U.S. Government Rights

The Software is “commercial computer software,” as defined by Federal Acquisition Regulation (“FAR”) 2.101. Pursuant to FAR 12.212 and 27.405-3 and Department of Defense FAR Supplement (“DFARS”) 227.7202, the U.S. government acquires commercial computer software under the same terms by which the software is customarily provided to the public. Accordingly, Keysight provides the Software to U.S. government customers under its standard commercial license, which is embodied in its End User License Agreement (EULA), a copy of which can be found at www.keysight.com/find/sweula. The license set forth in the EULA represents the exclusive authority by which the U.S. government may use, modify, distribute, or disclose the Software. The EULA and the license set forth therein, does not require or permit, among other things, that Keysight: (1) Furnish technical information related to commercial computer software or commercial computer software documentation that is not customarily provided to the public; or (2) Relinquish to, or otherwise provide, the government rights in excess of these rights customarily provided to the public to use, modify, reproduce, release, perform, display, or disclose commercial computer software or commercial computer software documentation. No additional government requirements beyond those set forth in the EULA shall apply, except to the extent that those terms, rights, or licenses are explicitly required from all providers of commercial computer software pursuant to the FAR and the DFARS and are set forth specifically in writing elsewhere in the EULA. Keysight shall be under no obligation to update, revise or otherwise modify the Software. With respect to any technical data as defined by FAR 2.101, pursuant to FAR 12.211 and 27.404.2 and DFARS 227.7102, the U.S. government acquires no greater than Limited Rights as defined in FAR 27.401 or DFAR 227.7103-5 (c), as applicable in any technical data.

Safety Notices

CAUTION

A CAUTION notice denotes a hazard. It calls attention to an operating procedure, practice, or the like that, if not correctly performed or adhered to, could result in damage to the product or loss of important data. Do not proceed beyond a CAUTION notice until the indicated conditions are fully understood and met.

WARNING

A WARNING notice denotes a hazard. It calls attention to an operating procedure, practice, or the like that, if not correctly performed or adhered to, could result in personal injury or death. Do not proceed beyond a WARNING notice until the indicated conditions are fully understood and met.
## Contents

1  Equalization

   Equalization Background / Theory  / 6
      The Problem  / 6
      Inter-Symbol Interference (ISI)  / 7
      The Solution: Equalization  / 9

   Feed-Forward Equalization (FFE)  / 10
      Mathematical Description of FFE  / 10
      Description of FFE Acting on a Waveform  / 11
      FFE Decision Diagram  / 13
      Understanding FFE Through Frequency Response Plots  / 13

   Continuous Time Linear Equalization (CTLE)  / 16

   Decision Feedback Equalization (DFE)  / 17
      Mathematical Description of DFE  / 17
      Description of DFE Acting on an Eye Diagram  / 18
      DFE Decision Diagram  / 20
      Understanding DFE Through Frequency Response Plots  / 21
      DFE Questions & Answers  / 23

   Taps  / 26
      How Many Taps Should You Use?  / 26
      What Tap Values Should You Use?  / 26

   Using the Equalization Wizard  / 28
      Step 1: Primary Configuration  / 28
      Step 2: Secondary Configuration  / 31
      Step 3: Thresholds  / 32
      Step 4: Clock Recovery  / 34
      Step 5: Acquisition  / 36
      Step 6: FFE/CTLE Setup  / 38
      Step 7: DFE Setup  / 41

   Manually Setting Up Equalization  / 43
      Setting Up Your Signal  / 43
      Available Equalization Setups  / 44
Equalization Dialog Box / 47
  Linear Eq (FFE/CTLE) Tab, FFE Selected / 48
  Linear Eq (FFE/CTLE) Tab, CTLE Selected / 50
  Equalization FFE/CTLE Scaling Dialog Box / 54
  Decision Feedback Eq (DFE) Tab / 54
  Advanced (FFE/CTLE) Tab / 56
  Bandwidth Limit Control / 58

Equalization Tap Setup Dialog Box / 61
  FFE Taps Tab / 61
  DFE Taps Tab / 63

Equalization Auto Tap Setup Dialog Box / 65
1 Equalization

There are two ways to set up the Infinium Serial Data Equalization application:

- The Equalization Wizard is the recommended setup method because it guides you through the process in a simplified, step-by-step fashion. See "Using the Equalization Wizard" on page 28.

- If you are comfortable with the Equalization dialog box controls and are familiar with equalization, you can use the manual setup method. See "Manually Setting Up Equalization" on page 43.

See Also If you prefer to view a PDF version of this help, see Equalization User's Guide.

NOTE You must have the D9020ASIA Advanced Signal Integrity Bundle installed on your oscilloscope to have access to the features described below.
Equalization Background / Theory

To understand how equalization works, you first need to understand the problem it corrects.

Next: "The Problem" on page 6

The Problem

A serial signal consists of a transmitter sending a signal over a transmission channel (examples: backplane, cable) to a receiver. As the signal rate increases, the channel the signal travels through distorts the signal at the receiver. This distortion can result in a partially or completely closed eye diagram where the clock or data cannot be extracted by the receiver. To recover a clock or data from the eye diagram, the eye must be re-opened. This is where equalization can help.

As shown in the following diagram, you can see that an open, clean eye leaves the transmitter and is sent through the channel. As it passes through the channel, random noise, crosstalk, and inter-symbol interference (ISI) distort the signal. These factors can cause the eye to close. In the diagram $s(t)$ is the transmitted signal, $r(t)$ is the received signal, and $e(t)$ is the equalized signal.

You can use equalization to re-open the eye by correcting for the ISI because ISI is deterministic (that is, the ISI can be determined prior to transmission).

The random noise that was introduced cannot be corrected for by equalization because it is non-deterministic. Therefore, you can re-open the eye, but maybe not completely due to the inability to correct for this random noise.

To see why ISI (and the closing of the eye) causes problems when analyzing serial data, look at the following two screen shots showing a data signal before and after traversing a backplane.
Looking at the five bits labeled 5, 4, 3, 2, and 1, you see the logical pattern is 11110 (decision threshold of V = 0). Also, notice even though the bit indicated by the arrow (bit 1) is a logical zero when it is transmitted, the logic level of the bit as seen by the receiver is right around the decision threshold. It may, therefore, be inaccurately counted as a logical one. This occurred because the frequency response of the backplane filtered out the high-frequency content of the waveform.

It is vital that your receiver measures the same pattern the transmitter sends. Equalization is a technique used to ensure this occurs.

Next: “Inter-Symbol Interference (ISI)” on page 7

Inter-Symbol Interference (ISI)

Inter-symbol interference (ISI) is caused by the non-flat frequency response of the channel the signal travels through (high frequencies exhibit more loss than low frequencies) and results in the distortion of pulse shapes in your signal.

Look at the following simplified frequency response plot.
You can see that at low frequencies, the frequency response is flat (like you want), but as the frequency increases, there is a drop in the amplitude. If your signal contains frequency components in this region, it will be distorted.

For example, imagine you are trying to send a serial data sequence (11010 . . .) from a transmitter, through a channel, and to a receiver. Theoretically, you could send each one of these bits as square pulses from the transmitter. In real life, however, you are limited by bandwidth and, therefore, they are somewhat rounded.

As this data sequence is sent through the channel, the medium it is traveling through distorts the rounded pulses by smearing and elongating them (the degree of this distortion depends on the frequency components). This can cause each bit to have some of its energy overlap with neighboring bits, thus impacting the voltage level of those bits. When the signal exits the channel and enters the receiver, the receiver may measure different bit voltage levels as a result.

If you were to plot an eye of a serial signal with high enough frequency components that ISI is a significant problem, you would see that the low-frequency trajectories of the waveform would still be accurate, but the high-frequency components would be attenuated, resulting in either the complete or partial closing of the eye.

ISI is caused by a combination of:
- The geometry of the circuit (that is, the design of the trace)
- The medium from which it is composed (that is, the conductor or dielectric)

Each of these factors can be determined prior to signal transmission. Hence, ISI is deterministic, and due to this, you can correct for it with equalization techniques.

Next: "The Solution: Equalization" on page 9
The Solution: Equalization

The main purpose of equalization is to correct for the problems caused by the transmission channel. Equalization techniques provide a way to discern the original signal (the signal coming out of the transmitter) given a distorted signal at the receiver.

In other words, equalization corrects for the high-frequency component voltage levels and, in the process, corrects the trajectories of these components in the corresponding eye diagram (that is, opens up the eye).

<table>
<thead>
<tr>
<th>Unequalized 6 Gb/s Eye Diagram</th>
<th>Equalized 6 Gb/s Eye Diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td>Notice that the eye is completely closed.</td>
<td>Notice that the eye is now open after equalization was applied.</td>
</tr>
</tbody>
</table>

The Infiniium oscilloscope has three equalization methods available:

- "Feed-Forward Equalization (FFE)" on page 10
- "Continuous Time Linear Equalization (CTLE)" on page 16
- "Decision Feedback Equalization (DFE)" on page 17
Feed-Forward Equalization (FFE)

Feed-Forward Equalization (FFE) is an equalization technique so named because, unlike "Decision Feedback Equalization (DFE)" on page 17, FFE corrects the received waveform with information about the waveform itself and not information about the logical decisions made on the waveform. FFE basically acts like a FIR (finite impulse response) filter and uses the voltage levels of the received waveform associated with previous and current bits to correct the voltage level of the current bit.

One key thing to remember when working with FFE is that the equalization is performed on the actual waveform. At no point in the FFE algorithm are logical decisions made (is this bit a 1 or a 0?). Instead, FFE is concerned only with correcting voltage levels in the waveform. This is in direct contrast to Decision Feedback Equalization (DFE).

FFE is described in four different ways in this section. Each description contains the same basic content, but lets you choose the viewpoint that best suits your understanding.

- "Mathematical Description of FFE" on page 10
- "Description of FFE Acting on a Waveform" on page 11
- "FFE Decision Diagram" on page 13
- "Understanding FFE Through Frequency Response Plots" on page 13

In addition to FFE, the Infiniium oscilloscope can also perform Decision Feedback Equalization (DFE) or both DFE and FFE in combination.

