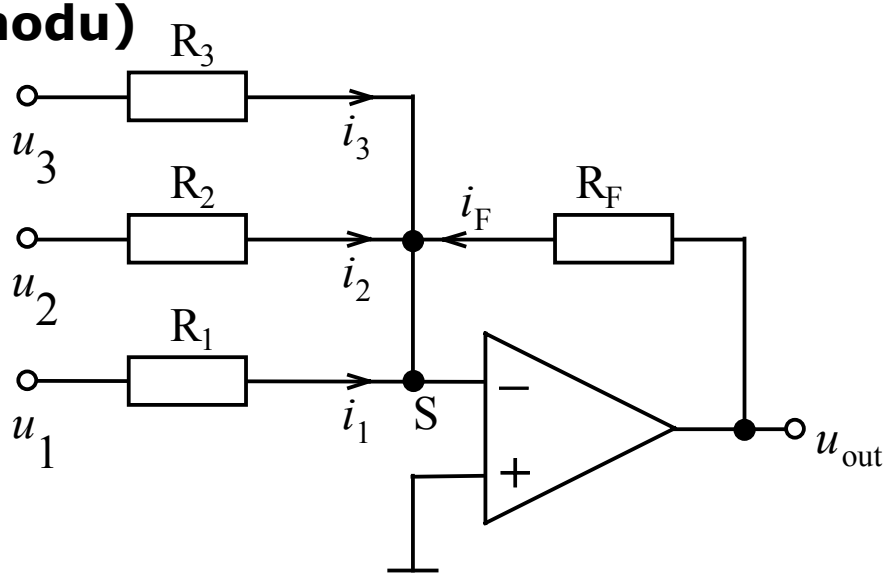
Linearna vezja z OP

- **seštevalnik (na – vhodu)**



$i_1 + i_2 + \ldots + i_3 + i_F = 0$

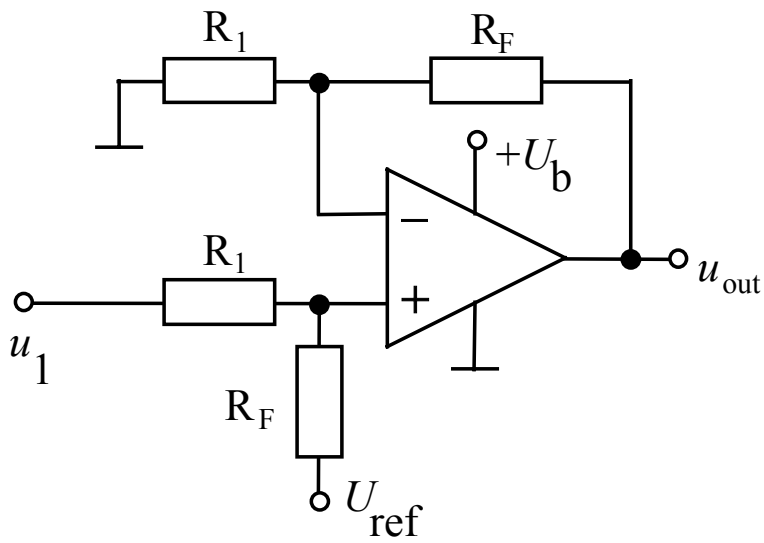
$$\frac{u_1}{R_1} + \frac{u_2}{R_2} + \ldots + \frac{u_3}{R_3} + \frac{u_{out}}{R_F} = 0$$

$$-u_{out} = \frac{R_F}{R_1} \cdot u_1 + \frac{R_F}{R_2} \cdot u_2 + \ldots + \frac{R_F}{R_3} \cdot u_3$$

