Appendix P

1090 MHz System Performance Simulation Results

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P 1090 MHz System Performance Simulation Results

P.1 Introduction

The air-to-air performance of 1090 MHz Extended Squitter (1090 ES) has been evaluated, as described in this Appendix. Two detailed evaluations were carried out using different techniques, although the air traffic scenarios evaluated were the same. The results from the two evaluations are relatively close and tend to support each other.

One evaluation was carried out by the Johns Hopkins University Applied Physics Laboratory (APL), and is described in Section P.2. The other evaluation was performed by MIT Lincoln Laboratory (LL), and is described in Section P.3. In both cases, the evaluations were applied to the ~~LA2020~~ Los Angeles Basin High Density (LA) scenario and the Low Density scenario defined in the ADS-B MASPS (RTCA DO-242A). For the LA~~2020~~ scenario, two cases were considered. In order to represent two potential worst-case interference environments, a nominal case with Mode A/C fruit rate of 24,000 per second, herein referenced as "LA~~2020~~-[24k]," and a more severe case of 30,000 Mode A/C fruit per second, herein referenced as "LA~~2020~~-[30k]." These scenarios are intended to represent the worst-case location for ADS-B reception within the LA Basin.

In other respects, very similar or identical models were used in the two evaluations.

- Aircraft Antenna Gain. The Technical Link Assessment Team (TLAT) model for aircraft antenna gain was used in both evaluations. This model, which is documented in Reference P-1, includes a function giving antenna gain vs. elevation angle, and also includes a statistical component, which has a defined distribution. The statistical distribution has a bell-shaped curve, skewed slightly toward negative values.
- Transmitter Power. The following statistical models were used in both evaluations. For class A0, power referred to the antenna is uniformly distributed between 48.5 and 51.5 dBm. For class A1 and class A2, power referred to the antenna input is uniformly distributed between 51 and 54 dBm. For class A3, power referred to the antenna is uniformly distributed between 53 and 56 dBm.
- Receiver MTL. Receiver MTL was treated as a constant in both evaluations, and was set to the worst-case value permitted by these MOPS.
- Fruit rates. Steps were taken to match the fruit rate models in the two evaluations. This was done by beginning with the APL model, running the part of the evaluation whose output is fruit rate and power distribution, shown separately for Mode A/C fruit and Mode S fruit. These curves were then used as inputs to the LL evaluation. The LL evaluation was performed under fruit conditions matched to the APL fruit rate results.

Analytical models and detailed simulations of data links operating in future scenarios are necessary to assess expected capabilities in stressed circumstances. Accurately modeling future capabilities for potential system designs in a fair way, however, is challenging. Since validation of simulation results in future environments is unrealistic, other means of verification such as the following are required. System characteristics represented in these simulations should agree with actual measurements on components of the proposed design, e.g., bench measurements on prototype equipment and calibrated flight test data

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should be used, when possible, for the receiver/decoder capabilities and as comparison with modeled link budgets. Similarly, suitable interference models help to support estimates of how these conditions may change in future scenarios. Credibility of any simulation results for future scenarios also requires that they be able to model current conditions and provide results that appropriately agree with measurements made under these conditions. Existing tools have been used as crosschecks where possible for the final detailed simulations and models. The differences between the results of the two evaluations are not surprising, given the above considerations and the different simulation approaches.

P.2 Performance Evaluation by APL

This section presents the evaluation of 1090 ES performance by APL, using the simulation models and techniques discussed below.

P.2.1 1090 Extended Squitter Detailed Simulation Features and Methodology

The APL 1090 ES detailed simulation is written in C and allows for horizontal, constant-velocity motion of the aircraft in the scenario. The simulation reads in the inputs specifying the particular case to be run (including a co-channel interference environment file produced by the Volpe/TASC simulator cited as Reference P-2), generates all of the ADS-B transmissions and additional interference for 300 seconds, calculates signal levels and times of arrival for each of these transmissions, and determines the corresponding message error rates for each ADS-B transmission at the individual times of arrival by all aircraft within line of sight of the victim receiver. This information is then written to an output file, one entry line for each ADS-B transmission, which is then analyzed by post-simulation software. A number of the real-world effects included in the simulation are discussed in Section P.2.1.1. Section P.2.1.2 will describe the post-simulation processing of the data.

P.2.1.1 1090 ES Detailed Simulation Features

This section describes some of the features of the 1090 ES detailed simulation:

- Propagation and other losses. The 1090 ES simulation calculates the free-space propagation loss for each transmission, using the range between transmitter and receiver at the time of transmission. There is also a receiver cable loss of 3 dB incorporated in the calculation. An optional transmit cable loss is also included in the simulation, but since the transmit powers have been defined at the antenna, the transmit cable loss has been set to zero for this study.
- Antenna gains. The antenna gain model used here was that specified in the TLAT Report [Reference P-1].
- Propagation delays. The propagation delay incurred by the signal in traversing the free space between transmitter and receiver has been included in the 1090 ES simulation.
- Co-channel interference. The 1090 ES transmissions co-exist with transmissions from other sources at the same frequency, such as Mode A/C, Mode S, and TCAS replies. These transmissions are responses to interrogations originating from ground interrogators and, in the case of TCAS, other aircraft. The ground interrogator environment is described in the TLAT report [Reference P-1]. All A2 and A3

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aircraft are assumed to be equipped with TCAS, for a total of 40% of all aircraft in the LA2020 scenario. The cases evaluated had no loading of the channel due to Mode S air-ground data link. Several different estimates of the co-channel interference environment were examined for the high-density LA~~2020~~ scenario:

- 24,000 Mode A/C, 2,500 Mode S at levels greater than –84 dBm
- 30,000 Mode A/C, 3,600 Mode S at levels greater than –84 dBm

For the low density scenario, a rate of 5,000 Mode A/C was used.

- Co-site interference. Co-site transmissions of 1090 ES messages, DME interrogations, Mode S interrogations and replies, whisper-shout interrogations, and Mode A/C replies are all modeled as interference in the 1090 ES simulation. All of these are treated as "self-interference," and it is assumed that no 1090 ES reception may occur during any of these co-site transmissions (including a 15 microsecond "ramp-down" period added to the end of each co-site transmission). (See RTCA DO-282 for more detailed explanation of the co-site interference environment.)
- Multiple interference sources. The arrivals of 1090 ES messages at the victim receiver is a random process, due to the random nature of the transmissions and the propagation delays. There may be a number of messages and other interfering signals (e.g., Mode A/C) overlapping one another, and these overlaps will be for variable amounts of time. This interference is accounted for in the multi-aircraft simulation. Multiple interferers are treated in the receiver performance model by combining their interference levels in a way consistent with bench test measurements. The simultaneous presence of 1090 ES interference, co-channel interference, and self-interference is treated in a detailed fashion by the model.
- Alternating transmissions. The model simulates the alternating transmission sequence between top and bottom antennas as specified for A1, A2, and A3 equipage. For A0 equipage, the model simulates transmission from a top antenna.
- Receiver diversity. For A1, A2, and A3 equipage, the model simulates receiver diversity by calculating the message error rate at both the top and bottom receive antennas and calculating the joint reception probability. For A0-equipped aircraft, reception is only permitted from a top antenna.
- Transmit power variability. The transmit power specified at the antenna of an aircraft is chosen from a uniform distribution given by the limits specified by the authors of these MOPS for the aircraft equipage. For this analysis the ranges used were:

  - A3: 53-56 dBm
  - A2/A1: 51-54 dBm
  - A0: 48.5-51.5 dBm

  Note: *These ranges were selected as being representative of equipment expected to be produced and deployed. It should be noted, however, that these MOPS allow for larger ranges of transmit powers and include, for example, the possibility of an A3 transmit power as low as 51 dBm.*

- Receiver re-triggering. The 1090 ES simulation checks each individual ADS-B message arriving at the victim receiver for its message error rate. This procedure amounts to allowing for re-triggering in the receiver, i.e. the potential for the receiver

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to switch from receiving a message to a stronger message signal that arrives after the start of the reception of the first message.

- Receiver performance model. The receiver performance model used in the 1090 ES simulation is based on experimental data collected on 1090 receivers that were provided for that purpose. The measurement data for these receivers were modified by simulation results provided by MIT Lincoln Laboratories (LL) and the FAA William J. Hughes Technical Center (FAATC). These simulation results were designed to emulate the enhanced decoding techniques, which have been incorporated as performance requirements for 1090 ES equipment. The development of the receiver performance model is described in Section 2 of this Appendix. The assumed sensitivity of the receiver is different for the different equipage classes, -84 dBm for class A3 and -79 dBm for A2/A1 equipage. This represents the signal level at which 90% of the messages are received correctly in the absence of interference. This parameter was validated in the simulation by examination of the signal vs. message error rate in the absence of interference. However, because the MOPS requirement of 15% message success at –87 dBm for A3 equipage is a more severe constraint, the effective MTL required is around –85.5 dBm for A3 aircraft. This is the value that was used in this analysis. The A1 equipage class receiver does not require the enhanced decoding techniques, so a different receiver performance model was used to evaluate A1 performance.
- Message transmission frequency and content. Section 2.2.3 defines the types of messages, their content, and the frequency of messages transmitted for each category of aircraft equipage. This is modeled in detail by the 1090 ES simulation.

P.2.1.2 Calculation of the Performance Metrics

The result of the 1090 ES detailed simulation is a file containing time-ordered information about each ADS-B squitter transmitted by every aircraft within line-of-sight of the victim receiver during the 300-second duration of the simulation. The main elements of information for each individual squitter include squitter type (information content) and the probabilities of reception on each of the top and bottom receive antennas. Each squitter will have individual reception probabilities which depend not only on signal level at each receive antenna at that time, but also on the interference environment at each of the antennas during the arrival of the squitter.

For each transmitting aircraft in a range bin of width ten nautical miles, the time-ordered sequence of squitters is then examined, and, using Monte Carlo techniques and the reception probabilities at each of the antennas, it is determined which of that transmit aircraft's squitters are successfully decoded by the receiver during the 300-second interval. From these successes, the State Vector update times are determined by computing the time difference between arrivals of successive squitters containing either position or velocity information. These update times are then ordered, and the 95th percentile value is then chosen. This value represents the 95th percentile update time for that particular transmitting aircraft. This procedure is then followed for each transmitting aircraft, resulting in a 95th percentile update time for each aircraft.

All of the 95th percentile update times for all of the aircraft in each range bin are then ordered, and the 95th percentile of these update times is selected for the 95-95 State Vector update time. Thus, 95% of the aircraft in each range bin will have a 95% State Vector update time that is better than the 95-95 value for that bin.

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The same procedure is then followed for the messages supporting Target State (TS) Reports, to determine the 95-95 update time for that type of message. The results of this analysis are presented in Sections P.2.3.2 and P.2.4.2 below, and results and conclusions are presented in Section P.2.5.

P.2.2 Receiver Performance Model

P.2.2.1 Background

In order to develop a receiver performance model for 1090 Extended Squitter (ES) to be used for the Technical Link Assessment Team (TLAT) ADS-B data link evaluation, bench test measurements of the Message Error Rate (MER) receive performance were made on an available 1090 ES receiver, which included a number of features of enhanced decoding. Development of this receiver performance model is described in the TLAT Report Appendix I. Subsequent to publication of the TLAT Report in April, 2001, the results of these measurements, compared with flight test measurements, led to the judgment that this receiver implemented a multi-sample technique that was not as effective at decoding 1090 ES messages as the multi-sampling technique incorporated in these MOPS. Thus, although some features of enhanced decoding were implemented in the tested receiver, it was felt that better performance could be achieved through modification of the decoding processing. For A2 and A3 category aircraft, these MOPS require performance equivalent to that achieved by the multi-sample techniques. Therefore, the receiver performance model was adapted to reflect those requirements.

P.2.2.2 Modifications to the Receiver Performance Model

The FAATC and LL developed and implemented simulations to predict 1090 ES receiver performance using enhanced decoding techniques, including multi-sampling. Several cases of Mode A/C interference were investigated, which led to detailed results for these cases being available for comparison with the predictions of the receiver performance model. The model was adjusted to account for these cases, resulting in a “modified receiver performance model.”

This modified receiver performance model was discovered to produce optimistic predictions in high-density environments, when compared with the overall results of the FAATC and LL predictions in these environments. It is not surprising that the results, which were based on a very small sample of the interference space, should differ from what is produced when extrapolated to and averaged over the entire high-density interference space. It was decided that it is more important to reflect the overall effects of the entire interference environment than to exactly replicate the few individual cases upon which the revised model was based.

The methodology adopted for this second modification of the receiver performance model was to “map” the model results to be consistent with the simulation results of the FAATC or LL, as appropriate. FAATC results were achieved by feeding video signals into a 1090 ES receiver front end and performing non-real-time software processing to determine message reception in a simulated high-density Mode A/C environment. The results were presented as the total message success probability as a function of the received desired signal level for the total Mode A/C interference environment. Individual cases were not identified, so a message success probability for a given signal level

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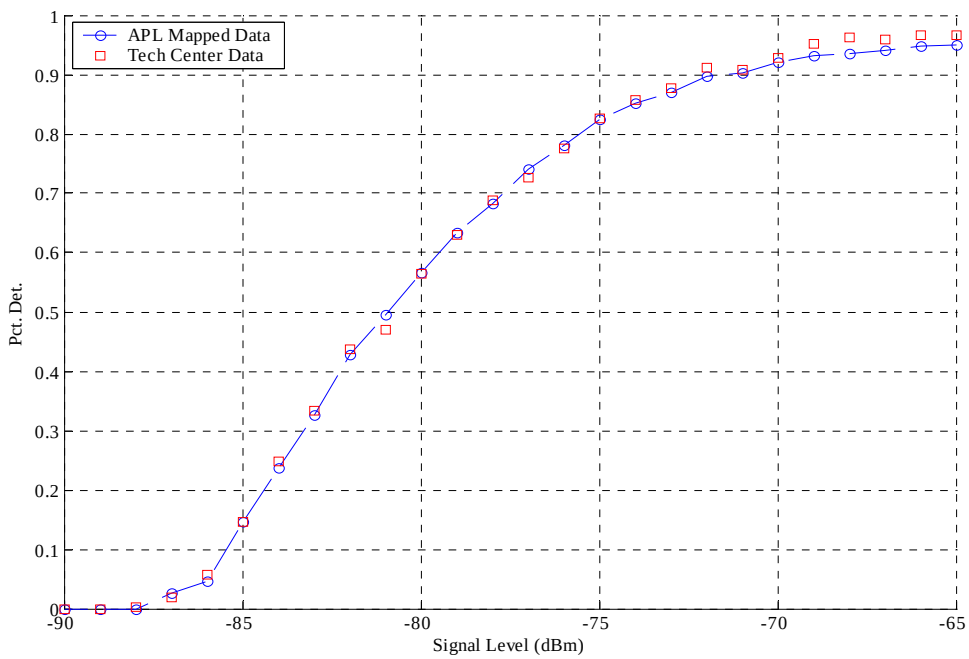
represents the averaging done over many different individual interference situations which characterize the entire interference environment.

