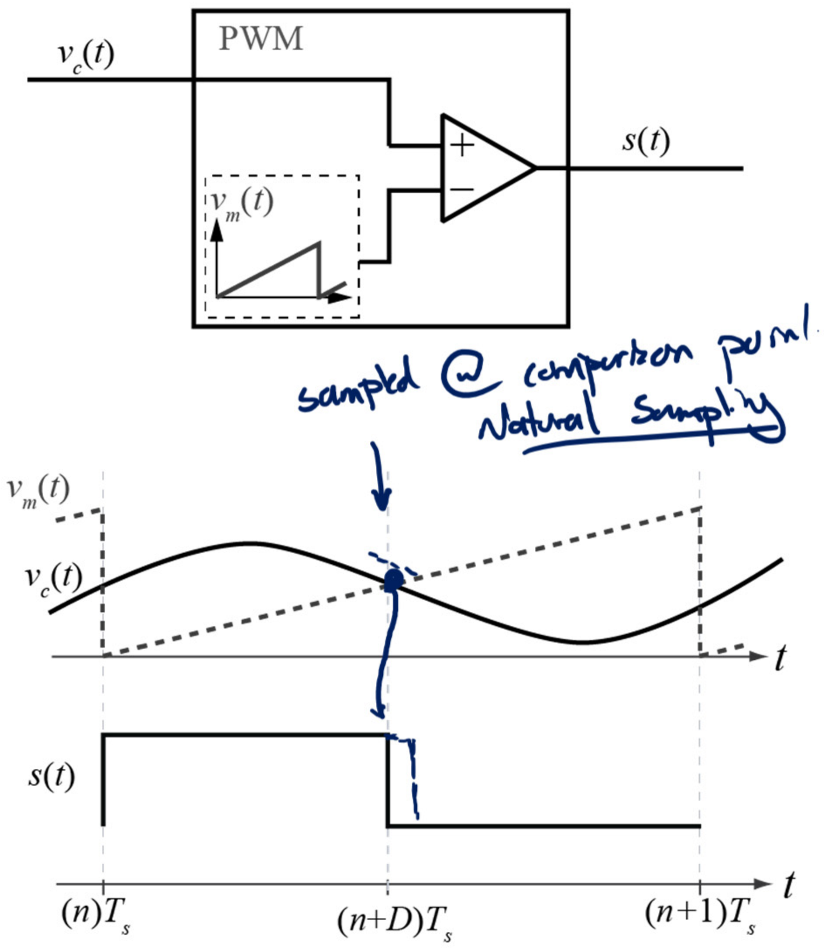
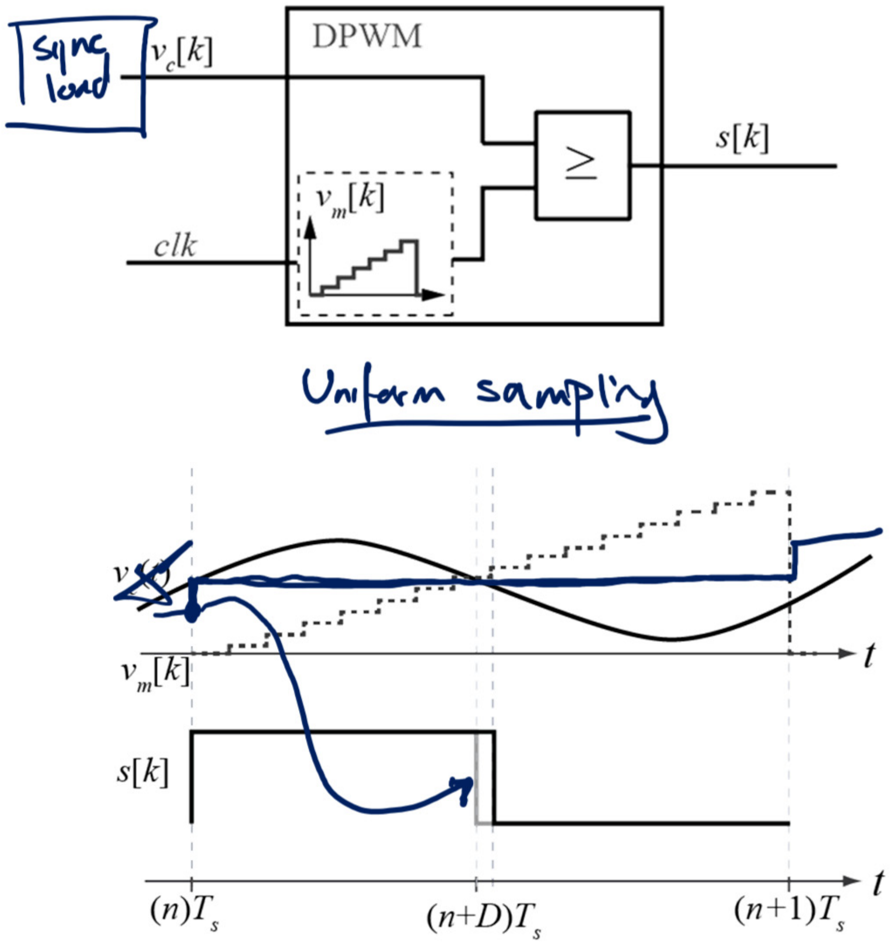
