Real part of complex number x

real(x) → computes real components of **x**

Imaginary part of complex number x

imag(x) → computes imaginary components of **x**

Magnitude of x

abs(x) → computes the absolute value of **x**. If **x** is complex, it computes its magnitude.

phase/angle of x

angle(x) → computes the phase angle of **x**. If **x** is real, it the angle is zero.

"hold on" → holds the figure window
"hold off"

freqz(num, den, w)→ computes the DTFT of a signal

where

w: the prescribed frequencies in radians at which DTFT should be computed

DTFT

```
w = -4*pi:8*pi/511:4*pi;
num = [2 1];den = [1 -0.6];
h = freqz(num, den, w);
subplot(2,1,1)
plot(w/pi,real(h));grid
title('Real part of H(e^{j\omega})')
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(2,1,2)
plot(w/pi,imag(h));grid
title('Imaginary part of H(e^{j\omega})')
xlabel('\omega /\pi');
ylabel('Amplitude');
pause
subplot(2,1,1)
plot(w/pi,abs(h));grid
title('Magnitude Spectrum |H(e^{j\omega})|')
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(2,1,2)
plot(w/pi,angle(h));grid
title('Phase Spectrum arg[H(e^{j\omega})]')
xlabel('\omega /\pi');
ylabel('Phase in radians');
```

Time Shifting property of DTFT

Time shift $x[n-n0] \rightarrow X(\omega)e^{-j\omega n0}$

```
w = -pi:2*pi/255:pi;
D = 10;
num = [1 2 3 4 5 6 7 8 9];
h1 = freqz(num, 1, w);
h2 = freqz([zeros(1,D) num], 1, w);
subplot(2,2,1)
plot(w/pi,abs(h1));grid
title('Magnitude Spectrum of Original
Sequence','FontSize',8)
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(2,2,2)
plot(w/pi,abs(h2));grid
title('Magnitude Spectrum of Time-Shifted
Sequence','FontSize',8)
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(2,2,3)
plot(w/pi,angle(h1));grid
title('Phase Spectrum of Original
Sequence','FontSize',8)
xlabel('\omega /\pi');
ylabel('Phase in radians');
subplot(2,2,4)
plot(w/pi,angle(h2));grid
title('Phase Spectrum of Time-Shifted
Sequence','FontSize',8)
xlabel('\omega /\pi');
ylabel('Phase in radians');
```

Frequency Shifting property of DTFT

Frequency shift x[n] $e^{-j\omega 0n}$→X(ω-ω0)

```
w = -pi:2*pi/255:pi;
wo = 0.4*pi;
num1 = [1 3 5 7 9 11 13 15 17];
L = length(num1);
h1 = freqz(num1, 1, w);
n = 0:L-1;
num2 = exp(-wo*i*n).*num1;
h2 = freqz(num2, 1, w);
subplot(2,2,1)
plot(w/pi,abs(h1));grid
title('Magnitude Spectrum of Original
Sequence','FontSize',8)
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(2,2,2)
plot(w/pi,abs(h2));grid
title('Magnitude Spectrum of Frequency-Shifted
Sequence','FontSize',8)
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(2,2,3)
plot(w/pi,angle(h1));grid
title('Phase Spectrum of Original
Sequence','FontSize',8)
xlabel('\omega /\pi');
ylabel('Phase in radians');
subplot(2,2,4)
plot(w/pi,angle(h2));grid
title('Phase Spectrum of Frequency-Shifted
Sequence','FontSize',8)
xlabel('\omega /\pi');
ylabel('Phase in radians');
```

