Corso di
ELETTRONICA INDUSTRIALE

"Convertitore Boost"

Convertitore innalzatore di tensione (boost)

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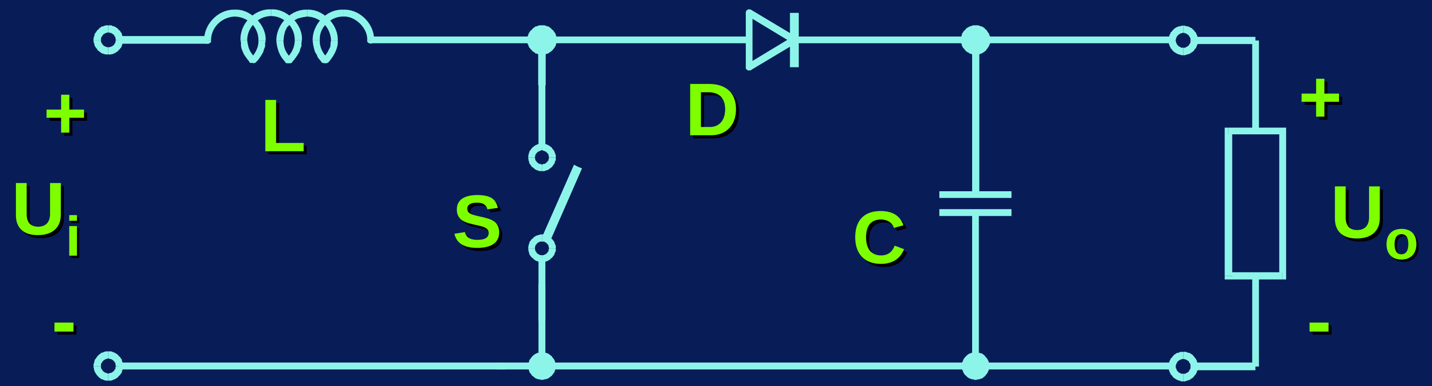
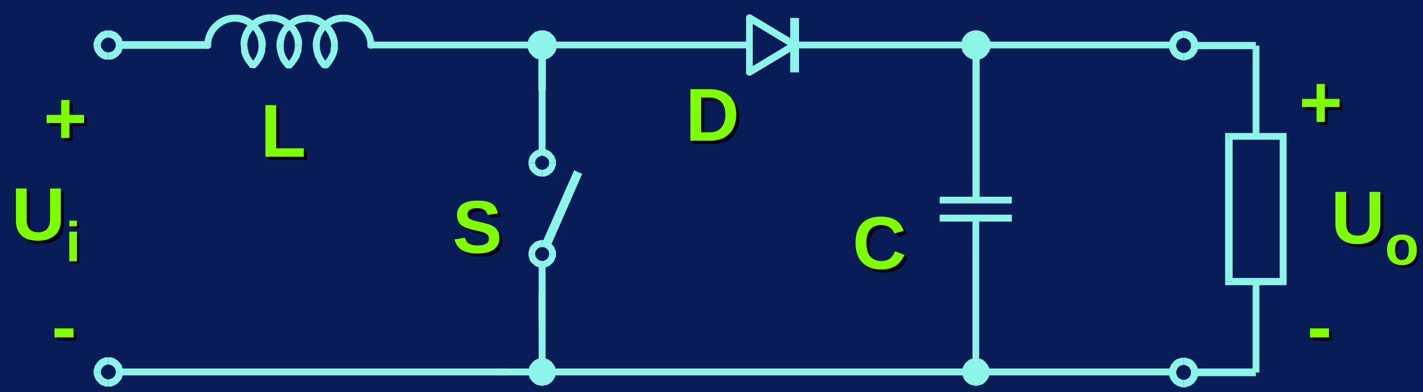


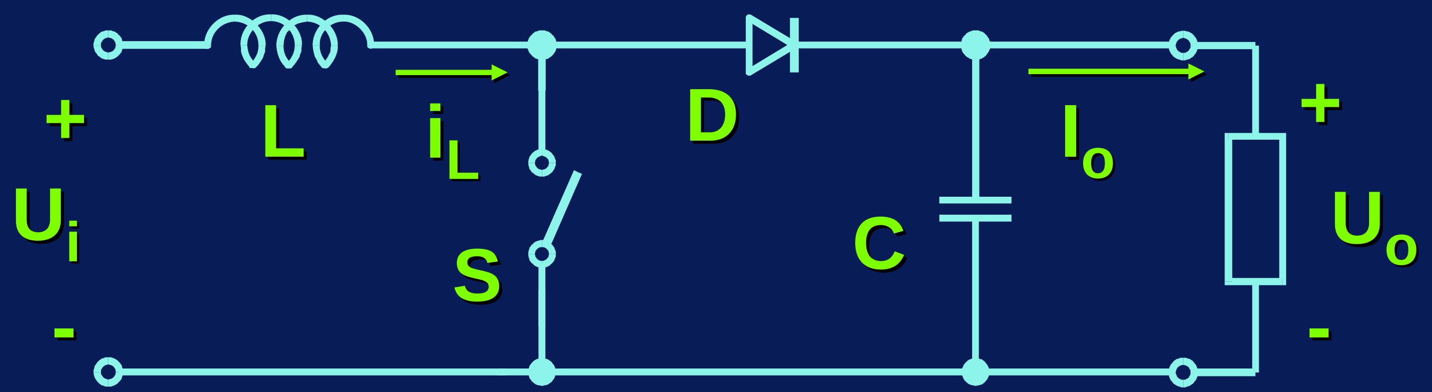
Convertitore innalzatore di tensione (boost)



Note:

1) Il diodo D collega direttamente ingresso e uscita e impone che sia $U_o \geq U_i$
2) La corrente assorbita dall'alimentazione é filtrata dall'induttanza L

Convertitore innalzatore di tensione (boost)



Ipotesi per lo studio:

- interruttore ideale (u_{Son}=0, i_{Soff}=0, t_{swon}= t_{swoff} =0)
- diodo ideale (u_{Son}=0, i_{Soff}=0, t_{swon}= t_{swoff}=0)
- L,C ideali (R_L=0, ESR=0, ESL=0)
- $u_i = U_i$ = costante
- $u_o = U_o$ = costante
- $i_o = I_o$= costante

Analisi del funzionamento continuo (CCM)

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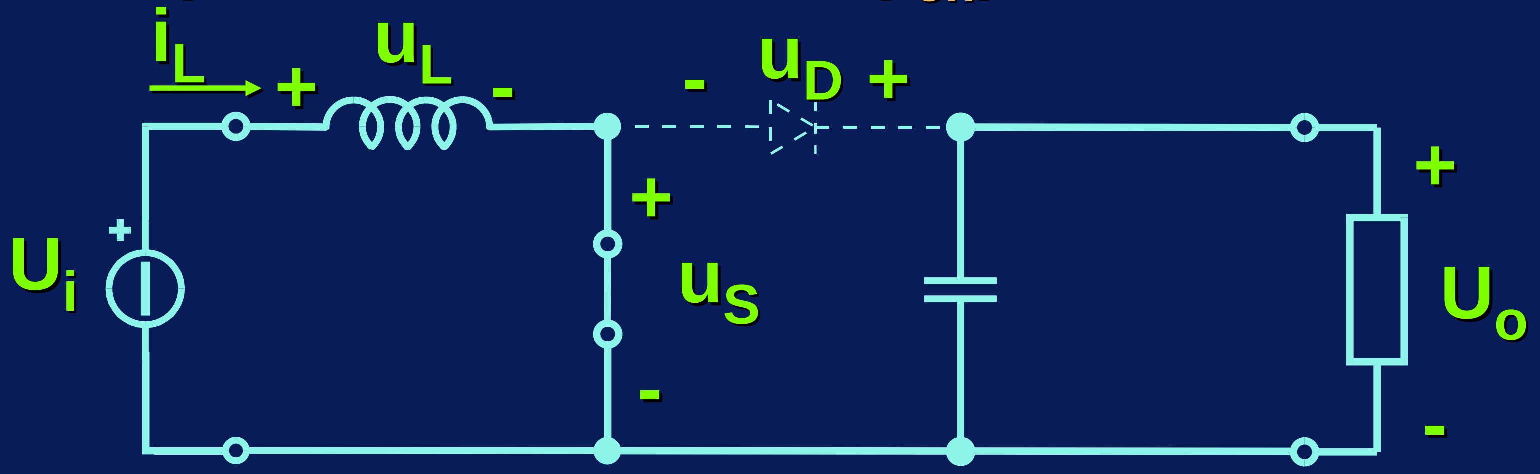
Tempo di chiusura di S (t_{on})   S on - D off



Analisi del funzionamento continuo (CCM)

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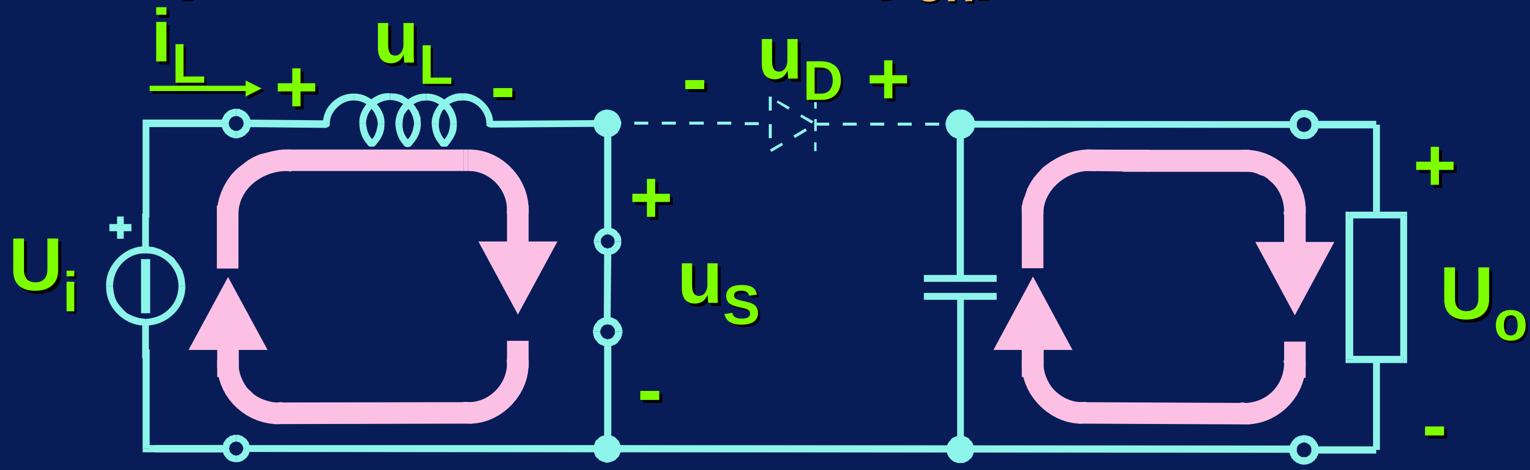
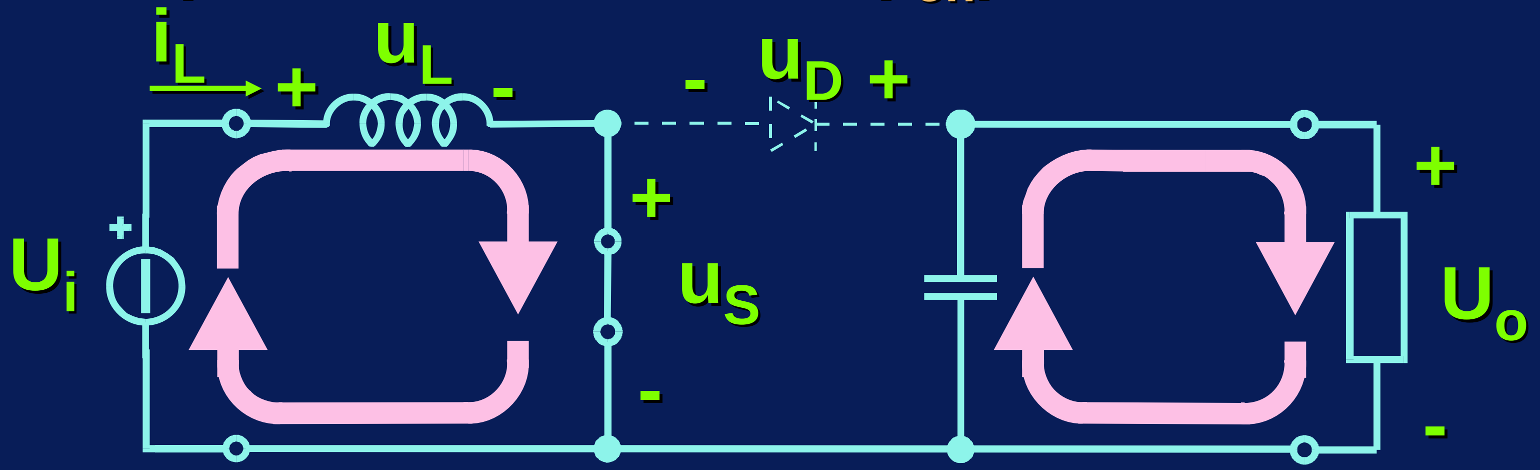


$u_L = U_i$

$u_D = U_o$

Analisi del funzionamento continuo (CCM)

Tempo di chiusura di S (t_{on})   S on - D off

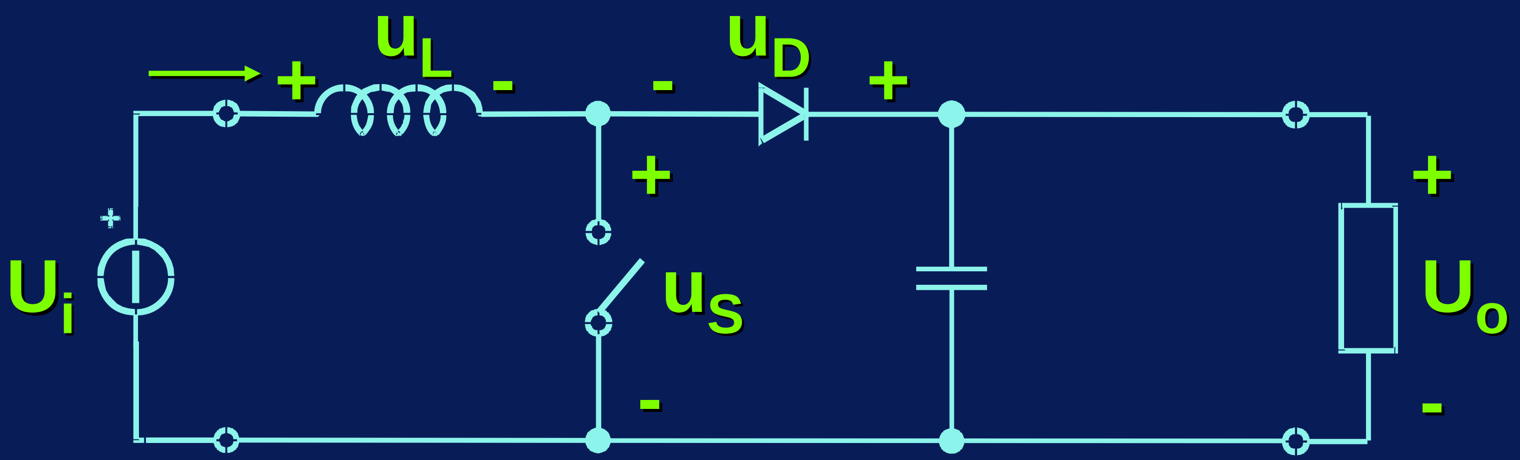


$u_L = U_i$ $u_D = U_o$

Durante questa fase viene trasferita energia dall'alimentazione all'induttanza

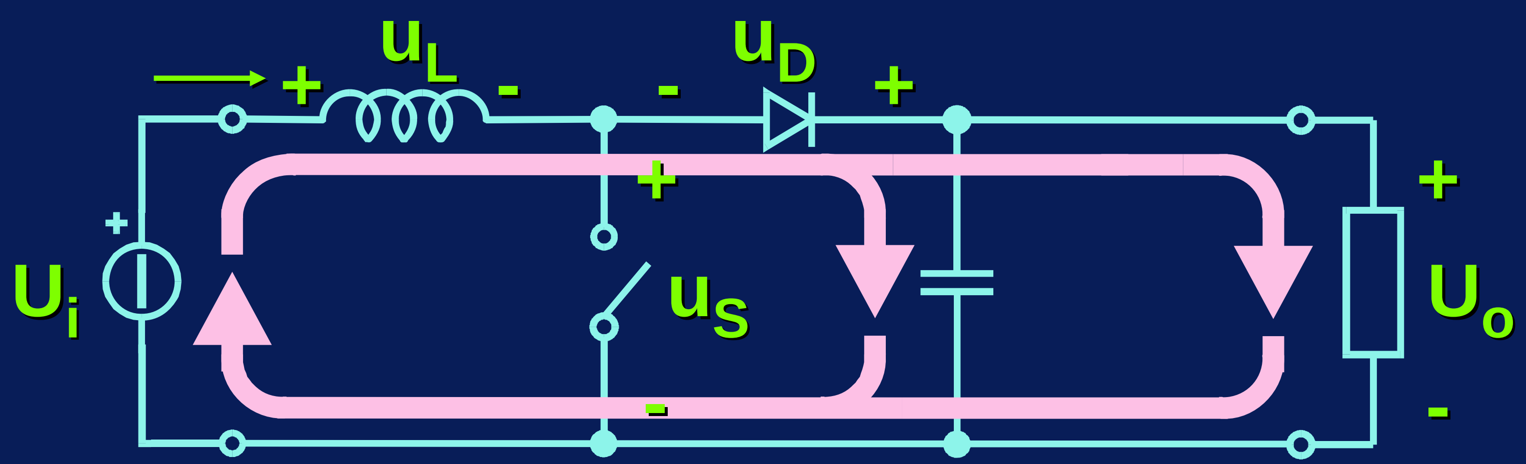
Analisi del funzionamento continuo (CCM)

