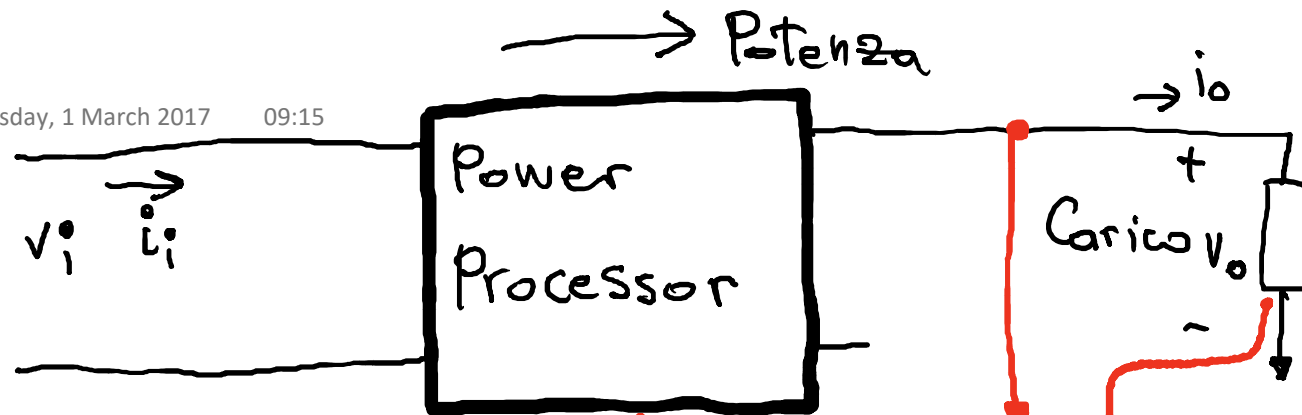


ELETTRONICA DI POTENZA

Wednesday, 1 March 2017 09:10

ha il compito di CONTROLLARE
e GESTIRE il flusso di ENERGIA ELETTRICA
fornendo TENSIONI e CORRENTI in
una forma ottimizzata per il carico
utente.

Wednesday, 1 March 2017 09:15



Per es:

- Rete di distribuzione 50Hz
- Batteria
- Gener. termoelettrico
- Cella PV

1. μC
2. sistema lin.

Consumo di potenza / Efficienza di conversione

Wednesday, 1 March 2017

09:23

P_o
 P_i

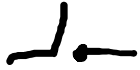
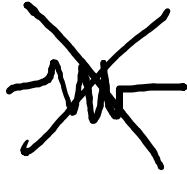
$$P_{\text{loss}} = P_i - P_o$$

$$\eta = \frac{P_o}{P_i} = \frac{P_o}{P_o + P_{\text{loss}}}$$

- Costo dell'energia
- Raffreddamento, Ingombro
- Affidabilità
- Costo del sistema

Idealmente voglio usare componenti che
non dissipino potenza

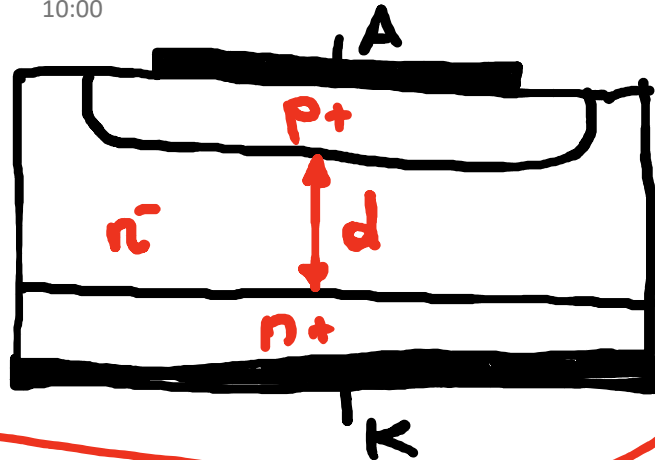
Wednesday, 1 March 2017 09:32



DIODO DI POTENZA

Wednesday, 1 March 2017 10:00

sezione



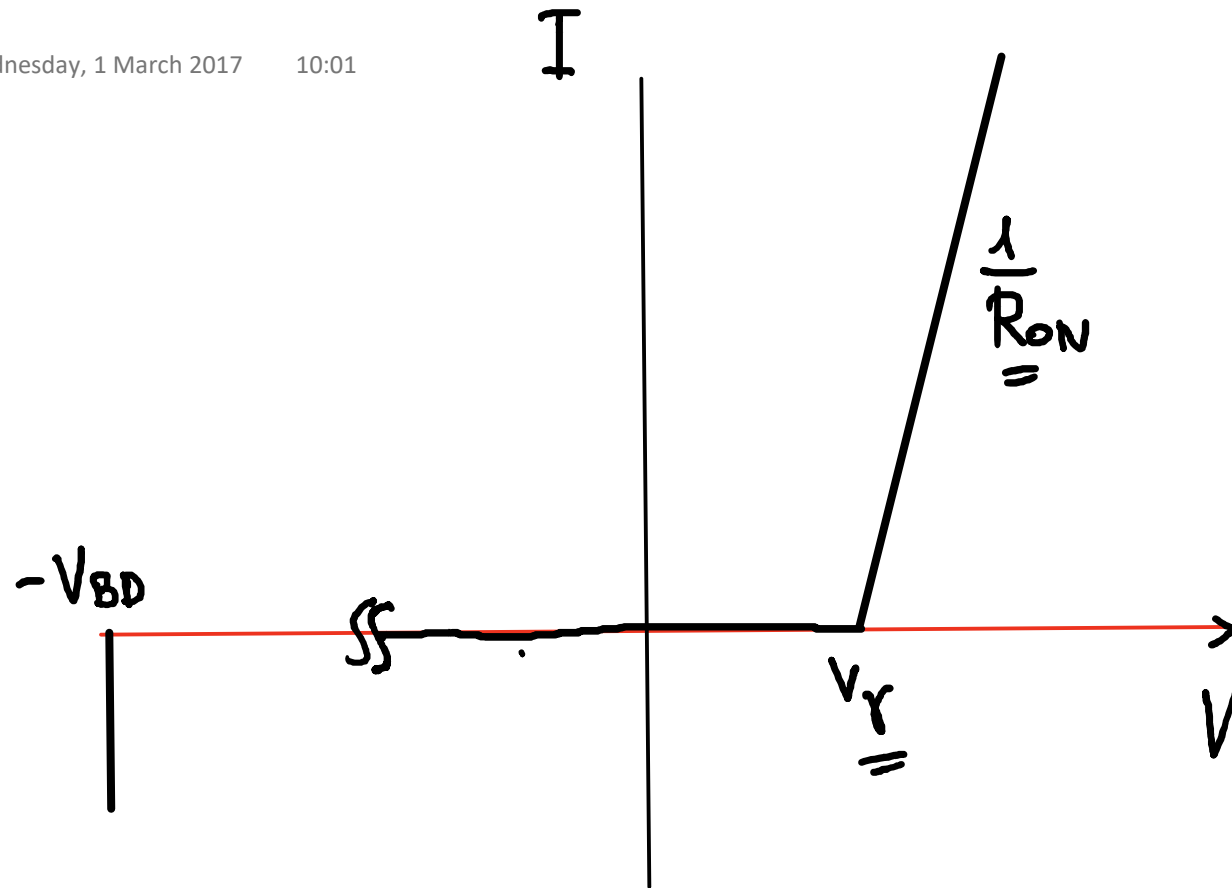
VERTICALE

REGIONE
DI DERIVA
[drift region]

Alta resistività (n^-)

↳ AUMENTARE LA TENSIONE DI BREAKDOWN (+)

↳ AUMENTARE R_{ON}



DIODO SENZA PUNCHTHROUGH

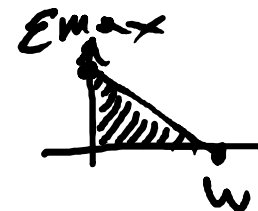
Wednesday, 1 March 2017 10:01

3) la zona di svuotamento NON raggiunge la regione n^+ \rightarrow tutto il potenziale cade nella regione di deriva

w spessore della zona di svuotamento

$$E_{\max} = \frac{qN_D w}{\epsilon_0 \epsilon_r}$$

$$\phi = \frac{1}{2} \frac{qN_D w^2}{\epsilon_0 \epsilon_r} =$$



$$= \frac{1}{2} E_{\max} w$$

AL BREAKDOWN

$$\phi_{BD} = \frac{1}{2} E_{BD} \cdot w_{BD} [w_{BD} < d]$$

Es. $E_{BD} = 2 \cdot 10^5 \text{ V/cm}$

Vogliamo $V_{BD} = 1000 \text{ V}$

$\rightarrow w_{BD} = 100 \mu\text{m}$

$\rightarrow N_D = \frac{E_{BD} \epsilon_0 \epsilon_r}{q w_{BD}} = \underline{\underline{1.3 \cdot 10^{15} \text{ cm}^{-3}}}$

Diodi CON PUNCHTHROUGH

Wednesday, March 8, 2017 8:46 AM

1) LA REGIONE DI SVUOTAMENTO ARRIVA ALLA ZONA n^+



$$\phi = \frac{(\mathcal{E}_{max} + \mathcal{E}_2) d}{2}$$

$$\frac{d\mathcal{E}}{dx} = -\frac{qN_D}{\epsilon_0 \epsilon_{Si}}$$

$$\mathcal{E}_2 = \mathcal{E}_{max} - \frac{qN_D}{\epsilon_0 \epsilon_{Si}} d$$

2) caso limite $[N_D \rightarrow 0 \rightarrow \mathcal{E}_2 \sim \mathcal{E}_{max}]$

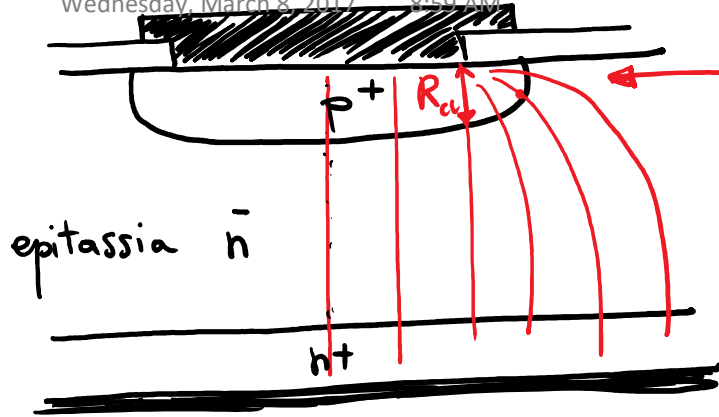
$$\phi = \mathcal{E}_{max} d \quad \text{AL BREAKDOWN}$$

$$V_{BD} = \mathcal{E}_{BD} d$$

A parità di d e \mathcal{E}_{BD} abbiamo $V_{BD} = 2 \times$ il caso di diodo senza punchthrough

CURVATURA DELLA DIFFUSIONE P⁺

Wednesday, March 8, 2017 8:59 AM



campo elettrico + alto in presenza delle curve

↓
RIDUZIONE DELLA V_{BD}

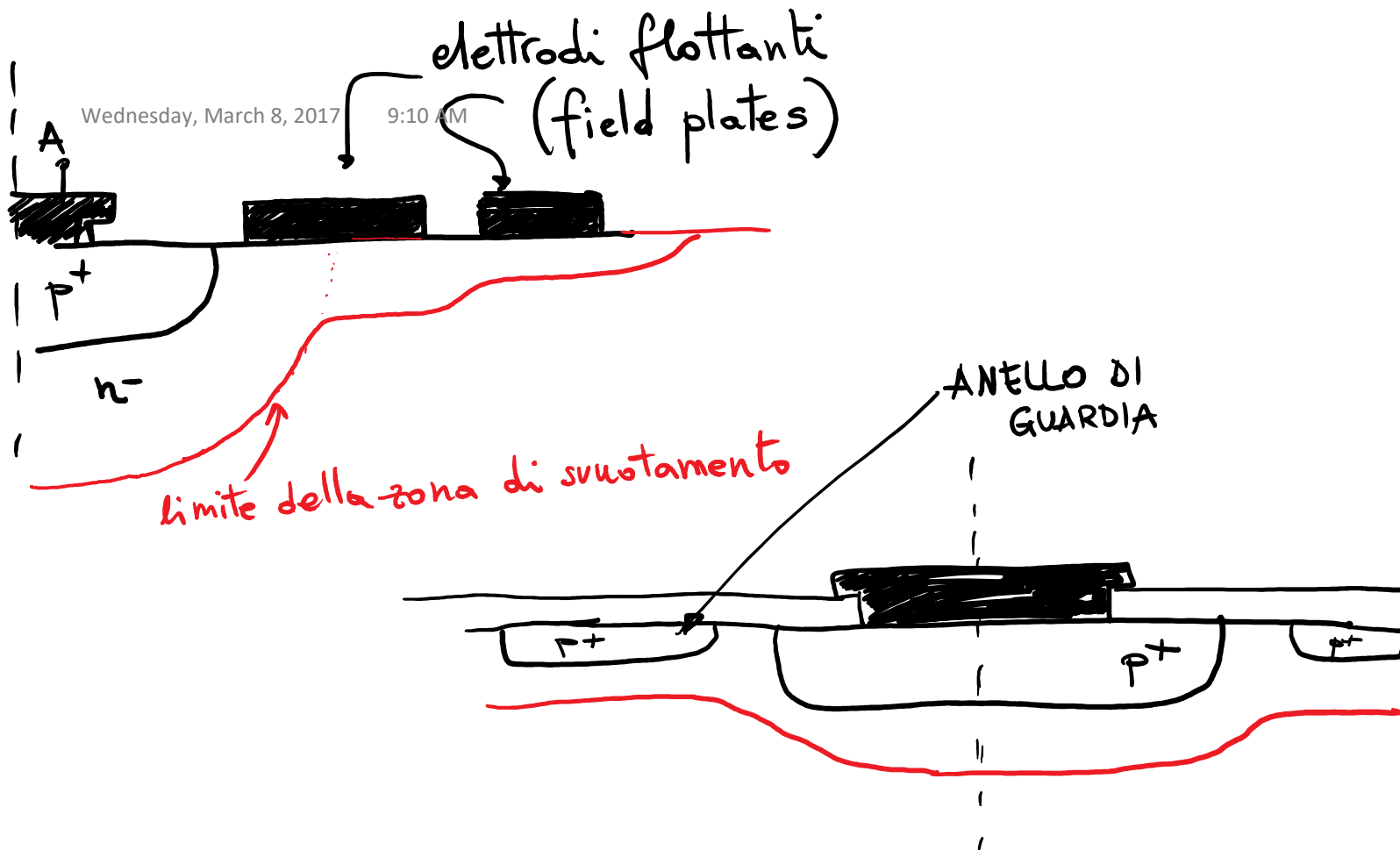
Per RIDURRE solo del 10% la V_{BD} è necessario che