See Also
- "Continuous Time Linear Equalization (CTLE)" on page 16
- "Decision Feedback Equalization (DFE)" on page 17

Mathematical Description of FFE

For the purpose of this discussion, assume the FFE algorithm we are using has three taps. (For more information on taps and how to determine the number to use, see "Taps" on page 26.) Taps are unitless correction factors applied to voltage levels to correct them. One way to think of these correction factors is to view them as the ratio of the voltage the receiver should have seen to the voltage the receiver did see.

The mathematical description of a three-tap FFE is as follows:

\[ e(t) = c_0r(t-0T_D) + c_1r(t-1T_D) + c_2r(t-2T_D) \]

where:
- \( e(t) \) is the corrected (or equalized) voltage waveform at time \( t \).
- \( T_D \) is the tap delay.
• \( r(t-nT_D) \) is the uncorrected input waveform \( n \) tap delays before the present time.
• \( c_n \) is the correction coefficient (tap) multiplied with the version of the uncorrected waveform that has been time-advanced by \( n \) tap delays.

So FFE obtains the corrected (or equalized) voltage level at the location of interest on the waveform (time \( t \)) by forming a sum of the taps and voltage levels of the previous two tap-delayed locations as well as the location of interest before being equalized.

Notice that if the FFE method above used a tap delay equal to one unit interval, then it would use three bits to correct one bit (it uses the bit of interest and the previous two bits). This is because we used three taps in the algorithm. If we had used five taps then the equation above would have two more terms added to the sum \([c_3r(t-3T_D)\text{ and } c_4r(t-4T_D)]\), which would mean the FFE algorithm would have used the bit of interest and the previous four bits to correct the bit of interest's voltage level.

Description of FFE Acting on a Waveform

Another way to understand FFE is to see how it acts on a waveform. Assume the unequalized waveform measured at the receiver looks like the following:

![Waveform](image)

Now, apply FFE and see how it progresses along the signal to correct it. Again, assume we are using three taps in our FFE algorithm.

![ corrected waveform ](image)
Equalization

The part of the waveform labeled as the "location of interest" is the voltage we are trying to correct (or equalize). The locations on the waveform marked 1 and 2 are determined by the tap delay you specify. Location 1 is one tap delay away from the location of interest and location 2 is two tap delays away from the location of interest.

It is important to note that we are working just with voltage levels in the waveform. At no point in the process are we going to use logical decisions (1's or 0's) in the FFE algorithm.

First we need to know the tap values for the distortion present in our transmission channel. Determining these values is discussed in "Taps" on page 26. For now, assume these three tap values have been determined (call them Tap0, Tap1, and Tap2 corresponding to $c_0$, $c_1$, and $c_2$ in the equation above).

The oscilloscope measures the voltage of the location of interest (location 0) and then multiplies it by the Tap0 value. Then the oscilloscope measure the voltage of location 1 and multiplies it by the Tap1 value. Next, the oscilloscope measures the voltage of location 2 and multiplies it by the Tap2 value. Finally, the oscilloscope adds each of these voltage/tap products together to obtain the corrected (or equalized) voltage for location 0. The voltage at the location 0 will then be adjusted to this corrected value.

Now the three Xs move along with the sampling rate to their next locations on the waveform.

![Diagram of waveform with labels 1, 2, and 0](image)

Notice the old "location of interest" (now labeled 1) has its new equalized voltage level. You can see the tap values caused the voltage level to drop for that location.

The same process is repeated for the new location of interest. Location 0's voltage level is multiplied by Tap0 and then added to the product of location 1's voltage and Tap1. Finally, this is added to the product of location 2's voltage and Tap2 to give bit 0's new corrected voltage.

The three Xs will then move along with the sampling rate again to their new locations and repeat the entire process. This continues until the entire waveform has been traversed.
FFE Decision Diagram

It may also be useful to see the decision diagram for a three-tap FFE.

where:
- \( r(t-\text{nT}_D) \) is the input waveform \( \text{n} \) tap delays before the present time.
- \( C_n \) is the \( n^{th} \) coefficient (tap).
- \( \text{T}_D \) is the tap delay.
- \( e(t) \) is the equalized waveform at time \( t \).
- CDR is Clock/Data Recovery.

This is just a different way of looking at the process described in the previous two sections. Again you see that each voltage level is multiplied by its corresponding tap value and then all of these products are summed together to give the new equalized voltage for the location of interest.

Understanding FFE Through Frequency Response Plots

One final way to understand FFE is in terms of the frequency response plot of your signal.
Ideally, you would like to transmit a signal whose frequency response was flat over the full bandwidth of the signal so every frequency component of the signal was equally represented. However, the channel sometimes attenuates the signal at higher frequencies (as shown in the plot above).

To correct for this attenuation, we can apply a peaking filter via equalization. With FFE, we apply a filter response as shown in the plot below (dashed line) such that the sum of the peaking filter response and the channel response yields a flat frequency spectrum (red line in plot below).
Remember, inter-symbol interference (ISI) is a result of the non-flat response of the channel. When we flatten the response, we are eliminating the ISI.
Continuous Time Linear Equalization (CTLE)

Continuous Time Linear Equalization (CTLE) is an alternate linear equalization method to Feed-Forward Equalization (FFE). It acts as a linear, low-pass filter. CTLE is defined in the frequency domain.

CTLE is standards-driven, so many of the coefficient values you enter come from the standard.

When you select the **CTLE** method in the Equalization dialog box (**Analyze > Equalization...**), the equation or graph for the filter is shown, and the remaining fields in the dialog box let you enter values for the equation's variables.

See: "Linear Eq (FFE/CTLE) Tab, CTLE Selected" on page 50.

See Also

- "Feed-Forward Equalization (FFE)" on page 10
- "Decision Feedback Equalization (DFE)" on page 17
Decision Feedback Equalization (DFE)

Decision Feedback Equalization (DFE) is an equalization technique so named because it makes logical decisions (whether a bit is a 0 or a 1) and then feeds that information back to help determine whether the current bit is a 1 or a 0.

There are multiple ways to implement DFE. This topic discusses the DFE algorithm used in the Infiniium oscilloscope.

Note that real-time eye must be enabled on the source signal in order to enable DFE.

DFE is described in four different ways. Each description contains the same basic content, but lets you choose the viewpoint that best suits your understanding.

- **Mathematical Description of DFE** on page 17
- **Description of DFE Acting on an Eye Diagram** on page 18
- **DFE Decision Diagram** on page 20
- **Understanding DFE Through Frequency Response Plots** on page 21

The Infiniium oscilloscope can also perform Feed-Forward Equalization (FFE) or both DFE and FFE in combination.

**NOTE**

Jitter analysis can be performed when DFE is enabled (on non-return-to-zero signals). However, jitter graphs are not valid and are not displayed when DFE is enabled.

**See Also**

- **DFE Questions & Answers** on page 23
- **Feed-Forward Equalization (FFE)** on page 10
- **Continuous Time Linear Equalization (CTLE)** on page 16

**Mathematical Description of DFE**

For the purpose of this discussion, assume the DFE algorithm we are using has two taps. Taps are unitless correction factors applied to voltage levels to correct them. One way to think of these correction factors is to view them as the ratio of the voltage the receiver should have seen to the voltage the receiver did see.

Before looking at the mathematical description of DFE, it is important to understand the results of the algorithm. Generally, DFE calculates a correction value that is added to the logical decision threshold (the threshold above which the waveform is considered a logical high and below which the waveform is considered a logical low). Therefore, DFE results in the threshold shifting up or down so new logical decisions can be made on the waveform based on this new equalized threshold level.
The mathematical description of the correction value added to the decision threshold for a two-tap DFE is as follows:

\[ V(k) = c_1 s(k - 1) + c_2 s(k - 2) \]

Where:
- \( V(k) \) = the correction voltage added to the decision threshold used when determining the logic value of bit \( k \).
- \( s(k-n) \) = the logic value of the data bit located \( n \) bits prior to bit \( k \).

The logic high value of \( s(n-k) \) is equal to the Upper Target field in the user interface while the logic low value of \( s(n-k) \) is equal to Lower Target (for more information on the Upper and Lower Target fields, see "DFE Taps Tab" on page 63).
- \( c_n \) = the correction coefficient (tap) for the bit \( n \) bits prior to the bit of interest.

So, for DFE to obtain the corrected voltage offset for the threshold level at the bit of interest, it first needs to be seeded with the correct bit values for the first several bits to get started. Assuming the logical decisions for the first several bits are correct, the algorithm can feed them forward to determine the logical value of the current bit.

For a two-tap DFE, the two bits previous to the current bit need to have their bit levels already determined. Then the algorithm multiplies their bit levels by their corresponding tap values. The sum of these two tap/bit level products gives the amount the decision threshold should be shifted. However, instead of shifting the threshold, the Infiniium oscilloscope leaves this constant and shifts the waveform relative to it.

Notice the DFE method above used two previous bits to correct the current bit. This is because we used two taps in the algorithm. If we had used four taps, the equation above would have two more terms added to the sum \([c_3 s(k-3) \text{ and } c_4 s(k-4)]\), which would mean the DFE algorithm would have used the previous four bits to correct the bit of interest's voltage level.

Also notice the bit of interest is not used in the summation. FFE uses previous bits and the current bit in its sum, but DFE uses only previous bits.

**Description of DFE Acting on an Eye Diagram**

Another way to understand DFE is to see how it acts on an eye diagram.

First, look at the following segment of a serial data signal.
The vertical red bars on the waveform correspond to the clock edges for each bit and the red segments at the bottom of the figure delineate the three unit intervals (UI) that will be overlapped on the display to form an eye diagram. The gray line is the logical threshold level (bits with voltages above this are considered logical 1s and those with voltages below this are considered logical 0s).

Now if you overlap these three unit intervals to form an eye diagram, the logical high voltage levels for unit intervals 2 and 3 will not be as high as unit interval 1. In other words, the trajectories from unit intervals 2 and 3 will result in the partial closing of the eye.

Let us equalize the voltage for bit 4 using two taps to correct unit interval 3.

First, we need to know the tap values for the distortion present in our transmission channel. Determining these values is discussed in "Taps" on page 26. For now, assume these two tap values have been determined (call them Tap1 and Tap2 corresponding to c1 and c2 in the equation above).

