# PHASED ARRAY RADAR STUDIES

## FINAL REPORT

Inter-Agency Agreement (IAA) #

HSHQDC-08-X-00454

by

**National Severe Storms Laboratory**

September 2009

# I. INTRODUCTION

This final report represents the results of the work accomplished by the National Severe Storms Laboratory (NSSL) under the interagency agreement HSHQDC-08-X-00454 between the Department of Homeland Security (DHS) and the NSSL for the period August 31, 2008 through August 31, 2009.

# II. TASKS:

### TASK 1 Windfarm Mitigation Study

1. **Description:** A Study will be conducted to determine the capability of phased array radar to mitigate the problems that have been identified by wind farms. NSSL and the University of Oklahoma will work on the following areas to determine mitigation strategies for wind farms using a phased array radar:
    - Enhancement of the existing time-series, phased array simulator to include contamination from wind turbines. Independent time-series data streams will be produced for each element of the array allowing the study of adaptive beam-forming algorithms.
    - Analyses of existing time-series data obtained with WSR-88D radars from wind farms.
    - Collection of time-series data with NSSL's polarimetric X-Band mobile radar (3 cm wavelength); suitable radar locations will be determined to obtain different "views" of existing wind farms in Oklahoma. Simulation results will be validated using these experiments.
    - Development of phased array methods of mitigation of moving clutter targets by leveraging previous work on sidelobe cancellation techniques. These methods are based on *spatial* filtering and do not require physically stationary targets. Therefore, there is promise that contamination from the rotating blades of the wind turbines can be mitigated. Given that the NWRT is not collocated with any existing wind farm, the enhanced radar simulator will be used for this study.
    - Utilization of spectral analysis to characterize wind turbine clutter signatures, detect the extent of contamination, and mitigate this contamination in an attempt to recover the underlying weather signal. Feasible mitigation techniques could be based on the adaptive scanning capabilities that are unique to phased-array radars.

### TASK 2 Simultaneous Weather and Aircraft Surveillance.

1. **Description:** A demonstration will be performed using the NWRT to show the phased array radars ability to simultaneously perform weather and aircraft surveillance.

- Data collection will occur on targets of opportunity this spring using a scan strategy designed to collect aircraft and weather data simultaneously.
- NSSL will work with the Federal Aviation Administration (FAA) and Basic Commerce Industries (BCI) to run their aircraft tracking software on the aircraft data.
- NSSL will process and display both the weather and aircraft tracks.
- The mono-pulse channels will be re-implemented and receivers added.
- Data collection will occur on targets of opportunity using the mono-pulse channels to better define the aircraft locations.

## III. ACCOMPLISHMENTS

TASK 1. This task was accomplished through a collaboration with the University of Oklahoma. A detailed final report is attached (Attachment A).

TASK 2. All of the sub-tasks for demonstrating simultaneous weather and aircraft surveillance were accomplished except one.

The one not accomplished was the collection of data using the mono-pulse channels. This was due to a delay in implementation of the multi-channel receivers that were funded by the National Science Foundation. The extra receivers required to re-implement the difference channels for mono-pulse are still being tested. When testing is completed, data will be collected using the mono-pulse channels. New resources will be required to fully implement the mono-pulse tracking software on the NWRT and was not part of this task.

A majority of the work under this task was accomplished through a sub-contract with Basic Commerce Industries with the help from the Federal Aviation Administration. A final report is attached (Attachment B).

## IV. FINANCIAL INFORMATION ($750K)

| Task | Total | Reserve | Committed | Obligated | Expended | Balance |
|---|---|---|---|---|---|---|
| 1 | $250K | | $250K | $250K | $250.0 | $0.00 |
| 2 | $500K | | $500K | $500K | $500.0 | $0.00 |
| TOTALS | $750.00K | | $750K | $750K | $750.0 | $0.00 |

**ATTACHMENT A.**

# Final Progress Report

August 31, 2009

# *Mitigation of Wind Turbine Clutter Using Phased Array Radars*

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## 1. Introduction & Motivation