For the A2 receiver, LL results were achieved by software simulation of signals and high-density interference (including phase and frequency fluctuations) and performing pulse-by-pulse non-real-time analysis to determine message reception. Again, as for the A3 results from the FAATC, the A2 results from LL (see Figure P-19) were presented as the total message success probability as a function of the received desired signal level for the total interference environment.

When compared to the results from the FAATC and LL simulations, which sampled the entire interference environment, the receiver performance model was found to be overly optimistic in its predictions of performance. In order to compensate for this bias, the receiver performance model was "mapped" separately to conform to the results of each of the two simulations, as illustrated for an A3 receiver in a 30,000 Mode A/C fruit environment shown in Figure P-1 below. This mapping was done separately to adjust the receiver performance model to the various interference levels and receiver sensitivities.



<u>Figure P-1:</u> Comparison of "Mapped" APL Receiver Performance Model Prediction with FAATC Simulation Results

Each of the various mappings (corresponding to scenario, fruit level, and multi-sampling type) was used for the appropriate receiver case. For example, to evaluate Class A3 performance in the 24,000 Mode A/C LA~~2020~~ scenario, the receiver performance model was mapped to match the FAATC results for the 10 MHz sampling rate enhanced decoder for this fruit rate.

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P.2.3 Los Angeles Basin ~~2020~~ High Density (LA~~2020~~)

P.2.3.1 LA~~2020~~ Scenario Description

This scenario is based on the LA Basin 1999 maximum estimate. It is assumed that air traffic in this area would increase by a few percent each year until ~~2020, when~~ it would be 50 % higher than in 1999. The distribution of aircraft in the scenario is based on approximations of measured altitude and range density distributions.

The following assumptions are made for the airborne and ground aircraft, and ground vehicles for the LA Basin ~~2020~~ scenario:

- The density of airborne aircraft is taken to be:
  - Constant in range from the center of the area out to 225 nautical miles (5.25 aircraft/NM), (i.e., the inner circle of radius one NM would contain approximately five aircraft, as would the ring from 224 to 225 NM) and
  - Constant in area from 225 NM to 400 NM (.00375 aircraft/NM^2).
- There are assumed to be a fixed number of aircraft on the ground (within a circle of radius 5 NM at each airport), divided among LAX, San Diego, Long Beach, and five other small airports, totaling 225 aircraft. Half of the aircraft at each airport were assumed to be moving at 15 knots, while the other half were stationary. In addition, a total of 50 ground vehicles are distributed at these airports as well.
- The altitude distribution of the airborne aircraft is assumed to be exponential, with a mean altitude of 5500 feet. This distribution is assumed to apply over the entire area.
- The airborne aircraft are assumed to have the following average velocities, determined by their altitude. The aircraft velocities for aircraft below 25000 feet are uniformly distributed over a band of average velocity +/- 30 percent.
  - 0-3,000 feet altitude 130 knots
  - 3,000-10,000 ft 200 knots
  - 10,000-25,000 ft 300 knots
  - 25,000-up 450 knots
- The aircraft are all assumed to be moving in random directions.
- In the LA~~2020~~ scenario, ADS-B equipage Class A0 aircraft are assumed to fly below 18,000 feet. All other aircraft are assumed to be capable of flying at any altitude. The aircraft in the LA~~2020~~ scenario are assumed to be in the following proportions:
  - A3 30%
  - A2 10%
  - A1 40%
  - A0 20%

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The scenario for the LA~~2020~~ high density ~~LA Basin~~ case contains a total of 2694 aircraft: 1180 within the core area of 225 NM, 1289 between 225-400 NM, and 225 on the ground. This represents a scaling of the estimated maximum 1999 LA Basin levels upward by 50 percent. Of these aircraft, 471 lie within 60 NM of the center. (This includes aircraft on the ground.) Around ten percent of the total number of aircraft are above 10,000 ft in altitude, and more than half of the aircraft are located in the outer (non-core) area of the scenario.

An attempt was made to at least partially account for the expected lower aircraft density over the ocean. In the third quadrant (between 180 degrees and 270 degrees), for distances greater than 100 NM from the center of the scenario, the density of aircraft is reduced to 25 % of the nominal value used. The other 75% of aircraft that would have been placed in this area are distributed uniformly among the other three quadrants at the same range from the center. This results in relative densities of 1:5 between the third quadrant and the others.

P.2.3.2 LA~~2020~~ Results and Analysis

The ADS-B MASPS requirements for ADS-B air-to-air surveillance range and report update interval are used to assess how each ADS-B link performs in relation to the free flight operational enhancements identified by the RTCA Safe Flight 21 Steering Committee. These requirements specify the minimum range for acquisition of the State Vector, Mode Status and Target State Reports where applicable, as well as the maximum update periods allowed for this information (See ADS-B MASPS, RTCA DO-242A). These air/air criteria specify ranges, use of short-term intent information (TS Reports), and update times. The projected Trajectory Change (TC) long-term intent reporting capabilities of 1090 ES are described in Appendix O of these MOPS.

Results are presented as a series of plots of 95% update times as a function of range for State Vector updates and intent updates, where applicable. The 95% time means that at the range specified, 95% of aircraft pairs will achieve a 95% update rate at least equal to that shown. The 95-95 metric was calculated by placing the aircraft in range bins of ten (10) NM width and plotted in the form of histograms. The ADS-B MASPS requirements are also included on the plots for reference. Since the transmit power and receiver configuration are defined for each aircraft equipage class, performance is shown separately for each combination of transmit-receive pair types for A2 and A3 class equipment. Results are shown in Figure P-2 through Figure P-13 and conclusions are presented below. Note that, due to unavailability of receiver performance results for A2 in the 30,000/second Mode A/C environment, results for A2 are presented only for the 24,000/second case. The ADS-B MASPS requirements for State Vector, and projected requirements for TS Report updates are also shown on the plots. Performance in compliance with MASPS requirements is indicated by results that are below the MASPS line.

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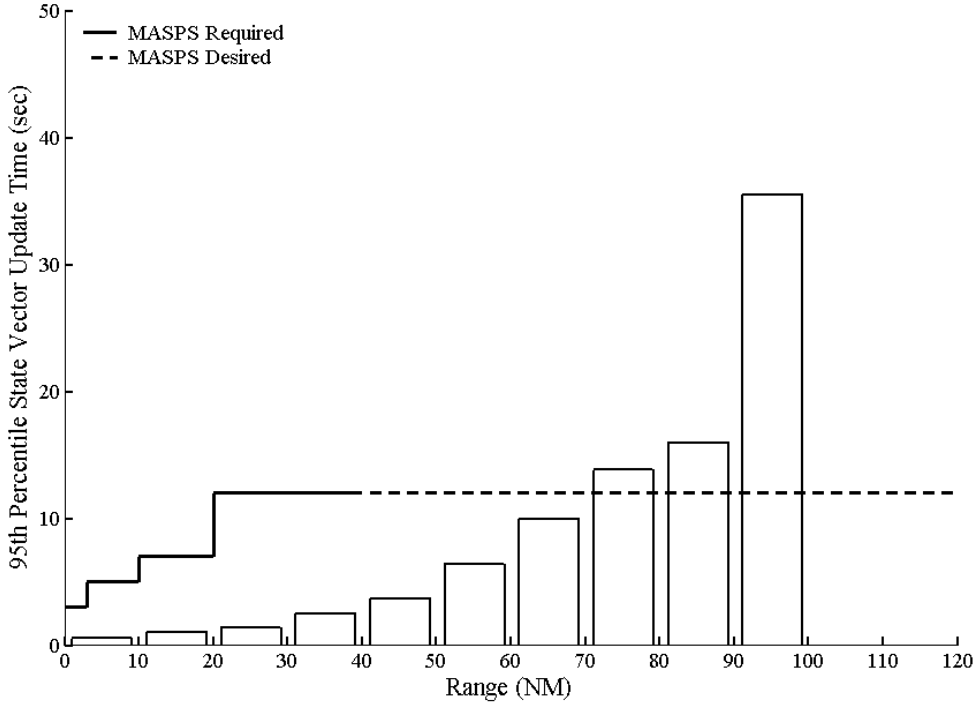

Figure P-2: **95-95 State Vector Update Rate for A3-to-A3 Air-to-Air Reception in LA~~2020~~-[24k]**

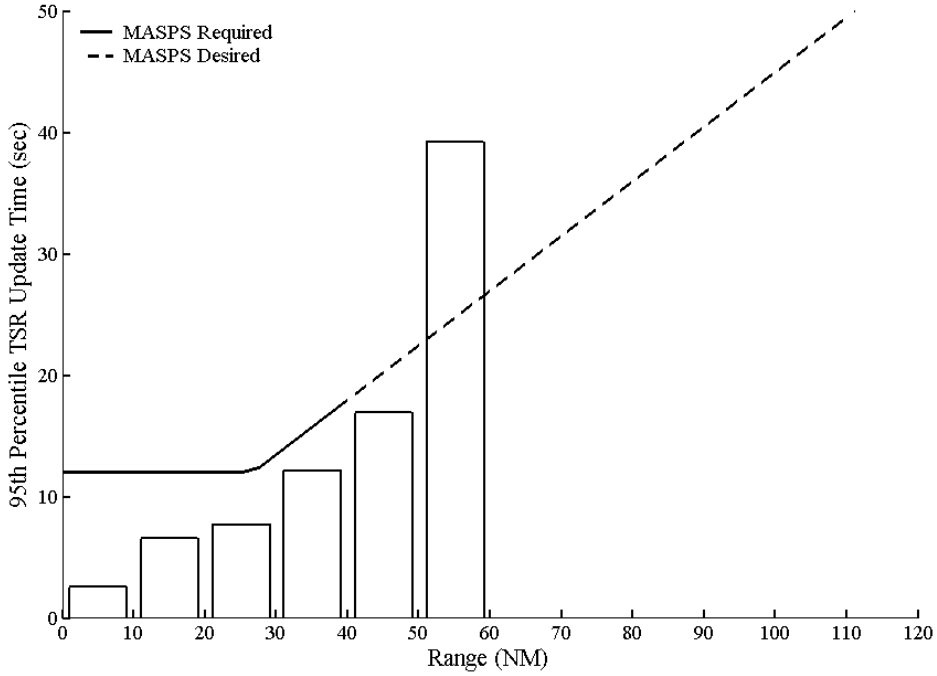

Figure P-3: **95-95 TSR Update Rate for A3-to-A3 Air-to-Air Reception in LA~~2020~~-[24k]**

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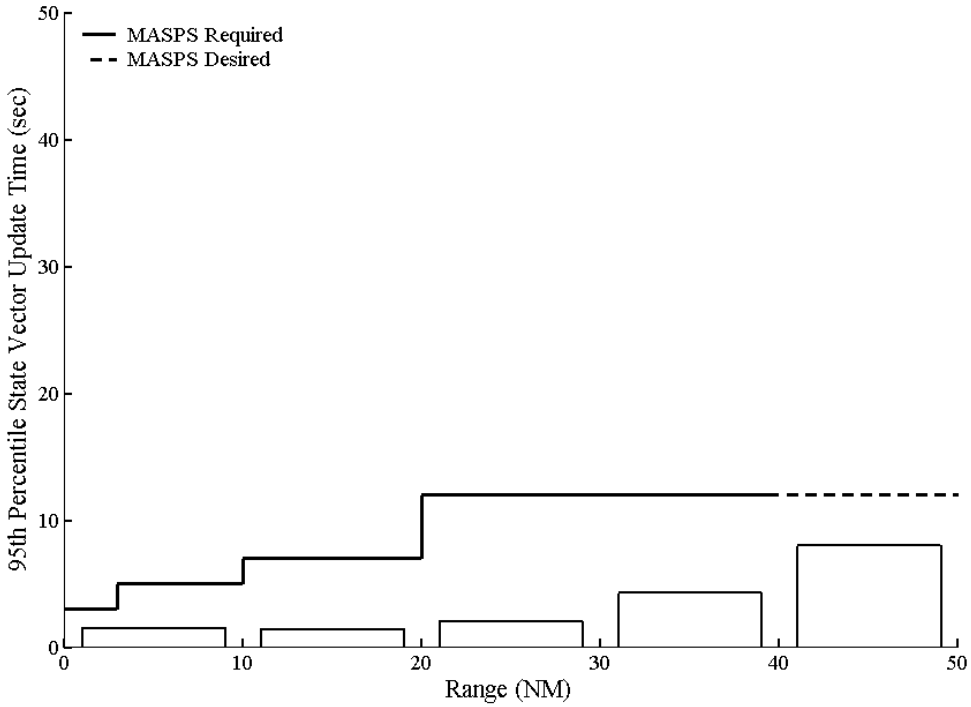

Figure P-4: **95-95 State Vector Update Rate for A2-to-A3 Air-to-Air Reception in LA~~2020~~-[24k]**

