Typical stages in digital signal processing
D/A Conversion

Dr. Ing. Rodrigo Gonzalez

rodralez@frm.utn.edu.ar
rodrigo.gonzalez@ingenieria.uncuyo.edu.ar

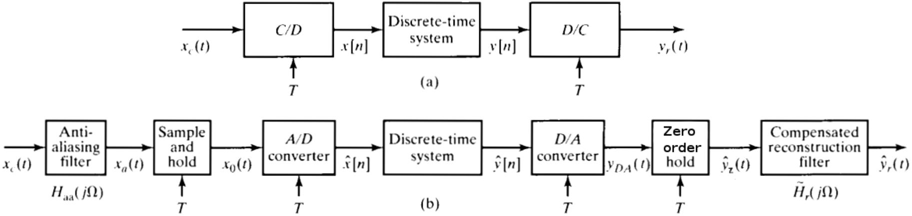
Summary

1. D/A Conversion
2. Ideal D/A Converter
3. Zero-order holder
4. Reconstruction Filter
5. Reconstruction Filtering Strategies

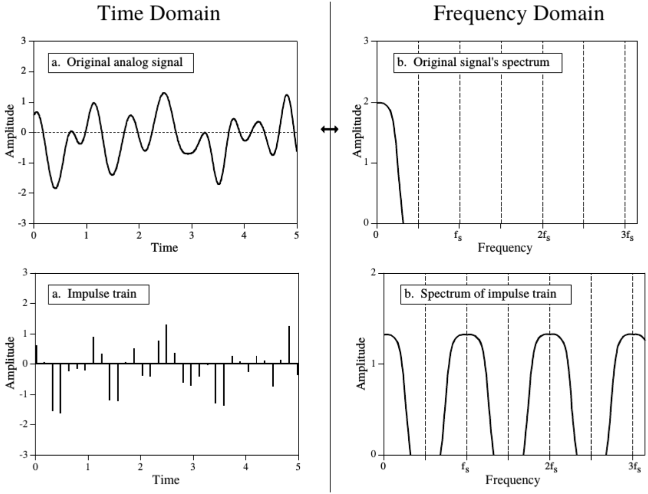
- The DAC (Digital-Analog Converter) reverses the ADC process.
- It converts an abstract finite-precision number (usually a fixed-point binary number) into a physical quantity (voltage).

Some important DAC features:

- **Resolution**: the number of possible output levels the DAC is designed to reproduce. This is usually stated as the number of bits of the DAC.
- **Maximum sampling rate**: the maximum speed at which the DACs circuitry can operate and still produce correct output. Su frecuencia define la frecuencia del tren de pulsos a su salida. A veces conviene una f mayor al conversor AD

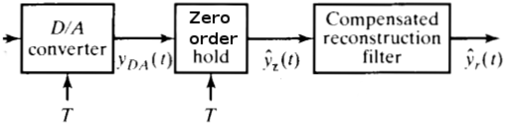


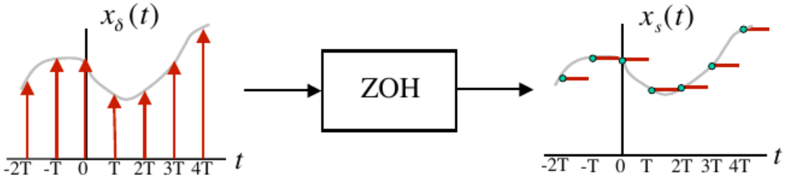
- DAC decodes the signal making a conversion from a bit sequence to an impulse train.
- The impulse train contains a duplication of analog signal spectrum.
- The original analog signal is reconstructed by passing this impulse train through a low-pass filter, with cutoff frequency equal to $f_s/2$.



Zero-order holder

- Impulse train is a mathematical method pure.
- DACs operate by **holding** the last value until another sample is received.
- **Zero-order holder** interpolates analog values between times T, $2T$, $3T$, ..., and produces the staircase appearance.



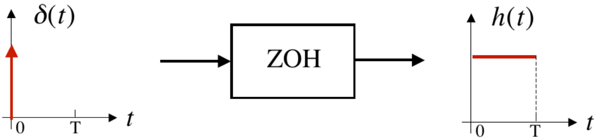


Sostiene el impulso para hacerlo un escalón de tiempo T

Zero-order holder, impulse response

Transforma impulos en pulso

The impulse response of a zero-order holder.