Tempo di apertura di S (t_{off})   S off - D on



Analisi del funzionamento continuo (CCM)

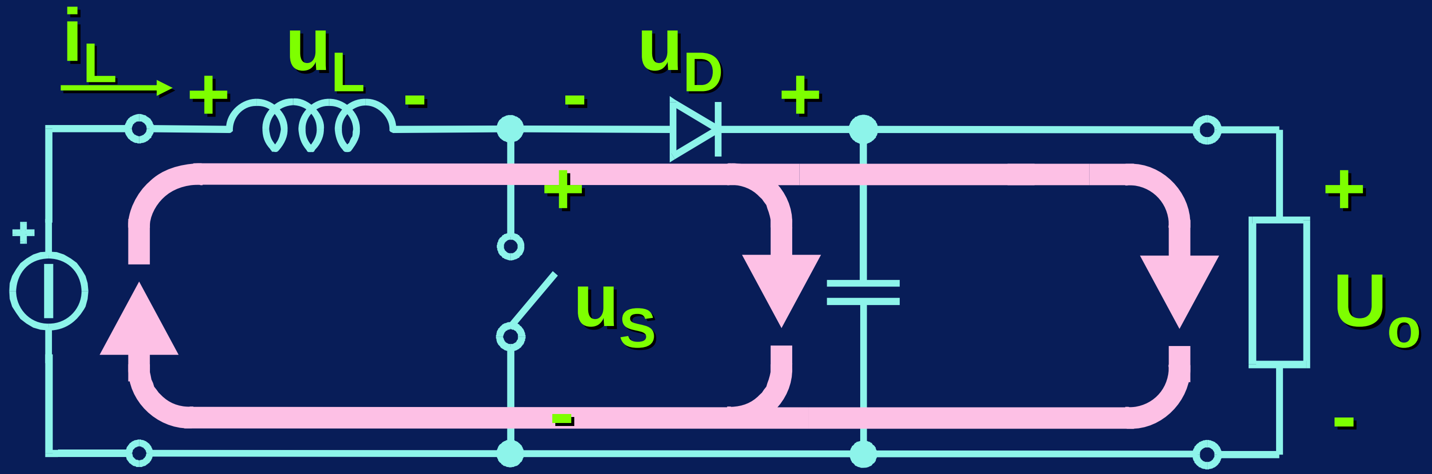
Tempo di apertura di S (t_{off})   S off - D on



$u_L = U_i - U_o$ $u_S = U_o$

Analisi del funzionamento continuo (CCM)

Tempo di apertura di S (t_{off})   S off - D on



$u_L = U_i - U_o$ $u_S = U_o$

Durante questa fase la sorgente e l'induttanza forniscono energia allo stadio di uscita

Boost - Forme d’onda in CCM: u_L

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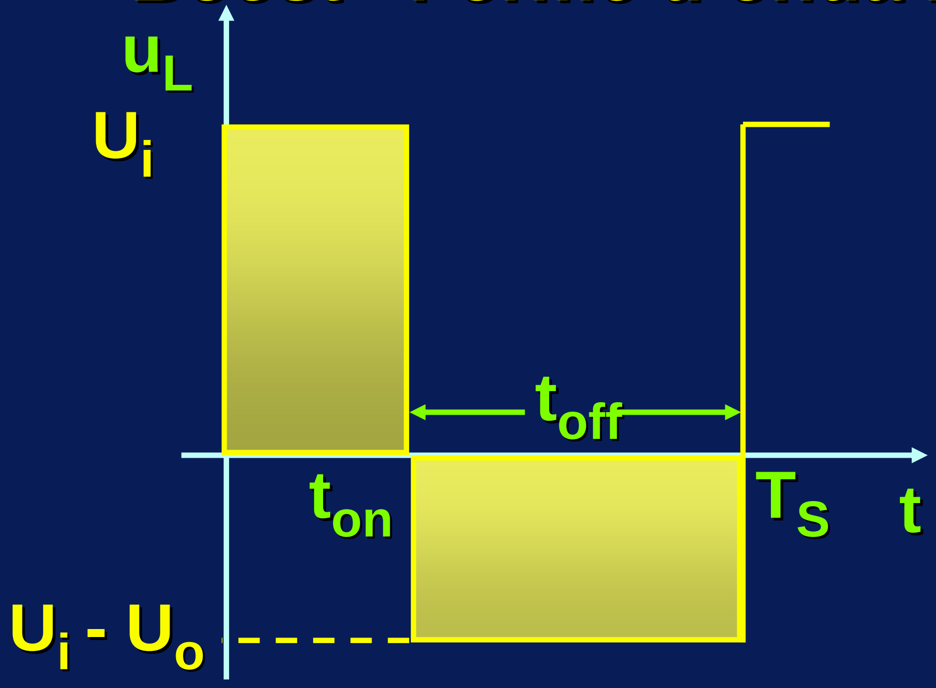
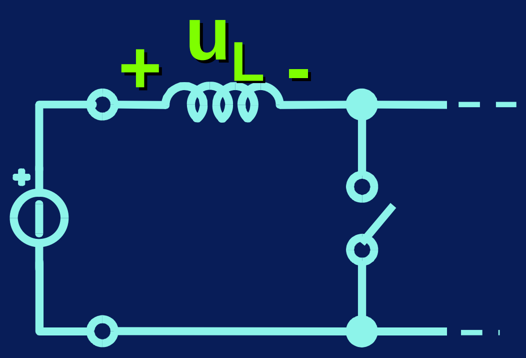
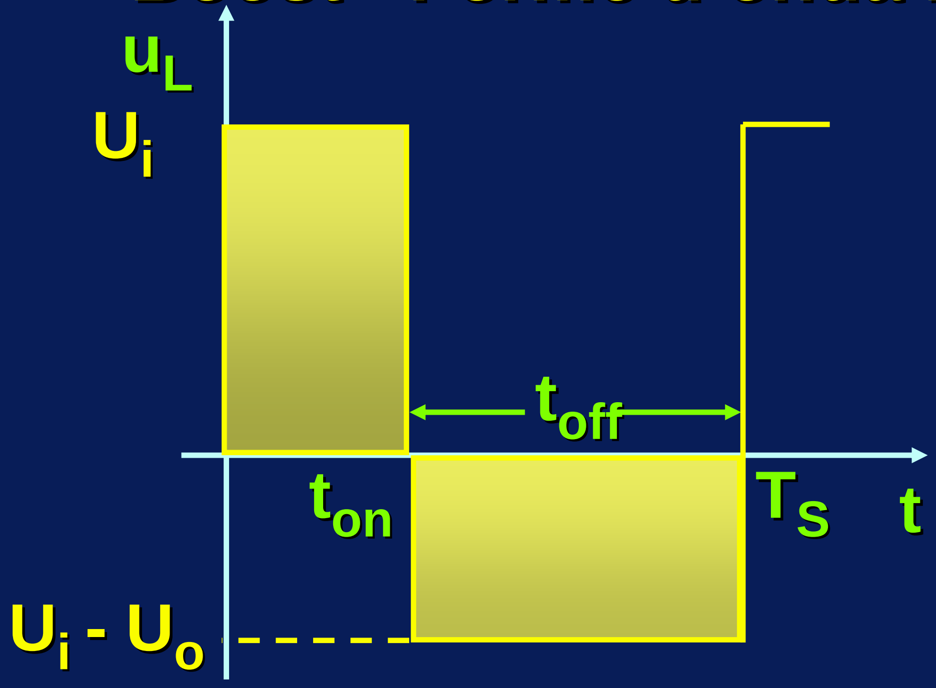
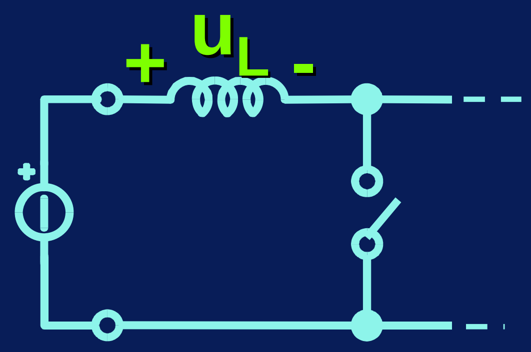




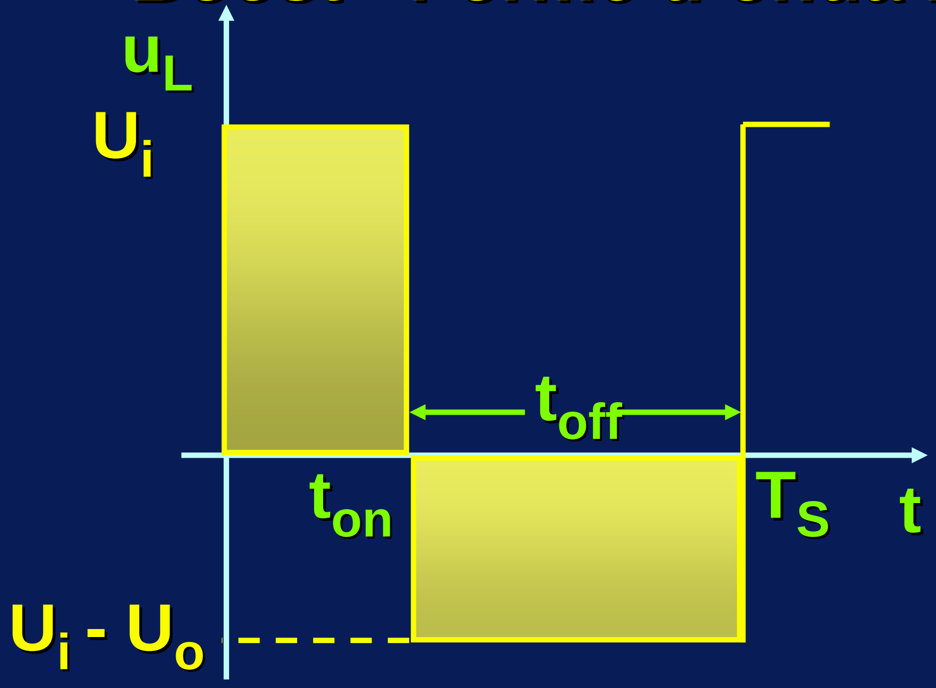
Boost - Forme d'onda in CCM: u_L

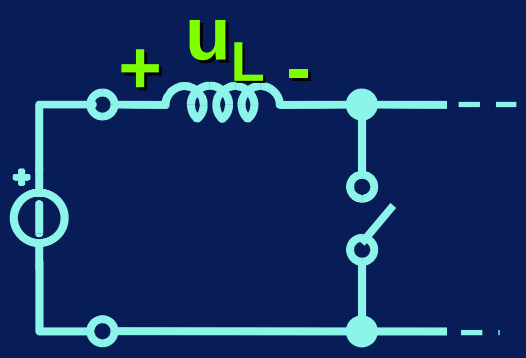




$$U_i \cdot t_{on} = \left(U_o - U_i\right) \cdot t_{off}$$

Boost - Forme d'onda in CCM: u_L

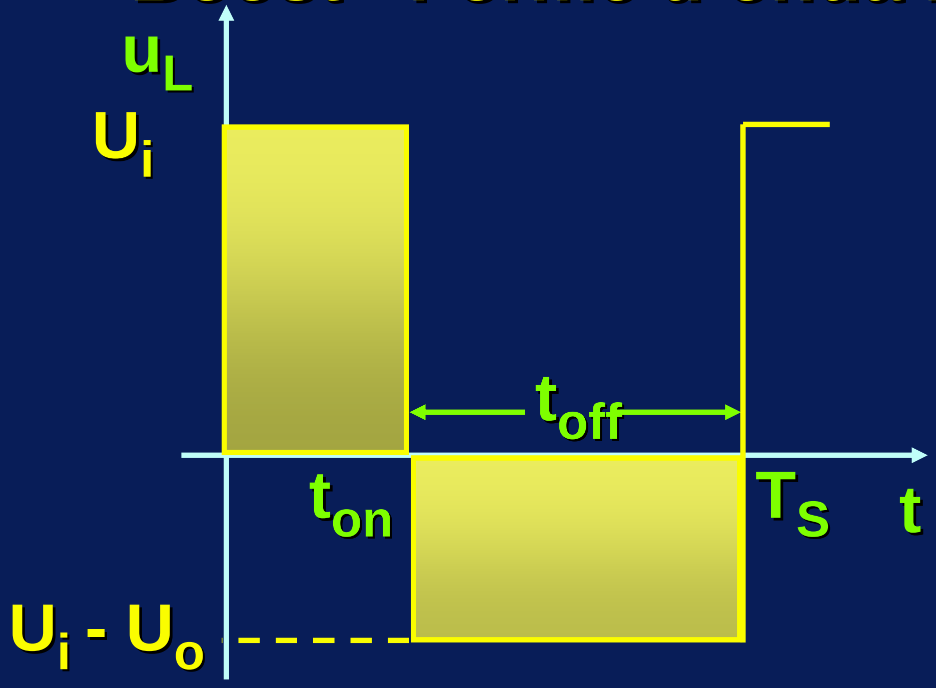


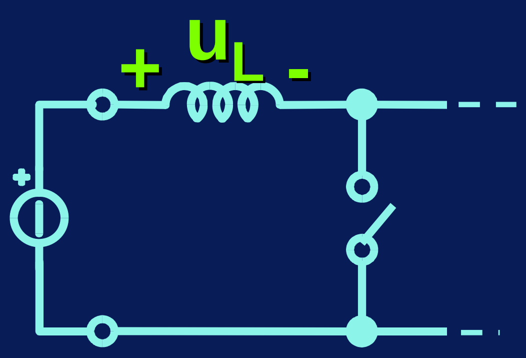


$$U_i \cdot t_{on} = \left(U_o - U_i\right) \cdot t_{off}$$

$$U_i \cdot T_S = U_o \cdot t_{off}$$

Boost - Forme d'onda in CCM: u_L





$$U_i \cdot t_{on} = (U_o - U_i) \cdot t_{off} \qquad U_i \cdot T_S = U_o \cdot t_{off}$$

