Lecture 2, !EXTRA! MARCH 6, 2009

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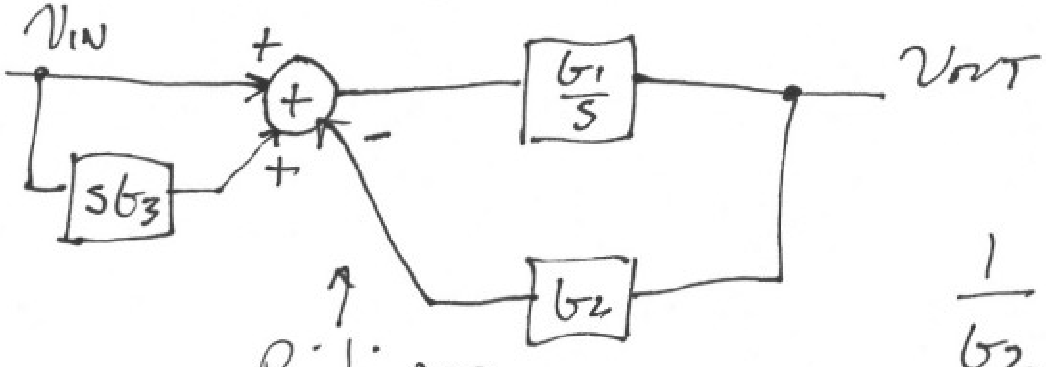
ECE 615 CMOS Mixed-Signal Circuit Design

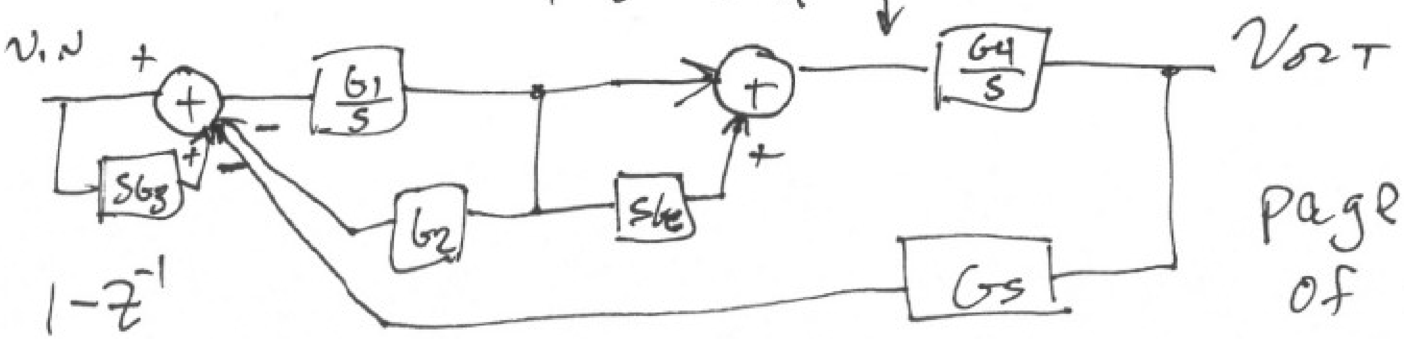
Sec. 4.3 Digital Filtering



Bilinear

$$\frac{1}{G_2} \cdot \frac{1 + s \cdot G_3}{1 + \frac{s}{G_1 G_2}}$$

$\frac{1}{1-z^{-1}}$ | $\frac{z^{-1}}{1-z^{-1}}$ Biquadratic



$1-z^{-1}$

Page 100 of the MSD book

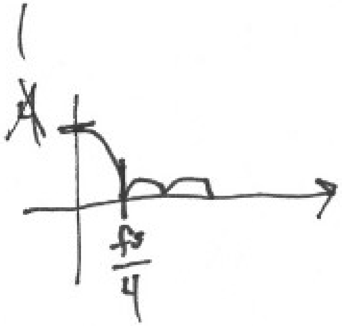
1)

