RTCA Special Committee 186, Working Group 3

ADS-B 1090 MOPS, Revision A

Meeting #12

Comparing Tech Center and Lincoln Evaluations

Presented by William Harman

SUMMARY

At the previous meeting, a difference was noted in the reception performance as evaluated by Lincoln Laboratory and by the Tech Center. A number of steps were taken to determine the cause of the difference. This paper describes what was learned. It is concluded that the Tech Center results are valid. A number of more detailed results also came to light, as documented here.

Comparing Tech Center and Lincoln Evaluations

William Harman

As a means of assuring effective performance of Extended Squitter receivers, the MOPS will define bench tests in which ATCRBS interference is overlapped with the signals. To provide the basis for these requirements, the bench tests are being executed or simulated in detail at the Tech Center and also at Lincoln Laboratory. Of course we would like the two different evaluations to agree, which would add to the confidence that the simulations are executing correctly, and that two different organizations have implemented the enhanced reception techniques effectively. Initial comparisons, months ago, indicated agreement, although this was not addressed thoroughly. But more direct comparisons made in April revealed that there was a noticeable difference. As discussed at the previous WG-3 meeting, we have been working on this issue to resolve the discrepancy.

The difference was observed in the reception probability in the ATCRBS fruit bench-test defined in the draft MOPS, DO-260A. Specifically, in the three-fruit test, where the fruit are at three different power levels, reception probability was evaluated as a function of received power level. The two results agreed on the right side of the curve (relatively strong signal power) but disagreed on the left. The Tech Center result was about 95% whereas the Lincoln result was about 85%.

After a substantial amount of work, we have resolved the discrepancy in most respects. This working paper summarizes the results.

<u>Samples per Microsecond</u>. The Tech Center evaluation consists of bench tests, sampling of signals, and software implementation of the reception techniques. The sampling rate is 10 samples per microsecond. The Lincoln evaluation is entirely a simulation, and is done using 8 samples per microsecond. In the past, we have thought that 10 per microsec. provides a small improvement, so we didn't pay much attention to it. But this difference may be a contributor to the discrepancy we are studying, so we have now modified the Lincoln simulation to run at 10 samples/microsec. as well as 8. The resulting performance is slightly higher, which removed part of the discrepancy.

<u>Three ATCRBS Fruit</u>. Tech Center has pointed out that their bench test is capable of executing the multiple ATCRBS fruit tests exactly as stated in the draft MOPS for up to three fruit. For more than three, the test is nearly perfect, but not exactly. Therefore, in studying this discrepancy, we limited our attention to three fruit or fewer. Also, since the performance is nearly 100% for two of fewer fruit, we therefore considered the 3-fruit case to be the most useful for studying the discrepancy.

<u>Multisample and 5-5 Techniques</u>. The discrepancy first came to light when we compared the Tech Center's multisample technique to Lincoln's 4-4 technique. Previously we had considered that the Improved Multisample Technique and the 5-5 technique were nearly the same in performance. But this difference may cause part of the discrepancy, so we limited attention to the 5-5 technique. John Van Dongen re-ran the assessment using the 5-5

technique. In fact, he is using 5-5 tables provided by Lincoln, so processing of the datablock by the two organizations should be exactly the same.

Frequency Offsets and Pulsewidth Deviations. In the Lincoln simulation, the carrier frequencies of the signal and the fruit can be exactly 1090 MHz or can include offsets. Normally when we are simulating an airborne environment, we assign the ATCRBS frequencies to include deviations over +/-2 MHz, and the signal frequencies over +/-1 MHz (random deviations over these ranges, with uniform distribution). Tech Center, on the other hand, uses signal generators for both signals and fruit, rather than actual transponders, and all of the carrier frequencies are 1090 MHz or very close. Therefore while working on this discrepancy, we are using zero deviations in frequencies in the Lincoln simulation.

Similarly the Lincoln simulation normally includes pulsewidth deviations, because previous work revealed that these effects are significant. To eliminate this as a difference in this study, we are now not including pulsewidth deviations in the Lincoln simulation, for purposes of comparison with the Tech Center.

