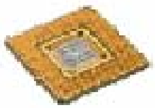
Modélisation dynamique de l’inverseur CMOS

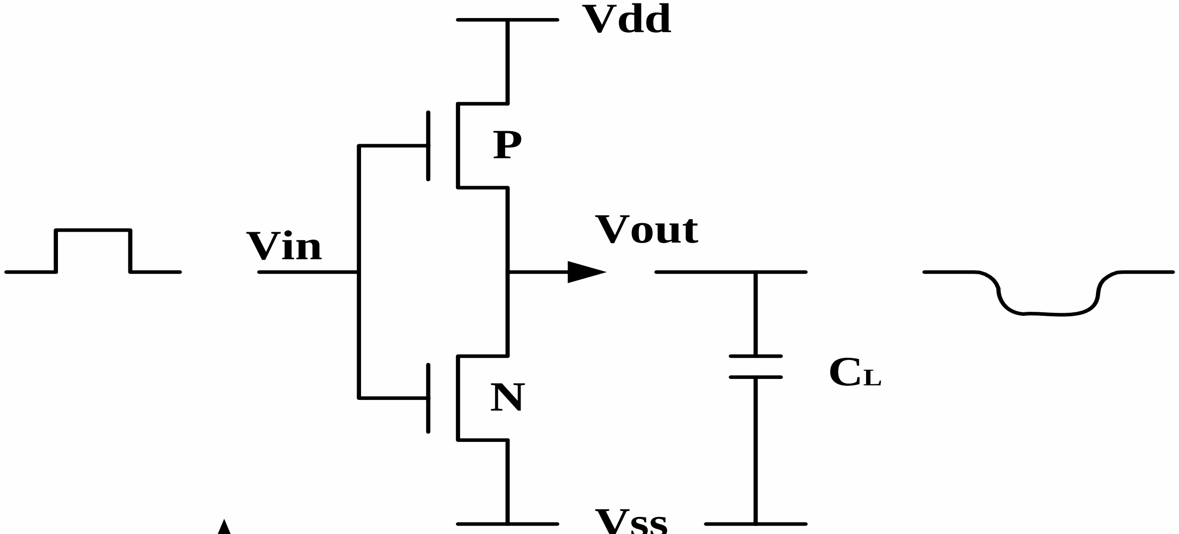
Analyse Temporelle

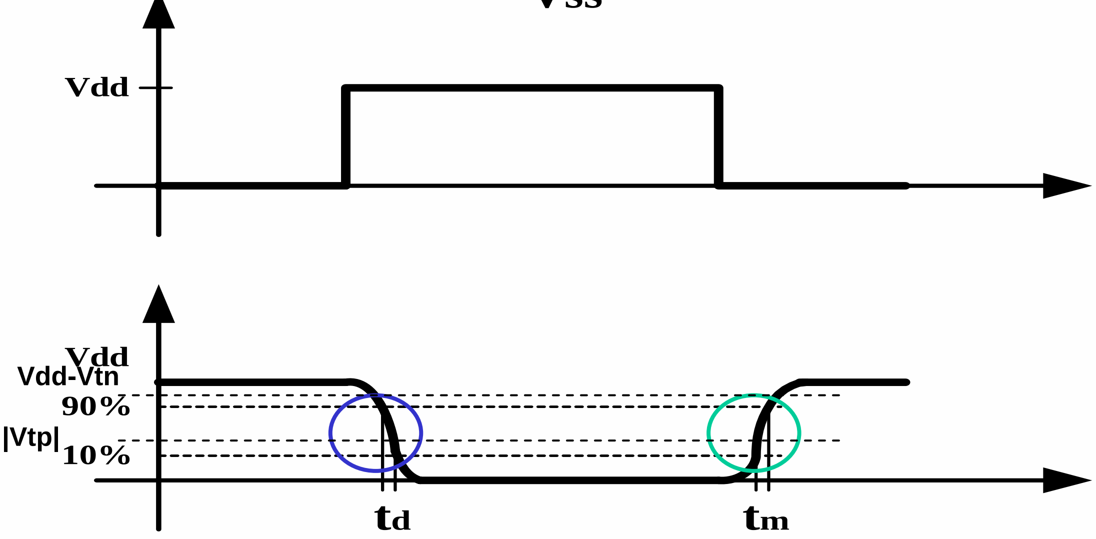
