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RTCA Special Committee 186, Working Group 5

ADS-B UAT MOPS

Meeting #3

UAT Performance in the Presence of DME Interference

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SUMMARY

In this paper we consider the effect of interference from Distance Measuring Equipment (DME) on the performance of Universal Access Transceiver (UAT) receivers. A representative scenario with multiple DME's is used to evaluate typical UAT performance. The UAT design is shown to be fairly resistant to interference when the changes previously suggested in paper UAT-WP-2-03 are included. Performance in the presence of a composite environment including DME's plus JTIDS and/or UAT self-interference has not yet been examined.

1. Introduction

In this paper we investigate the performance of a Universal Access Transceiver (UAT) operating at 981 MHz in the presence of interference from Distance Measuring Equipment (DME) ground transmitters tuned to 981 MHz and adjacent frequencies. To accomplish this task we will assume that the UAT design has been adjusted according to the changes recommended in UAT-WP-2-03, 20 February 2001. In particular, we will assume that the short ADS-B message has the error correction format RS(26, 18), the long ADS-B message has the format RS(46, 34), and the up link message has the format 6xRS(85, 65). It is also assumed that the up link message processing includes the 6x85 interleaver suggested in the previous paper. Finally, we will assume that the IF filter bandwidth has been reduced to the suggested value of about 1 MHz. It is possible that the exact formats of the messages will be subject to further adjustments due to the deliberations of WG-5. As long as these adjustments are minor, the main conclusions of this report will remain intact.

The performance of UAT is assumed to be exactly as described in UAT-WP-2-03.

The assumed characteristics of the DME transmitters will be described in the next section. Much of the information on DME was generously provided to us by John Barrows, to whom we give thanks.

In subsequent sections we will assess the effect of a single DME on the three UAT message types and then consider the UAT performance in a particular scenario with a number of DME’s. We hope that the assumed scenario represents something like a worst-case interference environment. We will end with a few concluding remarks.

2. DME Model

Since the frequency range of interest is a small span near 981 MHz, we limit the investigation to “X-mode” channels. This frequency range also implies only ground DME transmissions are involved. Each pulse is approximated by a raised cosine shape whose width at half maximum is 3.5 μsec and whose total width is 7 μsec. The separation between the two pulses is 12 μsec. The resulting amplitude profile is shown in Figure 1.

The spectrum of this waveform was determined by taking the square of the Fourier transform of the shape function. This spectrum is shown in Figure 2. The rapid wiggles in the spectrum are due to the spacing between the two pulses in the pair, and the overall shape of the spectrum is due to the shape of the individual pulses.

We assume that the pulse pairs are transmitted at random times, such that the minimum time between pairs (i.e., the time between a particular point in one pair and the same point in the next) is 60 μsec and the probability of transmitting at any given time thereafter is 0.00322 per μsec. The net result is the cumulative distribution shown in Figure 3. The average number of pulse pairs per second is almost exactly 2700.