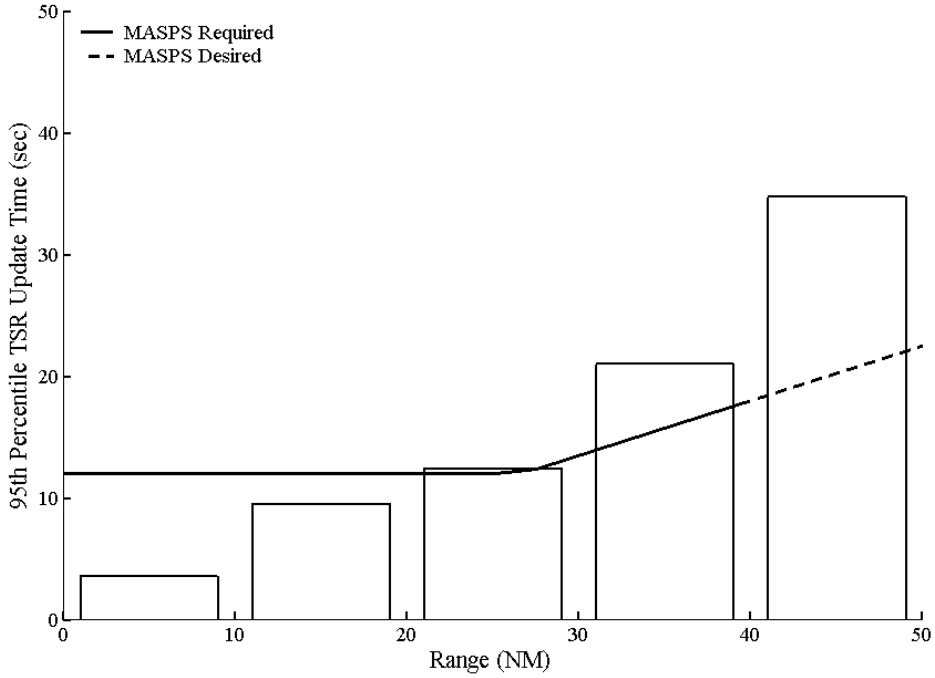

Figure P-5: **95-95 TSR Rate for A2-to-A3 Air-to-Air Reception in LA~~2020~~-[24k]**

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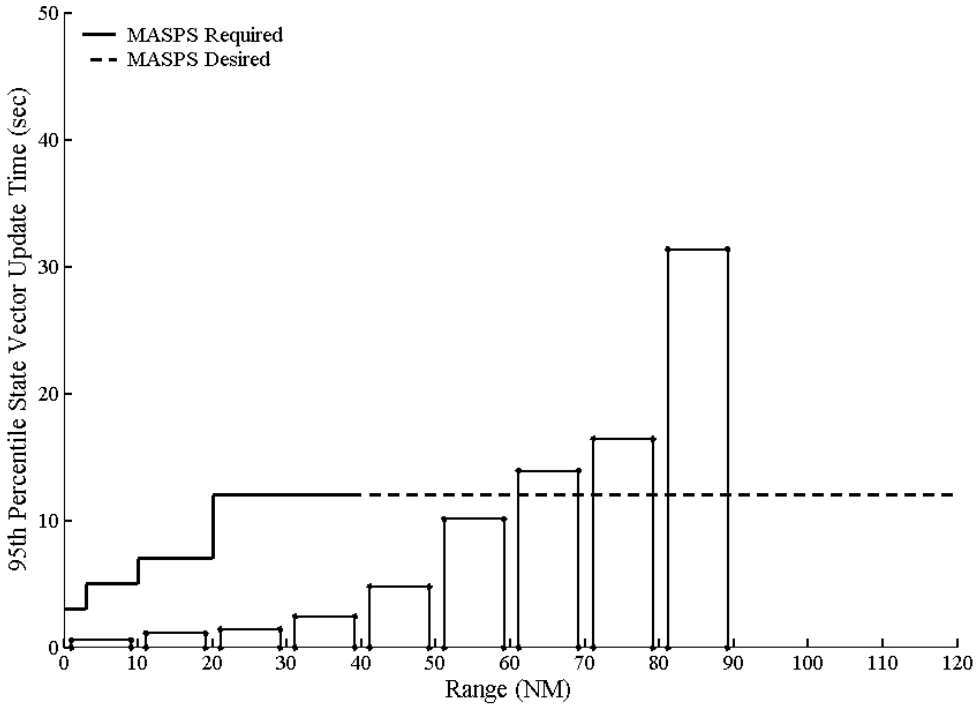

Figure P-6: **95-95 State Vector Update Rate for A3-to-A3 Air-to-Air Reception in LA~~2020~~-[30k]**

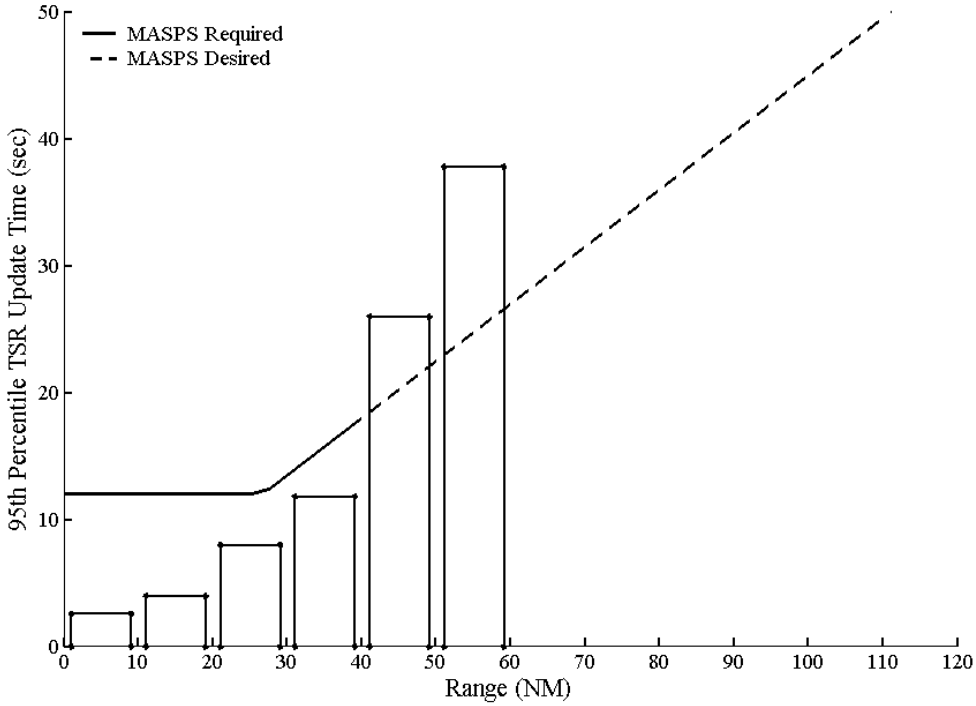

Figure P-7: **95-95 TSR Update Rate for A3-to-A3 Air-to-Air Reception in LA~~2020~~-[30k]**

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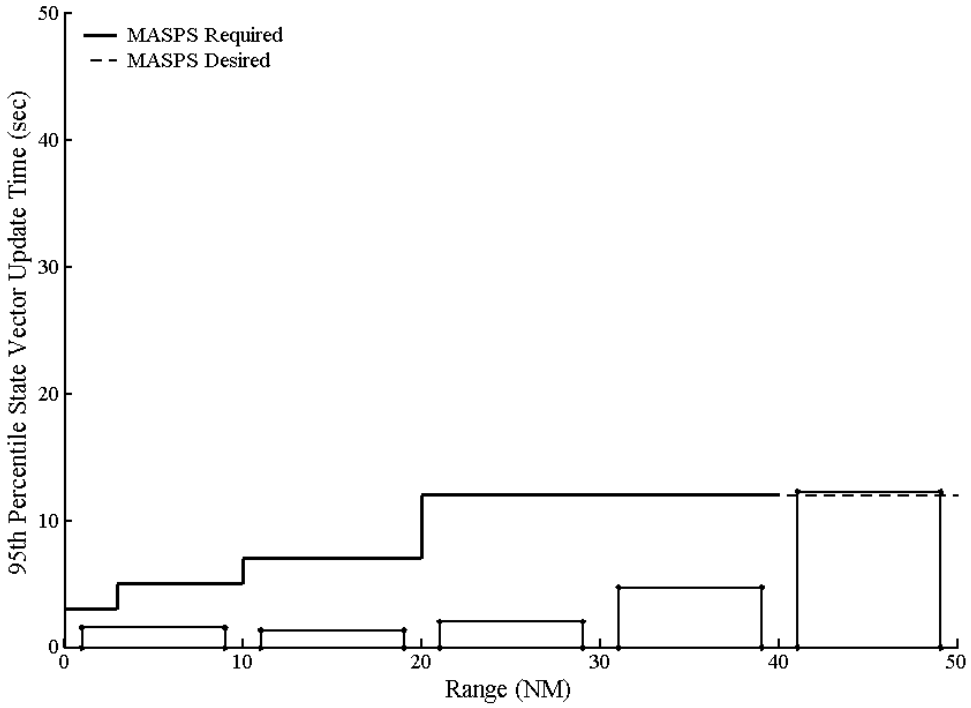

Figure P-8: **95-95 State Vector Update Rate for A2-to-A3 Air-to-Air Reception in LA~~2020~~-[30k]**

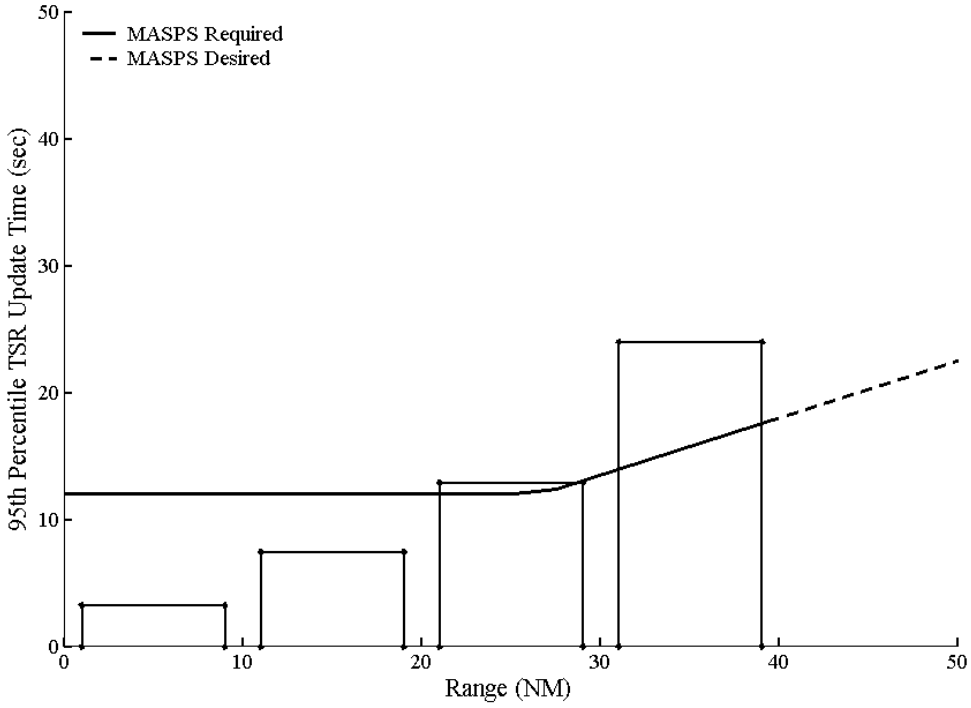

Figure P-9: **95-95 TSR Update Rate for A2-to-A3 Air-to-Air Reception in LA~~2020~~-[30k]**

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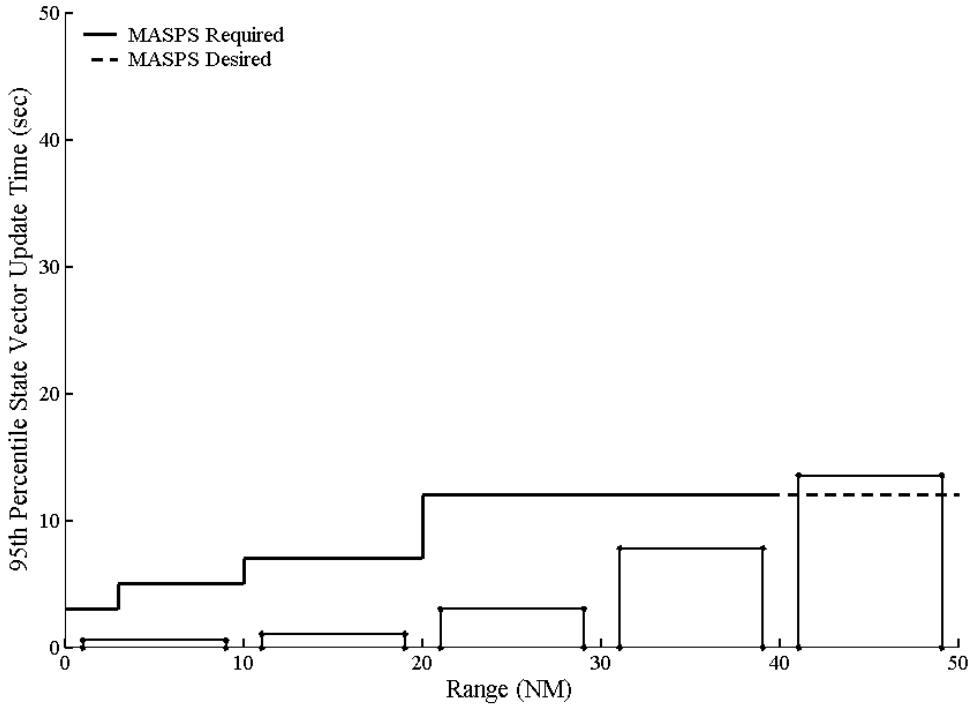

Figure P-10: **95-95 State Vector Update Rate for A3-to-A2 Air-to-Air Reception in LA~~2020~~-[24k]**

