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<u>ADS-B UAT MOPS</u>

<u>Meeting #9</u>

The Use of the Eye Diagram to Specify UAT Transmission Accuracy

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SUMMARY
This paper addresses Action Item 7-2. It proposes that the use of the so-called eye diagram is a convenient means of specifying and measuring the accuracy of UAT transmissions. Prospective wording for section 2.2.2.4 of the UAT MOPS is provided.

Introduction

The purpose of this paper is to propose that a measurement based on the so-called eye diagram would be a convenient way to determine the modulation accuracy requirement for a UAT transmitter in section 2.2.2.4 of the UAT MOPS. Furthermore, the same eye diagram measurement procedure may be a suitable means of testing for the frequency accuracy requirement in section 2.2.2.1 and the modulation rate requirement in section 2.2.2.2.

Background

The eye diagram of the transmitted UAT wave form can be constructed from a graph of frequency deviation versus time by overlaying multiple versions of the graph shifted by integral numbers of symbol (bit) periods. An example of the result of such an exercise can be seen in figure 1. This figure is a theoretical one, constructed using the example synchronization sequence shown in figure H-3 of Appendix H.

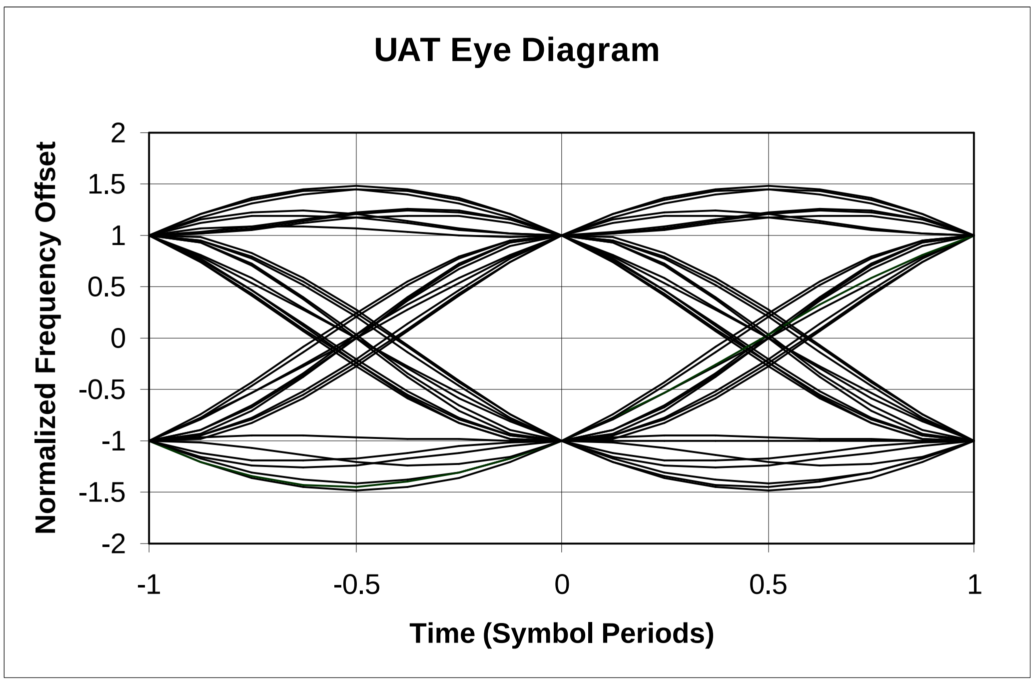

Figure 1. Ideal UAT Eye Diagram

The figure has a couple of interesting features. First, all of the lines are relatively "smooth," i.e., there are no abrupt transitions. This feature is correlated with the relative compactness of the associated spectrum. The second interesting feature is that all of the curves pass through +1 or –1 at times spaced by 1 symbol period. The timing of these points defines the "optimum sampling point" referred to in various places in the MOPS; and the frequency difference between the plus and minus deviations has a direct bearing on system performance as discussed below.