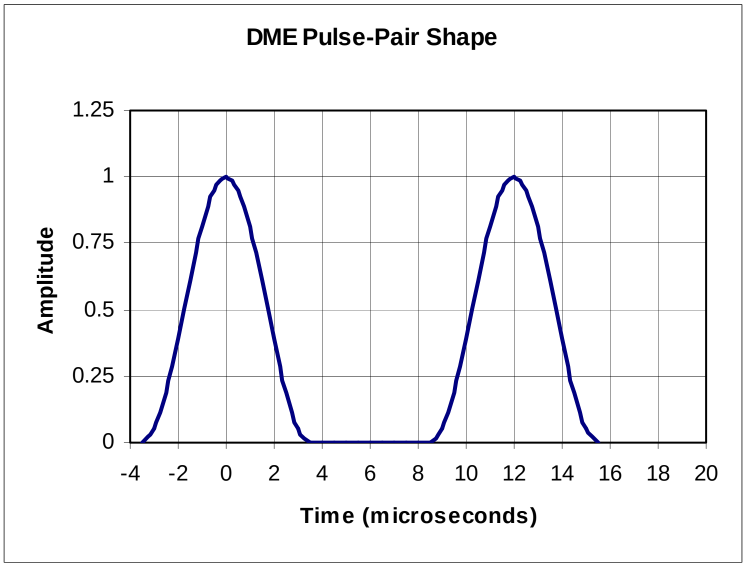

Figure 1. DME Pulse Pair Amplitude Profile

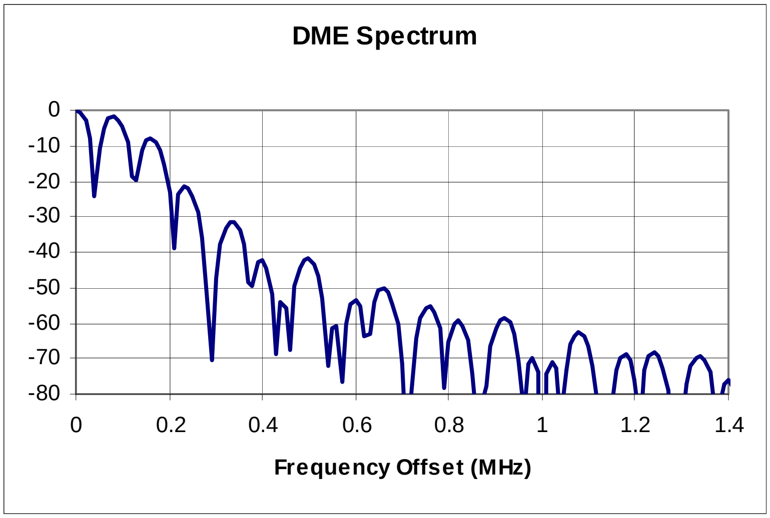

Figure 2. DME Spectrum

For this investigation, we will assume that the transmitted power of a DME is 1 kW. The signal is radiated from a directional antenna whose pattern is based on that of a particular DME ground antenna.[1] It is azimuthally symmetric, and the gain is assumed to be 8 dBi at a 3° elevation angle. The shape of the antenna pattern is shown in Figure 4. Note that the minimum gain is limited to –20 dBi near zenith. Except for a dip around 15°-20°, this pattern provides (very roughly) equal power to all links at a given altitude (as long as the elevation angle is greater than about 3°). This is similar in effect to a so-called cosecant-squared antenna.

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[1] Chu CA-3167 Cardion antenna described in ECAC-CR-87-056, “JTIDS Spectrum Supportability, Risk Assessment Operational Analysis, Cardion DME Beacon.”

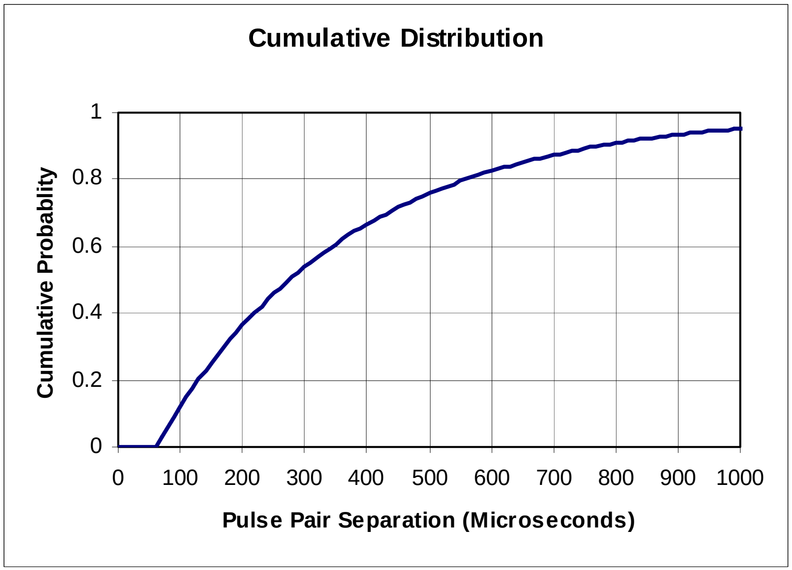

Figure 3. Cumulative Distribution of
the Separation of Pulse Pair Transmission Times

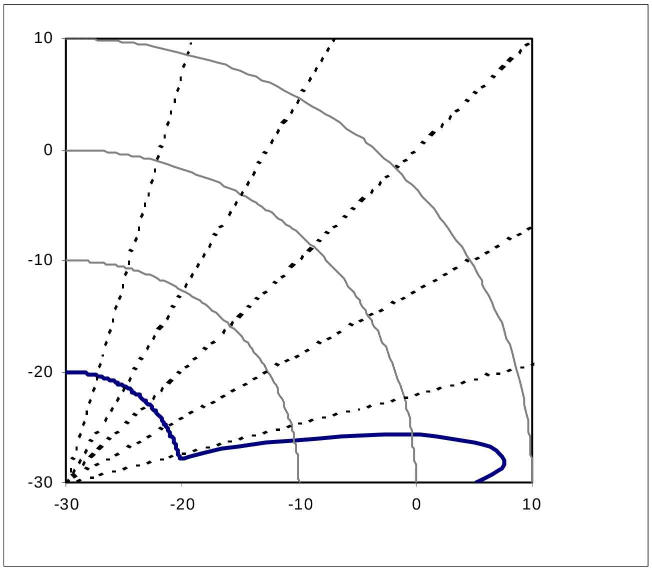

Figure 4. DME Antenna Pattern (8 dB gain at 3°)

