Project Report
272

Operational and Spectrum Tests for ATIDS at Dallas/Fort Worth Airport

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20 September 1999

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LEXINGTON, MASSACHUSETTS

Prepared for the Federal Aviation Administration.
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Springfield, Virginia 22161.

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
ATC-272		

4. Title and Subtitle	5. Report Date
Operational and Spectrum Tests for ATIDS at Dallas/Fort Worth Airport	20 September 1999
	6. Performing Organization Code
7. Author(s)	**8. Performing Organization Report No.**
M.L. Wood	ATC-272
9. Performing Organization Name and Address	**10. Work Unit No. (TRAIS)**
MIT Lincoln Laboratory 244 Wood Street Lexington, MA 02420-9108	11. Contract or Grant No.
12. Sponsoring Agency Name and Address	**13. Type of Report and Period Covered**
Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington, DC 20591	ATC / September 1999
	14. Sponsoring Agency Code

15. Supplementary Notes

This report is based on studies performed at Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology, under Air Force Contract F19628-95-C-0002.

16. Abstract

Runway Incursion (RI) prevention programs would benefit from improved surveillance and target identity on the airport surface. The Airport Target Identification System (ATIDS) is a prototype multilateration and Automatic Dependent Surveillance-Broadcast (ADS-B) system that can provide these improvements. ATIDS requires additional activity in the 1030 and 1090 MHz frequency bands that are presently used by Air Traffic Control Radar Beacon Systems (ATCRBS) in Modes A, C, and S, and also by the Traffic Alert and Collision Avoidance System (TCAS). This activity includes ATIDS interrogations to and replies from surface transponders in all modes for multilateration, plus the ADS-B extended Modes S (i.e., squitter) replies.

The Runway Incursion Reduction Program (RIRP) team, which includes the FAA Volpe National Transportation System Center, the Massachusetts Institute of Technology Lincoln Laboratory, and Trios Associates, Inc., has conducted interference tests at Dallas/Fort Worth Airport (DFW) to quantify the impact that ATIDS would have on that high-use environment. The tests included environmental 1030/1090 MHz measurements, ATCRBS false target investigations, and Mode S reinterrogation tests. This document reports the results of these tests.

The results showed that the DFW 1030/1090 MHz environment is not approaching a critical point. This is because the interrogations and fruit generated by ATIDS are constrained by design limits, and the resulting impact on transponder availability and Secondary Surveillance Radar (SSR) reply processing is such that SSR performance will not be degraded. Also, the potential ATCRBS false target problem due to leaving ATCRBS transponders "on" while on the airport surface was found to be less severe than previously observed at Atlanta. False target reports from surface ATCRBS transponders would be rare at DFW, and even more rarely displayed with alphanumerics to controllers.

The Mode S reinterrogation test results verified analytical predictions and Joint Spectrum Center worst case simulations that showed the reinterrogation rate increase due to ADS-B would be small, and would not degrade the performance of the airport SSRs. The tests also showed that the worst case situation will not occur at DFW, because only about 30 percent of ADS-B aircraft on the surface would be positioned relative to the airport SSR so as to actually interfere with SSR reception of Mode S roll call replies. The results were extended to address interference to the Mode S SSR from ATIDS induced whisper shout replies from Mode A/C transponders. The SSR performance degradation is again negligible and less than that associated with future ADS-B surface squitters.

17. Key Words	18. Distribution Statement
	This document is available to the public through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	72	

FORM DOT F 1700.7 (8-72) Reproduction of completed page authorized

EXECUTIVE SUMMARY

Runway Incursion (RI) prevention is on the National Transportation Safety Board's (NTSB) list of "10 Most Wanted" safety improvements. Improved surveillance on the airport surface is an important ingredient in that it improves situational awareness and improves the accuracy of tracks used by automation algorithms. Towards this goal, the Runway Incursion Reduction Program (RIRP) has been developing the Airport Target Identification System (ATIDS). ATIDS is a prototype multilateration and Automatic Dependent Surveillance - Broadcast (ADS-B) system. It requires the enabling of existing transponders on the airport surface

The surveillance performed by ATIDS requires the additional transmission of signals in the 1030 MHz and 1090 MHz spectrum. It is of interest to the FAA to quantify the interference effects ATIDS might have in an operational environment. Operational systems which may be impacted by ATIDS use of the 1030/1090 MHz spectrum includes the beacon secondary surveillance sensor (SSR) in both monopulse and beamsplitting modes, and the Traffic Alert and Collision Avoidance System (TCAS) carried by all civilian airliners.

The RIRP team, which includes the FAA Volpe National Transportation System Center (VNTSC), Massachusetts Institute of Technology Lincoln Laboratory (MIT/LL), and Trios Associates, Inc., has conducted interference tests at Dallas/Fort Worth Airport (DFW) to quantify the impact that ATIDS would have on that high-use environment. The tests included environmental 1030/1090 MHz measurements, ATCRBS false target investigations, and Mode S re-interrogation tests. This document reports the results of these tests.

Tests were conducted to determine the current 1030/1090 MHz activity at ground level, the effect of ATIDS on the rate at which the DFW Mode S SSR would have to re-interrogate Mode S targets, and the rate at which ATCRBS transponders on the airport surface might cause false target reports.

It was found that the current 1030/1090 MHz activity at ground level is comparable to that previously measured at 11,000 feet. Any additional activity due to ATIDS will not significantly increase the current level of activity, and will not adversely affect existing systems.

The Mode S reinterrogation test performed at DFW was supplemented by additional testing at Lincoln Laboratory and analysis of DFW 1030 MHz data. The results indicate that the reinterrogation rate will be less than analytical predictions and simulations, and that the overall Mode S blip/scan performance will not be adversely impacted by ATIDS

The test to determine the effect of leaving ATCRBS transponders on while on the airport surface indicated that the East SSR would experience little or no false target reports from surface transponders. At the West SSR, for every 100 real target reports from surface transponders, there may occur one or two that are false. The false reports that were observed were not consistent enough to support scan-to-scan correlation and therefore would not likely be tracked by the ARTS automation systems. Thus, controllers would see an occasional slash on their displays, but no alphanumerics.

ACKNOWLEDGMENTS

This program was jointly sponsored by AND-402 and AND-410. In particular, the author wishes to express appreciation to Vincent Capezzuto, Richard Lay, John Loynes, Bill Syptak, and Arthur Sullivan.

Also, the author would like to thank the following organizations for their support, which significantly contributed to the program.

Dallas Fort Worth Airport

FAA DFW Tower

FAA DFW TRACON

FAA Southwest Region

Trios Associates

Volpe National Transportation Systems Center

In addition, the author is indebted to his colleagues: R.W. Bush, Lynne Adamian, Jonathan Bernays, Martin Brennan, Peter Daly, Gabriel Elkin, William Harman, Arnold Kaminsky, John Saia, and Kenneth Saunders.

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1. INTRODUCTION

Runway Incursions (RI's) in the United States have experienced a 16 percent average yearly increase from 1993 to 1997. This fact, coupled with recent surface accidents in Atlanta, Detroit, Los Angeles and St. Louis, ranks RI's as a top priority in the Federal Aviation Administration (FAA) and is listed on the National Transportation Safety Board's (NTSB) "10 Most Wanted" safety improvements.

It is generally accepted that increased situational awareness among all users and improved surveillance of the airport will be effective in reducing RI's that could lead to accidents. To this end, seamless surveillance coverage, identification of aircraft on the surface and information sharing with airport users have become a priority for the FAA. This priority is reflected in the FAA's "concept of Operations for the National Airspace System (NAS) in 2005" and the NAS Architecture.

To help attain the goal of seamless surveillance and identification of aircraft on the airport surface, the Runway Incursion Reduction Program (RIRP) has been developing the Airport Target Identification System (ATIDS). ATIDS is a prototype multilateration and Automatic Dependent Surveillance - Broadcast (ADS-B) system which functions with all types of Air Traffic Control Beacon System (ATCRBS) transponders; e.g., new Mode S transponders carried by all TCAS-equipped aircraft and older Mode A/C transponders. ATIDS uses the pseudo random squitters of Mode S transponders to obtain position and identification information. To maintain surveillance on Air Traffic Control Radar Beacon System (ATCRBS) Mode A/C aircraft, ATIDS performs a whisper-shout sequence similar to the Traffic Alert and Collision Avoidance System (TCAS). Both modes require that the transponders remain active while on the surface and emit 1090 MHz transmissions.

Since the surveillance performed by ATIDS requires the additional transmission of signals in the 1030 MHz and 1090 MHz spectrum, it is of interest to the FAA to quantify what interference effects ATIDS might have in an operational environment. Operational systems at DFW which may be impacted by ATIDS use of the 1030/1090 MHz spectrum include the Mode S sensor in both Mode S and Interim Beacon Interrogator (IBI) modes, and TCAS. The impact on SSRs at other airports is similar to that of the Mode S sensor at DFW, which operates in both monopulse and beamsplit modes. A previous large-scale demonstration at Atlanta Hartsfield International Airport (ATL) revealed little noticeable impact. (Impact of Enabling Transponders on the Airport Surface, Trios Associates Inc. for FAA-AND-410; September 8, 1998.)

The RIRP team, which includes the FAA Volpe National Transportation Systems Center, Massachusetts Institute of Technology Lincoln Laboratory (MIT/LL) and Trios Associates, Inc., has conducted interference tests at Dallas/Fort Worth Airport (DFW) to quantify the impact that ATIDS would have on that high-use environment. The tests included environmental 1030/1090 MHz measurements, ATCRBS false target investigations, and Mode S reinterrogation tests. This document reports the results of these tests.

2. OVERVIEW OF ATIDS SURVEILLANCE

ATIDS surveillance is performed by two or three-dimensional multilateration. Two-dimensional multilateration is a position measuring method in which the time of arrival differences of a signal emitted by a target in the plane of three receivers are used to form two hyperbolas, the intersection of which determines, in most cases unambiguously, the target position in the plane. Three-dimensional multilateration is similar, except that the signal is received by four receivers, and the position is determined by the intersection of three hyperboloids. The emission of the target signal may be spontaneously, or by stimulation by an outside agent.

ATIDS will work with all current and planned versions of Air Traffic Control Radar Beacon Systems. ATIDS performs multilateration on the spontaneous squitters emitted by Mode S transponders, and on replies elicited from older ATCRBS Mode A/C transponders by whisper shout interrogations.

2.1 REVIEW OF ATCRBS MODES A AND C

ATCRBS, with Modes A and C, is a secondary radar beacon system which was developed as an outgrowth of the military Identification Friend or Foe (IFF) system used in World War II. Ground sensors are called secondary surveillance radars (SSRs) and they operate in either beam split or monopulse mode. In both modes, an azimuthally narrow rotating beam emits a continuous stream of interrogation signals that are responded to by all transponders within the beam. ATCRBS measures the range as the elapsed time between the emission of the interrogation and the reception of a reply. There are several interrogation modes. The Mode A interrogation is a pair of 0.8μs wide pulses (P1 and P3) spaced by 8μs, to which the transponder replies with two 0.45μs pulses (F1 and F2) spaced by 20.3μs. The reply also contains up to 13 pulses between F1 and F2. In Mode A, these pulses will contain a 12-bit identity code. Mode C interrogation pulses are spaced at 21μs. The replies contain 12 bits of altitude obtained from the aircraft altimeter. The interrogations are emitted with a Pulse Repetition Frequency (PRF) of several hundred. The beam is about 4 degrees wide, and rotates with about a 4.6-second period. In older SSRs, there are about 20 replies received as the beam sweeps past a target. The azimuth of the target is taken as the beam pointing direction when the middle reply is received. This azimuth measuring technique is called beamsplitting. Newer SSRs employ monopulse techniques for azimuth estimation and use PRFs that range from a quarter to a half that of beamsplitting SSRs.

Transponders cannot be interrogated by the sidelobes of the directional main beam because of a technique called Interrogate Side Lobe Suppression (ISLS). In ISLS, an additional interrogation pulse (P2) is transmitted 2μs after P1. This transmission is over an omnidirectional antenna. This pulse is thus stronger than P1 in the sidelobes, and weaker than P1 in the mainbeam. The transponder will not reply when P2 is greater than P1. ISLS was implemented in the 1960's.

Several years after the implementation of ISLS, a modification was developed that helped reduce false target reports caused by reflections of the mainbeam off a building. The geometry of such false target reports is that the target is in the sidelobe of the beacon, and the mainbeam is pointing at a building whose orientation is such that the building reflects the P1, P3 pulses toward the target. The target sees the P2 from the omni by a direct path. The P1, P3 is delayed by the need to travel to the building and then to the target. This destroys the 2μs spacing between P1 and P2, so the transponder is not suppressed, and will (undesirably) reply to the reflected P1, P3. The modification to prevent such replies is called Improved Interrogator Side Lobe Suppression (IISLS). It works by sending an additional P1 signal (at reduced power) out the omni pattern. Therefore, the target sees P1, P2 (from the omni) before the arrival of the reflected P1,P3. The target will be suppressed, and will not reply to the P1,P3.

SSR type surveillance is not practical for targets on the airport surface. In the early years of ATCRBS, before ISLS, all the transponders on the airport would be close enough to the airport SSR to be interrogated by essentially the full 360-degree sidelobes. Also, the synchronous garble problem would be severe for both surface aircraft and aircraft on approach. Synchronous garble exists whenever two targets are within a beamwidth, and within a reply length in range (1.67 nmi), of each other. Both would reply to the interrogation, and the replies would overlap in time, making the code bits unreadable. Another problem on the airport surface is the large number of buildings which act as reflectors of the pulse emissions by both the SSR and the transponders. The reflections cause garbling which interferes with the interrogation and reply detection processes. Finally, even if ATCRBS worked on the surface, the range measurements would be too inaccurate (compared to aircraft spacing and pavement dimensions) due to the several hundred-foot uncertainty associated with the transponder turnaround time. This inaccuracy is of little consequence in the air, but is not good enough on the surface where aircraft get close together. For these reasons, ATCRBS transponders are placed in standby mode on the airport surface, except when on the runway. They are active on the runway so that they can be acquired quickly after takeoff, or tracked as far down as possible while landing.

Multilateration has been recognized as having the potential to provide reliable and accurate surveillance on the airport surface for several decades, provided that an effective means is available to elicit replies on which to measure times of arrival. Multilateration accuracy would not be affected by transponder turnaround time, since it cancels out when time of arrival differences are computed. Propagation problems associated with building blockage and reflections, and fading associated with vertical multipath off the ground, would be mitigated by employing a redundancy of low cost receivers and making timing measurements on the first pulse of replies. The receivers would be low cost because the associated antennas would be simple fixed, broad beams, instead of expensive large rotating antennas such as those used for ATCRBS.

Historically, three means to elicit transponder replies have been used for multilateration. The first, by the Bendix Corporation in the 1970's used large aperture antennas with steerable narrow beams to interrogate only one transponder at a time. The expense of the antennas made the system impractical. However, the system worked well during tests at Boston Logan Airport. The accuracy was as predicted, about 20 feet standard deviation.

In the 1980's, the Cardion Corporation demonstrated a multilateration system with similar accuracy at Atlantic City Airport. The ATCRBS transponders were modified to emit a pair of replies spaced at about 175μs every second. The modification consisted of an onboard transponder tickler package. The receivers performed multilateration on replies received with that spacing. The pair concept eliminated the communications and computational intractability of trying to sort out the desired elicited replies from the thousands of replies (called "fruit" replies) that naturally exist in the environment due to the operation of other SSRs.

In the 1990's, the FAA and MIT Lincoln Laboratory contracted with Cardion to explore the application of the whisper shout technique that TCAS employs to perform garble free surveillance of ATCRBS targets on the airport surface. The concept demonstration experiment utilized pairs of whisper shout interrogations spaced at about 175μs, so that the resulting elicited replies could be distinguished from background fruit replies in the same manner as for the modified transponders described in the preceding paragraph. Only reply pairs with that spacing were sent to the central processing computer for use in multilateration computations.

2.2 MODE S

Mode S is an upgrade to ATCRBS in which each transponder has a unique address, and the beacon sensors may individually address interrogations to and receive replies from particular transponders. The United States Mode S sensors employ monopulse techniques for azimuth measurement on Mode A,C and S replies. European sensors and some future United States sensors do not have a Mode S discrete interrogation mode, but employ monopulse on Modes A and C.

Mode S was developed to eliminate the synchronous garble that ATCRBS suffers from, and to reduce the fruit on the 1090 MHz channel by using a lower PRF for surveillance of existing ATCRBS transponders. The azimuth accuracy is provided by using a monopulse technique in which the target offboresight position is measured by suitable processing of two beams (the "sum" and "difference" beams) formed by the elements of the phased array antenna. This monopulse technique provides good accuracy without the need for the high PRFs necessary for the beamsplitting technique.

Ground sensors measure the range as the elapsed time between interrogation transmission and reply reception. The azimuth is measured by the pointing direction of the azimuthally narrow rotating beam, augmented by the monopulse determination of the target location within the beam. The sensor must know the position and address of the transponder in order to interrogate it. This information may be initially given to the sensor by some means, or the sensor may obtain it unilaterally. The unilateral method involves an "all-call" search interrogation to which all Mode S transponders that are not currently known to the sensor will reply. The sensor will cause transponders it already knows the address of to be inhibited from replying to the all-call.

Mode S ATCRBS transponders have Mode A/C capability as well as Mode S so that they can be interrogated by the older Mode A/C SSRs. The Mode A/C capability is locked out to TCAS and ATIDS, which rely on the Mode S mode. The lockout is accomplished by including a P4 pulse

2μs after the P3 pulse. Mode S transponders recognize it and will not reply. ATCRBS A/C transponders do not recognize the presence of the P4 pulse. Finally, to prevent the long energies in the Modes S interrogations from interrogating Mode A/C transponders, the Mode S interrogation is preceded by two pulses separated by 2μs. These P1, P2 pulses suppress the Mode A/C transponders for the duration of the Mode S interrogation.

2.3 TCAS FEATURES APPLICABLE TO MULTILATERATION

The development of TCAS led to two features of beacon operation that enable the use of multilateration on the airport surface. In ATCRBS Mode A/C, the feature is "whisper shout", and in Mode S, it is the "squitter".

2.3.1 ATCRBS Whisper Shout

An operational requirement of TCAS was that it provide the TCAS equipped aircraft with collision avoidance protection against threatening intruder aircraft that are equipped with ATCRBS Mode A/C transponders. As mentioned in an earlier section, ATCRBS Mode A/C interrogations are responded to by all transponders that hear the interrogation (i.e., that are within the narrow rotating beam). However, it would not be possible to provide a TCAS aircraft with a narrow rotating beam. Size limitations necessitate the use of a small aperture antenna that is only capable of making beams about 90 degrees wide. TCAS is required to work in fairly dense airspace, and out to about 15 nmi. The potential number of ATCRBS in a 90-degree sector out to 15 nmi in dense airspace could be ten or more. If all these ATCRBS transponders replied to an interrogation, the replies would be hopelessly overlapped and garbled. Therefore, a technique whereby the transponders could be interrogated in manageable subsets was developed and is called whisper shout. Whisper shout exploits the ISLS feature of the ATCRBS transponders.

The TCAS whisper shout interrogation technique consists of a sequence of about 26 interrogations starting at a very low power and increasing to about 250 watts in 1-dB steps. In a possible target scenario of 10 ATCRBS transponders between 1 nmi and 15 nmi in range from the TCAS interrogating aircraft, the lowest power whisper shout interrogation might be heard by only the closest ATCRBS target, so the reply would be received by TCAS ungarbled. The next interrogation (1 dB higher) might be heard by the two closest aircraft. However, the closest transponder will not reply to the second interrogation even though it hears both the P1 and P3 pulses. The reason is because the interrogation includes an additional pulse (the S1 pulse) that is emitted 2μs before the P1, and with 1 dB less power than P1. The closest transponder hears the S1, P1 combination, which looks to the transponder like a suppression pair, and so it does not reply. The second transponder sees the P1 and P3, but the S1 is too weak to see (i.e., is below MTL), so the transponder replies. This process continues with another 24 interrogations. Eventually, on average, each transponder sees an interrogation to which it, and no other aircraft, replies.

At first glance, it would seem that two ATCRBS transponders at the same range from the TCAS aircraft would both reply to the same whisper shout interrogation because the path losses due to range are the same. But, in practice, the two aircraft have different antenna gains towards the TCAS transmitter, and the TCAS antenna has different gains toward the aircraft. This is due to the natural variations in antenna gains in various directions caused by the shape of the fuselage and the attitude of the aircraft. In addition, each transponder will tend to have different MTLs, receiver sensitivities, cable losses, etc. So, in fact, it is usually true that two aircraft at the same range from the TCAS actually reply to different whisper shout interrogations.

As described in a previous section, normal ATCRBS interrogations to closely spaced aircraft on the airport surface would result in synchronously garbled replies. These replies would not be usable for multilateration. However, tests of whisper shout performed with Cardion equipment at Atlanta Hartsfield Airport showed that the technique does degarble ATCRBS transponders on the airport surface sufficiently to perform multilateration position determination. (See "Multilateration on Mode S and ATCRBS Signals at Atlanta's Hartsfield Airport", M.L. Wood and R. W. Bush, Project Report ATC-260, Lincoln Laboratory, 8 January 1998).

Mode A/C interrogations from Mode S ground SSRs and whisper shout interrogations from either TCAS equipped aircraft or from ATIDS do not elicit replies from Mode S-equipped aircraft. This is achieved by transmitting a P4 pulse 2μs after the P3 pulse. The P4 pulse was introduced with the Mode S system.

2.3.2 Mode S Squitter

Even though Mode S transponders can be interrogated with ATCRBS interrogations, it would be beneficial for TCAS to use discrete addressed interrogations for Mode S intruders. However, the lack of a narrow rotating beam would make it virtually impossible to use the all-call technique used by Mode S ground SSR's to learn of the Mode S addresses of aircraft in the vicinity of the TCAS. Therefore, Mode S transponders were designed to spontaneously emit a "squitter" reply at an average rate of 1 Hz. This reply, which contains the Mode S address of the transponder, was specifically designed for TCAS so that TCAS units can learn of the address of nearby intruder aircraft and begin to make discretely addressed surveillance interrogations.

