RTCA Special Committee 186, Working Group 3

ADS-B 1090 MOPS, Revision A

Meeting #6

Status report: simulation to obtain values of reception probability

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SUMMARY

We have drafted performance requirements in the form of minimum reception probability under certain controlled conditions, but the actual values remain to be specified. As a means of developing these values, Lincoln Laboratory is using two techniques, one based on simulation and the other based on bench tests. The FAA Tech Center is doing similar studies.

The simulation portion of the work has progressed well since the previous WG-3 meeting. This paper presents recent simulation results, and describes the status of this work, and plans for further work.

Status report: Simulation to Obtain Values of Reception Probability

In order to develop values of reception probability for the MOPS requirements and tests, Lincoln Laboratory is conducting simulations under controlled conditions. For example, to correspond with the new MOPS test in which a single ATCRBS fruit is overlapping the Extended Squitter signal, this same condition is being created in simulation, and the reception probability is being determined by Monte Carlo trials. Similar work is in progress at the Tech Center.

The simulation we are using can be thought of as being in two parts, as illustrated in Figure 1. The first part generates the received signal, consisting of an Extended Squitter signal, plus ATCRBS interference, and receiver noise. This combination is generated in the form of log-video, sampled at a rate of 8 samples per microsec. Using this technique it is possible to overlap an Extended Squitter signal with 3, or some other number, ATCRBS fruit receptions, and to make their timing random, overlapping the data block. In another case the interference can be made to overlap the preamble.

The second part of the simulation represents the receiver, including the techniques for detecting and demodulating the signal, estimating the 112 bits and the associated confidence bits, and finally error detection/correction. This is being done using the enhanced reception techniques, but can also be done for the current TCAS reception techniques, or other defined techniques.

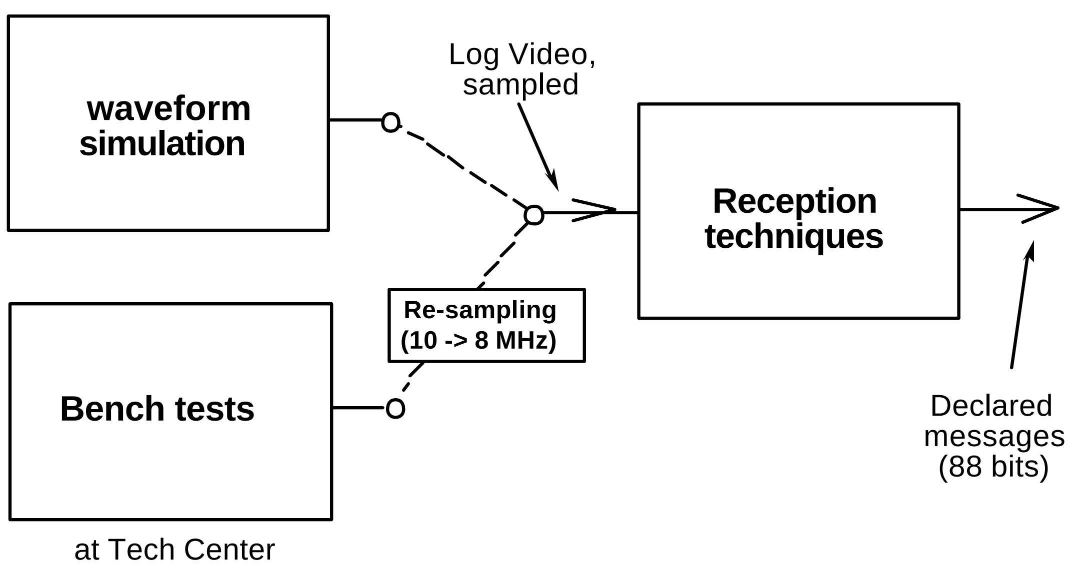

Figure 1. Main function of the simulation and bench tests.

Figure 1 shows the two main functions of the simulation as it is currently being used. The bench tests are an alternative way of generating the waveform, and this approach is planned to be used in the near future.

Initial results have been obtained under basic conditions. Figure 2 shows simulation results for cases that correspond to the MOPS tests we have drafted. In this case, an Extended Squitter signal is being overlapped with ATCRBS fruit, having power of -65 dBm. For 2 fruit overlaps, both have power -65 dBm. Results are shown here as a function of received signal power. This is the same format that was used in earlier working papers, presenting bench test that were performed on an LDPU.

