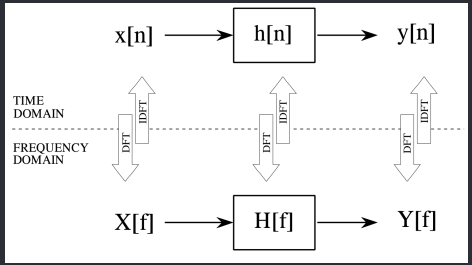
FACULTAD DE INGENIERIA
Universidad de Buenos Aires

Procesamiento de señales, fundamentos

Maestría en sistemas embebidos
Universidad de Buenos Aires
MSE 5Co2020

Clase 5 - Applicaciones de DFT



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SAPI DSP

Enuestas

Encuesta anónima clase a clase

Propiciamos este espacio para compartir sus sugerencias, criticas constructivas, oportunidades de mejora y cualquier tipo de comentario relacionado a la clase.

Encuesta anónima

https://forms.gle/1j5dDTQ7qjVfRwYo8

Link al material de la material

https://drive.google.com/drive/u/1/folders/1TlR2cgDPchL_4v7DxdpS7pZHtjKq38CK

Repaso Convolución

Multiplicacion?!

Algoritmo de Multiplicacion de 2do grado

	1	2
	3	4
	4	8
3	6	0
3	10	8

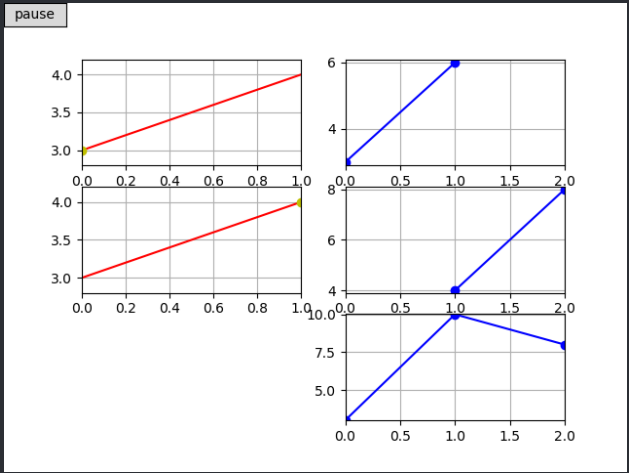
Repaso Convolución

Descomposición delta

SUma deltas desplazadas

1	2	0
3	0	0
3	6	0

0	1	2
0	4	0
3	6	0
0	4	8
3	10	8

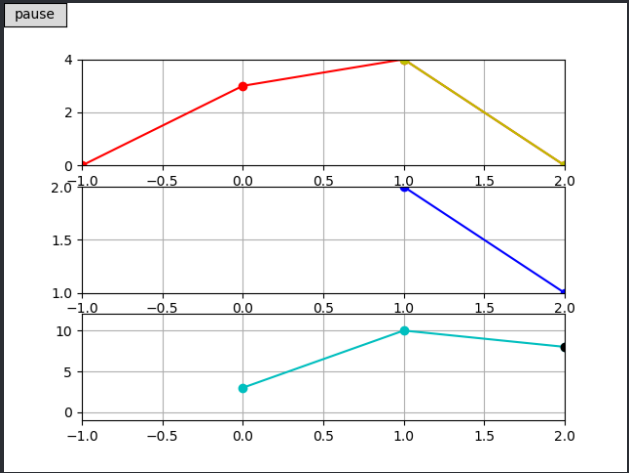


Repaso Convolución

Convolucion formal

Convolucion

2	1	0	0
0	3	4	0
	3	0	0
0	2	1	0
0	3	4	0
	3	10	0
0	0	2	1
0	3	4	0
	3	10	8



Repaso Convolución

Convolucion como producto de polinomios

$$(1x10^1 + 2x10^0) * (3x10^1 + 4x10^0) =$$
$$(3x10^2 + 4x10^1 + 6x10^1 + 8x10^0) =$$
$$(3x10^2 + 10x10^1 + 8x10^0) =$$
$$(300 + 100 + 8) = 408$$

Repaso Convolución

Multiplicacion?!