The Mode S squitter signal can be used for multilateration on the airport surface, as was demonstrated and described in the report referenced above.

2.4 TRANSPONDER OPERATIONAL ISSUES ON THE AIRPORT SURFACE

2.4.1 ATCRBS Transponders

For many years there has been an operational requirement that ATCRBS transponders be in standby on the airport surface, except when on the runways. This procedure was instituted many years ago before the introduction of:

a. Interrogate Side Lobe Suppression, and Improved Interrogate Side Lobe Suppression (ISLS, previously described)

b. Receive Side Lobe Suppression (RSLS, in which the SSR receiver can discard replies received in the sidelobes of the narrow mainbeam)

c. SSR processing algorithms that can eliminate ATCRBS false targets caused by reflections off of buildings in the vicinity of the airport, and

d. Mode S transponders, which considerably reduce the ATCRBS transponder population at major airports.

It is now probable that leaving relatively small numbers of ATCRBS transponders "on" while on the airport surface, including the taxiways and other portions of the movement area, will not cause disruption to the airport SSR, whether it is operating in beamsplitting or monopulse mode. Also, the TCAS system now includes features that prevent the issuing of TCAS warnings to airborne pilots due to ATCRBS aircraft on the ground.

One of the purposes of the tests described in this report is to verify that leaving ATCRBS transponders on while on the airport surface will not have any adverse system effects.

2.4.2 Mode S Transponders

Although not required by any formal procedure, it is customary for pilots to turn their Mode S transponders to "standby" mode when they are on the airport surface, except when on the active runway. Squitters are inhibited when in "standby". Another purpose of the tests described in this report is to see if there are any adverse effects if Mode S transponders continue to emit existing short (64μs) squitters or proposed new extended (120μs) ADS-B squitters over all the movement area. The Mode S transponders have a mode in which, when there is weight on the wheels, they will continue to squitter, and also reply to addressed interrogations, but will not reply to the all call interrogations or Mode A/C interrogations. This is the mode that is proposed to be invoked over the movement area, so that the squitters are available for multilateration.

3. ATCRBS FALSE TARGET TESTS

3.1 ATCRBS FALSE TARGET BACKGROUND

When a narrow beam sweeps past a Mode A/C equipped aircraft, the number of replies that are elicited depends on the type of SSR. About 5 replies will be elicited if the SSR is a monopulse such as the DFW sensor operating in the Mode S mode. About 20 replies will be elicited if the SSR is an ATCRBS Mode A/C beamsplitting sensor or a Mode S sensor operating in the Interim Beacon Interrogator (IBI) mode. The SSR contains algorithms that correlate the replies into a single target report, consisting of range, azimuth, Mode A identity code, and Mode C altitude. Additional algorithms perform scan-to-scan correlation of target reports from the same aircraft into a track for that aircraft within the sensor. The terminal automation system (ARTS) performs similar scan-to-scan processing to produce tracks and tags for airborne aircraft..

ATCRBS false targets can be created by reflections of the main beam interrogations off a building or other reflector. The false target report will have the same Mode A code and Mode C altitude as the real target. When the main beam points at the building, the interrogation pulses can be reflected towards a real target, whose transponder will reply. The reply will return to the SSR antenna over the same path via the building. The result is a target report at the azimuth of the building, and a range corresponding to the two-part distance from the SSR to the building to the target. ATCRBS, and the ATCRBS mode of the Mode S SSR, have two defenses against these false targets.

The first defense is called Improved Interrogator Side Lobe Suppression (IISLS). It is similar to ISLS, except that the P1 interrogation pulse is a combination of energy emitted from the main beam plus a contribution from the omni antenna pattern. Every target that is within the range of the sidelobes will thus see a P1 (from the combination mainbeam sidelobe and omni) and a P2 (from the omni). This pair will be received on a straight-line path. The relative powers of the transmissions are such that the P2 pulse will be greater than the P1. Therefore the transponder will suppress for 35μs, and this suppression will be in effect before the P1, P3 mainbeam reflection off the building arrives (due to the greater distance the reflection must travel). Thus, the transponder will be inhibited from replying to reflected interrogations.

The second defense is an algorithm within the sensor that recognizes the occurrence of two ATCRBS target reports with the same Mode A 4096 discrete code on the same scan, but at different ranges and bearings. If the report with the greater range has a bearing equal to that of a known reflecting building, and if the greater range equals the sum of the range to the known building plus the distance from the building to the other (presumably real) target report, then the greater range target report is not output. This algorithm also functions with non-discrete beacon codes with additional conditions for censoring. Receive Side Lobe Suppression is not a defense for the majority of reflections because they are received in the main beam.

3.2 FAILURE MECHANISM

There is a mechanism by which false target reports will be output and displayed to the controllers. It involves a dual failure of the two above-mentioned defenses. First, the IISLS function must fail. This can occur if the real target cannot receive the P1, P2 pre-emptive suppression pair, perhaps because the direct line of sight from the SSR to the target is blocked by a building. Thus, the transponder will be available to reply to the reflection of the mainbeam interrogation off a building. If, in addition, the real target is not visible to the sensor, because it does not receive the mainbeam P1, P3 interrogation, or it does but the replies are not decodable by the SSR receive processing, then the false target elimination algorithm will not be able to delete the false target.

This problem was observed at Atlanta Hartsfield airport when an ATCRBS target was behind the Delta hangar (with respect to the SSR) and therefore could not be pre-emptively suppressed, and could not be tracked within the sensor. The target was interrogated by mainbeam reflections of P1, P3 off the Hilton hotel, thus creating a false reports at the bearing of the hotel and at a range about a mile off the airport surface. The reports that passed scan-to-scan correlation within ARTS produced false tracks off the airport, but with the altitude of the airport surface.

The purpose of the ATCRBS false target tests at Dallas was to investigate whether such situations might occur at DFW.

3.3 THE TEST DESCRIPTION

The ATCRBS false target test was conducted by traveling on the East and West movement areas of DFW in a van equipped with an ATCRBS transponder operating with a monopole antenna on the roof about 7 feet above the ground. The transponder was interrogated by both the East and West SSRs. The SSRs were operated either in the Mode S monopulse mode or the IBI mode, and replies and reports were recorded. The van was also equipped with the Lincoln Laboratory Airborne Measurements Facility (AMF). The AMF detects and records the time, amplitude and width of either 1030 MHz or 1090 MHz pulses. Post processing of the recorded pulses can identify 1030 MHz interrogations or 1090 MHz replies. In addition, the AMF records GPS position data, and the transponder output to the suppression bus. The transponder outputs a signal to the suppression bus whenever the transponder replies. The purpose of the suppression bus is to inform receivers on the aircraft of emissions by on-board devices, such as the transponder. The receivers respond to this signal in a way that protects the receiver from the high energies of the emissions. This "suppression" of on-board receivers is not the same process as the internal "suppression" process in transponders that occurs when they see the two 1030 MHz pulses, spaced at 2μs, that constitute the ISLS and IISLS functions of the SSR and TCAS interrogators.

Figure 1 shows a black and white aerial photo of the DFW airport. Figure 2 is a diagram showing the runways and taxiways.

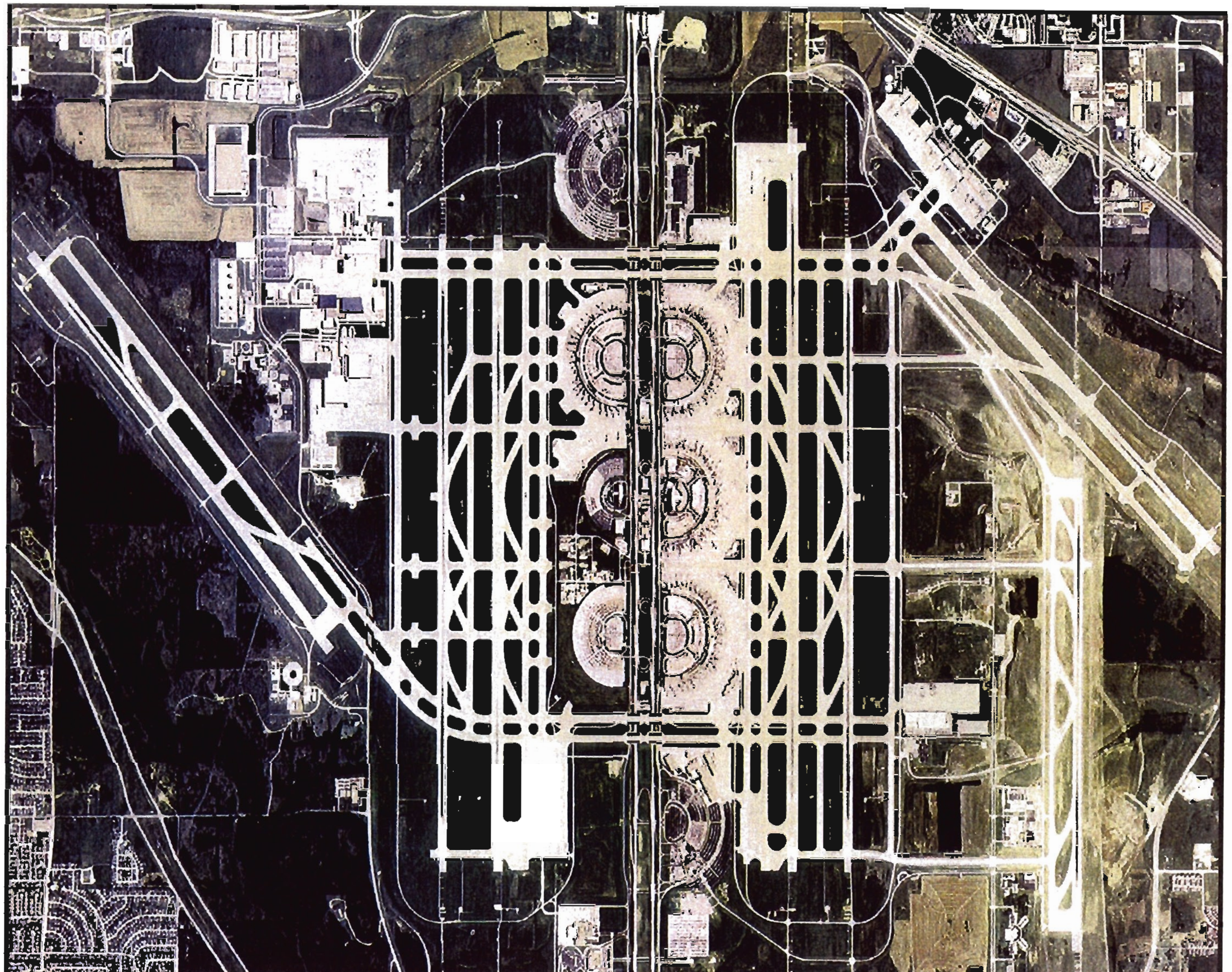

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Figure 1. Aerial photo of DFW Airport.
(Scale = 3425 ft/in)

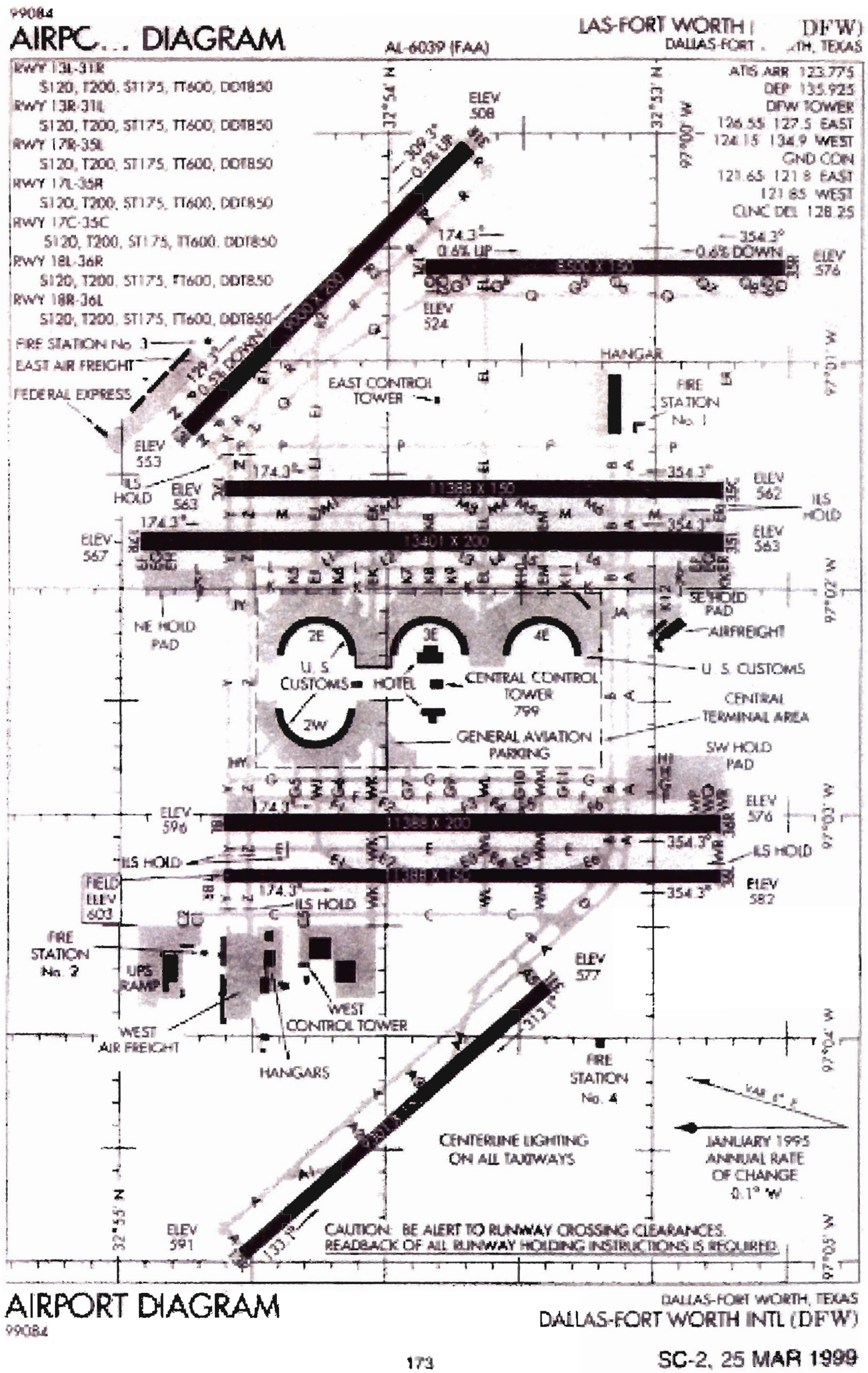


Figure 2. Diagram of DFW Airport.

The van's route and speed were chosen so as to allow the whole airport to be covered in a reasonable amount of available time during the night. To save time, the route concentrated on the taxiways, because ATCRBS transponders are "on", under current every day procedures, while on the runways, so the false target behavior would already be a matter of record. The route included driving segments of taxiway at anywhere from 10 to 40 mph, and stationary periods of a minute or so.

3.4 EXPERIMENTAL SESSIONS

The false target tests were conducted on the nights of Tuesday, 19 January 1999 (continuing into the next morning) and Wednesday, 20 January 1999 (continuing into the next morning). The following sections describe the results of these tests.

3.4.1 Tuesday, 19 January 1999

On Tuesday, 19 January 1999 (on into the next morning), the van with the ATCRBS transponder was driven on both the East and West sides of DFW airport. The West side SSR was operated in the Mode S mode, and ATCRBS replies and target reports were recorded. (Note that when SSRs operate in the Mode S mode, they still possess an ATCRBS mode for surveillance of ATCRBS targets. The mode uses a low Pulse Repetition Frequency (PRF), and determines azimuth from monopulse techniques.) It was planned to operate the East side SSR in the IBI mode and record data, but logistical problems arose preventing any data recording. (The IBI mode is when a Mode S SSR performs all surveillance in the ATCRBS beam-splitting mode, even for Mode S transponders. This mode uses a high PRF, and monopulse information is not utilized.) In addition, the AMF operator was not available for data recording during this night's test. Therefore, the Tuesday night data consisted of Mode S target report recording from the West SSR, operating in the Mode S mode, while the van traversed both sides of the airport. The van's ATCRBS transponder Mode A code was set to 0204.

3.4.1.1 Target Reports

Figure 3 shows the ATCRBS target reports (with Mode A code = 0204) received by the West SSR operating in the Mode S mode. The target reports are represented by the black dots, which appear in the center of gray circles so that the reports are discernible against the dark background of the aerial photo. Figure 4 shows the target reports positions on a grid. The (0,0) point on the grid is at longitude 97° 2.5' W, and latitude 32° 54.0' N, an arbitrarily chosen airport reference point. The thin lines show the path traveled by the van. The van's position was recorded by a laptop GPS system provided by Trios Associates. The data show that target report detection is fairly reliable on some portions of the movement area, and non-existent on other portions. The reasons for no reports are certain to include blockage by terminal and other buildings, and perhaps multipath phenomena that prevent either interrogation or reply decoding. These data are for ATCRBS interrogations and replies from the West SSR. The SSR was operating in the Mode S mode, with a PRF of about 100, so that there are only a few hits when the beam sweeps past the target on which to elicit replies to correlate into target reports.

3.4.1.2 Interrogation

Since the AMF was not operating on this night, there is no recording of SSR interrogation pulses, and no record of the ATCRBS transponder suppression output, which would indicate when the transponder replied. (The ATCRBS transponder outputs a signal on the "suppression bus output" whenever the transponder replies to an interrogation. This process is not the same as the internal suppression of the transponder when it sees two 1030 MHz pulses spaced at 2μs.) However, some indication of where the transponder can be interrogated can be inferred from the next night's AMF suppression bus recordings made on Wednesday, 20 January (on into the next morning). This is shown in Figures 5 and 6. Figure 5 shows transponder suppression bus outputs, corresponding to interrogations, caused by the West SSR operating in the IBI mode, during the van's traversal of both sides of the airport while target report data were being recorded at the East SSR operating in the IBI Mode (circuit 1). Figure 6 shows the same thing during the van's traversal while the East SSR was operating in the Mode S mode (circuit 2). Figures 5 and 6 are very similar, because the ATCRBS transponder in the van experienced the same interrogation activity from the West SSR (operating in the IBI mode) on each traversal of the airport. In general, the "dots" are from consecutive scans of the West SSR. Therefore, the speed of the van can be estimated, using the dot spacing, and the scan period, which is about 4.62 seconds. As can be seen, the van made "stops" along some of the taxiways, by turning off and holding briefly on a crossing taxiway.

Comparing Tuesday's Figure 4 with Wednesday's Figures 5 and 6 gives rise to the question of why aren't there Figure 4 received target reports over a greater region of the airport, since interrogations seem to be made over most of the airport. An answer to this question will require analysis of the AMF and SSR recorded data that may be done after this report is published. Possible explanations include that the interrogation link is stronger than the reply link, or that horizontal multipath caused by buildings is less detrimental to the interrogation detection process in the transponder than to the reply detection process in the SSR, or that Receive Side Lobe Suppression (RSLS) narrowed the reply beam more than ISLS narrowed the interrogate beam. RSLS for ATCRBS in the IBI mode has been added to the Mode S sensor as an upgrade, and its settings need to be examined.

Plots such as in Figures 5 and 6, showing the ATCRBS suppression bus outputs (which indicate that the transponder has replied to an interrogation) as a function of which SSR (East or West) and which mode (Mode S or IBI) are possible because the AMF samples and records the transponder's suppression bus outputs with an 8 MHz clock. On the Wednesday night that the AMF was operating, the West SSR was in the IBI mode the whole session. The East SSR was in the IBI mode the first half of the session, and the Mode S mode in the second half. Examination of the suppression bus outputs permitted identification of the ATCRBS interrogation spacings of the two SSR's in the two modes (excepting the West SSR in Mode S mode). The results are given in Table 1. The IBI mode PRF is about 400 to 500, and the Mode S PRF's are about 120 to 130.