Wind energy production has become increasingly important since its commercial realization as manufacturing costs have decreased and demand has increased. In the 1990s, the four largest markets for this energy were Germany, USA, Denmark, and Spain, which accounted for 80% of global sales between 1998 and 1999 (Hatziargyriou and Zervos 2001). By the end of 2000, wind turbines were operating in over 50 countries and produced almost 17,500 MW of energy. It is expected that within the next two decades wind energy will comprise approximately 20% of the total annual power consumed. Wind turbines harvest energy that is associated with low-level atmospheric winds and convert the kinetic energy into usable electrical energy. This energy is proportional to the area swept by the turbine blades and the speed of the wind (Richardson 1993), which increases with height above the ground because of a reduction in surface friction. Thus, larger turbines are desirable due to their greater power generation potential.

For radio applications, wind turbines generally do not interfere or pose much of a problem when they are not in the Fresnel zone of the transmitting source or the direct line of sight (Halliday 1993). However, it has been well documented that their presence is problematic for both air traffic control and weather radars (Isom et al. 2009),) especially under anomalous propagation conditions. This type of non-stationary interference has been termed *Wind Turbine Clutter* (WTC) and its detection/mitigation is the focus of this study.

Conventional clutter filters are based on the assumption that the clutter is physically stationary, which is typically the case for most undesired ground targets. Wind turbines, in contrast, have extremely large and highly reflective blades moving with speeds of up to 80 m/s near the tip. Since the spectral characteristics of WTC are similar to those of the desired weather signal, filters based on spectral characteristics are mostly ineffective. Phased array radars, which use spatially separated antenna elements and can vary their radiation pattern, are being considered as a replacement for conventional radars based on a mechanically steered dish antenna (Zrnić et al. 2007). Using such radars, it is possible to use *spatial* filtering methods (Le et al. 2009), based on the stationary *angle* of targets and not the stationary *Doppler* characteristics, to mitigate WTC contamination.

This report will focus on three major thrusts of the study: (1) WTC mitigation using spatial filtering with phased array radars, (2) application of fuzzy logic to automatic detection of WTC, and (3) initial results from X-band, polarimetric characterization of WTC. A brief summary of the results is provided in the remainder of this report.

## 2. Mitigation of Wind Turbine Clutter Using Phased Array Radars

### Numerical Simulation of Wind Turbine Clutter

Given that no readily accessible phased array radar exists in the vicinity of wind turbines, sophisticated numerical simulations based on the work of Cheong et al. (2008) were used to emulate phased array signals from weather and WTC. The scheme used for the simulator is illustrated in the left panel of Figure 1.

