Sampled-Analog Video Transport: High Accuracy and Perceptually Error Free

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Abstract

Video signal bandwidth continues to grow, with pressure to deliver higher resolution, wider color gamut, greater contrast, and faster refresh rates over longer distances. For conventional display drivers, accommodating this growing bandwidth means skyrocketing complexity and power.

Sampled Analog Video Transport (SAVT™) technology is 10X more efficient and has ample headroom to carry performance large display roadmaps into the future within the established cost and power envelope.

Author Keywords

Video Transport; Display driver IC; Sampled Analog; SAVT

1. Introduction

Consumer appetite for higher resolution, higher frame rates, and greater color depth is pushing video data rates beyond the capacity of conventional transport solutions. Today's high-end displays—such as 4K gaming at 360 Hz or 8K TVs at 120 Hz—require multiple parallel data pairs and complex equalization, which raise cost, power consumption, and system complexity. As the industry moves toward 8K120, 4K240, and advanced light-field displays, traditional video transport becomes increasingly strained.

SAVT is providing the solution for this impasse: Because of the video transfer principle ("Sampled Analog") the transfer of the video signal becomes an order of magnitude more efficient: instead of sending 10 digits (a stream of "1"s and "0"s), a single analog video level is accurately transmitted. This provides several generations of headroom to further bandwidth requirements for high performance displays.

The long-held consensus that video transfer must be bit-error-free is already eroding: HDMI and proposed in-panel compression introduce controlled error. This observation in turn shifts the comparison: small analog transfer errors can now be evaluated alongside so-called "lossless" digital links and compressed digital streams.

Bit errors can arise anywhere and can affect any of the 10 transmitted bits, while compression artifacts typically distort groups of pixels (for example, visible as MPEG block errors). In contrast, analog-transfer errors mainly influence only the lowest-order bits of a single pixel. The frequency and impact of these defects are examined below.

2. Perceived Image Accuracy

In data networking, even a single bit error in a symbol stream is typically unacceptable because the payload must be preserved exactly. Human visual perception, however, is far more tolerant. Double-blind studies [2] show that one video signal may be measurably superior to another while still appearing identical to even attentive viewers. Imposing bit-perfect requirements on video transport therefore adds an unnecessary and ultimately unsustainable digital overhead.

More specifically, the acceptable error rate for digital communication is effectively zero; even a 1-ppb error rate can cause critical failures within seconds. By contrast, a 1-ppb error rate in a video stream would produce only one incorrect subpixel every 40 frames on a 4K display; completely imperceptible. Even a 1% random error rate can still yield good video quality.

One way to quantify the effect of imperfect video transmission is to compare the visual impact of errors injected into a standard digital video signal versus an analog (SAVT) video signal, with both being transmitted through identical channels, and subsequently measure the resulting inaccuracies:

- In a digital signal, if a bit is influenced to the level where the bit-eye cannot be found anymore (~ 30% of signal level), the synchronization can be lost, requiring sync recovery over several frame intervals.
- In an SAVT signal, if a single sub-pixel level should deviate even up to 100% of the signal value, just one sub-pixel will see an incorrect value during one frame interval, immediately returning to the correct value in the next frame. Sync is preserved, and no perceivable error is created.

3. Electro-Optical Transfer Function (EOTF) optimization

Presently, EOTF and gamma correction are done in the display driver IC (DDIC) by applying non-linear reference voltages to the on-board resistor-ladder D/A Converter (DAC). This has its limitations:

- The number of reference voltages is limited (typically 18)
- The interpolation between the references is usually linear
- The reference voltages are usually hard-wired (although some meta-data driven exceptions exist)

SAVT technology implements its DAC at the transmission end of the chain, so the EOTF and gamma correction can be implemented with the same accuracy as the DAC (typically > 12 bits). This results in >12-bit accuracy of the reproduction of the display's EOTF.

4. Pre-compensation for wiring harness E/M propagation errors

When an analog signal is applied at the input terminal of a wiring harness, signal attenuation and reflections may occur at impedance transitions in the harness, as evidenced in the signal as measured at the corresponding wiring harness output terminal.

