High-Definition Cabling and Return Loss

By Stephen H. Lampen, Martin J. Van Der Burgt, and Carl W. Dole

Return loss is signal attenuation caused by impedance variations in the structure of a cable or associated connection parts. These variations cause the signal to reflect (return) back to the source. At lower frequencies, return loss is a minor effect; at frequencies above 50 MHz, it can have a significant effect; and at frequencies used for high-definition video, 1500 MHz and higher, it can be a major, even critical, factor. For this reason it is suggested that return loss be a key consideration in the measurement and verification of HD system performance.

Two types of measurements are concerned with reflection of signals on cable. One is return loss (RL) and the other is structural return loss (SRL), similar to return loss, but measured differently. With SRL, the analyzer is matched to the average cable impedance and the reflected signal is measured. With RL, the analyzer is set to nominal cable impedance (e.g., 75Ω) and the reflected signal is measured.

Return loss is a more accurate way of measuring reflections. In the real world one cannot adjust the input or output impedance of a device. SRL measurement, which nullifies the average cable input impedance mismatch, is not a real world test. RL, which is set to the desired impedance (in this case 75Ω), regardless of the actual cable or equipment, is more appropriate.

This paper will focus on return loss, which characterizes signal losses caused by errors in the design, manufacturing, or installation of a cable. The higher the RL number, the better.

Why Test RL?

In the computer networking world, there are detailed standards that specify how to measure and verify network performance. The results of these tests can be correlated and printed to provide the end user assurance of system performance before it is turned on.

No such verification or series of tests exist for video, much less digital or HD installations. Yet, as these signals use much greater bandwidth, and with ever-increasing data rates, such verification becomes even more critical. Similar to the computer networking world, it is felt that ultimately, an installer should test not only the cable in a video installation, but also the "link performance," that is, all passive devices such as cable, connectors, feed-throughs, patch panels, patch cords, etc. RL testing may be one of the most direct ways of verifying high-frequency digital and HD link performance.

Why Worry about RL?

HD takes us into a world that is less video and more radio frequency (RF). In fact, an uncompressed high-definition video signal (greater than 1500-MHz bandwidth) is more an RF signal than video signal. Therefore, many aspects of transmission line theory now apply to video signals.

The bandwidth of a single uncompressed high-definition video picture now exceeds that of a standard multichannel CATV/broadband signal. Further, the bandwidth limit of HD is often higher than the transmitted channel frequency! With such high frequencies, it is evident that new methods of performance verification are essential.

The History of Return Loss

Return loss has long been a parameter of wide-bandwidth and high-frequency systems. Many of these systems, such as microwave, have been around for 50 years, yet, it is only recently that performance requirements apply to video signals.

Entities interested in RL include the CATV/broadband industry; microwave; very high data rate computer network protocols such as 100BaseT emerging gigabit networking; and the telephone company, which routinely measures return loss on DS-3 cables.

What Causes RL?

Variations in the impedance of a cable produce RL; therefore, anything that affects impedance tolerance affects RL. This includes the basic construction of a video cable, from the size, shape, and make-up of the center conductor; choice and manufacturing of the insulation or dielectric; and choice of shield elements and materials. The jacket print method can also have an effect on return loss.

Return loss can also be dramatically affected by the choice of connectors and other passive components, such as feed-through or bulkhead connectors, patch panels, patch cords, and even the connectors attached to the inputs and outputs of equipment. During installation, return loss can be affected by the treatment of the cable. Bend radius and pull strength are often factors overlooked by wiring crews. These and other sources of return loss, will be discussed later.

How to Determine Impedance

Impedance is determined by three basic factors in a coaxial cable: the diameter of the center conductor (AWG), inner diameter of the shield, and dielectric constant of the material between the conductors as shown in Fig. 1.