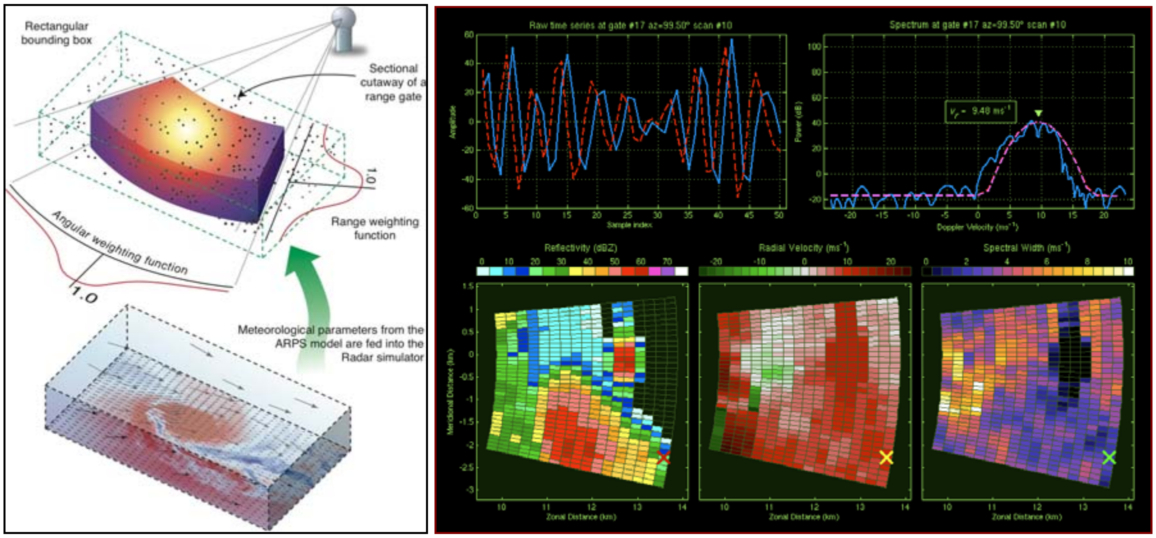


Figure 1: Illustration of numerical simulation scheme used (left) along with typical output from the simulator (right). Using this method, it is possible to produce individual time series data from each element of a phased array radar.

As shown, Monte Carlo scatterers are placed within a so-called bounding box. In addition, a simplified scattering model of a wind turbine was placed within the same bounding box. Backscattered electromagnetic signals from each scatterer (and points on the turbine) are coherently summed with weights defined by the antenna pattern (angular weighting) and range weighting function. The phase center of the received signal can be placed in any desired location. In this case, received signals from each of the 4352 elements of the National Weather Radar Testbed (NWRT) phased array radar (Zrnić 2007) were generated. Example time-series data along with the corresponding Doppler spectrum are provided in the right panel of Figure 1.

**Spatial Filtering Results**

Using the numerical simulation scheme just outlined, results from an adaptive spatial filtering method are shown next. Essentially, spatial filtering is used to place a null in the antenna pattern in the direction of the undesired signal. In this case, the wind turbine was placed at a 0-degree elevation angle broadside of the array. The antenna patterns for both conventional and adaptive beamforming are provided in the left panel of Figure 2 for elevation angles of 1.0, 1.5, 2.0, and 2.5 degrees. The purple circles indicate the location of the wind turbine. The right panel gives the Doppler spectra for conventional beamforming (Fourier) and adaptive beamforming (Capon) along with the ground truth from the simulator (weather signal only). As expected, the Fourier beamformer is adversely affected by the WTC with a severely contaminated Doppler spectrum. In contrast, adaptive Capon beamforming shows promise in the mitigation of WTC even with the moving blades of the turbines. Of course, this was expected given that spatial filtering, or adaptive beamforming, places a null at the angle of the undesired signal irrespective of any non-zero Doppler signature. In summary, spatial filtering using adaptive phased array radars hold promise in the mitigation of WTC at the cost of significant computational burden.