Since these are known, and unchanging, the effects of the attenuation and reflections can be pre-determined, and an adjustment in the signal path can be made so that the attenuation and reflections don't interfere with the exact sampling values and times of the SAVT DDIC. If any disturbance occurs outside the sampling window, it cannot be observed on the displayed image. Such pre-filtering is impossible in the case of digital transmission.

5. Results

5.1. Improved Video Transport Principle: Perceived Image Accuracy

The way in which the image is influenced can be modeled by combining basic signal transmission equations, information theory, and models of visual perception. A transmission line model of the electrical circuitry provides estimates of attenuation and transient shapes, as well as the effect of interference sources such as thermal noise and power supply spikes. The model then allows the calculation of symbol error rates based on these electrical transmission deviations, and demonstrates that SAVT technology is more resilient to these sources of error. Finally,

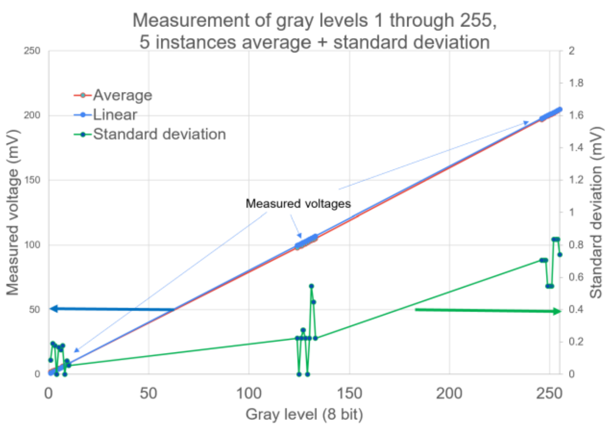

Figure 1: Measured signal levels of SAVT stream

visual perception models incorporate the low-pass nature of the human eye to show a higher perceived image accuracy in the operating regions of current and future interest.

Verification measurements confirming the reproduction of exact voltage levels were initially conducted by an oscilloscope. However, the accuracy required is out of reach of most measurement devices, since the noise on the input amplifiers exceeds the signal levels to be discriminated between. Instead, a spectrum analyzer in combination with a dedicated test signal (alternating between 0V and the voltage to be measured) is used, and the result is accurate to within the noise floor (several 10s of microvolts, fig. 1).

5.2. Greatly improved EOTF and gamma flexibility

Existing LCD versions have significantly differing T-V curves: TN, VA and IPS need different adaptations to linearize the optical response. To some extent, this can be done by implementing multiple reference voltages for "gamma"-voltages on the DDIC, but complete correction would require 256 support voltages (for 8-bits pixel values), and furthermore, each color channel would behave slightly different because of wavelength dispersion of the refractive index.

HYPHY has implemented a per-primary, 1024 level EOTF and gamma correction that allows unprecedented color accuracy and efficient light transmission (fig. 2). The latter can be seen in the influence per-color EOTF has on the transmission efficiency of an MVA LCD: Where a single EOTF will use a single transfer function in a continuously ascending part of the V-T curve (blue arrow, red, green dots), only a part of the red and green curves is used [3], whereas separate EOTF curves allow use of a much larger part of the three primaries (R, G, B arrows), resulting in higher total transmission and better efficiency. Measurement details will be provided in a future publication.

