DIGITAL FILTER PACKAGE

OPERATOR'S MANUAL

JULY 2001
REVISION B

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DFP-OM-E Rev B 0701

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KPMG Quality Registrar
The Quality Advantage

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Introduction

THE NEED

In today’s complex environment, data is frequently composed of a mixture of analog and digital components spread over a broad range of frequencies. In many applications, the relevant data is encoded or obscured. Capturing the right signals becomes a challenge. Engineers find it increasingly difficulty to examine only those parts of the data they are interested in. Traditional (or even smart) oscilloscope triggering cannot always provide a satisfactory answer.

For example, servo motors from disk drives add a low frequency component to the high frequency data output. It is hard to achieve an accurate analysis of data unless the low component is removed.

Another common example is switched power supply units, which inject the switching frequency component into many system parts. Viewing digital signals mixed with this switching frequency component could be very difficult. Filtering is definitely required.

Yet another example is in ADSL residential connectivity, where data is transmitted over 256 narrow bands. Each band is only 4.7kHz wide, and the gap between two adjacent bands is also 4.7kHz. Examining such complex waveforms with regular DSOs is almost impossible; filtering out unwanted frequency components is necessary.

THE SOLUTION

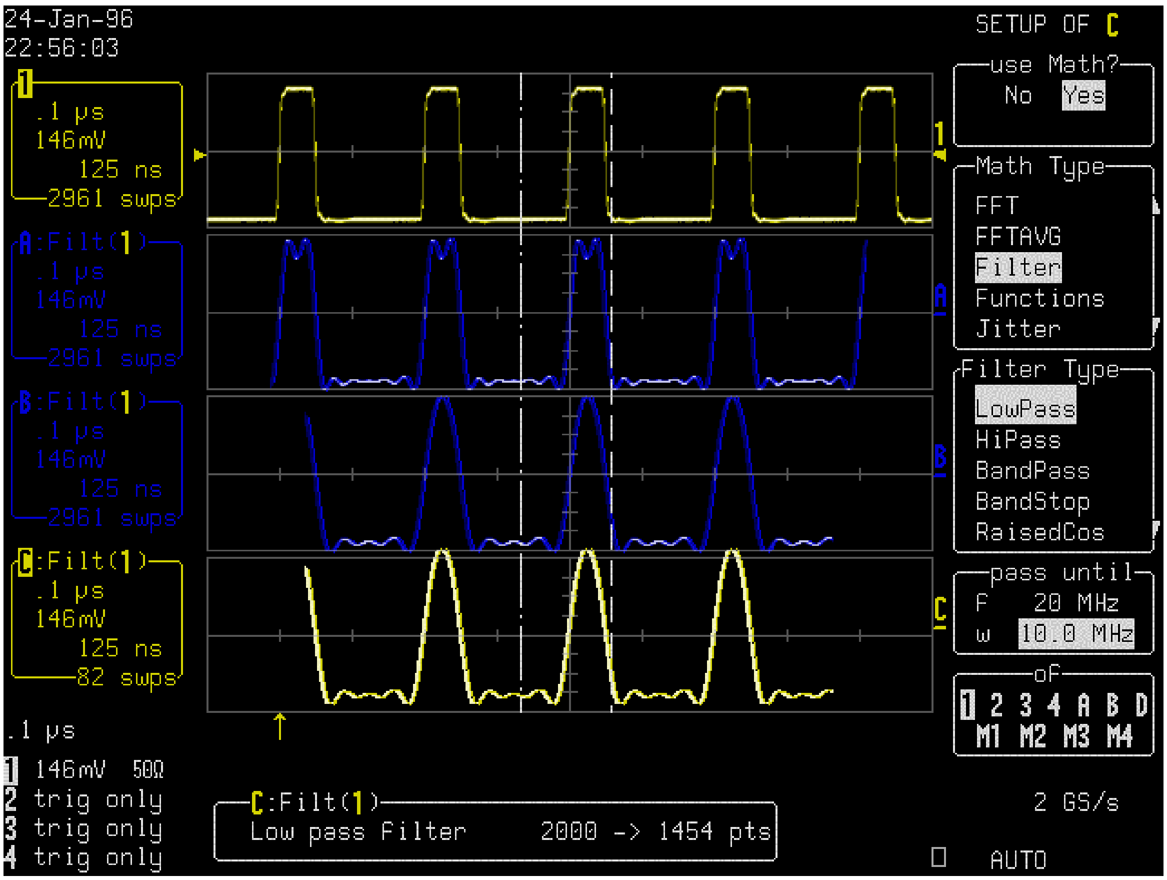
At present, these needs are addressed in two ways. One way is building analog filters and placing them in front of the oscilloscope, providing an already filtered signal to the DSO. The disadvantages of this approach are many. Analog filters depend heavily on the accuracy and stability of analog components. Although in some cases analog filters are easily implemented, they are quite impractical for low (< 100 HZ) or high (> 100 MHz) frequency ranges. In comparison, digital filters can provide the desired results in those cases.

The second approach, practiced by many engineers, is using the DSO as a digitizer. The digitized data output is then transferred to a PC for processing. This solution frequently provides the required results, but it might be too slow or too limited in flexibility for some applications.

With the Digital Filter Package, LeCroy provides a solution that combines the best of both worlds. This package includes seven of the most useful filter types, in addition to a custom design feature. You can easily set the edge (or corner) frequency in addition to the transition region width for each filter. It is possible to use single filters or multiple (up to four) filters cascaded for even more complex filtering. Once filtered, waveforms include mostly relevant frequency components, undesired parts being greatly attenuated.

