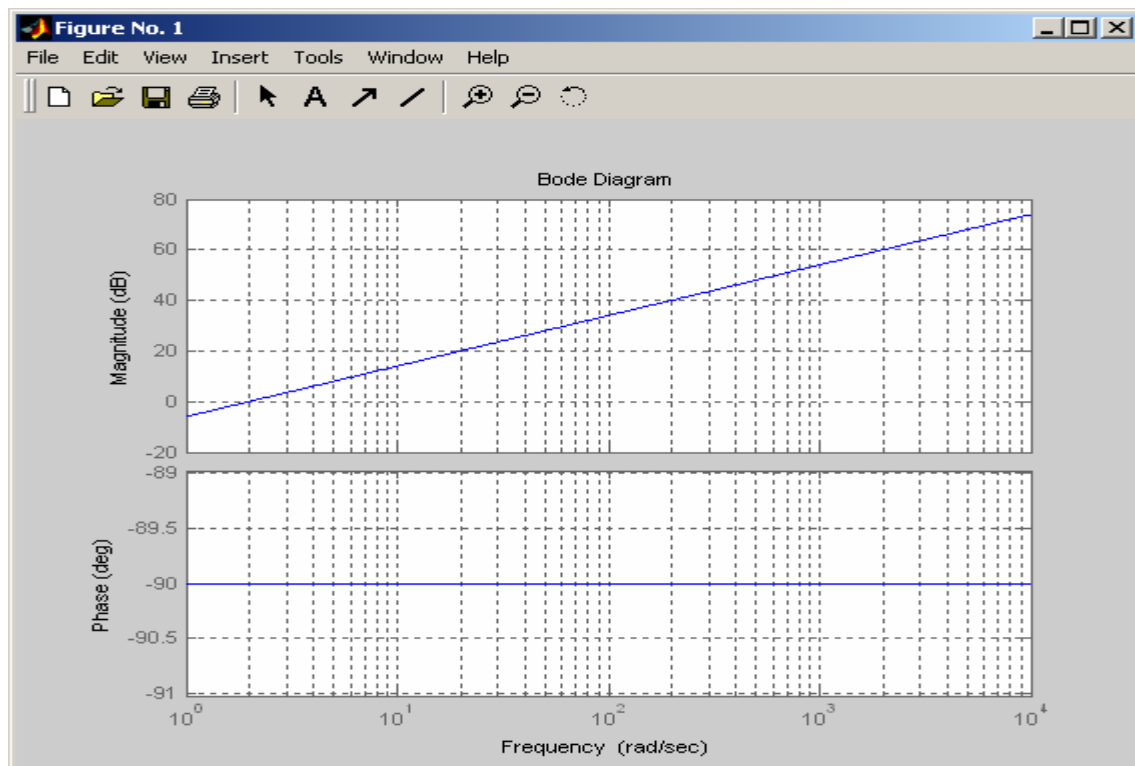


Figura 5.5

Se observa ca se obtine un filtru trece sus

- Circuitul este foarte sensibil la zgomote care pot satura AO ;
- De regulă, pentru a limita amplificarea, se utilizează schema următoare:

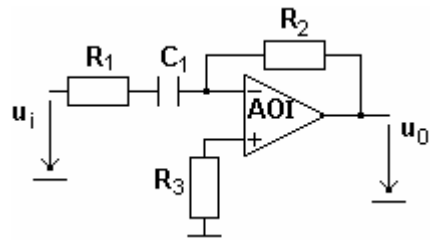


Figura 5.6

cu $R_2 \gg R_1$ (pentru a limita amplificarea).

