

IEEE 1394 (FireWire) for Industrial Cameras

What is IEEE 1394?

IEEE 1394 (also called i.LINK or FireWire) is an interface standard dedicated to applications such as industrial automation where high-speed, time-critical, reliable data transmission is required. FireWire is a serial bus interface standard that specifies cost-effective cabling and is simple in setup and application.

Why IEEE 1394?

FireWire has become one of the most accepted interface technologies for digital imaging, especially in machine vision, medical imaging, and intelligent traffic systems. More than 10 percent of all machine vision cameras are equipped with FireWire, and FireWire technology has been the most successful interface technology in the industrial camera market over the last few years.

Cameras conforming to version 1.3 or 1.31 of the DCAM (IIDC) specification meet the most current standards and are used in hundreds of applications and thousands of machines. IEEE 1394 has created a way to achieve cost-effective, powerful solutions. Because it is a robust design that is proven and easy to integrate, IEEE 1394 has pioneered the path for digital interfaces. Technologically, FireWire is used in industrial applications for several reasons, including:

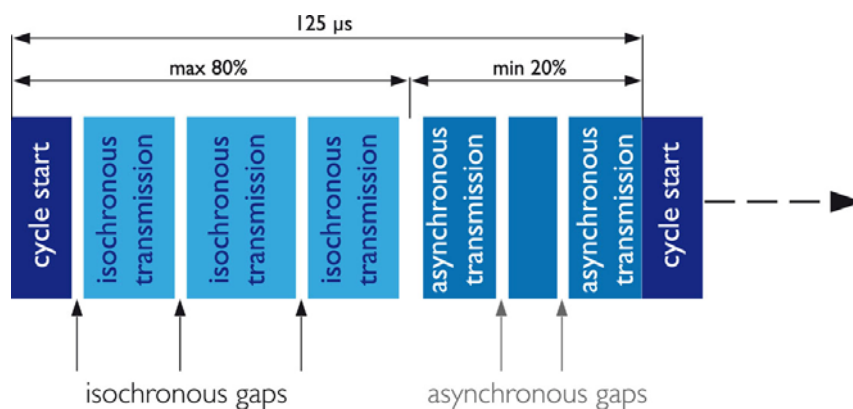
- Real-time capability by design via isochronous data channels
- Easy to integrate with all vision libraries
- Guaranteed bandwidth for each attached device
- Camera power over the data cable (with some exceptions)
- Asynchronous data transfer for setting camera parameters
- Large and growing variety of industrial grade accessories like cables and cards
- Interoperability with cameras from different vendors due to the DCAM (IIDC) specification
- Backward compatibility of IEEE 1394b with IEEE 1394a

How does IEEE 1394 work in detail?

The IEEE 1394 serial bus

A maximum of 63 devices can be attached to each IEEE 1394 bus. In industrial applications, a maximum of four cameras is normal for a single bus. The maximum cable length between two devices is specified as up to 4.5 meters.

In summary, the IEEE 1394 bus is a cost-effective, flexible serial bus with a standard communications protocol as defined by the Institute of Electrical and Electronics Engineers (IEEE). Due to its isochronous data transfer capability, IEEE 1394 offers real-time image transmission with very low, reliable latency time. An asynchronous channel is also provided and is used for setting camera parameters such as shutter, gain, or AOI (Area of interest). In contrast to USB, direct communication between all FireWire devices (peer-to-peer) is provided.



IEEE 1394a bandwidth

Within each 125 µs cycle of the bus, the IEEE 1394a specification for isochronous transfer supports transmission of up to 4096 bytes of data per packet. This results in a possible bandwidth of 400 Mbits/s. The maximum isochronous data transfer is 37.5 Mbytes/s, when using multiple devices.

IEEE 1394b bandwidth

Within each 125 µs cycle of the bus, the IEEE 1394b specification for isochronous transfer supports transmission of up to 8192 bytes of data per packet. This results in a possible bandwidth of 800 Mbits/s. The maximum isochronous data transfer is 75 Mbytes/s, when using multiple devices.

