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

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Updated UAT Performance Model and Co-channel Interference Results

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SUMMARY

This paper provides an analysis of the sensitivity measurements reported in UAT-WP-4-13. It also provides an analysis of some new measurements on co-channel performance. The focus is on determining the performance difference (if any) between two proposed IF receiver filter bandwidths. It is shown that the two filters are comparable in terms of their sensitivity performance, but the narrower filter suffers a 4 dB degradation in the co-channel interference case.

Modeling of Sensitivity Measurements

This note reports on some refinements to the UAT performance model originally described in working paper UAT-WP-2-03. The changes reflect the additional information about the effects of the narrow band IF filters provided in working paper UAT-WP-4-13. In the initial paper, the equation for the bit error probability was given as

$$P_b = \frac{1}{2} erfc\left(\sqrt{\frac{g}{2}}\right), \qquad (1)$$

with g equal to the signal-to-noise ratio (SNR). Because the new proposed filters are rather narrow with respect to the bit rate, there is a possible performance loss due to induced intersymbol interference (ISI) that can distort the so-called "eye diagram." The bit rate of UAT is 1.04166 MHz, and the widths of the two candidate filters are 0.8 MHz and 1.26 MHz. These are the advertised "typical" 3 dB widths (as opposed to the quoted minimum values of 0.75 MHz and 1.0 MHz) that will be used in this analysis.

It was found (by trial and error) that a good model of the loss is given by the revised equation

$$P_b = \frac{1}{2} erfc\left(\sqrt{\frac{g}{2f}}\right), \qquad (1')$$

where f is a loss factor given by

$$f = 1 + k \tanh(0.05g). \qquad (2)$$

The loss constant, k, was found to be 2.05 for the narrower filter and 0.45 for the wider one. The resulting performance graphs are shown below in figure 1. The figure includes a curve showing the original performance based on equation (1), i.e., with $k = 0$. It appears that there is a considerable loss to contend with –– up to about 5 dB for the narrower filter at high SNR. However, things are not as bad as they seem for two reasons:

- The noise is reduced due to the narrowness of the filters.
- Due to error correction, the operating point of the system (where the burst success rate is about 90%) corresponds to the level where BER is about 1% to 2%. At this level the loss is not so great.

We can evaluate the performance in terms of input level by assuming that the noise component of SNR is given by

$$N = BFkT_0 \qquad (3)$$

with

$$kT_0 = -174\, dBm/Hz$$
$$F = Noise\, Figure = 6.5 dB. \qquad (4)$$

B = 61 dBHz for the wider filter and 59 dBHz for the narrower one. Thus, the effective noise is –106.5 dBm for the wider filter and -108.5 dBm for the narrower one. The resulting performance curves are shown in figure 2.