Schemă de AO de curent alternativ neinversor

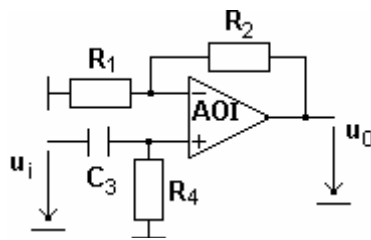


Figura 5.7

Pentru:

$$X_c = \frac{1}{\omega C_3} \ll R_4; \quad A_u = 1 + \frac{R_2}{R_1}$$

Obs: R_4 este absolut necesară în condiții reale.

$$H(j\omega) = \frac{Z_4}{Z_3 + Z_4} \left(1 + \frac{Z_2}{Z_1} \right) = \frac{R_4}{\frac{1}{j\omega C_3} + R_4} \left(1 + \frac{R_2}{R_1} \right) = \frac{j\omega C_3 \left(1 + \frac{R_2}{R_1} \right) R_4}{1 + j\omega C_3 R_4}$$

Remarcam că este o funcție de ordinul I, caracteristica pentru un exemplu fiind prezentată în figura 5.8

```
[num] = [1 0];
[den] = [0.5 1];
a = 0;
b = 4;
x = logspace(a,b,1000);
bode(num,den,x);
grid
```