$$M = \frac{U_o}{U_i} = \frac{T_S}{t_{off}} = \frac{1}{1-\delta} > 1$$

Boost - Forme d’onda in CCM: i_L

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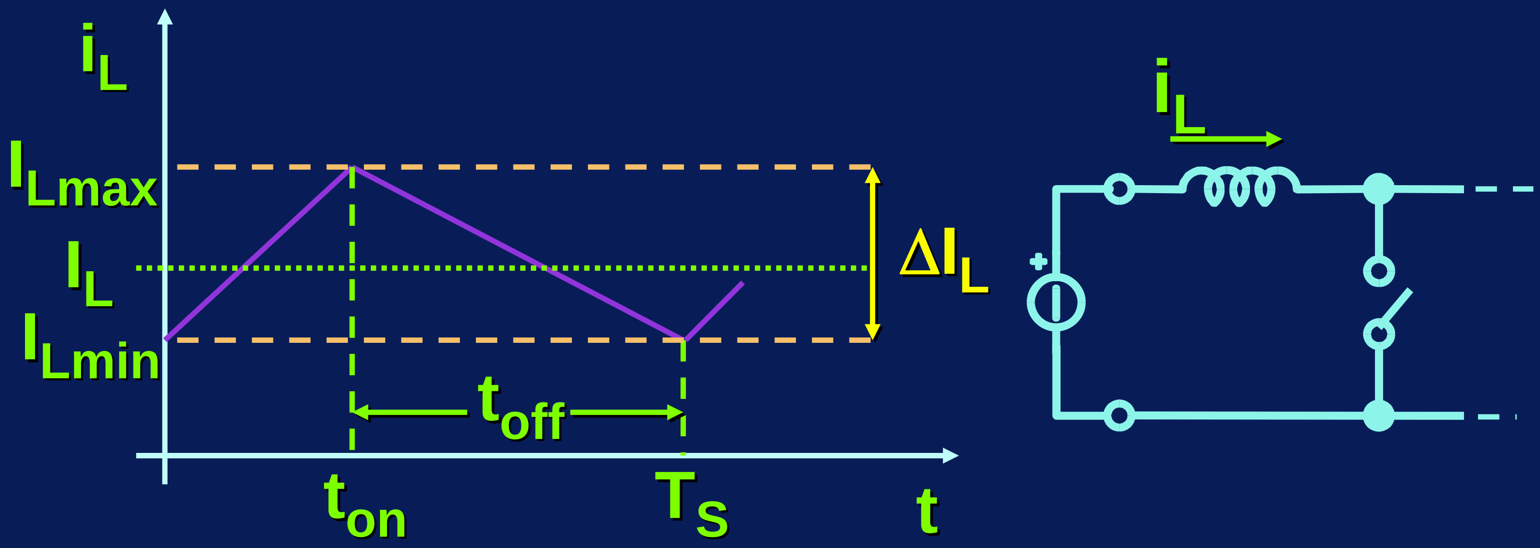
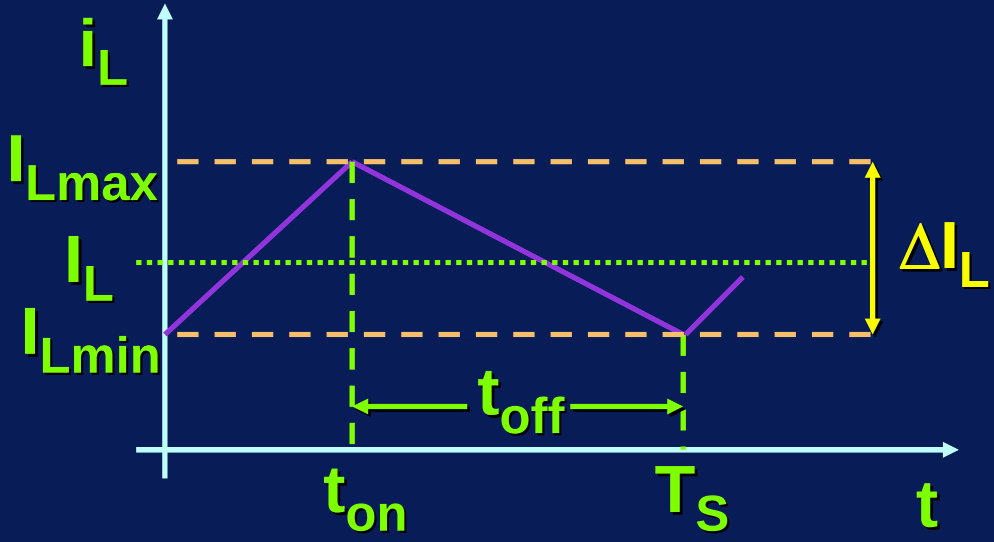
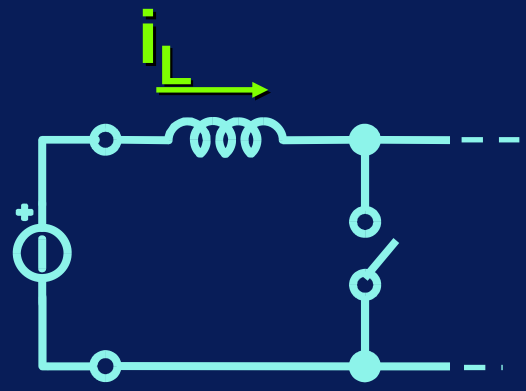


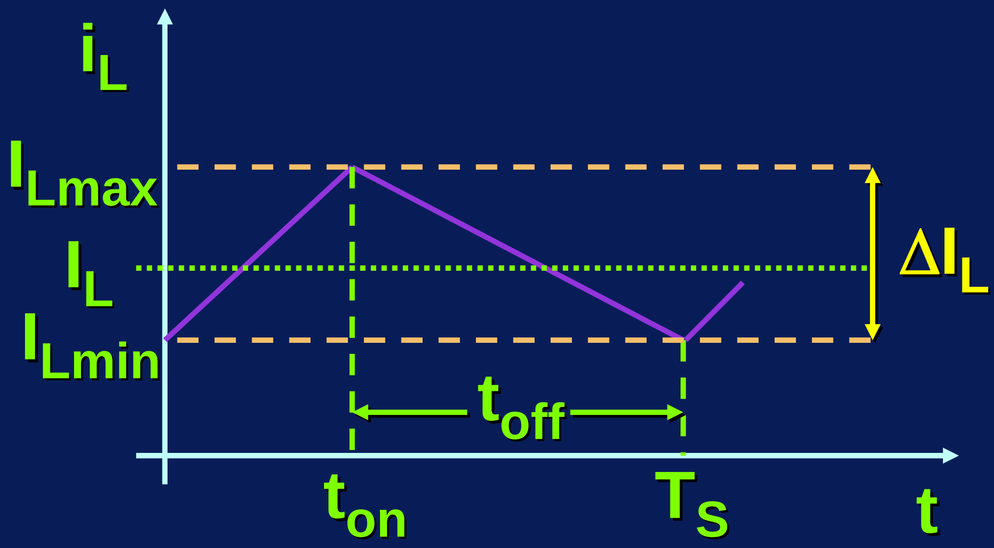
Boost - Forme d'onda in CCM: i_L

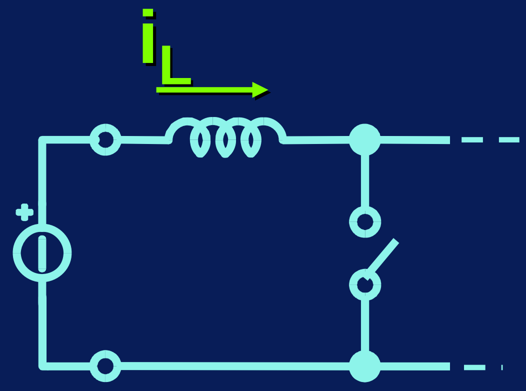




A regime:

Boost - Forme d'onda in CCM: i_L

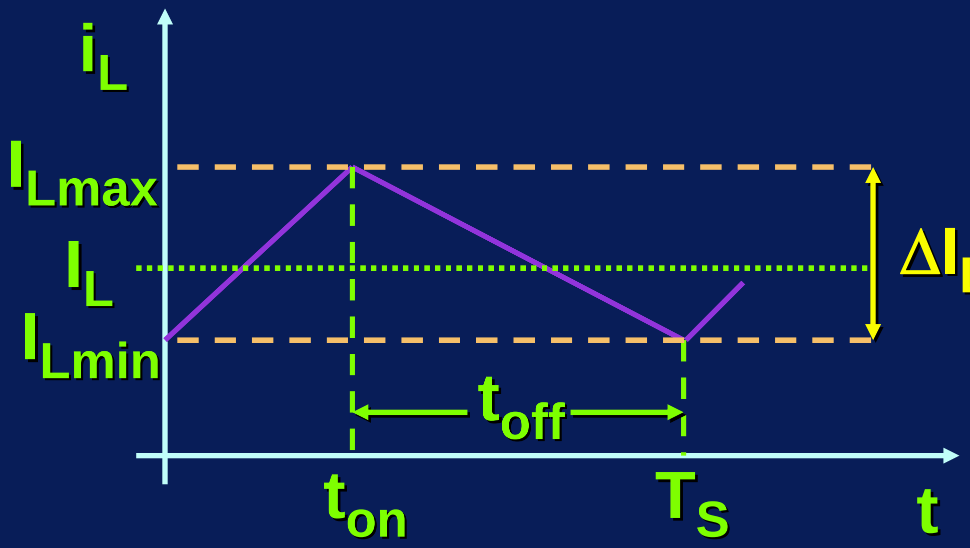


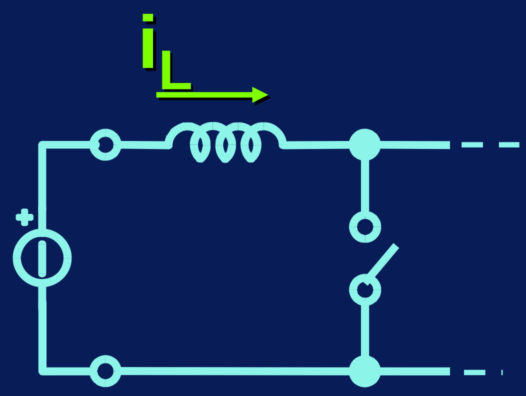


A regime:

$$\Delta I_{Lon} = \Delta I_{Loff} = \Delta I_L = \frac{U_i}{L} \cdot t_{on} = \frac{U_o - U_i}{L} \cdot t_{off}$$

Boost - Forme d'onda in CCM: i_L





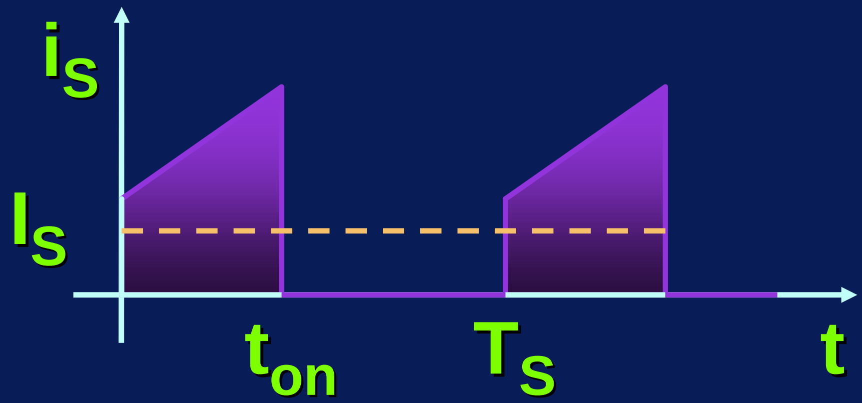
A regime:

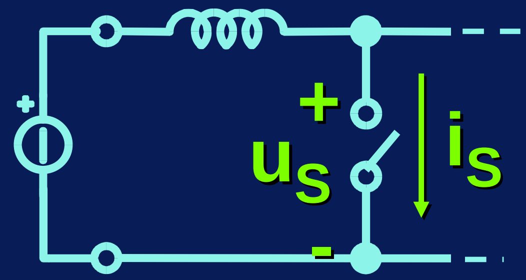
$$\Delta I_{Lon} = \Delta I_{Loff} = \Delta I_L = \frac{U_i}{L} \cdot t_{on} = \frac{U_o - U_i}{L} \cdot t_{off}$$

$$M = \frac{U_o}{U_i} = \frac{T_S}{t_{off}} = \frac{1}{1-\delta} > 1$$

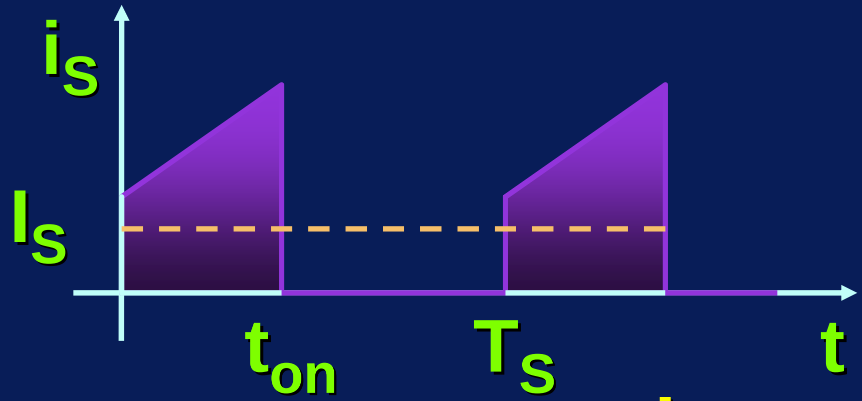
Boost - Forme d'onda in CCM: i_{S}, u_{S}

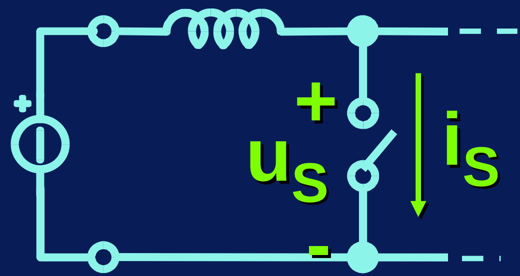
Boost - Forme d'onda in CCM: i_S, u_S





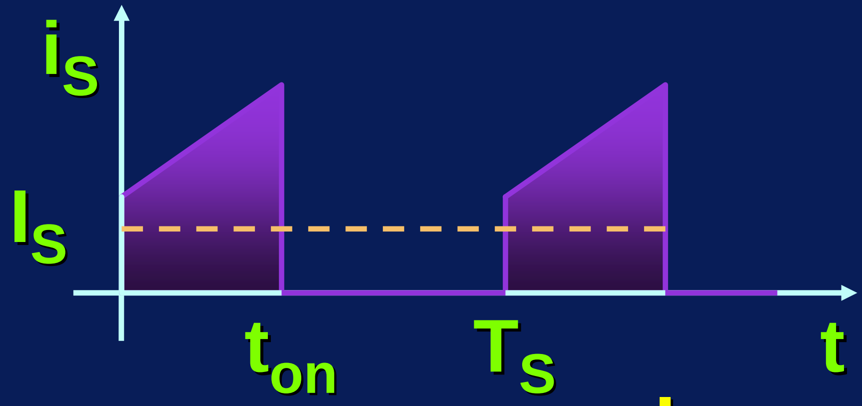
Boost - Forme d'onda in CCM: i_S, u_S

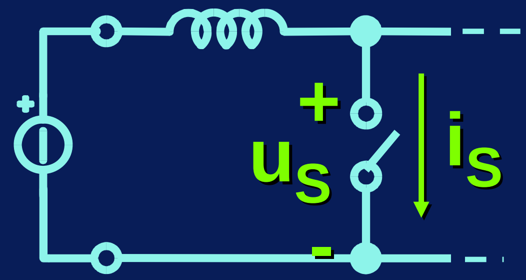




$$I_S = \frac{I_{L\,min} + I_{L\,max}}{2 \cdot T_S} \cdot t_{on} = I_L \cdot \delta$$

