

EE 722

CMOS mixed-signal $v_{in} \sim v_{out}$

$$v_{in}(t) = V_1 \sin 2\pi f t$$

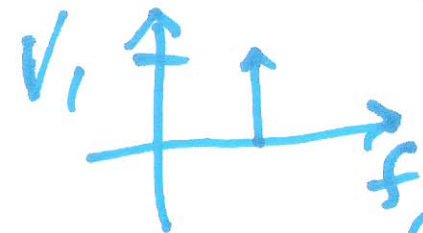
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$$\sqrt{\frac{2\pi T}{2\pi}} = \text{Neg}$$

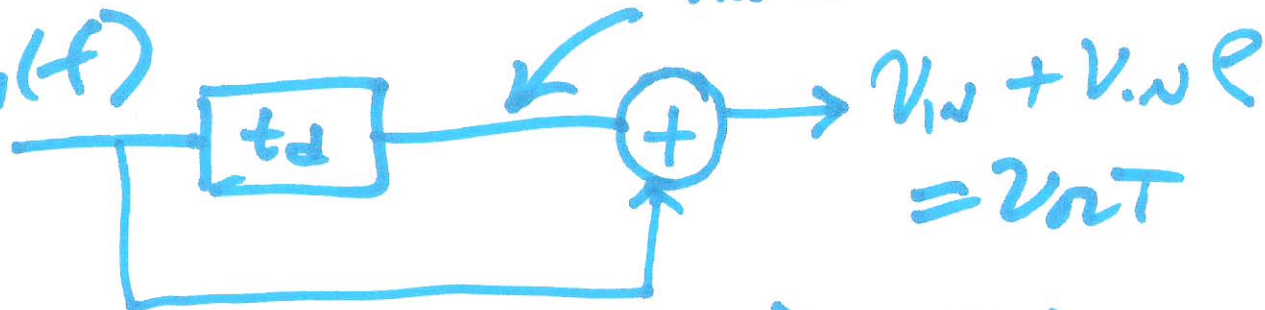
$$\theta = 360 \cdot \frac{t_d}{T}$$

Lecture

$$2 V_{in} e^{j2\pi \cdot (-t_d) \cdot f} - j2\pi f t_d$$



$v_{in}(f)$



$$v_{in} + v_{in} e^{-j2\pi f t_d} = v_{out}$$

xfer function of comb filter

$$\frac{v_{out}}{v_{in}} = 1 + e^{-j2\pi f t_d}$$

$$e^{j\theta} = \cos \theta + j \sin \theta$$

1)