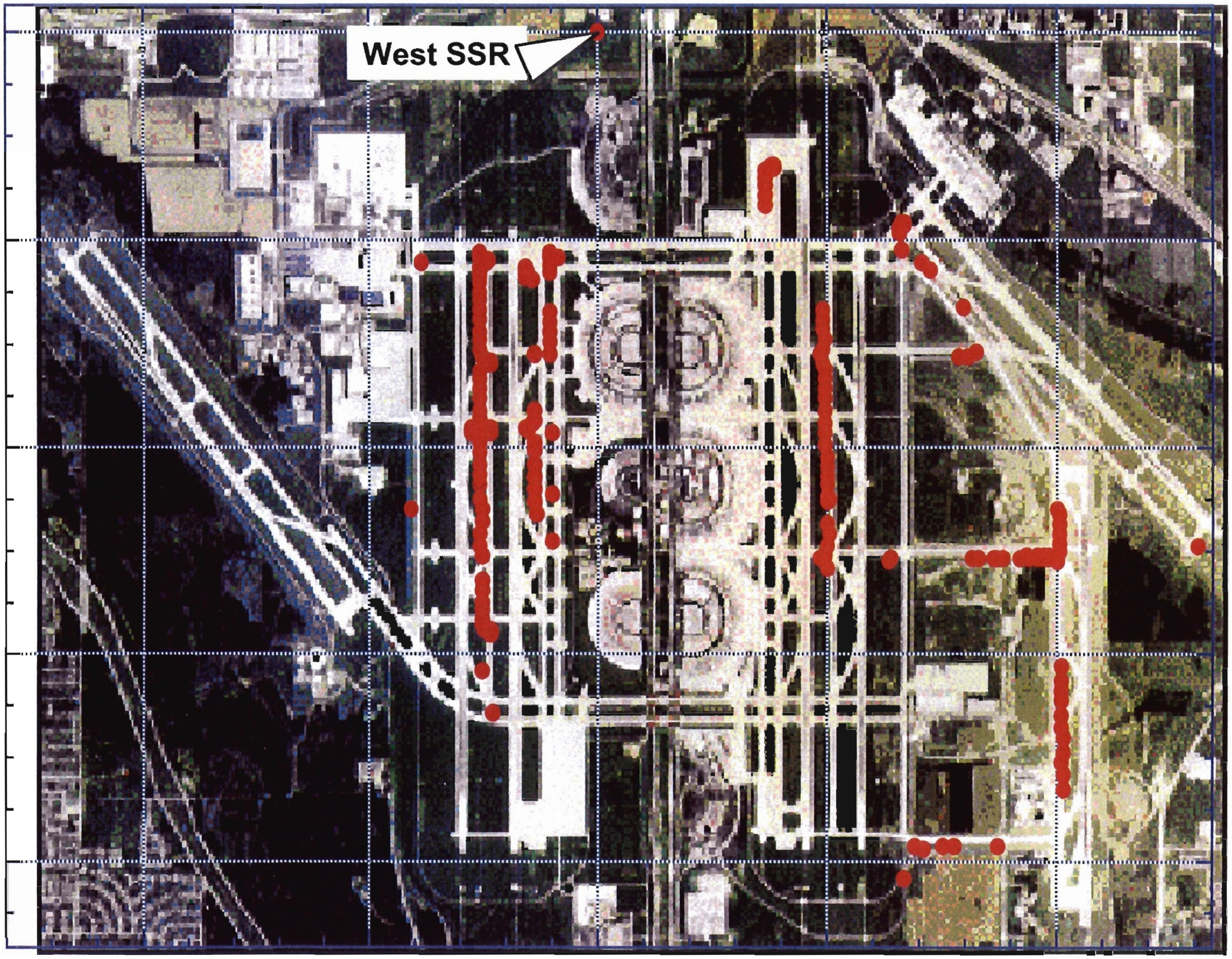


Figure 3. ATCRBS target reports, received by West SSR, operating in Mode S mode, (Tue, 1/19/99)

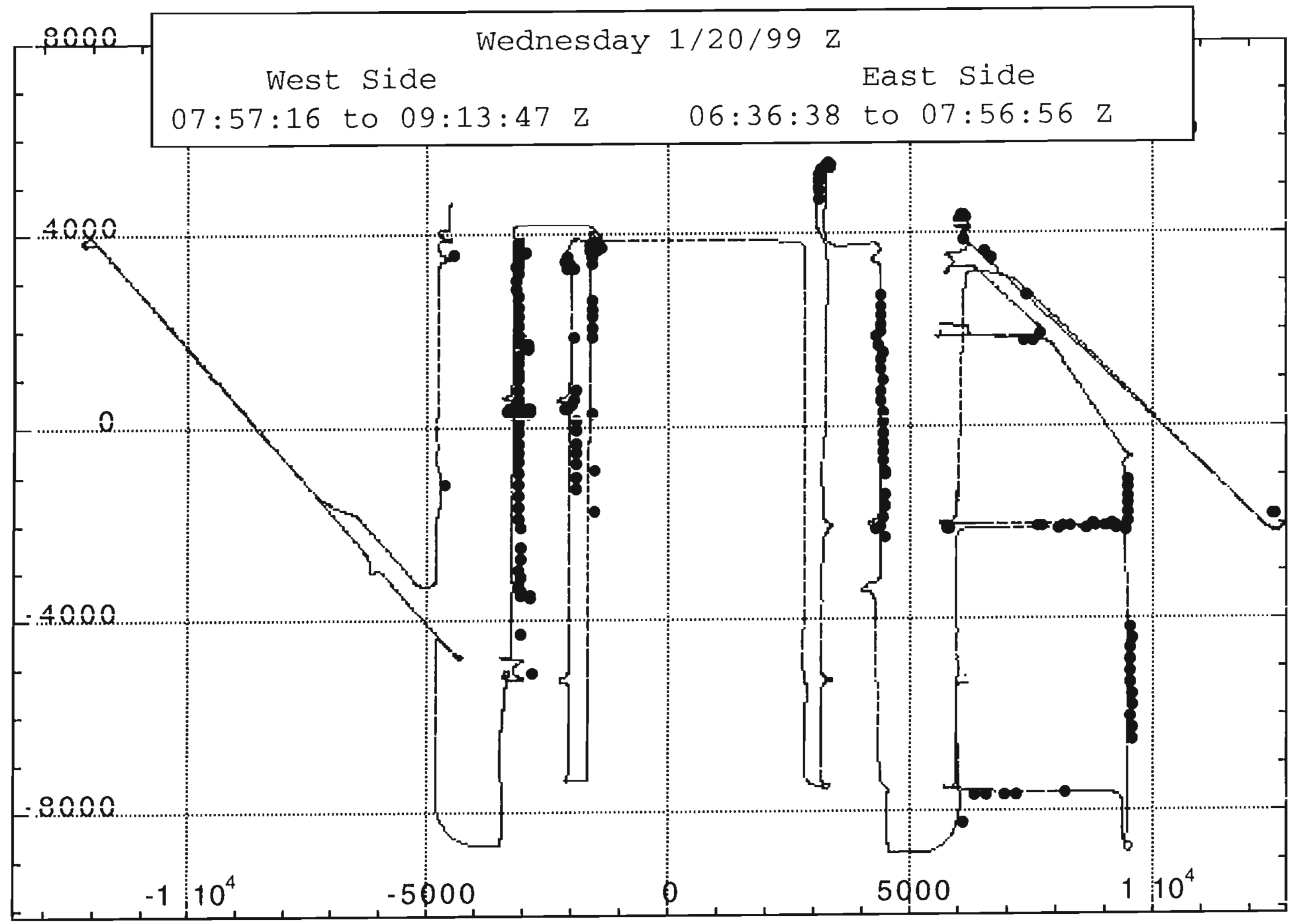


Figure 4. ATCRBS target reports with van route, received by West SSR, operating in Mode S mode, (Tuesday, 1/19/99, Local).

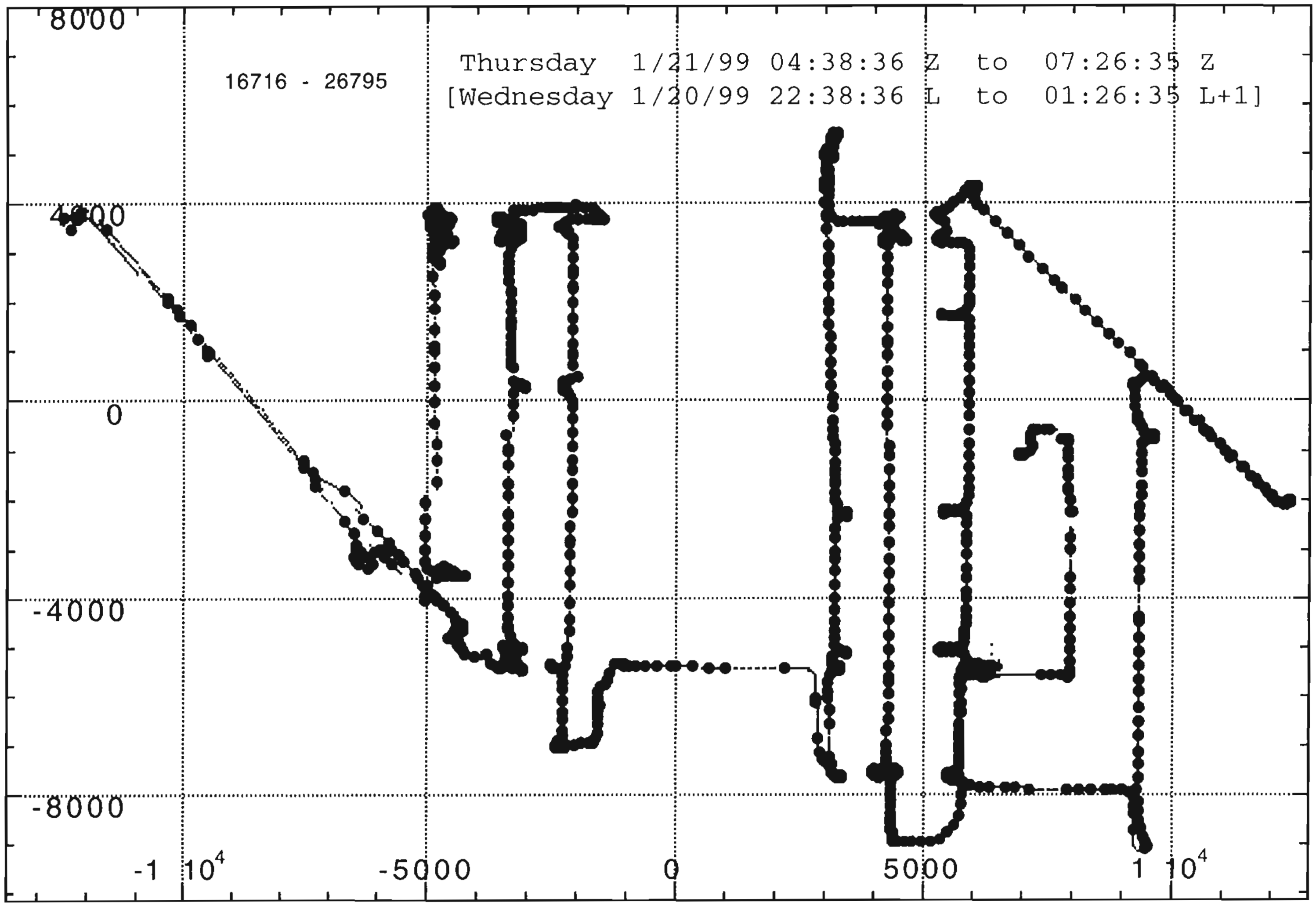


Figure 5. ATCRBS suppression bus outputs (recorded by AMF) caused by the West SSR, operating in the IBI mode (Wed, 1/20/99, circuit 1).

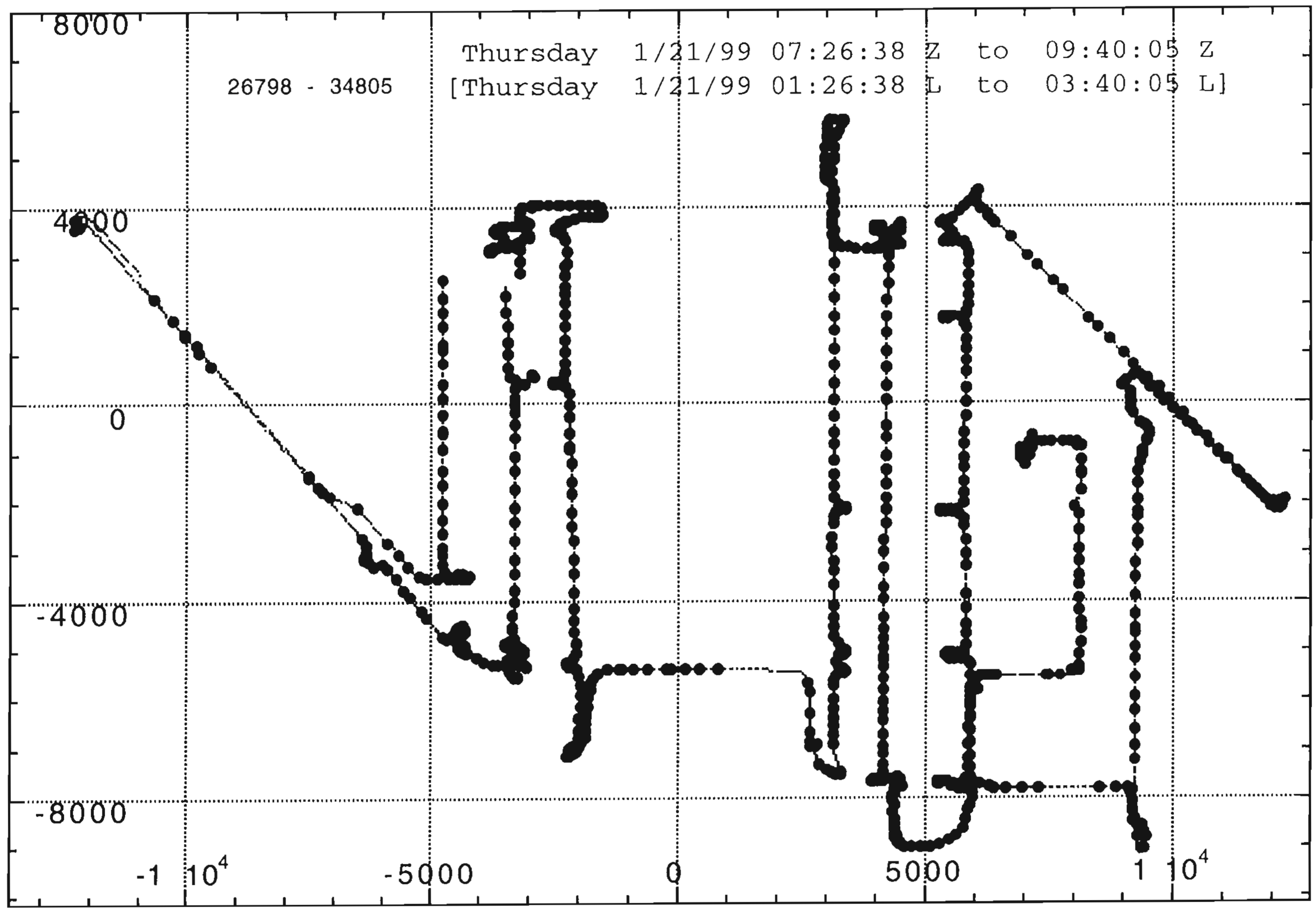


Figure 6. ATCRBS suppression bus outputs (recorded by AMF) caused by the West SSR operating in the IBI mode (Wed, 1/20/99, circuit 2).

Table 1. ATCRBS Interrogation Spacings (in 8 MHz counts)

IBI Mode		Mode S Mode	
East SSR	West SSR	East SSR (West Side Van Path)	East SSR (East Side Van Path)
16030	15807	60783	60800
16078	15856	61040	60880
16104	15881	61088	61055
18760	18502	61263	61136
18873	18612	61343	61375
18983	18725	61472	61552
22246	21937	61728	61808
24211	23878	65103	65215
32999	32541		

3.4.1.3 False Targets

Examination of Figure 4 shows no false target reports with the van's Mode A code within the area shown by the figure. Figure 7a shows all target reports with the van's Mode A code. There are 4 reports with the van's code that are false, indicated by the square symbols with slashes. Figures 7b through 7e show the location of the reflecting surface, indicated by an open square. (The numbers in the titles are the x values of the false report.) Table 2 below shows that the percent of false target reports from the van compared to the number of real target reports from the van is less than 2 percent for DFW. The Mode S sensor was using the limited static reflector capability. The new dynamic reflector software, which automatically locates and uses reflector information was not installed. This enhancement is scheduled for late 1999.

Three of the false target reports (Figures 7b, 7d, and 7e) were received when the van was stopped. This is significant, because it indicates that the mechanisms that caused these reports were not consistent enough, even though the geometry was constant, to produce enough target reports to form a track in the sensor or ARTS. Therefore, controllers would not see alphanumerics for these false reports.

The van was traveling at about 40 MPH when the false report in Figure 7c was received. At this speed, the van traveled almost 300 feet during a scan of the SSR. False track formation might be very unlikely at these speeds, because the geometry that causes the false track may not exist over a wide enough area to produce several scans of false reports that could be correlated into a false track. It is not possible to say whether a false track would have been created if the van had been stationary.

There was no real track on the van in the internal SSR track file for any of the 4 false target scenarios, and no real report received on the same scan as the false report. Therefore, neither the existing or new dynamic reflector algorithms would have censored the false reports.

Table 2. False Target Percentages, Mode S Mode from West SSR

	Real Surface Reports on the Van	False Surface Reports on the Van	Percent False
East Side	133	2	1.5 %
West Side	223	2	0.9 %

Figure 7f shows the locations of the reflectors related to Figures 7b through 7e. Accurate determination of the reflecting buildings would require a better aerial photo. Plausible guesses as to the particular structures that cause the reflections are:

7b. One of the hotels, perhaps the Harvey.

7c. A structure along MacArthur Blvd. near the intersection with US 30. A topographic indicates the presence of some radio towers, which may be the reflecting surface.

7d. A building, sign, or overpass at the junction of Rt. 114 and the Northwest Highway. Previous studies of false targets arising from airborne aircraft in the vicinity of DFW have also implicated structures along nearby major roads.

7e. A building north across the access road, or structure related to the intersection of Rt. 114 and Rt. 97, just north of the SSR.

3.4.2 Wednesday, 20 January 1999, Mode S Mode

On Wednesday night, 20 January (on into the next morning), the van with the ATCRBS transponder made two complete traversals of the entire airport, i.e., both the east and west sides. The transponder Mode A code was 4636. During the first traversal the East SSR was operated in the IBI mode, and ATCRBS target report data were recorded. On the second traversal the East SSR was operated in the Mode S mode, and ATCRBS target reports were recorded. The AMF was operational, and recorded 1030 MHz pulses, the output of the ATCRBS transponder suppression bus, and GPS positions. The transponder suppression bus outputs a signal whenever the transponder replies to an interrogation, and the AMF records the time of the signal. This section describes the results of ATCRBS surveillance by the Mode S mode of the East SSR.

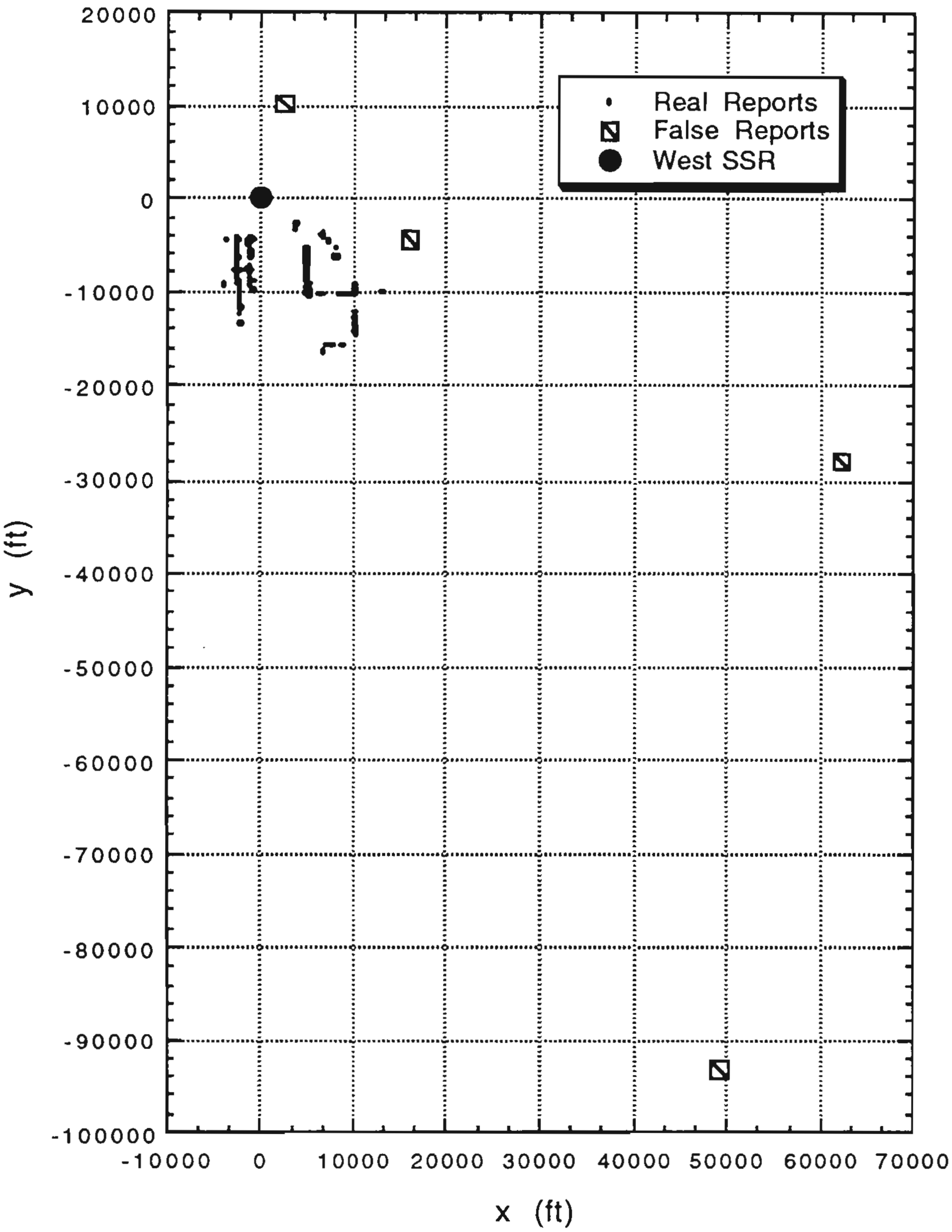


Figure 7a. All ATCRBS false target reports received by West SSR, operating in Mode S mode (Tue, 1/19/99).