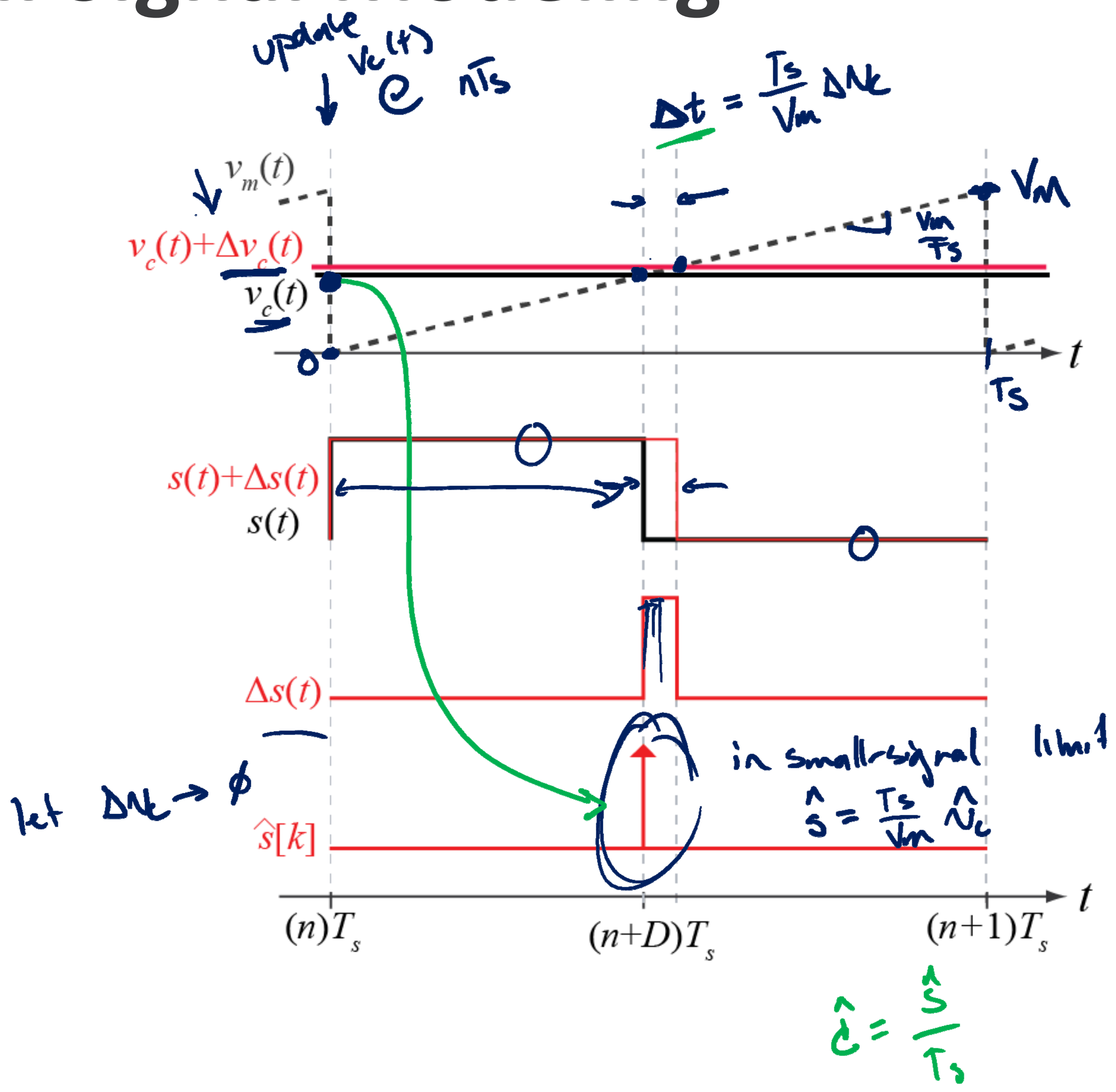
Sampling in Modulators

