<u>RTCA Special Committee 186, Working Group 3</u>

<u>ADS-B 1090 MOPS, Revision A</u>

<u>Meeting #15</u>

Action Item 14-01
Air-to-Air Performance in LA2020

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SUMMARY

In parallel with the performance assessment being done by Johns Hopkins APL, a similar assessment is being performed at Lincoln Laboratory, making use of two simulation tools developed previously. This Working Paper describes the simulation techniques being used, and summarizes the results for the LA2020 interference environment and an expanded interference environment, LA2020-Plus. This Working Paper addresses Action Item 14-01.

Air-to-Air Performance in LA2020

In parallel with the performance assessment being done by Johns Hopkins APL, a similar assessment is being performed at Lincoln Laboratory, making use of simulation tools developed previously. This work applies to the LA2020 interference model, for which the ATCRBS fruit rate is 24,000 per second (bottom antenna), and also an expanded interference model, "LA2020-Plus", for which the ATCRBS fruit rate is 30,000 per second (bottom antenna).

This study makes use of two simulations that were developed previously. The first tool is a pulse-level simulation, whose output gives the probability of correct reception of an Extended Squitter signal as a function of received signal power level. The second tool is a track-level simulation, whose input is the pre-squitter reception probability from the pulse-level simulation, and whose output gives the performance over a time period such as 12 seconds. When applied to long-range air-to-air surveillance, this simulation can be used to determine the maximum range at which 95 percent or more of the targets are being received sufficiently reliably to be in track and being updated regularly as required by the ADS-B MASPS (RTCA DO-242A).

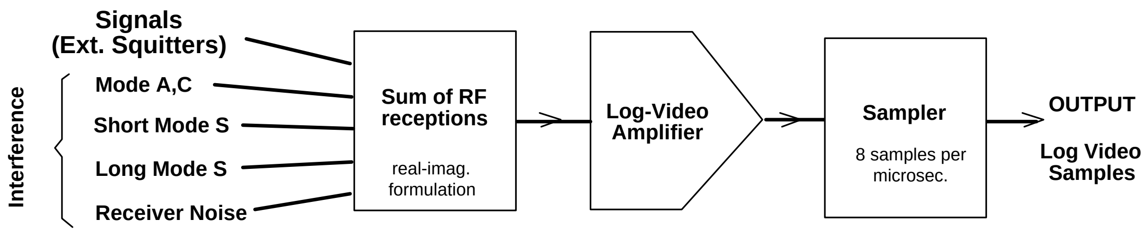
1. Pulse Level Simulation

The pulse-level simulation generates a received Extended Squitter signal in the presence of interference, consisting of Mode A,C fruit and Mode S replies and squitters, in both long and short formats. When used in this study, the interfering reception rates and power distributions were selected to match the interference environment in Los Angeles. The rates and power distributions are described below.

1.1 Formulation

This simulation was originally developed for the purpose of studying enhanced reception techniques for Extended Squitter. The simulation represents signals and interference as 1090 MHz radio frequency waveforms having amplitude and phase, so that destructive and constructive summation is represented. Each transponder is assigned a specific carrier frequency, which need not be exactly 1090 MHz. The frequency offsets were random, uniformly distributed over +/-1 MHz in this study. Minor pulsewidth deviations were also incorporated in this study. All pulse have risetimes and falltimes that correspond to the effects of both transmitter and receiver bandwidths. The simulation can be run using different values of receiver bandwidth. Bandwidth was set equal to 8 MHz in this study. In addition to the received interference, the simulation also includes receiver noise, whose power was -100.7 dBm referred to the antenna in this study.

The received waveform, which is a sum of the Extended Squitter signal and all overlapping interference plus noise is then converted to a log video waveform, which is sampled at a steady rate. These steps are illustrated in Figure 1. The simulation can be run at a sampling rate of 8 samples per microsecond or 10 seconds per microsecond. The former rate was used in the current study. The log video samples are then processed using the enhanced reception techniques. These techniques include an improved form of preamble detection, an improved method of declaring the 112 bits and associated confidence bits, and an improved error detection/correction technique called "Brute Force, n=5".



Signal-to-interference power ratios, controlled by aircraft ranges and fading.

Bandwidth affect on pulse shapes.

Frequency deviations for Mode A,C (±2 MHz typ.) and Mode S (±1 MHz typ.)

