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ADS-B UAT MOPS (DO-282), Revision A

Meeting #15

Potential Modification to Section 2.2.2.4 of DO-282

Prepared by Warren J. Wilson
The MITRE Corp.

SUMMARY

This paper addresses an issue that arose during recent discussions at AMCP WG-C. It appears that for the sake of completeness and to rule out some potential anomalous behavior, section 2.2.2.4 of the UAT MOPS (DO-282) should be amended to include a requirement for the horizontal dimension of the eye opening as well as the vertical dimension. A more detailed discussion of the issue and a suggested addition to section 2.2.2.4 are provided.

Introduction

At a recent meeting of the AMCP WG-C UAT Subgroup, a participant supporting the German delegation pointed out a potential minor oversight in the specification of transmitter performance contained in section 2.2.2.4 of DO-282. Section 2.2.2.4 currently specifies the minimum size (in Hertz) of the opening of the so-called eye diagram. It was intended that this measurement would be sensitive to most, if not all, of the potential deviations of the transmitted waveform from the ideal. In particular, it was felt that specifying the vertical size of the eye opening would identify degradations (1) in the desired frequency spread between a logical ONE and a logical ZERO and (2) in the baud rate. The gist of this discussion is that it may also be desirable to specify the horizontal extent of the eye opening.

Background

It is theoretically possible that in some cases a waveform can be generated that has an eye diagram that looks like a vertical slit. As an example of how this might occur, consider the two eye diagrams shown in Figures 1 and 2. Both Figures are eye diagrams based on the ADS-B synchronization sequence with raised cosine (RC) Nyquist filtering truncated at ±3 symbol periods. The only difference between the two is that Figure 1 uses a Nyquist filter roll-off factor (a) of 0.5 and Figure 2 uses a roll-off factor of 0. Both have the same opening in the vertical dimension, but it is easy to see that they differ a great deal in the horizontal size of their eye openings.

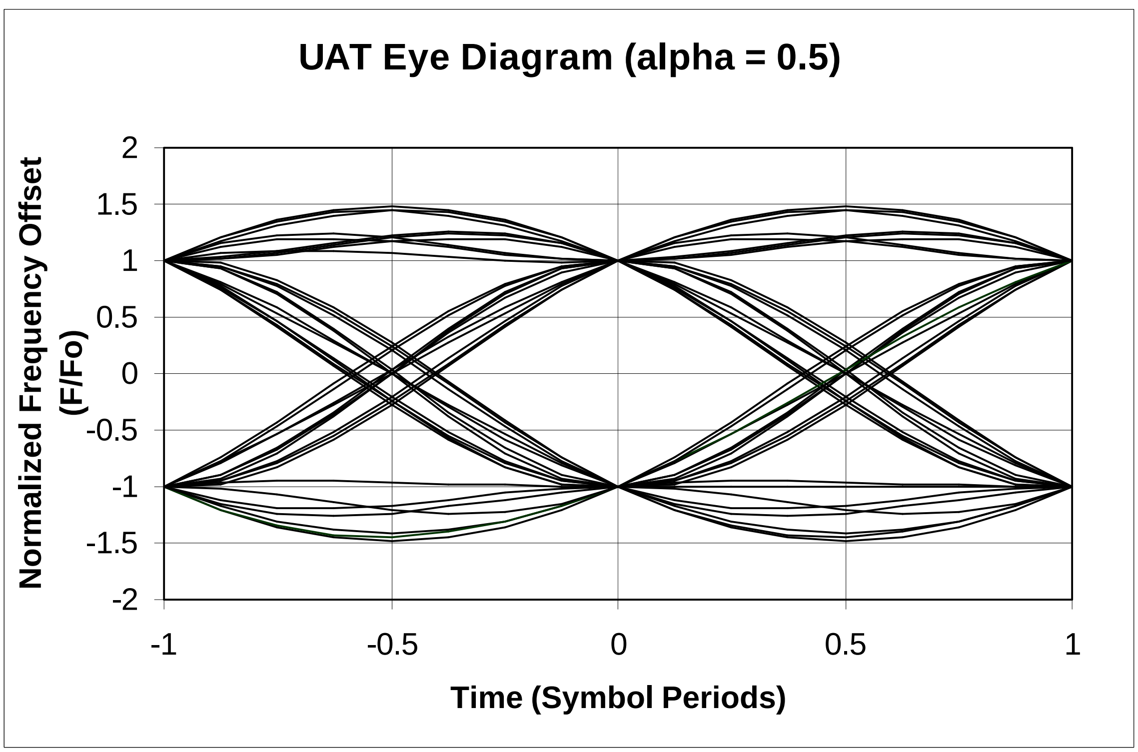


Figure 1. Eye Diagram for Alpha = 0.5.