One way to create a signal with the two desirable features mentioned above is to drive a frequency modulator with a base band signal that has passed through a Nyquist filter. This was the assumption used in generating figure 1. (Note the close agreement with figure 6 in UAT-WP-8-03A.) Other methods might also produce acceptable transmitted waveforms. For example, a frequency-modulated signal generated by a rectangular base band signal could be filtered at IF prior to up-conversion and amplification. This approach was used in the "pre-MOPS" UAT radios. In any case, it may happen that all of the curves do not go through discrete points as shown in figure 1, or the points may be separated by less then the desired 625 kHz. Examples of slightly degraded eye diagrams can be found in UAT-WP-8-03A.

The Relationship to System Performance

To estimate system performance when the signal-to-noise level is relatively high, the central limit theorem can be invoked to propose that the postdetection noise is approximately Gaussian. In that case the probability of a bit error is given by

$$P_b = \frac{1}{\sqrt{2\pi}\,\sigma}\int_{-\infty}^{F_0} \exp\left(\frac{-x^2}{2\sigma^2}\right) dx \qquad (1)$$

where $1/\sigma^2$ is proportional to the predetection signal-to-noise ratio. This equation assumes that the waveform is sampled at the optimum sampling point and that the curves of the eye diagram converge at $\pm F_0$.

A typical degradation of the eye diagram would involve smearing the convergence points in figure 1 over some range, e.g., from F_1 to F_2 (see, for example, figure 3 from UAT-WP-8-03A). For a given value of F_1 the worst case, from the point of view of signal-to-noise performance, occurs if the opening of the eye simply shrinks from $\pm F_0$ to $\pm F_1$ with no smearing. When the opening of the eye diagram is less than the nominal value, the bit error probability for a given noise level increases. Conversely, to maintain a particular noise level requires a higher input signal-to-noise ratio. In that case the input signal-to-noise level (in dB) must be increased by a factor of

$$\text{Loss} = 20\ \text{Log}(F_0/F_1) \qquad (2)$$

Thus, the transmitter loss for UAT can be limited to be no more than about 0.5 dB if F_1 is set at 295 kHz.

This method of specifying the modulation accuracy can be translated into MOPS language as follows:

2.2.2.4 Modulation accuracy

The minimum opening of the eye diagram of the transmitted signal (measured at the optimum sampling points) **shall** be no less than 590 kHz when measured over an entire long ADS-B message containing pseudorandom information.

Note that the length of a long ADS-B message (including the synchronization sequence) is 420 bits. If the data portion of such a message contains pseudorandom bits, the resulting test should probe most, if not all, of the different bit patterns that are needed to generate a "complete" eye diagram. Thus, only a small number of ADS-B messages (say, two or three) would provide an adequate statistical sample to test the requirement.

Other Uses of the Eye Diagram

The eye diagram approach might also be used in the test section of the MOPS to test the requirements of sections 2.2.2.1 and 2.2.2.2.

For example, the test for the modulation rate accuracy (2.2.2.2) can be folded into the modulation accuracy (2.2.2.4) test if it is stipulated that the eye diagram is measured over a number of complete long ADS-B messages. These messages are 420 bits long (including synchronization sequence). Thus, during the course of a message with a maximum modulation rate error of 20 PPM, the accumulated timing error would amount to 0.0084 bit periods ($0.0084 = 20 \times 10^{-6} \times 420$). Noting from figure 1 that the closing of the eye diagram is approximately linear with respect to the timing error, the maximum error corresponds to about $\pm$ 500 Hz. This additional error is small compared to the error associated with section 2.2.2.4 (i.e., 17.5 kHz = 312.5 kHz – 295 kHz).

Note that since the effect of the modulation rate error is expected to be small and cannot be separated from the overall eye diagram degradation, it may make sense to eliminate the separate requirement of section 2.2.2.2.

The test for transmission frequency (2.2.2.1) could be included in the eye diagram measurement if the center frequency of the eye can be accurately calibrated to be precisely at 978 MHz. The technique would work by first measuring the minimum positive and negative frequency deviations in the eye diagram (at the optimum sampling point). These can be designated F_U and F_L, respectively. Sections 2.2.2.2 and 2.2.2.4 could be tested by requiring that

$$F_U - F_L \leq 590\ kHz \qquad (3)$$

and section 2.2.2.1 could be tested by requiring that

$$\left|F_U + F_L\right| \leq 19.56\ kHz\ . \qquad (4)$$

The value of 19.56 kHz in equation (4) is equal to 978 MHz x 20 x 10^{-6}.