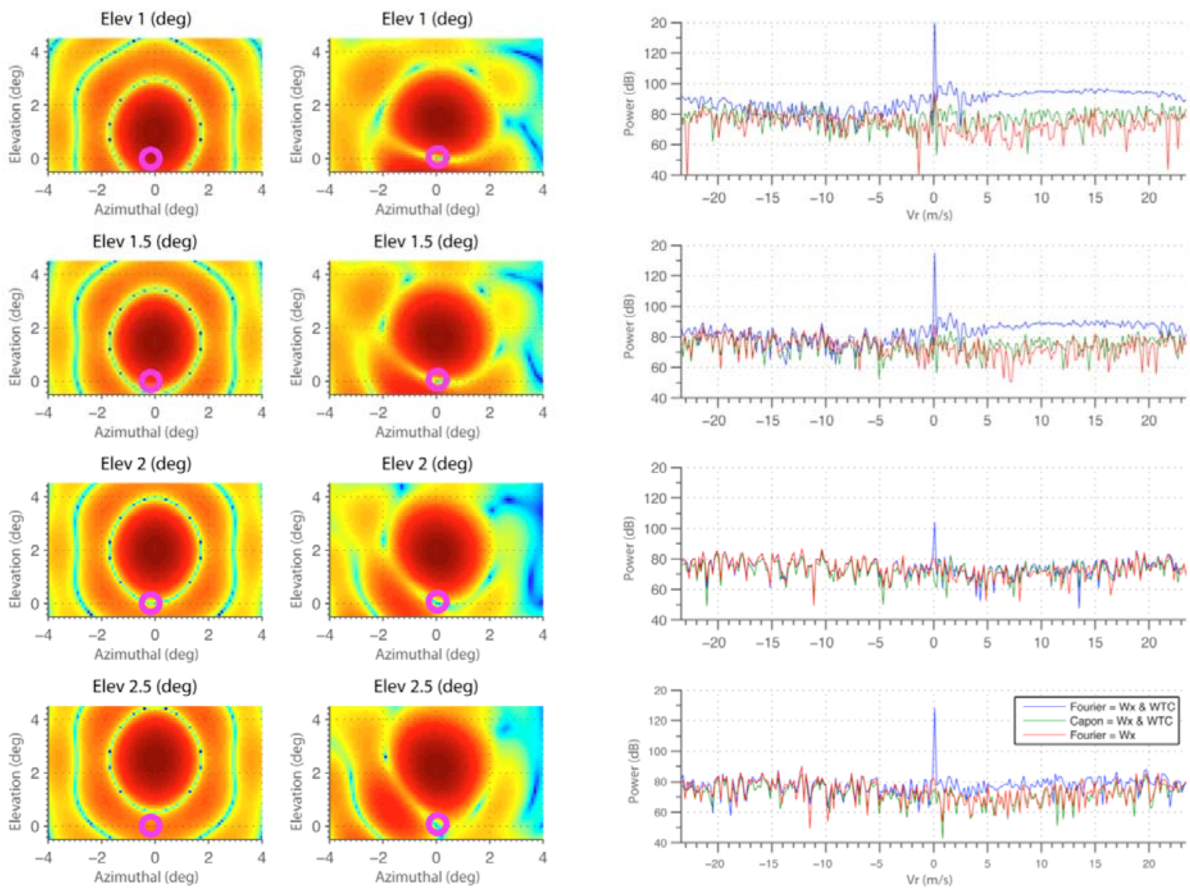

Figure 2: Beam patterns and output spectra from simulations of weather signals with WTC contamination. Purple circles indicate the angular location of the wind turbine. Doppler spectra are shown for weather signal only (Wx) and Fourier and Capon beamforming with WTC contamination (Wx + WTC).

## 3. Automatic Detection of Wind Turbine Clutter Using Fuzzy Logic

Automatic detection of WTC is the first logical step in a mitigation solution. In the context of weather radars, automatic WTC detection capabilities are critical as contamination “signatures” in the meteorological data are not unique and locations of contaminated regions may vary due to changing atmospheric conditions and the emergence of new, unaccounted wind farms. A WTC detection algorithm that operates independently on weather signals from each radar resolution volume (or range gate) is presented next. The algorithm employs spectral and temporal “features” of the weather signals that are typical of WTC contamination. An example of these features is shown in Figure 3, where the weather signal spectra and their corresponding feature values are plotted as a function of time. The coherent phase alignment (CPA) is a good indicator of stationary ground clutter in the resolution volume (Hubbert et al. 2009). However, both WTC and non-WTC ground clutter are expected to have a strong stationary component. Spectral features were designed to supplement CPA and provide effective detection of WTC-specific signatures. For example, the spectral flatness (SF) is aimed at detecting the “flashes” that occur periodically as the wind turbine blades reach maximum radial velocity. Also, higher-order spectral moments and the “hub-to-weather” ratio (HWR) cover the oscillating signatures of the turbine elements that are near the hub.