The results seen here are similar to the LDPU bench tests. When the signal is stronger than the interference, reception probability is essentially 100%. When the signal power is reduced such that it is approximately the same as the interference, reception probability is seen to be degraded. If the signal power is reduced further, reception probability improves significantly. This same behavior was seen previously in LDPU performance.

The results in Figure 2 also include a case in which no interference was added. This is the receiver MTL (Minimum Triggering Level) curve. Under these conditions, the receiver has an MTL value of about -81 dBm. This can be changed to test other values by changing the receiver threshold, which was -85 dBm for these initial runs.

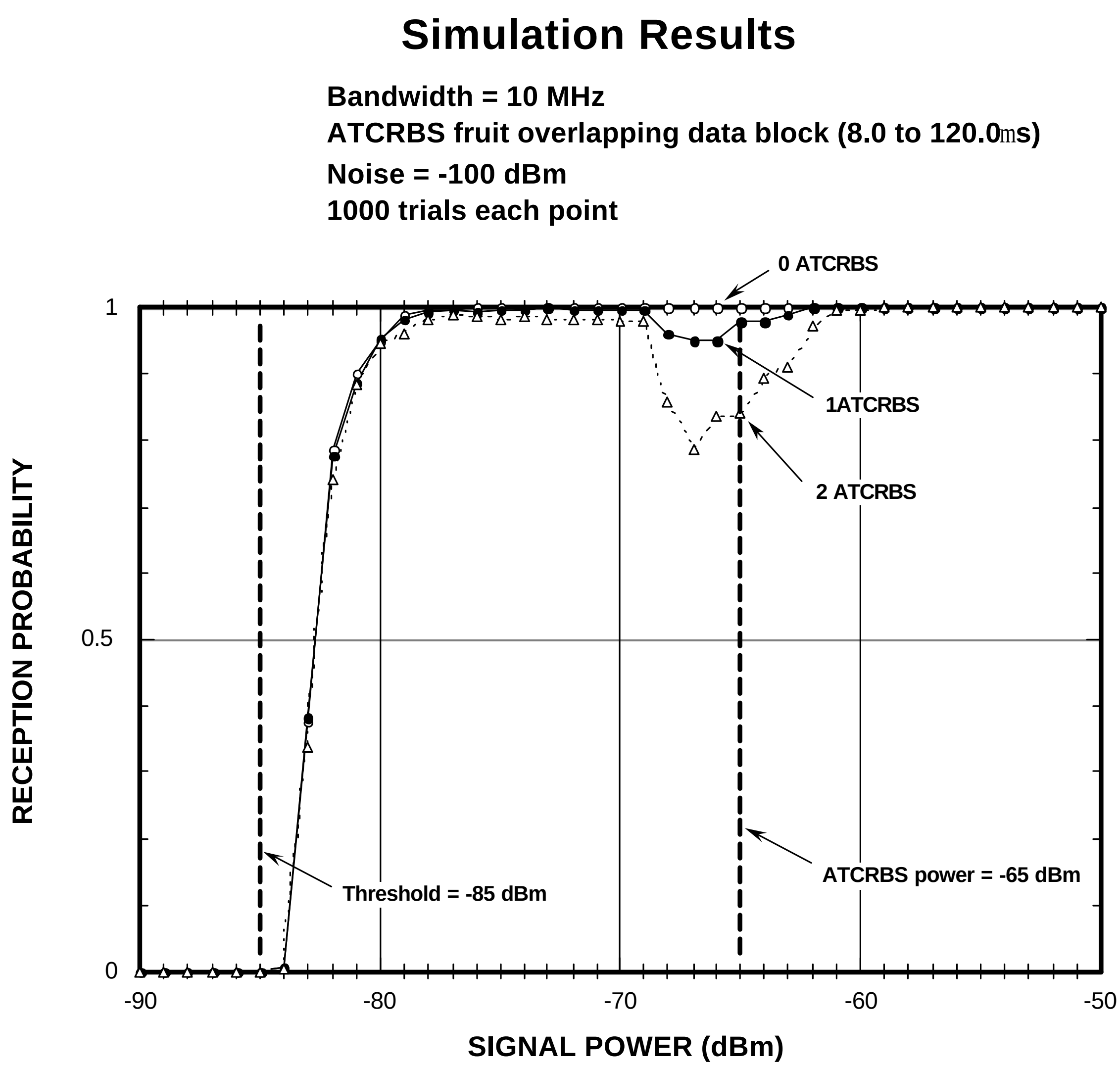

Figure 2. Simulation results, for ATCRBS fruit overlapping the data block.

