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Title: FireWire Bandwidth Calculations

PURPOSE

This article demonstrates how to calculate FireWire bandwidth. It shows practical examples of calculating FireWire bandwidth for a variety of camera configurations, including IEEE-1394a and IEEE-1394b cameras. It also discusses how to balance FireWire bandwidth among multiple cameras.

TECHNICAL DETAILS

Each IEEE-1394a FireWire bus can support 400 megabits/second of data transmission (i.e. 50 megabytes/second). This bandwidth is split between isochronous (e.g. image streaming) and asynchronous (e.g. camera control) data transfers. Eighty percent (80%) of this bandwidth is allocated for image streaming and the remaining 20% for camera control.

For image streaming on IEEE-1394a the theoretical rate is 40 MB/sec, but in practice should not exceed 32 megabytes/second. Image data on the IEEE-1394a bus is transferred at a rate of 4096 bytes every 125 microseconds this translates into 32 megabytes/second. This is the limit that should be used when calculating FireWire bandwidth for IEEE-1394a.

Each IEEE-1394b FireWire bus can support 800 megabits/second of data transmission (i.e. 100 megabytes/second). Like IEEE1394a, this bandwidth is split between isochronous (e.g. image streaming) and asynchronous (e.g. camera control) data transfers. Eighty percent (80%) of this bandwidth is allocated for image streaming and the remaining 20% for camera control.

For image streaming on IEEE-1394b the theoretical rate is 80 MB/sec, but in practice should not exceed 64 megabytes/second. Image data on the IEEE1394b bus is transferred at a rate of 8192 bytes every 125 microseconds this translates into 64 megabytes/second. This is the limit that should be used when calculating FireWire bandwidth for IEEE-1394b.

Figure 1 is an illustration of the maximum image data transfer rate for IEEE-1394a and IEEE-1394b.

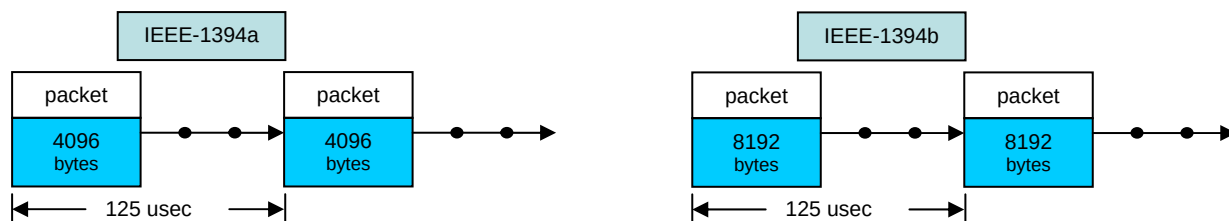


Figure 1: Illustration of data packets and transfer rate of IEEE-1394a and IEEE-1394b

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Single Camera FireWire Bandwidth Calculation:

There are two methods to calculate the FireWire bandwidth for a single camera. Method 1 is to use the *bytes_per_packet* parameter inside the Camera Configuration File (CCF) file for the camera. Method 2 is to calculate the bandwidth using the image size and frame rate of the camera. Use Method 2 when you don't have a CCF for the camera.

Inside of every FireWire Format_7 CCF file there is a parameter called *bytes_per_packet*. This parameter indicates how many bytes are sent with each data packet along the bus. From this value and knowing that data packets are transferred every 125 microseconds, one can calculate the FireWire bandwidth used by a camera.

These examples demonstrate both methods:

Method 1: Use *bytes_per_packet* parameter from CCF file:

Fire Wire Bandwidth (MB/sec) = (bytes_per_packet / 125 microseconds)
Per camera

IEEE-1394a: Maximum 4096 bytes_per_packet / 125 usec = 32 MB/sec

IEEE-1394b: Maximum 8192 bytes_per_packet / 125 usec = 64 MB/sec

Example:

Point Grey Research Flea2 FL2-08S2C Bayer Color 1024 x 770 from
pgr_flea2hicol_1024x770_ieee1394_32fps_op0.ccf

bytes_per_packet = 3264

FW Bandwidth = 3264 bytes / 125 usec = 26.1 MB/sec

Result: Since 26.1 MB/sec is less than 32 MB/sec this camera will operate normally on either an IEEE-1394a or IEEE-1394b FireWire adapter.

