grass valley

WHITEPAPER

3G HD-SDI and the Trinix Advantage

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How the emphasis on design excellence inside the routing frame of the Grass Valley™ Trinix™ NXT router can reap dividends by creating much-needed extra headroom outside of the frame, especially when dealing with legacy equipment and cabling systems.

Contents

The Challenge of 3 Gb/s HD-SDI

The transition to 1080p60 digital video has created more challenges in transmission of SDI signals. This new signal at 2.97 Gb/s is often called 3G HD-SDI, or simply 3G. This is twice the data rate of the 1080i60 HD-SDI signal that has been in use for about ten years.

Doubling the data rate has increased the difficulty of building equipment and systems. The bits are now about 3 inches or 7.5 cm long in a cable, and about 2 inches or 5 cm long on a circuit board trace. Almost all circuit interconnections must be treated as transmission lines. Cable losses increase by 40%, connector discontinuities become twice as significant, the signal bandwidth doubles, the crosstalk potential increases, and amplifier gain is harder to achieve at the higher bandwidth. All of these factors make building equipment more than twice as hard at 3G.

The good news is: it can be done successfully, with careful design and attention to details. We will focus this whitepaper on a review of digital advantages, cable and circuit board frequency response, cable frequency response comparison, cable distance considerations, interconnection problems, and crosstalk.

A Review of Digital Advantages

Analog storage and transmission systems have existed for a long time. Analog is generally simpler to implement. Analog signals can be damaged by things such as noise, crosstalk, bad frequency response, reflections, etc. Some of this damage can be fixed or partially repaired in an analog signal, but it is seldom the same as the original. The quality of analog recordings, photographs, or office copies deteriorates with each generation of copies.

A digital video signal is just a series of numbers representing the image. Digital copies can be flawless, if the numbers are recovered correctly from the source media, and transferred correctly to the destination media. Digital audio and video signals usually originate as analog signals that are converted to digital signals. Some of the fine details of the analog signal are lost in this conversion, but the infinite number of possibilities in an analog signal are converted into a finite set of numbers that can be stored and transmitted. How well the digital signal represents the image depends upon the precision, accuracy, and quantity of the numbers. This requires decisions to be made concerning sampling rates and the number of bits per sample. The digital signal numbers can be stored and transported in many ways without additional quality losses. Possible storage media includes hard disks, data DVDs, magnetic tape, paper tape, or even Roman numbers written on paper towels in old English script.

The numbers can be transmitted in many different methods, but the generally accepted format in professional television is SDI, as standardized in SMPTE standards. This is an 800 mV binary serial digital signal, transmitted at various data rates on coax cable. The binary representation has two possible values at the center of the bit time, 1 or 0. This digital signal is actually an analog representation of the numbers that represent the image, and becomes subject to the problems of an analog system. The challenge is to tell the difference between the two binary values, at the destination, with sufficient accuracy to recover all of the numbers correctly.

The advantage of digital transmission is much better immunity to noise and distortions. The price to pay is a significant increase in bandwidth. If the digital numbers are correctly received, the image is successfully transported with NO additional impairments.

Cable and Circuit Board Frequency Response Characteristics

Coax cable has signal losses that increase with frequency, much like a low pass filter. Some of the losses are due to resistance of the wire and skin effect, while other losses are caused by dielectric absorption in the insulation. The loss curve is approximated by the formula where L is the loss in dB per unit of cable length:

$$L = A + Cf + B\sqrt{f}$$

A, B, and C are constants that are dependent upon the type of cable and unit length. "f" is frequency. In many cases, the A and C components are ignored, resulting in the common approximation of cable losses being proportional to the square root of the frequency. This means, if the frequency is multiplied by 4, the attenuation of the cable, expressed in dB, doubles. This can be a good rule of thumb, but the other terms are still a part of the losses and may be important.

To properly recover the serial bits, it is desirable that the system, from the transmitter to the bit detector, has a frequency response that is nearly flat to at least ½ the clock rate. It is also desirable that the roll off be reasonably gentle out to 3 times the clock rate. Belden 1694A cable is specified to have a frequency dependent insertion loss of 26 dB per 100 meters at 1.5 GHz. This amount of loss requires equalization in order to work successfully for serial digital video. Since the length of a cable is not always predictable, adaptive equalizers have become the expected solution. They automatically adjust the equalization to match the apparent cable losses, up to a specified equalization limit.

Circuit boards also have losses that increase as the frequency increases. These losses are usually much greater per foot, than coax cable, but the trace lengths are usually less than a few feet. As traces become longer on circuit boards, the losses increase, and equalization may become necessary on the internal connections. Some ICs have built in equalization capability with fixed settings, but they may not be optimum for a given path. As a general rule, backplane signal interconnect lengths should be kept to the minimum necessary.

Cable Frequency Response Comparison

Not all video cables are created equal. Be careful that your choice of cable for long cable runs is acceptable. Many early equalizers for 270 Mb/s systems were optimized for Belden 8281 cable, since there was a lot if it already installed in analog systems. Belden 8281 is an excellent cable for analog video. Other cables are now available with better performance for digital video systems.