The IEEE 1394 standard

The FireWire bus was originally developed by Apple and applied to their Macintosh PCs. Development and standardization was finished in 1995. Since then, FireWire has become more commonly known by its IEEE standard number – IEEE 1394. Since 1997, Sony has used the FireWire interface in its PlayStation 2 under the trade name of i.LINK.

The IEEE 1394a standard (S400)

IEEE 1394a is the most common variation of the IEEE 1394 bus. An IEEE 1394a device can transmit at 100, 200, or 400 Mbits/s. IEEE 1394a bus features in detail are:

- A data rate of up to 400 Mbits/s
- A packet based transmission protocol
- Guaranteed bandwidth due to isochronous data transmission
- Designed with multimedia in mind
- Uses standard cables and connectors defined in the specification
- Supports hot plug and unplug
- Supports multiple devices within the same bus
- Peer-to-peer communication
- Direct Memory Access (DMA)

The IEEE 1394b standard (S800)

The IEEE 1394b standard was recently introduced in the industrial camera market. The standard allows compliant devices to transfer data at 800 Mbits/s. Yet IEEE 1394b cameras are fully backward compatible with IEEE 1394a devices.

IEEE 1394b bus features in detail are:

- A data rate of up to 800 Mbits/s
- The same benefits as 1394a (see above)
- Full backward compatibility with IEEE 1394a devices

1394 Trade Association and the Digital Camera Specification

The 1394 Trade Association was formed to encourage the growth of devices that use the 1394 bus. Working groups of industry-experienced volunteers develop specifications by consensus based on the expertise of the participants. In 1998, a working group of the association issued the 1394-based Digital Camera Specification (current version is 1.31). The specification defines a number of standard features and how those features should be implemented in a compliant camera, including:

- A variety of standard video formats and frame rates
- A flexible video format that allows variable image sizes and frame rates
- An external triggering method

In essence, the 1394 TA Digital Camera Specification (called DCAM or IIDC for short) defines the standard features and characteristics of an industrial camera that is capable of operating on an IEEE 1394 bus. The specification maintains flexibility by giving manufacturers the ability to add "special features" within a framework defined by the specification. The trade association also periodically refines the specification to meet current and future user needs.

Is IEEE 1394b backward compatible?

IEEE 1394b backward compatibility is as easy to explain as the technology itself. In essence, the “slowest” device in a network path defines the speed of the devices on that path. This means that in a network where IEEE 1394a and 1394b devices are mixed, all 1394b cameras that are part of a path which passes through a 1394a device will communicate at 1394a speed resulting in 400 Mbits/s of bandwidth. This is true for all cameras equipped with a bilingual IEEE 1394b connector like the Basler scout series.

Some examples:

Basler scout on an IEEE 1394a bus

The scout camera has a nine pin IEEE 1394b connector and is connected to a 1394a port on a PC or notebook.

In this case the Basler scout IEEE 1394b camera automatically communicates as an IEEE 1394a device.



Figure 1: IEEE 1394b camera: scA640-70fm

Basler A102f on an IEEE 1394b bus

The A102f camera is an IEEE 1394a device with a six pin 1394a connector. The A102f is connected to a bilingual IEEE 1394b port on a remote PC.

The advantage of bilingual IEEE 1394b ports is that they can communicate at IEEE 1394a or IEEE 1394b speed.

In general, the speed in an IEEE 1394b environment is defined by the “slowest” involved device. That means that the use of an IEEE 1394a device such as the A102f would limit the speed to S400 (400 Mbits/s).