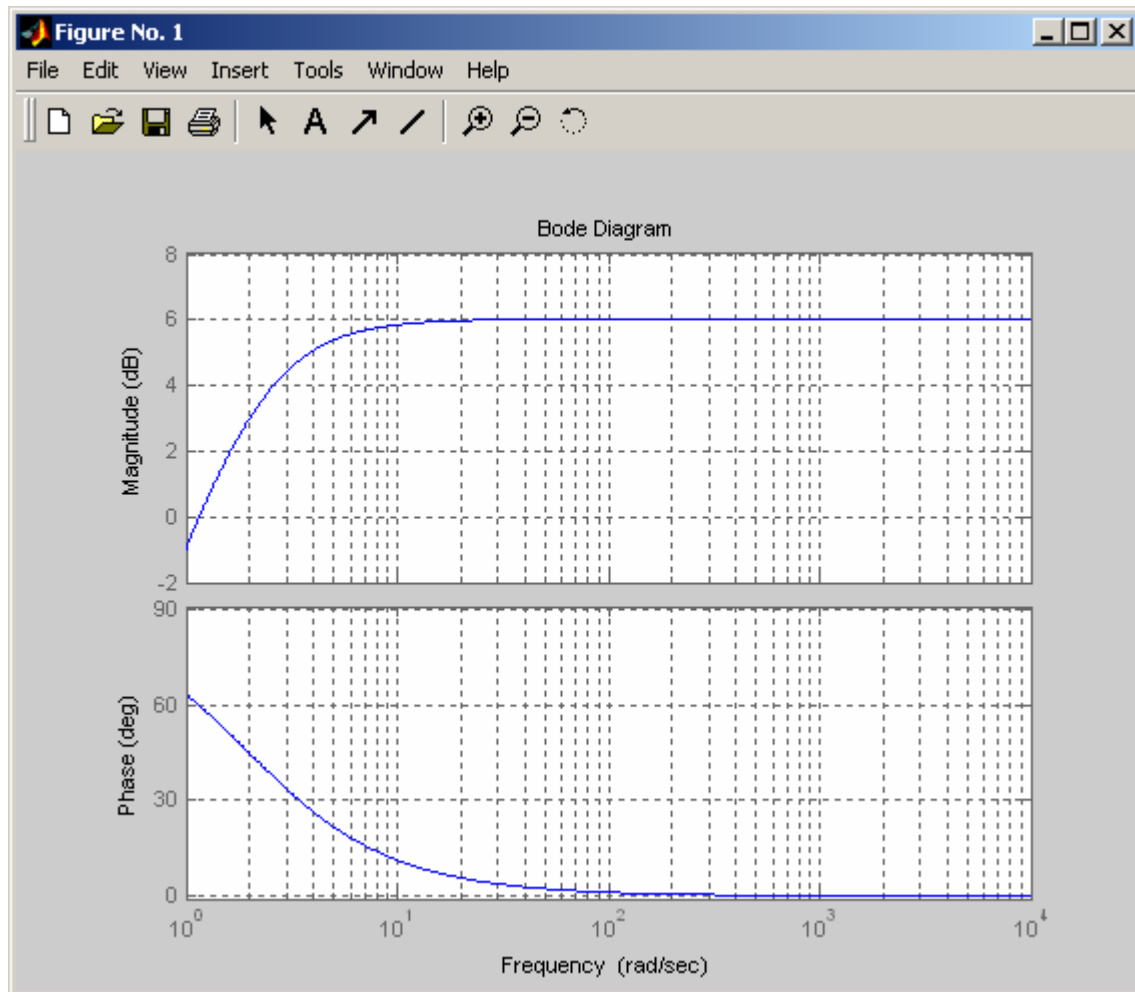


Figura 5.8
Schema de AO in curent alternativ cu defazare

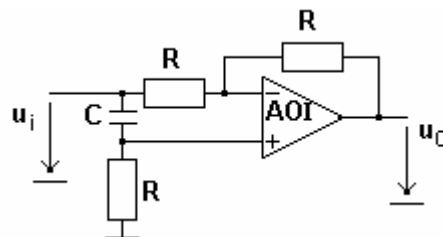


Figura 5.9

Calculăm tinand cont ca amplificatorul este in configuratie de amplificator diferentiaL :

$$H(j\omega) = -\frac{R}{R} + \frac{R}{R + \frac{1}{j\omega C}} \left(1 + \frac{R}{R} \right) = -1 + \frac{2Rj\omega C}{1 + Rj\omega C} = \frac{-1 + j\omega RC}{1 + j\omega RC} = -\frac{(1 - j\omega RC)^2}{1 + (\omega RC)^2}$$

$$H(j\omega) = -\frac{1 - (\omega RC)^2 - 2j\omega RC}{1 + (\omega RC)^2}$$

Notite

$$A_u = \|H(j\omega)\| = \frac{\sqrt{[1 - (\omega RC)^2]^2 - 4(\omega RC)^2}}{1 + (\omega RC)^2} = 1$$

Deci amplificarea nu depinde de pulsatie.

$$\phi = \arctg \frac{\text{Im } H}{\text{Re } H} = \pi - \arctg \frac{2\omega RC}{1 - (\omega RC)^2} = \pi - 2\arctg(\omega RC)$$

```
[num] = [0.5 -1];
```

```
[den] = [0.5 1];
```

```
a = -2;
```

```
b = 4;
```

```
x = logspace(a,b,1000);
```

```
bode(num,den,x);
```

```
grid
```