$$\frac{v_{NT}}{v_{in}} = 1 + e^{-j2\pi f \cdot t_d}$$

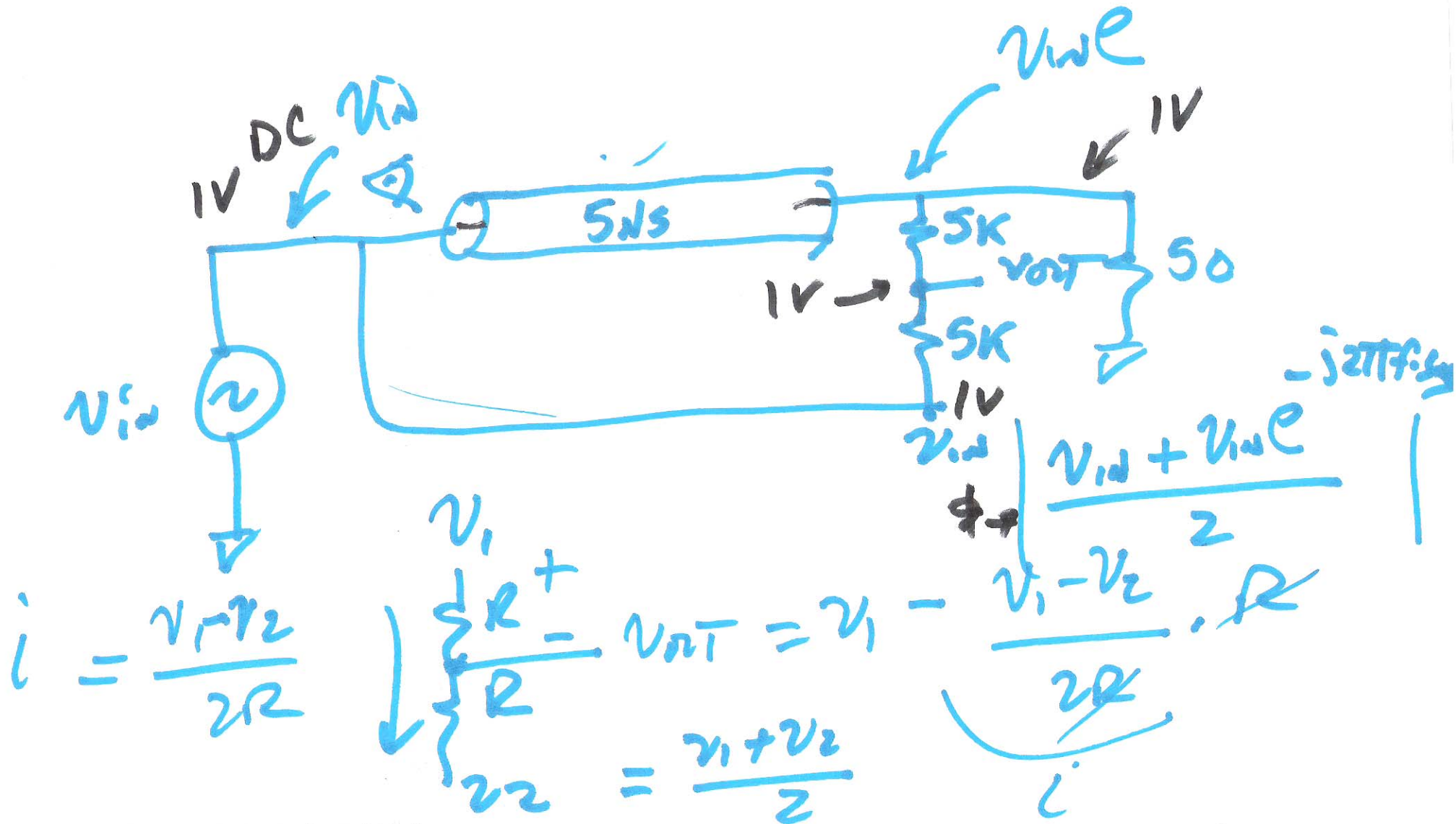
$$= 1 + \cos(-2\pi f \cdot t_d)$$

Real

$$+ j \sin(-2\pi f \cdot t_d)$$

$$\left| \frac{v_{NT}}{v_{in}} \right| = \sqrt{(1 + \cos(\uparrow))^2 + \sin^2(\uparrow)}$$
$$= 1 + \cos x = 2 \cos^2 \frac{x}{2}$$

$$\left| \frac{v_{out}}{v_{in}} \right| = 2 \left| \cos \pi f \cdot t_d \right| \quad (2\pi 5ns f)$$



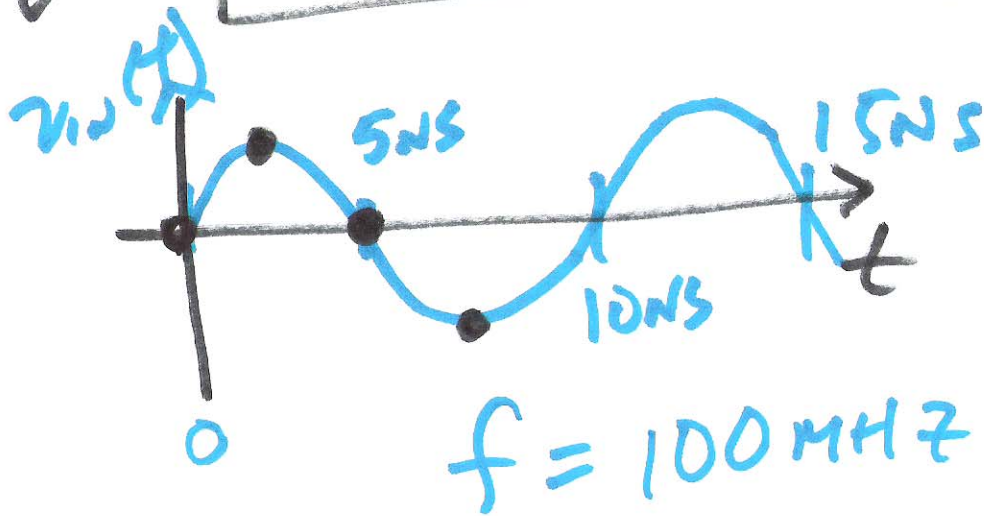
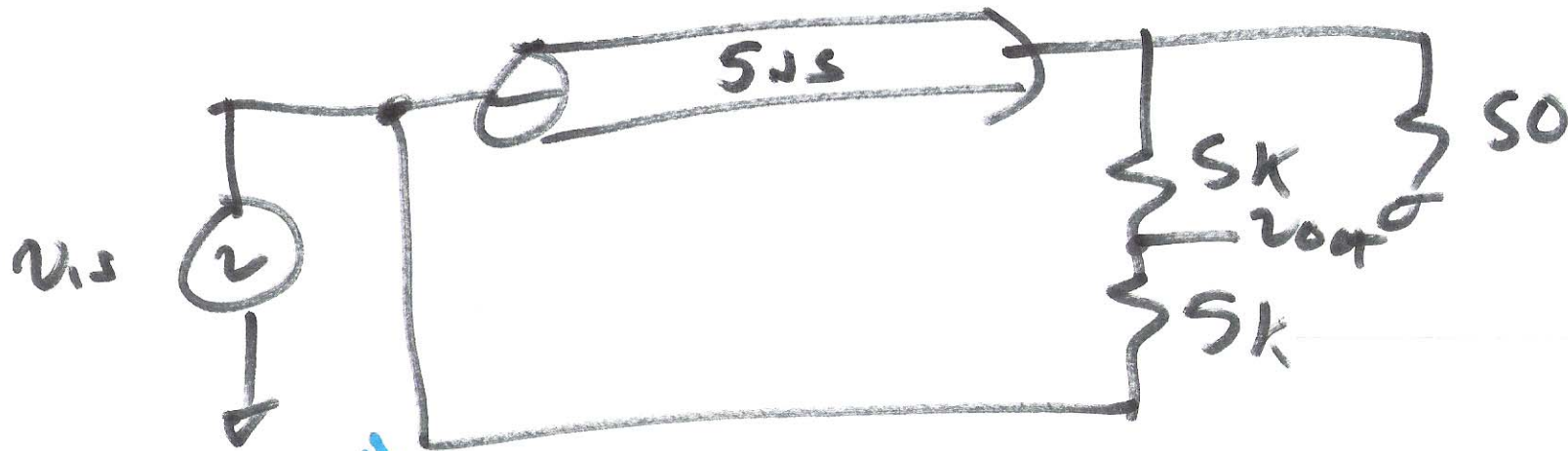
$$i = \frac{v_1 - v_2}{2R}$$