If filters with special characteristics are desired, the custom design feature allows you to design unique filters tailored to your specific needs. The required filter can be designed with a digital filter design or math package such as MATLAB® or Mathcad®. Filter coefficients can be directly downloaded from the program into the scope, using the DSOFilter utility. It is also possible to specify the filter coefficients on an Excel spreadsheet and to use DSOFilter to download them from the spreadsheet to the scope.

DFP's flexibility and ease of operation are demonstrated by the following example:



1: a signal composed of 5 MHz pulses is filtered by:

A: 40 MHz low-pass filter with a 20 MHz transition region width

B: 30 MHz low-pass filter with a 15 MHz transition region width

C: 20 MHz low-pass filter with a 10 MHz transition region width

Enhanced Solutions

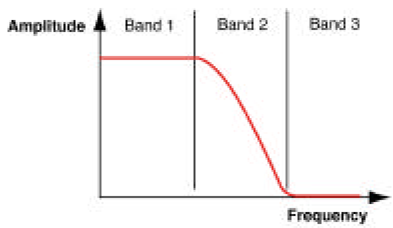
DFP can be coupled with other LeCroy software products — such as AORM, JTA, PMA1, or DDA — to enhance the capabilities of these products and to provide improved solutions.

For example

- Jitter Measurement: the DFP Band-pass Filter can be coupled with the JTA package to measure jitter over a narrow frequency range.
- Optical Recording: In some cases equalization with a different response is required. In such a case, the DFP custom filter feature can be used in conjunction with AORM. The required custom filter can be easily implemented to provide the necessary equalization, while all other AORM functions remain unchanged.
- Power Measurement: A Band-stop filter can be coupled with the PMA1 package to eliminate the switching power supply frequency component from power lines. The Band-stop filter can be tuned to match a specific power supply switching characteristic.

FILTER TYPES[1]

Low-pass Filter



Low-pass filters are useful for eliminating accumulated high frequency noise and interference, and for canceling high frequency background noise.

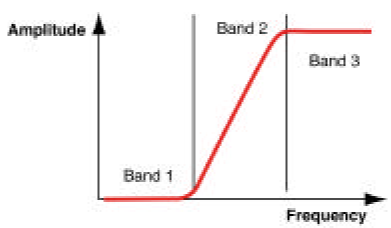
Sample applications are in datacom, telecommunications, and disk drive and optical recording analysis for accurate RF signal detection.

Band 1: Pass Band — DC to top of the transition region; signal passes unattenuated.

Band 2: Transition Region — edge frequency to edge frequency plus width; increasing attenuation.

Band 3: Stop Band — above end of transition region; signal is highly attenuated.

High-pass Filter



High-pass filters are useful for eliminating DC and low frequency components. Sample applications include Disk Drive and Optical Recording analysis (emulation of the SLICING function).

Band 1: Stop Band — DC to bottom of the transition region; highly attenuated.

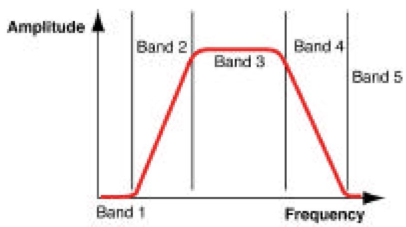
Band 2: Transition Region — edge frequency minus width to edge frequency; decreasing attenuation.

Band 3: Pass Band — above edge frequency; signal passes unattenuated.

1. Filters are optimal FIR filters of less than 1000 taps, according to the Parks-MacLellan algorithm described in *Digital Filter Design and Implementation* by Parks and Burros, John Wiley & Sons, Inc., 1987

LeCroy Digital Filter Package

Band-pass Filter



Band-pass filters are useful for emphasizing a selected frequency band. Sample applications include radio channel identification, broadband transmission, ADSL, clock generators (i.e., eliminating the central frequency and displaying harmonics only), and telecommunications (Jitter measurement over a selected frequency range).

Band 1: First Stop Band — DC to bottom of first transition region; highly attenuated.

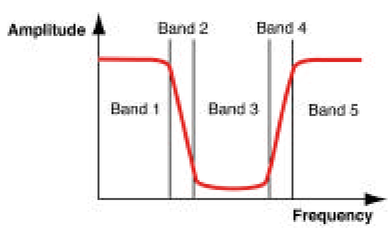
Band 2: First Transition Region — lower corner minus width to lower corner; decreasing attenuation.

Band 3: Pass Band — signal passes unattenuated.

Band 4: Second Transition Region — upper corner to upper corner plus width; increasing attenuation.

Band 5: Second Stop Band — signal highly attenuated.

Band-stop Filter



Band-stop filters are useful for eliminating a narrow band of frequencies. Sample applications include medical equipment, such as ECG monitors where the dominant ripple at 50/60 Hz is rejected, leaving the low energy biological signals intact. Digital troubleshooting: the inherent frequency of the switched power supply is blocked, revealing power line voltage drops and glitches caused by the system clock generator.

Band 1: First Pass Band — DC to bottom of first transition region; signal passes unattenuated.

Band 2: First Transition Region — lower corner minus width to lower corner; increasing attenuation.