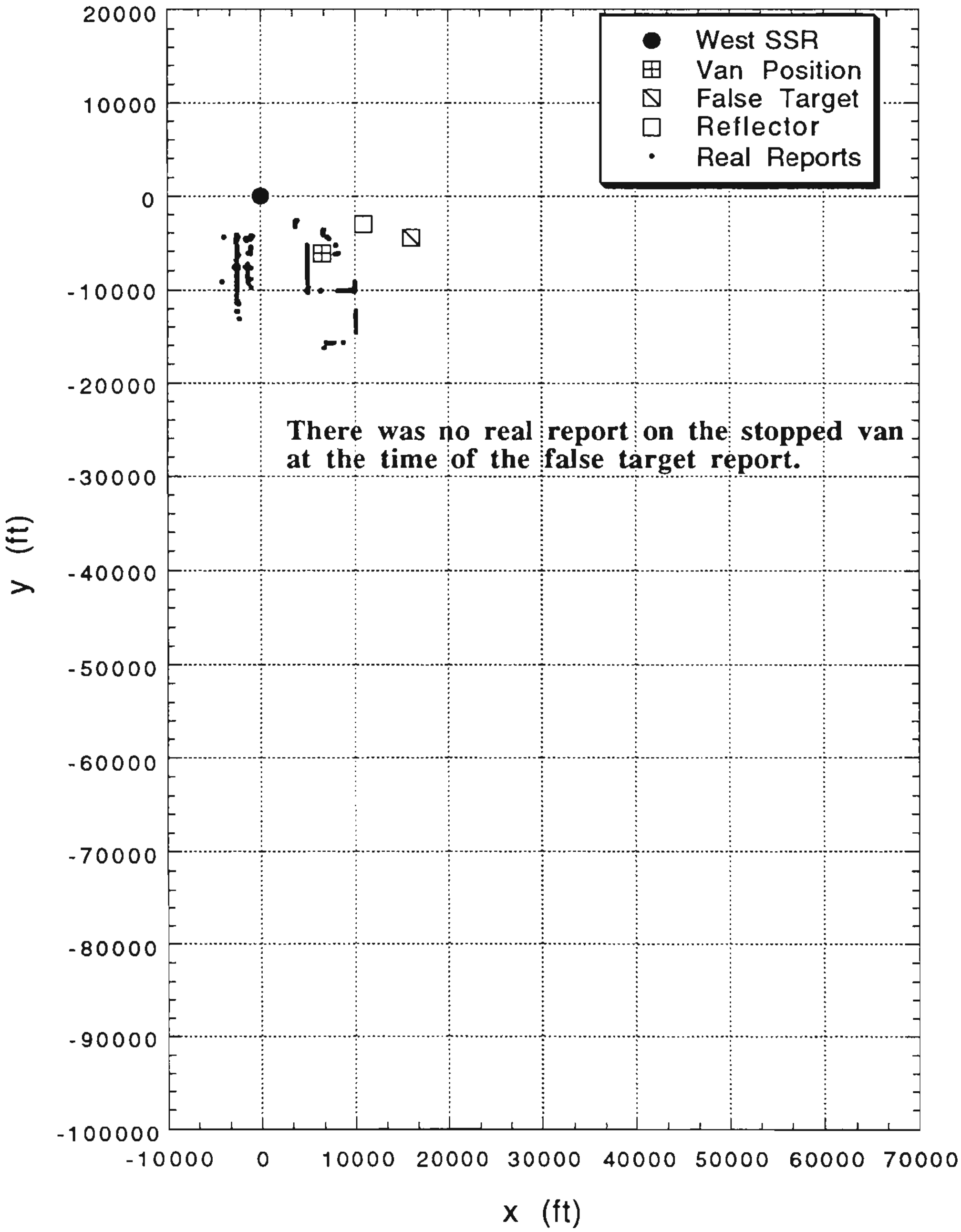


Figure 7b. ATCRBS false target report 16022, received by West SSR, operating in Mode S mode (Tue, 1/19/99).

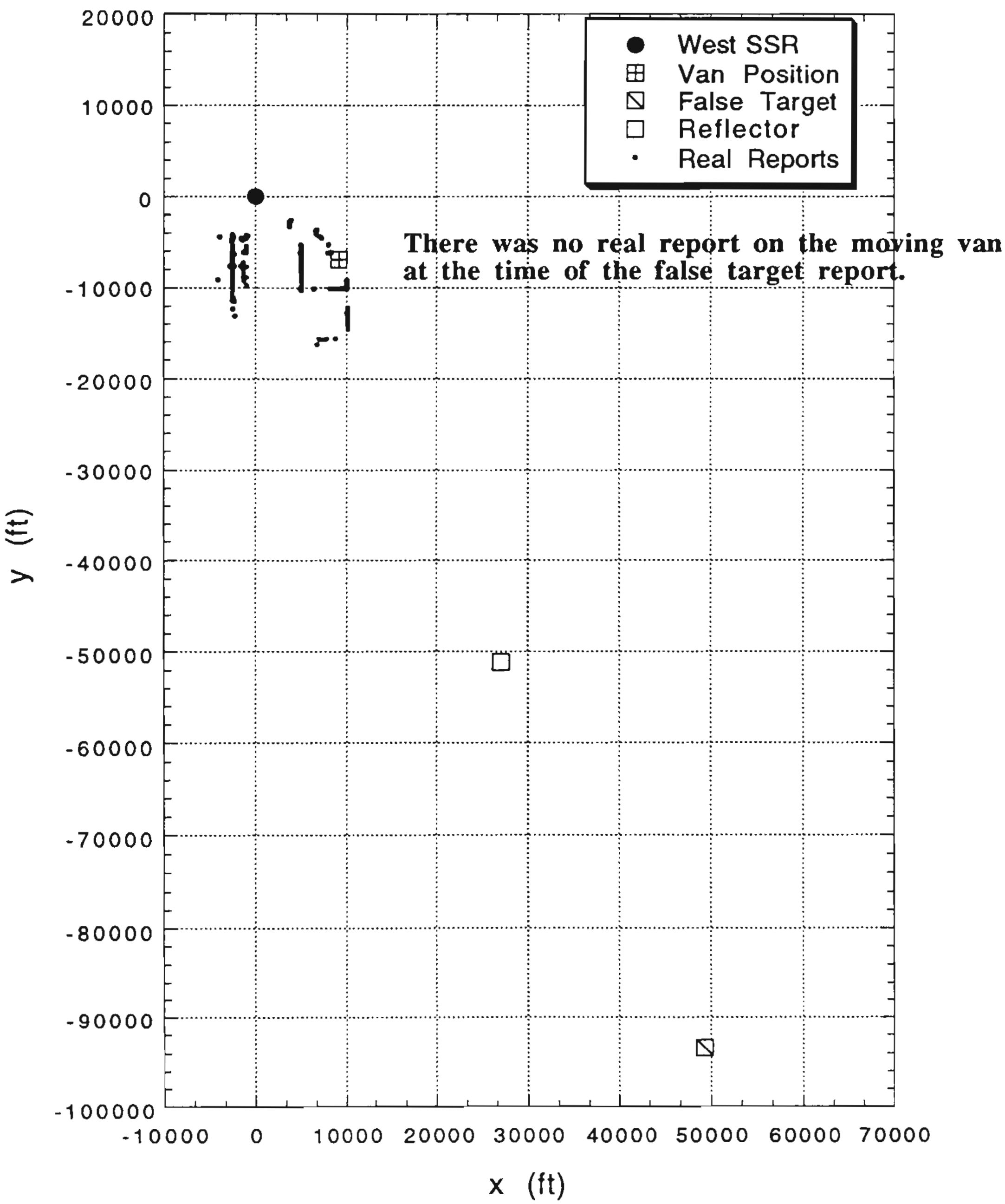


Figure 7c. ATCRBS false target report 49335, received by West SSR, operating in Mode S mode (Tue, 1/19/99).

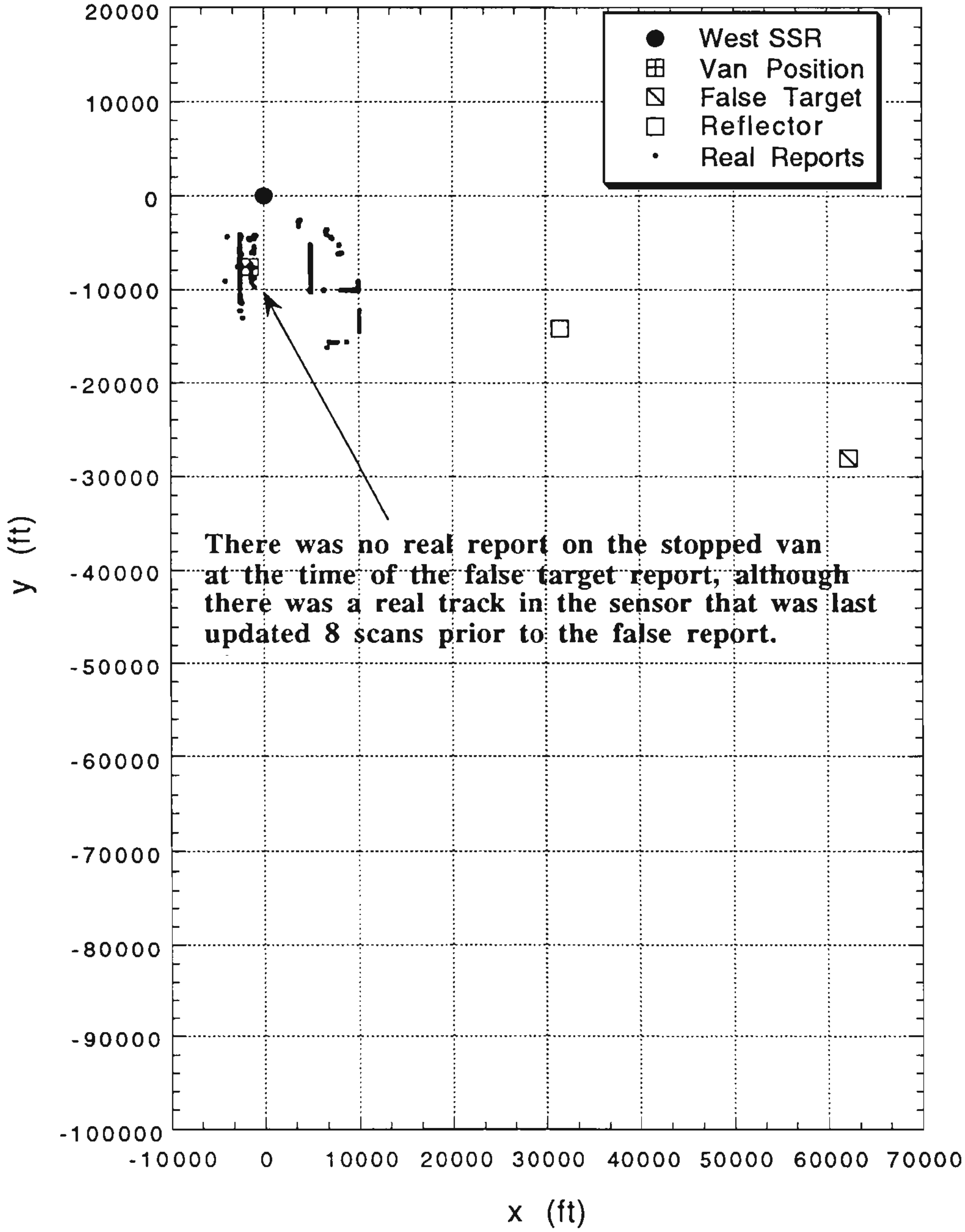


Figure 7d. ATCRBS false target report 62220, received by West SSR, operating in Mode S mode (Tue, 1/19/99).

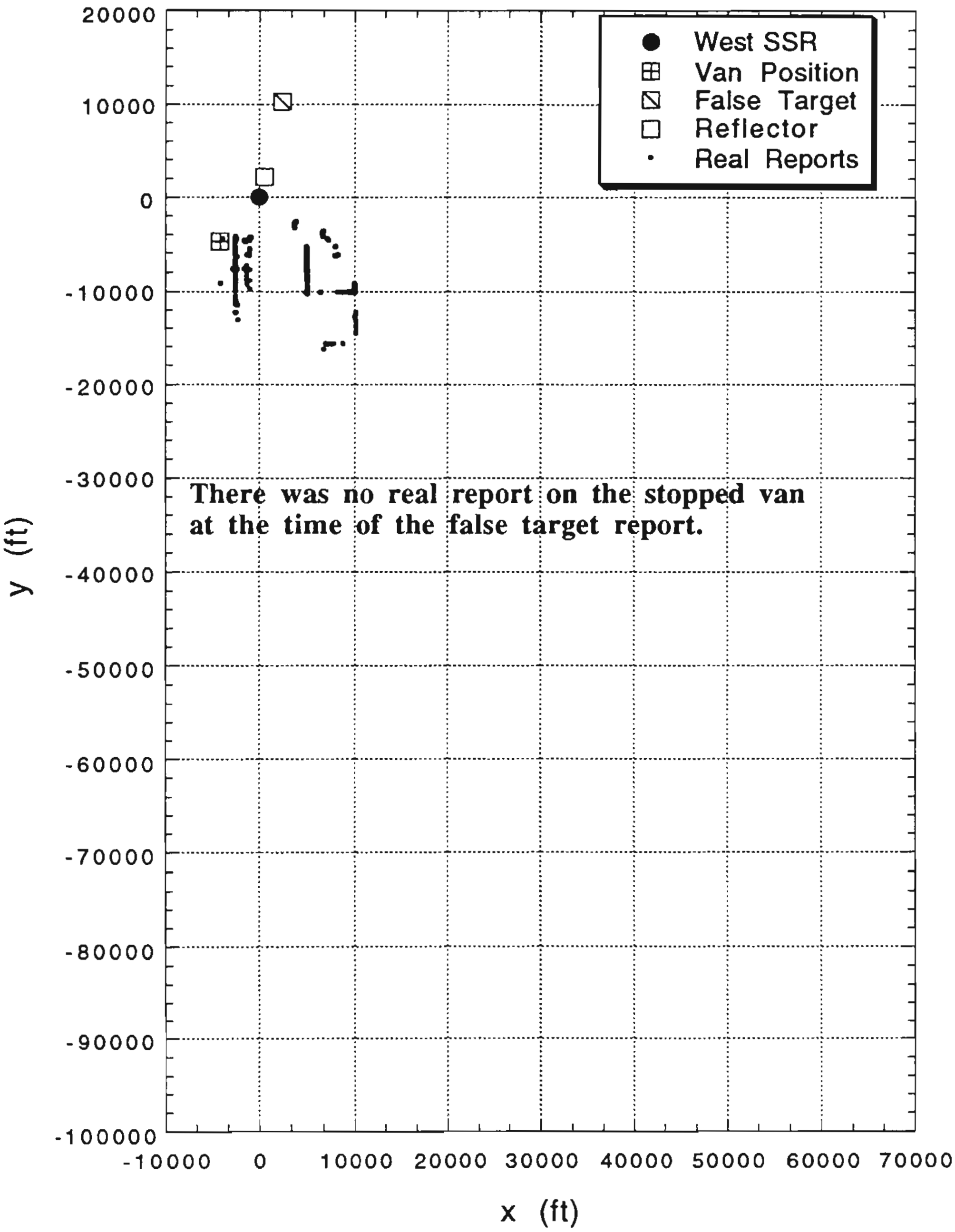


Figure 7e. ATCRBS false target report 2406, received by West SSR, operating in Mode S mode (Tue, 1/19/99).

Figure 7f. Reflector Locations.

3.4.2.1 Target Reports

Figure 8 shows the ATCRBS target reports (with Mode A code = 4636) received by the East SSR operating in the Mode S mode. The target reports are represented by the black dots, which appear in the center of gray circles so that the reports are discernible against the dark background of the aerial photo. Figure 9 shows the target report positions on a grid. The (0,0) point on the grid is at longitude 97° 2.5' W, and latitude 32° 54.0' N, an arbitrarily chosen airport reference point. The thin lines show the path traveled by the van, provided by the laptop GPS system. The data show that target report detection is fairly reliable on some portions of the east side, and non-existent on other portions. There is essentially no coverage of the west side by the east SSR. The reasons for no reports are certain to include blockage by terminal and other buildings, and perhaps multipath phenomena that prevent either interrogation or reply decoding.

3.4.2.2 Interrogations

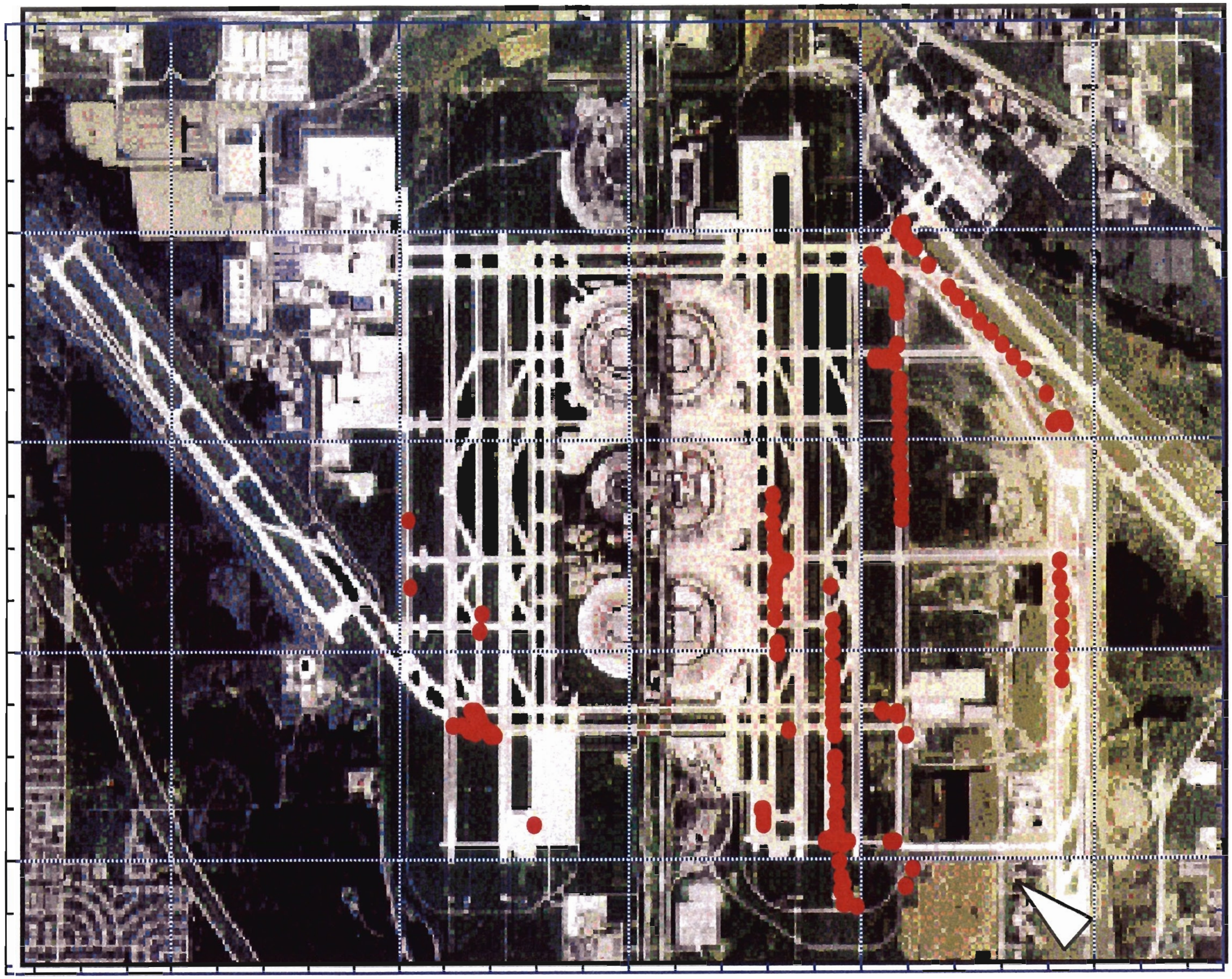
As described in Section 3.4.1.2, the interrogation spacings were determined for the East SSR in both the IBI mode and the Mode S mode. Figure 10 shows the transponder suppression bus outputs caused by the East SSR operating in the Mode S mode. As noted on Tuesday night, the interrogation process seems to be more reliable than the reply detection process. As mentioned in Section 3.4.1.2, it is possible that the interrogation link is stronger than the reply link, or that horizontal multipath caused by buildings is less detrimental to the interrogation detection process in the transponder than to the reply detection process in the SSR.

3.4.2.3 False Targets

Examination of Figure 9 shows no false target reports with the van Mode A code within the area shown by the figure. Figure 11 shows all target reports with the van's Mode A code out to a range of 100,000 ft. Manual examination of the data showed no false reports at ranges beyond 100,000 ft.

3.4.3 Wednesday, 20 January 1999, IBI Mode

On Wednesday, 20 January 1999 (on into the next morning) the van with the ATCRBS transponder, Mode A code 4636, was driven on both sides of the airport while the East SSR was operated in the IBI mode and target reports were recorded. The van contained the AMF, which recorded 1030 MHz pulses, the output of the transponder suppression bus, and the GPS position. The GPS laptop also recorded the van position.