$$\frac{v_1}{R} - \frac{v_2}{R} = v_{out} = v_1 - v_2 = \frac{v_1 + v_2}{2}$$

$$i = \frac{v_{id} + v_{id} e}{2} - \frac{v_{id} - v_{id} e}{2} \cdot R$$

3)

$$\left| \frac{v_{out}}{v_{in}} \right| = \cos \pi f \cdot t_d = \cos \pi \cdot 100 \times 10^6 \cdot 5 \cdot 10^{-9} = \cos \frac{\pi}{2}$$



$$\frac{v_{nT}}{v_{in}} = 1 + e^{j2\pi f \cdot (-t_d)}$$

$$= 1 + \cos(2\pi f(-t_d)) + j \sin(2\pi f(-t_d))$$

$$\angle \frac{v_{nT}}{v_{in}} = \tan^{-1} \frac{\sin(2\pi f \cdot (-t_d))}{1 + \cos(2\pi f \cdot (-t_d))}$$

$$\sin x = 2 \sin \frac{x}{2} \cos \frac{x}{2}$$

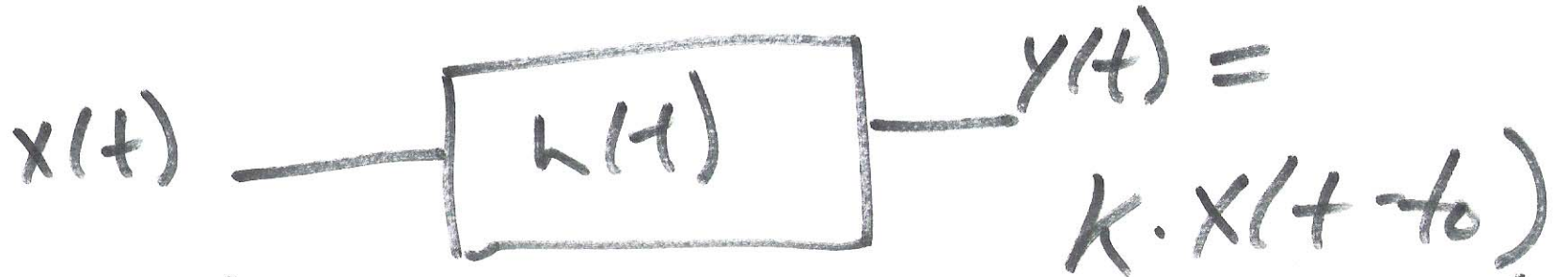
$$\angle \frac{v_{nT}}{v_{in}} = \pi(-t_d) \cdot f$$

$$\tan^{-1} \frac{0}{0} = \pm 90^\circ$$

9)

