Understanding the blocking capacitor effect on the HD/SD pathological signals

APPLICATION NOTE: AN-01 (rev 0.1)
Wrote by Renaud Lavoie.
www.brioconcept.com

Introduction

The goal of this application note is to demystify the effect of the blocking capacitor (also known as AC-coupling capacitor) effect on the SMPTE-424, 292 and 259 pathological signals. The designer can find articles on how the equalizer should handle the pathological signals, but the information about the blocking capacitor is not accessible on the internet. This application note explains the behavior of the blocking capacitor and show why the pathological signal is affected.

Pathological signal generation

The pathological signal is a result of the coding scheme of the SMPTE standards. The NRZI is use to increase the transition density in the serial data stream, but some sequences create the non desired pathological signals. The NRZI also allow the receiver to decode an inverted stream. The choice for the NRZI was the minimization of the overhead created by the encoding. Take as an example the 8b/10b encoding, from the 8 bits data, the encoder create 10 bits. With the 8b/10b encoding, the data stream have 25% speeds overhead due to the encoding, compare to 0% with the NRZI. However, the 8b/10b encoding creates a DC balance data stream. The NRZI encoding is accomplished after the concatenation of two functions:

$$G_1(X) = X^9 + X^4 + 1$$

$$G_2(X) = X + 1$$

As a consequence of this encoding scheme, runs of 0s and 1s can appear in the data stream. Applying 300_{hex} followed by 198_{hex} during the video active line produce 19 high (or low) data followed by a unique 1 low (or high) data. This run isn't a problem if this occur once, compared to 66b/64b that can produce 66 consecutive identical data (CID) .The problem with the NRZI encoding is the repetitive sequence of 300_{hex} followed by 198_{hex}, it produces the pathological signals. The following figure shows the pathological waveform that occurs in the active portion of the line.

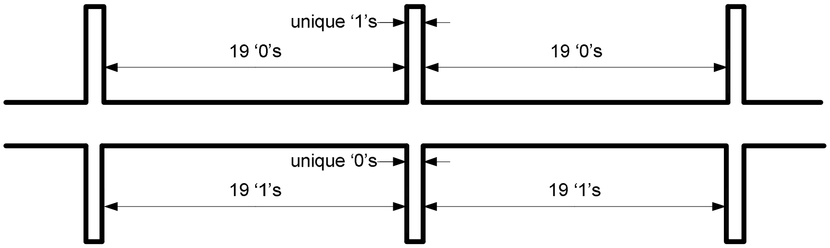

Figure 1. Pathological signal

Blocking capacitor effect

The blocking capacitor with the termination resistor forms a high pass filter. This filter should have a low cutoff frequency to minimize the distortion on the signal. The following figure shows the simplified model (note that the blocking capacitor affect differential signal as well).

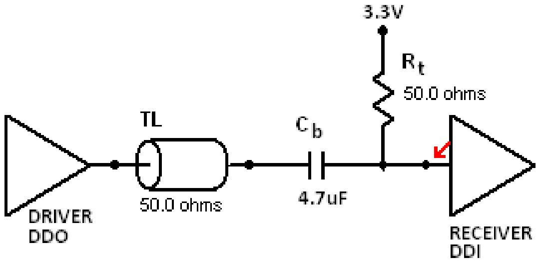

Figure 2. Typical AC-coupling capacitors

When long runs of consecutive identical bits are presented to this high pass filter, a voltage drop occurs, resulting in low frequency jitter. This jitter is pattern dependant. It is call pattern dependant jitter (PDJ) or data dependant jitter (DDJ).

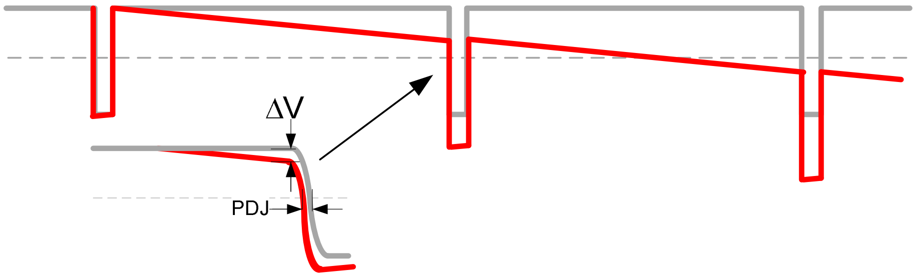

Figure 3. Voltage drop and low frequency jitter introduced by the high pass filter

In order to minimize the PDJ, the 3dB cutoff frequency should be set correctly. This frequency is directly related to the capacitor (C_b) and the resistor (R_t). If you use new component with internal termination, you have few value of R_t. The goal is to use a smaller capacitor size with the desire capacitance to minimized reflections. The following equations solve the capacitor's value:

$$C_b = \frac{-T * N_{CID}}{2 * R_t * ln\left(1 - \frac{1.2PDJ}{t_r}\right)}$$

Where:

$$PDJ = \frac{\Delta V}{slope}$$

$$\Delta V = 0.5V_{pp}\left(1 - e^{-t/\tau}\right)$$

t is the discharge time: N_{CID} * bit period.