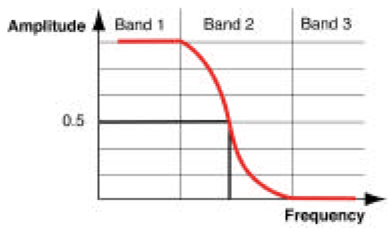
Band 3: Stop Band — signal is highly attenuated.

Band 4: Second Transition Region — upper corner to upper corner plus width; decreasing attenuation.

Band 5: Second Pass Band — signal passes unattenuated.

COMMUNICATION CHANNEL FILTERS

Raised Cosine (a low-pass filter)



These filters belong to the low-pass filter category (with a variety of shapes). Raised cosine is one of a class of filters used to minimize intersymbol interference: the time domain impulse response crosses zero at all bit time intervals except the one with the impulse.

Applying raised root cosine twice (or at the sending and receiving end of a signal, for example) results in a raised cosine filter effect. Sample applications include wireless cellular communications such as WCDMA, datacom, telecommunications, disk drive and optical drive analysis.

Band 1: Pass Band — DC to corner frequency minus half width; signal passes unattenuated.

Band 2: Transition Region — corner minus half width to corner plus half width; attenuation increases with frequency with a rolloff shape of *0.5cos(a) + 0.5*, where *a* ranges from 0 to ? over the transition region. This region is determined by ?, which is specified as a percentage of the corner frequency.

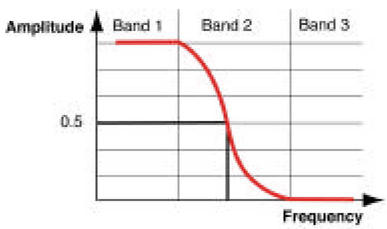
Band 3: Stop Band — above corner frequency plus half width; highly attenuated.

The impulse function for the raised cosine filter is:

$$h(t)= \frac{\left[\frac{\sin\left(\pi \frac{t}{T_s}\right)}{\pi \frac{t}{T_s}}\right]\cos\left(\pi\beta \frac{t}{T_s}\right)}{1-\left(2\beta \frac{t}{T_s}\right)^2}$$

LeCroy Digital Filter Package

Raised Root Cosine (a low-pass filter)



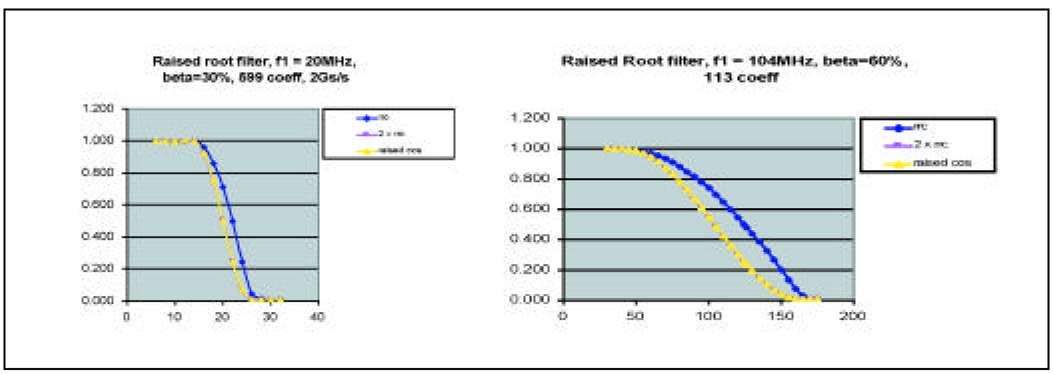
Band 1: Pass Band — DC to corner frequency minus half width; signal passes unattenuated.

Band 2: Transition Region — corner minus half width to corner plus half width; attenuation increases with frequency with a rolloff shape of *0.5[cos(a) + 0.5]*^{½}, where *a* ranges from 0 to ? over the transition region. This region is determined by ?, which is specified as a percentage of the corner frequency.

Band 3: Stop Band: — above corner frequency plus half width; signal is highly attenuated.

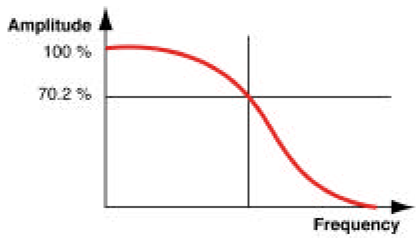
The impulse function for the square-root raised cosine filter is:

$$h(t) = \frac{4\beta}{\pi\sqrt{T_s}} \; \frac{\cos\left((1+\beta)\pi\frac{t}{T_s}\right) + \dfrac{\sin\left[(1-\beta)\pi\frac{t}{T_s}\right]}{4\beta\frac{t}{T_s}}}{1-\left(4\beta\frac{t}{T_s}\right)^2}$$



Illustrated above are two raised root cosine filters with different beta. The diagrams show that applying this filter twice results in a raised cosine response.

Gaussian



Band 1: Pass Band — DC to half power bandwidth% times modulation frequency, pass; 3 dB down at half power bandwidth.