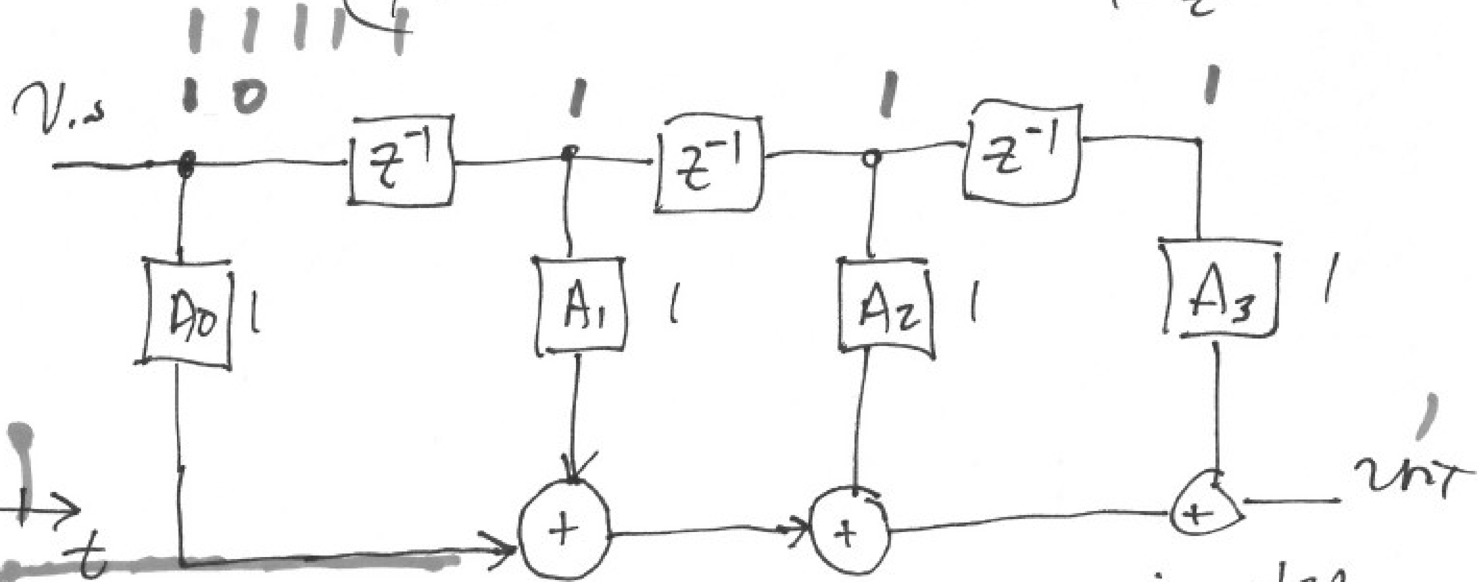
$$H(z) = A_0 + A_1 z^{-1} + A_2 z^{-2} + A_3 z^{-3}$$

