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Air Wing Fallon Large Force Test Data Analysis Report

December 12, 2016

Final Report

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16. Abstract

With the advent of 1090 Megahertz (MHz) Extended Squitters (ES) and the impending Automatic Dependent Surveillance-Broadcast (ADS-B), equipage mandate, spectrum regulators and civil aviation authorities are concerned about increased use of the 1030/1090 MHz radio frequency bands for transponder-based aircraft surveillance. To measure this effect, the Surveillance Branch of the Engineering Development Services Division of the Federal Aviation Administration (FAA) Portfolio Management & Technology Development Office, ANG-C33 was commissioned by the Department of the Navy to deploy an FAA test aircraft, N39, from the William J. Hughes Technical Center (WJHTC) to provide airborne measurements of transponder occupancy rates during a large force exercise by the Department of Defense (DOD) at the Naval Air Station in Fallon, Nevada.

Flight technicians aboard N39 recorded signals on the 1030 and 1090 MHz frequency bands for post-processing and analysis to assess the impact of the exercise on key elements of the National Airspace System (NAS), including SSR transponder occupancy and the 1090 MHz frequency band. Significant impacts on these elements of the NAS would put at risk the proper operation of SSR tracking, Traffic Alert and Collision Avoidance Systems (TCAS) and ADS-B technologies.

The DOD exercise caused an increase in transponder occupancy, but the increase was at a level that is acceptable in areas with low-density air traffic.

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Executive Summary

With the advent of 1090 Megahertz (MHz) Extended Squitters (ES) and the impending Automatic Dependent Surveillance-Broadcast (ADS-B), equipage mandate, spectrum regulators and civil aviation authorities are concerned about increased use of the 1030/1090 MHz radio frequency bands for transponder-based aircraft surveillance. To measure this effect, the Surveillance Branch of the Engineering Development Services Division of the Federal Aviation Administration (FAA) Portfolio Management & Technology Development Office, ANG-C33 was commissioned by the Department of the Navy to deploy an FAA test aircraft, N39, from the William J. Hughes Technical Center (WJHTC) to provide airborne measurements of transponder occupancy rates and 1090 MHz ATCRBS and Mode S FRUIT rates during a large force exercise by the Department of Defense (DOD) at the Naval Air Station in Fallon, Nevada.

The Fallon Training Range, a Special Use Airspace (SUA), is used by the Navy to conduct Air Combat Training on a continuous basis and to conduct full squadron exercises as well as pre-deployment training of the Air Wing. The Air Wing Fallon (AWF) exercise that was measured was a pre-deployment exercise which represents a maximum use scenario. The AWF exercise lasted a month with progressing increase in complexity and quantity of participating aircraft. The measurements were scheduled and conducted during the last 2 days of the exercise to coincide with the period of maximum aircraft participation, and subsequently, maximum impact to the 1030/1090MHz spectrum. Flight technicians aboard N39 recorded signals on the 1030 and 1090 MHz frequency bands for post-processing and analysis to assess the impact of the exercise on key elements of the National Airspace System (NAS), including SSR transponder occupancy and the 1090 MHz frequency band. Significant impacts on these elements of the NAS would put at risk the proper operation of SSR tracking, Traffic Alert and Collision Avoidance Systems (TCAS) and ADS-B technologies.

Section 6 includes an additional analysis of Secondary Surveillance Radar (SSR) data in the area of the test to determine the effect of the additional 1030 MHz interrogators on existing SSR systems.

Figure ES-1 shows a DOD map illustrating the location of the FAA test aircraft in relation to the military exercise (north is up). The two test events conducted November 18 were recorded from the southwest hold, and the November 19 events were recorded from the north hold. The east and southeast orbits are the locations of the E-2D aircraft. Note that this diagram depicts the location of the blue F/A-18 and E/A 18G (fighters) after initial engagement of the red F-16 (opposing forces) which originate in the southwest.

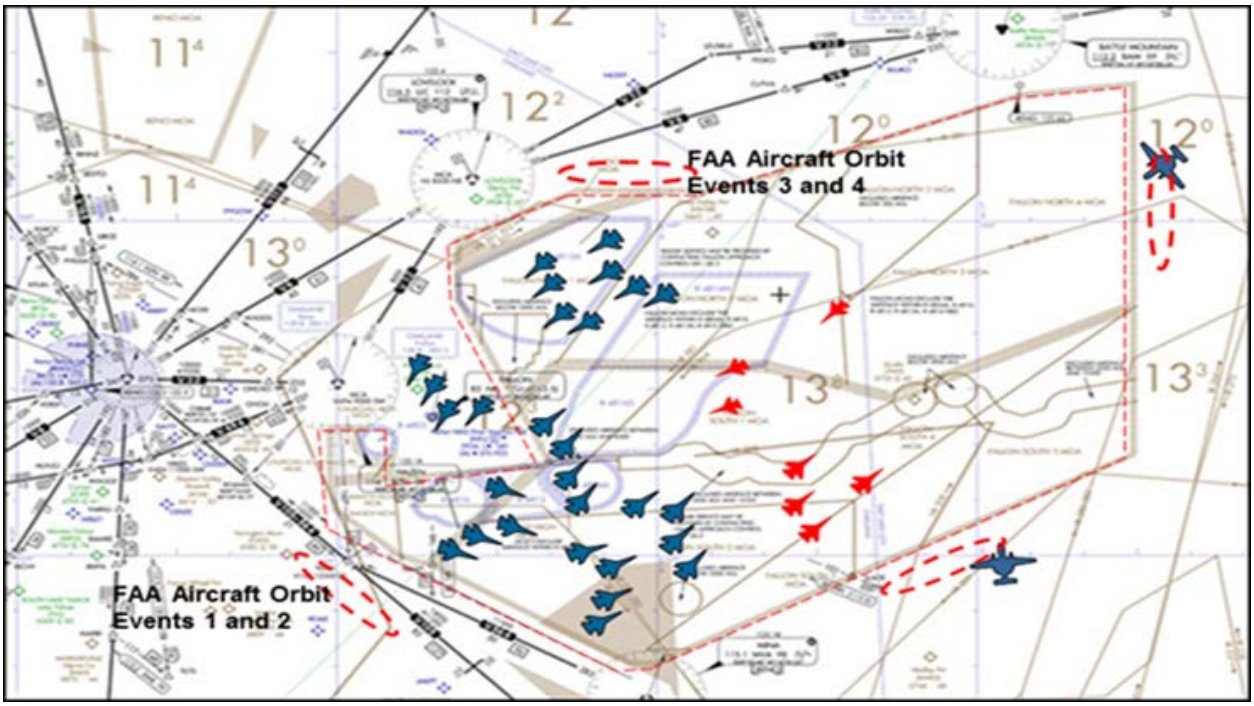

Figure ES-1 Test Event Aircraft and Approximate Locations (*Figure provided by DOD*)

Conclusions

The DOD exercise caused an increase in transponder occupancy, but the increase was at a level that is acceptable in areas with low-density air traffic.

- Typical Mode Select (Mode S) transponder occupancy increased from an average of 1 - 1½ percent prior to the exercises to peaks as high as 3 percent during the exercises.
- Worst-case Mode S transponder occupancy (transponders that just meet the required recovery and dead times) increased from an average of 2 percent to as much as 6 percent briefly during the exercise.
- Typical Air Traffic Control Radar Beacon System (ATCRBS) transponder occupancy increased from about 1 - 1½ percent average prior to the start of the exercise to as much as 10 percent briefly during the exercise.
- Worst-case ATCRBS transponder occupancy was only slightly higher than typical and increased to as much as 12 percent briefly during the test.

There was no increase in the 1090 MHz Mode S False Replies Unsynchronized In Time (FRUIT) environment during the DOD test events. No Mode S FRUIT increase was expected since the participating military aircraft do not interrogate Mode S. In two of the four events, the 1090 MHz ATCRBS FRUIT rates showed higher rates during the exercise than the baseline pre-test rates. In the other two events, there was no indication of elevated ATCRBS FRUIT rates. It was expected that there would be some impact on ATCRBS FRUIT because Mode 3/A and C interrogations are included in the participating military interrogation formats. The peak 1090 MHz ATCRBS FRUIT rates measured during the tests in areas of normally low-density air traffic were considerably lower than rates measured in areas of high-density air traffic such as the northeastern United States (U.S.)

- Mode S and ATCRBS FRUIT rates varied significantly prior to the start of the exercise as well as during the exercise.
- Mode S FRUIT rates peaked at about 400 per second (at -84 Decibels referenced to one milliwatt (dBm) and greater) during the exercise, but there was a peak of 500 per second measured prior to the start of one of the tests.
- The highest ATCRBS FRUIT rate measured was 4000 per second (at -79 dBm and greater) during one exercise, but rates as high as 3000 were measured when the exercise was not being conducted.

There was an increase in transponder occupancy levels and some increase in 1090 MHz ATCRBS FRUIT rates measured during the four DOD exercises. However, the measurements were less than those typically reached during peak times in areas of high-density air traffic. Since safe operation of air traffic is maintained in these areas of high-density air traffic, it can be concluded that exercises such as the large scale test conducted in Fallon in November 2014 cause no detriment to the NAS in this region. It is recommended that such exercises be conducted in areas with low-density air traffic.

Overall, there was little noticeable effect caused by the additional aircraft interrogators on the FLX SSR system, with the exception of a small decrease in Pd and a small increase in the number of false targets. During the exercise, the Mode S system performed within blue-sheet specifications and no degradation in system availability was observed.

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Acronyms

A to D	Analog to Digital
AC	Mode A/Mode C
ACP	Azimuth Change Pulse
ADS-B	Automatic Dependent Surveillance-Broadcast
AM	Ante Meridian
AMP	Amplitude
ANG-C	FAA NextGen Portfolio Management & Technology Development Office
ANG-C33	Engineering Development Services Division, Surveillance Branch
ASR-11	Airport Surveillance Radar - Model 11
ATCRBS	Air Traffic Control Radar Beacon System
Avg.	Average
AWF	Air Wing Fallon
Az	Azimuth
BAM	Battle Mountain Airport, Nevada
BI-6	Beacon Interrogator Model 6
BOT	Bottom Antenna
CLR	In the Clear
COMEX	Commence Exercise point
dB	Decibel
dBm	Decibels Referenced to One Milliwatt
DF	Downlink Format
DO	Document
DOD	Department of Defense
DOT	Department of Transportation
DPSK	Differential Phase Shift Keying
E-Event	End Test Event
ES	1090 MHz Extended Squitter OR Executive Summary
FAA	Federal Aviation Administration
FINEX	Finish Exercise point
FLX	Fallon Municipal Airport, Nevada
FRUIT	False Replies Unsynchronized In Time
GPS	Global Positioning System
ICAO	International Civil Aviation Organization
II	Interrogator Identifier
INT	Interrogation
KNFL	Fallon Naval Air Station, Nevada
KVM	Keyboard, Video, Mouse
LE	Leading Edge
LLMS	Low-Level Mode S
M	Mode
MA	Mode A
MC	Mode C
MHz	MegaHertz
Mode 1	Mode 1 military radar

Mode 2	Mode 2 military radar
Mode 3/A	Mode 3/A radar
Mode 4	Mode 4 military radar
Mode C	Altitude-Reporting Mode of Secondary Surveillance Radar
Mode S	Mode Select
MOPS	Minimum Operational Performance Standards
Mov. Avg.	Moving Average
MTL	Minimum Triggering Level
N/A	Not Applicable
NAS	National Airspace System
NFL	Fallon Naval Air Station, Nevada
NJ	New Jersey
Nmi	Nautical Miles
No.	Number
NTIS	National Technical Information Service
Pd	Probability of Detection
PDF	Portable Document Format
PLE	Pulse Leading Edge
PM	Post-Meridian
PRF	Pulse Repetition Frequency
RBL	Red Bluff Municipal Airport, California
Ref	Reflection
RF	Radio Frequency
RNO	Reno-Tahoe International Airport - NV
S-Event	Start Test Event
SSR	Secondary Surveillance Radar
SUA	Special Use Airspace
SUP	Suppression
TC	Technical Center
TCAS	Traffic Alert and Collision Avoidance System
TIR	Transponder Interrogation Recorder
TPH	Tonopah Airport, Nevada
TRAIS	Transportation Reporting And Inquiry System
U.S.	United States
UF	Uplink Format
UTC	Coordinated Universal Time
WJHTC	William J. Hughes Technical Center
μs	Microsecond

1 Introduction

1.1 Purpose

With the advent of 1090 Megahertz (MHz) Extended Squitters (ES) and the impending Automatic Dependent Surveillance-Broadcast (ADS-B), equipage mandate, spectrum regulators and civil aviation authorities are concerned about increased use of the 1030/1090 MHz radio frequency bands for transponder-based aircraft surveillance. To measure this effect, the Surveillance Branch of the Engineering Development Services Division of the Federal Aviation Administration (FAA) Portfolio Management & Technology Development Office, ANG-C33, was commissioned by the Department of the Navy to deploy an FAA test aircraft, N39, from the William J. Hughes Technical Center (WJHTC) to provide airborne measurements of transponder occupancy rates during a large force exercise by the Department of Defense (DOD) at the Naval Air Station in Fallon, Nevada.

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1.2 Scope

The Surveillance Branch performed post-processing and analysis on data recorded aboard FAA aircraft N39 flying holding patterns outside of restricted military airspace near Fallon Naval Air Station during four test events on November 18-19, 2014. Analysis focused on transponder occupancy data, False Replies Unsynchronized In Time (FRUIT) in the 1090 MHz frequency band, and SSR data.

2 System Overview

SSR systems provide many advantages over primary surveillance radar for use in air traffic control. Key improvements include the provision of pressure altitude to controllers, as well as a discrete aircraft addressing system in which specific aircraft transponders are interrogated with 1030 MHz signals and respond with the requested state data on the 1090 MHz frequency.

The January 1, 2020 ADS-B Out mandate is expected to further congest these frequencies and the ability of transponders to process the signals properly in areas with high densities of aircraft, such as the northeast corridor. Transponder performance can be limited by the time it takes to process multiple types of interrogations and replies, and this performance can be measured using the rates of transponder occupancy in various NAS environments. The following subsections provide a summary of occupancy requirements for Mode S and ATCRBS transponders, and samples of transponder occupancy data from previous tests.

2.1 Transponder Occupancy Data

- Transponder occupancy is calculated as the percentage of time a transponder is occupied on a per-second basis.
- Occupancy is calculated for different transponder types and functions:
  - Air Traffic Control Radar Beacon System (ATCRBS) transponder
  - Mode S transponder:
    - ATCRBS function
    - Mode S function
- Two occupancy values are calculated for each transponder and function, Typical and Worst Case:
  - Typical uses occupancy criteria defined by the International Civil Aviation Organization (ICAO) Aeronautical Surveillance Panel Technical subgroup, i.e., maximum allowable suppression duration = 35.5 microseconds (from the leading edge of Pulse 1 (P1 LE))
  - Worst case uses the maximum allowable time limit for each event, i.e., Suppression Duration = 47 microseconds (from P1 LE).

Example data from an unrelated test event is shown in Figure 2-1, below. The X-axis depicts time and the Y-axis shows the percentage of time the transponder is occupied. The plot shows the worst-case data in red and the typical data in blue, with a darker trend lines showing the 10-second moving average.

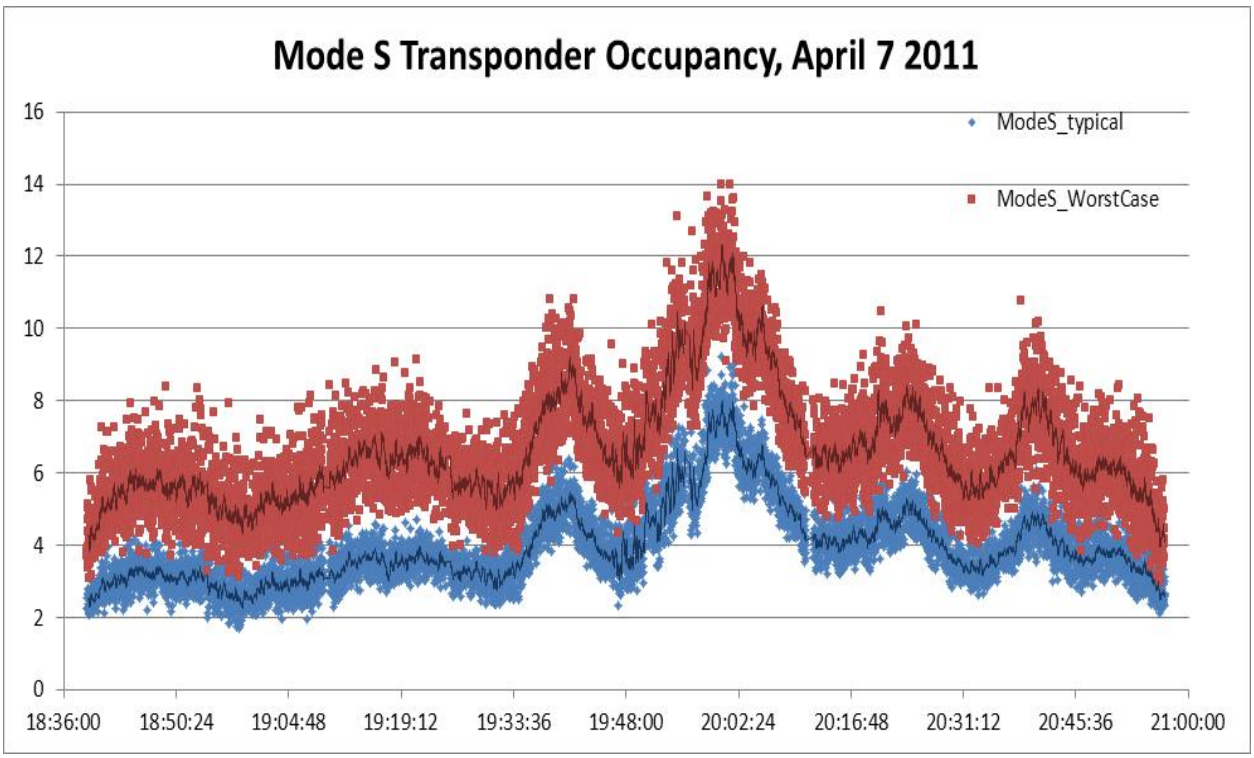

Figure 2-1 Example of Mode S Transponder Occupancy from an Unrelated Test

- The occupancy calculation process provides the contributing factors to the occupancy of the transponder:
    - Mode S Occupiers:
        - Interrogation acceptance and reply:
            - Mode S
            - ATCRBS
            - ATCRBS/Mode S
        - Recovery:
            - Mode S interrogations to other aircraft
            - Broadcasts
            - Locked out all-calls
        - Mutual suppression bus: Ownship TCAS interrogations
    - Mode S transponder ATCRBS function occupiers:
        - Interrogation acceptance and reply:
            - Mode S
            - ATCRBS
            - ATCRBS/Mode S
        - Suppression:
            - Side-lobe suppression
            - Mode S not replied to
            - Whisper-shout
            - ATCRBS-Only
        - Mutual suppression bus: Ownship TCAS interrogations
    - ATCRBS transponder occupiers:
        - Interrogation acceptance and reply:
            - ATCRBS
            - ATCRBS/Mode S
            - ATCRBS-Only
        - Suppression:
            - Side-lobe suppression
            - Mode S
            - Whisper-shout

An example of a plot of contributing factors to transponder occupancy is shown below in Figure 2-2 . The X-axis depicts time and the Y-axis shows the percentage of time the transponder is occupied. Color coding is used to highlight the various contributors to transponder receiver occupancy. This type of analysis is valuable in determining specific causes when increases in occupancy are measured.

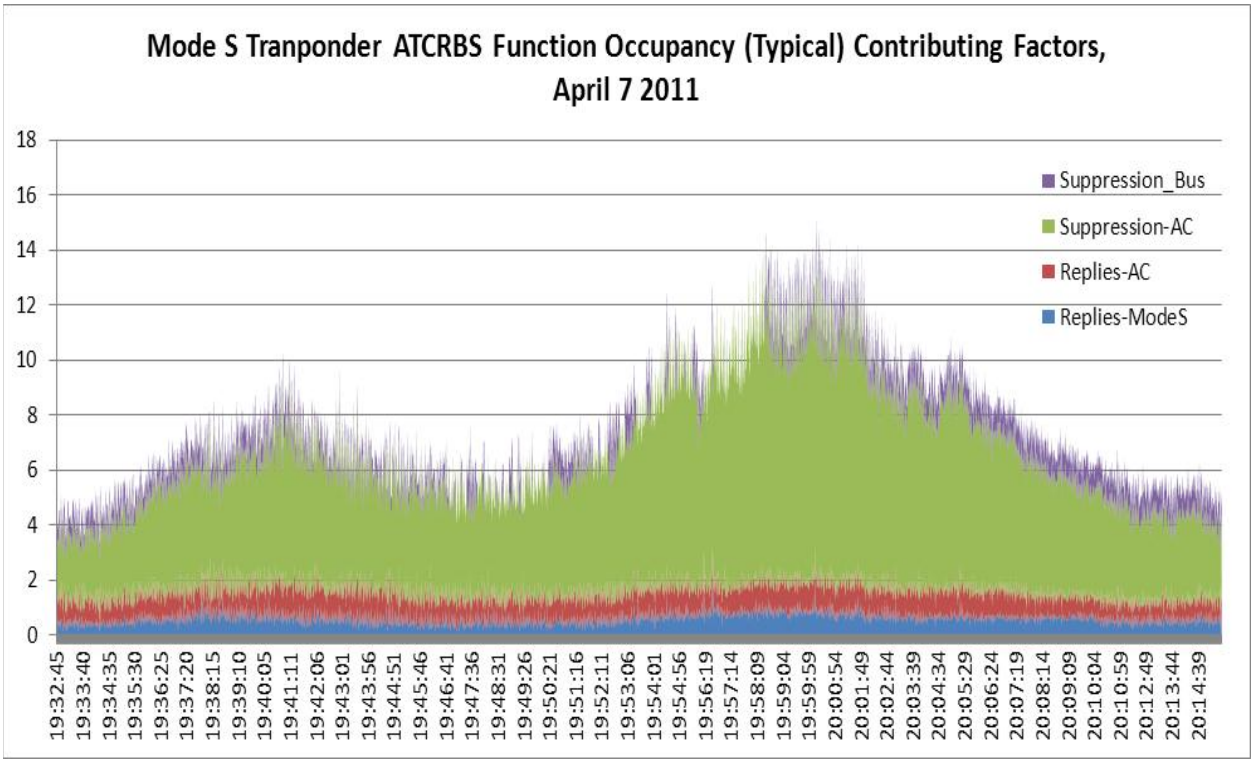

Figure 2-2 Example of Occupancy for the ATCRBS Function of a Mode S Transponder

- The occupancy calculation process provides a per-second count of the contributing factors by type:
  - Mode S (MS) Interrogation (INT) replies:
    - Correctly addressed Uplink Format (UF) 0, 4, 5, 16, 20, and 21
    - UF 11 not locked out (Mode S transponders)
  - ATCRBS/Mode S all-calls, Mode A and C replies (typically false, Mode S transponders):[1]
    - In the clear
    - Within a sub-Minimum Triggering Level (MTL) Mode S interrogation
    - Within a detected Mode 4 interrogation

[1] ATCRBS/Mode S All-Call interrogations are included for occupancy analysis because transponders are designed to reply to them. Even though there are no interrogators currently using them, RF Environment studies have shown that there are some false detections and subsequent replies, usually from Sub-MTL Mode S interrogations.

- ATCRBS Mode A and C replies (Mode S and ATCRBS transponders):
  - In the clear
  - Within a sub-MTL Mode S interrogation
  - Within a detected Mode 4 interrogation
- Mode S interrogations not replied (triggering a recovery period):
  - Unmatched address UF 0, 4, 5, 16, 20, 21
  - UF 11 locked out
  - Garbled interrogations (Mode S transponders)
- Mode S transponder ATCRBS function suppressions:
  - Side-lobe suppression
  - TCAS whisper-shout
  - ATCRBS only
  - Mode S interrogations not replied
  - Sub-MTL Mode S interrogations
  - Within a detected Mode 4 interrogation
- ATCRBS transponder suppressions:
  - Side-lobe suppression
  - TCAS whisper-shout
  - Mode S interrogations
  - Sub-MTL Mode S interrogations
  - Within a detected Mode 4 interrogation

The contributors to transponder occupancy as shown in Figure 2-2, can be broken down further by signal type. For example, the various types of suppressions or different types of interrogations can be color coded and plotted to show more details about the causes of transponder occupancy.

2.2 Occupancy Parameters

Table 2-1, Table 2-2, and Table 2-3 show the parameter values for the events that occupy a transponder. These values are units of time in microseconds that are applied when an event such as suppression is detected. The occupancy calculation is a summation of the total affected time per second. The post-processing keeps track of the current occupancy status of the different transponder types and will not apply occupancy events if the transponder was previously occupied.