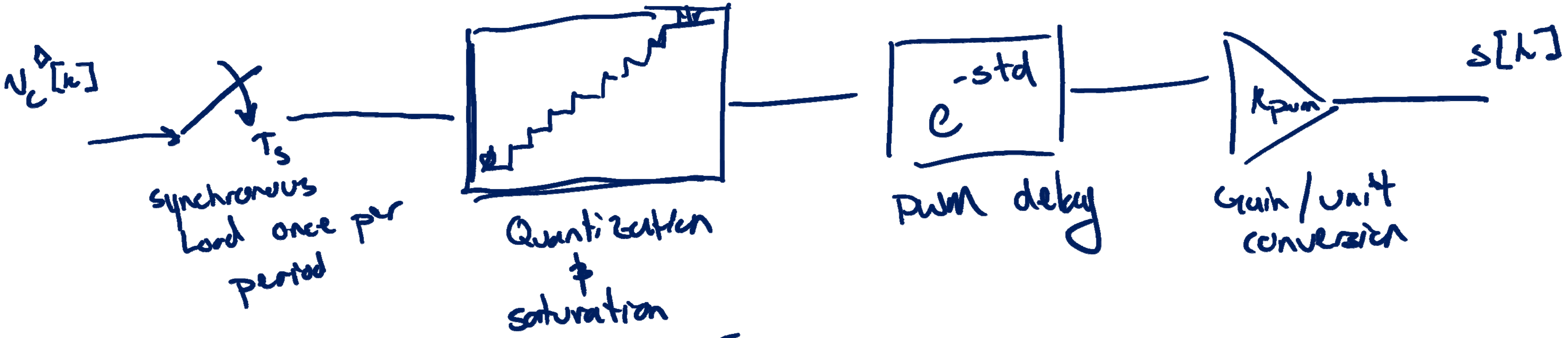




PWM Small Signal Modeling



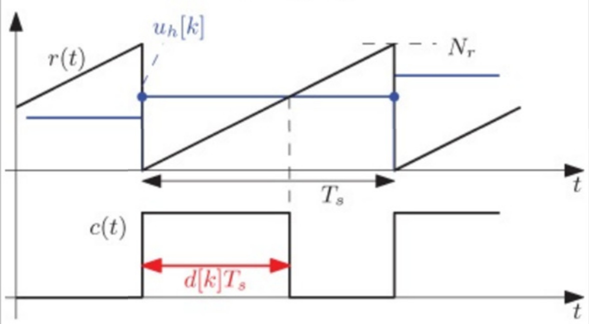
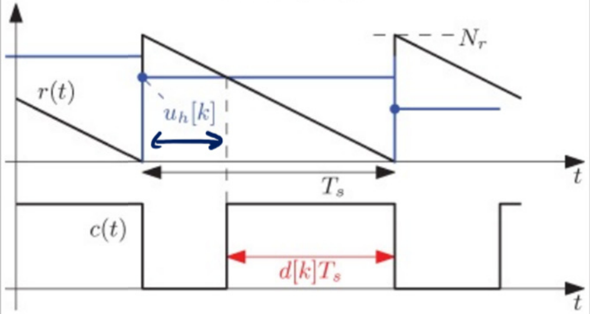
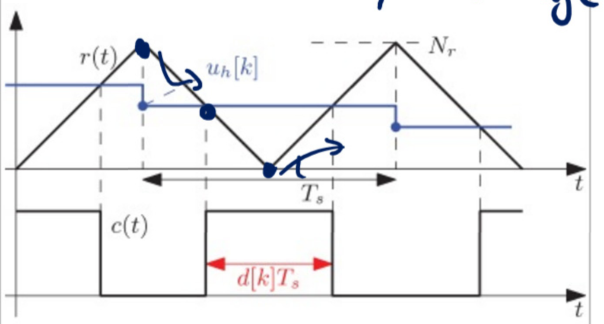
PWM Model



$$\emptyset \le v_c^\Delta[k] \le \frac{T_s}{T_{clk}} = N_r$$

$t_d \rightarrow$ depends on implementation

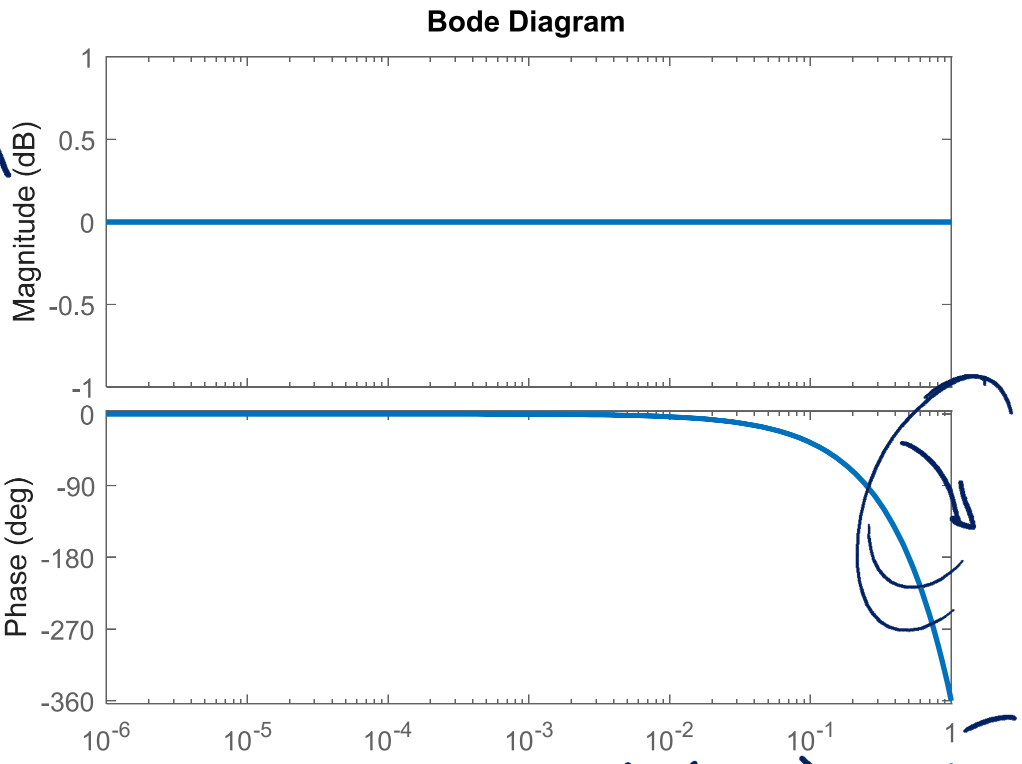
DPWM Implementations

Modulation Type	Frequency Response
Trailing-edge 	$t_d = DT_s$ $G_{PWM,TE}(j\omega) = \frac{e^{-j\omega DT_s}}{N_r}$
Leading-edge 	$t_d = (1-D)T_s$ $G_{PWM,LE}(j\omega) = \frac{e^{-j\omega(1-D)T_s}}{N_r}$
Symmetrical / dual-edge 	$t_d \approx \frac{T_s}{2}$ $G_{PWM,Sym}(j\omega) =$ $= \frac{\cos(\omega DT_s/2)}{N_r} e^{-j\omega\frac{T_s}{2}}$ $\approx \frac{e^{-j\omega\frac{T_s}{2}}}{N_r}$