3. UAT in the Presence of One DME

To get a preliminary idea of the effect that DME interference has on UAT reception, we initially consider the case of a single, very strong DME. The UAT and DME are modeled using a program written in Mathematica®. Performance is evaluated assuming that a DME at 981 MHz is being received at a level of –56 dBm. The level of the UAT signal is assumed to be –89 dBm for the cases of the two ADS-B message types and –82 dB for the up link message. (The 7 dB difference is an unimportant artifact of the fact that the ground message is typically assumed to be 7 dB stronger due to enhanced ground antenna gain.) The results of the simulations are shown in Table 1. For this table and *most* subsequent graphs, we simulate 4000 ADS-B messages or 500 ground messages.

Message Type	D/U Ratio	Failure Probability	# of Messages
Short ADS-B	-33 dB	0.061	4000
Long ADS-B	-33 dB	0.052	4000
Ground	-26 dB	0.04	500

Table 1. Maximum Effect of One DME Transmitter

This table indicates that the effect of a single DME is limited, even at very high interference levels. This is because the duty factor of a DME is, on the average, very low (< 4%); and the UAT error correction capability can usually handle the symbol errors that are generated.

4. DME Interference Scenario

To get a better idea of how DME interference might effect UAT performance in the real world, we propose a hypothetical scenario. To construct this scenario, we make certain assumptions. First, since DME's tuned to 981 MHz are, literally, few and far between there can be at most one such DME within line of sight at any given time. Our scenario assumes that we are unlucky enough to fly right over one. The populations of DME's tuned to 980 MHz and 982 MHz are also somewhat reduced; but (based on information about the Los Angeles basin) we assume that there are two of these in our scenario. The scenario is shown in Figure 5.

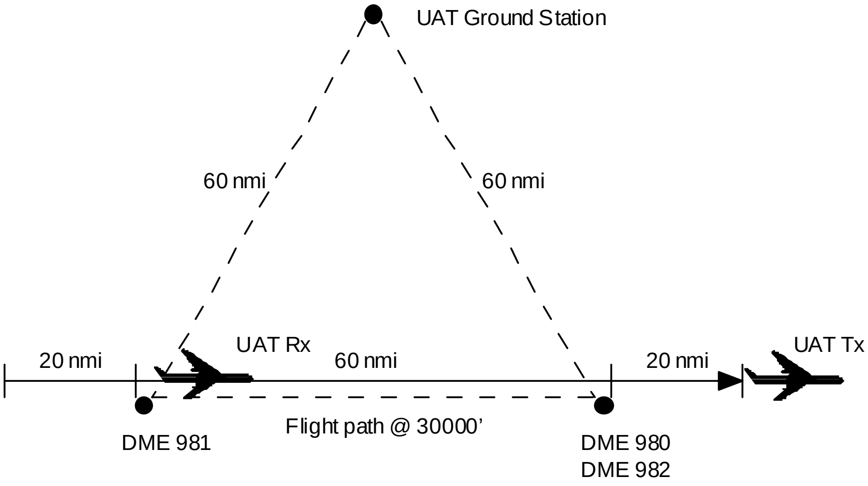

Figure 5. UAT/DME Interference Scenario

We have assumed that the DME's at 980 MHz and 982 MHz are close enough together so that we may conveniently put them at the same location to simplify the geometry. The two DME locations are separated by 60 nmi. In scenarios involving ground (up link) messages, we assume that the ground station is located at a corner of an equilateral triangle, 60 nmi from each of the DME locations. The victim receiver is flying along the line connecting the two DME locations. The altitude of the victim is (somewhat arbitrarily) chosen to be 30000 feet. In scenarios involving ADS-B messages the receiver is assumed to be trailing the transmitter at a fixed distance of 30, 60, or 90 nmi. The results of the simulations are plotted as the probability of failure as the victim flies along the 100 nmi track shown in Figure 5. The point “0” in the following graphs corresponds to the left end of the flight path and “100” corresponds to the right end. (Note that the altitudes and distances in this scenario allow us to use a flat earth approximation, which helps speed up the computer simulation.)