Convolution property of DTFT

Convolution in time x[n]*y[n] →X(ω).Y(ω)

```
w = -pi:2*pi/255:pi;
x1 = [1 3 5 7 9 11 13 15 17];
x2 = [1 -2 3 -2 1];
y = conv(x1,x2);
h1 = freqz(x1, 1, w);
h2 = freqz(x2, 1, w); hp = h1.*h2;
h3 = freqz(y,1,w);
subplot(2,2,1)
plot(w/pi,abs(hp));grid
title('Product of Magnitude Spectra','FontSize',8)
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(2,2,2)
plot(w/pi,abs(h3));grid
title('Magnitude Spectrum of Convolved
Sequence','FontSize',8)
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(2,2,3)
plot(w/pi,angle(hp));grid
title('Sum of Phase Spectra','FontSize',8)
xlabel('\omega /\pi');
ylabel('Phase in radians');
subplot(2,2,4)
plot(w/pi,angle(h3));grid
title('Phase Spectrum of Convolved
Sequence','FontSize',8)
xlabel('\omega /\pi');
ylabel('Phase in radians');
```

Modulation Property of DTFT

$$y[n] = x_1[n]x_2[n] \xleftrightarrow{\mathcal{F}} Y(e^{j\omega}) = \frac{1}{2\pi}\int_{2\pi} X_1(e^{j\Theta})X_2(e^{j(\omega-\Theta)})\,d\Theta$$

```
clf;
w = -pi:2*pi/255:pi;
x1 = [1 3 5 7 9 11 13 15 17];
x2 = [1 -1 1 -1 1 -1 1 -1 1];
y = x1.*x2;
h1 = freqz(x1, 1, w);
h2 = freqz(x2, 1, w); h3 = freqz(y,1,w); subplot(3,1,1)
plot(w/pi,abs(h1));grid
title('Magnitude Spectrum of First Sequence')
xlabel('\omega /\pi');
ylabel('Amplitude');
% plot the magnitude spectrum of x2
subplot(3,1,2)
plot(w/pi,abs(h2));grid
title('Magnitude Spectrum of Second Sequence')
xlabel('\omega /\pi');
ylabel('Amplitude');
% plot the magnitude spectrum of
subplot(3,1,3)
plot(w/pi,abs(h3));grid
title('Magnitude Spectrum of Product Sequence')
xlabel('\omega /\pi');
ylabel('Amplitude');
```

Time Reversal Property of DTFT

***x*[− *n*] → X(-w)**

```
clf;
w = -pi:2*pi/255:pi;
num = [1 2 3 4];
L = length(num)-1
h1 = freqz(num, 1, w);
= freqz(fliplr(num), 1, w);
h3 = exp(w*L*i).*h2;
subplot(2,2,1)
plot(w/pi,abs(h1));grid
title('Magnitude Spectrum of Original
Sequence','FontSize',8)
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(2,2,2)
plot(w/pi,abs(h3));grid
title('Magnitude Spectrum of Time-Reversed
Sequence','FontSize',8)
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(2,2,3)
plot(w/pi,angle(h1));grid
title('Phase Spectrum of Original
Sequence','FontSize',8)
xlabel('\omega /\pi');
ylabel('Phase in radians');
subplot(2,2,4)
plot(w/pi,angle(h3));grid
title('Phase Spectrum of Time-Reversed
Sequence','FontSize',8)
xlabel('\omega /\pi');
ylabel('Phase in radians');
```

Linearity

$$\mathcal{F}[\alpha x_1(n) + \beta x_2(n)] = \alpha \mathcal{F}[x_1(n)] + \beta \mathcal{F}[x_2(n)]$$

```
n = -2*pi:.01:2*pi;
x1=sin(10*2*pi*n);
x2=sin(20*2*pi*n);
y1 = 10*x1;
y2 = 5*x2;
Y1 = abs(freqz(y1));
Y2 = abs(freqz(y2));
subplot(2,1,1) , plot(Y1+Y2)
title('F[aX1 + bX2]');
X1 = abs(freqz(x1));
X2 = abs(freqz(x2));
X1 = 10*X1;
X2 = 5*X2;
subplot(2,1,2) , plot(X1+X2)
title('aF[X1] + bF[X2]');
```