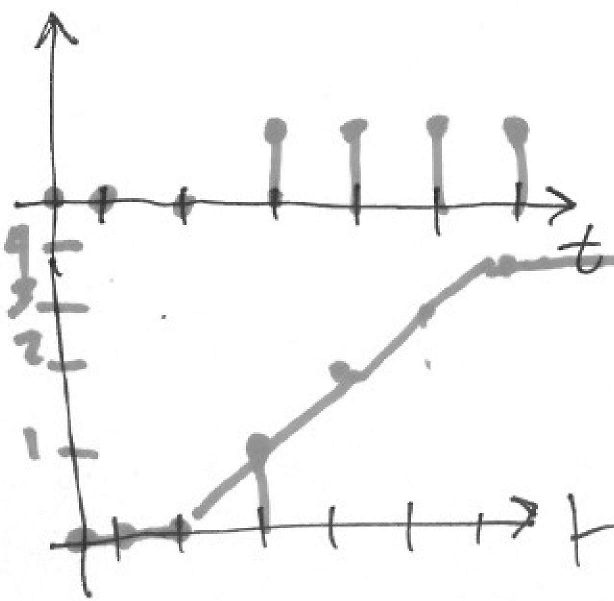
$$A_0 = A_1 = A_2 = A_3 = 1$$

FIR

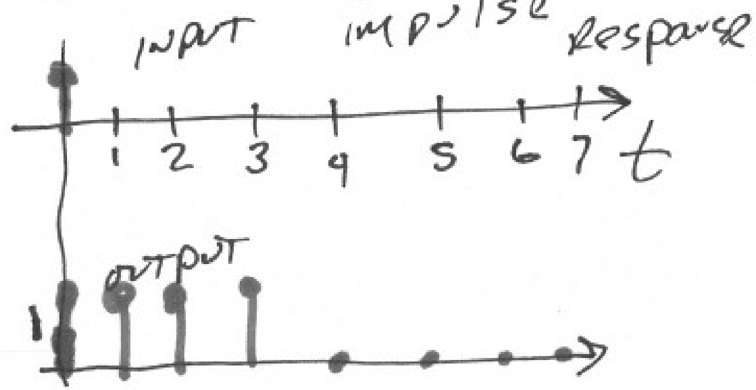
$$\left(1 + z^{-1} + z^{-2} + z^{-3}\right) \cdot \frac{1 - z^{-1}}{1 - z^{-1}}$$





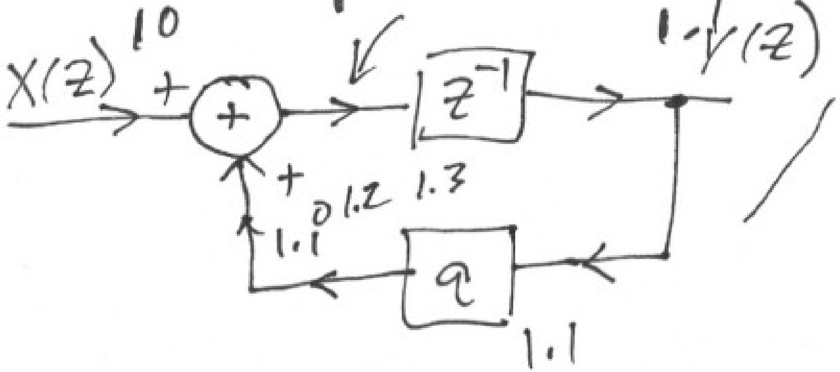


$$H(z) = \frac{1}{4} \frac{1 - z^{-4}}{1 - z^{-1}}$$



2)

weighted integrating filter



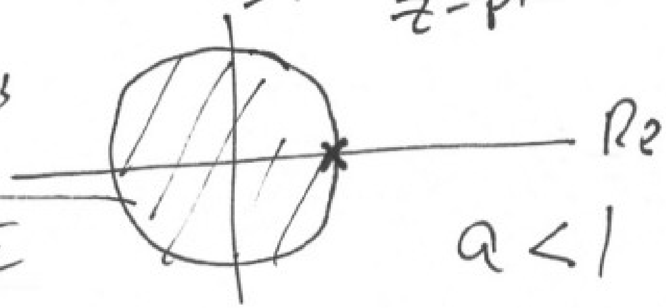
$a = 1$

$$\frac{z^{-1}}{1 - z^{-1}}$$

delay integ.