East SSR

Figure 8. ATCRBS target reports, received by East SSR, operating in Mode S mode, (Wed, 1/20/99)

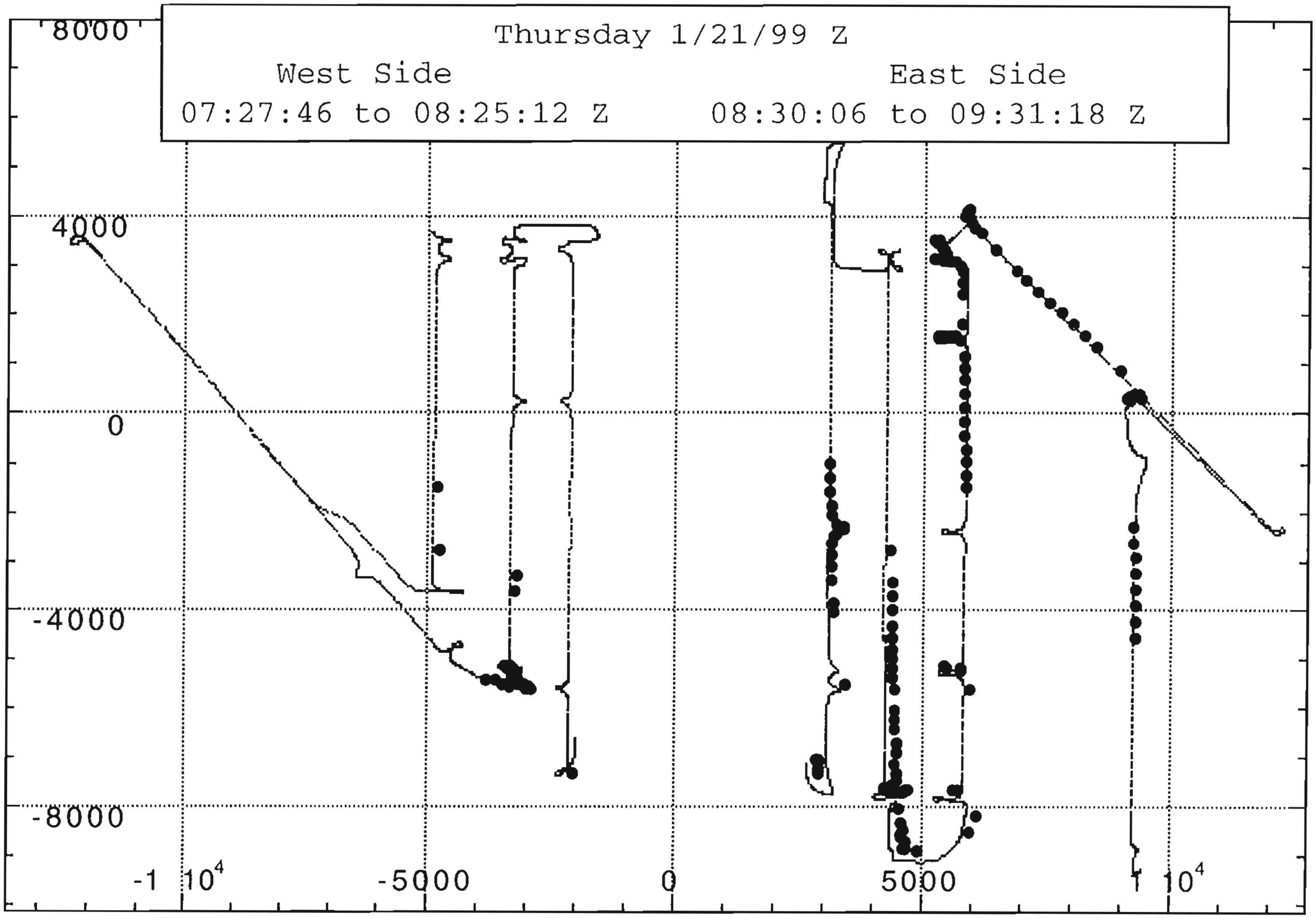


Figure 9. ATCRBS target reports with van route, received by East SSR, operating in Mode S mode (Wed,1/20/99, Local).

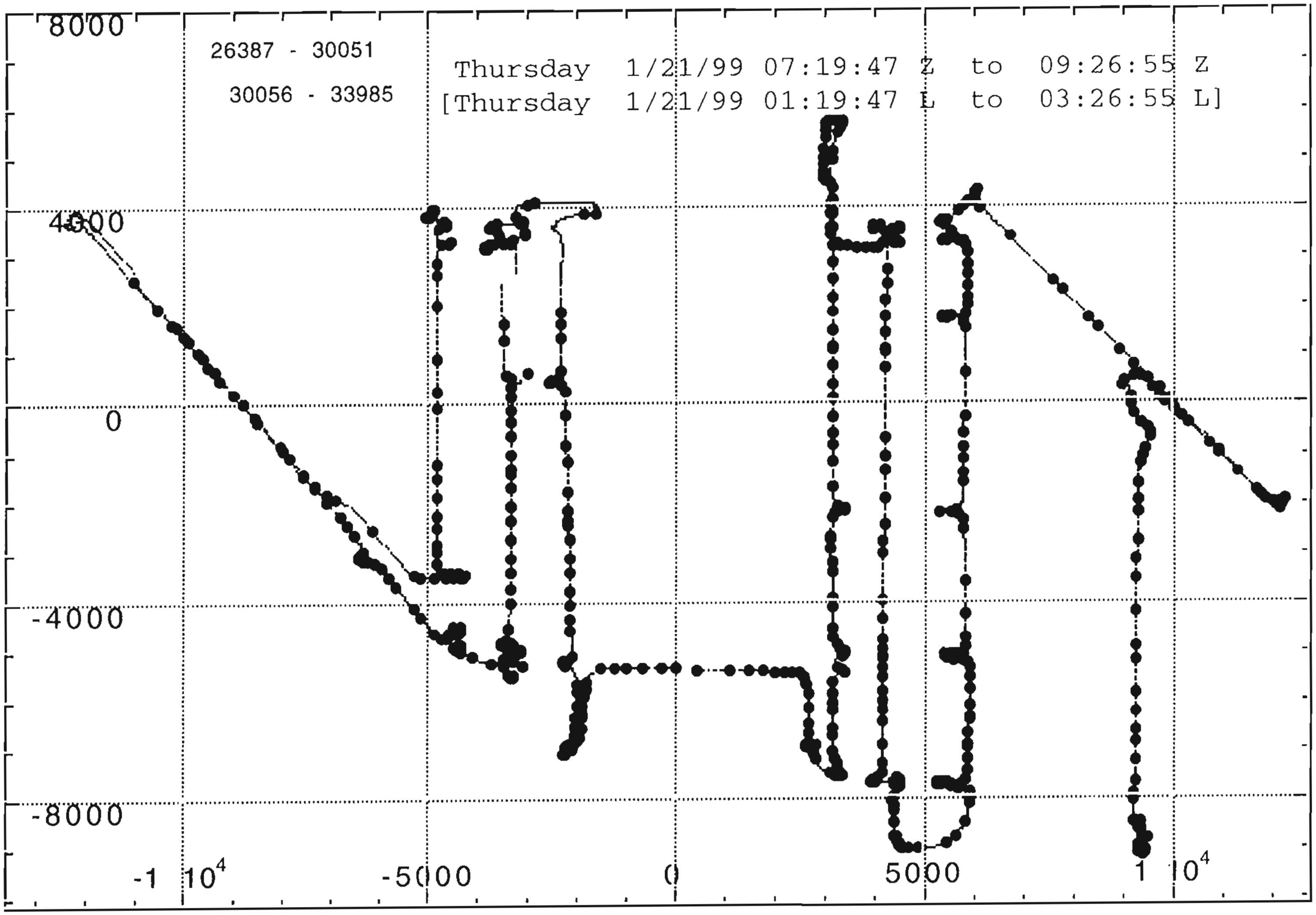


Figure 10. ATCRBS suppression bus outputs (recorded by AMF) caused by the East SSR, operating in Mode S mode (Wed, 1/20/99).

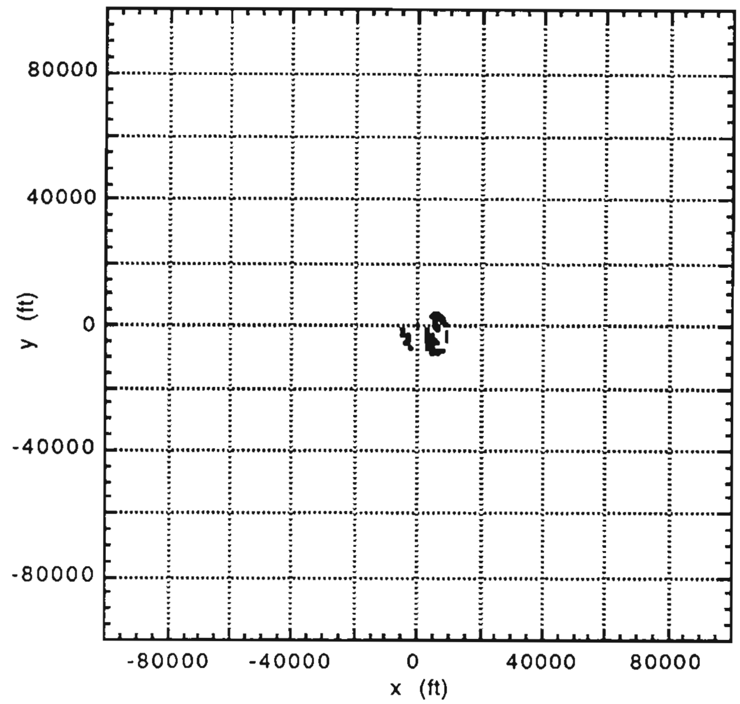


Figure 11. ATCRBS target reports to 100k ft, received by East SSR, operating in Mode S mode (Wed, 1/20/99).

3.4.3.1 Target Reports

Figure 12 shows the ATCRBS target reports (with Mode A code = 4636) received by the East SSR operating in the IBI mode. The target reports are represented by the black dots, which appear in the center of gray circles so that the reports are discernible against the dark background of the aerial photo. Figure 13 shows the target report positions on a grid. The (0,0) point on the grid is at longitude 97° 2.5' W, and latitude 32° 54.0' N, an arbitrarily chosen airport reference point. The thin lines show the path traveled by the van, provided by the laptop GPS system. The data show that target report detection is fairly reliable on some portions of the east side, and non-existent on other portions. There is essentially no coverage of the west side by the east SSR. The reasons for no reports are certain to include blockage by terminal and other buildings, and perhaps multipath phenomena that prevent either interrogation or reply decoding.

3.4.3.2 Interrogations

As described in Section 3.4.1.2, the interrogation spacings were determined for the East SSR in both the IBI mode and the Mode S mode. Figure 14 shows the ATCRBS suppression bus outputs caused by the East SSR operating in the IBI mode. As noted previously, the interrogation process seems to be more reliable than the reply detection and report formation processes. As mentioned in Section 3.4.1.2, it is possible that the interrogation link is stronger than the reply link, or that horizontal multipath caused by buildings is less detrimental to the interrogation detection process in the transponder than to the reply detection process in the SSR.

3.4.3.3 False Targets

Examination of Figure 13 shows no false target reports with the van's Mode A code within the area shown by the figure. Figure 15 shows all target reports with the van code out to a range of 100,000 ft. There are no false targets in the figure. Manual examination of the data showed no false reports at ranges beyond 100,000 ft.

3.4.4 Wednesday, 20 January 1999, Transponder Replies

As shown in Table 1, the PRI's of the SSRs were determined for the IBI modes, and the two frame patterns used for the Mode S mode at the East SSR on Wednesday night, 20 January 1999 (continuing on into the next morning). During the van's travels over two complete coverages of the airport during that session (including the east and west sides) the AMF was recording the suppression output of the ATCRBS transponder. These data were processed so as to determine the times of day in AMF clock units (at 8 MHz, and then associated with GMT time of day provided by the AMF's GPS receiver) at which suppression outputs occurred that had the PRI spacing of one of the modes of both the east and west SSRs. Each such time of day was recomputed modulo the scan time of the particular SSR. The resulting value has a one-to-one correspondence with the direction that the SSR antenna was pointing when the transponder made the particular reply. For example, if the transponder was stationary, then it would be interrogated every rotation of the antenna (i.e., every scan). The time of day of each reply, modulo the scan time would be a constant value as real time progresses. If the target were moving so as to rotate about the antenna (in the same direction as the antenna rotates) then the result of the modulo computation would increase as real time progresses.

A plot was made, for the East SSR, of the modulo value on the y axis, versus time of day in seconds on the x axis (see Figure 16a). Figure 16b shows the azimuth of the van, as seen by the East SSR vs. time of day. The azimuth was computed from the GPS position recording. Figures 16a and 16b are similar enough to verify that the East SSR PRIs were correctly determined. The difference between the two figures is apparent evidence that the scan rate of the SSR was not exactly constant.

In order to interpret Figure 16a, first consider the region from about 25500 to 26500 seconds. It is known from the GPS data that the van was waiting at the north end of taxiway C on the west side of the airport during this time. The van was either stationary, or making small excursions in preparation to proceed southward down C when clearance was obtained. (This point in time marks the end of circuit 1 and the beginning of circuit 2.) Notice that the y value is constant at about 0.8 seconds. This is because the SSR antenna pointed at the van at the same modulo time in each scan, which is equivalent to saying that the antenna was pointed in the same direction. Notice also during this time that there are no other "y" values other than those around 0.8 second, except for one at about $t = 25500$, $y = 1.2$. This means that the transponder was not consistently interrogated at any time within the scan except when the beam was actually pointing at the van. In other words, there were no consistent interrogations of the van through the beam sidelobes, and there were no consistent interrogations caused by a reflection of an interrogation that was directed at, for example, a building at some other azimuth with respect to the SSR than the van's azimuth.

The situation is very different in the region from times 19200 to 20000 seconds. The East SSR was in the IBI mode. The transponder in the van is apparently being interrogated by a very wide mainbeam, and by five sidelobes. The GPS indicates that the van was parked in the parking lot of the Delta maintenance hangar during this time period. (From the downward trend of the plot in this region we conclude that the scan time was not exactly the average value of 4.619 seconds that was used to make the plot.) Apparently, the propagation of the interrogation pulses is severely impacted by the buildings in the vicinity, so as to cause failure of the ISLS and/or IISLS systems. Additional analyses of the AMF interrogation pulse recordings may enable a more detailed understanding. However, there were no target reports (neither real nor false) with the van's code during this time, which indicates that the link from the transponder back to the East SSR will not support reply detection and/or correlation into target reports.

Further examination indicates some side lobe or reflection interrogations at 27000 to 28000. Figure 16b indicates that van was stationary at that time. Examination of the GPS data indicates that van was near the intersection of taxiways A and E on the west side.

Figures 17a and 17b are the West SSR counterparts to Figures 16a and 16b. Time did not permit a detailed examination of the results, but it is clear that the West SSR has more potential for false interrogations arising from either ISLS failures causing sidelobe interrogation, or IISLS failures leading to reflection interrogations. The fact that the West SSR has more extraneous interrogations than the East SSR is consistent with the fact that the West SSR had 4 false target reports from the van while the East SSR had none.

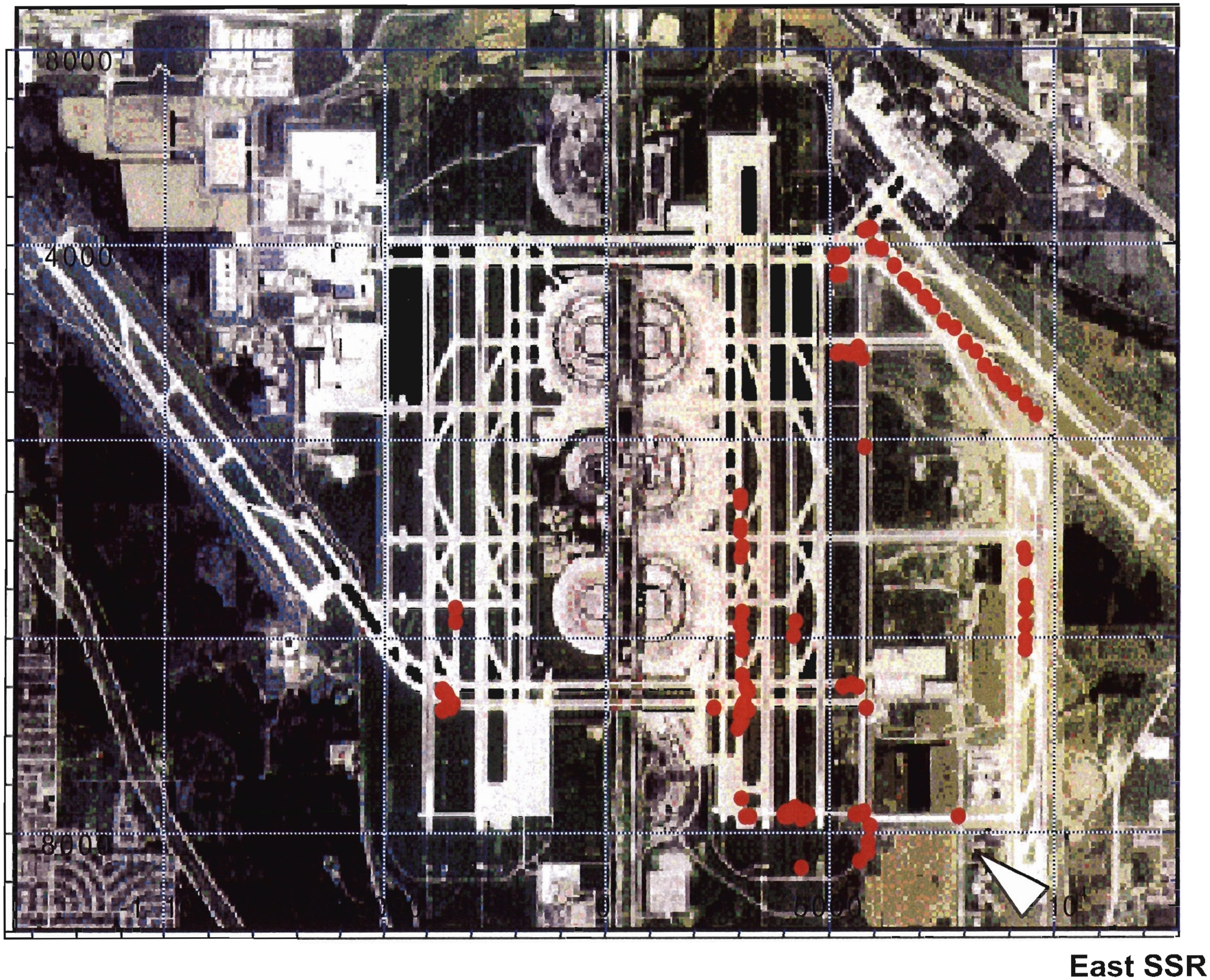


Figure 12. ATCRBS target reports, received by East SSR, operating in IBI mode, (Wed, 1/20/99).

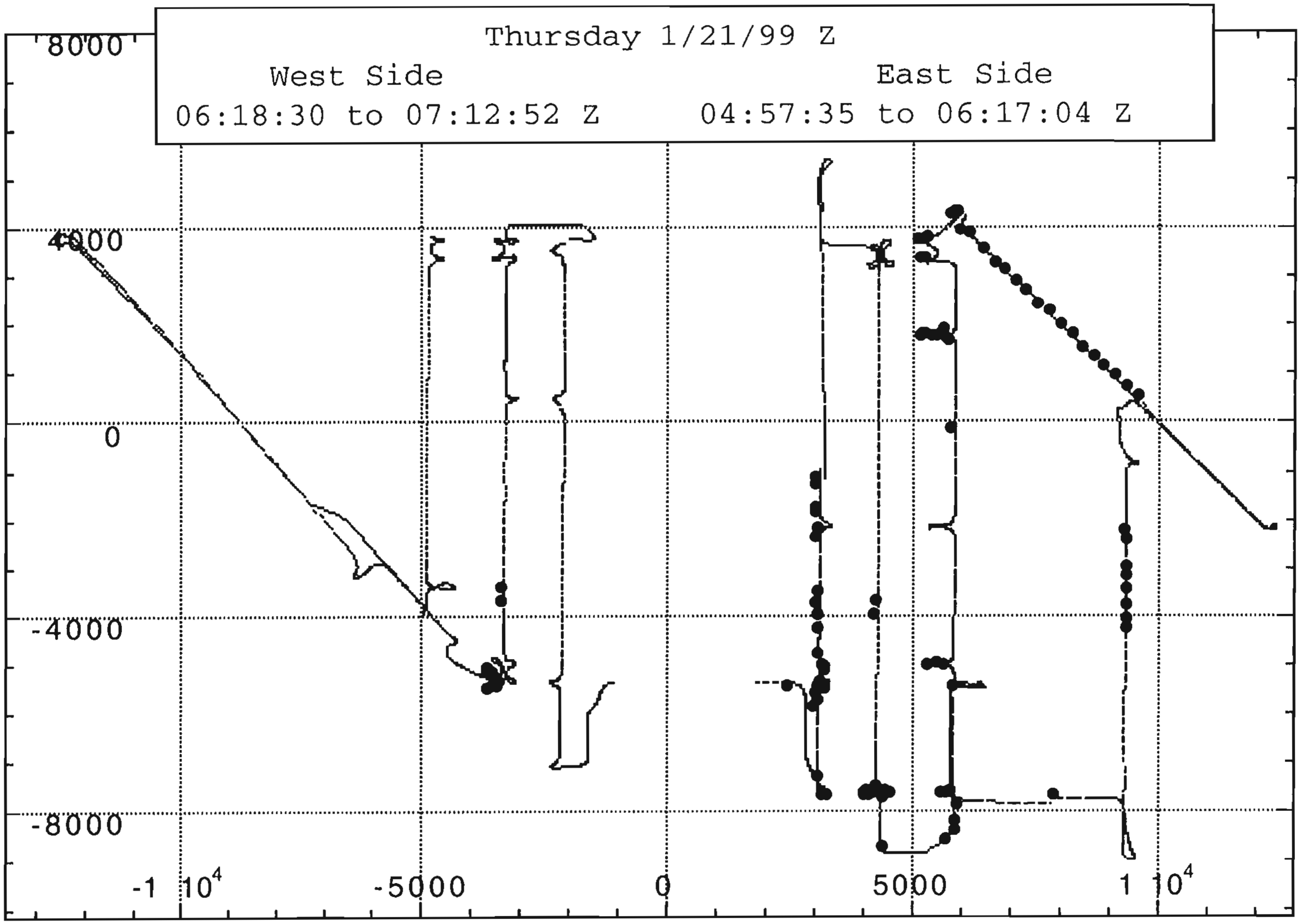


Figure 13. ATCRBS target reports with van route, received by East SSR, operating in IBI mode (Wed,1/20/99, Local).