$$\rightarrow \underline{R_{curvatura} > 6 W_{BD}}$$

richiederebbe uno spessore troppo alto della epitassia

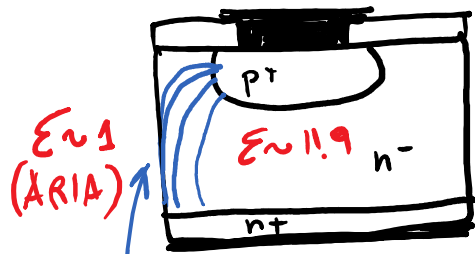
UNITATO A DIODI →
CON $V_{BD} < 600V$

PER $V_{BD} > 100V$
si usano
ANELLI DI GUARDIA
ELETTRODI FLOTTANTI

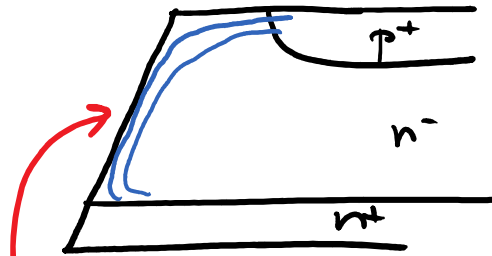


GESTIONE DELLA SUPERFICIE

Wednesday, March 8, 2017 9:16 AM



incremento del
campo elettrico
alla superficie con l'aria

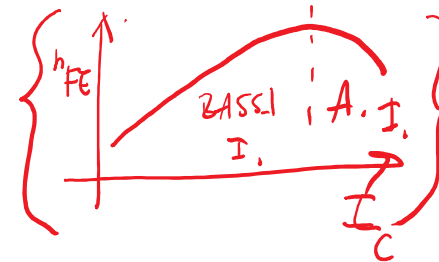
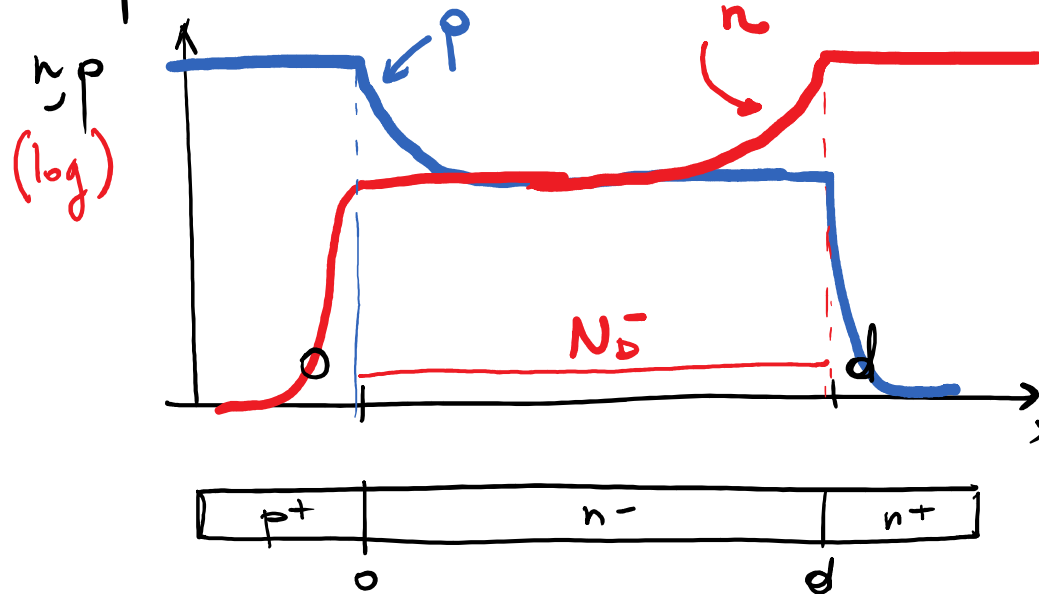


BEVELING
si aumenta la lunghezza
delle linee di forza per
ridurre il campo elettrico.
all'interfaccia con l'aria

MODULAZIONE DELLA CONDUTTIVITÀ

Wednesday, March 8, 2017 9:21 AM

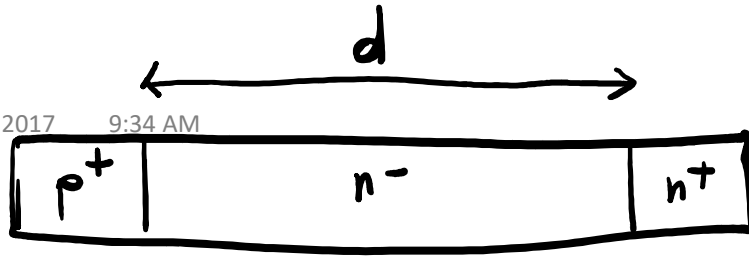
in polarizzazione diretta si fa funzionare il diodo in ALTA INIEZIONE



$$p \sim n \sim n_a \gg N_D^-$$

PLASMA DI CARICHE NELLA REGIONE DI DERIVA

↙
Aumenta molto la conduttività della regione di deriva



$$(n \approx p \approx n_a)$$

Corrente di deriva

$$I = Aq\mu_n n \left(\frac{V_d}{d} \right) + Aq\mu_p p \left(\frac{V_d}{d} \right) =$$

$$I = qA n_a (\mu_n + \mu_p) \left(\frac{V_d}{d} \right)$$

RICOMBINAZIONE

$$I = \frac{Q}{\tau} = \frac{Adqna}{\tau}$$

Tempo di vita dei portatori
nella regione di deriva

$$V_d = \frac{d^2}{\tau(\mu_n + \mu_p)}$$

introducono
la dipendenza
da I

$$V_d \propto d^2$$

RECAP

Wednesday, March 8, 2017 9:42 AM

INVERSA
(OFF)

$$V_{BD} \propto d$$

$$\begin{aligned} &\rightarrow V_{BD} = E_{BD} d \\ &\rightarrow V_{BD} \leq \frac{E_{BD} d}{2} \end{aligned}$$

DIODO CON
PUNCHTHROUGH
(caso limite)

DIODO SENZA
PUNCHTHROUGH

CONDUZIONE

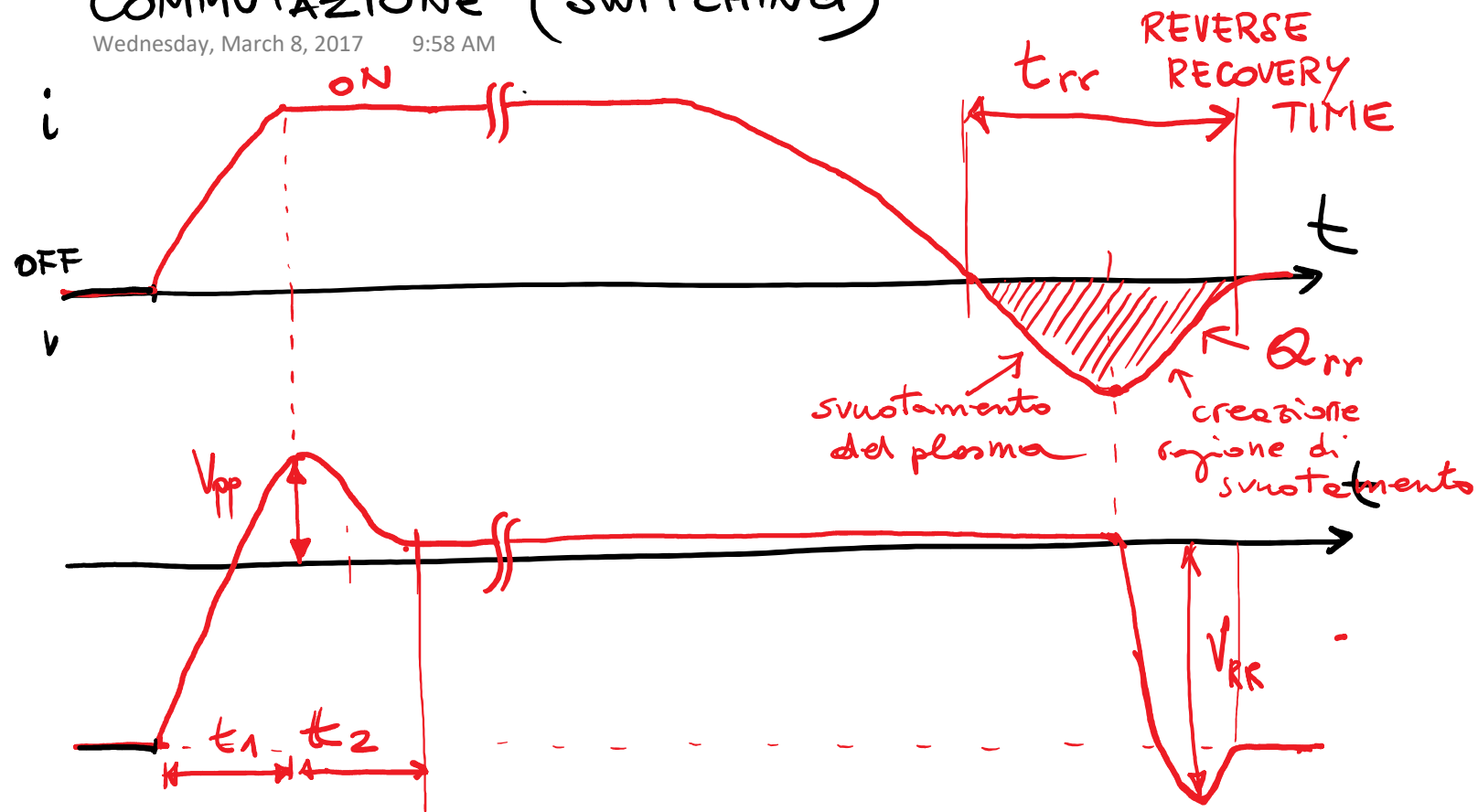
$$(ON) V_{ON} = V_j + V_d$$

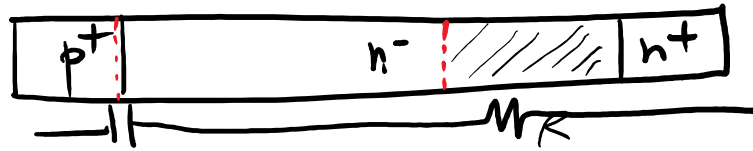
$$\rightarrow V_d \propto d^2$$

NON DIPENDE DAL
DROGGAGGIO

COMMUTAZIONE (SWITCHING)

Wednesday, March 8, 2017 9:58 AM



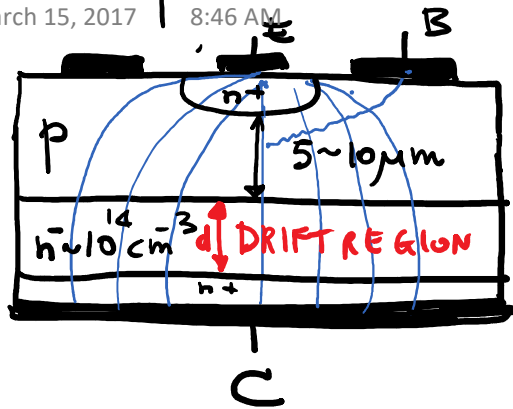


t_1 [ns] eliminazione della regione di smottamento
alta resistività nella regione di deriva

t_2 [ns] formazione del plasma
riduzione della resistività della regione di deriva

BJT di potenza

Wednesday, March 15, 2017 8:46 AM



$$n^+ \approx 10^{19} \text{ cm}^{-3}$$

$$p \approx 10^{16} \cdot 10^{17} \text{ cm}^{-3}$$

10-100 μm

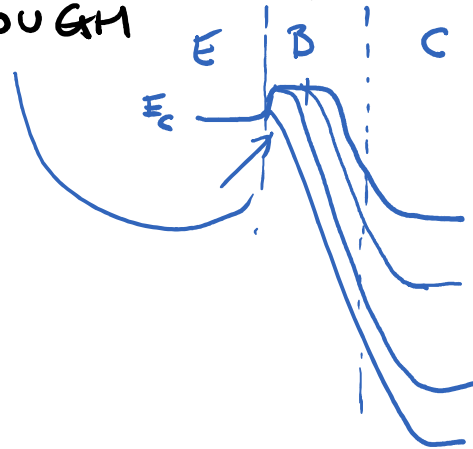
STRUTTURA VERTICALE

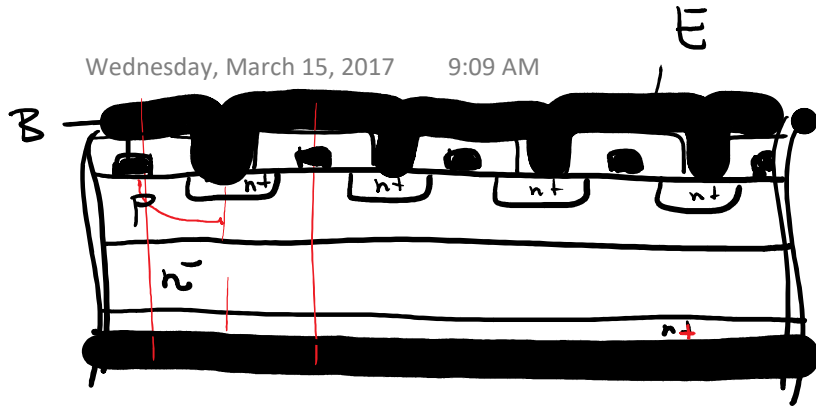
- ↳ alta sezione di conduzione
- ↳ "bassa" resistenza serie di C
- ↳ bassa resistenza termica