$$u_{out} = -\sum_{i=1}^{n} u_i$$

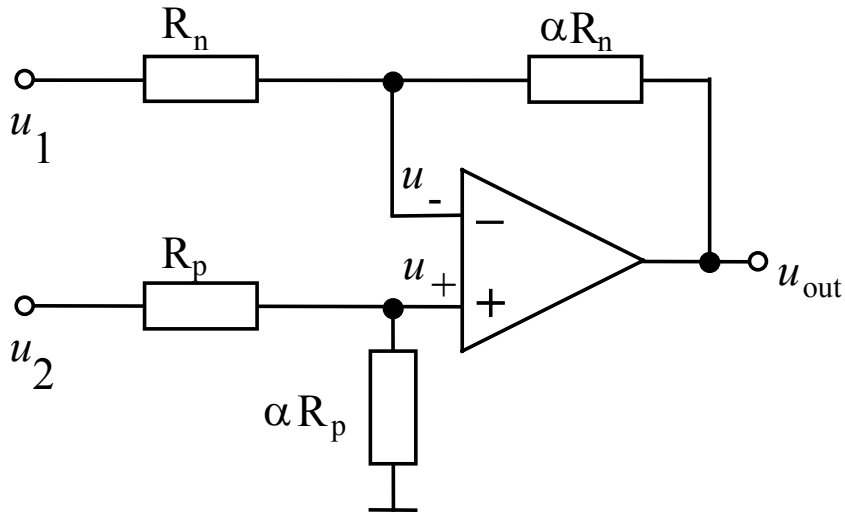
Linearna vezja z OP

- **seštevalnik (na + vhodu)**



Linearna vezja z OP

- **odštevalnik**



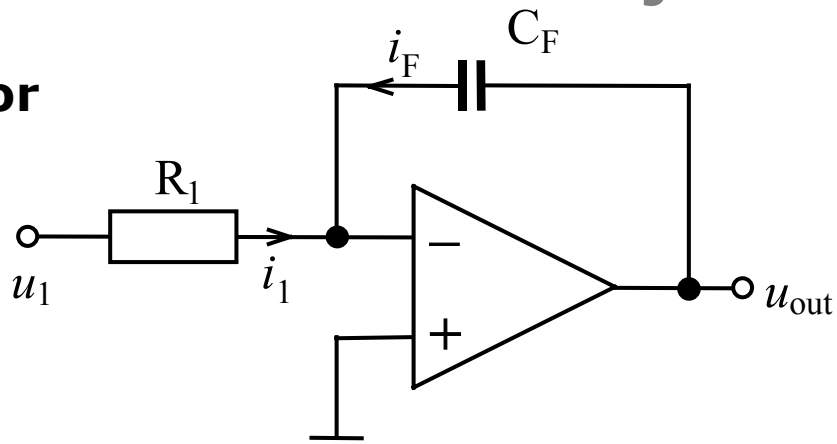
$$\frac{u_1 - u_-}{R_n} + \frac{u_{out} - u_-}{\alpha R_n} = 0 \quad \text{in s tem} \qquad \alpha u_1 + u_{out} = u_-(\alpha + 1)$$