Table 2-1 ATCRBS Transponder Occupancy Parameters

ATCRBS Typical		ATCRBS Worst Case
Replies: Interrogation + Delay + Reply + Dead Time Mode A/C, ATCRBS Only, ATCRBS/Mode S (A/C)		
Mode A	8 + 3 + 21 + 56.7 = **88.7 µS**	8 + 3 + 21 + 125 = **157 µS**
Mode C	21 + 3 + 21 + 56.7 = **101.7µS**	21 + 3 + 21 + 125 = **170 µS**

ATCRBS Typical	ATCRBS Worst Case
Suppressions: Suppression Duration from P1 Lead Edge All Interrogations with P1-P2 including: Suppressed ATCRBS, Suppressed ATCRBS Only, Suppressed ATCRBS/Mode S, Suppressed Mode 2, All Whisper-Shouts, Mode S, and Suppression Pairs	
41 µS	**47 µS**

Table 2-2 Occupancy Parameters for the ATCRBS Function of a Mode S Transponder

Typical		Worst Case
Replies: Interrogation + Delay + Reply + Dead Time Mode A/C, ATCRBS/Mode S, Mode S		
Mode A	8 + 3 + 21 + 16.5 = **48.5 µS**	8 + 3 + 21 + 125 = **157 µS**
Mode C	21 + 3 + 21 + 16.5 = **61.5 µS**	21 + 3 + 21 + 125 = **170 µS**
Mode S/A	10 + 128 + 64 + 16.5 = **218.5 µS**	10 + 128 + 64 + 125 = **327 µS**
Mode S/C	23 + 128 + 64 + 16.5 = **231.5 µS**	23 + 128 + 64 + 125 = **340 µS**
Mode S Short	4.8 + 128 + 64 + 16.5 = **213.3 µS**	4.8 + 128 + 64 + 125 = **321.8 µS**
Mode S Long	4.8 + 128 + 120 + 16.5 = **269.3 µS**	4.8 + 128 + 120 + 125 = **377.8 µS**
Suppressions: Suppression Duration from P1 Lead Edge All Interrogations with P1-P2 including: Suppressed ATCRBS, All ATCRBS Only, Suppressed ACRBS/Mode S, Suppressed Mode 1 and 2, Mode 4, All Whisper-Shouts, Mode S not Replied, and Suppression Pairs		
35.5 µS		**47 µS**
Suppression Bus: Defined Suppression Bus Duration for Top and Bottom Antennas Greater than -35 Decibels referenced to one milliwatt (dBm) (indicates from own aircraft): ATCRBS Only, Whisper-Shout, Mode S		
70 µS Top, 90 µS Bottom		**70 µS Top, 90 µS Bottom**

Table 2-3 Mode S Transponder Occupancy Parameters

Mode S Typical		Mode S Worst Case
Replies: Interrogation + Delay + Reply + Dead Time Mode A/C, ATCRBS/Mode S, Mode S		
Mode A	8 + 3 + 21 + 16.5 = **48.5 µS**	8 + 3 + 21 + 125 = **157 µS**
Mode C	21 + 3 + 21 + 16.5 = **61.5 µS**	21 + 3 + 21 + 125 = **170 µS**
Mode S/A	10 + 128 + 64 + 16.5 = **218.5 µS**	10 + 128 + 64 + 125 = **327 µS**
Mode S/C	23 + 128 + 64 + 16.5 = **231.5 µS**	23 + 128 + 64 + 125 = **340 µS**
Mode S Short	4.8 + 128 + 64 + 16.5 = **213.3 µS**	4.8 + 128 + 64 + 125 = **321.8 µS**
Mode S Long	4.8 + 128 + 120 + 16.5 = **269.3 µS**	4.8 + 128 + 120 + 125 = **377.8 µS**
Recoveries: Recovery period from: Mode S with wrong address, Locked out all-calls, Broadcasts		
34.2 µS		**45 µS**
Suppression Bus: Defined Suppression Bus Duration for Top and Bottom Greater than -35 dBm (indicates from own aircraft): ATCRBS Only, Whisper-Shout, Mode S		
70 µS Top, 90 µS Bottom		**70 µS Top, 90 µS Bottom**

3 Test Configuration

Figure 3-1 shows a DOD map illustrating the two holding patterns of the FAA test aircraft in relation to the military exercise conducted in the Fallon Range Training Complex (FRTC) SUA. The two test events conducted on November 18th were recorded from the southwest holding pattern, and the November 19th events were recorded from the north holding pattern. . The pattern to the south was chosen for events 1 and 2 due to the fact that this location provided the location of expected maximum impact due to the fact that the fighters were intercepting (and interrogating) opposing forces which were closest to this location. This provided both the location where the fighters were closest to the recording aircraft, and where they were interrogating for the maximum period while pointing toward the N39 data collection aircraft. The orbit to the Northwest for Events 3 and 4 was chosen because it was closer to the Fallon SSR and also closer to the civil air traffic density just outside of the SUA. Note that the E-2D orbits were to the northeast and southeast. Also, note that this diagram provides the locations of the platforms post initial engagement when the exercise is complete and opposing forces have moved out of initial location to the south-west.

The four events consisted of varying quantities of participating F/A-18, E/A-18G, and E-2D aircraft. The quantity of interrogating aircraft was nominally just below the 22 fighters and 2 E-2Ds approved in frequency assignments N 140427, 140429, 140478, and 140479. F/A-18 and E/A-18G platforms

intercepted (and interrogated) the opposing forces (F-16s) primarily from the north-northeast (on a south-southwest heading). The F/A E/A-18s typically engaged the opposing forces in waves of two or four aircraft, separated by 4 to 6 NM nominally. Specific details concerning whether aircraft were actively interrogating relative to their precise time or location was not collected as the objective was to collect the aggregate operational impact of a realistic, maximum participant, worst case event.

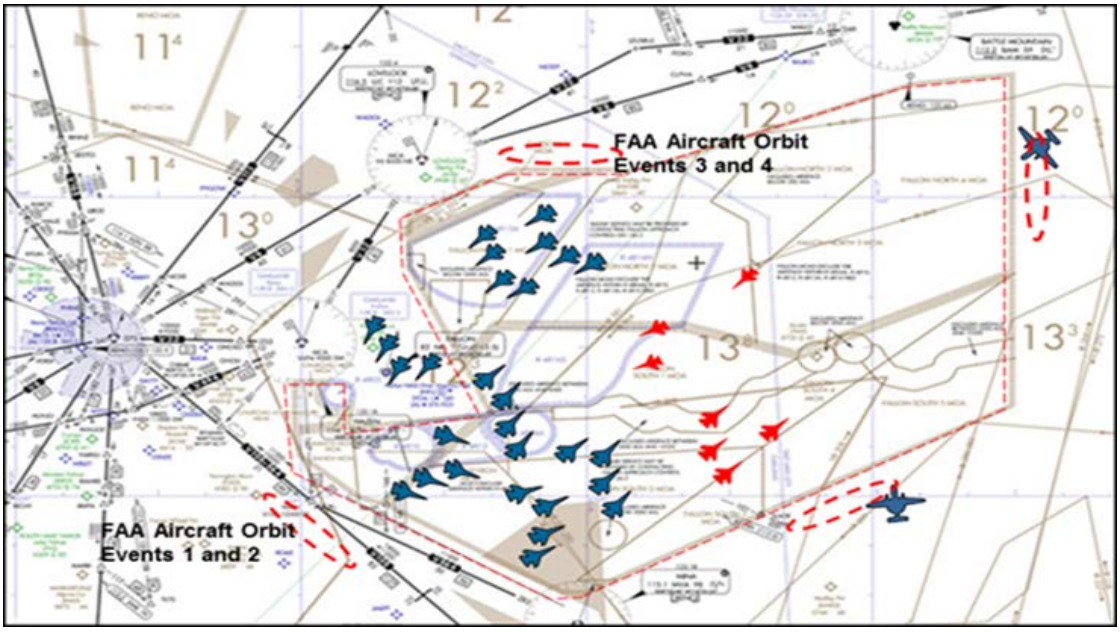

Figure 3-1 Test Event Aircraft and Approximate Locations (*figure provided by DOD*)

3.1 Flight Test Equipment

Engineers at the WJHTC have developed and configured test equipment to provide detailed measurements of the 1030/1090 MHz Radio Frequency (RF) environment that includes signals from SSR, TCAS and ADS-B, as well as other technologies that use these frequency bands. The equipment has been installed on aircraft for airborne measurements as well as ground vehicles or structures for surface measurements.

3.1.1 Airborne Measurement Equipment

3.1.1.1 Equipment Overview

Figure 3-2 shows the basic system configuration used for airborne measurements. The airborne configuration consists of a dual channel 1030 MHz receiver and a dual channel 1090 MHz receiver each for top and bottom antenna recording. (Note: Figure 3-2 shows two separate 1030 MHz receivers and is functionally correct but they are separate channels in one unit) Each receiver provides a log video signal output that is sampled at a rate of 10 MHz and recorded digitally for post-processing and analysis. The 1030 receivers also supply a synchronized Differential Phase Shift Keying (DPSK) signal for recording as well.

Because the log video signal is continuously recorded and post-processed, the ability to re-process the data after modifying the analysis tool is available. This has proven to be a valuable asset when certain anomalies are detected or there is interest in additional decode types. This is the case for both frequencies.

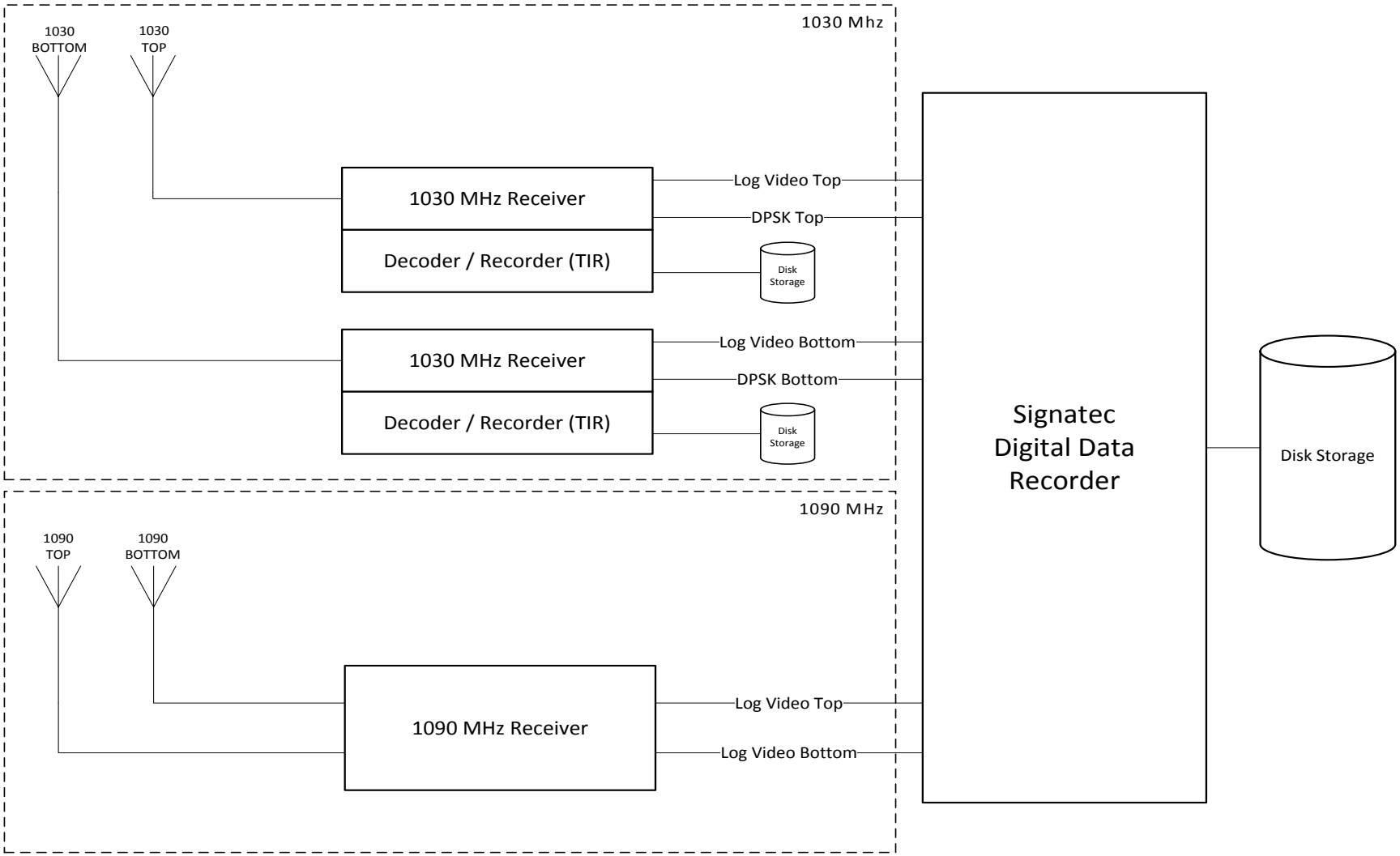

Figure 3-2 Basic 1090/1030 MHz RF Recording Configuration

3.1.1.2 Flight Test Configuration

Figure 3-3 shows a more detailed diagram specific to the flight test configuration. The 1090 MHz system uses receivers designed by FAA engineers and custom built by Freestate Electronics, Inc. to achieve a sensitivity of -87 dBm at the receiver input in order to allow up to 3 dB of cable loss to the aircraft antennas while providing at least -84 dBm sensitivity. The 1030 MHz receivers (Transponder Interrogation Recorders or TIRs) were specially developed at the WJHTC in conjunction with Freestate Electronics, Inc., to include a phase detector that provides an analog pulse representation of phase modulation to be recorded along with the other test data. This enables decoding of Mode S and TCAS interrogation messages. The 1030 MHz receivers have a sensitivity of -78 dBm to provide at least -75 dBm at the antenna. The log video from both receiver bands and DPSK signals (1030 MHz only) are connected to the digital recorder through an amplifier circuit used to adjust the amplitude range of the signal to maximize the analog-to-digital conversion. The signals are sampled and stored at a rate of 10 MHz with each sample size equal to one byte.

Amplitude calibration is achieved for both systems by recording the output of calibrated signal generators that are stepped through a sufficient range of amplitudes to produce a complete cross-reference of power for all Analog-to-Digital (A-to-D) values. For 1090 MHz the A-to-D range from 0 to 255 typically equates to about -95 to -10 dBm; for 1030 MHz, the A-to-D range is typically -85 to -10 dBm. The resulting calibration tables for each receiver channel are offset for cable losses between the project equipment and the associated L-band antenna on the airframe so that processed data power level tags indicate the received power at the antenna.

Both the 1030 and 1090 MHz systems are connected to the Global Positioning System (GPS) for accurate time synchronization. The TIR provides an external clock for the Signatec digital recorder so that all recording is time-synchronized. The TIR records onto a laptop computer connected via Ethernet. The Signatec system records to multiple solid-state large-capacity hard drives. The system is capable of recording for more than four hours.

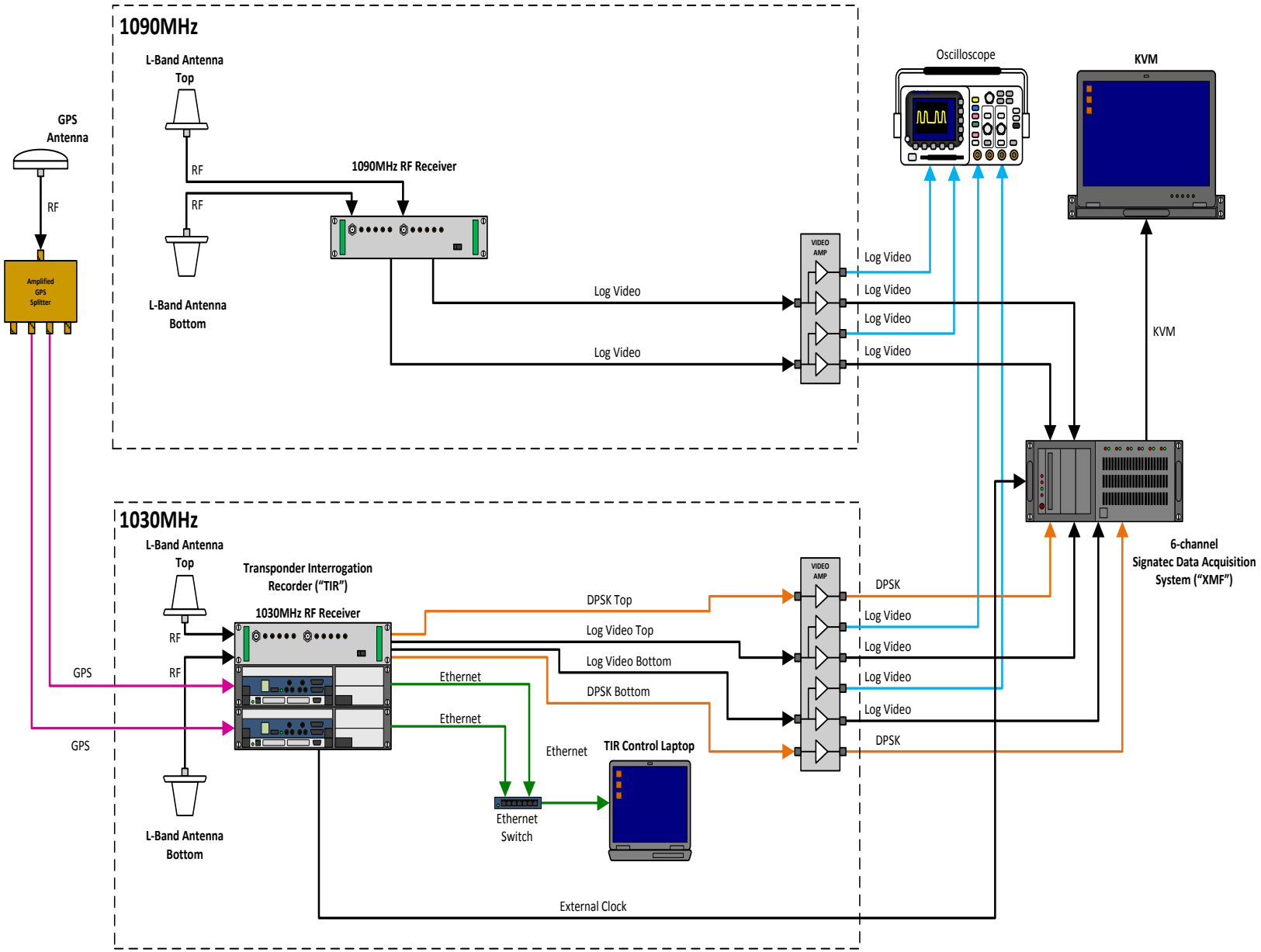

Figure 3-3 1030/1090 MHz Flight Test Equipment Configuration

4 Post-Processing

4.1 1090 MHz Post-Processing

The recorded 1090 MHz log video data is processed using the enhanced squitter reception technique defined in the RTCA Document (DO)-260B MOPS. Appendix I, Section I.4 for detection and decoding of Mode S format signals, including SSR replies, TCAS and ADS-B extended squitters.[2] In fact, the same post-processing software was used to develop and refine the technique defined in the MOPS.

The initial stage of the process defines pulses and their leading edges using the technique described in DO-260B, Sections I.4.1.3 and I.4.1.4. Mode S decoding is initiated through detection of a 4-pulse preamble, and ATCRBS replies are detected using these pulses. When 4-pulse preambles are detected and the remaining validation steps are passed, the baseline multiple-sample enhanced bit and confidence declaration is applied to decode the message. The amplitude of the message is determined using a process similar to the reference level generation algorithm (I.4.1.7) that is applied to include the data block pulses. An address parity test is applied, which returns the error syndrome of squitter messages, the interrogator identifier of all-call replies, or the ICAO address of replies to discrete interrogations. Where applicable, conservative and/or brute-force error correction techniques are applied. The decoded signals with time and amplitude are stored in a comma-delimited text file. There are two modes for post-processing the 1090 MHz data. One is the enhanced decoder process that strictly follows the enhanced decoder process described in DO-260B, Appendix I. This process is used to assess the probability of reception of 1090 MHz ADS-B ES, Mode S and TCAS messages. The second mode uses a variation of the enhanced decoding process to measure the 1090 MHz Mode S FRUIT environment more accurately. This process loosens message validation requirements to include all messages, including those severely garbled and those that are overlapping other signals to maximize the accuracy of total Mode S FRUIT counts. This process outputs a per-second cumulative distribution of Mode S FRUIT rates as related to received amplitude.

ATCRBS detection is only attempted in the spaces between Mode S signals. The pulses and leading edges that were located at the initial stage of the Mode S detection process are used to locate framing and code pulses. Pseudo leading edges are also used for ATCRBS detection due to garbling in high-FRUIT environments. The amplitude of ATCRBS decodes are derived from the samples following pulse leading edges to get peak amplitude. Similar to the Mode S output, the time- and amplitude-tagged data for each ATCRBS decode is stored.

The ATCRBS process also generates a cumulative distribution of FRUIT rates and amplitude similar to that of the Mode S process.

1090 MHz Post-Processing Summary:

- Data recorded from top and bottom antennas
- Sensitivity at least -84 dBm at antenna
- Accuracy of decode time is to the nearest GPS time-tagged 100 nanoseconds
- Uses an enhanced decoding process and applies error detection and correction for Mode S
- Stores decoded as well as unsuccessfully decoded data to measure all signals-in-space independent of signal quality

[2] RTCA DO-260B with Corrigendum 1, Minimum Operational Performance Standards for1090 MHz Extended Squitter Automatic Dependent Surveillance – Broadcast (ADS-B) and Traffic Information Services – Broadcast (TIS-B), December 13, 2011

- Generates a cumulative amplitude distribution of Mode S and ATCRBS FRUIT
- Decode types:
    - ATCRBS Mode A & C
    - Mode S Short or Long Replies
    - Acquisition Squitters
    - ADS-B Extended Squitters
    - TCAS Replies

4.2 1030 MHz Post-Processing

Similar to the 1090 MHz post-processing, the 1030 MHz process begins by locating pulses and their leading edges using the method defined in the RTCA DO-260B MOPS, Appendix I. The process uses the spacing of the pulse leading edges to trigger the various decodes. Mode S interrogations use the additional DPSK data for triggering and decoding. The amplitude of the various decode types are determined by the samples taken at the peak of the pulses that are indexed into the tables generated by the calibration process. The amplitude indicates the power of the interrogation at the receiving aircraft's antenna

1030 MHz Decode Types:

- SSR Interrogations: ATCRBS and Mode S
- Military: Mode 1, Mode 2 and Mode 4
- TCAS Interrogations: Whisper-Shout, ATCRBS-Only, UF 0, Broadcast (UF 16)

1030 MHz Post-Processing Summary:

- Data recorded from top and bottom antennas
- Sensitivity at least -75 dBm at antenna
- The decode time accuracy is to the nearest GPS time-tagged 100 nanoseconds
- Decode types:
    - Mode A, suppressed and non-suppressed
    - Mode C, suppressed and non-suppressed
    - Mode 2, suppressed and non-suppressed
    - Inter-mode A, suppressed and non-suppressed
    - Inter-mode C, suppressed and non-suppressed
    - ATCRBS-Only Mode A, suppressed and non-suppressed
    - ATCRBS-Only Mode C, suppressed and non-suppressed
    - Whisper-Shout Mode A, suppressed and non-suppressed
    - Whisper-Shout Mode C, suppressed and non-suppressed
    - Mode S short, suppressed and non-suppressed
    - Mode S long, suppressed and non-suppressed

- Mode 4
- Mode 1
- Tactical Air Navigation - Distance Measuring Equipment

- The process detects sub-MTL Mode S interrogations and detects other decode types that may be caused by them. (Sub [but near] -MTL Mode S data blocks that partially break the receiver threshold can cause spontaneous replies such as Mode A. Some transponder designs are more susceptible to this than others.)
- Other decode types can be added, and previously recorded data can be re-processed.

5 Airborne Data Analysis and Results

5.1 Mode S Occupancy

Mode S occupancy is a calculation of the percentage of time that the Mode S function of the transponder is occupied and therefore not available to respond to 1030 MHz interrogations. Mode S occupiers include the interrogation acceptance and the resulting reply process including dead time, recovery from interrogations with no reply, and mutual suppression bus activity. A complete description of the process for measuring transponder occupancy is contained in sections 2.1, 2.2, and below.

Occupancy is calculated for two sets of metrics, one for a “typical” transponder and the other for a “worst-case” assessment. Transponders are designed to meet the requirements outlined in the associated RTCA MOPS, some of which require a technical parameter between a minimum and maximum value, or simply a minimum or maximum allowable value. An example of this is “Recovery from a Mode S Interrogation if No Reply is Required,” which shall be within 3 dB of MTL no later than 45 microseconds after receipt of the sync phase reversal. Typical parameters are a value set that has been determined to be average based on data from measurements of production transponders operating in the airspace(s) under test. The typical value for the aforementioned recovery parameter is 34.2 microseconds. The worst-case parameters use the maximum allowable by the MOPS, 45 microseconds.

Figure 5-1 through Figure 5-8 show the calculated transponder occupancy from post-processing the recorded data from the four test events. In the first plot on each page, the typical occupancy is in red, the worst case is blue, and each data point is the occupancy for one second. The dark color band for each is the 10-second moving average. In the first plot on each page, key event times are marked with the vertical dotted/dashed lines as follows: S-Event: Start Test Event; COMEX: Commence Exercise; FINEX: Finish Exercise; E-Event: End Test Event. The second plot on each page shows the percent contribution from the four Mode S occupier categories for the typical occupancy calculation.

