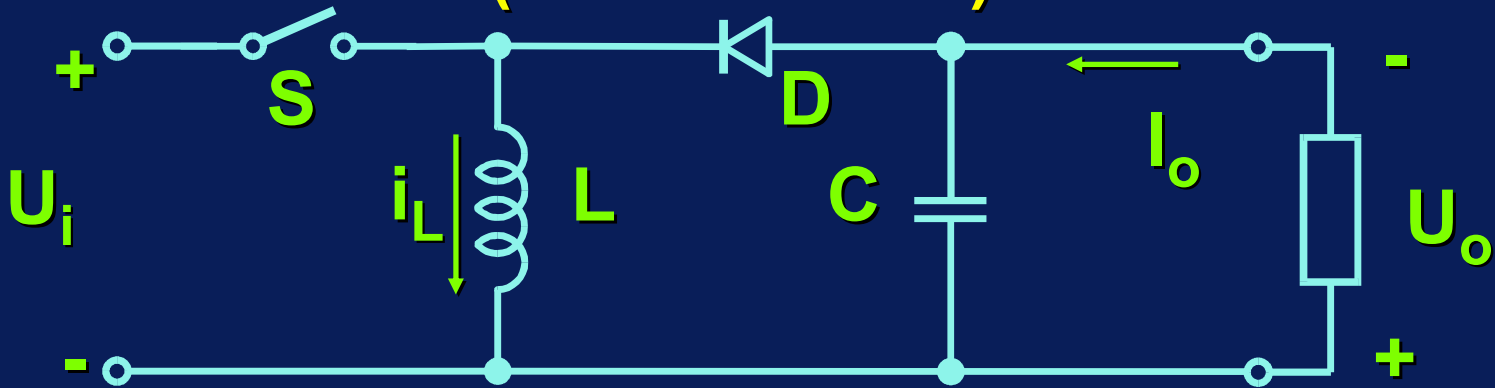


Corso di
ELETRONICA INDUSTRIALE

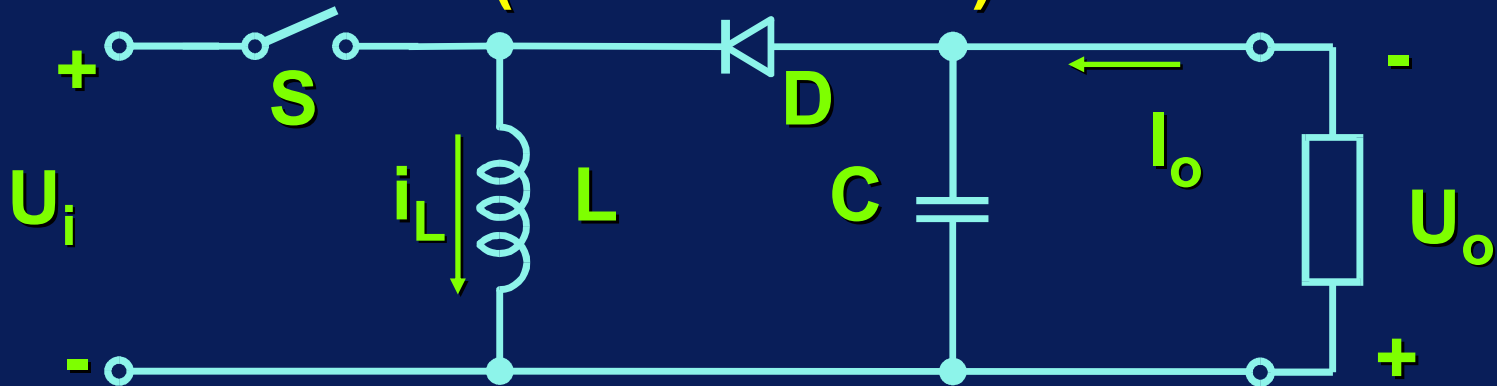
“Convertitore Buck-Boost”

Convertitore innalzatore/abbassatore (Buck / Boost)

Convertitore innalzatore/abbassatore (Buck / Boost)



Convertitore innalzatore/abbassatore (Buck / Boost)



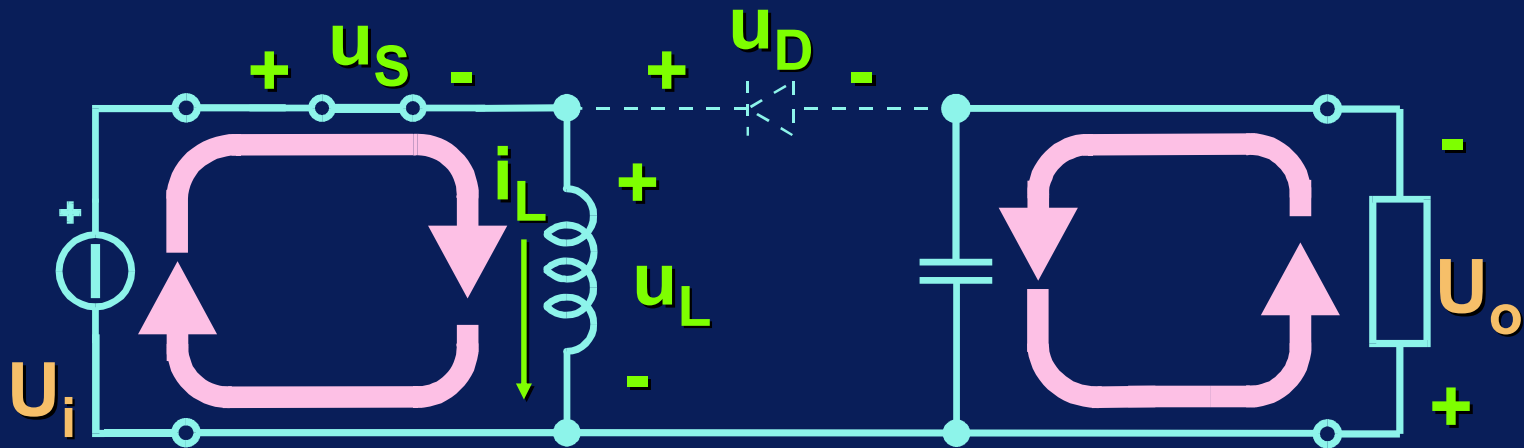
Ipotesi per lo studio:

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

Analisi del funzionamento continuo (CCM)

Analisi del funzionamento continuo (CCM)

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

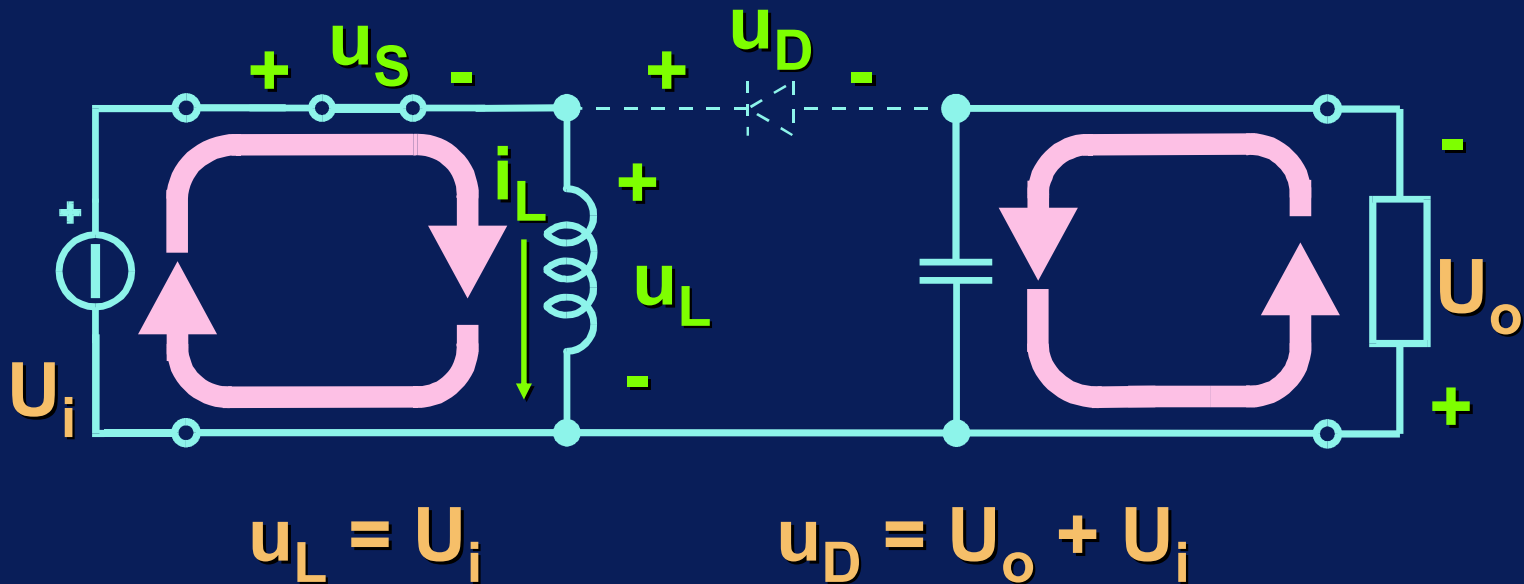


$$u_L = U_i$$

$$u_D = U_o + U_i$$

Analisi del funzionamento continuo (CCM)

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

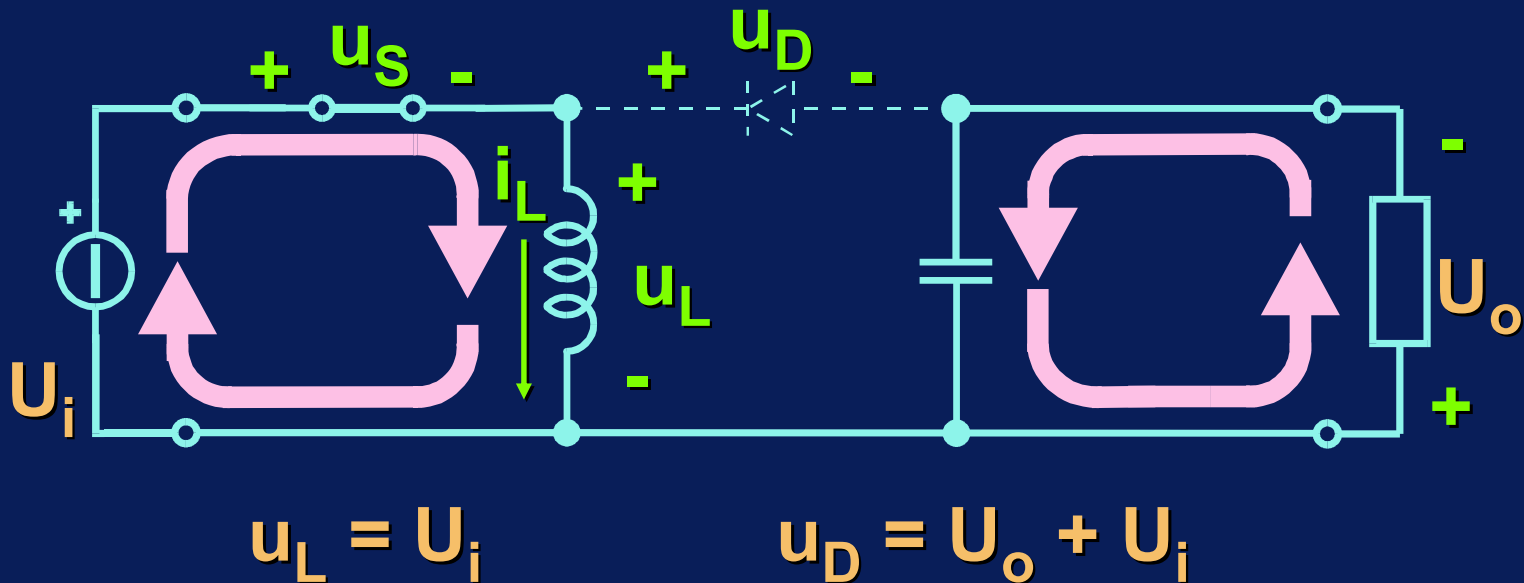


Nota:

La tensione di carico ha polarità negativa

Analisi del funzionamento continuo (CCM)

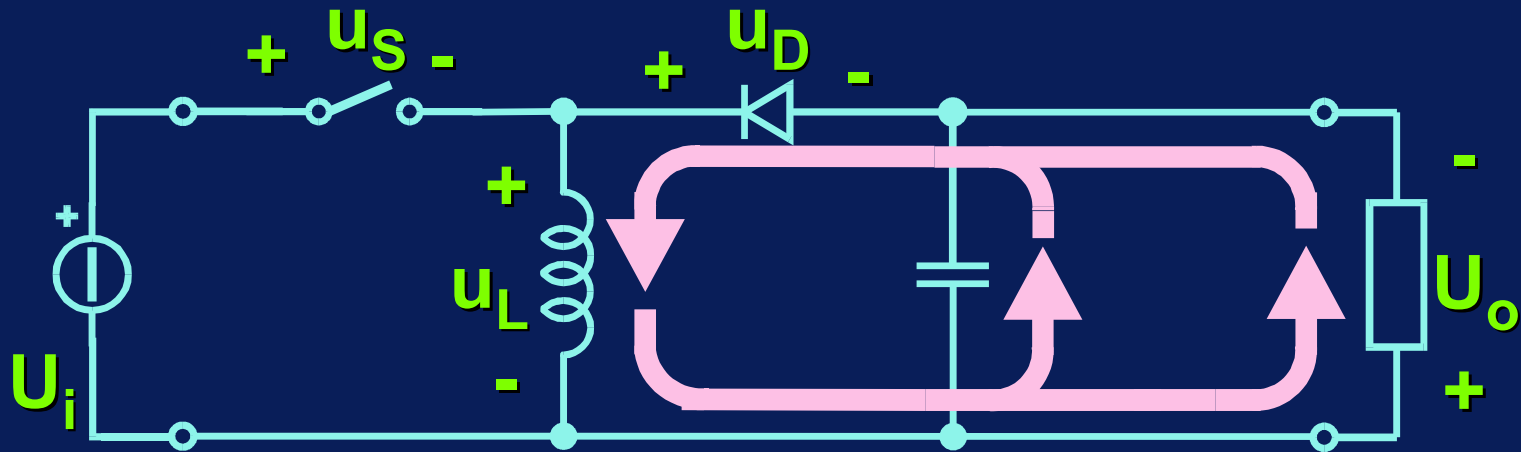
Tempo di chiusura di S (t_{on}) S on - D off