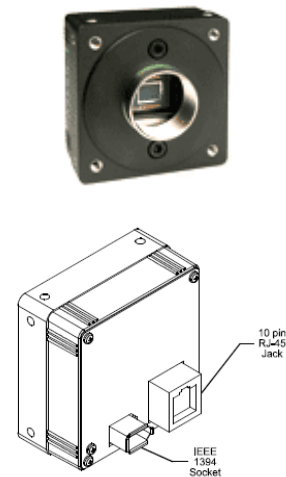
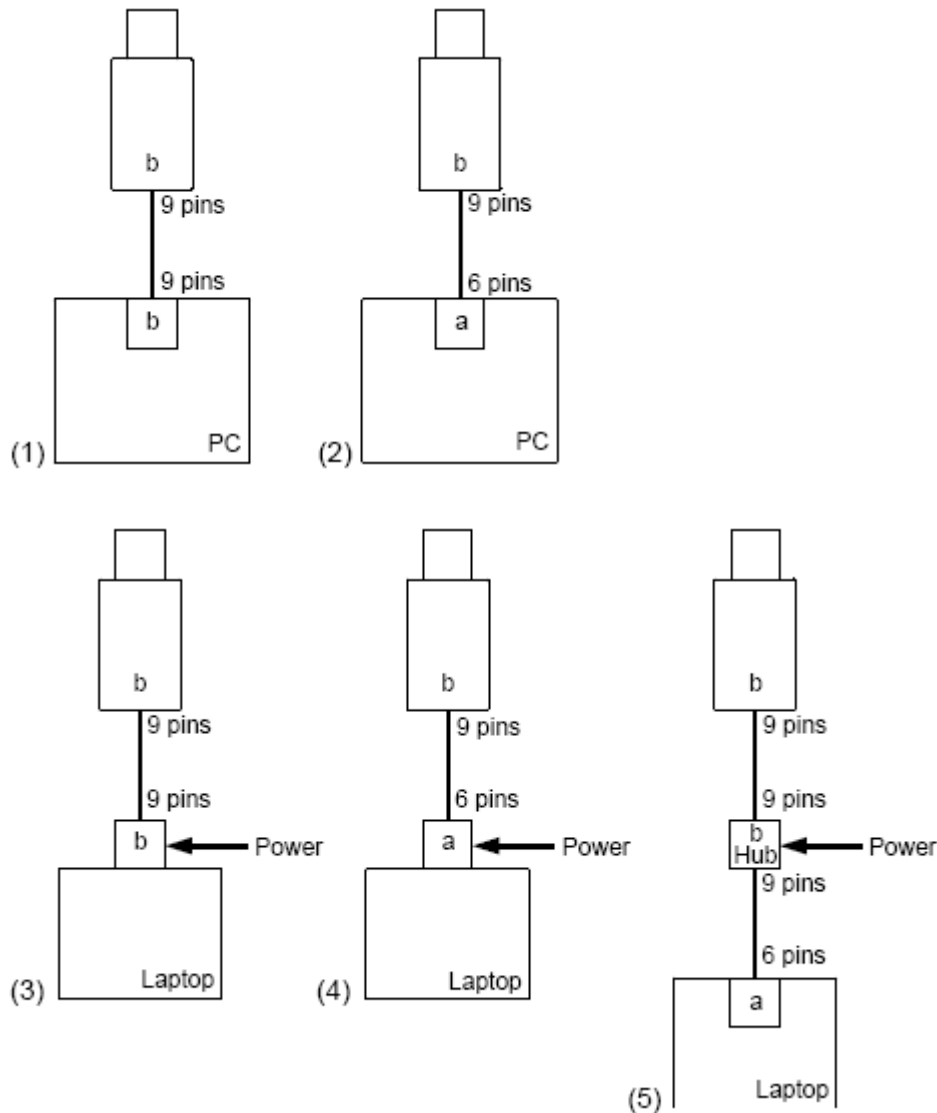


Figure 2: IEEE 1394b camera: scA640-70fm

How can an IEEE 1394b camera be attached to a PC or laptop?



- (1) Camera linked to a PC equipped with an IEEE 1394b compliant adapter. The camera receives power from the PC. Required cable: 1394b to 1394b.
- (2) Camera linked to a PC equipped with an IEEE 1394a compliant adapter. The camera receives power from the PC. Required cable: 1394b to 1394a.
- (3) Camera linked to a laptop computer equipped with a powered IEEE 1394b compliant adapter card. Required cable: 1394b to 1394b.
- (4) Camera linked to a laptop computer equipped with a powered IEEE 1394a compliant adapter card. Required cable: 1394b to 1394a.
- (5) Camera linked to a powered IEEE 1394b compliant hub which is linked to a laptop computer with an IEEE 1394a compliant adapter. Required cables: 1394b to 1394b and 1394b to 1394a.