Boost - Forme d'onda in CCM: i_S, u_S





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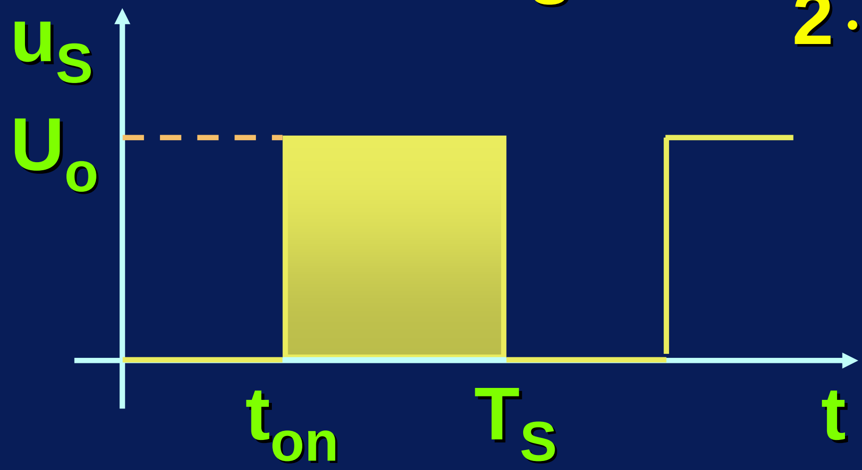

$$U_{Smax} = U_o$$

Boost - Forme d'onda in CCM: $i_{D,}$ u_D

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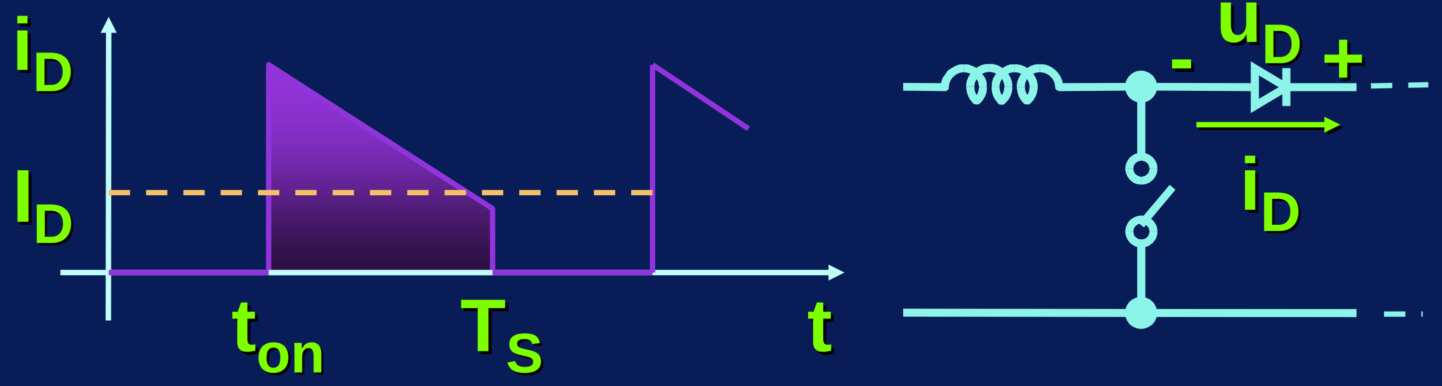
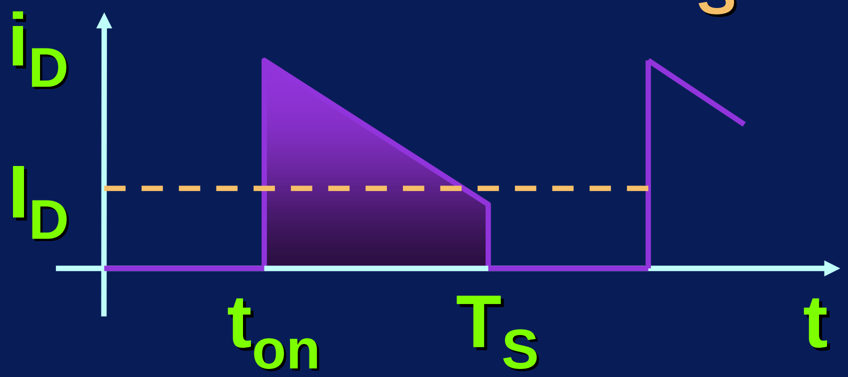
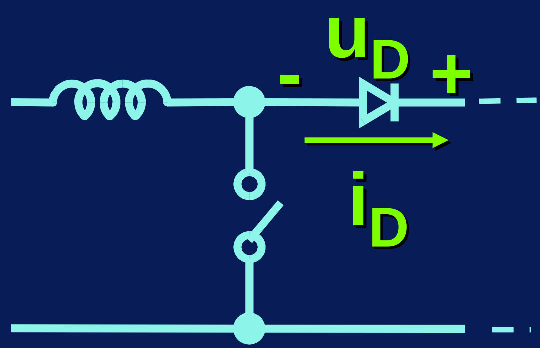


Boost - Forme d'onda in CCM: $i_{D,}$ u_D

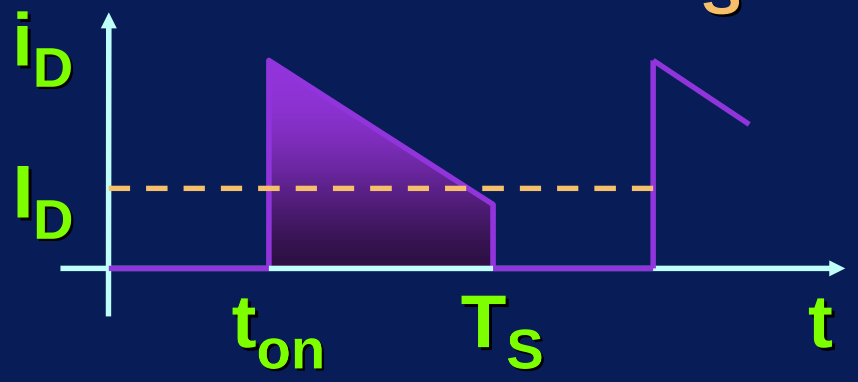
$$I_D = \frac{I_{L\,min} + I_{L\,max}}{2 \cdot T_S} \cdot t_{off} = I_L \cdot (1 - \delta)$$

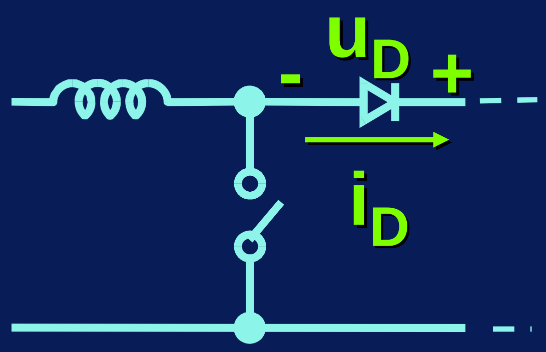


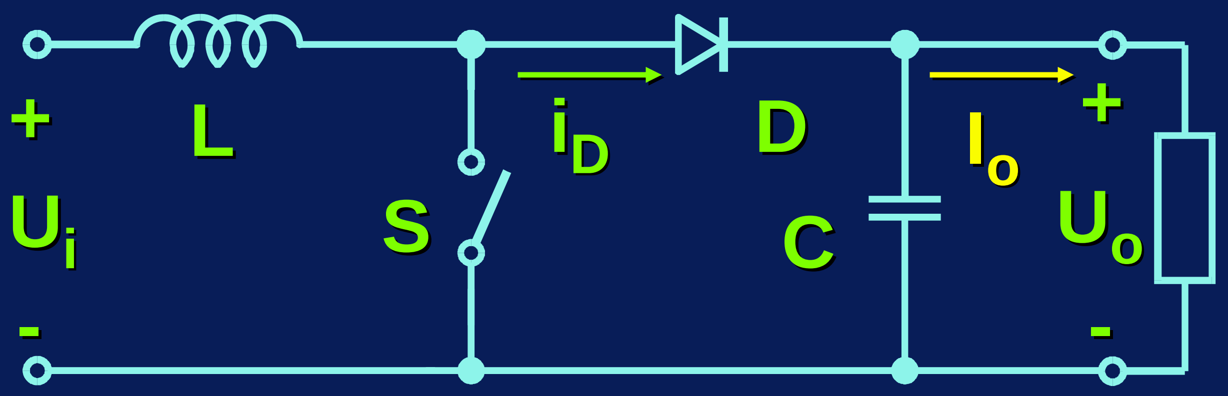


Boost - Forme d'onda in CCM: $i_{D,}\ u_D$

$$I_D = \frac{I_{L\,min} + I_{L\,max}}{2 \cdot T_S} \cdot t_{off} = I_L \cdot (1 - \delta)$$



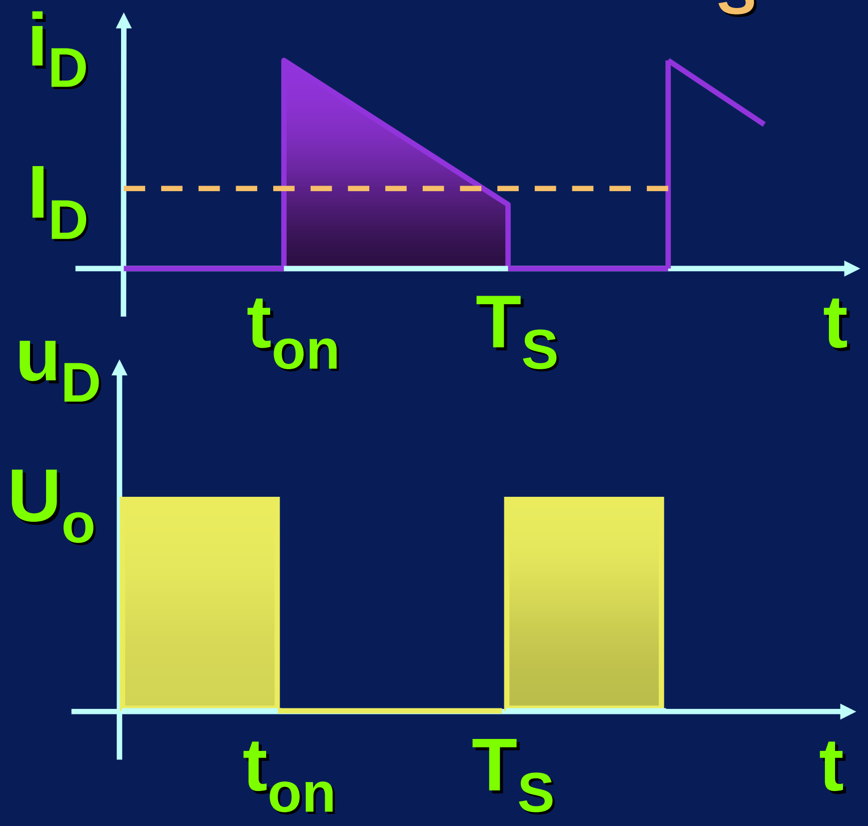


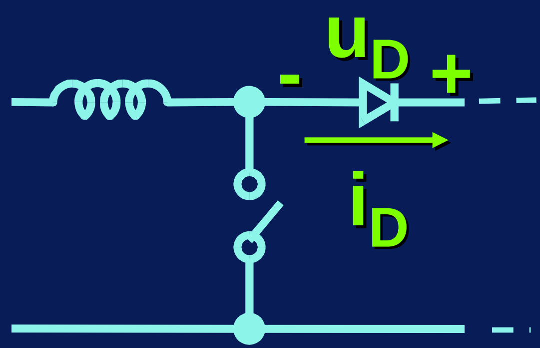


$$I_D = I_o$$

Boost - Forme d'onda in CCM: i_D, u_D

$$I_D = \frac{I_{L\,min} + I_{L\,max}}{2 \cdot T_S} \cdot t_{off} = I_L \cdot (1 - \delta)$$





$I_D = I_o$

$U_{Dmax} = U_o$

Convertitore boost in CCM

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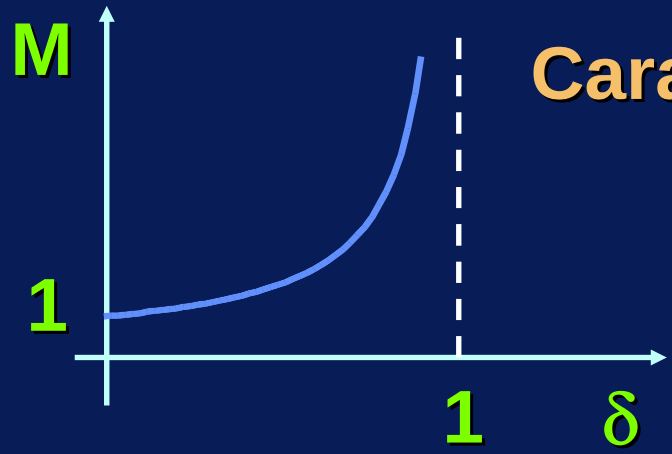
Caratteristica di controllo

$$M = \frac{U_o}{U_i} = \frac{1}{1-\delta}$$

Convertitore boost in CCM



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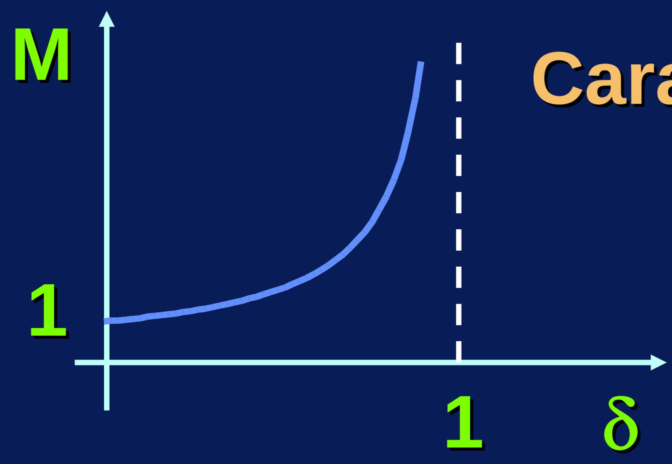
Convertitore boost in CCM



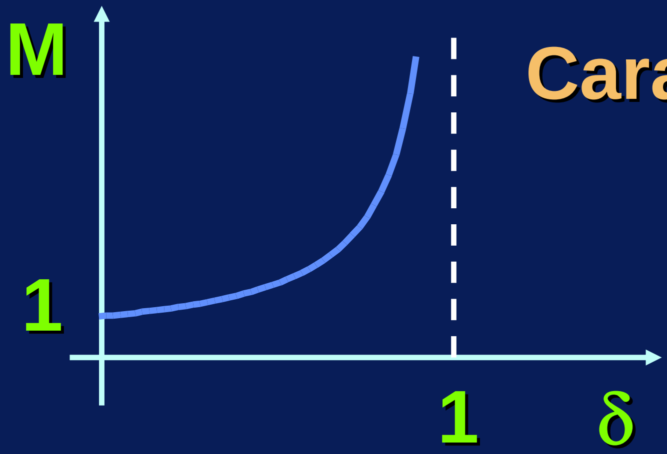
Caratteristica di controllo

$$M = \frac{U_o}{U_i} = \frac{1}{1-\delta}$$

Ondulazione di corrente

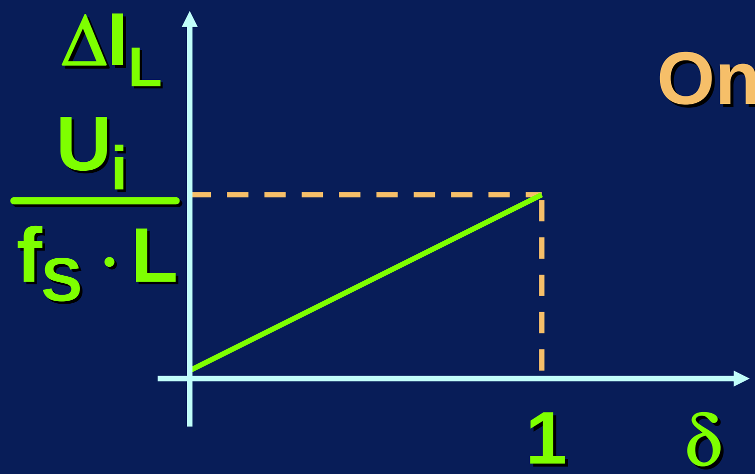
$$\Delta I_L = \frac{U_i}{L} \cdot t_{on} = \frac{U_i \cdot \delta}{f_S \cdot L}$$

Convertitore boost in CCM



Caratteristica di controllo

$$M = \frac{U_o}{U_i} = \frac{1}{1-\delta}$$



Ondulazione di corrente

$$\Delta I_L = \frac{U_i}{L} \cdot t_{on} = \frac{U_i \cdot \delta}{f_S \cdot L}$$

Analisi del funzionamento discontinuo (DCM)