The DFE algorithm is first seeded with the correct bit values (high or low) for the first several bits to get it started. Assuming the algorithm has correctly determined the initial bit values, it can feed forward previous bit values to determine the current bit. So, for our example, we assume the oscilloscope has already determined that bit 2 is low and bit 3 is high.

The DFE algorithm would then take the ideal high value for the third bit (+1, for example) and multiply it by Tap1. Then it would add this product to the product of the ideal low value for the second bit (-1, for example) and Tap2.

This sum would then give the amount the decision threshold should be shifted. The resulting threshold shift might be the shift marked by the blue line in the plot below.
Many DFE algorithms would then shift the voltage threshold (the dashed gray line) to this new voltage level at the location of the fourth bit, but the Infiniium oscilloscope does the opposite. Instead of shifting the voltage threshold down in this example, it keeps the threshold constant and shifts the bit four voltage level up by the same amount (the amount marked by the blue arrow).

This would have the effect on the eye of raising the corresponding trajectory, opening up the eye in the process.

The algorithm would then shift forward one index so the new bit of interest would be bit five and the two bits used to equalize it would be bits three and four. This process repeats itself until the entire signal has been traversed.

DFE Decision Diagram

It may also be useful to see the decision diagram for DFE.

where:

- $r(t)$ is the unequalized analog waveform voltage at time $t$.
- $s(k-n)$ is the logic value (either Upper Target or Lower Target) for the bit $n$ tap delays prior to the current bit.
- $C_n$ is the $n$th coefficient (tap).
• CDR is Clock/Data Recovery.
• V(k) is the correction voltage added to the decision threshold used when determining the logic value of bit k. (Remember that Infiniium leaves the threshold constant and shifts the waveform by this amount in the opposite direction.)

This decision diagram is just another way of looking at the process described above.

The DFE algorithm is seeded with several correct bit values to get started. Then there is a tap delay (corresponding to each clock edge) between each bit. Each previous bit used in the algorithm is determined to be either high or low and is then multiplied by its corresponding tap value. These voltage/tap products are summed to determine how much to shift the waveform relative to the logical decision threshold.

Understanding DFE Through Frequency Response Plots

One final way to understand DFE is in terms of the frequency response plot of your signal.

Ideally, you would like to transmit a signal through a channel whose frequency response was flat over the full bandwidth of the signal so every frequency component of the signal was equally represented. However, the channel response sometimes attenuates the signal at higher frequencies (as shown in the simple plot above).
To correct for this attenuation, we can apply a peaking filter via equalization. With DFE, we apply a peaking filter response as shown in the plot below (dashed line) such that the sum of the peaking filter response and the channel response yields a flat frequency spectrum (red line in plot below).

Remember inter-symbol interference (ISI) is a result of the non-flat response of the channel. When we flatten the response, we are eliminating the ISI.

To get the eye at the receiver to be the same size as the eye at the transmitter, we need to apply a gain term. To understand why the gain term is needed, remember what the frequency response looks like for FFE.
You can see we did not attenuate the low frequencies, but instead left them alone.

However, with the DFE response, we are attenuating the low frequencies because we have shifted the entire FFE response down. This means the flat response we obtain in the end will be shifted down as well. You can use the gain factor to shift the flat response back up to its correct value.

This makes the eye at the receiver the same size as the eye leaving the transmitter.

DFE Questions & Answers

- "How Do I Map DFE Voltage Tap Values to Unitless Tap Values?" on page 23
- "Why Does the DFE Real-Time Eye Have the Shape That It Does?" on page 24

**How Do I Map DFE Voltage Tap Values to Unitless Tap Values?**

In the Equalization Tap Setup dialog's **DFE Taps** group box, you find these DFE variables:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Target</td>
<td>This is the DC voltage of the one level.</td>
</tr>
<tr>
<td>Lower Target</td>
<td>This is the DC voltage of the zero level.</td>
</tr>
<tr>
<td>Gain</td>
<td>Scale to be applied to the resultant waveform to display it relative to the original DC levels of the input.</td>
</tr>
<tr>
<td>T1 ... Tn</td>
<td>Unitless tap values (Tap 1 ... Tap n).</td>
</tr>
</tbody>
</table>

To convert unitless tap values into the voltage applied to the waveform, first calculate the Amplitude (A) and Offset (O):
Amplitude (A) = (Upper Target – Lower Target) / 2
Offset (O) = (Upper Target + Lower Target) / 2

Then, for 1 tap DFE:

<table>
<thead>
<tr>
<th>Bit(0-1)</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>V = O + A * (T1 * 1)</td>
</tr>
<tr>
<td>0</td>
<td>V = O + A * (T1 * -1)</td>
</tr>
</tbody>
</table>

Or, for a 2 tap DFE:

<table>
<thead>
<tr>
<th>Bit(0-2)</th>
<th>Bit(0-1)</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>V = O + A * (T1 * -1 + T2 * -1)</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>V = O + A * (T1 * 1 + T2 * -1)</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>V = O + A * (T1 * -1 + T2 * 1)</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>V = O + A * (T1 * 1 + T2 * 1)</td>
</tr>
</tbody>
</table>

Or, for an n tap DFE:

V = O + A * Sum(Tn * (Bit(0–n) == 1 ? 1 : -1))

where Bit(0) is 1 or 0 of current bit, Bit(0-1) is 1 or 0 of previous bit, Bit(0-n) is 1 or 0 of previous nth bit, etc.

So, if you have DFE voltage tap values, H1 ... Hn, you can find the unitless tap values as follows:

Hn = O + A * Tn

Tn * A = Hn – O

Tn = (Hn – O) / A

Substituting Upper and Lower values for Amplitude (A) and Offset (O):

Tn = (Hn – (Upper + Lower) / 2)) / (Upper – Lower) / 2

Tn = 2(Hn – (Upper + Lower) / 2)) / (Upper – Lower)

Tn = (2Hn – (Upper + Lower)) / (Upper – Lower)

Why Does the DFE Real-Time Eye Have the Shape That It Does?

That is, why is there compression of the eye to the left of the bit and fanning out to the right?
Consider a case with a one-tap DFE. When the previous bit was a 0 and the current bit is a 0, DFE correction compresses the data (moves toward zero).

When the previous bit is a 0 and the current bit is a 1, correction is applied to shift the bit up. This compresses the data (moves toward zero) to the left of the bit of interest and causes it to fan out (moves away from zero) with greater amplitude to the right.

The same phenomenon occurs for 1 bits staying 1’s. They are shifted down, compressing the data. 1 bits transitioning to 0’s will be shifted down causing a compression on the left and fanning out on the right.
1 Equalization

Taps

Taps are dimensionless correction factors applied to the bit voltage levels in serial data patterns during equalization. One way to think of these correction factors is to view them as the ratio of the voltage the receiver should have seen to the voltage the receiver did see.

To see how taps are implemented in equalization, see "Mathematical Description of FFE" on page 10 and "Mathematical Description of DFE" on page 17.

• "How Many Taps Should You Use?" on page 26
• "What Tap Values Should You Use?" on page 26

How Many Taps Should You Use?

Generally, two taps will open your eye diagram significantly. However, there may be times when the signal error may span over more than two bits and in these cases, more taps will be required.

A simple way to see how many taps you need is a trial-and-error approach. Simply set the number of taps (perhaps start with 3–4) and then have the oscilloscope optimize the tap values for your signal (optimization is discussed below). Look at the tap values after they have been optimized and see if the higher tap values (for example, start with tap 4, then 3, ...) are contributing much or if they are near zero. If there is a tap value near zero, this tap is unnecessary. If all the tap values are significant then add more taps, re-optimize, and investigate again. This is a good approach if you do not know how many tap values to use for your specific setup.

Notice the user interface lets you enter up to 40 taps. More than likely, you are not going to have an error that spans 40 bits, but the oscilloscope lets you use this many taps in case you want to use more than one tap per bit. For instance, if you found you needed four taps when you used 1 tap/bit, you would probably need eight taps if you used 2 taps/bit.

What Tap Values Should You Use?

There are two ways to set up the tap values for your specific application:

• If you know what tap values to use for your device under test (DUT), you can enter them in the "Equalization Tap Setup Dialog Box" on page 61:
  a Choose Analyze > Equalization....
  b In the Equalization dialog box, click Tap Setup....
  c In the Equalization Tap Setup dialog box, select the # of Taps.
  d Enter the tap values in the Tap N fields.
• If you do not know which tap values to use, you can have the oscilloscope determine them for you through optimization.
The optimization process occurs when using the Equalization Wizard, but you can also run the optimization process from the "Equalization Tap Setup Dialog Box" on page 61:

a. Choose Analyze > Equalization....
b. In the Equalization dialog box, click Tap Setup....
c. In the Equalization Tap Setup dialog box, enter the # of Taps.
d. Click Auto Set....
e. In the Equalization Auto Tap Setup dialog box, set the controls appropriately. See "Equalization Auto Tap Setup Dialog Box" on page 65.
f. Click Run Auto Set.

The optimizer runs and reports the tap values to you in the Auto Tap Status box.

The optimized taps are automatically inserted into the Equalization Tap Setup dialog box.
Using the Equalization Wizard

The Equalization Wizard is one of two ways to set up the equalization feature. (The other way is to manually set it up—see "Manually Setting Up Equalization" on page 43.)

The wizard is the recommended setup method as it walks you through the process in a simplified, step-by-step fashion. Use the manual method only if you know exactly what you are doing and are familiar with equalization.

NOTE

The wizard does not set up your signal, so you need to have whatever channel, function, or waveform memory you want to perform equalization on already set up on the oscilloscope. The wizard will assume the signal is already there.

It is also recommended that only one signal be displayed prior to running the Wizard as it is difficult to discern one signal from another with real-time eye diagrams.

- "Step 1: Primary Configuration" on page 28
- "Step 2: Secondary Configuration" on page 31
- "Step 3: Thresholds" on page 32
- "Step 4: Clock Recovery" on page 34
- "Step 5: Acquisition" on page 36
- "Step 6: FFE/CTLE Setup" on page 38
- "Step 7: DFE Setup" on page 41

Step 1: Primary Configuration

The first step after the welcome page is the Primary Configuration page. This page provides a wide selection of options for setting up the equalization.
- **Select the signal to equalize** – Select which source you want to equalize (channel inputs, functions, or waveform memories).