$$u_+ = u_2 \frac{\alpha}{\alpha + 1}$$

Ker velja *u*p = *u*n, dobimo $u_{out} = \alpha(u_2 - u_1)$

Linearna vezja z OP

➢**integrator**



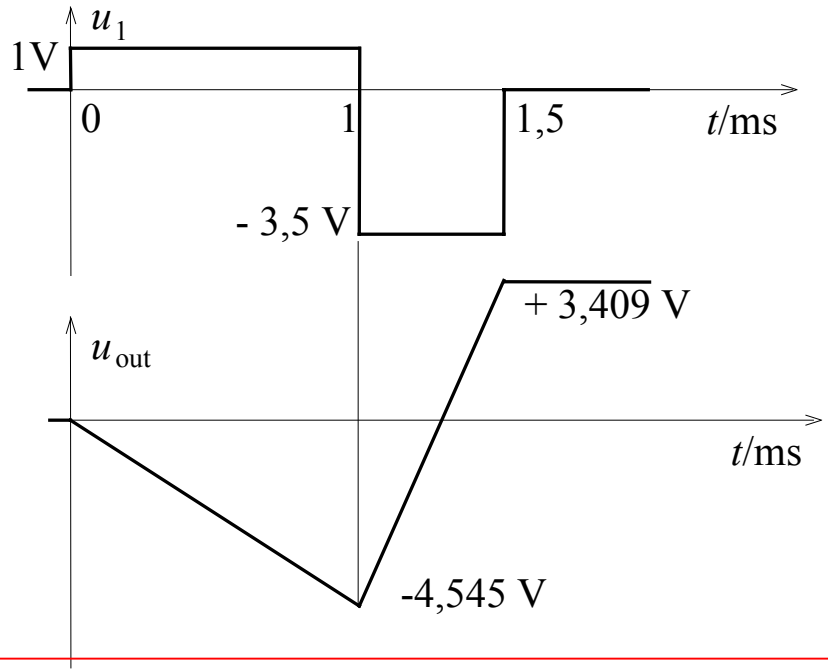
$$i_1 + i_F = 0$$

$$\frac{u_1}{R_1} + C_F \frac{du_{out}}{dt} = 0$$

$$du_{out} = -\frac{1}{R_1 C_F} u_1 dt$$

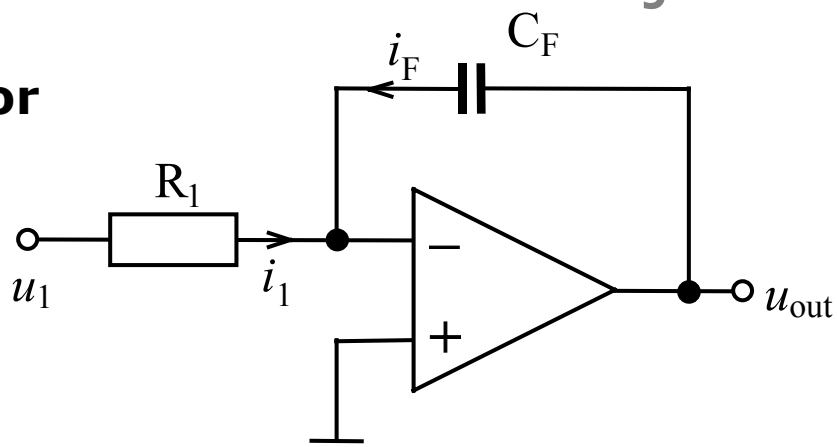
$$u_{out}(t) = -\frac{1}{T_I}\int_0^t u_1(t)dt + U_{out}(0)$$

R_1 = 10 kΩ in C_F = 22 nF



Linearna vezja z OP

➢**integrator**

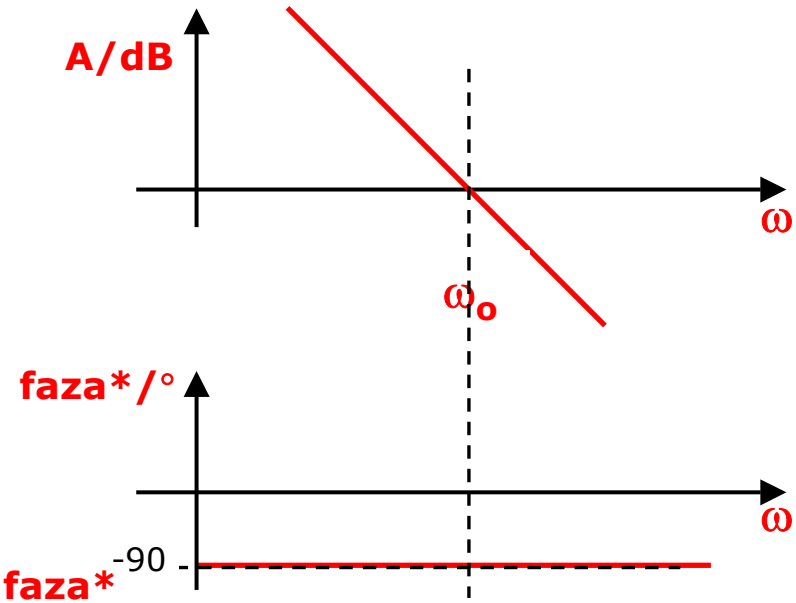


$$I_1 + I_F = 0$$

$$\frac{U_1}{R_1} + j\omega C_F \cdot U_{out} = 0$$

$$U_{out}(j\omega) = -\frac{1}{j\omega R_I C_F} U_1(j\omega)$$

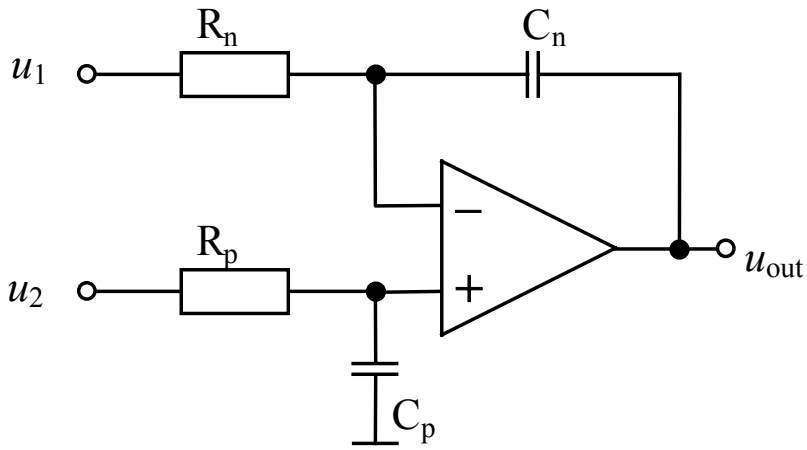
$$F(p) = \frac{U_{out}(p)}{U_1(p)} = -\frac{1}{T_I p}$$