Bandwidth and Risetimes. We also realized that there is a difference in bandwidth. Lincoln has been using a receiver bandwidth of 8 MHz and a further bandwidth limitation for the transmitter (pulse risetime = 100 ns). The combined bandwidth is approximately 5 MHz. Tech Center is using the LDPU whose bandwidth is built-in, and the test configuration uses relatively square pulse as the input. We have been told that the LDPU bandwidth is about 7 MHz. We have made some progress on this issue by exchanging data, as described below. Tech Center made a file of some of the sampled data from their bench tests. Looking at the pulse shapes is this data, we see that the risetimes are about 140 ns. This value is higher than expected for a bandwidth of 7 MHz (and corresponds more nearly to 4 MHz). Therefore, we do not believe that sharper pulses caused the Tech Center performance to be better.

Exchange of Data. We arranged to have Tech Center data sent to Lincoln. This was a bench test of 1000 Extended Squitters, all at -80 dBm, with three overlapping ATCRBS fruit (-76, -72, and -68 dBm). It took time to successfully process this data at Lincoln, because the software was not expecting data of that kind, and while doing this we discovered several bugs in the 10 per microsec. version of our processing. In the end, the result is 94.5 percent success for the Lincoln processing and 94.2 success for the Tech Center processing of the same sampled data. These now agree very well. Looking closely we see that Lincoln's processing was not successful for some of the signals that Tech Center received correctly, and vice versa, but the overall percentages are nearly identical.

These results answer the original question almost entirely. They show that the Tech Center performance is correct, because it can be replicated when the data is processed at Lincoln. Some additional work is on-going as described below.

More Detailed Results. In processing the 1000 signals, whose sampled data was sent by the Tech Center, we noticed some interesting more detailed results. The following table shows the performance for the individual trials from 1 to 200. In many cases, a particular signal that was missed when processed by the Tech Center was also missed when processed by Lincoln. But there are also many cases in which the Tech Center succeeded in correctly receiving a particular signal, although Lincoln's processing was not able to correctly receive the same signal, and vice versa.

Table 1. Results for Individual Trials

TRIAL NO.	Tech Center	Lincoln	
trial 11	miss	success	
trial 26	miss	miss	(no preamble)
trial 28	miss	success	
trial 40	miss	miss	(late preamble)
trial 45	miss	success	
trial 67	miss	success	
trial 70	miss	success	
trial 102	miss	miss	(no preamble)
trial 124	miss	miss	(high conf. bit error)
trial 125	success	miss	(high conf. bit error)
trial 133	success	miss	(high conf. bit error)
trial 149	miss	success	
trial 162	success	miss	(high conf. bit error)
trial 189	success	miss	(no preamble)
trial 195	miss	success	

These results also indicate the relative contribution of preamble detection. Among these 200 trials, there were 8 misses in Lincoln's processing. Four of these were caused by preamble detection failure and the other four were caused by datablock errors after the preamble had been correctly detected. Interestingly, the datablock misses were all caused by a high confidence bit error.

Figure 1 shows the results in a way that indicates the relative performance of the different steps in error detection and correction. We see that both types of error correction were useful. The final step, Brute Force Error Correction, is seen to have contributed only a small improvement: only one signal. This increased the overall performance by only 0.1 percent.