Distortionless transmission

$$e^{-j2\pi f \cdot t_0} = \cos(2\pi f \cdot t_0) + j \sin(-2\pi f \cdot t_0)$$



$$X(f)$$

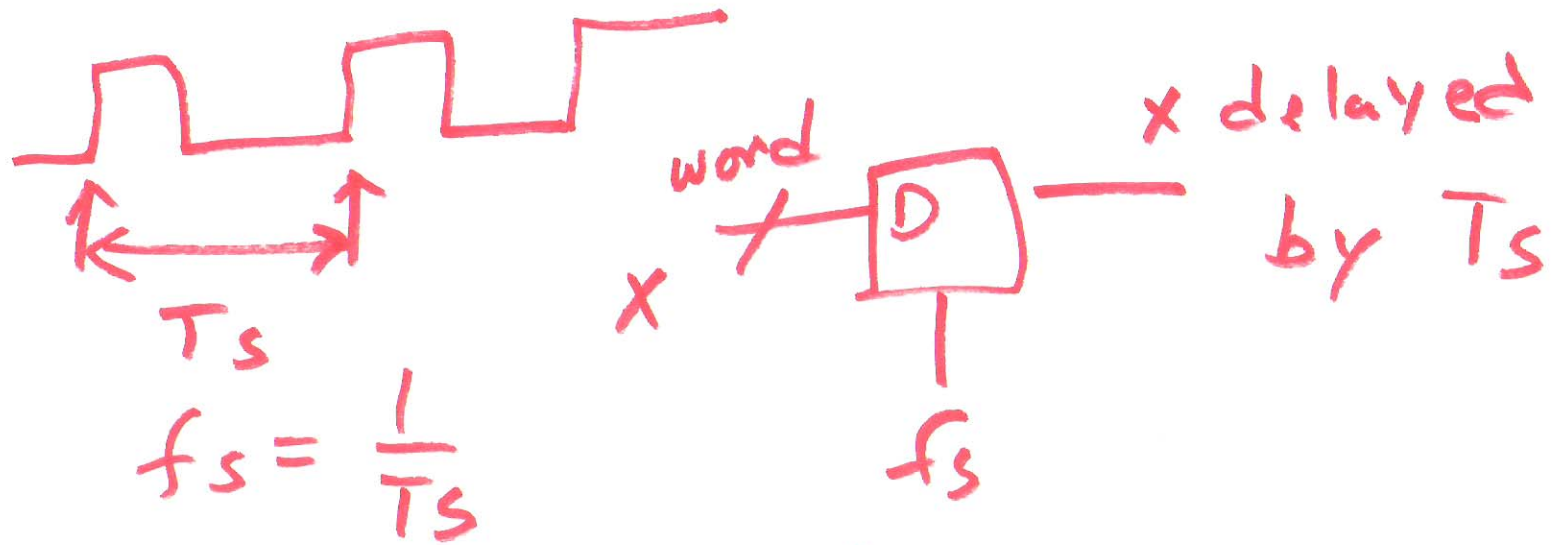
$$Y(f) = K \cdot X(f) e^{-j2\pi f \cdot t_0}$$

