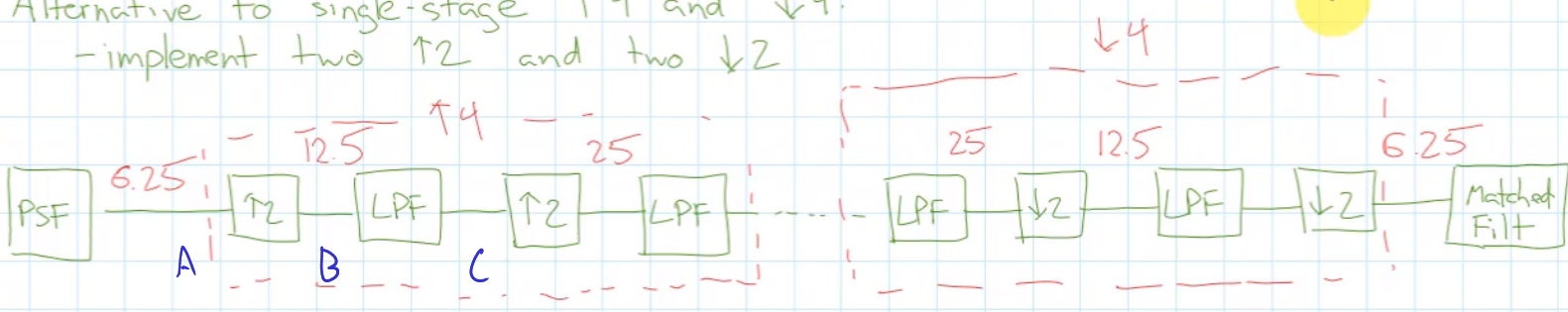


Alternative to single-stage $\uparrow 4$ and $\downarrow 4$:

- implement two $\uparrow 2$ and two $\downarrow 2$

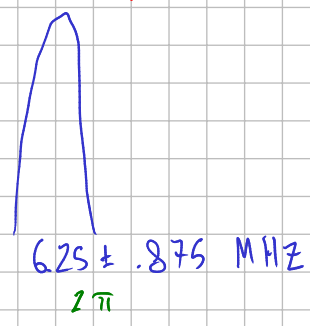
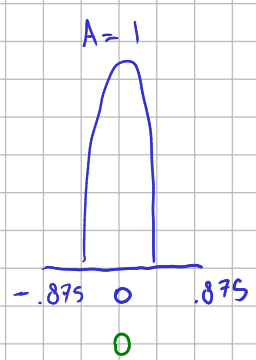


- key advantage: filters can be half-band filters (every 2nd coeff is 0)

- looks more complicated than $\uparrow 4$ and $\downarrow 4$, but may be more economical

@ A

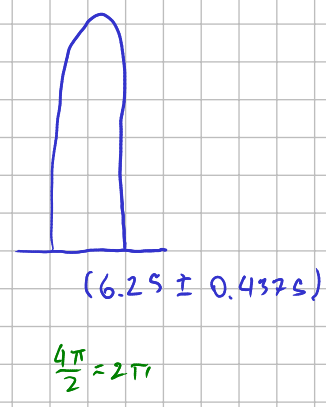
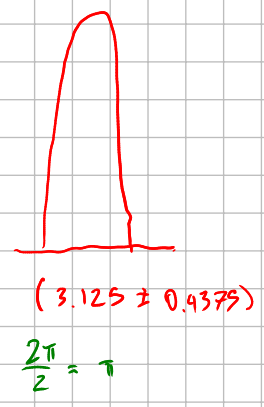
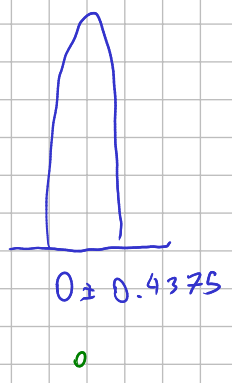
Upsample by $L=2$



$$F_s = 6.25 \text{ MHz}$$

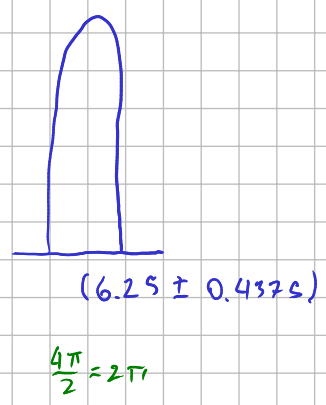
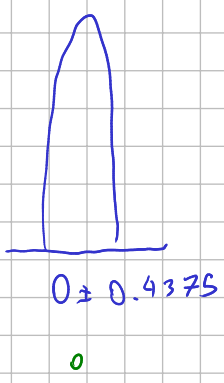
Upsampling doesn't affect Amp