$$\left(X(z) + Y(z)\cdot a\right)\cdot z^{-1} = Y(z)$$

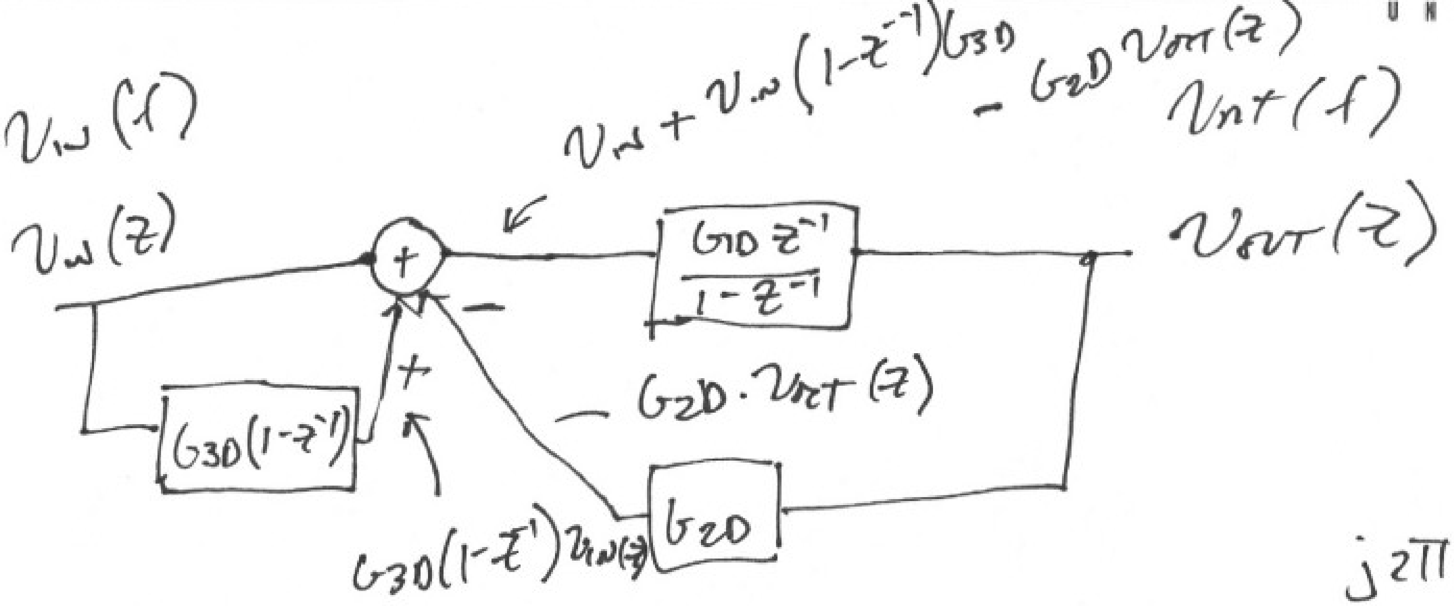
$$\frac{Y(z)}{X(z)} = \frac{z^{-1}}{1 - a z^{-1}} = \frac{1}{z - a}$$



system is STABLE

$a < 1$ pole is inside unit circle

Bilinear filter



$$\frac{V_{out}}{V_{in}} = \frac{1}{G_{2D}} \cdot \frac{1 + s \cdot G_{3D}}{1 + \frac{s}{G_{1D} G_{2D}}}$$

$$z = e^{j 2\pi \frac{f}{f_s}} \approx 1 + \frac{s}{f_s}, \quad f \ll f_s, \quad s = j\omega$$

Taylor series expansion

$$V_{in}\left[\left(1 + G_{3D}(1-z^{-1})\right) - \left(G_{2D} V_{out}\right)\right] \frac{G_{1D} z^{-1}}{1-z^{-1}}$$

$$= V_{out}$$

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(4.44)

$$\frac{v_{OUT}}{v_{IN}} = \frac{G_{1D}(1+G_{3D})}{z-(1-G_{1D})} \cdot \frac{z - G_{3D}/1+G_{3D}}{z}$$

$$\left(z \approx 1 + \frac{s}{f_s}\right)$$

$$\frac{v_{OUT}}{v_{IN}} = \frac{1 + j\dfrac{f}{f_s/2\pi G_{3D}}}{1 + j\dfrac{f}{G_{1D} \cdot f_s/2\pi}}, \quad G_2 = 1$$

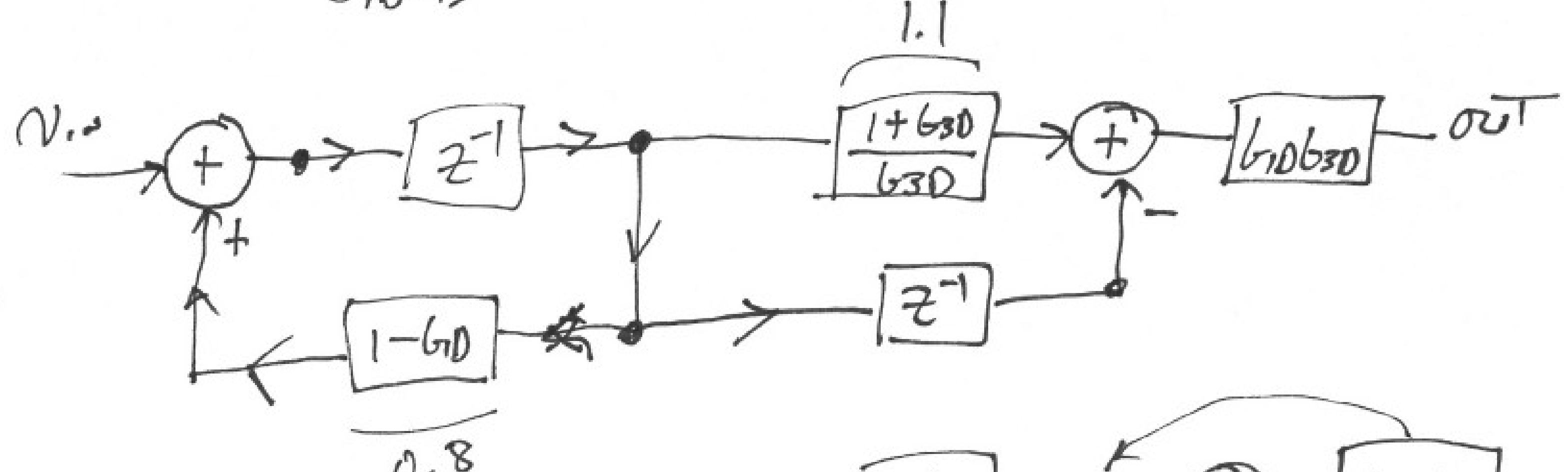
→ SAME AS eq (4.41)