Delay Transfer Function

$G(s) = e^{-s t_d}$

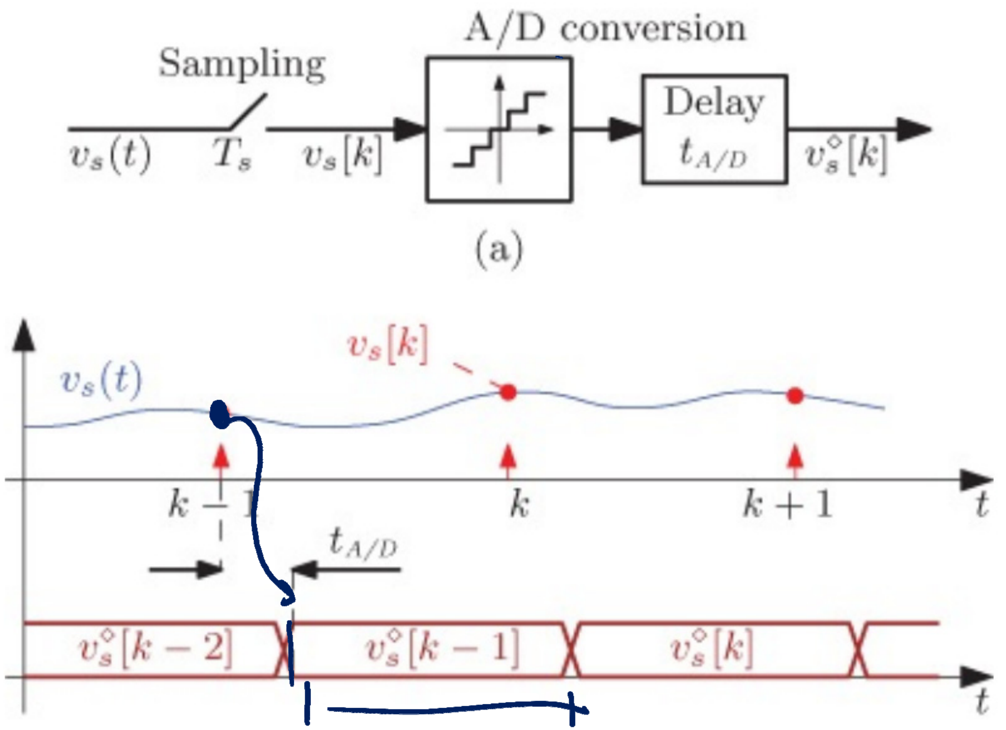
$\|G(s)\|$



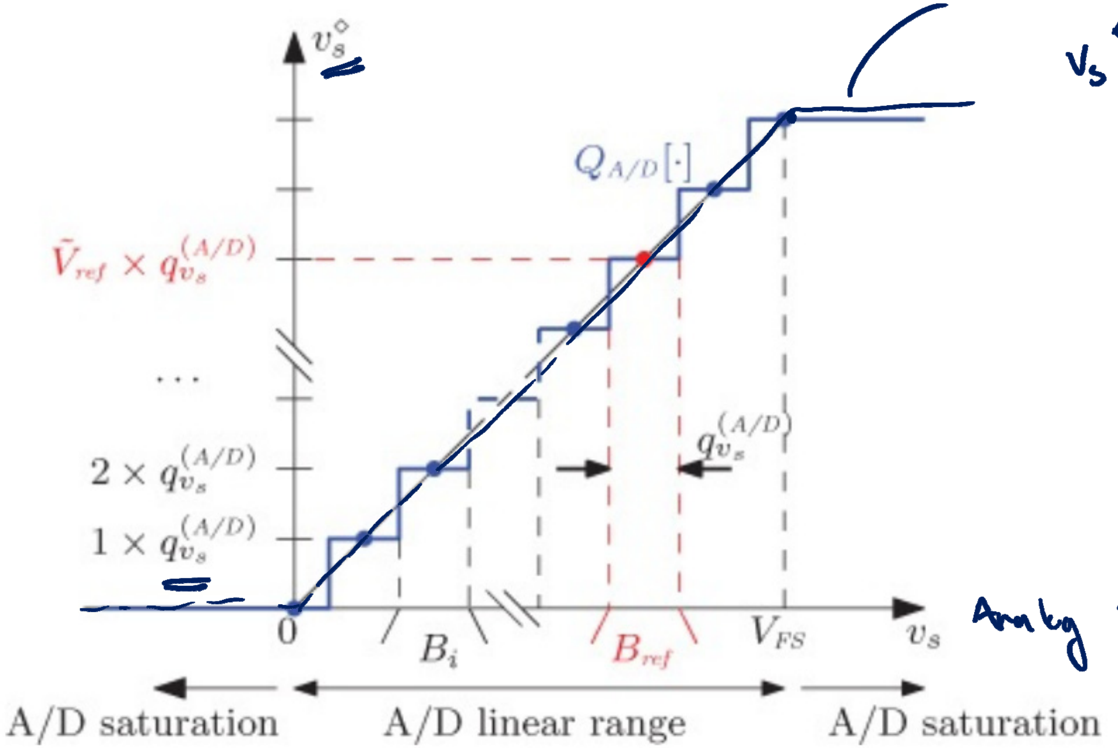
$\measuredangle G(s)$

frequency $f \cdot (2\pi t_d) \approx \frac{f}{f_d}$

ADC Modeling



ADC Quantization



linear Gain

$$v_s^\diamond \approx \frac{v_s}{V_{cc}} \times 2^{n_{A/D}}$$

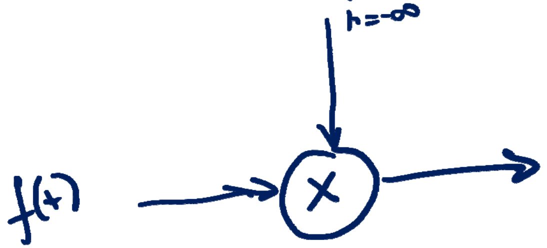
Analog Voltage [v]

$$q_{v_s} = \frac{V_{cc}}{2^{n_{A/D}}}$$