  Be sure you choose the correct signal.

- **Autoscale Vertical** – This button automatically sets the vertical V/division scale and vertical offset to the optimal values for all channels.

- **Select configuration in upper or only grid** – Click the option button next to the desired selection.

  The equalization selected will be displayed in the top grid (or the whole screen if you choose to not display anything in the bottom grid during Step 2) whereas the next step will have you select the equalization method to use and display on the bottom grid.
Table 1  Equalization Configuration Selections

<table>
<thead>
<tr>
<th>Graphical Representation of Setup</th>
<th>Description of Setup</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="FFE/CTLE" /></td>
<td>FFE/CTLE is applied, but the real-time eye is not shown. Instead the waveform resulting from applying FFE/CTLE is displayed.</td>
</tr>
<tr>
<td><img src="image2" alt="Clock Recovery" /></td>
<td>No equalization is implemented and the unequalized real-time eye is displayed. This is useful if you want to have a reference to compare to. For instance, you can put the unequalized eye in the top grid and the equalized eye in the bottom grid so you can compare them on the same screen.</td>
</tr>
<tr>
<td><img src="image1" alt="FFE/CTLE" /></td>
<td>FFE/CTLE is only used to recover the clock, but the actual displayed real-time eye is unequalized. This is useful if you want to have a reference to compare to, but your unequalized eye is completely closed. You cannot recover a clock on a closed eye, so FFE/CTLE is applied to open the eye so the clock can be recovered. In other words, this options serves the same purpose as the selection immediately above it, but is used with closed eyes.</td>
</tr>
<tr>
<td><img src="image1" alt="FFE/CTLE" /></td>
<td>A FFE/CTLE eye is displayed on the oscilloscope. This is a standard FFE/CTLE implementation and can be used on partially or completely closed eyes.</td>
</tr>
<tr>
<td><img src="image1" alt="FFE/CTLE" /></td>
<td>A Decision Feedback Equalized eye is displayed on the oscilloscope. This structure cannot be used on completely closed eyes because the clock cannot be recovered with this method. If the eye is closed and you want to implement DFE, use the option immediately below this.</td>
</tr>
</tbody>
</table>
Table 1  Equalization Configuration Selections (continued)

<table>
<thead>
<tr>
<th>Graphical Representation of Setup</th>
<th>Description of Setup</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="https://example.com/diagram.png" alt="Diagram" /></td>
<td>FFE/CTLE is used to recover the clock (but is not implemented in the real-time eye display) and a Decision Feedback Equalized eye is displayed on the oscilloscope. This lets you perform DFE on completely closed eyes.</td>
</tr>
<tr>
<td><img src="https://example.com/diagram.png" alt="Diagram" /></td>
<td>FFE/CTLE is applied and then DFE is applied to the real-time eye. Additionally, since FFE/CTLE also is used to recover the clock, this structure can be used on completely or partially closed eyes.</td>
</tr>
</tbody>
</table>

Step 2: Secondary Configuration

The next step involves selecting which setup to display in the lower grid of your oscilloscope's display. This is useful if you want to have a reference eye to compare to.

For instance, you could draw an unequalized eye in the lower grid and an equalized one in the upper grid for comparison. Or you could draw a DFE eye in the lower grid and a FFE/CTLE eye in the upper grid.

You can also choose to display nothing in the bottom grid (by clicking the option button next to **None**) and instead display the setup from **Step 1** using the entire display.
The choices you have available at this step depend on your selection in Step 1. The choices you see will include a subset of the same selections available in Step 1.

Step 3: Thresholds

This step sets up various parameters associated with the logical threshold applied to the serial data pattern.
**Auto Set Thresholds** — Clicking this button performs an analysis of the signal to automatically determine good threshold and hysteresis settings.

The threshold level is defined to be the voltage level above which the signal is considered to be a logical 1 and below which the signal is considered to be a logical 0.

**23 Threshold, 12 Threshold, 01 Threshold** — If you see these controls, the signal is a PAM-4 or PAM-3 signal (the 23 Threshold does not appear for PAM-3 signals). For more information on these controls, see the "PAM Measurements" help.

**Threshold** — Lets you set the threshold voltage (switching) level.

When **Snap to 0** is enabled, thresholds within ±10 mV are moved to zero. This is useful for differential signals.

**Hysteresis** — The hysteresis helps define what is considered an edge by the oscilloscope.

For example, if hysteresis is set to +/-5 mV, this means the signal must go through a 10 mV swing (-5 mV to 5 mV) to be considered an edge. If you make the hysteresis value too large, the oscilloscope may skip edges and incompletely recover the clock. If you make this value too small, the oscilloscope will mistake noise for edges. In most cases, +/-5 mV is a good setting, although you may need to increase or decrease this setting based upon your specific signal and the amount of noise.
Step 4: Clock Recovery

The clock recovery algorithms available in this step depend on your settings in Steps 1 and 2. In this step, the wizard lets you:

- Select a clock recovery preset and specify a data rate (if known). You can enter the data rate or click Measure Data Rate to populate the Nominal Data Rate field with the data rate measured on the input signal.

For more information on the clock recovery presets and nominal data rate settings, see Clock Recovery Dialog Box Controls in the online help.

If you see the Nominal Symbol Rate control, the signal is a PAM-4 or PAM-3 signal. For more information on this clock recovery control, see the "PAM Measurements" help.

- Specify the clock recovery method to use.
The algorithms will be a subset of the following list:

- First Order PLL (Phase Lock Loop).
- Second Order PLL
- Equalized First Order PLL
- Equalized Second Order PLL
- Constant Frequency
- Explicit
- Explicit First Order PLL
- Explicit Second Order PLL
- Fibre Channel

Generally, you want to choose the method that approximates the method your receiver uses.

Equalized First and Second Order PLL means first FFE is applied to the closed eye to open it (because the oscilloscope cannot extract a clock from a closed eye) and then the corresponding PLL algorithm is used to extract the clock.

For more information on the clock recovery methods you can select, see Clock Recovery Dialog Box Controls in the online help.
• Specify the options for the selected clock recovery method.

For more information on the clock recovery method options, see Clock Recovery Dialog Box Controls in the online help.

If you see the Clock Skew control, the signal is a PAM-4 or PAM-3 signal. For more information on these clock recovery controls, see the "PAM Measurements" help.

Step 5: Acquisition

This step sets up various parameters associated with the oscilloscope's acquisition of the signal.

The fields in this step will automatically be filled in based on the settings you chose in the clock recovery step. How these values were determined is explained in the text above each field in the user interface and is also discussed below.
• **Memory Depth** — There are two ways this value is set:

If you set Constant Frequency as your clock recovery method, the oscilloscope will determine how many samples per unit interval are acquired (it will tell you this value in the text at the top of the dialog box). The oscilloscope will then set the memory depth such that the oscilloscope displays 1,000 unit intervals \((\text{samples/unit interval}) \times 1000\). Displaying 1,000 unit intervals is arbitrary. If you want to display a different number of unit intervals, multiply the number you want times the samples per unit interval.

If you use a PLL or Fibre Channel clock recovery algorithm, the oscilloscope will calculate how much time it takes for the clock to lock to the data (assumes five time constants for PLL to set up so this time is calculated via \(5/(\text{loop bandwidth})\)). The oscilloscope will then recommend the memory depth based upon the following equation:

\[
\text{Memory Depth} = \left(\frac{5}{\text{loop bandwidth}}\right) \times \left(\frac{3}{2}\right)
\]

where 5 is the number of time constants for PLL to settle and 3/2 is used so some data after the PLL settles is included.

• **Sampling Rate** — The sampling rate is set to the maximum value possible for your specific oscilloscope model.

• **\(\text{Sin}(x)/x\) Interpolation** — Enable this for better effective resolution.
Step 6: FFE/CTLE Setup

This step lets you set various parameters associated with FFE/CTLE. If you selected choices in Steps 1 and 2 that did not involve FFE/CTLE, this step will be skipped.

**Linear Equalization** — Choose whether you want to use FFE or CTLE for your linear equalization method:

- **FFE:**

![Linear Equalization Wizard](image)

- **Data Rate** — This field is automatically filled in based on the settings you provided in the clock recovery step.
- **# of Taps** — This field lets you enter the number of taps to use (up to 40). For more information on what taps are, how to determine the number of taps to use, and how to set their values, see "Taps" on page 26.
- **# of Precursor Taps** — This control lets you specify how many precursor taps you want to use.

Remember that with standard FFE, the current bit is equalized by using its tap value along with tap values associated with bits prior to it.

Precursor taps are tap values associated with bits in front of the current bit.
For example, if you set **# of Precursor Taps** to zero and you were using three taps, the equalization would use the current bit's tap value, the previous bit's tap value, and the bit's tap value that was two behind the current bit. Now, if you set the **# of Precursor Taps** control to one then the current bit's tap value, the previous bit's tap value, and the bit in front of the current bit's tap value would be used.

This gives you a chance to specify which bits surrounding the "bit of interest" are used in the equalization algorithm. The **# of Taps** is the total number you want to use, and the **# of Precursor Taps** is the number of taps from this total that will be associated with bits in front of the current bit.

- **Band width** — See "Bandwidth Limit Control" on page 58.
- **Tap Delay** — Usually when you set the number of taps, it will be at a rate of 1 tap/bit. If you are indeed using 1 tap/bit then the tap delay is defined as (1/data rate) and you can set it to this by selecting the **Track Data Rate** choice for this field.

However, you can also set up the equalization such that multiple taps/bit are used. To do this, first set the **Tap Delay** field to **Manual**. Then compute how large to make the tap delay via the following equation:

\[
\text{Tap delay} = \frac{1}{(\text{data rate} \times \text{# of taps per bit})}
\]

- **Auto Set...** — After you set the number of taps, use this button to have the oscilloscope determine tap values through optimization:
  i. Click **Auto Set...**
  ii. In the Equalization Auto Tap Setup dialog box, set the controls appropriately. See "Equalization Auto Tap Setup Dialog Box" on page 65.
  iii. Then, click **Run Auto Set**.