Algoritmo de Multiplicacion

	1	2
	3	4
	4	8
3	6	0
3	10	8

Multiplicacion de polinomios

$$(1x10^1 + 2x10^0) * (3x10^1 + 4x10^0) =$$
$$(3x10^2 + 4x10^1 + 6x10^1 + 8x10^0) =$$
$$(3x10^2 + 10x10^1 + 8x10^0) =$$
$$(300 + 100 + 8) = 408$$

SUma deltas desplazadas

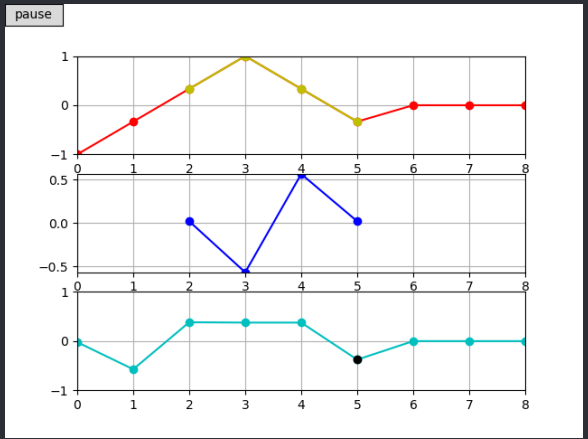
1	2	0
3	0	0
3	6	0
0	1	2
0	4	0
3	6	0
0	4	8
3	10	8

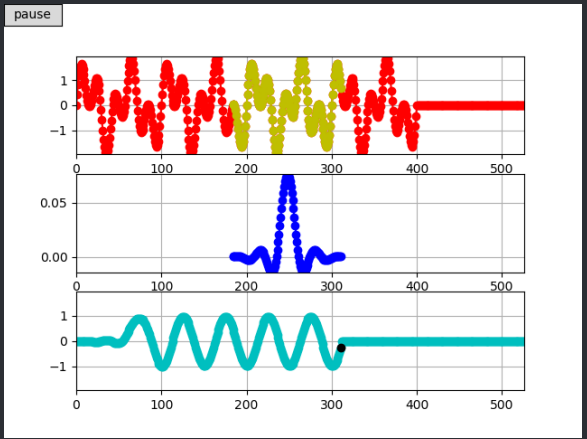
Convolucion

2	1	0	0
0	3	4	0
	3	0	0
0	2	1	0
0	3	4	0
	3	10	0
0	0	2	1
0	3	4	0
	3	10	8

Convolucion en tiempo

filtrado

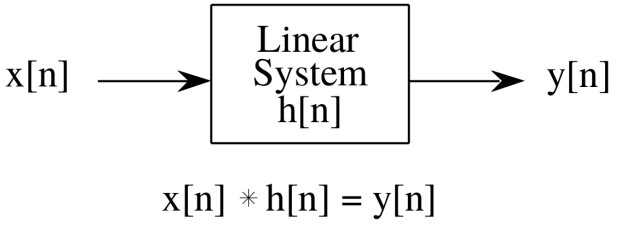




Repaso Convolucion

Propiedades

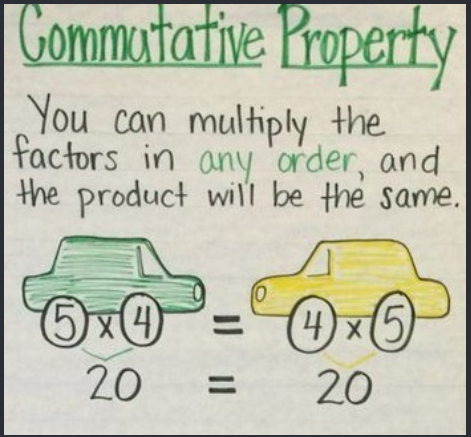
- Conmutativa
- Distributiva
- Asociativa