Linearna vezja z OP

- **integrator razlike**

Izpelji izraz za izh.napetost ob pogoju: $R_n C_n = R_p C_p = T_I$,

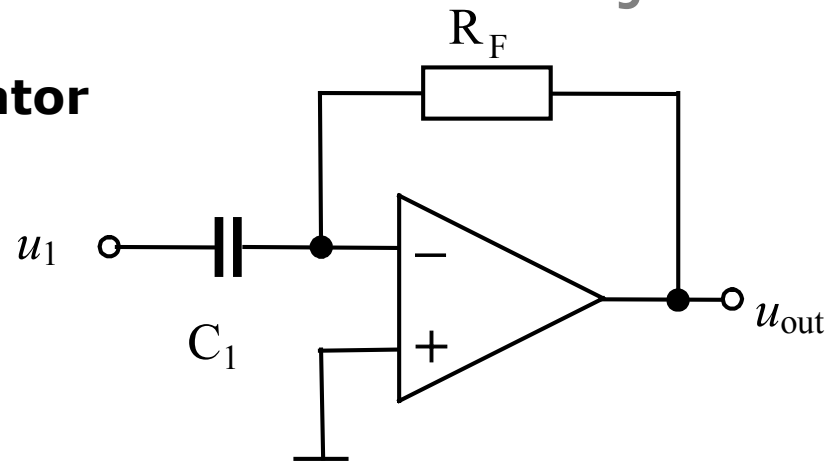


rešitev

rešitev

Linearna vezja z OP

- **diferenciator**

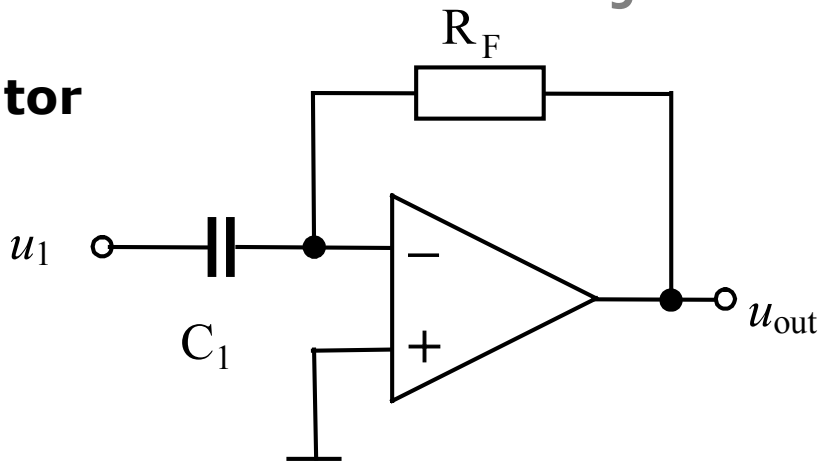


$$i_1 + i_F = 0$$

rešitev

Linearna vezja z OP

➢**diferenciator**

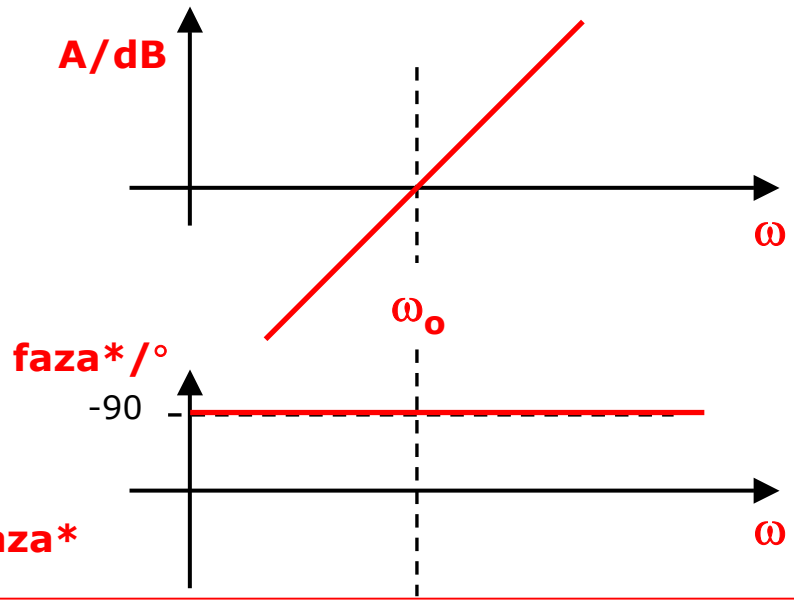


$$I_1 + I_F = 0$$

$$\frac{U_1(\mathrm{j}\omega)}{\frac{1}{\mathrm{j}\omega C_1}} + \frac{U_{out}(\mathrm{j}\omega)}{R_F} = 0$$

$$U_{out}(\mathrm{j}\omega) = -\mathrm{j}\omega R_F C_1 U_1(\mathrm{j}\omega) = -\mathrm{j}\omega T_D U_1(\mathrm{j}\omega)$$

