

Vlny na ideálním vedení

$$R = G = 0$$

$$\hat{Z}_V = Z_V$$

$$\hat{U} = \hat{U}_{\text{post}} + \hat{U}_{\text{odr}}$$

$$\hat{I} = \hat{I}_{\text{post}} + \hat{I}_{\text{odr}}$$

homogenní vedení

$$-\frac{\partial u}{\partial x} = L \frac{\partial i}{\partial t} \quad -\frac{\partial i}{\partial x} = C \frac{\partial u}{\partial t}$$

vlnové rovnice

$$\frac{\partial^2 u}{\partial x^2} = LC \frac{\partial^2 u}{\partial t^2} = \frac{1}{v^2} \frac{\partial^2 u}{\partial t^2}$$

$$\frac{\partial^2 i}{\partial x^2} = LC \frac{\partial^2 i}{\partial t^2} = \frac{1}{v^2} \frac{\partial^2 i}{\partial t^2}$$

$$v = \frac{1}{\sqrt{LC}} \quad (\text{m} \cdot \text{s}^{-1}; \text{H}, \text{F})$$

venkovní vedení cca 300 000 km/s

kabel cca 50 000 - 100 000 km/s

napětové vlny

$$\frac{\partial^2}{\partial t^2} = p^2 \quad \rightarrow \quad \frac{\partial^2 u}{\partial x^2} = \frac{p^2}{v^2} u$$

$$u(x, t) = K_1 \cdot e^{-\kappa x} + K_2 \cdot e^{+\kappa x}$$

$$\kappa = \frac{p}{v}$$

$$u(x, t) = u_1(x, t) + u_2(x, t)$$

$$u(x, t) = u_1(0, t) \cdot e^{-\frac{p}{v}x} + u_2(0, t) \cdot e^{+\frac{p}{v}x}$$

$$u(x, t) = u_1\left(0, t - \frac{x}{v}\right) + u_2\left(0, t + \frac{x}{v}\right)$$

u_1 – postupná vlna

u_2 – zpětná vlna, podmíněná odrazem na konci či rozhraní

$$u = u_p + u_1$$

proudové vlny

$$-\frac{\partial u}{\partial x} = L \frac{\partial i}{\partial t} \quad \rightarrow \quad \frac{\partial i}{\partial t} = -\frac{1}{L} \frac{\partial u}{\partial x}$$

$$i = -\frac{1}{L} \int \frac{\partial u}{\partial x} dt$$

$$i = -\frac{1}{L} \int \left(-\frac{p}{v} \cdot K_1 \cdot e^{-\frac{p}{v}x} + \frac{p}{v} \cdot K_2 \cdot e^{+\frac{p}{v}x} \right) dt$$

$$i = \frac{1}{Lv} \int \frac{\partial}{\partial t} \left(K_1 \cdot e^{-\frac{p}{v}x} - K_2 \cdot e^{+\frac{p}{v}x} \right) dt$$