The optimizer runs and reports the tap values to you in the **Auto Tap Status** box.

iv. Close the Equalization Auto Tap Setup dialog box to return to the Equalization Wizard.

If you want to enter the tap values manually after completing the Equalization Wizard, go to the "Equalization Tap Setup Dialog Box" on page 61.

- **CTLE**: 
- **Data Rate** — This field is automatically filled in based on the settings you provided in the clock recovery step.

- **Preset** — This field lets you quickly set up the remaining options by selecting from a list of industry-standard equalization definitions.

- **# of Poles** — Lets you select the number of poles in the CTLE filter.

When a 2-pole filter is selected, the following equation is shown:

\[
H(s) = \frac{A_{dc} \cdot \omega p_1 \cdot \omega p_2}{\omega Z} \cdot \frac{s + \omega Z}{(s + \omega p_1) \cdot (s + \omega p_2)}
\]

When a 3-pole 1 zero filter is selected, the following equation is shown:

\[
H(s) = \frac{A_{dc} \cdot \omega p_1 \cdot \omega p_2 \cdot \omega p_3}{\omega Z} \cdot \frac{s + \omega Z}{(s + \omega p_1) \cdot (s + \omega p_2) \cdot (s + \omega p_3)}
\]

When a 3-pole 2 zeros filter is selected, the following equation is shown:
When a USB 3.1 filter is selected, the following equation is shown:

\[
H(s) = \frac{A_{dc} \cdot \omega_{p1} \cdot \omega_{p2} \cdot \omega_{p3}}{\omega_{Z1} \cdot \omega_{Z2}} \cdot \frac{(s + \omega_{Z1}) \cdot (s + \omega_{Z2})}{(s + \omega_{p1}) \cdot (s + \omega_{p2}) \cdot (s + \omega_{p3})}
\]

The remaining fields in the dialog box let you enter values for the equation's variables:
- DC Gain \((A_{dc})\)
- Zero Frequency \((\omega_{Z})\)
- Zero 1 Frequency \((\omega_{Z1})\)
- Zero 2 Frequency \((\omega_{Z2})\)
- Pole 1 Frequency \((\omega_{p1})\)
- Pole 2 Frequency \((\omega_{p2})\)
- Pole 3 Frequency \((\omega_{p3})\)

Step 7: DFE Setup

This step lets you set various parameters associated with Decision Feedback Equalization. If you selected choices in Steps 1 and 2 that did not involve DFE, this step will be skipped.
• **# of Taps** — Specify the number of taps to use in the Decision Feedback Equalization. For more information on taps and how to choose the correct number of taps, see "Taps" on page 26.

• **Auto Set...** — After you set the number of taps, use this button to have the oscilloscope determine tap values through optimization:
  
  a Click **Auto Set...**.
  
  b In the Equalization Auto Tap Setup dialog box, set the controls appropriately. See "Equalization Auto Tap Setup Dialog Box" on page 65.
  
  c Then, click **Run Auto Set**.

  The optimizer runs and reports the tap values to you in the **Auto Tap Status** box.

  d Close the Equalization Auto Tap Setup dialog box to return to the Equalization Wizard.

If you want to enter the tap values manually after completing the Equalization Wizard, go to the “Equalization Tap Setup Dialog Box” on page 61.
Manually Setting Up Equalization

Manually entering the settings is one of the two ways to set up the Serial Data Equalization feature (the other way is to use the Equalization Wizard—see "Using the Equalization Wizard" on page 28).

The Equalization Wizard is the recommended setup method as it walks you through the process in a step-by-step fashion. Use the manual setup method only if you are comfortable with the manual controls and are familiar with equalization.

- "Setting Up Your Signal" on page 43
- "Available Equalization Setups" on page 44

Setting Up Your Signal

Before entering the Equalization dialog box, set up the channel, function, or waveform memory you want to equalize and turn on the real-time eye feature using the Real-Time Eye / Serial Data Analysis dialog box (Analyze > Real-Time Eye...). You will also need to set the sampling rate, memory depth, and timebase scale using the following recommendations.

1 **Sampling Rate** — (Setup > Acquisition...) This is generally set to the maximum possible value.

2 **Timebase Scale** — (Setup > Horizontal...) The timebase range (the width of the display) should be set to two-unit intervals to produce a nice display. Since the horizontal axis has 10 divisions, the timebase scale would then be calculated as:

   \[
   \text{Timebase scale} = \frac{2 \times \text{unit interval}}{10}
   \]

   As an example, if your signal's data rate is 6.0 Gb/s, the unit interval would be 167 ps (1/data rate). Multiplying this by two and then dividing by ten would give you a timebase scale of 33.4 ps.

3 **Memory Depth** — (Setup > Acquisition...) If you are going to use Constant Frequency as your clock recovery method, you need to first determine how many samples per unit interval will be acquired based on the data rate of your signal and the sampling rate of your oscilloscope. As an example, assume your signal's data rate is 6 Gb/s (so your unit interval is \([1/\text{data rate}]\) or 167 ps) and your sampling rate is 20 GSa/s. You could determine the samples per unit interval by multiplying your unit interval times your sampling rate and then converting units as in the following:

   \[
   \text{Samples/unit interval} = \left(20 \text{ GSa}/1 \text{ s}\right) \times \left(109 \text{ Sa}/1 \text{ Gsa}\right) \times \left(1 \text{ s}/1012 \text{ ps}\right) \times \left(167 \text{ ps}/1 \text{ unit interval}\right)
   \]

   \[
   \text{Samples/unit interval} = 3.34 \text{ Sa/unit interval}
   \]
Determine how many unit intervals you want to display and multiply the number you want times the samples per unit interval to calculate your needed memory depth. If you use a PLL or Fibre Channel clock recovery algorithm, the recommended memory depth is based on the following equation:

Memory depth = (5/loop bandwidth) x (3/2)

where 5 is the number of time constants for PLL to settle and 3/2 is used so some data after the PLL settles is included.

4 Thresholds — (Analyze > Real-Time Eye... and then click the Thresholds button) In the Measurements Thresholds dialog box, set the Thresholds field to Custom: Level +/- Hysteresis. For most differential signals, set the Threshold Level to 0 V. You can also manually set the threshold level to whatever value you want or set it to 50% of the peak-to-peak voltage.

- **Set to 50% Vp-p** — Clicking this button automatically sets the logical threshold level to be (Vmax + Vmin)/2. The logical threshold level is defined to be the voltage level above which the signal is considered to be a logical 1 and below which the signal is considered to be a logical 0. Pressing this button also sets the hysteresis to be 5% of the source waveform's amplitude.

- **Hysteresis** — The hysteresis helps define what is considered an edge by the oscilloscope. For example, the default hysteresis is set to +/-5 mV. This means the signal must go through a 10 mV swing (-5 mV to 5 mV) to be considered an edge. If you make this value too large, the oscilloscope may skip edges and incompletely recover the clock. If you make this value too small, the oscilloscope will mistake noise for edges. In most cases +/-5 mV is a good setting, although you may need to increase or decrease this setting based on your specific signal and the amount of noise.

Available Equalization Setups

The following table lists all possible equalization setups. The How to Manually Set Controls to Obtain Setup column assumes you are in the Equalization dialog box and are not using the Equalization Wizard. This column also covers only the initial setup variables. It does not cover parameters such as taps.
### Graphical Representation and Description of Setup

<table>
<thead>
<tr>
<th>Graphical Representation and Description of Setup</th>
<th>How to Manually Set Controls to Obtain Setup</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="FFE/CTLE" /></td>
<td>1. In the Serial Data Analysis dialog box (Analyze &gt; RTEye/Clock Recovery (SDA)...), uncheck the Real-Time Eye box.</td>
</tr>
<tr>
<td></td>
<td>2. In the Equalization dialog box's Linear Eq (FFE/CTLE) tab, check the On box.</td>
</tr>
<tr>
<td></td>
<td>3. Click Clock Recovery... and choose your clock recovery method.</td>
</tr>
</tbody>
</table>

**FFE/CTLE is applied, but the real-time eye is not shown. Instead, the waveform resulting from applying FFE/CTLE is displayed.**

1. Do not check the On box in the Linear Eq (FFE/CTLE) tab or the Enable box in the Decision Feedback Eq (DFE) tab.
2. Click Clock Recovery... and choose your clock recovery method.

| ![FFE/CTLE](image2)                                | 1. Do not check the On box in the Linear Eq (FFE/CTLE) tab or the Enable box in the Decision Feedback Eq (DFE) tab. |
|                                                  | 2. Click Clock Recovery... and choose either Equalized First Order PLL or Equalized Second Order PLL as your clock recovery method. |

**No equalization is implemented and the unequalized real-time eye is displayed. This setup is useful if you want to have a reference to compare to. For instance, you can put the unequalized eye in the top grid and the equalized eye in the bottom grid so you can compare them on the same screen.**

1. Do not check the On box in the Linear Eq (FFE/CTLE) tab or the Enable box in the Decision Feedback Eq (DFE) tab.
2. Click Clock Recovery... and choose your clock recovery method.

| ![FFE/CTLE](image3)                                | 1. In the Equalization dialog box's Linear Eq (FFE/CTLE) tab, check the On box. |
|                                                  | 2. Click Clock Recovery... and choose your clock recovery method. |

**FFE/CTLE is used only to recover the clock, but the actual displayed real-time eye is unequalized. This setup is useful if you want to have a reference to compare to, but your unequalized eye is completely closed. You cannot recover a clock on a closed eye, so FFE/CTLE is applied to open the eye so the clock can be recovered. In other words, this option serves the same purpose as the selection immediately above it, but is used with closed eyes.**

1. In the Equalization dialog box's Linear Eq (FFE/CTLE) tab, check the On box.
2. Click Clock Recovery... and choose your clock recovery method.

| ![FFE/CTLE](image4)                                | 1. In the Decision Feedback Eq (DFE) tab, check the Enable box. |
|                                                  | 2. Click Clock Recovery... and choose your clock recovery method. |

**An FFE/CTLE eye is displayed on the oscilloscope. This is a standard FFE/CTLE implementation and can be used on partially or completely closed eyes.**

1. In the Decision Feedback Eq (DFE) tab, check the Enable box.
2. Click Clock Recovery... and choose your clock recovery method.