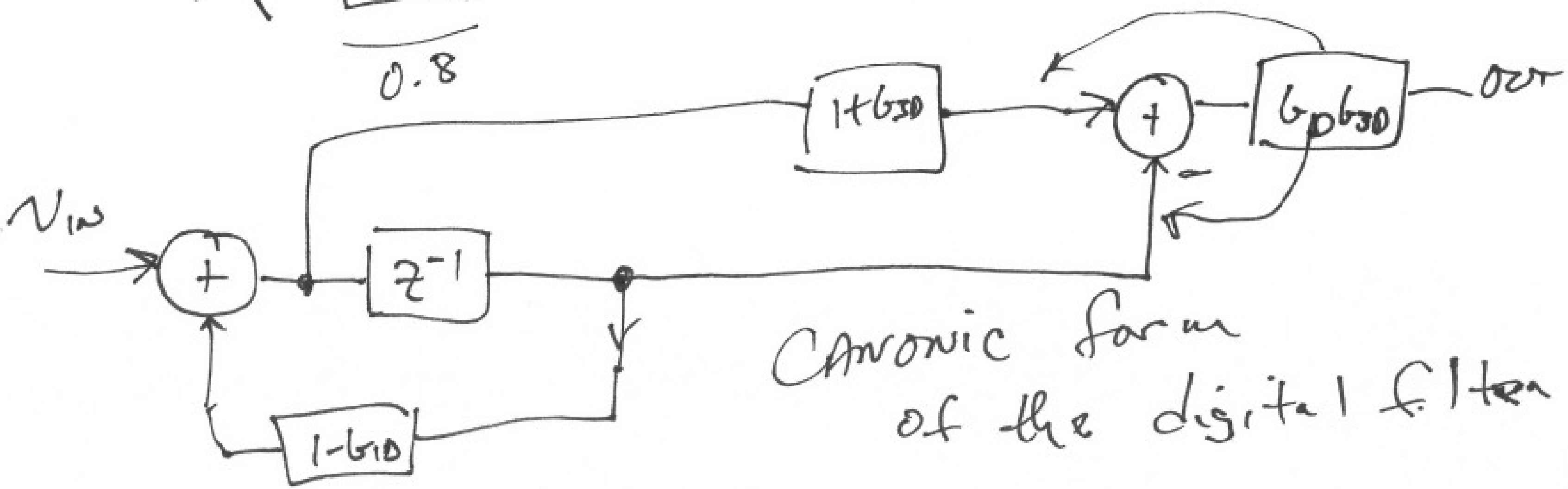
5)