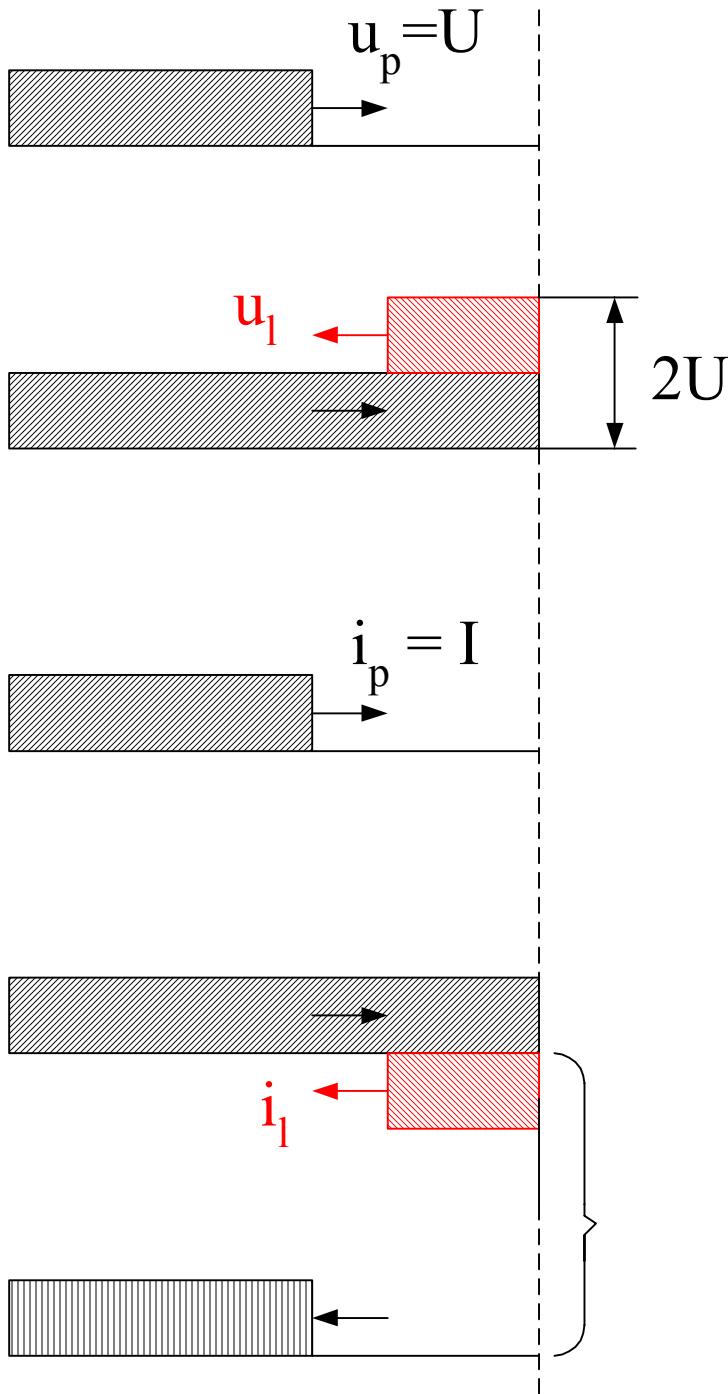
$$i = \frac{\sqrt{LC}}{L} (u_p - u_l) = \sqrt{\frac{C}{L}} (u_p - u_l) = i_p + i_l$$

$$i_p = \frac{u_p}{Z_v} \quad \text{vlna postupná}$$

$$i_l = -\frac{u_l}{Z_v} \quad \text{vlna odražená}$$

Pozn.: V dalším uvažujeme pravoúhlý tvar vln, tj. se strmým čelem.

Odraz na konci naprázdno



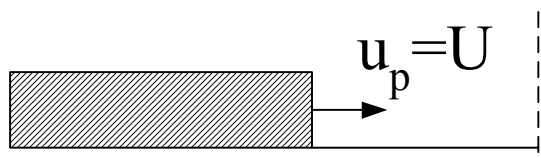
$$i = i_p + i_l = 0$$

$$\underline{i_l = -i_p}$$

$$i = \frac{u_p}{Z_v} - \frac{u_l}{Z_v} = 0$$

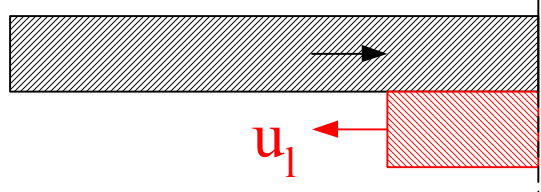
$$\underline{u_l = u_p}$$

Odraz na konci nakrátko



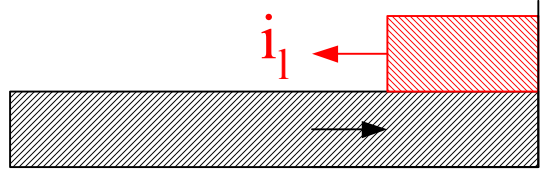
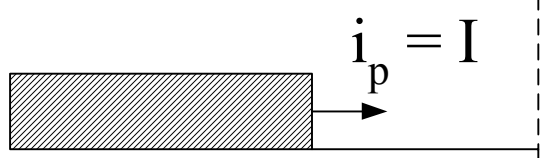
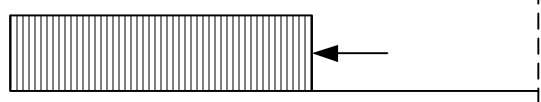
$$u = u_p + u_l = 0$$