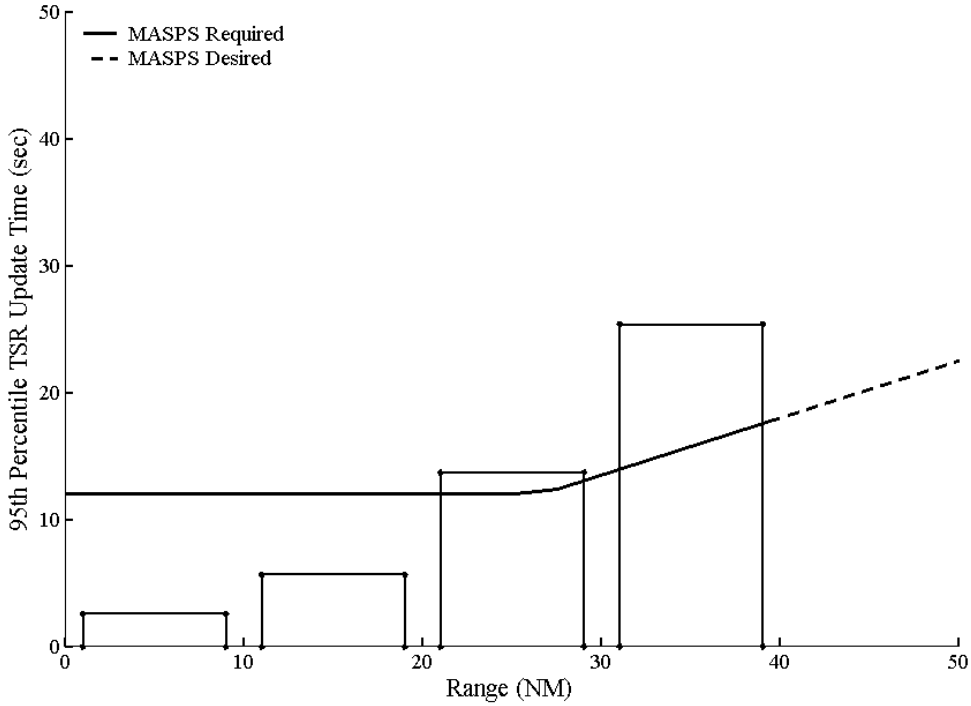

Figure P-11: **95-95 TSR Rate for A3-to-A2 Air-to-Air Reception in LA~~2020~~-[24k]**

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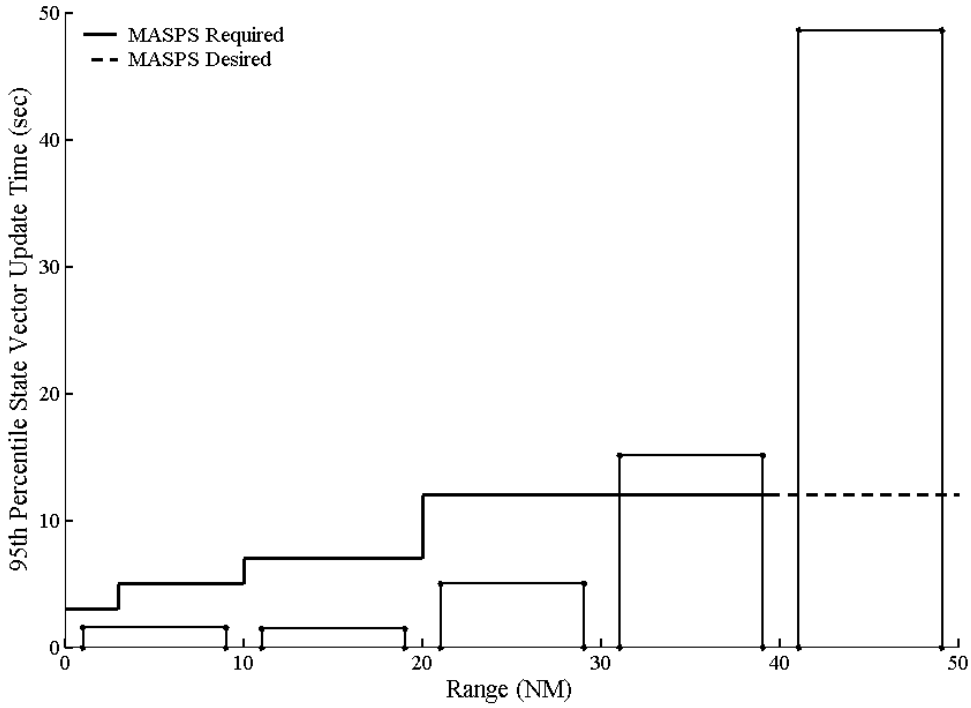

Figure P-12: **95-95 State Vector Update Rate for A2-to-A2 Air-to-Air Reception in LA~~2020~~-[24k]**

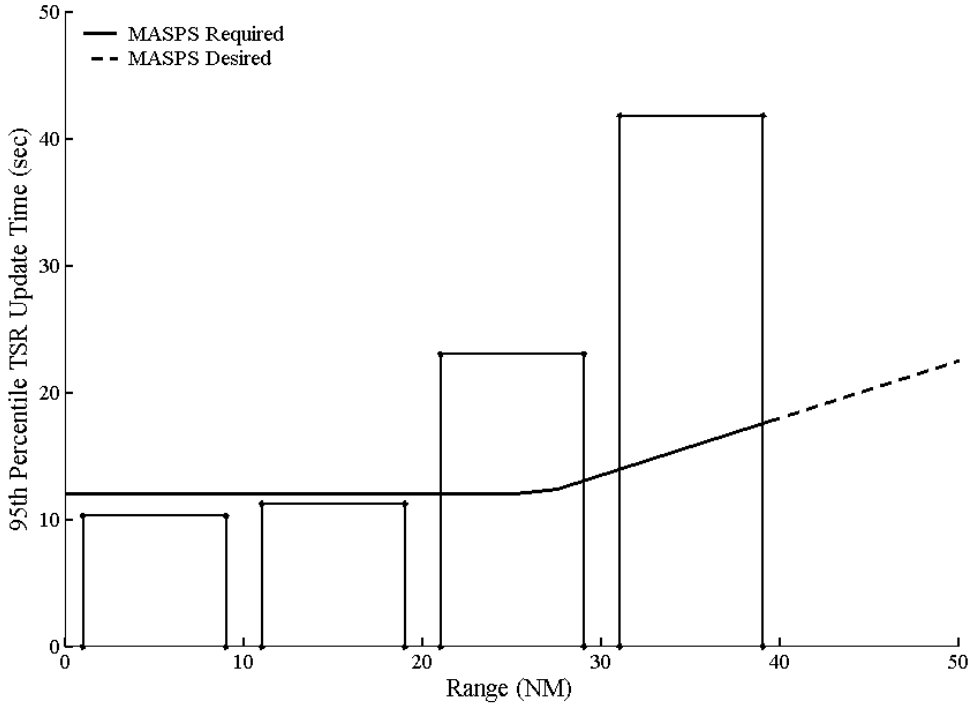

Figure P-13: **95-95 TSR Update Rate for A2-to-A2 Air-to-Air Reception in LA~~2020~~-[24k]**

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The results for LA~~2020~~ shown in Figure P-2 through Figure P-13 are summarized in Table P-1. The values in the table are determined from the histograms by looking at the bars in the ten-mile bins and using the upper range for the last bin that is under the requirement line. For example, in Figure P-13 above, the ten-mile bar from 10-20 NM is the last bin under the requirement line, so the range for the 95-95 metric for A2-to-A2 TSR updates is 20 NM.

Table P-1: APL Air-to-Air 1090 ES Performance Relative to ADS-B MASPS

Transmitter	Receiver	Mode A/C	Range to Which MASPS Performance is Met	
			State Vector	Target State
A3	**A3**	24,000	70 NM	50 NM
A2	**A3**	24,000	50 NM	20 NM
A3	**A3**	30,000	60 NM	40 NM
A2	**A3**	30,000	40 NM	20 NM
A3	**A2**	24,000	40 NM	20 NM
A2	**A2**	24,000	30 NM	20 NM

Note: *For the LA~~2020~~ scenario, two cases were considered, in order to represent two potential worst-case interference environments, a nominal case with Mode A/C fruit rate of 24,000 per second, herein referenced as "LA~~2020~~-[24k]," and a more severe case of 30,000 Mode A/C fruit per second, herein referenced as "LA~~2020~~-[30k]."*

P.2.4 Low Density Scenario

P.2.4.1 Low Density Scenario Description

In addition to the high-density LA~~2020~~ scenario described above, a scenario was also run to represent low-density traffic levels. This scenario, for simplicity, was developed by scaling the current LA Basin distributions downward by a factor of five, amounting to 360 total aircraft. These aircraft are uniformly distributed in the horizontal plane within a circle of 400 nautical miles. In the vertical direction, they are distributed uniformly between 25,000 feet and 37,000 feet. The velocities are all set to 450 knots and are randomly distributed in azimuth. All of the aircraft are assumed to be A3 equipped.

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P.2.4.2 Low Density Results and Analysis

Results of the simulation runs for the low-density scenario are shown in Figure P-14 and Figure P-15, and conclusions are presented below. The ADS-B MASPS requirements for State Vector and TSR updates are shown as black lines on the plots. The ADS-B MASPS specify that the maximum ranges for air-air update rates required for A3 to 90 NM (120 NM desired), while the Eurocontrol criteria extend to 150 NM for A3. Performance in compliance with MASPS requirements is indicated by results that are below the black line.

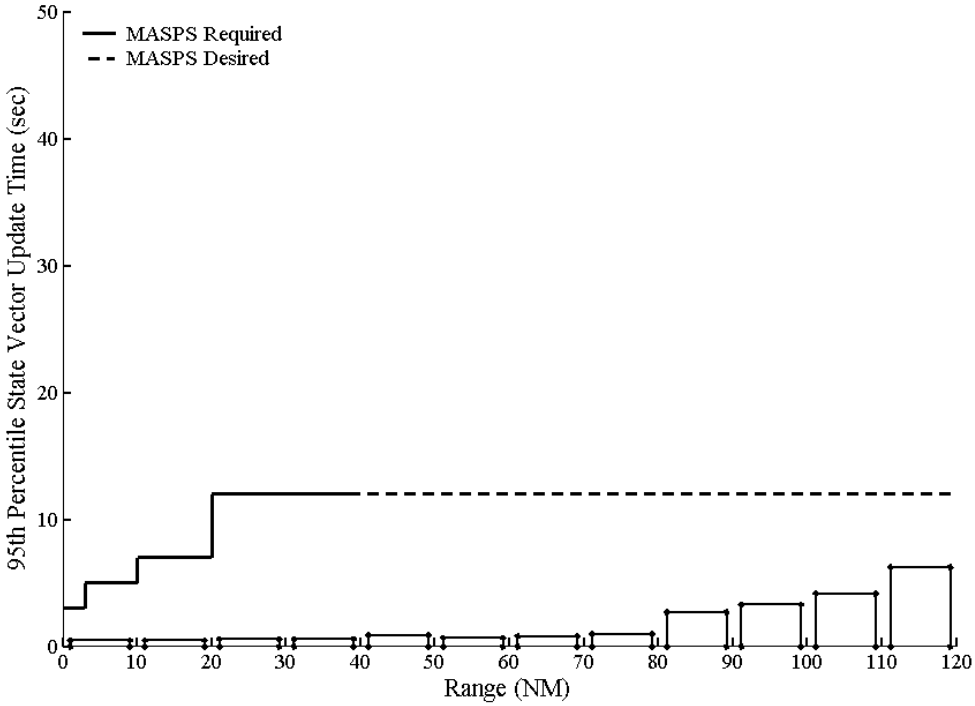

Figure P-14: 95-95 State Vector Update Rate for A3-to-A3 Air-to-Air Reception in 5,000 Mode A/C per Second in the Low Density Scenario

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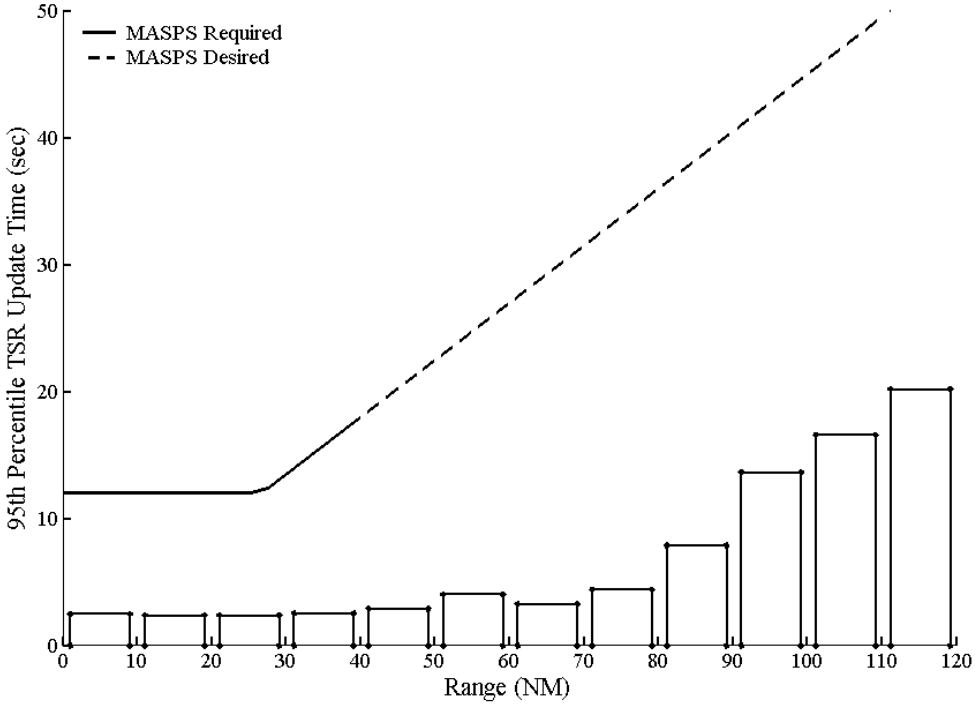

Figure P-15: 95-95 TSR Update Rate for A3-to-A3 Air-to-Air Reception in 5,000 Mode A/C per Second in the Low Density Scenario

The results for the low-density scenario may be summarized as follows:

- ADS-B MASPS air-air requirements and desired criteria are met for State Vector and TS Report updates at all ranges specified by the ADS-B MASPS for the low density scenario.

P.2.5 Results and Conclusions

This section summarizes the results of the APL simulation studies and states conclusions that may be drawn about expected 1090 ES performance in the scenarios considered. This summary will be presented in Section P.2.5.2. Section P.2.5.1 will first point out a number of considerations that should be taken into account when interpreting the results.