1) $\text{const } | | = k$

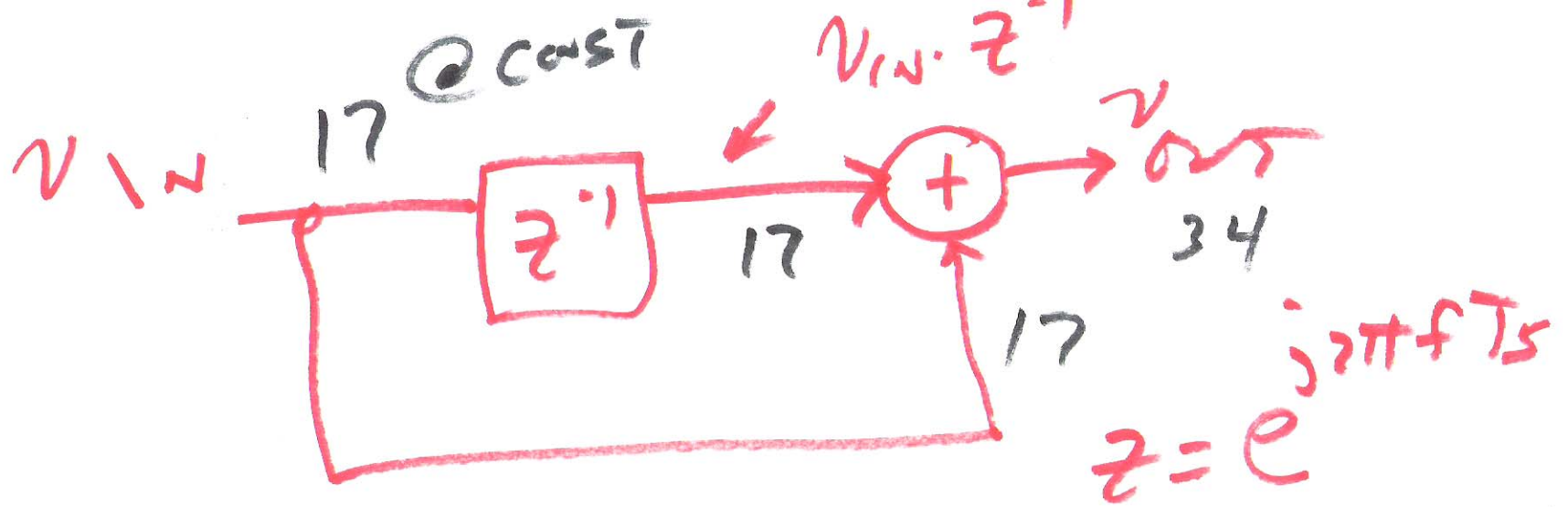
2) $\angle \frac{Y}{X} = \tan^{-1} \frac{\sin(-2\pi f \cdot t_0)}{\cos(-2\pi f \cdot t_0)} = -2\pi f \cdot t_0$

6)

Digital Comb filter



$$z^{-1} \Rightarrow e^{-j2\pi f \cdot T_s} = e^{-j2\pi \frac{f}{f_s}}$$



$$v_{in} + v_{in} z^{-1} = v_{out}$$

$$\frac{v_{out}}{v_{in}} = 1 + z^{-1} = \frac{z + 1}{z}$$

$$1 + e^{-j2\pi f \cdot T_s}$$

$$\left| \frac{v_{out}}{v_{in}} \right| = 2 \cos \pi \frac{f}{f_s}$$

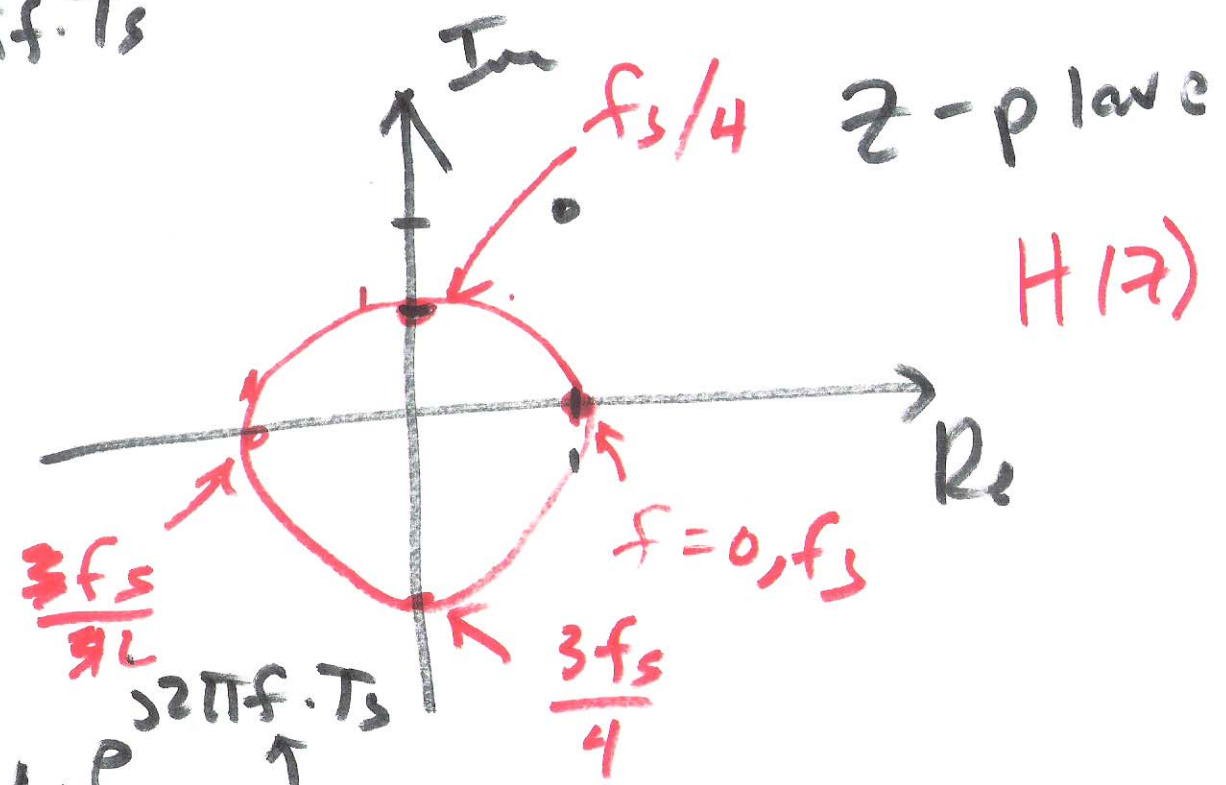
$$\angle = -\pi \cdot \frac{f}{f_s} \quad f < \frac{f_s}{2}$$

