# GPS-SQUITTER EXPERIMENTAL RESULTS*

Robert E. Boisvert, Kenneth W. Saunders, M. Loren Wood, Vincent A. Orlando

MIT Lincoln Laboratory, Lexington, Massachusetts

## ABSTRACT

GPS-Squitter is a system concept that merges the capabilities of Automatic Dependent Surveillance (ADS) and the Mode S beacon radar. The result is an integrated concept for seamless surveillance and data link that permits equipped aircraft to participate in ADS or beacon ground environments. This offers many possibilities for transition from beacon to ADS-based surveillance.

This paper briefly defines the GPS-Squitter concept and its principal applications. The thrust of the paper is the presentation of surface and airborne surveillance measurements made at Hanscom Field in Bedford, Massachusetts and at the Logan International Airport in Boston. In each case the measurements show the excellent surveillance performance provided by this concept.

## INTRODUCTION

GPS-Squitter is a system concept for aircraft surveillance that merges the capabilities of the Global Position System (GPS) for navigation with those of the Mode S beacon system for communications. In the GPS-Squitter concept, an aircraft determines its position using GPS, or more generally from a Global Navigation Satellite System (GNSS), and automatically broadcasts that information in a 112-bit message known as a squitter. GPS-Squitter is, therefore, a form of Automatic Dependent Surveillance Broadcast (ADS-B).

The GPS-Squitter concept was invented at MIT Lincoln Laboratory in early 1992. An intensive development program was then started in December 1992, under the sponsorship of the Federal Aviation Administration (FAA). The initial field testing of the system was performed at Hanscom Field in Bedford, Massachusetts and a second phase of testing is underway at Boston's Logan International Airport.

* This work was sponsored by the Federal Aviation Administration.

This paper provides a description of the system configuration used for the field testing at Hanscom Field and at Logan Airport as well as results from the testing. A brief overview of the GPS-Squitter concept and its potential applications to aircraft surveillance are also provided.

## GPS-SQUITTER OVERVIEW

All Mode S aircraft transponders transmit a spontaneous 56-bit broadcast message known as a squitter. This squitter contains the aircraft's unique Mode S address and is transmitted on the standard transponder frequency of 1090 MHz at a once per second rate. The Mode S squitter forms the basis for TCAS (Traffic Alert and Collision Avoidance System) acquisition of Mode S equipped aircraft. TCAS detects the presence of a Mode S aircraft by listening for the squitter and then discretely interrogates the aircraft to determine its location.

In the GPS-Squitter concept, a new squitter is created by adding a 56-bit ADS message field to the current format (Figure 1). The resulting 112-bit squitter is often referred to as an extended squitter. The ADS field may contain one of three types of messages. Two of these provide position information and the third provides the ICAO (International Civil Aviation Organization) identification of the aircraft (i.e., the flight ID for commercial aircraft and the tail number for general aviation aircraft).

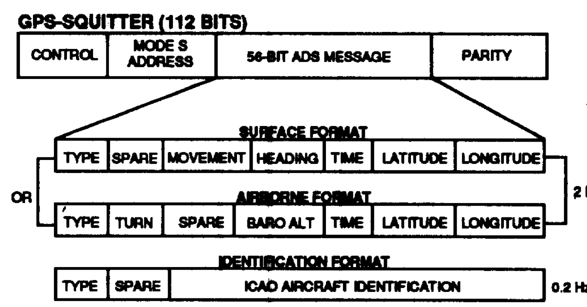



*Figure 1. GPS-Squitter Message Formats.*



0-7803-2425-0/94 $4.00 © 1994 IEEE

The position messages apply to either airborne or surface aircraft. The airborne message provides the latitude, longitude, and altitude of the aircraft as well as a time tag for the position fix. Latitude, longitude, and time would be based on GPS inputs, whereas, altitude would be obtained from a barometric altimeter to maintain compatibility with other aircraft. The surface message includes the following fields: time, latitude, longitude, heading, and movement. The appropriate position message is transmitted at an average rate of 2 Hz and the ID message is transmitted at 0.2 Hz. Since GPS-Squitter uses the Mode S waveforms to provide ADS information, the concept was originally known as ADS-Mode S.