$$\underline{V_{BD} \sim d E_{BD}}$$

SPESSORE della base 5-10 μm
per evitare il REACHTHROUGH

$$\hookrightarrow \beta_F \approx 5-10$$





Struttura
MULTI-EMETTORE

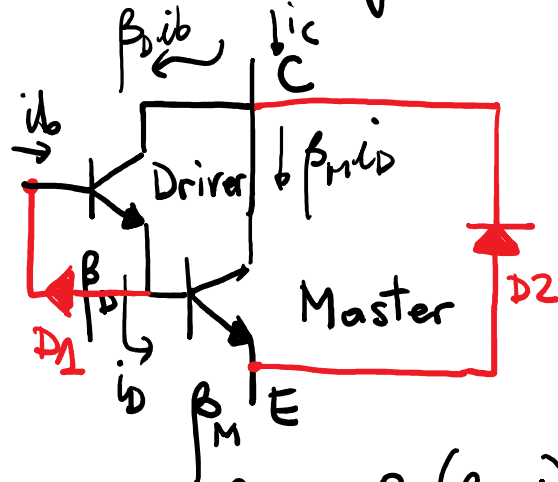
↓
Riduce l'effetto di
CURRENT CROWDING

↓
Riduce il rischio di
fuga termica

RIDUCE r_b

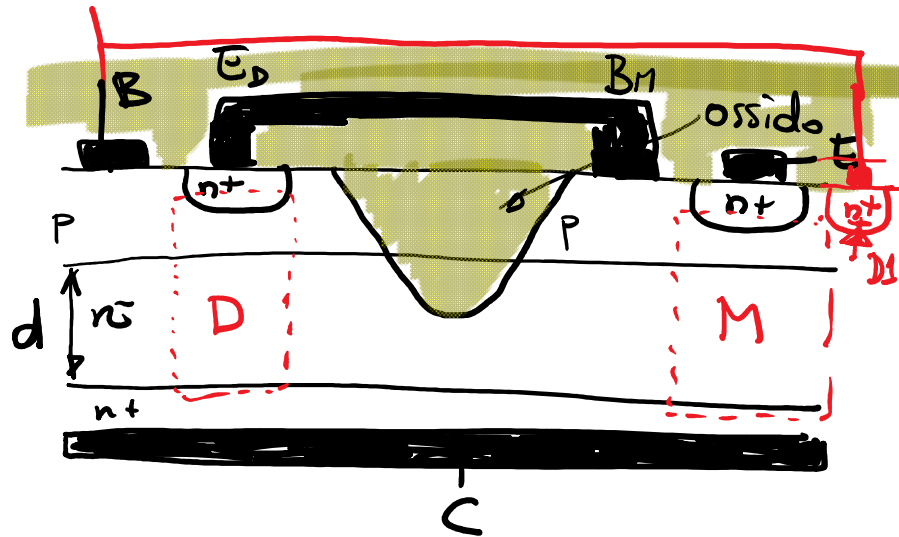
BJT Darlington

Wednesday, March 15, 2017 9:14 AM



$$i_c = \beta_M i_b + \beta_D i_b = \beta_M (\beta_D + 1) i_b + \beta_D i_b$$

$$\beta_{eq} = \frac{i_c}{i_b} = \beta_M \beta_D + \beta_D + \beta_M \sim \beta_M \beta_D$$

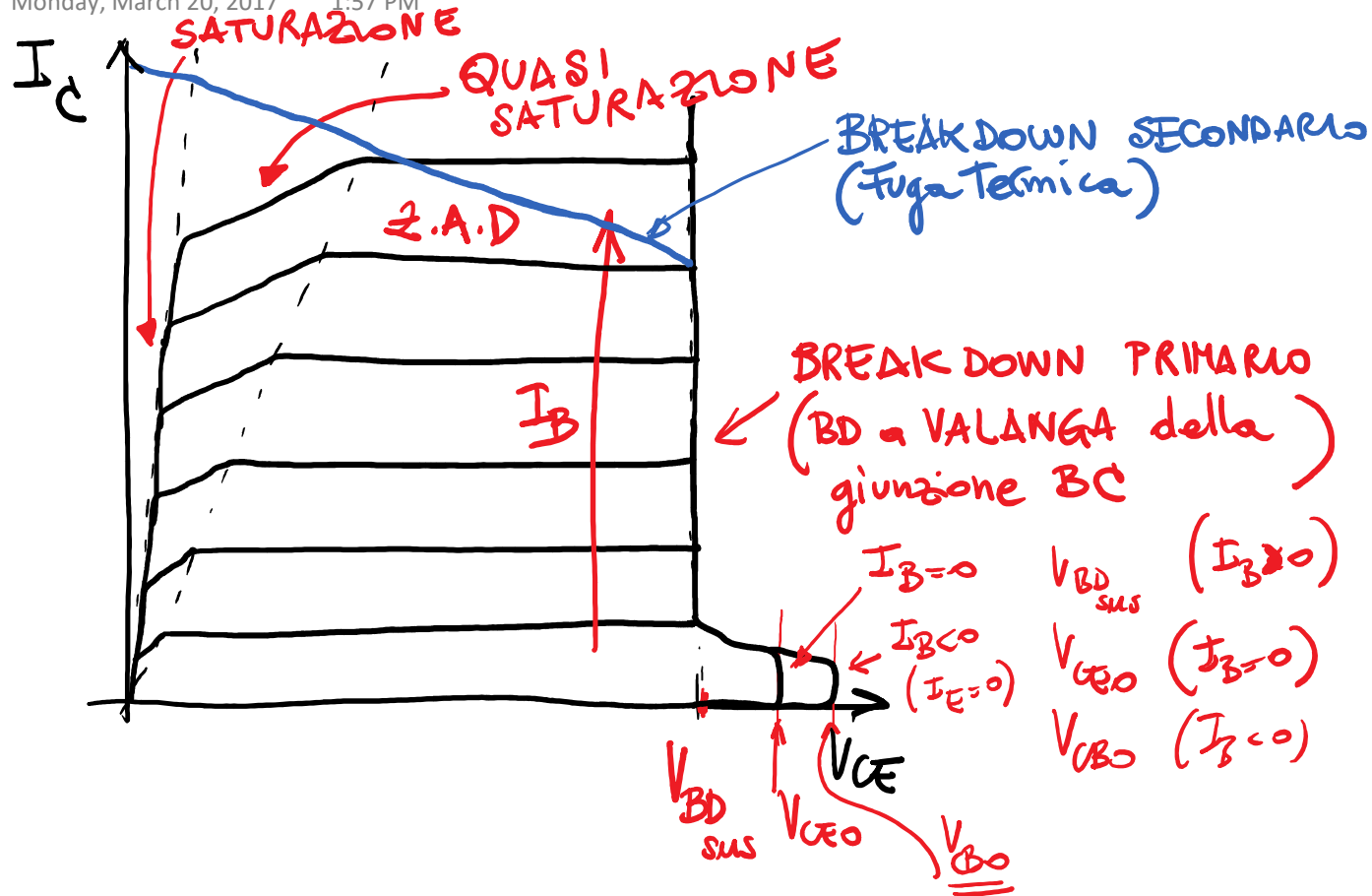


D1: Consente di applicare una i_{bc} durante lo spegnimento

D2: DIODO DI RICARICO

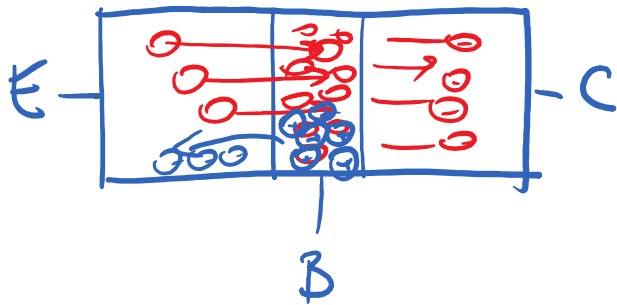
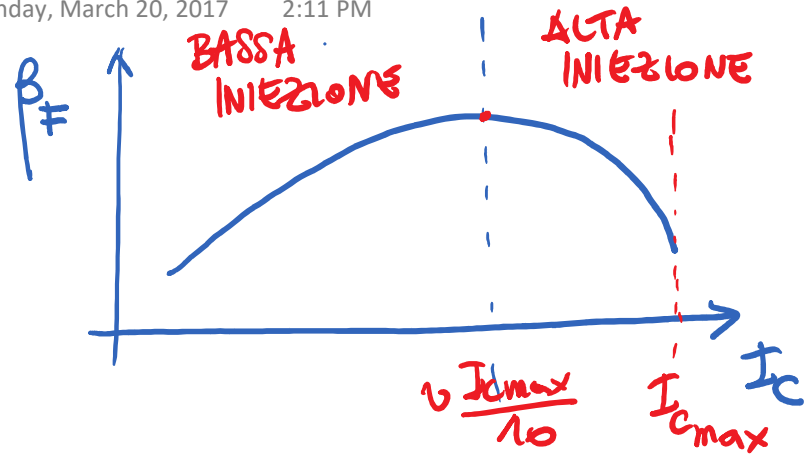
Caratteristiche di uscita

Monday, March 20, 2017 1:57 PM



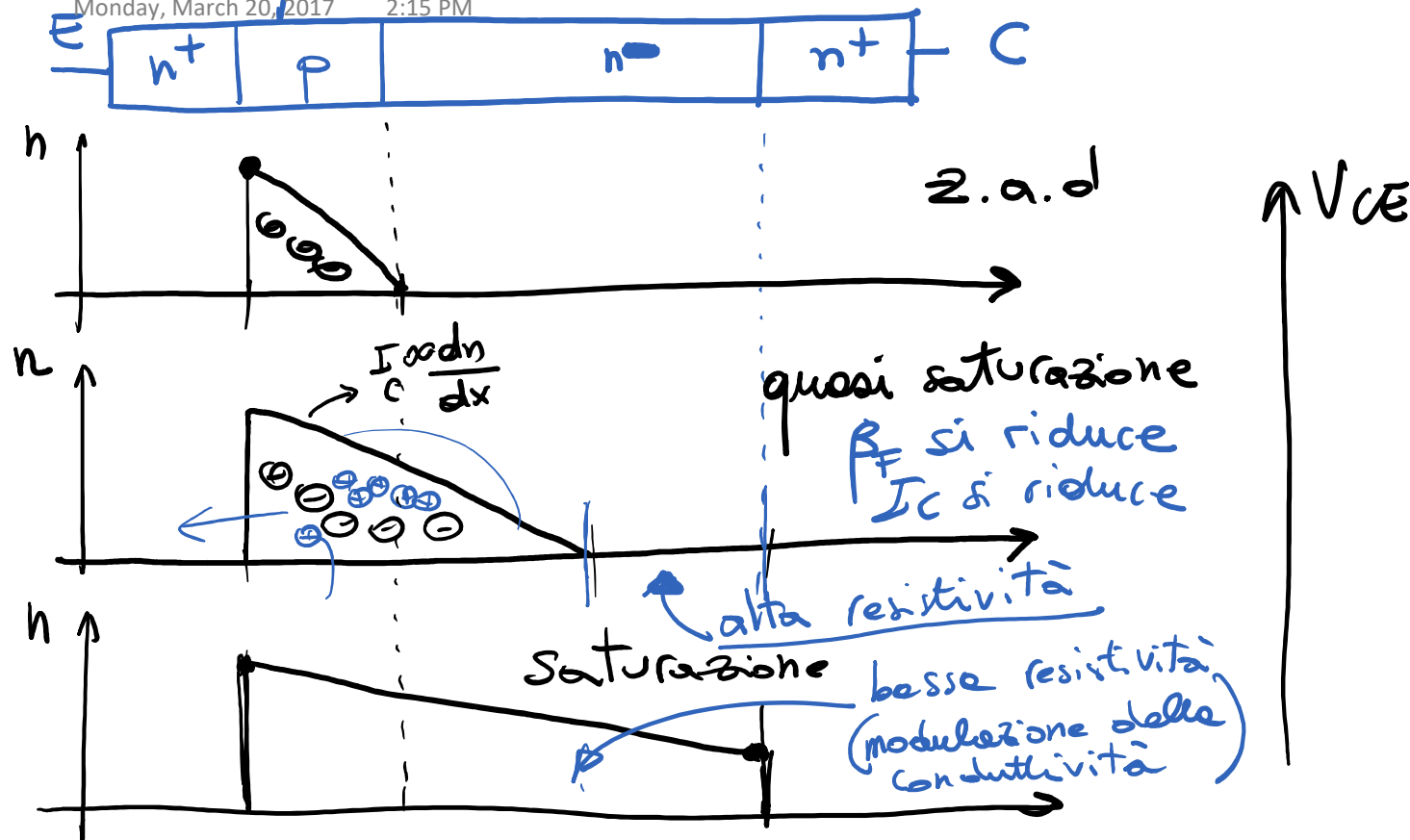
Alfa Iniezione

Monday, March 20, 2017 2:11 PM



Quasi saturazione

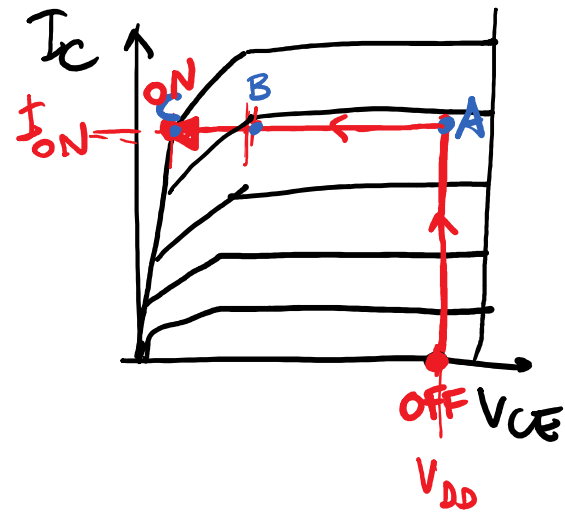
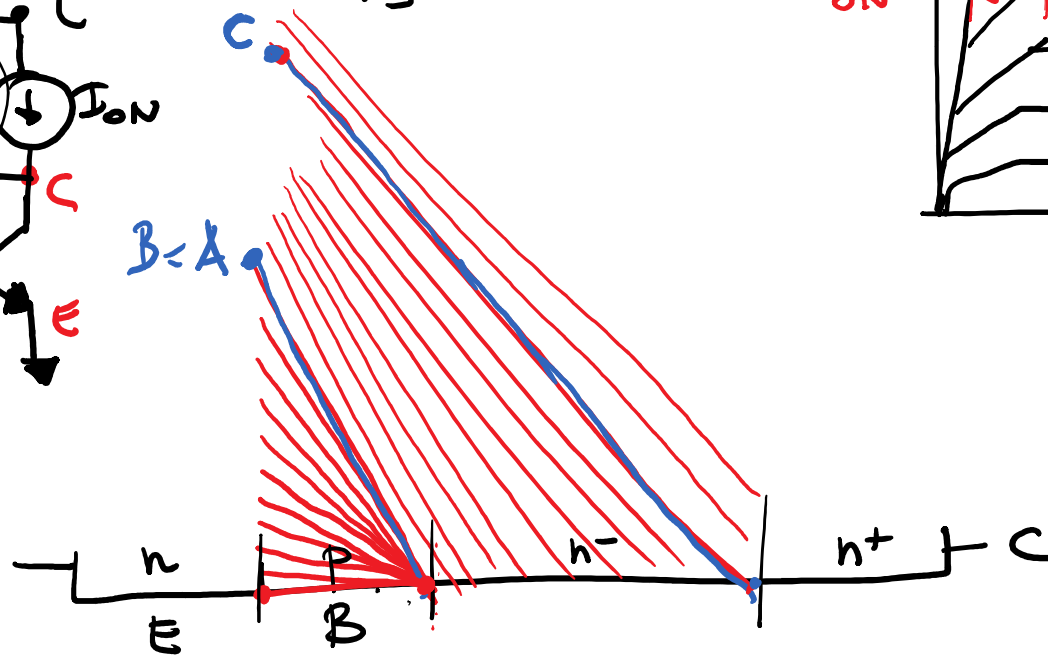
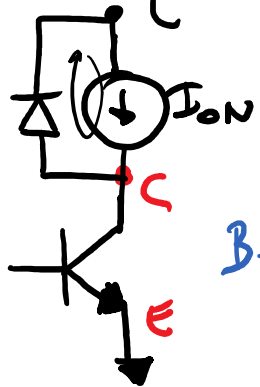
Monday, March 20, 2017 2:15 PM