@ B (output of $L=2$)



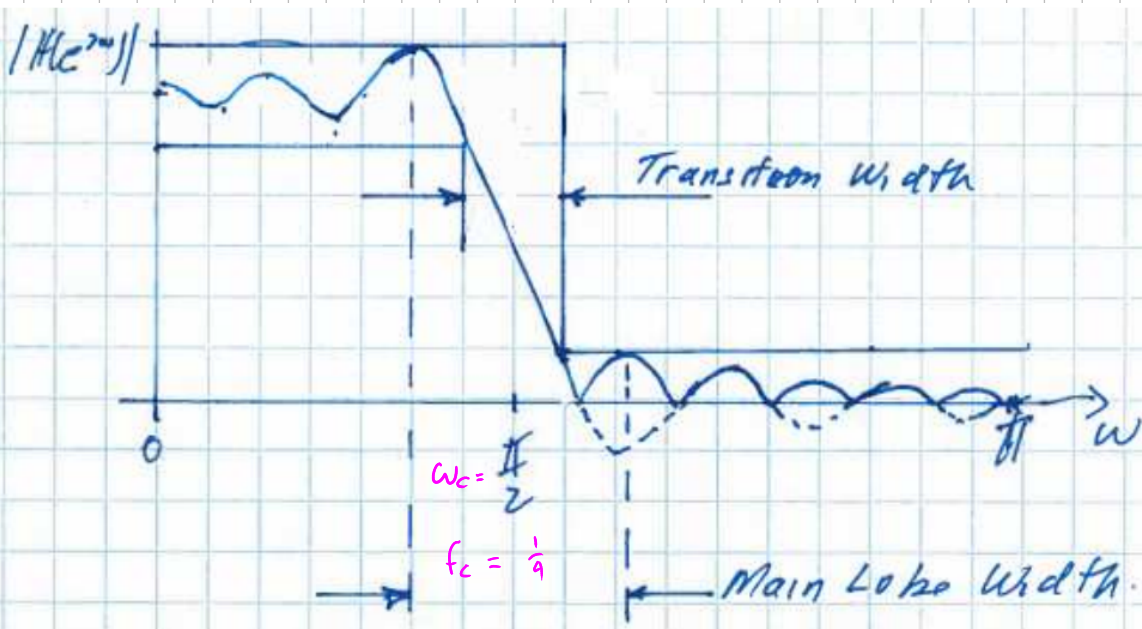
$$F_s = 2 \cdot 6.25 = 12.5 \text{ MHz}$$

@ C filter out middle range



$$F_s = 12.5 \text{ MHz}$$

$$F_{pass} > 0.4375 \text{ MHz}$$

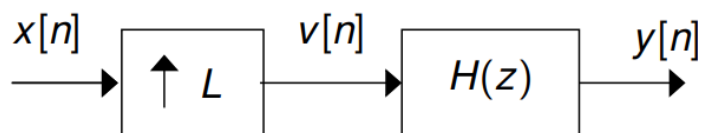


$$F_p = 0.4375 \text{ MHz}$$

$$\begin{aligned} F_c &= f_c \cdot F_s \\ &= 0.25 \cdot 12.5 \text{ MHz} \\ &= 3.125 \text{ MHz} \end{aligned}$$

$$\begin{aligned} F_s &= F_c + \frac{(F_c - F_p)}{2} \\ &= 3.125 + \frac{(3.125 - 0.4375)}{2} \\ &= 4.46875 \end{aligned}$$

A standard interpolator is defined as



$L=2$ 15 coeffs, all n coeffs where $n/2 \neq 0$ are 0 EXCEPT PEAK

$$H(z) = \sum_{i=0}^{N=14} h[i] z^{-i}, \quad H(z) = h_0 + h_2 z^{-2} + h_4 z^{-4} + h_6 z^{-6} + \dots + h_{14} z^{-14}$$