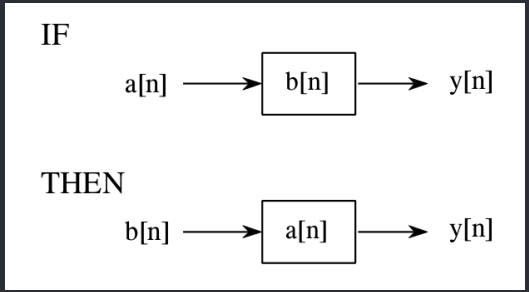


$$y[n] = x[n] * h[n] = \sum_{k=-\infty}^{\infty} x[k] \cdot h[n-k]$$

Repaso Multiplicacion

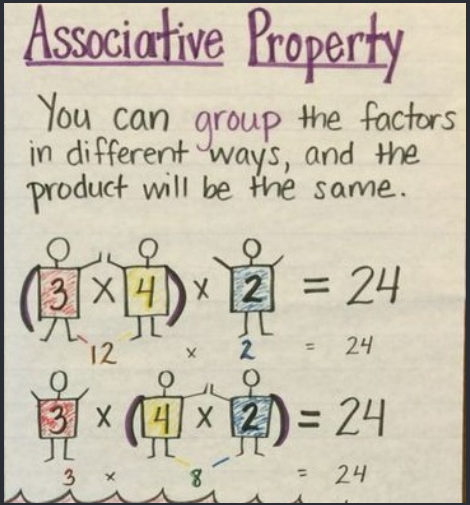
Propiedad conmutativa

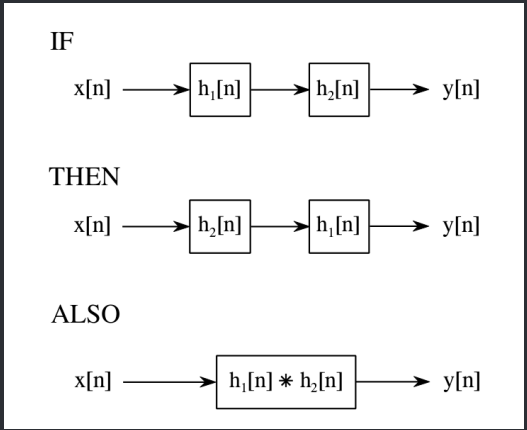




Repaso Multiplicacion

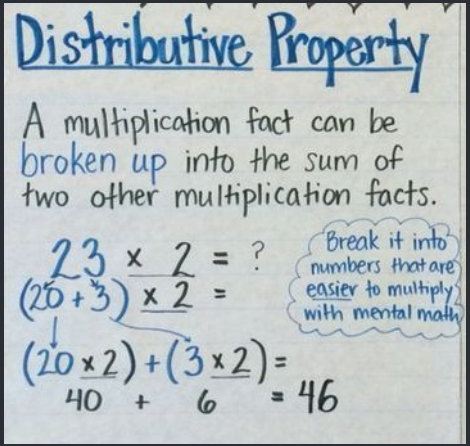
Propiedad asociativa

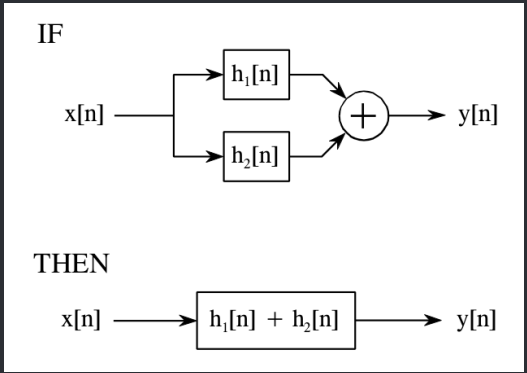




Repaso Multiplicacion

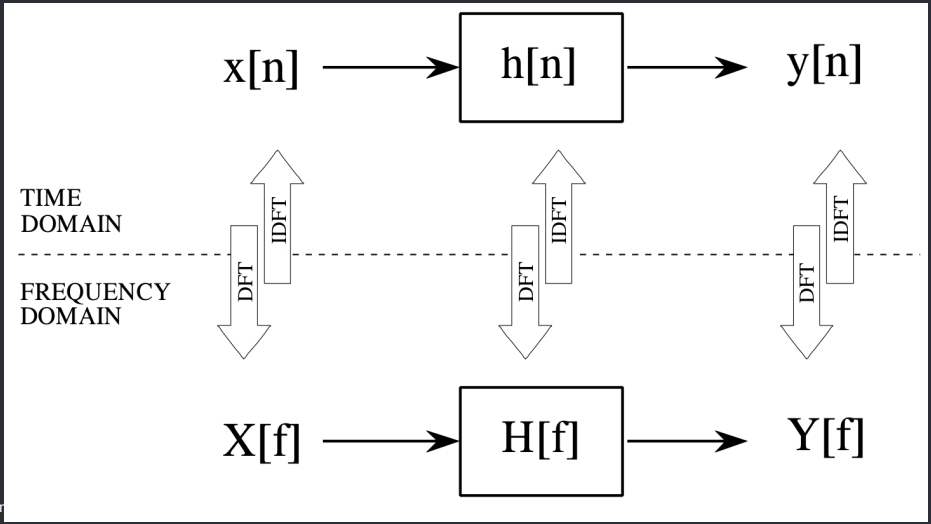
Propiedad distributiva





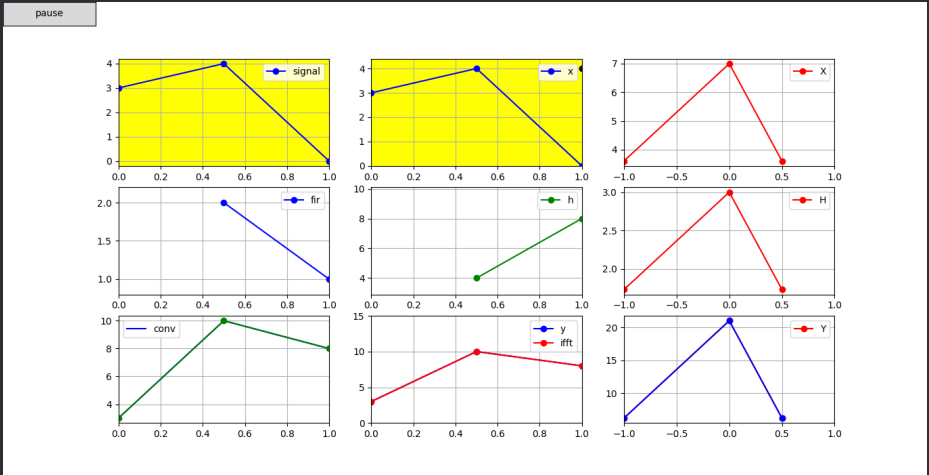