This whitepaper discusses various Belden cables, as an example, but the concepts also apply to cables from other manufacturers. If you examine the shape of the loss curve for Belden 8281 cable, the losses appear similar to Belden 1505A, but shape of the loss curve is somewhat different. 8281 has lower losses at low frequencies, such as the analog video it was designed for. 1505A has lower losses at the high frequencies encountered in Serial Digital Video systems. This is partially due to the use of foam versus solid dielectrics.

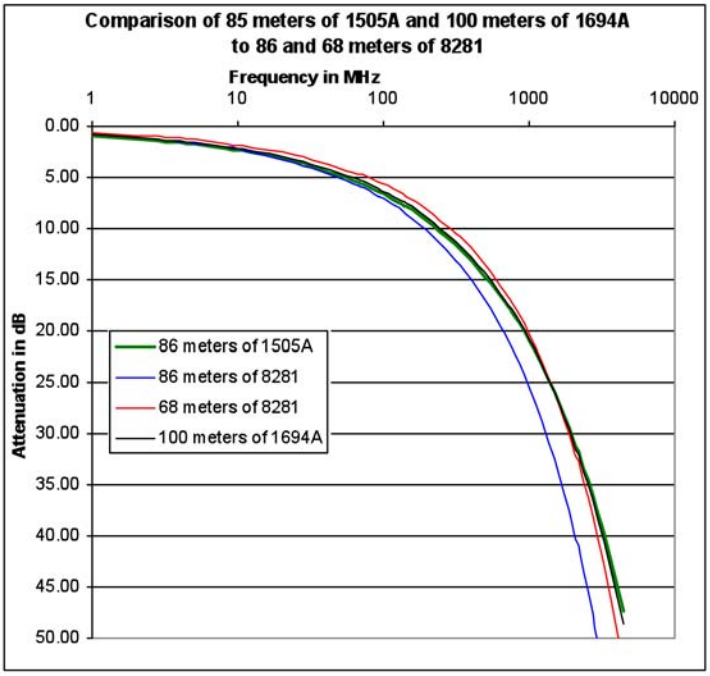

Figure 1 – *Comparison of 86 meters of Belden 1505A and 100 meters of Belden 1694A to 86 meters and 68 meters of 8281. The response of 86 meters of 1505A and 100 meters of 1694A are almost identical to each other.*

It is desirable to match the cable loss curve to the equalizer correction curve for best system performance. New equalizers are usually optimized for Belden 1694A and similar cables, but 8281 will probably work in most applications. Many of the new cables, for digital video, have similar shapes to their loss curves, but the loss per 100 meters is different for the individual cables. For example, 100 meters of 1694A has about the same losses across the signal spectrum as 86 meters of Belden 1505A. This gives a family of cables to choose from when deciding between cable size and cost.

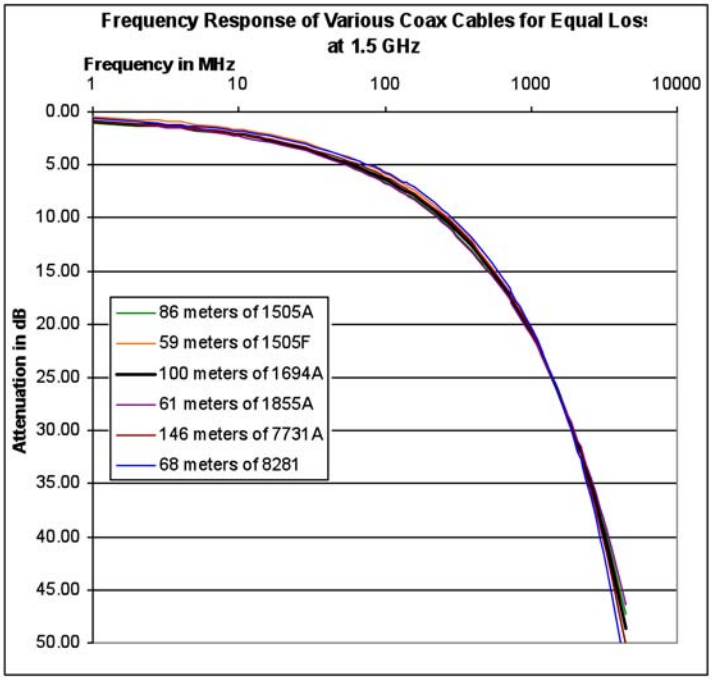

Figure 2 – *Cable length comparison for equal loss at 1.5 GHz.*

Cable Distance Considerations

How long can your cables go? How far do you need to go? 100 meters has been the common length for 1.5G cable lengths using a cable with losses similar to Belden 1694A. By just looking at cable loss equations, this would equal about 70 meters of the same cable for an equivalent 3G system. Is 70 meters enough for your system?

