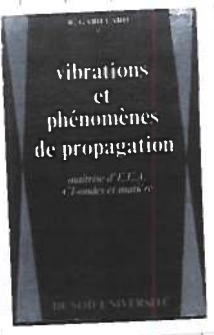


A space-themed background image showing a view of Earth from space, with a satellite or probe in the foreground and a bright light source (possibly the sun) in the distance. The text is overlaid on this image.

Conception Amont en Compatibilité Electromagnétique de Systèmes Lanceurs

Olivier MAURICE

Lagrangien



$$T = \frac{1}{2} L \dot{q}^2$$

$$\frac{d}{dt} \frac{\partial T}{\partial \dot{q}}$$



$$s L \dot{q}$$

force d'inertie
 v_i

$$U = \frac{1}{2} \frac{q^2}{C}$$

$$\frac{\partial U}{\partial q}$$

$$+ \frac{1}{sC} q$$

force de rappel
 v_R

$$F = \frac{1}{2} \int_t dt R \dot{q}^2$$

$$+ \frac{d}{dt} \frac{\partial F}{\partial \dot{q}}$$

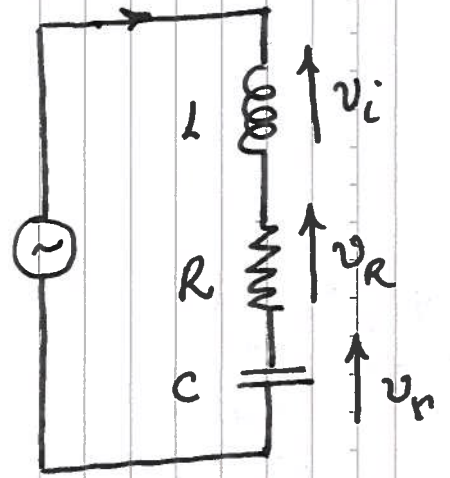
$$+ R \dot{q}$$

frottements
 v_f

force extérieure

$$= \bar{f}_e$$

$$= f_e$$



Dans l'espace des mailles $v_i + v_R + v_r = f_e$

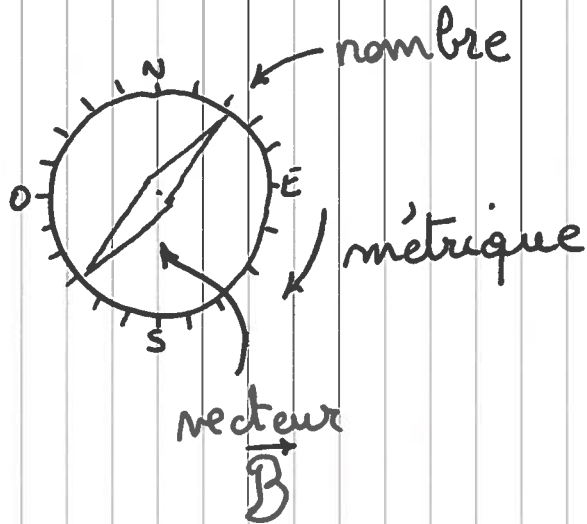
Dualité

\vec{u}_α
 vecteurs
 espace naturel

\vec{B}

\hat{u}^α covecteurs
 (nombres)
 co-espace dual
 \hat{B}

$\gamma: \vec{B} \rightarrow \hat{B}$



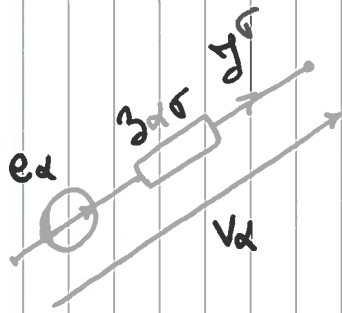
$$\vec{y} = y^\alpha \vec{u}_\alpha$$

$$\hat{v} = v_\alpha \hat{u}^\alpha$$

$$v_\alpha = g_{\alpha\sigma} y^\sigma$$

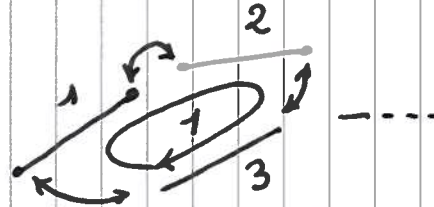
On se dote d'une métrique

Espace des mailles



$$e_\alpha = z_{\alpha\beta} y^\beta + v_\alpha$$

Assemblage :



$$\begin{bmatrix} y^1 \\ y^2 \\ y^3 \end{bmatrix} = \Lambda \begin{bmatrix} k^1 \\ 1 \\ 1 \\ 1 \end{bmatrix}$$

$$\longrightarrow y^\alpha = \Lambda^\alpha_\sigma k^\sigma$$

$$e_\alpha = z_{\alpha\beta} \Lambda^\beta_\sigma k^\sigma + v_\alpha \implies$$

$$\Lambda_\omega^\alpha e_\alpha = \underbrace{\Lambda_\omega^\alpha z_{\alpha\beta} \Lambda^\beta_\sigma}_{R_{\omega\sigma}} k^\sigma + \underbrace{\Lambda_\omega^\alpha v_\alpha}_0$$

$$T_\omega = R_{\omega\sigma} k^\sigma \quad \downarrow \quad \text{Loi des Mailles}$$

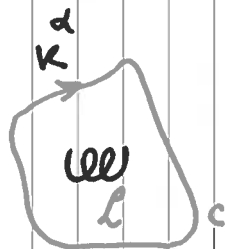
\mathcal{E} : espace des Mailles



Il manque un terme

$$R_{\mu\nu} \supset R, C$$

↘
(F, U)



$$\dot{\phi} = -s \oint_c dc^\alpha g_{\alpha\sigma} A^\sigma = -s \mathcal{L} k^\alpha$$

$$R_{\mu\nu} k^\nu = T_\mu \longrightarrow (R_{\mu\nu} + s \mathcal{L}_{\mu\nu}) k^\nu = T_\mu$$

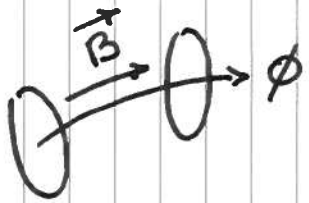
non invariant via $\Lambda \longrightarrow$ non tensoriel.

$R_{\mu\nu}, \mathcal{L}_{\mu\nu}$ tenseurs.

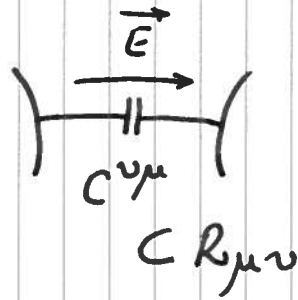
$$d\vec{c}_\mu \wedge d\vec{c}_\nu \approx \mathcal{L}_{\mu\nu} \rightarrow \text{f.c.} = \mathcal{L}_{\mu\nu} dc^\mu \wedge dc^\nu$$

moindre action $\frac{1}{\sqrt{2}} \int_t dt \sqrt{\mathcal{L}_{\mu\nu} k^\nu k^{*\mu}} = a$

Champ proche réactif

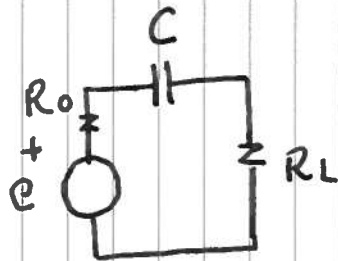
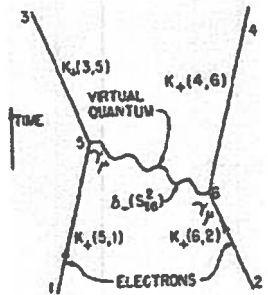


$$\Phi_{\mu} = \mu_{\nu\mu} k^{\nu} \Leftrightarrow M_{\mu\nu} C R_{\mu\nu}$$



$$\frac{1}{4s} \left\{ \frac{1}{j\omega C} k k^* - \frac{1}{j\omega L} k k^* \right\} = 0$$

$$\frac{1}{4s} \left\{ j\omega L k k^* - j\omega C k k^* \right\} = 0$$



$$V = \frac{R_L}{R_0 + R_L + \frac{1}{sC}} e$$

$\left. \begin{array}{l} E \text{ peut \hat{e}tre grand} \\ V \text{ faible} \end{array} \right\}$