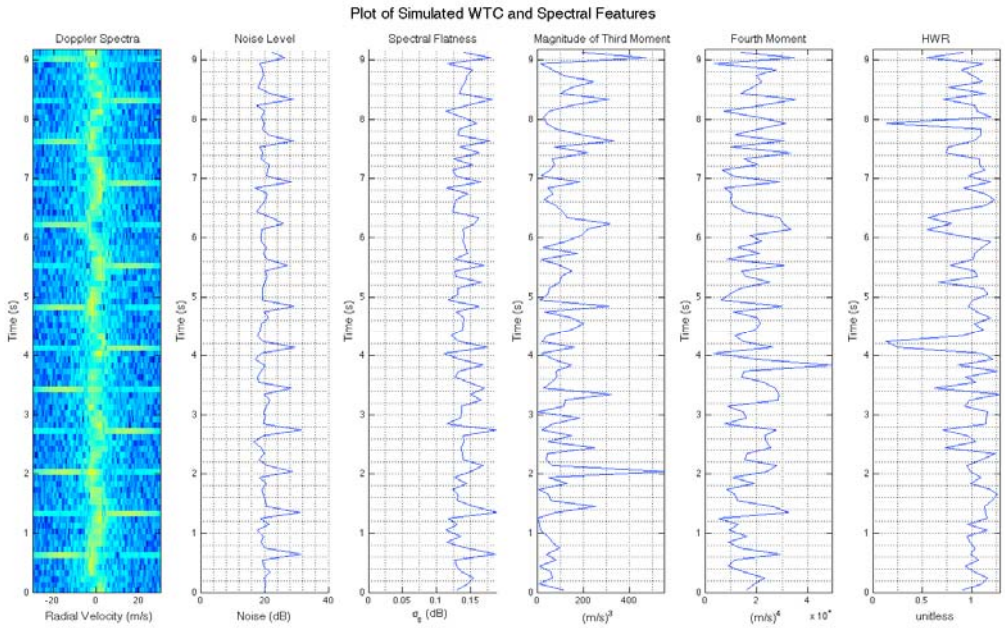


Figure 3: Example temporal evolution of Doppler spectra of WTC signals along with possible spectral features used in the fuzzy logic classification engine.

As shown in Figure 4, temporal and spectral features derived from weather signals are combined in a fuzzy-logic engine (FLE), where the membership functions for each feature have been tuned to provide optimum separation between WTC-contaminated and non-contaminated data. The performance of the FLE can be quantified in a controlled environment by using simulated weather and WTC signals. Weather signals were simulated to span the typical range of spectral moments measured by the US NEXRAD network. WTC signals were simulated using the model described in the previous section. Ground truth was determined by considering the additional amount of meteorological data bias generated by the WTC signals under typical processing conditions (e.g., after running the usual ground clutter filters). Obviously, the degree of contamination from WTC will depend on the relative strengths of the weather and the WTC signals. An example of performance of the FLE is shown in Figure 5 using the radar operating characteristics (ROC) curve and the accuracy of the detection algorithm for different output thresholds. As expected, the detection algorithm can trade probability of detection by false alarm rate, and the optimum setting will depend on requirements imposed by consumers (algorithms or users) of this information.

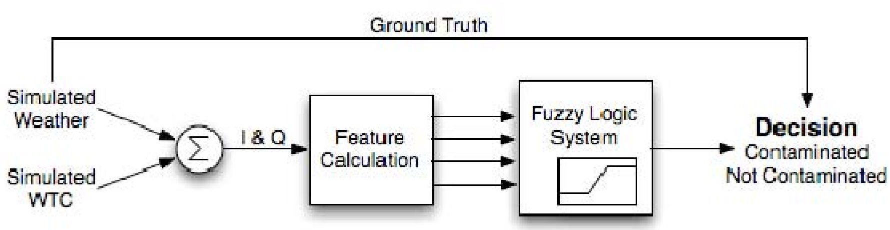


Figure 4: Block diagram of the proposed automatic detection algorithm based on fuzzy logic. As shown, the radar data are simulated in order to provide the ground truth needed for validation.