$$F(p) = \frac{U_{out}}{U_1} = -pT_D$$

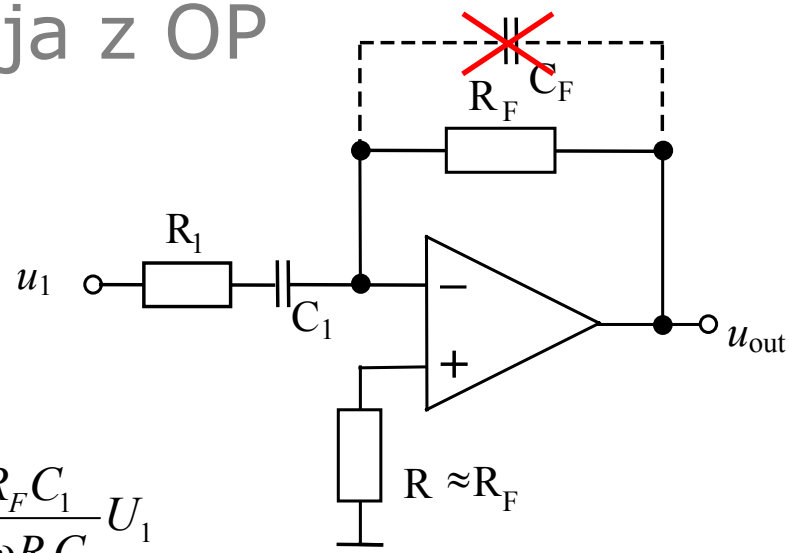


faza = 180 °+faza*

Linearna vezja z OP

➢**diferenciator**

1) analiza vezja brez kondenzatorja C_F



$$\frac{U_1(\mathrm{j}\omega)}{R_1+\frac{1}{\mathrm{j}\omega C_1}}+\frac{U_{out}(\mathrm{j}\omega)}{R_F}=0 \qquad \text{od tu}: \quad U_{out}=-\frac{\mathrm{j}\omega R_F C_1}{1+\mathrm{j}\omega R_1 C_1}U_1$$

če vstavimo $T_0 = R_1C_1$

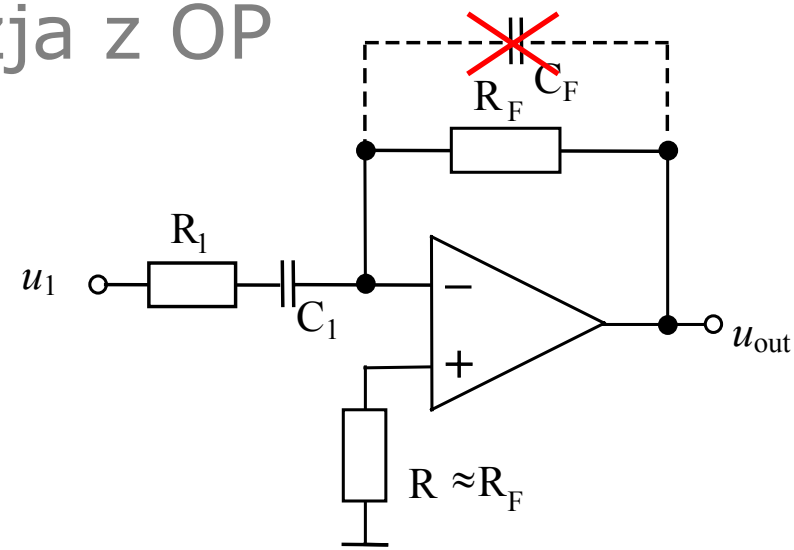
$$U_{out}(\mathrm{j}\omega)=-\frac{R_F}{R_1}\cdot\frac{\mathrm{j}\omega T_0}{1+\mathrm{j}\omega T_0}\cdot U_1(\mathrm{j}\omega) \quad \Rightarrow \quad F(p)=\frac{U_{out}(p)}{U_1(p)}=-\frac{R_F}{R_1}\cdot\frac{pT_0}{pT_0+1}$$