At higher frequencies, where wavelengths are short, return loss can be a significant loss factor. Thus, it is rarely a problem at analog baseband video (4.2-MHz bandwidth, 234-ft wavelength in air), but comes into play with

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digital video (270 Mbit/sec, 270-MHz or greater bandwidth, 7-ft wavelength in air). However, it is critical for HD 1.485 Gbit/sec, 1500 MHz, 16-in. wavelength in air). Periodicity can affect not only the primary wavelength, but also odd and even multiples of these frequencies, so that the result can have far-reaching effects throughout the spectrum.

Almost every step and process in the manufacturing of cable can introduce random flaws. In a well-manufactured cable, they show up as "grass," the overall return loss floor of a cable.

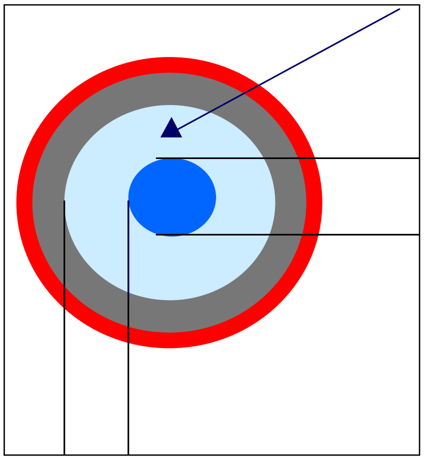

Figure 1. A cross-section of a coaxial cable with the dimensions and materials critical to impedance.

Figure 2 illustrates a return loss graph of a well-manufactured cable.

All cables used in these tests, and shown in these graphs, were 100-ft sections of Belden 1505A. The roll from which each section was cut was chosen at random, and, except for the standard testing done to every roll, this cable was not otherwise pre-tested or pre-selected. All 100-ft pieces were taken from the same roll. This was to allow comparison of a "good" cable in Fig. 2, to subsequent graphs showing potential problems.

Figure 2 shows the signal being reflected. Note this particular cable is typically below -30 dB, with occasional spikes in the -27 dB range. As will be shown, this is an excellent cable. All negative effects discussed from here on will raise this "floor."

Periodicity

Periodicity is an effect caused by periodic discontinuities. These are small, sometimes immeasurable changes, happening over and over. They are most often caused by imperfections in manufacturing such as a wheel out of round or a bad ball bearing. Since these defects occur every revolution, the effect repeats within the resultant cable.

Periodicity is most often a problem at high frequencies where the repeating defect is related to a specific wavelength. This is why periodicity is rarely a problem for analog baseband video (4.2-MHz bandwidth, wavelength 234 ft) but will be a factor with serial digital video (270 Mbit/sec, 135-MHz bandwidth, wavelength 7.3 ft), and a critical factor for HD (1.485 Gbit/sec, 750-MHz bandwidth, wavelength 1.3 ft).

Figure 3 shows the graph of a cable with prominent periodicity. In the figure, "spikes" of return loss indicate that the cable is resonant at such frequencies and thus causing additional attenuation to the signal at these points. The spikes act as a notch filter, possibly leading to a rise in bit errors, since the frequencies have been greatly attenuated.

In this example, the periodicity was introduced by using a common crimper to crimp BNC connectors onto cable. Every 10 ft on the 100-ft test piece, the cable was crimped, that is, the crimper was squeezed on the outer jacket. It should be noted that this effect was so subtle that it required marking the cable with tape at each of the points of compression just so they could be counted. The results, as seen, were not very subtle.

