Instruction Manual

DFP2
Digital Filter Package
Digital Filter Package 2 Software Instructions

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About This Software Manual

This manual covers the operation of the DFP2 software.

With the introduction of later versions of the 64-bit MAUI software, particularly version 8.3 and later, the graphical user interface on some instruments looked very different from what was offered on earlier instruments and included different touch screen capabilities.

In particular, software running on oscilloscope models without the OneTouch features may look somewhat different than what is shown in this manual. Despite the difference in appearance, however, the functionality is the same unless otherwise stated. Where there are differences or limitations in capabilities, these are explained in the text.
Introduction

With Digital Filter Package 2 (DFP2), Teledyne LeCroy provides a solution that includes seven of the most widely used Finite Impulse Response filters (FIR) and four Infinite Impulse Response (IIR) filters (Butterworth, Chebyshev, Inverse Chebyshev, Bessel). You can easily set the Cutoff Frequency in addition to the Stop Band Attenuation and Pass Band Ripple for each filter.

It is even possible to use single filters or multiple filters cascaded for even more complex filtering. Once filtered, waveforms include mostly relevant frequency components, undesired parts being greatly attenuated.

If you want filters with special characteristics, 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 with a math package such as MATLAB, Mathcad, or Excel. Filter coefficients can be directly downloaded from the program into the instrument.

DFP2 filters are added to the oscilloscope’s standard menu of Math operators, enabling them to be coupled with other Teledyne LeCroy software products to provide improved solutions.
Low-pass filters are useful for eliminating accumulated high-frequency noise and interference, and for canceling high-frequency background noise.

Example applications are: 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 filters are useful for eliminating DC and low-frequency components. Example applications are: 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.
Band-pass filters are useful for emphasizing a selected frequency band.

Example applications are: 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.

Example applications are: 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.
Communications Channel Filters

Raised Cosine

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.

Example applications are: 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 $0.5\cos(a) + 0.5$, where $a$ ranges from 0 to $p$ over the transition region. This region is determined by $b$, 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:

$$h(t) = \frac{\sin\left(\pi \frac{t}{T_s}\right)}{\pi \frac{t}{T_s}} \cos\left(\pi \frac{t}{T_s}\right)$$
**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 \(0.5[\cos(a) + 0.5]^{1/2}\), where \(a\) ranges from 0 to \(p\) over the transition region. This region is determined by \(b\), 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:

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

**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:

\[B = \text{half power bandwidth}\]

\[T = \text{bit (or modulation period)}\]
IIR Filters

Infinite Impulse Response (IIR) filters are digital filters that emulate analog filters. The four types offered by the DFP2 option are:

- Butterworth
- Chebyshev
- Inverse Chebyshev
- Bessel

The Butterworth or "maximally flat" filter has the flattest amplitude response of all the available filters. The Bessel filter is noted for its uniform phase response as a function of frequency. The following figure shows a comparison between Butterworth and Bessel filters. Note that the Bessel filter has a wider transition bandwidth, but linear phase within the pass band.

If you need the fastest rolloff, the Chebyshev filters have the narrowest transition region for a given number of stages. However, the Chebyshev filter has ripple in the pass band, while the Inverse Chebyshev filter exhibits a flat pass band response, but has ripple in the stop band.

In the setup of these filters, you have control of cutoff frequencies, transition region width, and stop band attenuation.
Filter Set Up

DFP2-specific operators are added to the instrument’s Math Filter submenu when the option is activated. To apply a DFP filter to a source input:

2. Open an available Function (Fn) dialog.
3. Choose to create a Single function if you want to perform just one filtering function on the trace, or Dual to perform additional math on, or apply a second filter to, the filtered output trace. See Multirate Filters for more information.
4. Touch Source1 and select the waveform to be filtered, or if OneTouch is available, drag the source descriptor box to the Source1 field.
5. In Operator1, choose the Filter operator from the Filter submenu.

Filter Subdialog

1. On the Filter subdialog, touch FIR/IIR and make your selection:
   - FIR (non-recursive) filters require a limited number of multiplications, additions, and memory locations.
   - IIR (recursive) filters, which are dependent on previous input or output values, in theory require an infinite number of each.
2. Touch Filter Kind and select a filtering operation. Some choices are not available for IIR.
3. If using a FIR filter:
   - Auto Length is selected by default to allow the oscilloscope to calculate the optimum number of taps based on the characteristics of the input signal. Alternatively, you can deselect Auto Length and touch Taps to enter a number.
   - For Cosine, Raised Root Cosine, or Gaussian filters, enter the respective Beta value.
   - Note: The suggested number of taps is a minimum required to meet the specification. Using more taps can give a more desirable response.
4. If using an IIR filter:
   - Touch Type and choose the filter type. See IIR Filters for more information.
   - Enter the number of StartupSamples.
   - Auto Length is selected by default to allow the oscilloscope to calculate the optimum number of stages based on the characteristics of the input signal. Alternatively, you can deselect Auto Length and touch Stages to enter a number.
Frequencies Subdialog
Depending on the class and kind of filter you selected, and whether or not Auto Length is enabled, you can change the Cutoff Frequency, Transition Width (edge width), Stop Band Attenuation, and Pass Band Ripple on the Frequencies subdialog. See the descriptions of each filter type for recommendations.

Frame Subdialog
This dialog only appears when you have selected to ReFrame Output. It offers the option to Always Fit Frame to Data (default), or to manually Fit Frame to Data Now when the Always Fit Frame... option is deselected.
Multirate Filters

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 very tightly in order to be processed.

Although the DFP2 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 a few simple steps by using the instrument’s built-in Dual function Math feature, or by chaining math functions (using one function as the source of another). For 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 three stages:

1. A first filter (with a relatively limited edge frequency) is applied.
2. The results of the first filter are decimated (using a sparsing function).
3. A second filter is applied to the decimated waveform, substantially reducing the lower edge frequency limit.

The last trace in the image below shows the zoomed trace of a signal which was filtered by a multistage filtering method. Notice that all high frequency noise components were removed.
The traces in the diagram above show (top to bottom): 1. A noisy sine wave with a frequency of 3 MHz; 2. The first low-pass filter applied with 20 MHz edge frequency and 30 MHz transition region; 3. A sparsed version of trace 1; 4. A second low-pass filter with an edge frequency of 5 MHz and a transition region width of 6 MHz applied to the sparsed trace in 3.
Custom Filters

If the standard filters provided with DFP2 are not sufficient for your needs, you can create filters with virtually any characteristic, up to 2000 taps. Choose a Filter Kind of Custom, then upload your Coefficients File.

The required Coefficients File is an ASCII file consists of numbers separated by spaces, tabs, or carriage returns. It can be designed with a digital filter design or math package such as MATLAB or Mathcad.

Note: Do not use commas as separators.

For a custom IIR filter there should be a multiple of 6 numbers. Each stage consists of 3 numbers for the numerator polynomial followed by 3 numbers for the denominator polynomial. They are in the order a b c where the polynomial is of the form: \( a + b \times z^{-1} + c \times z^{-2} \).
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