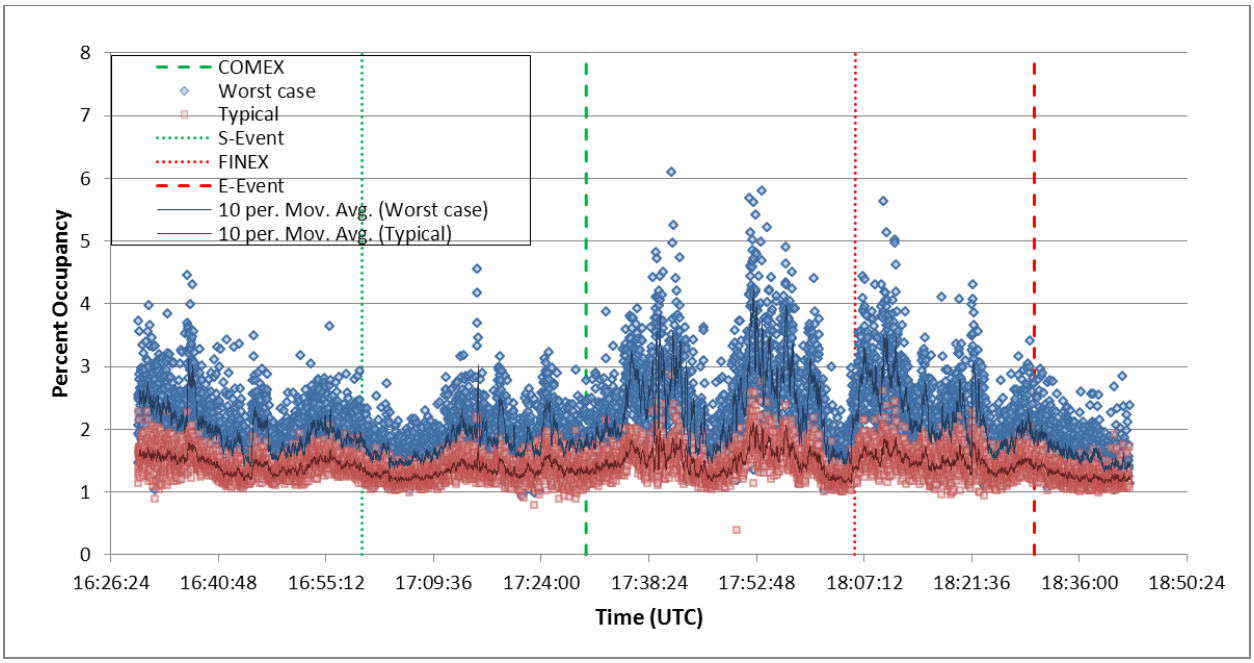

Figure 5-1 Mode S Occupancy 11-18-2014 AM

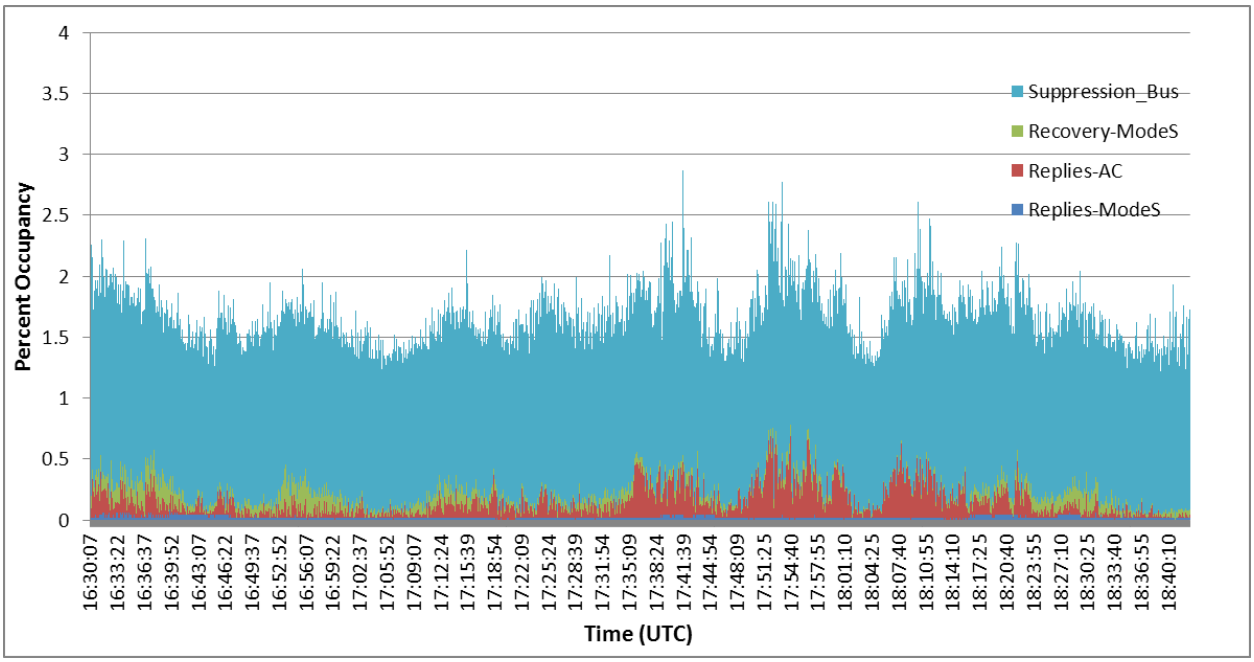

Figure 5-2 Mode S Typical Occupancy Showing Occupiers 11-18-2014 AM

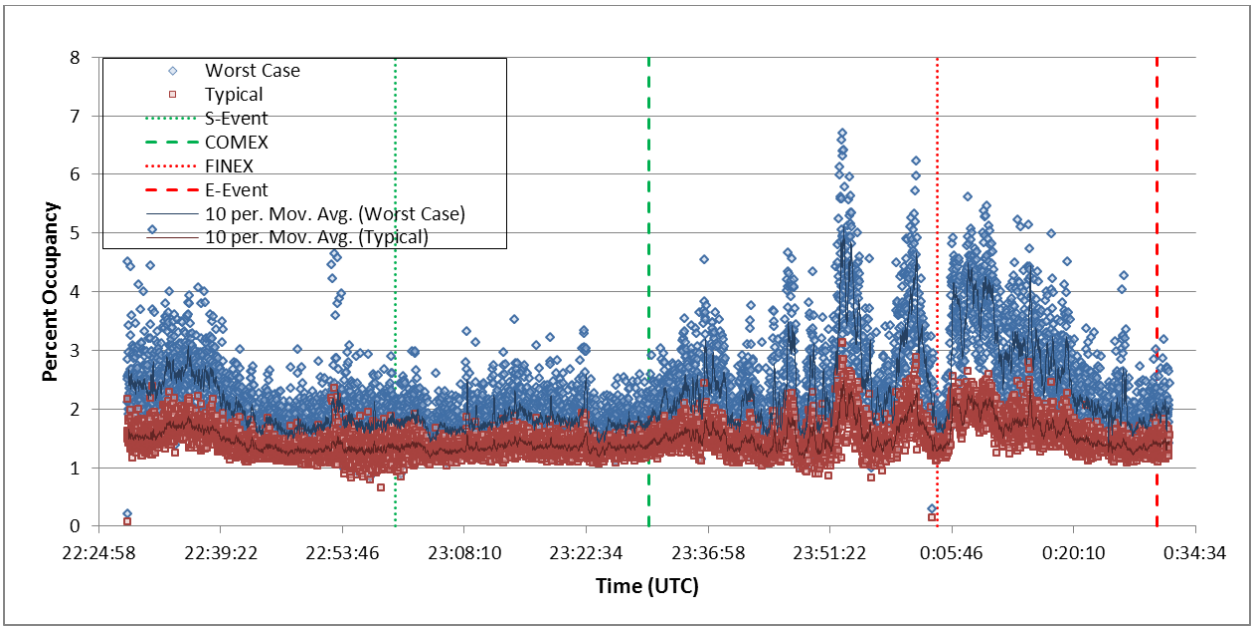

Figure 5-3 Mode S Occupancy 11-18-2014 PM

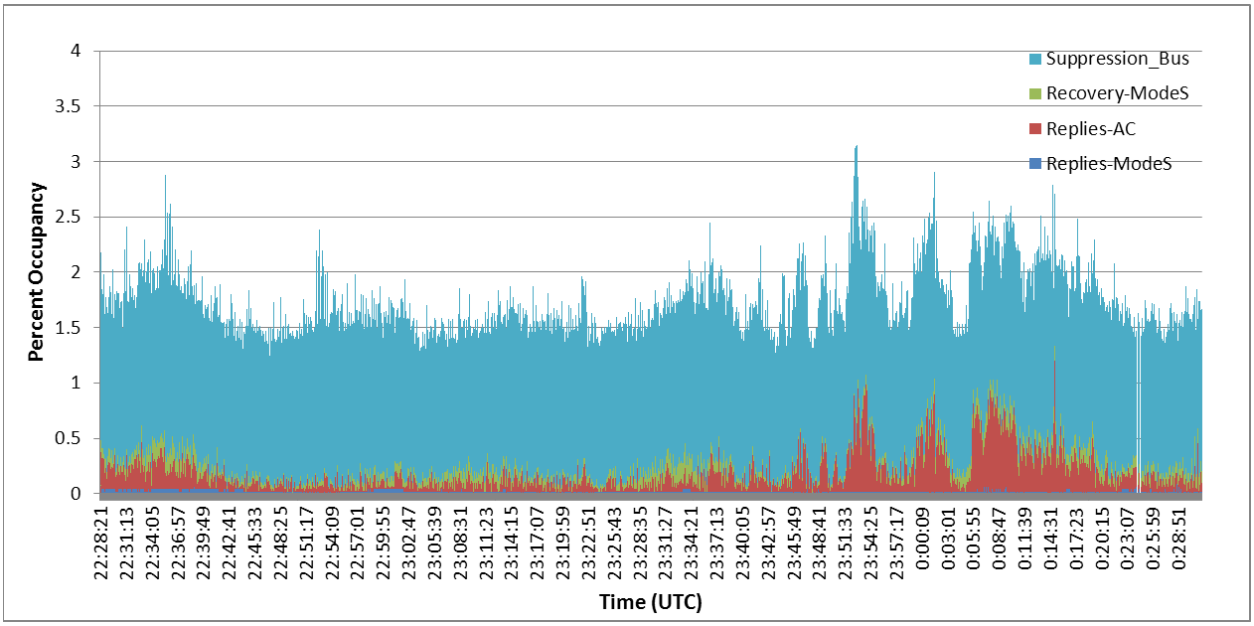

Figure 5-4 Mode S Typical Occupancy Showing Occupiers 11-18-2014 PM

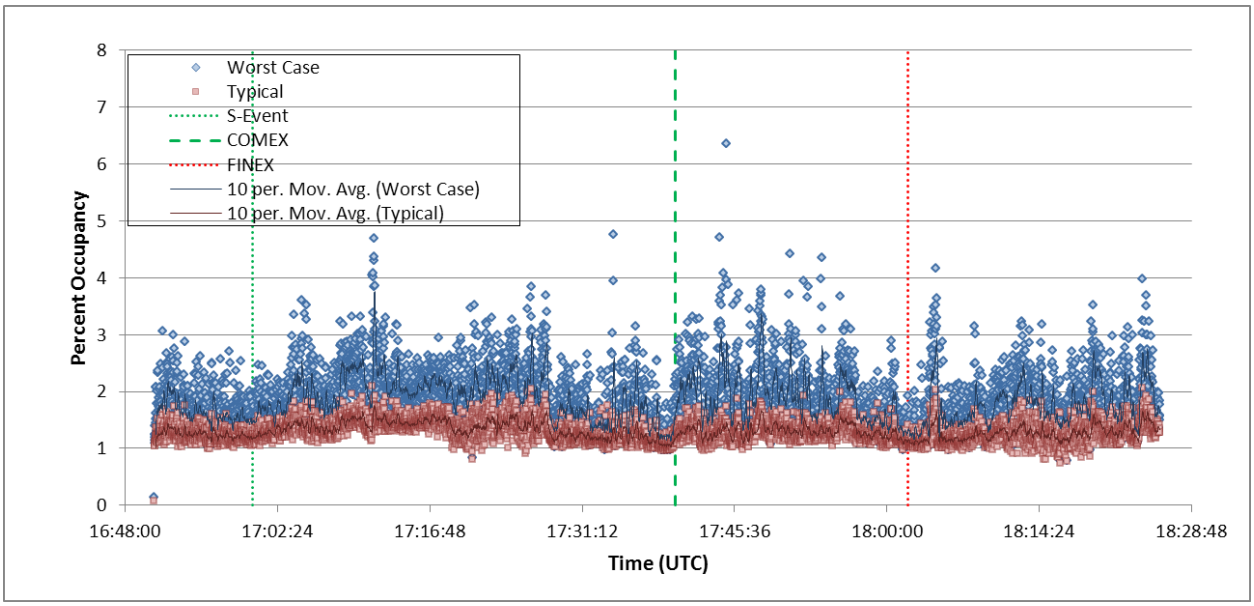

Figure 5-5 Mode S Occupancy 11-19-2014 AM

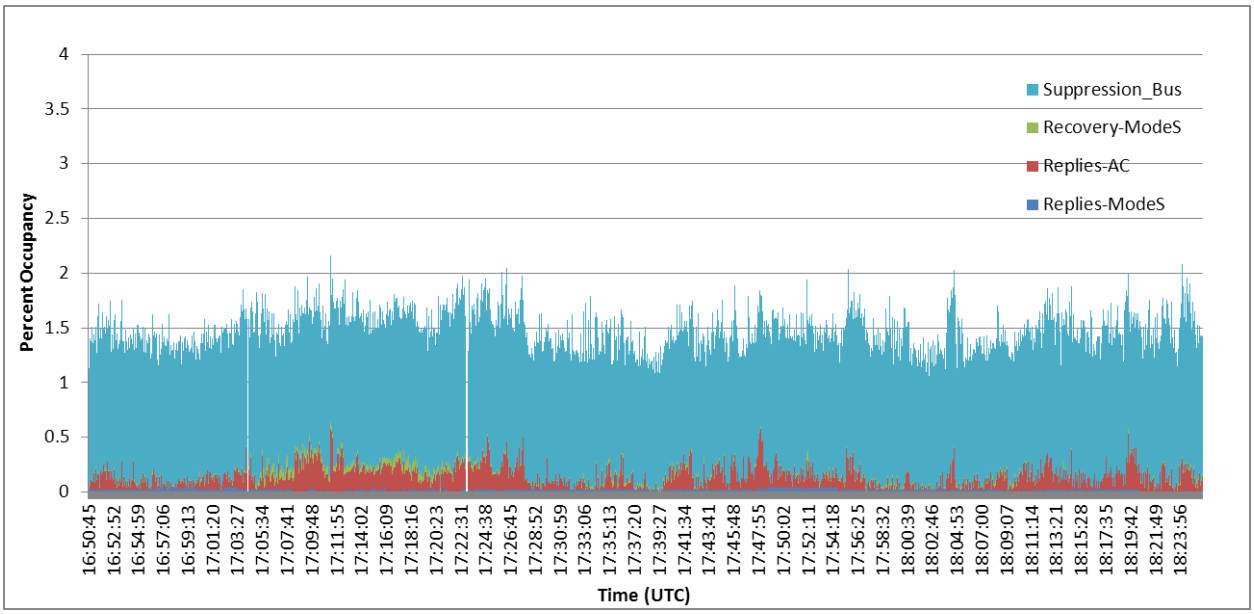

Figure 5-6 Mode S Typical Occupancy Showing Occupiers 11-19-2014 AM

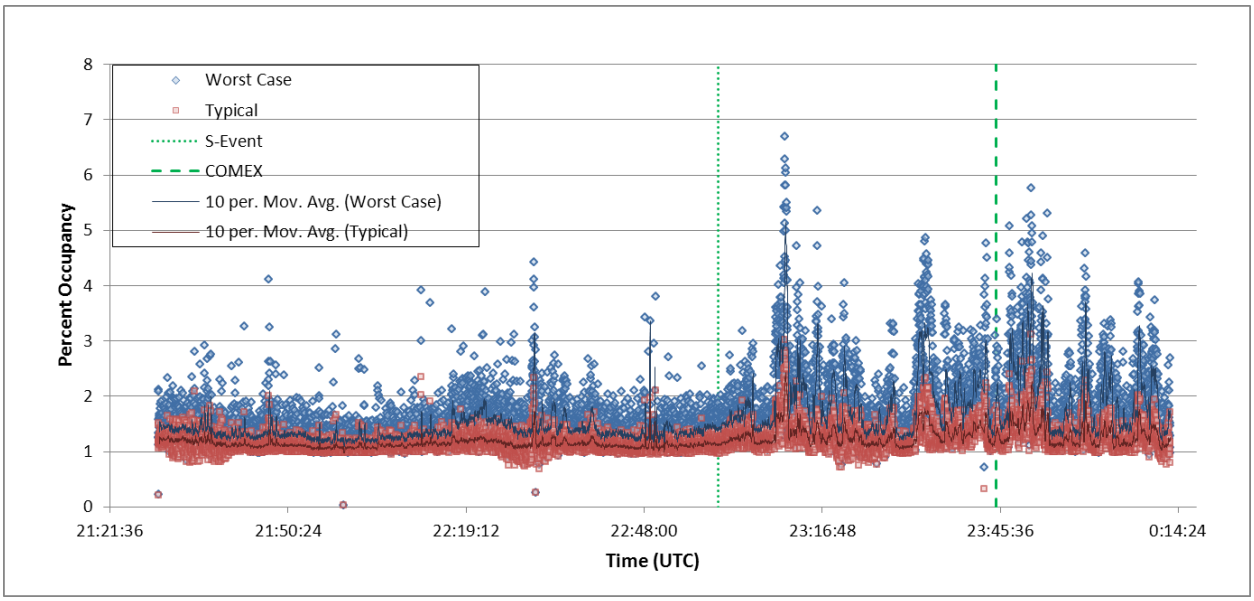

Figure 5-7 Mode S Occupancy 11-19-2014 PM

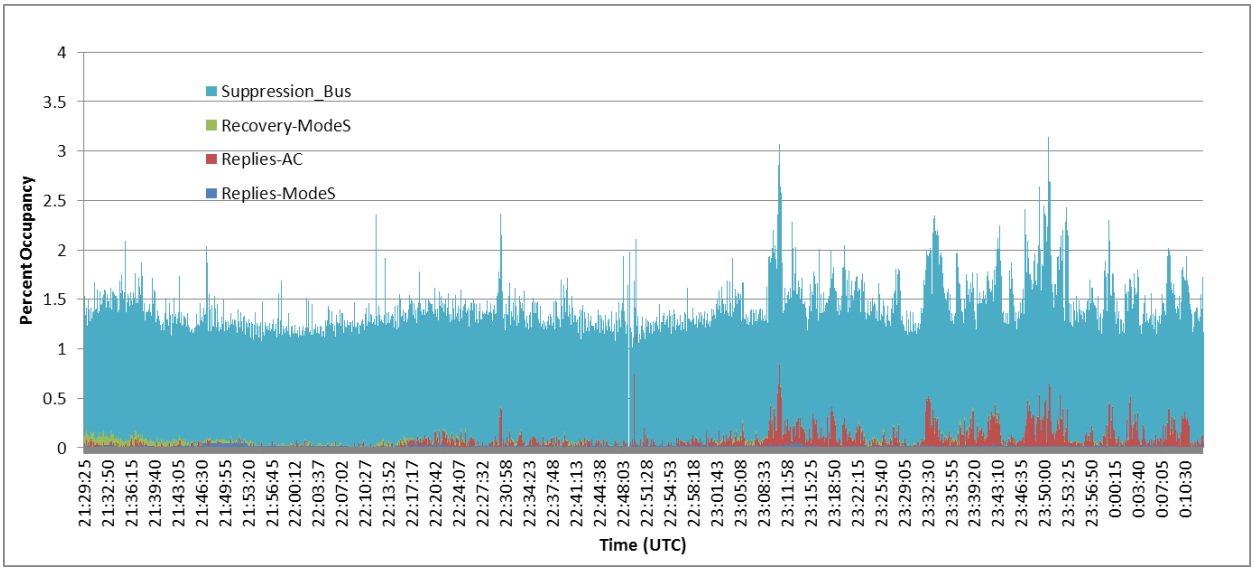

Figure 5-8 Mode S Typical Occupancy Showing Occupiers 11-19-2014 PM

The dominant occupier for Mode S in the four tests is the mutual suppression bus. The actual mutual suppression bus was not recorded or monitored during the test. The occupancy from the suppression bus was calculated based on interrogations from the onboard TCAS included in the recorded data. Each interrogation on the top antenna adds 70 microseconds, and each from the bottom adds 90 microseconds to the total occupancy. Occupancy times due to the suppression bus are based on information in the TCAS MOPS, DO-185B.[3]

There are brief increases in Mode S occupancy during the test events of as much as about 1.5% (from about 1.5% to about 3%) for typical transponders. Worst-case occupancy increases to above 6% from about 2% for brief periods during the test events (not shown). Figure 5-8 shows that these increases are mostly due to additional ATCRBS interrogations that trigger replies (Replies-AC, in red). The worst-case plots are significantly more affected by the extra replies because the dead time parameter is much greater for worst case, 125 microseconds, vs. 16.5 microseconds for typical.

5.2 ATCRBS Occupancy

ATCRBS occupancy is a calculation of the percentage of time that an ATCRBS transponder, or the ATCRBS function of a Mode S transponder, is occupied and therefore not available to respond to 1030 MHz ATCRBS interrogations. ATCRBS occupiers include Mode 3/A and C interrogation acceptance and the resulting reply process, including dead time and suppressions. In the following set of plots, ATCRBS occupancy is shown without including suppression bus activity. This is intended to represent the occupancy of aircraft equipped with ATCRBS only, since in most cases TCAS equipped aircraft are also equipped with Mode S. The Typical ATCRBS function of a Mode S transponder would have the same trend as shown in the plots, with the addition of about a constant 1.5% additional occupancy due to the suppression bus.

The data is presented in Figure 5-9 through Figure 5-16, similar to the Mode S occupancy, with the "typical" occupancy shown in red and the "worst case" shown in blue, each with the highlighted 10-second moving average. The second plot on each page shows the typical occupancy with the contributions from replies and suppressions shown in blue and red to indicate their respective contribution to the total occupancy.

[3] Change 2 to DO-185B, Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System II (TCAS II), March 20, 2013