L'amplitude du champ proche n'est pas li e au risque en CEM

Champ lointain actif

Jauge de Coulomb

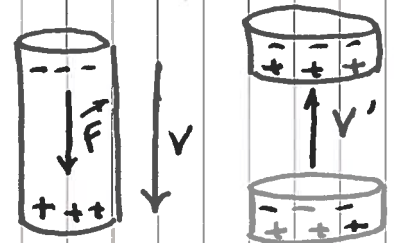
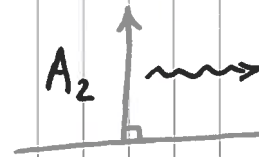
$$E_z = -s A_z$$

$$dA_z = \frac{\mu_0 dz'}{4\pi r} I(z') \underbrace{\left[\frac{e^{-s r/c}}{r} \right]}_{G_{zz'}} \leftarrow \text{MoM}$$

$$I(z') \supset \mathcal{J}^\alpha + s \varepsilon^{\alpha\beta} \frac{\partial V_\beta}{\partial z}$$

$$\underbrace{g_{\alpha\beta} h^\alpha}_{e_\alpha} E^\beta = \frac{g_{\alpha\beta} h^\alpha}{4\pi s \varepsilon_0} \int_L dz' \left(\frac{\partial^2}{\partial z'^2} G_{\alpha\beta} + \frac{s^2}{c^2} G_{\alpha\beta} \right) \mathcal{J}^{\beta'} = G_{\alpha\beta'} \mathcal{J}^{\beta'}$$

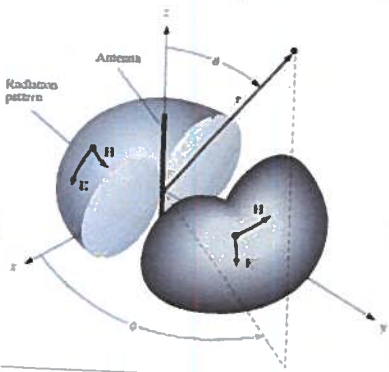
$$(R_{\mu\nu} + s \alpha_{\mu\nu} + s G_{\mu\nu}) k^\nu = T_\mu$$



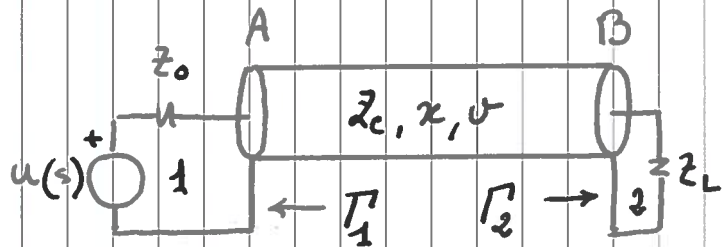
$$A_z \leftrightarrow s \varepsilon_0 V_z$$

$$\frac{1}{4s} \left\{ V_z \frac{V_z^*}{\rho_0} + V_z^* \frac{V_z}{\rho_0} \right\} \rightarrow R_\nu$$

$$\begin{cases} e = -s \oint_c d\mathbf{c} A_z \\ d > \phi(c) \end{cases}$$



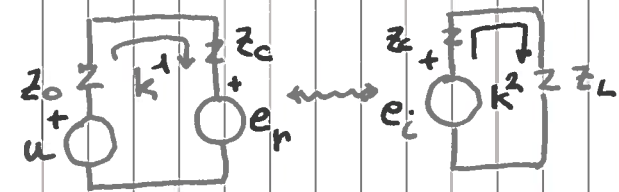
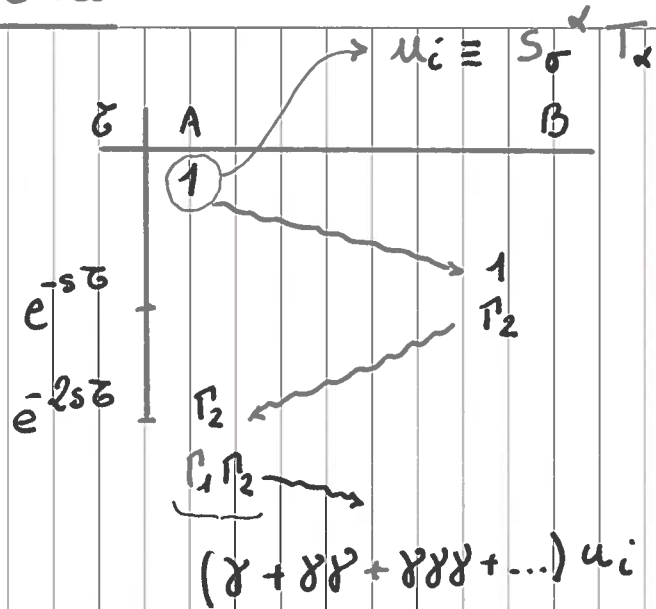
Ondes Guidées



espace des ondes

	P_1	r_1	P_2	r_2
P_1		Γ_1		
r_1				$e^{-s z_0}$
P_2	$e^{-s z_0}$			
r_2			Γ_2	

$$\gamma = \begin{bmatrix} 0 & \Gamma_1 & 0 & 0 \\ 0 & 0 & 0 & e^{-s z_0} \\ e^{-s z_0} & 0 & 0 & 0 \\ 0 & 0 & \Gamma_2 & 0 \end{bmatrix}$$



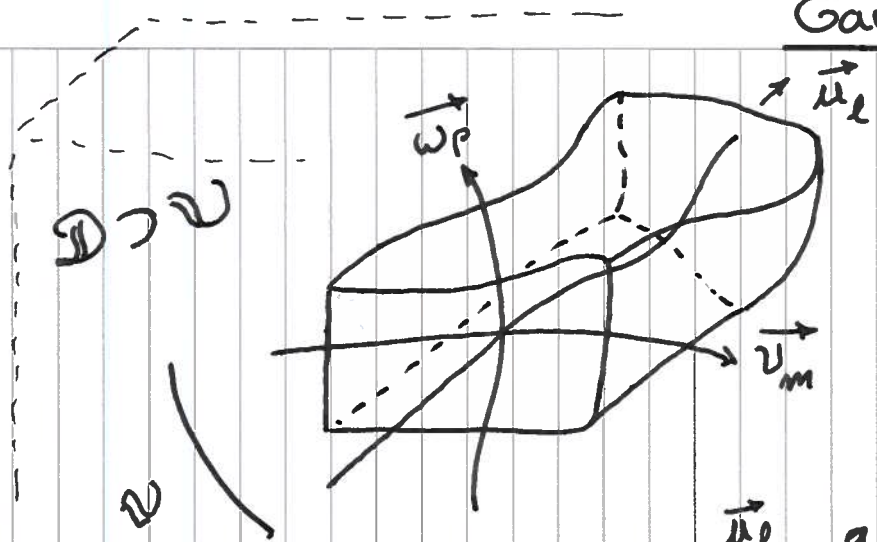
V matrice ondes \rightarrow mailles

$$\frac{1}{2} e_r = V_1^\sigma \bar{\gamma} S_\sigma^\alpha T_\alpha$$

$$\frac{1}{2} e_i = V_2^\sigma \bar{\gamma} S_\sigma^\alpha T_\alpha$$

$$(s K_{\mu\nu} + R_{\mu\nu} + s \alpha_{\mu\nu} + s G_{\mu\nu}) k^\nu = T_\mu + 2 V_\mu^\sigma \bar{\gamma} S_\sigma^\alpha T_\alpha$$