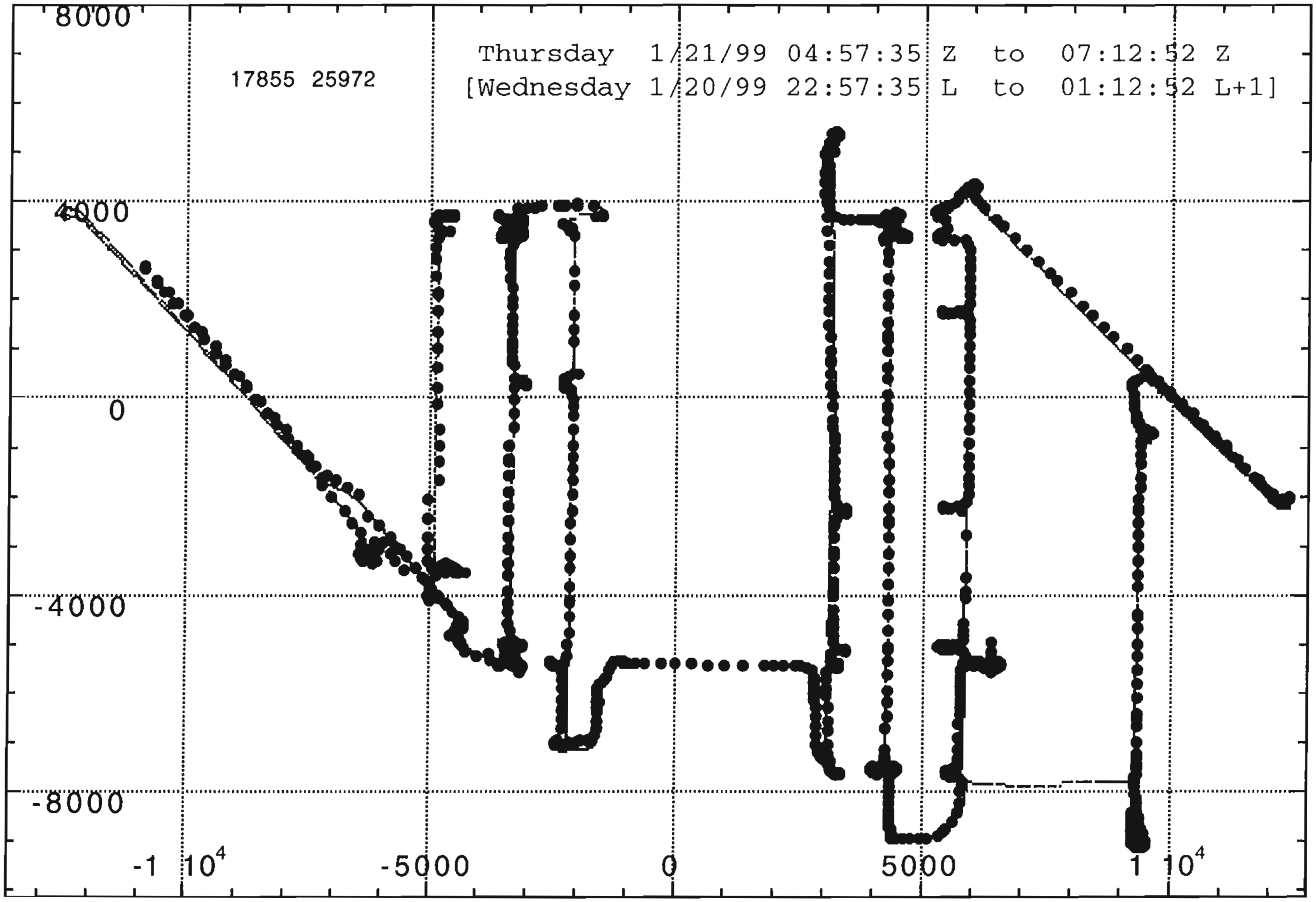


Figure 14. ATCRBS suppression bus outputs (recorded by AMF) caused by the East SSR, operating in the IBI mode (Wed,1/20/99, Local).

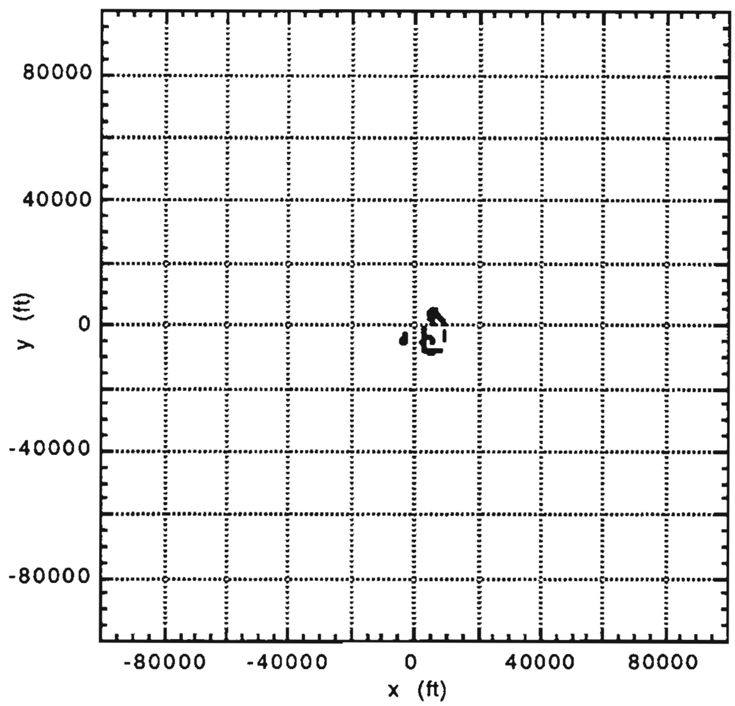


Figure 15. ATCRBS target reports to 100k ft, received by East SSR, operating in IBI mode (Wed, 1/20/99).

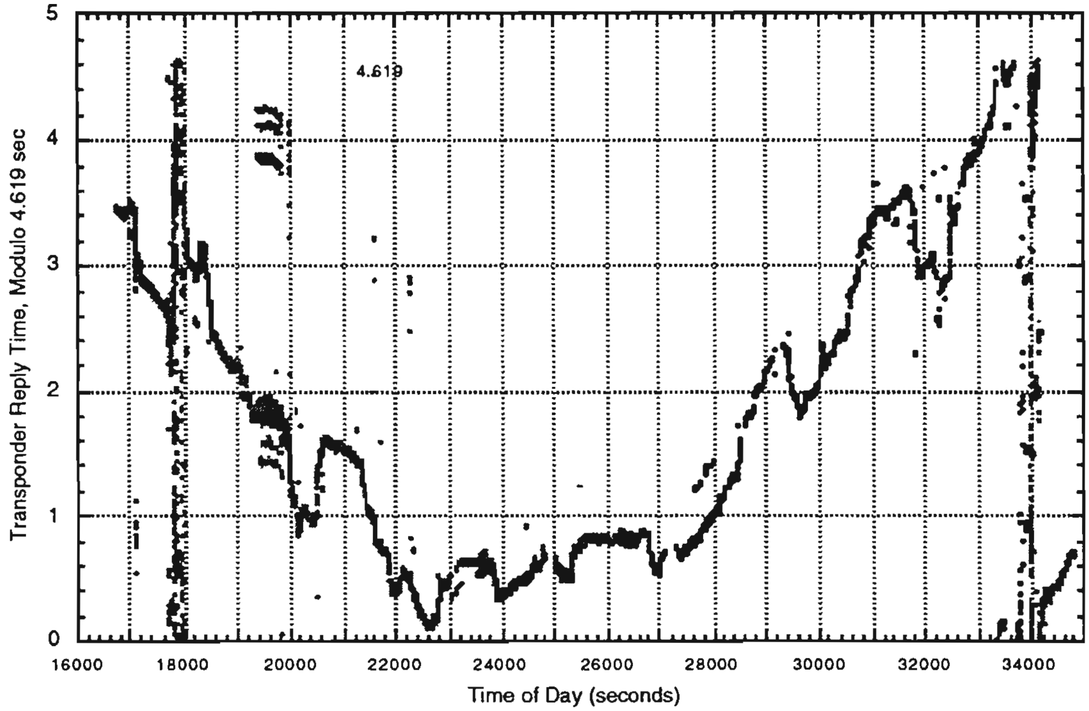


Figure 16a. Transponder reply times, to East SSR, modulo East SSR scan time (Wed, 1/20/99).

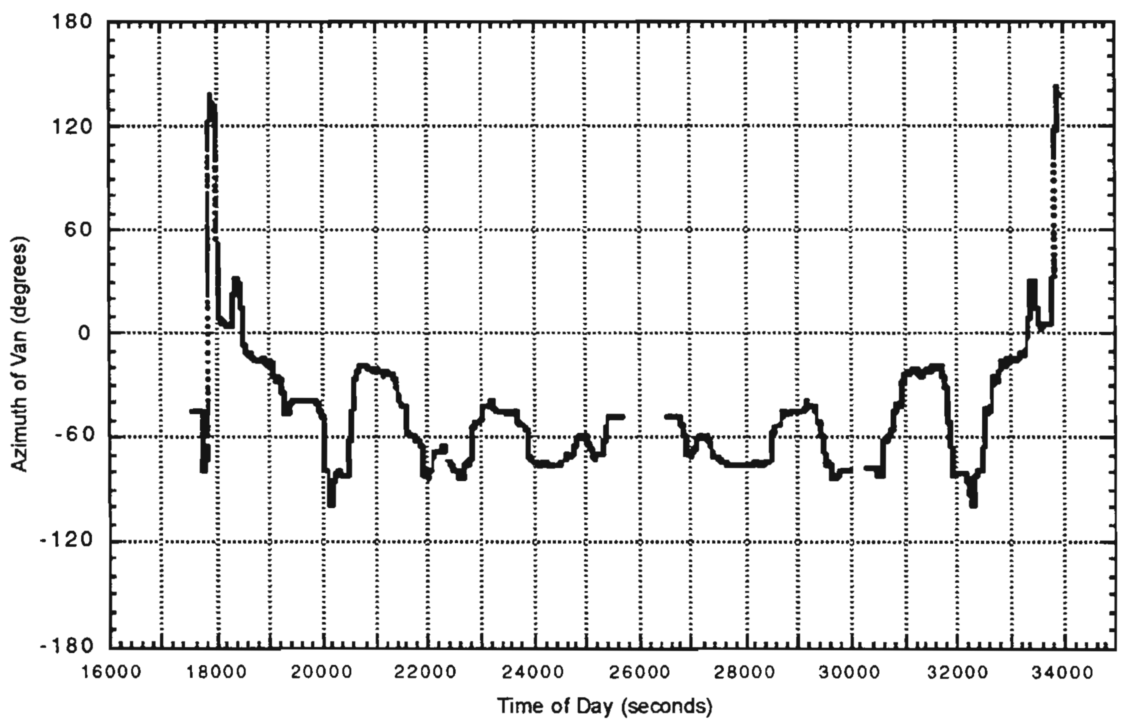


Figure 16b. Transponder (Van) Azimuth wrt to East SSR (computed from GPS positions).

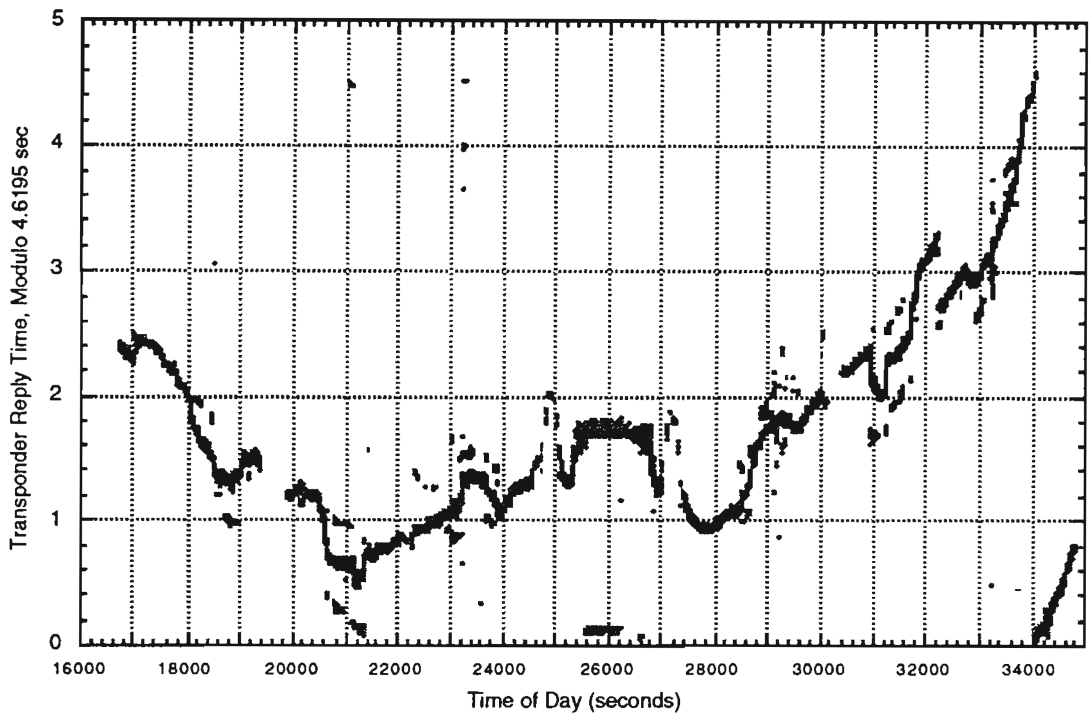


Figure 17a. Transponder reply times to West SSR, modulo West SSR scan time (Wed, 1/20/99).

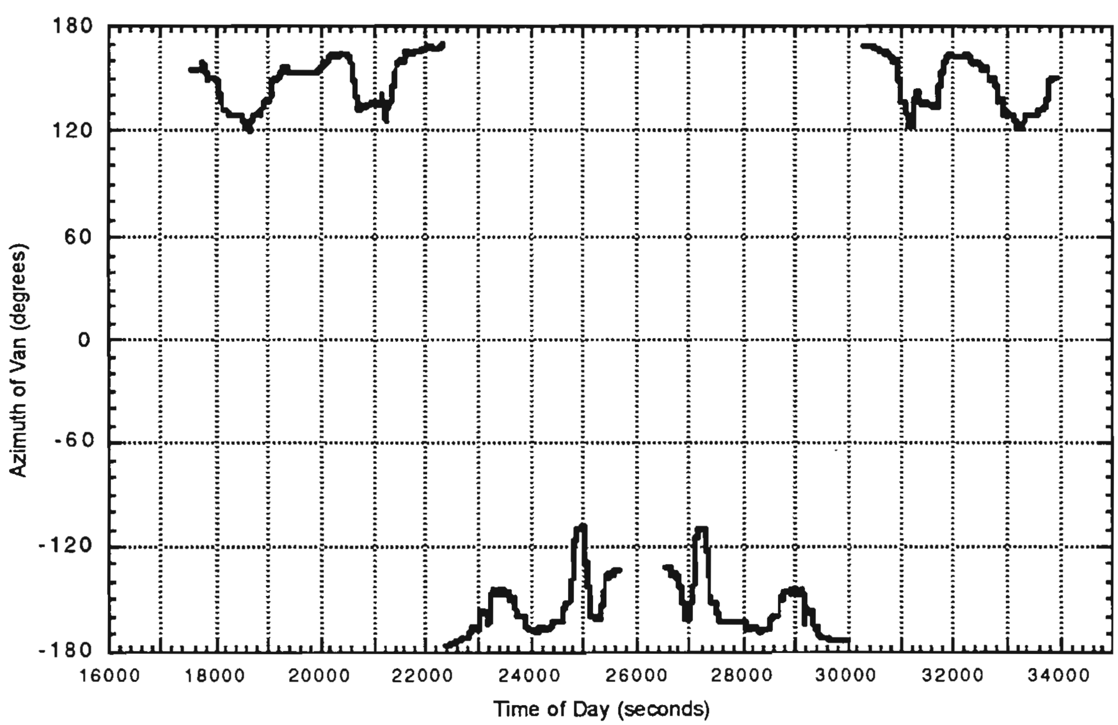


Figure 17b. Transponder (Van) Azimuth wrt to West SSR (computed from GPS positions).

4. 1030 MHZ AND 1090 MHZ ENVIRONMENT

ATIDS will add small amounts of activity on both the 1030 MHz uplink interrogation channel and on the 1090 MHz downlink reply channel. The ATIDS uplink activity will consist of whisper shout interrogations and infrequent Mode S interrogations to obtain altitude or Mode A ID from the transponder. The whisper shout interrogations will be limited in power and rate so as to occupy (by suppression or reply elicitation) the nearby transponders no more than one-quarter of a percent of the time. This limit is a design limit consistent with the specification provided by the FAA to the contractor. The ATIDS related downlink activity consists of ATCRBS fruit caused by the whisper shout interrogations plus existing short Mode S squitters from aircraft on the taxiways. The fruit replies elicited per nearby aircraft will be limited to 10 per second; aircraft away from the airport will generate even less fruit.

The impact of ATIDS contributions to the activity on the uplink and downlink channels is a function of the amount of existing activity associated with SSR and TCAS operation. The interrogation and fruit limitations imposed on ATIDS will be effective at limiting the impact on other systems, provided that the existing activity is not on the verge of overloading the channels. In other words, the ATIDS incremental activity must not be the straw that breaks the camel's back.

In order to verify that the DFW environment is not more severe than presumed, the AMF was used to record activity on both channels during a busy daytime period in the afternoon of Wednesday, 20 January 1999. The AMF used an omni antenna mounted on the top of the van, which was parked several hundred feet away from the East ATC tower at DFW airport. The DFW SSRs were operating in the IBI mode. These SSRs will eventually operate in Mode S mode, after the dynamic reflector processing is implemented.

4.1 DOWNLINK 1090 MHz FRUIT

The AMF pulses that were recorded at 1090 MHz for a ten minute period starting at 4:26 PM on Wednesday, 20 January 1999 were analyzed to determine the Mode S fruit rate and the ATCRBS fruit rate, for an MTL of -74 dBm. This is the threshold used in airborne transponders and ATIDS RTs. The results are shown in Figures 18 and 19. The y axis quantization by 100 is because the AMF sampled the 1090 MHz channel for 1 ms out of every 100 ms, to prevent the very high pulse rates from overloading the AMF data recorder. This sampling feature is standard AMF procedure in busy environments. The average Mode S fruit rate was 225 per second, and the average ATCRBS fruit rate was 2881 per second. By comparison, the Mode S fruit rate measured at 11,000 feet altitude over DFW airport several years ago, from the bottom antenna, was between 100 and 200 per second. The corresponding ATCRBS fruit rate was between 1000 and 2000. New airborne AMF measurements over DFW may be made for the FAA under the ADS-B program later this year.

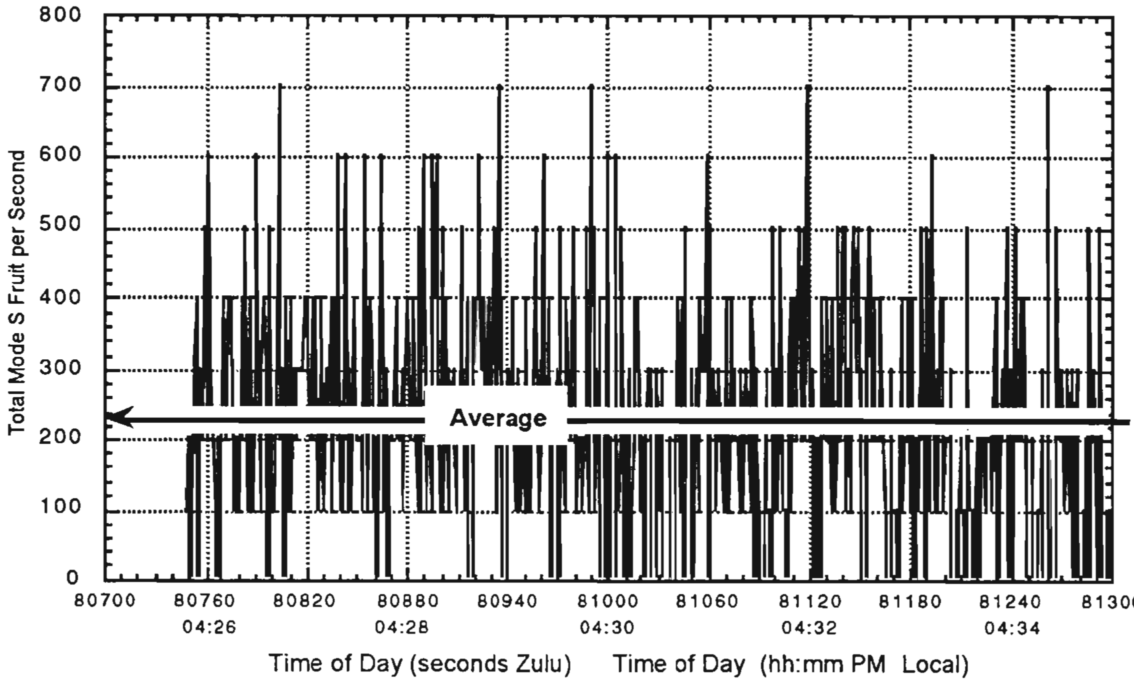


Figure 18. Mode S Fruit vs. Time.