Phases of each pulse

Pulsewidth deviations

Receiver noise (power = -100.7 dBm referred to the antenna, typ.)

Figure 1. Overview of the Pulse-Level Simulation

To generate reception probability as a function of received power level, the process is as follows. The user assigns a total number of aircraft (1000 aircraft for example) and provides a range distribution. The simulation generates the ranges of these aircraft using a pseudo-random process, following the given range distribution. Then for each aircraft, the nominal value of received power level is calculated using the following formula.

$$\text{Nom. Received power (dBm at antenna)} = -83.5 - 20 \log10(\text{range}/100 \text{ NM})$$

The next step is to apply a random power deviation to account for both transmitter power differences from aircraft to aircraft and antenna gain effects. The user also assigns transmission rate for three types of signals. The simulation is run for a fixed time period set by the user, typically 10 seconds. For each transmitting aircraft, the total number of transmissions are made random in time, uniformly distributed over the run time. Therefore the reception times are essentially a Poisson process, having a constant average reception rate for each of the three types of signals.

As each Extended Squitter is received, it is processed to determine whether the 112 bit message is correctly received, including the effects of error detection/correction. All such receptions, whether correct or not, are saved in bins according to the received power level. Two-dB bins were used in this study for some of the runs, and five-dB bins were used in other runs. After the full run, which includes several thousand reception opportunities in each of the major bins of interest, the number of correct receptions is compared with the total number of opportunities. The probability of correct reception is computed as the ratio:

$$\text{Probability of correct reception} = \\ (\text{no. of correct receptions}) / (\text{no. of opportunities})$$

1.2 Interference Rates and Power Distributions

In running the pulse-level simulation for the Los Angeles environments, it was necessary to specify the rates and power distributions of the interfering signals. For Los Angeles, this was done based on results from airborne measurements in the LA Basin in 1999 [Ref. 1] and on results from the Volpe simulation [Ref. 2]. It was found that the power distribution of ATCRBS fruit from the LA2020 Volpe simulation agrees with the airborne measurements, except being higher in fruit rate, which would be expected because of the futuristic conditions. The Volpe results were then used to provide the fruit-rate input to the Lincoln pulse-level simulation. Figure 2 shows the ATCRBS and Mode S fruit rates and power distributions used as inputs for this study. This applies to a scenario called LA2020, in which the receiving aircraft is located near LAX airport at 40,000 feet altitude. Mode S interference is characterized by short Mode S transmissions from each aircraft at a rate of 6 per second, and long Mode S transmission at a rate of 5.4 per second. The total ATCRBS fruit rate when referred to a power level of -84 dBm at antenna is 24,000 fruit per second, for bottom antenna receptions. For top antenna receptions the corresponding fruit rate is 18,000 fruit per second.