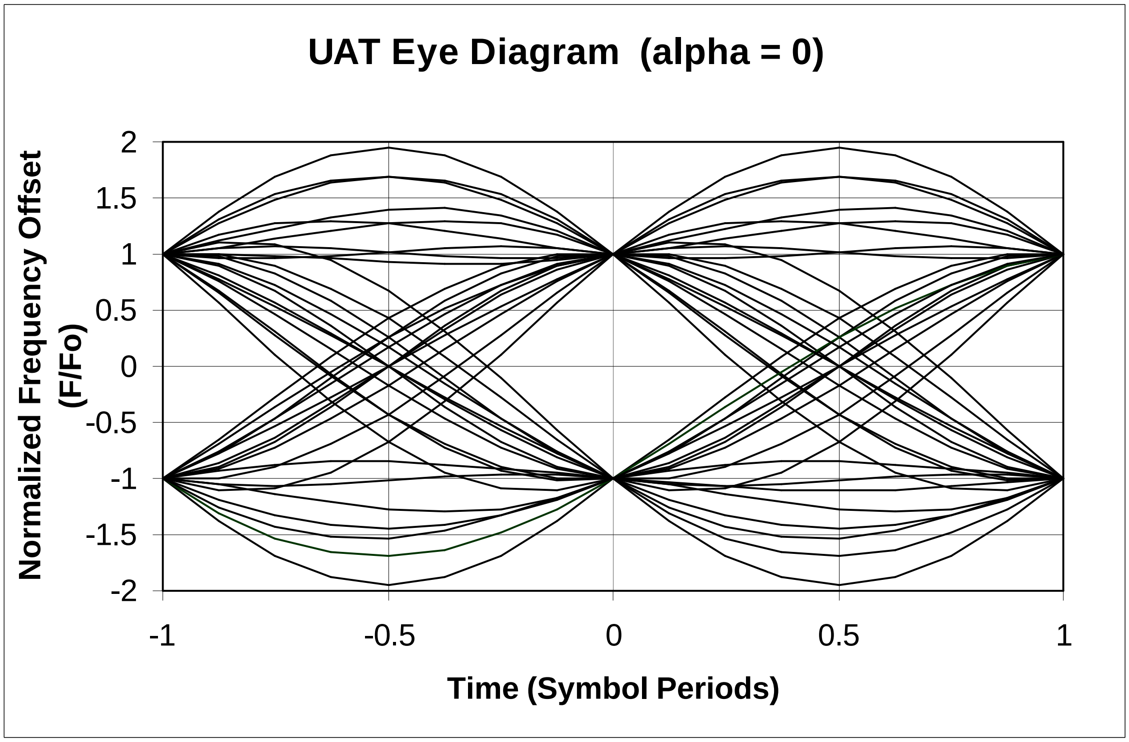


Figure 2. Eye Diagram for Alpha = 0.

The width of the diagram of Figure 1 is approximately 0.8 T, where T is the symbol period (0.96 μs). The width of the diagram of Figure 2 is approximately 0.5 T. It is a mathematical curiosity that if the filter of Figure 2 is truncated less and less (i.e., the filter becomes more like an infinite impulse response (IIR) filter) the eye becomes narrower and narrower. The practical effect of the narrowing of the eye would be that receiver performance would be much more sensitive to small sampling time offsets. Such offsets could be due noise in the synchronization process and/or the finite rate at which the received signal is sampled. Thus, a narrow eye opening could result in a degradation in overall system performance.

Proposal

Based on the above discussion it is proposed that a requirement related to eye width be added to section 2.2.2.4 of the MOPS. There is no point in making the requirement extremely stringent since the degradation in performance as the eye begins to narrow in (the horizontal dimension) is small. To provide some manufacturing margin it is suggested that the minimum width be specified as 0.65 T, measured at the nominal center frequency, i.e., 978 MHz.

