# Signal 89

# Digital Signal Processing

# For the TI-89

**Author:**

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# *Table of contents*

## *The reason this program exist*

The main reason is to have a fast reachable "portable Matlab program" at hand any time.
The second reason, it's fun.

## *What's New?*

| Version 2.3.1. | | |
|---|---|---|
| Type | Name / prog / func | Description |
| Changed | Help() | Improved. |

| Version 2.3.0. | | |
|---|---|---|
| Type | Name / prog / func | Description |
| New | Filter() | Filter a signal. |
| New | Eye() | Identity matrix or flipped when minus. |

| Version 2.2.2. | | |
|---|---|---|
| Type | Name / prog / func | Description |
| New | Xcorr2() | Correlation in 2-D. |
| New | FFTri() | New FFT and IFFT, code from "Numerical Recipes in C", Cambridge University Press. This brings out the real and imaginary part. |
| New | Help() | "Born to make you happy". |
| Changed | DFT2() | New name and from a program to a function. |
| Changed | IDFT2() | New name and from a program to a function. |
| Changed | DCT2() | New name and from a program to a function. |
| Changed | IDCT2() | New name and from a program to a function. |
| Changed | Xcorr() | From a program to a function. |
| Changed | MRound() | From a program to a function. |
| Changed | ZeroPad() | From a program to a function and some improvements. |
| Changed | Circ() | From a program to a function and some improvements. |
| Changed | Conv() | From a program to a function. |
| Changed | Conv2() | From a program to a function. |
| Changed | MENU89() | Some miner improvements. |

| Version 2.1.0. | | |
|---|---|---|
| Type | Name / prog / func | Description |
| New | FFT() | Radix-2 Fast Fourier Transform, decimation in frequency. It's a function. |
| New | IFFT() | Radix-2 Inverse Fast Fourier Transform, decimation in frequency. It's a function. |
| Changed | DFT() | Discrete Fourier Transform 1-D. It's a function. |

| | | |
|---|---|---|
| Changed | IDFT() | Inverse Discrete Fourier Transform 1-D.<br>It's a function. |
| Changed | DFTG() | New name.<br>Discrete Fourier Transform Graphic. |
| Changed | IDFTG() | New name.<br>Discrete Fourier Transform (Graphic). |
| New | Flip() | Flips a matrix vertical and horizontal.<br>It's a function. |
| New | FlipUD() | Flips a matrix horizontal.<br>It's a function. |
| New | FlipLR() | Flips a matrix vertical.<br>It's a function. |
| New | Rot90 | Rotate a matrix 90 degree,<br>counterclockwise.<br>It's a function. |
| Changed | MENU89() | New name and some additions. |
| Changed | Mswap() | New name, Flip(). |

| Version 2.0.0. | | |
|---|---|---|
| Type | Name / prog / func | Description |
| Changed | Documentation | Documentation made in Microsoft Word. |
| New | DFT2D() | Discrete Fourier Transform in 2 dimensions. |
| New | IDFT2D() | Inverse Discrete Fourier Transform in 2 dimensions. |
| New | DCT2() | Discrete Cosine Transform in 2 dimensions. |
| New | IDCT2() | Inverse Discrete Cosine Transform in 2 dimensions. |
| New | xcorr() | Correlation of two signals, auto or cross, depend on the input signal. |
| New | Conv2() | Convolution with x and h in 2 dimensions. |
| New | MNU1() | Menu for the "Signal89". |
| New | mswap() | Flips the matrix vertical and horizontal. |
| New | mround() | Makes round inside the matrix. |
| New | zeropad() | Makes some zero padding round the matrix. |
| New | clellan() | Function, McClellan. |
| Changed | conv() | New name. Convolution, list is changed to matrix. |
| Changed | circ() | New name. Circular (convolution), list is changed to matrix. |
| Changed | dft() | List is changed to matrix and some of the graphics. |
| Changed | idft() | List is changed to matrix. |