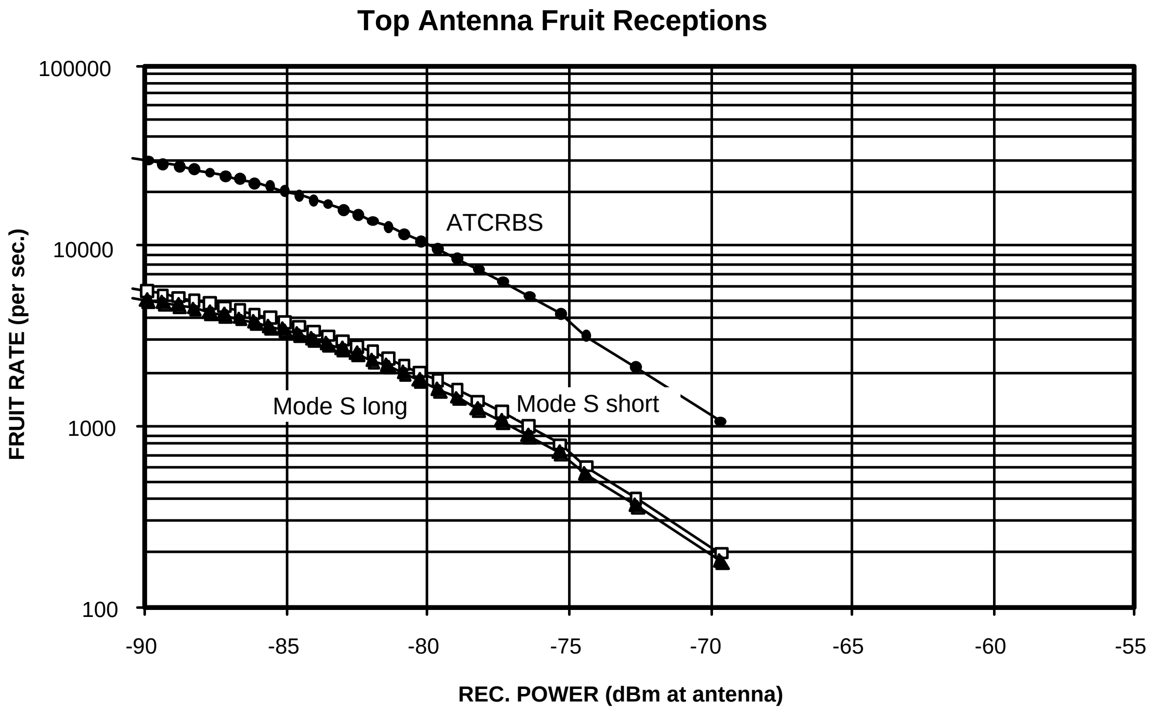


Figure 2-a. Bottom Antenna Fruit, LA2020.

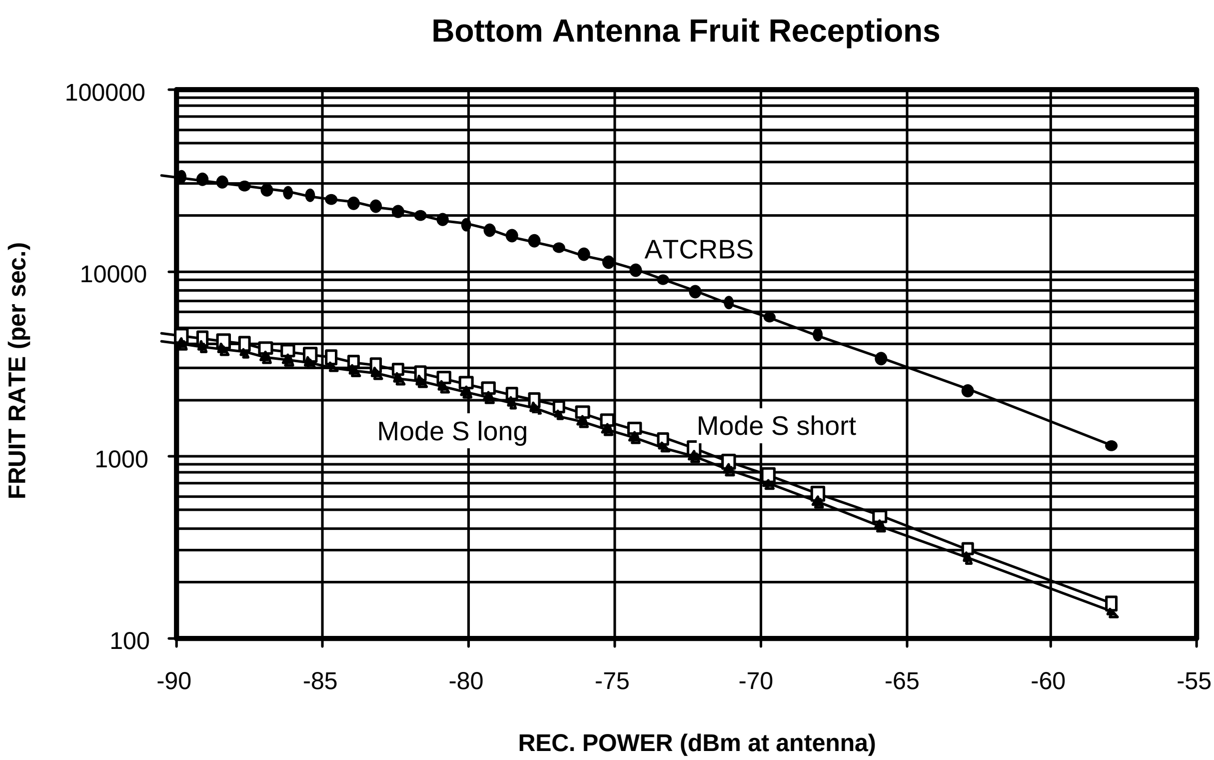


Figure 2-b. Top Antenna Fruit, LA2020.