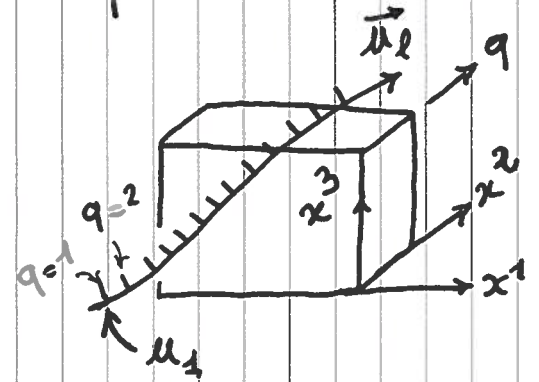
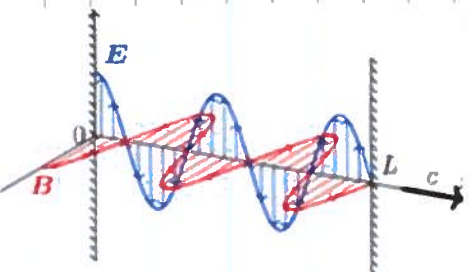
Cavités



base curviligne $(\vec{u}_l, \vec{v}_m, \vec{\omega}_p)$
 espace paramétré
 $\vec{u}_l \rightarrow$ dual $\hat{u}^l \Rightarrow u_l, \mu_q = g_{pq} x^p$

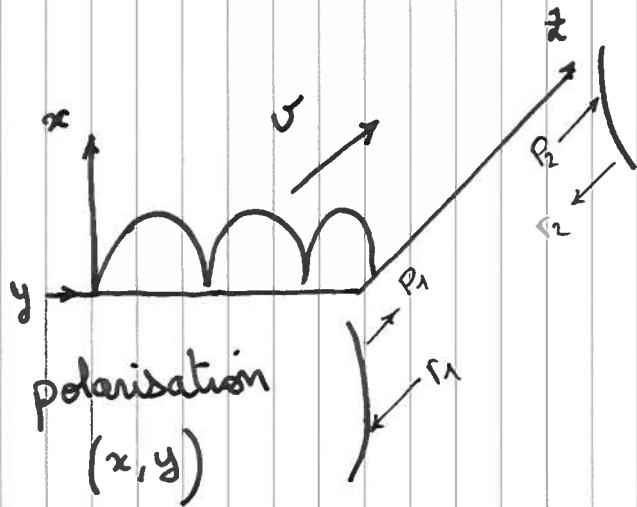
Pour 1 polarisation (ω, v)

$$V_i \leftarrow \left(\frac{\partial \omega_\alpha}{\partial \mu_\sigma}, \frac{\partial v_\alpha}{\partial \mu_\sigma} \right) = 0 \Rightarrow \gamma_i, \nu_i$$



$$n_c = 2 \int_0^{\vec{v}_m} \left[\left(g_{pq} dx^p \right)^2 \right]^{1/2} \longrightarrow n_c = \frac{c}{\sqrt{1 - \left(\frac{d}{n_c} \right)^2}}, \quad \underbrace{s = \alpha \sigma_i + j\omega}_{\gamma}$$

Cavités II



- approche Tollin

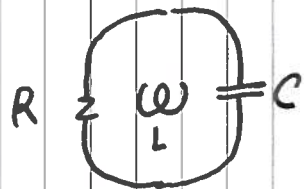
$$\gamma_x \approx \sqrt{\frac{\mu_0}{\epsilon_0}} \left(\frac{x}{a} - \pi \right)$$

Établissement de γ pour les modes considérés $\rightarrow \gamma(m, n, q) \rightarrow \gamma(m, n)_q$

$$\gamma(m, q)_n$$

$$\gamma(n, q)_m$$

En bande étroite \rightarrow résonateur



$$C_{mnq} \Rightarrow \frac{1}{2} \iiint_V dV \epsilon_0 E^2 = \frac{1}{2} CV^2$$

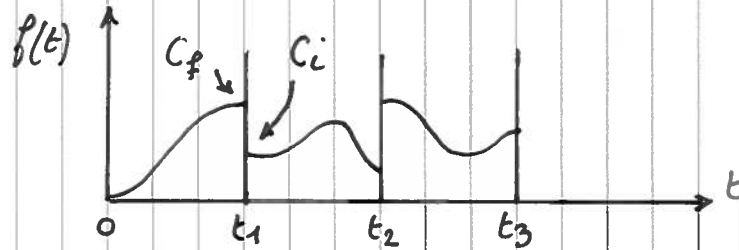
$$f_{mnq} = \frac{c}{2} \sqrt{\left(\frac{n}{x}\right)^2 + \left(\frac{m}{y}\right)^2 + \left(\frac{q}{z}\right)^2}$$

$$L_{mnq} = \frac{1}{4\pi^2 f_{mnq}^2 C_{mnq}}$$

$$Q_f = \frac{3}{2} \frac{V \sqrt{\mu_0 \epsilon_0}}{S} = \frac{L_{mnq} \omega_{mnq}}{R} \Rightarrow R$$

Electronique, dont non linéaire

2 outils : Laplace : fonctions d'ordre exponentiel



$$\exists \alpha, \varepsilon \quad e^{-\alpha t} f(t) < \varepsilon \text{ qd } t > T$$

$$C, d : Q_0, \phi_0$$

Le temps est un paramètre dans le coespace-temps : x_0, x_1, x_2, x_3

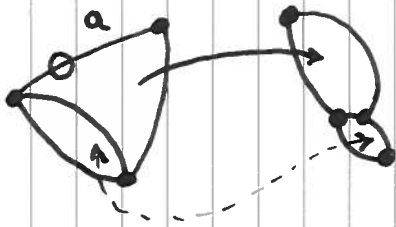
Notion de polarisation : $R_{\mu\nu} = \overset{\nu}{D}_\alpha R_{\mu\nu}^\alpha$.
 $\overset{\nu}{D}_\alpha$ ← paramètre de la base

Généralisation de la notion appliquée aux tubes, transistors, ...

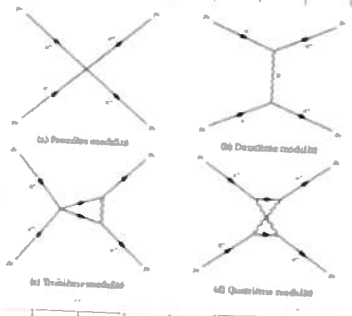
1 innovation : concept de corde $R_{\alpha\beta} = \frac{e_\alpha}{k\beta}$

Topologie

1 Graphes G

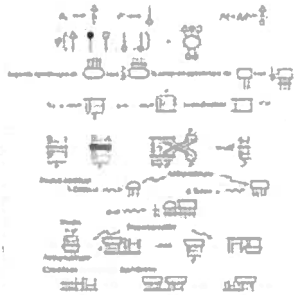


$$M = B - N + R$$



~ Penrose
Feynman

Bestiaire de symboles
Représentation d'ingénieur
des interactions



1 métrique g

$$R_{\mu\nu}; L_{\mu\nu}; G_{\mu\nu}; \sqrt{|V_{\mu}^{\sigma} \bar{y} S_{\sigma}^{\mu}|}$$








$$|T_{\mu}$$

• Système d'équations du problème
• voisinages $\sqrt{\frac{1}{B} \int_{\omega} g_{\mu\nu} k^{\mu} k^{*\nu} d\omega}$