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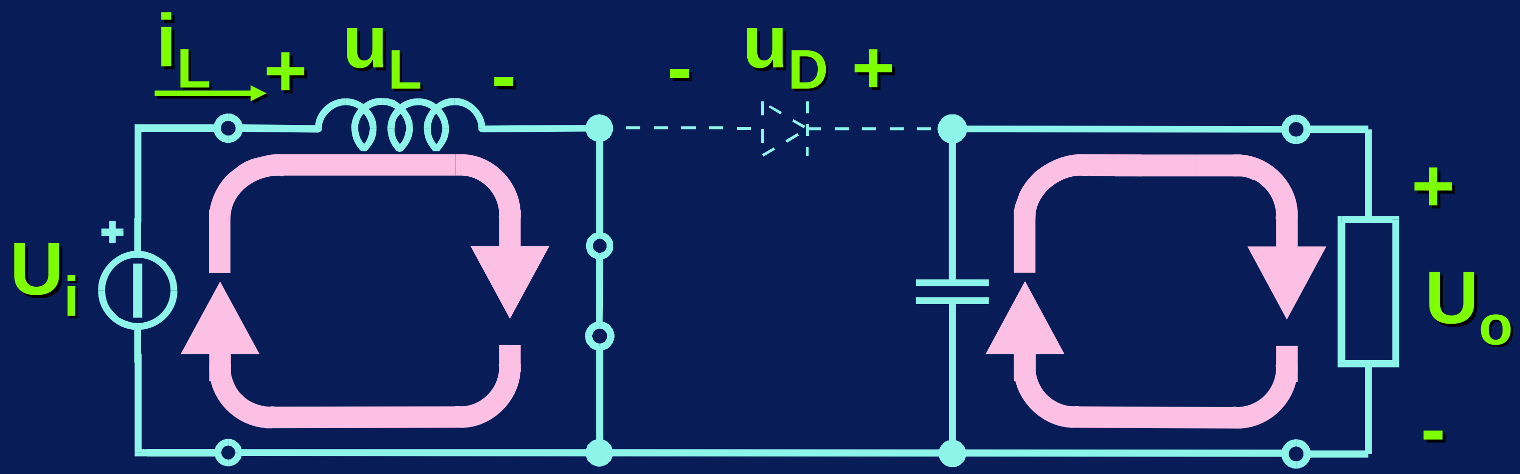
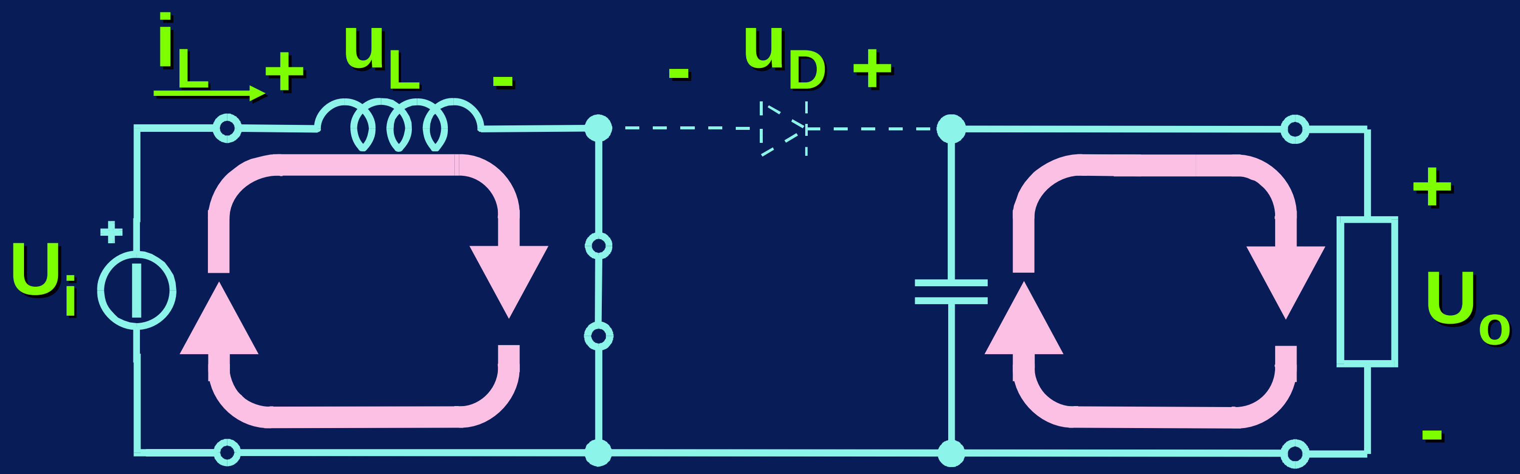
Tempo di chiusura di S (t_{on})   S on - D off



$u_L = U_i$ $u_D = U_o$

Analisi del funzionamento discontinuo (DCM)

Tempo di chiusura di S (t_{on})   S on - D off

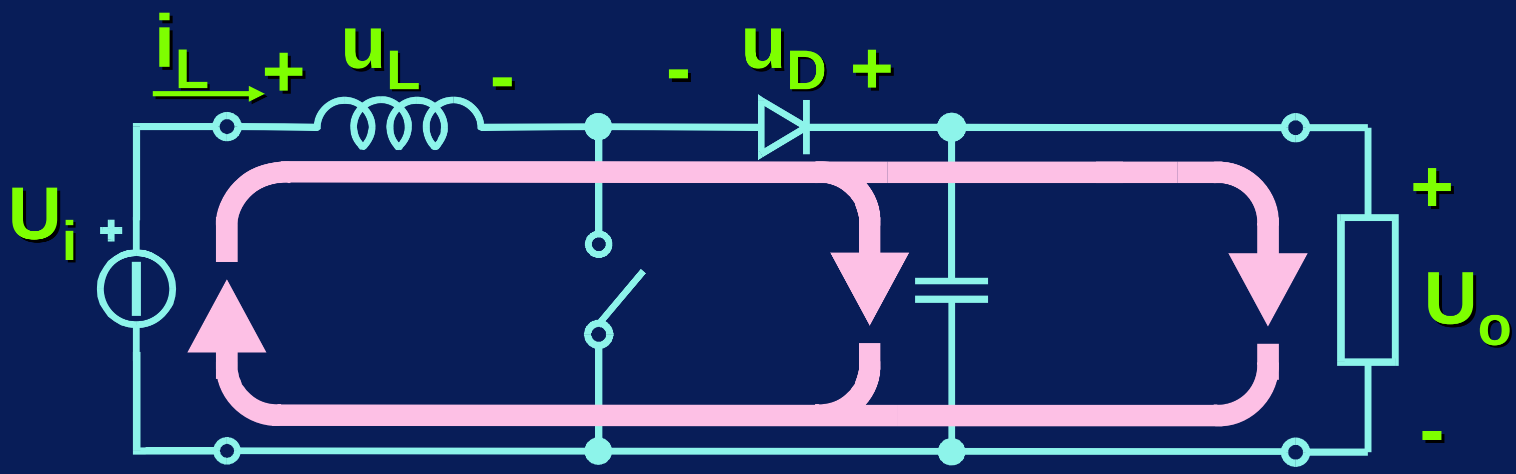


$u_L = U_i$ $u_D = U_o$

A differenza del funzionamento CCM la corrente i_L inizia con valore nullo.

Analisi del funzionamento discontinuo (DCM)

Tempo di apertura di S (t'_{off})   S off - D on

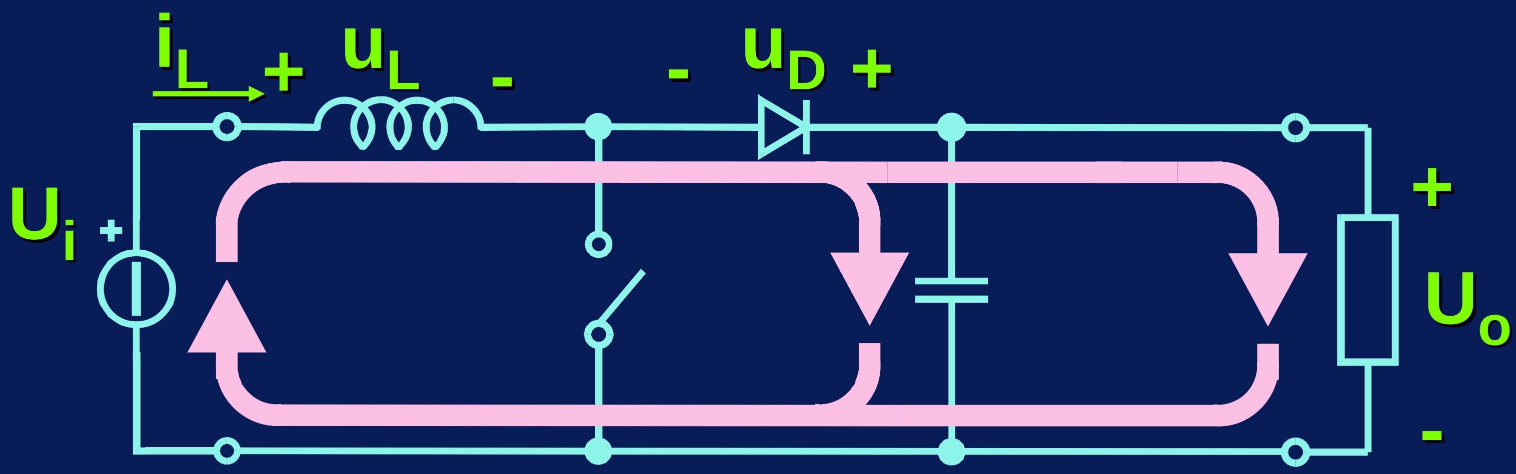


$u_L = U_i - U_o$

$u_S = U_o$

Analisi del funzionamento discontinuo (DCM)

Tempo di apertura di S (t'_{off}) S off - D on

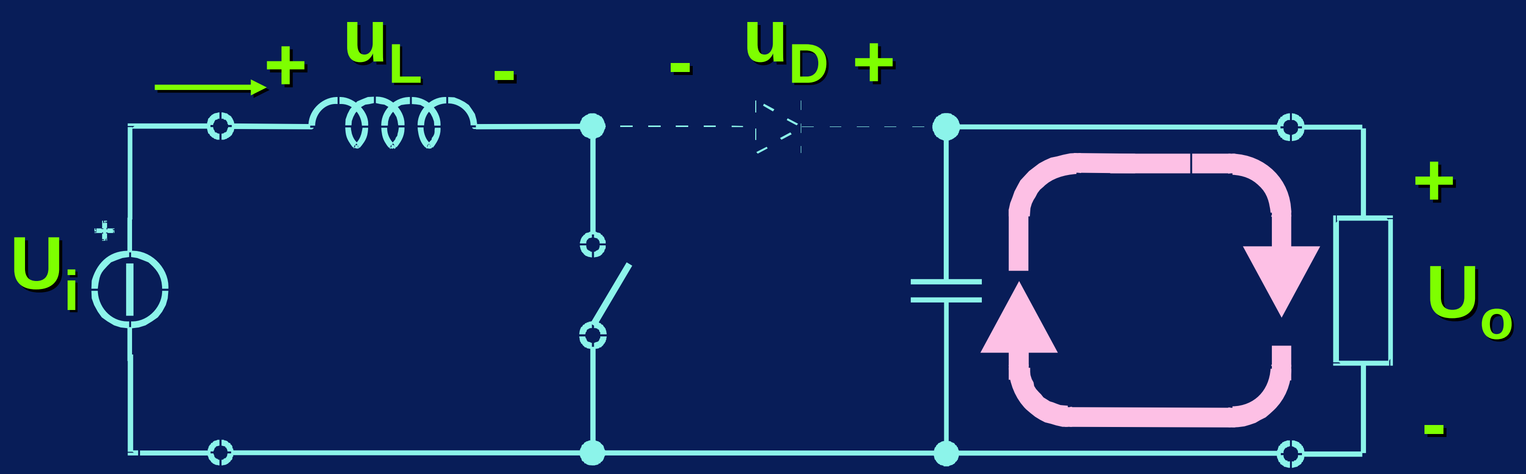


$u_L = U_i - U_o$ $u_S = U_o$

Alla fine di questa fase la corrente dell'induttanza si annulla

Analisi del funzionamento discontinuo (DCM)

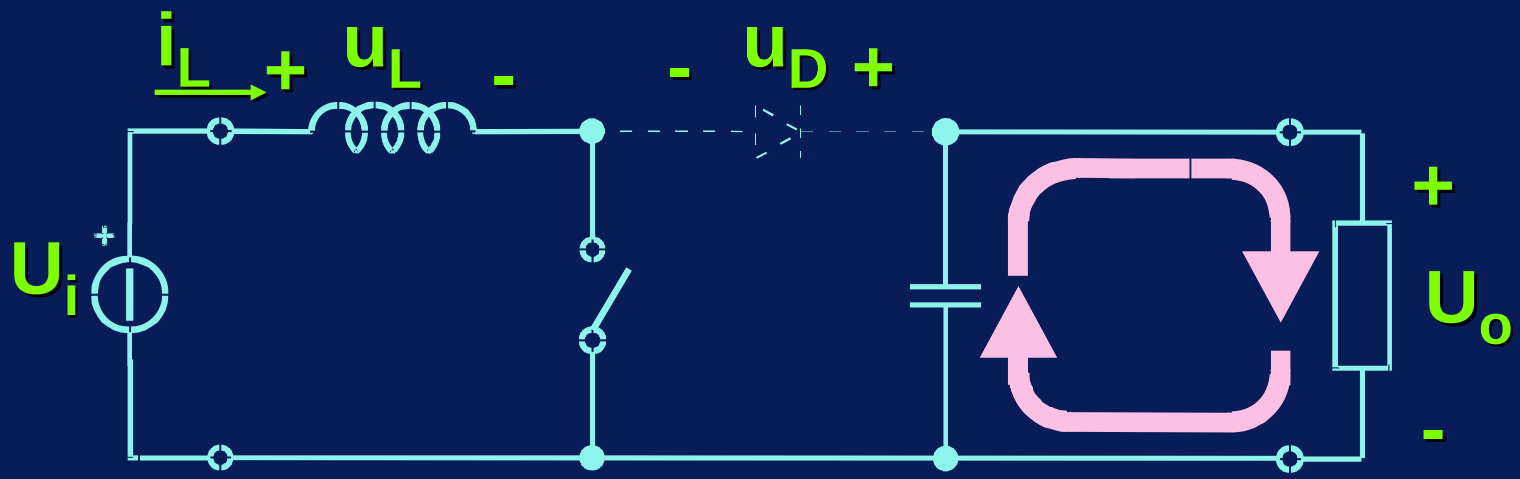
Tempo di apertura di S (t''_{off})   S off - D off



$u_D = U_o - U_i > 0$ $u_S = U_i$

Analisi del funzionamento discontinuo (DCM)

Tempo di apertura di S (t''_{off})   S off - D off

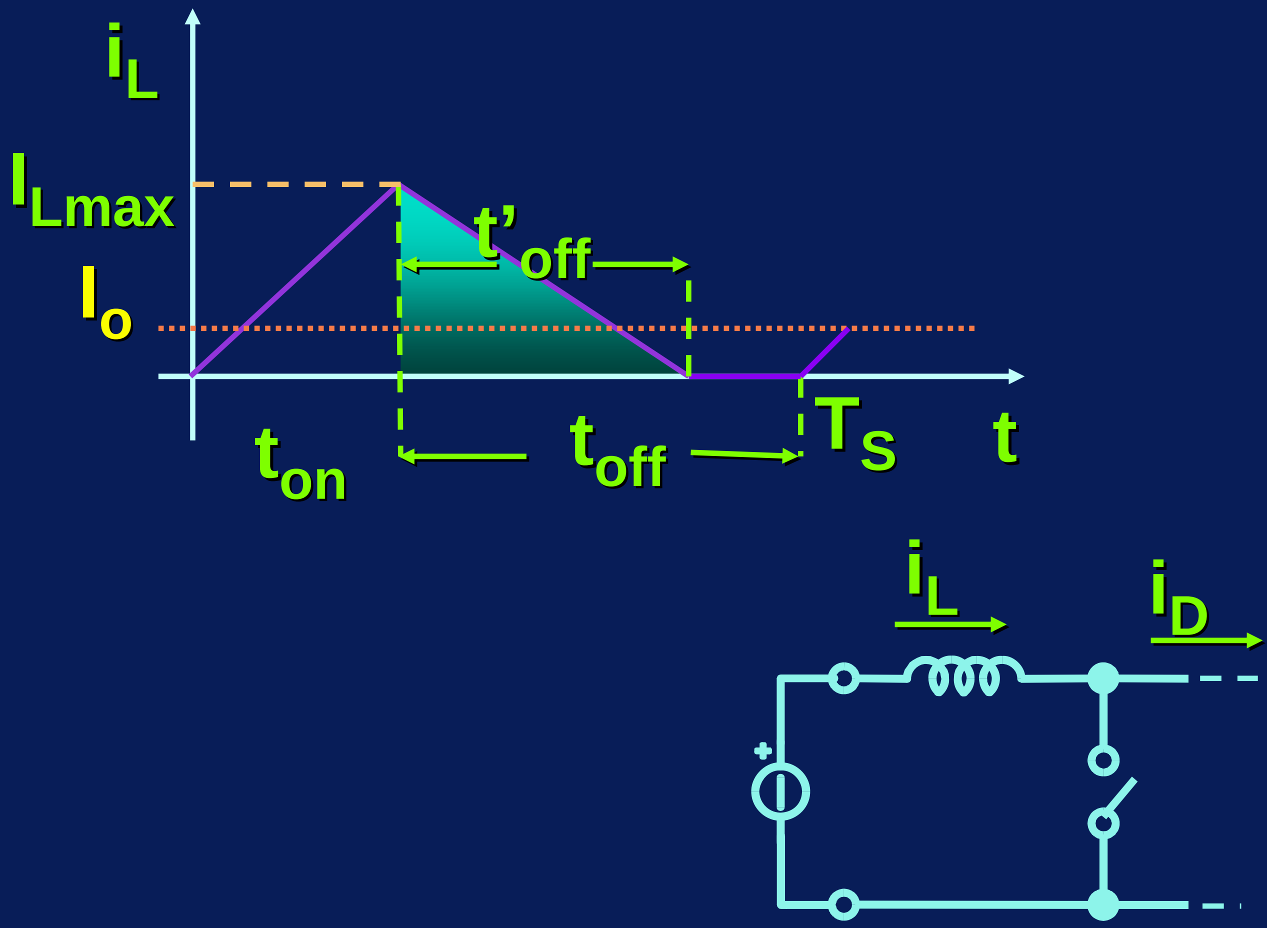


$u_D = U_o - U_i > 0 \qquad u_S = U_i$

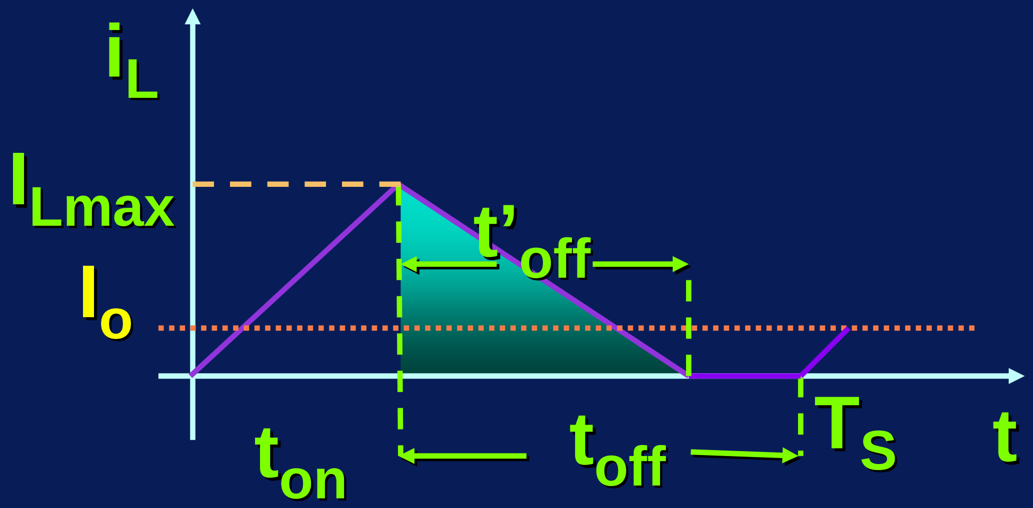
Durante questa fase il solo condensatore fornisce energia al carico