MASTER ACSI M2

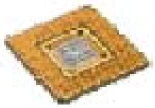
Habib MEHREZ



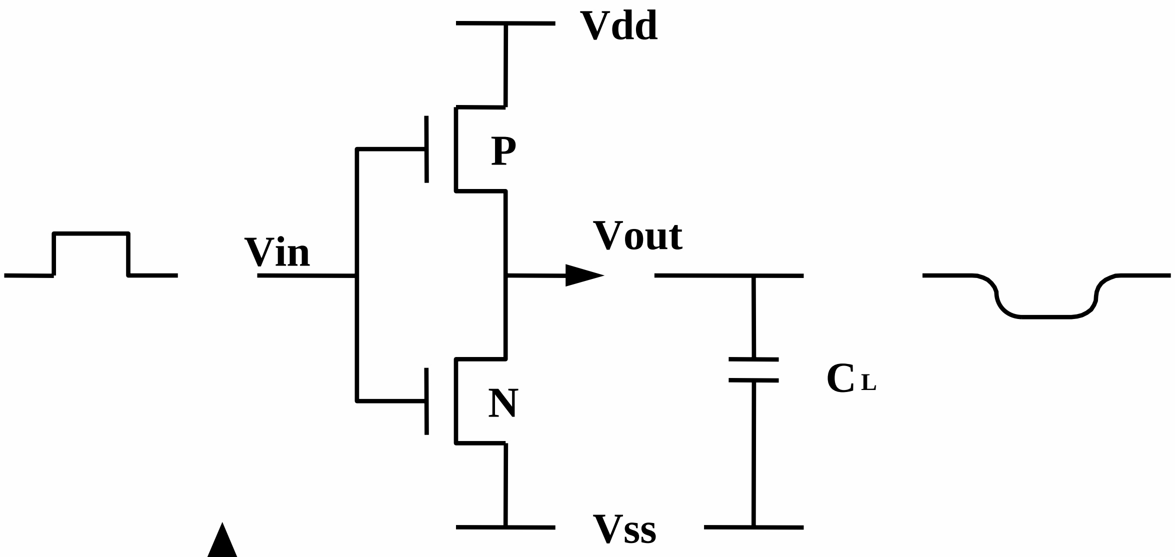
Modèle Dynamique de l'inverseur CMOS, Temps de Montée et de Descente

