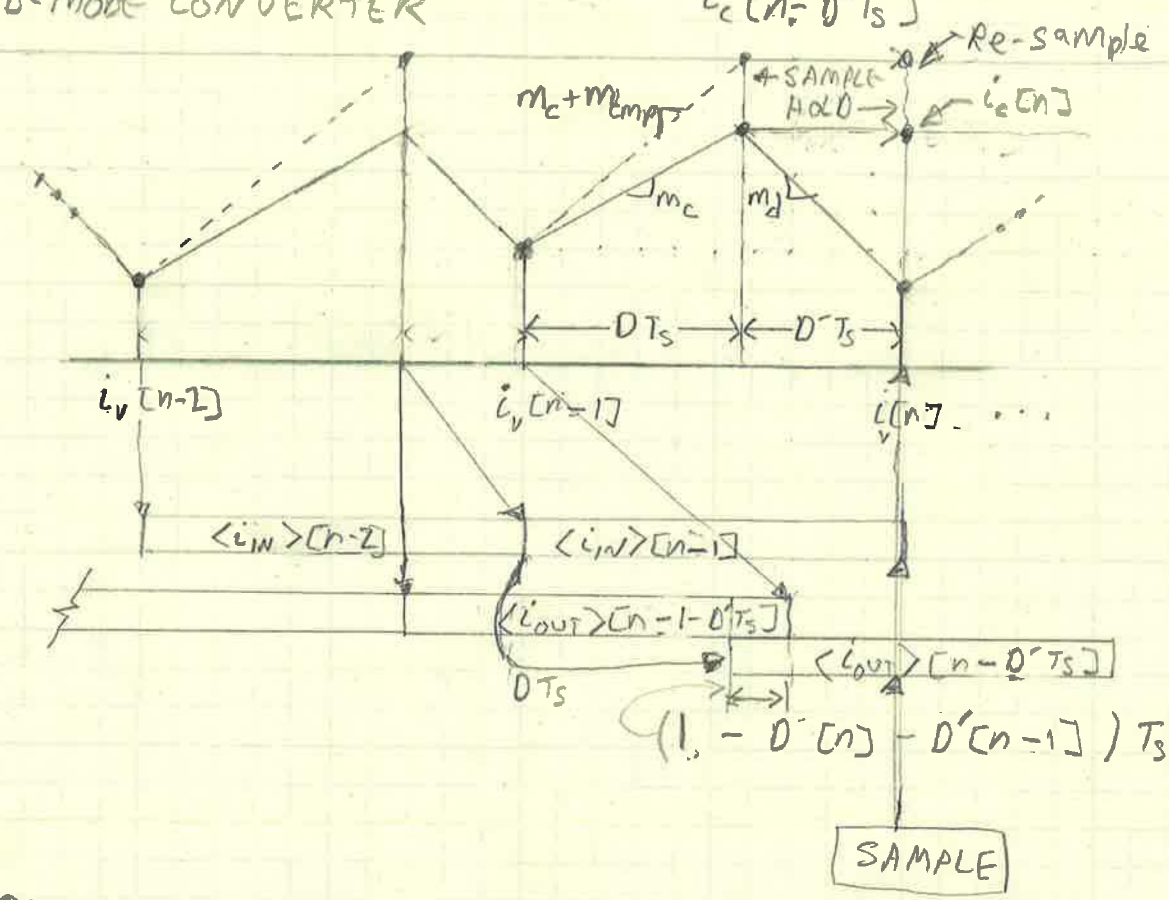
FORCED CONTINUOUS CONDUCTION MODE, PEAK-CURRENT PROGRAMMED MODE SWITCHED-MODE CONVERTER



Observations:

1. Valley currents $i_v[n]$ can be expressed exactly in a recurrence relation if the following conditions are met:

   A) Charging slope "m_c" and discharging slope "m_d" are constant over the sampling interval.

   $$m_c = \frac{V_{IN}}{L_{pri}}$$

   $$m_d = \frac{V_{OUT}}{L_{pri}}$$

   B) Compensating slope "m_{cmp}" is a constant

2. Averaged output current is delayed from averaged input current by DT_s.

3. Duty cycle "D" is a function of valley currents "i_v", charging slope "m_c", compensating slope "m_{cmp}" and control current "i_c".

   This quantity can be computed exactly from the outputs of the difference equation for $i_v[n]$.

TOPS

(4) The system is perturbed by changes in control current threshold, not duty cycle, i.e., duty is an output, not an input.

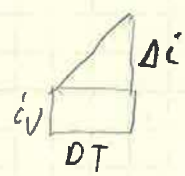
(5) Averaged currents can be computed from either energy transfer, or geometrically from duty cycle

A) Energy Transfer

$$\langle i_x \rangle = \frac{1}{2} L_{pri} (i_{pk}^2 - i_v^2) \cdot \frac{f_{sw}}{V_x}$$

f_{sw} = Switching frequency
V_x = Either input or output voltage, depending which current is being averaged.

B) Geometry;



$$\langle i \rangle = \left(i_v DT + \frac{1}{2} DT \Delta i \right) \frac{1}{T}$$

(6) Quasi-periodic sampling changes averaging interval. Sampling of average output current is periodic as long as Duty does not change.

The spill-over or deficit due to changing duty cycle can be added into the current averaging interval.

(7) The recurrence relation for valley currents $i_v[n]$ is an IIR filter convolved with the control current, $i_c[n]$.

(8) Since averaging can be computed entirely from $i_v[n]$ and values assumed constant during the averaging interval, it can be expressed as an FIR filter, that is, averaging is non-recursive.