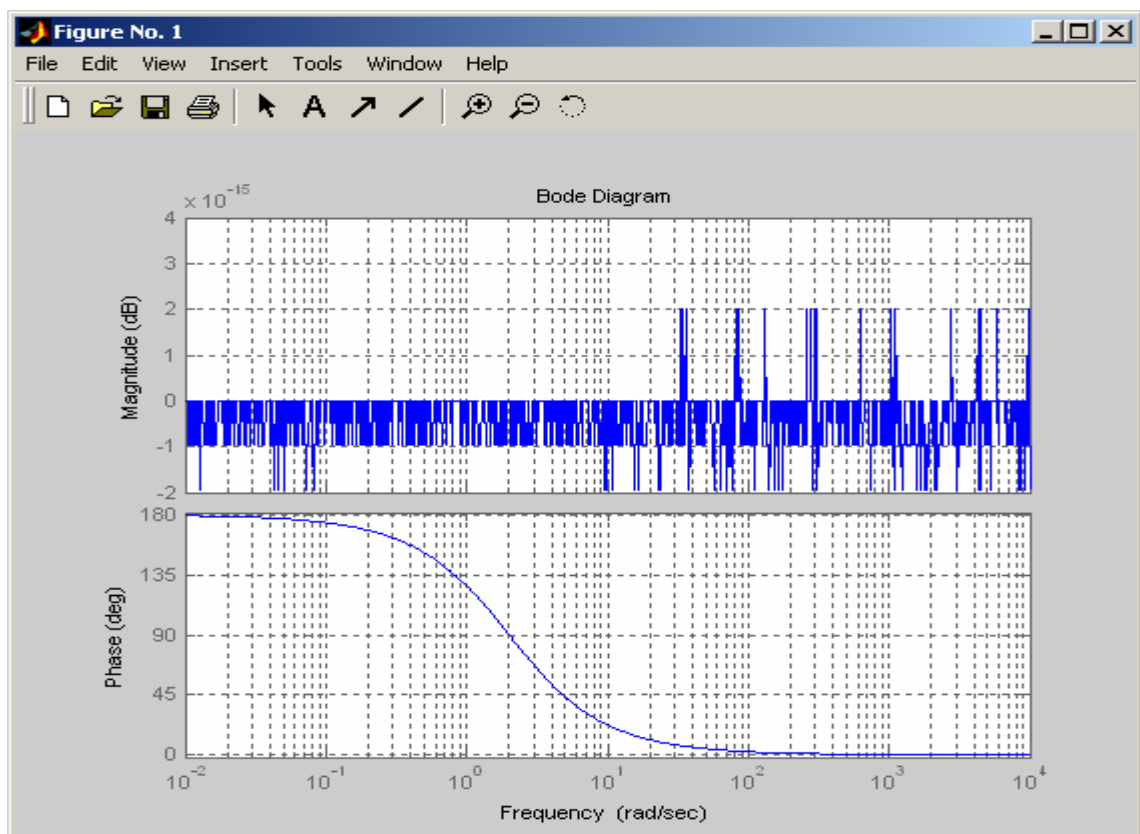


Figura 5.10

Observatii :

1) Pentru schema din figura 5.11 se folosește de obicei tehnica bootstrapării.

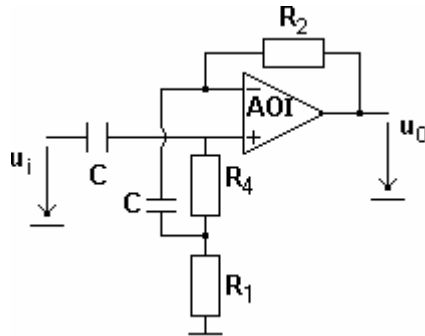


Figura 5.11

$$A_u \cong 1 + \frac{R_2}{R_1}$$

2) Schemă de integrator neinversor:

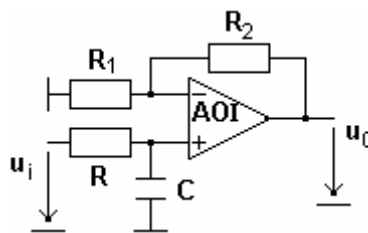


Figura 5.12

$$H(s) = \frac{1}{R + \frac{1}{sC}} \left(1 + \frac{R_2}{R_1} \right) = \frac{R_1 + R_2}{R_1(1 + RCs)}$$

$\Rightarrow A_u$

(de calculate)

Efectul neidealităților AO asupra integratorului

Influenta curenților de intrare $i_i, i_n \rightarrow i_p, i_d$

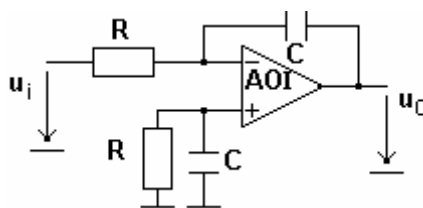


Figura 5.13

Pe borna + a amplificatorului se încearcă simetrizarea cu borna - $u_i=0 \rightarrow$ schema