One final ingredient in the simulation is the estimation of the amount of power from the DME’s at 980 MHz and 982 MHz that effects the UAT receiver at 981 MHz. The nominal receiver bandwidth of the UAT is assumed to be 1 MHz. Thus, virtually all of the power of the DME at 981 MHz gets into to front end of the UAT receiver, while only a small fraction of the power of the DME’s at 980 MHz and 982 MHz is effective. In this paper we call this phenomenon adjacent channel reduction (ACR). We show all the subsequent performance graphs with separate curves showing two possible values for ACR: -20 dB and –40 dB. These values were chosen after considering two candidate IF filters manufactured by SAWTEK, Inc. (PN 851544 and PN 851543). (This information was provided by Tom Mosher.) One has a 3 dB bandwidth slightly larger than 1 MHz, and the other one has a bandwidth slightly smaller than 1 MHz. When the advertised pass band shapes of these filters are multiplied and integrated with the DME spectrum shown in Figure 2, the resulting ACR values are –21.2 dB and –43.1 dB. To avoid being too product-specific, these numbers are rounded to give the values –20 dB and –40 dB.

We are now ready to present the results of our simulations. Figures 6, 7, and 8 show the results for the short ADS-B message for distances 30 nmi, 60 nmi, and 90 nmi, respectively. Figures 9, 10, and 11 show the results for the long ADS-B message for the same distances. Figure 12 shows the results for the ground message. The bumpiness of these curves is a result of the statistical nature of the simulation and the limited number of test messages that were simulated.

All these graphs indicate that the performance of the victim receiver is significantly degraded for the cases corresponding to ACR = -20 dB. On the other hand, the failure rates corresponding to ACR = -40 dB are all about 6% or less. Comparing this information with Table 1 shows that in these cases the UAT is behaving as if there were only one interferer. This means that the better ACR performance of the narrower filter effectively negates the impact of the adjacent channel interferers. It is interesting to note that these graphs also illustrate the fact that the effect of the interferers is felt not only in the vicinity of the sources, but is also projected over long distances due to the shape of the assumed antenna pattern as shown in Figure 4.