P.2.5.1 Considerations

The following considerations should be noted when interpreting the results of this analysis:

- The transmit power distribution for A3 transmitters, which was used for this analysis, was uniform from 53-56 dBm. These MOPS allow for A3 transmitters to extend as low as 51 dBm. This corresponds more closely to the transmit power distribution assumed for A2 class aircraft in this analysis; therefore, for a class A3 aircraft with a transmit power near the lower limit of the allowed range, it would be expected that performance would be given by A2 transmit results, rather than A3.

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- The receiver performance model that was used for this analysis was based on non-real-time simulation results provided by the FAATC and MIT Lincoln Laboratory. Several manufacturer representatives have indicated that they felt that performance equivalent to that required by these MOPS was achievable. Still, there has been no testing of performance on MOPS-compliant equipment, and until this is done the receiver performance model has not been validated and remains hypothetical. In addition, the receiver performance model thus derived was designed to match the average performance predicted by the simulation results discussed above. This was necessary due to time and resources constraints and may add some additional uncertainty to the results.

- The results of this study should not be directly compared with any analysis not described in this Appendix, without taking into account differences in assumptions and analysis techniques. For example, the 1090 ES analysis in the TLAT report [Reference P-1] assumed different transmit power distributions, receiver decode performance, and Mode A/C interference levels, so it is not surprising that the results of that study differ from those reported here.

- Finally, in evaluating expected performance through the use of simulations, it is important to be aware of the inherent uncertainties in results due to the indeterminate nature of the assumptions, as well as the uncertainties in the modeling process itself. This is true for performance predictions resulting from any type of simulation technique. For example, in this analysis it was assumed that the number of aircraft in the LA Basin would increase by 50%~~ by the year 2020~~, that most aircraft would be Mode S equipped, that a number of TCAS improvements would be universally deployed, and that the A3 transmit power would be as described above. These assumptions all include associated uncertainty; modifying any of the assumptions could result in a change in predicted performance.

P.2.5.2 Summary

Keeping in mind the conditions described in the previous section, the performance of 1090 Extended Squitter in the two scenarios examined may be summarized as follows:

- In the LA~~2020~~ high density air traffic scenario, this analysis concludes that A3 aircraft should be capable of participating with other A3 aircraft in the applications defined in RTCA DO-242A which require State Vector and TS Report for ranges up to and including 40 NM. For applications that require State Vector only, the range is extended to 60-70 NM, depending on the interference environment.

- In the low density air traffic scenario, this analysis concludes that A3 aircraft should be capable of participating with other A3 aircraft in the applications defined in RTCA DO-242A which require State Vector and TS Report for all required and desired ranges.

- In the LA~~2020~~ [24k] (24,000 Mode A/C) high density air traffic scenario, this analysis concludes that A3 aircraft should be capable of participating with A2 aircraft in the applications defined in RTCA DO-242A which require State Vector only for ranges up to and including 40 NM. The exchange of TS Report information is limited to 20 NM between A2 and A3 equipage aircraft.

- In the LA [24k]~~2020~~ (24,000 Mode A/C) high density air traffic scenario, this analysis concludes that A2 aircraft should be capable of participating with A2 aircraft in the applications defined in RTCA DO-242A which require State Vector only for

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ranges up to and including 30 NM. The exchange of TS Report information is limited to 20 NM between A2 equipage aircraft.

- Neither A1 nor A0 equipage was evaluated for this analysis.

This analysis has not evaluated the effect of transmitting more detailed intent information, such as TCRs. Future revisions of these MOPS should consider modifying the transmit power requirement for A3 equipage, so that the minimum power corresponds to that assumed in this analysis. In addition, improved A2 performance could be achieved by modifying either or both of the MTL requirement and the enhanced decoding techniques used.

P.3 Performance Evaluation by MIT Lincoln Laboratory

MIT Lincoln Laboratory employed two simulation tools to determine ADS-B reception performance as a function of range for the LA~~2020~~ (as defined in §P.2.3.1) and low density scenarios. 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 per-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).

P.3.1 Pulse Level Simulation

The pulse-level simulation generates a sample-by-sample 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 in two cases and the low density environment in the other. The interference rates and power distributions are described below.

P.3.1.1 Formulation of the Pulse-Level Simulation

This simulation was originally created for developing 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 pulse width deviations were also incorporated in this study. All pulses have rise times and fall times that correspond to the effects of both transmitter and receiver. 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.

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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 P-16. The simulation can be run at a sampling rate of 8 samples per microsecond or 10 samples per microsecond. The rate of 8 per microseconds was used in this evaluation. The log video samples are then processed using the enhanced reception techniques. These techniques include an improved form of preamble detection, the 4-4 table method of declaring the 112 bits and associated confidence bits, and the error detection/correction technique called "Brute Force, n=5".

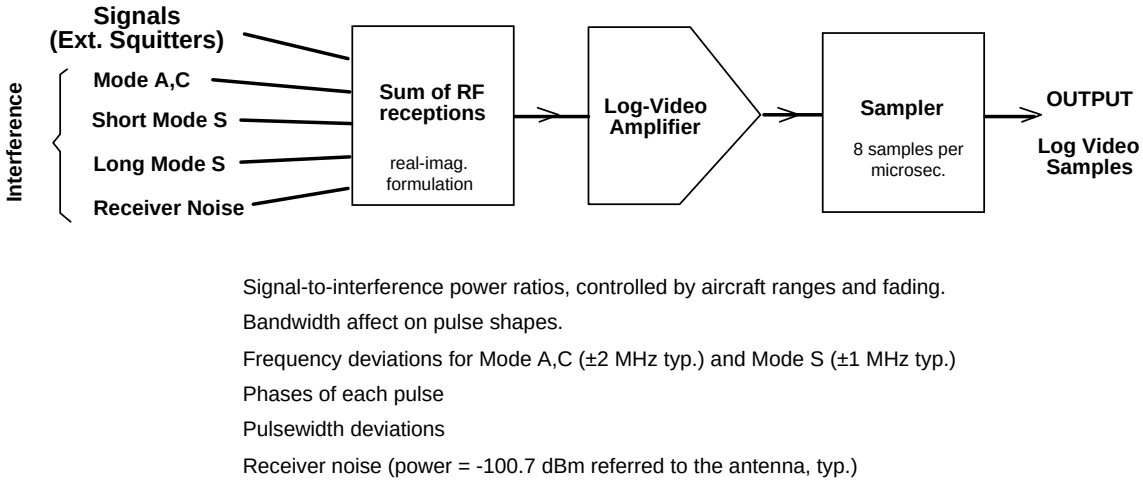

Figure P-16: Overview of the Pulse-Level Simulation

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 a transmission rate for each of the 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 transmissions are made random in time, uniformly distributed over the run time. The reception times are modeled as a Poisson process, having a constant average reception rate for each of the three types of signals.

These particular assignments of nominal power and power deviations are used only in the pulse-level simulation, and only for the purpose of generating a fruit distribution appropriate for the environment being studied.

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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. Five-dB bins were used in this study. After the full run, which includes several thousand reception opportunities in each of the major bins of interest, the number of correct receptions in compared with the total number of opportunities. The probability of correct reception is computed as the ratio:

Probability of correct reception = (no. of correct receptions)/(no. of opportunities)

P.3.1.2 Interference Rates and Power Distribution

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 and on results from the Volpe simulation [Reference P-3]. It was found that the power distribution of Mode A/C fruit from the LA~~2020~~ Volpe simulation agrees with the airborne measurements above –75 dBm, except being higher in fruit rate, which would be expected because of the future higher aircraft densities. The Volpe results were then used to provide the fruit-rate input to the Lincoln Laboratory pulse-level simulation. Figure P-17 shows the Mode A/C and Mode S fruit rates and power distributions used as inputs for this study. This applies to a scenario called "LA~~2020~~-[24k]," 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 Mode A/C 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.

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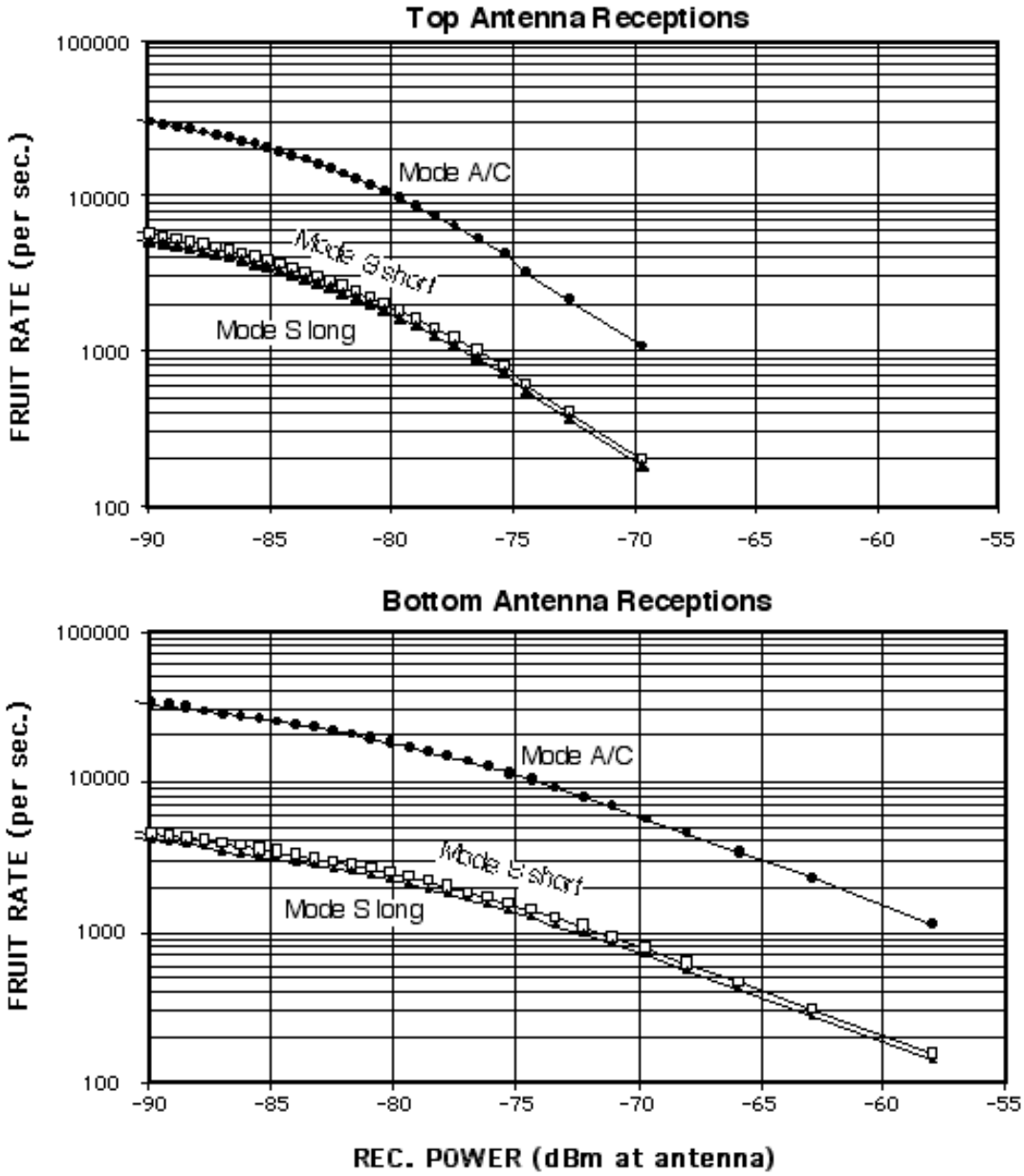

Figure P-17: Top and Bottom Antenna Fruit, LA~~2020~~-[24k]

P.3.1.3 Pulse-Level Simulation Results for A3 to A3

The pulse-level simulation was run for the LA~~2020~~ scenario with two different cases of fruit levels representing different interference environments for future higher aircraft densities. The first case called "LA~~2020~~-[24k]" has 24,000 Mode A/C fruit per second, as described above. The second, more severe case, called "LA~~2020~~-[30K]," has 30,000 Mode A/C fruit per second, with the same Mode S interference as in LA~~2020~~-[24k]. The pulse-level simulation results are shown in Figure P-18 for Air-to-Air performance of A3 to A3.

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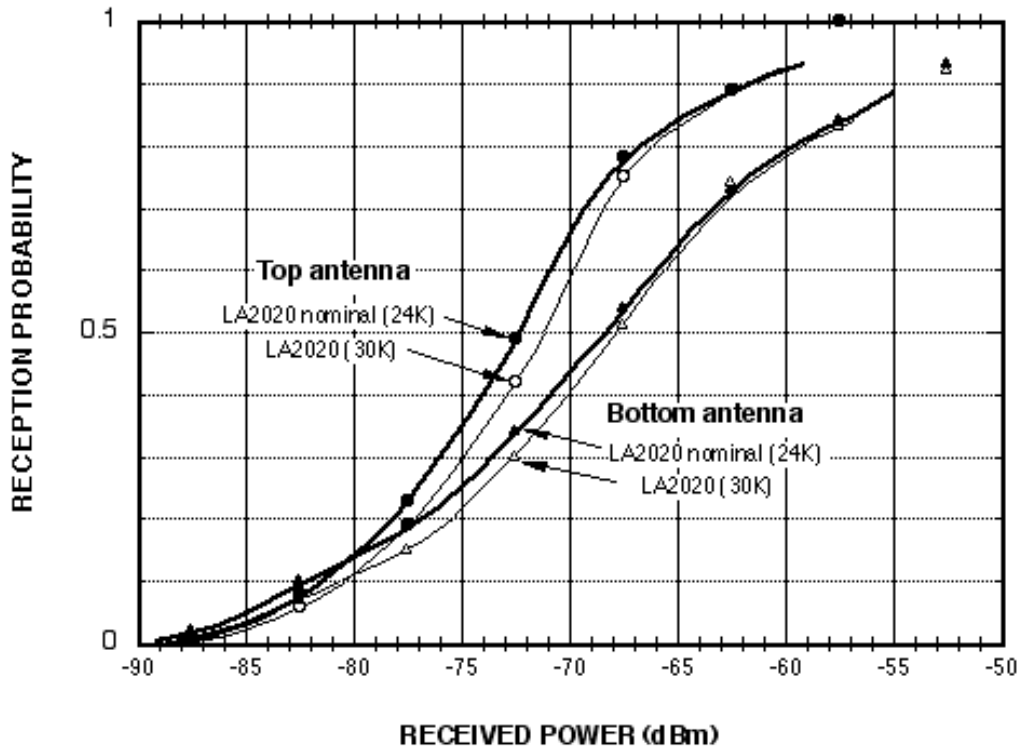

Figure P-18: **Reception Probability versus Received Power for A3-to-A3**

P.3.1.4 Pulse-Level Simulation Results for A2

The pulse-level simulation is used to determine reception probability as a function of received signal power level. The simulation results, plotted in Figure P-19, show a comparison between MTL = -79 dBm (Class A2) and MTL = -84 dBm (Class A3), for the LA~~2020~~-[24k] environment.