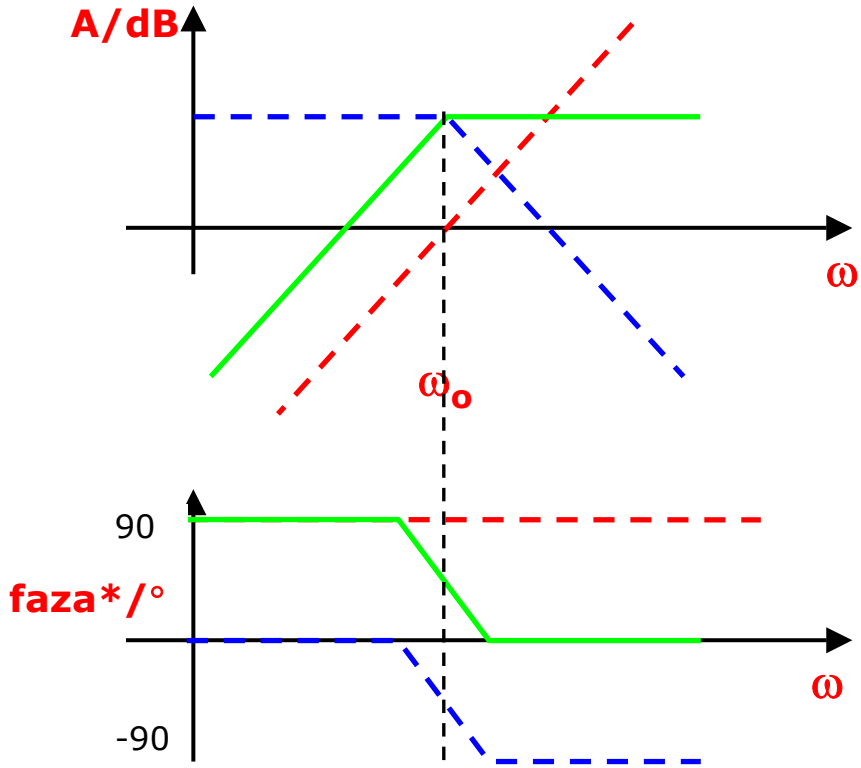
diferencialni člen 1.reda (DT_1)

Linearna vezja z OP

diferencialni člen 1.reda (DT_1)

$$U_{out}(j\omega) = -\frac{R_F}{R_1} \cdot \frac{j\omega T_0}{1 + j\omega T_0} \cdot U_1(j\omega)$$



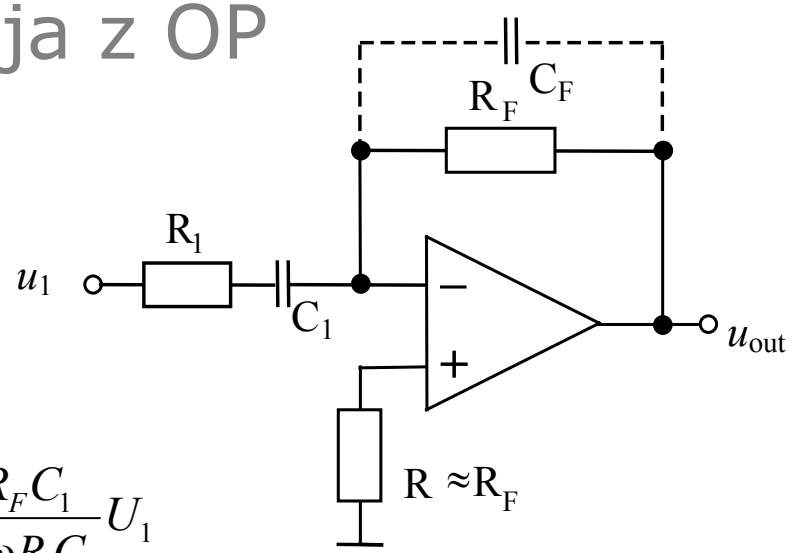


faza = 180 °+faza*

Linearna vezja z OP

- **diferenciator**

2) analiza vezja s kondenzatorjem C_F



$$\frac{U_1(\mathrm{j}\omega)}{R_1+\frac{1}{\mathrm{j}\omega C_1}}+\frac{U_{out}(\mathrm{j}\omega)}{R_F}=0 \qquad \text{od tu}: \quad U_{out}=-\frac{\mathrm{j}\omega R_F C_1}{1+\mathrm{j}\omega R_1 C_1}U_1$$

$$U_{out}(\mathrm{j}\omega)=-\frac{R_F}{R_1}\cdot\frac{\mathrm{j}\omega T_0}{(1+\mathrm{j}\omega T_0)(1+\mathrm{j}\omega T_1)}U_1(\mathrm{j}\omega)\text{, kjer je} \quad T_1=R_F C_F, T_0=R_1 C_1$$

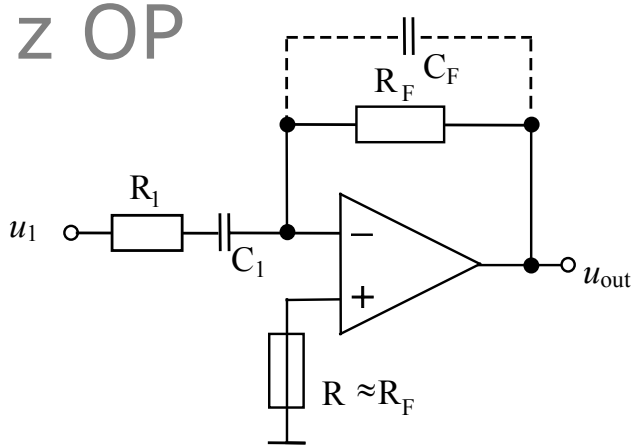
$$\Rightarrow \qquad F(p)=-\frac{R_F}{R_1}\cdot\frac{pT_0}{(1+pT_0)(1+pT_1)}$$