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Method 2: Calculate FireWire bandwidth from the image size and frame rate

Fire Wire Bandwidth (MB/sec) = (width * height) * (depth) * frame_rate
Per camera

Width = image width

Height = image height

Depth* = number of bytes per pixel (Bpp)

Frame_rate = maximum frame rate in frames/second

Note *: 1 Bpp for monochrome or Bayer color
3 Bpp for RGB 24-bit color images

Example:

Point Grey Research Flea2 FL2-08S2C Bayer Color 1024 x 770 @ 32 frame/sec

FW Bandwidth = (1024 * 770) * (1 bpp) * (32 fps) = 25.2 MB/sec

Result: Since 25.2 MB/sec is less than 32 MB/sec this camera will operate normally on either an IEEE-1394a or IEEE-1394b FireWire adapter.

Multi-Camera FireWire Bandwidth Calculation:

The method to calculate FireWire bandwidth for multiple cameras on the same FireWire bus is to simply sum the individual FireWire single camera bandwidths together. The important factor is that you must sum the cameras that **share** the same FireWire bus.

Note that some FireWire adapters may actually contain more than one FireWire bus. Use the utility called DCAM Doctor (installed with VisionPro) to determine how many FireWire buses may be on your adapter. Also note that adapters that contain both IEEE-1394a and IEEE-1394b ports will operate the lower speed of IEEE-1394a if an IEEE-1394a camera is plugged in.

Remember that every FireWire bus can support up to a maximum of 32 MB/sec on IEEE-1394a and 64 MB/sec on IEEE-1394b, this is on a per bus basis. This is why adding more Fire Wire adapters can be used to increase the total available bandwidth when using additional cameras in an application.

The general recommendation is to use IEEE-1394b adapters when using IEEE-1394b cameras and if IEEE-1394a cameras are also in the system that they be placed on their own IEEE-1394a adapter.

The following examples demonstrate multi-camera FireWire bandwidth calculation:

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Method 1: Sum *bytes_per_packet* parameter from all CCF files:

FireWire Bandwidth (MB/sec) = [Sum (*bytes_per_packet*)] / 125 microseconds

IEEE-1394a: Maximum 4096 *bytes_per_packet* / 125 usec = 32 MB/sec

IEEE-1394b: Maximum 8192 *bytes_per_packet* / 125 usec = 64 MB/sec

Example:

Camera 1: Basler Scout SCA1000 1032x776

(basl_sca1000_30fc_1032x776_ieee1394_30fps_op0.ccf)

Camera 2: Point Grey Research Flea2 FL2-08S2C Bayer Color 1024 x 770

(pgr_flea2hicol_1024x770_ieee1394_32fps_op0.ccf)

Camera 1 : *bytes_per_packet* = 3040

Camera 2 : *bytes_per_packet* = 3264

Total Bpp = 3040 + 3264 = 6304 Bpp

FW Bandwidth = 6304 bytes / 125 usec = 50.4 MB/sec

Result: Since 50.4 MB/sec is less than 64 MB/sec both cameras will operate normally on a single IEEE-1394b FireWire adapter. Alternatively, each camera can be placed on separate IEEE-1394a FireWire adapters. Additionally, the Total Bpp of 6304 exceeds the maximum *bytes_per_packet* for IEEE-1394a of 4096 bpp but is within the maximum *bytes_per_packet* for IEEE-1394b of 8196 Bpp.

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Method 2: Sum the FireWire bandwidth from the image size and frame rate for all cameras

Fire Wire Bandwidth (MB/sec) = Sum [(width * height) * (depth) * frame_rate] (for all cameras)

Width = image width

Height = image height

Depth* = number of bytes per pixel (Bpp)

Frame_rate = maximum frame rate in frames/second

Note *: 1 Bpp for monochrome or Bayer color

3 Bpp for RGB 24-bit color images

Example:

Camera 1: Basler Scout SCA1000 1032x776 @ 30 frames/second

Camera 2: Point Grey Research Flea2 FL2-08S2C Bayer Color 1024 x 770 @ 32 fps

Camera 1 : (1032* 776) * (1 Bpp) * (30 fps) = 24.0 MB/sec

Camera 2 : (1024* 770) * (1 Bpp) * (32 fps) = 25.2 MB/sec

Total FW Bandwidth = 24.0 + 25.2 = 49.2 MB/sec

Result: Since 49.2 MB/sec is less than 64 MB/sec both cameras will operate normally on a single IEEE-1394b FireWire adapter. Alternatively, each camera can be placed on separate IEEE-1394a FireWire adapters.

Balancing the FireWire Bandwidth:

When the FireWire bandwidth calculation exceeds the maximum allowable on the IEEE-1394a or IEEE-1394b bus, you can "throttle" the image stream data rate per camera by using the ccCameraBandwidth property in CVL or the CogAcq1394DCAM.CameraBandwidth property in VisionPro. This will allow more cameras to be placed on the same FireWire bus.

