# Determining Error Cliff Headroom in HD Signals

By Jim Boston

It is well known today that digital signals are nonlinear. To state the obvious, it is the "high" or "low" state of a serial digital signal, along with its transition time that determines the state of a data bit cell in a serial digital bit stream. The transition area between the high, and low states is undefined when determining the value of an individual bit. To maximize the chances of reliable detection, you want sufficient signal amplitude so noise or receiver inaccuracies do not cause errors.

The transitions, or "edges", between states are just as important. These transitions enable clock recovery from the bit stream in a self-clocking signal such as SMPTE 292M. Without a clock to use at the receiving end, there is no way to know when to check the status of an arriving bit. An algorithm is used to scramble data as it leaves the transmitter to create as many edges as possible. This assists the receiver's PLL circuitry in generating a local clock synchronized to the transmit clock.

The error correction and error masking in modern digital equipment insures that digital signals do not gradually degrade with increasing attenuation in the signal path as analog signals do. Instead, a digital transmission path continues to work perfectly up to the point where it suddenly does not work at all. This is the well-known "Cliff Effect", illustrated in Figure 1.

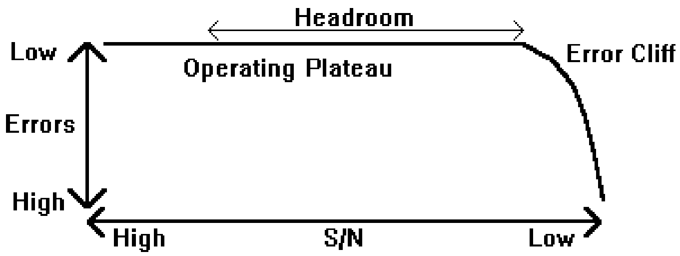


**Figure 1**

SDI (Serial Digital Interface) signals that are experiencing few, or no errors are somewhere on the operational plateau shown in Figure 1. Operation stays uneventful until you reach the "Error Cliff". As the path traverses over the knee of this cliff errors go rapidly from non-existent to enough to swamp recovery efforts, making the path unusable. As the path transverses the knee of the cliff as little as 3 extra feet of coax can be enough to send a signal over the cliff. Many things determine where you are on that operational plateau. Lets now examine how you go about determining exactly where you are on the plateau, and how to stay away from the cliff.

## *Bandwidth & Signal Requirements*

Although the way the SDI signal is used is “digital” in nature, many “analog” attributes of the signal can be used to predict how close to the error cliff a particular digital path is.  Figure 2 shows a typical SDI signal. The portion shown here is of three successive “1”s in a SMPTE 292M data stream.

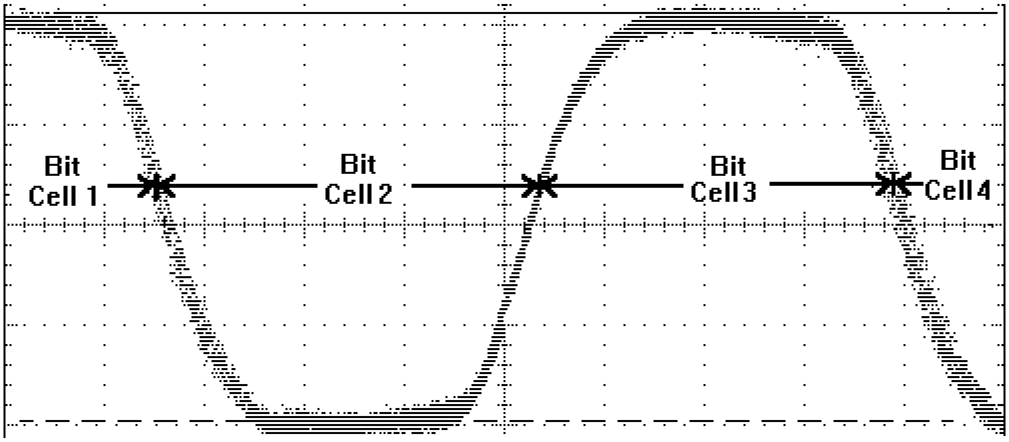


**Figure 2**

A SMPTE 292M data stream changes state at the start of each bit cell if the bit cell has a data value of “1”. The three transitions shown here indicate the transition changes at the start of each bit cell. This transmission scheme is known as NRZI (Non Return to Zero Inverted), which means that the receiver doesn’t need to worry about the polarity (high or low) of the incoming bit stream. This approach also yields a constant high or low if a string of zeros is encountered, hence the use of a bit-scrambling algorithm. The peak-to-peak value of this signal should be 0.8V, and the rise time, or transition time should be between the 20% and 80% amplitude points is only 270 ps.  If the length of a 53’ production trailer represented a second in time the rise time of a single HD transition would occur in less than 2 millionth of the thickness of a piece of paper hung on the wall. Put another way; using the distance of New York to Los Angeles to represent one second in time, the total time shown in Figure 2 would represent a single centimeter travel between the two cities.