Transistorio di accensione

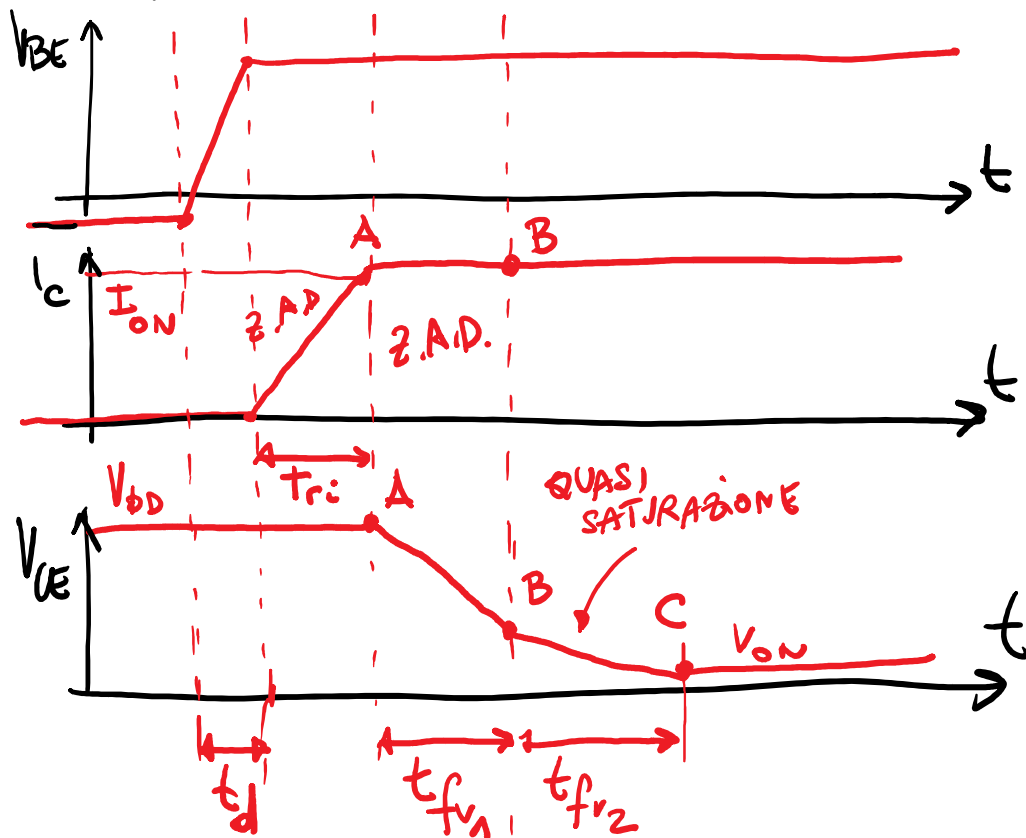
Monday, March 20, 2017 2:25 PM

V_{DD} [OFF \rightarrow SAT]

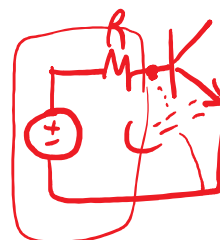


TRANSITORIO DI ACCENSIONE

Monday, March 20, 2017 2:37 PM

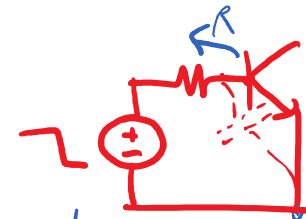
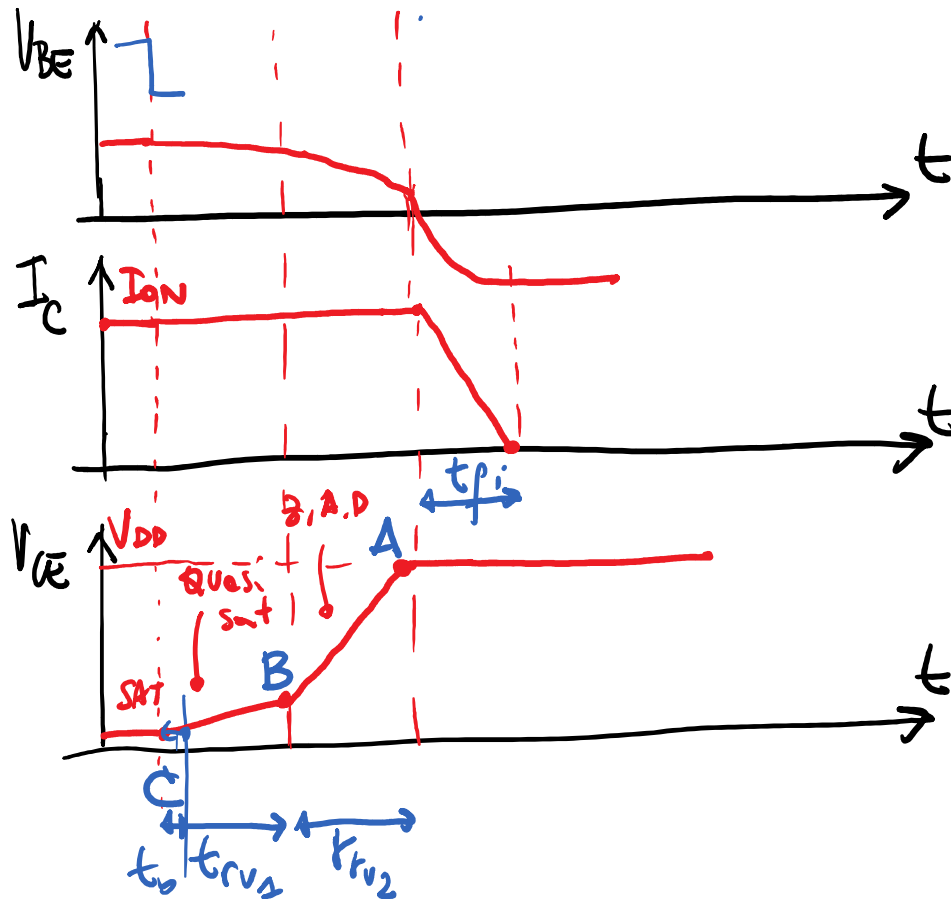


t_d current
 t_r rise time
 t_{fv} voltage
 t_{fv} fall time



TRANSITORIO DI SPEGNIMENTO

Monday, March 20, 2017 2:48 PM



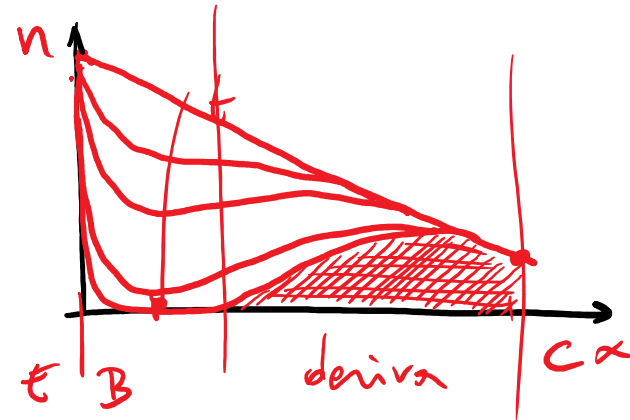
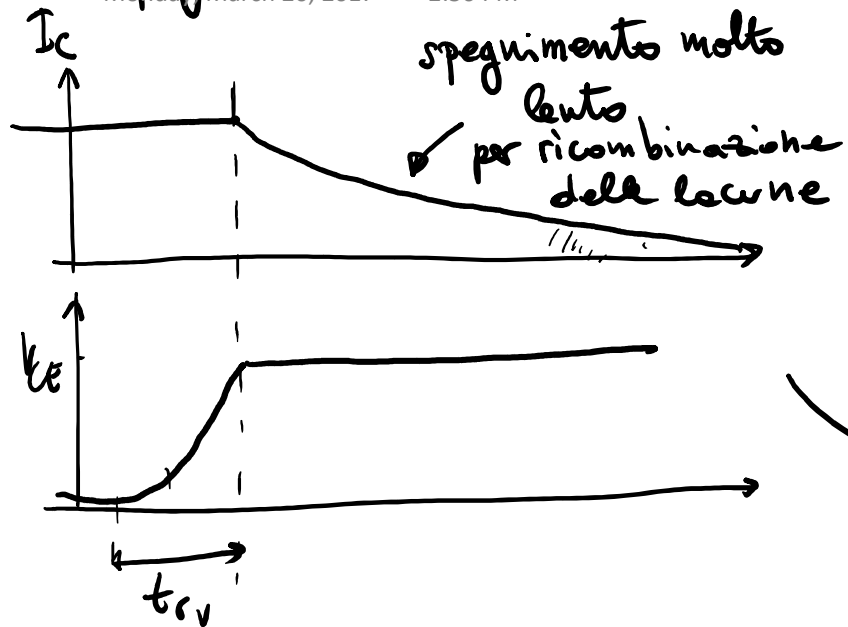
t_d delay time
 t_{rv1} voltage rise time
 t_{rv2} voltage rise time

t_{fi} current fall time

$$t_{rv1} + t_{rv2} \gg t_{fi}, t_d$$

Spegnimento non controllato

Monday, March 20, 2017 2:56 PM



LIMITE

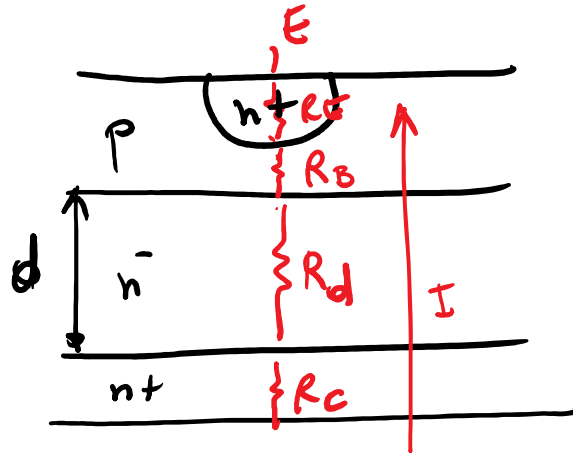
$$\frac{dI_B}{dt}$$

Circuito di protezione
(SNUBBER)

V_{ON}

Monday, March 20, 2017 3:03 PM

caduta di tensione in conduzione



$$V_{ON} = V_{ce_{sat}} + [R_E + R_B + R_D + R_C] I_{ON}$$

$$\frac{V_{BE_{sat}} - V_{BC_{sat}}}{\parallel}$$

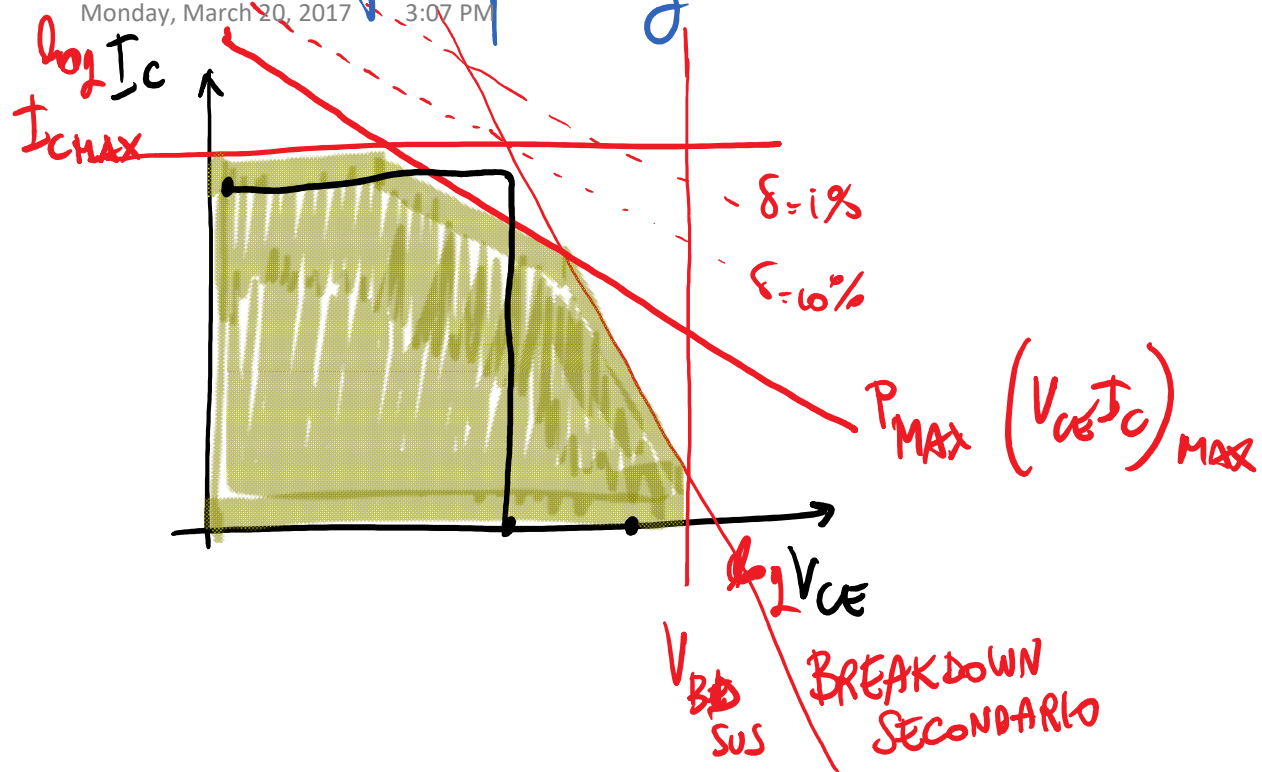
$$\sim 0.2V$$

$$V_{ON} \sim 1V$$

sono fortemente ridotte dall'effetto di modulazione della conduttività

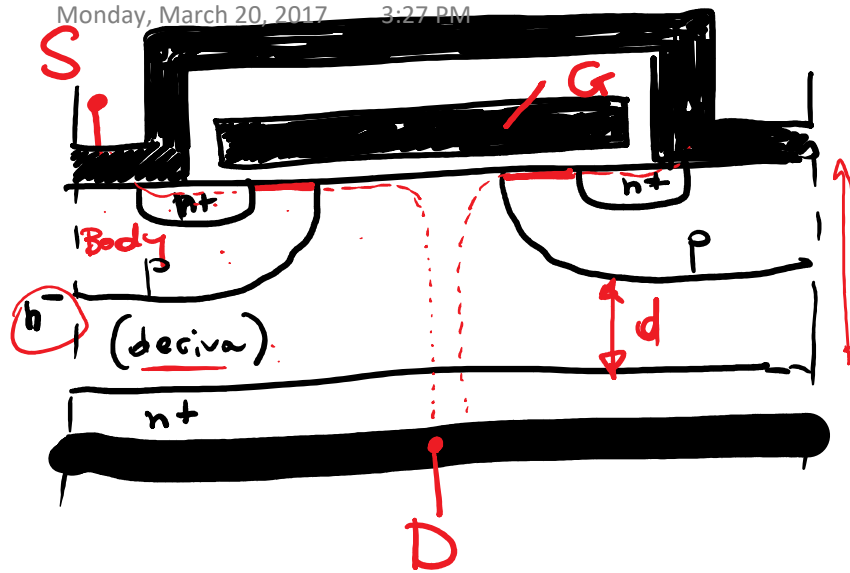
SOA Safe Operating Area

Monday, March 20, 2017 3:07 PM



MOSFET di POTENZA

Monday, March 20, 2017 3:27 PM



il GATE sulla regione di deriva
in ON: riduce la resistenza serie
in OFF: fa da FIELD PLATE