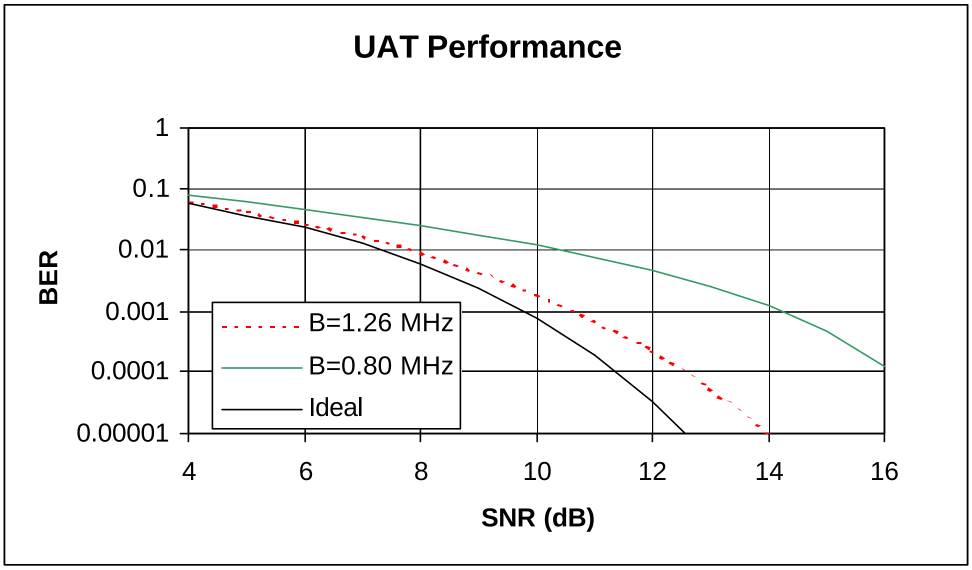

Figure 1. UAT Performance with Narrow Band Filters

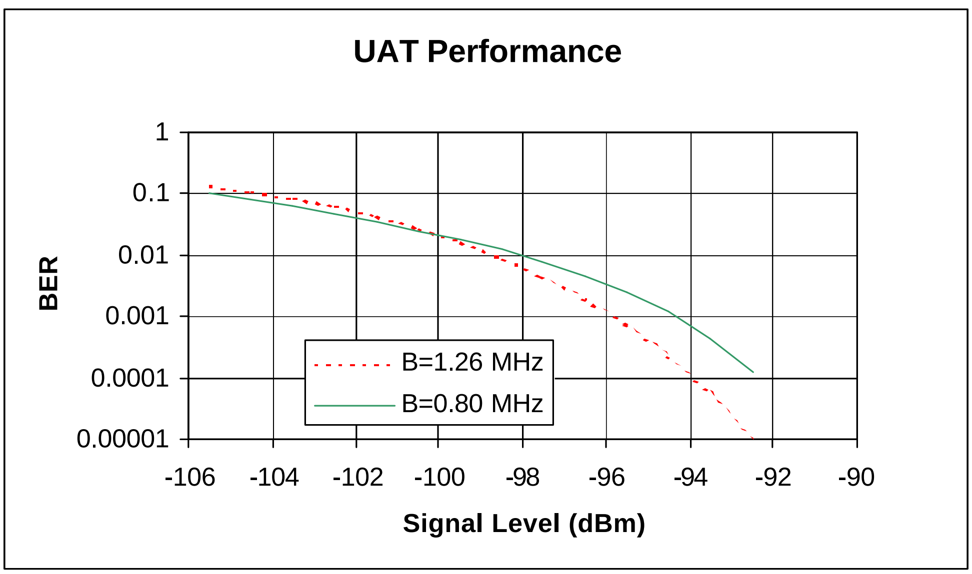

Figure 2. UAT Performance versus Signal Level

The performance can now be compared with the results measured in UAT-WP-4-13. Those results report on data measured on short ADS-B messages using the format with the error correction code RS(27,17). Some of the results are measured with the error correction "turned off," i.e., all 216 bits must be correct for a correct message; and for the remaining measurements the error correction was allowed to operate (correcting up to 5 8-bit symbol errors). The measurements, together the predictions based on equation (1') are shown in figures 3 and 4.