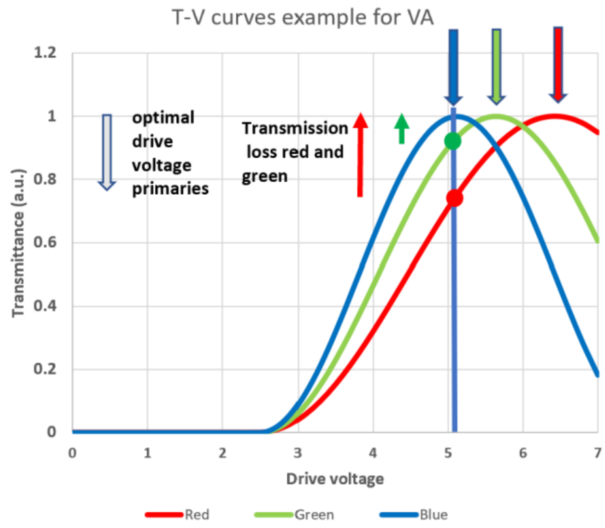

Figure 2: V-T curves of MVA display at primary wavelengths

5.3. Pre-filtering and correction for wiring harness transmission errors

Pre-processing the transmitted signal (FIR-filter, while the signal is in its digital form in the transmitter), introduces miniscule adaptations in the transmitted signals. This means any imperfections in the transmission line can be pre-distorted so the correct value arrives at the receiver at the other end of the transmission line. This means that for a given set of differential traces on a given wiring harness design, we can apply an inverse reflection filter that pre-distorts the signal so that the reflections self-correct and present the proper value to the input of the DDIC. We expect to see that by pre-distorting the signal we can achieve better than 1:1000 accuracy in the voltage amplitude as sampled by the DDIC.

5.4. Ab-Initio Modeling and Simulation

The system was modeled as an Asymmetric Differential Coplanar Stripline (ADCPS). To accurately model the transmission line characteristics, the physical dimensions and material properties were translated into the following electrical parameters:

- A wideband dispersion model for the dielectric substrate, including the Djordjevic-Sarkar model [4] to capture frequency dispersion and a constant dielectric loss tangent.
- AC resistance and skin depth modeling of the conductor.
- Vertical and side ground capacitances.

The simulation uses Vector Fitting and Recursive Convolution to process ongoing, non-periodic DAC streams in O(N) time. We use a 16-pole rational approximation of the transfer function. The model shows a direct feedthrough of 0.21, with poles in the negative half-plane at frequencies from 1 MHz through 10 GHz and residue magnitudes in the range [7x104, 7x108].

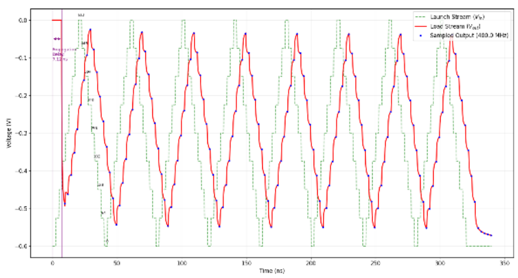

Figure 3: Input and output voltages

A plot of load stream vs launch stream voltages for a typical test pattern with a 400 MHz signaling rate are shown in Figure 3. It shows a propagation delay of 7.12 ns for a 1 m transmission line trace, and a signal attenuation of ~0.9. The blue dots show the sampling points 90% into the signaling windows and show excellent agreement with detailed SPICE simulations.

6. Discussion

Using SAVT^{TM} technology brings several significant improvements in display driving and color accuracy. In the examples in this paper, it is made clear that image transport to the DDICs is much more robust, and small errors, if present, will not influence the image accuracy in any perceivable way. Also, the color reproduction using SAVT technology is strongly positively affected: The applied voltages (column voltages appearing on the LCD column / source contacts) is demonstrably more accurate than for legacy products, color correction for EOTF / Gamma are significantly better using greater than 10 bit accuracy in determining the correction voltages, resulting color efficiency is greatly improved by implementing a separate (native) EOTF optimization per primary color, and image transmission over longer distances than legacy devices has been extensively demonstrated

7. Conclusion

HYPHY's unique technological innovation finally removes the video throughput barrier currently stalling the widespread market adoption of high-performance UHD displays.

Implementation in commercial products will mean a milestone in video transport, among others helped by the phenomena described in this paper. Transport accuracy, robustness, color and brightness and transmission channel requirements are significantly improved, and at the same time manufacturing efficiency, color depth, resolution and frame rate are increased.

Commercial application of HYPHY's video transmission technology will open the way to better video reproduction on any medium

8. References

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