FCCM CONVERTER: DIFFERENCE EQUATION

$i_v[n]$ = Valley Current, Sampled at termination of cycle

$i_c[n - D'T_s]$ = Peak control current at time of sampling

m_c = Slope of charging interval $= \frac{V_{IN}}{L_{PRI}}$

m_{cmp} = Slope compensation = Constant

m_d = Slope of discharging interval $= \frac{V_{OUT}}{L_{PRI}}$

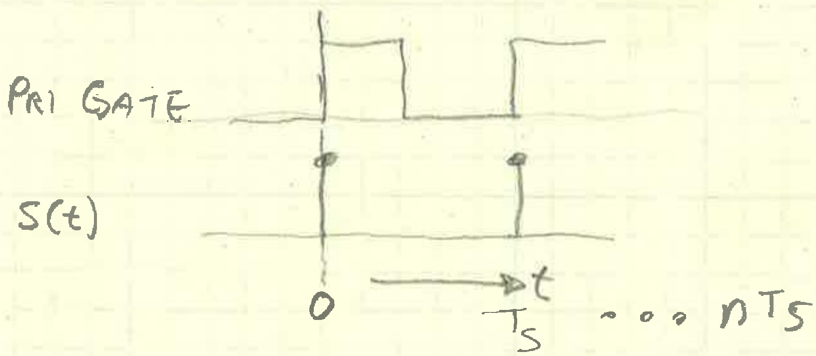
T_s = Sampling period

To use $i_c[n]$ directly in the recurrence relation, the following block diagram is assumed.

$$s(t) = \sum_{n=0}^{\infty} \delta(t - nT_s)$$

Single-sided (causal) sampling function

The rising edge of the primary gate is synchronized to $t=0$, or $s(t)$



$$\begin{aligned}
i_v[n] &= i_v[n-1] + DT_s m_c - ((1-D)T_s m_d) \\
&= i_v[n-1] + DT_s m_c - (T_s m_d - DT_s m_d) \\
&= i_v[n-1] + DT_s m_c - T_s m_d + DT_s m_d \\
&= i_v[n-1] + DT_s(m_c + m_d) - T_s m_d
\end{aligned}$$

DUTY

$$\boxed{D(i_v[n]) = \frac{i_c[n] - i_v[n-1]}{(m_c + m_{cmp})T_s}}$$

$D[i_v[n]]$

FCCM CONVERTER: DIFFERENCE EQUATION

$$i_V[n] = i_V[n-1] + \left(\frac{i_c[n] - i_V[n-1]}{(m_c + m_{cmp})T_s}\right)(m_c + m_d)T_s - T_s m_d$$

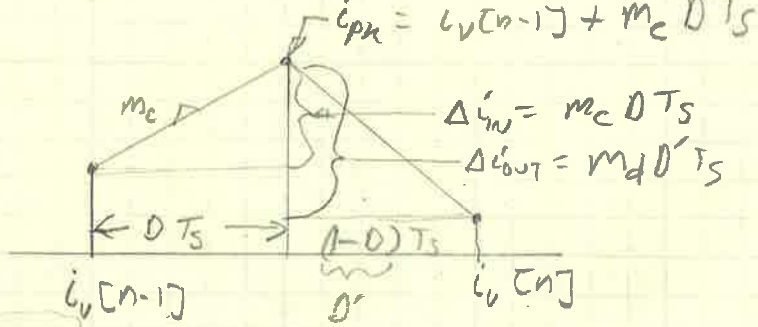
Substitute $\alpha = \dfrac{m_c + m_d}{m_c + m_{cmp}}$

$$i_V[n] = i_V[n-1] - i_V[n-1]\alpha + \alpha i_c[n] - T_s m_d$$

$$\boxed{i_V[n] = (1-\alpha) i_V[n-1] + \alpha i_c[n] - T_s m_d}$$

$i_V[n]$

- This is an FIR FILTER — But Non-LTI
- SPICE can handle this expression accurately



INPUT CURRENT

$$\langle i_{IN} \rangle = \left(\frac{1}{2} D T_s (m_c D T_s) + i_v[n-1] \cdot D T_s \right) \frac{1}{T_s}$$

$$\boxed{\langle i_{IN} \rangle = \frac{1}{2} D^2 T_s m_c + D i_v[n-1]}$$

$\langle i_{IN} \rangle$

OUTPUT CURRENT

$$\langle i_{OUT} \rangle = \left(\frac{1}{2} D' T_s m_d D' T_s + i_v[n] D' T_s \right) \frac{1}{T_s}$$

$$\boxed{\langle i_{OUT} \rangle = \frac{1}{2} D'^2 T_s m_d + D' i_v[n]}$$

$\langle i_{OUT} \rangle$

DUTY CLAMPING

If the converter averaged model is implemented in SPICE, DUTY must be clamped. The recurrence relation does not constrain $D_{MIN} < D < D_{MAX}$ naturally.

$$D = \frac{i_c[n] - i_v[n-1]}{(m_c + m_{cmp}) T_s}$$

$$D_{MIN} < \frac{i_c[n] - i_v[n-1]}{(m_c + m_{cmp}) T_s}$$

$$-(m_c + m_{cmp}) T_s D_{MIN} < -i_c[n] + i_v[n-1]$$

$$i_v[n-1] > i_c[n] - (m_c + m_{cmp}) T_s D_{MIN}$$

$$D_{MAX} > \frac{(i_c[n] - i_v[n-1])}{(m_c + m_{cmp}) T_s}$$

$$-(m_c + m_{cmp}) T_s D_{MAX} > -i_c[n] + i_v[n-1]$$

$i_v[n-1] < i_c[n] - (m_c + m_{cmp}) T_s D_{MAX}$	D_{MAX}
$i_v[n-1] > i_c[n] - (m_c + m_{cmp}) T_s D_{MIN}$	D_{MIN}

TOPS