GPS-Squitter will be able to satisfy many types of aircraft surveillance needs including: surface surveillance; improvements to TCAS; en route and terminal area air surveillance; and Precision Runway Monitoring. More information on the GPS-Squitter concept, its potential applications, and on its surveillance capacity may be found in Refs. [1-5].

## FIELD TESTING OF GPS-SQUITTER

Initial field testing of the GPS-Squitter concept has been performed. A Proof-of-Concept Evaluation was held at Hanscom Field in Bedford, Massachusetts during the Summer and Fall of 1993, and an Operational Suitability Assessment was initiated at Boston's Logan International Airport in early 1994. The GPS-Squitter system configuration for these experiments will be described in this section and the results of the testing will be provided in the next two sections.

### Ground Equipment

The equipment used during the GPS-Squitter field testing is shown in Figure 2. The ground equipment included: a differential GPS (dGPS) reference station; transmit/receive ground stations; a central control computer; and, a display system.

### dGPS Reference Station

The horizontal position accuracy of GPS is reported to be within 100 meters 95% of the time [Ref. 6]. This is sufficient for most airborne applications of GPS-Squitter. However, surface surveillance requires greater precision. During the surface testing of GPS-Squitter, differential GPS techniques were utilized for improved accuracy. A Trimble 4000RL differential reference station provided the dGPS range and pseudorange corrections.

### Ground Stations

The GPS-Squitter ground stations served two basic purposes during the GPS-Squitter testing: they received the extended squitters emitted by the test vehicle and they transmitted dGPS corrections to the vehicles. Two ground stations were assembled by Lincoln Laboratory for the Hanscom Field evaluation. Each of these ground stations was connected to a simple antenna with an omnidirectional pattern in azimuth.

Ground stations were obtained from AlliedSignal for the experiments at Logan Airport. These station are known as Ground Interrogator Receiver Units (GIRUs) and four of them were deployed at Logan Airport. The GIRUs are TCAS II processors with minor RF (radio frequency) hardware and software modifications.

Two types of GIRU antennas were installed at Logan Airport. One type was based on antennas used by cellular telephone companies which has an azimuth beamwidth that is adjustable between 60 and 140 degrees. This antenna is known as a variable wing antenna and the 140 degree setting was used at Logan Airport. The other antenna is the type used by the FAA's Distance Measuring