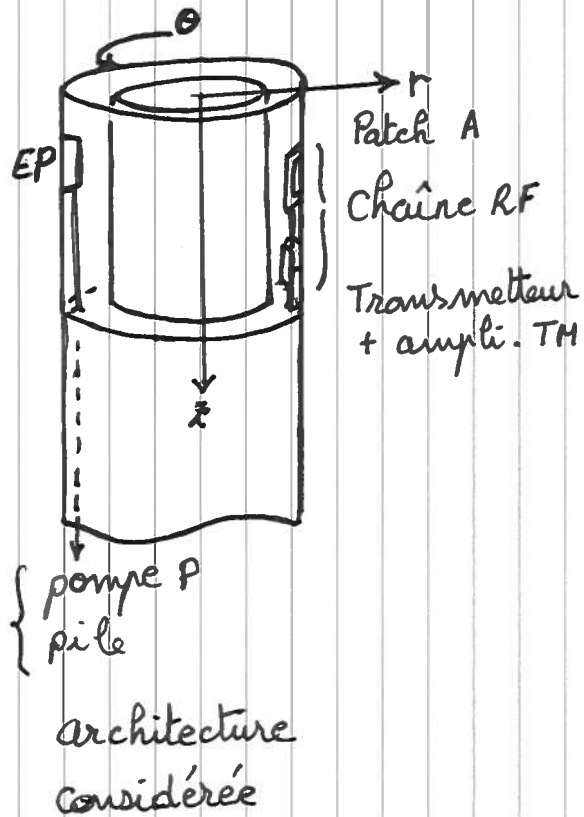
→ $\mathcal{M}(G, g) \leftarrow \mathbb{R}^1 : \mathcal{F}$
de genre $\dim(M)$

→ homotopies, homologies

Symbolique du Graphie

	mutuelle inductance
	champ électrostatique
	champ rayonné
	Réductance
	onde guidée
	rayonnement ionisant
	électronique

Un exemple : électronique de puissance dans un lanceur.



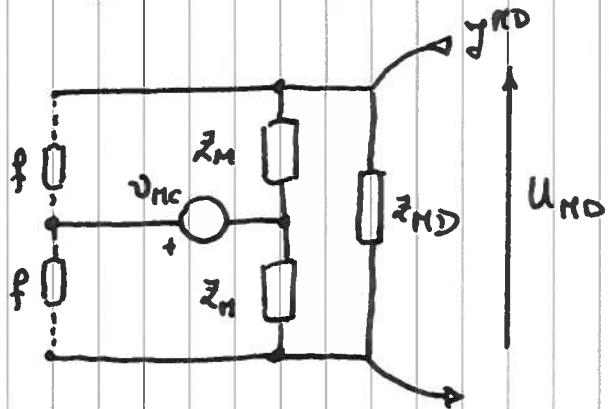
1. Matrice d'interaction

R. E.	EP	P	A	TM	Personnel	---
EP			○	○		
P			○	○		
A					○	
TM						
Fond.	○	○	○	○	○	

Synthèse le travail à effectuer en conception amont pour la CEM

Collection de sous-variétés constituant \mathcal{V}

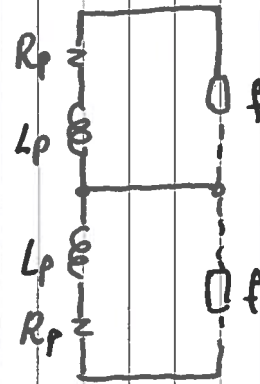
EP Modèle Labrousse - Révol - Coste
'LRC'



$$R_{\mu\nu} : \begin{bmatrix} z_{MD} & -z_{MD} & 0 & 0 \\ -z_{MD} & z_M + 2z_{MD} & -z_M & z_n \\ 0 & -z_M & z_M + a & 0 \\ 0 & z_M & 0 & z_M + a \end{bmatrix}$$

$$\mathcal{M}_{EP} (G_{LRC}, R_{\mu\nu})$$

P charge (Pile)

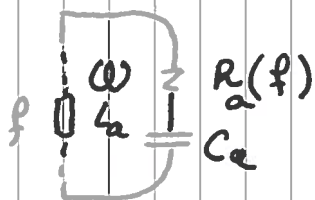


$$R_{\mu\nu} : \begin{bmatrix} R_p + f & 0 \\ 0 & R_p + f \end{bmatrix} \quad s d_{\mu\nu} : \begin{bmatrix} s L_p & 0 \\ 0 & s L_p \end{bmatrix}$$

$$\mathcal{M}_P (G_P, R_{\mu\nu} + s d_{\mu\nu})$$

Collection de sous-variétés constituant \mathcal{U}

Antenne A

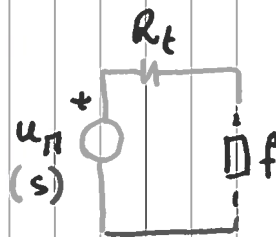


$$R_{\mu\nu} : R_a(f) + \frac{1}{sC_a} + f$$

$$s d_{\mu\nu} : s L_a$$

$$\mathcal{M}_A (G_a, R_{\mu\nu} + s d_{\mu\nu})$$

Amplificateur TM



$$R_{\mu\nu} : R_t + f$$

$$\mathcal{M}_{TM} (G_{TM}, R_{\mu\nu})$$

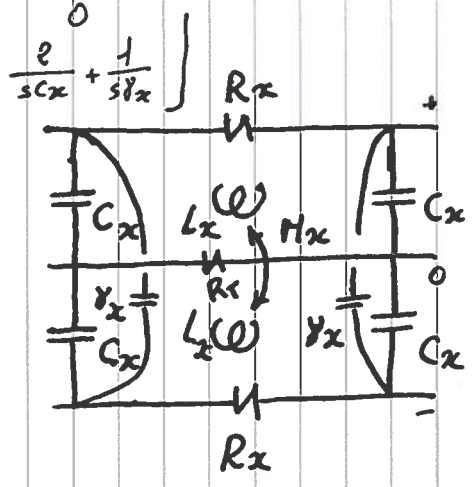
$$g_{\mu\nu}^i: \begin{bmatrix} R_x + R_T + \frac{2}{sC_x} + sL_x & R_T & -\frac{1}{sC_x} & \frac{1}{sC_x} \\ R_T & R_x + R_T + \frac{2}{sC_x} + sL_x & \frac{1}{sC_x} & -\frac{1}{sC_x} \\ -\frac{1}{sC_x} & \frac{1}{sC_x} & \frac{2}{sC_x} + \frac{1}{sR_x} & 0 \\ \frac{1}{sC_x} & -\frac{1}{sC_x} & 0 & \frac{2}{sC_x} + \frac{1}{sR_x} \end{bmatrix}$$

Chaîne EP

$$l_i \geq \frac{\lambda}{2}$$

$$M_{CEP}^i (G_{CEP}^i, g_{\mu\nu}^i)$$

Liaisons

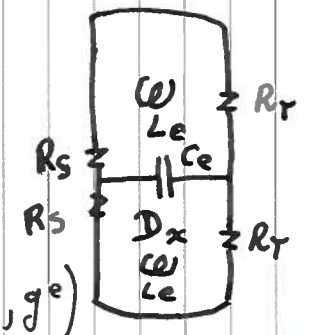


domaine interne

$$g_{\mu\nu}^e: \begin{bmatrix} R_s + R_T + sL_e + \frac{1}{sC_e} & -\frac{1}{sC_e} \\ -\frac{1}{sC_e} & R_s + R_T + sL_e + \frac{1}{sC_e} \end{bmatrix}$$