SMPTE 292M and SMPTE 424M state that the input cable distance should be specified by the manufacturer of the receiver. These two standards also suggest this will be common when the cable losses are in the range of 20 dB at one half of the clock rate of the signal. SMPTE 259M, for 270 Mb/s, 360 Mb/s, and 540 Mb/s systems, suggests a cable loss range of 20 dB to 30 dB.

Belden, and other cable manufacturers, may give a suggested cable length for a given cable. This is based upon an assumed value for the equalization capability of the receiver. The maximum cable lengths listed by Belden are for a 20 dB equalizer in the receiver. In real systems, this distance will increase or decrease depending upon the receiver characteristics. If a better receiver is available, the maximum cable lengths will be extended.

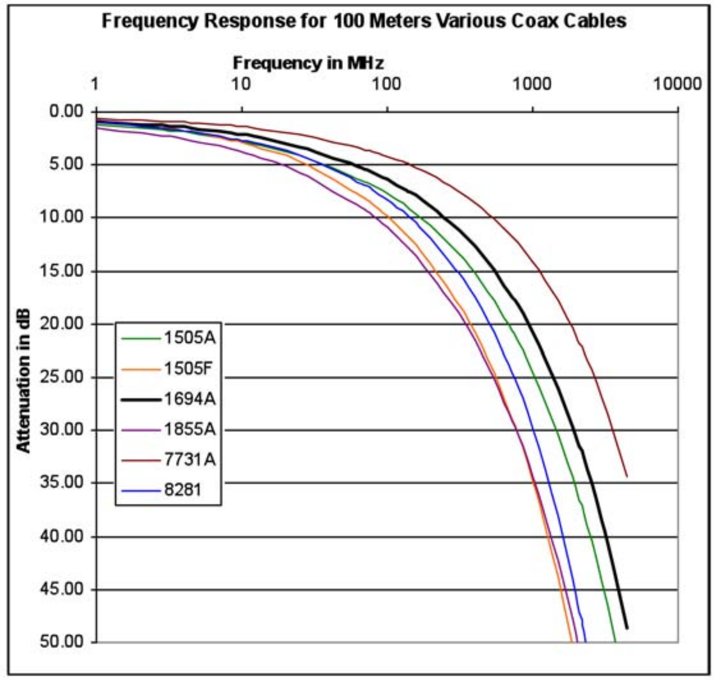

Figure 3 – *Comparison of frequency response for 100 meters of various cables.*

Choose your cable types wisely. In general, a physically smaller coax cable will have higher losses, resulting in a shorter maximum distance. You must also be careful about the characteristics of the cables within a given physical size.

Belden 1505F, the more flexible version of 1505A, has about 43% more losses than regular 1505A. This gives 1505F about the same losses as the physically smaller 1855A up to 1.5 GHz, and greater losses above 1.5 GHz. The plenum rated cable, Belden 1506A, has losses slightly higher than 1505F, and significantly higher than 1505A. The plenum rated cable, Belden 1695A, has losses 26% greater than 1694A. Belden 7731A has lower losses than most of the other digital cables, but it is also larger and heavier. 7731A may help you on long cable runs to the far ends of your facility.

You must consider what happens when you mix cable types. If your receiver is specified for 100 meters of 1694A, it may not work correctly if you use 70 meters of 1694A connected to 30 meters of 1855A. This will be the equivalent of about 120 meters of 1694, exceeding the receiver specifications, even though the physical length is only 100 meters. Losses or problems in the interconnecting barrels or patch panel and connectors may further reduce the working distance.

Interconnection Problems

The interconnection between digital video devices is subject to many issues. The best option is a single length of coax cable that has less loss than the capability of the receiving device to equalize. Patch panels, transitions to other cable types, damaged cables and connectors, and even coax barrel connections can cause additional signal losses, impedance bumps, and signal reflections or standing waves. A single weak barrel or connector can cost 1 meter of 1694A cable length, while a good barrel will have much smaller losses.

It can be demonstrated that one impedance bump or discontinuity between a signal source and destination is not too serious. It will have some effect upon the signal transmission. The reflected signals will be absorbed at the ends of the transmission line. Figures 4 and 5 demonstrate that a good 75Ω barrel and connector cause very little disturbance in frequency response. Figure 6 shows that a single 50Ω barrel increases the losses at 1.5 GHz by 0.5 dB, and starts to put ripples in the frequency response. Figure 7 shows significantly worse return loss than achieved with the 75Ω barrel.