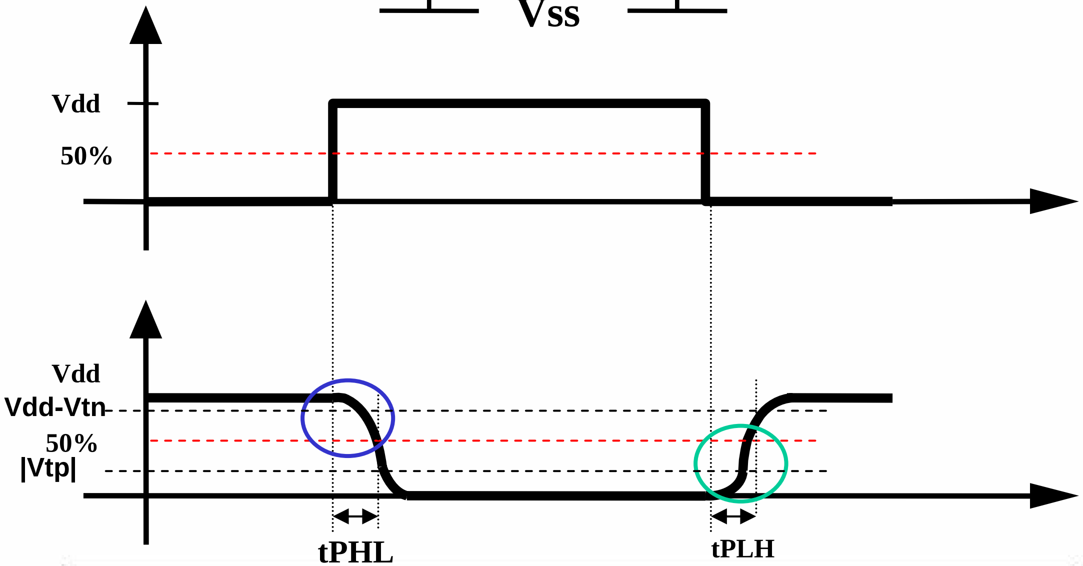




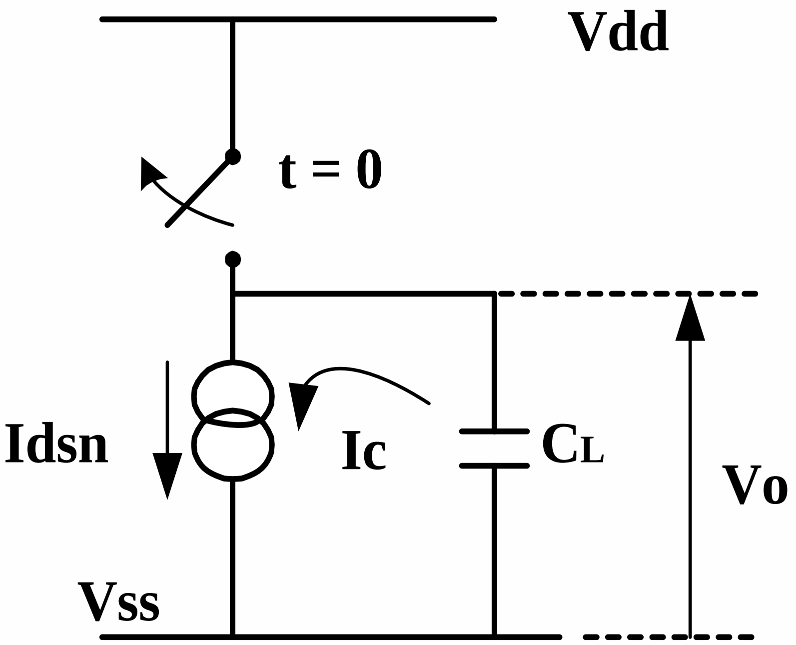


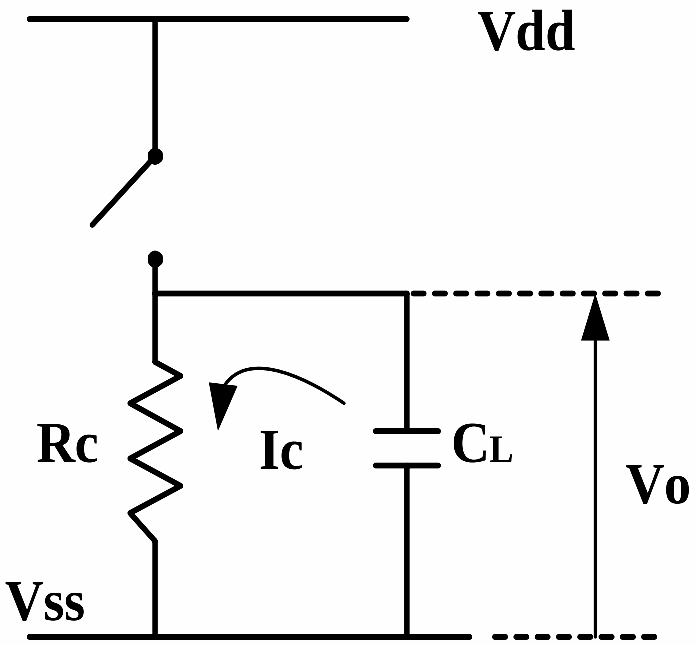
Modèle Dynamique de l'inverseur CMOS, Temps de propagation