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

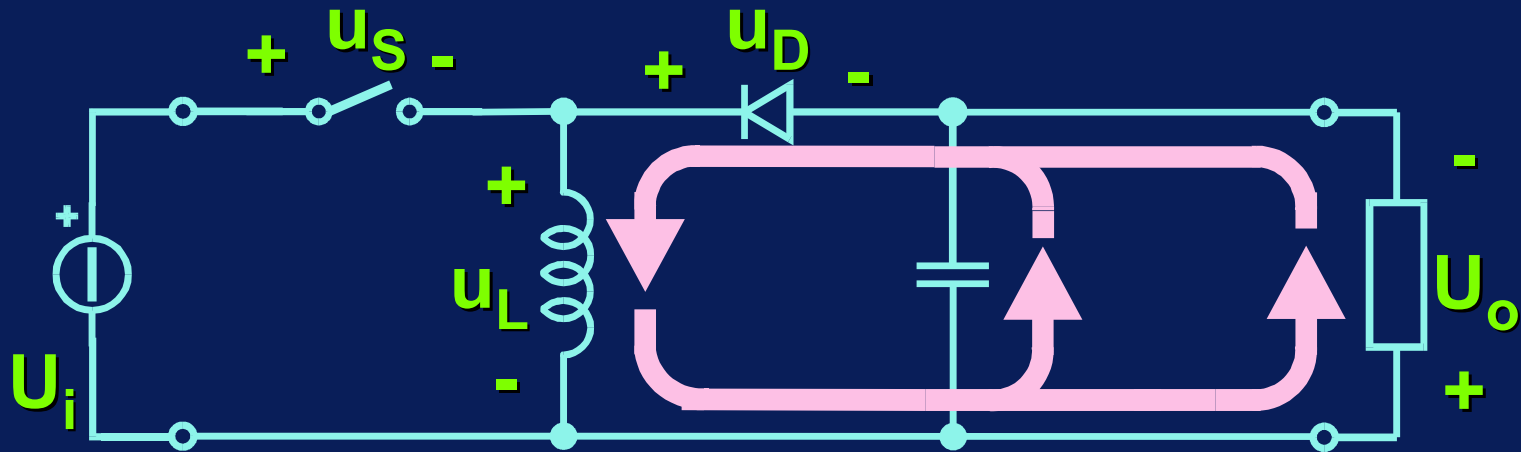


$$u_L = -U_o$$

$$u_S = U_o + U_i$$

Analisi del funzionamento continuo (CCM)

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

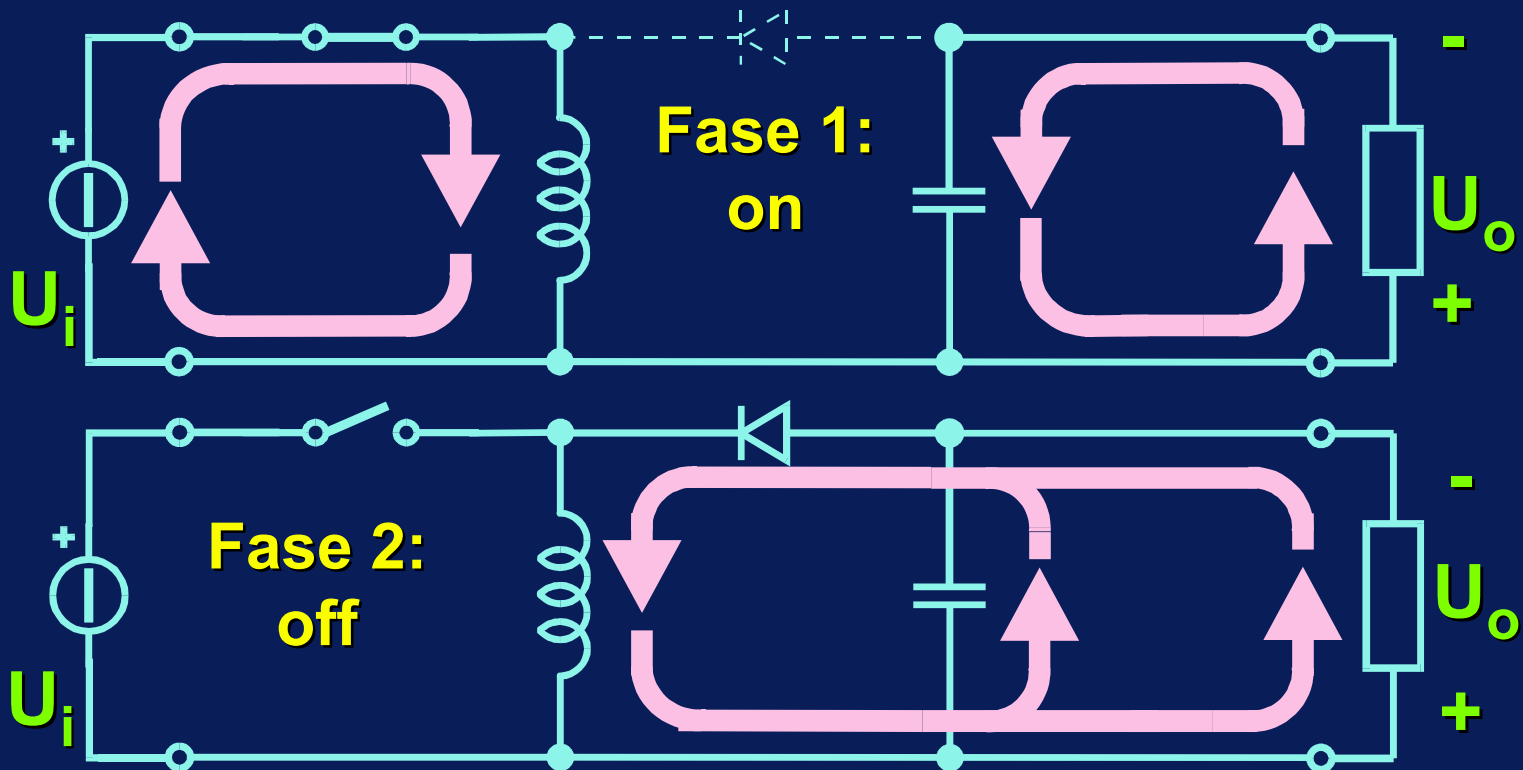


$$u_L = -U_o$$

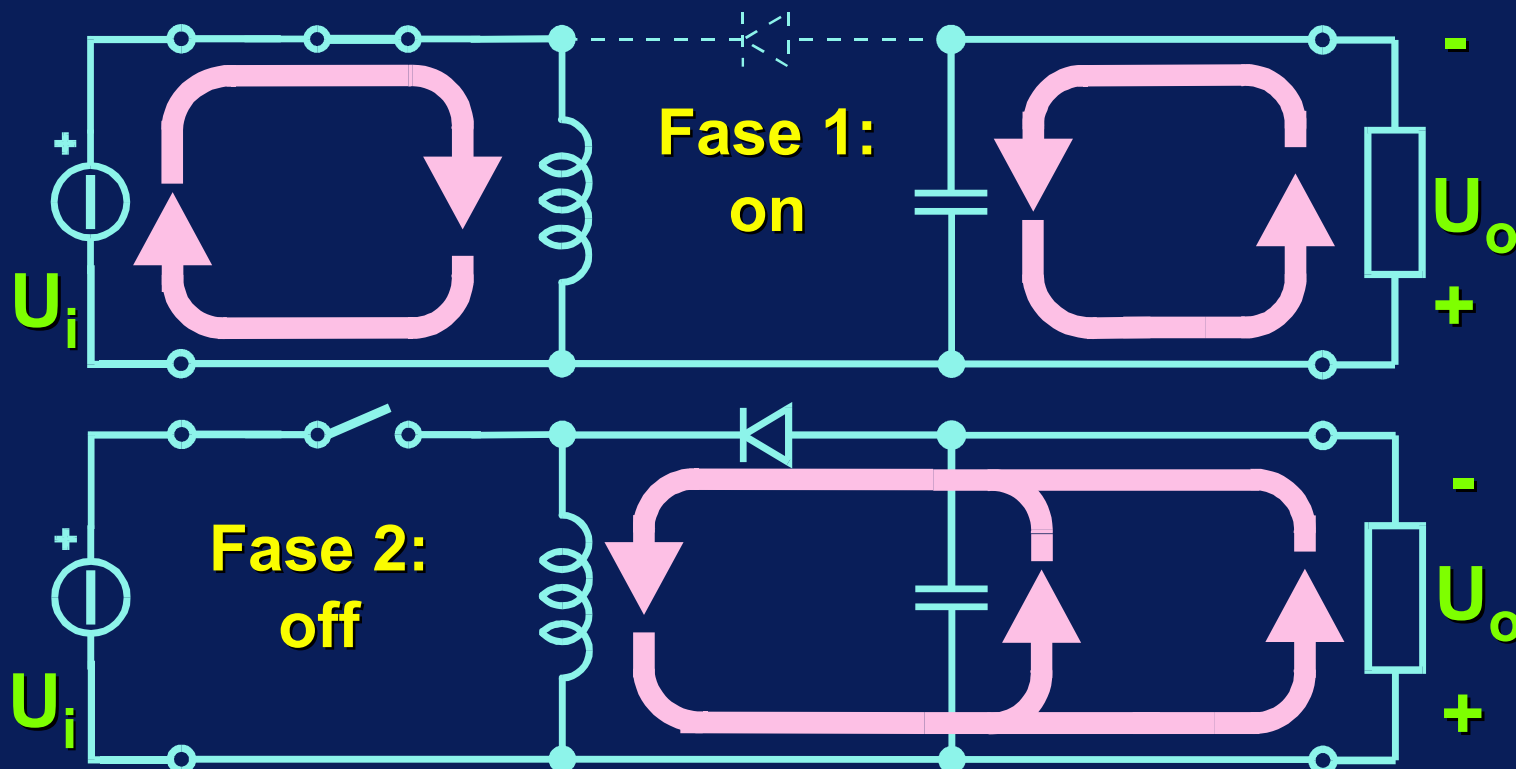
$$u_S = U_o + U_i$$

Durante questa fase la sola induttanza fornisce energia allo stadio di uscita

Analisi del funzionamento continuo (CCM)

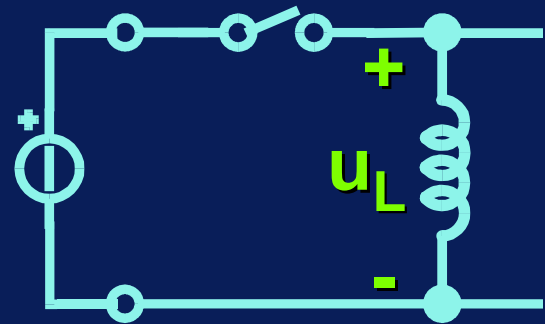
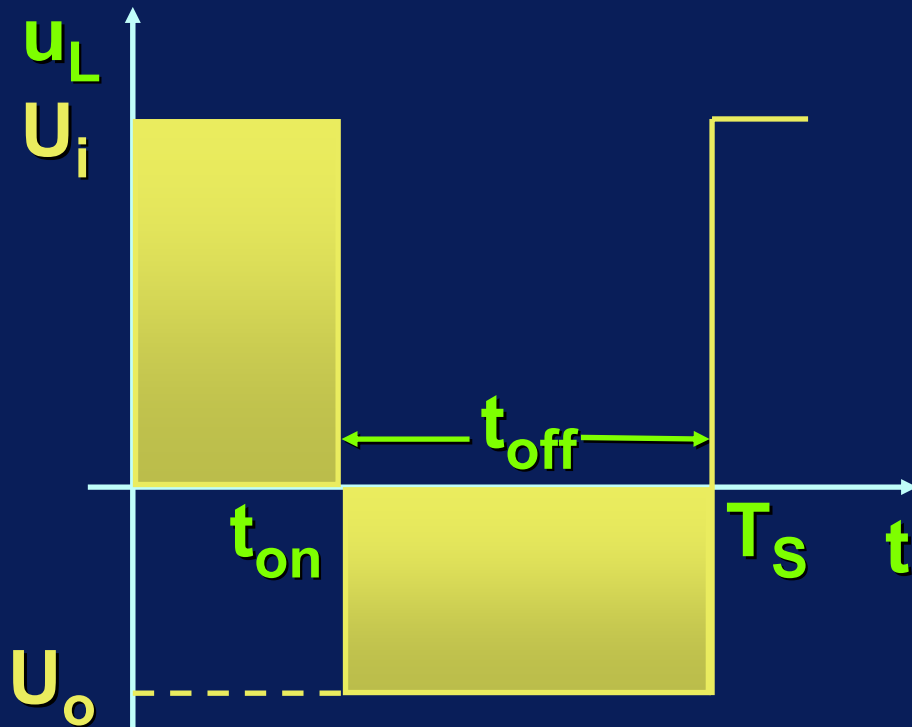


Analisi del funzionamento continuo (CCM)

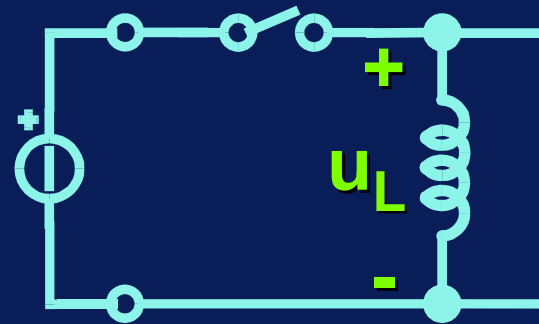
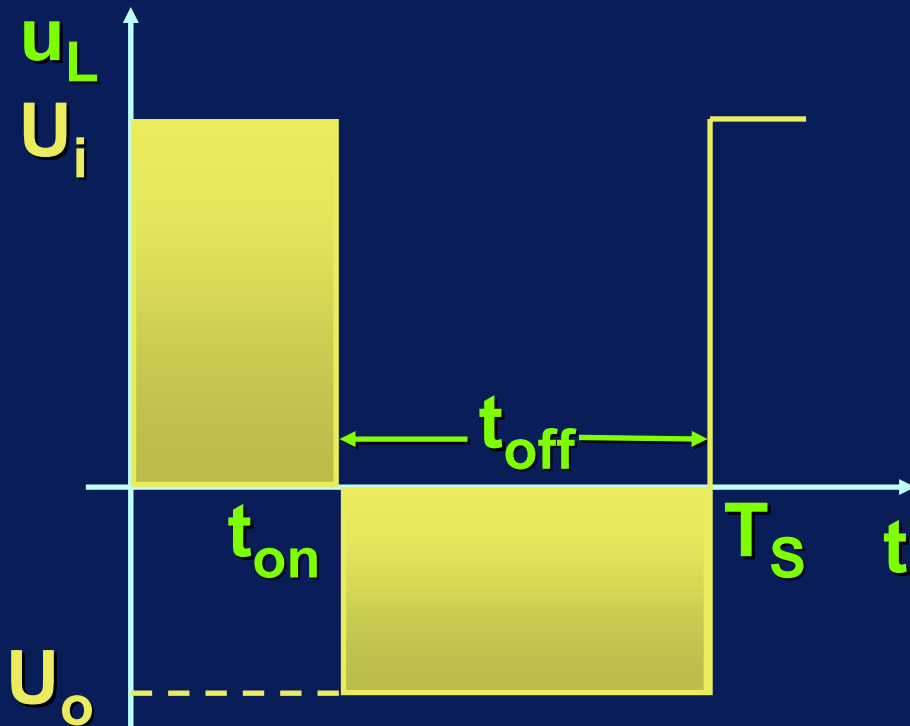