In the frequency domain:

T de Fourier

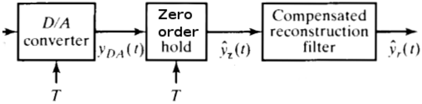
$$H_{ZOH}(f) = \mathcal{F}\left\{ rect\left(\frac{t - T_S/2}{T_S} \right) \right\} = \frac{sin\left(\pi f / f_s\right)}{\left(\pi f / f_s\right)} = sinc\left(\pi f / f_s\right) \quad (1)$$

funcion rectangular

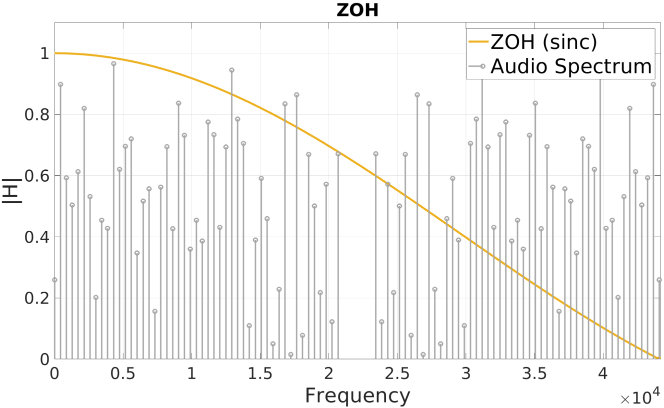
seno cardinal

sinc: sine cardinal function.

- ZOH is the convolution of the impulse train with a rectangular pulse.
- In the frequency domain, ZOH Fourier transform (sinc) is being multiplied by the impulse train spectrum.

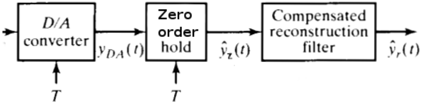


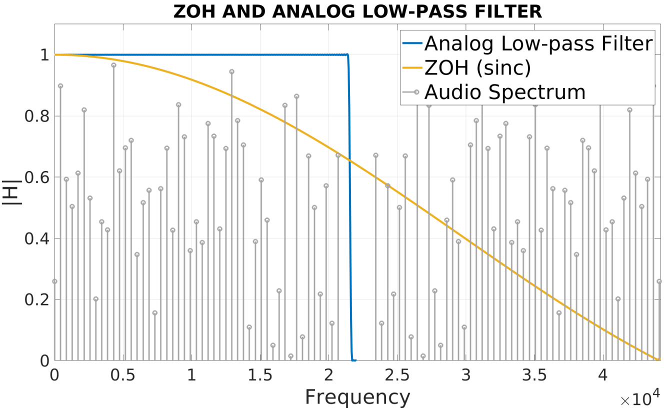
Example for audio: $f_N = 22050$ Hz, $f_s = 44100$ Hz.



Esta respuesta es un mal filtro pasa bajo.

An analog low-pass filter is required to cut frequencies > 22010 Hz.



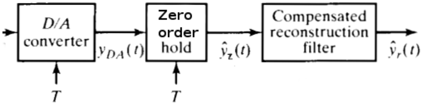


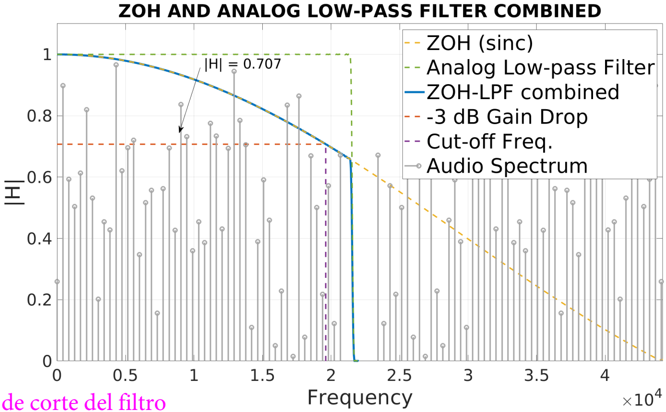
Convolucion de esos elementos es producto en dom de las f

Hay que quitar el reflejo

- The ZOH spectrum (sinc) produces a gain drop of - 3 dB.
- The cut-off frequency is decreased to $\approx$ 20 kHz.