| ![FFE/CTLE](image5)                                | 1. In the Decision Feedback Eq (DFE) tab, check the Enable box. |
|                                                  | 2. Click Clock Recovery... and choose your clock recovery method. |

**A Decision Feedback Equalized eye is displayed on the oscilloscope. This structure cannot be used on completely closed eyes as the clock cannot be recovered with this method. If the eye is closed and you want to implement DFE, use the option immediately below this one. Note that real-time eye must be enabled on the source signal in order to enable DFE.**
### Equalization

<table>
<thead>
<tr>
<th>Graphical Representation and Description of Setup</th>
<th>How to Manually Set Controls to Obtain Setup</th>
</tr>
</thead>
</table>
| ![Diagram 1](image1.png) FFE/CTLE is used to recover the clock (but is not implemented in the real-time eye display) and a Decision Feedback Equalized eye is displayed on the oscilloscope. This lets you perform DFE on completely closed eyes. | 1 In the Decision Feedback Eq (DFE) tab, check the Enable box.  
2 Click Clock Recovery... and choose either Equalized First Order PLL or Equalized Second Order PLL as your clock recovery method. |
| ![Diagram 2](image2.png) FFE/CTLE is applied and then DFE is applied to the real-time eye. Because FFE/CTLE is also used to recover the clock, this setup can be used on completely or partially closed eyes. | 1 In the Decision Feedback Eq (DFE) tab, check the Enable box.  
2 Select FFE as your Source.  
3 Click Clock Recovery... and choose your clock recovery method. |
Equalization Dialog Box

Controls / 47
Accessing / 47

The Equalization dialog box is where you launch the Equalization setup wizard (see "Using the Equalization Wizard" on page 28) or manually enter your equalization settings (see "Manually Setting Up Equalization" on page 43).

For background information on equalization settings, see:
- "Equalization Background / Theory" on page 6
- "Feed-Forward Equalization (FFE)" on page 10
- "Continuous Time Linear Equalization (CTLE)" on page 16
- "Decision Feedback Equalization (DFE)" on page 17

Controls

The controls that appear in the Equalization dialog box depend on the selected tab:
- "Linear Eq (FFE/CTLE) Tab, FFE Selected" on page 48
- "Linear Eq (FFE/CTLE) Tab, CTLE Selected" on page 50
- "Decision Feedback Eq (DFE) Tab" on page 54
- "Advanced (FFE/CTLE) Tab" on page 56

Accessing

To access the Equalization dialog box, choose Analyze > Equalization... from the main menu.
Linear Eq (FFE/CTLE) Tab, FFE Selected

- **On** — Enables linear equalization.
- **Scaling...** — Opens the "Equalization FFE/CTLE Scaling Dialog Box" on page 54 where you can specify the vertical scaling options for the equalized signal waveform.
- **Source** — Lets you select the input signal source. You can choose between channel inputs, functions, or waveform memories.

**NOTE**
Be sure you choose the correct signal source. It is also recommended that only one signal be displayed prior to running the equalization as it is difficult to discern one signal from another with real-time eye diagrams.

- **Nominal Data Rate** — Enter the data rate of your signal into this field.
- **Auto** — Automatically sets the optimal data rate.
- **# of Taps** — Lets you set how many taps to use in the equalization. (For more information on how to determine the number of taps, see "Taps" on page 26.)
- **# of Precursor Taps** — Lets you specify how many precursor taps you want to use.

Remember that with standard FFE, the current bit is equalized by using its tap value along with tap values associated with bits prior to it. Precursor taps are tap values associated with bits in front of the current bit.

For example, if you set # of Precursor Taps to zero and you were using three taps, the equalization would use the current bit's tap value, the previous bit's tap value, and the bit's tap value that was two behind the current bit. Now, if you
set the **# of Precursor Taps** control to one then the current bit's tap value, the previous bit's tap value, and the bit in front of the current bit's tap value would be used. This gives you a chance to specify which bits surrounding the "bit of interest" are used in the equalization algorithm.

The **# of Taps** is the total number you want to use and the **# of Precursor Taps** is the number of taps from this total that will be associated with bits in front of the current bit.

- **Auto Set...** — Opens the "Equalization Auto Tap Setup Dialog Box" on page 65 where you can have the oscilloscope determine tap values for you through optimization. See also: "What Tap Values Should You Use?" on page 26.

- **Tap Setup...** — Click this button to open the "Equalization Tap Setup Dialog Box" on page 61 where you can:
  - Choose to have the oscilloscope determine the tap values using optimization.
  - Manually enter tap values.

- **Show Taps on Real-Time Eye** — Select this check box to display a pop-up box on the eye showing tap information.

- **Make Thresholds the same for all channels** — Select this check box to use the same threshold definitions for all channels, functions, and waveform memories. Clear this check box to use separate threshold definitions for each waveform.

- **Make Clock Recovery the same for all channels** — Select this check box to use the same clock recovery settings for all channels, functions, and waveform memories. Clear this check box to use separate clock recovery settings for each waveform.

- **Waveform** — This column shows the waveforms on which you can perform equalization.

- **Threshold** — Click the buttons in the first field of this column to open the Measurement Thresholds dialog box where you can set a waveform's threshold levels and hysteresis (to prevent false edges due to noise).

Click the **Auto** button to automatically set the recommended threshold method for that waveform. Using the **Auto** button is the best way to get optimal results. In many cases, the default measurement threshold definitions using **10%,50%,90% of top, base** are changed to **Custom: threshold +/- hysteresis** (as is done when using the setup wizard).

A yellow outline around a waveform's threshold field indicates that the threshold setting is not the optimal setting. For best results, click the **Auto** button.

- **Clock Recovery** — Click the buttons in the first field of this column to open the Clock Recovery dialog box where you can specify the options to recover an embedded clock or time reference from a waveform.
Click the **Auto** button to automatically set the recommended clock recovery method. The default clock recovery settings are often not the best and need to be changed. See Clock Recovery Recommendations in the online help. A red outline indicates that the clock recovery setting will not work with real-time eye. Click the **Auto** button to set the best method.

Equalized First and Second Order PLL means first FFE is applied to the closed eye to open it (because the oscilloscope cannot extract a clock from a closed eye) and then the corresponding PLL algorithm is used to extract the clock.

- **Real-Time Eye** — The check box lets you enable or disable a real-time eye on the equalized signal waveform.

  When enabled, click the **Setup...** button to open the Real-Time Eye dialog box where you can specify the real-time eye options.

  **See Also**  
  • "Feed-Forward Equalization (FFE)" on page 10

**Linear Eq (FFE/CTLE) Tab, CTLE Selected**

![](image)

- **On** — Enables linear equalization.
• **Scaling...** — Opens the "Equalization FFE/CTLE Scaling Dialog Box" on page 54 where you can specify the vertical scaling options for the equalized signal waveform.

• **Source** — Lets you select the input signal source. You can choose between channel inputs, functions, or waveform memories.

**NOTE**

Be sure you choose the correct signal source. It is also recommended that only one signal be displayed prior to running the equalization as it is difficult to discern one signal from another with real-time eye diagrams.

• **Nominal Data Rate** — Enter the data rate of your signal into this field.

• **Auto** — Automatically sets the optimal data rate.

• **Preset** — Lets you quickly set up the remaining options by selecting from a list of industry-standard equalization definitions.

• **# of Poles** — Lets you select the number of poles in the CTLE filter.

When a 2-pole 1 zero filter is selected, the following equation or graph is shown:

\[
H(s) = \frac{A_{dc} \cdot \omega_{p_1} \cdot \omega_{p_2}}{\omega_Z} \cdot \frac{s + \omega_{Z}}{(s + \omega_{p_1}) \cdot (s + \omega_{p_2})}
\]

When a 3-pole 1 zero filter is selected, the following equation or graph is shown:

\[
H(s) = \frac{A_{dc} \cdot \omega_{p_1} \cdot \omega_{p_2} \cdot \omega_{p_3}}{\omega_Z} \cdot \frac{s + \omega_{Z}}{(s + \omega_{p_1}) \cdot (s + \omega_{p_2}) \cdot (s + \omega_{p_3})}
\]
When a 3-pole 2 zeros filter is selected, the following equation or graph is shown:

\[ H(s) = \frac{A_{dc} \cdot \omega_{p1} \cdot \omega_{p2} \cdot \omega_{p3}}{\omega_{Z1} \cdot \omega_{Z2}} \cdot \frac{(s + \omega_{Z1}) \cdot (s + \omega_{Z2})}{(s + \omega_{p1}) \cdot (s + \omega_{p2}) \cdot (s + \omega_{p3})} \]

When a 2-pole AC gain filter is selected, the following equation or graph is shown:

\[ H(s) = A_{ac} \cdot \omega_{p2} \cdot \frac{s + \frac{A_{dc}}{A_{ac}} \cdot \omega_{p1}}{(s + \omega_{p1}) \cdot (s + \omega_{p2})} \]

- **Show Settings on Real-Time Eye** — Select this check box to display a pop-up box on the eye showing your equalization settings.
- **DC Gain** — Specifies the \(A_{dc}\) variable value in the filter equation.
- **Zero Frequency** — Specifies the \(\omega_{Z}\) variable value in the filter equation.
- **Zero 1 Frequency** — Specifies the \(\omega_{Z1}\) variable value in the filter equation.
- **Zero 2 Frequency** — Specifies the \(\omega_{Z2}\) variable value in the filter equation.
- **AC Gain** — Specifies the \(A_{ac}\) variable if the USB 3.1 CTLE is selected.
• **Pole 1 Frequency** — Specifies the \( \omega_{p1} \) variable value in the filter equation.

• **Pole 2 Frequency** — Specifies the \( \omega_{p2} \) variable value in the filter equation.

• **Pole 3 Frequency** — Specifies the \( \omega_{p3} \) variable value in the 3-pole filter equation.

• **Real-Time Eye** — This area contains:
  
  - **Make Thresholds the same for all channels** — Select this check box to use the same threshold definitions for all channels, functions, and waveform memories. Clear this check box to use separate threshold definitions for each waveform.

  - **Make Clock Recovery the same for all channels** — Select this check box to use the same clock recovery settings for all channels, functions, and waveform memories. Clear this check box to use separate clock recovery settings for each waveform.