The remainder of this working paper is a more detailed description of the simulation, showing how signals and interference are combined, taking account of their amplitudes and phases.

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SIMULATION DESCRIPTION

Formulation: The simulation is run as a function of time for a duration that is entered by the user. Example: duration = 10 second.

Complex superposition. Signals and noise are added as complex amplitudes. The conversions between dBm and complex amplitude are as follows.

To convert a power in dBm to complex amplitude: pwr = 10^[(dBm + 70)/10] vI = sqr(pwr) cos(phi) vQ = sqr(pwr) sin(phi) To convert a complex amplitude to dBm: dBm = 10 log10(vI^2 + vQ^2) - 70

Note that pwr is the power relative to 10^{-7} mw.

After combining signal and interference and noise, the complex amplitude is converted to dBm. This is taken as the log video waveform available for processing.

Carrier Frequency. Each aircraft is also assigned a frequency, in a band 1090 ± a parameter entered by a user. The frequency is generated at random, with a uniform distribution over the band. For each aircraft, its frequency is kept constant. Mode S and ATCRBS bands can be assigned different values.

For example, we normally use these values.

For Mode S, f = 1090 ± 1 MHz

For ATCRBS, f = 1090 ± 2 MHz

Phase. The combination of multiple signals and noise is done by adding their complex representations. A random phase is generated for each pulse. In one reply, phase is independent from pulse to pulse.

Pulse Shapes. The initial simulation work was done with a trapezoidal shape in dB. Currently this has been replaced with a model based on bench tests, and which includes a parameter to apply to different values of bandwidth. The model begins by calculating the rise time and fall time, which are defined to be the 10% to 90% values.

Rise time = t_R = sqr[$(680/B)^2$ + $(100ns)^2$]

Fall time = t_F = (6/5) * t_R

where B is the 3-dB bandwidth in MHz. Next the pulse shape is calculated, in terms of its amplitude (not in dB). Amplitude varies from zero to 1. Begin with a given nominal pulse that has a nominal leading edge, and a nominal trailing edge, and pulse width (the difference between leading and trailing edges).

Let t = 0 at the nominal leading edge. Let

amplitude = 0 for $t < -(5/6) * t_R$

amplitude = 1 for $t > (5/6) * t_R$

amplitude = $f(x) = 0.5 + 1.5\,x - 2\,x^3$ otherwise

where $x = 0.6\,t / t_R$.

For the trailing edge, let t' = 0 at the nominal trailing edge. Let

amplitude = 1 for $t' < -(5/6) * t_F$

amplitude = 0 for $t' > (5/6) * t_F$

amplitude = $1 - f(z) = 0.5 - 1.5\,z + 2\,z^3$ otherwise

where $z = 0.6\,t' / t_F$.

Noise. Receiver noise is superimposed on the complex-amplitude signals. Noise is generated as independent random samples in phase and in quadrature, using

nI = sigma sqr(-2 ln(ran1))*cos(2 pi ran2)
nQ = same formula, independently generated

where sigma is a parameter entered by the user. The nominal value of sigma is

sigma = 0.031 (volts)

After generating this white noise, the samples are smoothed using an alpha filter twice.

output = (alpha) * (current sample) + (1 - alpha) * (previous output)

where alpha = 0.8. This provides correlation between noise samples. Used twice, this reduces the noise standard deviation by a factor of 0.667 in both components (-3.5 dB).

The noise power in this simulation is controlled by the parameter sigma. The nominal value (0.031 volts) corresponds physically to the following noise power.

Noise power $= N = \text{aver}(vI^2 + vQ^2)$

$= \text{sigma}^2 * \text{aver.}(g1^2 + g2^2)$

$= 2\ \text{sigma}^2$

$= 1.92\ (10^{-3})$ which equals -27.2 dB

After smoothing this is reduced to

$$N = 1.92\ (10^{-3}) * 0.667^{2} = 0.853\ (10^{-3}) = -30.7\ \text{dB}$$

Since this is relative to 10^{-7} mw, the power in dBm is:

$$N = -30.7 - 70 = -100.7\ \text{dBm}$$

The simulation of the reception process includes preamble detection, bit demodulation, confidence bit assignment, and error detection and correction.