Convolución vs Multiplicación

Teorema de la convolución



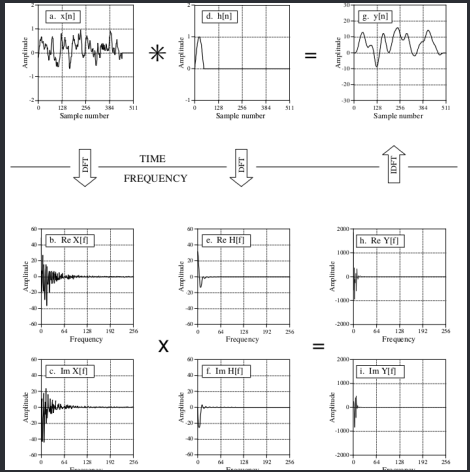
Multiplicación con DFT

Tiempo vs Frecuencia



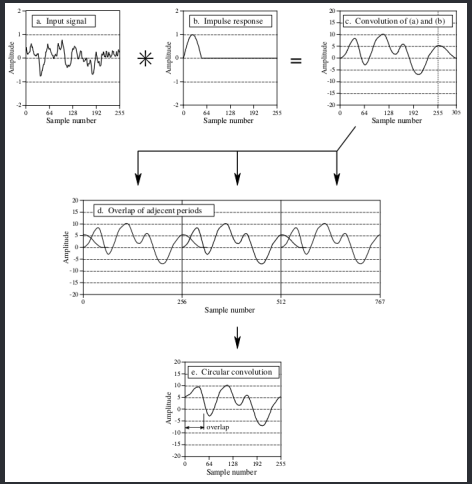
Convolución vs Multiplicación

Teorema de la convolución



Convolución vs Multiplicación

Convolución circular



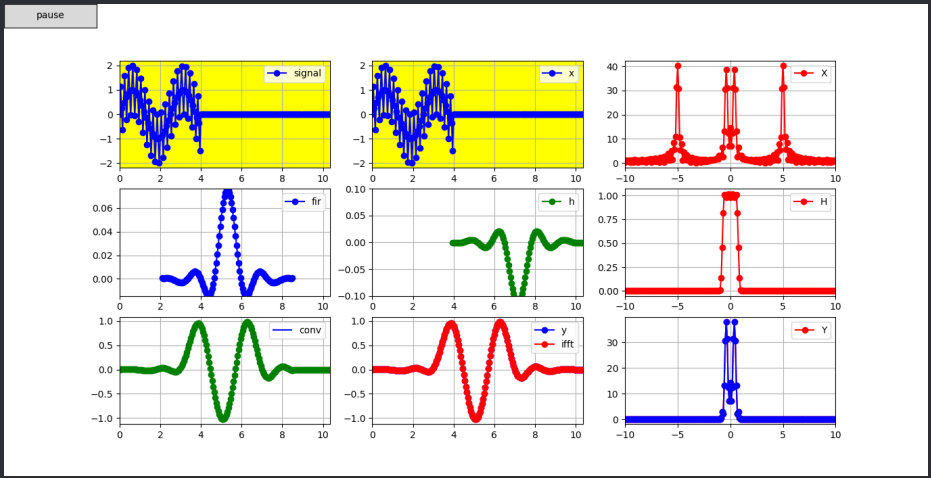
Convolución vs Multiplicación

Teorema de la convolución

$$x * y = \mathrm{DTFT}^{-1}\left[\mathrm{DTFT}\{x\} \cdot \mathrm{DTFT}\{y\}\right]$$