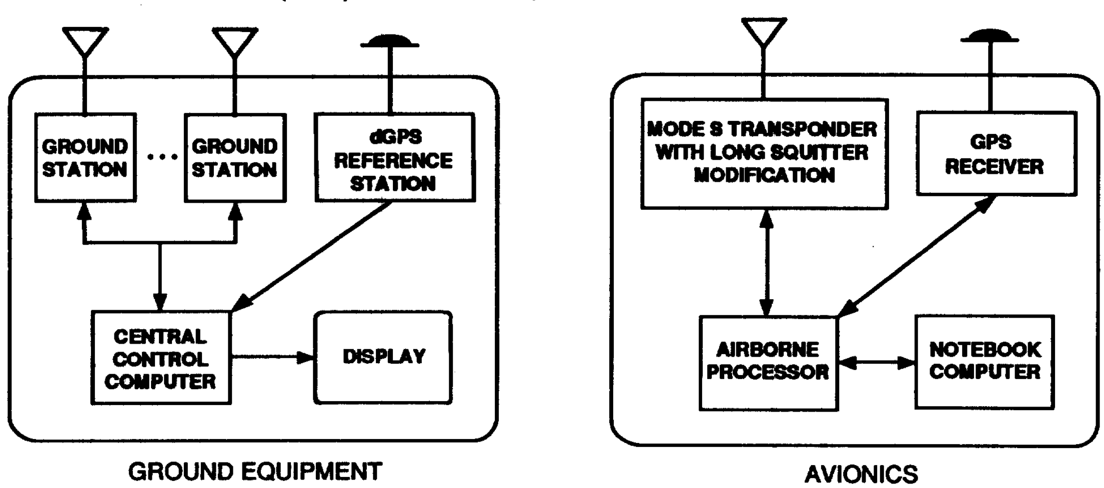



*Figure 2. GPS-Squitter Field Testing Equipment.*

Equipment (DME). The DME antenna has an omnidirectional beam in azimuth. Figure 3 shows the GIRU ground station configuration with both types of antennas.

**Central Control Computer**

A Sun Sparc10 workstation served as the central control computer. This computer performed the following tasks: (1) it received the dGPS corrections from the reference station and reformatted them for transmission by the ground stations; (2) it decoded the extended squitters received by the ground stations; (3) it was the primary data recording device; and, (4) it acted as the real-time target display system.

**Avionics**

Three test vehicles were equipped with GPS-Squitter avionics for the field testing. Two of them – a Cessna 172 and a stepvan – were available at Hanscom Field. A Cessna 421 was later added for the Logan Airport experiments. The test vehicles were equipped with the following avionics: a Mode S transponder modified for GPS-Squitter; a GPS receiver; an airborne processor; and, a notebook computer.

**GPS-Squitter Transponder**

Transponders, modified to transmit the GPS-Squitter messages, were obtained from the Collins Division of Rockwell International. These transponders are based on the Collins TPR-900 Level 3 Mode S transponder. Only a minor software modification to this transponder was required to provide it with the extended squitter capability.

**GPS Receiver**

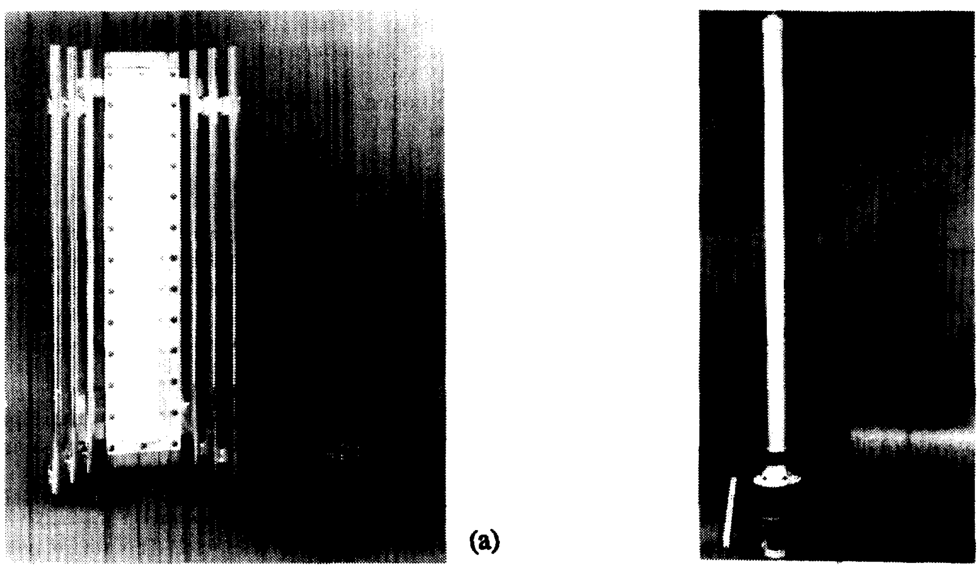
Each test vehicle was equipped with a Trimble TNL-2100 GPS receiver. This GPS receiver is capable of processing dGPS correction messages. Information available from the receiver at a 1 Hz rate includes: GPS time, latitude, longitude, speed, and heading.