$$l_e \geq \frac{\lambda}{2}$$

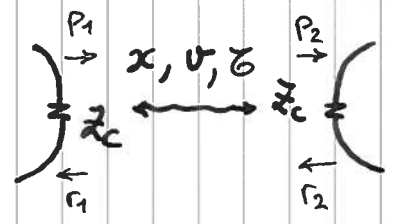
$$M_{CEP}^e (G_{CEP}^e, g_{\mu\nu}^e)$$



domaine externe

Chaîne RF

Source adaptée
domaine interne

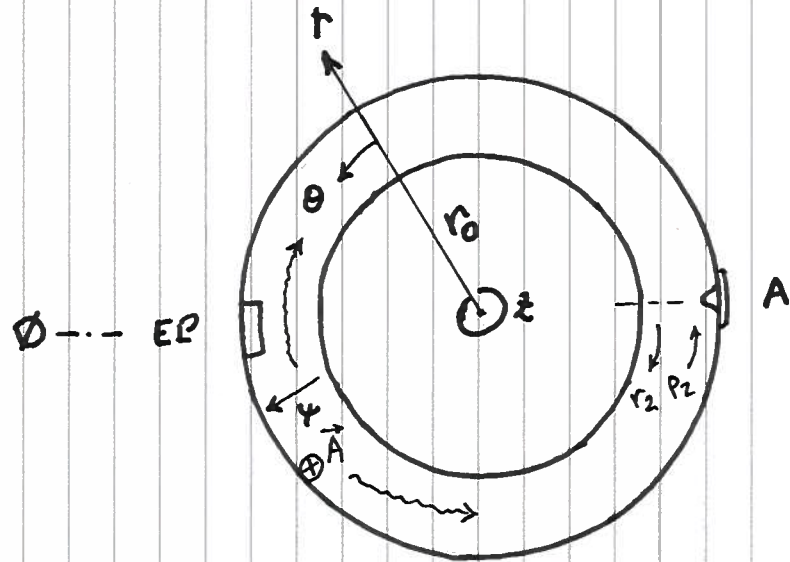


$$\bar{Y} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & e^{-s\tau} \\ e^{-s\tau} & 0 & 0 & 0 \\ 0 & 0 & T_2 & 0 \end{bmatrix} + \dots$$

$$M_{RF}^i (G_{RF}^i, \bar{Y}^i)$$

domaine externe → idem chaîne EP

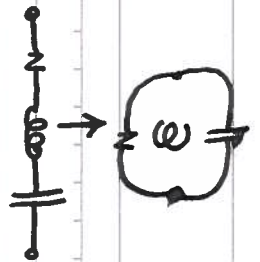
Cavité lanceur



- Modes possibles

$$\Psi_r \cos\left(n\pi \frac{\theta}{2\pi}\right) \sin\left(m\pi \frac{z}{H}\right)$$

$$Y_\theta: \begin{bmatrix} 0 & \Gamma_1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ e^{-s\pi r_0} & 0 & 0 & e^{-s\pi r_0} \\ 0 & 0 & \Gamma_2 & 0 \end{bmatrix} \text{ ou}$$



$$\Gamma_1 = \Gamma_2 = 0$$

Pour Y_2 , $\Gamma_1 = \Gamma_2 = -1$ $Q \approx \frac{3}{2} \frac{V}{S} \sqrt{\pi f \mu \epsilon}$

$$\begin{aligned} &\rightarrow Q = L\omega/R \\ &\rightarrow S_x^\beta \supset Q \end{aligned}$$

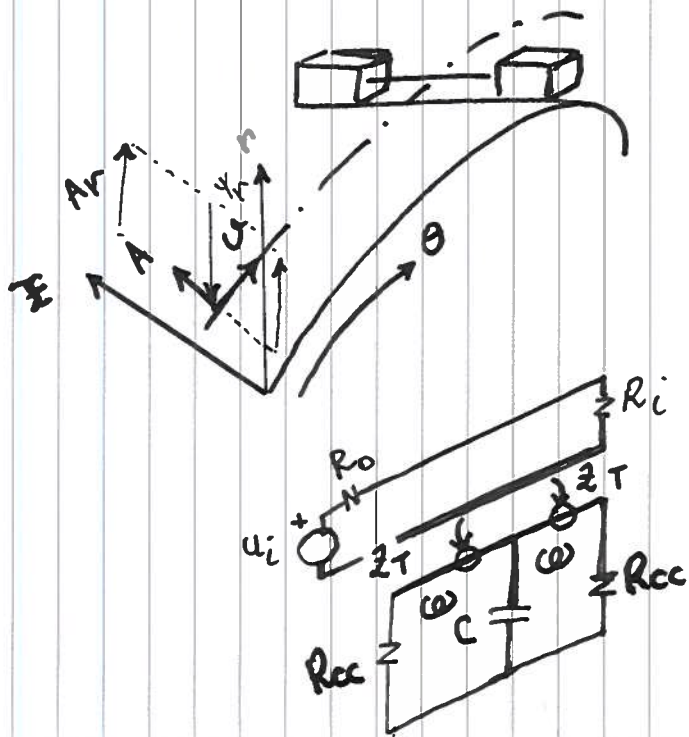
$$\frac{1}{2} CV^2 = \frac{1}{2} \iiint_V dv \epsilon_0 E^2$$

$$\omega_{mnq} = \pi c \sqrt{\left(\frac{n}{x}\right)^2 + \left(\frac{m}{y}\right)^2 + \left(\frac{q}{z}\right)^2}$$

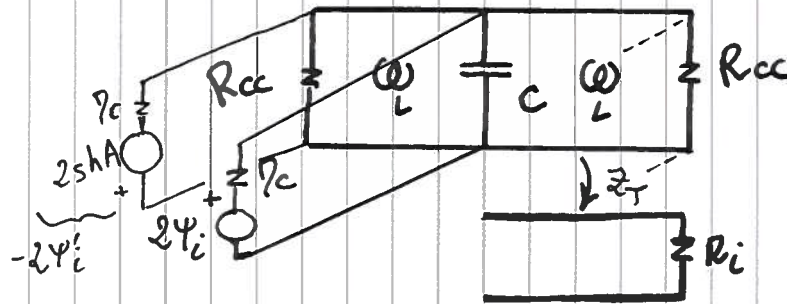
$$L_{mnq} = \frac{1}{4\pi^2 C_{mnq} f_{mnq}^2}$$

Couplage mode-circuit

Règle = couplage champ modal - circuit =
couplage circuit - champ modal.



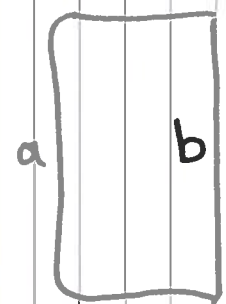
$$\Psi = \int_n d\mathbf{n} \cdot \mathbf{s} A_n$$



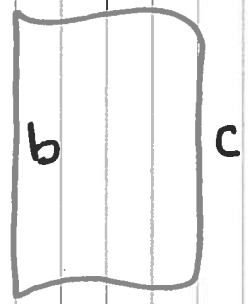
$$\Psi_j = S_j^i u_i \rightarrow \Psi_i = V_i^j \gamma_{\theta} S_j^i u_i$$