8)

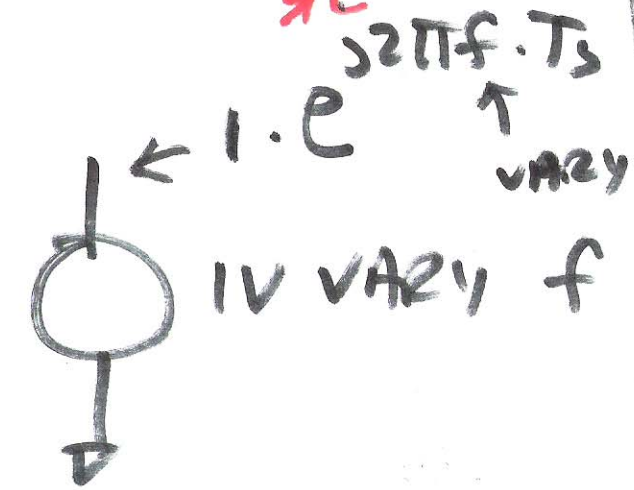
$$H(z) = 1 + z^{-1}$$

$$z^{-1} = e^{-j2\pi f \cdot T_s}$$

$$1 + 2j$$

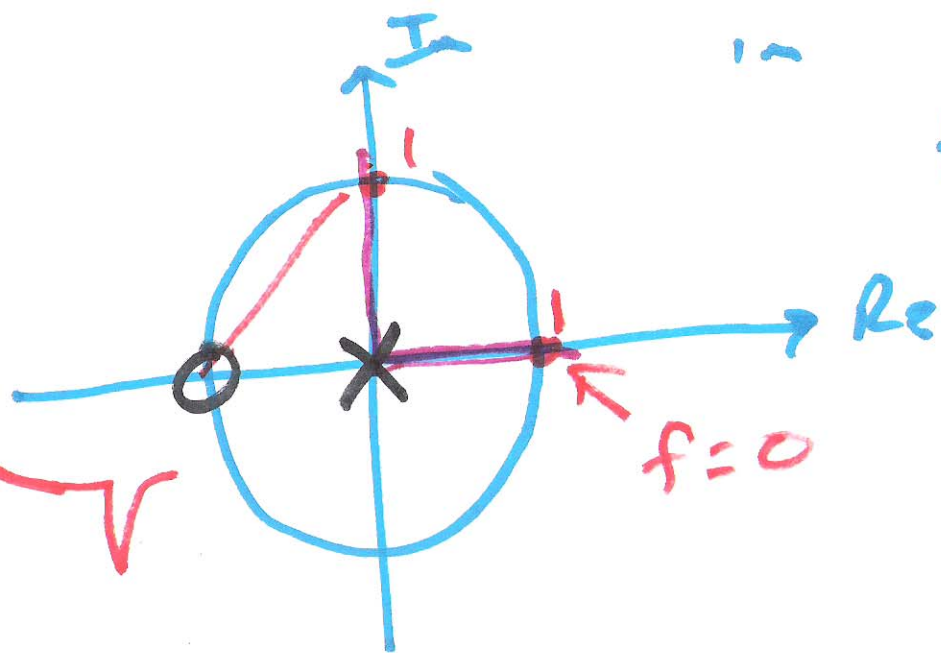


$$H(z) = \frac{V_{out}(z)}{V_{in}(z)}$$



$$\angle 2\pi f \cdot T_s = \theta$$

$$f = \frac{f_s}{4} = \frac{1}{4T_s}$$



$$H(z) = 1 + z^{-1}$$

$$= \frac{z + 1}{z}$$

↑
poles

$$|H(z)| = 2 \cos \pi \frac{f}{f_s} = \frac{\text{length of the zeros}}{\text{length of the poles}}$$