The shape of a Gaussian filter's frequency response is a Gaussian distribution centered at DC. The signal becomes more attenuated with increasing frequency. It is not possible to specify a transition region or a stop band for Gaussian filters. However, the BT value, a fraction of the symbol frequency, determines the filter's width, where:

B = half power bandwidth

T = bit (or modulation period)

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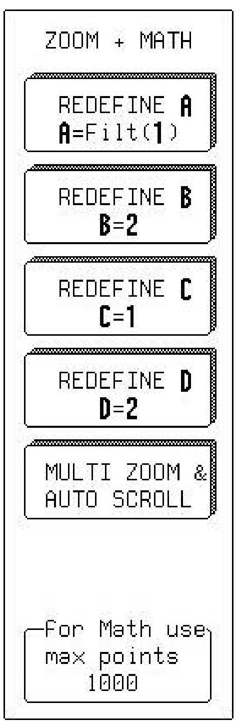
Operation

SETTING UP THE SCOPE

There are five basic steps to select and set up a filter:

1. Select MATH functions.
2. Select Filter as the Math Type
3. Select the filter type.
4. Set desired values for the frequency edge and the transition region width.
5. Select an oscilloscope channel as the filter's input.

Running DFP



To select the Math function

1. Press the **MATH** button (**MATH SETUP** or **MATH TOOLS**).
2. From the "ZOOM + MATH" menu, press the soft key alongside the desired math trace (here, Redefine A)

Pressing a Zoom + Math **TRACE ON/OFF** (A–D) button will bring up the next menu.

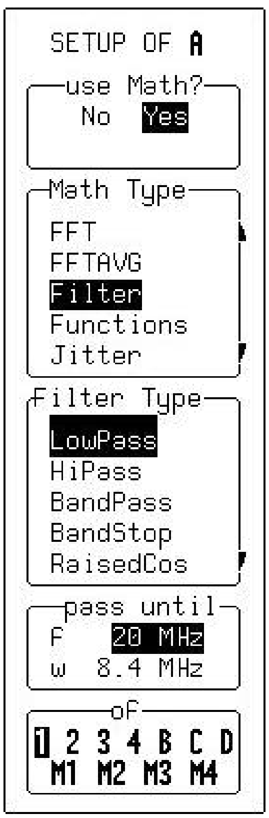
Note

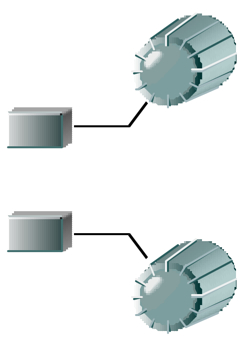
The number of "max points" displayed has no influence on filter operation.

After you select the desired trace, the following menu shown here is displayed.

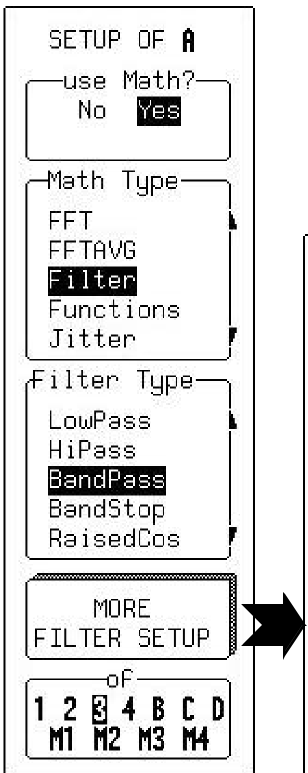
From the "SETUP OF A" menu

1. Select **Yes** from "use Math?".
2. Select the **Filter** option from the "Math Type" menu.
3. Select a filter from the "Filter Type" menu.
4. In the example at left, the **LowPass** filter was selected. The "pass until" box allows you to set the values for the frequency edge (f) and the transition region width (w). Press the corresponding soft key to switch between frequency and width.
5. Turn the associated adjustment knob to set the desired values.
6. From the "of" menu, select the channel to which the filter is to be applied.

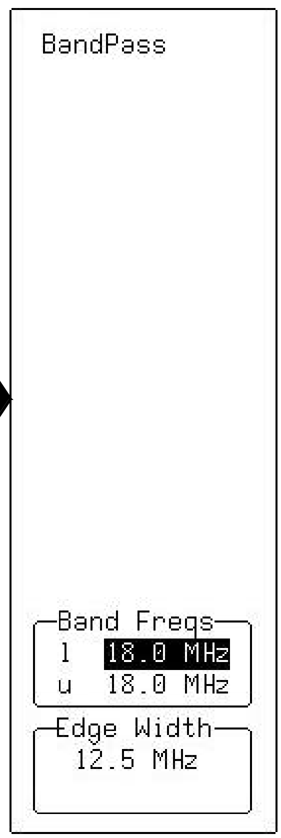




When you select the Band Pass filter, the menu at left appears:

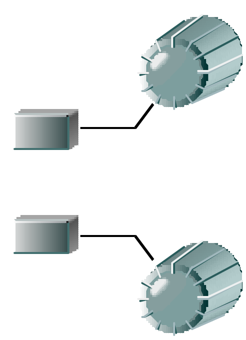


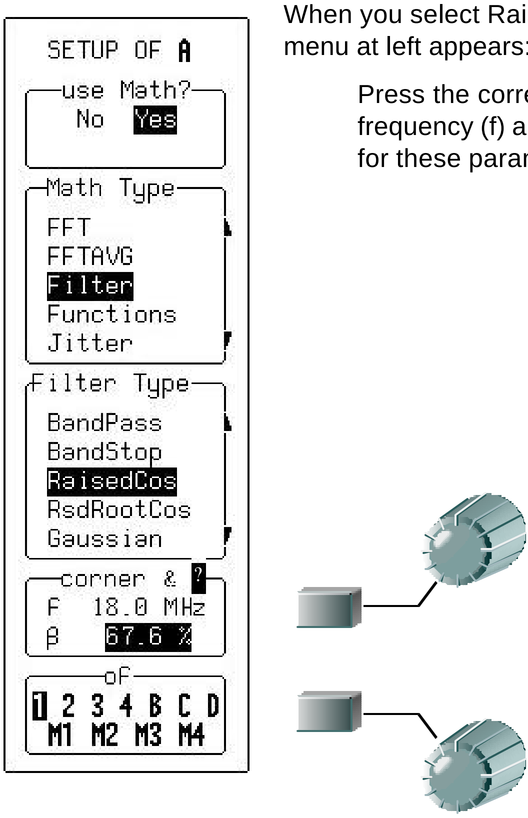
Press the "MORE FILTER SETUP" soft key. The following menu appears:



The soft key toggles between the lower (l) and upper (u) frequency edges. Use the associated adjustment knob to set values for both parameters.

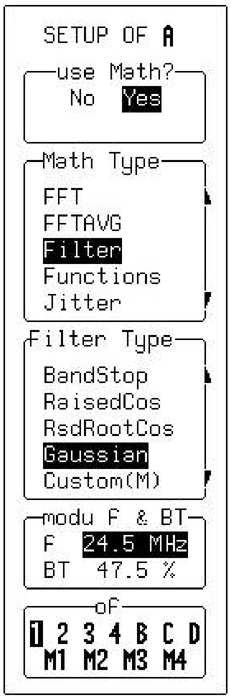
Edge Width is set from the lower box. Use the soft key to increase the width, or the knob to adjust the value.





When you select Raised Cosine or Raised Root Cosine filters, the menu at left appears:

Press the corresponding soft key to switch between corner frequency (f) and beta (?). Turn the associated knob to set values for these parameters.



When you select Gaussian filters, the menu at left appears:

Press the corresponding soft key to switch between modulation frequency (f) and BT, where B = half power bandwidth expressed as a fraction of the modulation frequency and T = bit (or modulation) period. Turn the associated knob to set values for these parameters.

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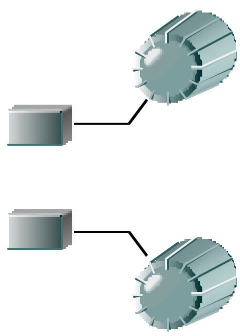

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Remote Commands

DEFINE COMMAND

The DFP option adds one new <equation> to the existing DEFINE remote command. The new function available with the DFP option is FIR(<source>).

Several parameters are added to support the FIR math function. They are:

FTYPE,<ftype>

FREQ, <lfreq>

UFREQ,<ufreq>

FWIDTH,<fwidth>

FBETA,<fbeta>

MCOEFF,<memory>

Values associated with the above parameters are:

<ftype>:=[LOWPASS | HIPASS | BANDPASS | BANDSTOP | RAISEDCOS | RSDROOTCOS | GAUSSIAN | CUSTOM]

<lfreq> := lower corner or only corner frequency, in Hz

<ufreq>:=upper corner frequency, in Hz. Must be greater than or equal to <lfreq>

<fwidth>:=transition region width in Hz. Must be >0.3% of sample rate. <lfreq> - <fwidth> must be greater than 0.1% of sample rate.

<fbeta>:= 0 to 100 percent. For raised cos and raise root cos, this is the % of <lfreq> + and - over which the transition region extends. For Gaussian, this is BT, the % of <lfreq> at which the response is 3dB down from DC response.

<memory>:=[M1 | M2 | M3 | M4]

Examples

Not all of these need to be set for any <ftype>. Here is an example of those that are actually needed:

Low Pass filter: TA:DEF EQN,"FIR(C1)",FTYPE,LOWPASS,LFREQ,71.5E+6 HZ,FWIDTH,40E+6 HZ

High Pass filter: TA:DEF EQN,"FIR(C1)",FTYPE,HIPASS,LFREQ,71.5E+6 HZ,FWIDTH,40E+6 HZ

Band Pass filter: TA:DEF EQN,"FIR(C1)",FTYPE,BANDPASS,LFREQ,60E+6 HZ,UFREQ,70E+6 HZ,FWIDTH,40E+6 HZ

Band Stop filter: TA:DEF EQN,"FIR(C1)",FTYPE,BANDSTOP,LFREQ,60E+6 HZ,UFREQ,70E+6 HZ,FWIDTH,40E+6 HZ

Raised Cosine filter: TA:DEF EQN,"FIR(C1)",FTYPE,RAISEDCOS,LFREQ,60E+6 HZ,FBETA,30 PCT

Raised Root Cosine filter :

TA:DEF EQN,"FIR(C1)",FTYPE,RSDROOTCOS,LFREQ,60E+6 HZ,FBETA,30 PCT

Gaussian filter: TA:DEF EQN,"FIR(C1)",FTYPE,GAUSSIAN,LFREQ,60E+6 HZ,70E+6 HZ,FBETA,30 PCT

Custom filter: TA:DEF EQN,"FIR(C1)",FTYPE,CUSTOM,MCOEFF,M2

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Custom Filters

CUSTOM FILTER SETUP

If the seven standard filters provided with DFP are not sufficient, you can create and use filters with virtually any characteristic, up to 1000 taps.

The required custom filter can be designed with a digital filter design or math package such as MATLAB® or Mathcad®.