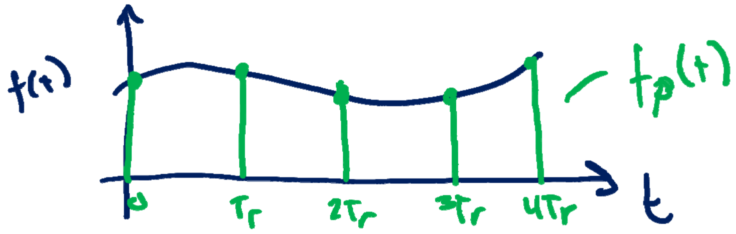
$n_{A/D}$ = # of bits in ADC

Aliasing Review

$$\sum_{k=-\infty}^{\infty} \delta(t-kT_r) = \delta_T(t)$$



$$f_p(t) = f(t) \times \delta_T(t) = \sum_{k=-\infty}^{\infty} f(kT_r)\,\delta(t-kT_r)$$



$$f_r = \frac{1}{T_r}$$

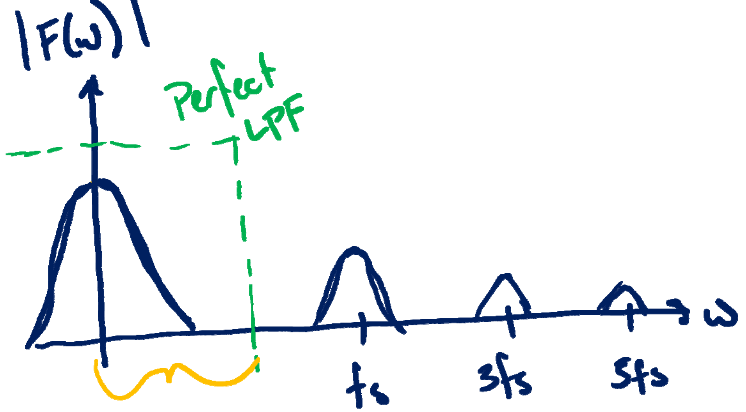
Fourier Transform:

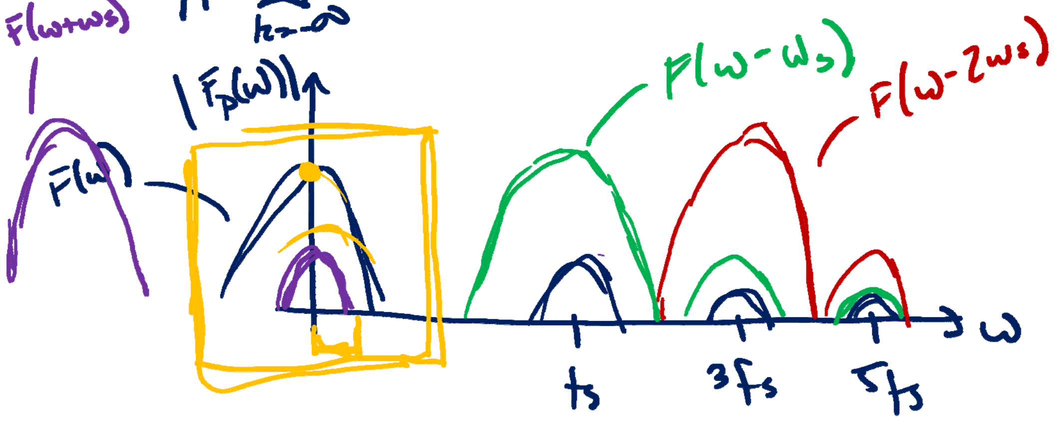
$$\mathcal{F}[\delta_T(t)] = \omega_r \sum_{k=-\infty}^{\infty} \delta(\omega - k\omega_r)$$