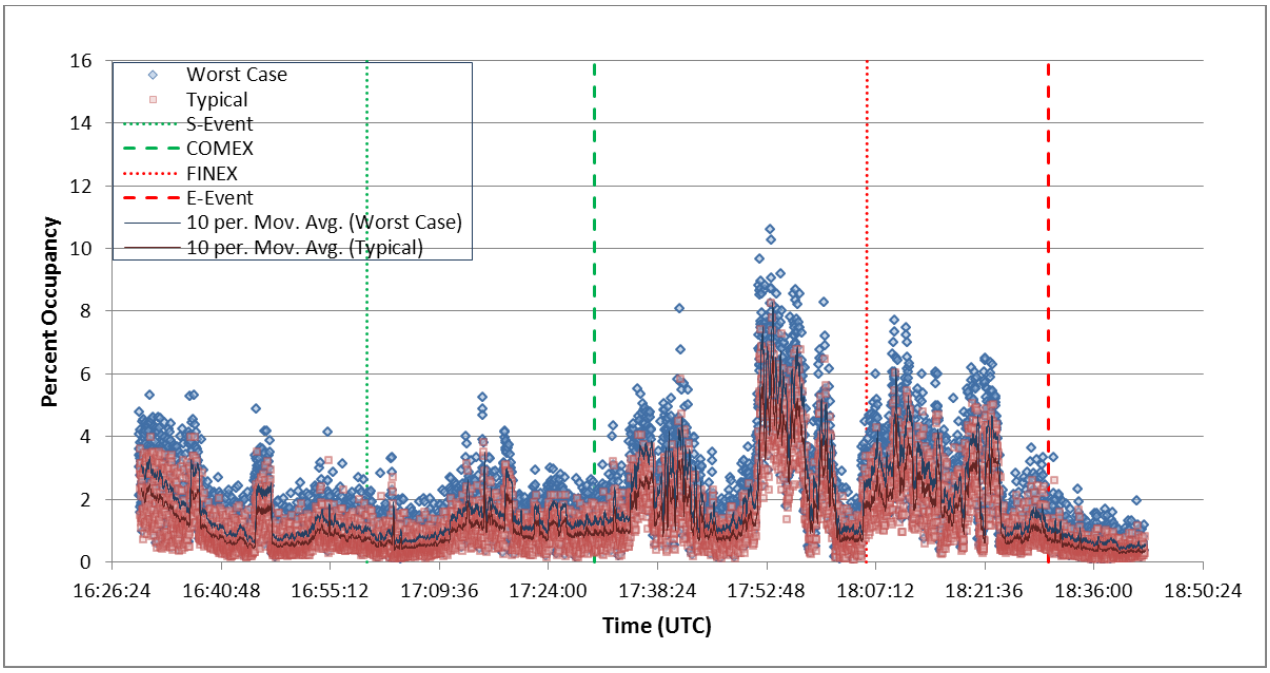

Figure 5-9 ATCRBS Occupancy 11-18-2014 AM

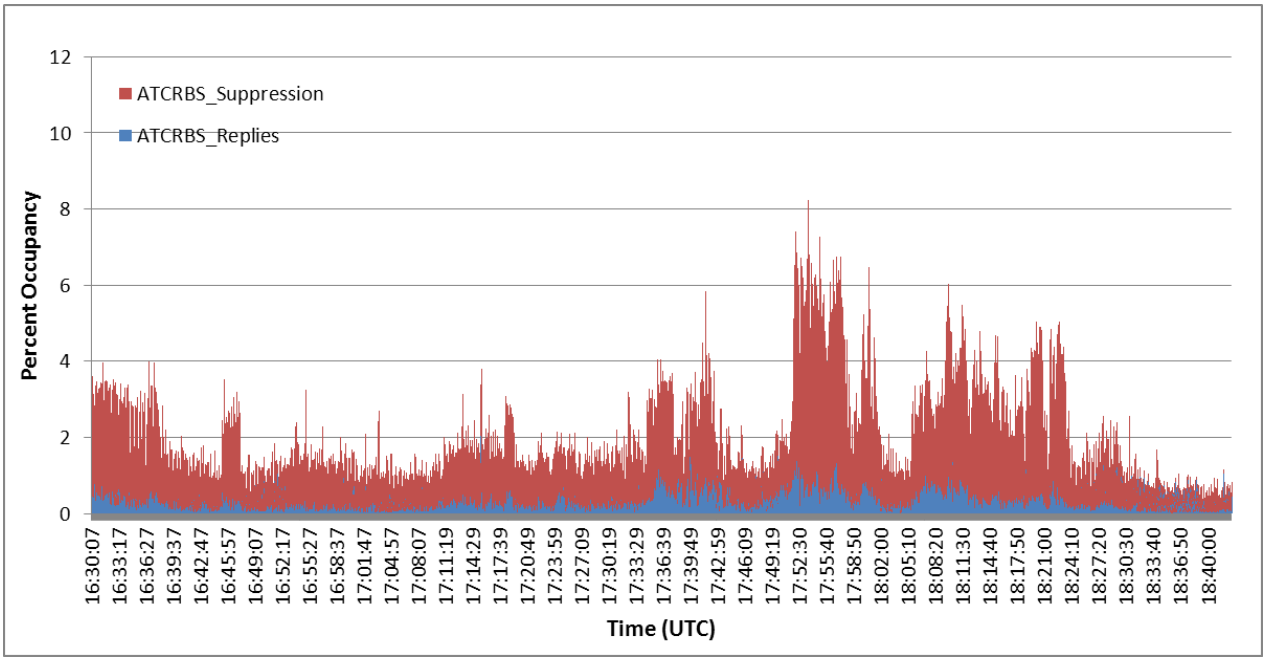

Figure 5-10 ATCRBS Typical Occupancy Showing Occupiers 11-18-2014 AM

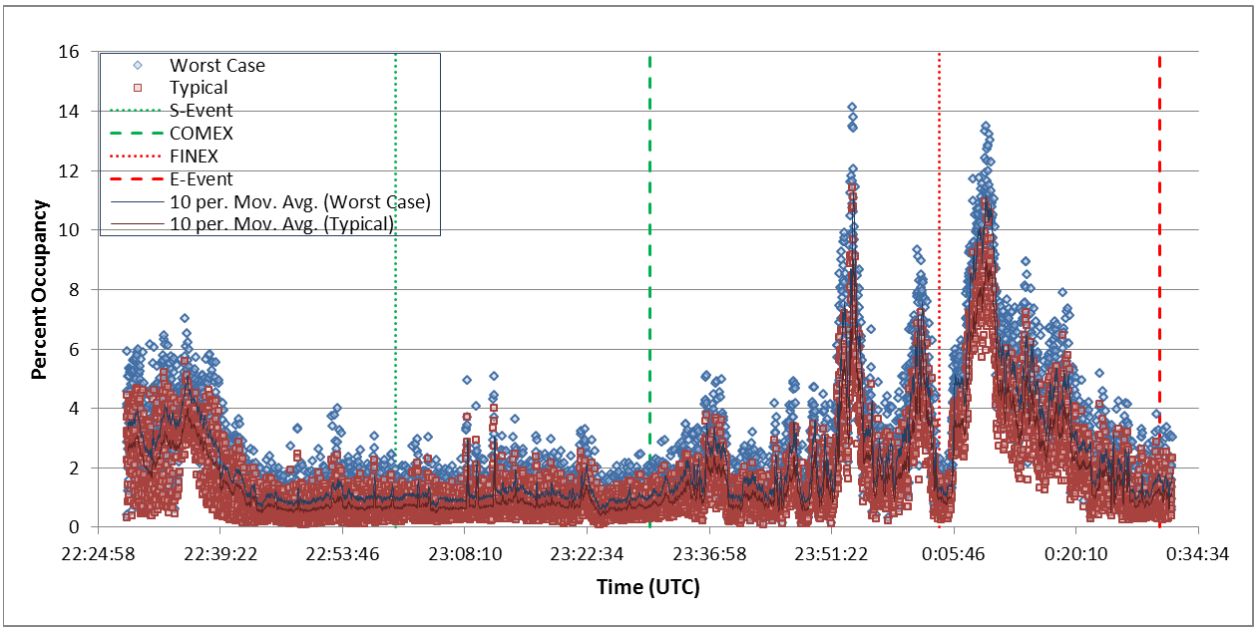

Figure 5-11 ATCRBS Occupancy 11-18-2014 PM

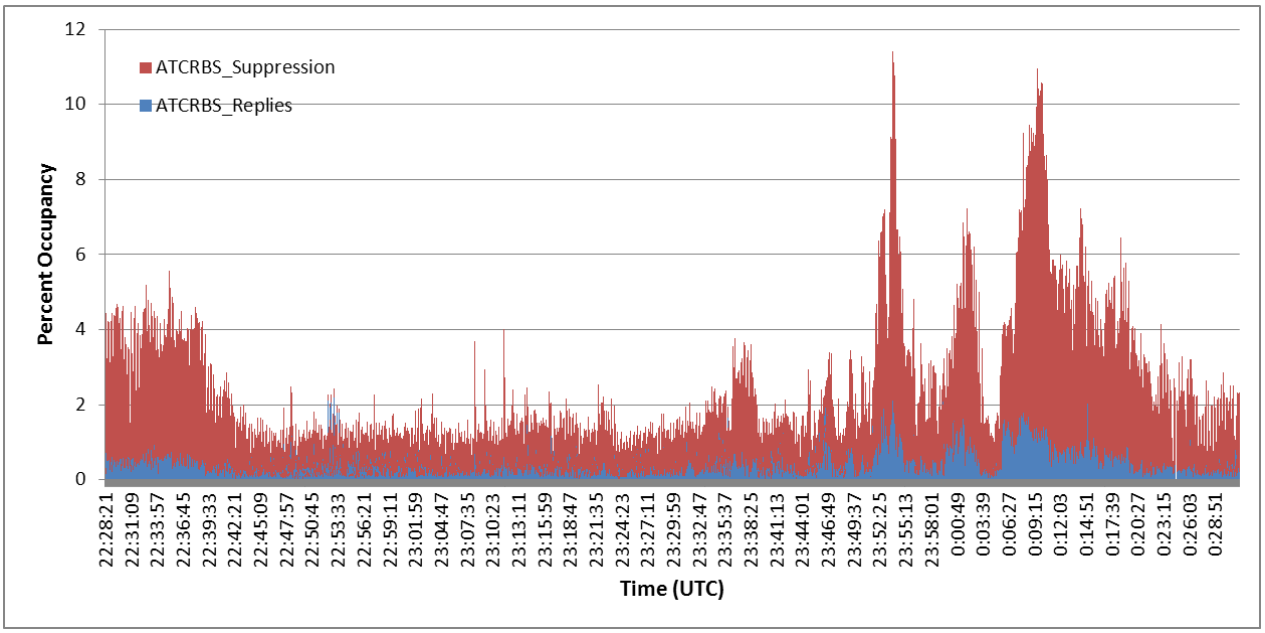

Figure 5-12 ATCRBS Typical Occupancy Showing Occupiers 11-18-2014 PM

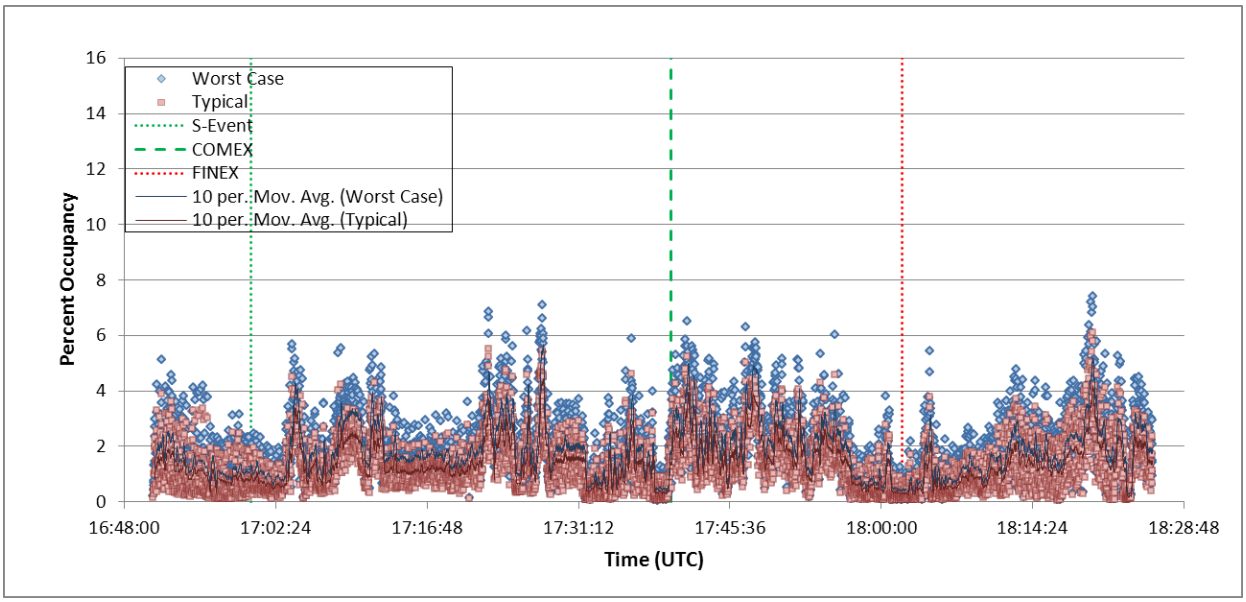

Figure 5-13 ATCRBS Occupancy 11-19-2014 AM

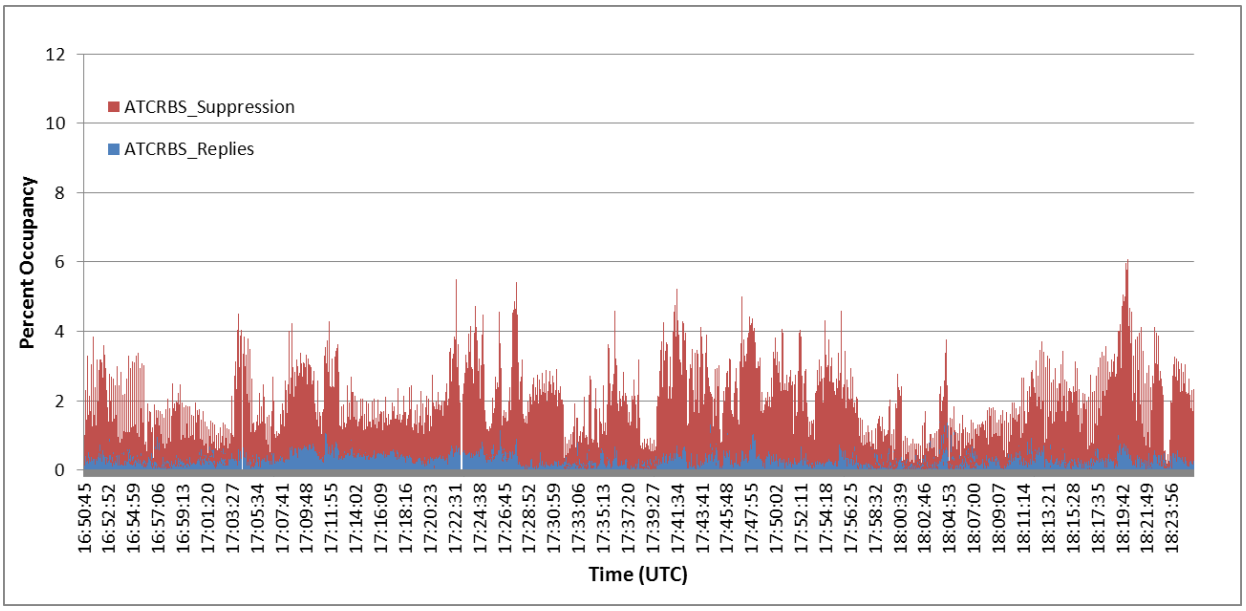

Figure 5-14 ATCRBS Typical Occupancy Showing Occupiers 11-19-2014 AM

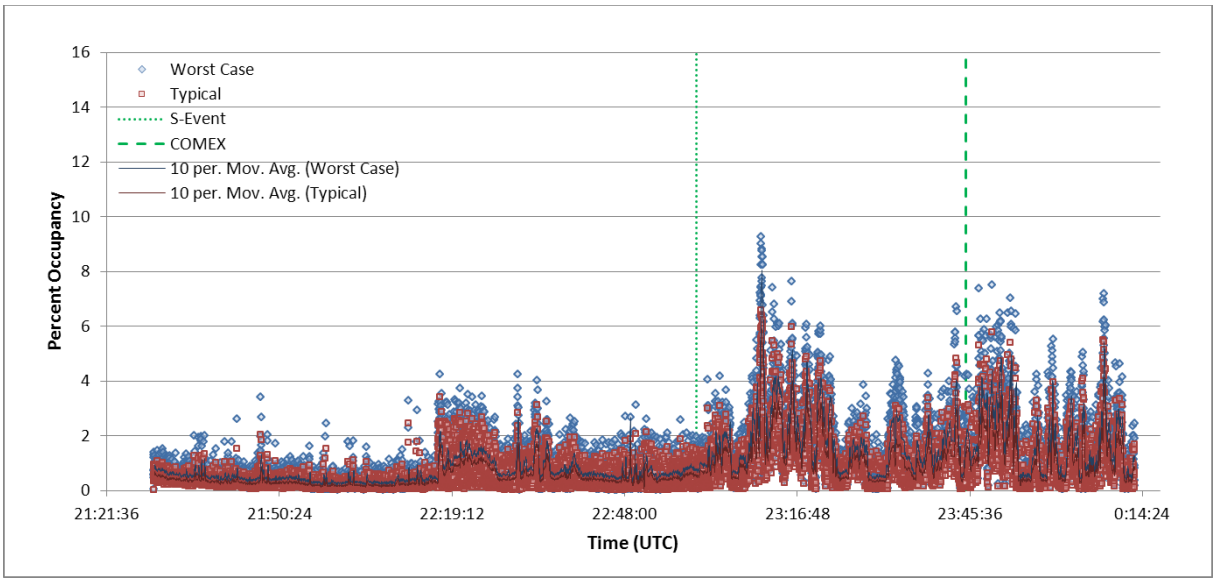

Figure 5-15 ATCRBS Occupancy 11-19-2014 PM

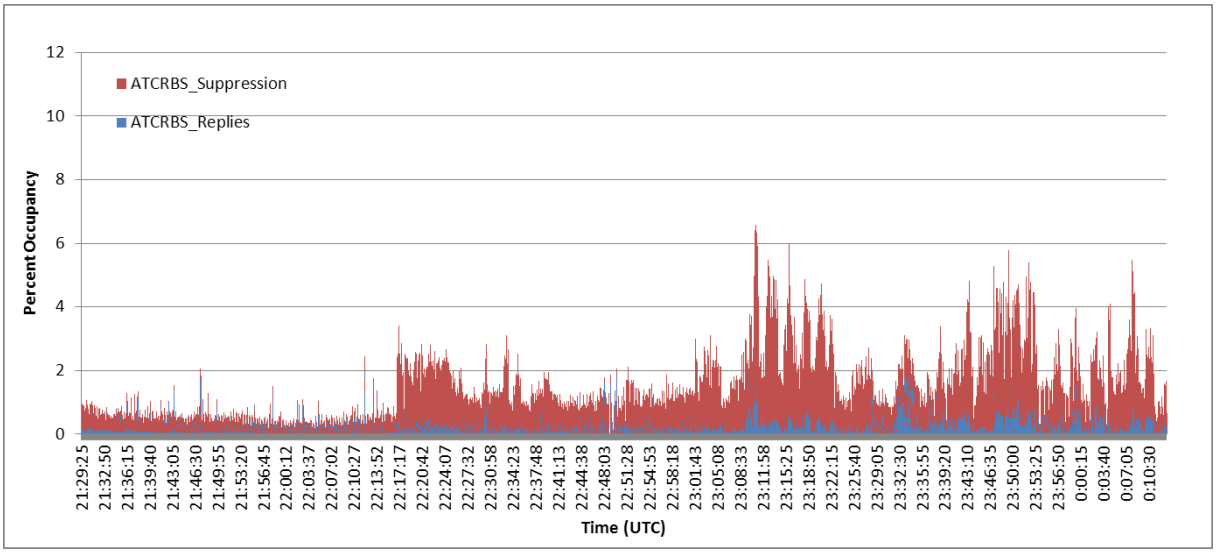

Figure 5-16 ATCRBS Typical Occupancy Showing Occupiers 11-19-2014 PM

There are significant increases in ATCRBS occupancy during most of the test events. The typical and worst-case occupancy totals are very similar since the suppressions dominate the ATCRBS occupancy and the suppression duration is a similar value for both (41 vs. 47 microseconds). The baseline data prior to the start of each test event shows ATCRBS occupancy averaging less than 2%. During Test Events 1 and 2 on November 18th, the typical occupancy increased to over 6%, with spikes over 10%. The variations in occupancy are likely related to variations in the distance between the test aircraft and the military interrogating aircraft, as well as variations in the number of military aircraft. The ATCRBS occupancy on the morning of the 19th (Event 3) does not show any significant effect from the military test. For this test, the test aircraft was located to the north of the military aircraft, while on the 18th it was in a hold to the southwest. The test aircraft was in the same northern hold on the afternoon on the 19th (Event 4) and the data shows increased ATCRBS occupancy at times around 6%.

5.3 Occupancy Details

The post-analysis process provides the capability of identifying different types of interrogations and suppressions that contribute to transponder occupancy. This section shows those details.

5.3.1 Occupancy Due to ATCRBS Replies

Sections 5.1 and 5.2 showed that the processing of Mode 3/A and Mode C interrogations and the subsequent replies were a constant contributor to transponder occupancy, and that the per-second rate of interrogations increased during the test events. In addition to actual Mode 3/A and Mode C interrogations (identified in the following plots as "in the clear" (MA-CLR)), there are other signals in the environment that trigger replies, such as Mode 4 (MA-M4) and low-level Mode S interrogations (MA-LLMS) that are falsely interpreted as Mode 3/A and Mode C interrogations.

Low-level Mode S interrogations are near or just below the MTL of the receiver and are not detected as a valid Mode S. Such signals sporadically transition above and below the receiver threshold and result in pulses detected at various spacings. Replies are triggered when these pulses align with a receiver decoder and the initial P1-P2 suppression pair is also undetected. Because of the length of Mode S interrogations, these are almost always Mode 3/A, but when signals combine with other signals there are occasionally Mode C replies triggered in a similar way. Previous investigations into this phenomenon revealed that some transponder types are more prone to this than others. Since the military aircraft involved in the test events were not interrogating Mode S, it was not expected that ATCRBS replies triggered by low-level Mode S would be prevalent.

Low-level Mode 4 interrogations can trigger replies in a similar manner. A more common cause of ATCRBS replies from Mode 4 interrogations of various amplitudes is the expiration of the suppression period before the end of the Mode 4 interrogation. The initial four pulses of a Mode 4 interrogation are spaced two microseconds apart, providing at least three chances to initiate suppression. However, the required ATCRBS suppression duration must not exceed 45 microseconds. If at the end of this period the next meaningful pulse spacing from the continuing Mode 4 is 8 or 21 microseconds, a reply will be triggered. Most often, a subsequent 2-microsecond suppression is initiated again, but sometimes a Mode 3/A or Mode C reply is triggered, with Mode 3/A being much more common than Mode C in these cases. Because the military aircraft were interrogating Mode 4 during the test events, it was expected that some of the increase in ATCRBS replies would be due to Mode 4 interrogations.

Figure 5-17 through Figure 5-32 on the following eight pages contain data showing Mode 3/A and C replies from the test events. There are two pages of plots for each of the four events. The first page shows Mode 3/A and C data derived from the 1030 MHz analysis. The types of input signals that might trigger a reply are color-coded. The second page shows the Mode 3/A and C reply rates from the test aircraft's onboard transponder, derived from analysis of the1090 MHz data. Definitions for undefined acronyms can be found in the Acronyms list.

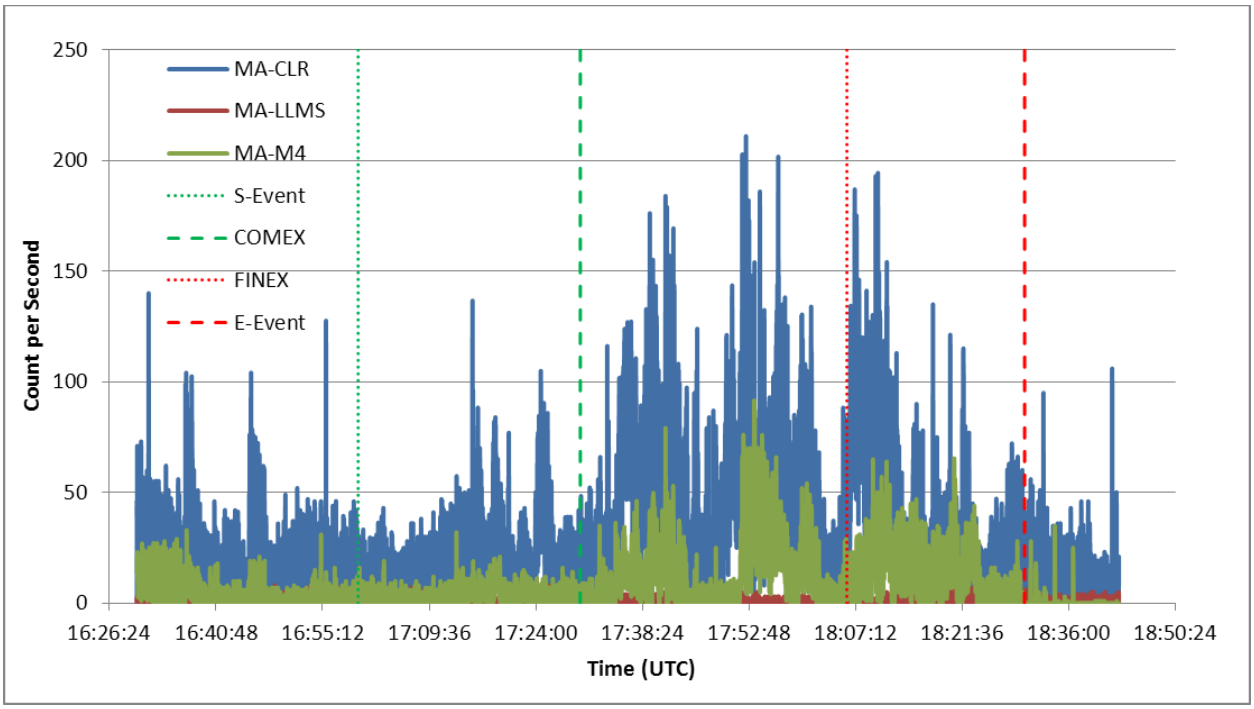

Figure 5-17 Detected 1030 MHz Signals that Could Elicit Mode 3/A Replies 11-18-14 AM

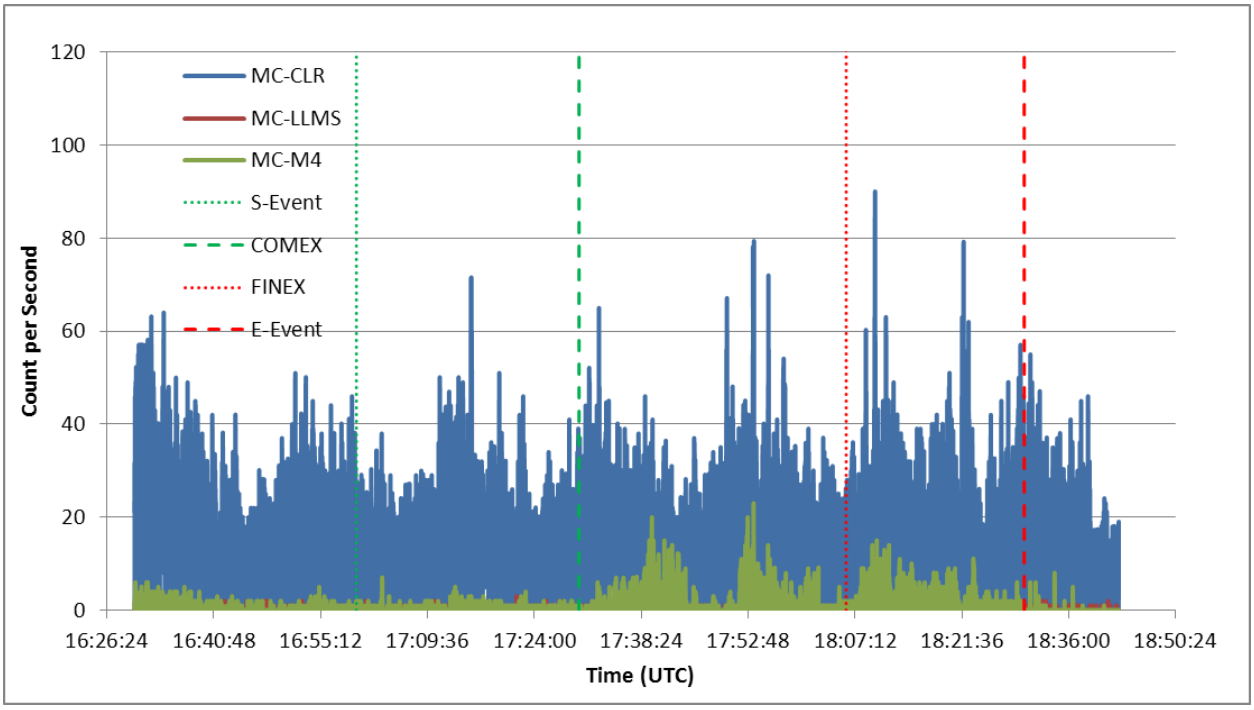

Figure 5-18 Detected 1030 MHz Signals that Could Elicit Mode C Replies 11-18-14 AM