VD MOSFET

V_{PMOS}

D_{MOS}

Vertically Diffused

$$V_{bd} \approx E_{max} d$$

Body e source in corto
(non parassita inibito)

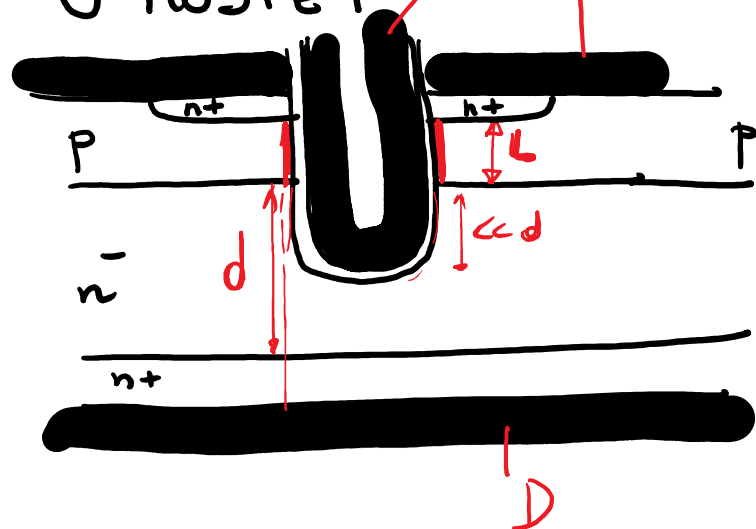
NON C'È MODULAZIONE
DELLA CONDUITIVITÀ

3:40 PM

3:40 PM

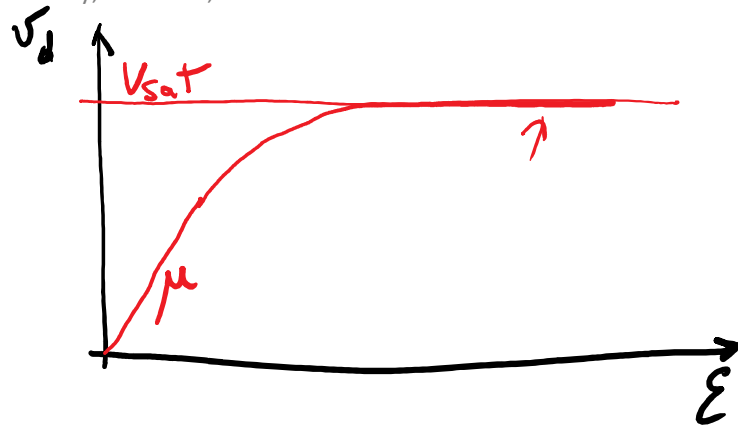
0 PM

G S



Saturazione della velocità

Monday, March 20, 2017 3:46 PM



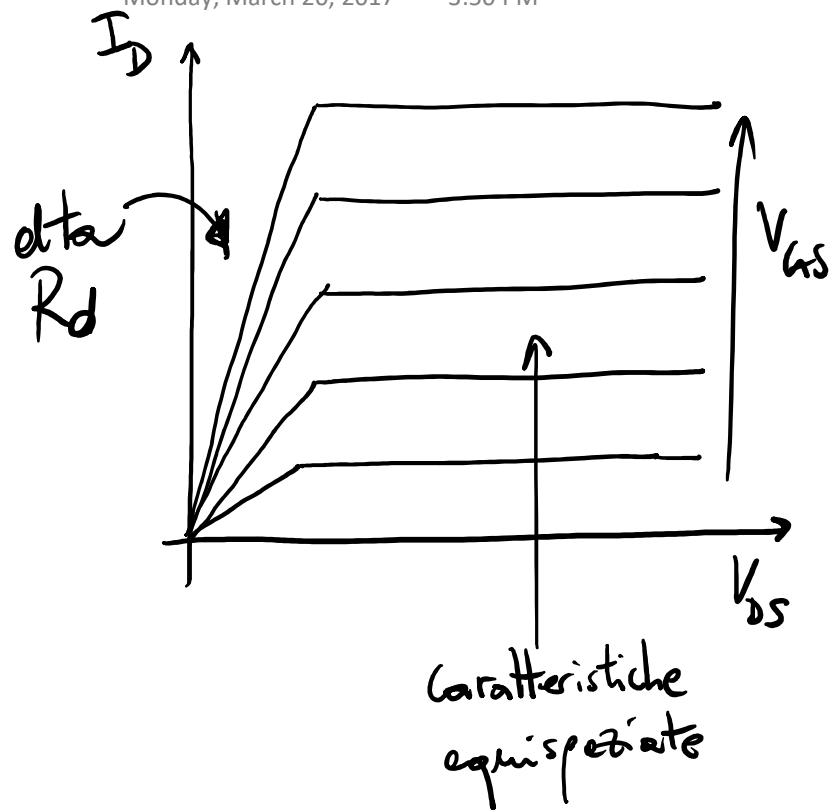
$$I \propto Q v_d$$
$$\text{se } Q \propto (V_{GS} - V_T)$$
$$v_d \propto E \propto V_{GS} - V_T$$
$$\downarrow$$
$$I \propto (V_{GS} - V_T)^2$$

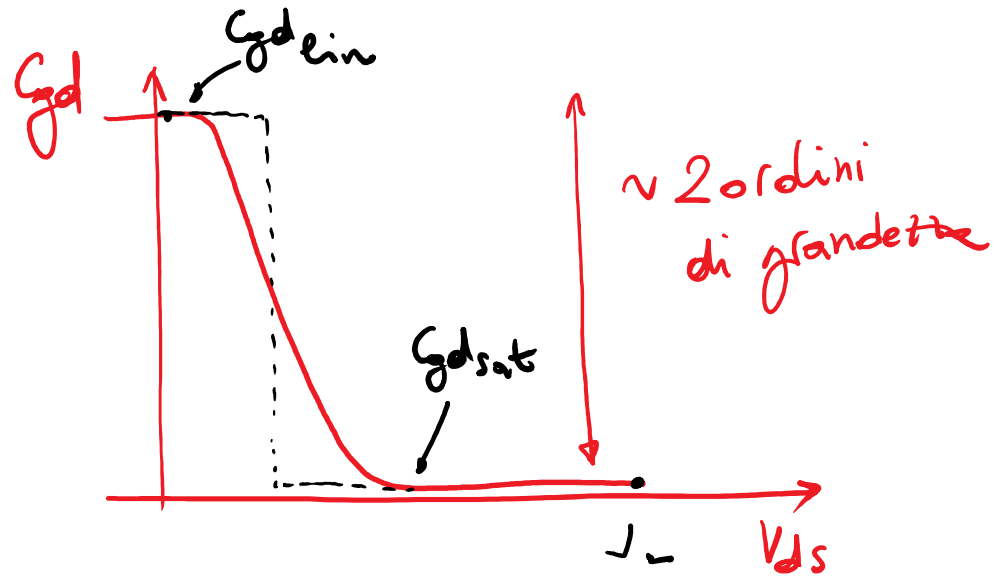
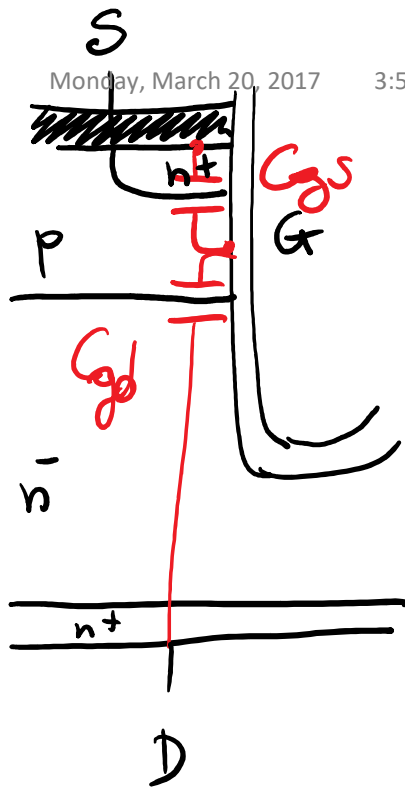
in condizioni di $v_d = v_{sat}$

$$I \propto \underline{\underline{(V_{GS} - V_T) v_{sat}}}$$

Caratteristiche di uscita

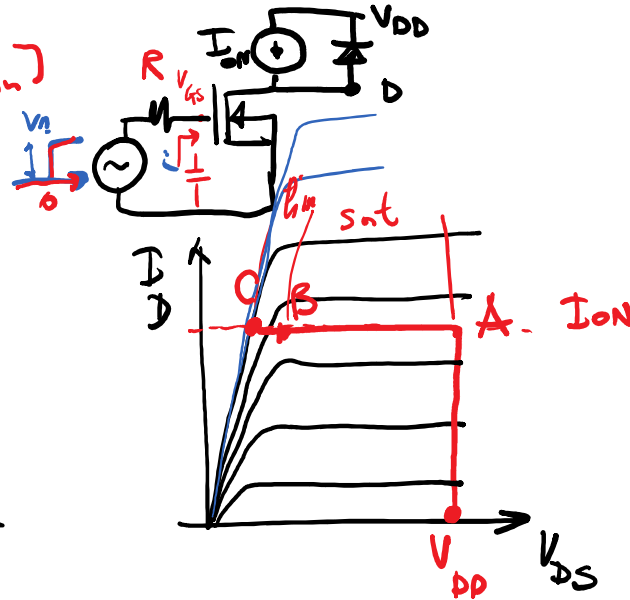
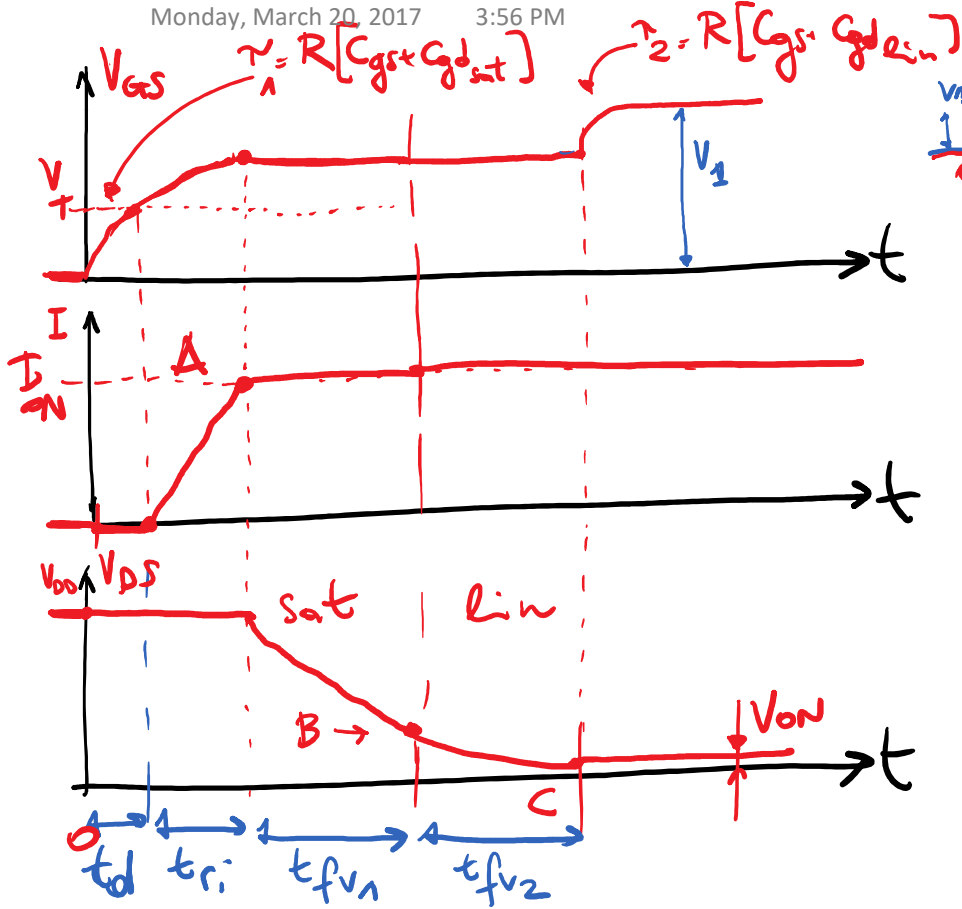
Monday, March 20, 2017 3:50 PM