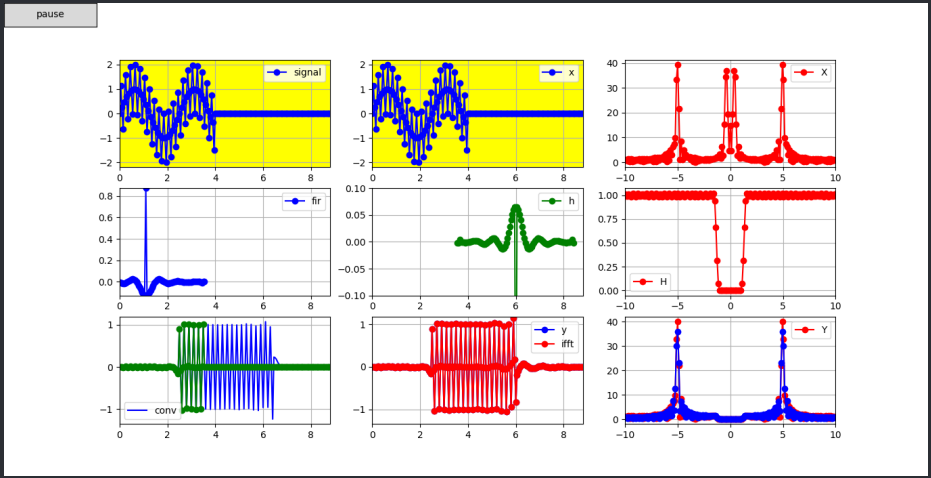
Filtrado

Pasabajos



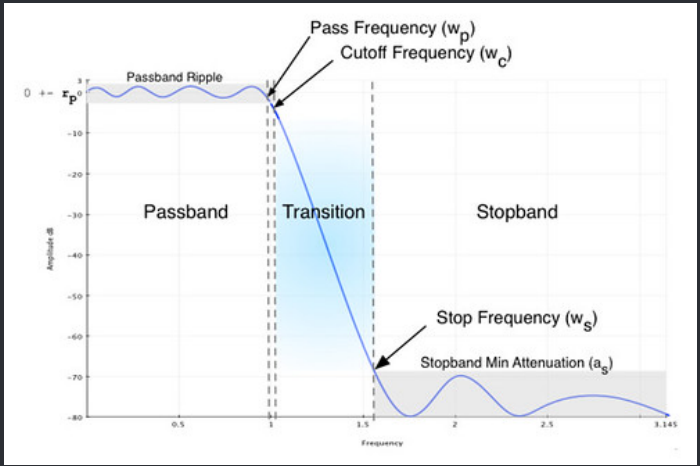
Filtrado

Pasaaltos



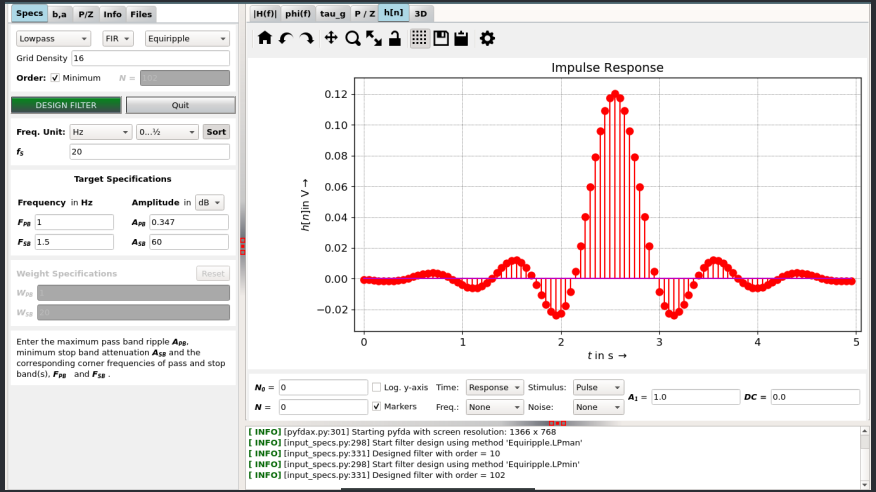
Filtrado

Definición



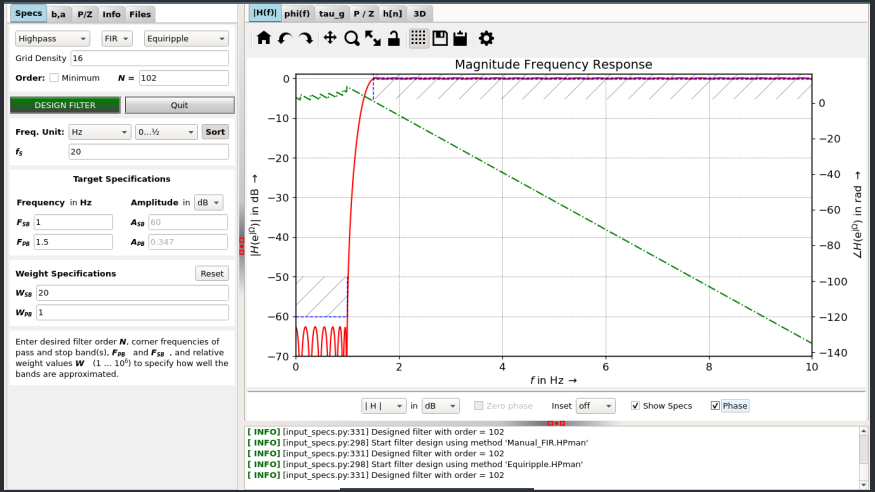
Filtrado

PyFDA /opt/anaconda3/bin/pyfdax



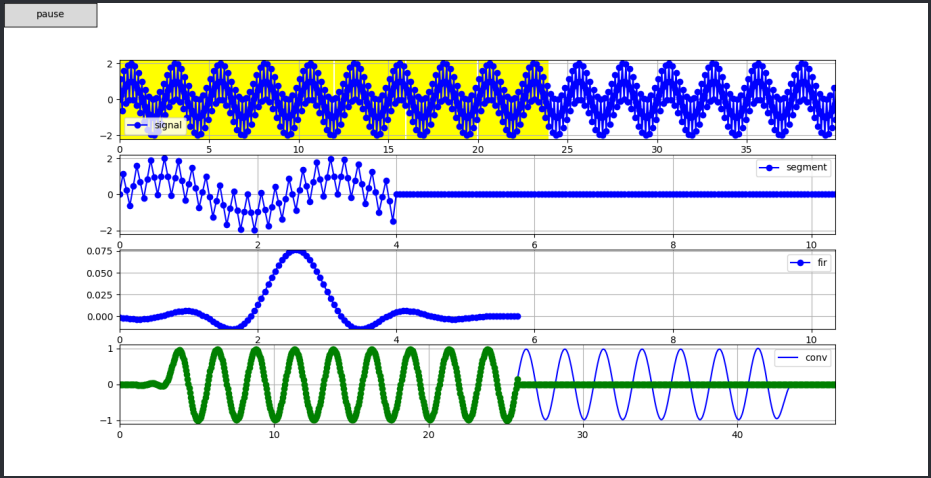
Filtrado

Pyfda /opt/anaconda3/bin/pyfdax



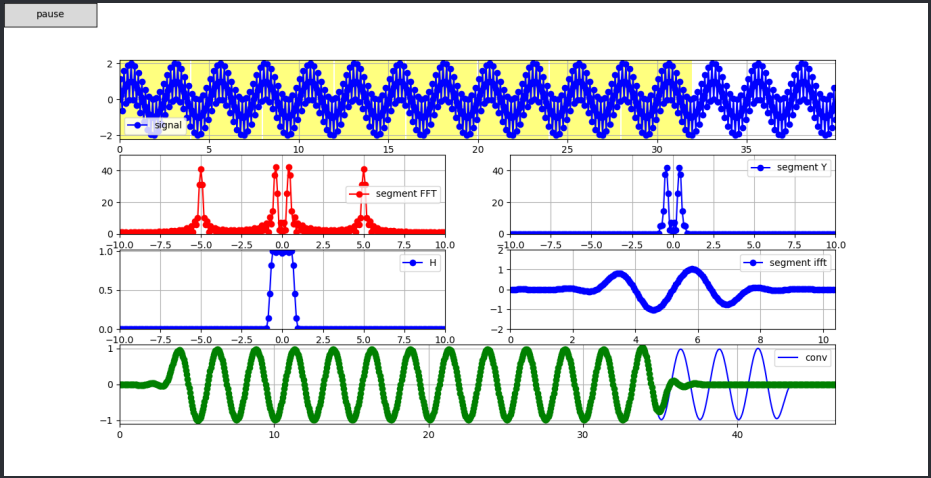
Convolución

Superponer y sumar



Convolución con FFT

Superponer y sumar



Filtrado con CIAA

Conversor PyFDA a fir.h para C

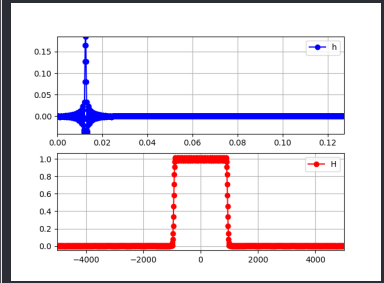
Código en Python para convertir los coeficientes del fir extendidos en Q1.15 en C

```
import numpy as np
import matplotlib.pyplot as plt
import scipy.signal as sc
#-------------------------------------
fig          = plt.figure()
fs           = 10000
N            = 1024
firData,=np.load("5_clase/low_pass_1k.npy").astype(float
        )
firData=np.insert(firData,0,firData[-1]) #ojo que pydfa
        me guarda 1 dato menos...
M            = len(firData)

firExtendedData=np.concatenate((firData,np.zeros(N-1)))
impar=((N+M-1)%2)
#-------------------------------------
tData=np.linspace(0,(N+M-1)/fs,N+M-1,endpoint=False)
fData=np.concatenate((np.linspace(-fs/2,0,(N+M-1)//2,
        endpoint=False),\
        np.linspace(0,fs/2,(N+M-1)//2+impar,endpoint=
                False)))
#-------------------------------------
firAxe  = fig.add_subplot(2,1,1)
firLn,  = plt.plot(tData,firExtendedData,'b-o',label="h"
        )
firAxe.legend()
firAxe.grid(True)
firAxe.set_xlim(0,(N+M-2)/fs)
firAxe.set_ylim(np.min(firData),np.max(firData))
#-------------------------------------