$$\frac{G_{3D}}{f_s} = 100\,\text{ns} \rightarrow G_{3D} = 10$$

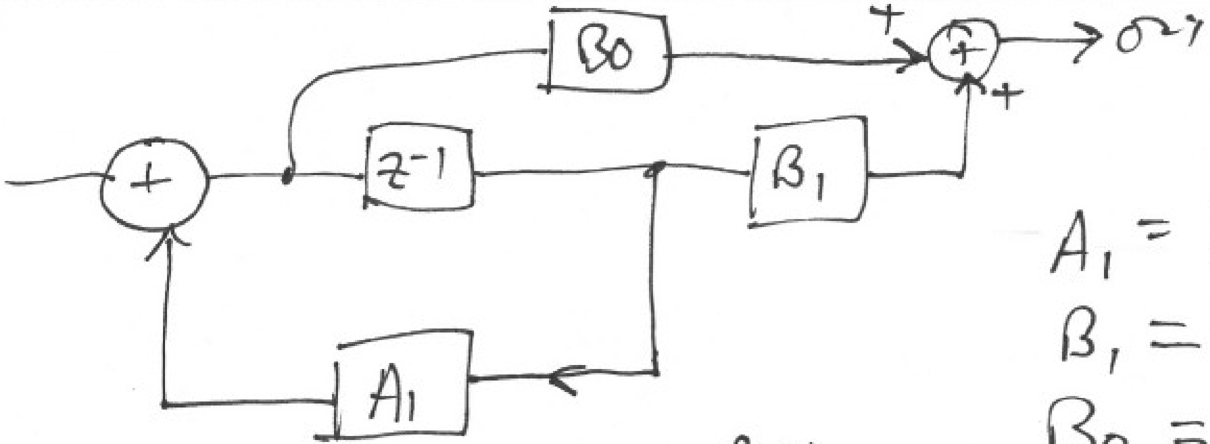
If $f_s = 100\,\text{MHz}$, $\frac{1}{f_s} = 10\,\text{ns}$

$$\frac{1}{G_{1D} \cdot f_s} = 50\,\text{ns} \qquad G_{1D} = 0.2$$





CANONIC form of the digital filter



$$A_1 = 1 - G_{1D}$$

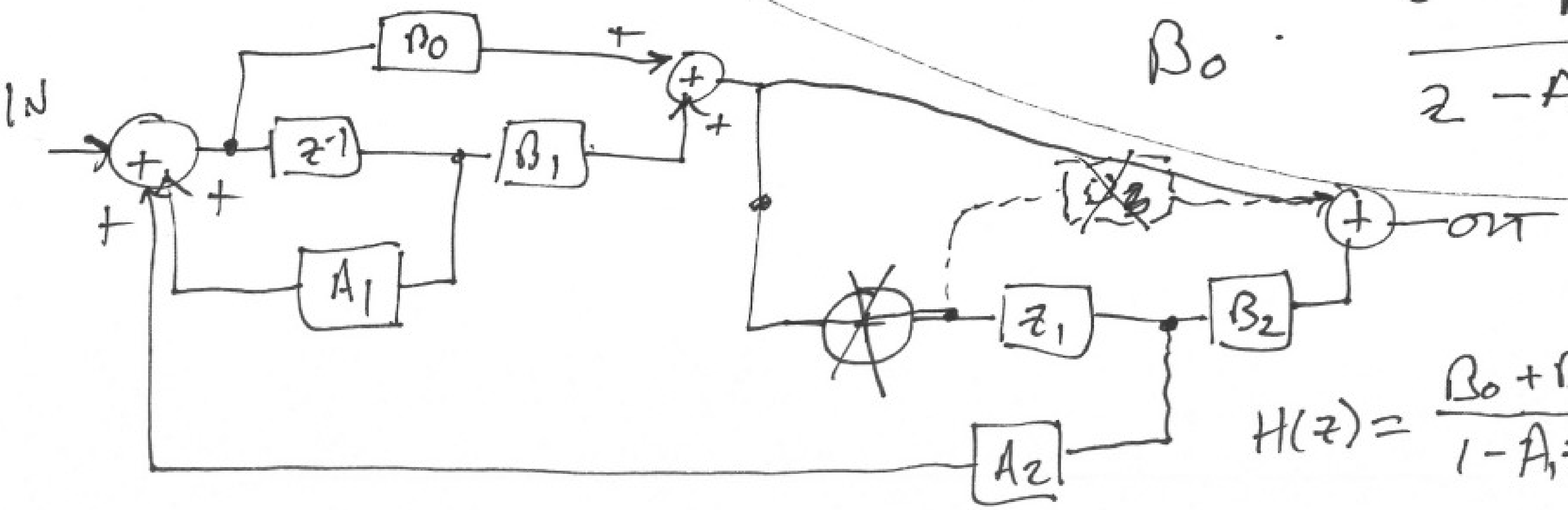
$$B_1 = -G_{1D}G_{3D}$$

$$B_0 = (1+G_{3D})G_{1D}G_{3D}$$

CANONIC first order filter

$$H(z) = \frac{B_0 + B_1 z^{-1}}{1 - A_1 z^{-1}} \qquad B_0 \cdot \frac{z + \frac{B_1}{B_0}}{z - A_1}$$