To get some idea as to the feasibility of this requirement, two Figures showing measured data are presented below. Figure 3 shows the data from an implementation of the RC filter with a = 0.5 using the "pre-MOPS" transmitter. Figure 3 looks very much like

Figure 1. The width of the eye, measured at 978 MHz, is 0.79 T (to be compared with 0.8 T in Figure 1). Figure 4 is the result of an implementation that does not use the RC filter, but rather uses a 1.2 MHz SAW filter to control the spectrum. It has a vertical opening that is almost as big as that of Figure 3, and the width is about 0.82 T. Note that the width at the widest point is a little bigger, but the widest point does not occur at exactly 978 MHz. Both these implementations easily meet the proposed requirement. An implementation using an RC filter with a = 0 (i.e., Figure 2) would not meet the requirement.

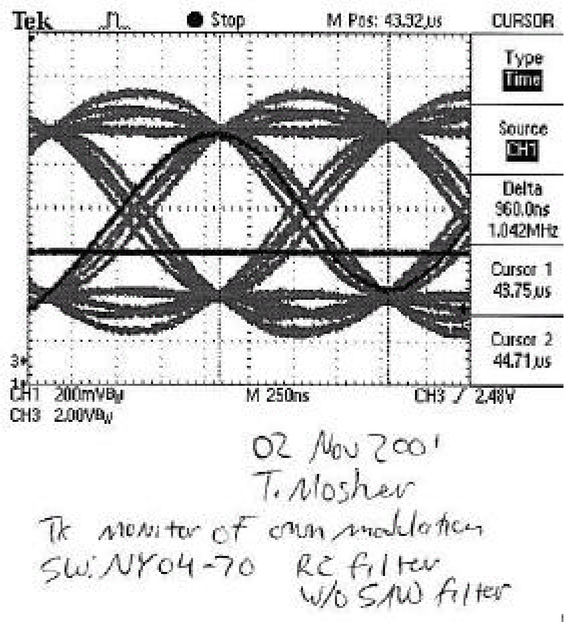


Figure 3. Eye Diagram of Pre-MOPS Radio with RC Filter.
(Provided by T. Mosher of UPS AT)

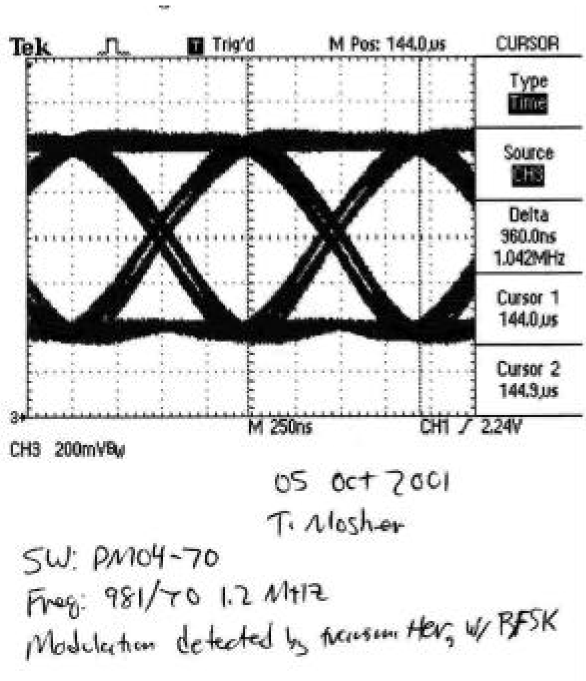


Figure 4. Eye Diagram of Pre-MOPS Radio with SAW Filter.
(Figure 3 from UAT-WP-8-03A)

Recommendation

It is recommended that section 2.2.2.4 of DO-282 be augmented with a second sentence so that it reads as follows:

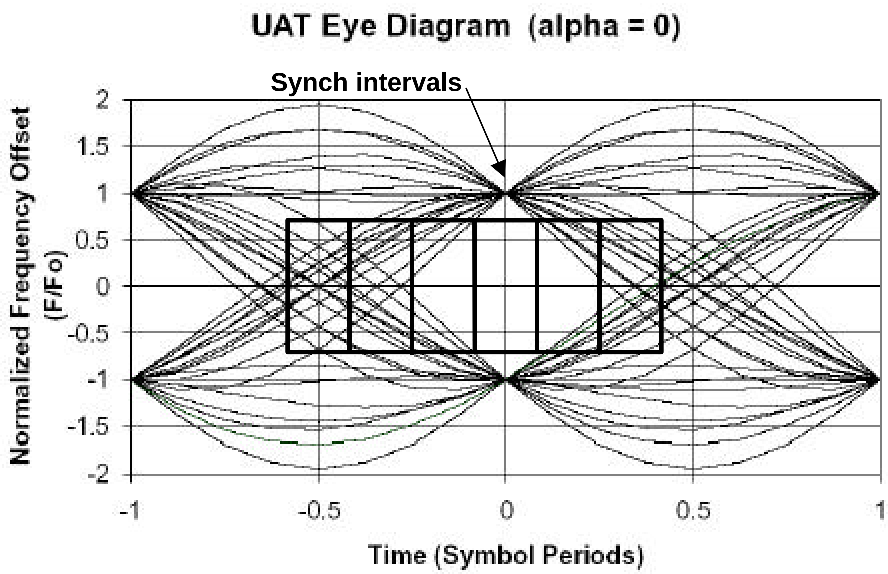
The minimum vertical opening of the eye diagram of the transmitted signal (measured at the optimum sampling points) **shall** be no less than 560 kHz when measured over an entire Long ADS-B message containing pseudorandom payload data.

The minimum horizontal opening of the eye diagram of the transmitted signal (measured at 978 MHz) **shall** be no less than 0.624 µs (0.65 symbol periods) when measured over an entire Long ADS-B message containing pseudorandom payload data.

The new wording is underlined.

Appendix: Further Discussion

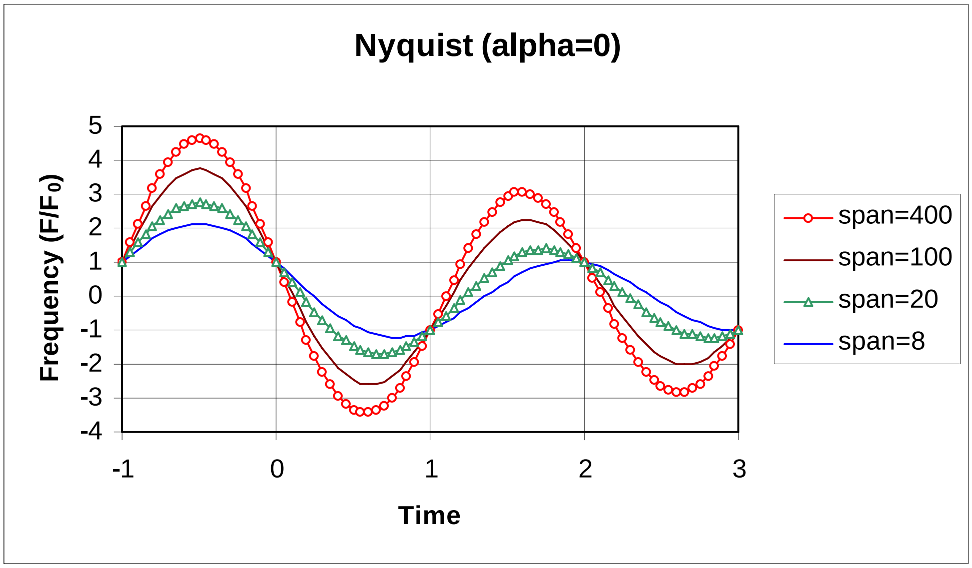
In a response to an early draft of this paper, Ed Valovage of Sensis Corp. suggested an alternative approach to specifying this width of the eye opening. He has proposed that the trajectory of the eye diagram should be excluded from a rectangular region as shown below. The width of the rectangle is equal to the sampling period of the receiver. It is expected that the timing determined by the synchronization process will fall within this region, so the worst case will occur at the corners of the rectangle.