HData=np.fft.fft(firExtendedData)
circularHData=np.concatenate((HData[len(HData)//2+impar
        :],HData[0:len(HData)//2+impar]))
```

```
HAxe  = fig.add_subplot(2,1,2)
HLn,  = plt.plot(fData,np.abs(circularHData),'r-o',label
        ="H")
HAxe.legend()
HAxe.grid(True)
HAxe.set_xlim(-fs/2,fs/2)
#-------------------------------------
def convertToC(h,H,fileName):
    cFile  = open(fileName,"w+")
    cFile.write("#define h_LENGTH {}\n".format(len(
            firData)))
    cFile.write("#define h_PADD_LENGTH {}\n".format(len(
            h)))
    cFile.write("#define H_PADD_LENGTH {}\n".format(len(
            H)))
    h*=2**15
    h=h.astype(np.int16)
    H*=2**15
    cFile.write("q15_t h[]={\n")
    for i in h:
        cFile.write("{},\n".format(i))
    cFile.write("};\n")
#   cFile.write("q15_t H[]={\n")
#   for i in H:
#       cFile.write("{},{},\n".format(np.real(i).astype
            (np.int16),np.imag(i).astype(np.int16)))
#   cFile.write("};\n")

convertToC(firExtendedData,HData,"5_clase/ciaa/psf2/src/
        fir.h")
plt.get_current_fig_manager().window.showMaximized()
plt.show()
```



Filtrado con CIAA

Con padding y convolución

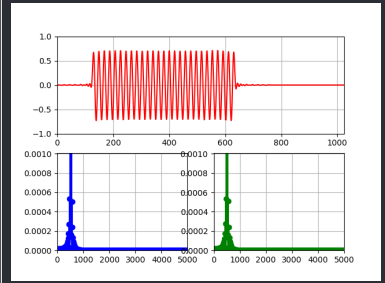
Convolución en tiempo con padding en CIAA para filtrado

```
#include "sapi.h"
#include "arm_math.h"
#include "arm_const_structs.h"
#include "fir.h"
#define MAX_FFT_LENGTH 2048
#define BITS 10
int16_t fftLength = 512;
int16_t hLength = h_LENGTH;
int16_t adc   [ MAX_FFT_LENGTH];
q15_t x       [ MAX_FFT_LENGTH]       ;
q15_t fftOut [ ( MAX_FFT_LENGTH)*2 ]  ;
q15_t fftMag [ ( MAX_FFT_LENGTH)/2+1 ];

uint32_t maxIndex    = 0;
q15_t maxValue       = 0;
arm_rfft_instance_q15 S;