Il meccanismo di trasferimento di energia in due fasi (sorgente \rightarrow induttanza \rightarrow carico) consente di alimentare il carico a qualunque tensione

Buck/Boost - Forme d'onda in CCM: u_L

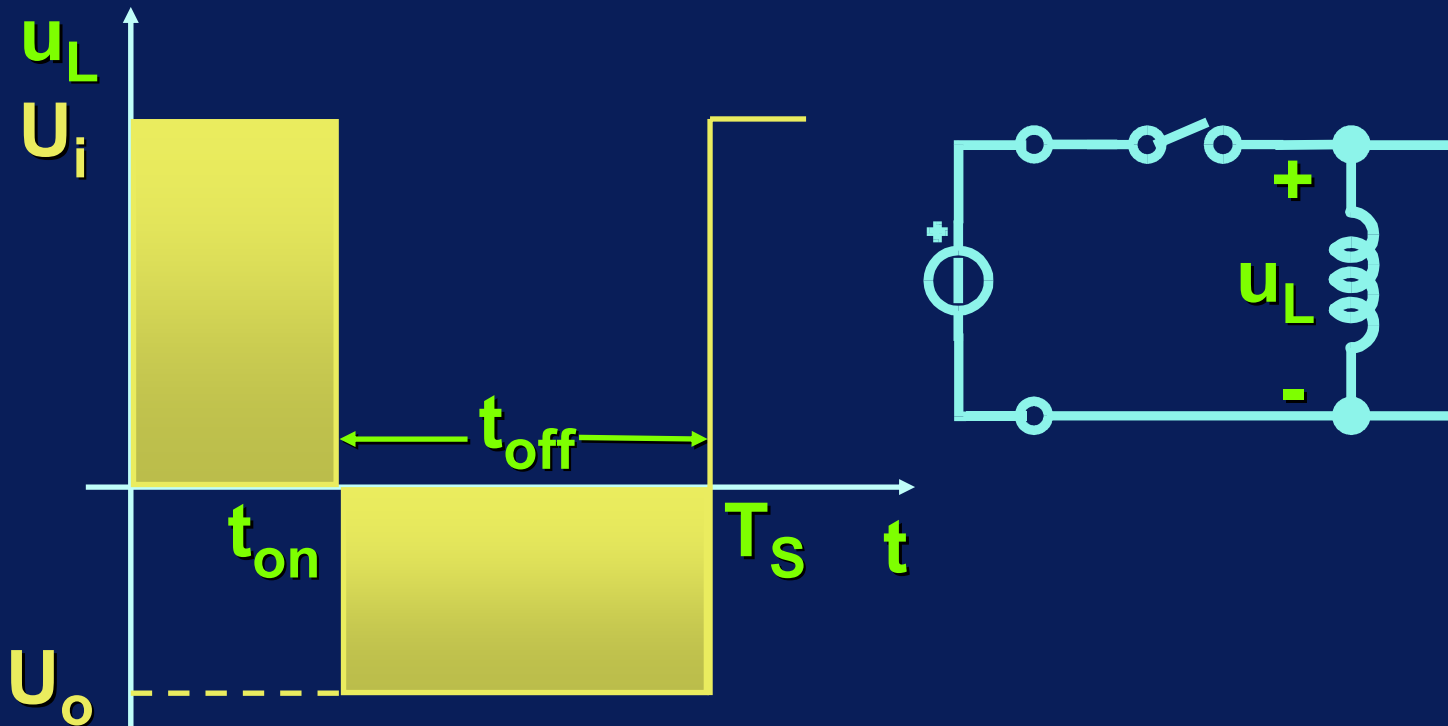


Buck/Boost - Forme d'onda in CCM: u_L



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

Buck/Boost - Forme d'onda in CCM: u_L

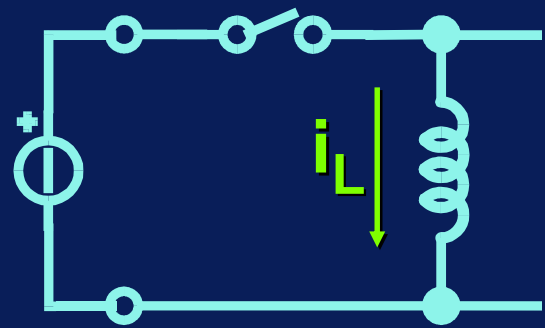
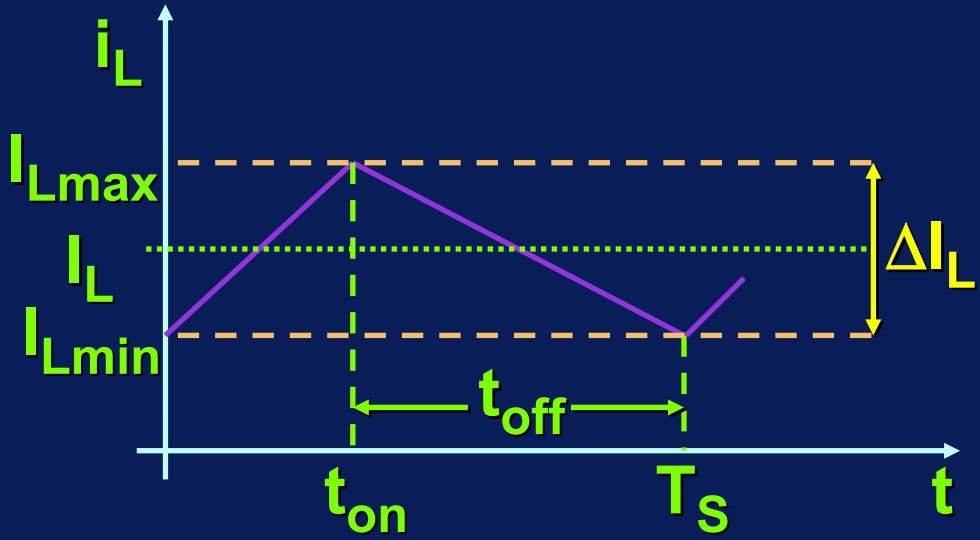


$$U_i \cdot t_{on} = U_o \cdot t_{off}$$

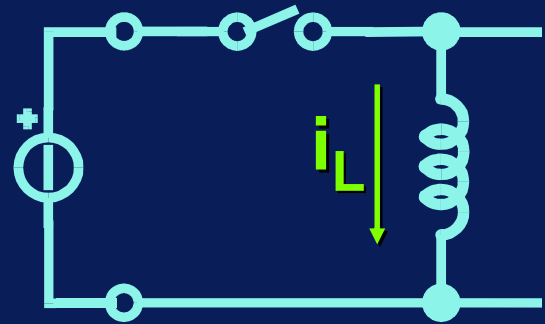
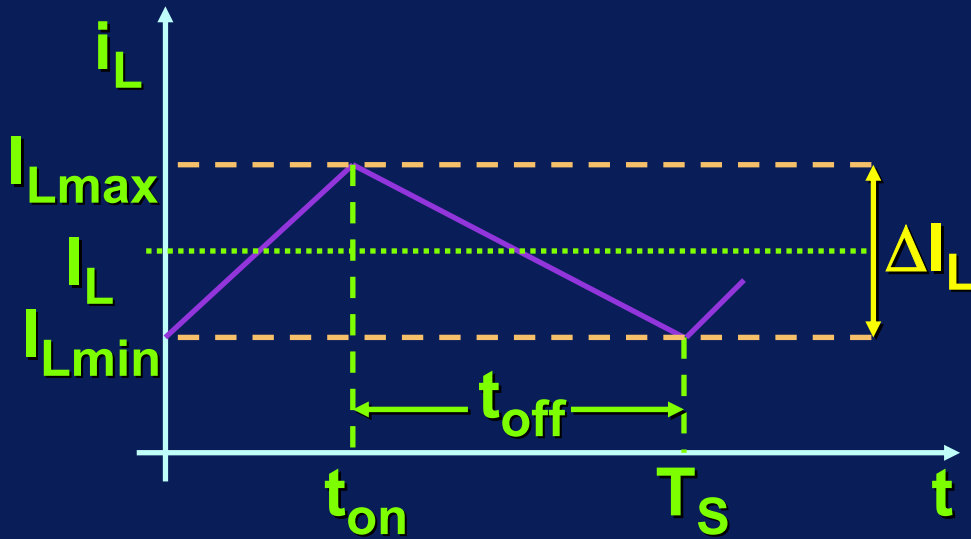
$$M = \frac{U_o}{U_i} = \frac{t_{on}}{t_{off}} = \frac{\delta}{1 - \delta}$$

Buck/Boost - Forme d'onda in CCM: i_L

Buck/Boost - Forme d'onda in CCM: i_L

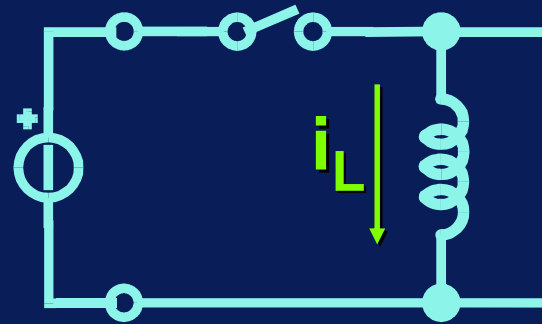
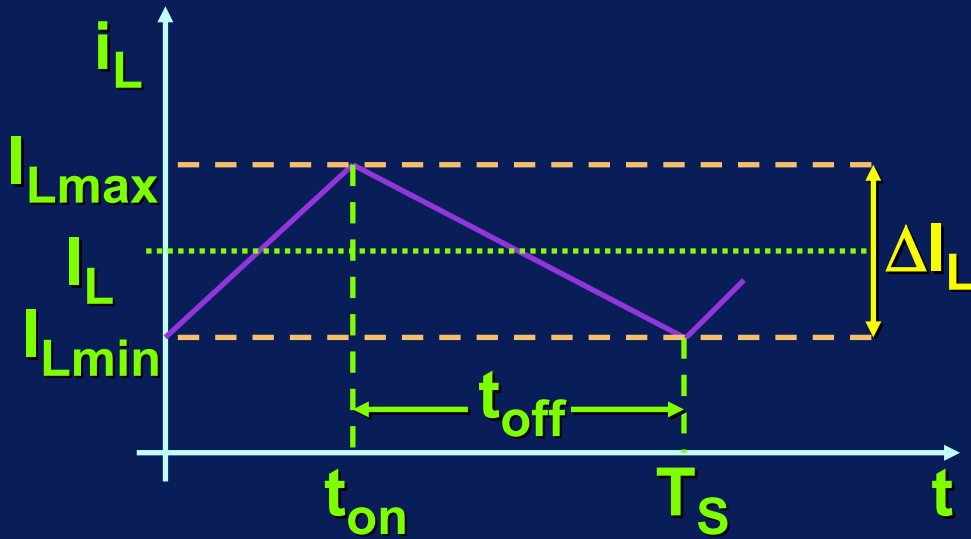


Buck/Boost - Forme d'onda in CCM: i_L



A regime:

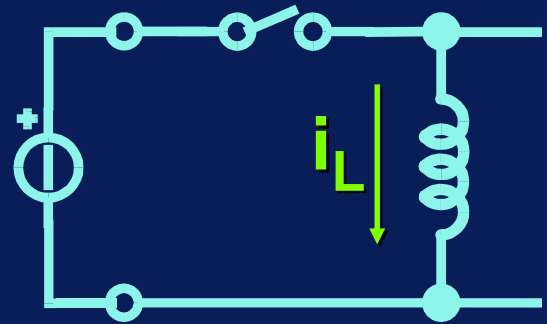
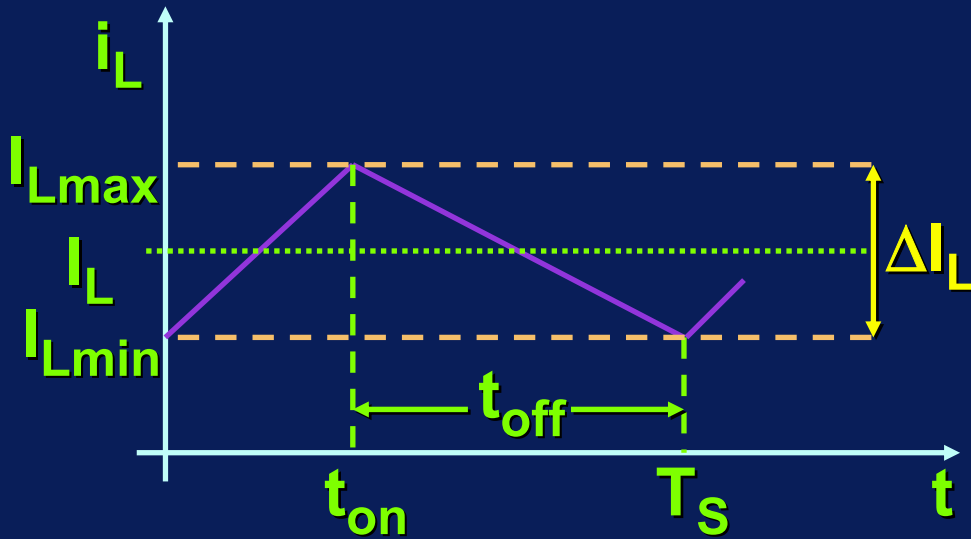
Buck/Boost - Forme d'onda in CCM: i_L



A regime:

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

Buck/Boost - Forme d'onda in CCM: i_L



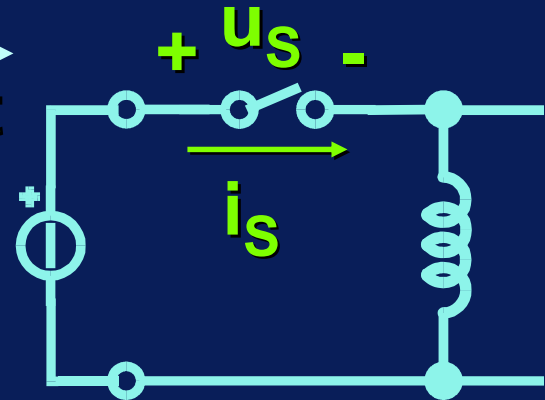
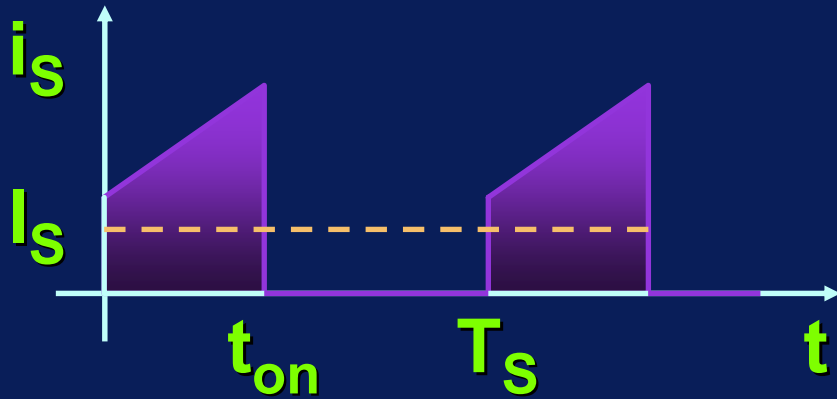
A regime:

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

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

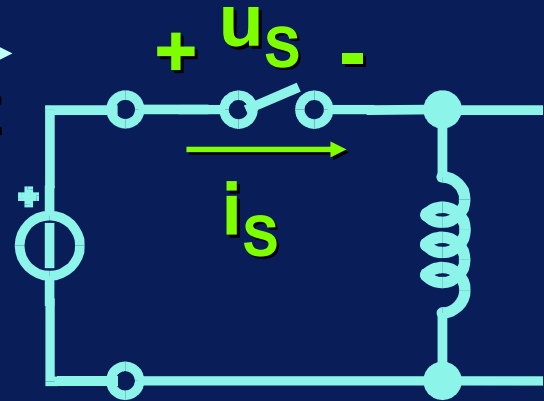
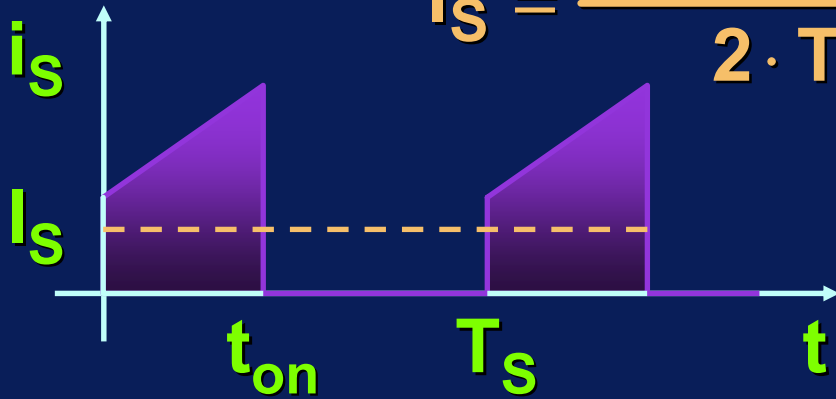
Buck/Boost - Forme d'onda in CCM: i_S, u_S

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



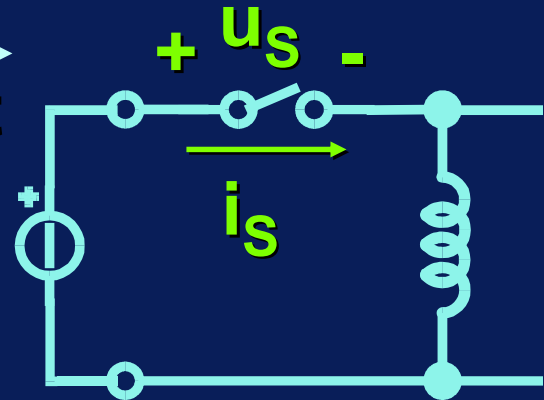
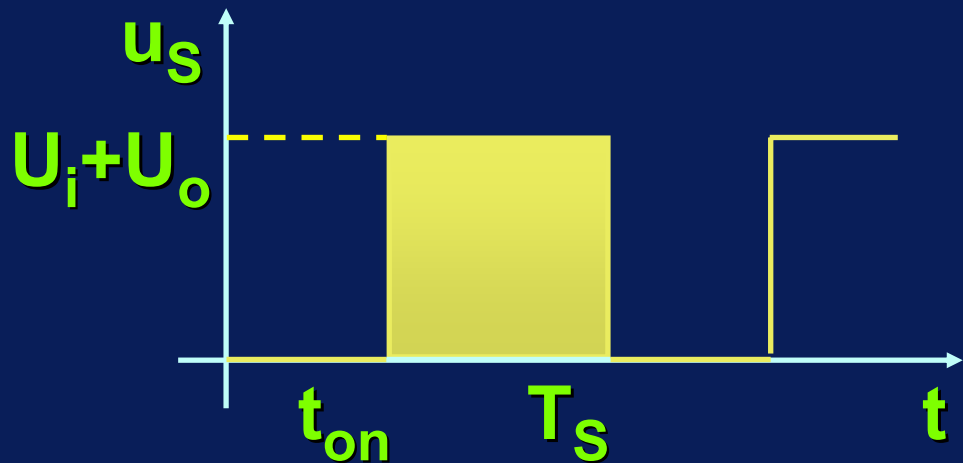
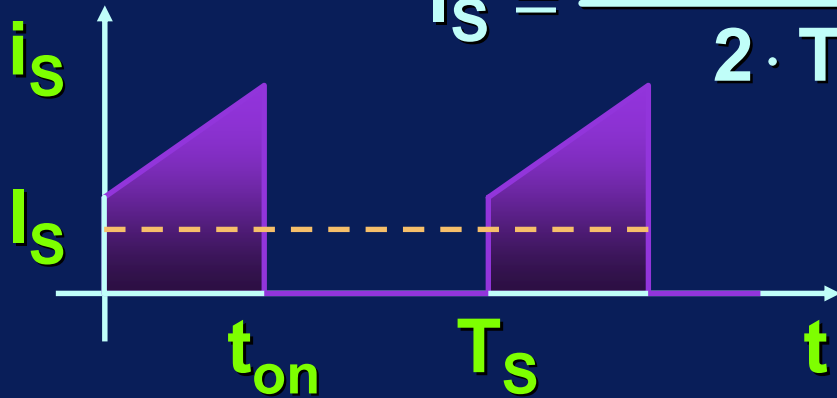
Buck/Boost - Forme d'onda in CCM: i_S, u_S

$$I_S = \frac{I_{Lmin} + I_{Lmax}}{2 \cdot T_S} \cdot t_{on} = I_L \cdot \delta$$



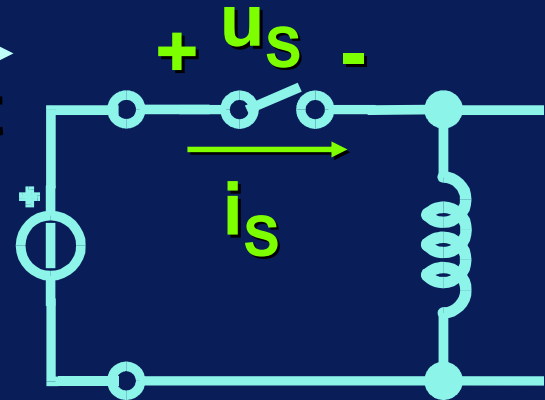
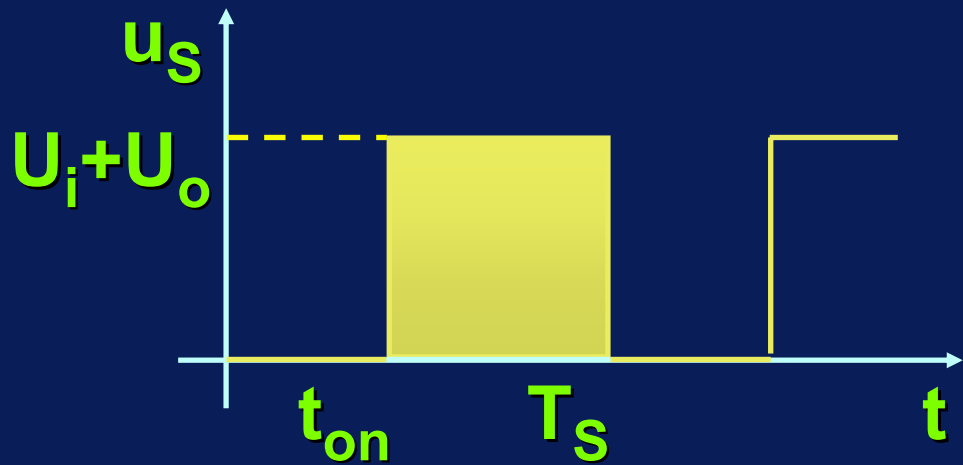
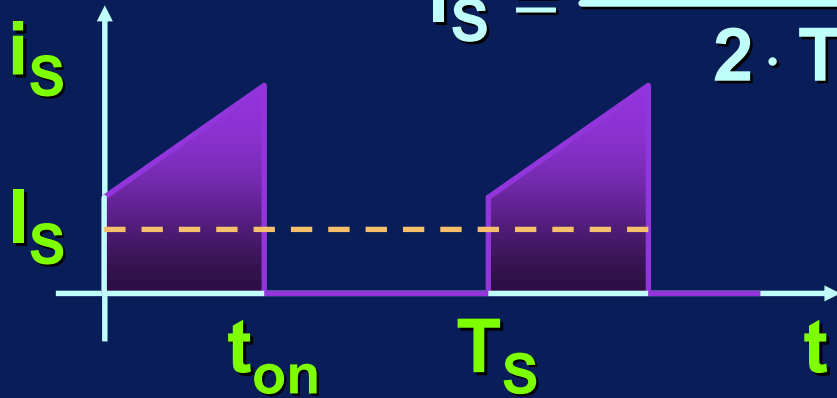
Buck/Boost - Forme d'onda in CCM: i_S, u_S

$$I_S = \frac{I_{Lmin} + I_{Lmax}}{2 \cdot T_S} \cdot t_{on} = I_L \cdot \delta$$



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

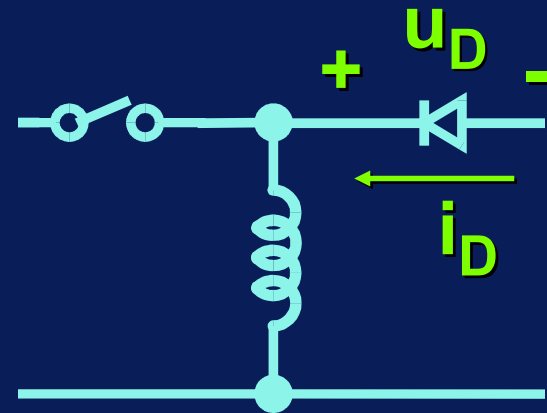
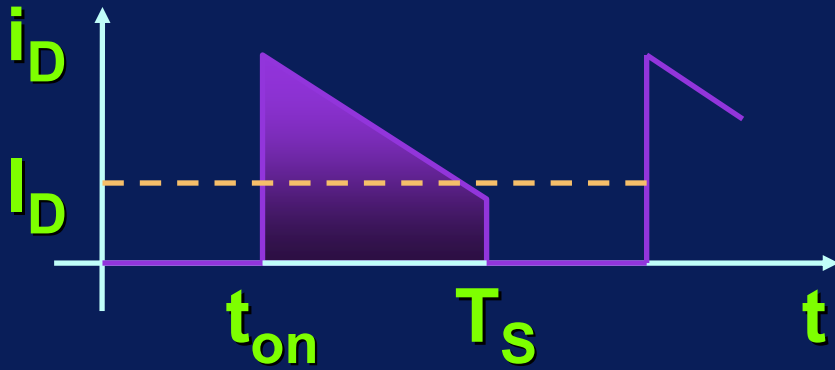
$$I_S = \frac{I_{Lmin} + I_{Lmax}}{2 \cdot T_S} \cdot t_{on} = I_L \cdot \delta$$



$$U_{Smax} = U_i + U_o$$

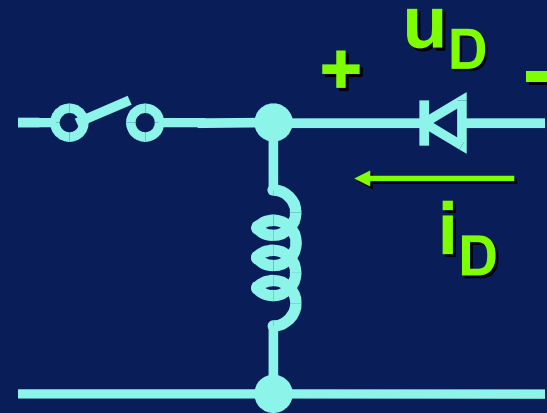
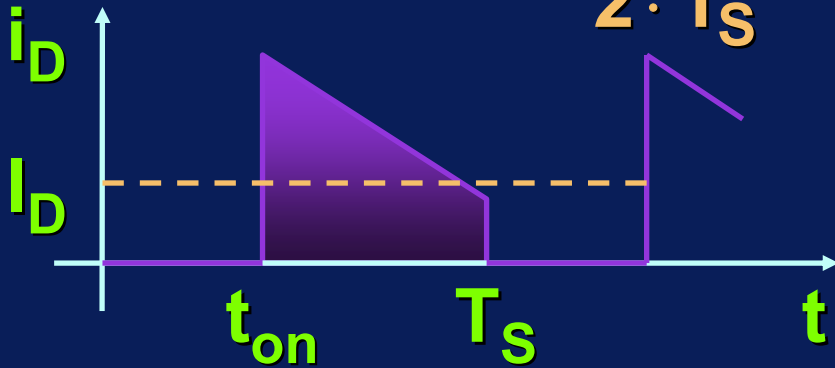
Buck/Boost - Forme d'onda in CCM: i_D, u_D

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



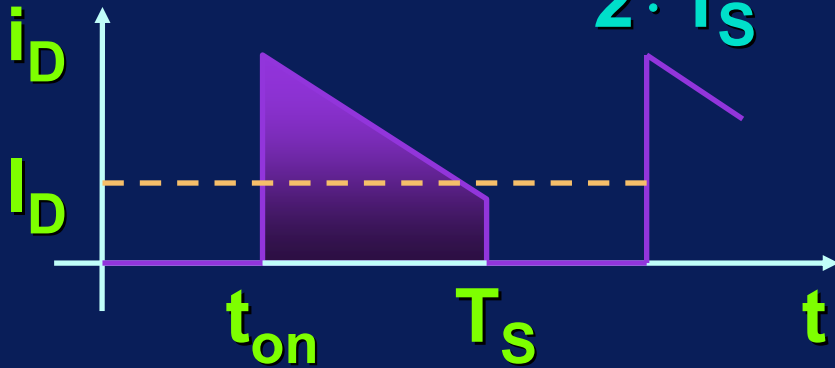
Buck/Boost - Forme d'onda in CCM: i_D, u_D

$$I_D = \frac{I_{Lmin} + I_{Lmax}}{2 \cdot T_S} \cdot t_{off} = I_L \cdot (1 - \delta)$$