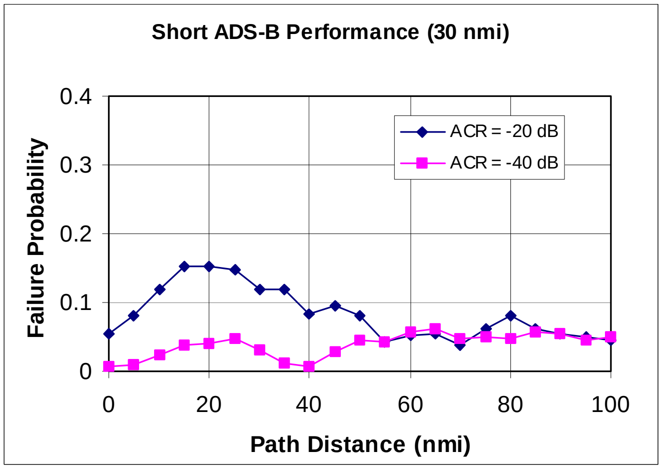

Figure 6. Short ADS-B Message Performance at 30 nmi

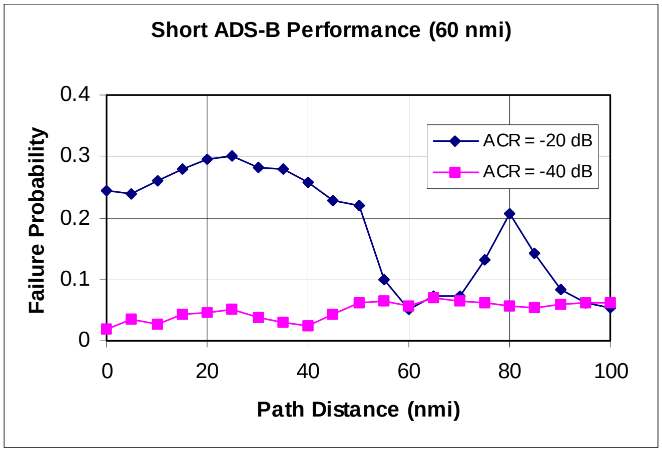

Figure 7. Short ADS-B Message Performance at 60 nmi

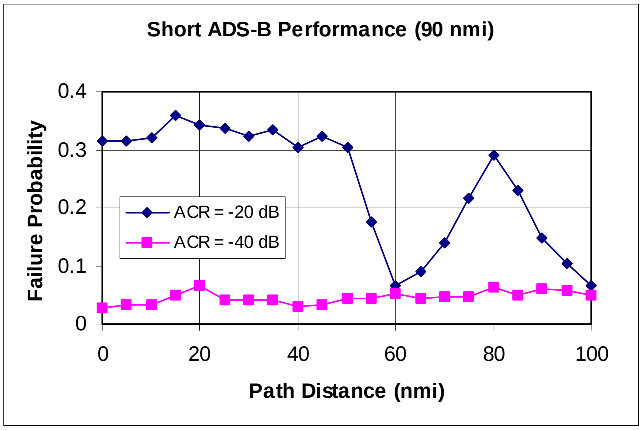

Figure 8. Short ADS-B Message Performance at 90 nmi

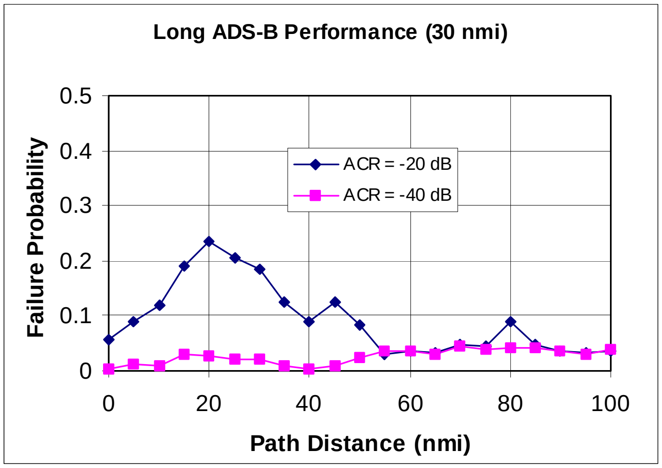

Figure 9. Long ADS-B Message Performance at 30 nmi

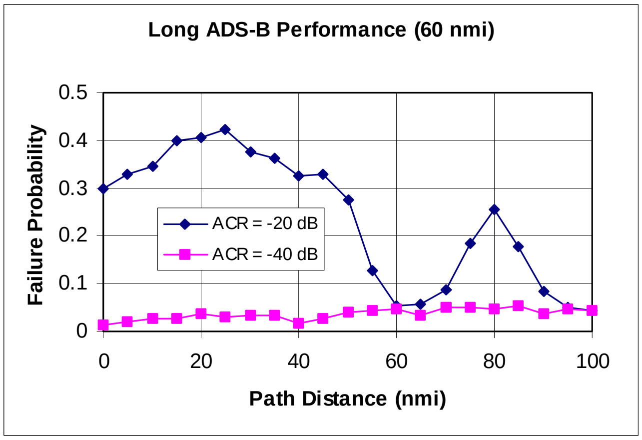

Figure 10. Long ADS-B Message Performance at 60 nmi

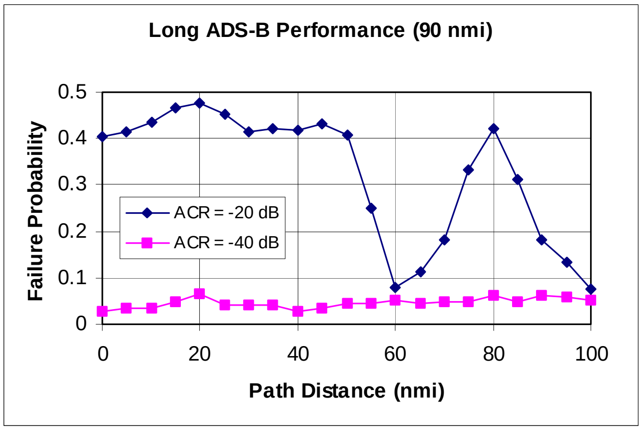

Figure 11. Long ADS-B Message Performance at 90 nmi

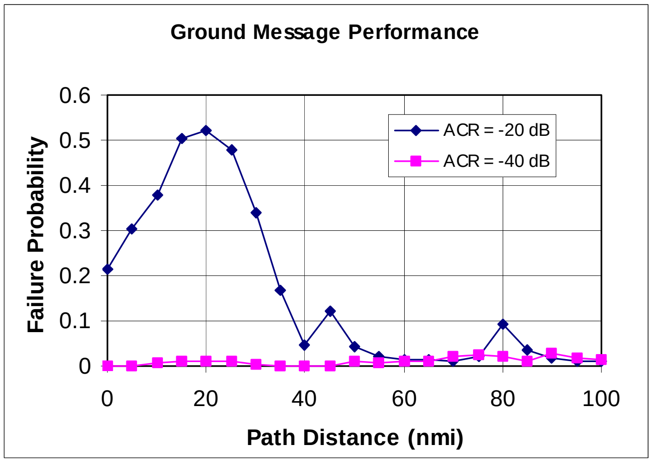

Figure 12. Ground Message Performance

Another way to reduce interference would be to remove the DME's at 981 MHz (and, presumably, replace them with DME's at alternative frequencies). To assess the usefulness of such a plan of action, all of the previous performance evaluations are repeated, with the DME at 981 MHz removed. The results are presented as Figures 13 through 19.

If the ACR value is –20 dB, these graphs indicate that some of the long range ADS-B scenarios experience significant performance degradation that, in some cases, is worse than the performance with the 981 MHz transmitter present together with an ACR of –40 dB. This seems to be telling us that it is more important to use the narrowest possible filter than to eliminate the DME's at 981 MHz.