Transitorio di accensione

Monday, March 20, 2017 3:56 PM

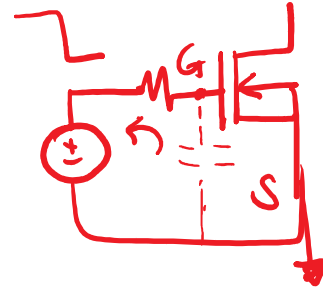
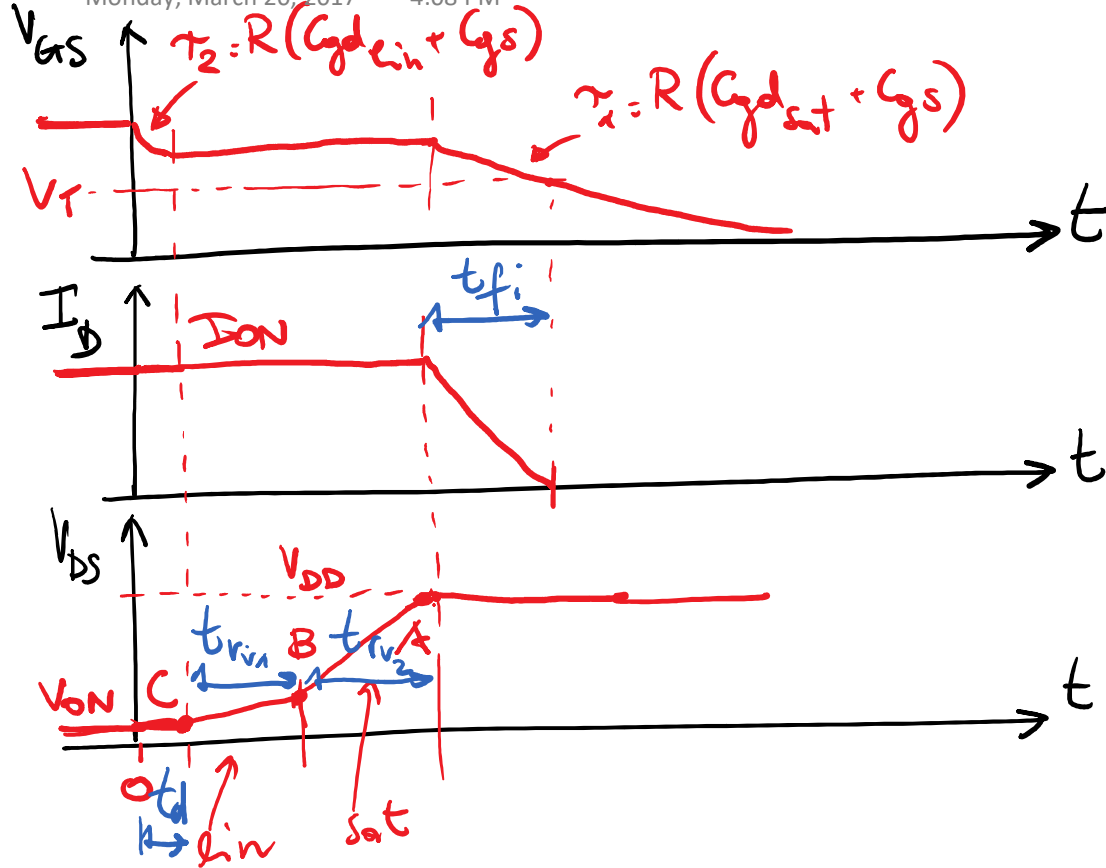


$$i = \frac{dQ}{dt} = \frac{d(CV_G)}{dt}$$

$$= \frac{dC}{dt} V + \frac{dV}{dt} C$$

TRANSISTORE DI SPEGNIMENTO

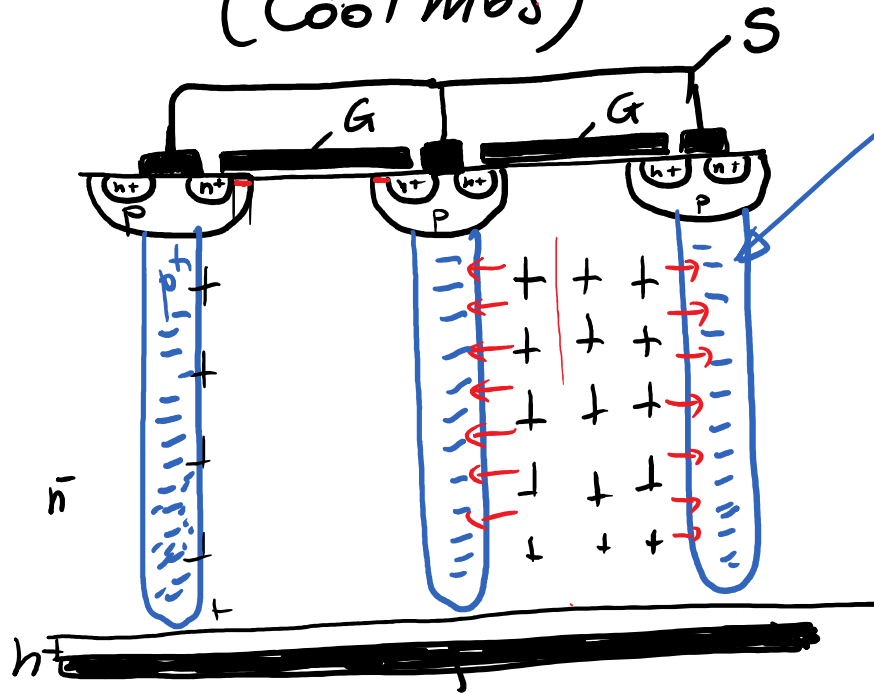
Monday, March 20, 2017 4:08 PM



SUPERJUNCTION MOSFET

Monday, March 20, 2017 4:19 PM

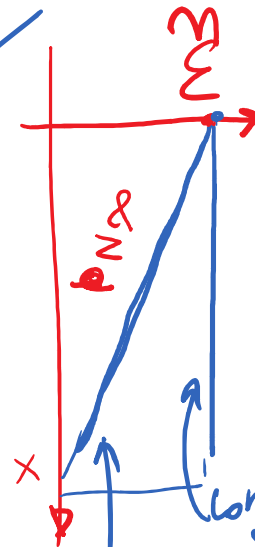
(Coolmos)



~~NORMALE~~

IMPIANTAZIONE P^+

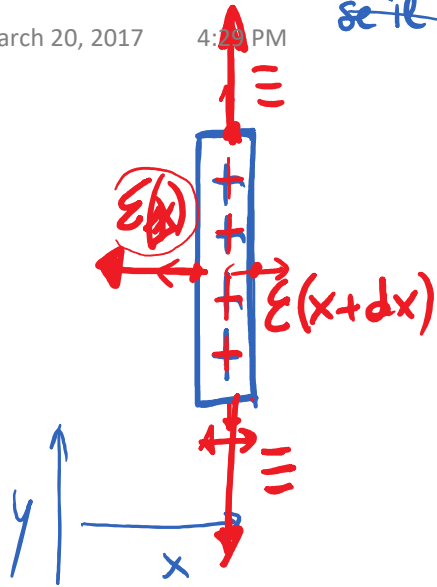
A PARITÀ DI
DROGAGGIO
DELLA
REGIONE
DI PERIVA



LA SUPERGIUNZIONE
MI GARANTISCE
UNA V_{BD} PIÙ
ALTA

senza
superjunction
con
superjunction

se il campo \vec{E}

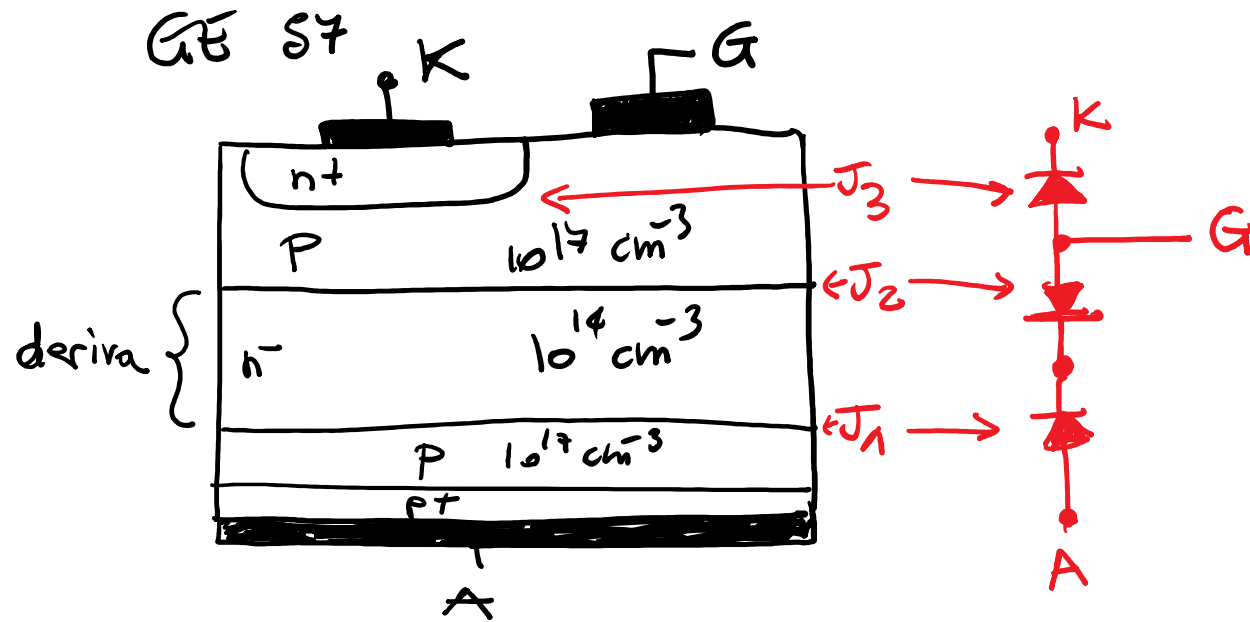


$$\underline{\vec{E}(x+dx)} = \vec{E}(x) - \frac{dx \frac{N_d q}{\epsilon_0 \epsilon_x}}{\epsilon_0 \epsilon_x}$$

TIRISTORE (Thyristor)

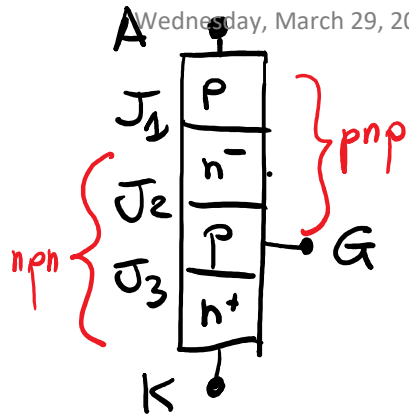
Wednesday, March 29, 2017 8:55 AM

↳ SCR (Silicon controlled rectifier)



Tiristore intrinseco

Wednesday, March 29, 2017 9:02 AM



⊙ Forward blocking ($V_{AK} > 0$)

J_2 sostiene la V_{AK}

$$\underline{V_{BO}} \sim \underline{dE_{BD}}$$

↑
Break over

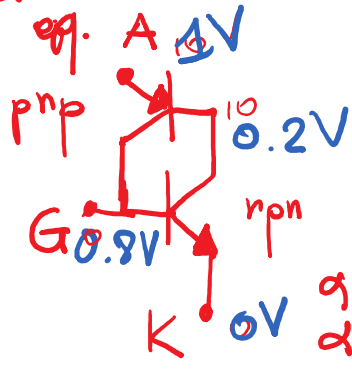
⊙ Reverse blocking ($V_{AK} < 0$)

J_1, J_3 sono polarizzate inversamente

J_1 sostiene la V_{AK}

$$\underline{V_{RB}} \sim \underline{dE_{BD}}$$

circuito



$$\alpha_{pnp} \sim 0.01 - 0.1$$

$$\alpha_{npn} \sim 0.9 - 0.95$$

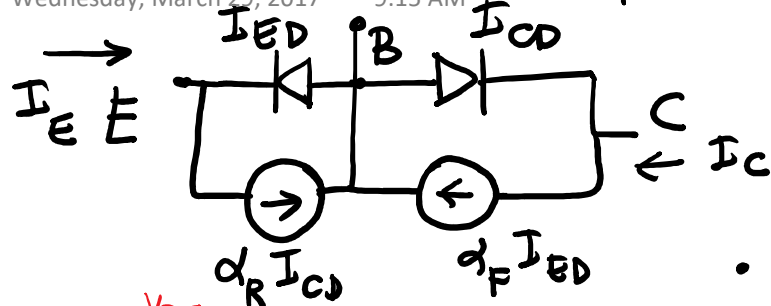
2 STATI

OFF

ON

EBERS-MOLL MODEL (npn)

Wednesday, March 29, 2017 9:15 AM



in zona attiva ($V_{BE} < 0$)

$$I_{CD} = -I_{CS}$$

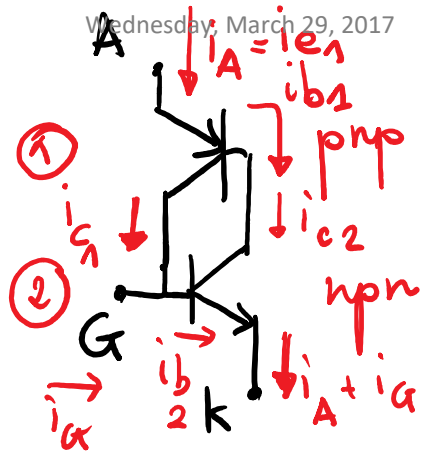
$$I_E = -I_{ED} - \alpha_R I_{CS}$$

$$I_C = \alpha_F I_{ED} + I_{CS} =$$

$$I_C = -\alpha_F I_E + \underbrace{I_{CS}(1 - \alpha_R \alpha_F)}_{I_{CO}}$$

$$I_{CO} = I_{CS} \left(e^{\frac{V_{BE}}{V_T}} - 1 \right)$$

$$I_C = -\alpha_F I_E + I_{CO}$$



$$i_A = i_{b1} + i_{c1} = i_{c2} + i_{c1}$$

$$i_A = -\alpha_{npn} i_{e2} + i_{c2} + \alpha_{pnp} i_A + i_{c1}$$

\downarrow
 $-(i_A + i_G)$

\downarrow
 i_{e1}

$$i_A = \frac{\alpha_{npn} i_G + I_{c2} + I_{c1}}{1 - \alpha_{npn} - \alpha_{pnp}}$$