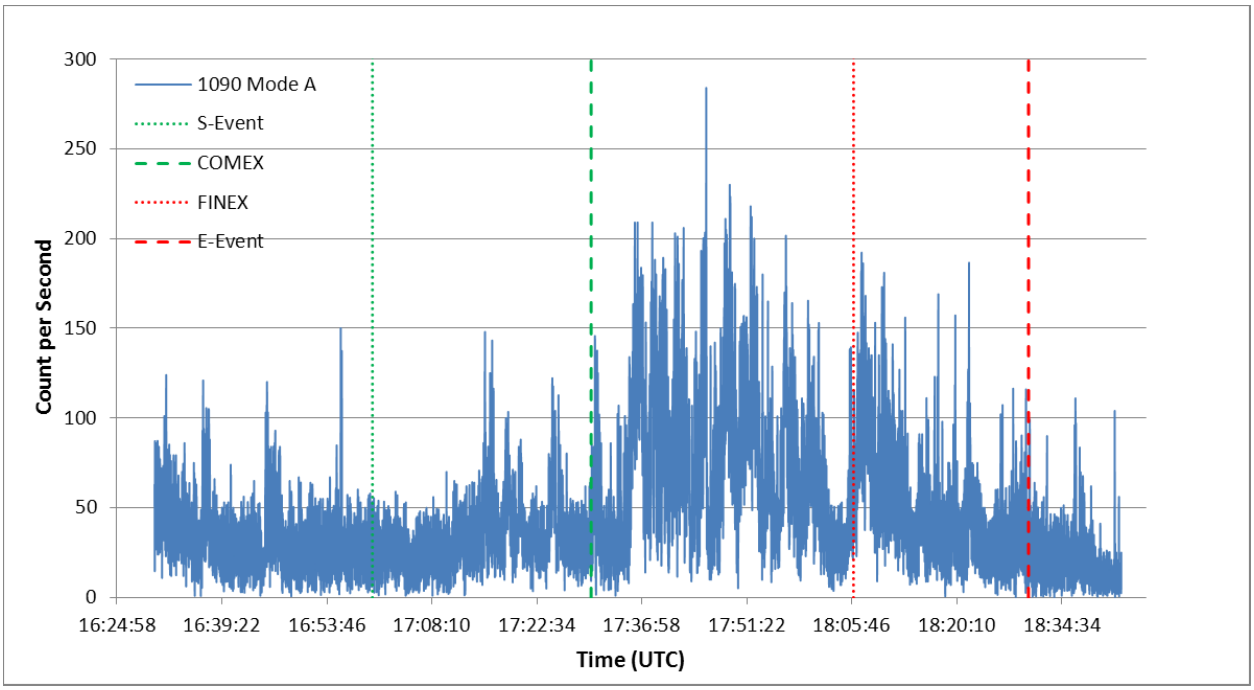

Figure 5-19 N39 Mode 3/A Replies 11-18-14 AM (from 1090 MHz Data)

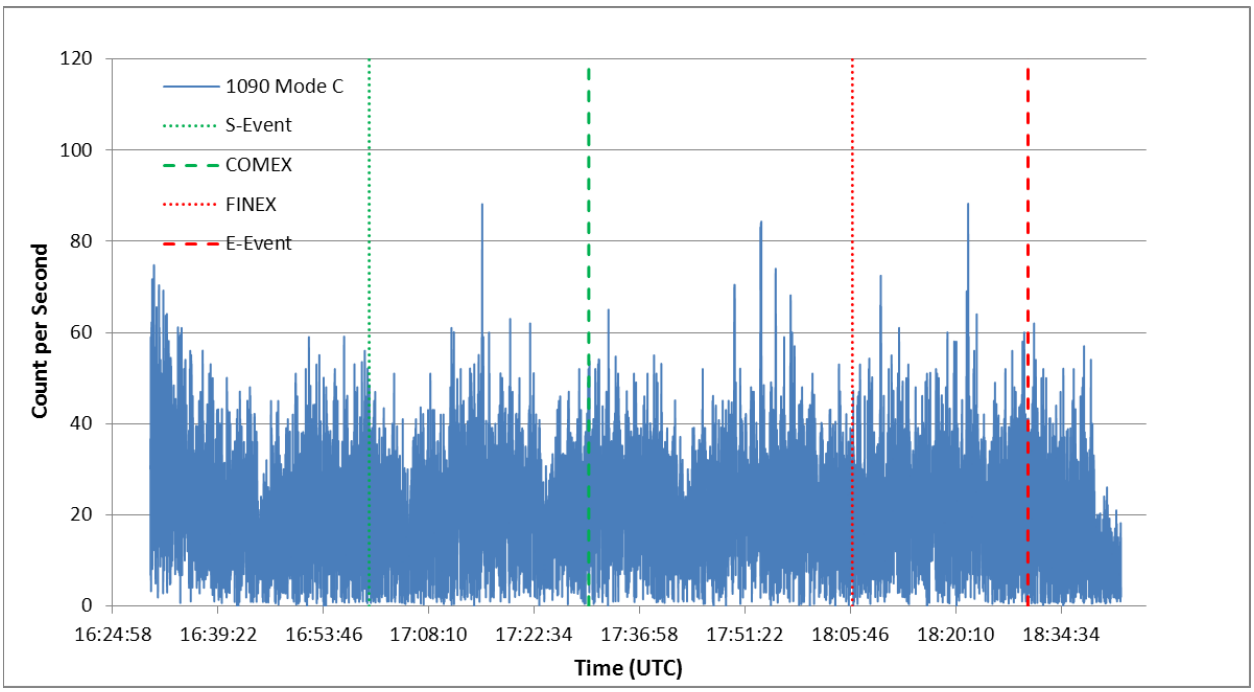

Figure 5-20 N39 Mode C Replies 11-18-14 AM (from 1090 MHz Data)

Both the 1030 and 1090 data above show a clear and significant increase in Mode 3/A reply activity during Event 1 on the morning of November 18. There doesn't appear to be an increase in Mode C. Mode 3/A goes from an average of less than 50 per second to over 200 at times. Most are from actual Mode 3/A interrogations, with some additional replies triggered by Mode 4.

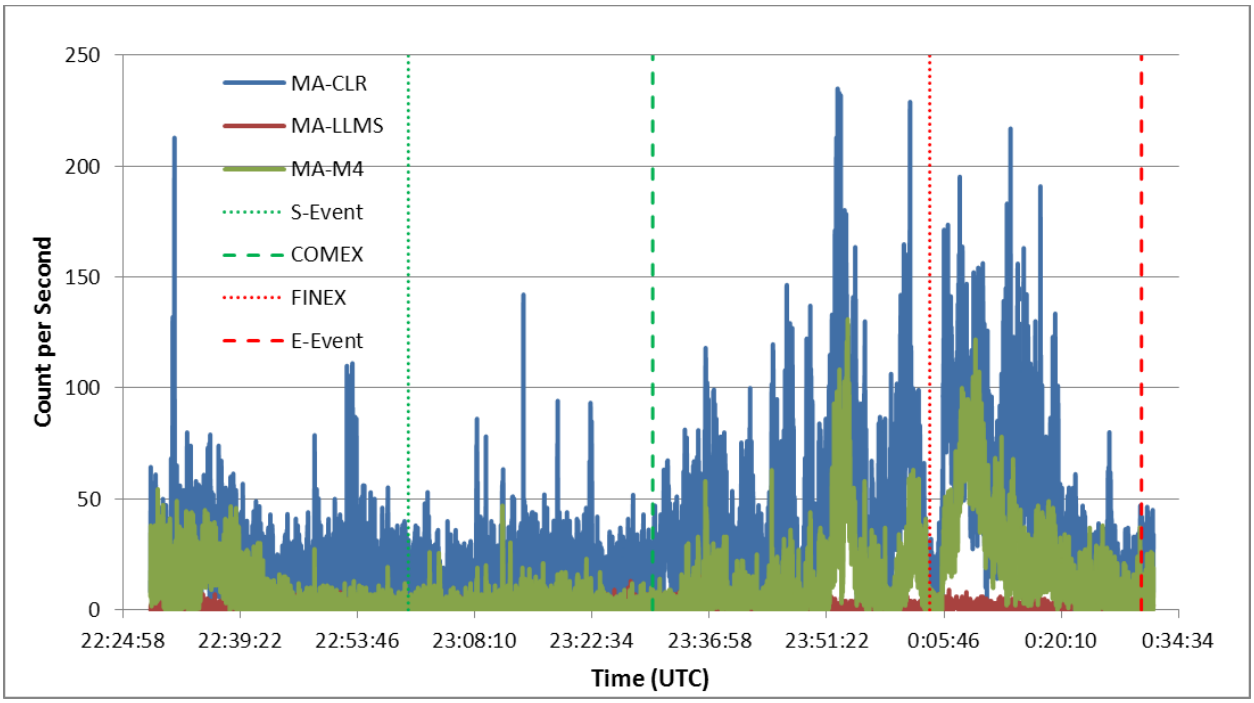

Figure 5-21 Detected 1030 MHz Signals that Could Elicit Mode 3/A Replies 11-18-14 PM

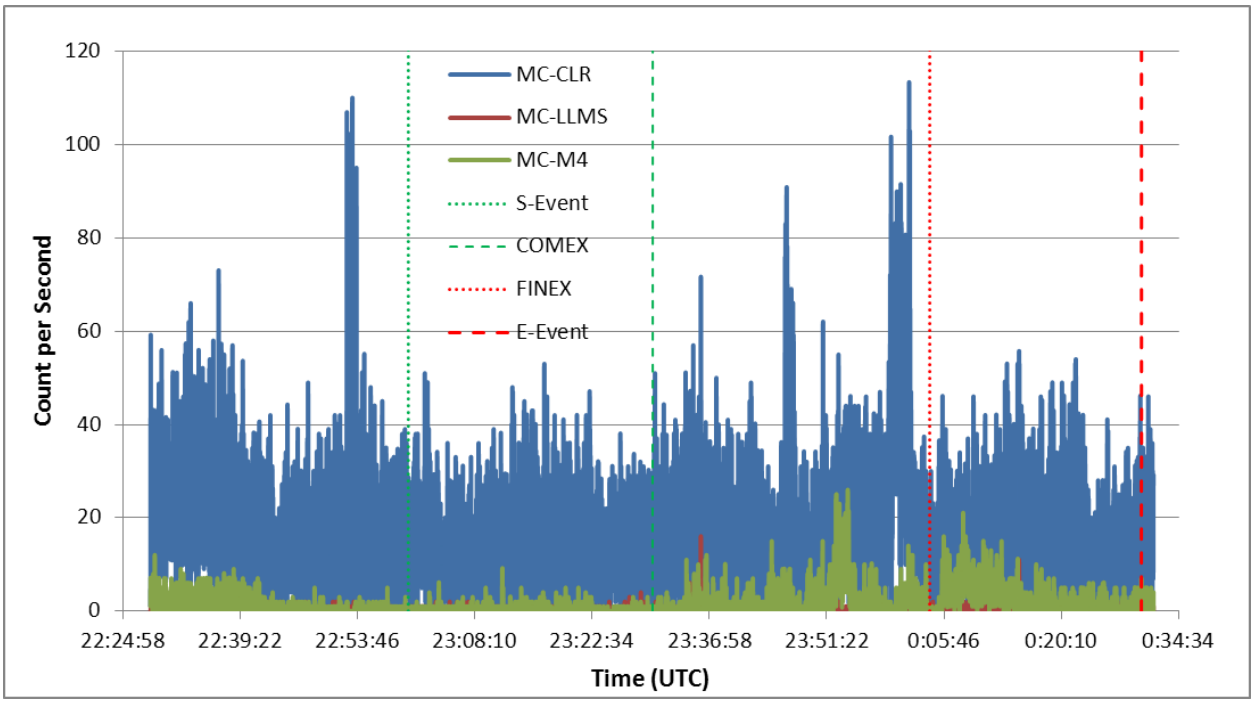

Figure 5-22 Detected 1030 MHz Signals that Could Elicit Mode C Replies 11-18-14 PM

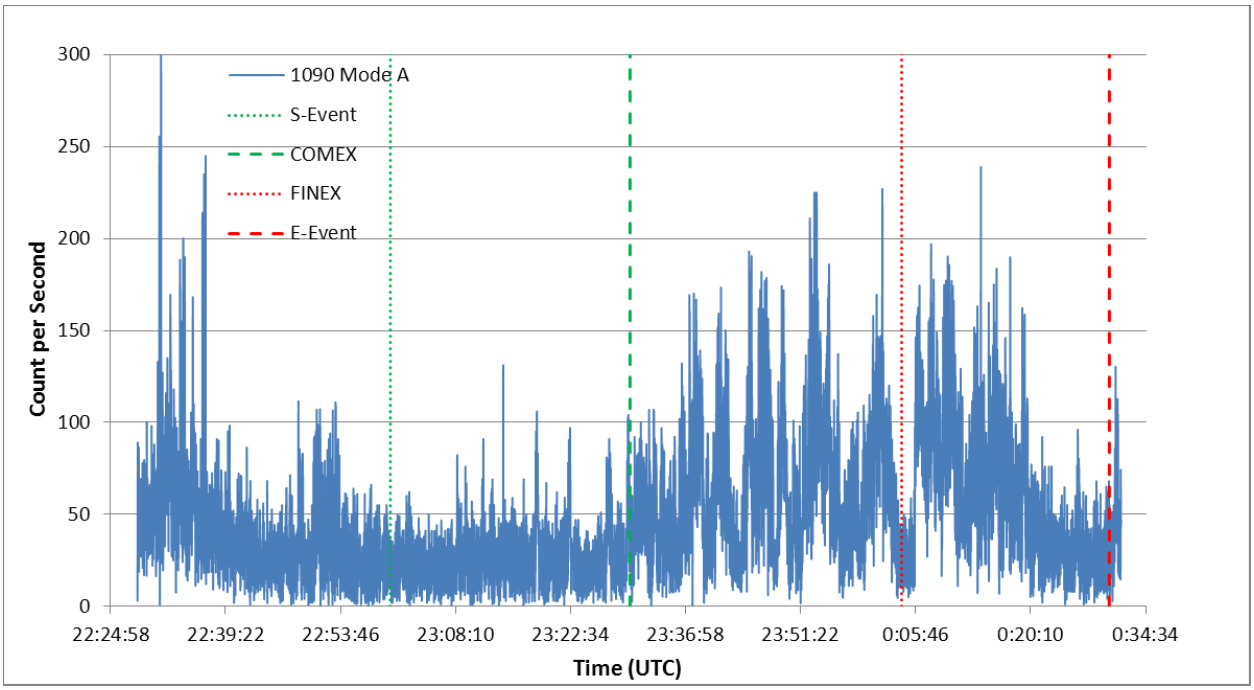

Figure 5-23 N39 Mode 3/A Replies from 1090 MHz Data 11-18-14 PM

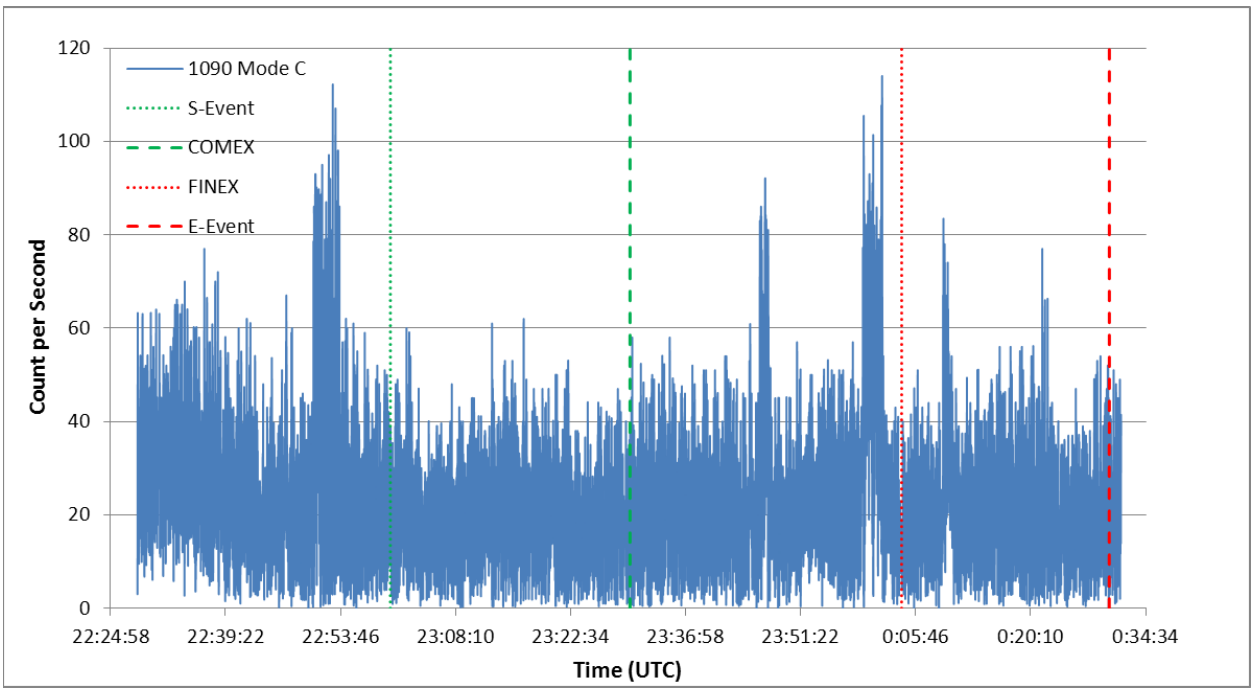

Figure 5-24 N39 Mode C Replies from 1090 MHz Data 11-18-14 PM

The data from Event 2 above shows a similar increase in Mode 3/A as Event 1, both in magnitude and in time relationship with the test event. On Mode C, there is a significant surge to about 100 per second just prior to the FINEX line, but there is a similar surge prior to the start of the test event. It is unclear if this surge is related to the test.

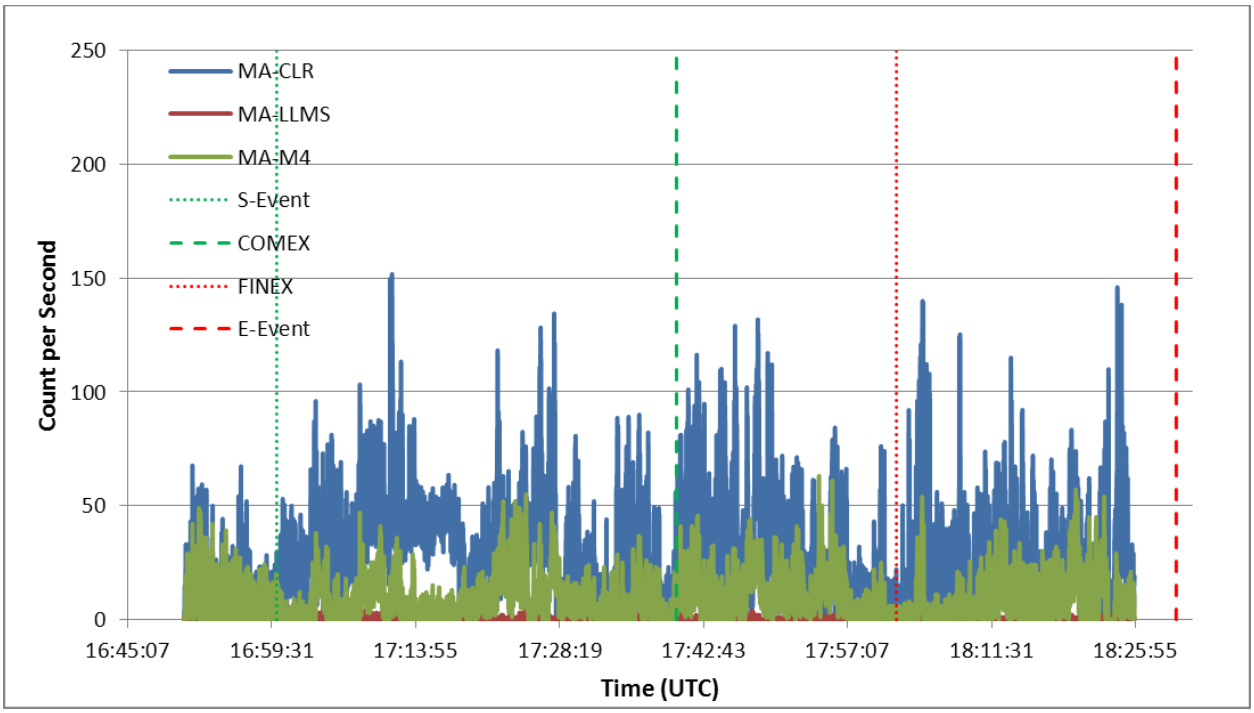

Figure 5-25 Detected 1030 MHz Signals that Could Elicit Mode 3/A Replies 11-19-14 AM

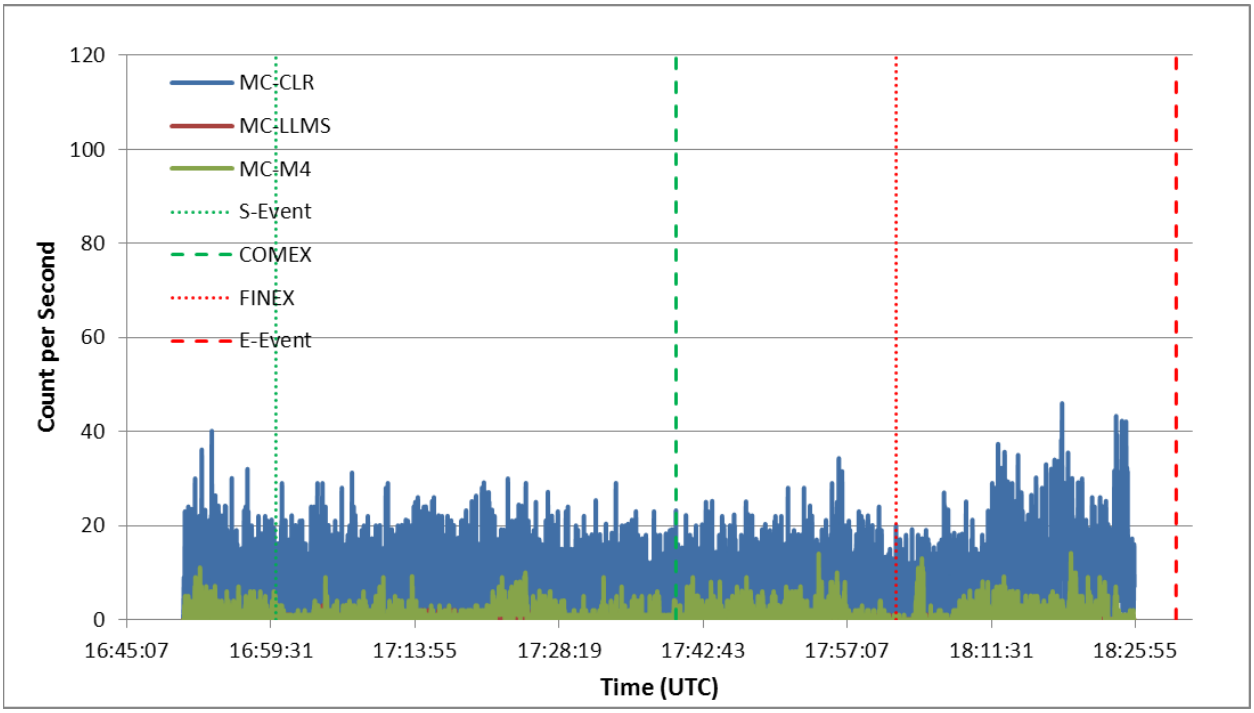

Figure 5-26 Detected 1030 MHz Signals that Could Elicit Mode C Replies 11-19-14 AM

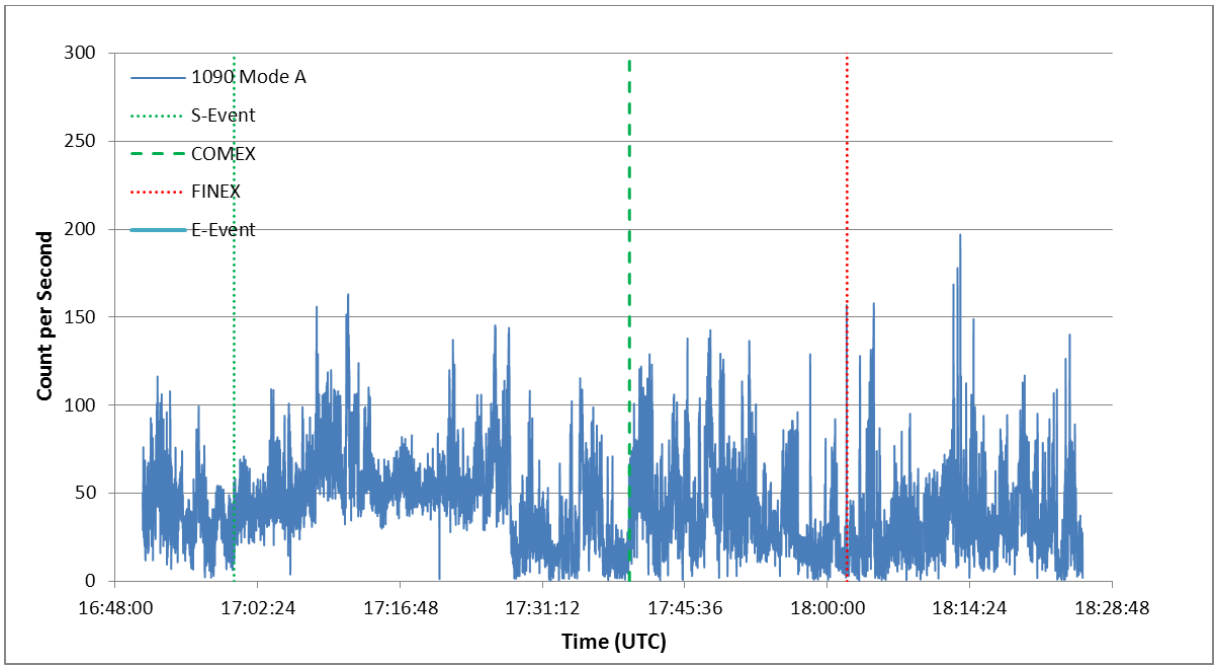

Figure 5-27 N39 Mode 3/A Replies from 1090 MHz Data 11-19-14 AM

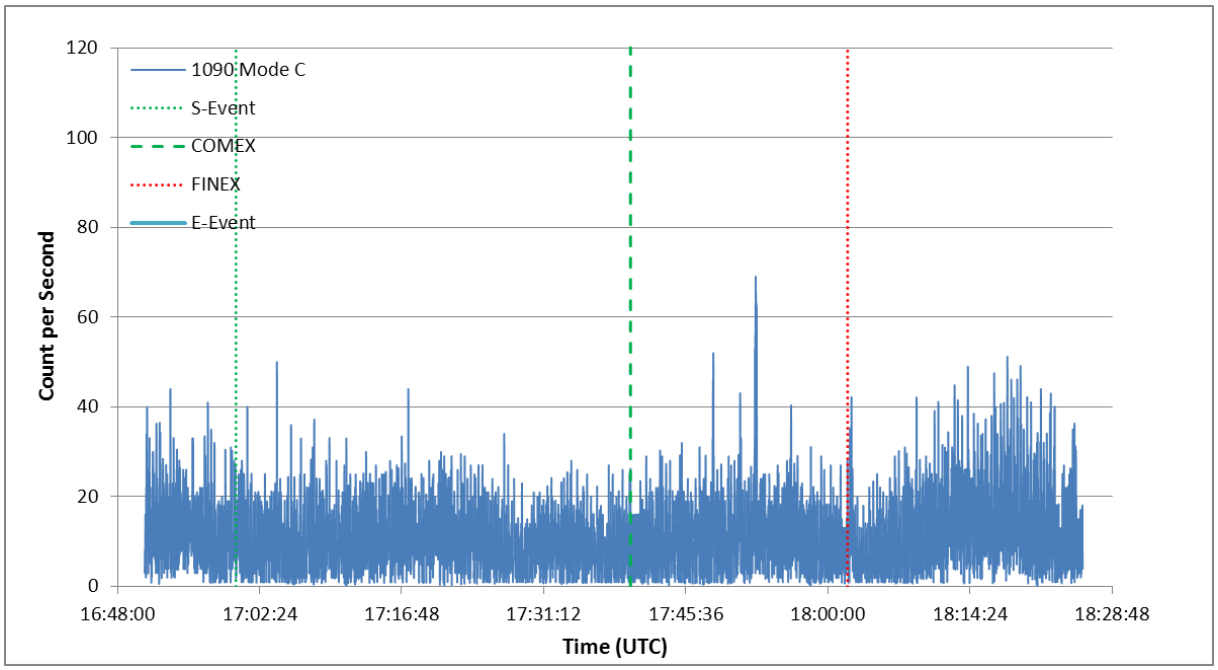

Figure 5-28 N39 Mode C Replies from 1090 MHz Data 11-19-14 AM

There doesn't appear to be any significant effect to either mode associated with Event 3 except for a possible small increase in both Mode 3/A and C near the end of the processed data. The data recording for this test ended prior to the "end of event" time, leaving it somewhat inconclusive. The data recording aircraft had flown a holding pattern to the north of the exercise area for this event, whereas it was in a hold to the southwest for Events 1 and 2.