Boost - Forme d’onda in DCM: i_L

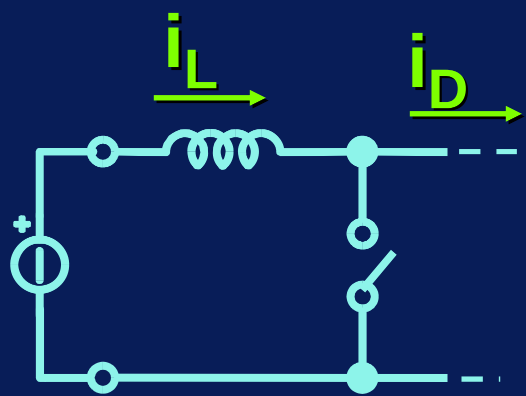
Boost - Forme d'onda in DCM: i_L



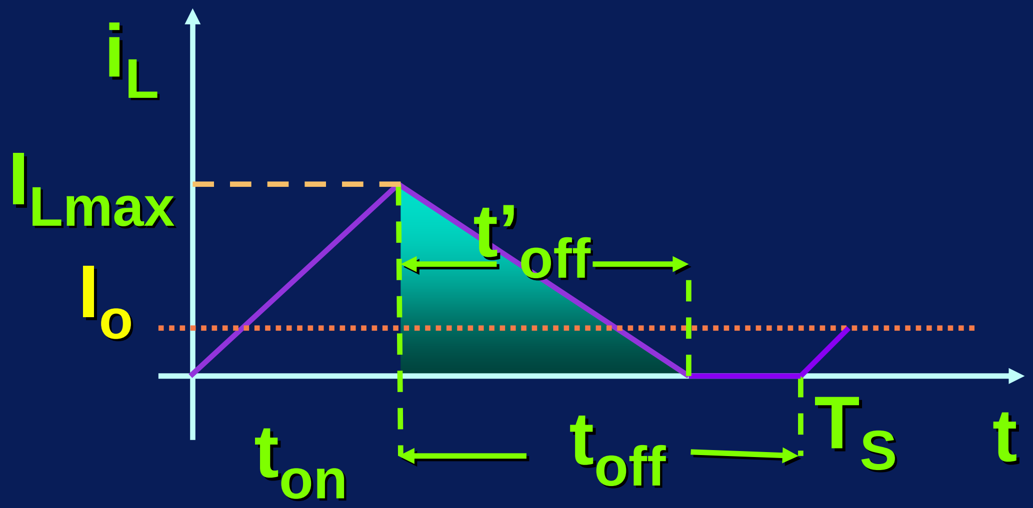
Boost - Forme d'onda in DCM: i_L



$$I_{L\,max} = \frac{U_i}{L} \cdot t_{on}$$

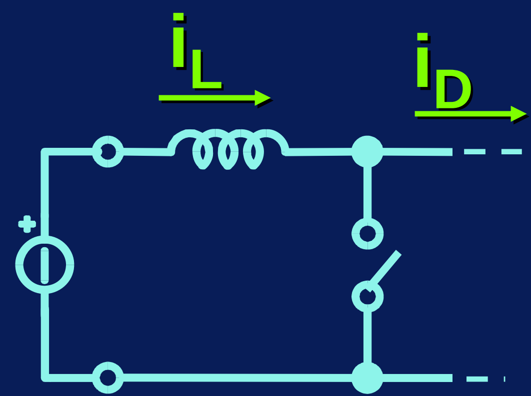


Boost - Forme d'onda in DCM: i_L



$$I_{L\,max} = \frac{U_i}{L} \cdot t_{on}$$

$$I_o = I_D = \frac{I_{L\,max} \cdot t'_{off}}{2 \cdot T_S}$$



Boost - Forme d’onda in DCM: u_L

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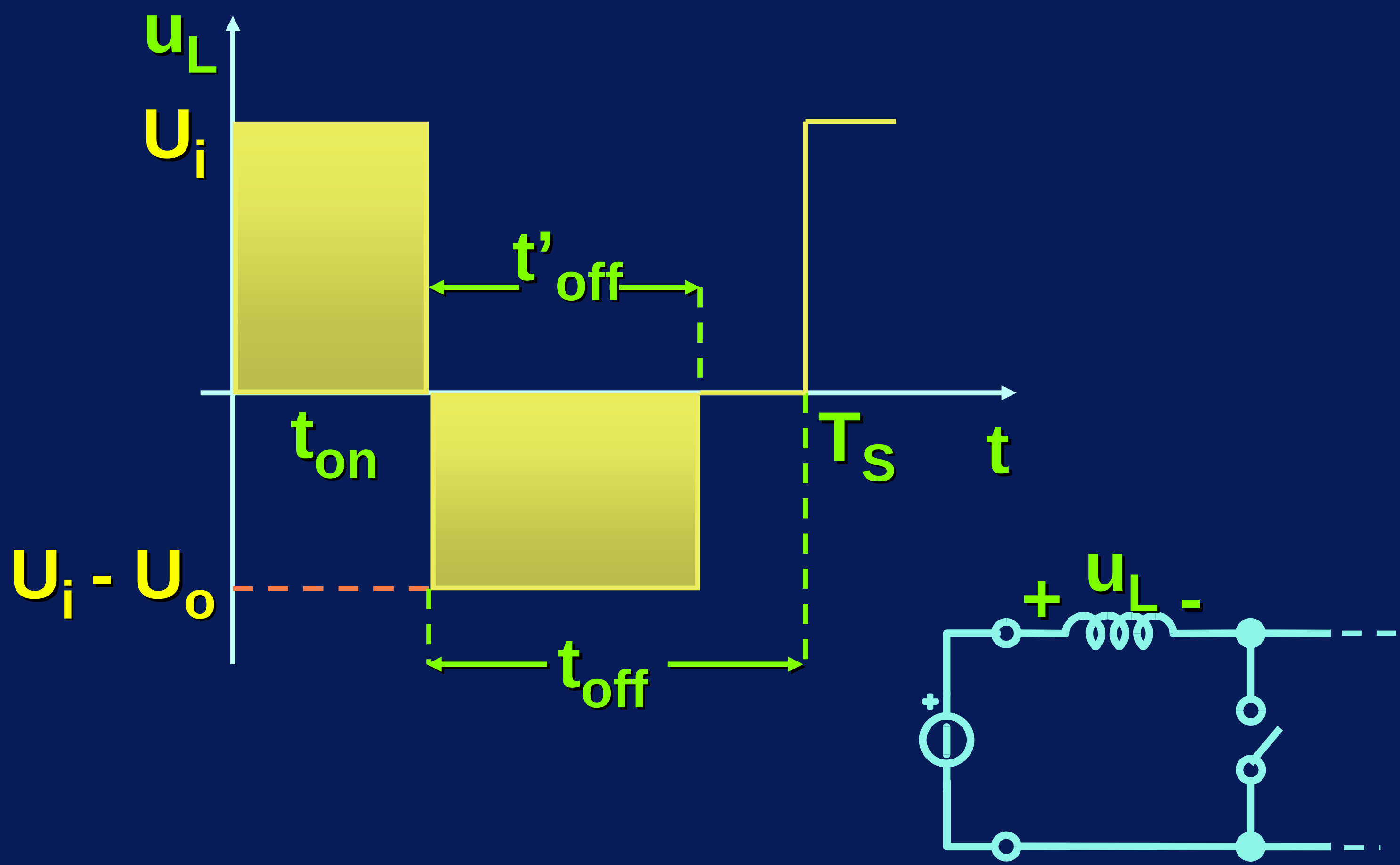
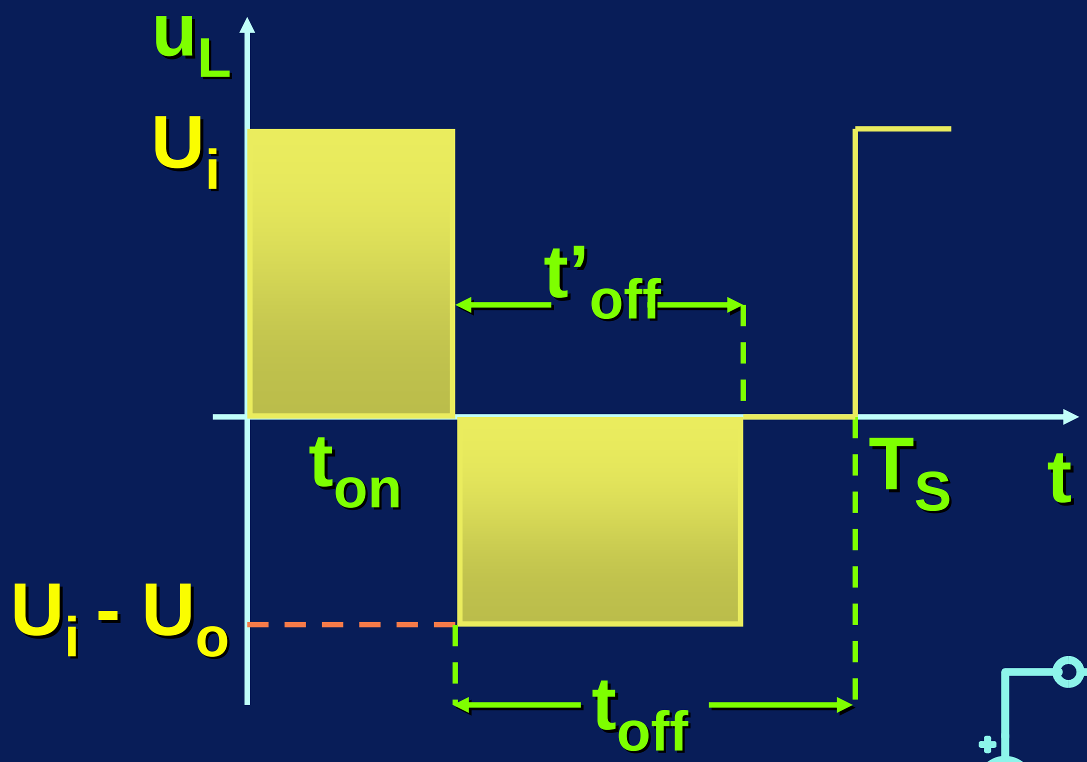
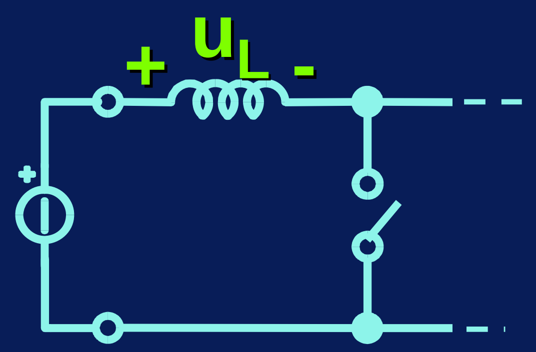


Boost - Forme d'onda in DCM: u_L





$$U_i \cdot t_{on} = (U_o - U_i) \cdot t'_{off}$$

Boost: Caratteristica di controllo in DCM

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$$I_o = \frac{I_{L\,max} \cdot t'_{off}}{2 \cdot T_S}; \qquad I_{L\,max} = \frac{U_i}{L} \cdot t_{on};$$

$$t'_{off} = \frac{U_i}{U_o - U_i} \cdot t_{on}$$

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$$\Downarrow$$

$$M = \frac{U_o}{U_i} = 1 + \delta^2 \cdot \frac{U_i}{2 \cdot f_S \cdot L \cdot I_o} = 1 + \delta^2 \cdot \frac{I_N}{I_o}$$

dove: $I_N = \dfrac{U_i}{2 \cdot f_S \cdot L}$

Nota: $U_{o_{DCM}} > U_{o_{CCM}}$

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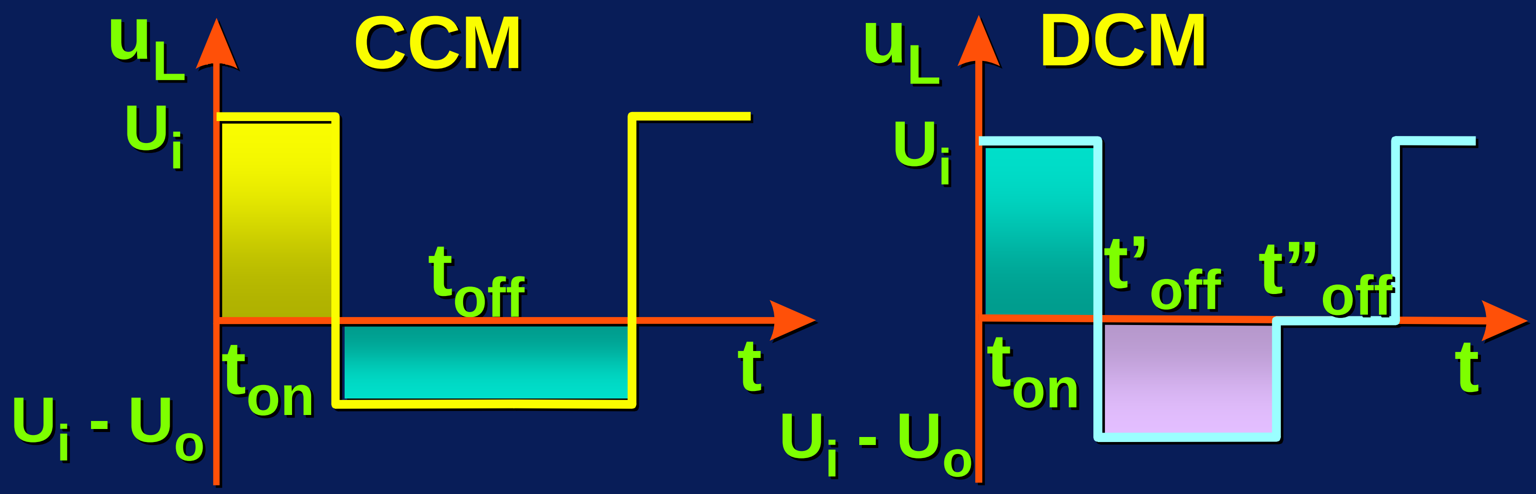
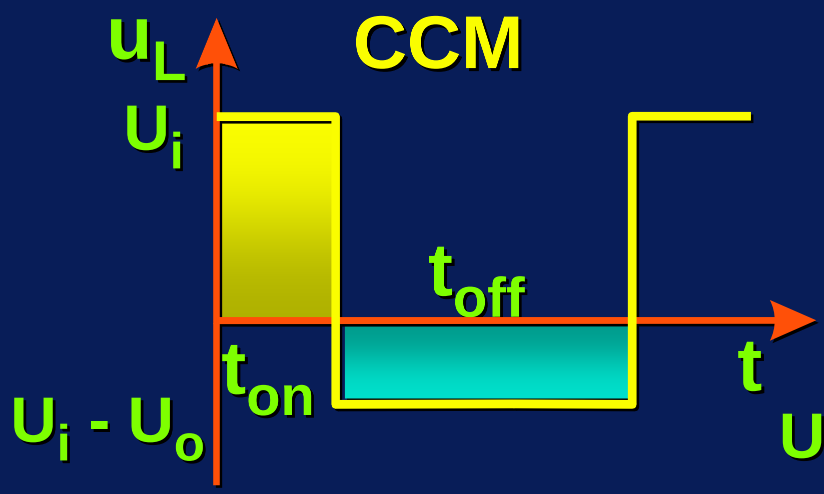
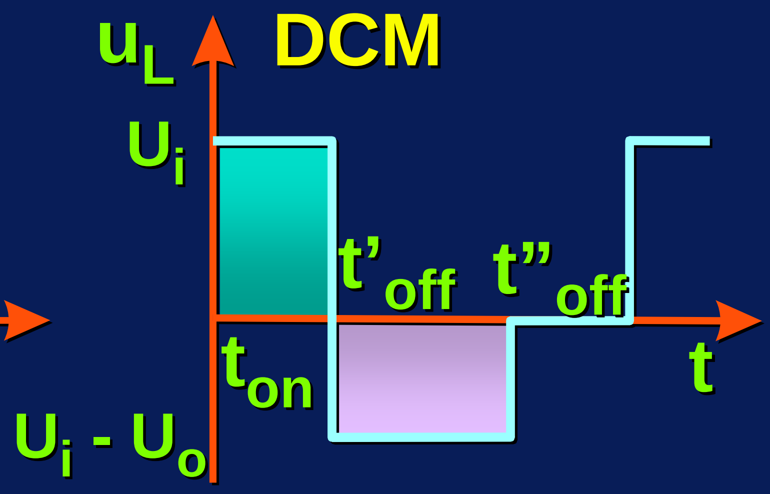