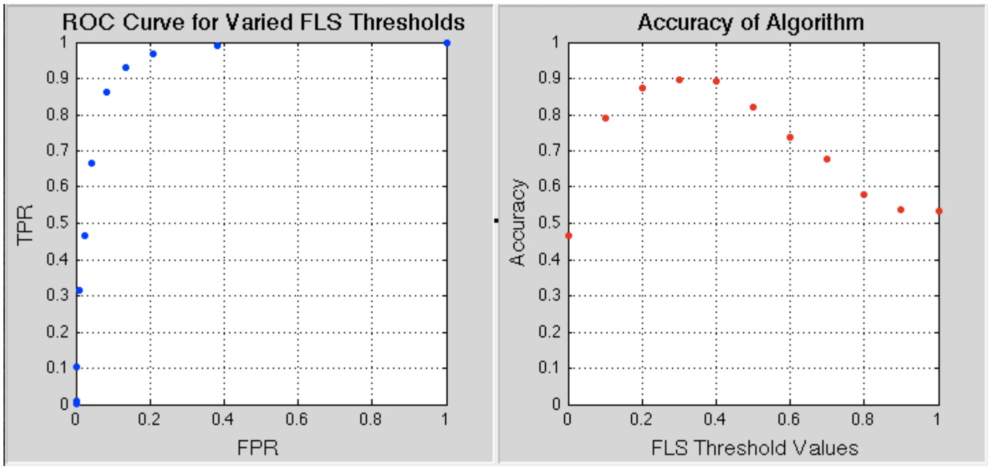


Figure 5: Radar Operating Characteristics (ROC) curves (left) with accuracy measure (right) for the proposed fuzzy logic classifier for different fuzzy-logic (FLS) output thresholds. ROC curves plot the probability of detection or true-positive ratio (TPR) as a function of the false alarm rate or false-positive ratio (FPR). The accuracy is the fraction of true-positive and true-negative cases over the total number of cases.

## 4. Initial Analysis of X-Band Polarimetric Radar Signatures

As shown in the last section, careful numerical simulations can provide a stable foundation on which to build signal processing algorithms. Nevertheless, actual experiments always provide new ideas and emphasize the complexity of the real world. For this phase of the project, a field campaign was planned and executed near Weatherford, Oklahoma, where an extensive wind farm exists. Since no phased-array or WSR-88D radar is close to this location, the new mobile, polarimetric, X-band radar, recently built by NSSL and called NOXP, was used for the experiment. A photograph of the radar is shown in the left panel of Figure 6. The advanced signal processor of the NOXP is capable of collecting time-series data, which was important for the current analysis.


Figure 6: Picture of the NOXP mobile radar used in the polarimetric study (left). Also provided in the right panel is a map of the experimental region near Weatherford, OK. The white circles on the map represent the locations of the wind turbines. The two radar locations are marked with a picture of the radar along with coverage angels marked with red lines (Location 1) and yellow lines (Location 2). The

red circle provides the location of the particular turbine, from which data were collected and shown in the Figure 7.

The right panel of Figure 6 shows a map of the experiment region near Weatherford, OK. The two locations, where the radar was deployed, are denoted by small pictures of the radar. The red and yellow lines provide the coverage areas for Location 1 and Location 2, respectively. The blue line denotes the exact azimuth angle from which the data example provided next was taken.

As mentioned earlier, real data can be complex but can also provide insight not easily discerned from simulations. Time series data from the turbine marked by the red circle in Figure 6 were collected on November 25, 2008 at approximately 18:33:56 UTC. An elevation angle of 0.4834$^o$ was used with an azimuth angle of 37$^o$ in the so-called *spotlight* mode, where the antenna is stationary allowing extremely long time series to be collected from the same locations. The range to the turbine was approximately 9.728 km. With a pulse repetition time of 0.4 ms and pulse width of 0.25 μs, the Doppler spectra were calculated as a function of time. An example of the polarimetric spectra over a 5-sec period is provided in Figure 7.

The expected evolution of the spectra (Isom et al. 2009), caused by the rotation of the blades, is evident in the power spectra (two left-most panels). Unlike previous examples of Doppler spectra, these results show an extremely complex structure likely caused by the close proximity of the turbine to the radar or by the angle between the rotor and the radar line-of-sight. Results from other studies have shown rapidly evolving *flashes* in spectra (see Figure 4) and have not shown the detail of these data. In addition to the power distribution, spectral densities can be calculated for the polarimetric variables ($Z_{DR}$, $\rho_{HV}$, $\phi_{DP}$) (Bachmann and Zrnić 2007). Examples of these polarimetric spectral densities are provided in the three right-most panels of Figure 7. Although just recently discovered, these encouraging results show that radar polarimetry has promise for distinguishing turbine echoes from meteorological targets. For example, note that the $\rho_{HV}$ values are near unity for the highest velocity regions of the spectra, which likely correspond to the tips of the blades. Further experiments and theoretical analyses are needed to verify this assertion. It should be emphasized that the complexity of the signatures is a challenge and it is expected that the polarimetric features will eventually become an integral part of the fuzzy logic detection engine described in the previous section.