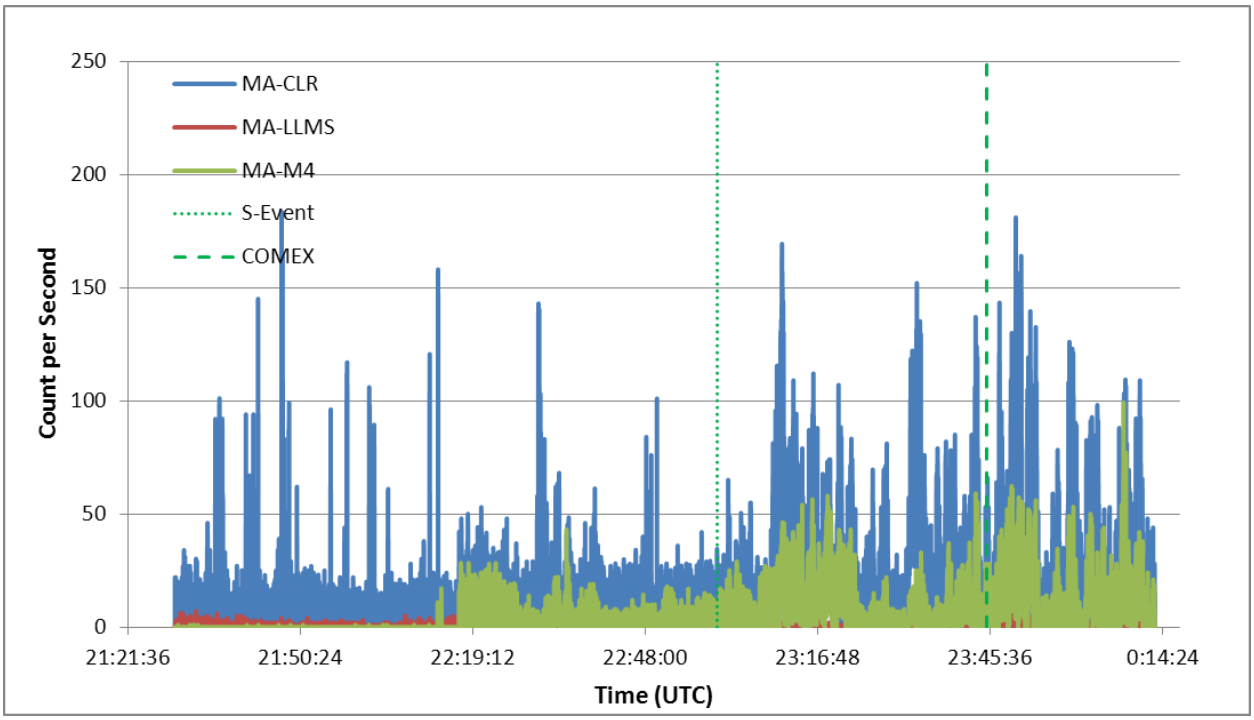

Figure 5-29 Detected 1030 MHz Signals that Could Elicit Mode 3/A Replies 11-19-14 PM

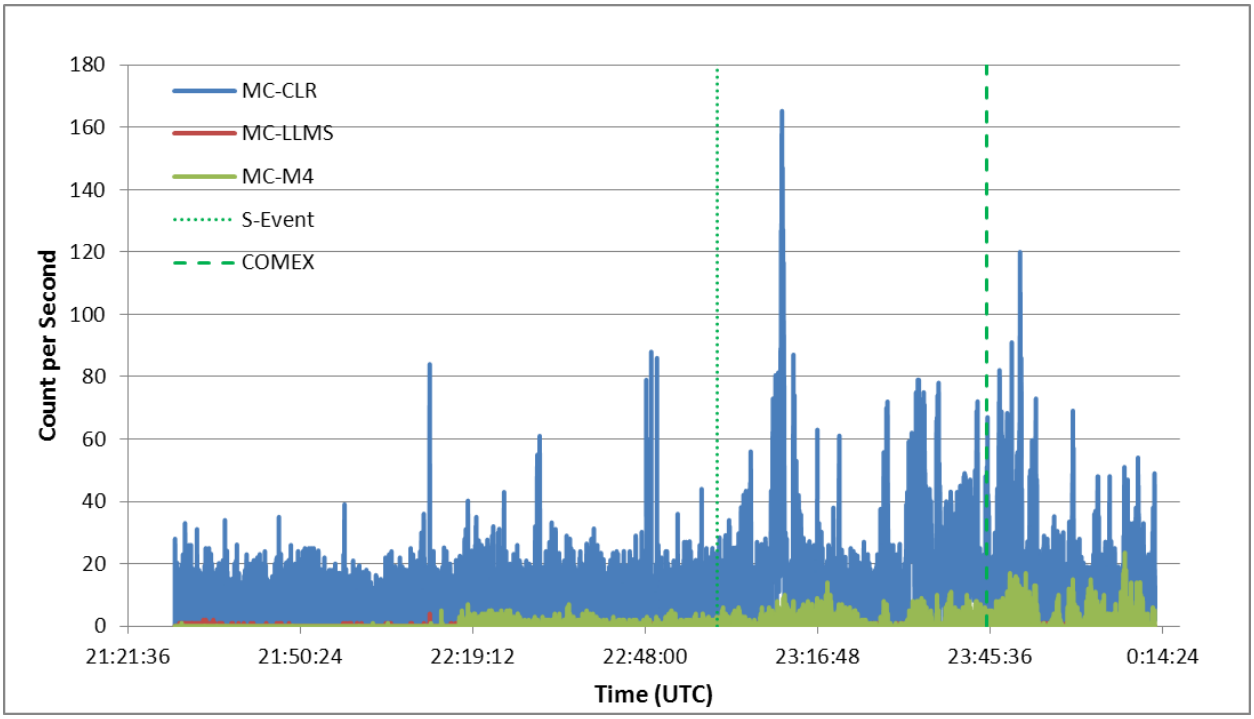

Figure 5-30 Detected 1030 MHz Signals that Could Elicit Mode C Replies 11-19-14 PM

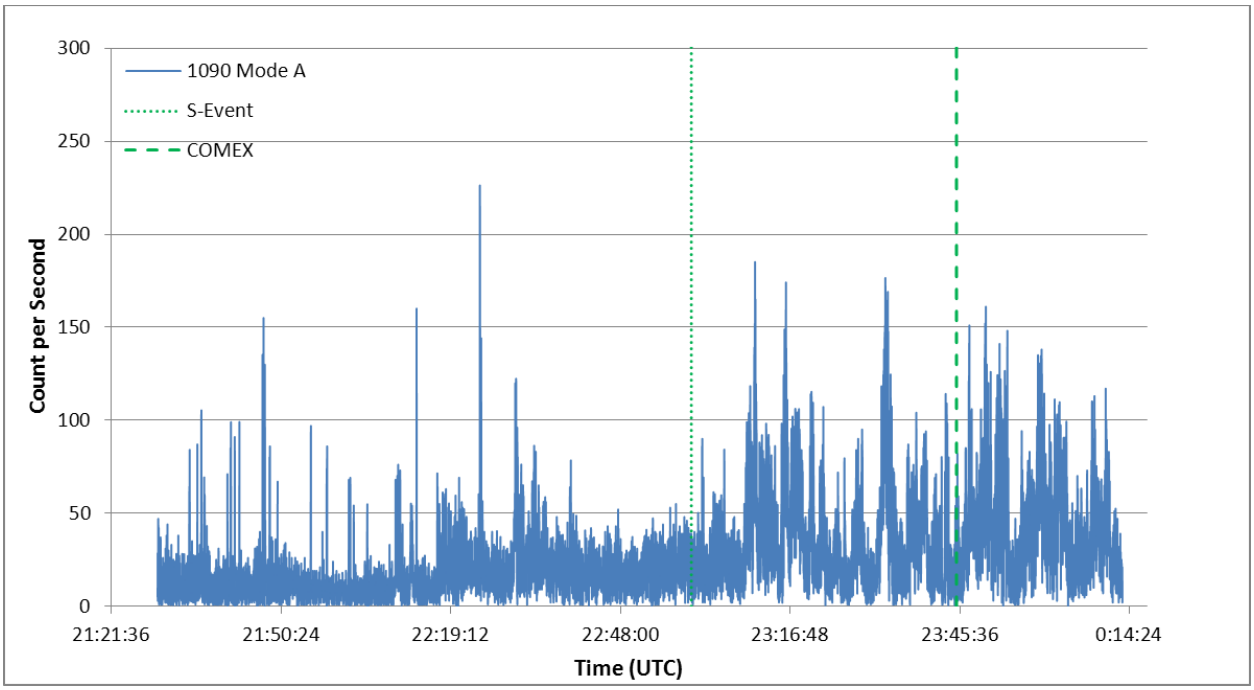

Figure 5-31 N39 Mode 3/A Replies from 1090 MHz Data 11-19-14 PM

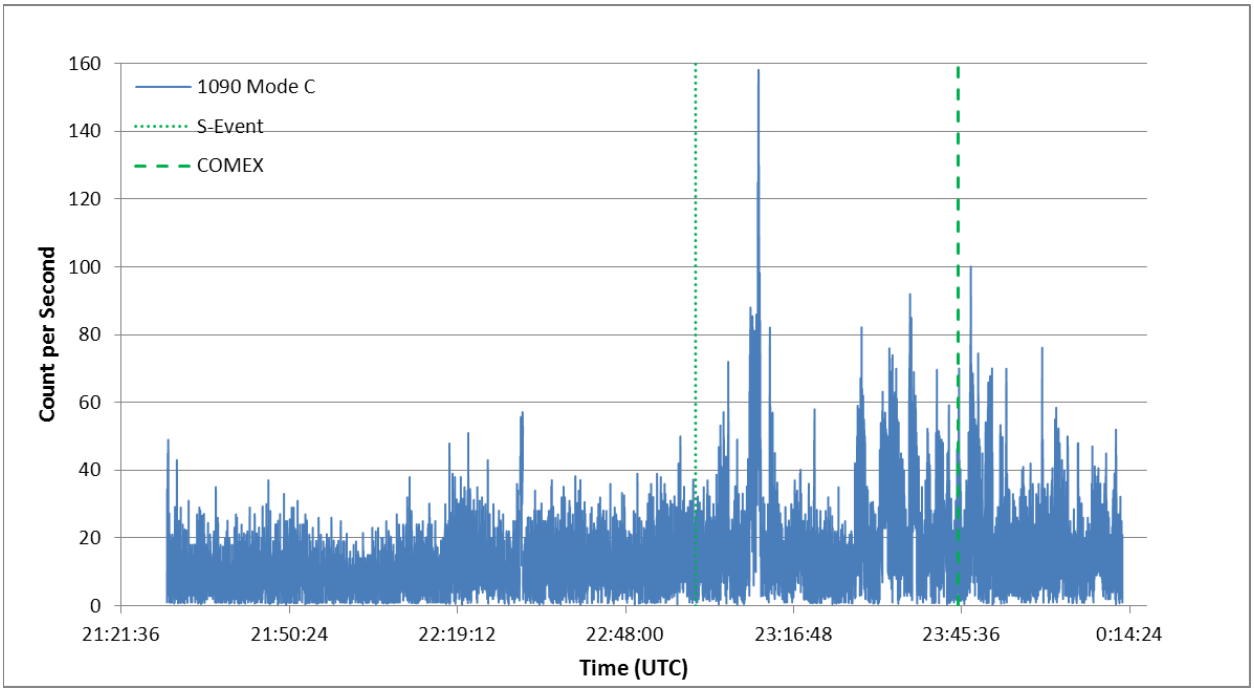

Figure 5-32 N39 Mode C Replies from 1090 MHz Data 11-19-14 PM

The data for Event 4 shows an increase in both Modes 3/A and C after the start of the test event. For this event, the recording aircraft was flying in a holding pattern to the north of the test, just as in Event 3. There appears to be a small but sudden increase in each mode, including Mode 4, at around 22:19, perhaps as participating aircraft and interrogators began preparing for the event. Data recording for this event was stopped prior to the end of the event.

Overall, there is an increase in transponder occupancy for aircraft within range of interrogating military aircraft due to an increase in ATCRBS replies when exercises of this type are being conducted. This is expected since the participating aircraft include Modes 3/A and C in the interrogation sequence. Given the large scale of the exercise, the maximized effect due to the proximity of the measurement aircraft, and the measured impact of various interrogations on transponder occupancy, the risk of such exercises is acceptable in areas with low-density air traffic.

5.3.2 Occupancy Due to ATCRBS Suppressions

The analysis of ATCRBS transponder occupancy in section 5.2 shows that the primary contributor to ATCRBS occupancy was suppressions, especially during increases in occupancy during the test events. When the FAA measurement aircraft was within side-lobe range of interrogating aircraft participating in the test, it was expected that the number of suppressions would increase, and the data supports this. The exact locations of individual military aircraft were not tracked by the test aircraft, but the rise and fall of measured suppression rates is an indication of going in and out of side-lobe suppression range of one or more interrogators. Data presented in this section shows the various interrogation types that contributed to total suppressions.

The suppression counts were derived from post-processing the 1030 MHz recorded data. To qualify as a suppression, a P1 – P2 pair must be detected with a maximum 200-nanosecond spacing tolerance and the P2 amplitude must be greater than P1 minus 4 dB. These are reasonable criteria that meet the MOPS requirements. (The MOPS requires that a transponder must accept a suppression if the P1 to P2 spacing is within 150 nanoseconds and the P2 power is equal or greater than P1. However, the “must reject” requirements are a spacing of 700 nanoseconds and greater, and the P2 power is 9 dB less than P1.)

In the following eight plots of suppression data shown in Figure 5-33 through Figure 5-40, there are two plots per page and each page represents one test event (events 1 through 4). The first plot shows the count per second of Mode 3/A and C suppressions. The second plot shows the count per second of military interrogation types including Modes 1, 2 and 4.