## *Definition of Fourier Transform Equation*

Time domain

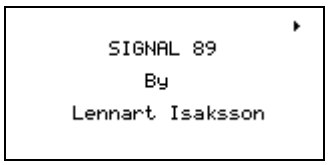
$$h(t) = \int_{-\infty}^{\infty} H(f) \cdot e^{2\pi i f t} df$$

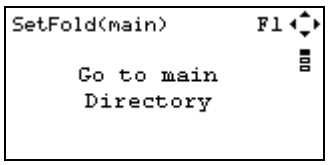
Frequency domain

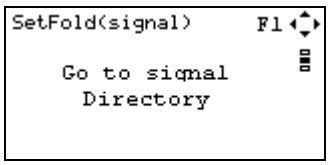
$$H(f) = \int_{-\infty}^{\infty} h(t) \cdot e^{-2\pi i f t} dt$$

# *Help, Help( )*

To make things easier.



# *Filter, 1-D, filter( , , )*

This is a one dimensional digital filter. The filter is a “Direct Form II Transposed”.
If a[1] is not equal to 1, FILTER normalizes the filter coefficients by a[1].
The length of x is the same as the result.

$$H(z) = \frac{B(z)}{A(z)} = \frac{b(1) + b(2)z^{-1} + \ldots + b(nb+1)z^{-n}}{a(1) + a(2)z^{-1} + \ldots + a(na+1)z^{-n}}$$

```
[2  1  3]->b
[2  .5]->a
[1  1  1  1]->x

filter(b,a,x)->[2  1.2500  2.6875  2.3281]
```

It’s a function, so the result is presented directly.

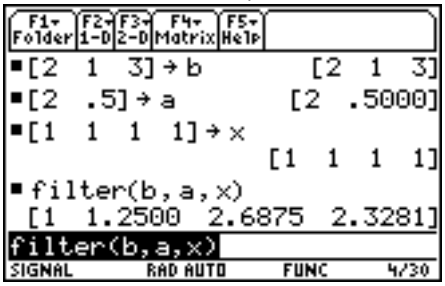



**Figure 1**

# *Convolution, 1-D, conv( , )*

```
Make a convolution of two signals.
[0,1,2,3]->x
[1,1,0,0]->y
conv(x,y)

or

conv([0,1,2,3],[1,1,0,0])

It's a function, so the result is presented directly.
```

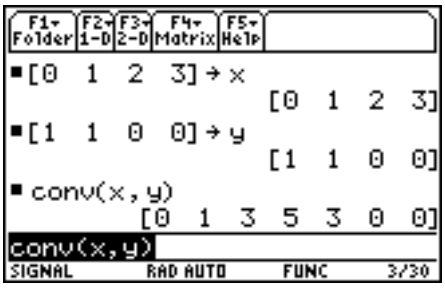



**Figure 2**

# *Convolution, 2-D, Conv2( , )*

Make a convolution of two matrixes.

```
[1,4;2,8]->x
[3,7;2,6]->y
conv2(x,y)
```

or

```
conv2([1,4;2,8],[3,7;2,6])
```

It's a function, so the result is presented directly.

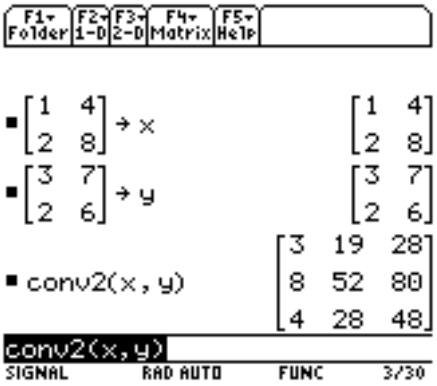



**Figure 3**

Considerations.
1. When using conv2(), both matrixes has to be the same size. If not, use the zeropad().
2. The minimum size of the matrix is 2 by 2.