The filter coefficients can then be loaded into the scope, using the DSOFilter utility. GPIB, LAN, or a serial RS-232 connection between the PC and oscilloscope is required. However, if these connections are not available, it is also possible to load the file with a diskette.

DSOFilter is an ActiveX control that can be downloaded free of charge from LeCroy's web site at www.lecroy.com.

Following are two examples of how custom filters can be created and loaded into the scope with DSOFilter. The first demonstrates a filter design using the Mathcad program. The second shows how to use an Excel spreadsheet. Both examples use the DSOFilter utility for downloading coefficients in the scope.

Example 1: Using Mathcad 2000 (Visual Basic Script)

Sending FIR coefficients to a DSO from Mathcad, using the LeCroy DSOFilter Control:

i := 0..200

sinx(x) := sin(x)/x

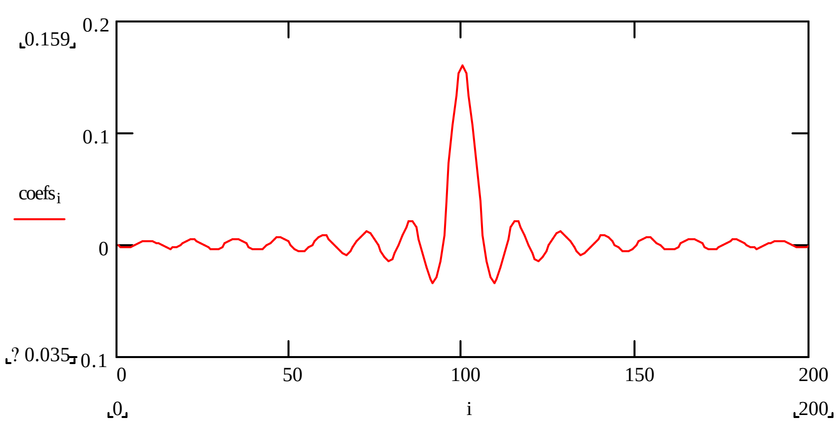
$$coefs_i :? \frac{1}{2?}\,\text{sin}\;x?\frac{?i\;?\;100.0001?}{2}?$$

200 point sin(x)/x, a low-pass filter.

Note: Real world filters would either be windowed or made by the Remez exchange algorithm. The point of this example is not to make a good filter, but to show how to transfer a filter to the scope.

$$check :? \;?\; coefs$$

check = 0.987   This is the DC gain of the filter



To send it, we need to include the LeCroy DSOFilter Control, which is an ActiveX control, as a scriptable object. Remember the name you specify for this instance of the ActiveX control. Mathcad acts as an ActiveX scripting host. It makes the methods of the object available using the name you specified. It invokes a VBScript interpreter (because this example uses VBScript as the scripting language) and calls three routines: ScriptObj_Event.Start(), ScriptObj_Event.Exec (Inputs, Outputs), and SciptObjec_Event.Stop(). Mathcad calls these three in order when calculating. Mathconnex can Start, followed by 0, 1, or many invocations of Exec, followed by Stop.

To make the connection to the ActiveX control choose Insert, Component, Scriptable Object; then click Next.

Check "New" and select "LeCroy DSOFilter Control" from the list. (If you don't see it, the control has not been installed). Click Next.

Select "VB Script Language." This tells Mathcad, the scripting host, which interpreter to load. Click Next.

Give this object a Name. For this example, accept the default name "ScriptObj".
The VBScript uses this name to access the object's methods. For example: ScriptObj.Beep().
Set this object to require 2 inputs from Mathcad and to return no output values.
In this example the two inputs to the script are the coefficient array, and a value specifying the number of points in the array. The destination is assumed to be M1. The connection is assumed to be at GPIB address 5. These assumptions could be eliminated. Only the "_Exec" function takes arguments, so the connect method could be called from ScriptObjEvent_Exec() instead of ScriptObjEvent_Start(), and we could pass in an extra argument to specify the connection method, as a string, from Mathcad.

The format of the string would be, for example, either "GPIB: 5" or "COM1: 19200,8,N,1" (RS-232 on COM1, at 19200 baud, 8 bits per character, no parity, one stop bit; the other choices for parity are E for even or O for odd) or "IP: 128.211.87.234". Similarly, if ScriptObjEvent_Exec() took four arguments, the fourth could be a string specifying the destination. This fourth string would be passed to the SetFilter method of the DSOFilter control instead of the fixed string "M1". The script uses the inputs from Mathcad to invoke the SetFilter method of the object.

DSOFilter
(coefs 201)

The script that is run to connect Mathcad to the DSOFilter Active X control for this example is:

```
Sub ScriptObjEvent_Start()
  REM Set up - tell the DSOFilter how to talk to the scope
  ScriptObj.Connect("GPIB: 5")
End Sub

Sub ScriptObjEvent_Exec(Inputs,Outputs)
  REM Get the inputs
  numcoefs = Inputs(1).Value
  REM Need numcoefs as Long
  numcoefs = CLng(numcoefs)
  REM Send the coefficients to M1 - have to put them in an array
  Dim coefs(999)
  Dim foo
  foo = inputs(0).value      ' assign inputs(0).value to a local variable
  For i = 0 to numcoefs-1
    dtmp = foo(i)
    coefs(i) = CSng(dtmp)  ' they can be double, too; but single is enough
  Next
  retval = ScriptObj.SetFilter( "M1", numcoefs, coefs)
  If (retval = False) Then
    MsgBox( "SetFilter returned False - problem")
  End If
  REM Make the scope beep to make sure we got here
  ScriptObj.Beep()
End Sub
Sub ScriptObjEvent_Stop()
  REM Nothing to do for clean-up
End Sub
```

Example 2: Sending FIR Coefficients from Excel

When you start the DSOFilt utility, an Excel spreadsheet similar to the following one opens. (You must enable macros beforehand in the pop-up dialogue box.) In this example, a low-pass filter with 200 coefficients is specified on the Excel spreadsheet. The PC is connected to the oscilloscope via a GPIB connection. Click the "Make Scope Beep" button to check this connection. A beep will be heard after a few seconds.