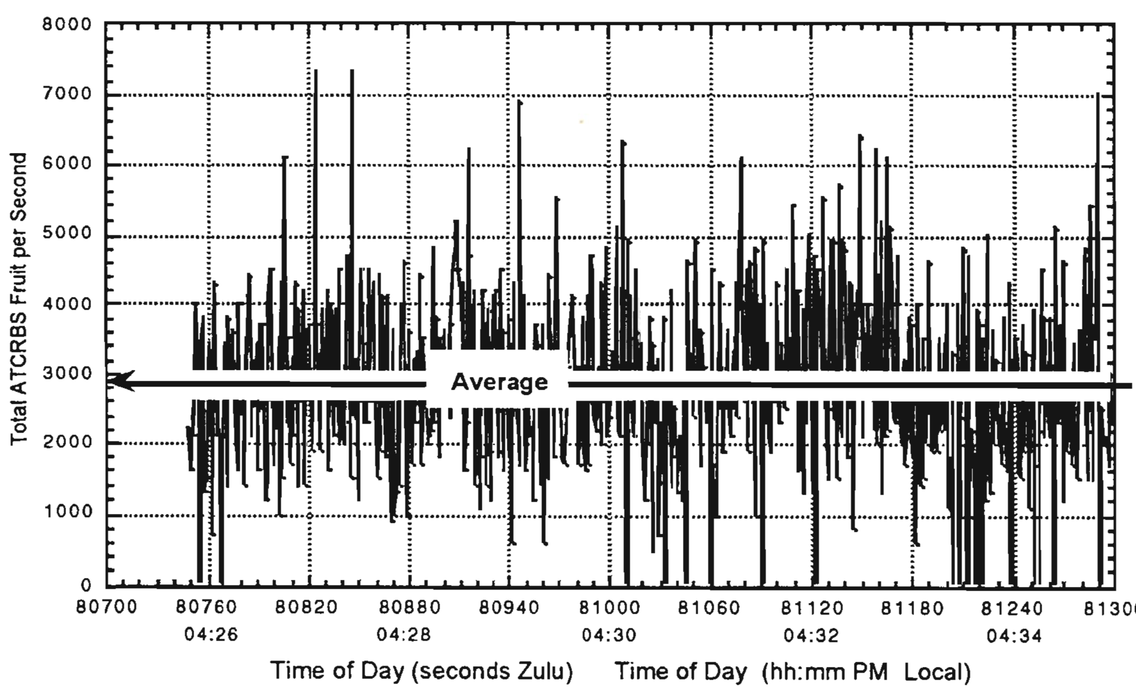


Figure 19. ATCRBS Fruit vs. Time.

4.2 UPLINK 1030 MHz INTERROGATION

The AMF pulses that were recorded at 1030 MHz for a ten minute period starting at 4:36 PM on Wednesday, 20 January 1999 were analyzed to determine the interrogation rate in all modes (ATCRBS, Mode S, and TCAS) and the two-pulse suppression rate, for an MTL of -74 dBm. The results are shown in Figures 20 and 21. The average interrogation rate was 74 per second, and the average suppression rate was 214 per second. By comparison, the interrogation rate, measured at 11,000 feet altitude over DFW airport several years ago, from the bottom antenna, was about 280 per second. The corresponding suppression rate was about 1000 per second. The difference between surface and airborne interrogation and suppression rates is attributable to normal propagation effects; i.e., remote SSRs do not have line of sight coverage to the DFW airport surface.

4.3 ENVIRONMENTAL SUMMARY

The results of the AMF environmental measurements are summarized in the Table 3 below. On the 1090 MHz downlink channel, the activity seen on the ground seems slightly greater than what was seen several years ago at 11,000 feet. The increase in the Mode S fruit rate might be explained by an increase in the number of aircraft with Mode S transponders and TCAS. The increase in the ATCRBS fruit rate could be explained by it being a busier day or by the addition of SSRs in the vicinity of DFW; DFW now has 4 ASR-9's in the area.

On the uplink 1030 MHz channel, the activity seen when on the ground is substantially less than seen in the air. This is explained by the fact that the AMF on the ground could only see the two airport SSRs (which were in IBI mode) and a subset of the airborne TCAS interrogators as limited by line-of-sight considerations. On the other hand, the AMF at 11,000 feet several years ago was exposed to many ground SSRs and to more TCAS.

Table 3. Comparison of Environmental Measurements

	1990's, at 11,000 feet by AMF aircraft's bottom antenna (MTL=-74 dBm)	20 January 1999, 4:40 PM local, on the ground (MTL=-74 dBm)
1090 MHz		
Mode S fruit rate	100-200	225
ATCRBS fruit rate	1000-2000	2881
1030 MHz		
Interrogation rate (all modes)	280	74
Suppression rate	1000	214

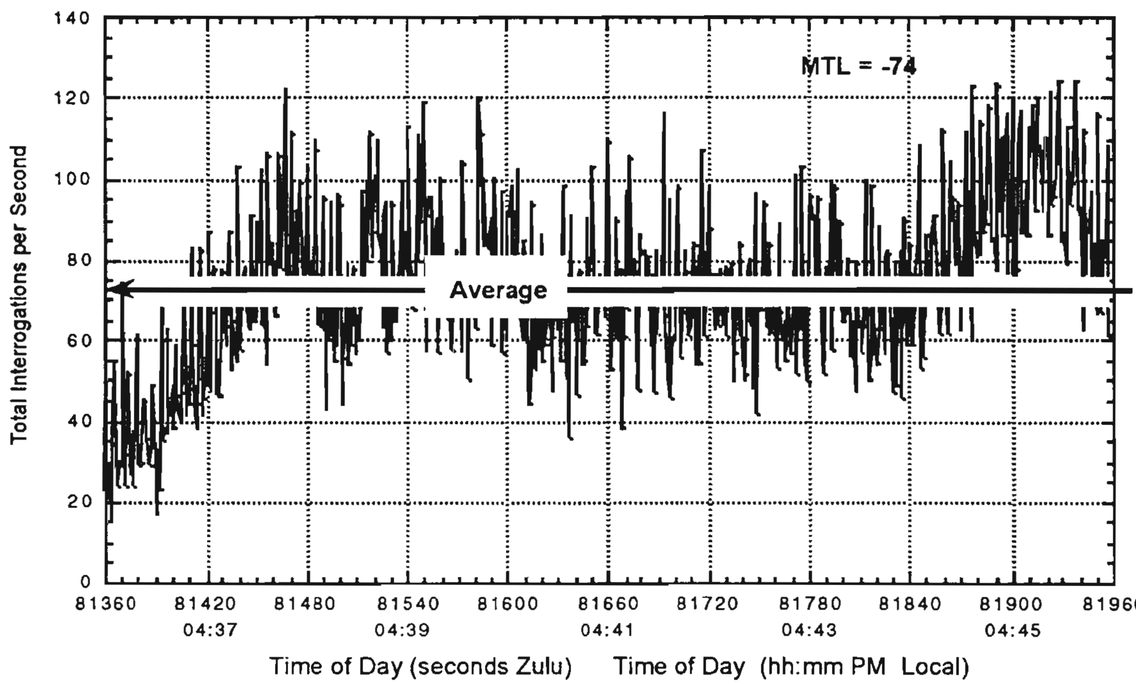


Figure 20. Interrogations vs. Time.

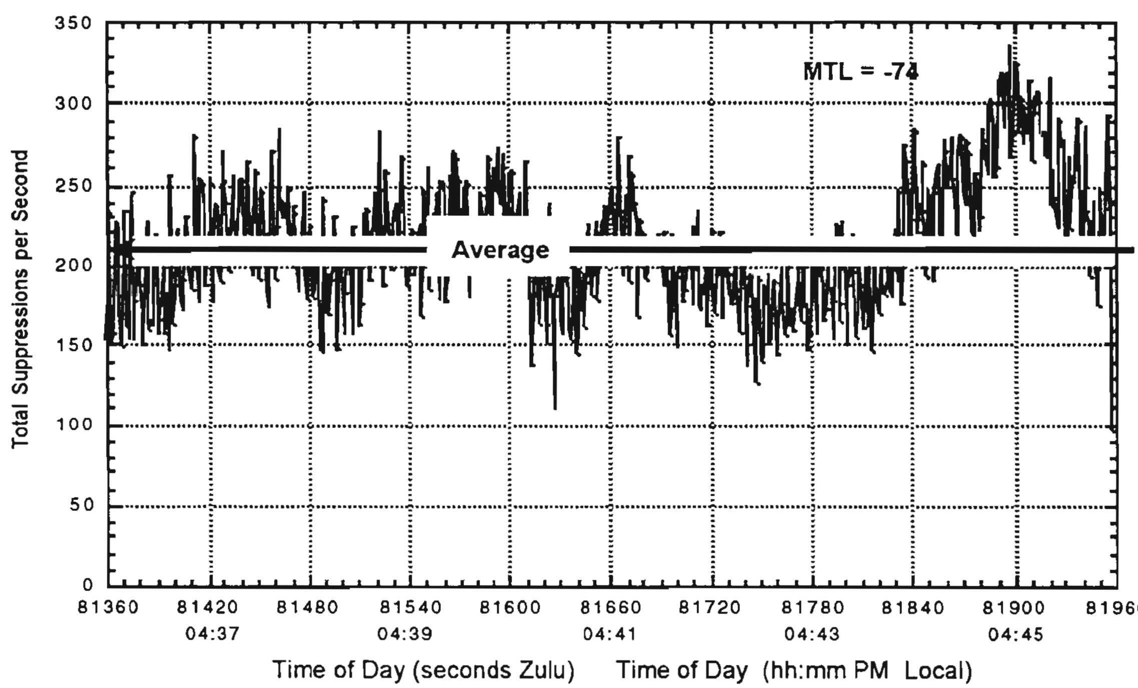


Figure 21. Suppressions vs. Time.

4.4 ATCRBS FRUIT FROM SURFACE TRANSPONDERS

Leaving ATCRBS transponders "on" while on the surface will increase ATCRBS fruit because of existing SSR and TCAS interrogations and because of new ATIDS interrogations. An interrogation rate of 74 per second was observed on the ground at DFW on 20 January 1999. Of these 74, about 10 per second were due to ground based SSR Mode A and Mode C interrogations, about 14 were due to TCAS, and about 50 were Mode S interrogations (probably due to TCAS because the East and West DFW SSRs do not yet use Mode S mode). The Mode A and Mode C interrogations will elicit responses from the ATCRBS transponders on the ground; Mode S transponders on the ground do not respond to these interrogations by design. Therefore if 10 ATCRBS surface transponders were left "on" while on the ground, the increase in the ATCRBS fruit rate would be 240 per second. To this should be added the fruit caused by ATIDS whisper shout interrogations. This value is limited by ATIDS design to 10 fruit per second per ATCRBS transponder and 0 per Mode S transponder, or another 100 fruit per second from the surface ATCRBS transponders. There will also be 10 fruit per second from nearby airborne ATCRBS aircraft, of which we assume there will be two. Thus, the total additional ATCRBS fruit attributable to ATIDS is 240 + 100 + 20 = 360 fruit per second, which is a 12.5 percent increase over the measured pre-ATIDS value of 2881.

The downlink channel occupancy attributable to all ATCRBS fruit will be (2881 + 360) times 20.3μs, divided by three (the pulses are on only one-third of the time) which yields only 2.2 percent. This value will have virtually no effect on ATCRBS target report generation for SSRs operating in the IBI mode, where interrogation run lengths are 16 or greater because only about 5 replies are needed for target report generation, and the reply processor can handle 4 overlapped replies.

The additional ATCRBS fruit will also negligibly impact SSRs operating in Mode S MSSR mode. ATCRBS reply processing functions on run lengths of 4 and is designed to operate at much higher fruit rates via the use of monopulse estimates on reply data. Mode S reply reliability is impacted in proportion to fruit rate, but the sensor has a re-interrogation capability used to handle much higher fruit rates. Also, the Mode S waveform is designed to be resilient to single overlapping fruit replies. In Section 5.6, Mode S reply degradation attributable to surface Mode S fruit is examined in detail and it is shown that the effect on overall sensor performance of 200 ADS B surface transmissions per second is imperceptible. Since ATCRBS fruit is of shorter duration than ADS B long squitters (20.3μs vs. 120μs), the worst case impact of 360/sec new surface ATCRBS fruit is 30 percent that of 200/sec ADS B squitters. Mode S system features further reduce the impact.

The ATCRBS fruit from TCAS interrogations (140 per second) and ATIDS interrogations (100 per second maximum by design limitation) will affect both DFW SSRs in a random fashion. The effect on Mode S roll call replies will be minimal because the Mode S SSR can correct the bit errors caused by a single ATCRBS fruit overlap. At a particular DFW SSR, the fruit elicited by the other SSR will also be random, and mitigated by this error correction. The additional ATCRBS replies elicited by the interrogating SSR will not affect the Mode S roll call replies associated with that SSR because the fruit will not be elicited during the roll call period in the interrogation schedule.

When the DFW SSRs convert from IBI operation to MSSR operation, ATCRBS fruit from surface and airborne transponders will decrease due to the lower PRFs; also airborne fruit from Mode S-equipped aircraft should be reduced by elimination/modification of the non-compliant transponder fix which is temporarily installed in the Mode S system. Therefore, the percentage impact of ATIDS upon the overall ATCRBS fruit environment will increase but the overall fruit environment and the minimal system performance degradation attributable to fruit will be improved.

In summary, surface fruit will increase when ATIDS is installed because of ATCRBS transponders being left "on" while on the movement area. This fruit is a significant fraction of existing surface fruit and is of greater signal strength than distant airborne fruit. However, because of Mode S waveform and SSR design features, the impact of this additional fruit on overall sensor performance is expected to be negligible. Experimental data and analytical results confirming this conjecture are discussed in Section 5.6 for the more challenging case of surface ADS B Mode S fruit.

4.5 ATIDS ENVIRONMENTAL INTERFERENCE LIMITING

The ATIDS equipment specification includes restrictions on the amount of transponder occupancy and fruit generation that is permitted. The restrictions were imposed to both guarantee that ATIDS would not adversely impact other systems sharing the 1030/1090 frequencies and to enhance the likelihood that a frequency allocation could be obtained from FAA ASR to support testing at DFW. The imposed limitations are that the aggregate average occupancy and fruit caused by the whisper shout interrogations of the ensemble of RTs at a given airport be one-fourth of the limits imposed on TCAS. The TCAS average limits are one percent for transponder occupancy, and 40 ATCRBS replies per ATCRBS transponder. Therefore, the ATIDS at a given airport shall not occupy victim transponders more than an average of 1/4 percent of the time, and shall not elicit more than an average of 10 fruit per second per victim ATCRBS transponder.

The proposed DFW ATIDS system will have 6 RTs. A potential whisper shout sequence for each RT contains 12 levels separated by 2 dB, transmitted once per second for each RT. If there exist victim transponders within range of each RT's lowest level (a conservative assumption) then those victims would be suppressed 72 times per second. Since the suppression duration is 35μs, the occupancy would be 1/4 percent. All other victims would be occupied by a lesser amount.

The ATIDS system to be tested at DFW has two whisper shout modes of operation. One mode transmits a Mode A interrogation at each whisper shout level, in a fashion similar to the way TCAS transmits Mode C interrogations. (TCAS needs target altitude, whereas AIDS needs the Mode A code.) The levels are separated in time by 2 ms. An ATIDS RT has only one beam, which is shaped so as to direct most of the energy onto the airport surface. An RT does not have additional beams corresponding to the TCAS left, right, and back beams. The transmission of a single Mode A interrogation is called the singlet interrogation mode. The second ATIDS whisper shout mode uses two transmissions at each whisper shout level; a Mode A and a Mode C. The two transmissions are separated by a nominal time value such as 175μs. This is a legacy mode based on the Cardion CAPTS system. (See Multilateration on Mode S and ATCRBS Signals at Atlanta's Hartsfield Airport, M. L. Wood and R. W. Bush, Lincoln Laboratory Report ATC-260, 8 January 1998.) It enables defruiting at each RT, based on the known spacing. However, since each of the two interrogations and replies must succeed, it has the disadvantage of a lower probability of receiving data with which to perform multilateration. It also causes more victim transponder occupancy and ATCRBS fruit.

A potential whisper shout sequence for singlet mode would have 4 dB separation between the suppression pulse and the P1 pulse. This separation combined with the 2 dB step separation would produce two replies per sequence for a victim ATCRBS transponder that replies in the middle of the sequence. A victim that replied twice to each of the 6 RT's whisper shout sequences would reply 12 times per second. This would be a rare victim; it is much more likely that a victim would reply once or twice to 3 or 4 of the RT's and perhaps once or not at all to the others, resulting in less than the limit of 10 replies per second. The average number of replies per victim would fall well within the specified limit of 10. For doublet mode operation, the revisit time per RT must be approximately halved to remain within the specified limit.

The ATIDS system will be tested in the factory and at DFW to confirm that it complies with the specified interference limiting. Tests will be run with both singlet and doublet mode for whisper shout.

5. MODE S RE-INTERROGATION TEST

5.1 BACKGROUND

As previously described, multilateration position measurements are based on signals emitted by the target. ATIDS intends to use the Mode S squitter as a multilateration signal. The original Mode S squitter is a short Mode S reply with DF = 11, and is emitted at a 1 Hz average rate. The signal consists of a preamble having 4 pulses, each 0.5μs wide, spanning 8.0μs, followed by 56 intervals, each 1.0μs wide, corresponding to 56 bits of information. Each 1.0μs wide interval is divided into two halves, only one of which will have energy. A "0" is represented by energy in the second half, and a "1" by energy in the first half. The first 5 bits contain the DF code. The next 3 bits contain a field called "CA". The next 24 bits contain the Mode S ID of the aircraft (ID's are a mathematical transformation on the aircraft tail number). The last 24 bits contain a parity field, computed as a transformation on the first 32 bits.

The operational procedure for ATCRBS transponders has been to only have them "on" and capable of replying to interrogations while on the active runway. They are supposed to be placed in "standby" while on other parts of the airport movement area. The mode change may be manual or based on the "weight on wheels" switch status. Pilots sometimes do not follow this procedure, and occasionally an ATCRBS transponder will be active throughout the aircraft's time on the movement area.

The Mode S transponder was designed to have a negligible effect on existing SSRs and TCAS when the aircraft is on the airport surface. The transponder accepts a signal from the aircraft's "weight on wheels" switch, and when the aircraft is on the ground, it will only reply to Mode S interrogations that are addressed exclusively to the transponder. It will also continue to squitter, but it will not reply to any "universally addressed" interrogations; for example, a P1, P3 ATCRBS interrogation from an ATCRBS SSR, or a P1, P3, long P4 interrogation from a Mode S SSR, or a P1, P2, P6 interrogation from a Mode S SSR, in which the address contained in the 56 bit DPSK encoded P6 pulse is 24 "ones". The latter interrogation is the "Mode S Only All-Call".

As a result, an ATCRBS SSR cannot interrogate a Mode S transponder on the ground. A Mode S SSR cannot discover the Mode S address of transponders on the ground, and therefore would not normally perform surveillance on them. However, the transponder will reply to addressed interrogations, so if a Mode S SSR is performing surveillance on a landing aircraft, the surveillance can continue, if desired, after the wheels have touched the ground. TCAS units will hear the squitters from Mode S transponders on the ground, but TCAS surveillance and threat logic functions are designed to not issue Resolution Advisories against transponders on the ground, either by observing the "on the ground bit" of Mode S transponders or if the reported altitude is within 180 feet of the ground. Change 7 of the TCAS MOPS will propose a method not susceptible to errors in the Mode S transponder's on the ground bit.

Therefore, there is no reason to inhibit the use of squitters when the aircraft is on the ground by placing the transponder in standby mode. There is no rule, and no procedure, to prevent a pilot from putting the Mode S transponder into the mode which continues to squitter even when there is weight on the wheels. The design process of Mode S determined that squitters from aircraft in the movement area would not unduly degrade the performance of the airport SSR, nor of TCAS.

Recently, a system called Automatic Dependent Surveillance–Broadcast (ADS-B) has been proposed, in which Mode S transponders will emit a longer version of the squitter, having an extra 56 bits which contain the aircraft latitude and longitude, as determined by an on-board GPS receiver. Variations on this squitter may contain other information of interest. The squitter rate for these extended squitters for surface aircraft will be 2 Hz in some circumstances when moving and less when stopped. Extended squitters would take place on the surface and in the air.

ADS-B is not a multilateration system. Although the multilateration surveillance system being developed as part of ATIDS could certainly make use of the longer, and higher rate, ADS-B squitters, ATIDS can perform its multilateration surveillance perfectly well on the current short, one Hz, squitters that are already permitted for use on the airport movement area. Nevertheless, it was useful to try to assess the effect that ADS-B squitters from a large number of aircraft on the airport movement area would have on the airport SSR. A study performed by Joint Spectrum Center (JSC) for a Los Angeles environment indicated there could be a measurable increase in Mode S roll call reinterrogation, but no degradation in surveillance reliability, e.g., the report blip/scan ratio.

An experiment was planned to investigate this issue at DFW, which was approved by FAA ASR and DFW AT and AF personnel. The plan had two parts. First, a Mode S transponder would be placed in a central part of the airport movement area so as to have a good line of sight to the West SSR, during a peak traffic time. The SSR would be operated in the Mode S mode so that it would be making discrete roll-call interrogations to the aircraft in the terminal area. The transponder would be made to emit short squitters at a rate so high that it would simulate the amount of 1090 MHz channel loading of many ADS-B aircraft on the surface. Then, roll-call data would be recorded at the SSR, with the transponder cycled between on and off, so that the rate at which the Mode S SSR had to re-interrogate targets could be measured. The presumption would be that the replies from the transponder would enter the SSR receiver by both the main beam and sidelobes and thereby sometimes garble the reception of replies from interrogated aircraft, thus necessitating a re-interrogation to obtain surveillance on that particular aircraft.

The second part of the plan was to drive the van with the squittering transponder on the movement area, late at night, while recording the SSR's reception of replies of the type being emitted by the transponder. This would enable a determination of from what parts of the airport movement area a squittering transponder could actually impact the operation of the SSR.

Because of a number of factors, including forecasts of unusually severe impending weather, the first test was conducted at night instead of a peak daytime period, and from a road near the SSR instead of a location on the airport surface. Also, the second part of the plan was scrubbed for that evening. Future tests of these type may be requested.