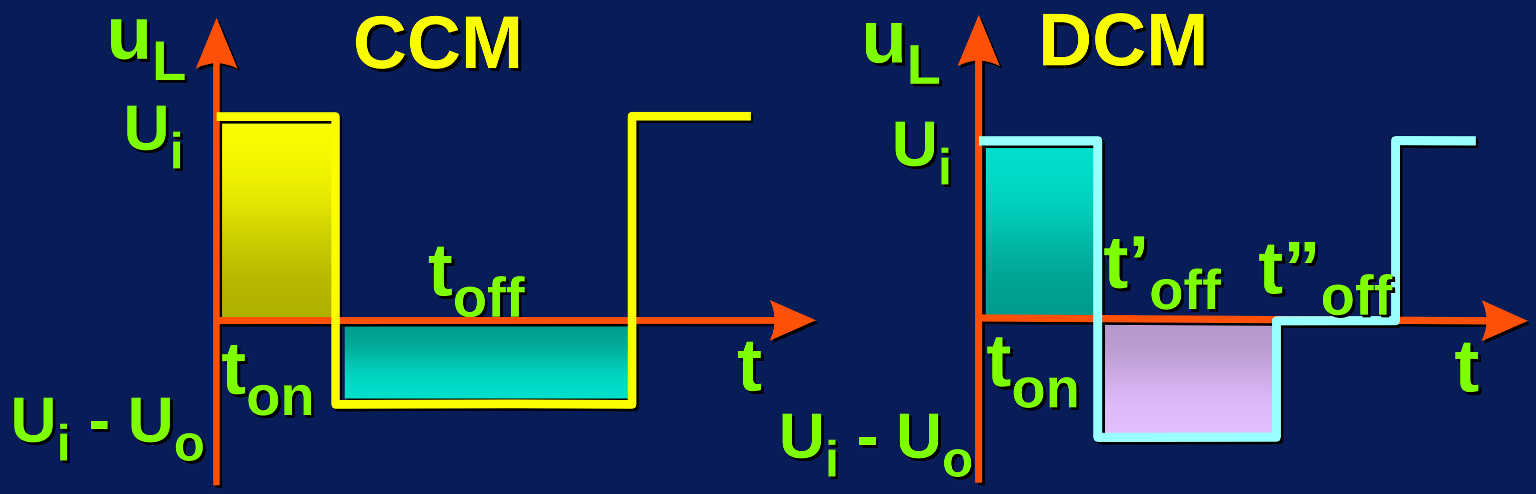
Nota: $U_{oDCM} > U_{oCCM}$





$$U_i\, t_{on} = (U_{oCCM} - U_i)t_{off} = (U_{oDCM} - U_i)t'_{off}$$

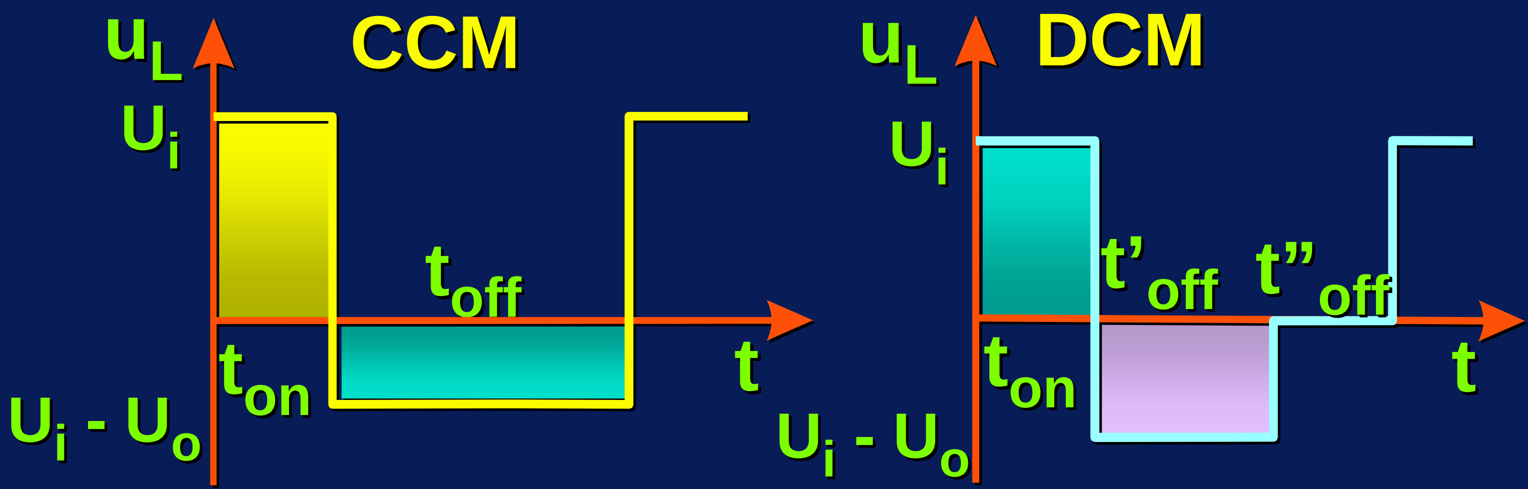
Nota: $U_{o_{DCM}} > U_{o_{CCM}}$



$$U_i\, t_{on} = (U_{o_{CCM}} - U_i)t_{off} = (U_{o_{DCM}} - U_i)t'_{off}$$

$$\frac{U_{o_{DCM}} - U_i}{U_{o_{CCM}} - U_i} = \frac{t_{off}}{t'_{off}} > 1 \Rightarrow U_{o_{DCM}} > U_{o_{CCM}}$$

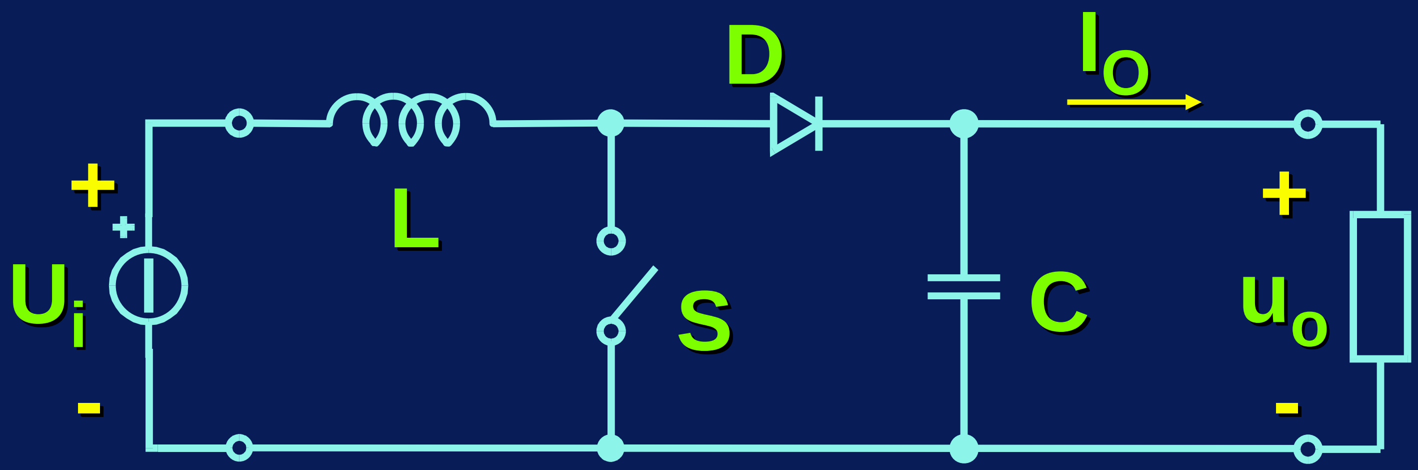
Nota: $U_{oDCM} > U_{oCCM}$



$$U_i\, t_{on} = (U_{oCCM} - U_i)t_{off} = (U_{oDCM} - U_i)t'_{off}$$

$$\frac{U_{oDCM}}{U_{oCCM}} = 1 + \frac{t_{on}t''_{off}}{T_S t'_{off}} > 1$$

NOTA: **A vuoto (I_o =0) il convertitore non è controllabile**



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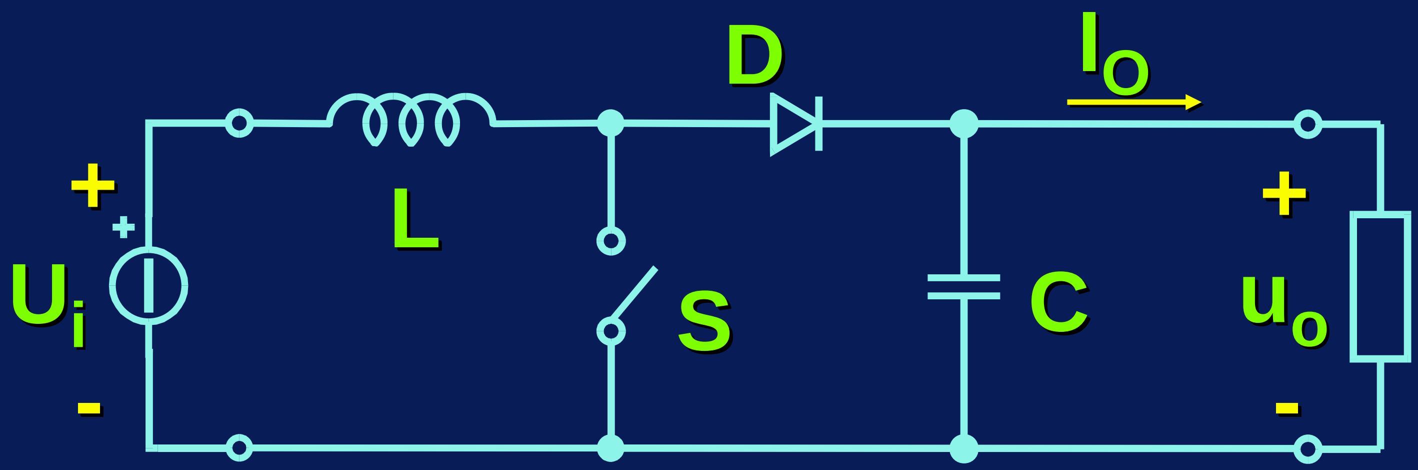

Se I_o = 0 non c'è assorbimento di energia dal carico. L'energia fornita dall'alimentazione si accumula progressivamente nel condensatore C, la cui tensione U_o cresce indefinitamente.