# *Correlation , 1-D, Xcorr( , )*

If you have two different signals then it's cross correlation. If you have the same signal then it's auto correlation.

Auto correlation of a signal.

```
[1,2,1,1]->x
xcorr(x,x)
```

or

```
xcorr([1,2,1,1],[1,2,1,1])
```

It's a function, so the result is there directly.

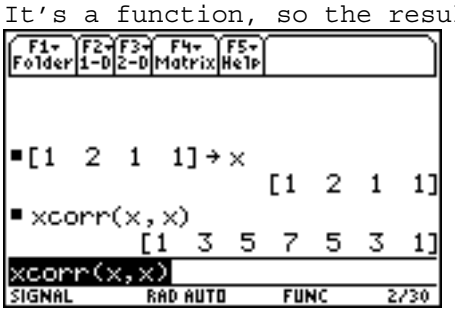



**Figure 4**

# *Correlation , 2-D, Xcorr2( , )*

Make a correlation of two matrixes.

```
[1,4;2,8]->x
[3,7;2,6]->y
xcorr2(x,y)
```

or

```
xcorr2([1,4;2,8],[3,7;2,6])
```

It's a function, so the result is presented directly.

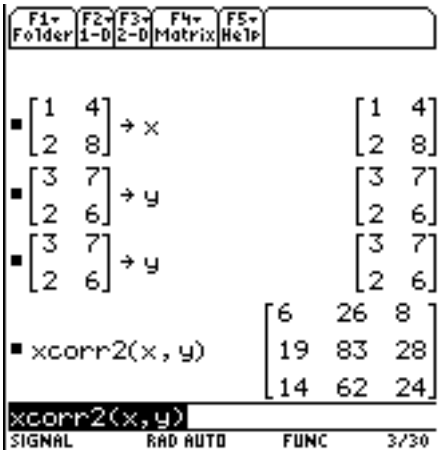



**Figure 5**

Considerations.
1. When using xcorr2(), both matrixes has to be the same size. If not, use the zeropad().
2. The minimum size of the matrix is 2 by 2.

# *Circular, 1-D, Circ( , )*

Circular (convolution), use the Convol() first.
The second parameter is the size of the vector. If it's set by zero it takes the length of the vector.

```
[0,1,3,5,3,0,0]->t
circ(t,4)

or

circ([0,1,3,5,3,0,0],4)
```

It's a function, so the result is presented directly.

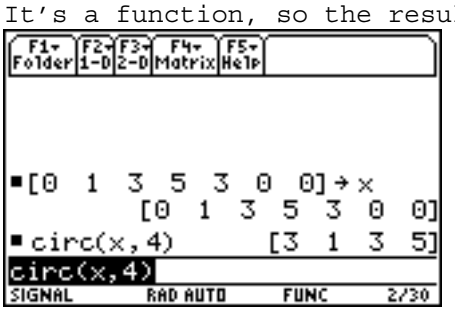



**Figure 6**

# *Radix-2 Fast Fourier Transform, 1-D, FFT( )*

This is a radix-2 Fast Fourier Transform decimation in frequency. This make a split X(k) into even- and odd number samples. The function is making an auto zero padding if necessary. See **Definition of Fourier Transform Equation.**

The matrix should be $2^x$.

But what is a FFT anyway?
FFT is a DFT, but FFT is divided the calculation in a more intelligent way.

$$g_1(n) = x(n) + x\left(n + \frac{N}{2}\right) \qquad g_2(n) = \left(x(n) - x\left(n + \frac{N}{2}\right)\right) \cdot e^{\left(\frac{-i \cdot 2 \cdot \pi \cdot n}{N}\right)}$$

$$X(2 \cdot k) = \sum_{n=0}^{(N/2)-1} g_1(n) \cdot e^{\left(\frac{-i \cdot 2 \cdot \pi \cdot n \cdot k}{N/2}\right)} \qquad X(2 \cdot k + 1) = \sum_{n=0}^{(N/2)-1} g_2(n) \cdot e^{\left(\frac{-i \cdot 2 \cdot \pi \cdot n \cdot k}{N/2}\right)}$$

```
[0,1,2,3]->x
fft(x)

or

fft([0,1,2,3])
```