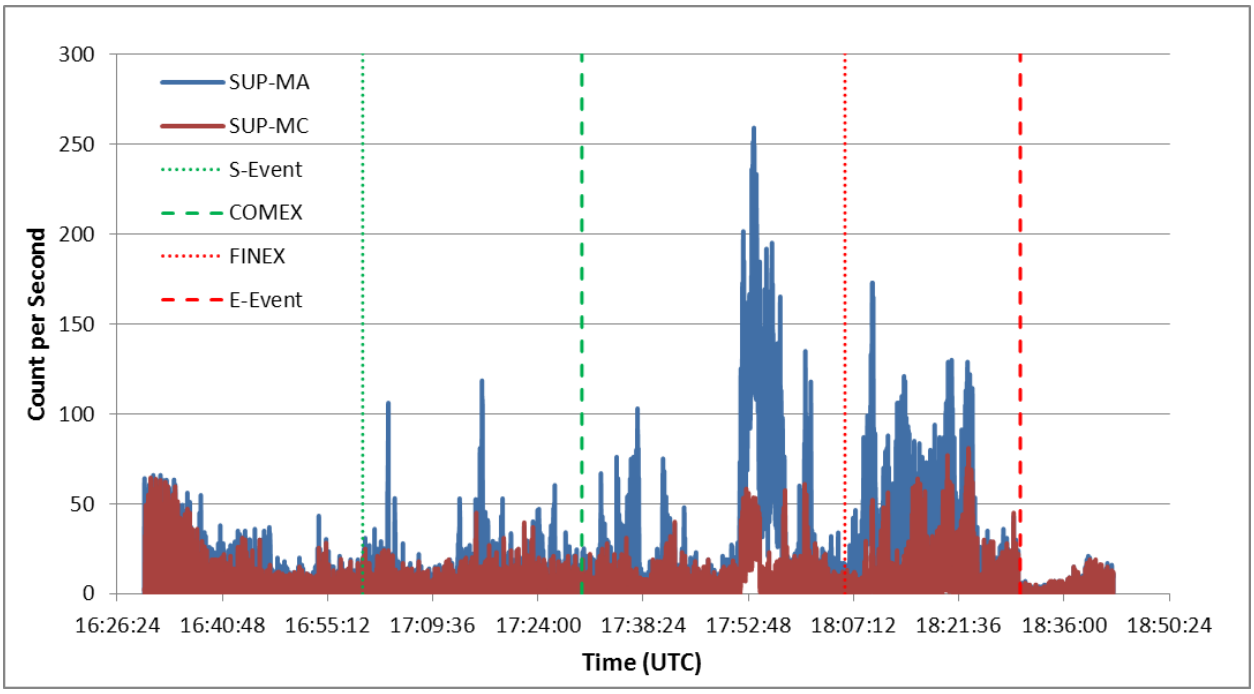

Figure 5-33 Suppressed Mode 3/A and Mode C Interrogations 11-18-14 AM

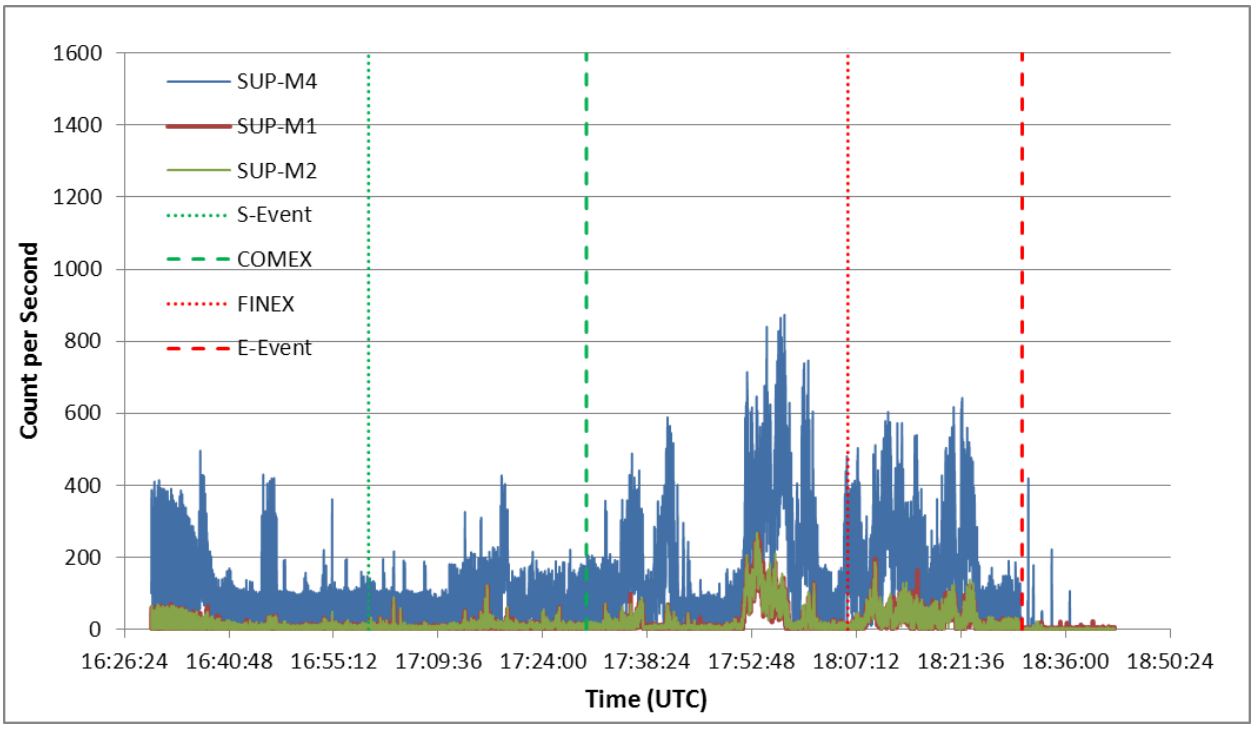

Figure 5-34 Suppressed Interrogations, Military Types 11-18-14 AM

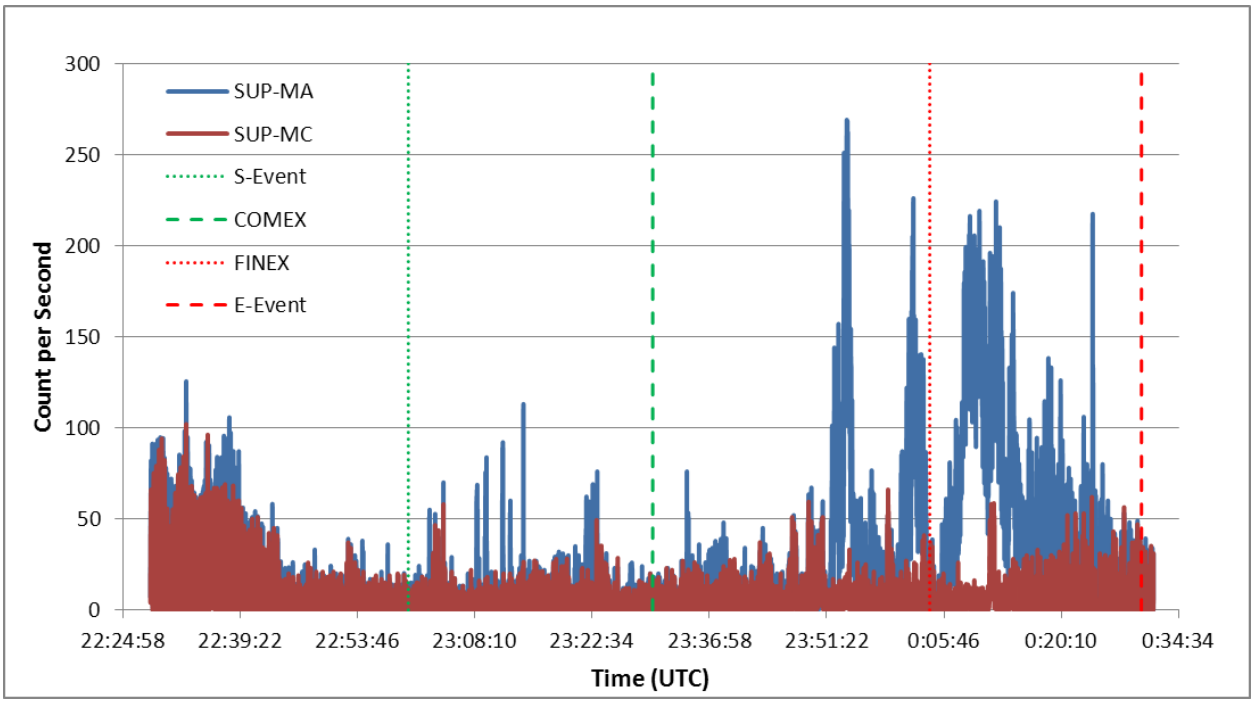

Figure 5-35 Suppressed Mode 3/A and Mode C Interrogations 11-18-14 PM

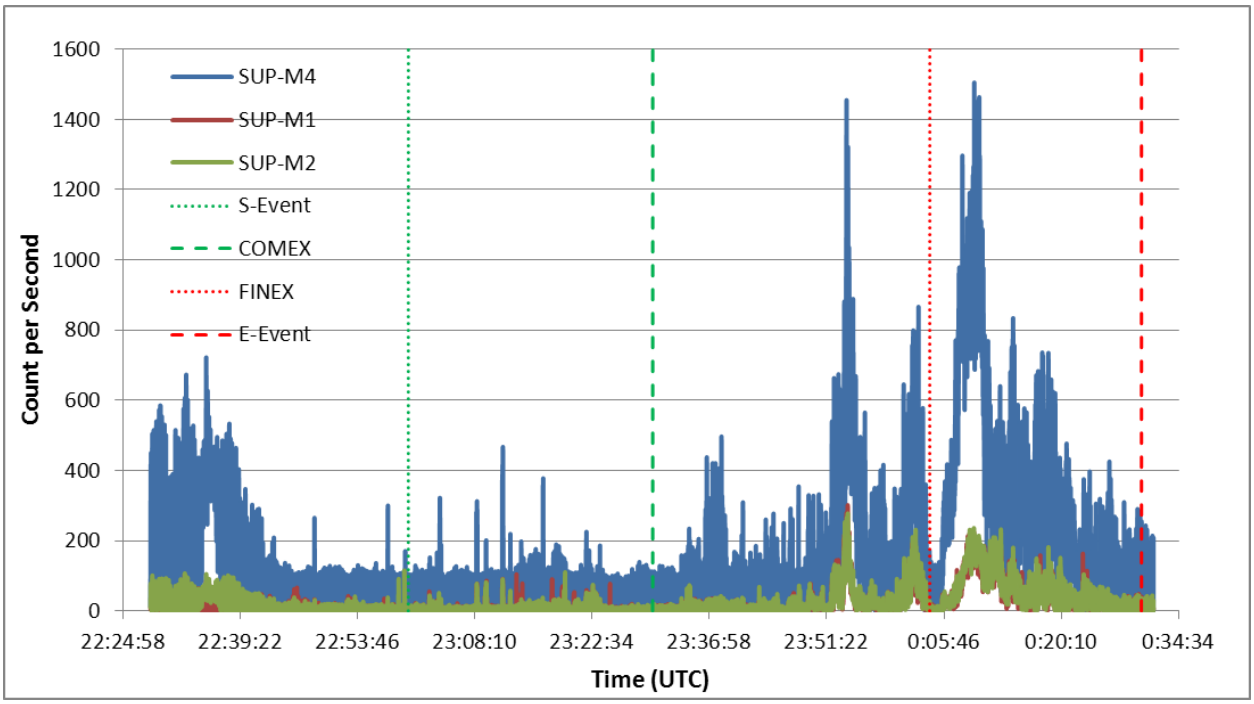

Figure 5-36 Suppressed Interrogations, Military Types 11-18-14 PM

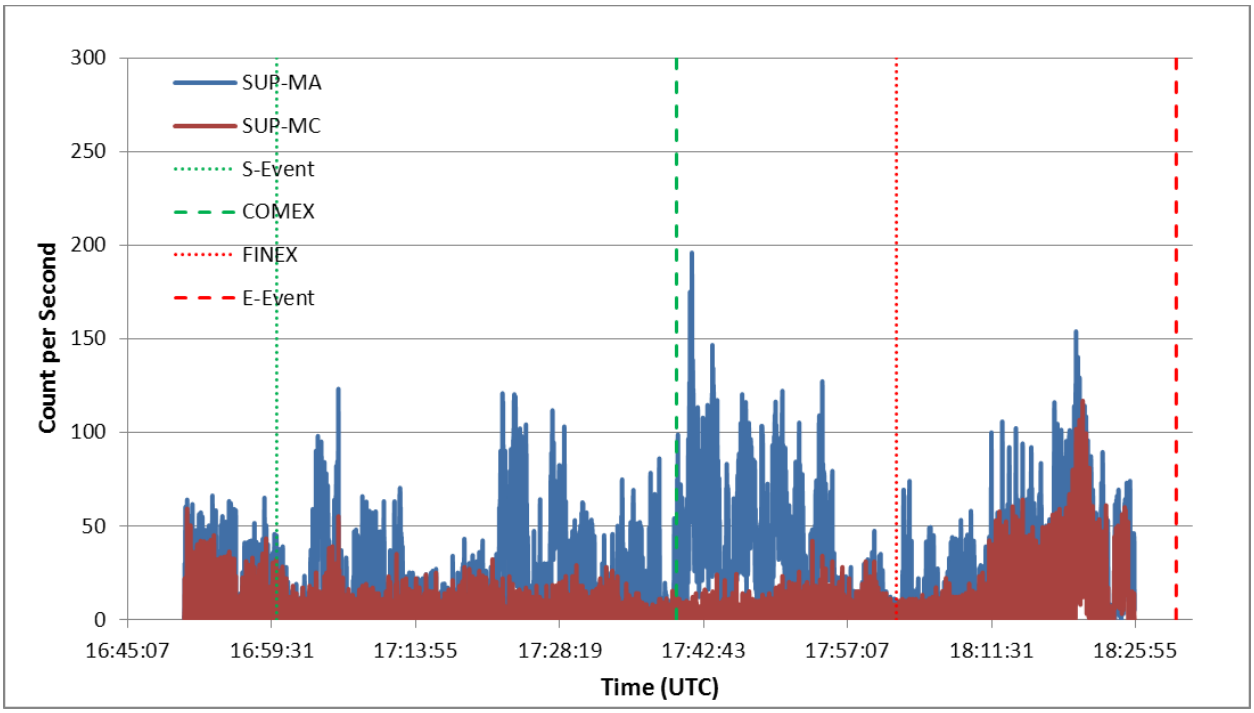

Figure 5-37 Suppressed Mode 3/A and Mode C Interrogations 11-19-14 AM

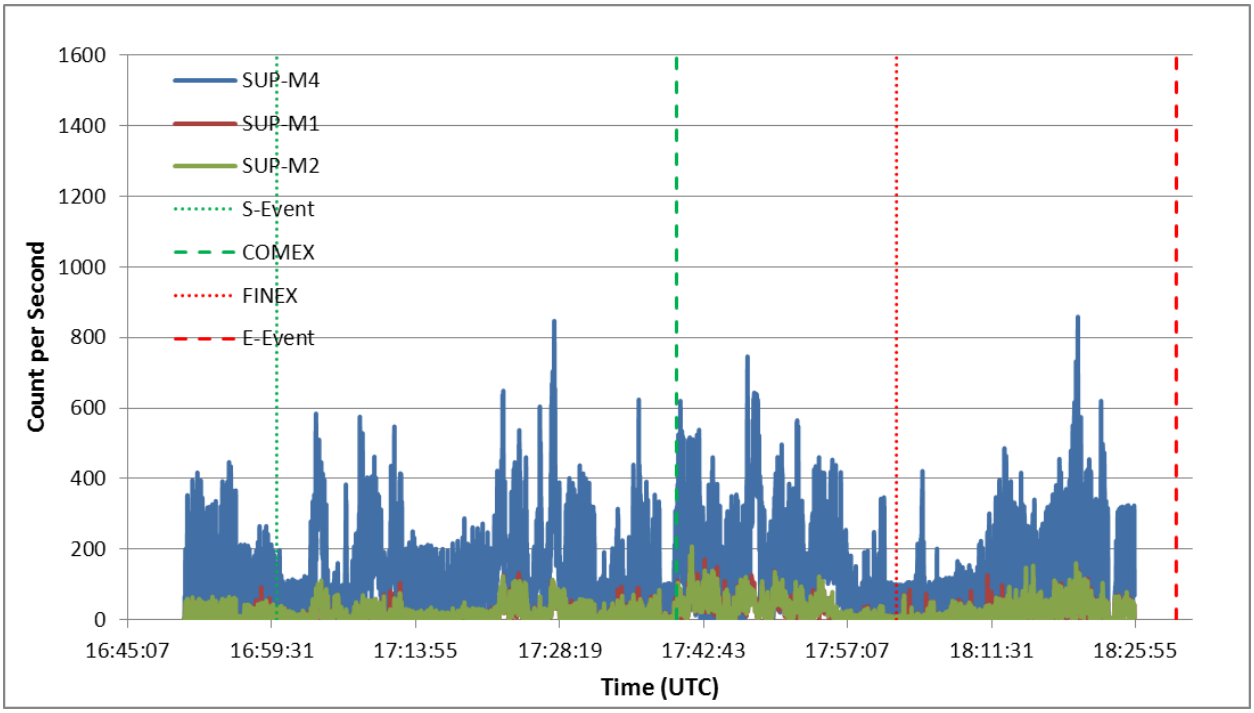

Figure 5-38 Suppressed Interrogations, Military Types 11-19-14 AM

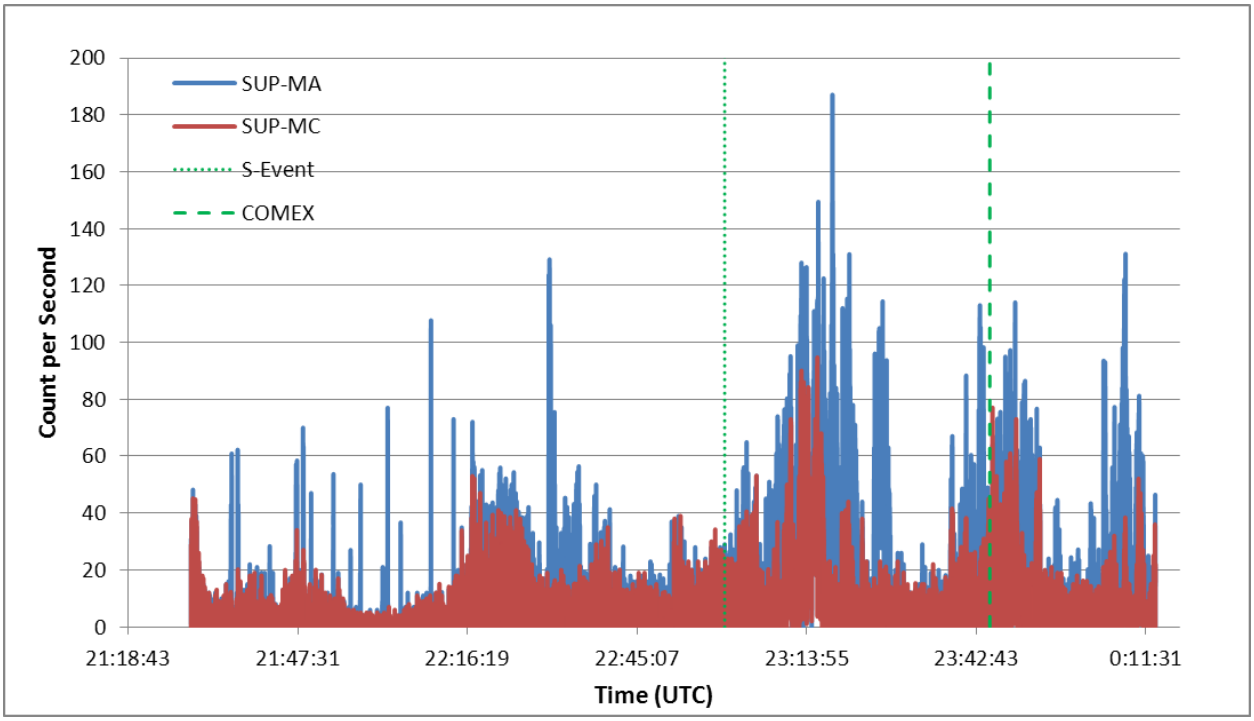

Figure 5-39 Suppressed Mode 3/A and Mode C Interrogations 11-19-14 PM

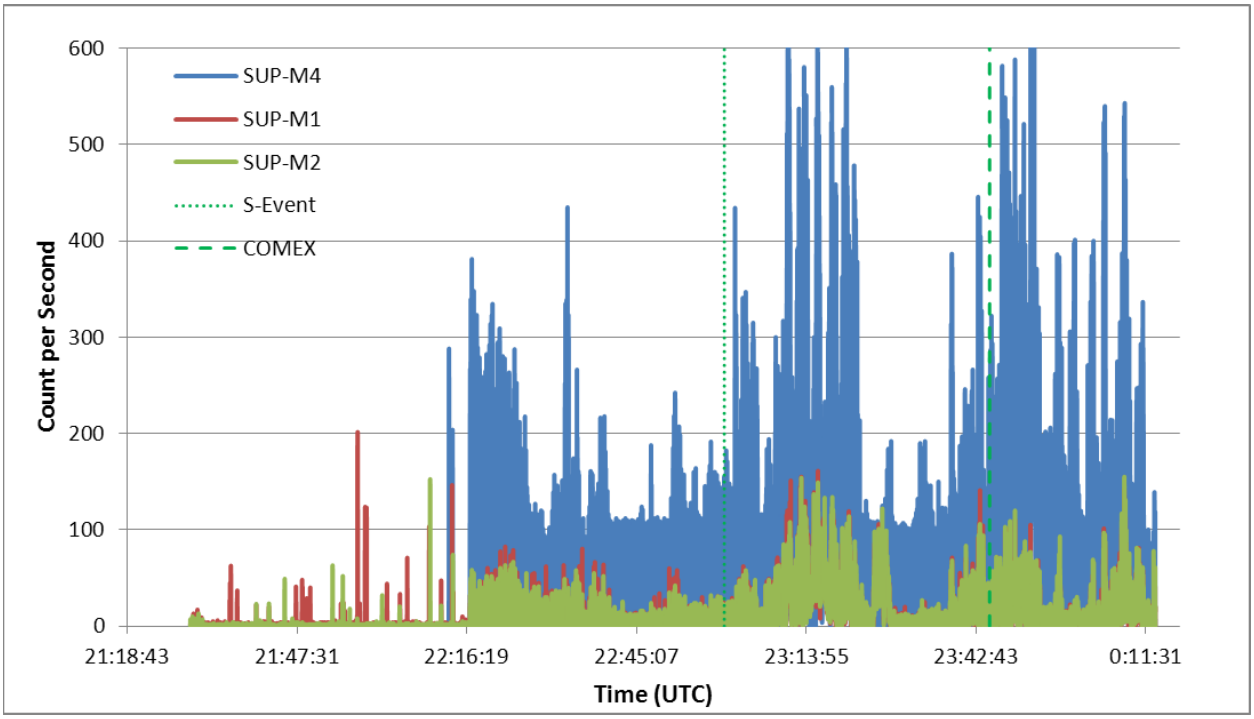

Figure 5-40 Suppressed Interrogations, Military Types 11-19-14 PM

During each test event, there were significant surges in the number of suppressions per second. Mode 4 caused most of the suppressions. A greater number of suppressions were detected during the November 18 test events than the November 19 tests. This is probably due to the relocation of the recording aircraft to the north of the military airspace on the 19th.

The rise in the suppression rate at times during the test was contributing to the ATCRBS transponder occupancy, as was indicated in the plots in section 5.2. The data analysis in this section shows that most of the suppressions were from Mode 4 interrogations, followed by suppressed Mode 3/A interrogations.

5.4 1090 MHz FRUIT

Equipment aboard the measurement aircraft was designed to record the log video signal from two 1090 MHz receivers, with one connected to an omni-directional L-band antenna on the top of the aircraft and the other to the same type of antenna on the bottom of the aircraft. The recorded signal data was post-processed to measure the amount of FRUIT in the 1090 MHz environment independently from the two antennas. FRUIT rates are separated into two categories: ATCRBS and Mode S FRUIT. The ATCRBS FRUIT includes Mode 3/A and Mode C replies, which are counted as one since they cannot be distinguished in the environment. Mode S FRUIT is comprised of Mode S replies, which include SSR and TCAS, as well as TCAS acquisition squitters, ADS-B extended squitters, and TCAS broadcast messages. High 1090 MHz FRUIT rates are a concern in the NAS because of the potential for interference with the probability of reception and decoding of the signal types identified above.

In Figure 5-41 through Figure 5-48 on the following pages, the ATCRBS and Mode S FRUIT are presented for each test event. Each plot shows the top antenna data in red and the bottom in blue, with a darker trend line showing the 10-second moving average. The ATCRBS FRUIT rate is cumulative, including all amplitudes from -79 dBm and above, and the Mode S is from -84 dBm and above.