$$\underline{u_l = -u_p}$$



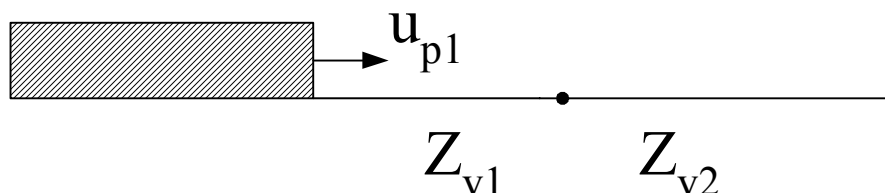
$$i_l = -\frac{u_l}{Z_v} = +\frac{u_p}{Z_v} = i_p$$

$$\underline{i_l = i_p}$$



Průchod rozhraním

Rozhraní = skoková změna vlnové impedance



$$u_1 = u_2$$

$$i_1 = i_2$$

$$u_{p1} + u_{l1} = u_{p2} + u_{l2}$$

$$u_{l2} = 0$$

$$i_{p1} + i_{l1} = i_{p2} + i_{l2}$$

$$i_{l2} = 0$$

$$u_{p1} + u_{l1} = u_{p2}$$

$$\frac{u_{p1}}{Z_{v1}} - \frac{u_{l1}}{Z_{v1}} = \frac{u_{p2}}{Z_{v2}}$$

koeficienty odrazu

$$u_{l1} = \frac{Z_{v2} - Z_{v1}}{Z_{v1} + Z_{v2}} u_{p1}$$

$$i_{l1} = \frac{Z_{v1} - Z_{v2}}{Z_{v1} + Z_{v2}} i_{p1}$$

koeficienty prostupu

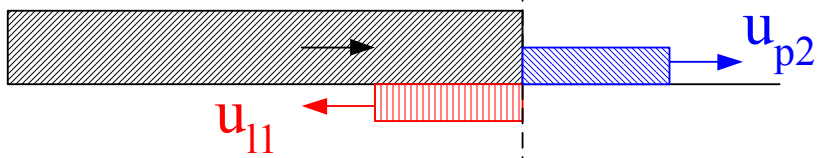
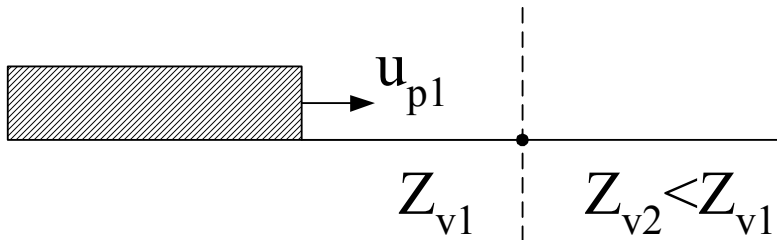
$$u_{p2} = \frac{2Z_{v2}}{Z_{v1} + Z_{v2}} u_{p1}$$

$$i_{p2} = \frac{2Z_{v1}}{Z_{v1} + Z_{v2}} i_{p1}$$

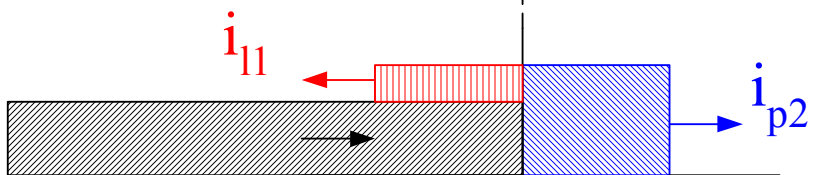
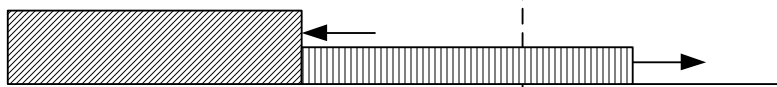
Pozn.: Rozvětvení vedení odpovídá paralelní kombinaci Z_{v2}, Z_{v3}, \dots

Rozhraní vedení – kabel

($Z_{v1} \doteq 400 \Omega$; $Z_{v2} \doteq 40 \Omega$)