• **Waveform** — This column shows the waveforms on which you can perform equalization.

• **Threshold** — Click the buttons in the first field of this column to open the Measurement Thresholds dialog box where you can set a waveform's threshold levels and hysteresis (to prevent false edges due to noise).

  Click the **Auto** button to automatically set the recommended threshold method for that waveform. Using the **Auto** button is the best way to get optimal results. In many cases, the default measurement threshold definitions using 10%, 50%, 90% of top, base are changed to **Custom: threshold +/- hysteresis** (as is done when using the setup wizard).

  A yellow outline around a waveform's threshold field indicates that the threshold setting is not the optimal setting. For best results, click the **Auto** button.

• **Clock Recovery** — Click the buttons in the fist field of this column to open the Clock Recovery dialog box, where you can specify the options to recover an embedded clock or time reference from a waveform.

  Click the **Auto** button to automatically set the recommended clock recovery method. The default clock recovery settings are often not the best and need to be changed. See Clock Recovery Recommendations in the online help. A red outline indicates that the clock recovery setting will not work with real-time eye. Click the **Auto** button to set the best method.

  Equalized First and Second Order PLL means first FFE/CTLE is applied to the closed eye to open it (because the oscilloscope cannot extract a clock from a closed eye) and then the corresponding PLL algorithm is used to extract the clock.

• **Real-Time Eye** — The check box lets you enable or disable a real-time eye on the equalized signal waveform.

  When enabled, click the **Setup...** button to open the Real-Time Eye dialog box where you can specify the real-time eye options.
Equalization FFE/CTLE Scaling Dialog Box

- **Vertical:**
  - **Automatic** — Automatically sets the vertical scale and offset of the equalized signal waveform.
  - **Manual** — Lets you set the vertical scale and offset of the equalized signal waveform.

Decision Feedback Eq (DFE) Tab

- **Enable** — Enables or disables the DFE.
  
  Real-time eye must be enabled on the source signal in order to enable DFE.
- **Source** — Lets you select the input signal source. You can choose channel inputs, functions, or waveform memories.
Additionally, you can choose FFE/CTLE as a source for DFE if you want to perform the two optimization techniques together.

**NOTE**
Be sure you choose the correct signal source. It is also recommended that only one signal be displayed prior to running the equalization as it is difficult to discern one signal from another with real-time eye diagrams.

- **# of Taps** — Lets you set how many taps to use in the equalization. (For more information on how to determine the number of taps, see "Taps" on page 26.)
- **Auto Set...** — Opens the "Equalization Auto Tap Setup Dialog Box" on page 65 where you can have the oscilloscope determine tap values for you through optimization. See also: "What Tap Values Should You Use?" on page 26.
- **Tap Setup...** — Click this button to open the "Equalization Tap Setup Dialog Box" on page 61 where you can:
  - Choose to have the oscilloscope determine the tap values using optimization.
  - Manually enter tap values.
- **Show Taps on Real-Time Eye** — Select this check box to display a pop-up box on the eye showing tap information.
- **Real-Time Eye** — This area contains:
  - **Make Thresholds the same for all channels** — Select this check box to use the same threshold definitions for all channels, functions, and waveform memories. Clear this check box to use separate threshold definitions for each waveform.
  - **Make Clock Recovery the same for all channels** — Select this check box to use the same clock recovery settings for all channels, functions, and waveform memories. Clear this check box to use separate clock recovery settings for each waveform.
  - **Waveform** — This column shows the waveforms on which you can perform equalization.
  - **Threshold** — Click the buttons in the first field of this column to open the Measurement Thresholds dialog box where you can set a waveform's threshold levels and hysteresis (to prevent false edges due to noise).

Click the **Auto** button to automatically set the recommended threshold method for that waveform. Using the **Auto** button is the best way to get optimal results. In many cases, the default measurement threshold definitions using **10%,50%,90% of top, base** are changed to **Custom: threshold +/- hysteresis** (as is done when using the setup wizard).

A yellow outline around a waveform's threshold field indicates that the threshold setting is not the optimal setting. For best results, click the **Auto** button.
Equalization

- **Clock Recovery** — Click the buttons in the first field of this column to open the Clock Recovery dialog box, where you can specify the options to recover an embedded clock or time reference from a waveform.

  Click the **Auto** button to automatically set the recommended clock recovery method. The default clock recovery settings are often not the best and need to be changed. See Clock Recovery Recommendations in the online help. A red outline indicates that the clock recovery setting will not work with real-time eye. Click the **Auto** button to set the best method.

  Equalized First and Second Order PLL means first FFE/CTLE is applied to the closed eye to open it (because the oscilloscope cannot extract a clock from a closed eye) and then the corresponding PLL algorithm is used to extract the clock.

- **Real-Time Eye** — The check box lets you enable or disable a real-time eye on the equalized signal waveform.

  When enabled, click the **Setup...** button to open the real-Time Eye dialog box where you can specify the real-time eye options.

  See Also  •  “Decision Feedback Equalization (DFE)” on page 17

Advanced (FFE/CTLE) Tab

- **Bandwidth** — See "Bandwidth Limit Control" on page 58.

- **Tap Delay** — Usually when you set the number of taps, it will be at a rate of 1 tap/bit. If you are indeed using 1 tap/bit, the tap delay is defined as (1/data rate), and you can set it to this by selecting the **Track Data Rate** choice for this field.
However, you can also set up the equalization such that multiple taps/bit are used. To do this, first set the Tap Delay field to Manual. Then compute how large to make the tap delay via the following equation:

tap delay = 1/[data rate X (# of taps per bit)]

- **Real-Time Eye** — This area contains:
  - **Make Thresholds the same for all channels** — Select this check box to use the same threshold definitions for all channels, functions, and waveform memories. Clear this check box to use separate threshold definitions for each waveform.
  - **Make Clock Recovery the same for all channels** — Select this check box to use the same clock recovery settings for all channels, functions, and waveform memories. Clear this check box to use separate clock recovery settings for each waveform.
  - **Waveform** — This column shows the waveforms on which you can perform equalization.
  - **Threshold** — Click the buttons in the first field of this column to open the Measurement Thresholds dialog box where you can set a waveform's threshold levels and hysteresis (to prevent false edges due to noise).

Click the Auto button to automatically set the recommended threshold method for that waveform. Using the Auto button is the best way to get optimal results. In many cases, the default measurement threshold definitions using 10%, 50%, 90% of top, base are changed to Custom: threshold +/- hysteresis (as is done when using the setup wizard).

A yellow outline around a waveform's threshold field indicates that the threshold setting is not the optimal setting. For best results, click the Auto button.

- **Clock Recovery** — Click the buttons in the first field of this column to open the Clock Recovery dialog box, where you can specify the options to recover an embedded clock or time reference from a waveform.

Click the Auto button to automatically set the recommended clock recovery method. The default clock recovery settings are often not the best and need to be changed. See Clock Recovery Recommendations in the online help. A red outline indicates that the clock recovery setting will not work with real-time eye. Click the Auto button to set the best method.

Equalized First and Second Order PLL means first FFE/CTLE is applied to the closed eye to open it (because the oscilloscope cannot extract a clock from a closed eye) and then the corresponding PLL algorithm is used to extract the clock.

- **Real-Time Eye** — The check box lets you enable or disable a real-time eye on the equalized signal waveform.
When enabled, click the Setup... button to open the Real-Time Eye dialog box where you can specify the real-time eye options.

Bandwidth Limit Control

To understand the Bandwidth limit control for equalization, we must first discuss some aspects of equalization.

As discussed in "Feed-Forward Equalization (FFE)" on page 10, one way to think of equalization is in terms of the frequency response of the channel your signal travels through. Ideally, you would like to transmit a signal through a channel whose frequency response was flat over the full bandwidth of the signal so every frequency component of the signal was equally represented.

In practice, your frequency response plot may look something like the simplified plot below where the signal attenuates at higher frequencies. This is what causes ISI and makes the eye diagram close.

![Pascal's Triangle](image)

To correct for this attenuation, we can apply a peaking filter response (dashed line in plot below) such that the sum of the peaking filter response and the channel response yields a flat frequency spectrum (red line in plot below).
Figuring out what this response should be and applying it is what you are doing when you perform equalization.

Now, in the above example, the unequalized response plot was very simplistic. A more realistic frequency response plot might look more like the following:

Notice that after a certain frequency (or bandwidth) there is very little data and mostly noise. If you apply a response via equalization as discussed above, you will end up amplifying the noise as well as the data.
The **Bandwidth** control lets you minimize this noise gain by rolling off the response above the frequency where there is mostly just noise.

There are three options for the **Bandwidth** control:

- **Manual** — If you know at what frequency you want the response to roll off, you can enter it manually.

- **Track Source Bandwidth** (default) — This option simply generates a response up to the bandwidth of the source. For example, if your source is channel 1 and its bandwidth is set to 12 GHz, the response will go to 12 GHz before rolling off. This is the method that maximizes the noise gain.

- **Track Tap Delay** — This option forces the response to roll off at a typical ratio of bandwidth to data rate (0.75 x data rate). This will minimize the noise and is best used if you are unsure where in the frequency spectrum the noise is the dominant factor, but would like to minimize the noise gain.

**See Also**

- "Advanced (FFE/CTLE) Tab" on page 56
- "Step 6: FFE/CTLE Setup" on page 38
Equalization Tap Setup Dialog Box

Controls / 61
Accessing / 61

Controls

The controls that appear in the Equalization Tap Setup dialog box depend on the selected tab:

• "FFE Taps Tab" on page 61
• "DFE Taps Tab" on page 63

Accessing

To access the Equalization Tap Setup dialog box:

1 Choose Analyze > Equalization... from the main menu.
2 In the Equalization dialog box, click Tap Setup...

See Also

• "Taps" on page 26

FFE Taps Tab

• Auto Set... — Opens the "Equalization Auto Tap Setup Dialog Box" on page 65 where you can have the oscilloscope determine tap values for you through optimization. See also: "What Tap Values Should You Use?" on page 26.

• Delay — Equalization may cause your eye diagram to drift so the clock is no longer centered on the eye. The Delay field lets you specify this shift in order for the eye to be brought back to its original location relative to the unequalized signal.
• **# of Taps** — Adjusts the number of taps. See "How Many Taps Should You Use?" on page 26.