After ensuring that the connection works properly, the coefficients may be sent. First, a destination must be specified (such as memories M1–M4 in the DSO). It is also possible to send the coefficients to a file. In that case, a filename must be specified.

Note: If other than GPIB serial connection between the PC and the scope is used (such as RS-232 or Ethernet 10/100 MB/s), GPIB: 5 should be set for the correct connection type.

RS-232

- COM1: 19200,8,N,1 (COMn: baud, bits, parity, stop)

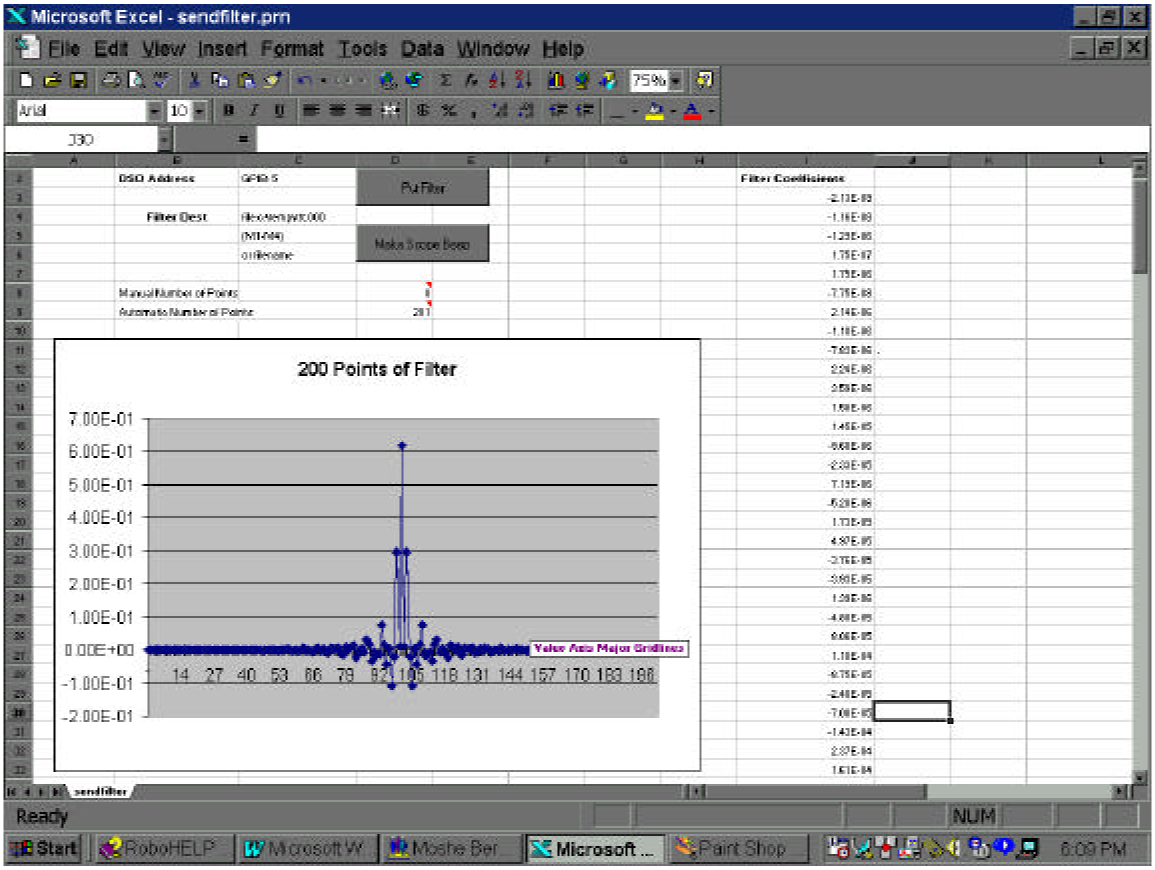
LAN (Ethernet 10/100)

- IP: 128.211.87.234 (IP: a,b,c,d)

Click the "Put Filter" button to send the list of coefficients. Upon completion, the beep is sounded again.

Number of Points: If “Manual Number of Points” is set to 0, the “Automatic Number of Points” is determined by the number of coefficients, However, if “Manual Number of Points” is other then 0, it overrides the Automatic setting, making it possible to examine the results with only a limited number of coefficients before employing the full filter.

Notes: 1. The chart is used only as a display tool. It shows the filter in the time domain, but it has no influence on operation.
2. You may simply replace the coefficients in the example with your filter's coefficients.