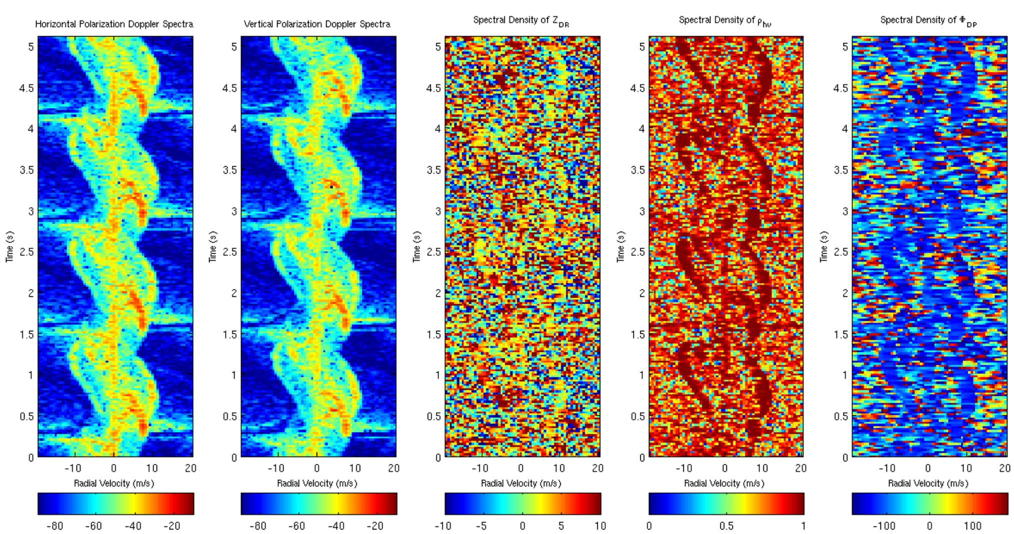


Figure 7: Temporal evolution of polarimetric spectral characteristics using the NOXP radar. Note the complexity of the data emphasizing the challenge of automatic detection and ultimately mitigation.

## 5. Conclusions

This report documents this past year's efforts on three major thrusts: (1) WTC mitigation using spatial filtering with phased array radars, (2) application of fuzzy logic to automatic detection of WTC, and (3) initial results from X-band, polarimetric characterization of WTC. Despite having increased computational complexity, spatial filtering shows promise in mitigating WTC signal contaminations when the weather signals of interest originate from different locations in space. However, collocated WTC contamination coming through the antenna main beam cannot be handled this way. Thus, a signal processing solution to mitigate collocated WTC contamination is needed but expected to be quite challenging due to the non-stationarity and spectral signatures of WTC signals. It has been verified that with good characterization of WTC signals, temporal and spectral features can be designed to effectively detect WTC in an automatic manner. Further exploration of dual-polarimetric signatures is likely to expose additional information needed to improve automatic detection performance and may bring us a step closer towards a WTC mitigation solution.

## References


Bachmann, S., and D. Zrnić, Spectral Density of Polarimetric Variables Separating Biological Scatterers in the VAD Display. J. Atmos. Oceanic Technol., 24, 1186–1198, 2007.

Cheong, B. L., R. D. Palmer, M. Xue, A Time-Series Weather Radar Simulator Based on High-Resolution Atmospheric Models, Journal of Atmospheric and Oceanic Technology, 25, 230-243, 2008.

Halliday, J., Wind energy-an option for the UK?, IEE Proceedings A, vol. 140, no. 1, pp. 53–62, 1993.

Hatziargyriou, N., and A. Zervos, Wind Power Development in Europe, Proc. IEEE, vol. 89, no. 12, pp. 1765–1782, 2001.