uint16_t convLength = 0;
uint16_t sample      = 0;

int calcFftLength(int N,int M) {
   int convLength=N+M-1,i;
   for(i=MAX_FFT_LENGTH;i>=convLength;i>>=1)
      ;
   return i<<1;
}
int sendStr(char A[],int N) { uartWriteByteArray ( UART_USB ,A
      ,N ); }
int sendBlock(q15_t A[],int N) { uartWriteByteArray ( UART_USB
         ,(uint8_t* )A ,2*N ); }

int main ( void ) {
   boardConfig        (                          );
   adcConfig          ( ADC_ENABLE               );
   cyclesCounterInit  ( EDU_CIAA_NXP_CLOCK_SPEED );
   while(1) {
      convLength=calcFftLength(fftLength,hLength);
      for(sample=0;sample<fftLength;sample++) {
         cyclesCounterReset();
         adc[sample] = (((int16_t )adcRead(CH1)-512)>>(10-BITS)
                     )<<(6+10-BITS);
         gpioToggle( LEDR);
         while(cyclesCounterRead()< 20400)
            ;
      }
      for(sample=fftLength;sample<convLength;sample++)
         adc[sample]=0;
      sendStr   ( "header"    ,6 );
      sendBlock ( &fftLength ,1 );
      sendBlock ( &convLength   ,1 );
      arm_conv_fast_q15 ( adc,fftLength,h,convLength-fftLength
                +1,x );
      sendBlock         ( x ,convLength        );
      arm_rfft_init_q15 ( &S ,convLength ,0 ,1 );
      arm_rfft_q15      ( &S ,x      ,fftOut    );
      arm_cmplx_mag_squared_q15 ( fftOut ,fftMag ,convLength
                  /2+1           );
      arm_max_q15               ( fftMag ,convLength/2+1 ,&
                  maxValue ,&maxIndex );
      sendBlock ( fftOut    ,convLength );
      sendBlock ( &maxValue   ,1 );
      sendBlock ( (q15_t* )&maxIndex ,1 );
      gpioToggle( LEDR);
   }
}
```