It's a function, so the result is presented directly.

```
[6  -2+2i  -2  -2-2i]
```

# *Radix-2 Inverse Fast Fourier Transform, 1-D, IFFT( )*

This is a radix-2 Inverse Fast Fourier Transform decimation in frequency. This make a split X(k) into even- and odd number samples. The function is making an auto zero padding if necessary. See **Definition of Fourier Transform Equation.**

$$g_1(n) = x(n) + x\left(n + \frac{N}{2}\right) \qquad g_2(n) = \left(x(n) - x\left(n + \frac{N}{2}\right)\right) \cdot e^{(\frac{i \cdot 2 \cdot \pi \cdot n}{N})}$$

$$X(2 \cdot k) = \frac{1}{N} \cdot \sum_{n=0}^{(N/2)-1} g_1(n) \cdot e^{(\frac{i \cdot 2 \cdot \pi \cdot n \cdot k}{N/2})} \qquad X(2 \cdot k + 1) = \frac{1}{N} \cdot \sum_{n=0}^{(N/2)-1} g_2(n) \cdot e^{(\frac{i \cdot 2 \cdot \pi \cdot n \cdot k}{N/2})}$$

```
[6,-2+2i,-2,-2-2i]->x
ifft(x)

or

ifft([6,-2+2i,-2,-2-2i])

It's a function, so the result is presented directly.
[0  1  2  3]
```

## *Radix-2 Fast Fourier Transform, 2-D, FFT2( )*

Same as FFT( ) but with Row and Column decomposition

## *Radix-2 Inverse Fast Fourier Transform, 2-D, IFFT2( )*

Same as IFFT( ) but with Row and Column decomposition

# *Radix-2 (with real and imaginary part) FFT and IFFT, 1-D, FFTri( , )*

This is a radix-2 Fast Fourier Transform and Inverse Fast Fourier Transform decimation in frequency. (Originally it was a graphic program but I made it more general and a function). See **Definition of Fourier Transform Equation.**
As you can se, the code is excellent to use in C++, C or other program language.
(The original code is from "Numerical Recipes in C", Cambridge Univ Press, but it's wrong, so I made some changes to it. The error was then going from frequency domain back to the time domain, it didn't divided the amount of samples as you should do. Changed by Lennart Isaksson.)

```
r stands for real part.
i stands for imaginary part.
```

FFTri(x,1) FFT=1

```
[0,0,1,0,2,0,3,0]->x
 r i r i r i r i
FFTri(x,1)

or

FFTri([0,0,1,0,2,0,3,0],1)

It's a function, so the result is presented directly.
[6.00 0.00 -2.00 2.00 -2.00 0.00 -2.00 -2.00]
 r    i     r    i     r    i     r     i
```

FFTri(x,-1) IFFT=-1

```
[6.00 0.00 -2.00 2.00 -2.00 0.00 -2.00 -2.00]->x
 r    i     r    i     r    i     r     i
FFTri(x,-1)

or

FFTri([6.00 0.00 -2.00 2.00 -2.00 0.00 -2.00 -2.00],-1)

It's a function, so the result is presented directly.
[0.00 0.00 1.00 0.00 2.00 0.00 3.00 0.00]
 r    i    r    i    r    i    r    i
```

## *Discrete Fourier Transform, 1-D, DFT( )*

Discrete Fourier Transform takes the signal from the time domain to the frequency domains. See **Definition of Fourier Transform Equation.**

```
[0,1,2,3]->x
dft(x)

or

dft([0,1,2,3])

It's a function, so the result is presented directly.
[6  -2+2i  -2  -2-2i]
```

