Távvezeték (TV) V2

$\lambda = c/f$

$\gamma = \sqrt{(R+j\omega L)(G+j\omega C)} = \alpha + j\beta$

(x-ed részre csillapodás: $e^{-\alpha z} = \frac{1}{x} \to z = \dots$)

id. TV: $\beta = \frac{2\pi}{\lambda} = \frac{\omega}{v_f} = \omega\sqrt{\mu\varepsilon}$, $\alpha = 0$

$v_f = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{\mu\varepsilon}} = \frac{c}{\sqrt{\mu_r\varepsilon_r}} \underset{\text{id. légszig.}}{=} c$

$v_f = \frac{\omega}{\beta}$, $v_{csoport} = \frac{\partial\omega}{\partial\beta}$

$Z_0 = \sqrt{\frac{R+j\omega L}{G+j\omega C}}$

id. TV: $Z_0 = \sqrt{\frac{j\omega L}{j\omega C}} = \sqrt{\frac{L}{C}} = \sqrt{\frac{\mu}{\varepsilon}}$ id. légszig TV: $Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} \cong 120\pi$

$Z_{be} = Z_0 \frac{Z_2\cos\beta l + jZ_0\sin\beta l}{Z_0\cos\beta l + jZ_2\sin\beta l} = Z_0\frac{Z_2 + jZ_0\,tg\beta l}{Z_0 + jZ_2\,tg\beta l}$

→ szakadás $Z_2 = \infty$: $Z_{be} = -Z_0\, j\frac{1}{tg\beta l}$

→ rövidzár $Z_2 = 0$: $Z_{be} = Z_0\, j\,tg\beta l$

másrészt: $Z_{be} = \frac{U_1^+}{I_1^+}$

$S = P + jQ = \frac{1}{2}\frac{|U_1|^2}{Z_{be}^*}$

$r_{(2)} = \frac{U_2^-}{U_2^+} = -\frac{I_2^-}{I_2^+} = \frac{Z_2 - Z_0}{Z_2 + Z_0}$

→ $Z_2 = \infty \to r = 1$

→ $Z_2 = 0 \to r = -1$

→ $Z_2 = Z_0 \to r = 0$

$r_u = -r_i$

$P_1 = P_2 = P_{középen} = \frac{1}{2}\,Re\{Z_{be}\}\cdot I_1^2$

$G = \frac{\hat{U}_{max}}{\hat{U}_{min}} = \frac{U_2^+(1+|r|)}{U_2^+(1-|r|)} = \frac{1+|r|}{1-|r|}$

$U_2^+ = I_2^+ Z_0$

$U_2^- = -I_2^- Z_0$

$\hat{I}_1 = \frac{\hat{U}_1}{|Z_{be}|}$

$\hat{U}_{max} = |\hat{U}^+| + |\hat{U}^-|$

$\hat{U}_{min} = |\hat{U}^+| - |\hat{U}^-|$

koax:

$Z_0 = \sqrt{\frac{\mu_r}{\varepsilon_r}}\cdot 60\ln\frac{r_2}{r_1}$

$u(z,t) = U^+ e^{-\alpha z}\cos(\omega t - \beta z - \varphi^+)$, $\varphi^+ = 0$

pl. id. légszig TV. nyitott végétől z távolságra $u(z) = \hat{U}_2\cos(\beta z)$

Lecher:

$Z_0 = \sqrt{\frac{\mu_r}{\varepsilon_r}}\cdot 120\ln\frac{d}{\sqrt{r_1 r_2}}$

(ált: $r_1 = r_2$)

$T = \frac{l}{v_f} \overset{\text{légszig}}{=} \frac{l}{c}$ ($T_{oda-vissza} = \frac{2l}{c}$)

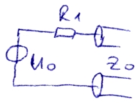
rezonancia frekvenciák

→ szak-szak / rz-rz $\Rightarrow l = \frac{\lambda}{4}\cdot 2n$

→ szak-rz / rz-szak $\Rightarrow l = \frac{\lambda}{4}(2n+1)$

TV. időfügg.-e

pl. $u = \frac{Z_0}{Z_0 + R_1}\cdot U_0(1 + r_2 + r_1 r_2 + r_1 r_2^2 + \dots)$ ($0 < t < 2T$; $2T < t < 4T$)



EM hullámok

analógia:

TV	U	I	L	C	R	G	$Z_0 = \sqrt{\frac{R+j\omega L}{G+j\omega C}}$	$\gamma = \sqrt{(R+j\omega L)(G+j\omega C)}$	rövidzár	szakadás
SH	E	H	μ	ε	–	G	$Z_0 = \sqrt{\frac{j\omega\mu}{G+j\omega\varepsilon}}$	$\gamma = \sqrt{j\omega\mu(G+j\omega\varepsilon)}$	fémsík	szigetelő

↳ síkhullám (SH)

= a terjedési irányra merőleges síkban a térerősséget helytől függetlenek

$Z_0 = \frac{E^+}{H^+} = \sqrt{\frac{\mu}{\varepsilon}} = \sqrt{\frac{\mu_r}{\varepsilon_r}}\cdot 120\pi$

$E = E^+ + E^- = E^+(1+r)$

$H = H^+ + H^- = H^+(1-r)$

$r = \frac{E^-}{E^+} = -\frac{H^-}{H^+} = \frac{Z_{02} - Z_{01}}{Z_{02} + Z_{01}}$