The GUI lets you manually adjust up to 40 tap values.

• **# of Precursor Taps** — Lets you specify how many precursor taps you want to use.

Remember that with standard FFE, the current bit is equalized by using its tap value along with tap values associated with bits prior to it. Precursor taps are tap values associated with bits in front of the current bit.

For example, if you set **# of Precursor Taps** to zero and you were using three taps, the equalization would use the current bit's tap value, the previous bit's tap value, and the bit's tap value that was two behind the current bit. Now, if you set the **# of Precursor Taps** control to one then the current bit's tap value, the previous bit's tap value, and the bit in front of the current bit's tap value would be used. This gives you a chance to specify which bits surrounding the "bit of interest" are used in the equalization algorithm.

The **# of Taps** is the total number you want to use and the **# of Precursor Taps** is the number of taps from this total that will be associated with bits in front of the current bit.

• **Normalize** — This button makes the tap values sum to one for the output to have unity gain at DC. This lets you see the same size eye diagram at the receiver as you do at the transmitter.

If you want to use this feature, first enter your tap values and then press the **Normalize** button. Your tap values will be adjusted so they sum to one.

• **Tap 0, Tap 1, ...** — Lets you manually enter FFE tap values.

• **Load Taps..., Save Taps...** — Lets you load (read) tap values from, or save tap values to, an .xml file.

• **Default Taps** — Sets the FFE tap values to their defaults.

See Also

• "Taps" on page 26
• "Feed-Forward Equalization (FFE)" on page 10
DFE Taps Tab

- **Auto Set...** — Opens the "Equalization Auto Tap Setup Dialog Box" on page 65 where you can have the oscilloscope determine tap values for you through optimization. See also: "What Tap Values Should You Use?" on page 26.

- **Upper Target, Lower Target** — These fields dictate the high and low logical values used in the DFE algorithm.
  
  For example, in DFE, when a bit is determined to be a logical high, its value will be equal to the Upper Target. Similarly, if a bit is determined to be a logical low, its value will be equal to the Lower Target.

- **Delay** — Equalization may cause your eye diagram to drift so the clock is no longer centered on the eye. The Delay field lets you specify this shift in order for the eye to be brought back to its original location relative to the unequalized signal.

- **Gain** — In the discussion on DFE theory/background (see "Decision Feedback Equalization (DFE)" on page 17), you can see that the eye drawn after DFE is applied is attenuated. To amplify the eye back to its original size (so you can directly compare the eye at the receiver to the eye at the transmitter) a gain factor needs to be applied. The Gain field lets you enter a constant that is applied to both the unequalized input signal and the corrected decision threshold value. Setting this field to 1 means there is no gain applied to the DFE eye diagram (like multiplying by 1).


- **Tap 1, Tap 2, ...** — Lets you manually enter DFE tap values.
You can set negative DFE tap values by:

- Clicking Auto Set...
- Entering a negative Min Tap Value in the Equalization Auto Tap Setup dialog box.
- Closing the Equalization Auto Tap Setup dialog box.
- Entering negative tap values (down to the specified Min Tap Value) in the Tap 1, Tap 2, ... fields.

See Also

- "Taps" on page 26
- "Decision Feedback Equalization (DFE)" on page 17
Equalization Auto Tap Setup Dialog Box

Controls / 65
Accessing / 67

**Controls**

<table>
<thead>
<tr>
<th>For FFE</th>
<th>For DFE</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Equalization Auto Tap Setup" /></td>
<td><img src="image" alt="Equalization Auto Tap Setup" /></td>
</tr>
</tbody>
</table>

- **Eye Width** — Specifies how much of the eye to use in the optimization.

  This field ranges from zero to one. Entering zero means the eye is optimized only at the location of the clock. Entering one means the entire acquisition is used.

  - Typically with FFE, the receiver samples data not only at the location of the clock, but also in its vicinity. The default is set to 0.333 UI (unit interval) to account for this variance in the sample location. Typically values between 0.0 UI - 0.5 UI are the most useful.

  - For DFE, true receivers only sample data at the location of the clock so a value of 0.0 UI (unit interval) is used as the default. If you want to include more of the eye, simply set this number to a higher value (0.0 UI - 0.5 UI would make sense for DFE).

  If you are unsure about what value to enter here, but do not want to use the default, think about whether you have more margin vertically or horizontally (where is your uncertainty?). If you use a narrow portion of the eye to optimize the tap values, your eye will have a greater peak, but only near its center.
If you use more of the eye to optimize the tap values, your eye will not be peaked as high, but will be more spread out horizontally.

- **Run Auto Set** — Runs the optimizer and reports the tap values to you in the Auto Tap Status box.

  The optimized taps are automatically inserted into the Equalization Tap Setup dialog box.

- **Normalize DC Gain** — Automatically scales the eye diagram so it is the same size as the transmitted eye.

  In the discussion on DFE (see "Decision Feedback Equalization (DFE)" on page 17), you can see that the eye drawn after DFE is applied is attenuated. To amplify the eye back to its original size (so you can directly compare the eye at the receiver to the eye at the transmitter) a gain factor needs to be applied.

- **Max Tap Value, Min Tap Value** — Lets you enter maximum and minimum values for the generated taps.

  Some serial data standards have limits on the tap values that can be used for DFE (you can look-up these limits in the standard specification documents for your technology).

**NOTE**

You can set negative tap values by entering a negative **Min Tap Value**.
Accessing

To access the Equalization Auto Tap Setup dialog box:

1. Choose Analyze > Equalization... from the main menu.
2. In the Equalization dialog box, click Tap Setup....
3. In the Equalization Tap Setup dialog box, click Auto Set....

See Also

- "Step 6: FFE/CTLE Setup" on page 38
- "Step 7: DFE Setup" on page 41
- "FFE Taps Tab" on page 61
- "DFE Taps Tab" on page 63
Index

A
acquisition setup, equalization wizard, 36
Advanced (FFE/CTLE) tab in Equalization dialog box, 56
auto tap status, 27, 39, 42, 66
autoscale vertical, equalization wizard, 29

B
Bandwidth limit control, equalization, 58

C
clock recovery, equalization wizard, 34
Constant Frequency, 35
Continuous Time Linear Equalization (CTLE), 39
Continuous Time Linear Equalization (CTLE), background, 16
copyright, 2
correction value, DFE, 18
crosstalk and Equalization, 6
CTLE (Continuous Time Linear Equalization), 39
CTLE setup, 39

D
data rate, equalization wizard, 38, 40
Decision Feedback Eq (DFE) tab in Equalization dialog box, 54
Decision Feedback Equalization (DFE), 41
Decision Feedback Equalization (DFE), background, 17
Decision Feedback Equalization (DFE), decision diagram, 20
Decision Feedback Equalization (DFE), frequency response plots, 21
Decision Feedback Equalization (DFE), how it acts on an eye diagram, 18
Decision Feedback Equalization (DFE), mathematical description, 17
DFE (Decision Feedback Equalization), 41
DFE and jitter analysis, 17
DFE real-time eye shape, 24
DFE setup, equalization wizard, 41
DFE Taps tab in the Equalization Tap Setup dialog box, 63
DFE voltage tap values, 23

E
Equalization, 5
Equalization Auto Tap Setup dialog box, 65
Equalization background/theory, 6
Equalization dialog box, 47
Equalization FFE/CTLE Scaling dialog box, 54
equalization methods, 9
Equalization Tap Setup dialog box, 61
equalization, manual set up, 43, 44
equalization, manual signal set up, 43
Equalization, problem it corrects, 6
Equalization, purpose of, 9
equalized eye in upper grid, 31
Equalized First Order PLL, 35
Equalized Second Order PLL, 35
Explicit First Order PLL, 35
Explicit Second Order PLL, 35
eye width, auto tap setup, 65

F
Feed-Forward Equalization (FFE), 38
Feed-Forward Equalization (FFE), background, 10
Feed-Forward Equalization (FFE), decision diagram, 13
Feed-Forward Equalization (FFE), frequency response plots, 13
Feed-Forward Equalization (FFE), how it acts on a waveform, 11
Feed-Forward Equalization (FFE), mathematical description, 10
FFE (Feed-Forward Equalization), 38
FFE setup, 38
FFE Taps tab in the Equalization Tap Setup dialog box, 61
Fibre Channel, 35
First Order PLL, 35

I
Infiniium Serial Data Equalization application, 7
Inter-Symbol Interference (ISI), 7, 15, 22
Inter-Symbol Interference (ISI) and Equalization, 6
ISI (Inter-Symbol Interference), 7

J
jitter analysis when DFE is enabled, 17

L
Linear Eq (FFE/CTLE) tab in Equalization dialog box, 48, 50
linear equalizer type, equalization wizard, 38
logical decision threshold, correction value added by DFE, 17, 18
logical threshold level, DFE, 19

M
max/min tap value, DFE auto tap setup, 66
memory depth, equalization wizard acquisition setup, 37
memory depth, signal set up for equalization, 43

N
normalize DC gain, DFE auto tap setup, 66
notices, 2

P
Phase Lock Loop, 35
PLL, 35
primary configuration, equalization wizard, 28

R
random noise and Equalization, 6
reference eye in lower grid, 31
Index

S

sampling rate, equalization wizard
    acquisition setup, 37
sampling rate, signal set up for
equalization, 43
Second Order PLL, 35
secondary configuration, equalization
    wizard, 31
Serial Data Analysis, 7
Serial Data Equalization application, 5
sin(x)/x interpolation, equalization wizard
    acquisition setup, 37

T

tap coefficient, 11, 13, 18
tap delay, 10, 12, 13
tap delay, equalization wizard FFE setup, 39
tap values, auto set, 39, 42
tap values, negative, DFE auto tap
    setup, 64, 66
Taps, 26
taps, how many to use, 26
taps, values to use, 26
thresholds, equalization wizard, 32, 33
thresholds, signal set up for
equalization, 44
timebase scale, signal set up for
equalization, 43
track data rate, equalization wizard, 39
track oscilloscope BW, equalization, 60
track tap delay, equalization, 60

U

unequalized eye in lower grid, 31

W

warranty, 2
wizard, equalization, 28