Assemblage : couture topologique

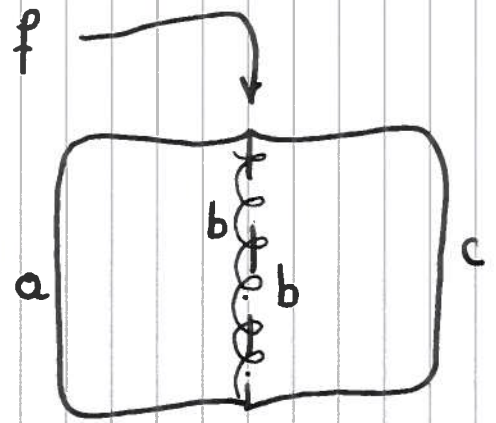
$$\mathcal{M}_1(G_1, g_1) \oplus \mathcal{M}_2(G_2, g_2) + f$$



$$g_1 = a + b$$

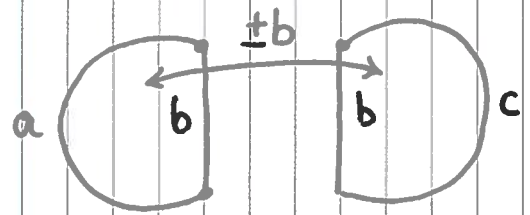


$$g_2 = b + c$$



$$\mathcal{M}_3(G, g)$$

$$\begin{bmatrix} a+b & \pm b \\ \pm b & b+c \end{bmatrix} : g$$

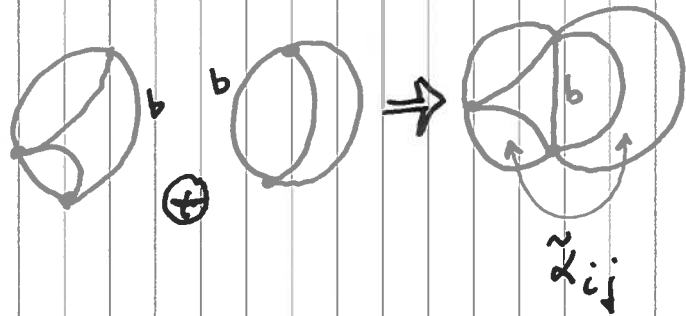


frontière cousue \Leftrightarrow Corde



La CEM est Systémique

Système de la Somme \neq Somme des Systèmes



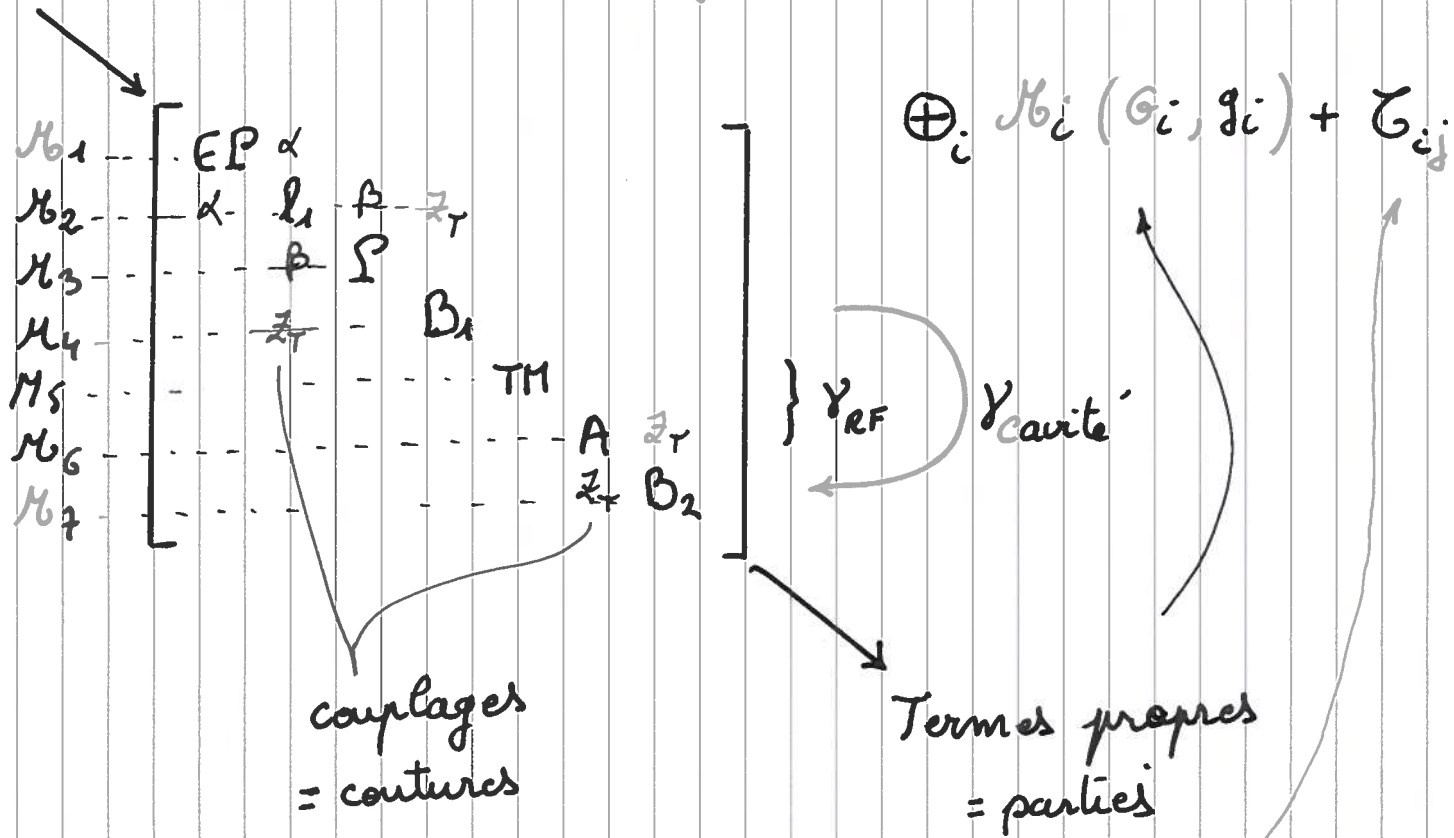
$$\mathcal{M}_a(G_a, g_a) = \bigoplus_i \mathcal{M}_i(G_i, g_i) + \mu_{ij} + \underbrace{(\{\tilde{b}_{ij}\}, \tilde{d}_{ij})}_{\text{Emergence}}$$

Emergence

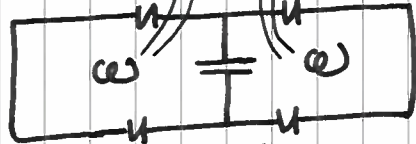
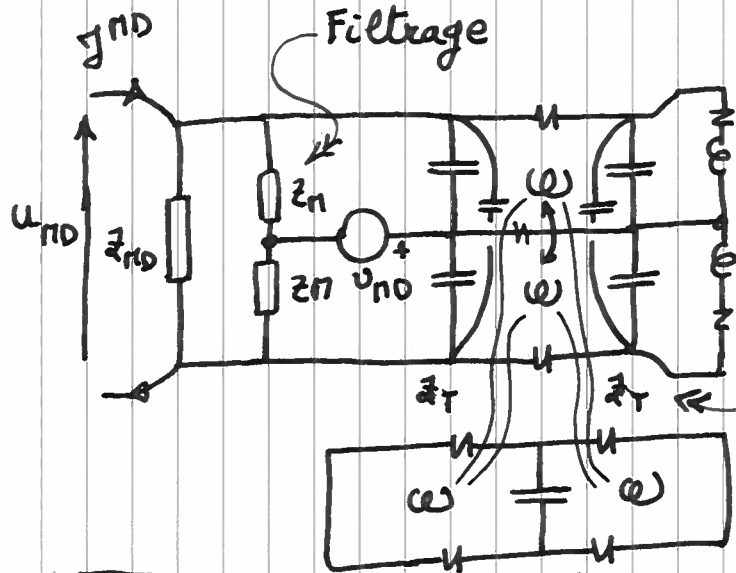
Des couplages non désirés apparaissent \rightarrow

c'est le sujet d'étude de la CEM!