Modèles Dynamiques Equivalents

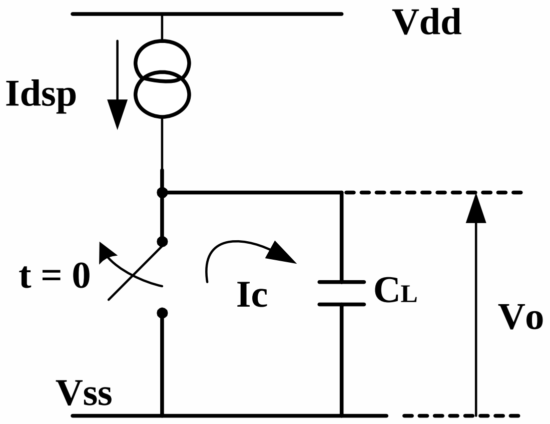




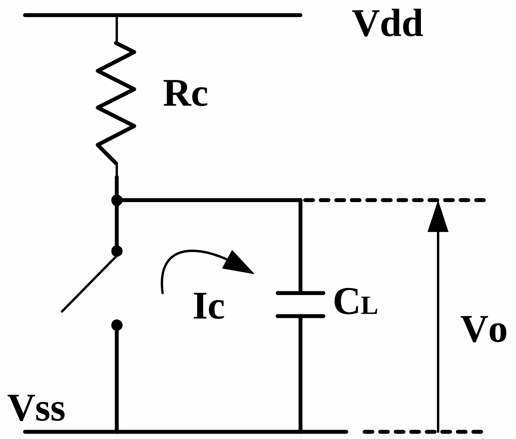
saturation: $V_o \geq V_{DD} - V_{tn}$

linéaire: $0 < V_o < V_{DD} - V_{tn}$

Modèles Dynamiques Equivalents



Saturation



linéaire

$$V_{DSp} < V_{GSp} - V_{tp} < 0$$

$$V_o - V_{DD} < 0 - V_{DD} - V_{tp} < 0$$

$$V_o < -V_{tp}$$

$$-V_{tp} + V_{GSp} < V_{DSp} < 0$$

$$V_o > -V_{tp}$$

V_{TP} algébrique ≈ -0.6V pour Vdd=5V

Etude du temps de descente

Td$_1$: $0.9V_{DD} > V_o > V_{DD} - V_{tn}$

Td$_2$: $V_{DD} - V_{tn} > V_o > 0.1V_{DD}$

□ $I_C = I_{DSn}$ saturation $V_o > V_{DD} - V_{tn}$

$$-C_L \frac{dV_o}{dt} = K_n (V_{DD} - V_{tn})^2$$

$$\Rightarrow C_L \frac{dV_o}{dt} + K_n (V_{DD} - V_{tn})^2 = 0$$

$$t_{d1} = \frac{C_L}{K_n (V_{DD} - V_{tn})^2} \int_{V_{DD} - V_{tn}}^{0.9V_{DD}} dV_o$$

$$t_{d1} = \frac{C_L (V_{tn} - 0.1V_{DD})}{K_n (V_{DD} - V_{tn})^2}$$

Etude du temps de descente

- linéaire $V_o < V_{DD} - V_{tn}$

$$-C_L \frac{dV_o}{dt} = K_n[2(V_{DD} - V_{tn})V_o - V_o^2] \qquad C_L \frac{dV_o}{dt} + K_n[2(V_{DD} - V_{tn})V_o - V_o^2] = 0$$

$$\frac{K_n}{C_L} dt = \frac{dV_o}{V_o^2 - 2(V_{DD} - V_{tn})V_o}$$

$$t_{d2} = \frac{C_L}{K_n} \int_{V_{DD}-V_{tn}}^{0.1V_{DD}} \frac{dV_o}{V_o^2 - 2(V_{DD} - V_{tn})V_o} \qquad t_{d2} = \frac{C_L}{K_n(V_{DD} - V_{tn})} \log \frac{19V_{DD} - 20V_{tn}}{V_{DD}}$$

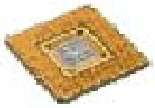
$$t_d = t_{d1} + t_{d2} = \frac{C_L}{K_n(V_{DD} - V_{tn})} \left(\frac{V_{tn} - 0.1V_{DD}}{V_{DD} - V_{tn}} + \frac{1}{2} \log \frac{19V_{DD} - 20V_{tn}}{V_{DD}} \right)$$

<u>A.N</u>

$V_{tn} \approx 0.2V_{DD} \approx 1V$

pour VDD= 5V

$$t_d \approx \frac{C_L}{K_n V_{DD}}$$



Etude du temps de montée

Etude identique que pour le temps de descente mais il faut considérer que V_o évolue de:

$$0.1V_{DD} \rightarrow |V_{tp}| \Rightarrow t_{m1}(saturation\ \ )$$

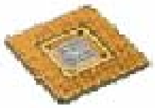
$$|V_{tp}| \rightarrow 0.9V_{DD} \Rightarrow t_{m2}(linéaire\ \ )$$

$$t_m = \frac{C_L}{K_p(V_{DD}-|V_{tp}|)}\left[\frac{|V_{tp}|-0.1V_{DD}}{V_{DD}-|V_{tp}|}+\frac{1}{2}\log\frac{19V_{DD}-20|V_{tp}|}{V_{DD}}\right]$$