When both "fixes" are used, i.e., the transmitter at 981 MHz is removed and the better value of ACR applies, we were unable to induce *any* errors on *any* UAT message type. This seems to point to the possibility that these two changes constitute a prescription for "complete" UAT/DME compatibility. This may be overstating the case; the actual degree of compatibility could be probed by repeating selected scenarios with the victim receiver at lower and lower altitudes to see if errors can be induced. The results of repeating some of the simulations at 10000' (instead of 30000') are shown in Figure 20, in which the range of the ADS-B links is assumed to be 90 nmi. This figure shows that at this altitude a small number of errors in the ADS-B messages are induced by the DME's at 980 MHz and 982 MHz at locations near the maximums of the ground antenna directivity. The ground messages experience no errors.

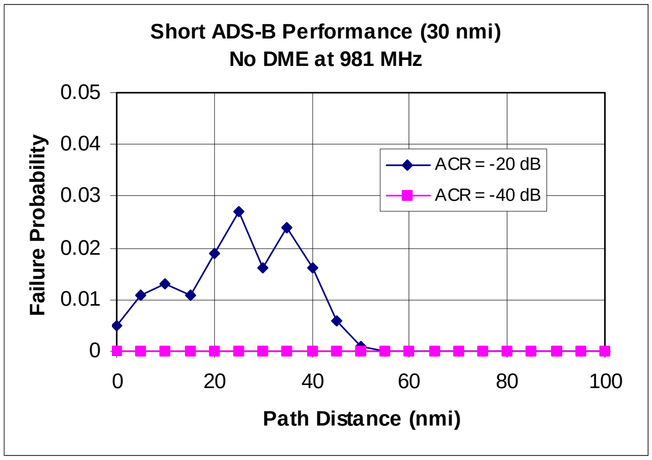

Figure 13. Short ADS-B Message Performance at 30 nmi (No DME @ 981 MHz)

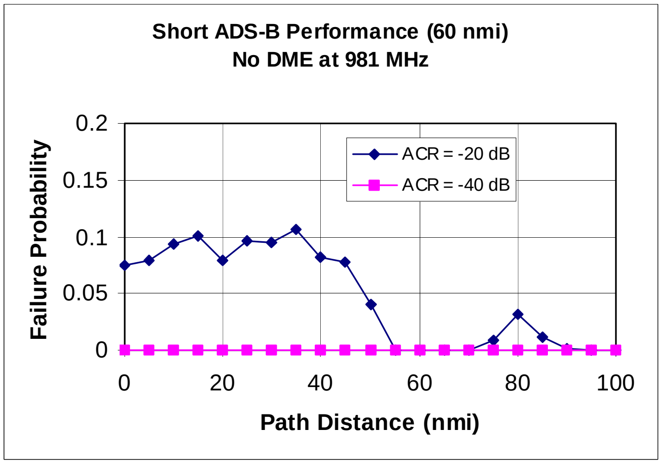

Figure 14. Short ADS-B Message Performance at 60 nmi (No DME @ 981 MHz)