**Airborne Processor and Notebook Computer**

In addition to a modified transponder and a GPS receiver, the test vehicles were also outfitted with an airborne processor and a notebook computer. The Lincoln Laboratory-developed airborne processor served as the interface between the GPS receiver and the GPS-Squitter transponder. The notebook computer was used for onboard data recording.

## HANSCOM FIELD RESULTS

The GPS-Squitter concept was first tested at Hanscom Field in a series of experiments known as the Proof-of-Concept Evaluation. The primary objective of the Hanscom Field testing was to demonstrate the feasibility of using the extended squitter to downlink position information. Other objectives included: (1) evaluating the reliability of the 1030/1090 MHz data link on an airport surface; (2) determining the surface surveillance performance for a two ground station deployment; and, (3) demonstrating air surveillance with a simple ground station antenna.



(a) (b)

*Figure 3. Ground Stations at Logan Airport With Associated Antennas, (a) Variable Wing Antenna, (b) DME Antenna.*

**Surface Testing**

Since the GPS-Squitter concept is based on the use of Mode S waveforms, its performance in air-to-ground and air-to-air applications was well understood from past experience with Mode S. It was not as clear, however, how well the extended squitter would work on the airport surface where blockage from buildings or multipath reflections may prevent a transmission from being correctly decoded. The testing at Hanscom Field initially focused on the surface surveillance objectives.

An example of the surface surveillance performance is shown in Figure 4. During this test, the surface vehicle was taxied along the perimeter of Hanscom Field and the GPS-Squitters were received by the two ground stations shown in the figure. Once per second updates were received by one of the ground stations 96% of the time and by the second station 93% of the time. The combined coverage was 99.6%. Additional surface testing at Hanscom Field with the surface vehicle and the Cessna 172 showed similar results. Blockage from the control tower and multipath interference occasionally affected the ground stations but rarely did these problems affect both ground stations simultaneously. A complete description of the surface surveillance results from Hanscom Field is provided in Ref. [4].

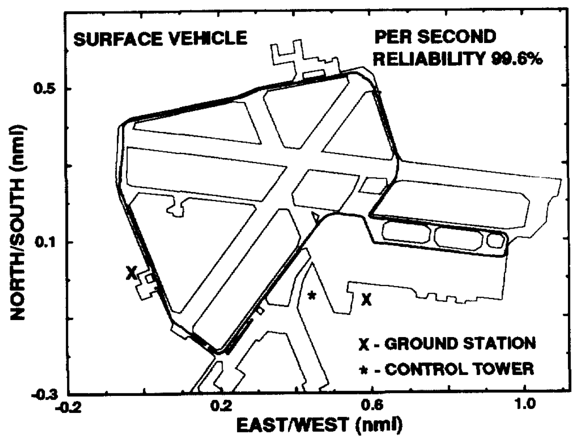



*Figure 4. GPS-Squitter Coverage at Hanscom Field.*

**Airborne Testing**

A long range airborne test was performed using the Cessna 172 and one of the ground stations at Hanscom Field. For this test the ground station was connected to a DME antenna like the one shown in Figure 3b. System studies had predicted that the DME antenna would be sufficient to provide terminal area air surveillance out to a range of 50 nmi [Ref. 1].

The flight path taken by the Cessna 172 is shown in Figure 5. The Cessna 172 flew generally to the northwest of Hanscom Field out to a maximum range of 110 nmi. On the outbound leg, the plane flew at 10,000 ft altitude; it returned at 9,000 ft altitude. The plot indicates the nominal four-thirds earth radar horizon for a 0.5 degree mask angle (the tree line from the ground station at Hanscom Field is at an elevation of ~ 0.5 degrees). Three types of symbols are used to indicate extended squitters that were received during the flight. A small dot indicates a GPS-Squitter that was received within 3 sec of the previous one (i.e., a 3 sec or better surveillance update rate), an open circle for updates between 3 and 5 sec, and a square for update received more than 5 sec after the preceding one.