If the transmission path that this signal takes had infinite bandwidth, and no phase delay, or group delay, it would be a perfect squarewave.  But no transmission path is ideal.

The small snapshot of data seen in Figure 2 has a fundamental frequency of 750 MHz. This is because data bit cells occur at a rate of 1500 MHz. Two of those bit cells in succession constitute a positive and negative half of a square wave with a frequency of 1500 MHz /2, or 750 MHz. That 750 MHz wave has a 750 MHz sine wave as its fundamental (Figure 3).

## *Square Wave Fundamentals*

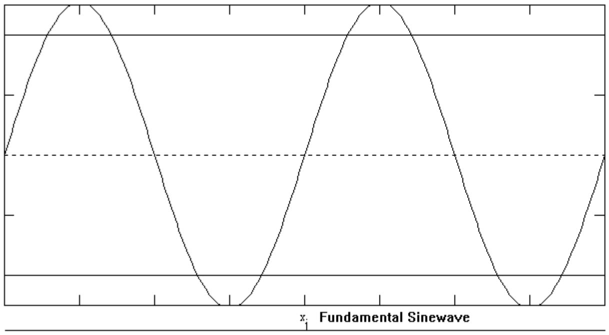


**Figure 3**

If the third harmonic is added to our fundamental (3 * 750 MHz) the waveform in Figure 4 is produced.

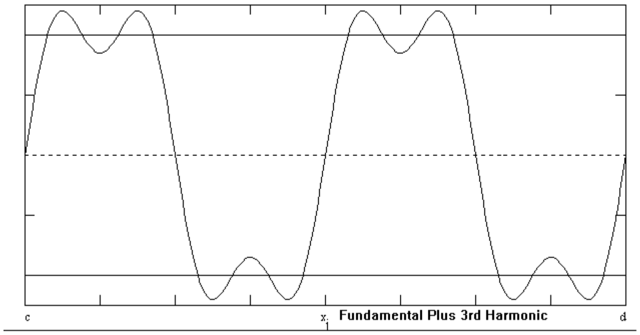


**Figure 4**

If some additional odd harmonics are added in the correct amplitude and phase the waveform in Figure 5 results.

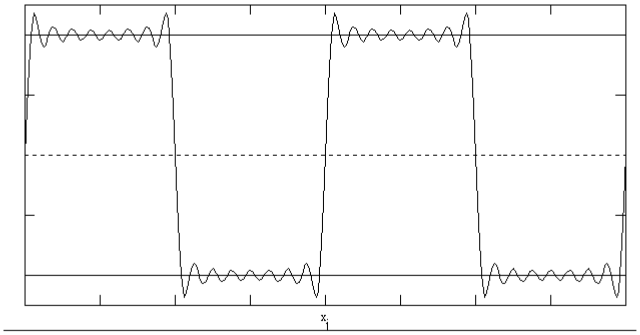


**Figure 5**

Notice that only the odd harmonics are needed in building the above square wave. Figure 6 shows why.

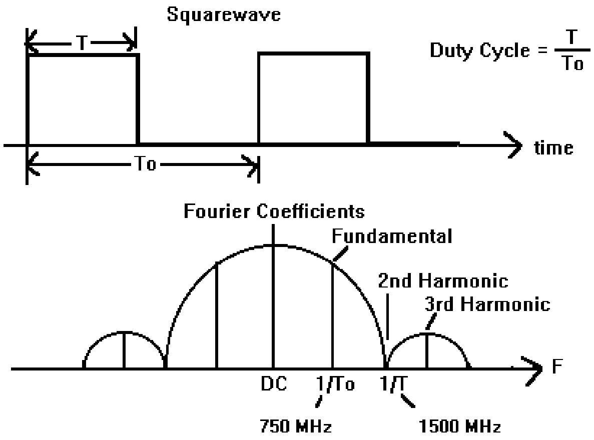


**Figure 6**

A square wave with 50% duty cycle has the fundamental frequency, plus the 3rd, 5th, etc. or the odd harmonics. But notice, the 2nd, 4th, etc. are missing.