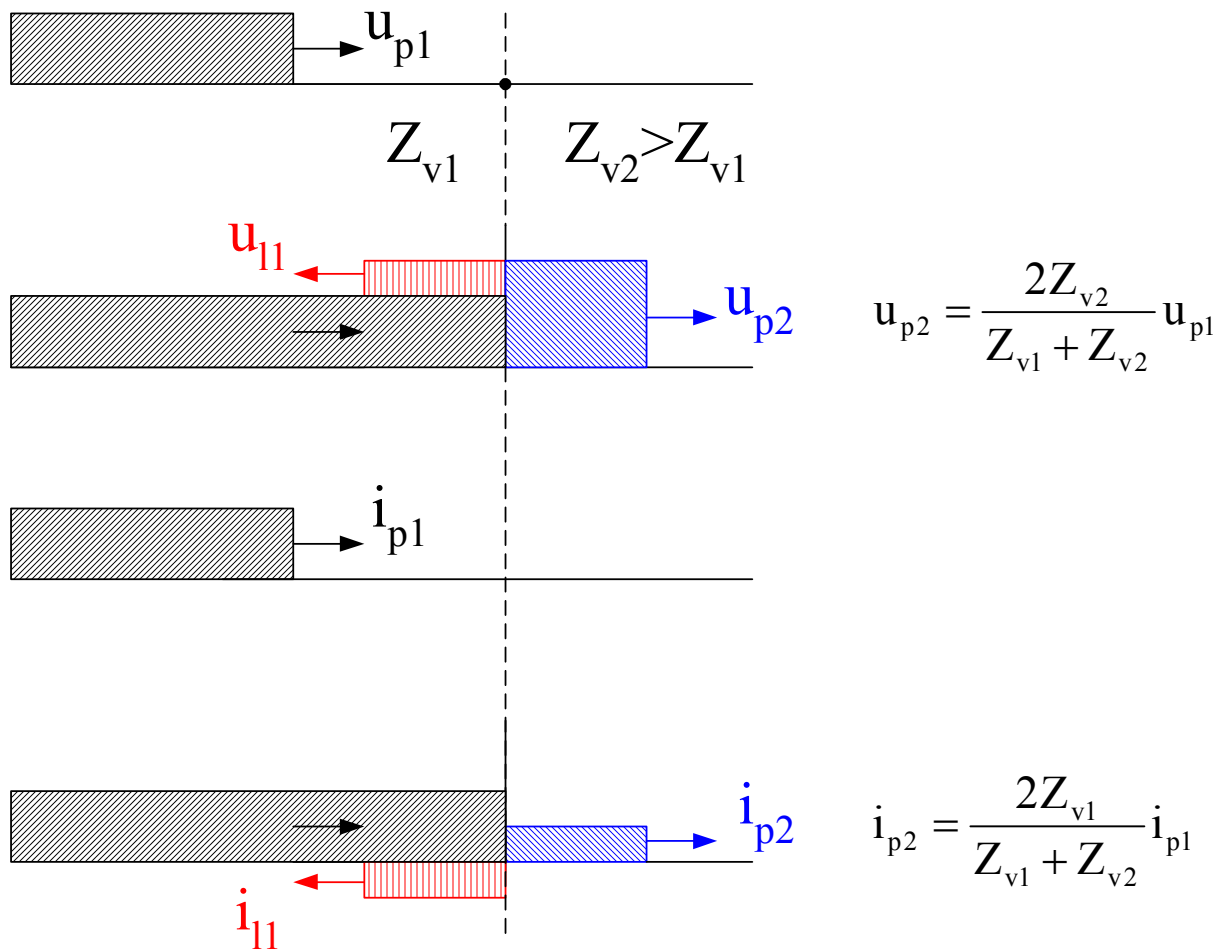


$$u_{p2} = \frac{2Z_{v2}}{Z_{v1} + Z_{v2}} u_{p1}$$

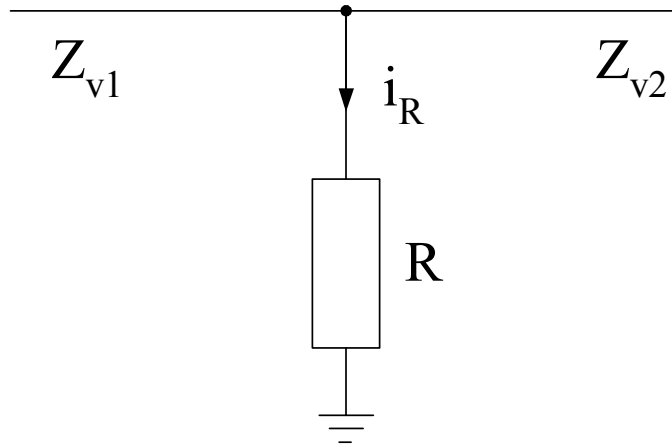


$$i_{p2} = \frac{2Z_{v1}}{Z_{v1} + Z_{v2}} i_{p1}$$

Rozhraní kabel – vedení



Činný odpor napříč (svodič přepětí)