Present terminal area air surveillance is performed with an update rate of ~ 5 sec. Within 50 nmi of Hanscom Field this update rate was attained 100% of the time. In fact, with only one exception, updates were obtained every 3 sec or less within this range. The performance beyond 50 nmi was also very good out to the radar horizon.

## LOGAN AIRPORT RESULTS

The testing at Hanscom Field showed that a GPS-Squitter system with two ground stations can provide very good surface surveillance at a relatively small airport. The primary interest in surface surveillance, however, is at the busiest airports. The Hanscom Field experiments, therefore, were followed by an Operational Suitability Assessment at Logan Airport. Testing at Logan Airport centered on the surface surveillance application and individual experiments were performed to assess the coverage in the movement area, the gate area coverage, dynamic coverage, and the difference in performance between bottom-mounted and top-mounted transponder antennas.

**Movement Area Coverage**

Two early morning tests were conducted at Logan Airport to determine the surveillance coverage in the movement area. One of these occurred on 4 February and the second on 30 June 1994. Figure 6 shows the track taken by the surface vehicle during the 30 June test. The surface vehicle traversed nearly every portion of the aircraft movement area during the test. A very similar track was followed during the 4 February test. Figure 6 also shows the location of the 4 ground stations at Logan Airport. Three were placed on buildings on one side of the airfield and these all used directional antennas like the one shown in Figure 3a. The fourth ground station was housed in a van and deployed on the field. This station used the omnidirectional DME antenna (Figure 3b).