A pulse with its duty cycle less than 50% will have the response demonstrated in Figure 7.

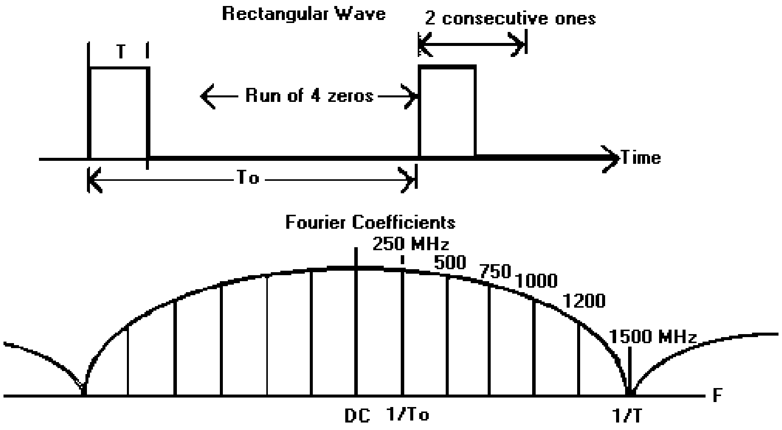


**Figure 7**

It takes many more harmonics than needed for a simple square wave to describe the function at the top of Figure 7. The top half of Figure 7 illustrates that edge transition time takes place at the start of each bit cell.

Thus, if only a continuous string of ones are sent, the spectrum shown in Figure 6 would occur. The fact of the matter is that various runs of “ones” and “zeros” are sent, which results in a spectrum more resembling Figure 7 being sent. It takes a lot more low frequency energy to create a signal with the duty cycle shown in Figure 7, versus the one in Figure 6.

Many things still happen at traditional television rates. Pairs of SAV, and EAV (Start of Active Video, End of Active Video timing reference signals) occur at the horizontal line rate. The patterns encountered during the vertical interval still occur at the field rate. This ensures that considerable energy will occur at fairly low frequencies.

## *Spectral Analysis*

The weak link in most serial digital systems is the path from the transmitter in one box to the receiver in the next box. The physical layer used to transport the data from one "box" to the next is comprised of mostly coax. Some connectors, and perhaps a jackfield might be included in an average path. But coax provides the greatest exposure to problems for a video data stream. Coax can be thought of as an infinite network composed of inductive and resistive components in series, with distributed shunt capacitance. This works out to be a low pass filter whose poles increase in number, and move closer to zero with length. This means that the longer the cable, the greater the attenuation of all frequencies, with the roll-off increasing as a function of frequency. As an illustrative example, if a given coax had the response of Figure 8, it would show the response of Figure 9 if its length where increased by a factor of ten.

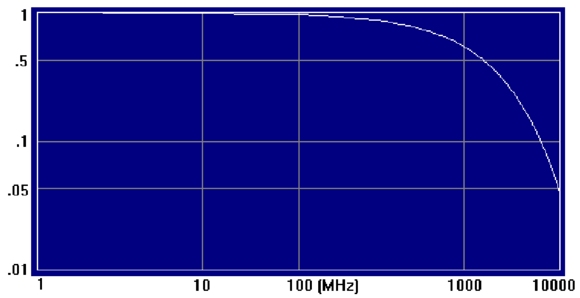


**Figure 8**

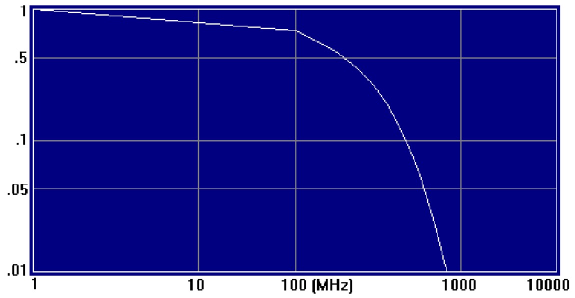


**Figure 9**

It is obvious that another decade increase would eliminate the higher frequency content altogether, rendering the signal unrecoverable. Since the signal is attenuated as the frequency increases, the upper harmonics of our signal disappear, and our square wave data signal starts to look more like a sinewave. Additionally, with all the low frequency and DC energy still available our squarewave starts to look like Figure 10.