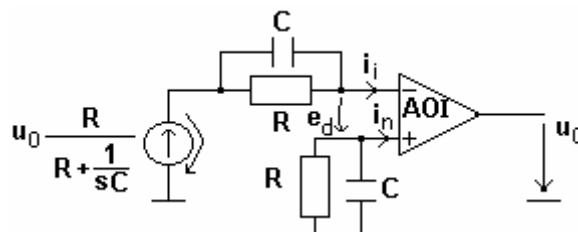


Figura 5.14

Aplicand transformata Laplace se deduce:

Notite

$$u_0 \frac{R}{R + \frac{1}{sC}} = \frac{R \cdot \frac{1}{sC}}{R + \frac{1}{sC}} i_i + e_d - \frac{R \cdot \frac{1}{sC}}{R + \frac{1}{sC}} i_n \quad \Rightarrow \quad u_0 \left(\frac{RsC}{1 + RsC} + \frac{1}{A_0} \right) = \frac{R}{1 + RsC} (i_i - i_n)$$

$$u_0 = -A_0 \cdot e_d$$

$$i_i - i_n = i_D$$

Pentru $A_0 \rightarrow \infty \Rightarrow$

$$u_0 = -\frac{1}{\tau s} u_i(s) + i_D(s) \frac{R}{\tau s} = -\frac{1}{\tau s} [u_i(s) - Ri_D(s)]$$

Revenind in domeniul timp se observa ca pentru ca

$I_D \downarrow$ trebuie ca $R \downarrow, u_i \gg RI_D, t \downarrow$

(t este timpul de integrare)

Influenta tensiunii de decalaj

Consideram ca $U_i=0$

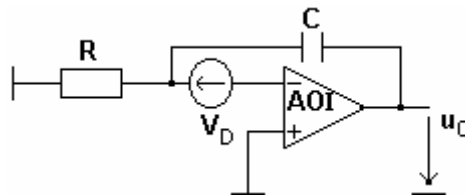


Figura 5.15

Dupa echivalarea Thevenin obtinem circuitul din figura 5.16

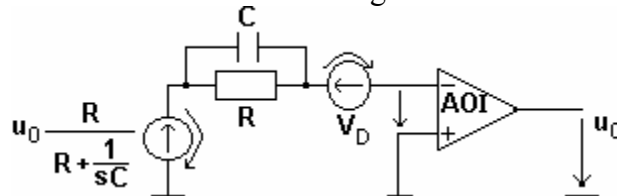


Figura 5.16

$$u_0 \frac{RsC}{1 + RsC} = u_D \quad \Rightarrow \quad u_0 = u_D \left(1 + \frac{1}{s\tau} \right)$$

Adun efectul cumulativ :

$$u_0(s) = -\frac{1}{\tau s} [u_i(s) - Ri_D(s) + u_D(s)] + u_D(s)$$

Se observă că tensiunea de decalaj se integrează.

Influenta A_0, Z_i, R_p

R_p =rezistenta de pierderi a capacitatii (figura 5.17)

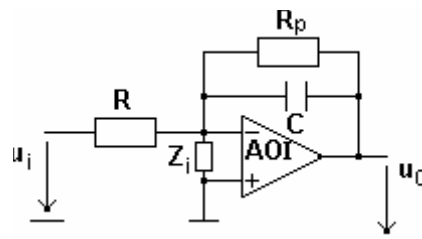


Figura 5.17

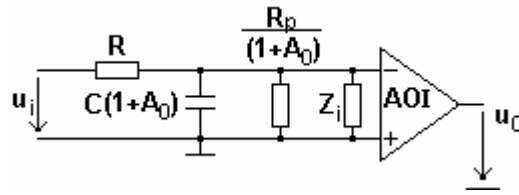


Figura 5.18

$$Z_{echiv} = \frac{\left(Z_i \parallel \frac{R_p}{1+A_0} \right) R}{R + Z_i \parallel \frac{R_p}{1+A_0}}; \quad u_{iechiv} = u_i \cdot \frac{Z_i \parallel \frac{R_p}{1+A_0}}{R + Z_i \parallel \frac{R_p}{1+A_0}} \Rightarrow$$