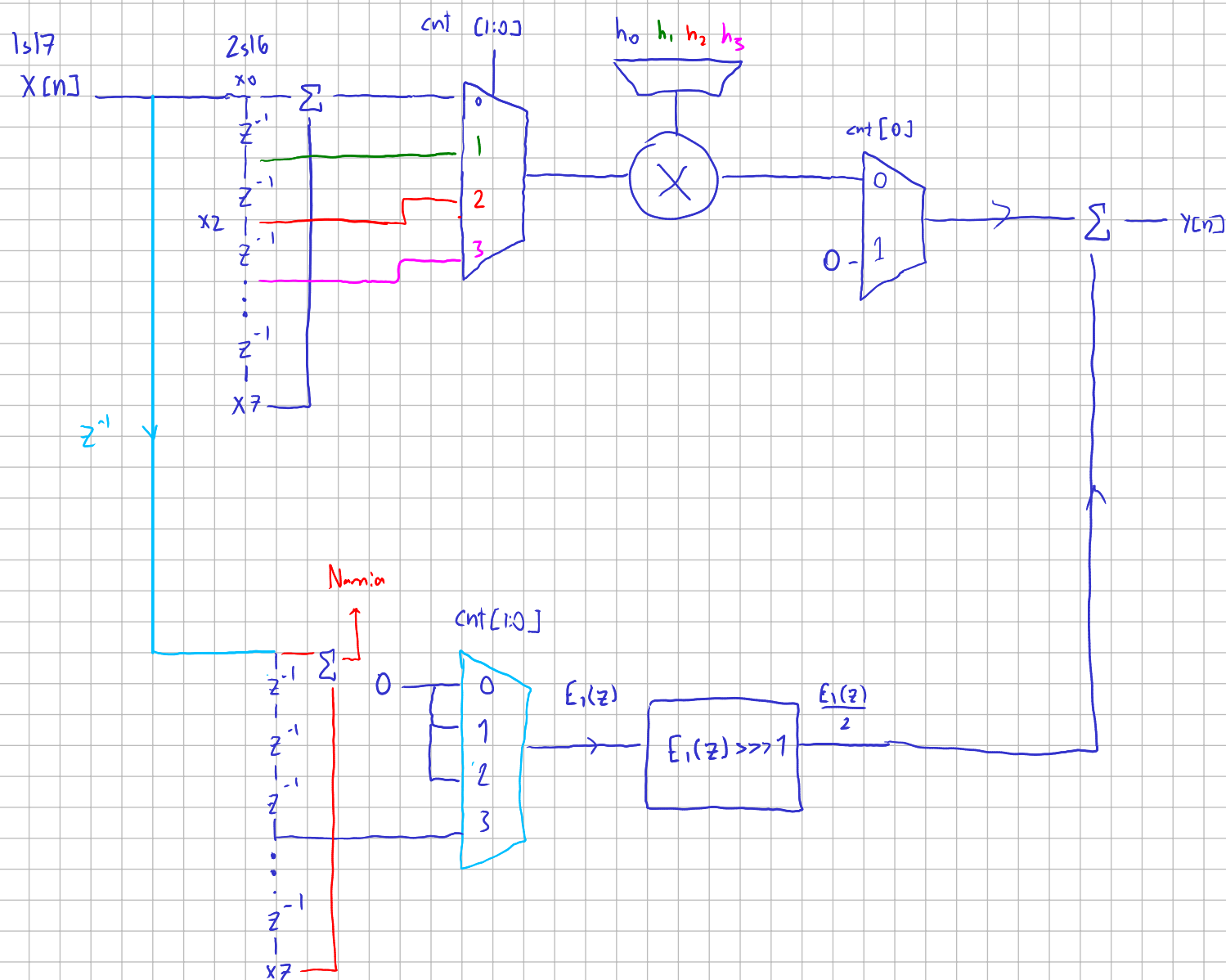
$$+ z^{-1} [h_1 z^{-1} + h_3 z^{-3} + \dots + h_7 z^{-7} + \dots h_{13} z^{-13}]$$

$h_0 = h_{14}$
 $h_2 = h_{12}$
 \vdots

$$E_0 = h_0 + h_2 z^{-1} + h_4 z^{-2} + h_6 z^{-3} + h_8 z^{-4} + h_{10} z^{-5} + h_{12} z^{-6} + h_{14} z^{-7}$$