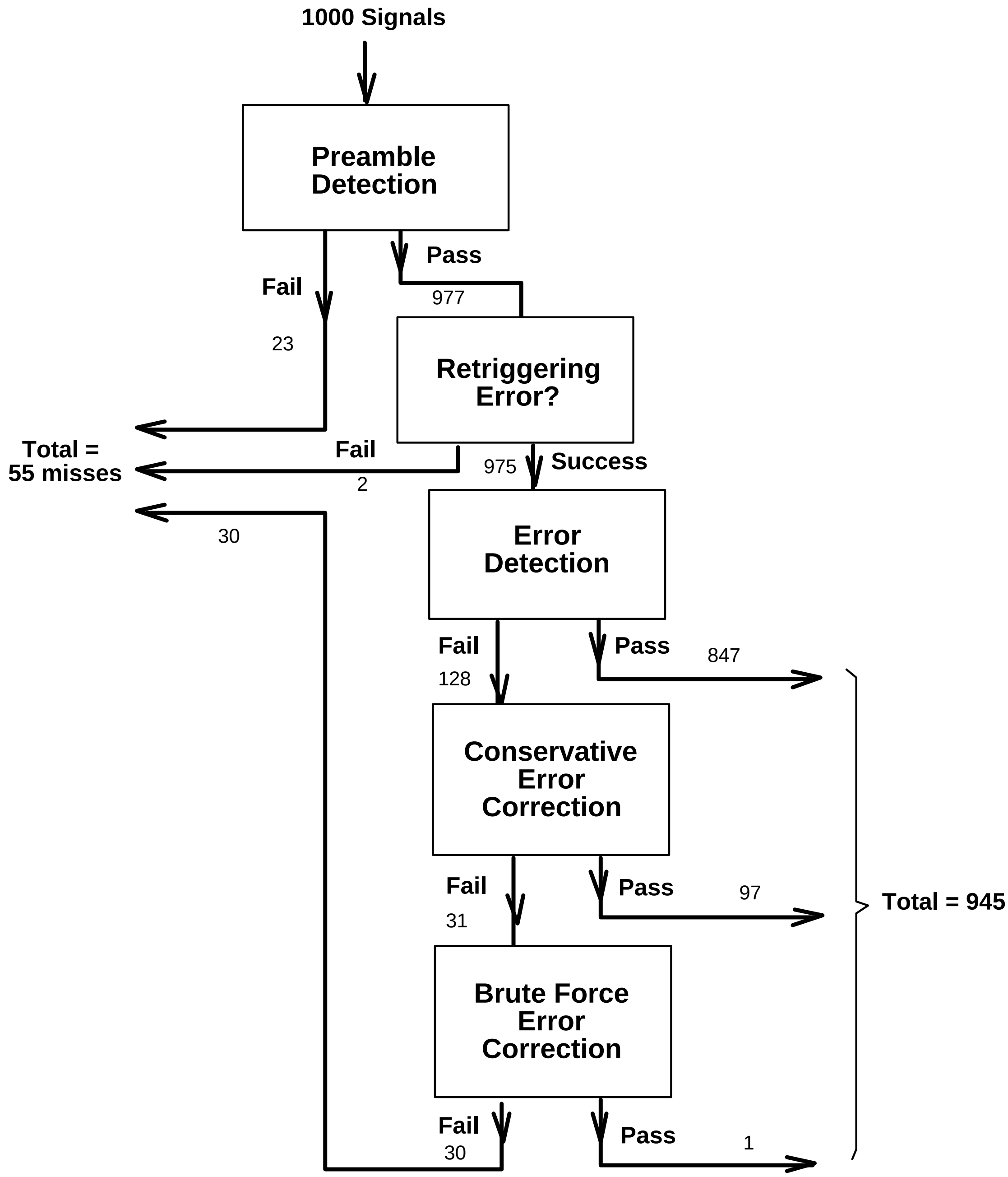

Figure 1. Steps in Reception Performance
1000 Ext. Squitters and 3 ATCRBS fruit
Sampled data from Tech Center, processed by LL, 5-5 technique

Note, however, that the interference conditions in this bench test are not very severe. The three overlapping fruit have the effect of degrading reception from 100% to about 95%, whereas in a dense environment, such as Frankfurt, Germany, we know that reception is degraded to about 20% at this power level (-80 dBm). We still consider the Brute Force technique to be a significant benefit under operational conditions.

Comparison. Figure 2 shows reception performance as a function of received power for Tech Center and Lincoln evaluations. These Lincoln results were entirely generated at Lincoln, rather than being sampled data from Tech Center. The performance benefit of using 10 samples per microsecond is apparent. Seeing this significant difference, WG-3 should consider basing the MOPS standards on the performance using 10 samples.

The figure also shows that there still is a difference between the Lincoln results and Tech Center results. We have been studying this, and have reason to think that the difference is caused by risetime differences. We have tried different risetimes in the Lincoln simulation, and the results show that performance improves significantly when risetimes are shortened. But this explanation is not complete, because we have measured the risetimes in the sampled data from the Tech Center, and found that they are even longer than the normal Lincoln risetimes.