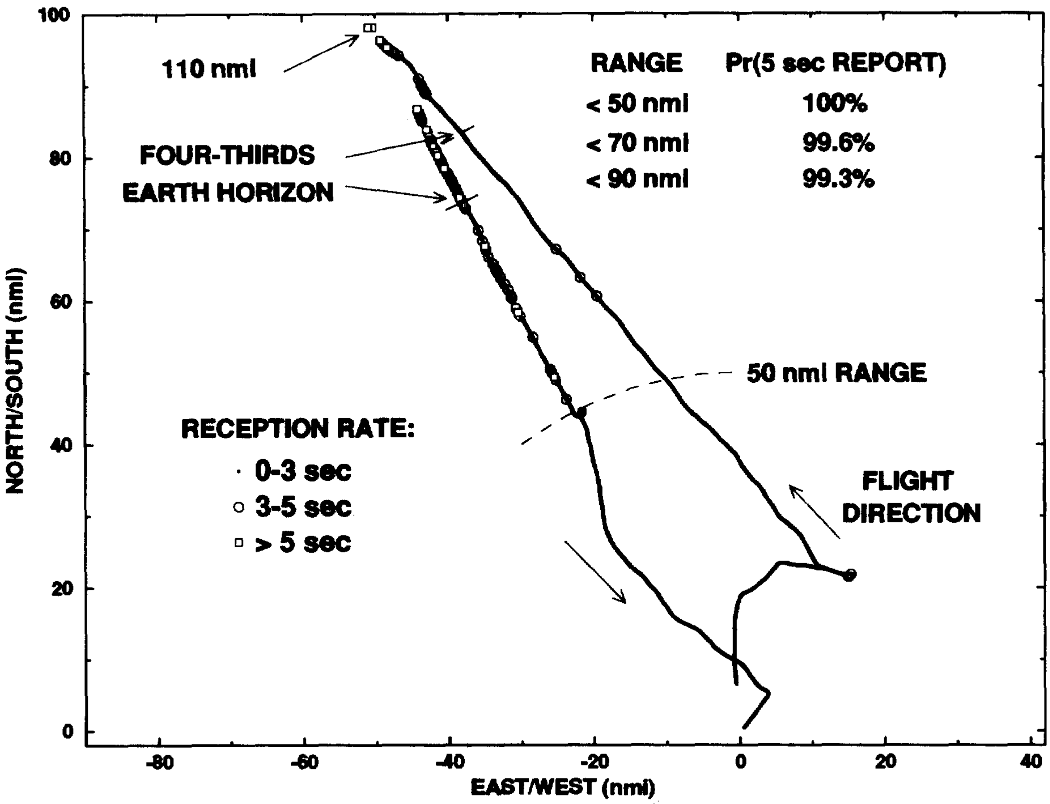



*Figure 5. GPS-Squitter Air Surveillance Results.*

The surveillance coverage on the surface vehicle was excellent during both tests. On 4 February, once per second surveillance updates were obtained on the vehicle by at least one of the four ground stations 99.6% of the time and on 30 June updates were received 99.9% of the time.

**Gate Area Coverage**

The GIRUs were deployed at Logan Airport to provide good surveillance of the movement areas. No consideration was given to maximizing the coverage in the gate areas. However, there was an interest in assessing this coverage for data link purposes (the ground stations could provide data link services to surface aircraft). On 30 June the surface vehicle was also taxied throughout the gate area as shown in Figure 7. As expected, the per second coverage was not as excellent as in the movement area but it was still quite good – 85.9%. This number only represents the success of the 1090 MHz downlink frequency. Two-way data link would also require the 1030 MHz uplink channel. The performance at 1030 MHz was not assessed but is anticipated to be similar to the 1090 MHz performance.

**Dynamic Coverage**

Dynamic coverage refers to the coverage as affected by dynamic, that is, moving, objects such as other aircraft and vehicles. Of particular concern are cases in which the aircraft of interest is in the midst of other aircraft that may block the desired squitter or serve as sources of multipath reflections that garble it. Three observations of dynamic coverage have been made; one for a commercial aircraft target of opportunity, one with the Cessna 172, and one with the Cessna 421.

In November 1993, when only the GIRU at the top of Figure 6 was operational, a Midwest Express aircraft was observed taxiing in preparation for takeoff. The tail number was noted and converted to the aircraft's Mode S address. The aircraft was equipped with TCAS and it happened to be emitting short squitters once per second during taxi. This relatively small aircraft was in line with other larger aircraft, and was often visually obscured by them from the vantage of the GIRU antenna. The larger aircraft were also possible sources of multipath reflections. Analysis of the GIRU recorded data showed that the squitters were received quite reliably, with only