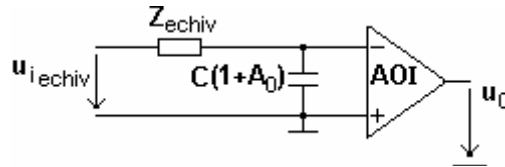


Figura 5.19

$$u_0(s) = -\frac{1}{sC(1+A_0)} \cdot \frac{1}{Z_{echiv} + \frac{1}{sC(1+A_0)}} \cdot A_0 \cdot u_{iechiv}(s) = -\frac{1}{1 + Z_{echiv}sC(1+A_0)} \cdot u_i(s) \cdot \frac{Z_i \parallel \frac{R_p}{1+A_0}}{R + Z_i \parallel \frac{R_p}{1+A_0}} \cdot A_0$$

Notând

$$k = \frac{Z_i \parallel \frac{R_p}{1+A_0}}{R + Z_i \parallel \frac{R_p}{1+A_0}} \Rightarrow u_0(s) = -kA_0 u_i(s) \frac{1}{1 + \tau' s}$$

$$\tau' = Z_{echiv} C(1+A_0)$$

Consider că se aplică un impuls treapta în domeniul timp:

Observatie: $L(e^{-at}) = \frac{1}{a+s}$

$$u_i(s) = \frac{E}{s}$$

$$u_0(t) = -kA_0 E \left(1 - e^{-\frac{t}{\tau'}} \right)$$

Dezvoltând în serie Taylor:

$$u_0(t) = -kA_0 E \left[1 - \left(1 - \frac{t}{\tau} + \frac{1}{2} \left(\frac{t}{\tau} \right)^2 - \dots \right) \right] = -kA_0 E \frac{t}{\tau} \left(1 - \frac{1}{2} \frac{t}{\tau} \right) = -kA_0 E \frac{t}{\tau} (1 - \varepsilon)$$

Eroarea:

Notite

$$\varepsilon = \frac{1}{2} \frac{t}{C(A_0 + 1)Z_{echiv}} = \frac{1}{2} \frac{t}{C(1 + A_0)} \left(\frac{1}{R} + \frac{1}{Z_i} + \frac{1 + A_0}{R_p} \right)$$

$$\varepsilon \rightarrow 0 \Rightarrow A_0 \rightarrow \infty, \quad t - mic, \quad Z_i \rightarrow \infty, \quad R_p \uparrow.$$

Inițializarea integratoarelor se face cu un comutator electronic.
Rezistența r se introduce pentru a limita curentul.

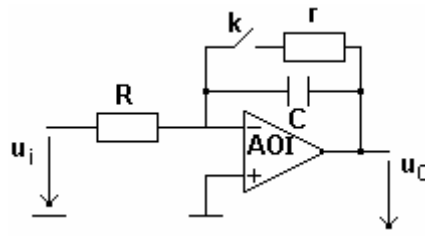


Figura 5.20

$$u_0(0) = u_i(0) \left(-\frac{r}{R} \right)_{\rightarrow 0} \Rightarrow r \downarrow R \uparrow$$

Solutie: se utilizeaza un comutator dublu.

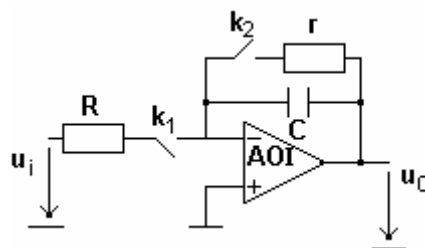


Figura 5.21

K_1 și K_2 acționează în antifază. Dacă ele acționează în fază se realizează un circuit de eșantionare.