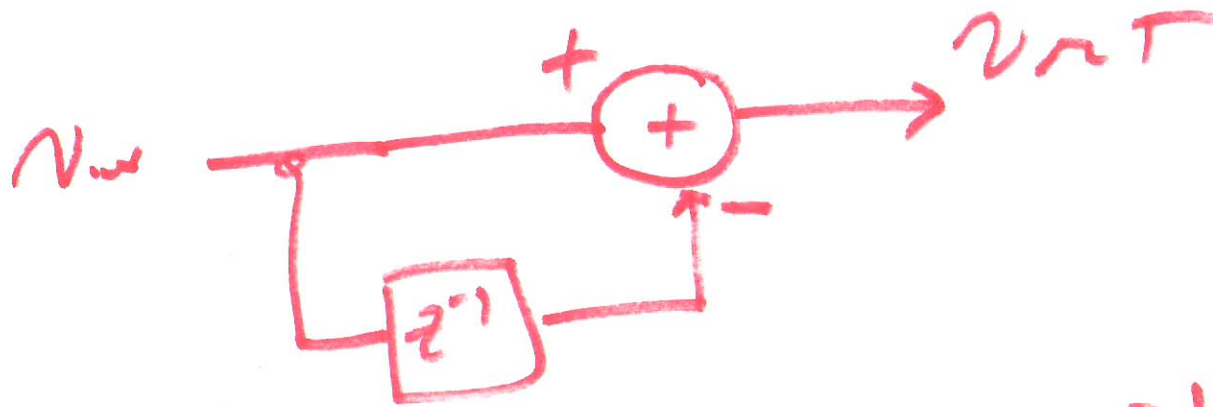
at $f=0$ $|H| = \frac{2}{1}, \angle = 0 - 0 = 0$

$f = \frac{f_s}{4}$ $|H| = \frac{1\sqrt{2}}{1} = \sqrt{2}$

$\angle 45 - (90) = -45$

10)