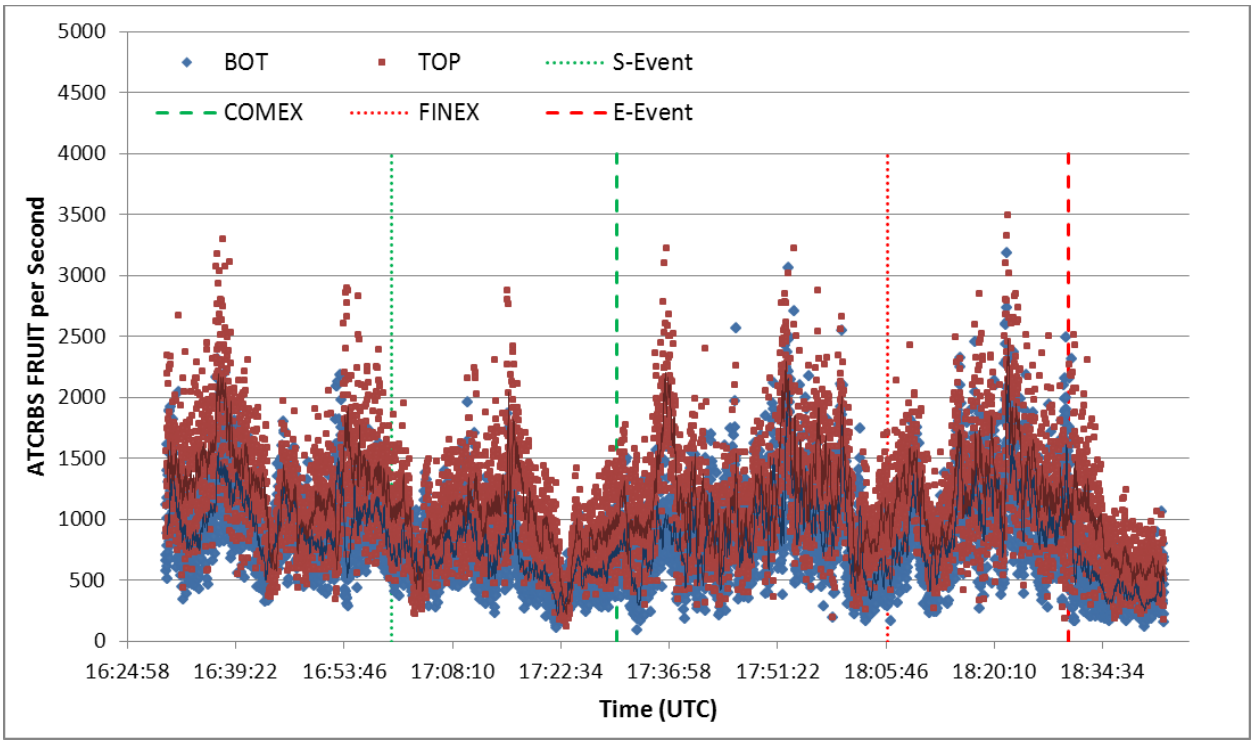

Figure 5-41 1090 MHz ATCRBS FRUIT Rate @ -79 dBm 11-18-14 AM

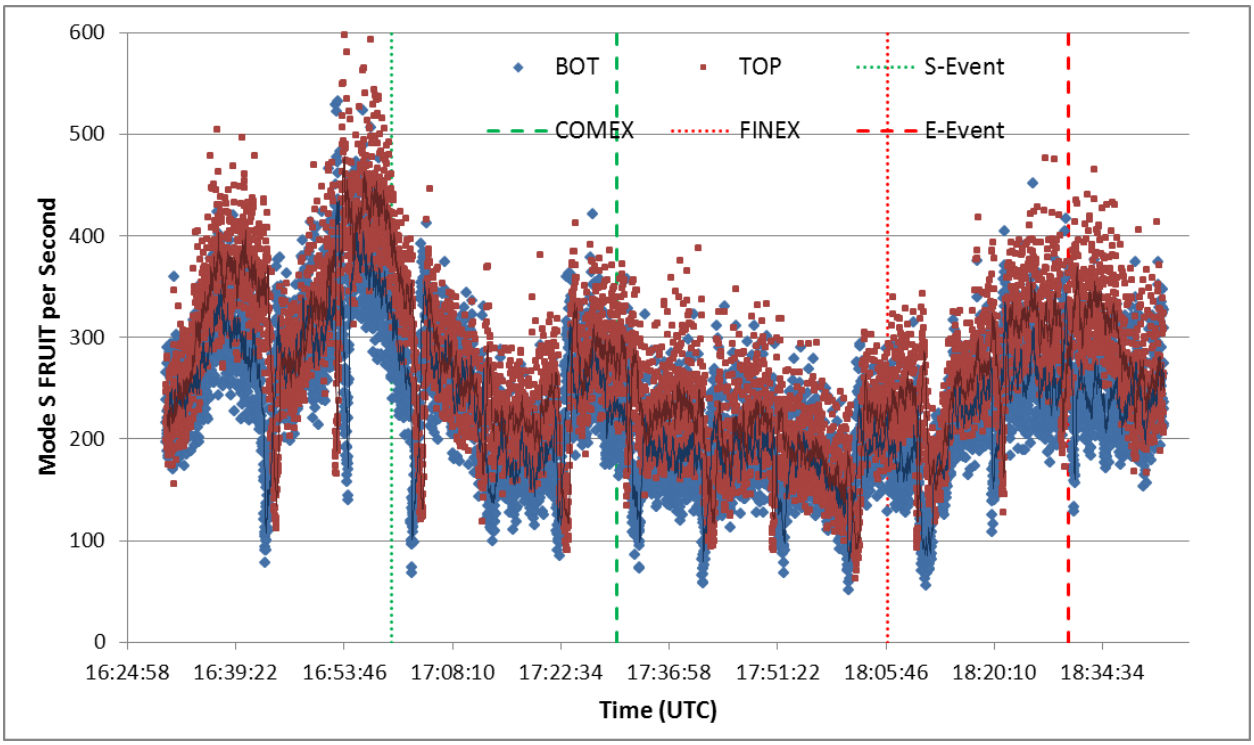

Figure 5-42 1090 MHz Mode S FRUIT Rate @ -84 dBm 11-18-14 AM

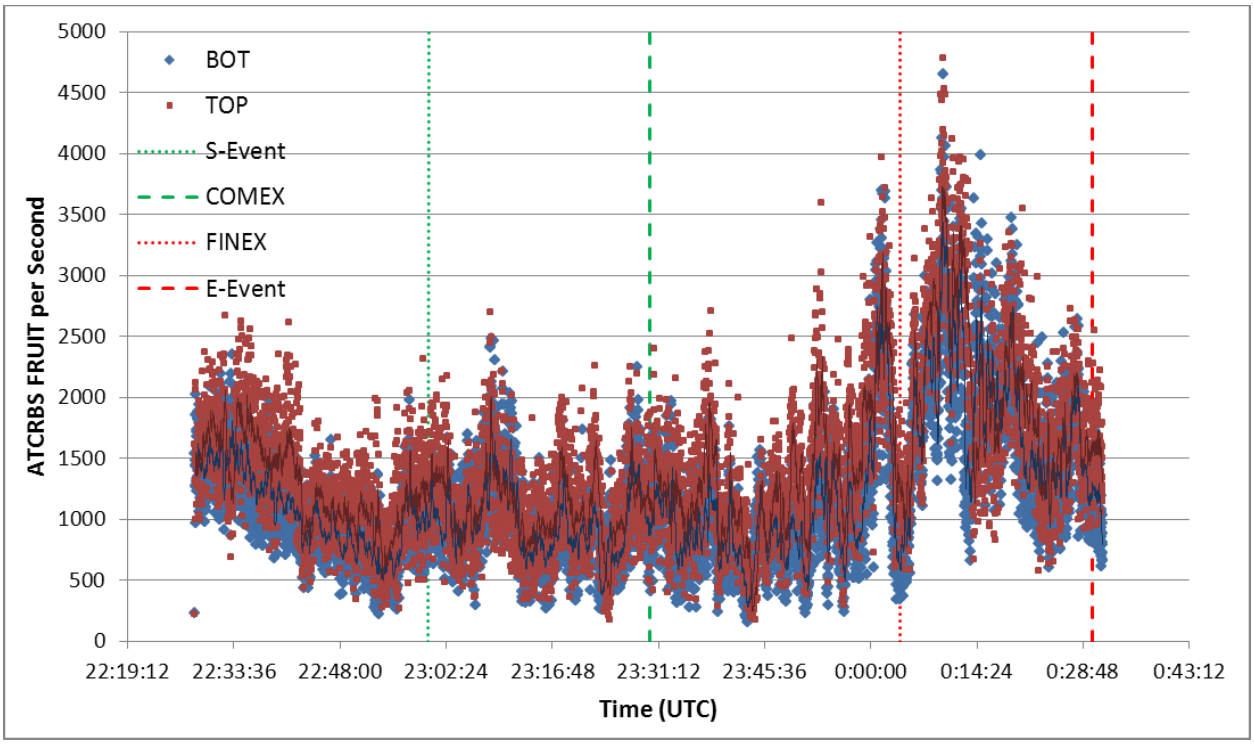

Figure 5-43 1090 MHz ATCRBS FRUIT Rate @ -79 dBm 11-18-14 PM

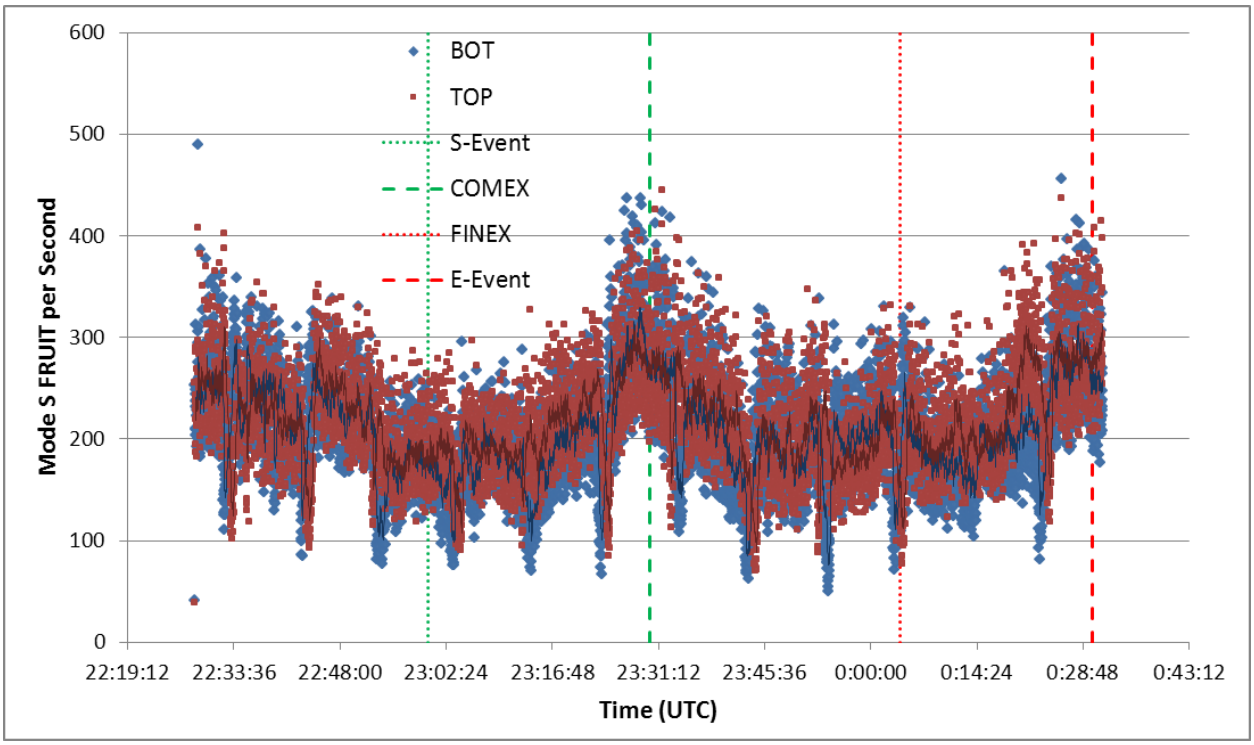

Figure 5-44 1090 MHz Mode S FRUIT Rate @ -84 dBm 11-18-14 PM

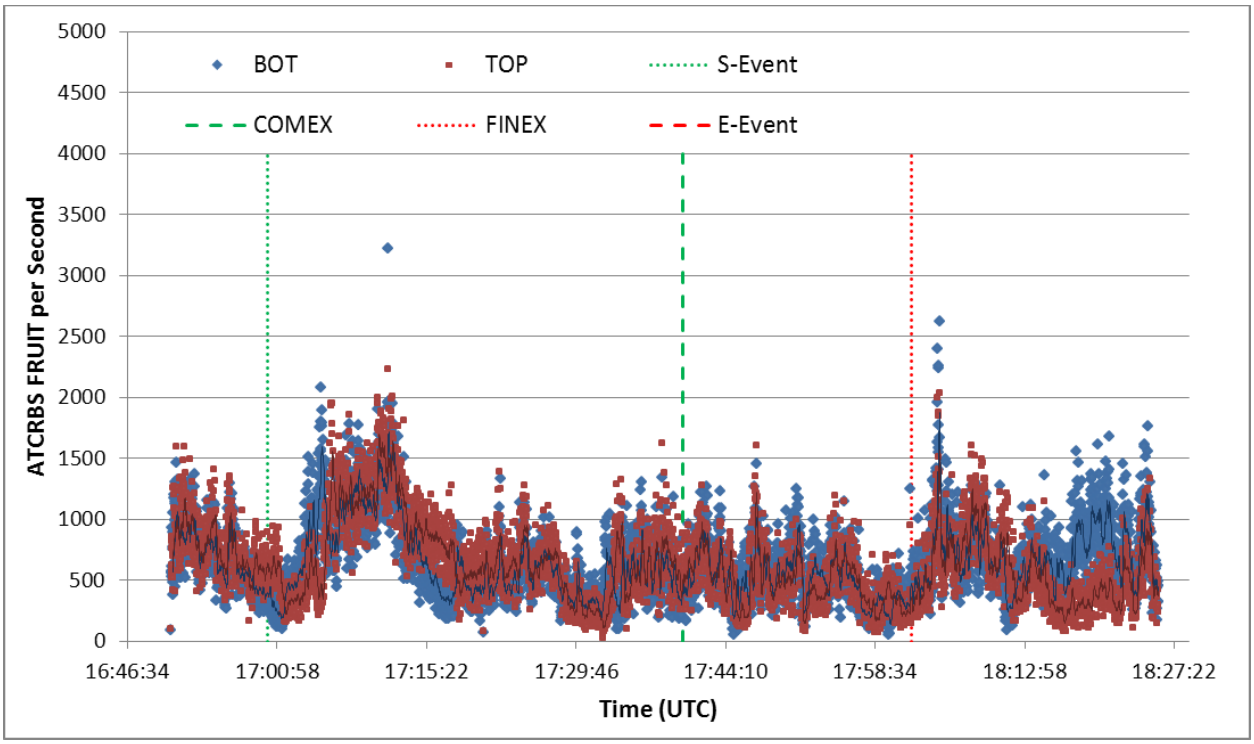

Figure 5-45 1090 MHz ATCRBS FRUIT Rate @ -79 dBm 11-19-14 AM

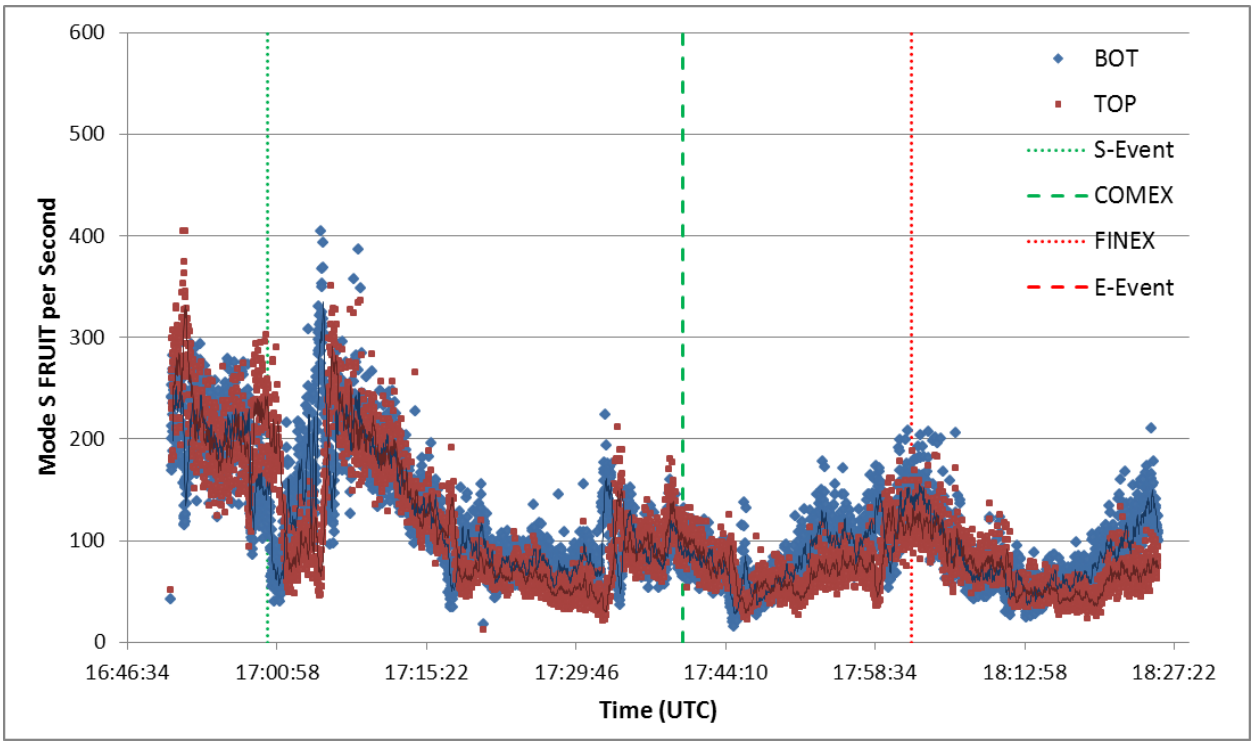

Figure 5-46 1090 MHz Mode S FRUIT Rate @ -84 dBm 11-19-14 AM

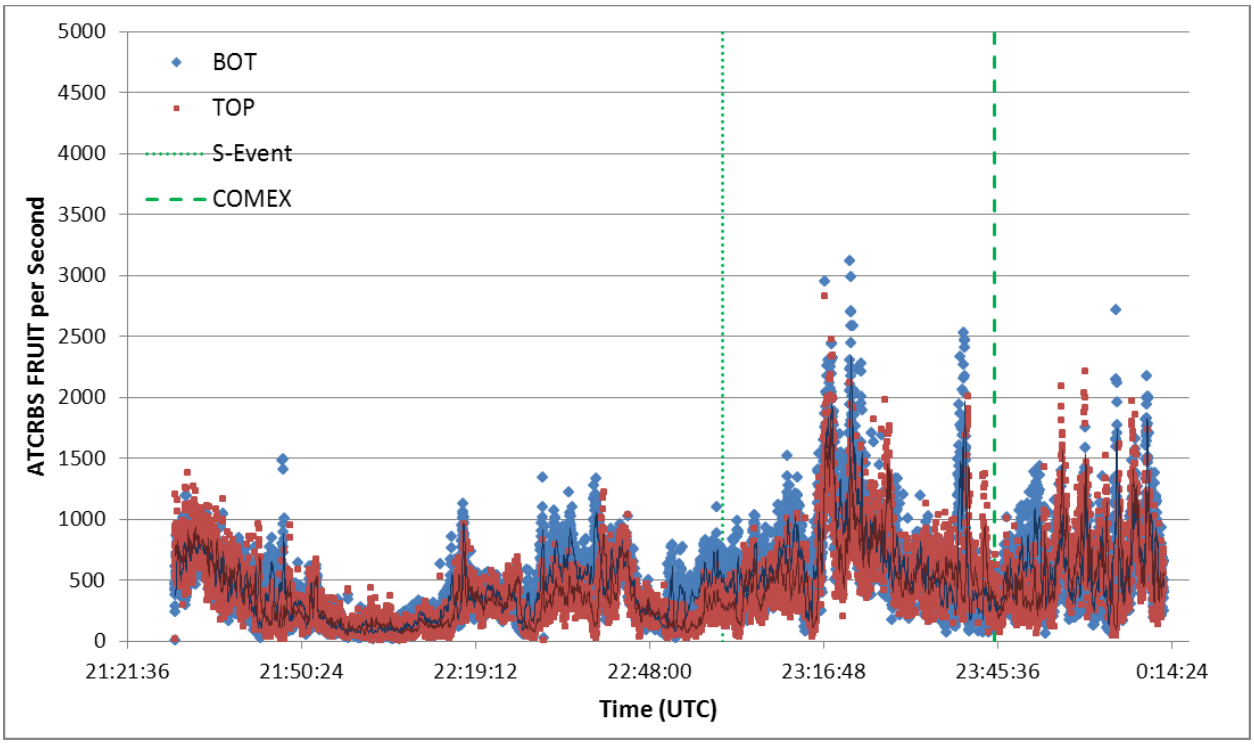

Figure 5-47 1090 MHz ATCRBS FRUIT Rate @ -79 dBm 11-19-14 PM

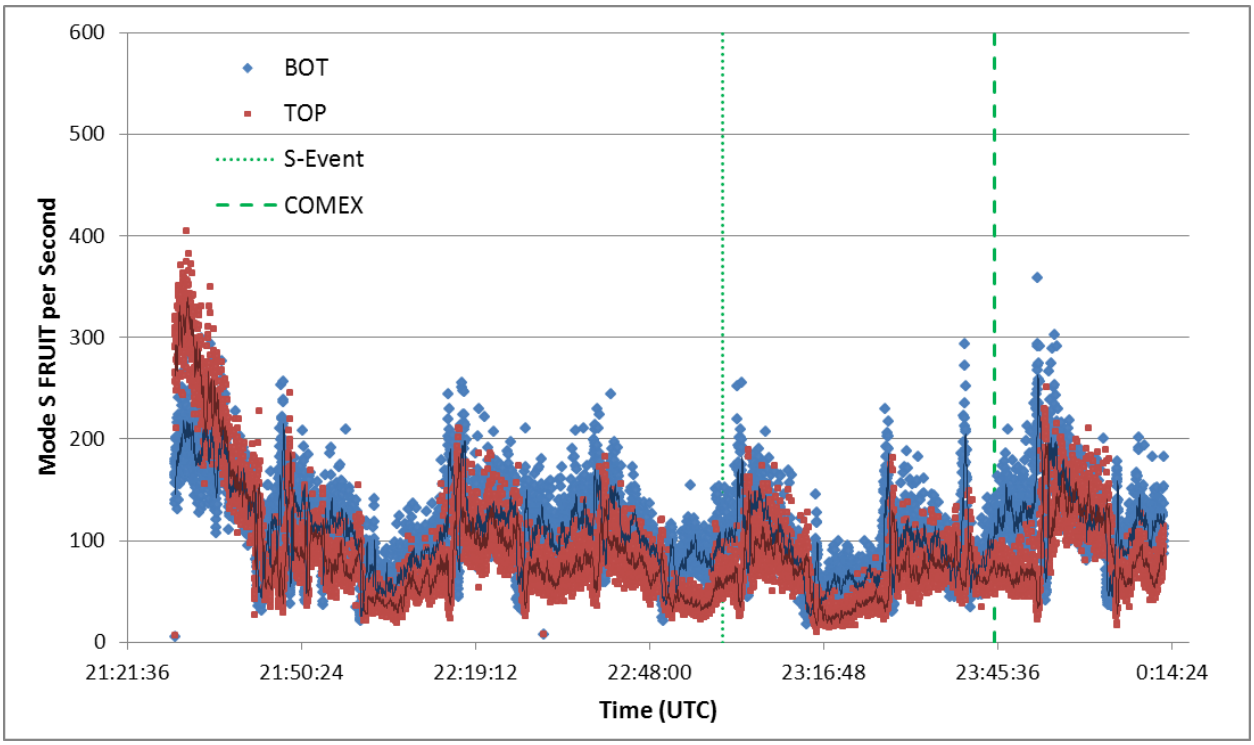

Figure 5-48 1090 MHz Mode S FRUIT Rate @ -84 dBm 11-19-14 PM

Both ATCRBS and Mode S FRUIT rates from top and bottom antennas vary considerably in each plot. There are higher peaks in 1090 MHz ATCRBS FRUIT during Events 2 and 4 conducted after noon on November 18th and 19th than during the baseline measurement periods before the start of the tests. On the other two tests, there isn't a distinguishable increase in ATCRBS FRUIT. The highest ATCRBS FRUIT rate measured during these tests was about 4,000 per second (not shown in charts). As a comparison, ATCRBS FRUIT rates as high as 25,000 to 30,000 were measured in the northeastern U.S. corridor with a high density of air traffic in April 2011.

The military aircraft participating in the test were not interrogating Mode S or any signal that would elicit Mode S replies. As expected, there was no correlation between any increases in Mode S FRUIT and when test events were conducted.

6 SSR Data Analysis

6.1 Introduction

6.1.1 Purpose

The Navy requested the William J Hughes Technical Center (WJHTC) to record Secondary Surveillance Radar (SSR) data from the SSR systems providing coverage of the airspace used during the transponder occupancy testing. The purpose of the data collection and subsequent analysis was to determine the effect of the additional 1030 MHz interrogators on existing SSR systems.

6.1.2 Scope

The Surveillance Branch performed analysis on data recorded at the WJHTC before, during and after four test events on November 18th – 19th, 2014. Analysis focused on observed decreases in Probability of Detection (Pd) and increases in the number of false targets.

6.2 System Overview

See Section 2 for an overview of Secondary Surveillance Radars

6.3 Test Configuration

See Section 3 for a map and other details of the test environment.

6.4 Data Collection

The surveillance team collected data at the WJHTC from a combination of Airport Surveillance Radar Mode 11 (ASR-11), Beacon Interrogator Model 6 (BI-6) and Mode S SSR systems covering the area of the exercises, including Battle Mountain (BAM), Fallon (FLX), Red Bluff (RBL), Reno (RNO), and Tonopah (TPH). One of the terminal sites, (RNO), had a faulty data feed coming into the WJHTC rendering its data unusable.

The site closest to the exercise was the FLX SSR, located approximately two miles from the Fallon Naval Air Station (NFL). FLX is a Mode S Long Range system with a range of 200 miles. Data was collected one-half hour before, during, and one-half hour after each of the four events on the 18th and 19th of November 2014.

6.5 Analysis and Results

Prior to the exercise, a theory was proposed that the increased interrogations from the additional aircraft interrogators would cause a drop in Pd, but after analysis of the data, the drop appears to be the result of the tracking of the military aircraft.

Overall, there was little noticeable effect caused by the additional aircraft interrogators on the FLX SSR system, with the exception of a small decrease in Pd and a small increase in the number of false targets. During the exercise, the Mode S system performed within blue-sheet specifications and no degradation in system availability was observed.

As expected during each exercise, the Pd decreased by 0.38% to 1.10% of its value prior to the event (see Table 6-1).

Table 6-1 Probability of Detection (Pd)

Event	1	1	1	2	2	2	3	3	3	4	4	4
Period	**Prior**	**During**	**After**	**Prior**	**During**	**After**	**Prior**	**During**	**After**	**Prior**	**During**	**After**
Pd	99.29%	98.91%	99.41%	99.21%	98.68%	98.73%	99.36%	98.26%	99.49%	99.31%	98.39%	99.12%
Change		-0.38%			-0.53%			-1.11%			-0.93%	

During the exercise, the Pd of the military aircraft ranged from 92.93% to 94.06% (see Table 6-2). The reason for the low Pd of the military aircraft could not be identified. This data was not available during the exercises; additional data extraction from the Mode S system would be required to perform this analysis. Based on the available data, some possible reasons for the low Pd are: 1) the concentration of the aircraft in a confined area, 2) aircraft maneuvers and supersonic, fast turning aircraft, which are not designed to be tracked by SSRs.(These maneuvers and aircraft stores (pods) may cause the antennas to be shielded from the Mode S sensor), or 3) the mountainous terrain blocking the line of site from the sensor to the aircraft. Another possibility is a faulty transceiver, but the available data does not support that theory.

Table 6-2 Exercise Pds

Exercise	Pd Military Only	Pd Without Military
1	93.57%	99.32%
2	94.06%	99.20%
3	92.93%	98.76%
4	94.06%	99.24%

An increase of false targets occurred prior to and following each exercise (see Table 6-3). This was attributed to aircraft on the runway at the NFL military base and not the increase in aircraft interrogators.

Table 6-3 False Targets

Exercise 1	Before	During	After
Total False Target Reports	0.26%	0.11%	0.07%
Split	0.17%	0.03%	0.01%
Ring	0.06%	0.01%	0.01%
Down Reflection	0.00%	0.02%	0.00%
PRF	0.00%	0.01%	0.00%
Up Reflection	0.04%	0.04%	0.05%
A/S	0.01%	0.01%	0.00%
Other	0.00%	0.00%	0.00%

Exercise 2	Before	During	After
Total False Target Reports	0.25%	0.10%	0.41%
Split	0.19%	0.03%	0.05%
Ring	0.03%	0.01%	0.05%
Down Reflection	0.01%	0.02%	0.00%
PRF	0.00%	0.00%	0.00%
Up Reflection	0.03%	0.04%	0.30%
A/S	0.00%	0.00%	0.00%
Other	0.00%	0.00%	0.00%

Exercise 3	Before	During	After
Total False Target Reports	0.20%	0.43%	0.09%
Split	0.16%	0.03%	0.02%
Ring	0.00%	0.03%	0.03%
Down Reflection	0.00%	0.22%	0.00%
PRF	0.00%	0.01%	0.00%
Up Reflection	0.04%	0.15%	0.05%
A/S	0.00%	0.01%	0.00%
Other	0.00%	0.00%	0.00%

Exercise 4	Before	During	After
Total False Target Reports	0.22%	0.29%	0.46%
Split	0.13%	0.07%	0.09%
Ring	0.00%	0.02%	0.04%
Down Reflections	0.00%	0.02%	0.01%
PRF	0.01%	0.01%	0.01%
Up Reflections	0.08%	0.17%	0.31%
A/S	0.00%	0.00%	0.00%
Other	0.00%	0.00%	0.00%

A line of buildings, as shown in Figure 6-1 and Figure 6-2, between the sensor and the runway are acting as reflectors (ref), causing a high number of false targets due to uplink and downlink reflections when planes are on the runway or to the west of the sensor (see Figure 6-3).

Figure 6-1 Reflector 1

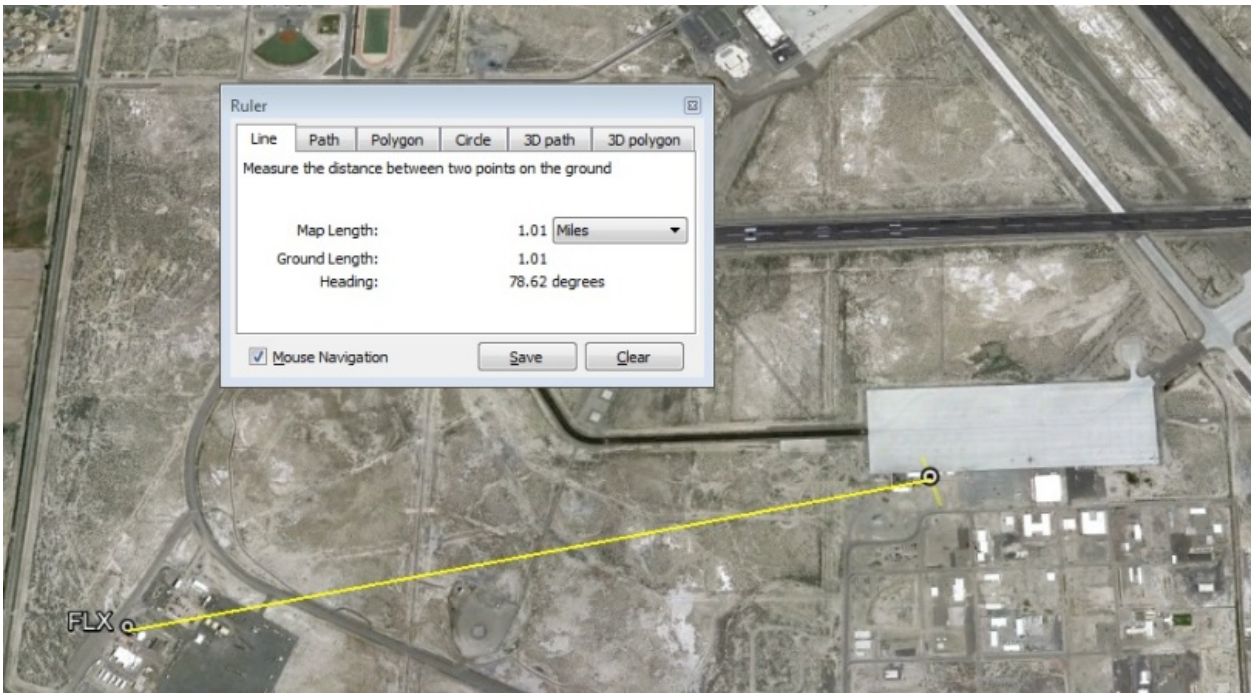

Figure 6-2 Reflector 2

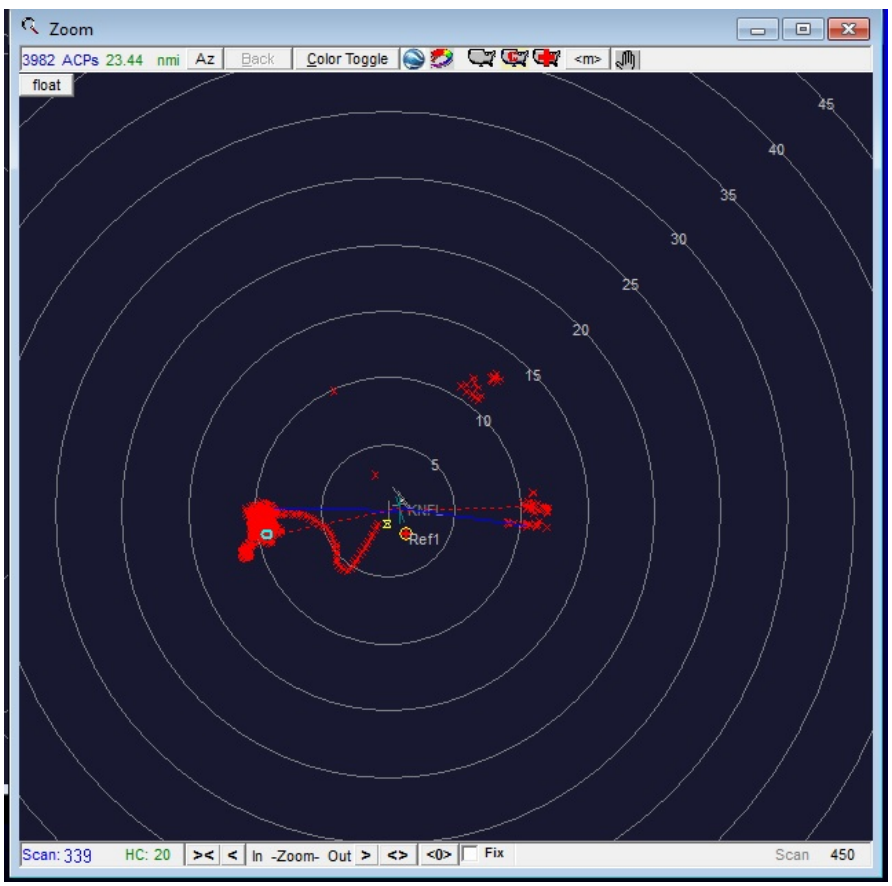

Figure 6-3 False Targets Around KNFL