1.3 Pulse-Level Simulation Results

The pulse-level simulation was run for two scenarios representing different interference environments for future higher aircraft densities. The scenario called LA2020 has 24,000 ATCRBS fruit per second, as described above. The higher interference scenario, called LA2020-Plus, has 30,000 ATCRBS fruit per second, with the same Mode S interference as in LA2020. The pulse-level simulation results are shown in Figure 3.

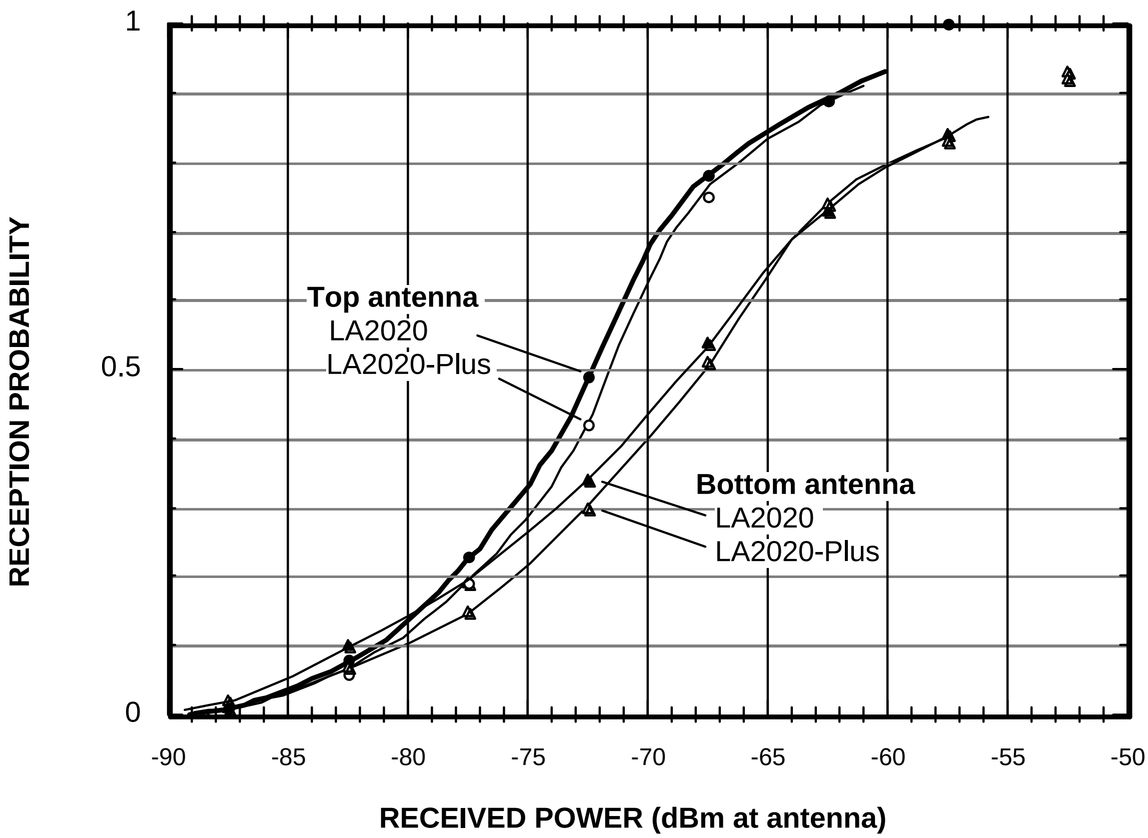


Figure 3. Reception Probability Versus Received Power.

2. Track-Level Simulation

After the pulse-level simulation has generated results in the form of Figure 3, the track-level simulation can be used to determine system performance.

2.1 Formulation

The track-level simulation is formulated using the Monte Carlo technique in which one run represents one pair of aircraft at a given air-to-air range. In each run, pseudo random variables are used to generate the antenna gain values and the transmitter power for that particular transmitting aircraft.

The TLAT model is used for the statistical variation of aircraft antenna gains. The scenario considered in these runs applies to altitudes that are nearly the same, and for which the antenna vertical patterns are not used. Altitude differences were studied separately, as described below.