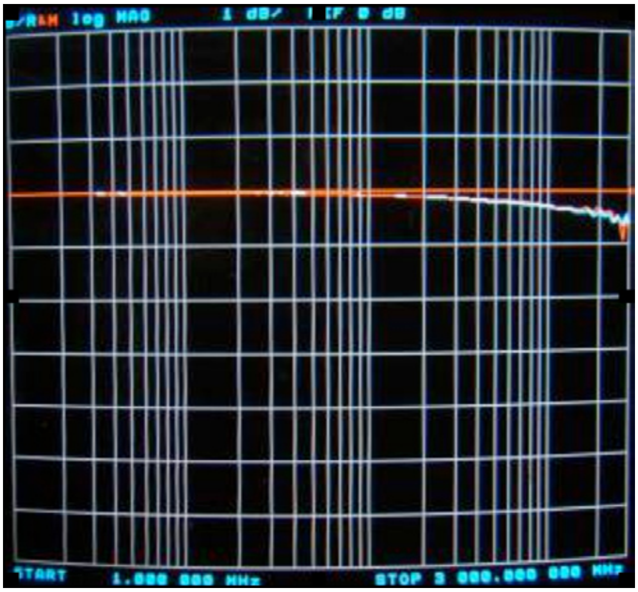

Figure 4 – *The blue curve is the frequency response of two ½ meter cables connected with a 75Ω barrel. The horizontal red line is a 0 dB reference line and the red curve is a 1 meter cable. The response is down about 0.4 dB at 1.5 GHz and almost matches the 1 meter cable.*

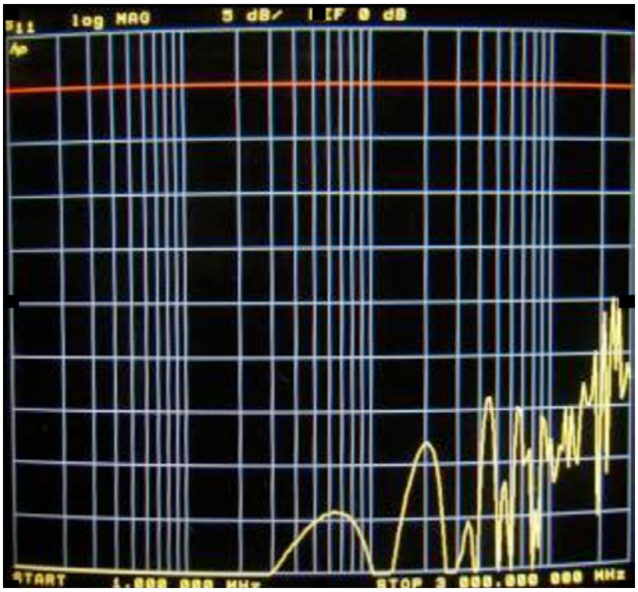

Figure 5 – *Return loss of two ½ meter cables connected with a good 75Ω barrel. The return loss is better than 20 dB to 3 GHz.*

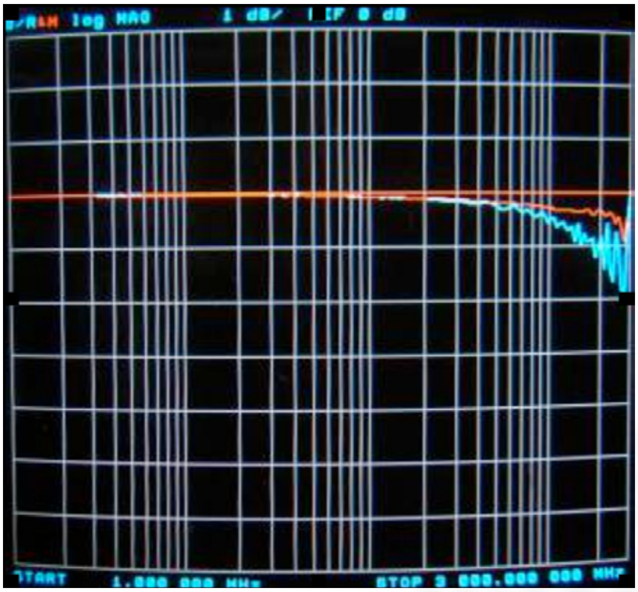

Figure 6 – *The blue curve is the frequency response of two ½ meter cables connected with a 50Ω barrel. The horizontal red line is a 0 dB reference line and the red curve is a 1 meter cable. The response is down about 0.9 dB at 1.5 GHz. Some evidence of reflections is present.*

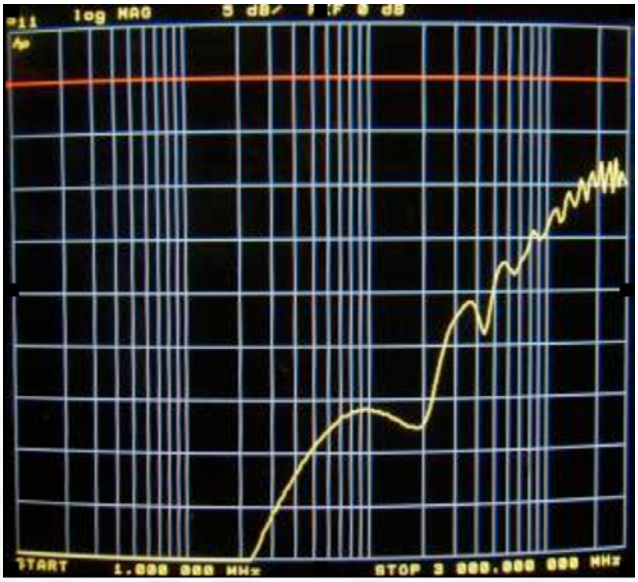

Figure 7 – *Return loss of two ½ meter cables connected with a 50Ω barrel. The return loss is worse than 15 dB at frequencies above 800 MHz.*

Interconnection Problems (cont.)