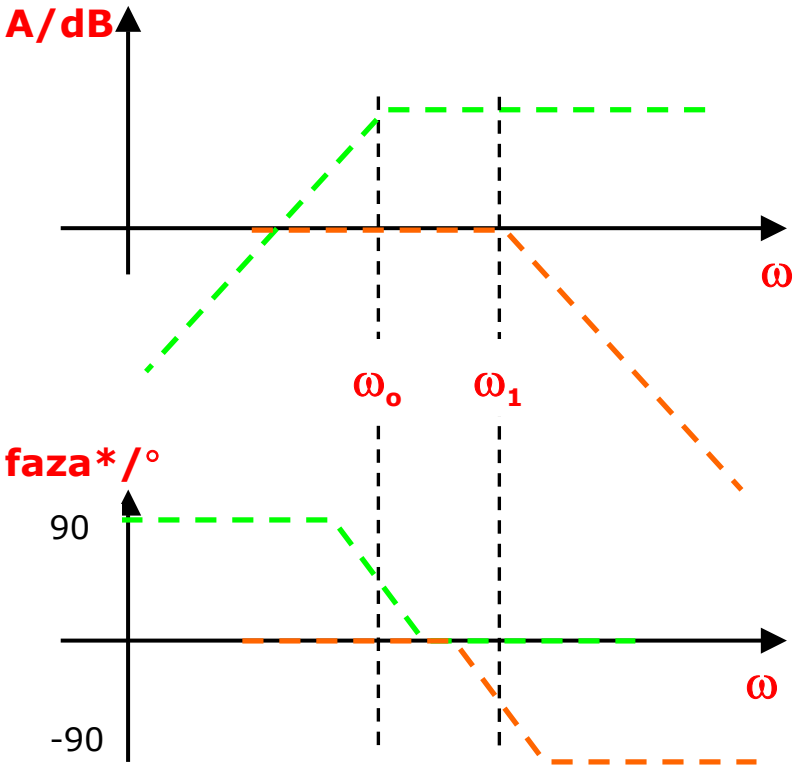
diferencialni člen 2.reda (DT_2)

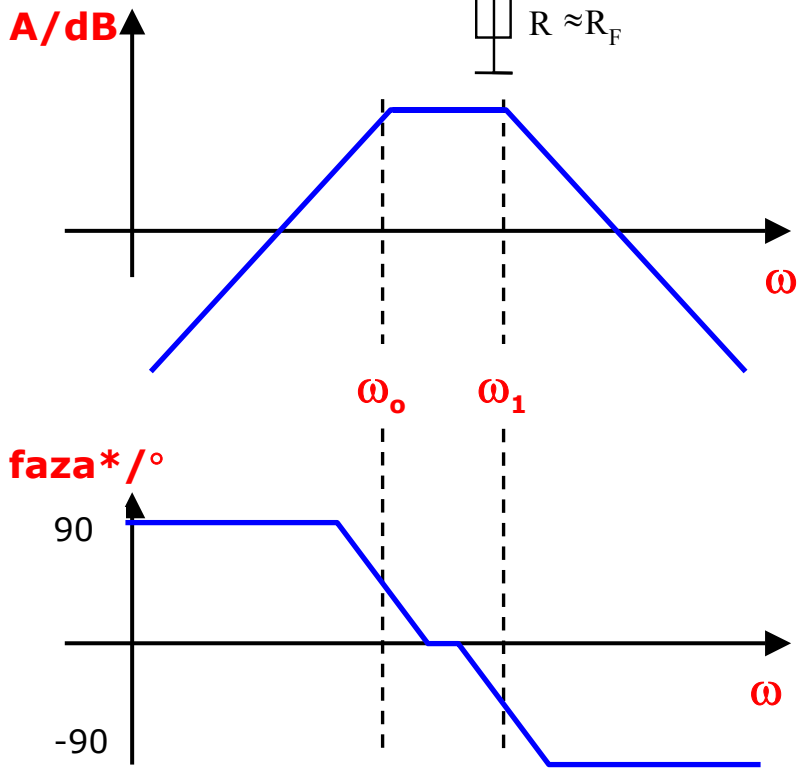
Linearna vezja z OP

diferencialni člen 2.reda (DT_2)

$$U_{out}(j\omega) = -\frac{R_F}{R_1} \cdot \frac{j\omega T_0}{(1+j\omega T_0)(1+j\omega T_1)} U_1(j\omega)$$