## *Inverse Discrete Fourier Transform, 1-D, IDFT( )*

Inverse Discrete Fourier Transform takes the signal from the frequency domains to the time domain. See **Definition of Fourier Transform Equation.**

```
[6,-2+2i,-2,-2-2i]->x
dft(x)

or

dft([6,-2+2i,-2,-2-2i])

It's a function, so the result is presented directly.
[0  1  2  3]
```

## *Discrete Fourier Transform Graphic, 1-D, DFTG( )*

Graphic interface.
Discrete Fourier Transform takes the signal from the time domain to the frequency domains. See **Definition of Fourier Transform Equation.**
But what is it?
Do you have a stereo with graphic equalizer? Yes the thing that is jumping up and down is the values from DFT that's coming from your cd. The result is the Frequency bars jumping up and down.

```
[0,1,2,3]->x
dft(x)

or

dft([0,1,2,3])

The result in variable y = [6  -2+2i  -2  -2-2i]
```

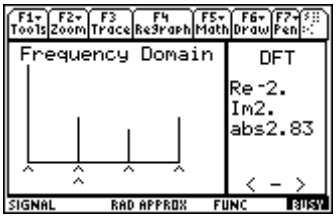



**Figure 7**

```
Send the result in variable y to the variable t.
t->y

[1,1,0,0]->x
dft(x)

or

dft([1,1,0,0])

The result in variable y = [2  1-i  0  1+i]
```

## *Inverse Discrete Fourier Transform, 1-D, IDFTG( )*

Inverse Discrete Fourier Transform takes the signal from the frequency domains to the time domains. See **Definition of Fourier Transform Equation.**

```
[12  4i  0  -4i]->y
idft(y)

or

idft([12  4i  0  -4i])

The result in variable t = [3  1  3  5]
```

# *Discrete Fourier Transform, 2-D, DFT2( )*

Discrete Fourier Transform in 2 Dimensions. See **Definition of Fourier Transform Equation.**

```
[1,1;1,1]->x
dft2(x)

or

dft2([1,1;1,1])
```

It's a function, so the result is there directly.

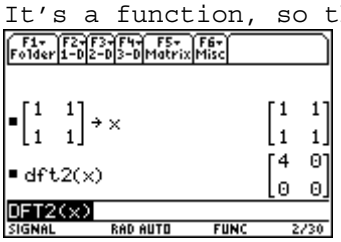



**Figure 8**

# *Inverse Discrete Fourier Transform, 2-D, IDFT2( )*

Inverse Discrete Fourier Transform in 2 Dimensions. See **Definition of Fourier Transform Equation.**

```
[4,0;0,0]->y
idft(y)

or

idft([4,0;0,0])
```

It's a function, so the result is there directly.

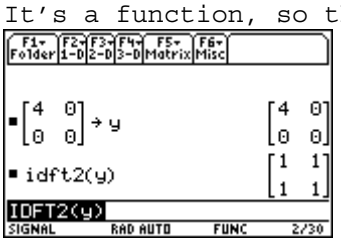



**Figure 9**

# *Discrete Cosine Transform, 2-D, DCT2( )*

Discrete Cosines Transform in 2 Dimensions. See **Definition of Fourier Transform Equation.**

```
[1,2;3,4]->x
dct2(x)

or

dct2([1,2;3,4])
```

It's a function, so the result is there directly.

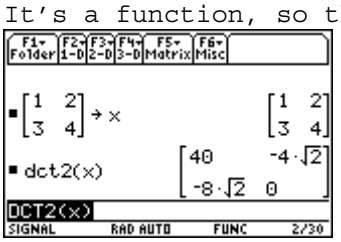



**Figure 10**

This is used frequently in compressing file format like "jpg".
The idea is to minimize the amount of information. In the above figure, variable t, we have four coefficients. Reduce the information by setting one element [1,2]=5.65685 to zero. Then you have a matrix like this:
[40,0;-11.3137,0]

If you then take the idct() to restore you picture, you are getting this:
[1.5,1.5;3.5,3.5]
As you have seen before on pictures, it got some square like pattern on the picture. Now you know why.