$$\mathcal{F}[f(t)] = F(\omega)$$

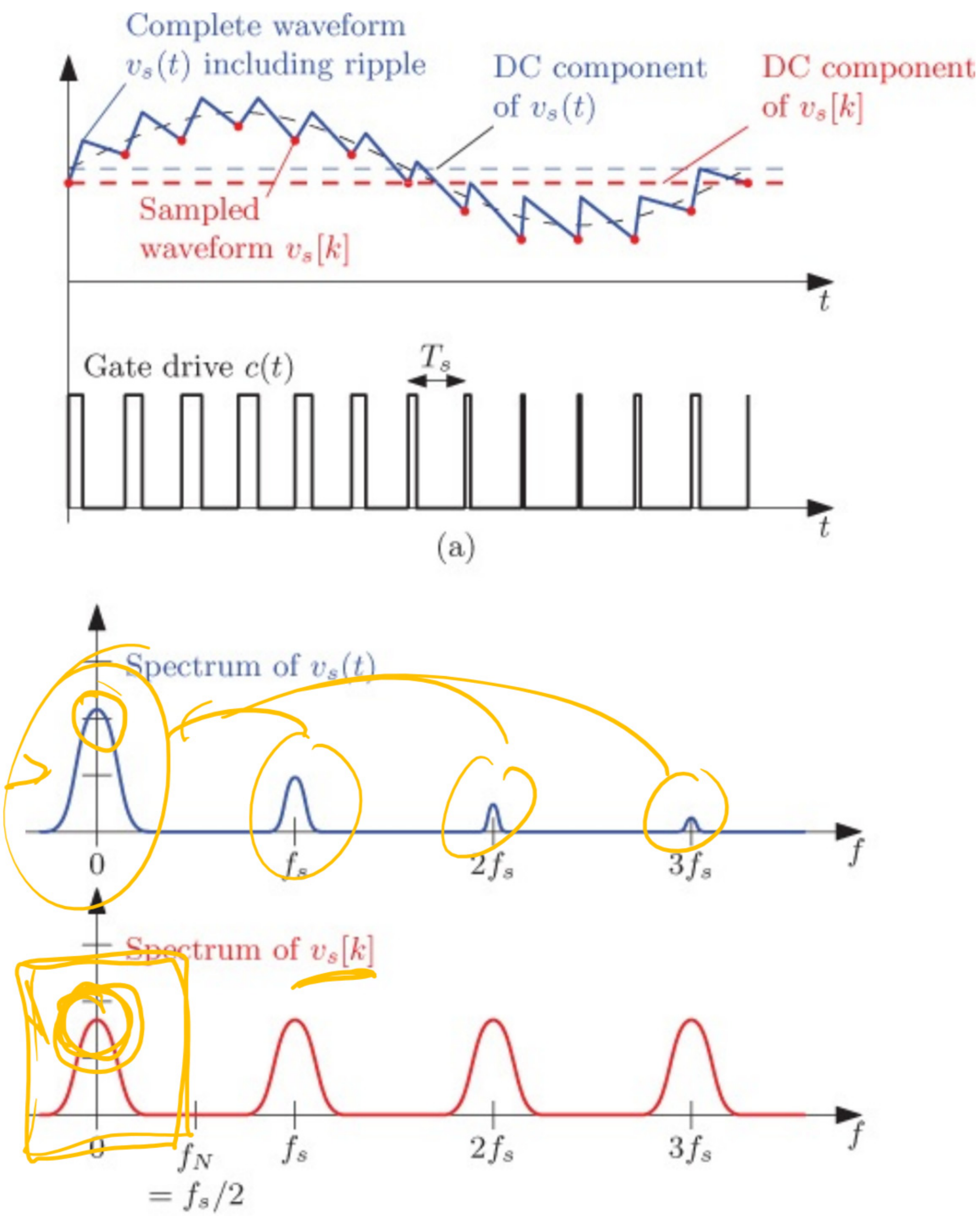
$$\mathcal{F}[f_p(t)] = \frac{1}{2\pi}\mathcal{F}[f(t)] * \mathcal{F}[\delta_T(t)]$$