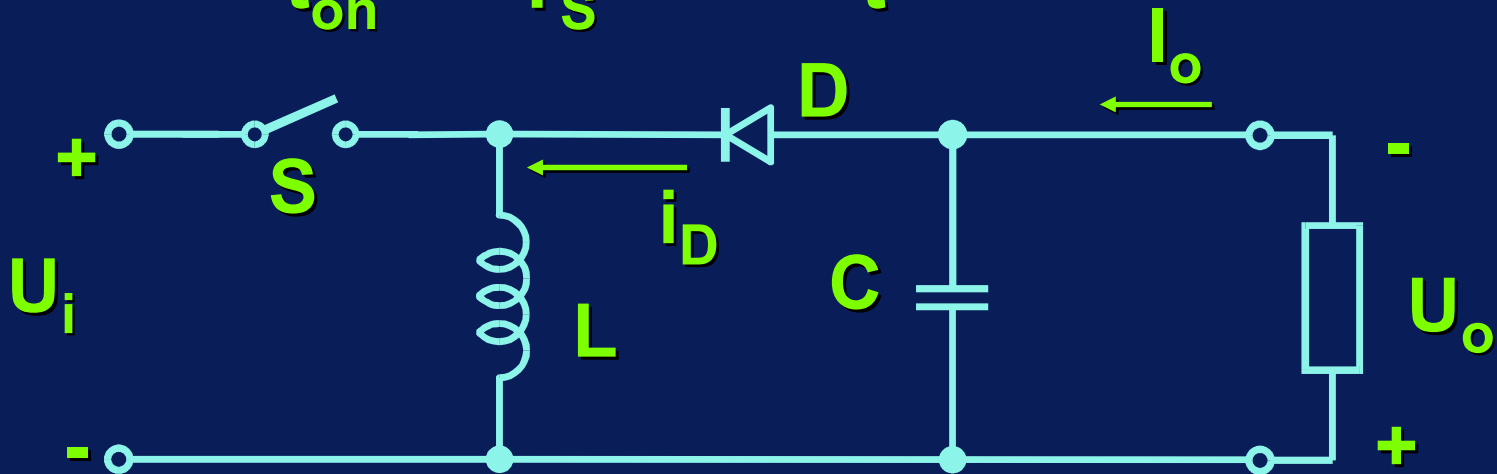


Buck/Boost - Forme d'onda in CCM: i_D, u_D

$$I_D = \frac{I_{Lmin} + I_{Lmax}}{2 \cdot T_S} \cdot t_{off} = I_L \cdot (1 - \delta)$$

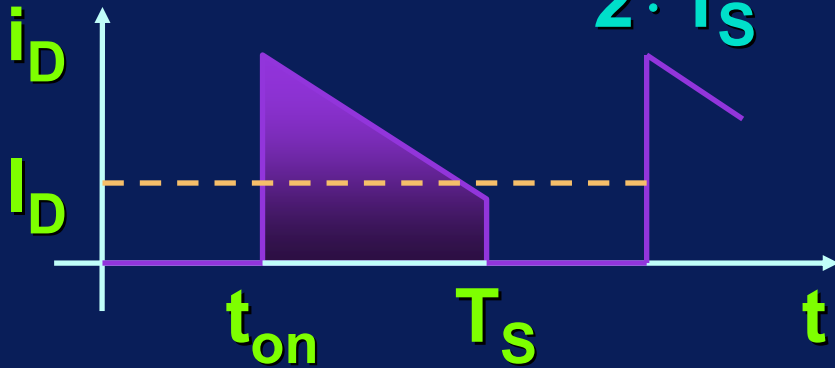


$$I_D = I_o$$

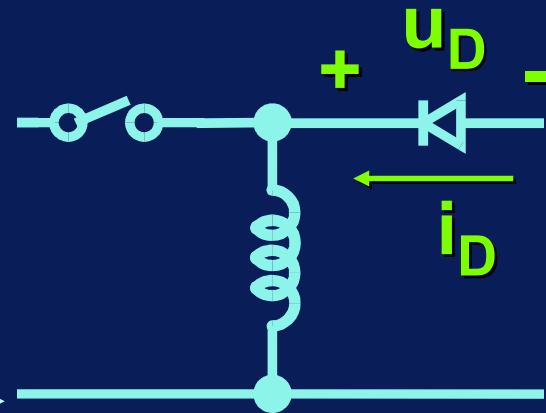
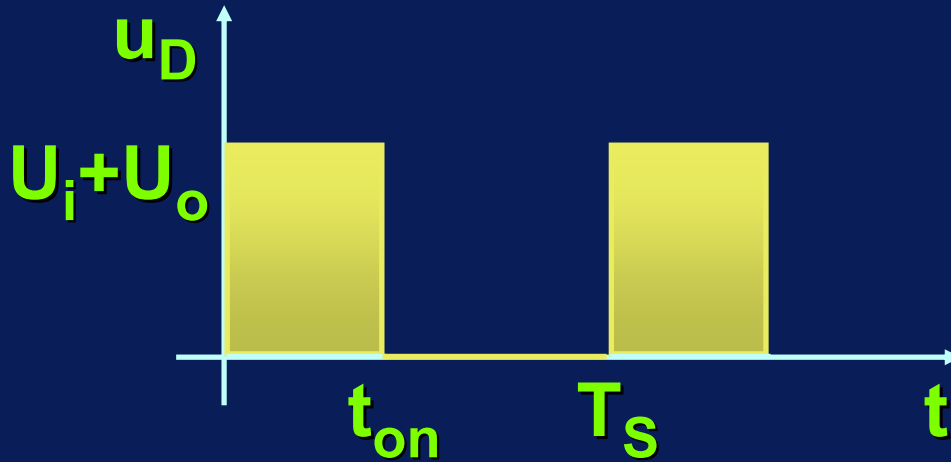


Buck/Boost - Forme d'onda in CCM: i_D, u_D

$$I_D = \frac{I_{Lmin} + I_{Lmax}}{2 \cdot T_S} \cdot t_{off} = I_L \cdot (1 - \delta)$$

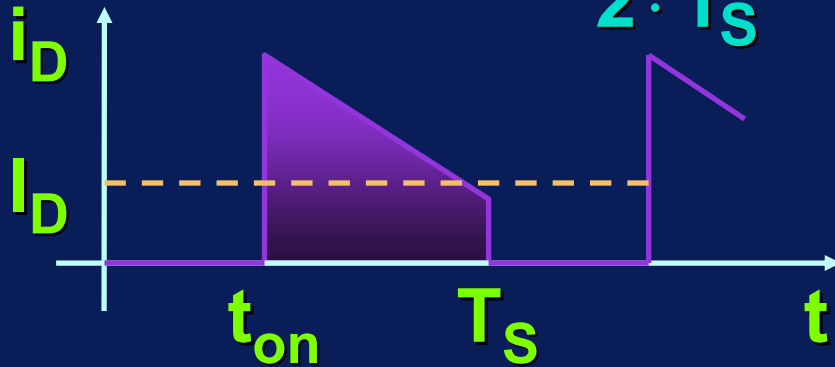


$$I_D = I_o$$

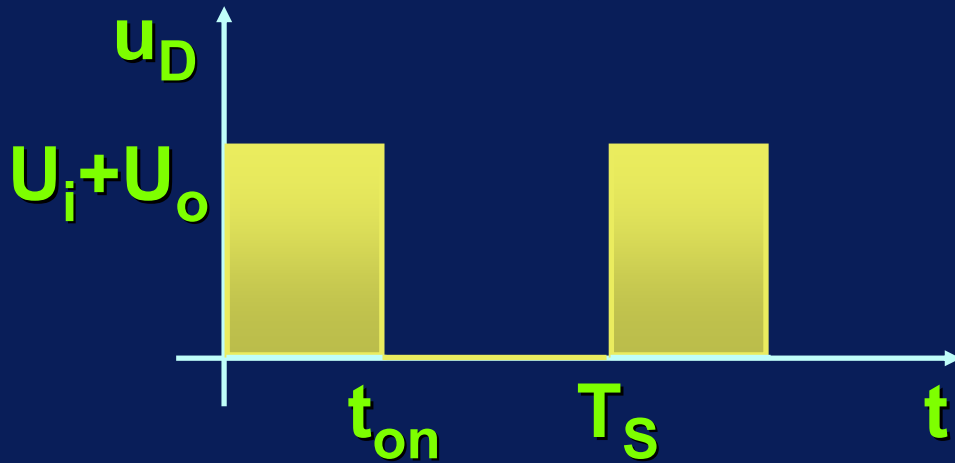


Buck/Boost - Forme d'onda in CCM: i_D, u_D

$$I_D = \frac{I_{Lmin} + I_{Lmax}}{2 \cdot T_S} \cdot t_{off} = I_L \cdot (1 - \delta)$$



$$I_D = I_o$$



$$U_{Dmax} = U_i + U_o$$

Nota

$$U_{Smax} = U_{Dmax} = U_o + U_i$$

Le maggiori capacità di regolazione di questo convertitore si associano a maggiori sollecitazioni in tensione dei componenti

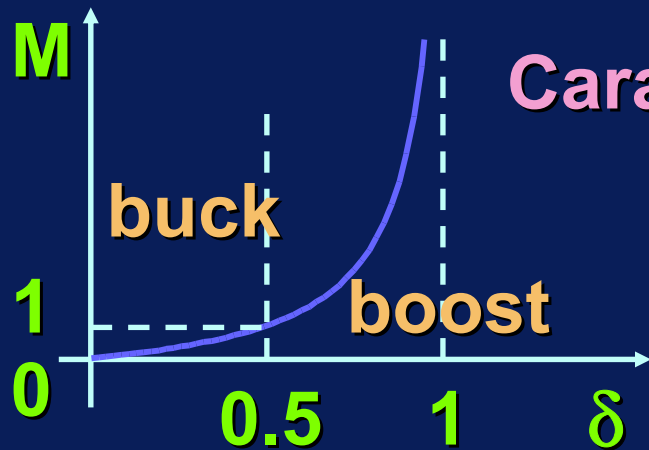
Convertitore Buck/Boost in CCM

Convertitore Buck/Boost in CCM

Caratteristica di controllo

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

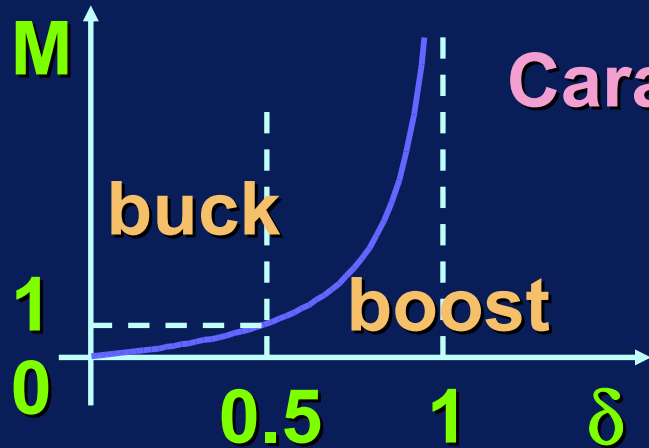
Convertitore Buck/Boost in CCM



Caratteristica di controllo

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

Convertitore Buck/Boost in CCM



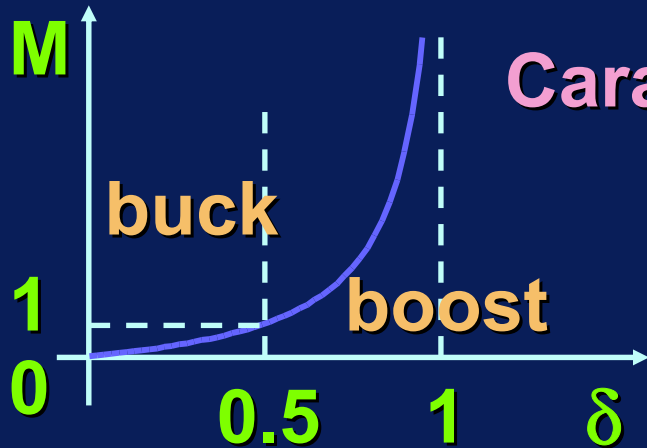
Caratteristica di controllo

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

Ondulazione di corrente

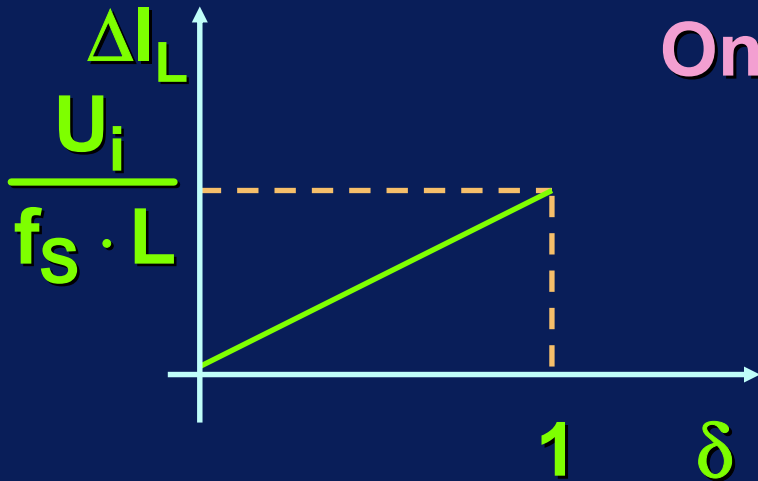
$$\Delta I_L = \frac{U_i}{L} \cdot t_{on} = \frac{U_i \cdot \delta}{f_s \cdot L}$$

Convertitore Buck/Boost in CCM



Caratteristica di controllo

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



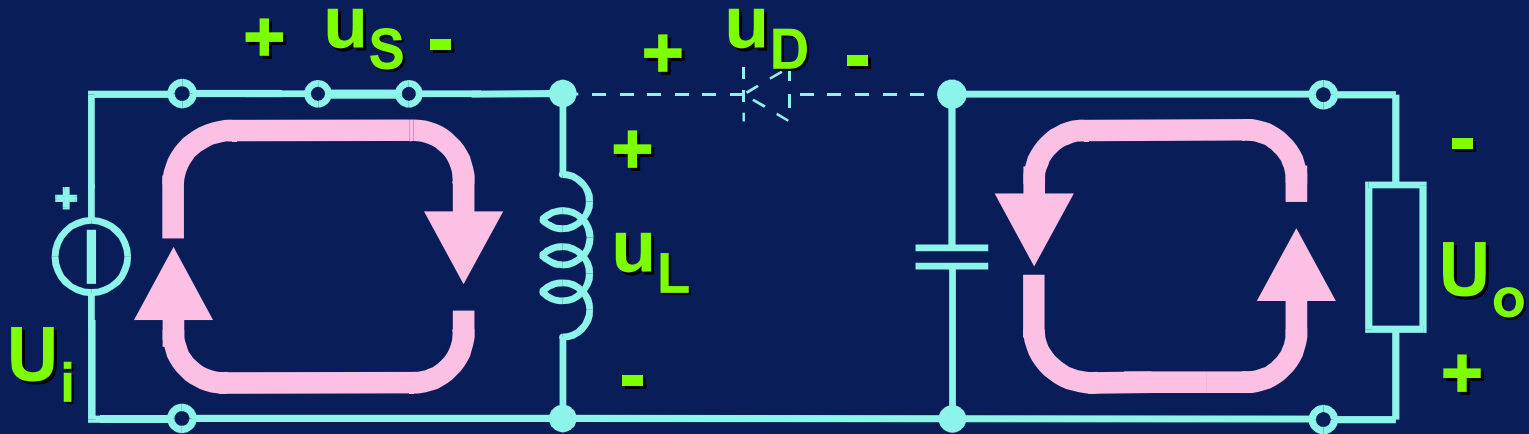
Ondulazione di corrente

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

Analisi del funzionamento discontinuo (DCM)