It's very near the optimum result you had before.
The optimum result is:
[1 2 3 4]

Matlab 5.x are using another definition.

# *Inverse Discrete Cosine Transform, 2-D, IDCT2( )*

Inverse Discrete Cosines Transform in 2 Dimensions. See **Definition of Fourier Transform Equation.**

```
[40  -5.65685  -11.3137  0]->y
idct2(y)

or

idct2([40  -5.65685  -11.3137  0])
```

It's a function, so the result is there directly.

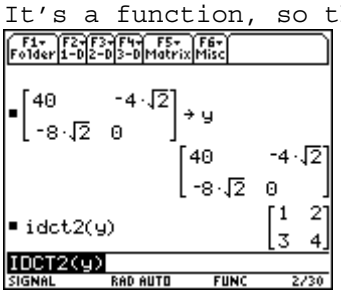



**Figure 11**

## *Matrix Flip, 2-D, flip( )*

The Matrix is flipped vertical and horizontal.

```
[1,2;3,4]->x
flip(x)

or

flip([1,2;3,4])
```

It's a function, so the result is there directly.

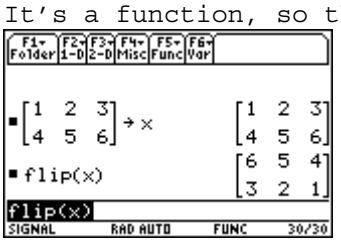



**Figure 12**

## *Matrix FlipUD, 2-D, flipud( )*

The Matrix is flipped horizontal.

```
[1,2;3,4]->x
flipud(x)

or

flipud([1,2;3,4])
```

It's a function, so the result is presented directly.

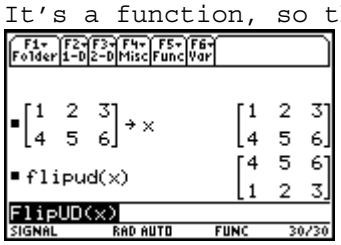



**Figure 13**

## *Matrix FlipLR, 2-D, fliplr( )*

The Matrix is flipped vertical.

```
[1,2;3,4]->x
fliplr(x)

or

fliplr([1,2;3,4])
```

It's a function, so the result is presented directly.

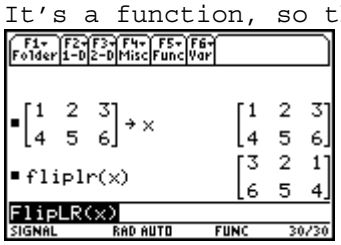



**Figure 14**

## *Matrix Rot90, 2-D, rot90( )*

The Matrix is rotated 90 degree counterclockwise.

```
[1,2;3,4]->x
rot90(x)

or

rot90([1,2;3,4])
```

It's a function, so the result is presented directly.

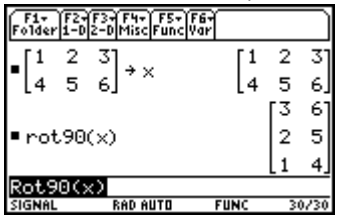



**Figure 15**

## *Matrix Round, 2-D, Mround( , )*

The Matrix is round off both the real and imaginary part.

```
[1.23,3.14i]->x
mround(x,1)

or

mround([1.23,3.14i],1)
```

It's a function, so the result is presented directly.

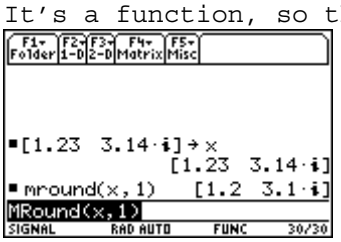



**Figure 16**

## *Matrix Zero Padding, 2-D, Zeropad( , )*

Zero padding a matrix to a certain size.

```
[1,1;1,1]->x
zeropad(x,3)

or

zeropad([1,1;1,1],3)
```

It's a function, so the result is presented directly.