Boost: Caratteristiche di controllo

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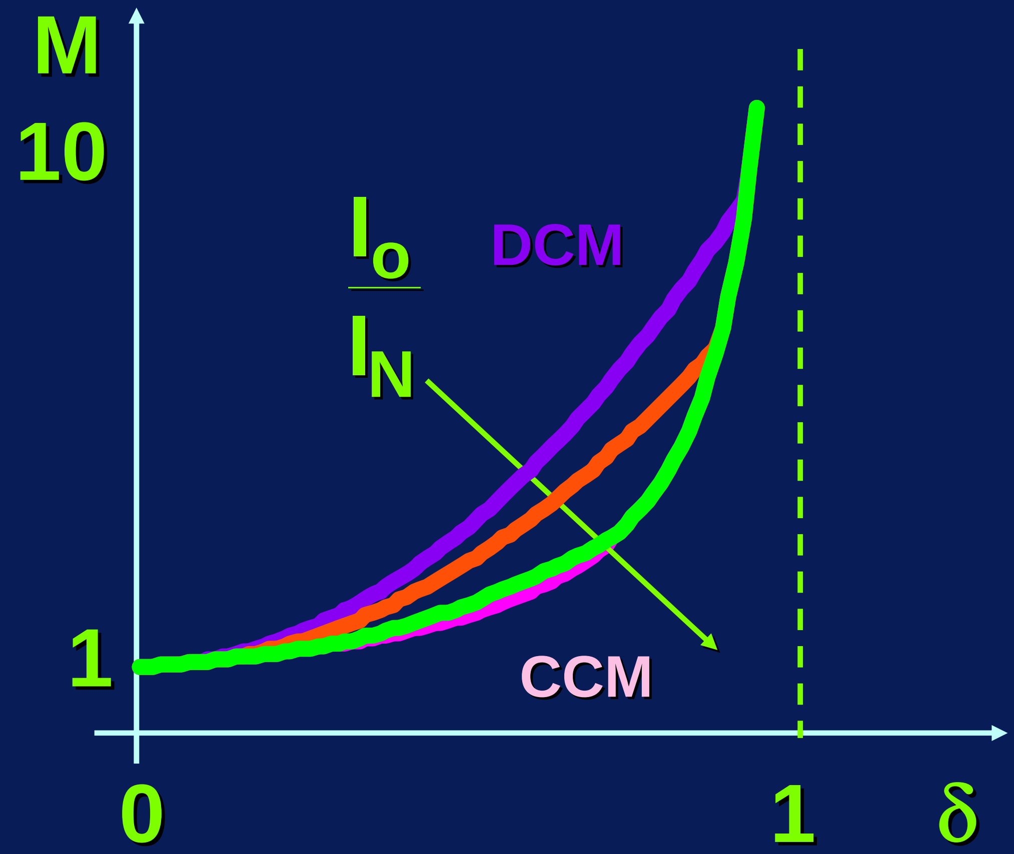
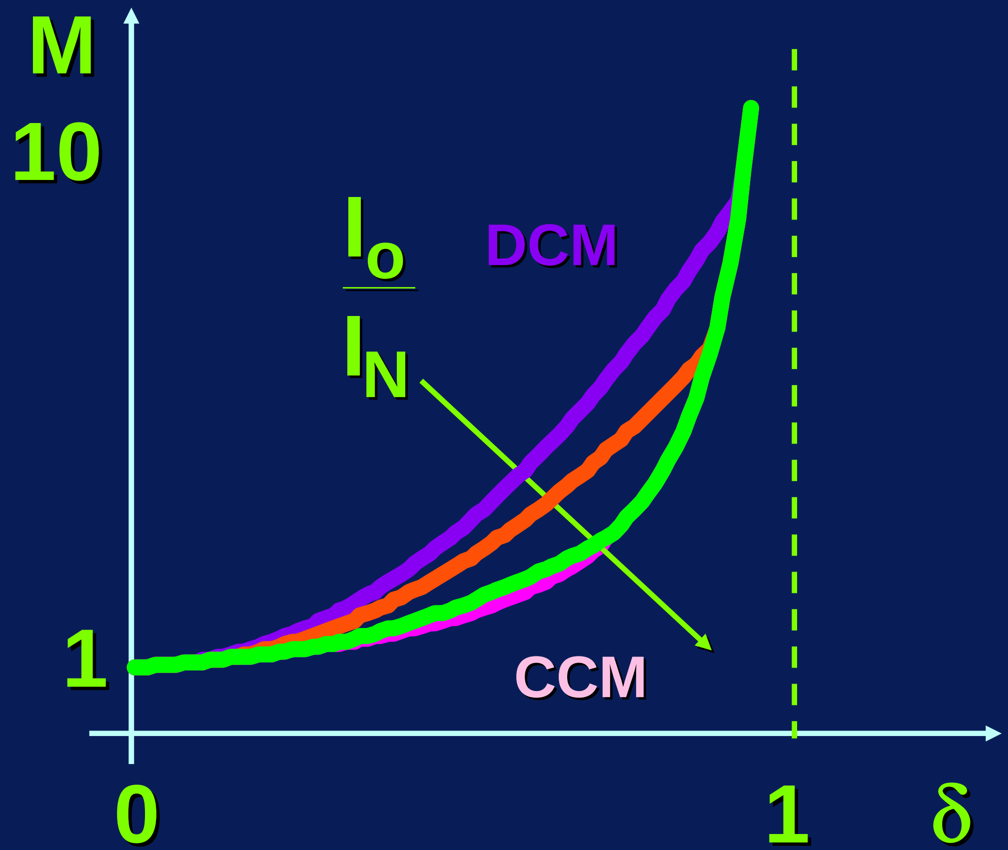
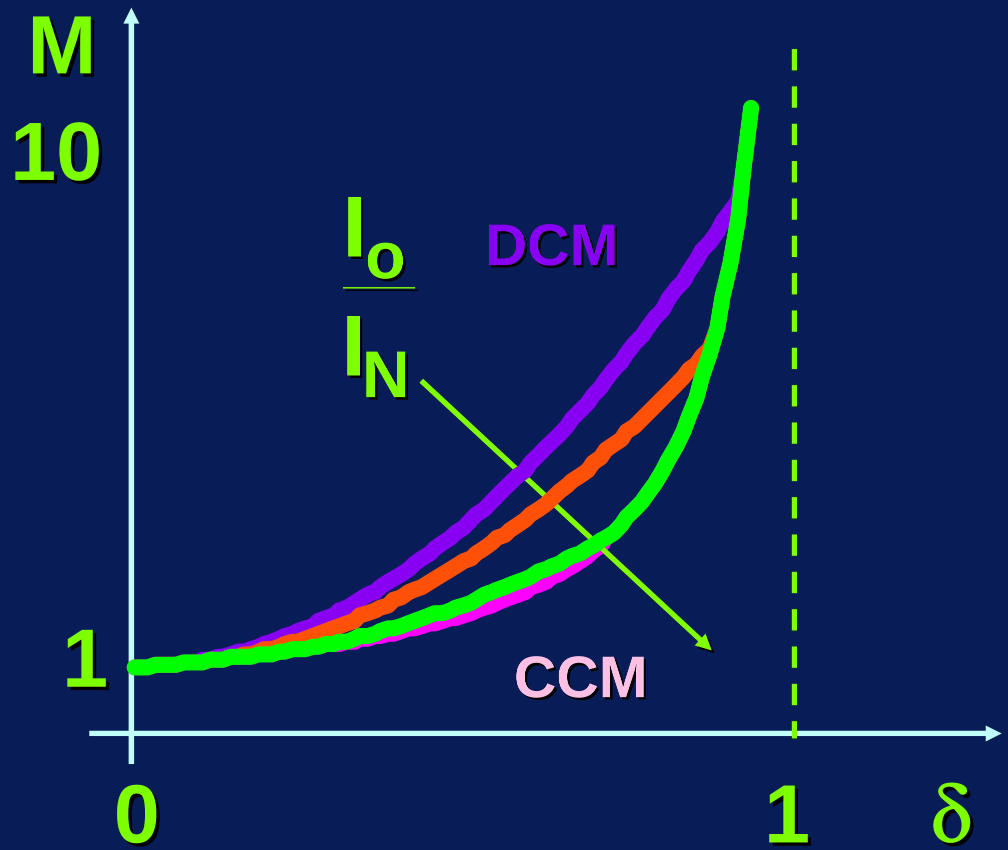


Boost: Caratteristiche di controllo



Anche in questo caso valgono le curve che danno tensione d'uscita più elevata

Boost: Caratteristiche di controllo



Il funzionamento è continuo per valori di δ estremi, discontinuo per valori intermedi

Ondulazione di corrente

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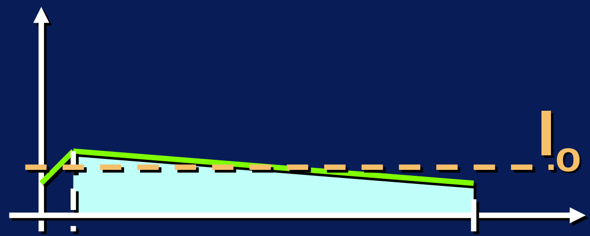
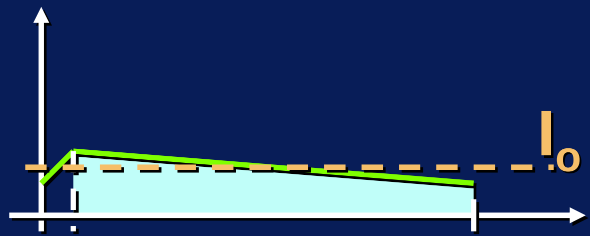
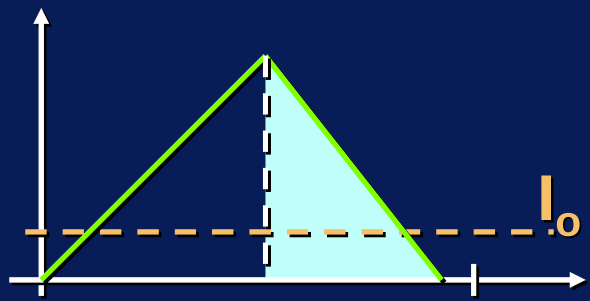


δ piccolo

Ondulazione di corrente

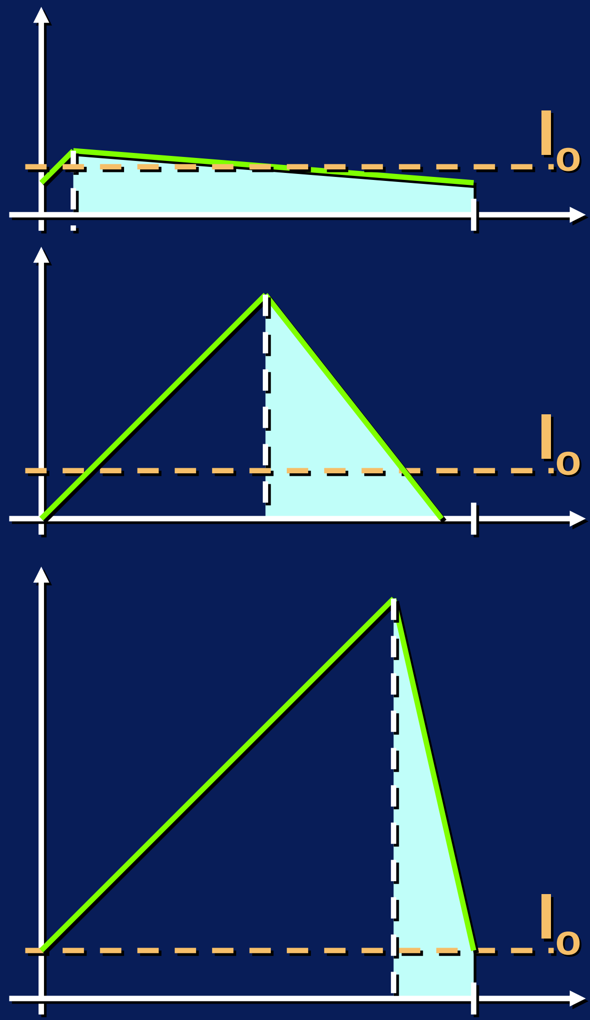


δ piccolo



δ intermedio

Ondulazione di corrente

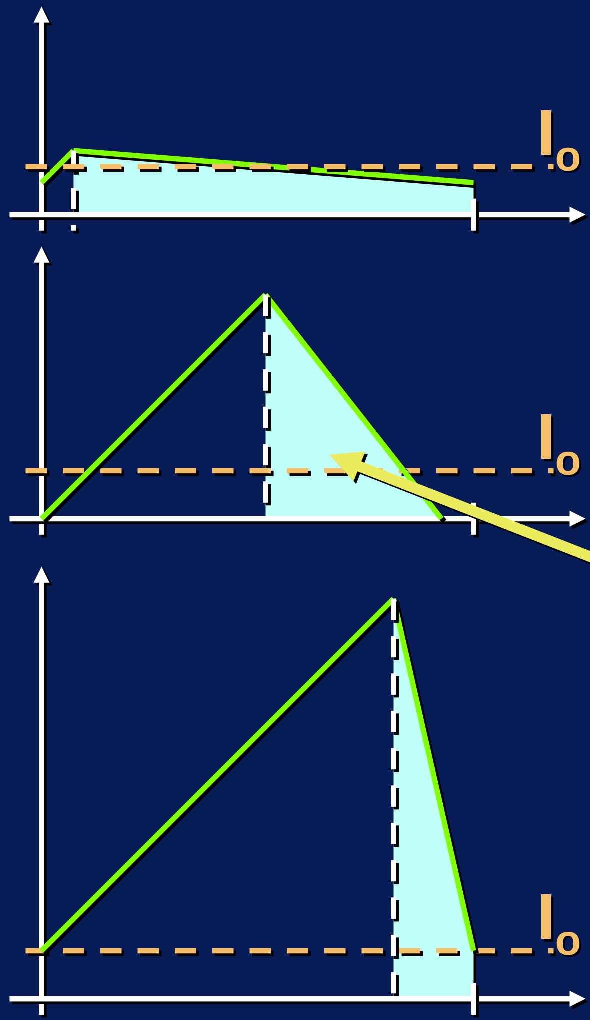


δ piccolo

δ intermedio

δ elevato

Ondulazione di corrente



δ piccolo

A parità di I_o l'intermittenza si può avere per $\delta \cong 0.5$

Boost: Caratteristiche d’uscita

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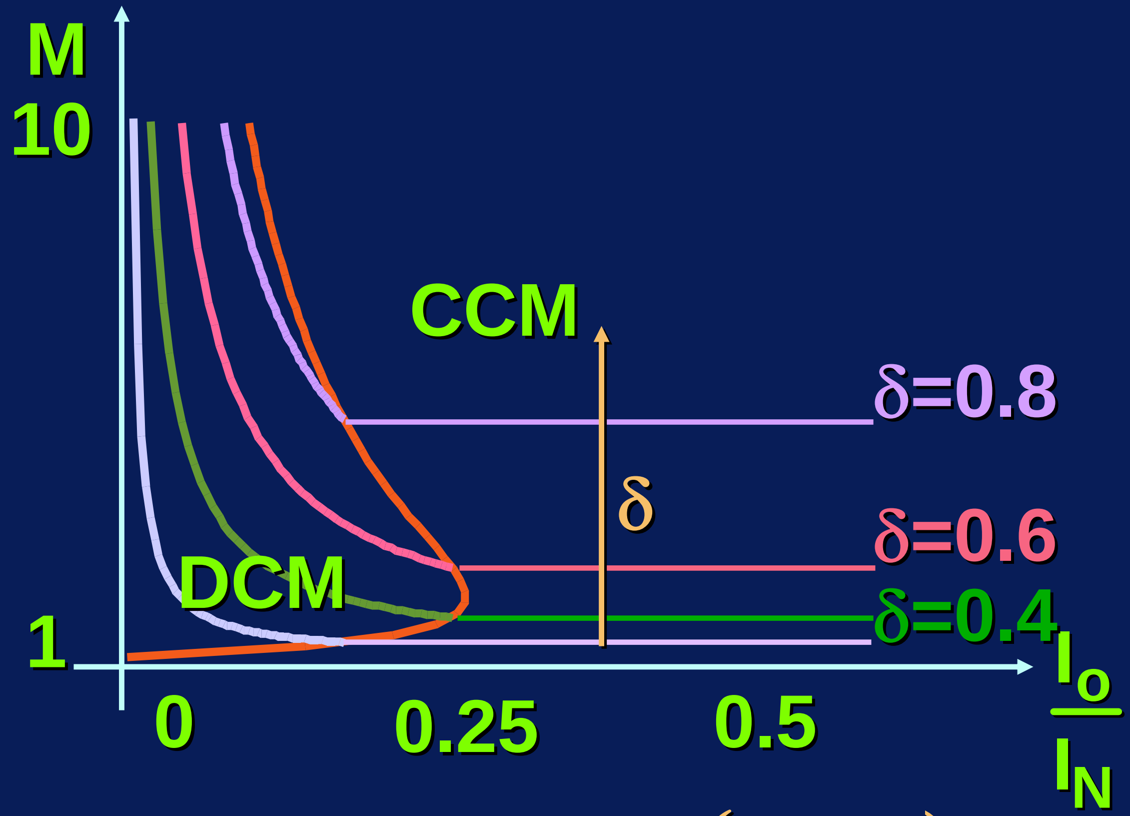

Curva limite: $$\frac{I_o}{I_N} = \frac{1}{M} \cdot \left(1 - \frac{1}{M}\right)$$

Caratteristica di controllo in DCM per carico resistivo

Caratteristica di controllo in DCM per carico resistivo

$$M = \frac{1}{2} + \sqrt{\frac{1}{4} + \frac{\delta^2}{k}}$$

dove:

$$k = \frac{2 \cdot f_S \cdot L}{R_o}$$

Corrente del condensatore di filtro: i_C

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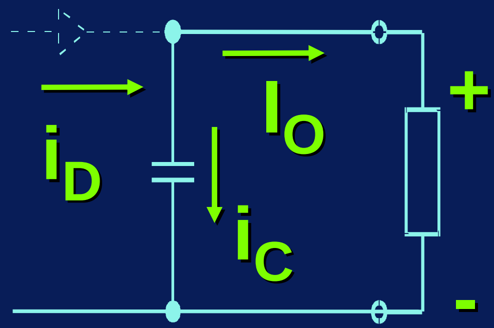
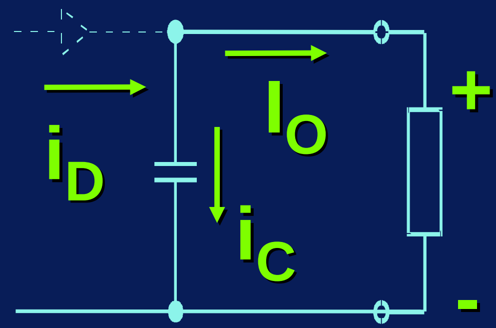
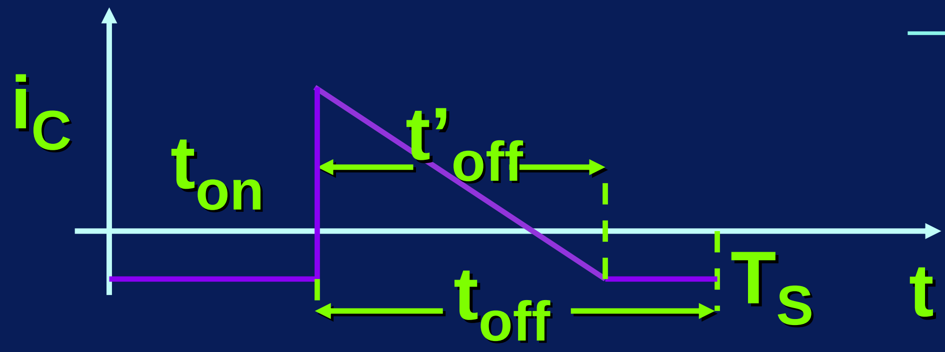
$$i_C = i_D - I_o$$



Corrente del condensatore di filtro: i_C

$$i_C = i_D - I_o$$





i_C ha fronti ripidi; l'induttanza parassita di C (ESL) deve quindi essere minima

Note

- Le tecniche di controllo sono le stesse del convertitore Buck
- La risposta dinamica è però difficile da dominare (caratteristica statica nonlineare, modello ai piccoli segnali a parametri variabili e zero a parte reale positiva)
- Schemi a trasformatore basati sulla topologia boost risultano complessi e sono poco usati