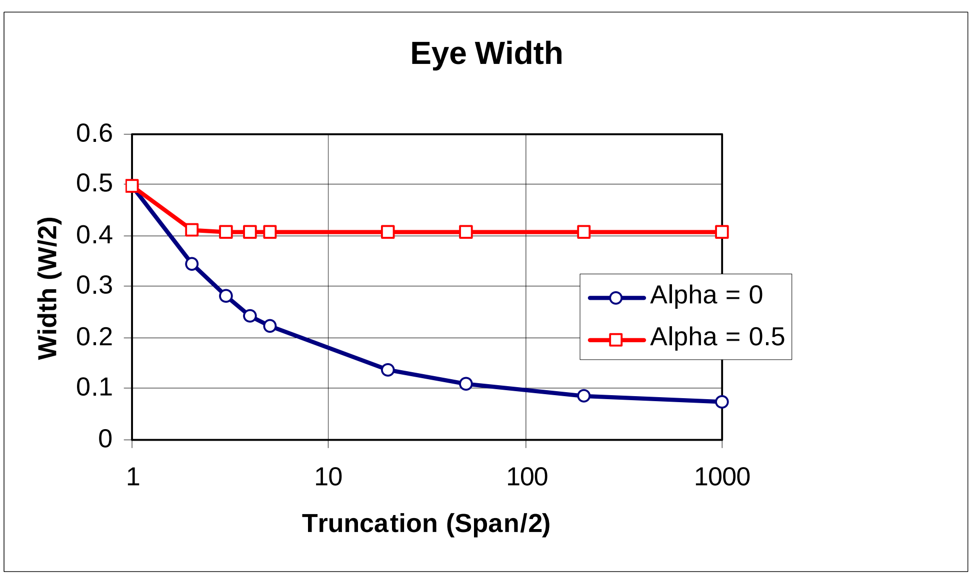
His suggestion is based on sound reasoning and is, in principle, a viable means of dealing with the issue. However, as Ed himself was careful to point out, the width of his suggested exclusionary rectangle is somewhat implementation specific. Choosing the width of the rectangle to be 1/6 of a bit period is related to the 6 samples per bit sampling rate that I had suggested in Appendix H. If this bit of arbitrariness is acceptable, then Ed's approach would work. Nevertheless, I would take issue with the specific value he chose for the height of the rectangle. His number is based on an analysis of my Figure 2. This Figure depicts the eye diagram for an implementation using a Nyquist filter with a =0.0. It was put in the paper as an example of what should *not* be done. The preferred design would use a =0.5, i.e., my Figure 1. Using that Figure would yield revised dimensions of 16 µs x 513 kHz. The number of 440 kHz suggested by Ed is much too lenient, in my opinion, and might result in a significant degradation in link performance. Recall that the current height specification is 560 kHz, which is already reduced from the ideal value of 625 kHz. *If Ed's suggestion is adopted* then I would suggest that the size be 16 µs x 500 kHz.

On the other hand, the alert reader will have noticed that the shapes of all the eye openings in my paper are diamond-shaped. This universal shape is due to the restricted bandwidth of the signal. Abrupt changes in slope are simply not possible without violating the laws of physics (or Nyquist).

Some insight into what's going on can be gleaned from observing the following graph.



This shows the changing trajectory of the frequency deviation (which defines the eye diagram) for an implementation with a =0.0 as the amount of filter truncation changes. In the Figure the "span" refers to the total number of symbol periods retained in the filter implementation. The bit sequence that generates the curves is …0101011010101… This is the worst case in terms of generating a large negative slope at time T = 0 (which defines the narrowness of the eye). As the span increases, the eye gets narrower. This happens because the distant bits all contribute to the value between –1 and 0 with the same sign and the contributions build up logarithmically. This phenomenon happens *only* for a =0.0, which is why that value is never used for Nyquist filters. Another way to look at this is shown in the next Figure.



This shows the half-width of the eye diagram as the span increases for both a =0.0 and a =0.5. For a =0.0, the width continues to decrease as the span increases, while the half-width reaches a plateau of 0.408 for a =0.5.

Because the eye openings are always diamond-shaped and because it is a little more generic (in that it doesn’t rely on choosing the width of a rectangle somewhat arbitrarily), I preferred the approach mentioned in the body of this paper.