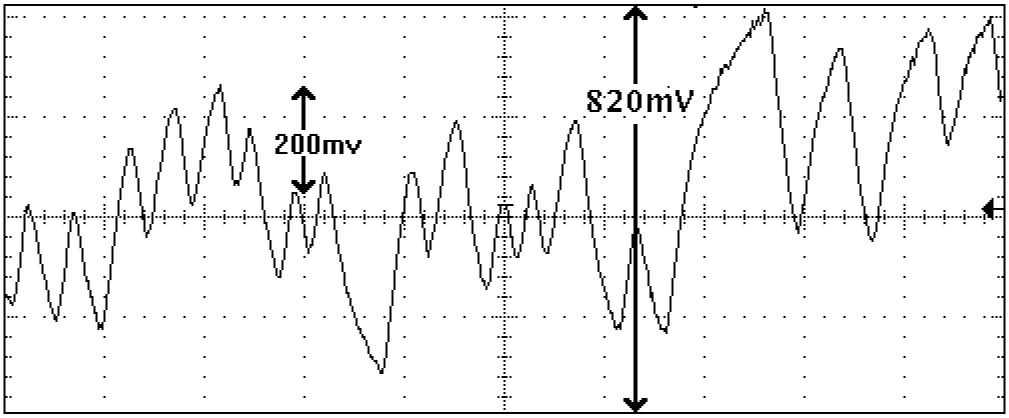
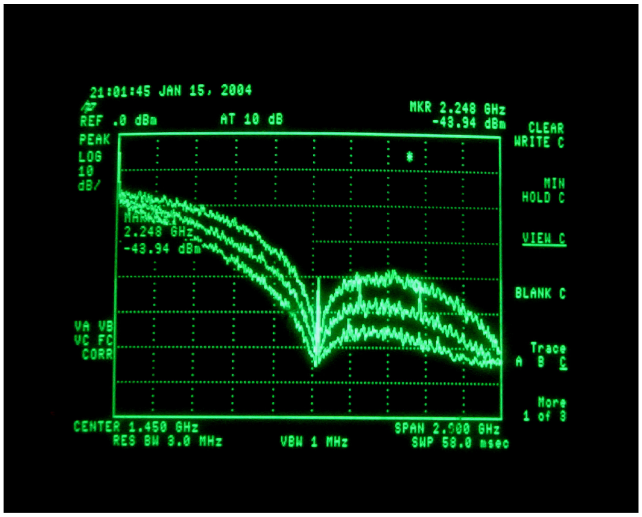


**Figure 10**



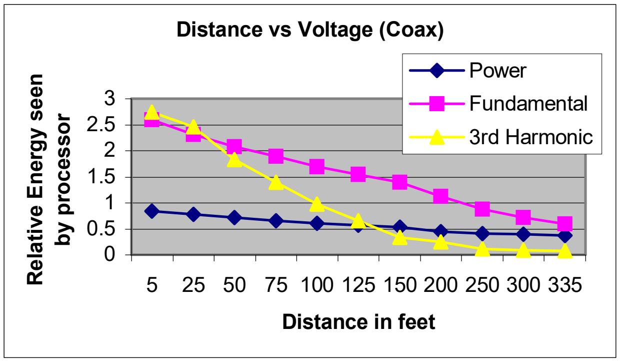


**Figure 11**

**Figure 12**

## *The Bottom Line*

There is an axiom in building facilities: the weight of the cabling to turn an equipment list into a system is often close to the weight of the equipment itself. Because of that many systems, especially those that find themselves on the road, are designed and built using the lightest cables possible. Thus even with HD many systems use mini-coax such as Belden 1855A cable. The physics of smaller diameter cable results in increased losses as a function of frequency. Whereas Belden 1694A has 5 dB loss per 100 feet at 750 MHz, 1855A has 9.59 dB of loss. At 2250 MHz (the center of the third harmonic band) 1694A has 9.14 dB per hundred feet, while 1855A has 16.0 dB over the same distance.

Figure 11 shows super-imposed spectrum waveforms at distances of 50, 100, and 150 feet over 1855A. It can be plainly seen that while the fundamental energy drops as distance increases, the third harmonic energy drops at a much greater rate. Figure 12 shows this reduction in energy graphically. While overall power will drop by only half as cable is increased from 0 to over 300 feet, the fundamental will drop to a third of its original value, and the upper harmonic, the energy that allows the HD serial bit stream to be recovered, will fall to the noise floor over that distance.

Designing, building, and maintaining HD facilities do not dismiss many concerns that seemed pertinent only in the analog domain. Bandwidth only becomes narrower as distance increases. Simple inexpensive ways of checking the health of transfer functions in your HD paths become paramount.