Two impedance bumps that are separated by a few inches, such as an old patch panel, a couple of bad barrels, or even bad connectors, can cause reflections to occur between the two bumps, setting up standing waves and significantly distorting the frequency response of the connection system. These multiple impedance discontinuities will increase the interconnection losses and reduce the distance the signal can travel.

A TDR, or time domain reflectometer, can be used to look at impedance discontinuities in a system and observe the reflections that result. Most TDR units are built for 50Ω systems, but they can also function for 75Ω systems. A reading of 200m corresponds to 75Ωs. A reading of 0 corresponds to 50Ωs.

Figure 8 is the actual TDR for two 50Ω barrels separated by 22 cm of cable. The actual impedance of the barrels measured about 53.3Ω. The second barrel is identical, but appears different because some of the original TDR pulse was reflected back by the first barrel. There is a small reflection visible 2 ns after the second barrel. This is a result of a reflection from the second barrel bouncing off the first barrel and then off the second barrel again.

Figures 9 and 10 show the frequency response and return loss for this combination. Note the large ripples in the frequency response. The return loss is also much worse than the single barrel.

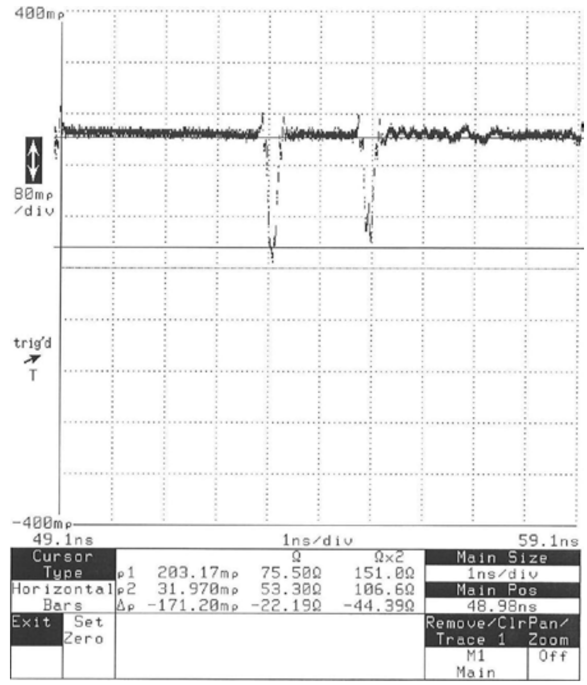

Figure 8 – *TDR of two 50Ω barrels separated by a 22 cm cable, with a 50 cm cable on each end. Note the reflection two divisions before the end of the trace. This is due to reflections between the two barrels.*

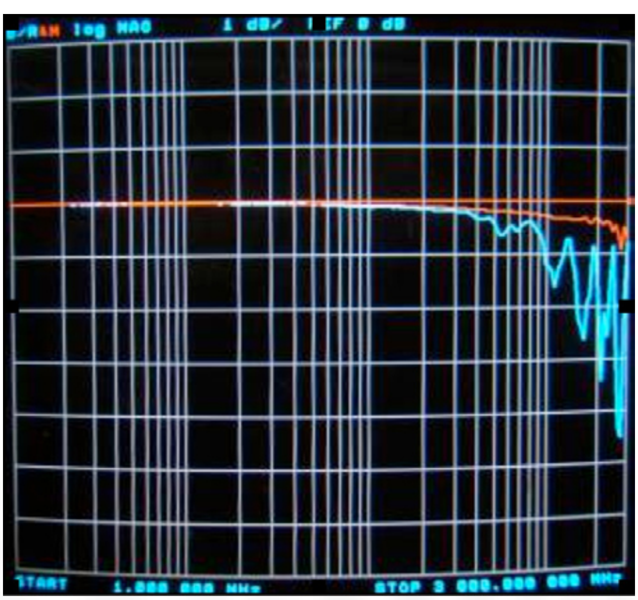

Figure 9 – *Frequency response of two 50Ω barrels separated by a 22 cm cable, with a 50 cm cable on each end.*