5.2 PREDICTED IMPACT

The predicted impact of 400 short squitters per second is that the reinterrogation rate could increase by as much as 5 percent. The use of 400 short (64μs) squitters per second in the reinterrogation test was intended to approximate the channel loading of 100 aircraft emitting long (120μs) squitters twice per second. This upper bound assumes that any amount of overlap of the roll call reply by an interfering squitter would cause garbling of the roll call reply. In this case, the Poisson failure rate is approximated by the product of the squitter rate (400) times the combined duration of the roll call reply and the squitter (64μs plus 64μs). The result is 0.05, corresponding to a roll call reply reception failure rate of 5 percent. In actuality, some overlap is tolerable, because the Mode S error correction process can repair some amount of garble. In addition, if the roll call reply is higher in power than the squitter, then there would not be any garbling. For these and other reasons, a reasonable estimate would be that the reinterrogation rate might go up by 2 percent. The probability of both the first interrogation and a second interrogation failing would be less than one half percent. The Mode S frame structure provides time for multiple interrogations to any targets that might be garbled by such a squitter environment. Therefore, there would be no degradation of the Mode S SSRs ability to handle any current or predicted target density.

5.3 TEST SET-UP

The test set up is shown in Figure 22. An IFR Corporation Transponder Test Set Model 1400A coupled with a S-1403 interrogated a KT-70X Mode S transponder at 400 Hz with DF=11 interrogations with an address of 77777777, and an II code of 6, corresponding to the West SSR. The West SSR was in Mode S mode. The interrogations were through a circulator such that the reply from the transponder was directed to a quarter wave stub on a ground plane mounted on the roof of the van. A portion of the signal to the antenna was tapped and detected, and displayed on a scope, to verify transponder output. The transponder could not be interrogated by signals entering the roof top antenna, due to the circulator.

This setup was tested at Lincoln Laboratory prior to going to Dallas. The transponder antenna was placed about 1118 feet in range and 155 feet lower in height from Lincoln's Mode S SSR. The Mode S sensor recorded all-call replies with the sensors II code, and the data were found to contain many all call replies with the transponder's ID, both in the mainbeam and at many azimuths corresponding to the SSRs side and back lobes.

The same test setup was used at Dallas, including the same transponder, transponder test set, circulator and detector. The scope indicated that the transponder was emitting short Mode S downlink messages at 400 Hz. The van antenna was the same one used during the ATCRBS false target tests.

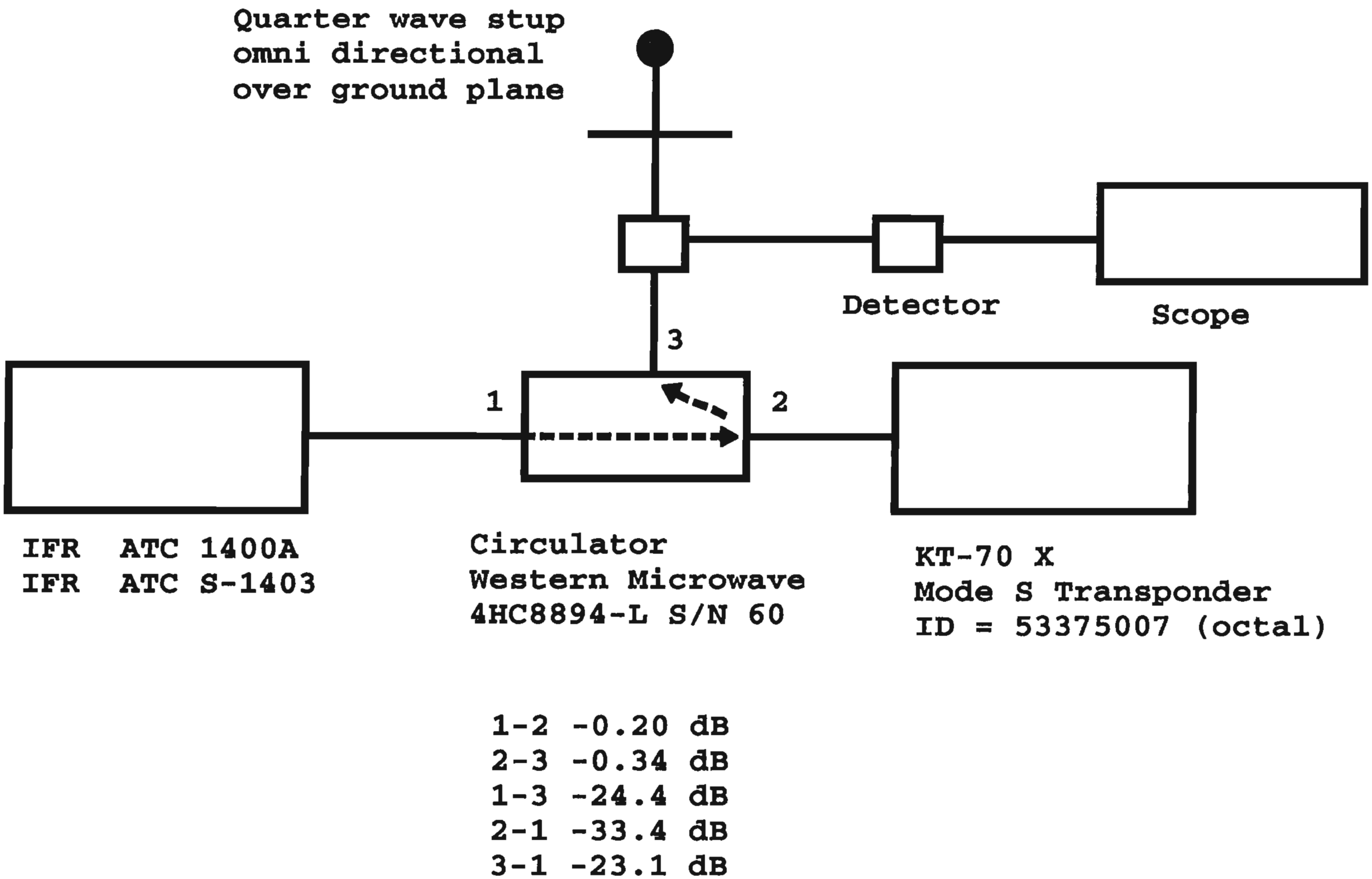


Figure 22. Re-interrogate Test Set Up.

The original plan called for placing the van in the middle of the airport surface (but not on movement area pavement) during a peak busy period. As previously described, this plan could not be implemented. The van was positioned at the beginning of the access road to the West SSR, and was about 876 feet from the SSR and at about the ground level of the base of the West SSR tower. The tower is about 75 feet high. The conditions were thought to be similar to those used in the checkout tests at Lincoln.

The test was conducted in the time during which DFW personnel were available to monitor the ATC displays to be sure the test caused no adverse surveillance effects. Two 10 minute recordings of Mode S roll-call data were made in coordination with AOS personnel around 11:00 PM local time on Thursday, 21 January 1999. One period was with the transponder off, and one with the transponder emitting the all-call replies.

5.4 TEST RESULTS AT DFW

The recorded roll call data were analyzed to determine the probability of successfully interrogating the target and receiving the reply on the first attempt on the scan. Here it is important to note that the Mode S system is designed to interrogate early as the beam sweeps across a target, such that sufficient time remains to schedule additional interrogations if necessary while the target is still within the main beam. With regard to the test performed at DFW, we are examining the probability that no re-interrogation was necessary. The analysis was performed for the approximately 10 minute long period when the transponder was off, and the approximately 10 minute long period when the transponder was emitting all call replies. However, because of unanticipated constraints/changes imposed on the experiment at the last minute, there was a period of about 10 minutes between these two recordings when the transponder was being set up, and during which no data was recorded.

The recorded data indicate that the probability of success on the first attempt was 0.666 when the transponder was off, and 0.591 when the transponder was emitting all call replies. Both results were unexpectedly low, and the difference/change of 7.5 percent* was greater than the expected 5 percent value. It is interesting to note, however, that even with these low probabilities, the overall blip scan ratio of the sensor was in excess of 99 percent in both cases and this was achieved by using the re-interrogation capability of the sensor.

A Mode S sensor is designed to operate in target environments more dense that DFW. Neither of the DFW sensors are functioning in Mode S; they are being used operationally in the IBI mode until such time as the Mode S sensor computers and software are updated with new dynamic reflector software to improve performance against reflectors such as buildings and signs in the vicinity of the airport. The sensors are commissioned to operate in Mode S mode; we do not understand why the probability of interrogation success was so low for the west sensor.

* This number is significantly larger than an erroneous 0.1 percent number reported prematurely by others.

In an attempt to partially understand the low probability of success on the first interrogation at DFW, we examined the interrogation failures and concluded the DFW Mode S SSR frequently began interrogating targets well before the beam reached the target. This condition caused the low value of the probability of success on the first interrogation. The probability was further evaluated as a function of target range for the data recorded when the transponder was off. The probability of success was 0.833 for targets greater than 50 nmi away, and 0.554 for targets less than 50 nmi away. The reason for this range dependence was not explored. This range dependent performance is believed to be the major factor for the 7.5 percent performance change when the transponder was on since the target distribution changed considerably during the 10-minute period between the transponder being off, and its emitting of all call replies. Our analysis shows that a much larger percentage of targets were at short range during the time that the transponder was emitting all call replies. This explains why the apparent impact of the all call replies was greater than expected; i.e., part of the 7.5 percent reduction was due to the greater concentration of targets at short range when the transponder was on.

It is concluded that the test results were not inconsistent with the predictions. Unfortunately, the data are not sufficient to enable us to separate out the effects of range dependence and estimate the performance degradation due to the transponder alone. The originally planned test would have provided such data. Since a close examination of sensor performance and a retest at DFW was difficult to conduct in the time period allocated to preparation of this report, a test was run at the Lincoln Laboratory Mode S SSR to give an independent assessment of the effect of the all call replies.

5.5 TEST RESULTS AT LINCOLN LABORATORY

The transponder was set up in the same location described in Section 5.3. However, this time a directional antenna was used that had about 10 dB of gain toward the Mode S SSR antenna. Before the reinterrogation test was performed, the link margin was determined. A variable attenuator was inserted into the cable between the transponder and antenna, and the attenuation was varied while the SSR tracked the transponder on the roll call. The roll call interrogations failed when the attenuation reached 22 dB. The transponder was about 1118 feet from the SSR, and at such range the SSR attenuation due to the STC function was 43 dB. Therefore, the margin was 65 dB. The sensor was properly set up for Mode S operation at the site, and all call data was recorded and showed that all call replies were received at many azimuths corresponding to the SSR side and back lobes.

Roll call data was then recorded continuously for 12 minutes, divided into 6 two-minute segments with the transponder alternating between "off", and "on". The results were that the probability of success on the first roll call interrogation was 0.868 when the transponder was off, and 0.847 when the transponder was emitting all call replies. The all call replies' interference caused a 2.1 percent reduction in the probability of success on the first interrogation. Because of the alternation of two-minute sessions, the target distribution was approximately the same for the "off" data as the "on" data. The fact that the impact of the interference was less than the 5 percent worst case predicted impact is not surprising for at least two reasons. First, interference received through the side lobes would be at lower amplitude than the desired roll call replies from short-range targets in the main beam, and therefore not strong enough to garble the roll call reply. Secondly, partial overlap of the roll call reply by the interference may be tolerable due to the ability of the Mode S to perform error correction in certain garbling conditions. Therefore, it is concluded that the test results at Lincoln were consistent with the predictions and the results should be used in lieu of the DFW data in regard to demonstrating that the effects of squittering transponders on the surface upon a Mode S sensor will be less than the worst case used by JSC in their analyses. Furthermore, the overall effect on the sensor performance is negligible because of the built in re-interrogation capability of the sensor.

5.6 LINK MARGIN ON THE DFW SURFACE

As described in Section 5.1, the second part of the plan was to drive the van with the high rate squittering transponder on the movement area, while recording the west SSR's reception of those transmissions. The purpose was to determine from which parts of the movement area squitters would enter the SSR's side and back lobes above MTL, and thereby be able to preempt the processing of roll call replies, or garble their reception. Although this test was not conducted, the same information could be inferred from the AMF data collected at 1030 MHz on Wednesday, 20 January 1999, for both the East and West SSRs operating in the IBI mode.

As shown in Figures 5 and 14, the ATCRBS transponder was interrogated by the west (Figure 5) and east (Figure 14) SSR's in the IBI mode over almost the entire movement area of both sides of the DFW airport. The AMF recorded the suppression bus output (indicating transponder reply) of the transponder, and also recorded the 1030 pulses, including their amplitude. The AMF data allows calculation of the main beam link margin to each SSR. SSR antenna pattern measurements provided by the manufacturer can provide the side and backlobe gains relative to peak of beam.

The probability of a short roll call reply not being preempted, garbled, monopulse-invalidated, or otherwise ruined by a long squitter emitted from a surface aircraft is equal to the sum of a number of terms representing various mutually exclusive outcomes. The dominant term is the probability that no long squitter be received above MTL from the period starting 128μs before the beginning of the roll call reply to 64μs after the beginning of the roll call reply. Under the Poisson assumption this would be, where lambda is 100 aircraft emitting 2 long squitters per second;

P(success) > e exp [- lambda * (128 + 64) * 10 exp (-6)]

P(success) >~ 1 – [lambda * (128 + 64) * 10 exp (-6)]

P(success) >~ 1 – [100 * 2 * (128 + 64) * 10 exp (-6)]

P(success) >~ 0.962

Additional terms would include the probability that the squitter did not preempt the roll call reply, but did arrive during the roll call reply period, but with a power too low to disturb the monopulse estimate or the message decoding. In the analysis herein, we will conservatively ignore such additional terms.

The calculation above indicates that the effect of long ADS-B squitters from 100 moving surface aircraft would be to degrade the probability of a success on the first roll call interrogation by 3.8 percent.

Now, we will incorporate the AMF measurements to estimate how many of the squitters that are received through the side and back lobes will actually be above MTL. For this purpose, and based on antenna pattern measurements provided by the SSR antenna manufacturer, we assume that the side and back lobes are uniformly 35 dB below the main beam peak. The results are shown in Figure 23, which shows, for each SSR, the cumulative distribution of side and back lobe received powers of squitters emitted from a random position on either side of the DFW movement area. (This distribution did not include periods when the van was stationary.) If the SSR MTL is –75 dBm, then only 35 percent of the 100 squittering aircraft would be capable of garbling East SSR roll call replies, and only 25 percent for the West SSR. These percentages change the lambda in the calculations above. Taking an average value of 30 percent over the two SSR's indicates that the probability of not having to reinterrogate due to garbling by long squitters from 100 surface aircraft would be better than:

$$P(\text{success}) <\sim 1 - [\ 0.30 * 100 * 2 * (128 + 64) * 10 \exp(-6)\ ]$$

$$P(\text{success}) <\sim 0.989$$

Putting the result in the opposite sense, the data indicate that the increase in Mode S roll call reinterrogation rate due to leaving the Mode S transponders on in the ADS-B squitter mode would be slightly greater than 1 percent.

The JSC simulation of the Los Angeles environment showed a 1.9 percent increase in the reinterrogation rate for 40 surface aircraft emitting 128µs extended squitters at 2.2 times per second. It assumes that any overlap of a roll call reply by a squitter garbles the reply, and also assumes that each squitter gets into the SSR receiver by the side or back lobes, The poison prediction for this scenario is 1.7 percent.

$$P(\text{success}) <\sim 1 - [\ 40 * 2.2 * (128 + 64) * 10 \exp(-6)\ ]$$

$$P(\text{success}) <\sim 0.983$$

Thus, the JSC simulation agrees with and confirms the poison prediction. The JSC simulation found no degradation in the Mode S discrete blip/scan ratio.

Here it is important to recall that the squitters used in this analysis are long squitters being proposed for ADS-B operation both in the air and on the ground. The squitter numbers to be experienced near term at DFW and other airports due to short squitters from existing equipment is significantly less; e.g., 1 short squitter per second now vs. 2 long squitters per second in the future.

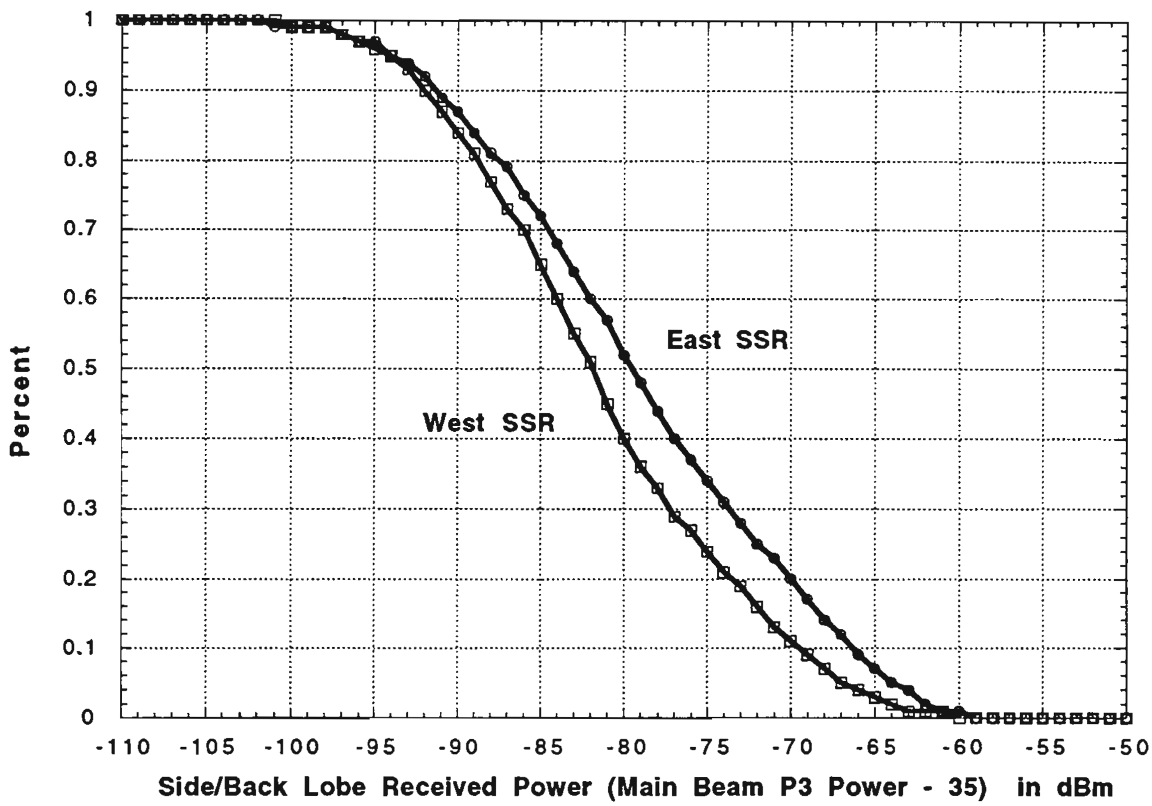


Figure 23. Received power of surface squitters through the SSR side/back lobes.

6. CONCLUSIONS

Conclusions for the issues addressed by the tests conducted at DFW are given below.

Measured spectrum at 1030 MHz and 1090 MHz on the DFW airport surface.

The measurements were consistent with expectations. The DFW surface environment is not approaching a critical point; therefore, ATIDS will not be the "straw that broke the camel's back". The interrogation limits imposed by the FAA specification on the ATIDS contractor should assure no degradation to existing systems; e.g., SSRs operating in either beamsplit or monopulse modes, or TCAS.

ATCRBS Mode A/C false targets on the DFW airport surface.

The ATCRBS false target problem at DFW is less than that observed at Atlanta. Much of the difference is attributable to the wide open airport with most reflectors spaced a greater distance from the movement area than at Atlanta. False reports were generated from 4 locations on the taxiways. The reports were very intermittent and would likely not generate tracks in ARTS or alphanumerics on controller displays for moving aircraft. A few locations may exist that could generate a stationary off airport track, but it would be at the altitude of the airport surface.

Mode S reinterrogation test.

This test was intended to verify JSC simulations that indicate that the use of ADS-B extended squitters on the airport surface will impact, but not degrade, Mode S SSR performance. Unfortunately, the test was cancelled due to weather. Additional tests at Lincoln Laboratory and analysis of other DFW data indicate that the actual reinterrogation rate increase attributable to ADS-B squitters is only 1/3 to 1/2 of what JSC would predict.

ATCRBS Fruit from Surface Transponders.

Surface fruit will increase when ATIDS is installed because of ATCRBS transponders being left "on" while on the movement area. The fruit will be elicited by ground SSRs, TCAS, and ATIDS whisper shout. This fruit represents at most a 12 percent increase over the existing fruit experienced by the airport SSR. Although it may be of greater signal strength than distant airborne fruit, link margins from surface locations to the airport SSR are such that only 30 percent of the surface fruit would enter the SSR side/back lobes above MTL. Also, because of Mode S waveform and SSR design features (Mode S reply modulation is interference resistant, and error correction is used), the impact of this additional fruit on overall sensor performance is expected to be negligible.

Link performance.

The tests seemed to indicate that the Mode A/C interrogation link for the SSR is more reliable than the reply link. Since ATIDS will rely on whisper shout interrogations for multilateration on Mode A/C transponders, it would be useful to conduct further analysis of the AMF 1030 MHz pulse data, and the Mode S and IBI Mode A/C reply data to better understand link performance on the airport surface. Such analysis could aid in selecting the whisper shout sequences, and in refining the siting of the ATIDS Receiver/Transmitters to improve coverage and reliability.

The apparent link imbalance may be due to high interrogation power from the SSR or RSLS settings in the SSR. If so, then the results seen in the tests described here may not apply to ATIDS whisper shout operation. This is because whisper shout tends to interrogate transponders near their MTLs., and the RTs do not use RSLS.

TCAS.

No tests of the impact of ATIDS on TCAS were conducted. If TCAS operates as specified by the TCAS MOPS, then ATIDS should have no impact.