After being generated at random, the antenna gain values are held constant for that particular pair of aircraft. The cases being addressed in this study apply to antenna diversity on both the transmitting and the receiving aircraft. Therefore each aircraft pair has four antenna gain values. These four values are generated independently in the simulation. Transmitter power, for a class A3 aircraft, is modeled as uniformly distributed over 53 to 56 dBm referred to the antenna.

The simulation is run for a particular air-to-air range. Using the transmitter power and the four antenna gains, the four values of received power are calculated (top-to-top, top-to-bottom, bottom-to-top, and bottom-to-bottom). For each case the Figure 3 curve is then used to determine the reception probability for that particular antenna combination.

To account for receiving antenna diversity, the probability of correct reception is calculated using the following formula.

$$\text{Prob(correct)} = 1 - (1 - P(\text{top})) * (1 - P(\text{bot}))$$

where P(top) and P(bot) are the reception probabilities for top only and bottom only. Subsequently, to account for transmitting antenna diversity, the reception probability is calculated separately for top-transmit and bottom-transmit, and these two values are averaged. This averaging is based on the fact that each antenna transmits 50 percent of the squitters.

This process yields the value of reception probability for a particular pair of aircraft. The process is repeated for a large number of aircraft pairs (1000 pairs). Performance for the 95th percentile pair is determined by sorting the 1000 values and identifying the value that is exceeded by 95 percent of the population. This result gives the 95-percentile reception probability for the range being considered. Repeating the process for different ranges provides system performance as a function of range.

2.2 Simulation Results

Beginning with the LA2020 scenario, both the pulse-level simulation and the track-level simulation were run, yielding the results plotted in Figure 4. Results in this form are somewhat general, because the needed level of reception probability depends on specifics of different cases. For example, for air-to-air surveillance, a value of 0.061 is sufficient to provide MASPS-compliant performance at long range (20 NM and beyond) [Ref. 3].

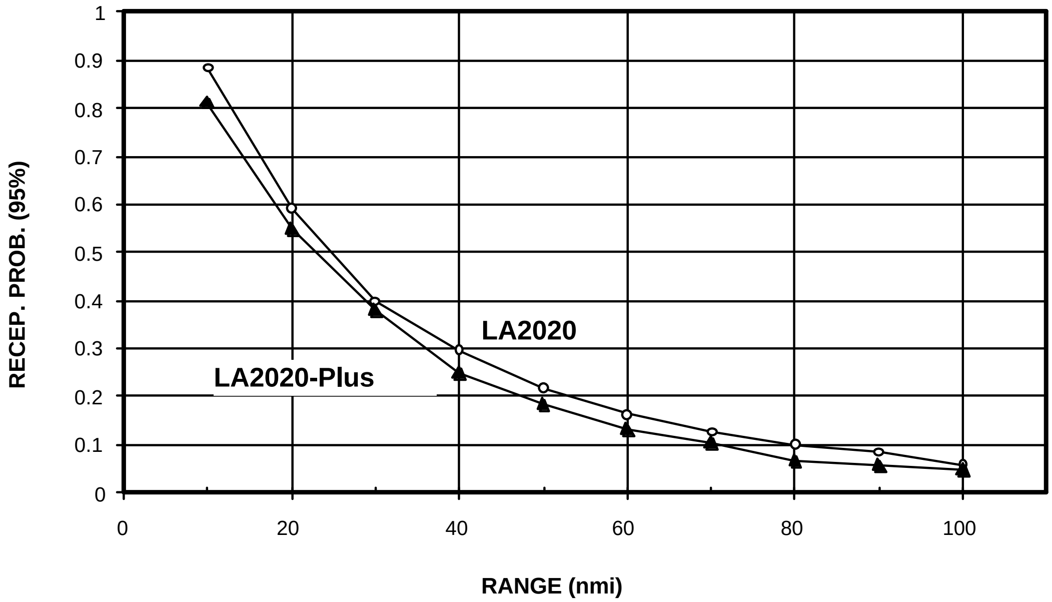


Figure 4. Future System Performance in the Los Angeles Basin.