$$u_1 = u_2$$

$$i_1 = i_2$$

$$u_{p1} + u_{l1} = u_{p2}$$

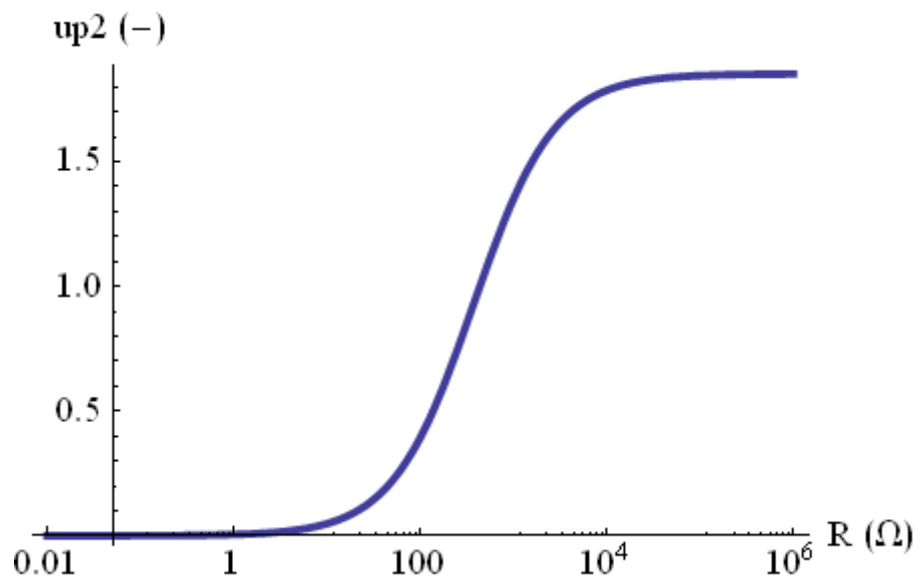
$$i_{p1} + i_{l1} = i_{p2} + i_R$$

$$u_{p1} + u_{l1} = u_{p2}$$

$$\frac{u_{p1}}{Z_{v1}} - \frac{u_{l1}}{Z_{v1}} = \frac{u_{p2}}{Z_{v2}} + \frac{u_{p2}}{R}$$

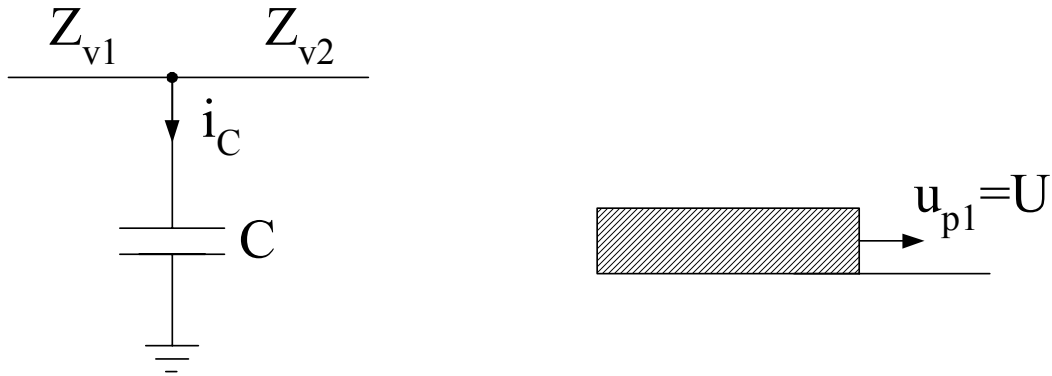
$$u_{p2} = \frac{\frac{2}{Z_{v1}}}{\frac{1}{Z_{v1}} + \frac{1}{Z_{v2}} + \frac{1}{R}} u_{p1}$$

př.: $Z_{V1} = 400 \Omega$, $Z_{V2} = 5000 \Omega$, $u_{p1} = 1$



Kapacita napříč

(vedení - kondenzátorová průchodka - TRF)