τ is the RC constant (C_b and R_t), twice R_t considering the driver impedance.

$$slope = V_{pp} * \frac{0.6}{t_r}$$

V_{PP} is the voltage swing.
t_r is the rise time of the signal (20%-80%)

The following table shows the correct capacitor's value for different frequency and encoding pattern. In this example, we set the PDJ value to 0.01UI (Unit interval) and rise time = 0.2UI.

Table 1. C_b value for different N_{cid}

Standard	Bit rate	Encoding	N_{CID} max	R_{TOTAL} ($2*R_t$)	Resulting C_b
SD-SDI	270Mbps	NRZI	19	100	5.9nF
HD-SDI	1.485Gbps	NRZI	19	100	4.2nF
custom	270Mbps	8b/10b	5	100	1.57nF
custom	1.485Gbps	8b/10b	5	100	1.1nF
custom	2.5Gbps	8b/10b	5	100	0.4nF
custom	3.125Gbps	8b/10b	5	100	0.25nF

If the pattern only occurs once, the blocking capacitor for 270Mbps, NRZI encoding should be 5.9nF. In the specification SMPTE-259 and SMPTE-292, the pattern can be repetitive up to 1920 and 720 time for SMPTE-292, SMPTE-259 (270Mbps) respectively. The difference between the number of 0 and 1 over a long time can be call as the *cumulative bit difference* (CBD).

Eye diagram after the blocking capacitor

With the Table 1, we can clearly see that the pathological problem is not the CID but the DC unbalance over the line period (CBD). In other word the capacitor will not stay at the midpoint for the entire line. This effect demonstrates in figure 3, moves the unique '1' or '0' over the time far from the decision point, creating errors. The following figures show the eye diagram at the end of the line for 270Mbps pathological signal (half line).

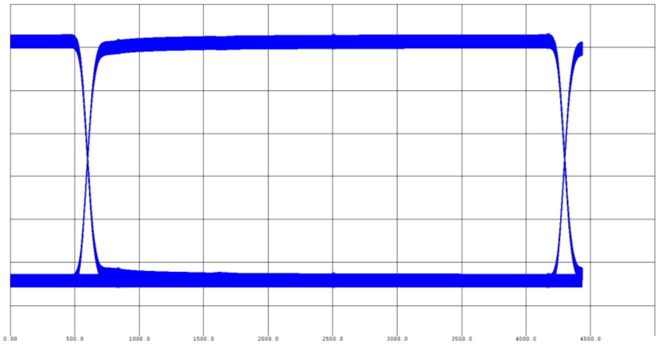

Figure 4. Eye diagram 270Mbps, C_b = 4.7µF

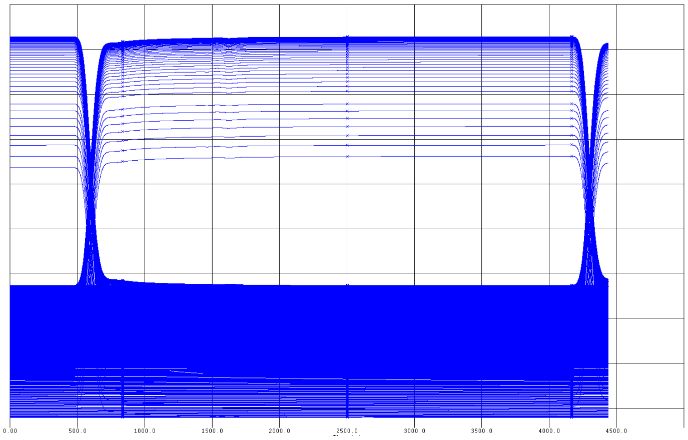

Figure 5.Eye diagram 270Mbps, C_b = 6nF

Note: This model has been created with the generic CML IBIS model.