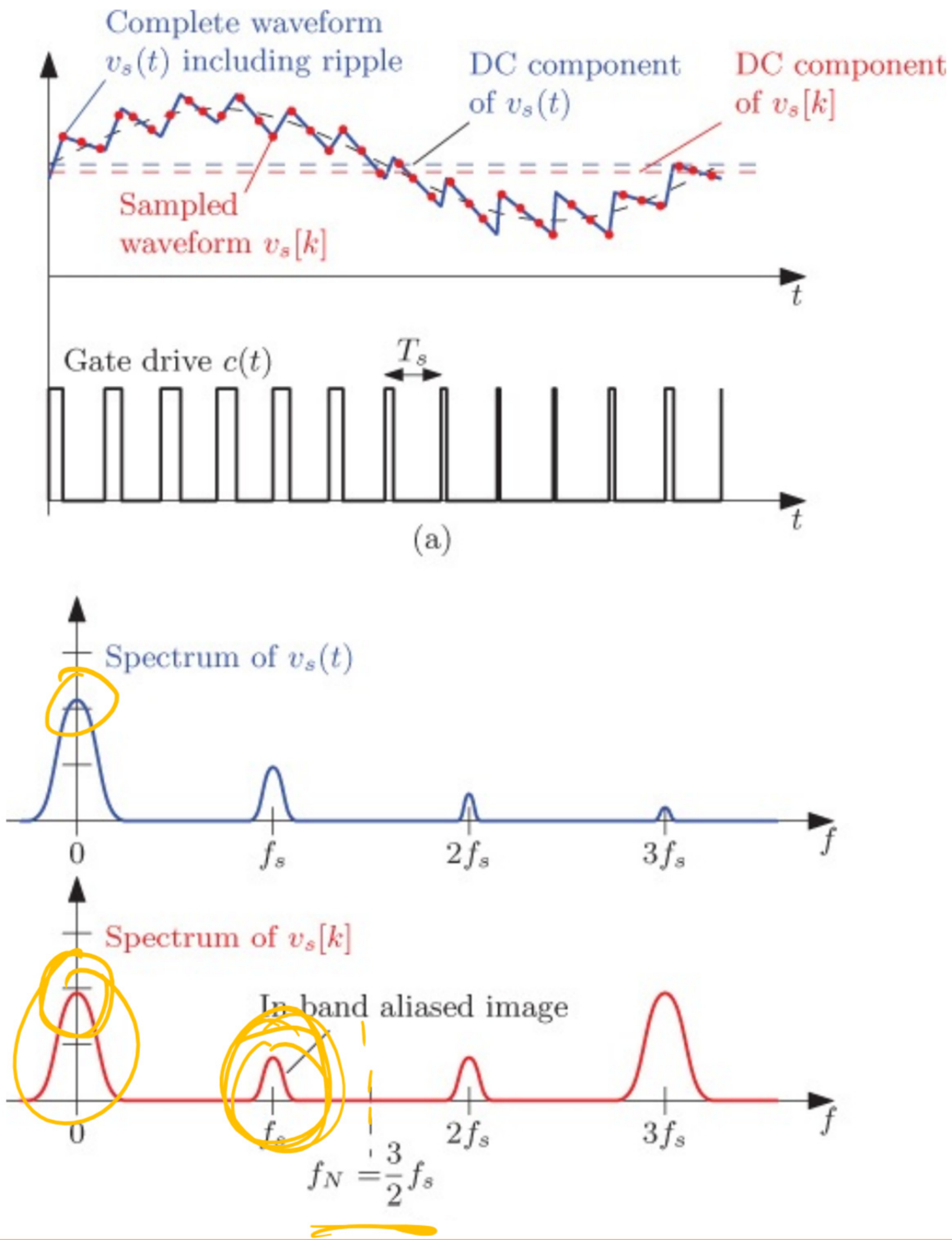
$$= f_r \sum_{k=-\infty}^{\infty} F(\omega - k\omega_r)$$