-3dB gain drop es la perdida de la mitad de la potencia. En ese punto se define f de corte





Linea en azul es respuesta efectiva. Producto de las anteriores

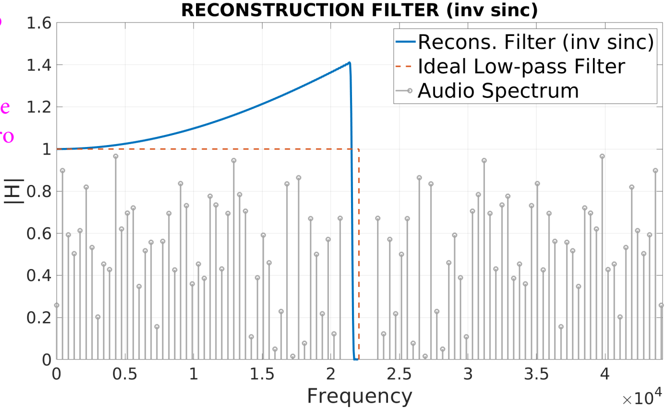
Modifica la f de corte del filtro

Reconstruction Filter

- RF removes all frequencies above $f_s/2$.
- It boosts the frequencies by the reciprocal of the zeroth-order holder's effect.
- It is also known as invert sinc filter (inv sinc).

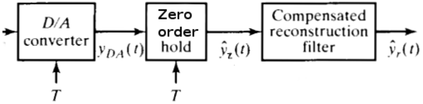
$$H_{RF}(f) = \frac{(\pi f/f_s)}{sin(\pi f/f_s)} = 1/sinc(\pi f/f_s) \tag{2}$$

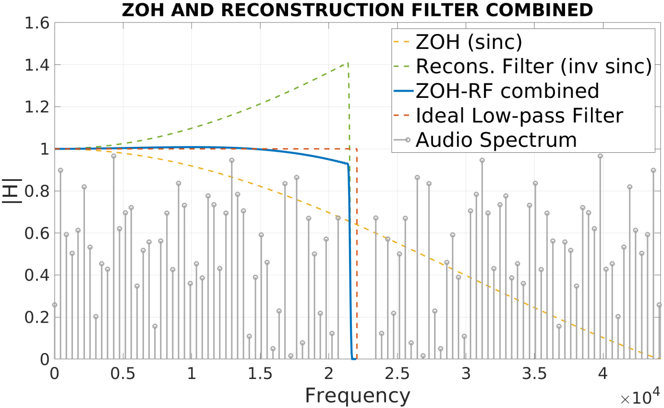
Se saca filtro analógico comun y corriente y se pone un filtro especial



Es la inversa del seno cardinal. Da mas ganancia al aumentar la frecuencia

The reconstruction filter compensates the gain drop.





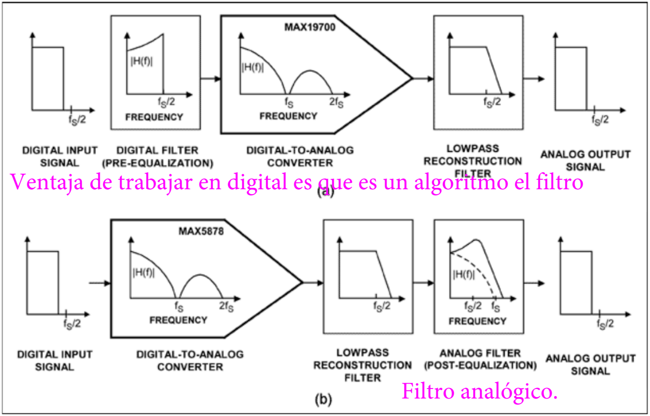
Reconstruction Filtering Strategies

1) **Ignore** the effect of the zero-order holder and **accept** the consequences.

2) **Pre-equalizing**: digital filter to remove the sinc effect [3].

3) **Post-equalizing**: analog filter to remove the sinc effect [3].