Another way to represent the blocking capacitor effect is in frequency domain. The next figure compares the frequency spectrum of the Pathological signal versus a random stream applied to the blocking capacitor circuit. Note the power close to DC for the pathological signal (red). All the energy below the cutoff frequency will be attenuated, reducing the SNR and thus degrading the Bit error rate. (338Hz for the 4.7µF and 265 kHz for the 6nF)

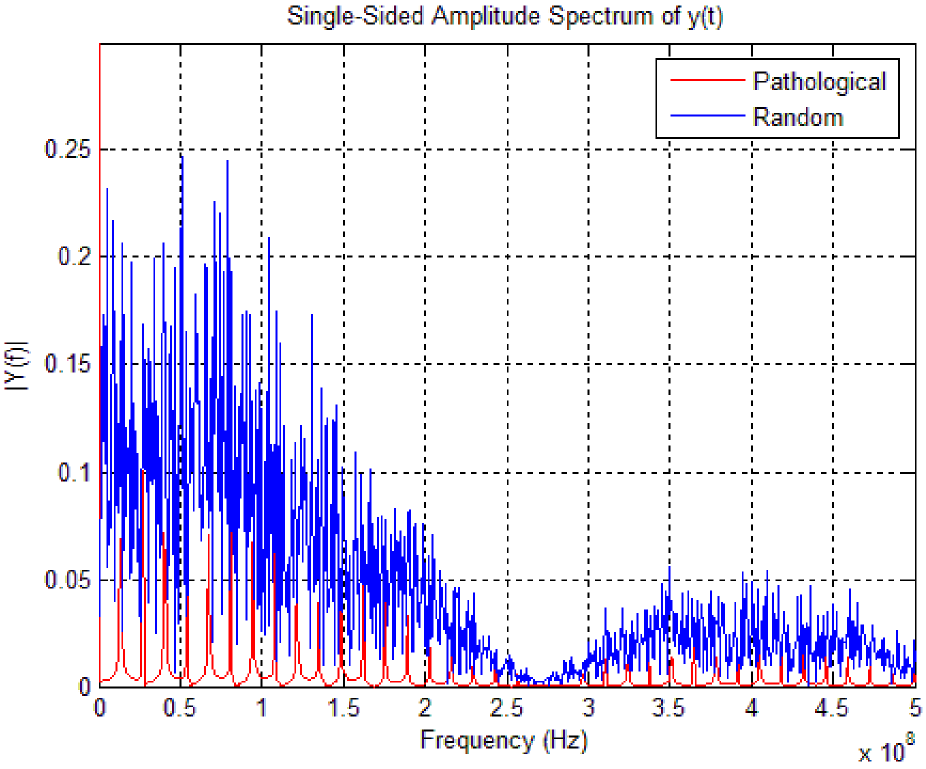

Figure 6. Frequency spectrum 270Mbps: Random signal (blue), pathological (red)

Possible changes on C_b and R_t

The previous waveform demonstrates the pathological frequency spectrum versus a perfect random signal with ‘1’ and ‘0’ balance. To preserve the maximum SNR, the cutoff frequency of 338Hz appears to be a good choice. Let change the internal termination from 50Ω to 75Ω and keeping the same cutoff frequency, now the value of C_b is 3.3μF. This 3.3μF capacitor can be smaller in size, can better stability in temperature and the eye diagram look exactly like the one show in figure 4.

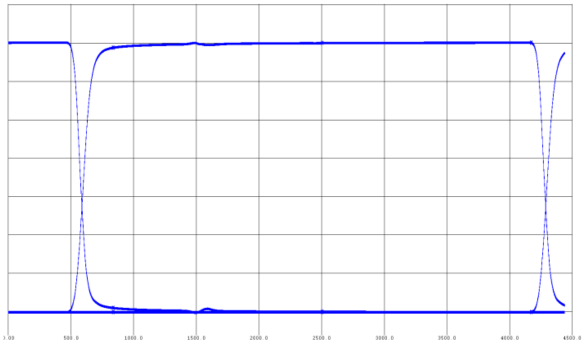

Figure 7. Eye diagram 270Mbps, C_b = 3.3μF, R_t = 75Ω

Conclusion

In this application note, the simulation models were created to show the blocking capacitor’s effect on the pathological signal. This effect can be controlled by designing the system to have a low 3dB cutoff frequency and by ensuring an equal number of one and zero over the time. In SMPTE standards the second option isn’t possible; the designer should set the cutoff frequency very low to keep the SNR as high as possible or use DC-coupling when the technology permit it.

The HD and 3G HD waveforms can be downloaded at www.brioconcept.com/download/AN-01/AN-01-C.pdf

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