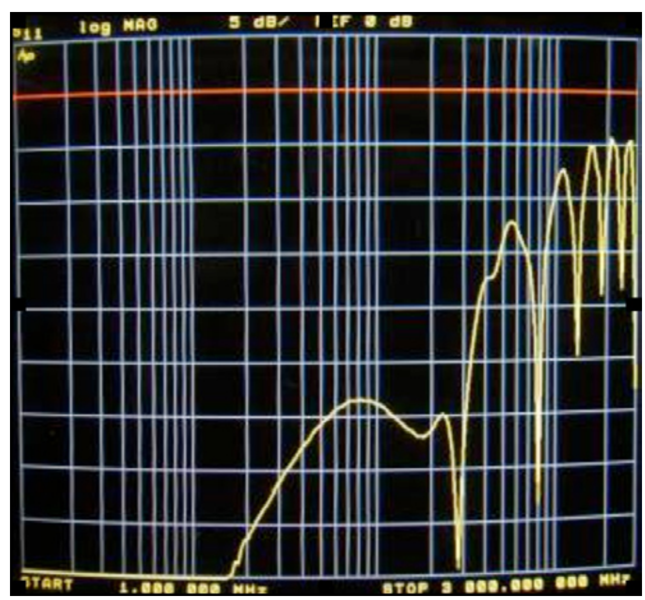

Figure 10 – *Return loss of two 50Ω barrels separated by a 22 cm cable, with a 50 cm cable on each end.*

Interconnection Problems (cont.)

Figure 11 is a set of simulated TDRs for the two 50Ω barrel conditions. 200 mV corresponds to 200m and is equivalent to 75Ω. 0 mV corresponds to 50Ω. The purpose of this simulation is to compare a simulation of the actual TDR to simulated TDR plots with slower rise and fall times. The slower rise and fall times correspond to various SDI data rates. It demonstrates that with lower data rates, having slower rise and fall times, the discontinuities caused by the barrels are less disturbing. Thus, as the data rate is increased, we must be more careful with cabling and connectors. The discontinuities become more significant as they become a larger fraction of the bit time.

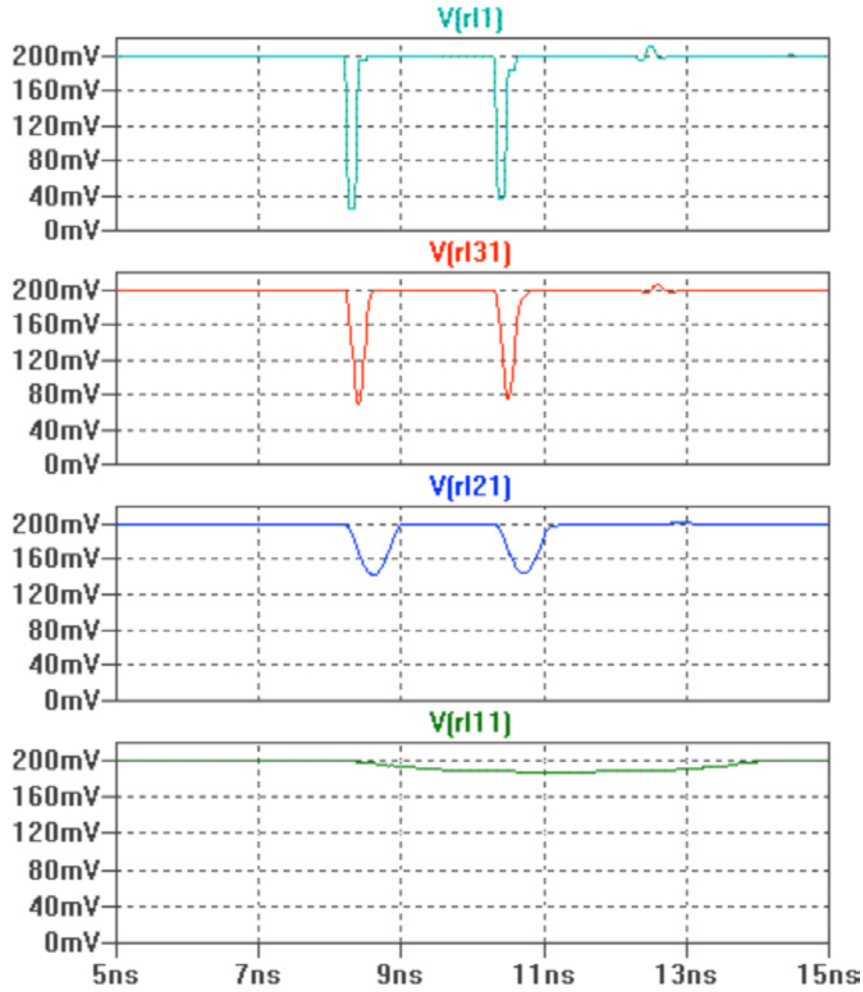

Figure 11 – *TDR simulation of two 50Ω barrels separated by a 22 cm cable. The top trace TDR pulse shape is set to match the actual TDR. The next three traces show simulations matching the pulse shapes of 3 Gb/s, 1.5 Gb/s, and 270 Mb/s pulses.*

Crosstalk

Crosstalk is another issue of concern in signal-dense situations. Crosstalk is similar to adding noise into the signal, but it is not random. It occurs when one or more interfering signals are coupled into the desired signal. Crosstalk may have many sources. Crosstalk between cables in a cable tray is theoretically possible, but has not been observed to be a problem in television systems. The signals are generally well contained inside coax cables and connectors that are in good condition. Crosstalk is usually more of a problem where many signals come together in a piece of equipment, such as a multichannel distribution amplifier.