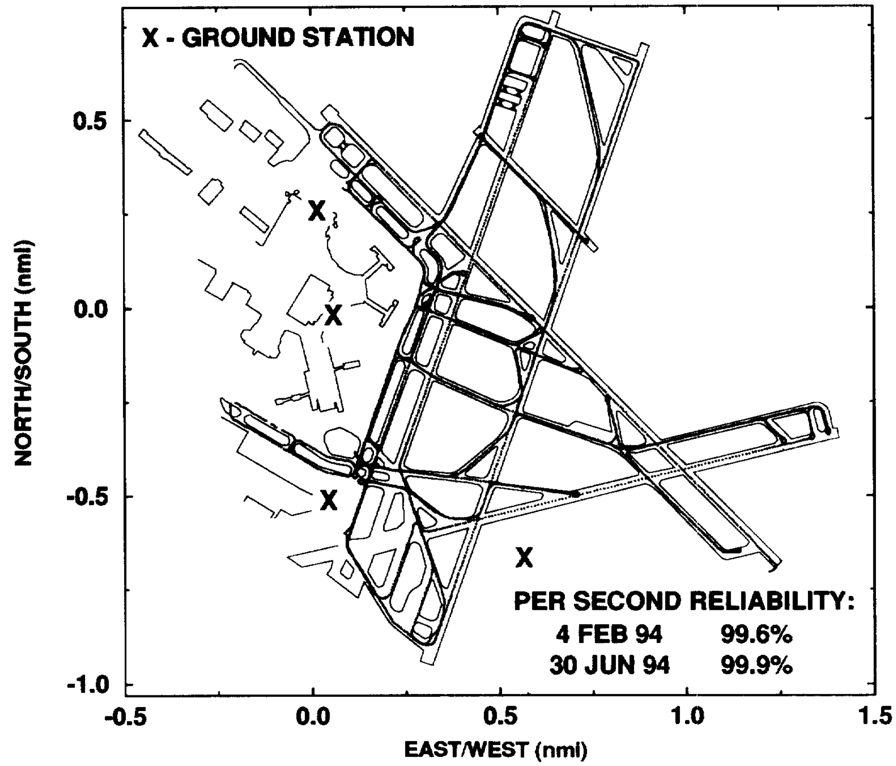



*Figure 6. GPS-Squitter Track of Surface Vehicle in Movement Area.*

occasional misses. The largest number of consecutive misses was three, which only occurred once. This result was considered quite promising since, by extrapolation, it suggested a high probability of receiving at least one squitter per second when 4 GIRUs are available and when the emission rate is 2 per second.

In February 1994, the Cessna 172 taxied three times within 100 feet of other larger aircraft. In each instance the larger aircraft visually blocked the signal path to one of the GIRUs, and served as possible sources of multipath to the other three. Nevertheless, at least one GIRU received a long squitter each second.

Later that same day, the Cessna 421 joined a line of larger taxiing aircraft on the outer taxiway in preparation for an intersection takeoff from RWY 4L. There were also large aircraft within 1000 feet. As in the case of the Cessna 172, at least one GIRU received a long squitter each second.

### Top vs. Bottom Antenna Coverage

The Cessna 172 used in the GPS-Squitter testing has both top-mounted and bottom-mounted Mode S transponder antennas. During most of the testing, the Cessna

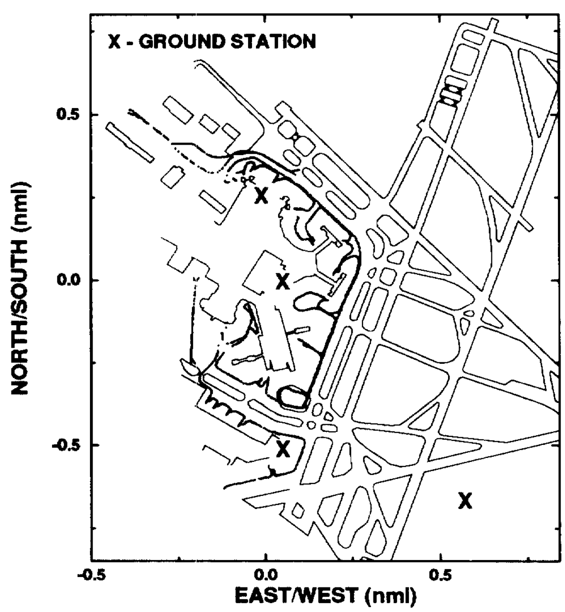



*Figure 7. Gate Area Coverage.*

radiated squitters by alternating between the two antennas when it was airborne and radiated out the top antenna only while it was on the surface. This mode of operation is expected to provide the best performance. While it is common for commercial aircraft to have both top and bottom antennas, general aviation aircraft typically have only a bottom-mounted one. For this reason, a surface test was conducted to compare the performance of the bottom antenna versus that of the top antenna.

During this test, the Cessna 172 taxied along a route using its top antenna and then repeated the same route using the bottom antenna. The route taken is shown in Figure 8. Since this test was conducted during the day, the route was limited so that the test would not interfere with regular airport operations. The route contained the inner and outer taxiways (alpha and kilo) near the terminal buildings as well as one of the runways. The performance in each case was remarkably similar. With the top antenna once per second position updates were received 98.6% of the time and with the bottom they were received 98.4% of the time.