The camera bandwidth property is a value between 0 and 1, where the default 1 means to allocate the maximum amount of bandwidth needed for this camera to operate. You can reduce the amount of bandwidth for each camera by lowering this value. Note that using the camera bandwidth will result in a longer time to acquire the image since it is throttling the image data stream from the camera. For example, setting the camera bandwidth value to 0.5 will result in it taking twice as long to acquire a full image, but has the benefit of reducing the size of the packets sent along the FireWire bus.

In VisionPro QuickBuild, the camera bandwidth property can be set in the Image Source FireWire tab as shown in Figure 2:

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The screenshot shows the 'FireWire' tab of the 'VisionPro QuickBuild Job Image Source Form'. The 'Bandwidth Allocation' section is circled in red, showing 'Camera Bandwidth' set to 1.00. Other sections include 'Camera Information' (Vendor ID, Controller ID, Node Number, Bus Number), 'Register Access' (Address, Value, Read, Write buttons), and 'Misc'.

Figure 2: FireWire bandwidth setting in VisionPro QuickBuild Job Image Source Form

Here is one example of how to use the camera bandwidth parameter to balance a multi-camera FireWire application:

Example:

A six (6) camera application using the Basler Scout SCA640 658x494 @ 70 fps

Each Camera : $(658 * 494) * (1 \text{ Bpp}) * (70 \text{ fps}) = 22.8 \text{ MB/sec}$

Camera Bandwidth = 1.0 (default):

Total FW Bandwidth = $22.8 * 6 \text{ cameras} * (1.0) = 136.5 \text{ MB/sec}$

Camera Bandwidth = 0.4

Total FW Bandwidth = $22.8 * 6 \text{ cameras} * (0.4) = 54.6 \text{ MB/sec}$

Result: Placing all 6 cameras on the same FireWire IEEE-1394b adapter with a camera bandwidth set to the default value 1.0 will exceed the maximum bandwidth available on IEEE-1394b of 64 MB/sec. Lowering the camera bandwidth to 0.4 for each camera will allow all six cameras to operate **simultaneously** on a single IEEE-1394b adapter, but at the expense of taking longer to acquire each image.

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Special Considerations:

Cameras are designed either for the IEEE-1394a or IEEE-1394b or specification. Due to the plug and play nature of the FireWire technology it is acceptable to plug in IEEE-1394a cameras into IEEE-1394b adapters (using 6 to 9 pin converters). It is also acceptable to plug in IEEE-1394b cameras into IEEE-1394a adapters.

It is especially important to note that plugging IEEE-1394a cameras into IEEE-1394b adapters will not result in an available bandwidth of 64 MB/sec. When using a mix of IEEE-1394a and IEEE-1394b cameras and adapters, it is the lower IEEE-1394a bandwidth that will dictate the available bandwidth. Attaining IEEE-1394b bandwidth can only be achieved by using IEEE-1394b cameras and IEEE-1394b adapters, without any IEEE-1394a cameras on the same bus.

It should also be noted that the type of the acquisition trigger model has an effect on when and for how long the bandwidth on the FireWire bus is held. When using a hardware trigger model (a.k.a auto trigger) or when using the free run trigger model the allocation of the bandwidth is created once at the time the acquisition fifo is constructed, and never released. This means that even when the camera is not acquiring images the bandwidth will not be released to other cameras. However, when using the software trigger model (a.k.a. manual) the bandwidth is only allocated on an "as needed" basis. For every new acquire bandwidth is arbitrated on the bus, thus allowing multiple cameras to share the bus at the same time.

The equations and methods discussed in this paper are true when using all the various trigger models. But software triggered acquisition will not permanently allocate the bandwidth like hardware trigger acquisitions. What's important regardless of trigger model is calculating bandwidth usage to ensure enough is available when all the cameras on the bus acquire at the same time.

The setting of Camera Bandwidth only applies when using Format_7 CCF's and is not supported when using Generic FireWire CCF's (for example: gene_dcam_1600x1200_ieee1394_15fps_op0.ccf). Generic CCF's have a fixed *bytes_per_packet* value that can not be modified.

MOVING FORWARD

The FireWire technology has some advantages in that the image data stream can be controlled on a per camera basis, but there is a limit on the maximum throughput for both IEEE-1394a and IEEE-1394b buses. Adding more FireWire adapters is a good way of increasing bandwidth for multi-camera applications.

For additional information regarding other aspects of the FireWire technology and more detailed information comparing the differences between IEEE-1394a and IEEE-1394b see this Cognex [White Paper](#).