A.N: $|V_{tp}| = 0.2V_{DD} \Rightarrow t_m \approx \dfrac{C_L}{K_pV_{DD}}$

Equilibre: $t_d = t_m \Rightarrow K_n = K_p$

$$\Rightarrow \mu_n\frac{W_n}{L_n} = \mu_p\frac{W_p}{L_p}$$



Etude du temps de propagation tPHL

tPHL$_1$: $V_{DD} > V_o > V_{DD} - V_{tn}$

tPHL$_2$: $V_{DD} - V_{tn} > V_o > 0.5V_{DD}$

□ $I_C = I_{DSn}$ saturation $V_o > V_{DD} - V_{tn}$

$$-C_L \frac{dV_o}{dt} = K_n(V_{DD} - V_{tn})^2$$

$$\Rightarrow C_L \frac{dV_o}{dt} + K_n(V_{DD} - V_{tn})^2 = 0$$

$$t_{PHL1} = \frac{C_L}{K_n(V_{DD} - V_{tn})^2} \int_{V_{DD}-V_{tn}}^{V_{DD}} dV_o$$

$$t_{PHL1} = \frac{C_L(V_{tn})}{K_n(V_{DD} - V_{tn})^2}$$

Etude du temps de propagation tPHL

- linéaire $V_o < V_{DD} - V_{tn}$

$$-C_L\frac{dV_o}{dt} = K_n[2(V_{DD}-V_{tn})V_o - V_o^2] \qquad C_L\frac{dV_o}{dt} + K_n[2(V_{DD}-V_{tn})V_o - V_o^2] = 0$$

$$\frac{K_n}{C_L}dt = \frac{dV_o}{V_o^2 - 2(V_{DD}-V_{tn})V_o}$$

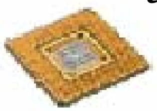
$$t_{PHL2} = \frac{C_L}{K_n}\int_{V_{DD}-V_{tn}}^{0.5V_{DD}} \frac{dV_o}{V_o^2 - 2(V_{DD}-V_{tn})V_o}$$

$$tPHL = tPHL_1 + tPHL_2 = \frac{C_L}{K_n(V_{DD}-V_{tn})}\left(\frac{2V_{tn}}{V_{DD}-V_{tn}} + \log\left(\frac{4(V_{DD}-V_{tn})}{V_{DD}} - 1\right)\right)$$

A.N

$V_{tn} \approx 0.2V_{DD} \approx 1V$

$$t_d \approx \frac{C_L}{K_n V_{DD}}$$



Etude du temps de propagation tPLH

Etude identique que pour le temps de descente mais il faut considérer que V_o évolue de:

$$V_{SS} \rightarrow |V_{tp}| \Rightarrow t_{PLH\,1}(saturation\ )$$

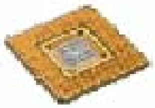
$$|V_{tp}| \rightarrow 0.5V_{DD} \Rightarrow t_{PLH\,2}(linéaire\ )$$

$$tPLH = \frac{C_L}{K_p(V_{DD} - |V_{tp}|)}\left[\frac{2|V_{tp}|}{V_{DD} - |V_{tp}|} + \log\left(\frac{4(V_{DD} - |V_{tp}|)}{V_{DD}} - 1\right)\right]$$

A.N: $|V_{tp}| = 0.2V_{DD} \Rightarrow t_{PLH} \approx \dfrac{C_L}{K_p V_{DD}}$

Equilibre: $t_{PHL} = t_{PLH} \Rightarrow K_n = K_p$

$$\Rightarrow \mu_n \frac{W_n}{L_n} = \mu_p \frac{W_p}{L_p}$$



Dimensions W/L en fonction des temps

$$K_n = \mu nCox \frac{Wn}{Ln}$$

$$Kp = \mu pCox \frac{Wp}{Lp}$$

$$tPHL = \frac{C_L}{K_n(V_{DD} - V_{tn})}\left(\frac{2V_{tn}}{V_{DD} - V_{tn}} + \log\left(\frac{4(V_{DD} - V_{tn})}{V_{DD}} - 1\right)\right)$$

$$\frac{Wn}{Ln} = \frac{C_L}{tPHL\ \mu nCox\,(V_{DD} - V_{tn})}\left(\frac{2V_{tn}}{V_{DD} - V_{tn}} + \log\left(\frac{4(V_{DD} - V_{tn})}{V_{DD}} - 1\right)\right)$$