Ten foot sections between compression points indicate a wavelength of 3 m, which corresponds to a frequency of 100 MHz. Periodicity can affect not

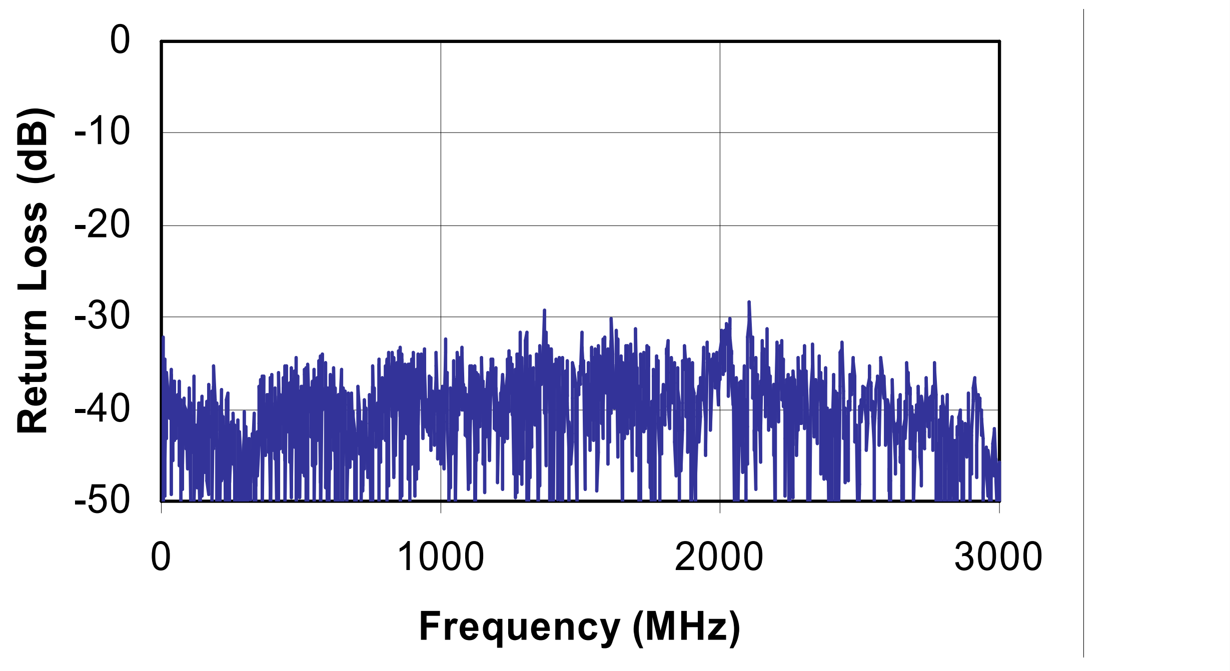

Figure 2. Return loss of a well-manufactured cable.

only the frequency corresponding to the half-wavelength spacing of the periodic discontinuities, but also odd integer multiples of this frequency.

Center Conductor

If the center conductor is the wrong size, or randomly varies in size, it will affect impedance and return loss. Effects will also occur if it is not in the center or varies randomly in its position. Constant variations in size, caused by a supply wheel that is out-of-round, would be a periodic variation, as previously mentioned.

Dielectric

When the dielectric is extruded around the center conductor, a number of factors can affect impedance and return loss, such as dimensional or velocity variations incorrect for the desired impedance.

The foam can be mixed correctly, with perfect dielectric value, but if it is too soft, even bending the cable can cause the center conductor to “migrate” through the foam. At this point, the cable will not be the desired impedance and return loss will occur.

Shield

Shields around cables intended for high frequencies usually have a foil-braid combination. The braid is effective from 100 kHz to around 10 MHz. The foil shield is effective from 10 MHz up into the gigahertz range. However, if the braid coverage is low, it may not hold down the foil. This effect is called ballooning and will affect impedance and return loss. As long as high braid coverage is maintained, at least 90%, ballooning will be minimized. Further, a cable factory employs rows and rows of braiders, which contain many wheels and gears and are therefore significant sources of periodic discontinuities and random “grass” variations.

Jacket

While the jacket extrusion has little or no effect on RL, there can be problems with print wheels, which mark the information along the cable. Print wheels put pressure along one side of the cable, potentially distorting the dimensions inside. It is ironic to note that customers demanding crisp print legends, which require higher pressure to obtain, are potentially trading off impedance and return loss. This is especially true in audiophile/videophile high-end cables where print legend quality is a key requirement.