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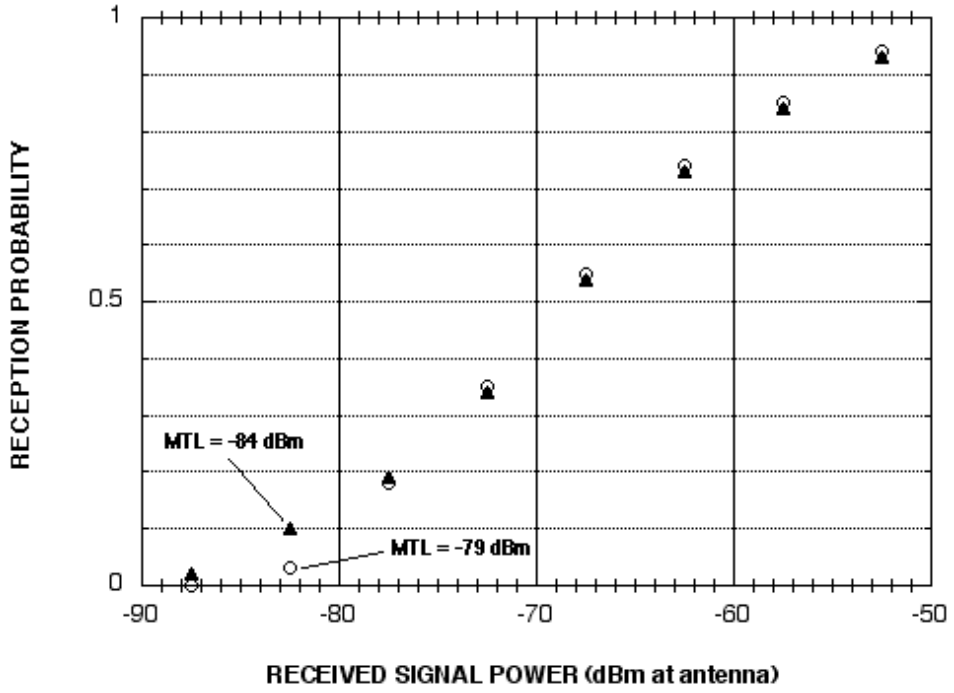

Figure P-19: Pulse-Level Simulation Results (bottom antenna receptions)

The results indicate that the only significant effect is near MTL. Class A2 reception probability is reduced in the vicinity of the MTL power level, and otherwise nearly the same as for Class A3. A curve fit was applied to the data in Figure P-19, for use in the Track-Level Simulations and is shown in Figure P-20.

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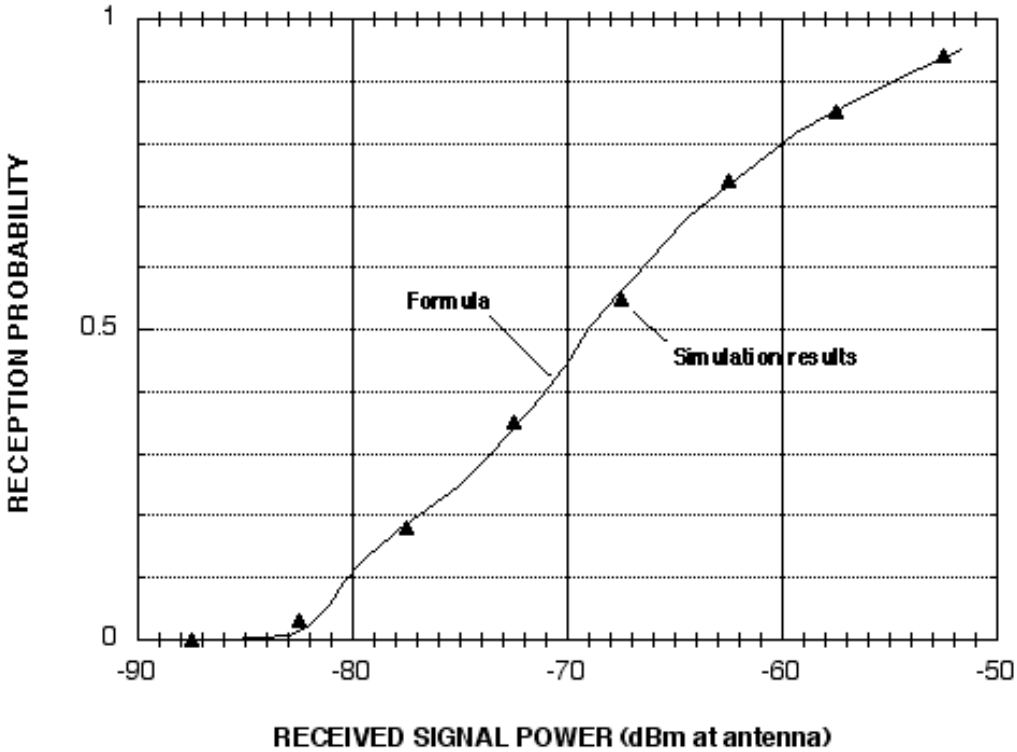

Figure P-20: **Curve Fit to Simulation Results**

P.3.2 Track-Level Simulation

After the pulse-level simulation has generated results in the form of reception probability as a function of received signal power, the track-level simulation can be used to determine system performance.

P.3.2.1 Formulation of the Track-Level Simulation

The track-level simulation is formulated using a 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 is generated at random using a given distribution. For a Class A3 aircraft, is modeled as uniformly distributed over 53 to 56 dBm referred to the antenna.

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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 probability curve (from the pulse-level simulation) is then used to determine the reception probability for that particular antenna combination.

Receiver blanking caused by co-site interference is included at this point. The values of reception probability calculated as above are now multiplied by 0.93 to account for these effects.

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

$$\text{Prob(correct)} = \text{Maximum}[P(\text{top}) , P(\text{bot})]$$

where **P(top)** and **P(bot)** are the reception probabilities for top only and bottom only. In other words, only the better of the two receiving antennas is used; the other does not contribute to performance.

Subsequently, to account for transmitting antenna diversity, the reception probability is calculated separately for top-transmit and bottom-transmit, and then 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% 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.

P.3.2.2 Track-Level Simulation Results for A3-to-A3

For the LA~~2020~~-[24k] scenario, both the pulse-level simulation and the track-level simulation were run, yielding the results given in Table P-2, and shown in Figure P-21 and Figure P-22.

Table P-2: LL A3-to-A3 Performance as a Function of Range for LA~~2020~~-[24k]

RANGE NM	Prob (95) Reception Probability	T95/95 second
10	0.681	0.7
20	0.429	1.3
30	0.272	2.4
40	0.185	3.7
50	0.130	5.4
60	0.106	6.7
70	0.077	9.3
80	0.058	12.5
90	0.055	13.2
100	0.045	16.3

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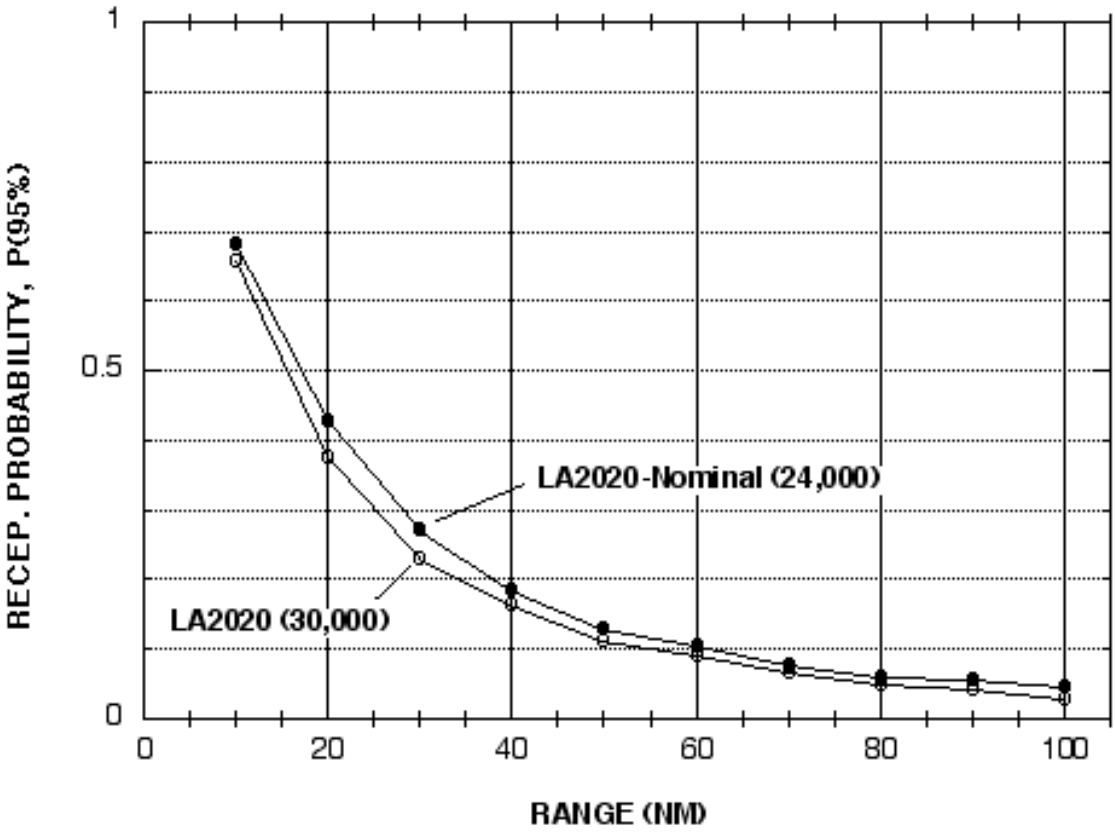

Figure P-21: **Future A3-to-A3 System Performance in the Los Angeles Basin**

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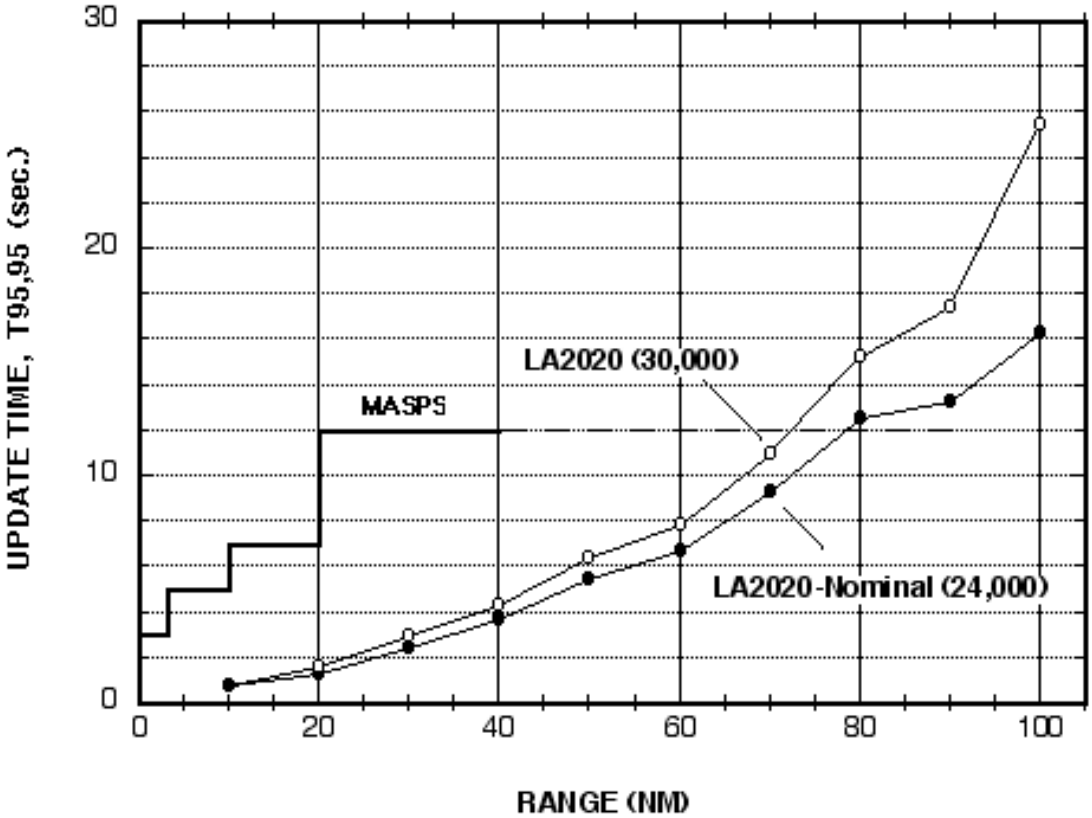

Figure P-22: State Vector Update Performance for A3-to-A3

The results in Figure P-22, showing State Vector update time, were generated from the probability values as follows. In a time **T**, the number of reception opportunities is:

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

Given the reception probability from the pulse-level simulation, 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. Requiring 95% reception in time **T**, or **P(recep. in T) = 0.95**, the solution for time **T** is:

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

This calculation is made for each pair of aircraft among 1000 pairs. The results are sorted, in order to determine the **T95** value for which performance is as good or better for 95% of the aircraft pairs. The result is denoted **T95/95** to indicate that it applies to 95% surveillance update reliability for 95% of aircraft pairs.