$$U_{p1}(p) = \frac{U}{p}$$

$$U_{p1}(p) + U_{ll}(p) = U_{p2}(p)$$

$$I_{p1}(p) + I_{ll}(p) = I_{p2}(p) + I_c(p)$$

$$\frac{U_{p1}(p)}{Z_{v1}} - \frac{U_{ll}(p)}{Z_{v1}} = \frac{U_{p2}(p)}{Z_{v2}} + pCU_{p2}(p)$$

$$U_{p2}(p) = \frac{2Z_{v2}}{Z_{v1} + Z_{v2}} \frac{1}{1 + pT} U_{p1}(p)$$

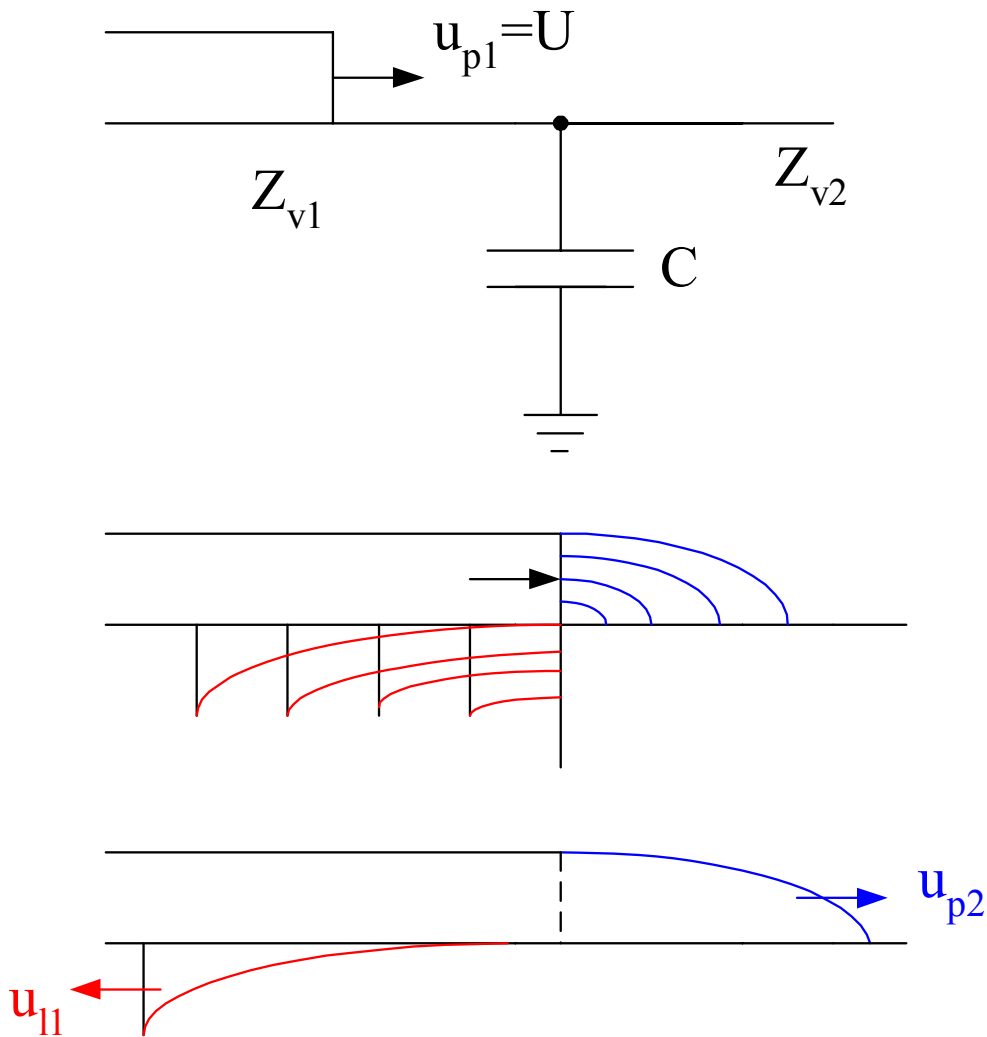
$$T = \frac{CZ_{v1}Z_{v2}}{Z_{v1} + Z_{v2}} \quad (\text{s}; F, \Omega)$$

$$u_{p2} = \frac{2Z_{v2}}{Z_{v1} + Z_{v2}} (1 - e^{-\frac{t}{T}}) U$$

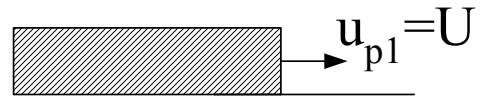
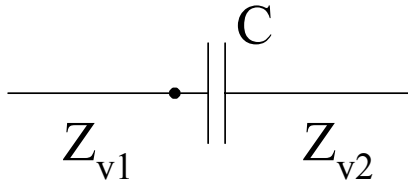
PRO $t = 0:$ $u_{p2} = 0$