There is an alternate way to mark cables, using ink-jet printing. In this method, the writing is “shot” with little dots of ink onto the cable. This is very fast, and the printing device does not even touch the cable. It is also common for commercial and industrial cables, where appearance is a secondary issue. Ink jet also allows the use of consecutive numbers or other changing print legend information, since it can be computer controlled. However, it should be pointed out that the cable must still pass through rollers and wheels in order to be accurately measured. Consecutive numbers are often at exact length measurement, such as one marking per foot or per meter. The accuracy of the marking, therefore, is directly related to the pressure of the wheels from which the measurement is extracted.

Installation Factors

Once the cable is purchased it is subject to further stresses that can affect impedance variations. For instance, it is common for installers to step on the cable, or run over it with moving equipment, such as a tool table, or other wheeled objects. When placing equipment in racks, installers routinely put equipment on bundles of cable. Perhaps it is felt that this gives the equipment a cushion before it is hoisted and screwed into place. For HD cable, it might be more damaging to the cable than the equipment being protected.

Damage also occurs during actual

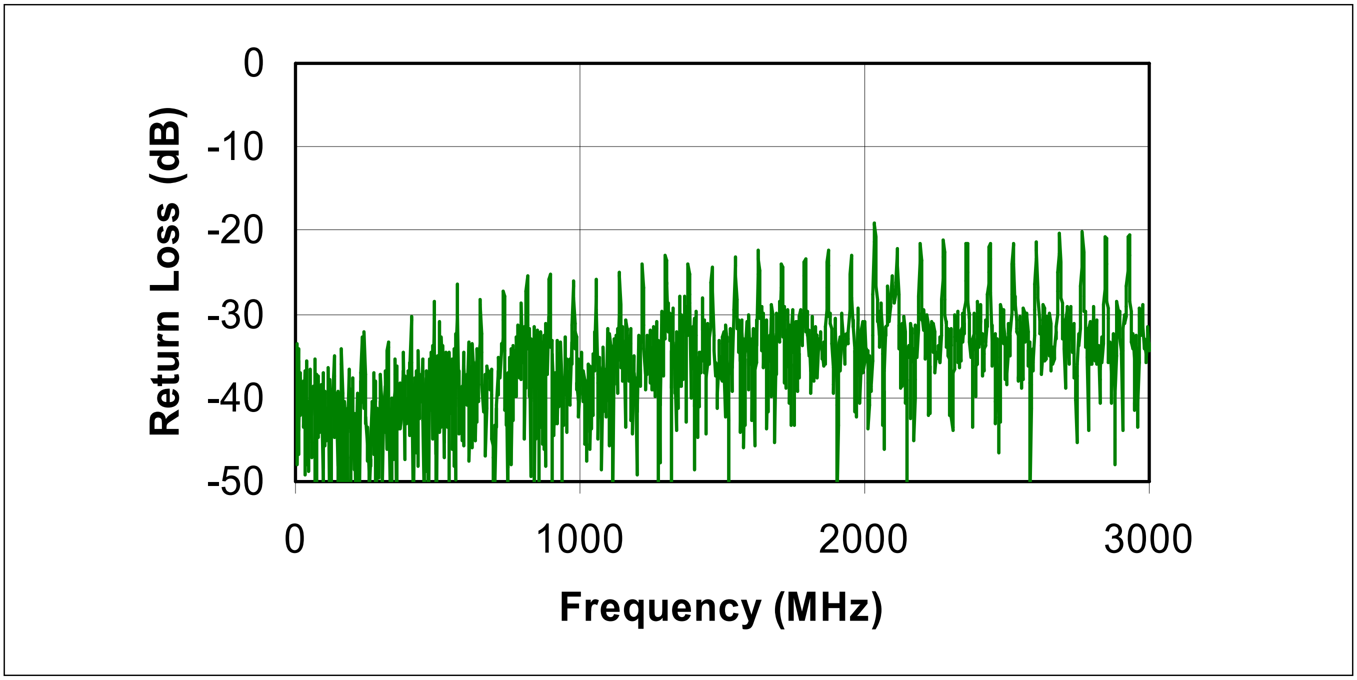

Figure 3. A cable with a serious periodicity problem.

installation, starting with the recommended bend radius of the cable. Industry standards have never exceeded "ten times the diameter of the cable," but this requires knowledge of the diameter. Table 1 shows a chart of common HD cables with diameters and minimum recommended bend radius.