More specific results, showing surveillance update performance, are shown in Figure 5. These results were generated from the data in Figure 4 as follows. In a time T, the number of reception opportunities is

$$N = T / 0.25 \text{ seconds.}$$

Given the reception probability from Figure 4, the probability of correct reception during the time T is therefore

$$P(\text{recep. in } T) = 1 - (1 - p1)^N$$

where p1 is the single-squitter reception probability from Figure 4. Requiring 95% reception in time T, or P(recep. in T) = 0.95, the solution for time T is:

$$T95/95 = 0.25 * \ln(0.05) / \ln(1 - p1)$$

This value of update time is denoted T95/95 to indicate that it applies to 95% surveillance update reliability for 95% of aircraft pairs.

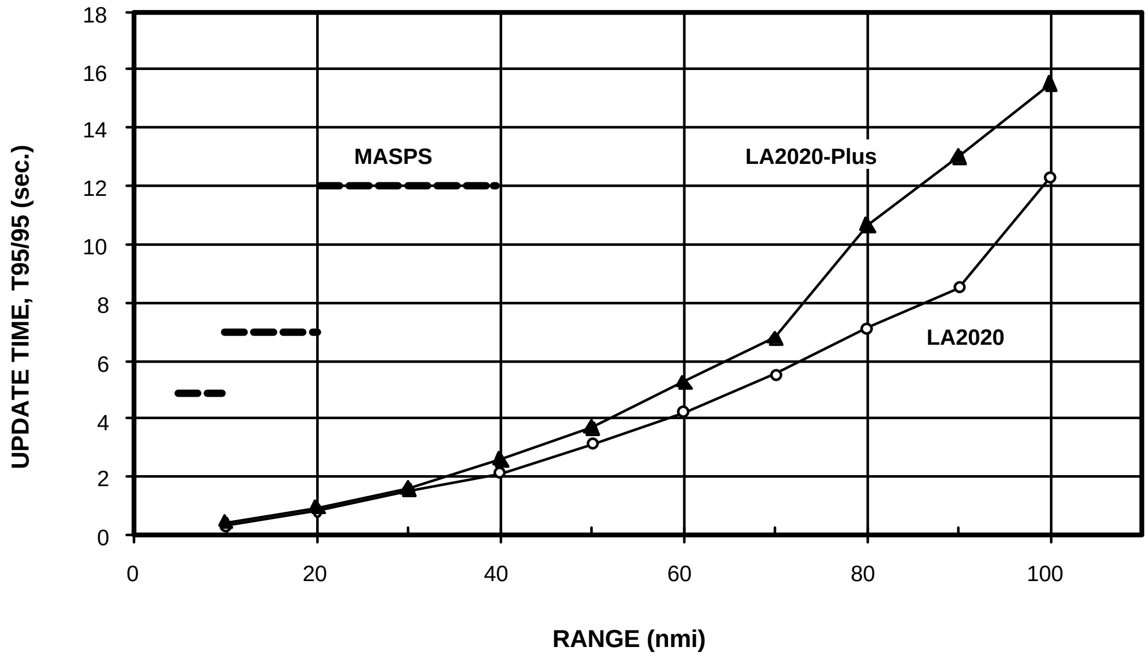


Figure 5. Surveillance Update Performance.

3. Effects of Altitude

We added altitude to the simulation in order to determine the effects of an altitude difference between the transmitter and the receiver. In the normal formulation, the two aircraft are considered to be at approximately the same altitude, and therefore the elevation-angle portion of the antenna gain model is not used (only the statistical portion). The formulation was changed so that the transmitting aircraft has a specific altitude (a parameter entered by the user) and the receiving aircraft has a specific altitude (another parameter entered by the user). We assigned the receiving altitude to be 40,000 feet, and assigned the transmitting altitude one of several values. Therefore the results depend on the transmitter altitude.

Figure 6 shows the results for two values of transmitter altitude.

These results indicate that performance is degraded when the transmitter is changed from 40,000 feet to 5000 feet, with the degradation occurring inside of 50 NM. Beyond 50 NM, performance is essentially unchanged.

Looking at the intermediate results from the simulation, I can see several reasons why altitude would not have much effect at long range. For long range, the elevation angle change is small. For example, for range of 100 NM and transmitter altitude of 5000 feet, the elevation angles are +/-3.3 degrees. According to the TLAT antenna gain model, this causes a drop by only 1.1 dB for one antenna and a boost by 1.0 dB for the other. The effects are small and nearly identical.