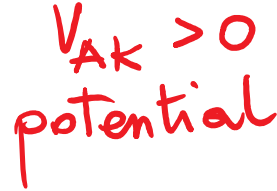
\downarrow \downarrow
0.9 0.01-0.1

$$\text{SE } \alpha_{npn} + \alpha_{pnp} < 1$$

OFF

$$\text{SE } \alpha_{npn} + \alpha_{pnp} = 1$$

ON

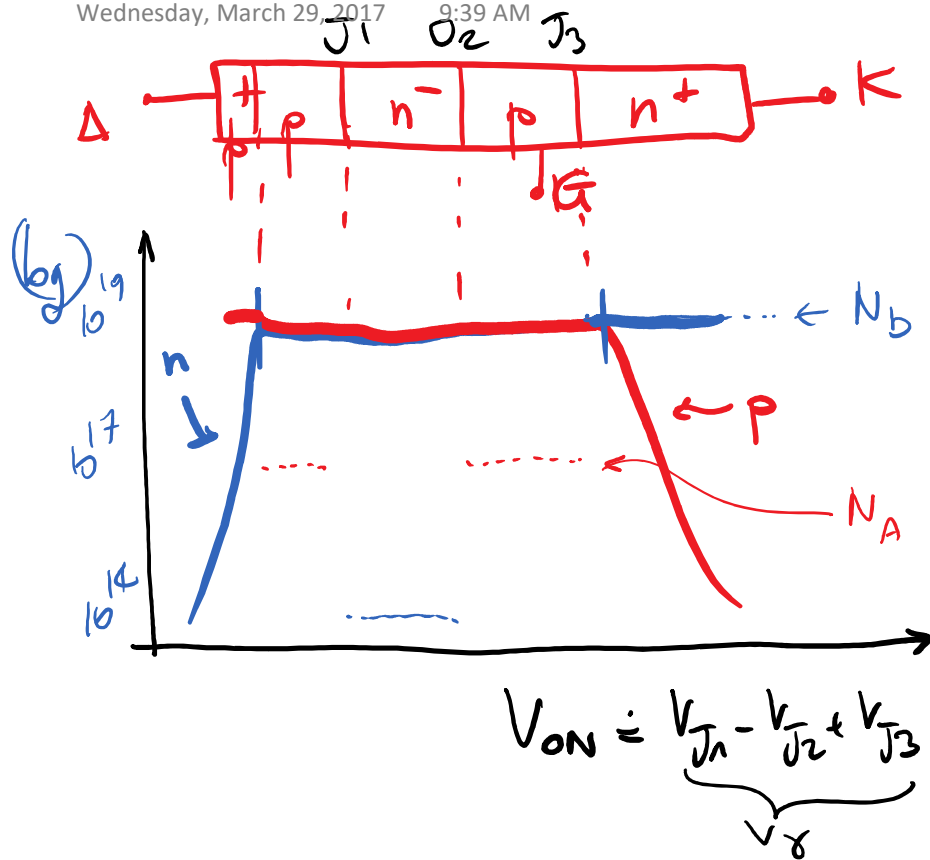


SE $V_{AK} \uparrow$, si riduce la base del pnp \rightarrow $\beta_{pnp} \downarrow$ on
($I_G = 0$)

d) Se $I_G \uparrow$, aumenta $d_{nph} \rightarrow ON$

ON STATE

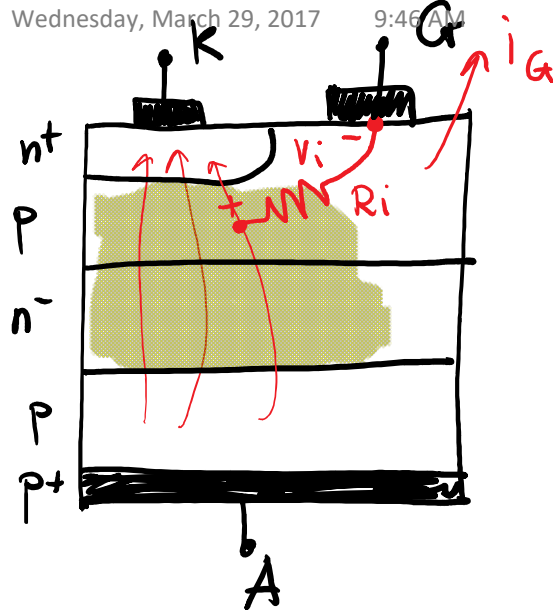
Wednesday, March 29, 2017 9:39 AM



$n \sim p \sim n_a \gg N_D, N_A$
modulazione
della conduttività

TURN OFF

Wednesday, March 29, 2017 9:46 AM

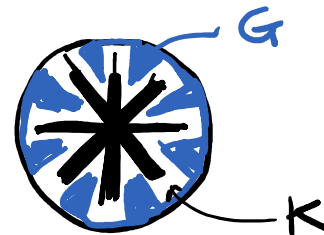


$$\text{Se } i_G < 0$$

la caduta di tensione sulla resistenza di dispersione della regione p è troppo alta per polarizzare inversamente la J_3 (giunzione BE dell' npn)

2) Possiamo solo applicare $V_{AK} < 0$

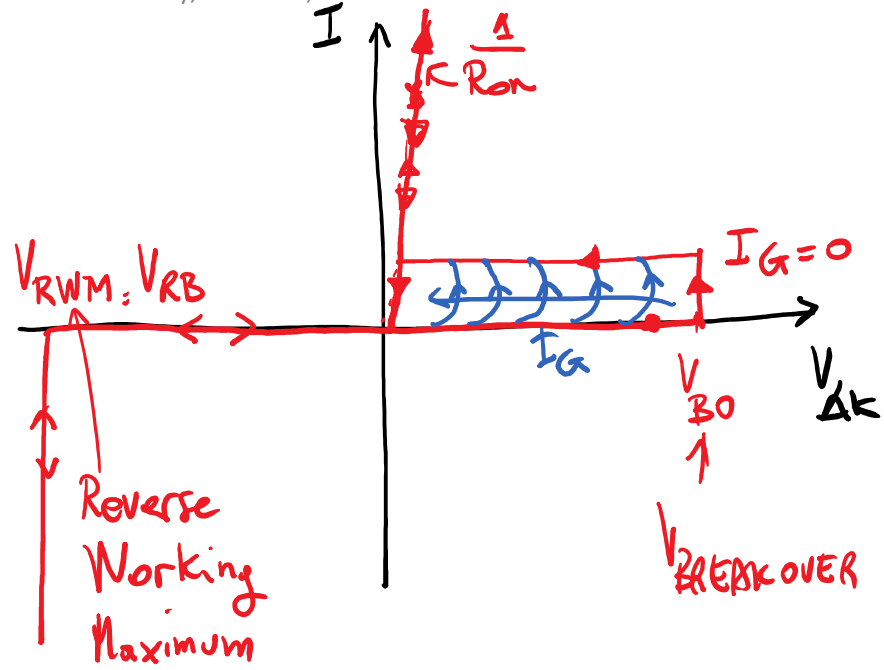
Catodo interdigitato



DC

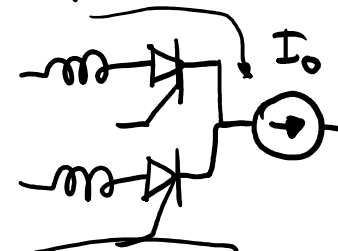
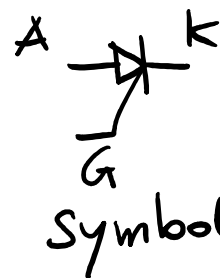
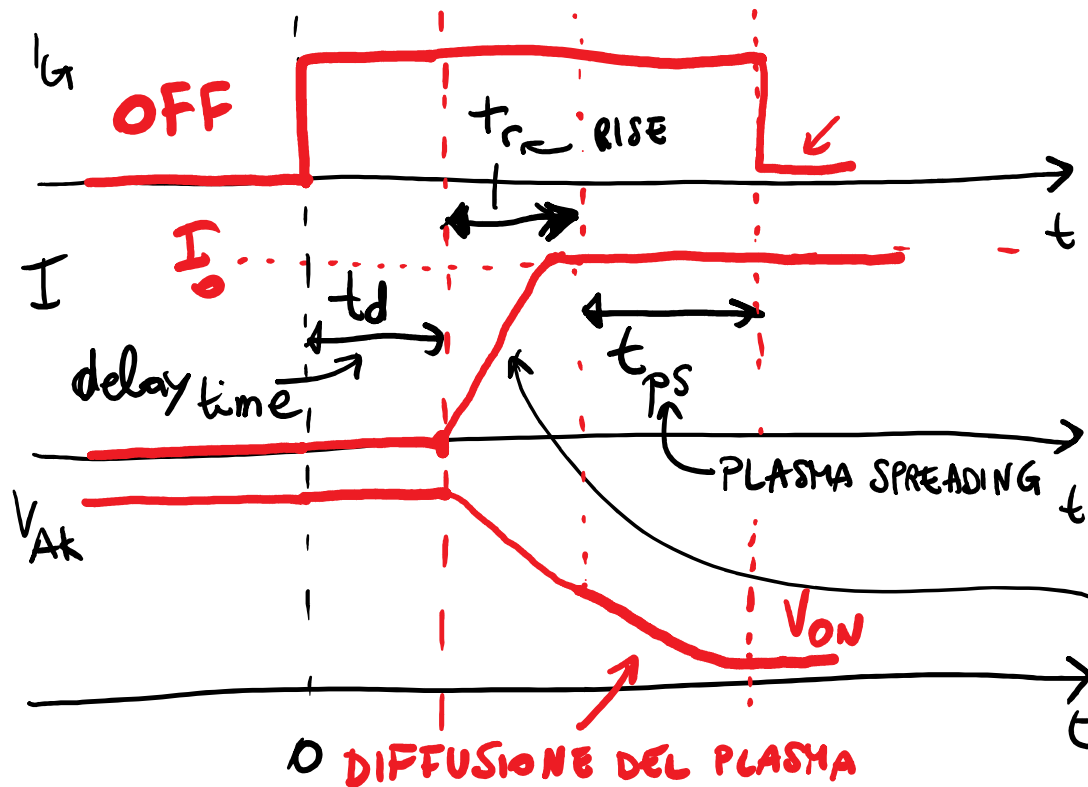
Wednesday, March 29, 2017

9:58 AM



TRANSITORIO DI ACCENSIONE

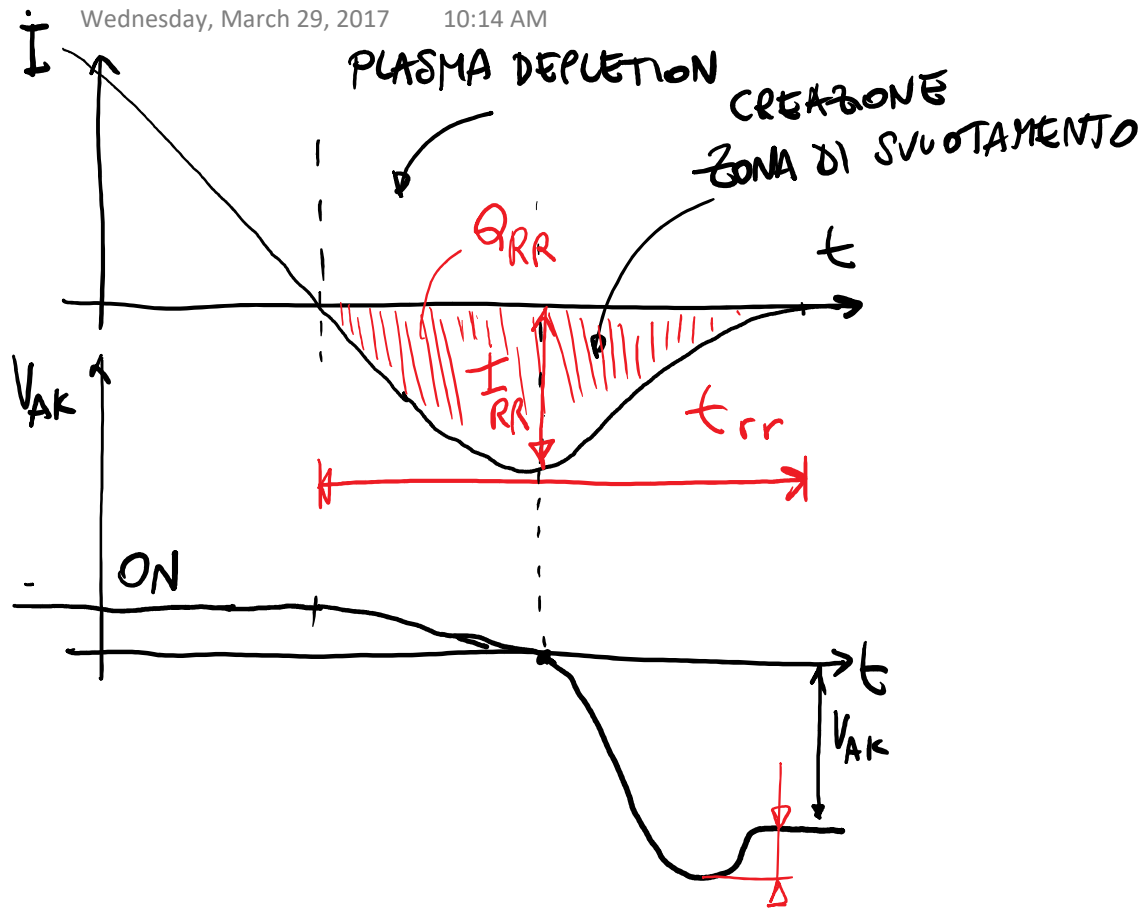
Wednesday, March 29, 2017 10:04 AM



MAX dI/dt
per evitare la
fuga termica

TURN OFF

Wednesday, March 29, 2017 10:14 AM



Wednesday, March 29, 2017 10:18 AM

Wednesday, March 29, 2017 10:18 AM

← SI SPEGNE $I_G < 0$

RIDUCONO
LA Ri

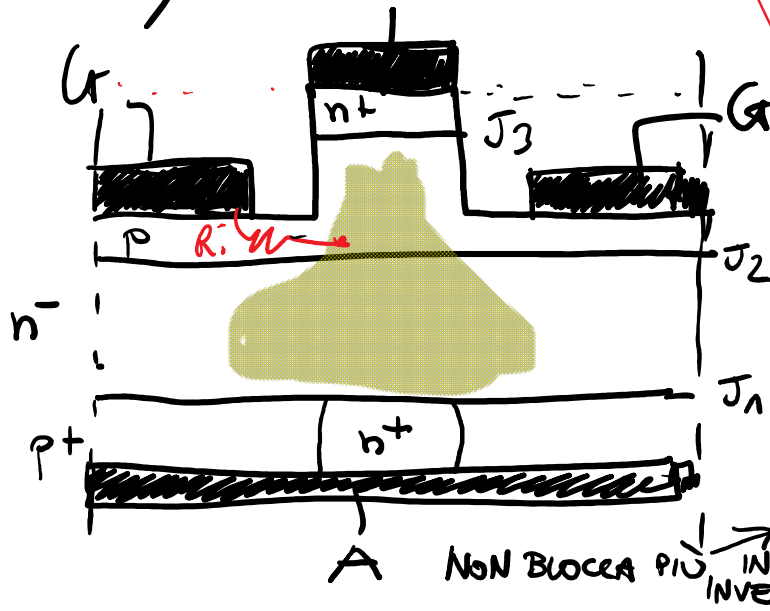
1. Struttura molto interdigitata (più di 1k moduli in parallelo)