Bending creates pressure on the center conductor, causing it to move through the dielectric toward the inside of the bend. This affects impedance and return loss. Bending, especially tight bends that approach or exceed the rule of thumb, no bends tighter than ten times the diameter, cause significant pressure on the center conductor. The center conductor may attempt to alleviate the pressure by moving down through the foam vertically. This can dramatically affect impedance at that point with resultant return loss.

Solid dielectrics are extremely good for preserving center conductor position, but the attenuation at high frequencies is greater than with foamed cables. Foam has greater impedance variation than solid material, but dramatically improves high-frequency response. So essentially, high-frequency performance (attenuation) is traded for impedance variations and return loss. Many manufacturers produce cables with low-density foam, which test well in the lab, but are significantly worse after installation. Further, low-density foam often causes slow conductor migration. Conductor migration is the gradual movement of the conductor through the dielectric material caused by internal stress from bending. This effect can worsen over time, slowly altering the impedance and return loss of the cable. Such a cable may test fine one day but will not test well at a later date.

The installer should also consider the pull strength of the cable, which is difficult because most cable manufacturers do not publish this data. Excessive pulling can cause elongation of the center conductor, which has a significant effect on impedance and resultant return loss. It can also cause braid shields to act like a "Chinese finger trap" that squeezes and deforms the dielectric under the shield.

In the computer network world, excessive pulling tension is a major factor in degradation of network performance. Therefore, it is strongly suggested that installers consult the cable manufacturer to obtain the maximum permissible pulling tension (Table 2). Maximum pulling tension is calculated to be 40% of the cable breaking strength.

Table 1—Common HD Cables

Cable Part No.	Diameter	Minimum Bend Radius
1855A	.159	1.59 in.
1505A	.235	2.35 in.
1694A	.275	2.75 in.
8281	.305	3.05 in.
7731A	.405	4.05 in.

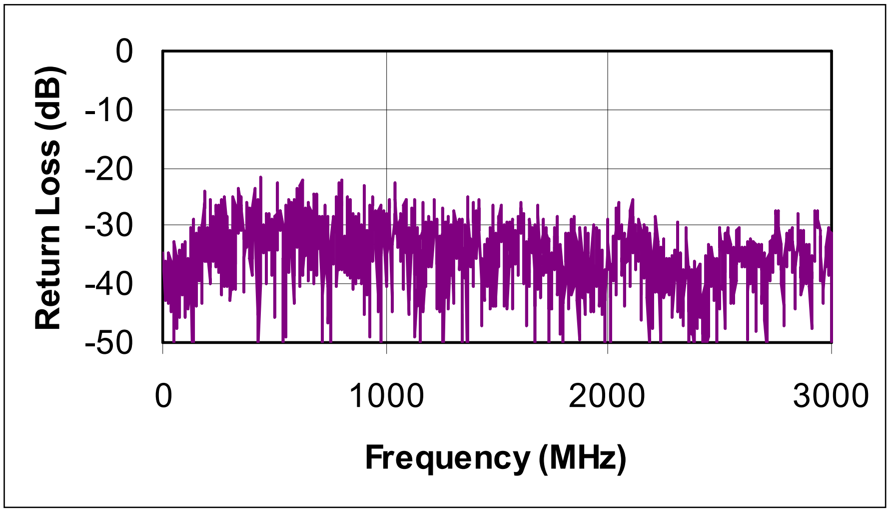

Figure 4. A very badly manhandled cable.