Filtrado con CIAA

Con padding y FFT

Convolución en tiempo con padding en CIAA para filtrado

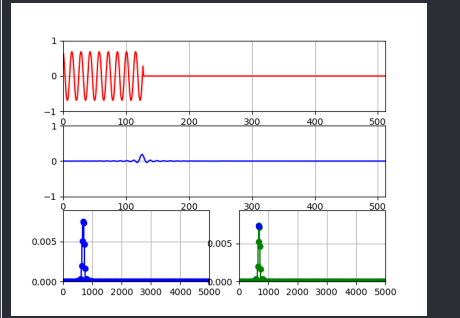
```
#include "sapi.h"
#include "arm_math.h"
#include "arm_const_structs.h"
#include "fir.h"
#define MAX_FFT_LENGTH 1024
int16_t fftLength = 128;
int16_t hLength = h_LENGTH;
int16_t adc [ MAX_FFT_LENGTH    ];
q15_t x     [ MAX_FFT_LENGTH    ];
q15_t fftOut[ 2* MAX_FFT_LENGTH ];
q15_t H     [ 2* MAX_FFT_LENGTH ];
q15_t hTemp [ 2* MAX_FFT_LENGTH ];

uint32_t maxIndex   = 0;
q15_t maxValue      = 0;
arm_rfft_instance_q15 S;
uint16_t convLength = 0;
uint16_t sample     = 0;

int calcFftLength(int N,int M) {
   int convLength=N+M-1,i;
   for(i=MAX_FFT_LENGTH;i>=convLength;i>>=1)
      ;
   return i<<1;
}
int sendStr(char A[],int N) { uartWriteByteArray ( UART_USB ,A
         ,N ); }
int sendBlock(q15_t A[],int N) { uartWriteByteArray ( UART_USB
         ,(uint8_t* )A ,2*N ); }

int main ( void ) {
   boardConfig       (                       );
   uartConfig        ( UART_USB, 460800      );
   adcConfig         ( ADC_ENABLE            );
   cyclesCounterInit  ( EDU_CIAA_NXP_CLOCK_SPEED );
```

```
   while(1) {
      convLength=calcFftLength(fftLength,hLength);
      for(sample=0;sample<fftLength;sample++) {
         cyclesCounterReset();
         adc[sample] = ((int16_t )adcRead(CH1)-512)<<6;
         gpioToggle( LEDB);
         while(cyclesCounterRead()< 20400)
            ;
      }
      for(sample=fftLength;sample<convLength;sample++)
         adc[sample]=0;
      sendStr           ( "header"    ,6        );
      sendBlock         ( &fftLength ,1         );
      sendBlock         ( &convLength   ,1      );
      sendBlock         ( adc ,convLength       );
      sendBlock         ( h ,convLength         );
      arm_rfft_init_q15 ( &S ,convLength ,0 ,1 );
      arm_rfft_q15      ( &S ,adc     ,fftOut  );
      for(int i=0;i<convLength;i++)
         hTemp[i]=h[i];
      arm_rfft_init_q15 ( &S ,convLength ,0 ,1 );
      arm_rfft_q15      ( &S ,hTemp     ,H    );
      for(int i=0;i<convLength;i++)
         H[i]=H[i]*convLength;
      arm_cmplx_mult_cmplx_q15(fftOut,H,H,convLength);
      sendBlock ( H     ,convLength );
      arm_cmplx_mag_squared_q15 ( H ,H ,convLength/2+1
                                 );
      arm_max_q15                ( H ,convLength/2+1 ,&maxValue
                  ,&maxIndex );
      sendBlock ( &maxValue  ,1 );
      sendBlock ( (q15_t* )&maxIndex ,1 );
      gpioToggle( LEDR);
   }
}
```



Bibliografía

Libros, links y otro material

[1] *ARM CMSIS DSP*. https://arm-software.github.io/CMSIS_5/DSP/html/index.html

[2] Steven W. Smith. *The Scientist and Engineer's Guide to Digital Signal Processing*. Second Edition, 1999.

[3] *Wikipedia*. https://en.wikipedia.org/wiki/Convolution_theorem