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P.3.2.3 Track-Level Simulation Results for A2-to-A2

Using the curve fit shown in Figure P-20, the Track-Level simulation was run for 1000 aircraft pairs (one aircraft transmitting and one receiving). The formulation of the simulation is documented §P3.2.1. The simulation includes co-site interference in the form of 93% receiver availability.

For the case of A2 to A2 aircraft pairs, the results are shown in Table P-3.

Table P-3: LL Simulation Results for A2-to-A2 in LA~~2020~~

Range NM	Reception Prob 95 percentile	State Vector T95/95 (sec.)	TS Report T95/95 (sec.)
10	0.597	0.8	4.1
15	0.418	1.4	6.9
20	0.333	1.8	9.2
25	0.255	2.5	12.7
30	0.209	3.2	16.0
35	0.145	4.8	23.9
40	0.105	6.8	33.8
45	0.068	10.6	53.2
50	0.048	15.2	76.1
55	0.032	23.0	115.1
60	0.014	53.1	265.6

P.3.2.4 Track-Level Simulation Results for A3-to-A2

The other case to consider is Class A3 transmissions received by Class A2 aircraft. The only difference between this case and the first case is the higher power level of the A3 transmitters. In the model being used, A3 transmitters are between 53 and 56 dBm whereas Class A2 transmitters are between 51 and 54 dBm. This difference affects the results as a 2 dB change in ranges for each level of performance. Therefore the results in Table P-3 can be converted to the results in Table P-4 for the A3 to A2 case.

Table P-4: LL Simulation Results for A3-to-A2 in LA~~2020~~

Range NM	Reception Prob 95 percentile	State Vector T95/95 (sec.)	TS Report T95/95 (sec.)
12.3	0.597	0.8	4.1
18.9	0.418	1.4	6.9
25.2	0.333	1.8	9.2
31.5	0.255	2.5	12.7
38	0.209	3.2	16.0
44	0.145	4.8	23.9
50	0.105	6.8	33.8
57	0.068	10.6	53.2

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These results are plotted in Figure P-23 and Figure P-24, where they are compared with the ADS-B MASPS (RTCA DO-242A) standards. Air-to-air surveillance is seen to satisfy the MASPS standards in both cases, A2-to-A2 and A3-to-A2. Air-to-air communication of TS Report information (Figure P-24) satisfies the MASPS standards for A3-to-A2, whereas in the case of A2-to-A2, performance falls short of the MASPS beyond about 24 NM.

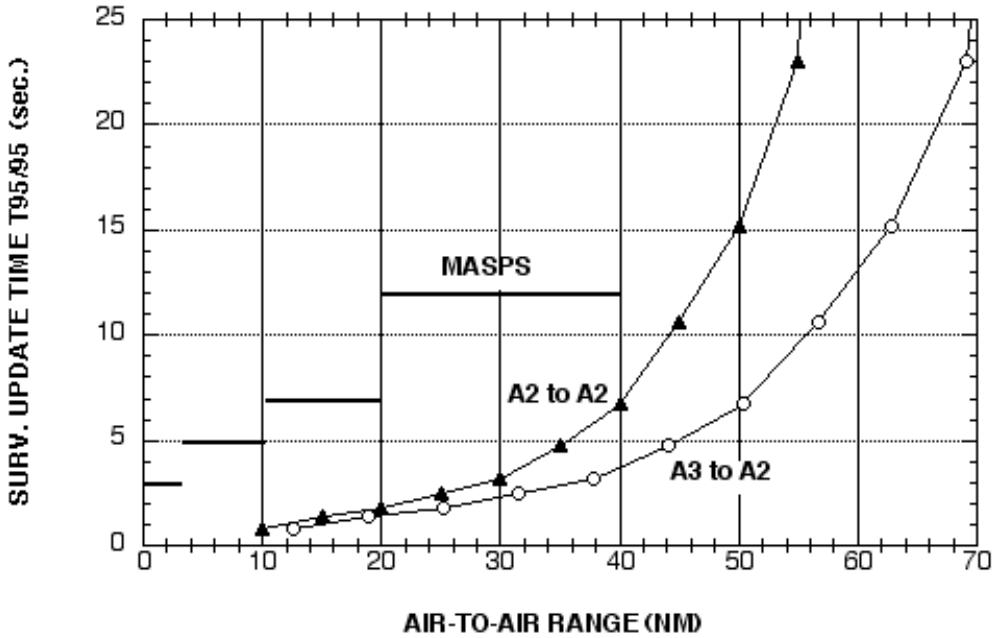

Figure P-23: State Vector Update Rate for A3-to-A2 in LA~~2020~~

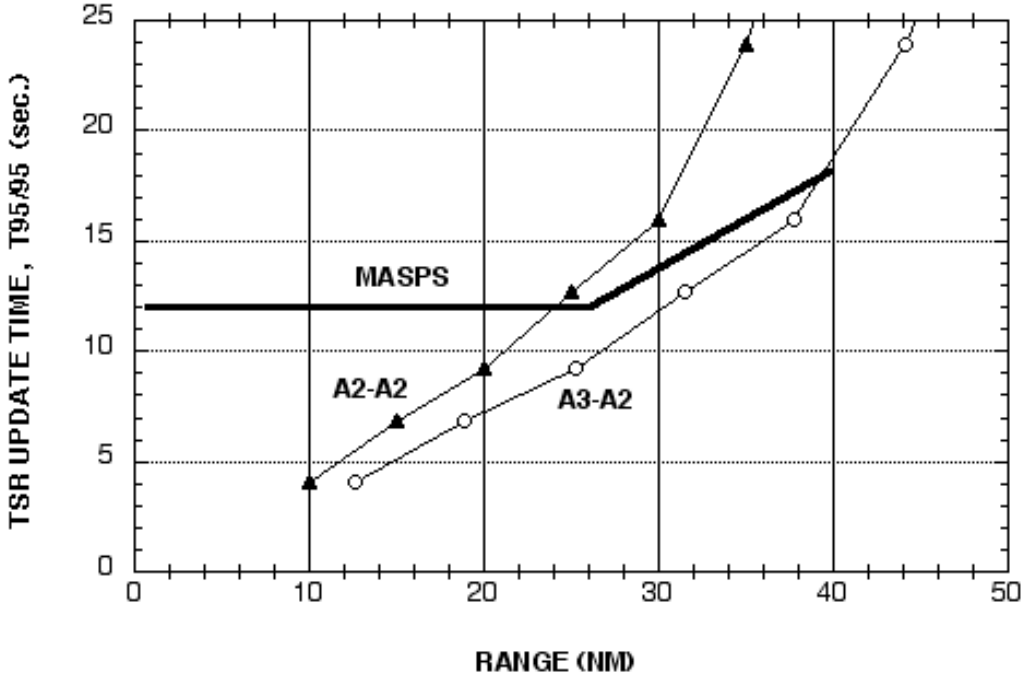

Figure P-24: TSR Update Rate for A3-to-A2 in LA~~2020~~

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P.3.3 Effects of Altitude

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 was not used (only the statistical portion was used). For an additional study of altitude effects, the formulation was changed so that the transmitting aircraft has a specific altitude (a parameter entered by the user) while the receiving aircraft is at the fixed altitude of 40,000 feet. Therefore the results depend on the transmitter altitude. The TLAT model of aircraft antenna gain as a function of elevation angle was used in this study [Reference P-1].

The results for several values of transmitter altitude are shown in Figure P-25 and Figure P-26. The results indicate that performance is somewhat degraded when the transmitter is changed from 40,000 feet to 5000 feet. The degradation is more pronounced at shorter range, which seems reasonable because of the steeper elevation angles. Beyond 50 NM, performance is not changed significantly.

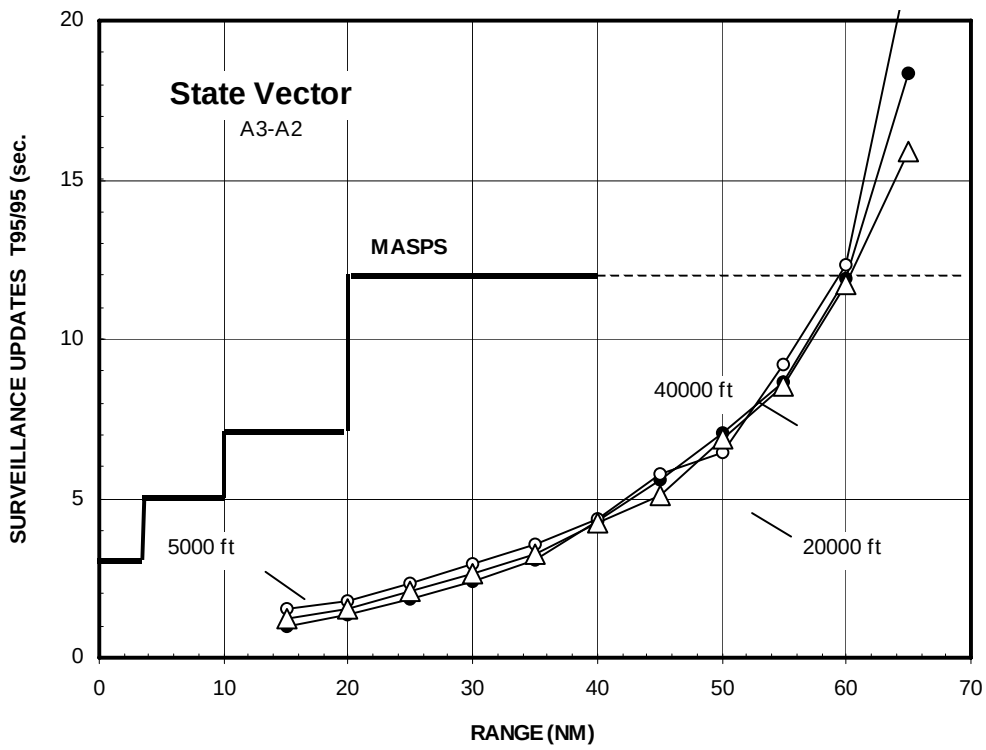

Figure P-25: Effects of Transmitting Aircraft Altitude (A3-A2, LA~~2020~~-[24k]) on State Vector

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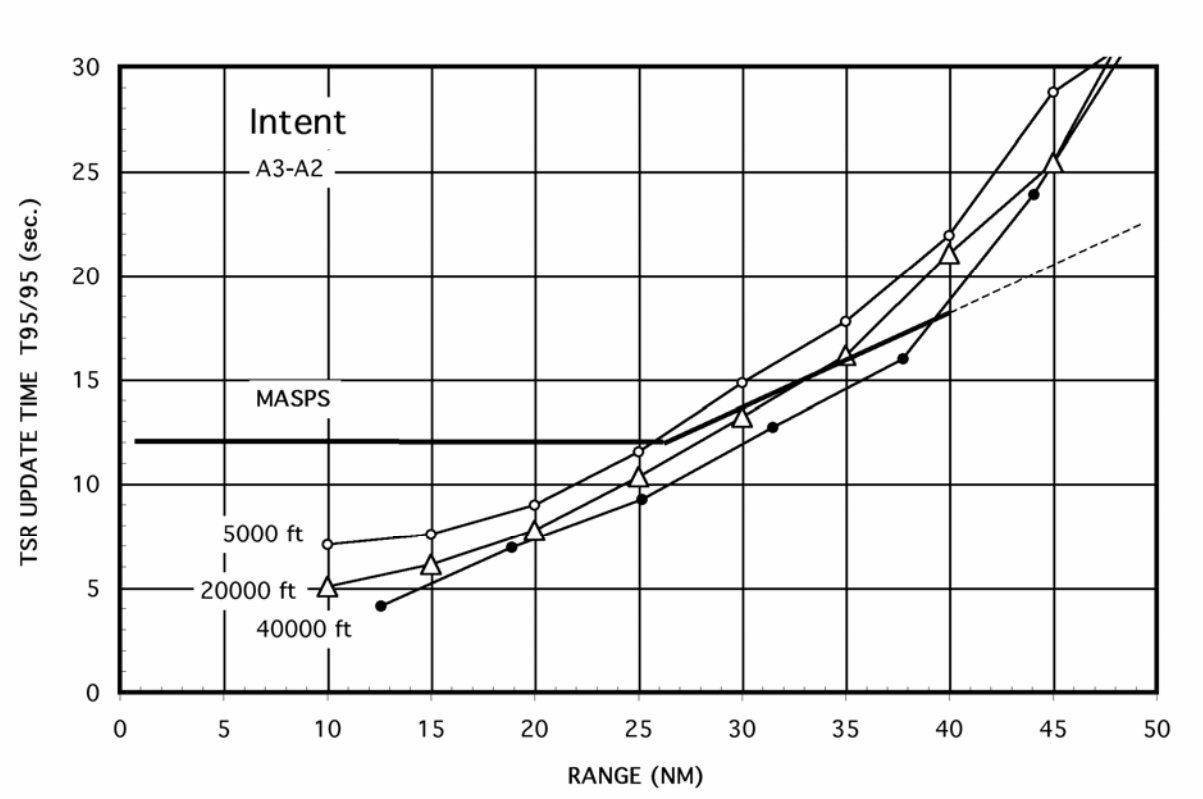

Figure P-26: Effects of Transmitting Aircraft Altitude (A3-A2, LA~~2020~~-[24k]) on TSR Update Rate

Note: *Altitudes marked in the figure apply to the transmitting aircraft. The receiving aircraft is at 40,000 feet.*

Looking at intermediate results from the simulation, one can see several reasons why altitude would not be expected to 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 P-26 indicates that the slope of the performance curves is similar to the slope of the TSR requirement. As a result, the relatively small degradation in TSR performance in this figure causes the MASPS intersection point to drop more dramatically. Although the MASPS requirement is not strictly met beyond that point, the performance is only a few seconds different from the requirement.

In conclusion, the results from the normal runs, in which altitude differences were not used, have been shown to be accurate at long ranges, regardless of the actual altitude of the transmitting aircraft. The results indicate that performance is not very sensitive to transmitter altitude between 20,000 feet and 40,000 feet, although sensitivity increases for very low transmitters.

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P.3.4 Higher Fruit LA Environment

In performing the evaluation for the higher-fruit case, 30,000 Mode A/C fruit per second, the same process was followed. The results are included in Figure P-21 and Figure P-22.