What are the main differences between IEEE 1394a and IEEE 1394b?

Parameter	IEEE 1394a	IEEE 1394b
Max. bandwidth	400 Mbits/s data rate	800 Mbits/s data rate
Max. number of devices	63	63
Direct Memory Access (DMA)	yes	yes
Max. packet size	4096 bytes	8192 bytes
Bus cycle time	125 μ s	125 μ s
Driver support	- Basler BCAM 1.8	- Basler BCAM 1.9 - Basler pylon driver package
Features	- real time capability	- real time capability - backward compatibility
Remarks		- screwable connector on scout cameras

How do IEEE 1394 multi-camera applications work?

The use of more than one camera on a single bus is possible and was anticipated in the IEEE 1394 specification. IEEE 1394 buses allow up to 63 devices per bus. In industrial imaging, however, this is really only a theoretical number. In practice, the maximum bandwidth offered by the IEEE 1394 is a “bottle neck” and restricts the number of devices that can share the same bus. The 1394a bus offers up to 37.5 MBytes/s of data transfer capacity (max. 32 Mbytes/s for a single device), while the 1394b bus is capable of carrying up to 75 MBytes/s. So the number of cameras that you can use on a single bus is always a question of the amount of data transmitted by each camera per second (max. 64 Mbytes/s for a single device).

Some examples:

1. Operating at full resolution and speed, Basler’s scA1400fm/fc transmits 1.45 mega pixel images (frames) at 17 frames per second resulting in a data rate of about 25 MByte/s. In this case, only one camera can be used on an IEEE 1394a bus or three cameras with IEEE 1394b.
2. Operating at full resolution and speed, Basler’s scA640-70fm transmits images with VGA resolution (0.32 megabytes) at 71 fps resulting in a data rate of about 23 MByte/s. In this case, only one camera can be used on an IEEE 1394a bus or three cameras with IEEE 1394b.
3. Operating at full resolution and speed, Basler’s scA640-74fm transmits VGA resolution images (0.32 megabytes) at 74 fps. If you run this camera at a speed of 30 fps rather than 74, the resulting data rate for one camera is about 10 MByte/s. In this case, up to three cameras can be used on an IEEE 1394a bus and theoretically, up to seven cameras with IEEE 1394b.

Examples 1 and 2 show that multi-camera applications using IEEE 1394 must be considered and planned very carefully. If multiple cameras are required, this can be handled either by using the IEEE 1394b bus and/or using more than one FireWire interface card in your PC (each interface card represents a separate bus).

In some typical analog solutions, up to four VGA cameras operating at 60 fps can be used with only one frame grabber. IEEE 1394a can’t offer sufficient bandwidth to replace this solution with a single IEEE 1394a adapter card. IEEE 1394b, however, can handle up to three VGA cameras operating at 60 fps on a single card. This offers many possibilities to do a one-to-one replacement of analog solutions.

If you are using active network components such as hubs with 1394, the situation immediately gets tricky. Hubs can connect a reasonable number of devices without problems. But hubs have one disadvantage, they send all incoming packets to all attached recipients.

If a very flexible, high-performance network environment is required, a Gigabit Ethernet solution should be considered. The Basler portfolio offers GigE Vision based cameras equivalent to nearly all of our available IEEE 1394 cameras. These equivalent GigE cameras are part of Basler's scout series. In addition, the Basler pioneer series is available for high-resolution, high-speed image capturing. Gigabit Ethernet's networkability by design offers several advantages and supports a bandwidth of up to 100 MByte/s.

Basler IEEE 1394 product range

Series	Interface	Resolution	Frame Rate [fps]	Number of Models
Basler scout	IEEE 1394b	VGA, CCIR, XGA, 1.4 megapixels, and 2 megapixels	14 to 77	18
A100	IEEE 1394a	1.4 megapixels	15	2
A300	IEEE 1394a	VGA, CCIR	53 to 80	6
A600	IEEE 1394a	VGA, 1.4, and 2 mega pixels	14 to 100	9
A600 Board Level	IEEE 1394a	VGA	60 to 100	4



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