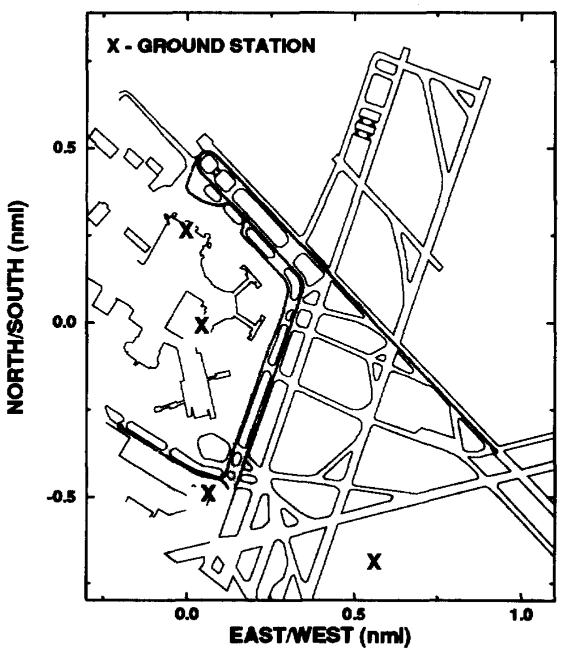



*Figure 8. Taxi Route for Transponder Antenna Comparison.*

## SUMMARY

Field Testing of the GPS-Squitter concept for aircraft surveillance has been performed. A Proof-of-Concept Evaluation at Hanscom Field was held during the Summer and Fall of 1993 and an Operational Suitability Assessment was initiated at Logan International Airport in early 1994.

The testing at Hanscom Field demonstrated the feasibility of using the extended squitter messages to downlink GPS-based position information for both surface surveillance and air surveillance. In both cases excellent surveillance performance was achieved using simple ground hardware and avionics. Continued testing at Logan Airport has shown that excellent surface surveillance can also be performed at a major airport. With only four, low-cost ground stations, continuous surveillance coverage of the entire movement area was demonstrated.

## ACKNOWLEDGMENTS

The authors wish to thank Mr. Ron Jones, Mr. John Heurtley, Mr. P. Douglas Hodgkins, and Mr. Gene Wong, all of the FAA, for their support. We also with to thank the Hanscom Field Control Tower personnel and MASSPORT officials for the assistance they provided during the testing. In addition, we wish to acknowledge the contributions provided by our colleagues at Lincoln Laboratory in support of the testing.

## REFERENCES

1. R. E. Boisvert and V. A. Orlando, *ADS-Mode S System Overview*, 12th Digital Avionics Systems Conference, IEEE/AIAA, Ft. Worth, October 25-28, 1993, pp. 104-109.

2. G. H. Knittel and V. A. Orlando, *ADS-Mode S*, 38th Annual Air Traffic Control Association Conference Convention Proceedings, ATCA, Nashville, October 24-28, 1993, pp. 230-36.

3. E. T. Bayliss, R. E. Boisvert, and G. H. Knittel, *Demonstration of GPS Automatic Dependent Surveillance of Aircraft Using Spontaneous Mode S Beacon Reports*, Proceedings of ION GPS-93, Sixth International Technical Meeting of the Satellite Division of the Institute of Navigation, Salt Lake City, September 22-24, 1993, pp. 185-97.

4. R. E. Boisvert, K. W. Saunders, and G. H. Knittel, *Airport Surface Surveillance Using Differential GPS and the Mode S Data Link*, Proceedings of the ION-94 50th Annual Meeting, Colorado Springs, 6-8 June 1994.

5. V. A. Orlando and W. H. Harman, *GPS-Squitter Capacity Analysis*, ATC-214, MIT Lincoln Laboratory, 20 May 1994.

6. T. Logsdon, The NAVSTAR Global Positioning System, (Van Nostrand Reinhold, New York, New York, 1992).