Assemblage

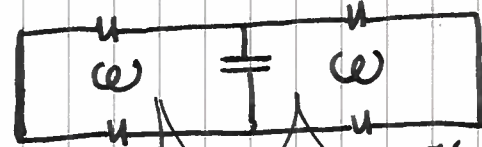


Assemblage : $\oplus_i G_i + r_{car}$



Cordes \equiv réglages des interactifs

$$y_{car} \leftrightarrow \tilde{z}_{ij}$$



Assemblage : $\oplus g_{ij}^L + \mu_{ij}^{LL'}$

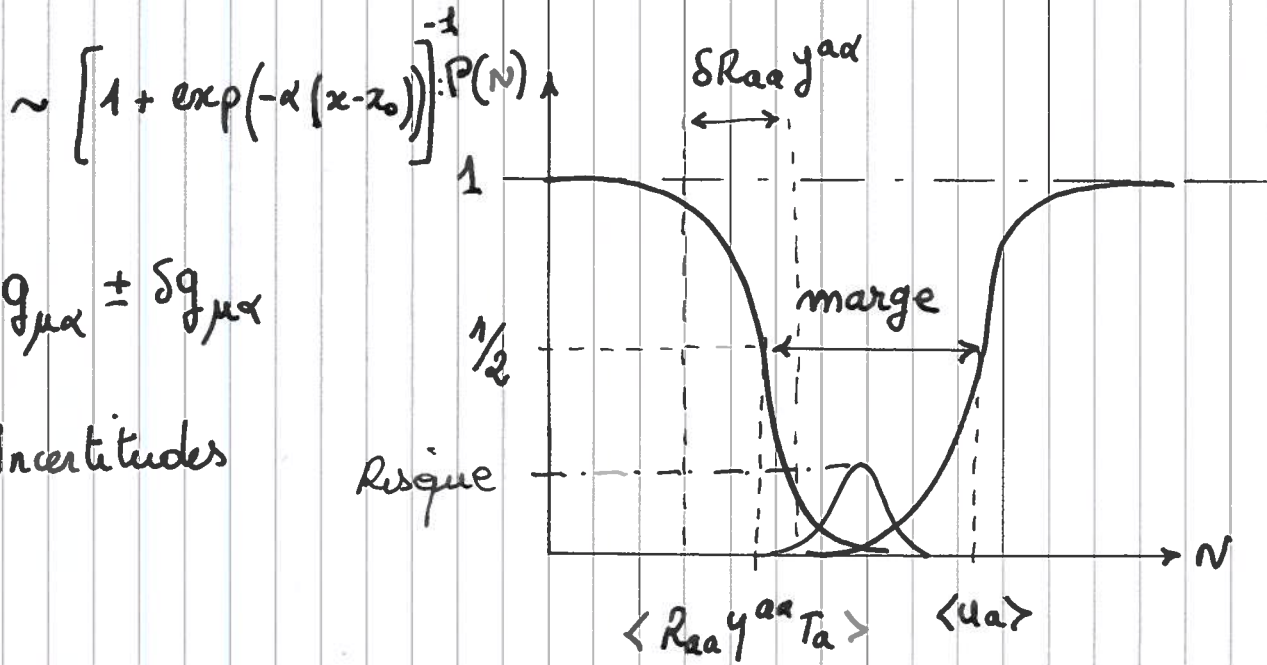
T
 U_{HD}
 V_{HD}
 V_{HD}
 V_{SK}
 V_{SK}
 U_a
 V_{SK}

g	Z_{HD}	$-Z_{HD}$																			
	$-Z_{HD}$	$Z_{HD} + 2Z_{SK}$	$-Z_T$	$+Z_T$																	
		$-Z_T$	$Z_T + \frac{1}{sC_x}$					$-\frac{1}{sC_x}$													
			$+Z_T$	$Z_T + \frac{1}{sC_x}$	$-\frac{1}{sC_x}$																
				$-\frac{1}{sC_x}$	$\frac{R_2 + sL_x + R_1}{sC_x}$	$-sR_1$	$-\frac{1}{sC_x}$	$-\frac{1}{sC_x}$			$-Z_T$	$-Z_T$									
				$\frac{1}{sC_x}$	$-sR_1$	$\frac{R_2 + sL_x + R_1}{sC_x}$	$\frac{1}{sC_x}$			$-\frac{1}{sC_x}$	$-Z_T$	$-Z_T$									
					$-\frac{1}{sC_x}$	$\frac{1}{sC_x}$	$\frac{R_2 + 1}{sC_x}$	$\frac{1}{sC_x}$	$-\frac{1}{sC_x}$												
						$-\frac{1}{sC_x}$	$\frac{1}{sC_x}$	$R_1 + \frac{1}{sC_0} + sL_p$													
							$-\frac{1}{sC_x}$	$\frac{1}{sC_x}$		$R_1 + \frac{1}{sC_0} + sL_p$											
											$\frac{1}{sC_0} + R_1 + sL_p$										
												$\frac{1}{sC_0} + R_1 + sL_p$									
													$\frac{1}{sC_0} + sL_p + R_1$	$-Z_T$	$-Z_T$						
														$\frac{1}{sC_0} + R_1 + sL_p$	$-Z_T$	$-Z_T$					
															$-Z_T$	$-Z_T$	$2R_a$				
																$-Z_T$	$-Z_T$	$2R_a + sL_a + \frac{1}{sC_a}$			

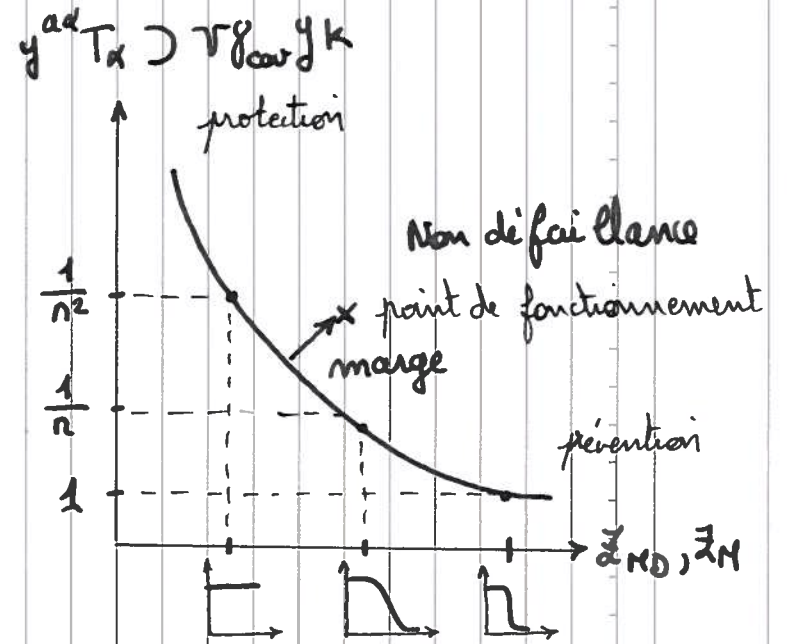
Exploitation

$$K^a = y^{a\alpha} T_a \longrightarrow \tilde{\mu}_a = R_{aa} K^a$$

$$\frac{S}{N} = \frac{v \gamma S u_a}{R_{aa} y^{a\alpha} T_a}$$



Notion de marge



Stratégie

$\sigma_{\mu\alpha} \pm \delta \sigma_{\mu\alpha}$
Incertitudes

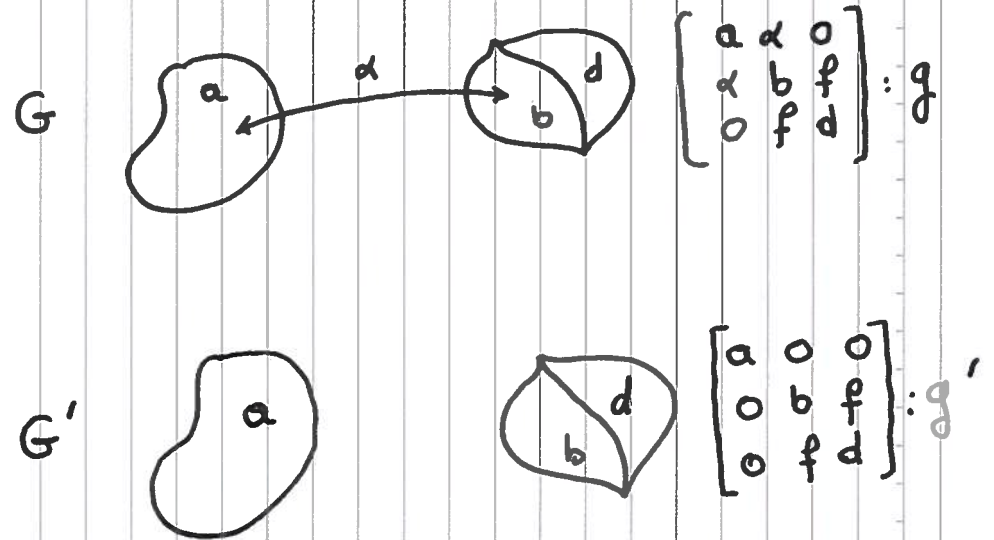
Une partie du boulot est faite !

matrice d'interaction

	A
EP	OK

Correction apportée

$$\tilde{\mathcal{M}}(G, g) \longrightarrow \mathcal{M}(G', g')$$



prévenir ou protéger, c'est découdre!