$$K_1 \downarrow K_2 \downarrow \text{"sample"} \Rightarrow u_0^t = -\frac{r}{R} u_i^t = u_c^t$$

$$K_1 \uparrow K_2 \uparrow \text{"hold"} \Rightarrow u_0^{t+1} = u_c^t$$

Un bun circuit trebuie să aibă:

$$C \uparrow, \quad R_p \uparrow, \quad R_{off(K_1, K_2)} = mare, \quad i_i = mic.$$

Aplicatii:

Circuitul S&H in montaj neinversor:

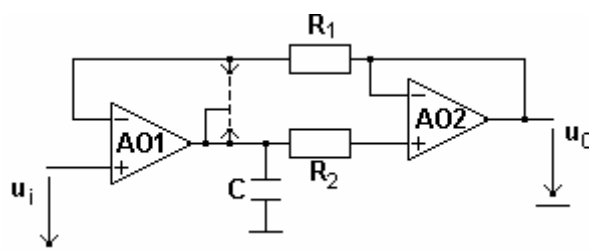


Figura 5.22

Măsurarea accelerației

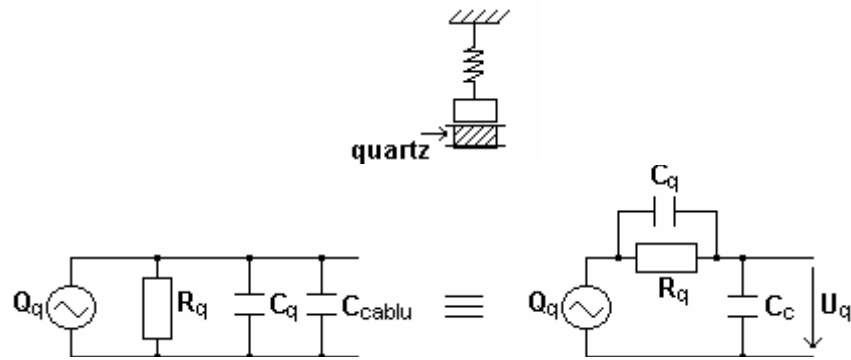


Figura 5.23

$$U_q \cong \frac{Q_q}{C_c + C_q}; \quad S_U \cong 2,32 \text{mV} / \text{ms}^{-2}; \quad S_Q \cong 2,83 \text{pC} / \text{ms}^{-2}; \quad R_q \geq 1 \text{G}\Omega;$$

Obligatoriu : $Z_i \uparrow$

ex : LMC649

$$Z_i \geq 10^{13} \Omega = 10 \text{T}\Omega$$

ex : $C_c + C_q \rightarrow 0.15 \text{nF}$ (1,5 m)

$\rightarrow 0.5 \text{nF}$ (5m)

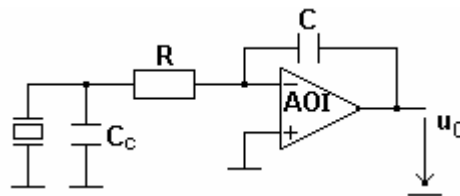


Figura 5.24

Amplificator de sarcina (alta aplicatie pentru circuitul integrator)

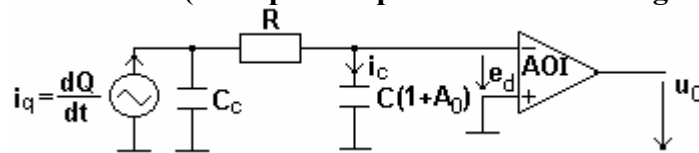


Figura 5.25

$$\begin{cases} i_c = C(1 + A_0) \frac{de_d}{dt} \\ i_c = i_q \\ u_0 = -A_0 e_d \end{cases} \Rightarrow \frac{dQ}{dt} = -\frac{C(1 + A_0)}{A_0} \frac{du_0}{dt}$$

$$U_0 = -\frac{Q}{C} \cdot \frac{A_0}{1 + A_0} \cong -\frac{Q}{C}$$

A_0 = mare (formată din mai multe etaje)

R = mică (zeci de Ω)

C = zeci-sute de pF