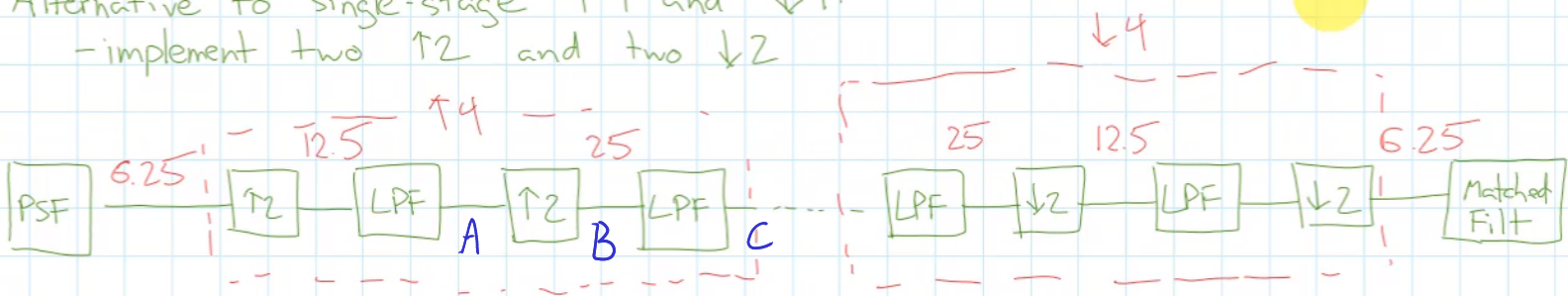
$$E_1 = h_7 z^{-3}$$

$$x[n] \rightarrow E_n(z) \rightarrow \uparrow 2 \rightarrow y[n]$$



Alternative to single-stage $\uparrow 4$ and $\downarrow 4$:

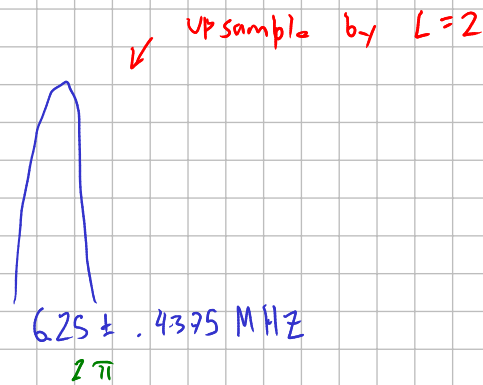
- implement two $\uparrow 2$ and two $\downarrow 2$



- key advantage: filters can be half-band filters (every 2nd coeff is 0)

- looks more complicated than $\uparrow 4$ and $\downarrow 4$, but may be more economical

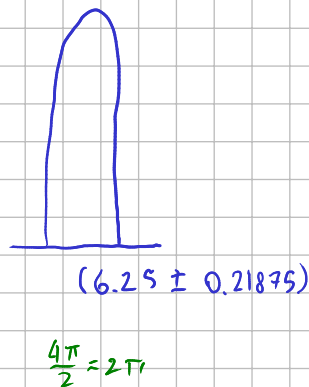
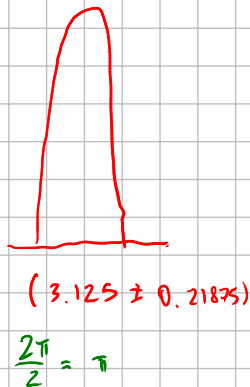
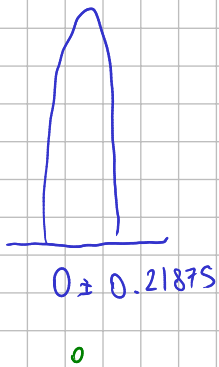
@ A



$$F_s = 12.5 \text{ MHz}$$

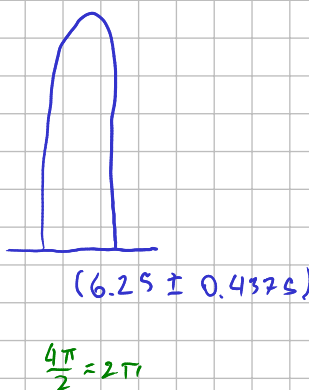
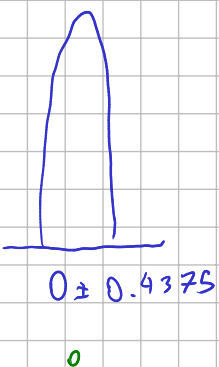
Upsampling doesn't affect Amp

@ B (output of $L=2$)



$$F_s = 2 \cdot 12.5 \text{ MHz} = 25 \text{ MHz}$$

@ C filter out middle image



$$F_s = 25 \text{ MHz}$$

$$F_{\text{pass}} > 0.4375 \text{ MHz}$$

*When filter is @ 12.5 MHz, can utilize the 50 MHz clock for time-sharing