→ supprimer les émergences

Simulation numérique & cycle en V

Complémentarité

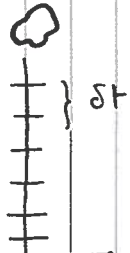
Calcul



$$y(t) = h - \frac{1}{2}gt^2$$

modèle complexe
connaissance de l'ingénieur
équations précises

Simulation Num.

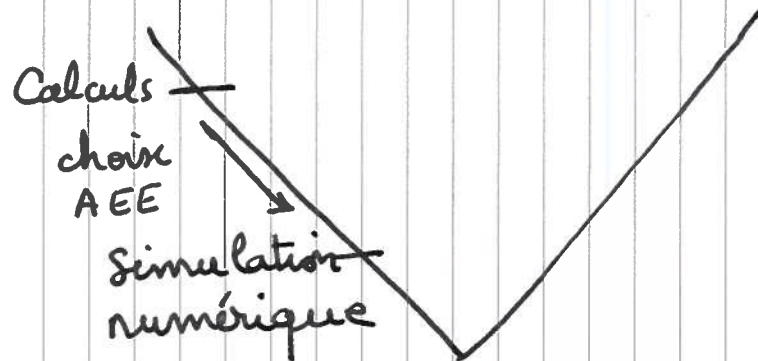


$$\delta y(n) = h - \frac{1}{2}g \sum \delta t^2$$

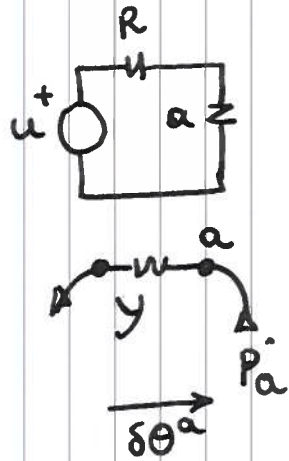
expérience virtuelle
ordres faibles
maîtrise de la CAO
géométrie précise

←→
convergences locales

- Le calcul théorique et son application numérique permettent de Comprendre & anticiper.
- La simulation numérique permet de réaliser une expérience virtuelle et de confirmer l'attente.
- La simulation doit intégrer les moyens de mesure.



un peu plus sur l'ATR : électrothermique



$$\begin{cases} u = R(1 + \alpha\theta)k + a(1 + \alpha'\theta)k \\ \alpha k k^* = \gamma_{aa} \theta^a, \quad \theta^a = \Delta T \\ \theta = T_a + \Delta T \end{cases}$$

$$c = g_{\mu\nu\alpha} dx^\mu dx^\nu dx^\alpha$$

$$R(1 + \alpha\theta)k \rightarrow R \theta^0 k^1 + \alpha R \theta^1 k^1$$

composantes $\theta^a k^a$

↓
compliqué!

pragmatique

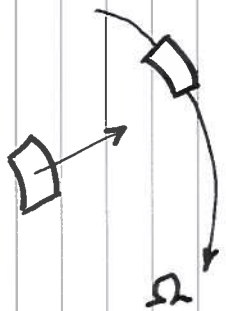
Théorique.

électrique	mécanique	fluide
q	u	Δp
$J = \dot{q}$	$v = \dot{u}$	$\Delta \dot{v}$
L	M	$\rho l / \phi$
$\frac{1}{C}$	k	$1/\alpha v$
R	K_R	R_a

} équivalences tensorielles.

Un peu plus sur l'ATR : référentiels

Référentiels en mouvements relatifs accélérés. \Rightarrow machine de Kron.



champ proche

$$\begin{aligned}
 & s(M_{\mu\nu} k^\nu) \rightarrow \\
 & \frac{d}{dt} M_{\mu\nu} k^\nu + M_{\mu\nu} \frac{d}{dt} k^\nu \\
 & = \frac{\partial}{\partial u^\alpha} \Omega^\alpha M_{\mu\nu} k^\nu + M_{\mu\nu} s k^\nu \\
 & = \Gamma_{\mu\nu, \alpha} \Omega^\alpha k^\nu + M_{\mu\nu} s k^\nu
 \end{aligned}$$

\xrightarrow{c} \xrightarrow{v}

$$\begin{aligned}
 & \frac{d}{dt} \Lambda_\omega^\mu G_{\mu\nu} k^\nu \\
 & \rightarrow \Gamma_{\omega, \alpha}^\mu v^\alpha G_{\mu\nu} k^\nu + \\
 & \Lambda_\omega^\mu \frac{d}{dt} G_{\mu\nu} k^\nu + \\
 & \Lambda_\omega^\mu G_{\mu\nu} \frac{dk^\nu}{dt}
 \end{aligned}$$

$$\begin{aligned}
 & (R_{\mu\nu} + s \delta_{\mu\nu} + \Gamma_{\mu\nu, \alpha} \Omega^\alpha + \Gamma_{\omega, \alpha}^\mu v^\alpha G_{\mu\nu} + \Lambda_\omega^\mu \frac{d}{dt} G_{\mu\nu} + \Lambda_\omega^\mu G_{\mu\nu} s) k^\nu \\
 & = T_\mu + 2 \sqrt{\mu} \sigma \bar{\gamma} S_\sigma^\alpha T_\alpha
 \end{aligned}$$

- un peu plus sur l'ATR : Mécanique Quantique

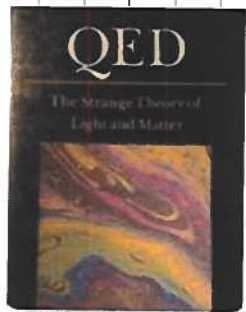
CEM } CEM \Leftrightarrow Maxwell : INFINI !
 Electronique } Ce sont les composants électroniques qui sont perturbés

$$R_{\mu\nu} = \frac{1}{\epsilon^{\nu\mu}} \frac{\rho}{\phi} \quad C^{\alpha\beta} = \epsilon^{\alpha\beta} \frac{\phi}{\ell} \quad L_{\sigma\nu} = \mu_{\sigma\nu} \frac{\phi}{\ell}$$

$$S^{33} = \left(g_{12} \ x^1 x^2 \ V_3 \ V_3^* \right)^{-1} \int_{x^3} dx^3 \ \Psi^* H_{G\alpha} \Psi^\alpha$$

Méca Q $\xrightarrow{\int_x dx}$ R, L, C, G \leftarrow espace M, γ

↑
 espace des ondes & probabilités



Conclusion

" -- le calcul tensoriel permet une systématisation qui, non seulement a la propriété de s'appliquer à tous les cas quelle que soit leur complexité, mais aussi donne un moyen de réaliser un examen méthodique des circuits, de les décomposer en parties simples, de les superposer ou interconnecter."

" Un ingénieur, électricien ou radioélectricien ne doit plus ignorer la méthode de Kron ; sa culture technique serait incomplète."

M. Denis-Papin, A. Kaufmann. 1966.