Formas de implementar el filtro de reconstruccion



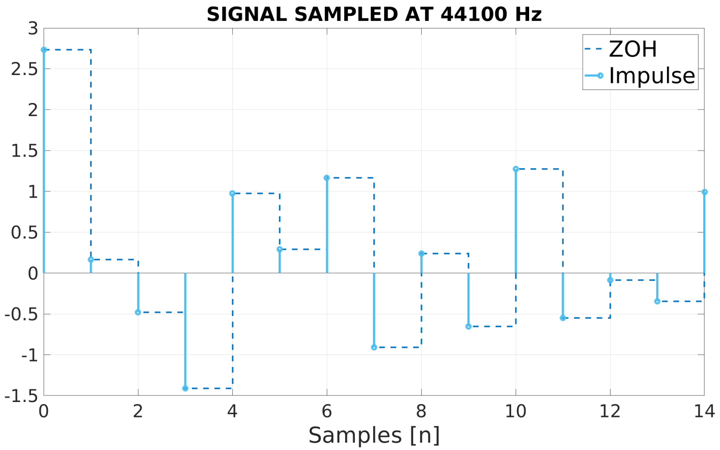
Ventaja de trabajar en digital es que es un algoritmo el filtro

Filtro analógico.

*Figure 4. A pre-equalization digital filter is used to cancel the effect of sinc rolloff in a DAC (**a**). As an alternative, you can use a post-equalization analog filter for the same purpose (**b**).*

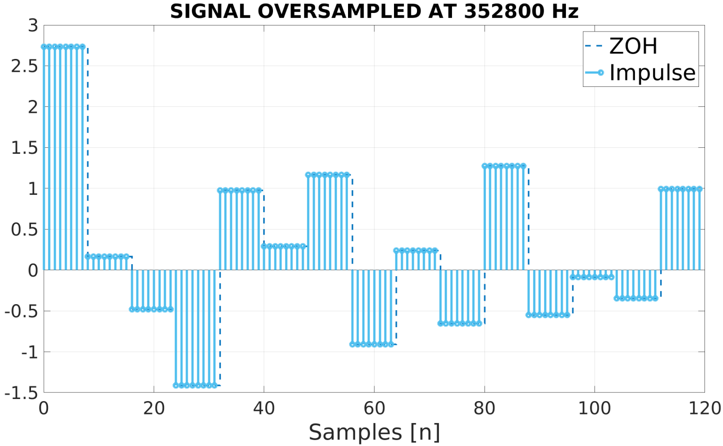
4ta opcion de implementacion del filtro

In CD players, data sampling rate is 44.1 kHz. Se implementa en estos reproductores esta solucion



Reconstruction Filtering Strategies, Oversampling, 2

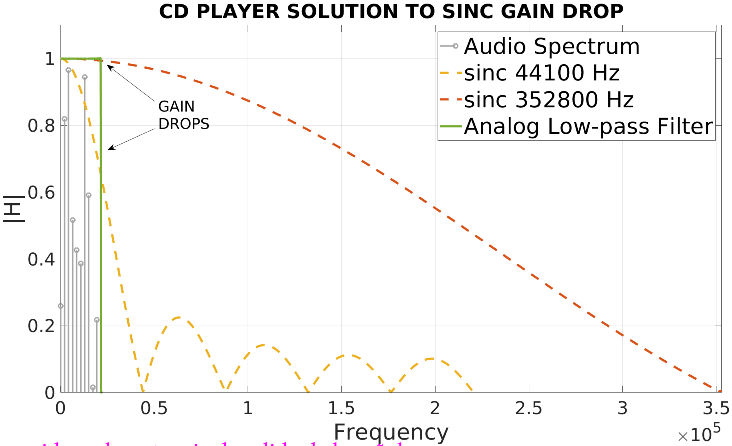
Data is oversampled by a factor of 8 to 352.8 kHz.



No da informacion, pero da pulso mas pequeño a la salida del zoh. Esto en el dom de la frecuencia se va a transformar en un seno cardinal más ancho.

Reconstruction Filtering Strategies, Oversampling, 3

- At 80 % of Nyquist frequency, the output amplitude is attenuated by 2.42dB.
- Distortion for ZOH is effectively eliminated by using oversampling.



Casi no hay caida en la potencia de salida de la señal

Bibliografía

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2. Steven W. Smith. The Scientist and Engineer's Guide to Digital Signal Processing. Chapter 3, ADC and DAC. Link.
3. Maxim Integrated. Equalizing Techniques Flatten DAC Frequency Response. Application Note 3853. August 2012.