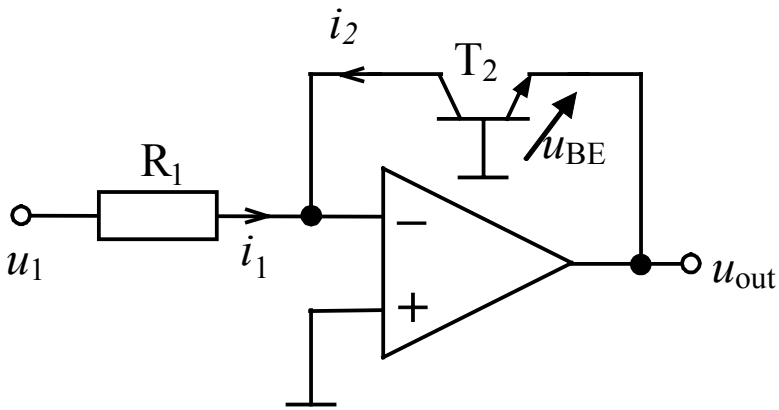




faza = 180 °+faza*

Nelinearna vezja z OP

➢**logaritemski ojačevalnik** - osnova analognega množenja



$$i_C \approx I_{ES}\left(e^{\frac{u_{BE}}{U_T}}-1\right)-I_{CS}\left(e^{\frac{u_{BC}}{U_T}}-1\right)$$

u_{BC} = 0

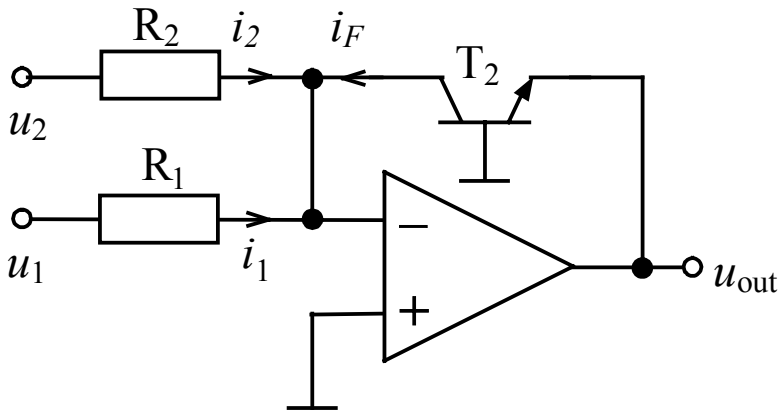
obratovanje pod napetostjo kolena pn spoja!

$$u_{OUT} = -U_T \cdot \ln\left[\frac{u_1}{I_{ES}\cdot R_1}+1\right] \Rightarrow u_{OUT} = -U_T \cdot \ln\left[\frac{u_1}{I_{ES}\cdot R_1}\right]$$

Nelinearna vezja z OP

➢**množilnik**

$$\ln u_1 + \ln u_2 = \ln(u_1 \cdot u_2)$$

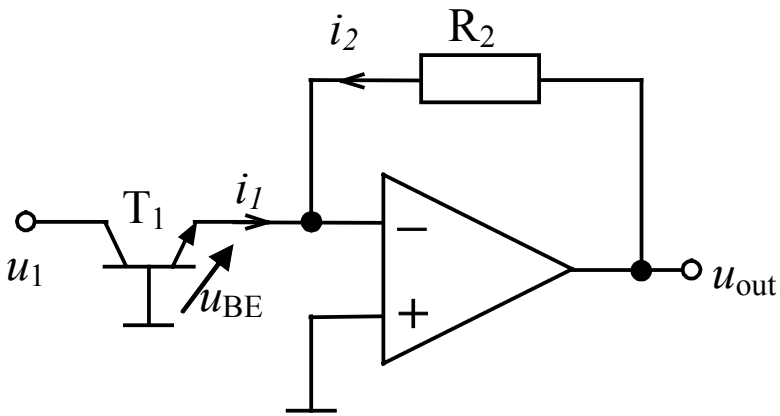


$$u_{OUT} = -U_T \cdot \left[\ln\left[\frac{u_1}{I_{ES} \cdot R_1} \right] + \ln\left[\frac{u_2}{I_{ES} \cdot R_2} \right] \right]$$

izraz je treba antilogaritmirati

Nelinearna vezja z OP

➢**eksponencialni ojačevalnik**



u_{BE} = 0

$$i_C \approx I_{ES}\left(e^{\frac{u_{BE}}{U_T}} - 1\right) - I_{CS}\left(e^{\frac{u_{BC}}{U_T}} - 1\right)$$

obratovanje pod napetostjo kolena pn spoja!

$$u_{OUT} = I_{CS}R_2\left[e^{\frac{-u_1}{U_T}} - 1\right] \Rightarrow u_{OUT} = I_{CS}R_2 e^{\frac{-u_1}{U_T}}$$