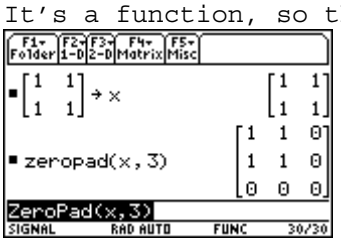



**Figure 17**

# *Eye, Identity Matrix , 2-D, Eye( )*

Make an Identity matrix with a certain size. Yes, where is already a function named "indentity()", but this is better.

```
Eye(3)
```

It's a function, so the result is presented directly.

```
[1 0 0]
[0 1 0]
[0 0 1]
```

Special case,(this is not the identity matrix), but it's handy when flipping a matrix.

```
Eye(-3)
```

It's a function, so the result is presented directly.

```
[0 0 1]
[0 1 0]
[1 0 0]
```

# *McClellan, 2-D, Clellan( , )*

```
[0.2pi]->x
clellan(x,x)

or

clellan(0.2pi,0.2pi)

The result is 0.636271
```

```
McClellan is -0.5+0.5cos(w1)+0.5cos(w2)+0.5cos(w1)cos(w2).
As you can see, it's circular in the middle and squarer near the sides.

Figure below is a low pass filter with McClellan. 2-D FIR filter design
using frequency transformation. 1-D FIR filter, using the transform T. Here
is T the McClellan.
```

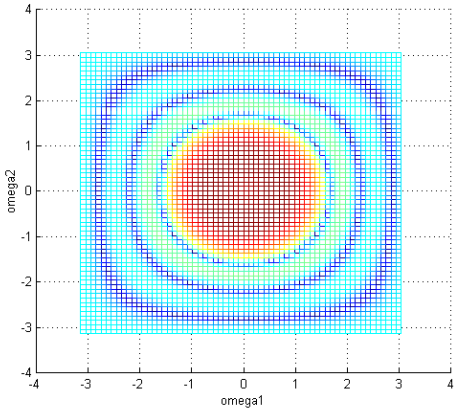



**Figure 18**

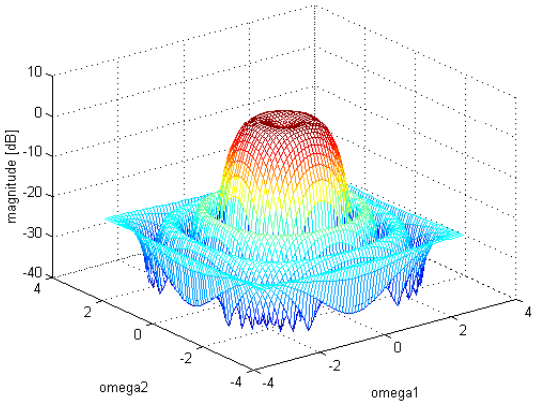



**Figure 19**

Figures above is made in Matlab.