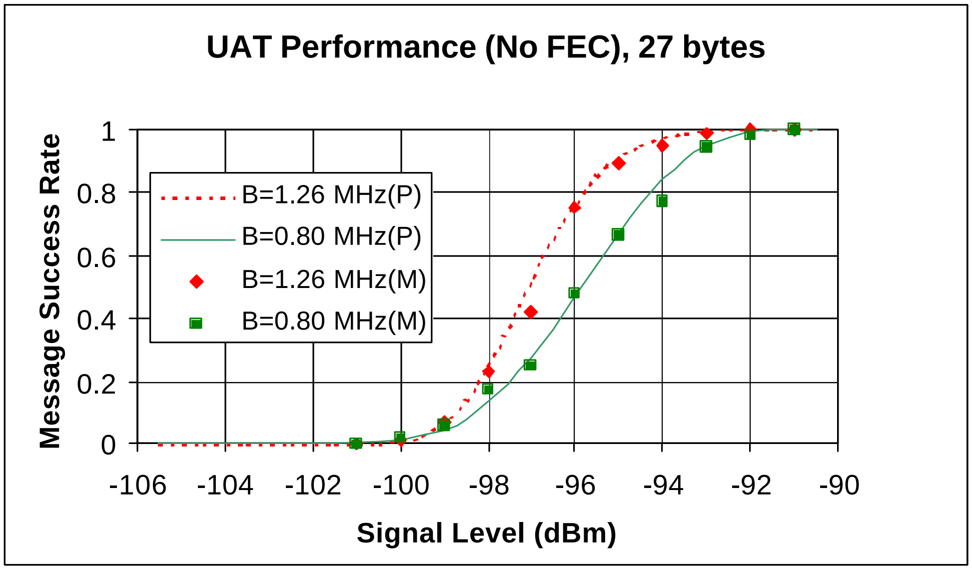

Figure 3. UAT Performance without FEC

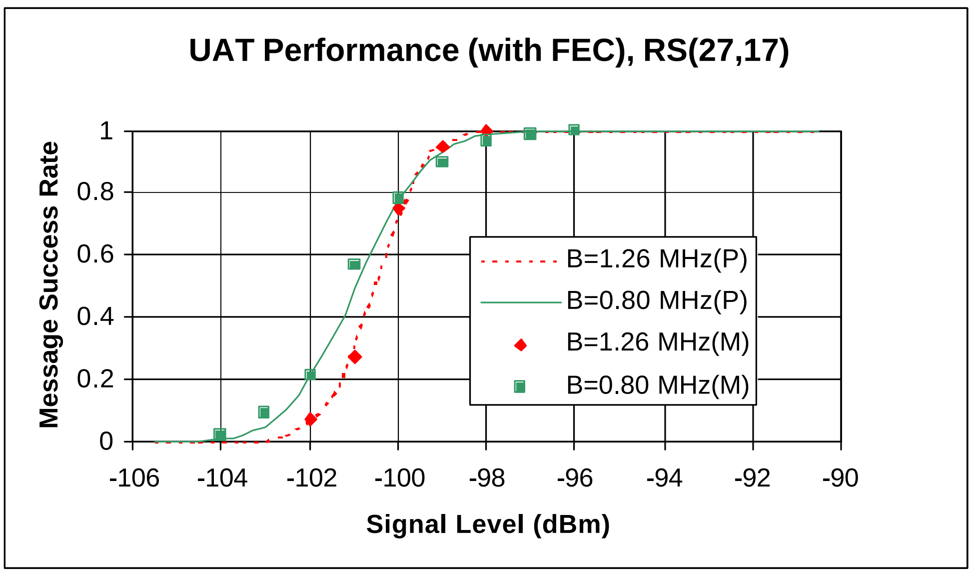

Figure 4. UAT Performance with FEC

The close fit between the predictions and the data indicates that the model of equation (1') represents a good empirical description of the UAT prototype receiver over a wide range of signal-to-noise ratios. This indicates that we can use the model to predict the performance of the UAT system when it is subject to small changes. For example, there has been some discussion of changing the formats of the short and long ADS-B messages to RS(30,18) and RS(48,34), respectively. These changes will allow for an increase in the size of the payload of both message types by one byte, lower the undetected error probabilities below 10^{-8}, and increase their performance in the presence of noise. The down side of those changes is that the longer message lengths may increase susceptibility to self-interference. The predicted performance of the possible new message formats (with the narrower filter) is shown in figure 5. For the sake of completeness, the performance of the current up-link message format is also included.

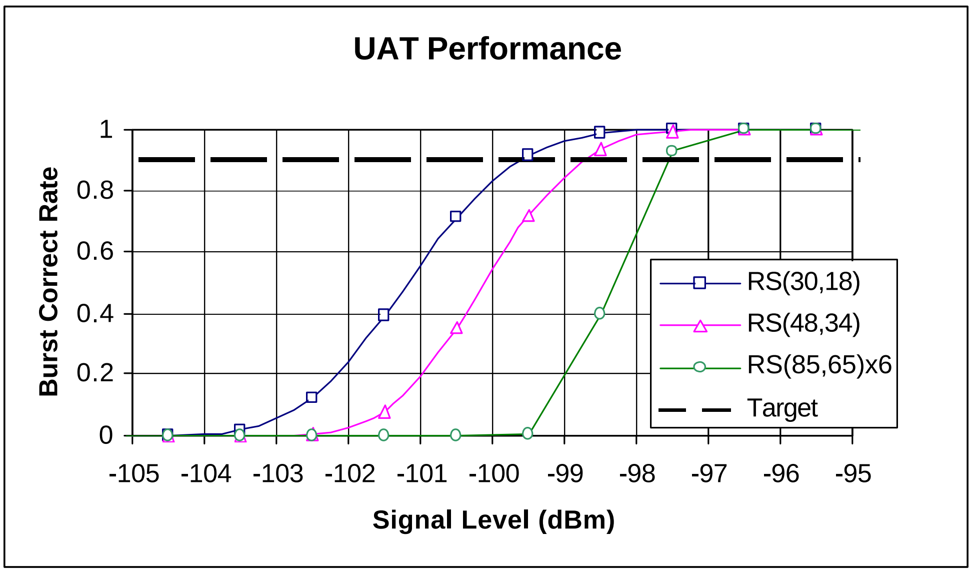

Figure 5. Potential UAT System Performance (800 kHz IF Filter)

Figure 5 shows that if a 90% success rate is taken as a benchmark, then the sensitivities of the receiver to the three message types is about –99.5 dBm, -98.5 dBm, and –97.5 dBm for the short ADS-B, long ADS-B, and up-link messages, respectively. (Note that these values pertain to the prototype units only and may not apply to production units.)