2. CATHODE ISLAND

3. Corto di Anodo (ANODE SHORT)

VIA PER LO SVUOTAMENTO DEGLI ELETTRONI

NON BLOCCA PIÙ IN INVERSA



IGBT

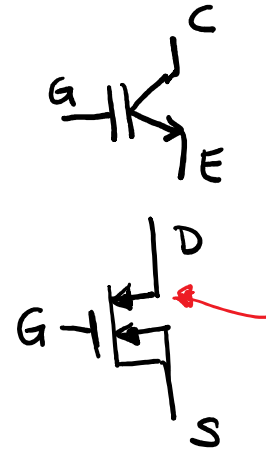
Monday, April 10, 2017 1:51 PM

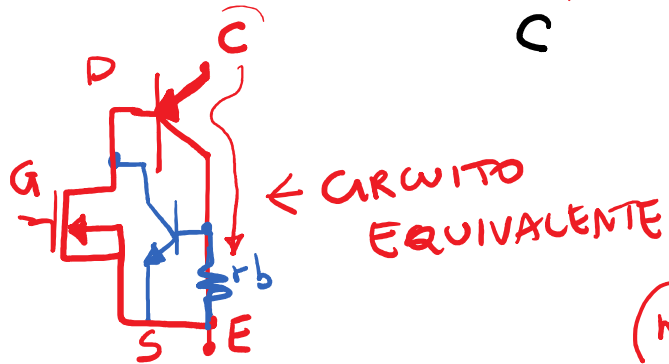
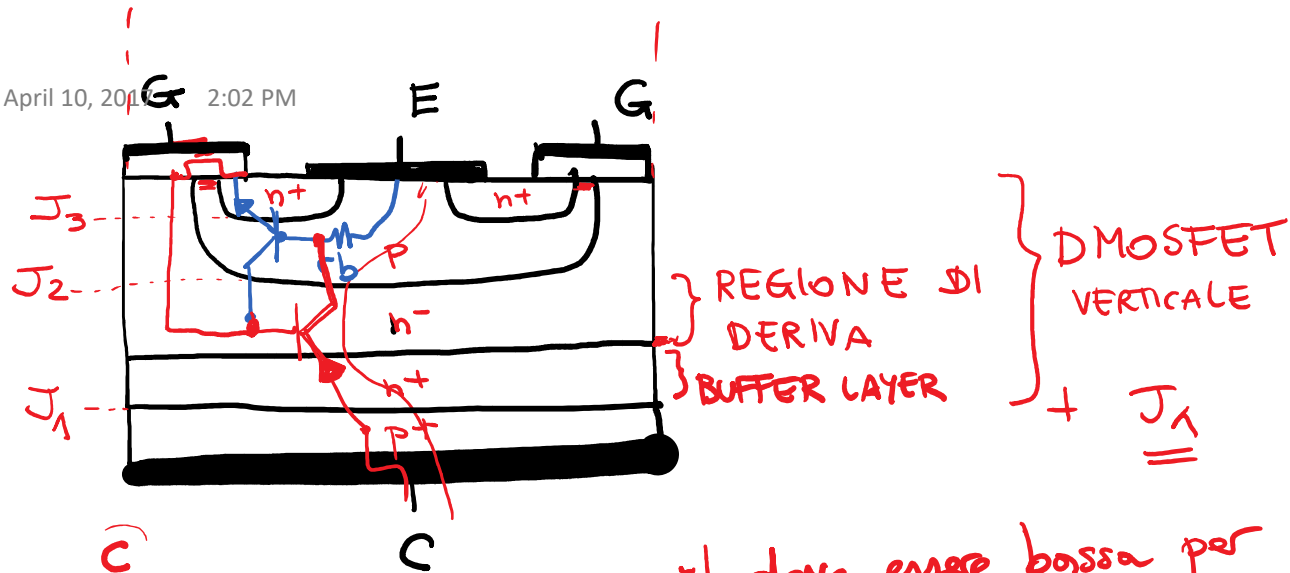
805 · Baliga

Insulated - Gate Bipolar Transistor

	PRO	CON
MOSFET	TURN OFF VELOCE	VON ALTA
BJT	VON BASSA	TURN OFF LENTO

IGBT

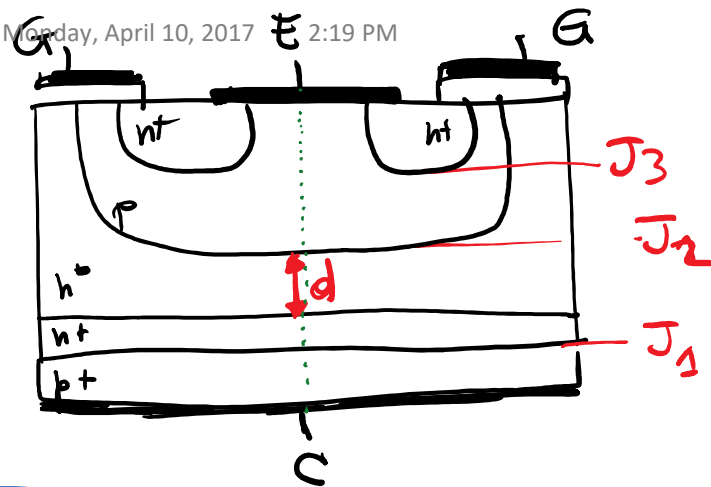




r_b deve essere bassa per garantire che il transistor $n-p-n$ PARASSITA sia spento
 (npn + pnp formano un TIRISTORE che NON SI DEVE INNESCARE)

STATO DI BLOCCO

Monday, April 10, 2017 2:19 PM



→ MOSFET OFF

SE $V_{CE} > 0$

la tensione è sostenuta
da J_2 $V_{BD} \sim d \epsilon_{MAX}$

SE $V_{CE} < 0$

IGBT
ASIMMETRICO

→ SE È PRESENTE IL BUFFER LAYER
la tensione è sostenuta da J_3

$V_{RB} \sim \underline{\underline{20-30 V}}$

SE NON È PRESENTE IL BUFFER LAYER

IGBT
SIMMETRICO

→ la tensione è sostenuta da J_1

$V_{RB} \sim V_{BD}$

EFFETTO DEL BUFFER LAYER

Monday, April 10, 2017 2:27 PM

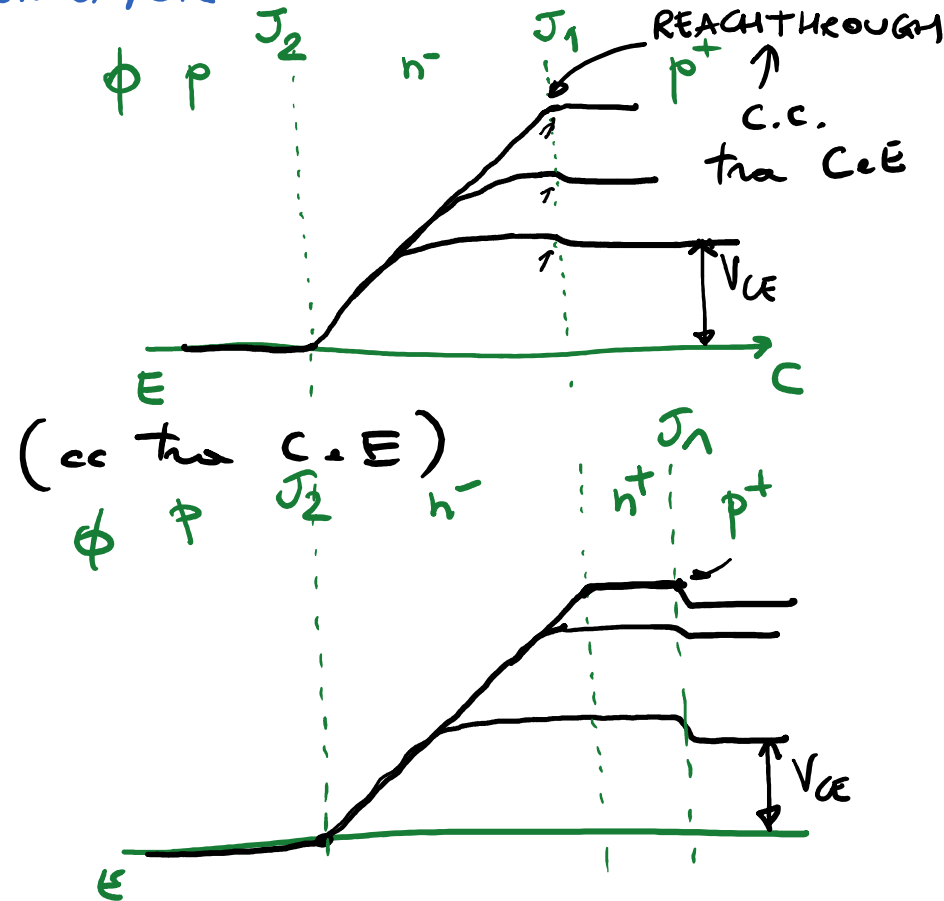
NO BUFFER LAYER

NON POSSO SVUOTARE
COMPLETAMENTE LA
REGIONE DI DERIVA

[PUNCHTHROUGH
COINCIDE CON IL
REACHTHROUGH

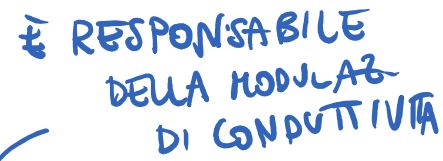
CON BUFFER LAYER

POSSO OTTENERE IL
PUNCHTHROUGH IN
SICUREZZA



Monday, April 10, 2017 2:40 PM

Monday, April 10, 2017 2:40 PM

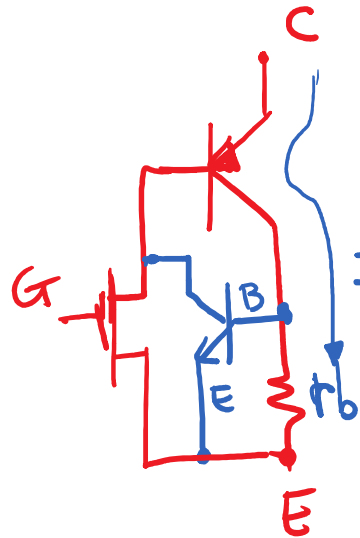

$$V_{ON} = V_{J_1} + R_{ON} I \approx \underline{\underline{1.2V}}$$


IL BJT
← NON
VA IN
SATURAZIONE

tipicamente la maggior parte delle corrente pome dal MOSFET ($\alpha_{pnp} \sim 0.3-0.9$)

LATCH UP

Monday, April 10, 2017 2:55 PM



$$I_E = \alpha_{PNP} I_C$$

CONDIZIONE DI LATCHUP STATICO

$$r_b \cdot I_E < V_{TURN ON}$$

$$r_b \cdot \alpha_{PNP} I_C < V_{TURN ON}$$

$$I_C < I_{MAX STATIC} = \frac{V_{TURN ON}}{r_b \alpha_{PNP}}$$

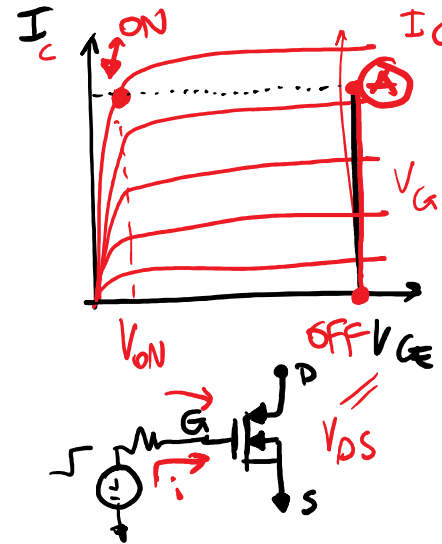
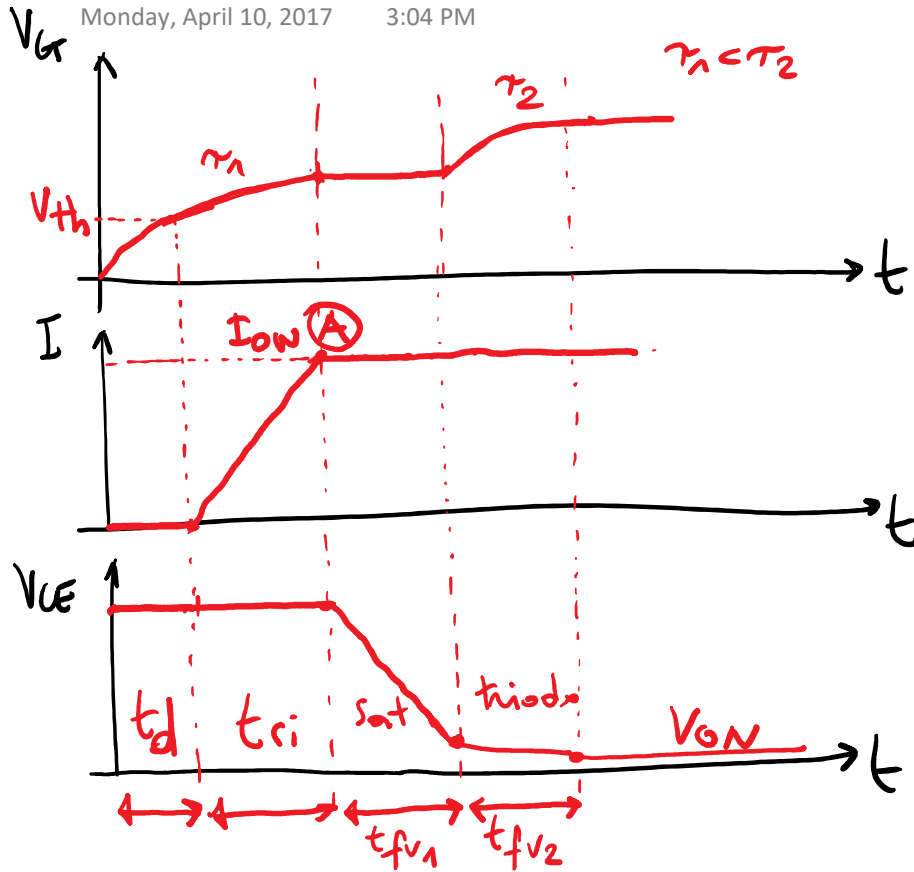
CONDIZIONE DI LATCHUP DINAMICO DURANTE LO SPEGNIMENTO

$$r_b \cdot I_C < V_{TURN ON}$$

$$I_C < \frac{V_{TURN ON}}{r_b} = I_{MAX DYN}$$

TRANSITORI DI ACCENSIONE

Monday, April 10, 2017 3:04 PM



$$i_c = \frac{dQ}{dt} = \frac{dC}{dt} V + \frac{dV}{dt} C$$

TRANSITORIO DI SPEGNIMENTO

Monday, April 10, 2017 3:18 PM