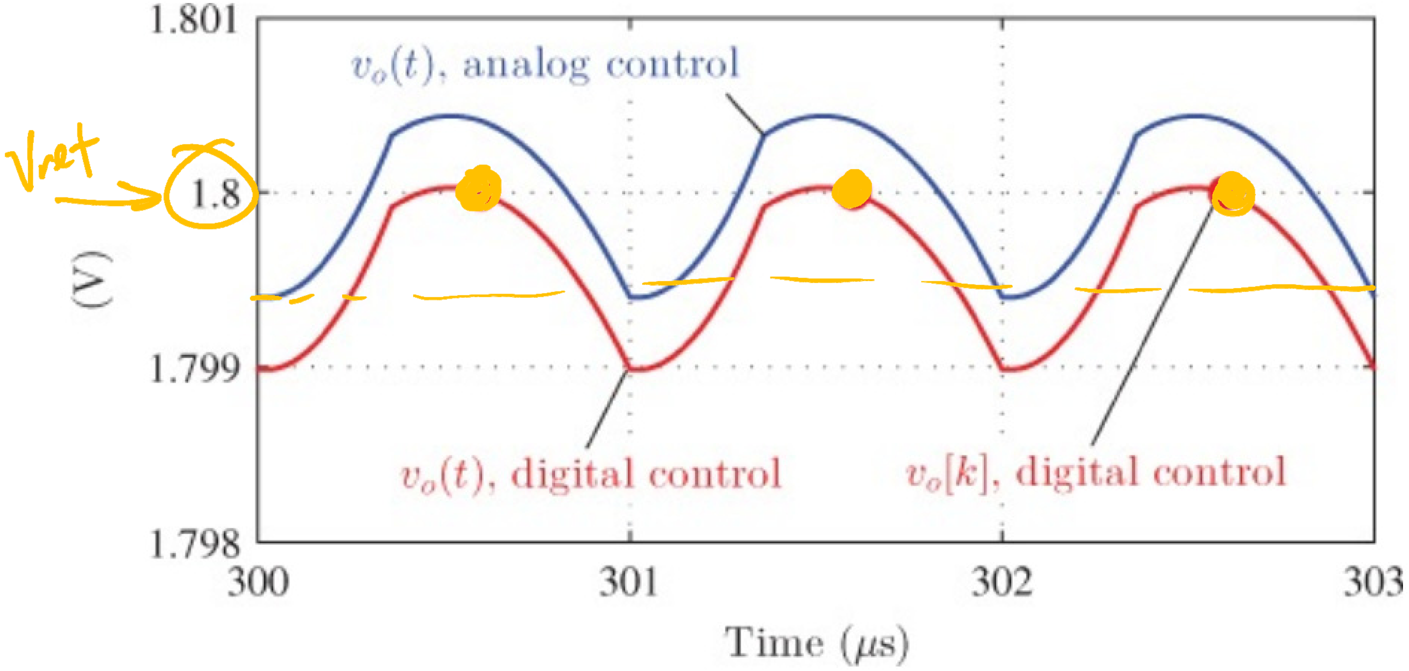


$T_r = T_s$

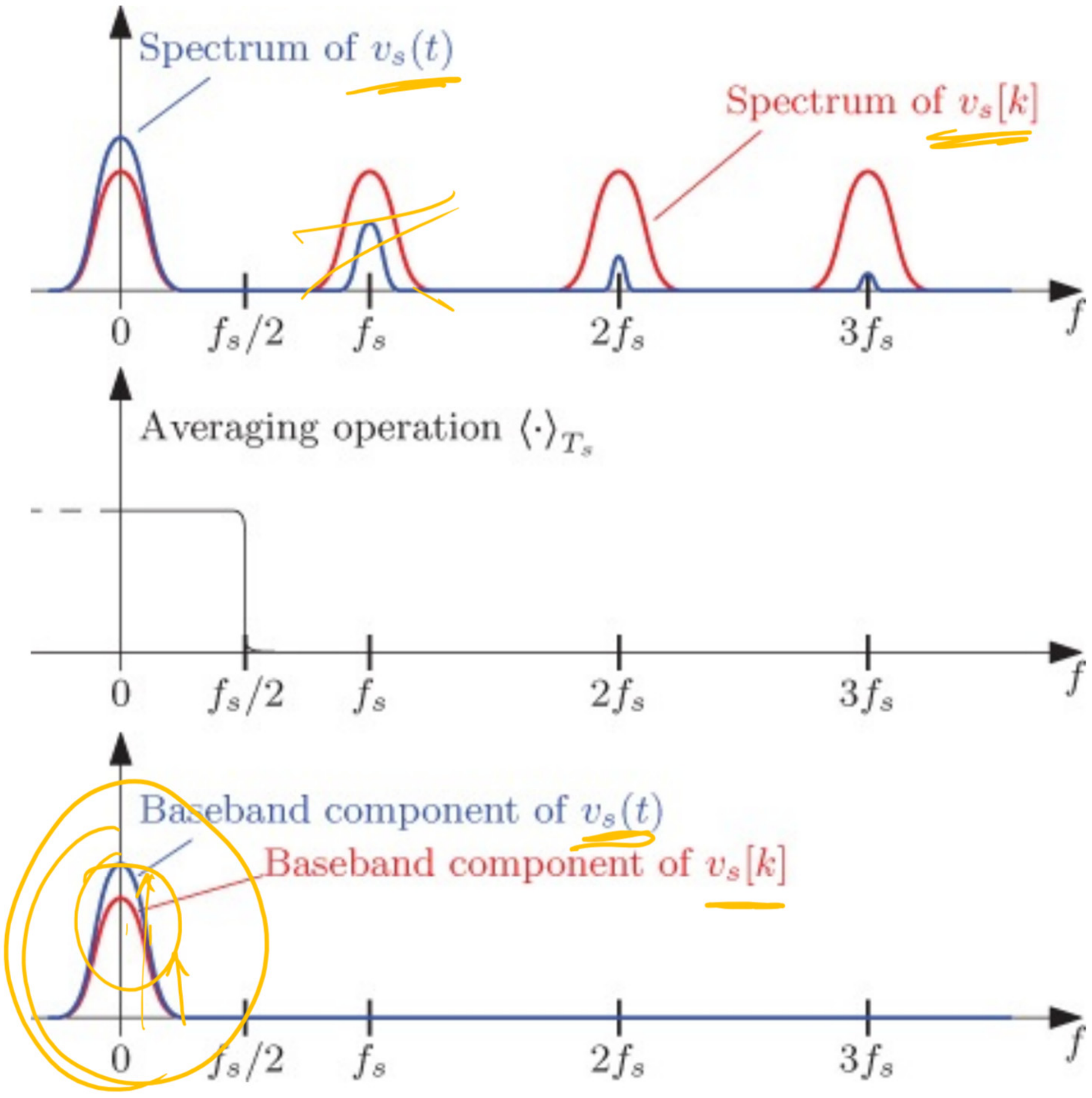

Complete waveform
$v_s(t)$ including ripple
DC component
of $v_s(t)$
DC component
of $v_s[k]$
Sampled
waveform $v_s[k]$
t
Gate drive $c(t)$
T_s
t
(a)
Spectrum of $v_s(t)$
0
f_s
$2f_s$
$3f_s$
f
Spectrum of $v_s[k]$
0
f_N
$= f_s/2$
f_s
$2f_s$
$3f_s$
f


Complete waveform
$v_s(t)$ including ripple
DC component
of $v_s(t)$
DC component
of $v_s[k]$
Sampled
waveform $v_s[k]$
t
Gate drive $c(t)$
T_s
t
(a)
Spectrum of $v_s(t)$
0
f_s
$2f_s$
$3f_s$
f
Spectrum of $v_s[k]$
In-band aliased image
0
f_s
$2f_s$
$3f_s$
f
$f_N = \frac{3}{2} f_s$

DC Aliasing



Vref
1.801
1.8
1.799
1.798
(V)
$v_o(t)$, analog control
$v_o(t)$, digital control
$v_o[k]$, digital control
300
301
302
303
Time (μs)



Spectrum of $v_s(t)$
Spectrum of $v_s[k]$
0
$f_s/2$
f_s
$2f_s$
$3f_s$
f
Averaging operation $\langle\cdot\rangle_{T_s}$
Baseband component of $v_s(t)$
Baseband component of $v_s[k]$