In general, crosstalk will be at least proportional to frequency. This means an increase of at least 6 dB in crosstalk with each doubling of the data rate. In digital systems, crosstalk will usually show up as increased jitter. A typical crosstalk specification for regular analog video switchers is –60 dB, or 0.1%. This is usually to a frequency of 5 MHz or less. If that amount of coupling, is translated to 1.5 GHz, using an increase of 6 dB each time the frequency doubles, the crosstalk will be about -10 dB. This is too much crosstalk for the serial digital system to work well. Thus careful mechanical and electrical design is necessary to get adequate isolation.

Cable equalization at the switcher inputs compounds this problem. If the interfering signals are coming in on short cables, from a nearby source, and the desired signal is coming on a cable near the maximum length, you have what is called hostile crosstalk. Crosstalk at the switcher inputs reduces the capability of the equalizer circuit to properly recover the signal. When the desired signal is boosted 26 dB by the equalizer, the interfering crosstalk is also boosted 26 dB. Therefore, if you assume a necessary budget of 20 dB signal to crosstalk ratio, and 26 dB of equalization in hostile systems, you need at least 46 dB of isolation between the sum of the hostile signals and the input being used. This isolation is needed at frequencies up to at least one half of the clock rate, or 1.5 GHz for 3G video. For 36 dB of equalization capability, at least 56 dB margin is required between the sum of the crosstalk sources and the selected input. This is roughly equivalent to 106 dB of isolation at 5 MHz

There must be sufficient margin between the interfering signals and the desired signal to get the full benefit of a long distance equalizer circuit. If the isolation is not adequate, it will reduce the usable reach of the equalizer system, when hostile crosstalk is present.

Crosstalk can also occur within the switcher circuitry, following the cable equalizer circuits. At this point, the signals inside the switcher have been equalized, and are all at the same amplitude, but crosstalk there can still damage or destroy the signal. Careful attention to the internal design and construction is required, due to the high number of high-speed signals in a very small space.

Effect of Crosstalk Occuring Before Cable Equalizer

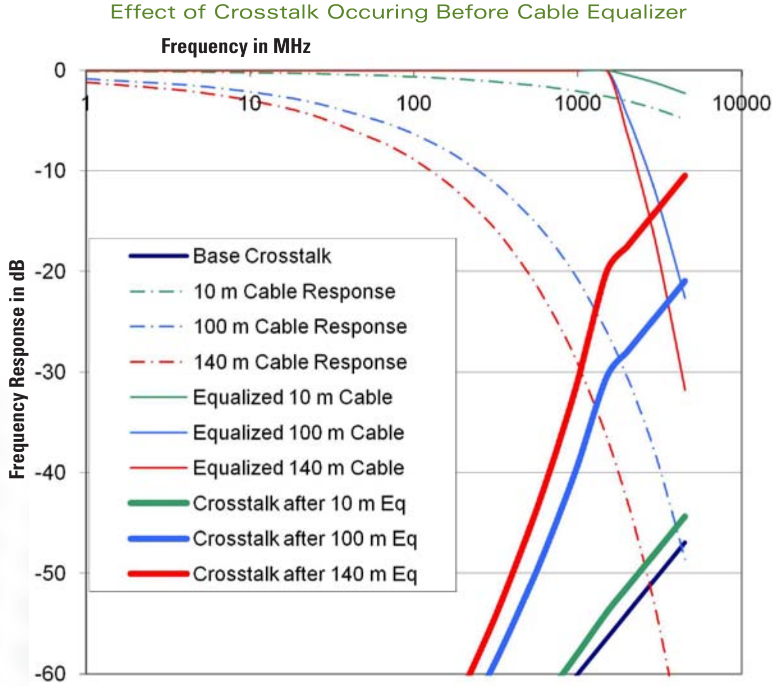

Figure 12 – *Crosstalk occurring before the equalizer is amplified by the equalizer along with the incoming signal.*

The Trinix NXT Advantage

The Grass Valley Trinix NXT system design allows us to provide exceptional performance within the issues discussed above. We studied all of the components we could find and tested several of each type. We chose the combination of parts that gives us the best performance. When new parts come along that make a better system, we will use them. Trinix NXT has the extra performance capability that allows you to use the same 100 meters of cable you installed for your 1.5G system, and make it work at 3G. It also gives you an extra margin to go longer distances, or headroom for some problems in cabling systems.