Digital Differentiation



$$v_{out} = v_{in} - v_{in} z^{-1}$$

$$\frac{v_{out}}{v_{in}} = 1 - z^{-1} = \frac{z - 1}{z}$$

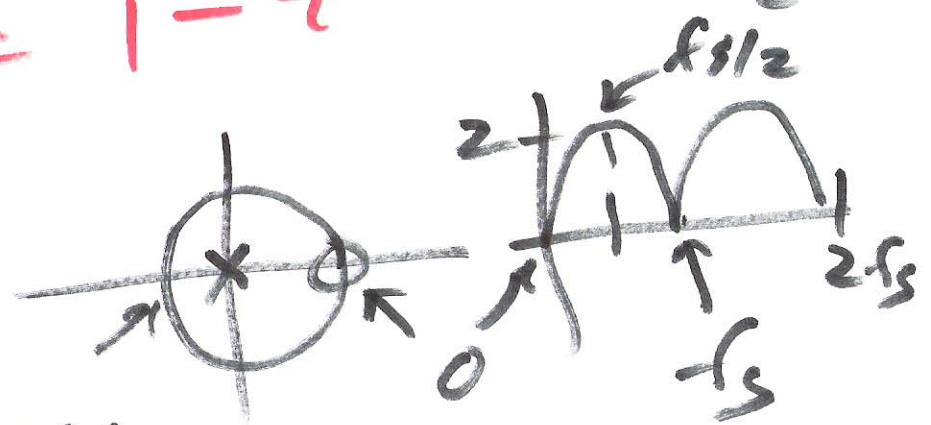
$$1 + z^{-1}$$

$$1 - z^{-1}$$

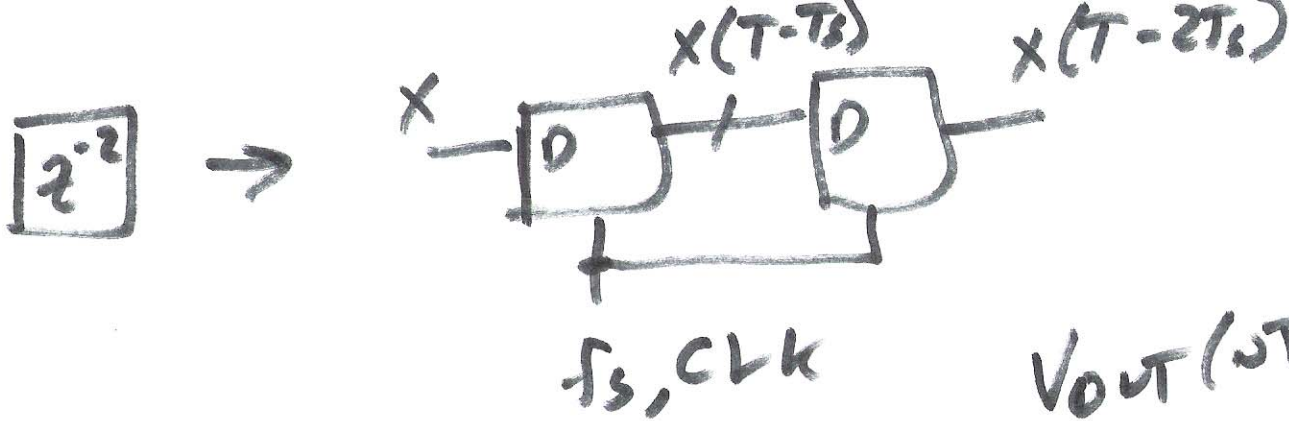
FIR

Non-recursive

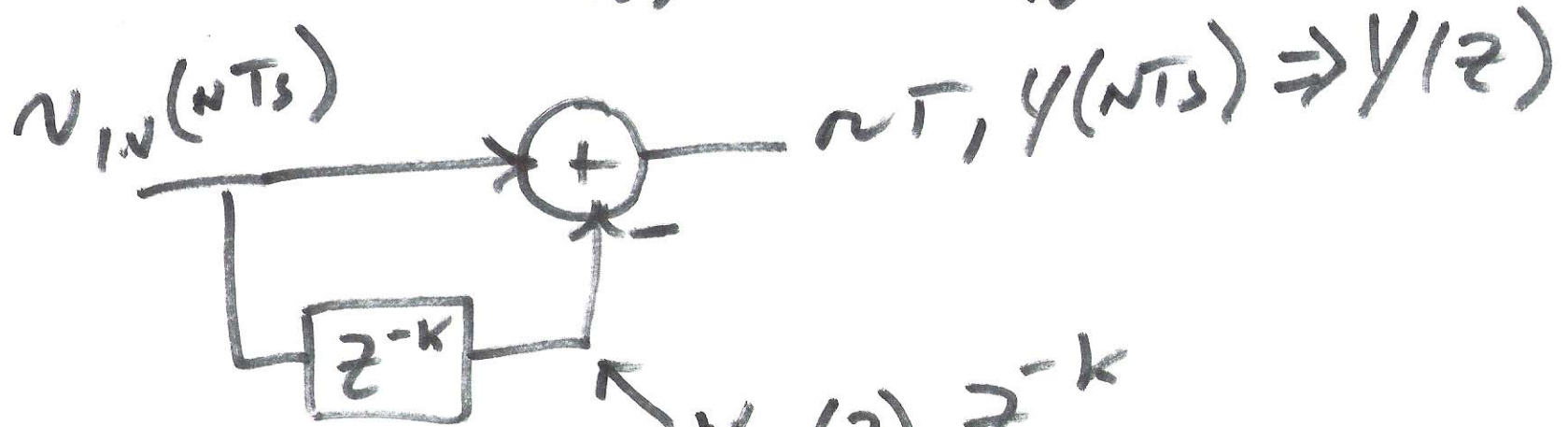
linear phase



101)



$$V_{OUT}(nT_s) = V_{IN}(z)$$



$$\frac{V_{OUT}}{V_{IN}} = H(z) = \frac{1}{1 - z^{-k}}$$

$$v_{IN}(z) \cdot z^{-k}$$

$$v_{IN}(nT_s - kT_s)$$

$$V_{OUT}(z) = V_{IN}(z) - V_{IN}(z) z^{-k}$$

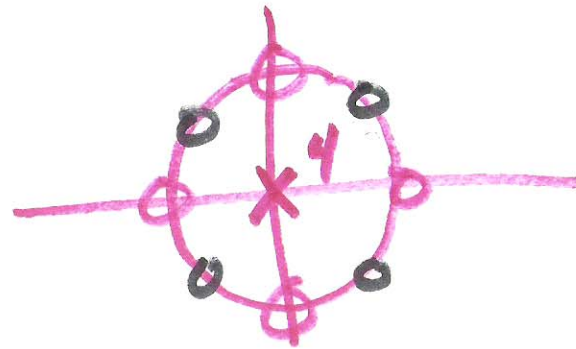
$$v_{OUT}(nT_s) = v_{IN}(nT_s) - v_{IN}(nT_s - kT_s)$$

14)

$$H(z) = 1 - z^{-k} = \frac{z^k - 1}{z^k}$$

$$k = 4 \quad k = 8$$

$$z^4 - 1 =$$



$$(z - 1)(z + 1)(z - j)(z + j) \\ = z^4 - 1$$