Analisi del funzionamento discontinuo (DCM)

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

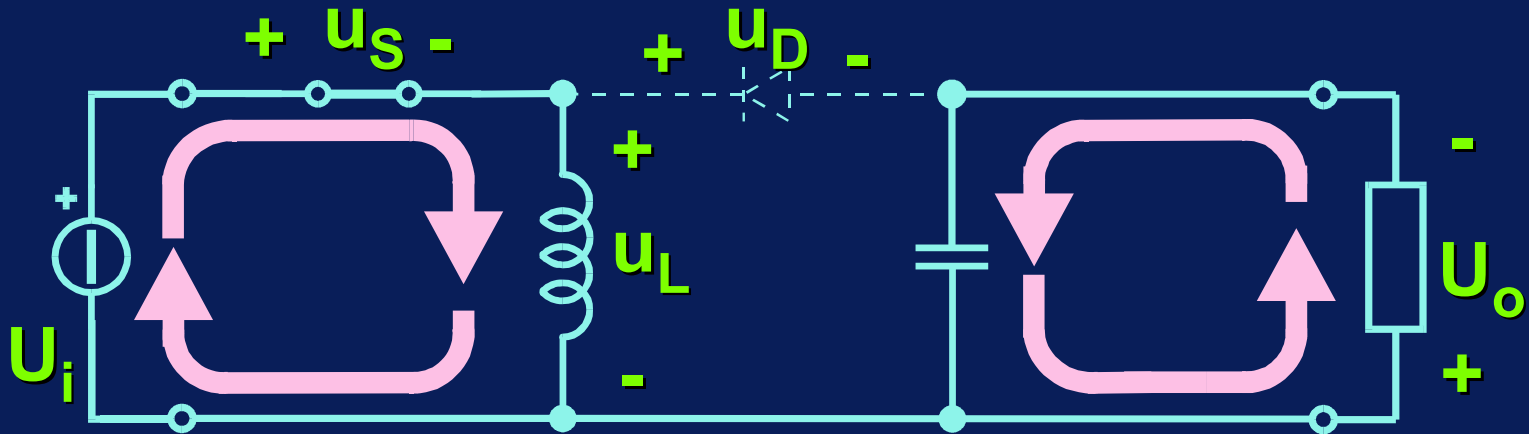


$$u_L = U_i$$

$$u_D = U_o + U_i$$

Analisi del funzionamento discontinuo (DCM)

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



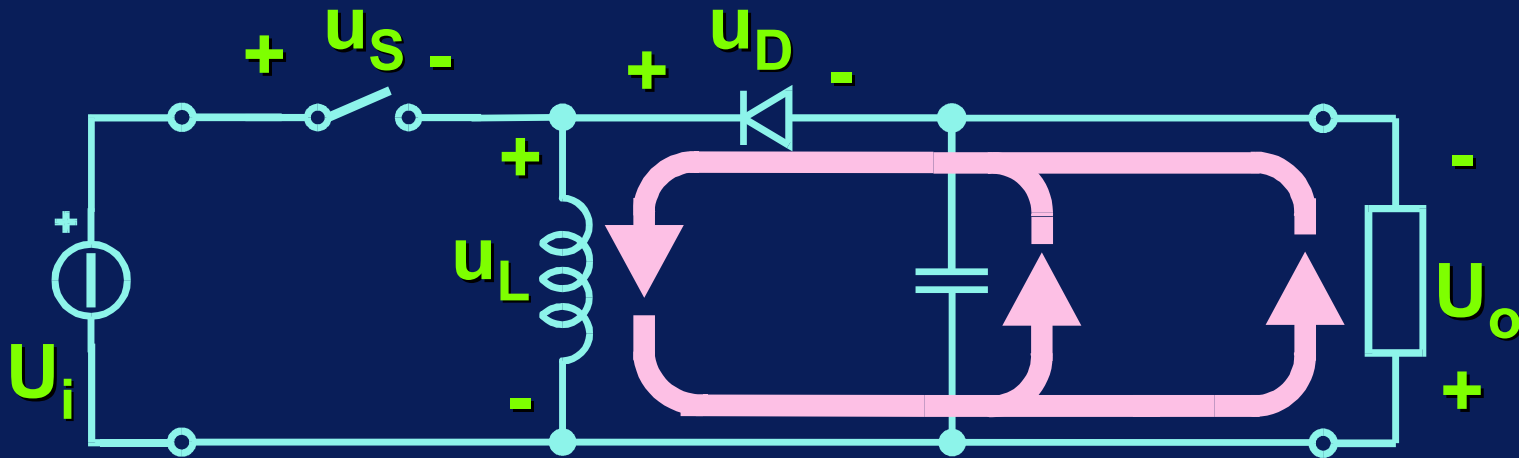
$$u_L = U_i$$

$$u_D = U_o + U_i$$

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

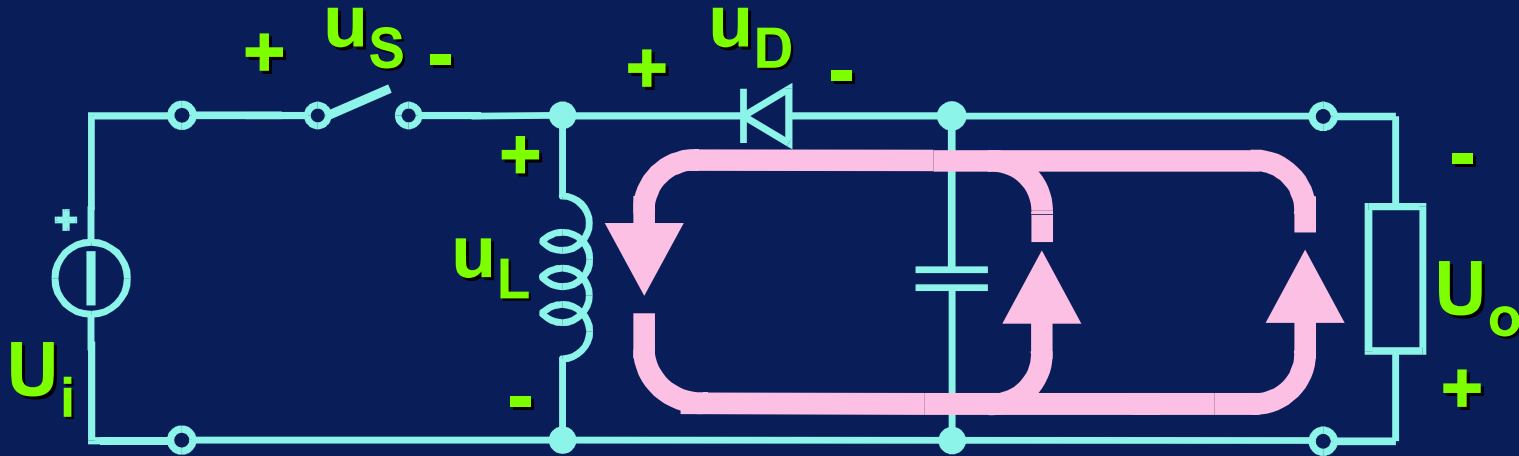


$$u_L = -U_o$$

$$u_S = U_o + U_i$$

Analisi del funzionamento discontinuo (DCM)

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

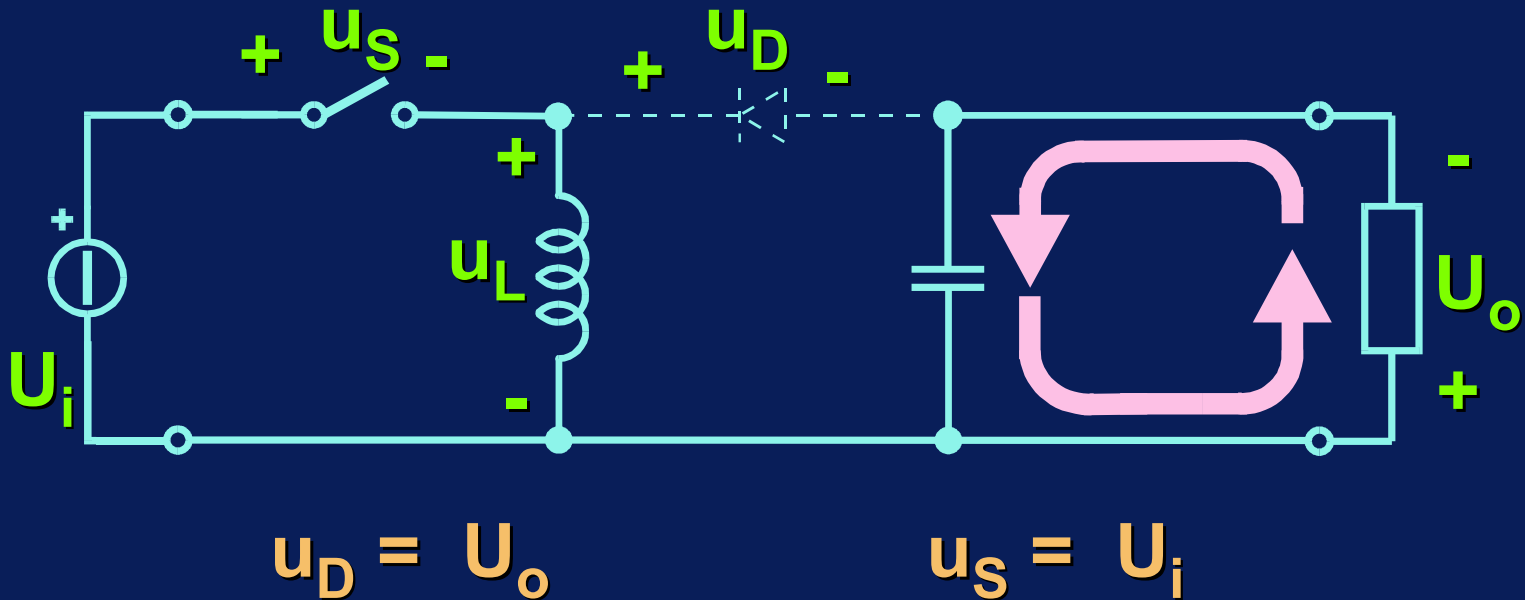


$$u_L = -U_o \quad u_S = U_o + U_i$$

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

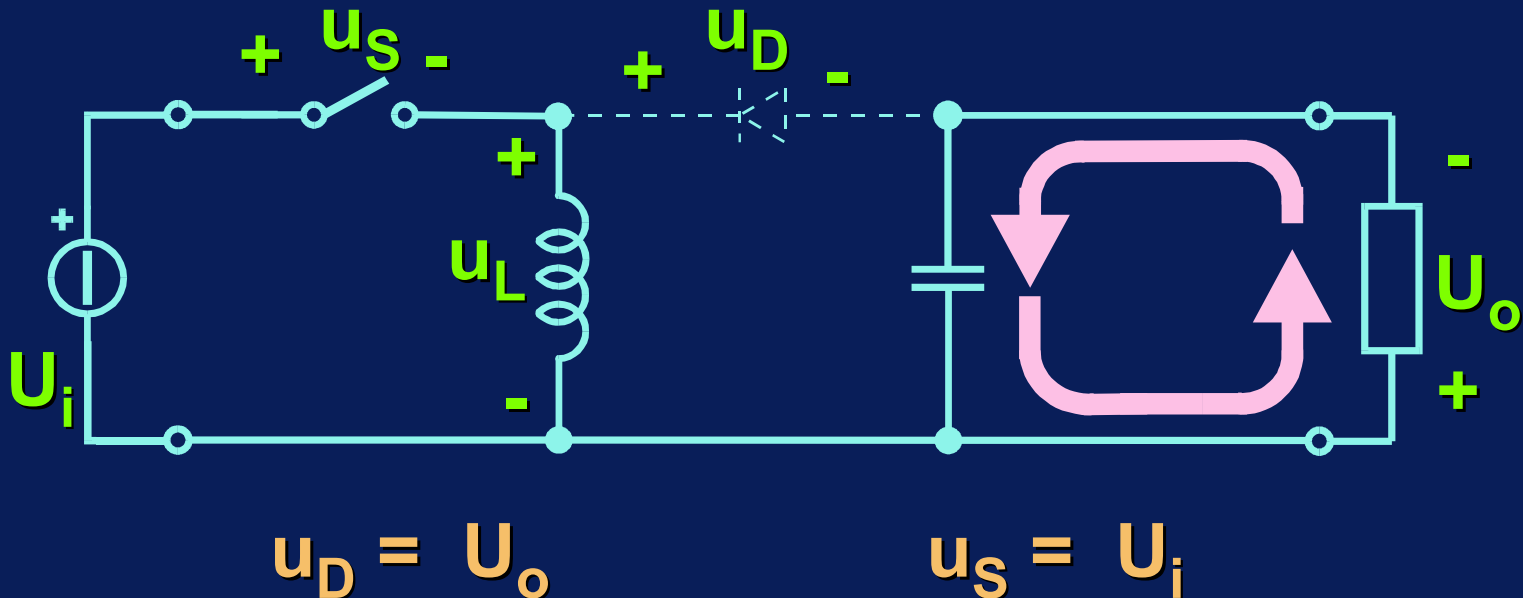
Analisi del funzionamento discontinuo (DCM)

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



Analisi del funzionamento discontinuo (DCM)

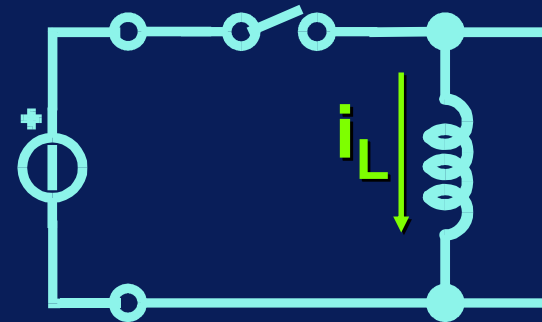
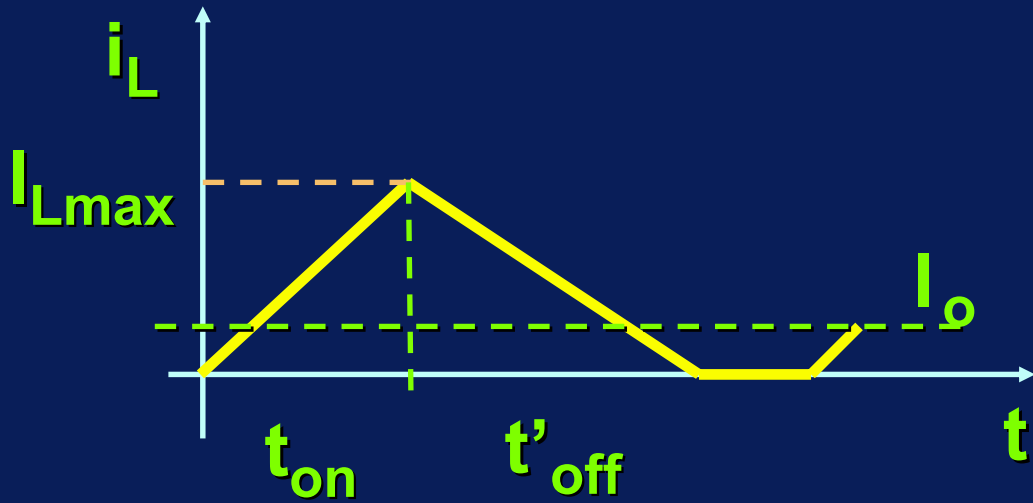
Tempo di apertura di S (t''_{off}) S off - D off