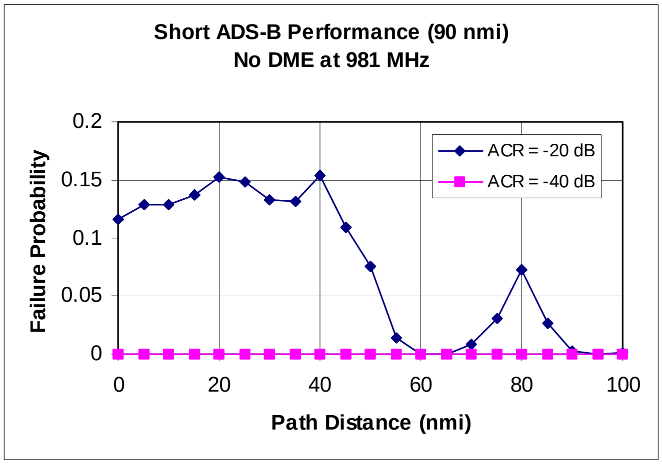

Figure 15. Short ADS-B Message Performance at 90 nmi (No DME @ 981 MHz)

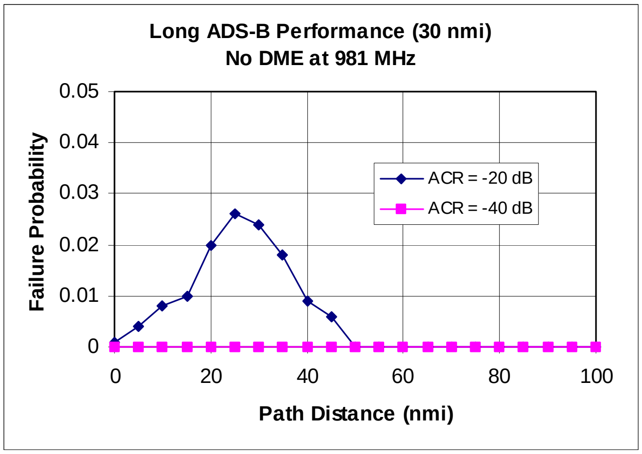

Figure 16. Long ADS-B Message Performance at 30 nmi (No DME @ 981 MHz)

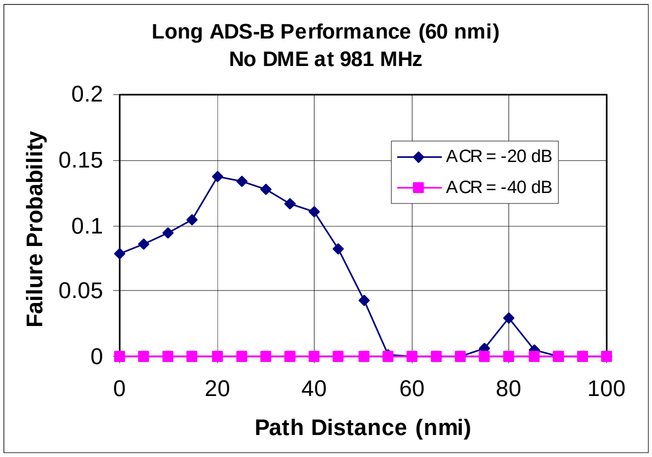

Figure 17. Long ADS-B Message Performance at 60 nmi (No DME @ 981 MHz)

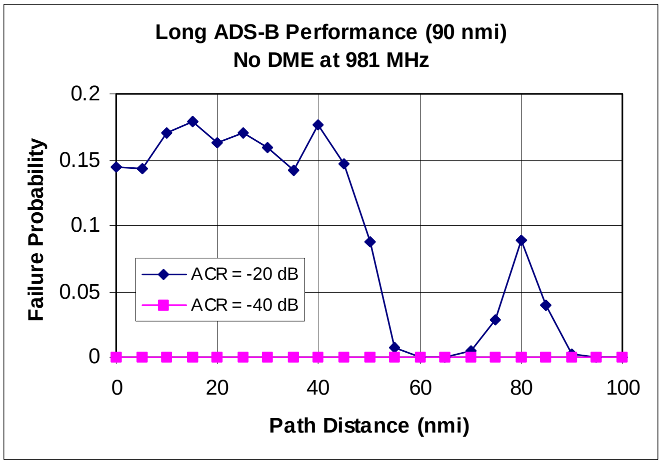

Figure 18. Long ADS-B Performance at 90 nmi (No DME @ 981 MHz)