Biquad



$$H(z) = \frac{B_0 + B_1 z^{-1} + B_2 z^{-2}}{1 - A_1 z^{-1} - A_2 z^{-2}}$$

(3.62)

$$\frac{v_{OUT}}{v_{IN}} = \frac{a_2 s^2 + a_1 s + a_0}{s^2 + \left(\frac{2\pi f_0}{Q}\right)s + (2\pi f_0)^2}$$

$$H(z) = \frac{v_{OUT}(z)}{v_{IN}(z)} = \frac{B_0 z^2 + B_1 z + B_2}{z^2 - A_1 z - A_2}$$

$$z \simeq 1 + \frac{s}{f_s}, \quad f \ll f_s$$

$$a_2 = B_0$$

$$a_1 = f_s(2B_0 + B_1)$$

$$a_0 = f_s^2(B_0 + B_1 + B_2)$$

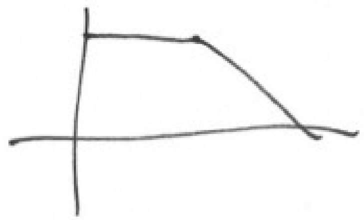
$$\frac{2\pi f_0}{Q} = f_s(2 - A_1), \quad f_0 = \frac{f_s}{2\pi} \cdot \sqrt{(1 - A_1 - A_2)}$$

8)

Ex. 4.12

digital Biquad is $f_s = 100\,MHz$

$f_0 = 1.59\,MHz$ $Q = 0.707$



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$B_0 = B_1 = 0$

$A_1 = 1.859$

$A_2 = -0.869$

$B_2 = 0.01$

a)

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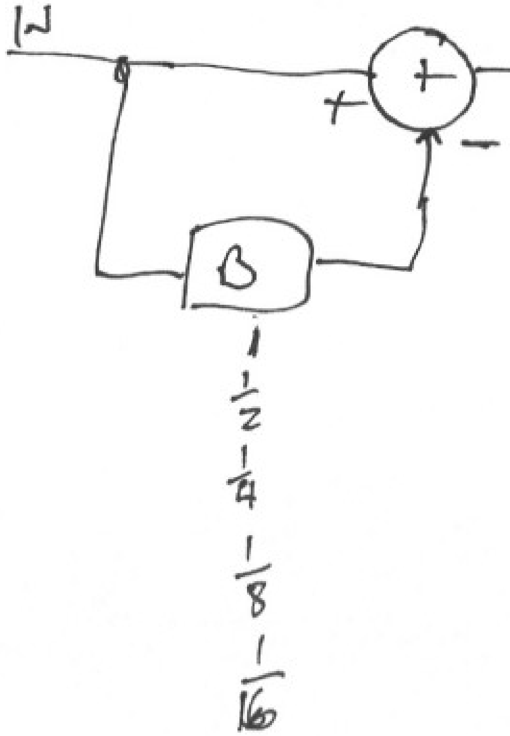
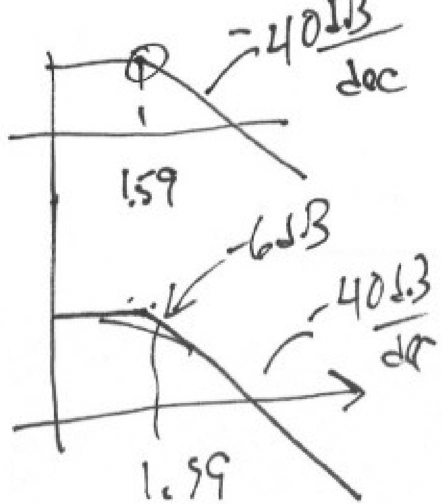
$\frac{1}{2}, \frac{1}{4}, \frac{1}{8}$

010000) $\times \frac{1}{2}$ .9375

001000) $\frac{1}{4}$

000100





B	Multiply by
1	0
$\frac{1}{2}$	$\frac{1}{2}$
$\frac{1}{4}$	0.75 1.125
$\frac{1}{8}$	.875
$\frac{1}{16}$ (0.0625)	.9375

10)