Table 2—Cable Pull Strength

Cable Part No.	Suggested Maximum Pull Strength
8281	116 lbs.
1505A	47 lbs.
1694A	69 lbs.

It should also be noted that installations with plastic wire ties located equal distances apart can introduce periodic variations and added return loss. Computer network installers have become aware of this and are now using "soft" cable ties located at random distances. These can include Velcro-based ties, which can only be tightened to the strength of the Velcro adhesion, or to standard or extra-wide plastic wire ties tightened by hand. If a wire-tie gun is used, it is suggested that it be set to the minimum setting. Additionally, one might place a short "stub" of cable under the tie, with the other cables, and remove it after tightening with a wire-tie gun. This will assure loose ties and minimal periodic or impedance variations.

It is fully realized that past video installers often prided themselves in the uniformity of tie spacing and the tight and beautiful grouping of cables in an installation. These neat and beautiful installations may be part of the problem working against ideal system performance.

Figure 4 shows a 100-ft cable that has been crushed, knotted, stepped-on, squeezed into a ball of wire and otherwise manhandled far beyond that expected in even the roughest installation. Note that almost 10 dB of "return loss headroom" has been lost. On the other hand, this cable still passes the SMPTE requirement of 15 dB return loss, thus showing the robustness of this hard-cell high-density construction.

Connectors

Connectors are a major consideration in impedance and return loss. Broadcast installers are now aware that 50Ω BNC connectors, fine for analog baseband, are unacceptable for digital. Where 75Ω BNC was once important, it is now critical, and connectors must maintain this impedance up to the highest frequency required for the signal format. One can often obtain charts (e.g., Smith Charts) from connector manufacturers that show impedance performance up into the gigahertz range. What will be available in the future? 1080p? This uncertainty is one of the reasons that Belden tests all of its HD coaxial cables to 3 GHz.

How Much Return Loss?

SMPTE 292M[1] recommends a return loss, up to the clock frequency (1.485 GHz), greater than 15 dB. Is this an appropriate number for a system-wide HD spec? Consider this: converted to voltage standing wave ratio (VSWR), a 15-dB RL number is equivalent to a VSWR of 1.43:1. If this is an acceptable number, then 15 dB is also acceptable.

The author suggests that a cable RL of 15 dB from the manufacturer may not be acceptable. This is due to the fact that the suggested 15-dB return loss in the SMPTE standard applies not only to cable, but also connectors, feed-throughs or bulkhead connectors, patch-panels, patch cords, and all other passive devices in the chain. Since each contributes its share of RL, it is strongly suggested that one start with RL higher than 15 dB. In the case of cable, at least 20 dB of RL is appropriate.

How to Minimize Return Loss

The only way to minimize return loss caused by manufacturing defects is to choose a quality product made by a reputable manufacturer. Once a cable is purchased, a good suggestion is to review installation guidelines with in-house engineering staff or the integrator chosen for a particular project.

Conclusion

HD installers should consider return loss testing to determine and verify acceptable cable and link performance. Currently, the test equipment necessary for this consists of a network analyzer with a fixed bridge, configured to 75Ω. Variable bridges, such as those used to measure SRL, should be avoided. The test performed is known as an S_{11} reflection measurement, which indicates that the signal is generated and measured at the same port.

There are currently no portable, much less handheld, units for return loss measurements. However, it is expected that test equipment manufacturers will notice the value of this testing and produce portable, cost-effective return loss analyzers that can measure return loss analysis to at least 3 GHz, have pre-set limits established in the tester, and store and download graphs or data.

Further, if a user wishes to establish a return loss limit, then each cable or link could be determined as a pass/fail situation. Ideally, these determinations could be established and recorded in the tester for later download in table form.

References

1. SMPTE 292M, "Television—Bit-Serial Digital Interface for High-Definition Television Systems," *SMPTE J., 107*:849, Sept. 1998.

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