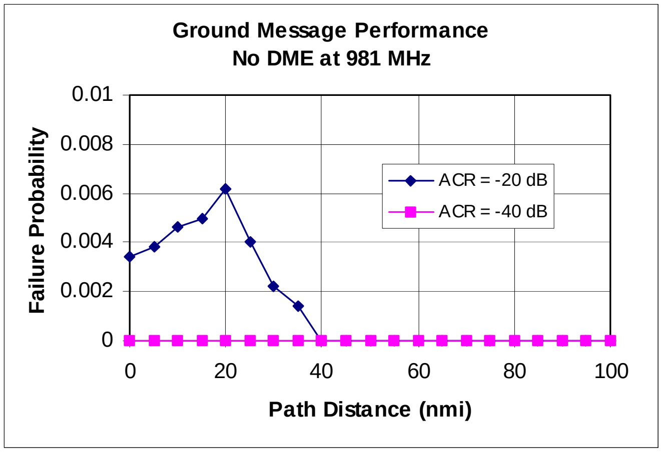

Figure 19. Ground Message Performance (No DME @ 981 MHz)

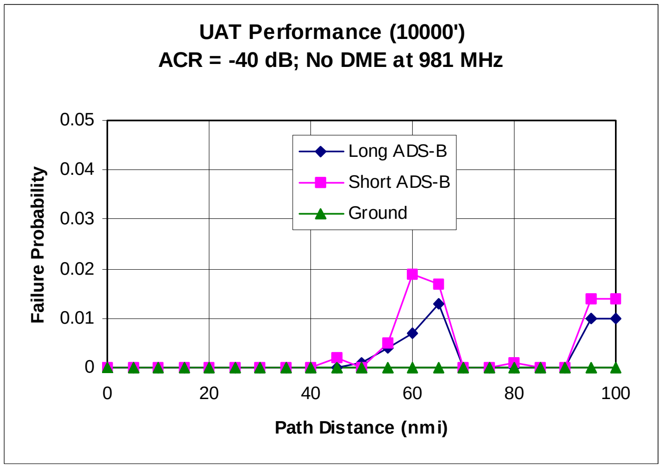

Figure 20. Performance Summary at 10000'
(No DME @ 981 MHz, ACR = -40 dB, ADS-B Range = 90 nmi)

5. Summary and Discussion

This paper has focused on two techniques for limiting the effect of DME interference on UAT performance. Listed in order of importance, these are:

(1) Use the narrowest practical IF filter bandwidth,

(2) Remove DME's tuned to 981 MHz wherever possible.

There may be a technical issue associated with the use of the narrow IF filter assumed in suggestion (1). The filter may be narrow enough to cause distortion in the received signal. This may have the effect of slightly closing the so-called "eye diagram," making the receiver more susceptible to noise. However, it should be borne in mind that the

UAT employs a *binary* waveform and it is necessary only to distinguish between upward and downward shifts in the received frequency. Distortion may not be a critical factor. When the UAT waveform was initially being designed, the base-band signal was filtered (using a truncated Nyquist filter) prior to FM modulation in order to limit the occupied bandwidth. The simulated receiver filter was then varied to optimize overall signal-to-noise performance. The optimal value of the noise bandwidth was found to be about 60% of the bit rate. However, the idealized filter simulation did not include group delay variation, which would exist (to some extent) in any real filter. The narrow filter that we are suggesting in this paper has a noise bandwidth of about 80% of the bit rate and it may have an acceptable level of distortion. Testing with actual hardware could resolve this issue.

Another issue not addressed here is the possibility that DME equipment operating at frequencies other than 980, 981 and 982 MHz could interfere with UAT reception by raising the overall noise floor. This may have some effect if the density of DME's in some geographical area is high enough.

Even though we have suggested that DME transmissions, by themselves, do not create a large number of UAT failures, it is likely that they will reduce the system margin for other sources of error such as JTIDS transmissions and (in the case of ADS-B messages) other UAT transmissions. These effects can be added to our simulation, but doing so will greatly increase the run-time for each case. Nevertheless, we intend to run a very limited number of such cases to test the overall validity of the performance model. For this exercise to be useful, the interference scenario will need to be very carefully chosen.

6. Recommendation

It is recommended that Working Group 5 consider the information contained in this paper in its deliberations on the UAT MOPS. The Working Group is also encouraged to agree on a very limited number of comprehensive interference scenarios (including DME's, JTIDS, and UAT self-interference) that can be investigated through the use of an expanded performance simulation.