# *Menu, menu89( )*

```
Menu of Signal89.

Menu89()

Sets the custom menu.
```

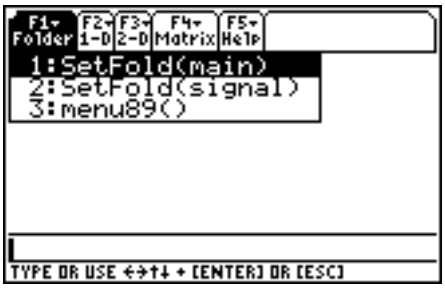



**Figure 20**


**Figure 21**

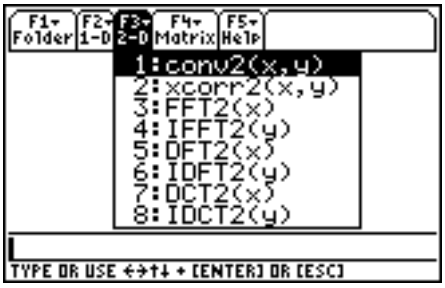



**Figure 22**

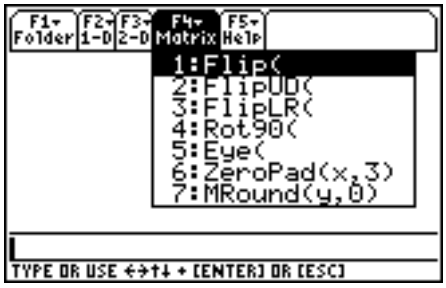



**Figure 23**


**Figure 24**

# *Examples*

## *How to use dft and idft, instead of convolution.*

The idea is to take x and h from the time domain to X an H in the frequency domain. Make the multiplication in the frequency domain. Go back to the time domain. Another way is to make a convolution in the time domain, for that you use the conv2().

We first starts to initialize two variables x and h.

```
[1,1;1,1]->x
[1,2;3,4]->h
```

Take zeropad(x,3) (see zeropad) to make extra space in the matrix. It's necessary because otherwise the matrix is being circular convolution.

Considerations.

1. When multiply two matrixes, it has to be the same size and use the dot multiplication (.*).
2. Calculate the amount of zero padding by taking the size of matrix x adding the size of matrix h and reduce by one. In short, x+h-1. In our example, 2+2-1=3.

```
zeropad(x,3)->x
zeropad(h,3)->h
```

After zero padding use the dtf2d(x) and dtf2d(h).

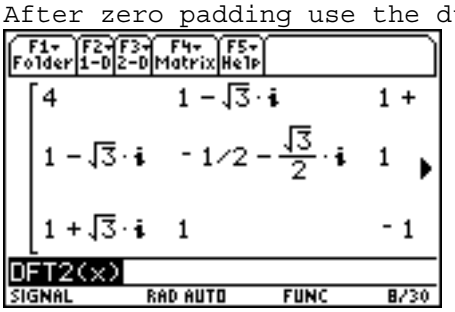



**Figure 25**

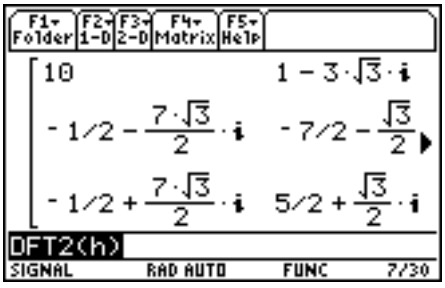



**Figure 26**

As you can see when going to the frequency domain, you have to expect imaginary number.
Take the two and make a dot multiplication.

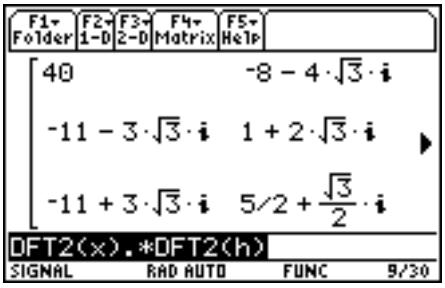



**Figure 27**

The last step is to use the idft2d() to go back to the time domain.

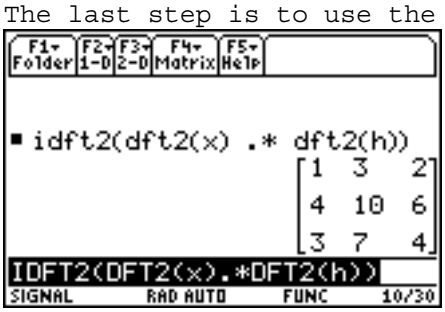



**Figure 28**

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Any Questions or comments send an email or ICQ.

## Credits

Mark Vulfson, USA, to a more compact code for dft() and idft().

Scott Campbell, USA, to converted FFTir() (Originally FFT) from TI83 to TI89.
The original code is from "Numerical Recipes in C", Cambridge Univ Press.

## *Reference*

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