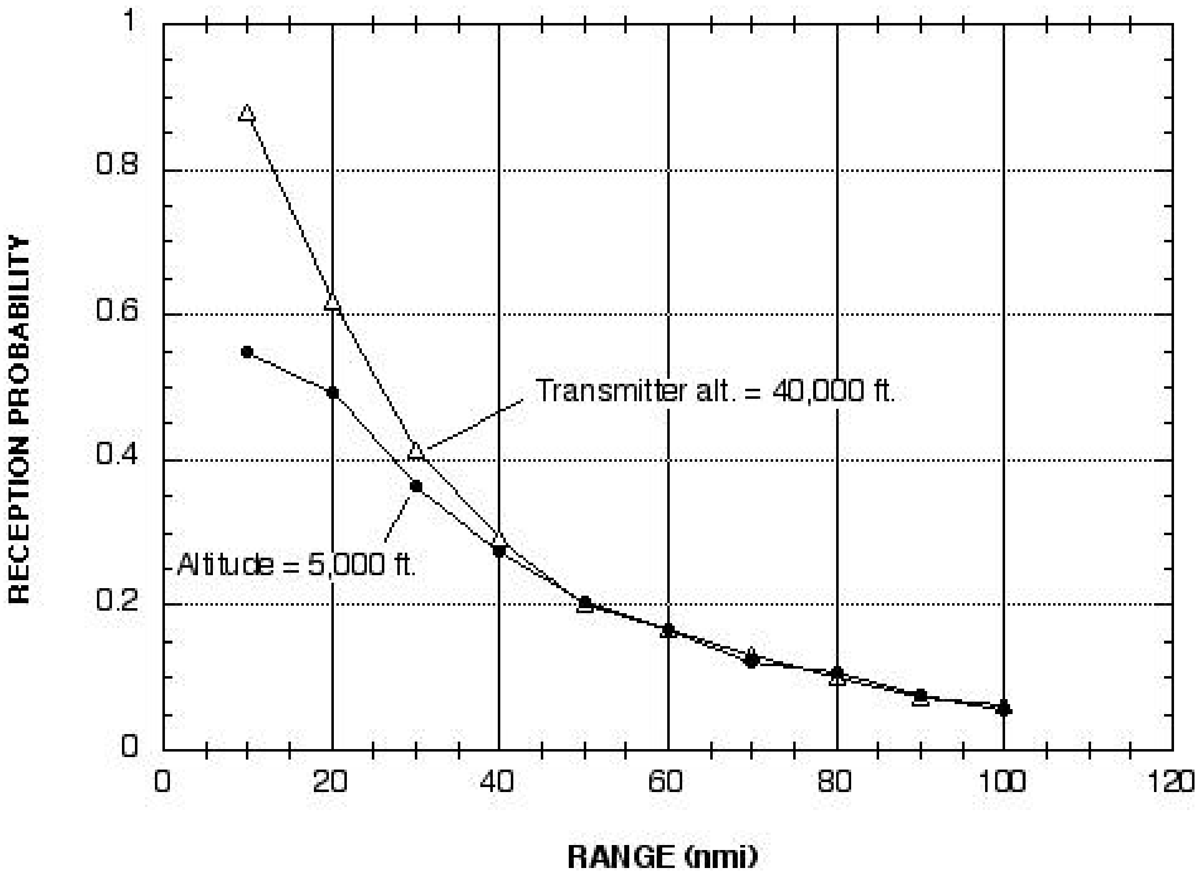


Figure 6. Effects of Transmitting Aircraft Altitude.

In conclusion, the results from the initial runs, in which altitude differences were not used, appear to be accurate at long ranges, regardless of the actual altitudes of the transmitting aircraft. The results indicate that air-to-air performance for Class A3 aircraft will support the MASPS standards for surveillance update rate out to a range of about 100 NM in the LA2020 interference environment. In the LA2020-Plus environment, air-to-air range is degraded to about 85 NM.

REFERENCES

1. "Measurement of 1090 MHz Extended Squitter Performance In the Los Angeles Basin," DOT/FAA/ND-00/7, May 2000.

2. A. G. Cameron, et al, "The 1030/1090 MHz Interference Simulation Technical Description and Initial Results," TR-9454-02-01, TASC Inc., April 2001.

3. "1090 MHz Extended Squitter Assessment Report," prepared by the FAA and EUROCONTROL, June 2002, Appendix B.