White Paper

Excellence in vision

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Factors limiting performance in Camera Link® connections, and how to get around them.

Camera Link® is a universal standard for the transmission of high speed digital images over medium distances (around 10 meters). The standard is well-established in the machine vision industry, and it is broadly adopted. A large number of Camera Link® cameras are available. It is therefore important to identify and analyze the factors limiting the performance of Camera Link® connections; and to consider methods aimed at compensating those limiting factors, to increase the performance of Camera Link® connections.

Let us note that there are several implementations of Camera Link®. This paper will not discuss those implementations. But we need to remember that a Camera Link® connection is composed of a number of parallel digital data pairs, one of which being the clock that times the data signals. The data pairs themselves are used in baseband mode (meaning that they do not always exhibit periodic 0-1 or 1-0 transitions), and are not "auto-clocked".

From a statistical perspective, it is impossible to guarantee perfect and completely error-free operation of any communication medium. Camera Link® connections are considered to operate satisfactorily if the bit error rate (BER) is less than 10-12. This number is arbitrary, but in fact, it is sufficiently small to consider it the limit of reliable performance. Experience has shown that performance degradation is fairly abrupt, in function of the factors affecting it, so setting the BER at a smaller value typically does not result in very different operating conditions. Camera Link® specifications are limited to 85 MHz, but there is nothing "magical" about this limit. Let us now define the single measure of performance that we will try to improve, by analyzing the effect of the various limiting factors. It is simply the highest achievable frequency that the connection will support. In fact, it was imposed by the technology used in early Camera Link® implementations.

Let us first look at the external factors upon which we have no control:

- **The electromagnetic noise generated by the external environment.** This is obviously an external factor over which we have no control. However, it is obvious that long cables are more affected than short cables, in a noisy environment.
- **Signal distortions generated by the camera.** There are three types of distortion:
  - Skewness between the digital data pairs at the output of the camera
  - Jitter in the data transitions, in one or several data pair
  - Clock jitter

  Some cameras are better than others, in that respect. This explains that some cameras might work at a given level of performance, whereas others may not. These distortions might be compensated by the frame grabber, but obviously, the higher the distortion level, the tougher the job of the frame grabber.

The Camera Link® cable itself induces additional factors limiting the performance:

- **The attenuation of the signal is definitely a very strong limiting factor.** This attenuation, expressed in dB/meter or dB/foot, at several frequencies, is a characteristic of a specific cable. Higher frequencies are more attenuated than lower frequencies, and a perfect square signal is again distorted into a signal in which the nominal value (0 or 1) is attained after a rise or fall time that depends on the spectrum of attenuation. This yields the famous "eye", the opening between rising and falling signals, visible on an oscilloscope.
- **The cross-pair coupling or interference.** Because it is typically not a dominating factor, it is not often mentioned, and almost never explicitly quantified. It can also be expressed in dB/meter or dB/foot, at several frequencies. Unlike attenuation, the cross-pair coupling often increases with the frequency, but proper shielding should keep this factor within manageable limits.
- **The difference in propagation velocity between data pairs** (and the clock pair). This generates additional skewness in the signals (on top of the skewness generated by the camera itself). The additional skewness between pairs is expressed as a time difference per unit of cable length, for example in picoseconds/meter or picoseconds/foot. Again, the longer the cable, the more the additional cable skewness will affect performance.

All three factors above are strongly dependent on the length of the cable. This is why a specified performance level, in MHz, will be achieved up to a critical cable length, and also why performance degrades so quickly if that "critical length" is exceeded.

There are several ways to mitigate the effect of the length, on the performance reduction of Camera Link® connections, and to achieve satisfactory performance or frequency with much greater cable lengths. Obviously, selecting a good camera, and using (very) high-quality cable, with low loss, low cross-talk, and low skewness specs will help increasing the "critical length", for a given performance level. But two features can be implemented in the frame grabber, much more cost-effectively:

- Equalizers at the input of the Camera Link® connection on the frame grabber will improve the aspect of the signal (the "eye") by restoring the high frequencies in the signal. However, it does not make sense to amplify high frequencies indefinitely, because this could also increase the amount of externally induced noise. This is why *adaptive* equalizers constitute the best solution for optimal line-conditioning for longer Camera Link® connections.
- De-skewers aimed at reducing or eliminating the differences in propagation time on the various data lines will also greatly reduce the effect of increased length. Again, adaptive de-skewers that adjust themselves to the (sometimes varying) skewness between cable pairs are the best solution.
- The combination of adaptive equalizers, properly adjusted, and adaptive de-skewers is a powerful approach for increasing the "critical length" for a given performance level or frequency.

In the above discussion, we have introduced features aimed at improving performance in a "dual" way: either increasing the "critical length" for a specific frequency, or increasing the maximum frequency for a given cable length. In fact, a third way of looking at the issue is as follows: for a given frequency, and a given cable length, these features might also allow operation in a more noisy environment, or with lower quality (less expensive) cables.

In conclusion, Camera Link® operation can be substantially improved, or made much more cost-effective, by the introduction of two features in the frame grabber, namely line equalization, and de-skewing.

For more information about Euresys Camera Link frame grabbers and going beyond the limits of Camera Link, please see www.euresys.com