Microsoft Excel - sendfilter.prn
File Edit View Insert Format Tools Data Window Help
DSO Address
GPIB 5
Put Filter
Filter Dest
Make Scope Beep
Manual Number of Points
Automatic Number of Points
Filter Coefficients
200 Points of Filter
7.00E-01
6.00E-01
5.00E-01
4.00E-01
3.00E-01
2.00E-01
1.00E-01
0.00E+00
-1.00E-01
-2.00E-01
Value Axis Major Gridlines
sendfilter
Ready
NUM
Start
RoboHELP
Paint Shop
6:09 PM

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Multirate Filters

DESCRIPTION

In many of today's development environments, digital filter design has become most challenging. Specifications typically require higher order filters, implying increased storage capacity for filter coefficients and higher processing power. Moreover, high-order filters can be difficult, if not impossible, to design. In applications such as 3G wireless systems, for example, at the receiver end data must be filtered in large magnitude in order to be processed.

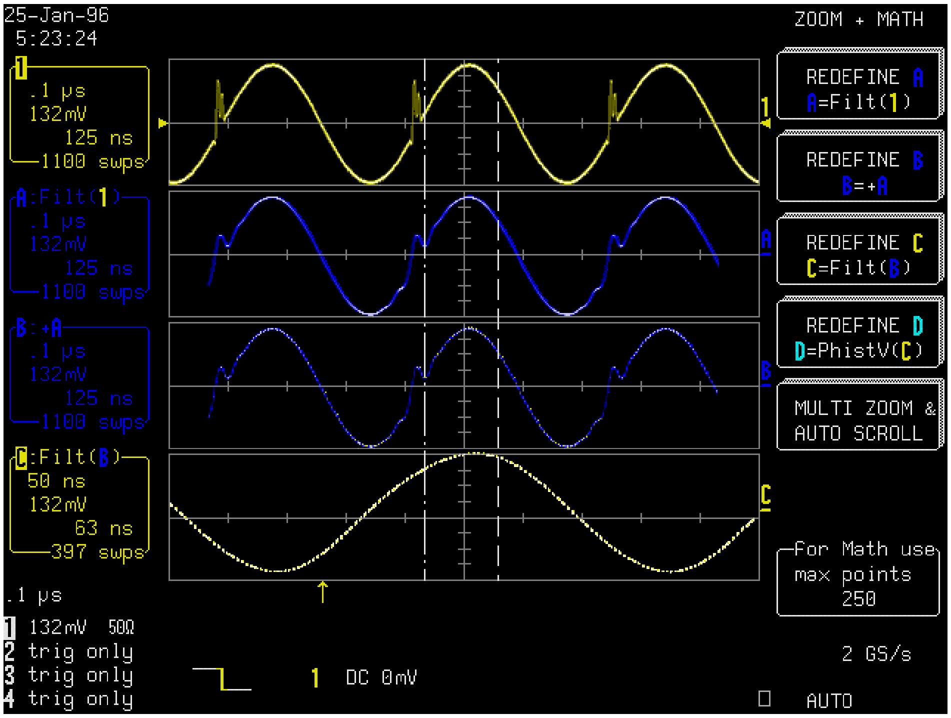
Although the LeCroy DFP option provides many filter types, the correlation between edge frequencies and sample rate may be a limiting factor: edge frequencies are limited from 1% to 49.5% of the sample rate, while the minimum transition width region is 1% of the sample rate.

Multirate, multistage filters are a practical solution for the design and implementation of FIR filters with narrow spectral constraints. Multirate filters change the input data rate at one or more intermediate points within the filter itself, while maintaining an output rate that is identical to the input rate. This approach provides a solution with greatly reduced filter lengths, as compared to standard single-rate filters.

This can be achieved in two or more simple steps. First, a filter (with a relative limited edge frequency) is applied and the results are decimated. Then, a second filter is applied to the decimated waveform, substantially reducing the lower edge frequency limit.

EXAMPLE

A sine wave with a frequency of 3 MHz has a higher frequency noise component. A low-pass filter is required to remove the noise component. The sample rate of the scope is 2 GS/s. The minimum edge frequency of the low-pass filter for this sample rate is 20 MHz. While this filter is sufficient for removing part of the noise, it cannot remove the high frequency component completely. In such a case, the problem can be solved in two stages.



1. Channel 1 represents a noisy sine wave with a frequency of 3MHz.
2. The first low-pass filter with 20 MHz edge frequency and 30MHz transition region is applied.
3. Trace B is a decimated version of trace A. This is accomplished by using the identity function and setting "for Math use" in the ZOOM & MATH menu to 250 points.
4. A second low-pass filter with an edge frequency of 5 MHz and a transition region width of 6 MHz is applied to trace B. The result is displayed in trace C.
5. Trace C shows the zoomed signal, which was filtered by a multistage filtering method. Notice that all high frequency noise components were removed.

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Specifications

- The pass-band gain of all filters (except custom) is normalized to 1.
- The group delay of all filters is 0.
- The maximum number of coefficients for all filters is less than 1000.
- The number of input data points in memory should exceed that of coefficients by a factor of 10.
- The minimum transition region width is 1% of the sample rate.
- Edge frequencies for the low-pass, high-pass, band-pass, and band-stop filters are a minimum 1% of the sample rate. (It is possible to further reduce the lower limit by using a multirate filter system using multiple filters and an identity — sparse — function.)
- The grain (minimum step) for setting frequencies is 0.1% of the sample rate; for widths it is 0.02% of the sample rate; and for fractions (e.g., ?) it is 0.1%.

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