P.3.5 Low Density Environment

The Low Density Environment defined in the ADS-B MASPS (RTCA DO-242A) was also evaluated. The aircraft are uniformly distributed in area over a circle of 400 NM radius. The total number of aircraft is 360, so the density is 0.0007 aircraft per square NM.

P.3.5.1 Reception Probability versus Signal Power

In evaluating performance in this environment, the first step was to determine reception probability as a function of range. The conclusion is that the MTL curve by itself is an appropriate characterization of reception performance as a function of received power in the low density environment. The MTL curve used in this evaluation was based on bench tests performed at the FAATC. The curve satisfies both MTL requirements (90% at -84 dBm and 15% at -87 dBm) and is otherwise the worst-case curve.

P.3.5.2 Low Density Environment Track-Level Simulation

The track-level simulation was then run, using the same procedure as was used for LA~~2020~~-[24k] except for the probability input curve, which embodies the characteristics of the low density environment. The runs apply to Class A3 transmissions received by Class A3 aircraft. Both aircraft have antenna diversity. A receiver dead time factor of 0.93 was also used.

The simulation results are given in Table P-5 and shown in Figure P-27 and Figure P-28. These results exhibit more statistical fluctuations than in the previous cases, which can be attributed to the abruptness of the MTL curve. As a result, the simulation was run twice at each range. Both points were tabulated and plotted, to indicate the degree of accuracy in these results as influenced by the number of trials (1000 aircraft pairs contributing to each point).

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Table P-5: LL Performance in the Low Density Environment

Range NM	Reception Probability P(95)	T95/95 seconds
70	0.696 0.676	0.629 0.665
80	0.481 0.552	1.142 0.933
90	0.465 0.465	1.197 1.197
100	0.465 0.465	1.197 1.197
110	0.464 0.402	1.201 1.457
120	0.215 0.278	3.094 2.299
130	0.142 0.094	4.890 7.587
140	0.018 0.018	41.232 41.232

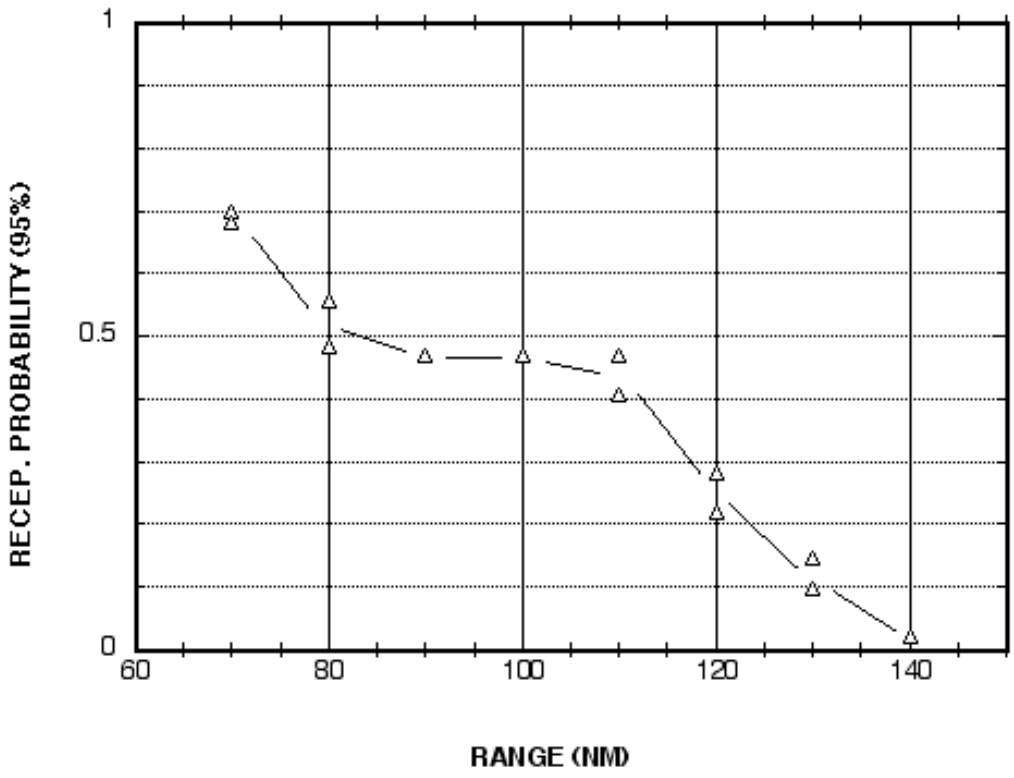

Figure P-27: Reception Probability in the Low Density Environment

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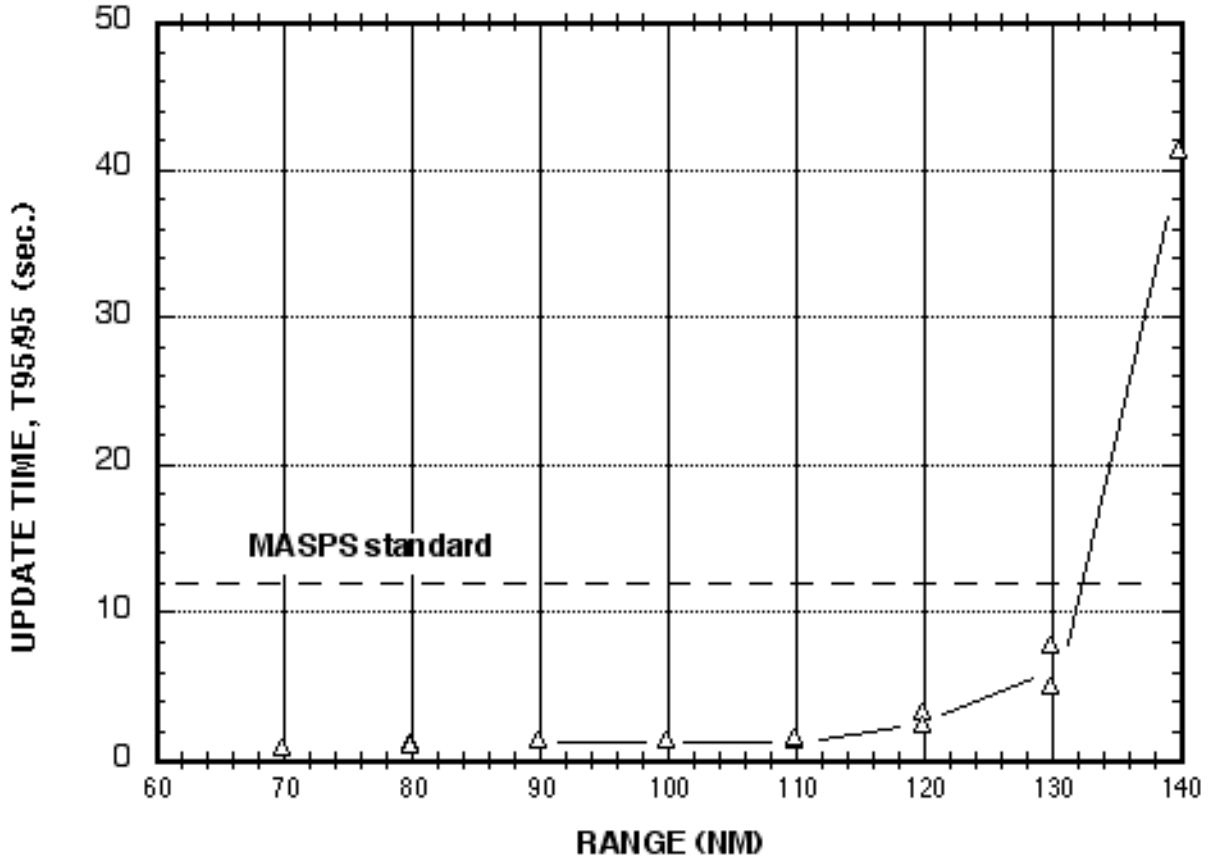

<u>Figure P-28:</u> State Vector Updates in the Low Density Environment for A3-to-A3 with 1250 Mode A/C Fruit

The results exhibit an interesting flat spot from 80 to 110 NM. Looking at this, one can see that it is a result of the steep MTL curve. It's not common, but occurs at around the 95 percentile worst cases, that one of the two transmitting antennas has higher power, for which reception is the maximum value (0.93), while the other transmitting antenna has lower power, for which reception is zero. Therefore the overall probability is (0.93 + 0)/2 = 0.465. This is the probability value at the flat spot.

The results in Figure P-28 indicate that the MASPS standards for State Vector are met out to about 130 NM air-to-air range for Class A3-to-A3. The same evaluation was performed for TS Reports, and the results indicate that the MASPS standards are met out to about 130 NM for Class A3-to-A3 avionics.

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P.4 Summary

Table P-6 and Table P-7 summarize the results from the simulations run by Johns Hopkins University Applied Physics Laboratory (APL), and by MIT Lincoln Laboratory (LL). These tables show to what range the report update requirements from the ADS-B MASPS, RTCA DO-242A where met for a given equipment class combination and Mode A/C fruit level. Also shown is the range to which the update requirements are required and desired as described in RTCA DO-242A.

Note: *For the high density scenarios of 24,000 and 30,000 Mode A/C fruit (see §P.1), RTCA DO-242A specifies that operational ranges are only to extend to 40 NM. However, it should be noted that as applications are developed and validated, these required ranges might be extended to 90 NM in high density airspace for A3 equipment.*

Table P-6: Simulation Summaries for State Vector Report Update Ranges

Transmitter	Receiver	Mode A/C	APL	LL	RTCA DO-242A	
					Required	Desired
A3	**A3**	24,000	70 NM	78 NM	40 NM	120 NM
A2	**A3**	24,000	50 NM	62 NM	40 NM	50 NM
A3	**A3**	30,000	60 NM	70 NM	40 NM	120 NM
A3	**A2**	30,000	**[1]**	53 NM	40 NM	120 NM
A2	**A3**	30,000	40 NM	55 NM	40 NM	50 NM
A2	**A2**	30,000	**[1]**	42 NM	40 NM	50 NM
A3	**A2**	24,000	40 NM	59 NM	40 NM	120 NM
A2	**A2**	24,000	30 NM	47 NM	40 NM	50 NM
A3	**A3**	5,000	>120 NM	115 NM	90 NM	120 NM
A3	**A3**	1,250	>120 NM	~130 NM	90 NM	120 NM

Table P-7: Simulation Summaries for Target State Report Update Ranges

Transmitter	Receiver	Mode A/C	APL	LL	RTCA DO-242A	
					Required	Desired
A3	**A3**	24,000	50 NM	40 NM	40 NM	50 NM
A2	**A3**	24,000	20 NM	32 NM	40 NM	50 NM
A3	**A3**	30,000	40 NM	28 NM	40 NM	50 NM
A3	**A2**	30,000	**[1]**	**[1]**	40 NM	50 NM
A2	**A3**	30,000	20 NM	28 NM	40 NM	50 NM
A2	**A2**	30,000	**[1]**	21 NM	40 NM	50 NM
A3	**A2**	24,000	20 NM	40 NM	40 NM	50 NM
A2	**A2**	24,000	20 NM	24 NM	40 NM	50 NM
A3	**A3**	5,000	>120 NM	115 NM	40 NM	50 NM
A3	**A3**	1,250	>120 NM	~130 NM	40 NM	50 NM

[1] - Not evaluated

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The above summary tables show that the 1090 MHz ES ADS-B system, as defined in these MOPS, will meet the report update requirements from RTCA DO-242A beyond the required ranges for A3 equipment interacting with A3 equipment at recommended power levels. It should be noted, however, that if the operational range of 40 NM for high density airspace would be increased to that of 90 NM used for low-density airspace, the performance of the 1090 MHz ES system would not meet the update requirements through that extended range.

For State Vector update performance, the requirements for RTCA DO-242A are also met for A3 equipment interacting with A2 equipment at recommended power levels. Performance requirements up to 40 NM for State Vector updates will be met in the high density environments between A3 and A2 equipment, however, results are unclear if A2-to-A2 communications will meet the 40 NM requirement in LA~~2020~~. The results show that update requirements will not be met in high density airspace for the TS Reports for A2 equipment interfacing with either A2 or A3 systems.

The transmission rate for A2 equipment has been selected in light of the current 6.2 transmissions per second limit and is tailored to A3 equipment, and retains capability to support the Trajectory Change Reports (see Appendix O). Future editions of these MOPS may consider increasing the transmission rate of short term intent information supporting TS Reports for A2 equipment in order to provide longer range performance in the highest density environments.

As described in §P.3.3, relatively small variations in predicted TSR performance may result in significant differences in the ranges at which the MASPS TSR updates rates are satisfied.

Table P-6 shows performance for the MASPS low density scenario with two different Mode A/C fruit rates. These results indicate for Mode A/C fruit rates approaching 5000 per second that the 1090 MHz system for A3-to-A3 interactions offers the MASPS desired range of 120 NM.

The performance results reported in Appendix P were derived from two independent evaluations, one by APL and the other by LL. Examination of Tables P-6 and P-7 shows (only) three differences in simulated performance results provided by APL and LL that impact the determination of whether particular RTCA DO-242A requirements are projected to be met by the 1090 MHz Extended Squitter system in the LA~~X 2020~~ air traffic scenario (Table P-6, A2 transmitter and A2 receiver at 24,000 Mode A/C fruit; Table P-7, A3 transmitter and A3 receiver at 30,000 Mode A/C fruit; and Table P-7, A3 transmitter and A2 receiver at 24,000 Mode A/C fruit). A significant effort was made to understand the reason for any differences between the results reported by each evaluation. The APL and LL evaluation techniques, while using similar assumptions on, for example, probability of correct reception of a single Extended Squitter as a function of received signal power, use different simulator architectures and, for A3 receivers, a different sampling rate. These differences, in conjunction with uncertainties inherent in the simulation processes, are the likely source of the differences in the values for update ranges obtained.

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P-1. "Technical Link Assessment Report," Safe Flight 21 Steering Committee, ADS-B Technical Link Assessment Team (TLAT), March 2001.

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P-3. "Measurement of 1090 MHz Extended Squitter Performance In the Los Angeles Basin," DOT/FAA/ND-00/7, May 2000.

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