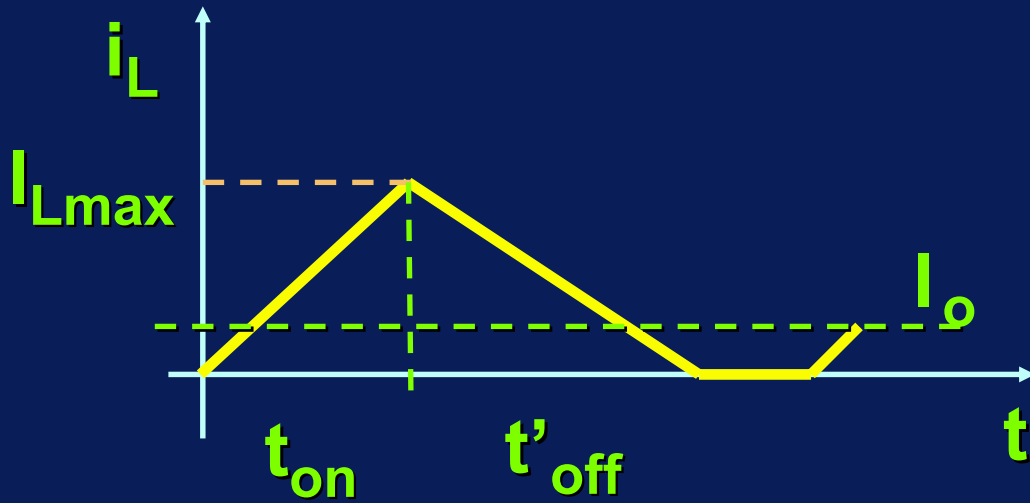
Durante questa fase il solo condensatore fornisce energia al carico

Buck/Boost: Forme d'onda in DCM: i_L

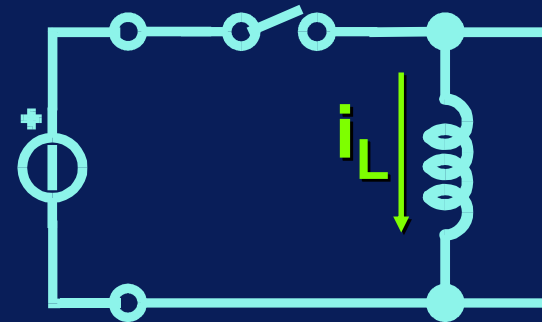
Buck/Boost: Forme d'onda in DCM: i_L



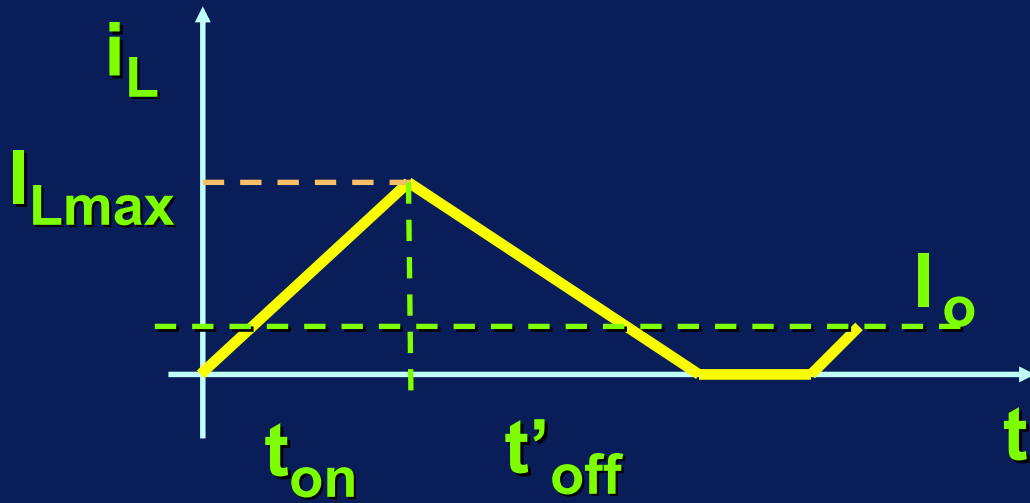
Buck/Boost: Forme d'onda in DCM: i_L



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

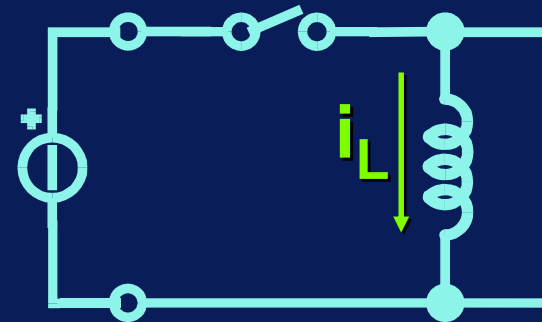


Buck/Boost: Forme d'onda in DCM: i_L



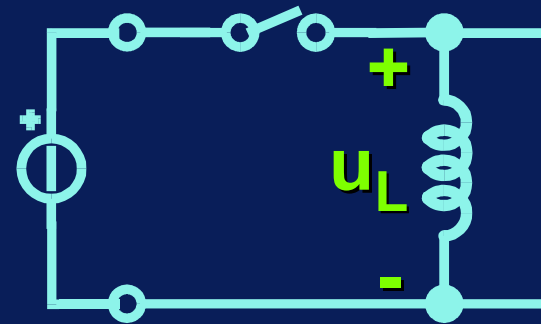
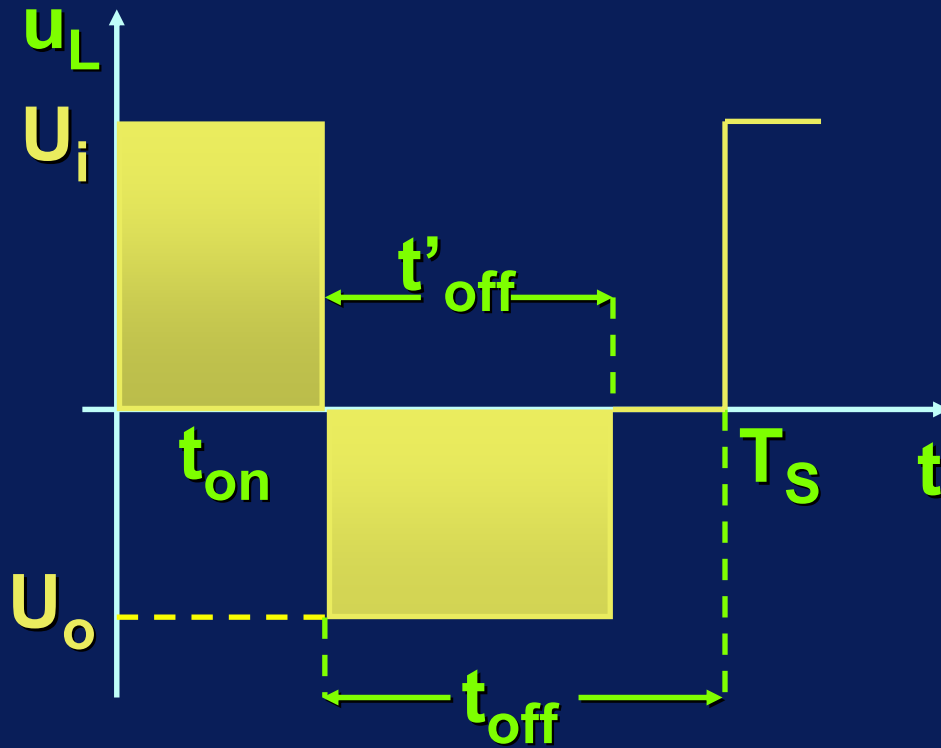
$$I_{Lmax} = \frac{U_i}{L} \cdot t_{on}$$

$$I_o = \frac{I_{Lmax} \cdot t'_{off}}{2 \cdot T_s}$$

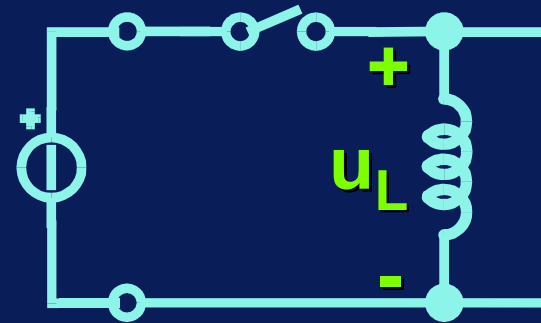
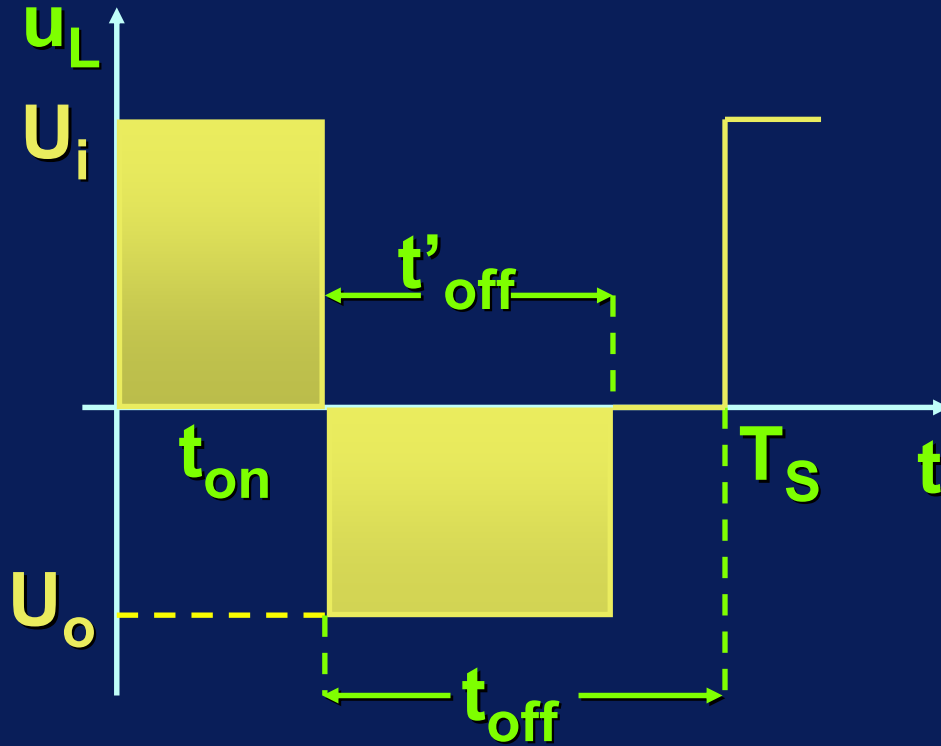


Buck/Boost: Forme d'onda in DCM: u_L

Buck/Boost: Forme d'onda in DCM: u_L



Buck/Boost: Forme d'onda in DCM: u_L



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

Caratteristica di controllo in DCM

Caratteristica di controllo in DCM

$$I_o = \frac{I_{L\max} \cdot t'_{\text{off}}}{2 \cdot T_s}; \quad I_{L\max} = \frac{U_i}{L} \cdot t_{\text{on}};$$

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

Caratteristica di controllo in DCM

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

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



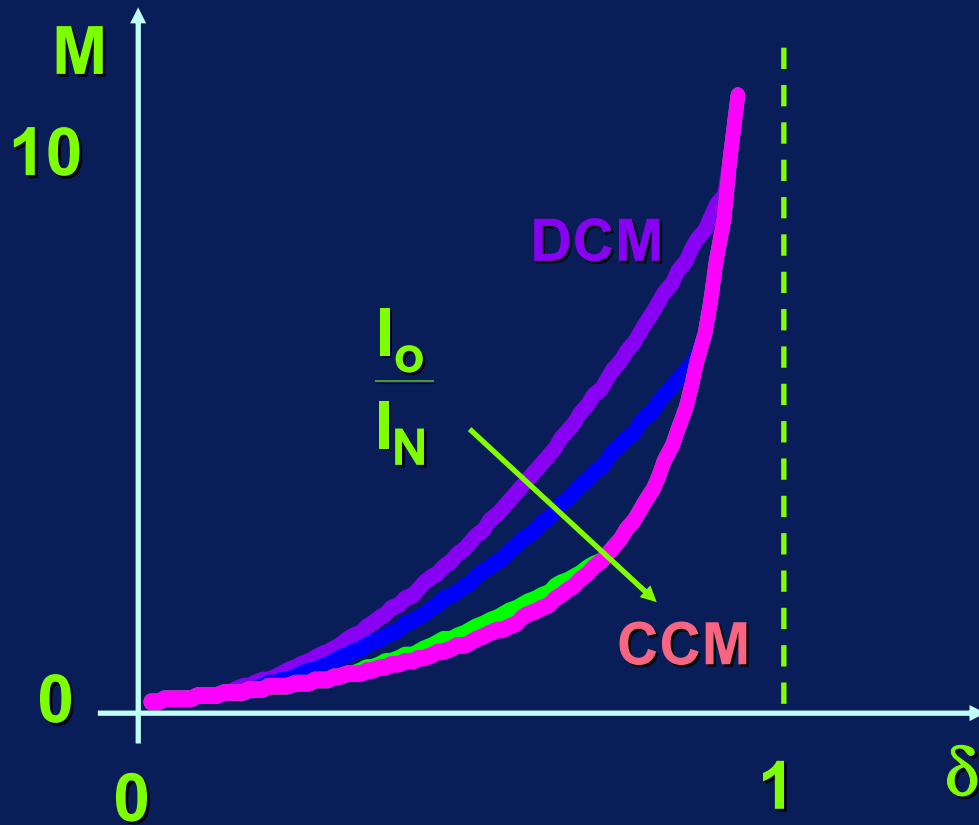
$$M = \frac{U_o}{U_i} = \delta^2 \cdot \frac{U_i}{2 \cdot f_S \cdot L \cdot I_o} = \delta^2 \cdot \frac{I_N}{I_o}$$

dove:

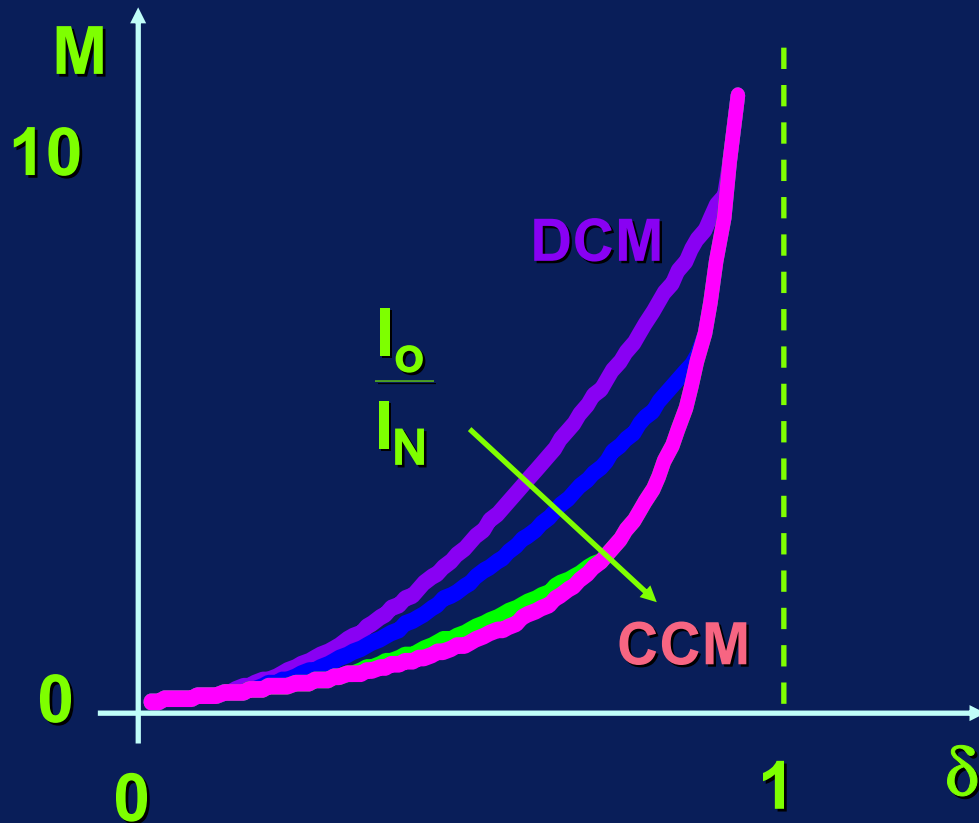
$$I_N = \frac{U_i}{2 \cdot f_S \cdot L}$$

Caratteristiche di controllo totali

Caratteristiche di controllo totali

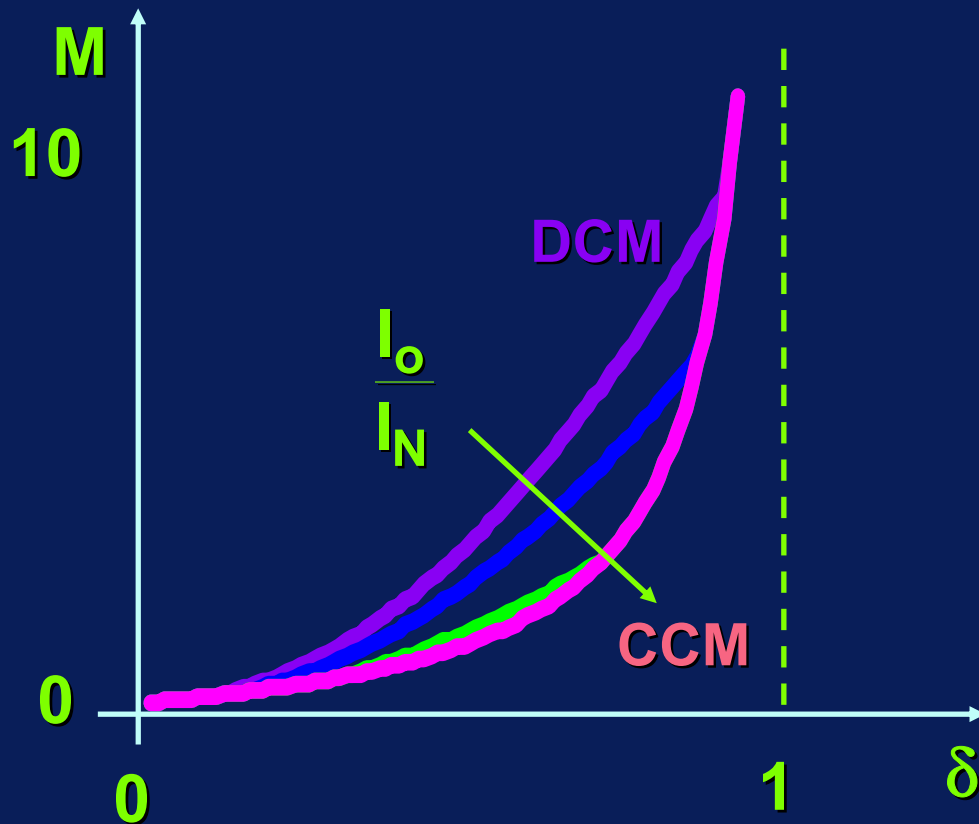


Caratteristiche di controllo totali



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

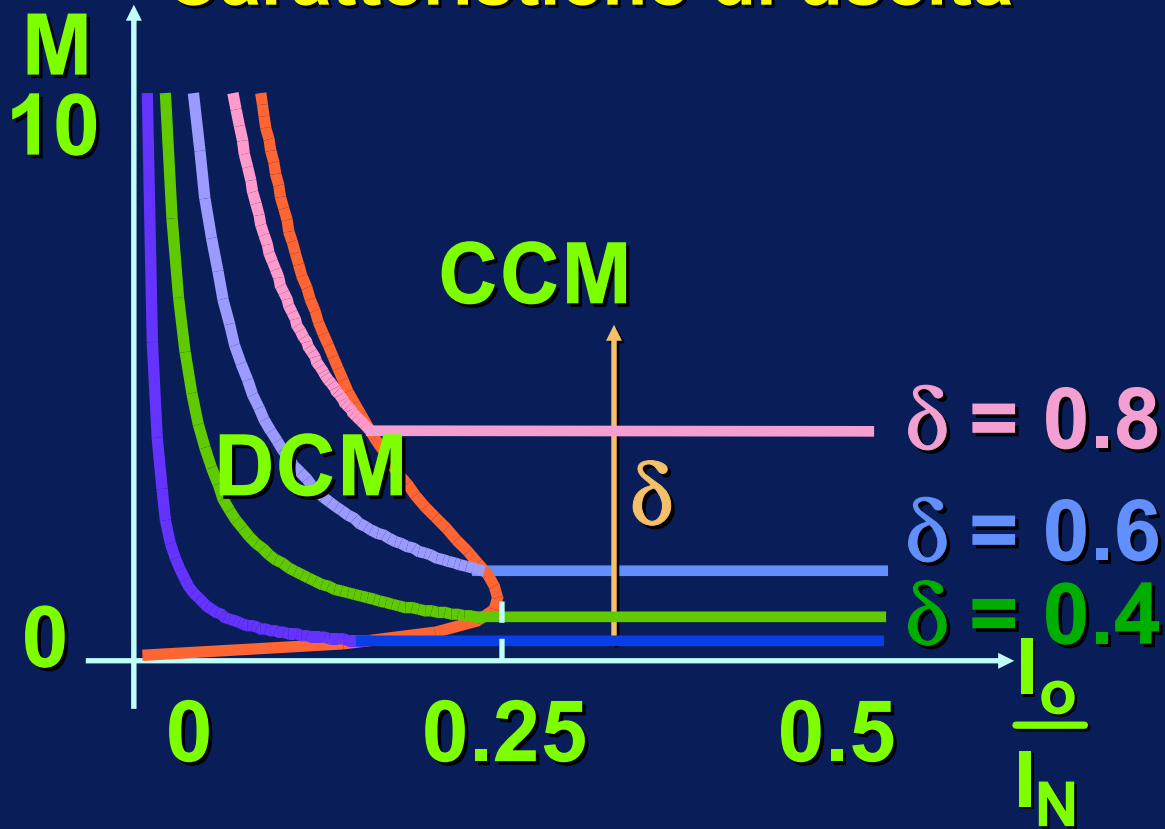
Caratteristiche di controllo totali



Il funzionamento intermittente può manifestarsi per valori centrali di δ

Caratteristiche di uscita

Caratteristiche di uscita



Curva limite:
$$\frac{I_o}{I_N} = \frac{M}{(1+M)^2}$$

Caratteristica di controllo in DCM per carico resistivo

Caratteristica di controllo in DCM per carico resistivo

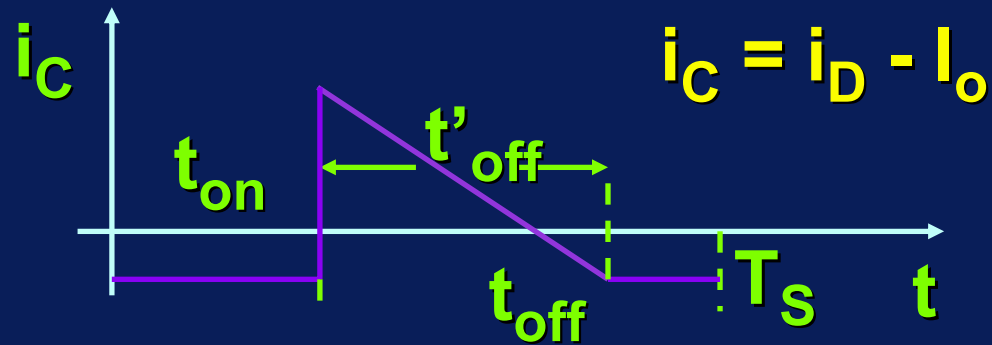
$$M = \frac{\delta}{\sqrt{k}}$$

dove:

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

Nota: Correnti nei filtri capacitivi

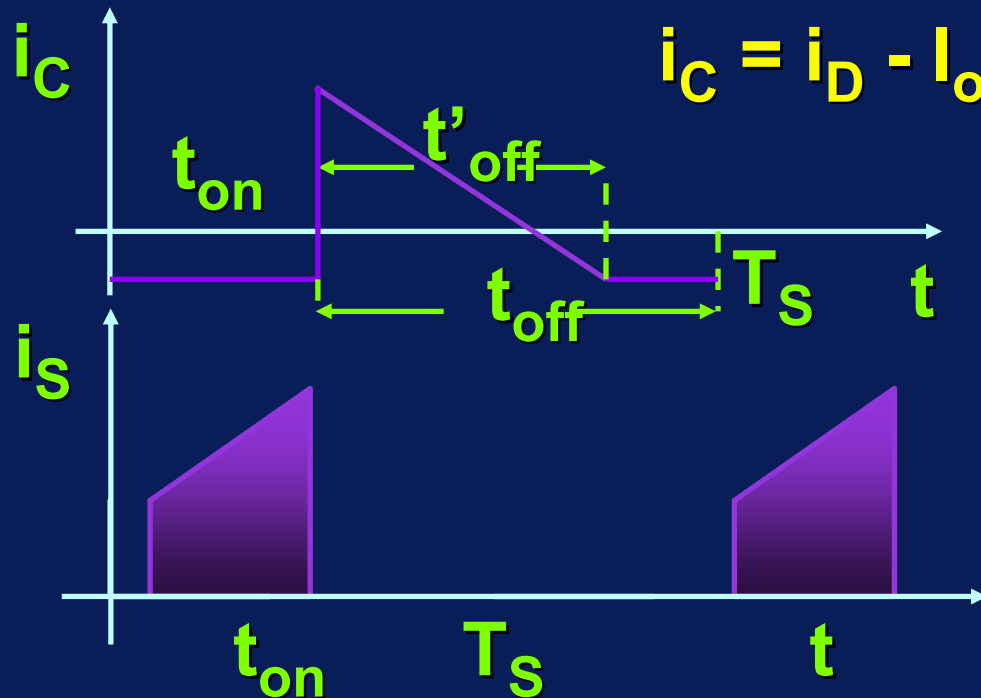
Nota: Correnti nei filtri capacitivi



Note:

i_C presenta fronti ripidi

Nota: Correnti nei filtri capacitivi

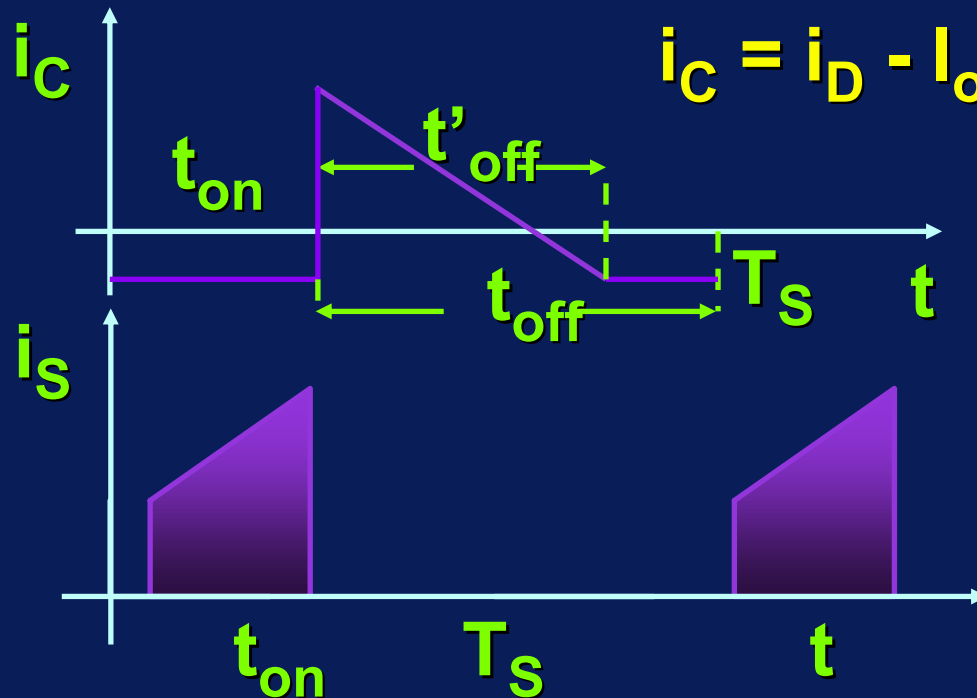


Note:

i_C presenta fronti ripidi

$i_i = i_S$ presenta anch'essa fronti ripidi

Nota: Correnti nei filtri capacitivi



Sia il condensatore di filtro d'ingresso che quello di uscita devono avere bassa ESL

Note

- Le tecniche di controllo sono le stesse del convertitore Buck
- La risposta dinamica è però difficile da dominare in CCM (caratteristica statica nonlineare, modello ai piccoli segnali a parametri variabili e zero a parte reale positiva). In DCM invece si ha solo un polo con costante di tempo $R_0C/2$.
- Lo schema buck-boost a trasformatore (flyback) è molto usato per piccole potenze

Conclusioni

- I convertitori boost e buck-boost consentono di estendere il campo di regolazione del regolatore buck
- Ciò viene pagato con maggiori sollecitazioni in tensione dei componenti e con una maggiore difficoltà di controllo
- Il regolatore boost ha il vantaggio di filtrare la corrente d'ingresso
- Il regolatore buck-boost ha una semplice configurazione a trasformatore (flyback)