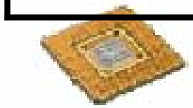
$$tPLH = \frac{C_L}{K_p(V_{DD} - |V_{tp}|)}\left[\frac{2|V_{tp}|}{V_{DD} - |V_{tp}|} + \log\left(\frac{4(V_{DD} - |V_{tp}|)}{V_{DD}} - 1\right)\right]$$

$$\frac{Wp}{Lp} = \frac{C_L}{tPLH\ .\mu p\,.Cox\ (V_{DD} - |V_{tp}|)}\left[\frac{2|V_{tp}|}{V_{DD} - |V_{tp}|} + \log\left(\frac{4(V_{DD} - |V_{tp}|)}{V_{DD}} - 1\right)\right]$$

French MPC

General electrical parameters for 2 mic. 2 metal CMOS processes

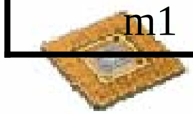
Parameter	Unit	typical		min - max	
		N-channel	P-channel	N-channel	P-channel
Threshold V_{TO}	v	.7 <->.9	-.9<->-.7	.5 <->1.2	-1.2 <->-.4
TransconductanceK (1/2µCox)	$a.v^{-2}.E\text{-}6$	30<->37	9<->13	24<->45	6.5<->13
Bulk threshlold KB,λ $\left(\frac{\sqrt{2\, q e_{si} N_{sub}}}{Cox}\right)$	$v^{1/2}$	.65<->.9	.4<->.75	.55<->1.1	.4<->.9
Poly Field threshold Voltage VTFP	v			10	-10
Breakdown voltage BVDS	v			7	-7
Delta L (drawn minus effective channel length)	m.E-6	.3<->.5	.5<->.9	<.8	<1.3
Delta W (drawn minus Effective channel width)(*)	m.E-6	1.2<->1.8	1.2<->1.5	<2.3	<2



French MPC

General electrical parameters for 2 mic. 2 metal CMOS processes

Parameter	Unit	typical		min - max	
		N-channel	P-channel	N-channel	P-channel
Junction capacitances:					
surface	f.m^{-2} E-6	210<->390			
periph.	f.m^{-1} E-12	270<->420			
Capacitances :					
poly/ thin ox	f.m^{-2} E-6	860<->1150		780<->1250	
field ox	f.m^{-2} E-6	36<->60		32<->70	
m1/ thin ox	f.m^{-2} E-6	30<->50		27<->58	
field ox	f.m^{-2} E-6	19<->28		16<->32	
poly	f.m^{-2} E-6	35<->50		31<->58	
m2/ thin ox	f.m^{-2} E-6	17<->23		15<->27	
field ox	f.m^{-2} E-6	13<->17		11<->20	
poly	f.m^{-2} E-6	17<->25		12<->29	
m1	f.m^{-2} E-6	28<->45		22<->52	



French MPC

General electrical parameters for 2 mic. 2 metal CMOS processes

Parameter	Unit	typical		min - max	
		N-channel	P-channel	N-channel	P-channel
Resistances:					
well	Ω / sq	2000<->3500		1500<->3500	
P^+	Ω / sq	60<->200		40<->220	
N^+	Ω / sq	35<->50		25<->55	
Poly	Ω / sq	18<->25		14<->30	
métal 1	Ω / sq	.05<->.1		.04<->.11	
métal 2	Ω / sq	.03<->.05		.02<->.06	
2×2 µcontact :					
N^+	Ω	35<->50		20<->150	
P^+	Ω	25<->60		15<->200	
poly	Ω	10<->20		5<->50	
2.5×2.5 µvias	Ω	.1<->.2		.1<->.3	
Thin oxyde thickness	m E-10	250<->400		230<->440	

French MPC

General electrical parameters for 2 mic. 2 metal CMOS processes

Parameter	Unit	typical		min - max	
		N-channel	P-channel	N-channel	P-channel
Max. current density					
métal 1	a.E-3/m.E-6	.3			
métal 2	a.E-3/m.E-6	1			

:

Delta WN = .2 ∓ .4
Delta WP = .1 ∓ .4

Définition $R_ƀ$

$$R = \rho \frac{w}{l \cdot e} = \frac{\rho}{e} \cdot \frac{w}{l} = R_ƀ \cdot \frac{w}{l}$$