Modeling of Cochannel Performance Measurements

The allusion to self-interference in a previous section points to a remaining issue that should be addressed prior to accepting the idea of using the narrower IF filter. It is very possible that the increased distortion introduced by this filter will reduce performance in the presence of co-channel interference. Because the bandwidth of the undesired signal is the same as that of the desired signal, the poorer SNR performance of the narrower filter is not necessarily counteracted by a reduced noise value.

To probe this issue, additional testing was performed with an undesired signal (modulated like a UAT signal) set at –39 dBm and a desired signal set at various levels to create graphs showing message success rate as a function of the desired-to-undesired ratio (D/U). Once again, the testing was repeated using both filter bandwidths. The results are shown in figures 6 and 7. In these figures the measured data are represented by the markers. The curves are described below.

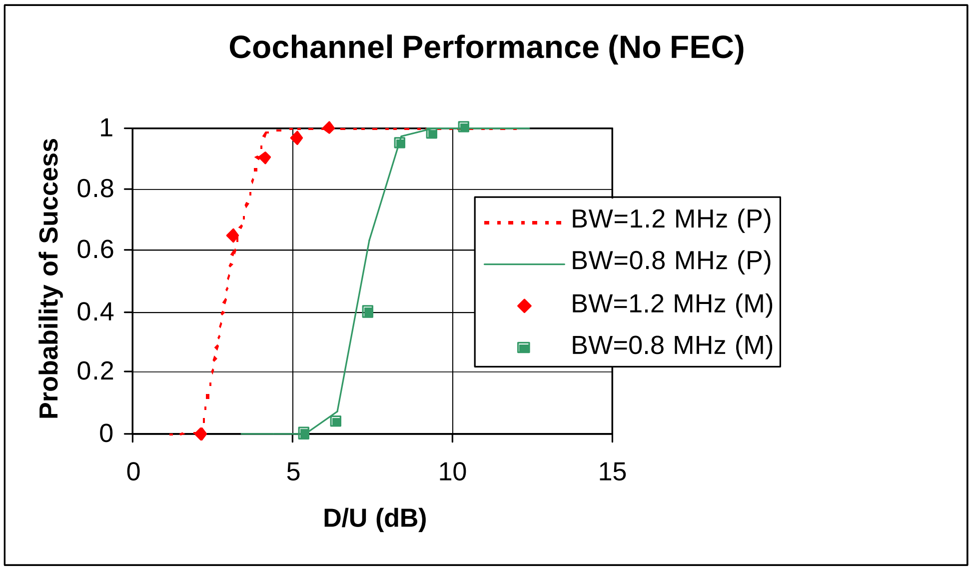

Figure 6. Cochannel Performance Comparison with no FEC

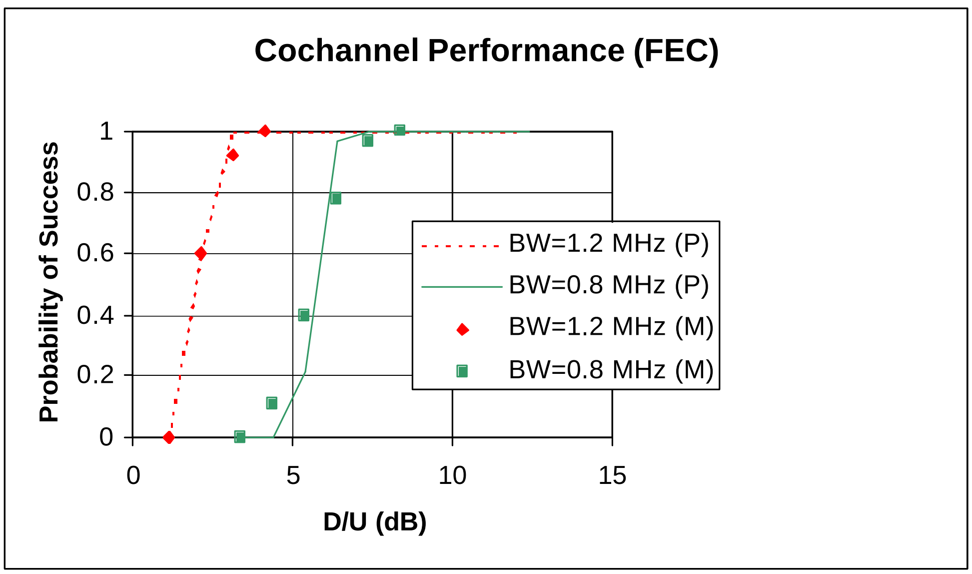

Figure 7. Cochannel Performance with FEC [RS(27,17)]