The Trinix NXT system has input modules, output modules, and matrix modules like many other distribution switchers. It also has a backplane board to interconnect the signal modules. The mechanical and electrical design of the system was conceived to minimize the length of the traces on the high-speed backplane. The longest signal traces on the backplane are about 35 cm or 14 inches in length. Most of the traces are much shorter. This minimizes the high-frequency signal losses in the backplane, and improves the signal integrity within the Trinix NXT system. The module-to-backplane connectors were selected to have excellent performance for 1.5 Gb/s signals, and provide isolation between the signals. Although the original design target for the Trinix NXT backplane was 1.5 Gb/s, we didn't stop with good enough. We made it the best we could. That same backplane also performs extremely well at 3G. We even had it tested by an independent lab to assure the backplane and module interconnections would be adequate for 3G. They are more than adequate, and they do work well.

With Trinix NXT, it is less than 2.5 cm or 1 inch from the end of your cable to the circuitry on the board. The I/O circuit boards plug directly into the back of the BNC connectors, using a patented design. Every input and output on the board is almost identically spaced and placed near the BNC connectors. This gives excellent matching between channels, resulting in consistent performance. Since the input equalizers are located very close to the input connectors, it minimizes the opportunity for weak signals to be corrupted by crosstalk from strong signals nearby.

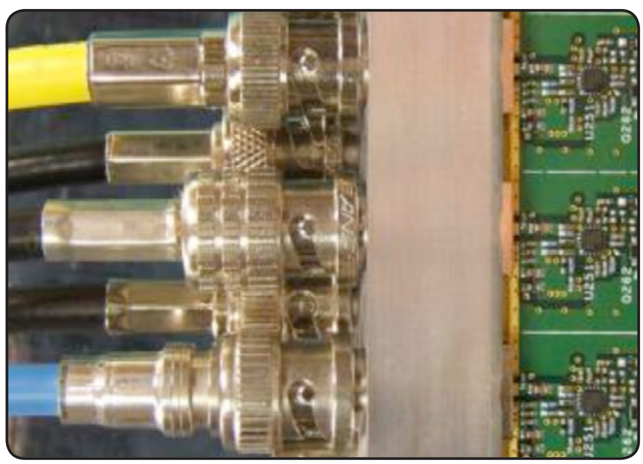

Figure 13 – *Trinix I/O connector panel system gets the circuitry very close to the BNC cables.*

The Trinix NXT Advantage (cont.)

Other systems usually have at least one circuit board or set of cables to connect the BNC connectors to the I/O boards. These are often called "mid plane" designs. This can cause several problems:

- First, no connector is absolutely perfect. These systems need an additional connector and the interconnecting circuit board or cables. The second connector adds additional imperfections to the impedance matching of the system. This can cause standing waves to occur between the two connectors, and attenuate the high-frequency components of the signals. The extra connector and the distance between the connectors make it more difficult to meet return loss specifications. Many times, the interconnection length will vary from path to path through the interconnecting board or cables.
- Second, the interconnecting media can enable more crosstalk to occur, due to the close physical proximity of the signals, especially signals received through short cables are close to signals received through long cables.
- Third, this interconnecting media will also have high frequency losses, whether it is miniature coax, circuit board strip line, or microstrip transmission lines.

The Trinix NXT design allows us to reach 140 meters of 1694A cable at 3G with hostile crosstalk on the surrounding inputs. This means the surrounding inputs are all being driven through short cables from other 3G signals. At NAB 2009, a Trinix NXT system was demonstrated at 3G, with no errors, running 170 meters of 1694A into the Trinix input. This illustrates the longer distances possible when hostile crosstalk is eliminated.

Miniature I/O connectors have captured a lot of attention. They allow the rear panel to be smaller for a given number of inputs and outputs. This can be an advantage in tight places, but it also has risks:

- First, the connectors may not be well matched to 75Ω, and thus cause impedance bumps.
- Second, the signals are closer together, enhancing the possibilities for crosstalk to occur between inputs.
- Third, the small connectors require small cable to be installed in them. This may be fine for tight spaces and small facilities, but if you need to go a long distance, you need better cables. This requires a transition panel from small cables to regular sized cables. The higher losses of small cable limits the signal reach of your inputs and outputs. You must plan for these losses in your cable budget.

Trinix NXT is not as I/O-dense on the rear panel as some other systems, but that is not necessarily a bad thing. How many cables can you manage per square foot on the rear of your switcher? How many cables can fit within, between, or under your racks? Do you really want to use small cables and transition to other cables? What is more important, cable reach or rack units? Does it matter that another switcher is smaller, if it does not work well?

Don't just take our word for it that the Trinix NXT has the best 3G system performance. The Trinix NXT system, along with systems from several other router manufacturers, was tested by a respected independent laboratory in Germany. They ran a 3G signal through five passes on the system. Trinix NXT was the only system that passed with no CRC errors. In fact, we have run a 3G signal 32 passes through the Trinix NXT with no errors! The lab was amazed by the length of cable that Trinix inputs can accept. They were also surprised by the good and consistent return loss at the system inputs and outputs.

We encourage you to explore the Trinix NXT advantage, and find out for yourself.

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