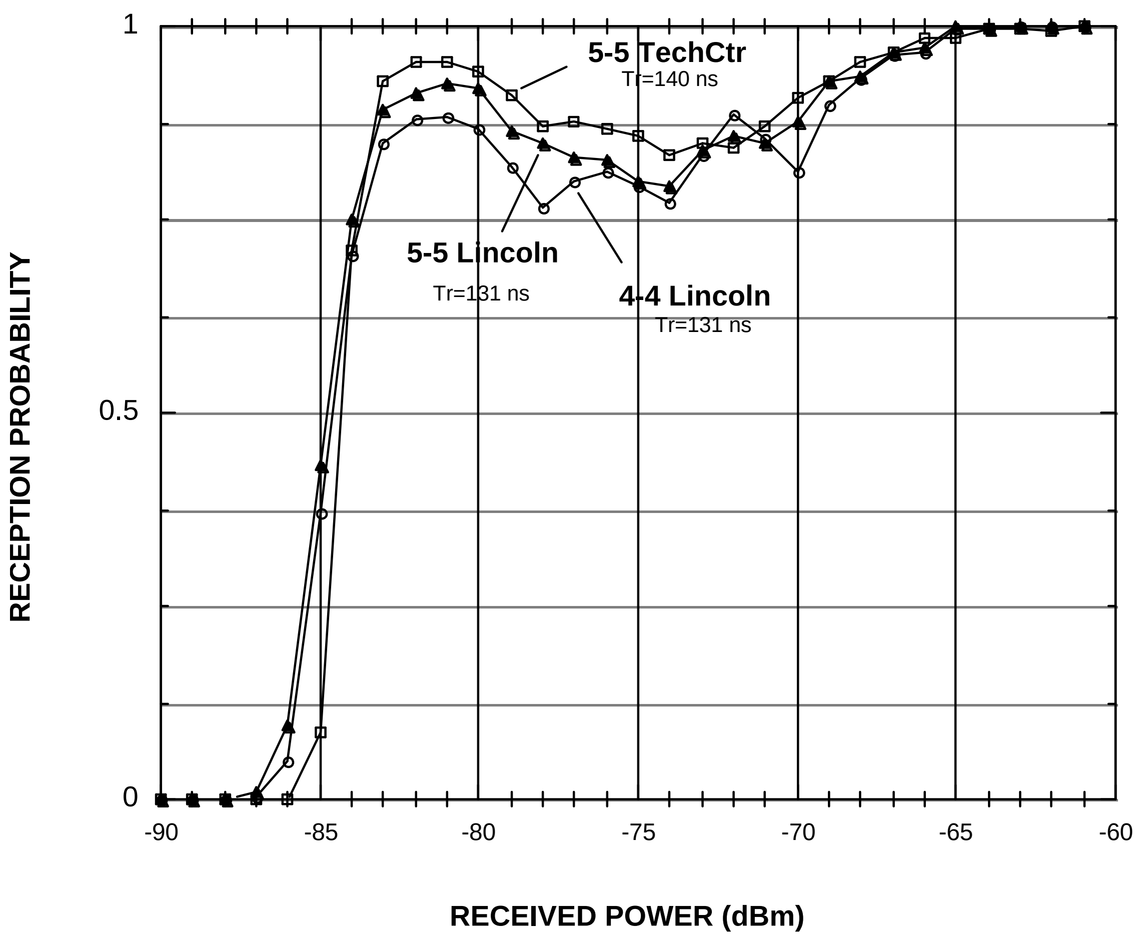

Figure 2. Comparison shown as a function of power level.

One other unexpected condition came to light in this work, which is that the pulsewidths in the sampled data from the Tech Center are about 400 ns rather than the nominal 500 ns for Mode S preamble pulses. This could be caused by a minor adjustment in the signal generator, but this minor deviation would not be expected to improve reception performance.

Tuning a Receiver for Bench Tests. While working on this problem, it has come to our attention that the enhanced reception techniques have a number of parameters, which might be optimized for bench test conditions rather than for operational use. We realize that several of the tests included in these techniques are intended for operational conditions and are not exercised in the draft MOPS bench tests. Therefore, we believe there is a danger that avionics designers may be tempted to adjust the receiver parameters to pass the bench tests at the expense of operational performance.

One way of providing a mechanism to insure good performance operationally might be to add a MOPS test using actual data obtained airborne, such as a portion of data recorded in Frankfurt or Los Angeles.

Summary. From the results above, we conclude that the performance evaluations conducted by the Tech Center’s appear to be valid. Also we have learned that 10 samples per microsecond provides a significant performance benefit relative to 8, and we have gained insight into the relative performance contributions by the preamble detector, and the two error correction techniques. Some work is ongoing to determine how performance is affected by pulse risetimes.