PRO $t \rightarrow \infty (t \geq 3T):$ $u_{p2} = \frac{2Z_{v2}}{Z_{v1} + Z_{v2}} U$

pozn: $t = 0$ - jako nakrátko
 $t \rightarrow \infty$ - jako by C nebyl
 ! $u_{ll} = u_{p2} - u_{p1}$



Kapacita podél (sériová kompenzace)



$$U_{p1}(p) = \frac{U}{p}$$

$$U_{p1}(p) + U_{11}(p) = U_c(p) + U_{p2}(p)$$

$$I_{p1}(p) + I_{11}(p) = I_{p2}(p)$$

$$\frac{U_{p1}(p)}{Z_{v1}} - \frac{U_{11}(p)}{Z_{v1}} = \frac{U_{p2}(p)}{Z_{v2}}$$

$$U_c(p) = \frac{I_{p2}(p)}{pC} = \frac{U_{p2}(p)}{pCZ_{v2}}$$

$$U_{p2}(p) = \frac{2Z_{v2}}{Z_{v1} + Z_{v2}} \frac{pT}{1 + pT} U_{p1}(p)$$

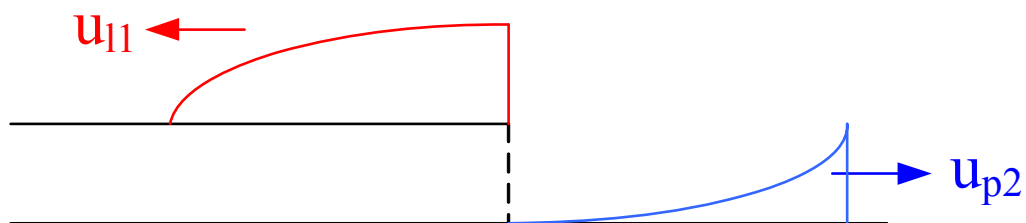
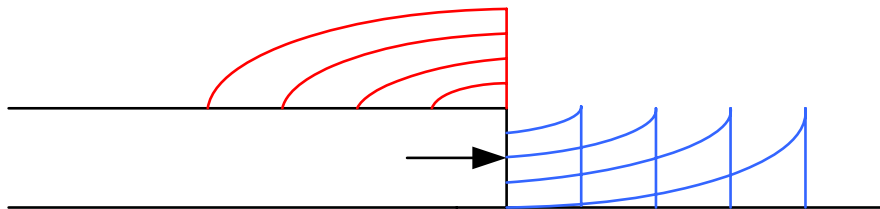
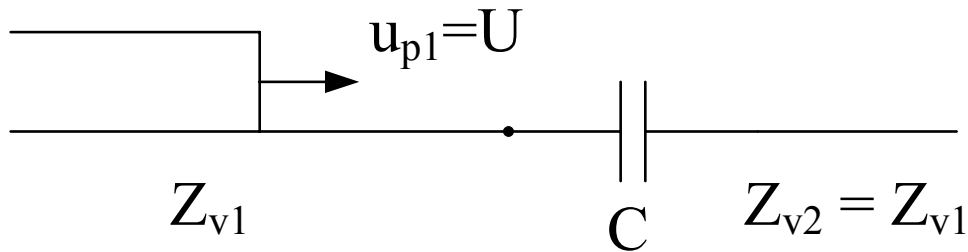
$$T = C(Z_{v1} + Z_{v2}) \quad (s; F; \Omega)$$

$$u_{p2} = \frac{2Z_{v2}}{Z_{v1} + Z_{v2}} \cdot e^{-\frac{t}{T}} \cdot U$$

PRO $t = 0:$ $u_{p2} = \frac{2Z_{v2}}{Z_{v1} + Z_{v2}} U$

PRO $t \rightarrow \infty (t \geq 3T):$ $u_{p2} = 0$

pozn: $t = 0$ - jako by C nebyl
 $t \rightarrow \infty$ - jako naprázdno



Pozn.: L napříč (podélně) se chová jako C podélně (napříč).