... satöbbi (analógia mindenre)

légszig síkkondi: $J = \frac{\partial D}{\partial t} = \varepsilon\frac{\partial E}{\partial t} = \varepsilon\frac{\partial}{\partial t}\frac{u(t)}{d}$ ($u = Ed$)

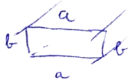
csőtápvonal (terjedés feltétele: $\lambda < \lambda_{határ\,min}$ vagy $f > f_h$)

pl. $TE_{10} \to m = 1, n = 0$

$f_h = \frac{\omega_h}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{k_x^2 + k_y^2}{\mu\varepsilon}} = \sqrt{\frac{k_x^2 + k_y^2}{4\pi^2\mu\varepsilon}}$

$k_x = \frac{m\pi}{a}$

$k_y = \frac{n\pi}{b}$



(ha csak pl. TE_{10}-re akarjuk, akkor felső korlátot ad az, ha TE_{20}-at és TE_{11}-et vizsgáljuk)

$\omega^2\varepsilon\mu + \gamma^2 = k_x^2 + k_y^2$ ($\varepsilon_0\mu_0 = \frac{1}{c^2}$)

dipólantenna: (ϑ: antenna elevációs szöge)

a távoltér függv. minusos

$E(\vartheta) = E(90°)\sin\vartheta$ ($E_{max} = E(90°)$)

$H(\vartheta) = H(90°)\sin\vartheta$ $H_{max} = H(90°)$

Hertz-dipólus

$\frac{E_2}{E_1} = \frac{\sin\vartheta_2}{\sin\vartheta_1}$, ha $r_1 = r_2$

$\frac{S_2}{S_1} = \left(\frac{r_1}{r_2}\right)^2$, ha $\vartheta_1 = \vartheta_2$

V2+

TÁVVEZETÉK egyenletek

$$\frac{\partial^2 u}{\partial x^2} = LC\frac{\partial^2 u}{\partial t^2} + (RC+GL)\frac{\partial u}{\partial t} + RGu$$

$$\frac{\partial^2 i}{\partial x^2} = LC\frac{\partial^2 i}{\partial t^2} + (RC+GL)\frac{\partial i}{\partial t} + RGi$$

másik felírás:

$$\frac{\partial u}{\partial z} = -L'\frac{\partial i}{\partial t} - Ri$$

$$\frac{\partial i}{\partial z} = -C'\frac{\partial u}{\partial t} - Gu$$

ugyanez, időben szin. „komplex":

$$\frac{\partial^2 u(x)}{\partial x^2} = \gamma^2 u(x)$$

$$\frac{\partial^2 i(x)}{\partial x^2} = \gamma^2 i(x)$$

$$\begin{bmatrix} U_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} ch\,\gamma l & Z_0\, sh\,\gamma l \\ \frac{1}{Z_0} sh\,\gamma l & ch\,\gamma l \end{bmatrix}\begin{bmatrix} U_2 \\ I_2 \end{bmatrix}$$

TV egyenletek megoldása:

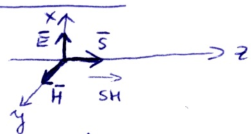
$$u(x,t) = (\hat{u}^+ e^{-\gamma x} + \hat{u}^- e^{\gamma x})e^{j\omega t} = \hat{u}^+ e^{-\alpha x} e^{j(\omega t - \beta x)} + \hat{u}^- e^{\alpha x} e^{j(\omega t + \beta x)}$$

$$i(x,t) = \left(\frac{\hat{u}^+}{Z_0} e^{-\gamma x} - \frac{\hat{u}^-}{Z_0} e^{\gamma x}\right) e^{j\omega t} = \ldots$$

EM hullámok

MINDENFÉLE FISZEMFASZOM TELJESÍTMÉNY:

$(\bar{E}, \bar{H}, \bar{S})$: jobbsodrású rendszer pl.



$$S(z,t) = E(z,t)H(z,t) = \frac{E^2(z,t)}{Z_0} \Rightarrow S_{átl} = \frac{1}{2}\frac{|\hat{E}|^2}{Z_0}$$

$\left(P = \int_A S_{átl}\, dA = S_{átl} \cdot A\right)$ ← $S_{átl}$ (konst.)

másrészt $S_{átl} = E(z,t)H(z,t)\Big|_{átl} = \frac{EH}{2}\cos(\varphi_E - \varphi_H)$

megjegyzés:

$E(z,t) = E\cos(\omega t - \beta z + \varphi_E)$

$H(z,t) = H\cos(\omega t - \beta z - \varphi_H)$

(pl. $E_x = 35 e^{j60°}\, \frac{V}{m} \rightarrow \varphi_E = 60°$

$H_y = j4 \cdot 10^{-3}\, \frac{A}{m} \rightarrow \varphi_H = 90°$)

dipól antenna

$$P = \frac{1}{2} R_s \hat{I}^2 = R_s I_{eff}^2$$

$$R_s = \frac{2}{3}\pi\sqrt{\frac{\mu}{\varepsilon}} \cdot \left(\frac{l}{\lambda}\right)^2$$

$$S_{átl} = \frac{1}{2}\frac{E^2(\vartheta)}{Z_0} = \frac{1}{2}H^2(\vartheta)Z_0$$

(Poynting)

$$S_K = \frac{1}{2} E \times H^*$$

$$P = A \cdot \frac{1}{2} E^+ H^+ \cos\varphi$$

$$P = Re\left\{\frac{1}{2}\int_A \bar{E} \times \bar{H}^* d\bar{A}\right\}$$ ← a hatásos telj. felírása a komplex Poynting vektor segítségével