As before, the measured data can used to generate some *ad hoc* equations for BER. After some trial and error, the following was found to generate a good fit:

$$P_b = \frac{1}{2}\exp\left(-A\frac{g-1}{g_0-g}\right). \qquad (5)$$

In these equations, $g = D/U$ (numerical value). For the narrow filter, $A = 14$ and $g_0 = 17$. For the wide filter, $A = 28$ and $g_0 = 7.5$. These equations result in the curves shown in figures 6 and 7 and in the curves for BER shown in figure 8. They indicate that when D/U is high enough the BER drops to zero. This feature is related to the fact that the interferer has a constant envelope waveform. Also, when $g = 1$, the probability of bit error goes to 0.5 since the receiver is then faced with two equal, seemingly valid UAT-type signals. Note that there is much less "FEC gain" in the co-channel curves compared to the sensitivity curves. This is related to the fact that the BER curves in figure 8 are much steeper than those in figures 1 and 2.

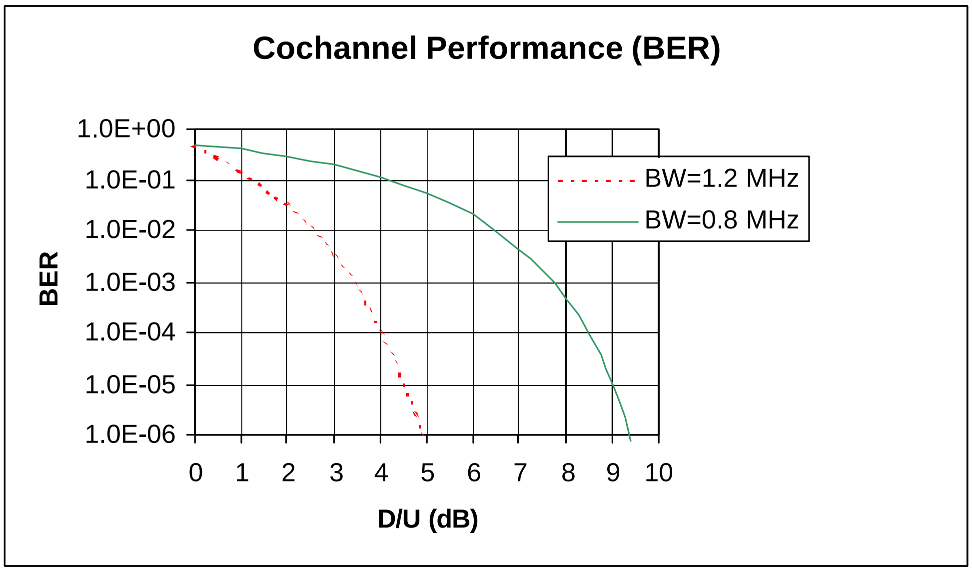

Figure 8. Cochannel BER Comparison

The fit between the curves and the data seems to be good; however, it should be noted that this is because the parameters were chosen based on the data. The curves are *not* theoretical predictions; however, the forms of equations (5) and (1') are based on theoretical insight and may be helpful in simulations.

The major point of the figures is to emphasize that the measurements indicate that there is a significant difference in co-channel performance between the two filters. The narrower filter is about 4 dB worse than the wider one at the point where the corrected message success rate is 90%.

Summary

This paper has addressed the issue of determining whether or not there is a significant difference in UAT performance depending on which of the two proposed IF filters is used in the receiver. The difference appears to be slight in the case of the sensitivity measurements. That is because the decrease in signal-to-noise performance is compensated by a corresponding decrease in the effective noise level. This phenomenon does not persist in the co-channel interference case, where there appears to be about a 4 dB performance penalty associated with using the narrower filter.

The choice of filter is not obvious. It depends on the relative importance of minimizing the effects of self-interference *versus* the effects of interference from DME ground transmitters on neighboring channels. (The difference in performance in JTIDS/MIDS scenarios may be minimal.) If the operating frequency of UAT is put at 978 MHz, then there may actually be no such interference within the United States. Thus, the question may be reduced to interference scenarios involving DME transmitters situated outside the United States (e.g., Europe). If not for this issue, the preferred filter would be the wider one. It is recommended that the European DME issue be addressed as soon as possible.

Whichever filter is chosen, this paper has also proposed mathematical models for UAT performance in the presence of noise and self-interference which may be useful in future simulations.