Hubbert, J. , M. Dixon, S. M. Ellis, and G. Meymaris, Weather Radar Ground Clutter. Part I: Identification, Modeling, and Simulation, Journal of Atmospheric and Oceanic Technology, 26, 1165-1180, 2009.

Isom, B., R. D. Palmer, G. S. Secrest, R. D. Rhoton, D. Saxion, L. Allmon, J. Reed, T. Crum, and R. Vogt, Detailed Observations of Wind Turbine Clutter With Scanning Weather Radars, Journal of Atmospheric and Oceanic Technology, 26, 894-910, 2009.

Le, K., R. D. Palmer, B. L. Cheong, T.-Y. Yu, G. Zhang, S. Torres, On the Use of Auxiliary Receive Channels for Clutter Mitigation on Phased Array Weather Radar, IEEE Transactions on Geoscience and Remote Sensing, 47(1), 272-284, 2009.

Richardson R. and G. McNerney, Wind Energy Systems, Proc. IEEE, vol. 81, no. 3, pp. 378–389, 1993.

Zrnić, D. S., and J. F. Kimpel and D. E. Forsyth and A. Shapiro and G. Crain and R. Ferek and J. Heimmer and W. Benner and T. J. McNellis and R. J. Vogt, Agile beam phased array radar for weather observations, Bull. Amer. Meteor. Soc., November, 2007.

# ATTACHMENT B

NWRT-ATP Final Test Report

## Adjunct Track Processor (ATP)

## FINAL TEST REPORT

September 2009

Prepared for:

Weather Processor and Weather Sensors Group, AJP B4
Federal Aviation Administration (FAA)
William J. Hughes Technical Center (WJHTC)
Atlantic City International Airport, NJ 08045

Submitted by:

Basic Commerce and Industries, Inc.
Systems and Software Engineering
304 Harper Drive, Suite 203
Moorestown, NJ 08057

# Adjunct Track Processor (ATP)

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## EXECUTIVE SUMMARY

The Weather Processors and Sensors Group (AJP B4), William J. Hughes Technical Center (WJHTC), and the Basic Commerce and Industries, Inc. system engineering group, successfully conducted the Installation Test of the Adjunct Track Processor (ATP). Testing was conducted May 19, 2009 through May 21, 2009 at the PAR National Weather Radar Testbed (NWRT) Lab in Norman, OK. All planned tests were completed.

The objective of this testing was to prove that a COTS system could perform non-interfering tracking (Track While Scan) of aircraft at NWRT and port the track data to the WDSS-II display at NSSL.

Overall, AJP B4 found the design and implementation of the ATP capable of identifying and tracking aircraft in a track while scan environment. The ability to ingest the radar data over the FPDP interface and process track data from NWRT I/Q data demonstrates the capability to perform track while scan processing with the COTS ATP. The tracks were also ported to and displayed on the NSSL display, proving system integration to NSSL's WDSS-II software. Data analysis will be used to illustrate the performance of the ATP against ASR-9 data obtained from the same area of investigation.

# TABLE OF CONTENTS

## LIST OF FIGURES

# 1. INTRODUCTION

## 1.1 Purpose

The purpose of the ATP Test Final Report is to document the results of the test conducted by the WJHTC Weather Processors and Weather Sensors Group (AJP B4) in accordance with the Installation Test Plan. The test was conducted May 19, 2009 through May 21, 2009 at the PAR NWRT Lab in Norman, OK. Additional tasks were completed in the PAR lab at BCI Moorestown utilizing the raw data collected during installation.

## 1.2 Scope

This test report presents the results of the ATP Installation Test based on the data observed/collected during the testing period at the PAR NWRT Lab using ATP and ASR-9 data. Additional details of the installation can be found in the document "**ATP_InstallationNotes_05282009**". In addition, details of the hardware and software are contained in the documents "**NWRT-ATP-HDD-001 / ATP Hardware Design Description**" and the "**NWRT-ATP-SUM-001 / ATP Software User's Manual**" that were delivered in June 2009.

# 2. REFERENCE DOCUMENTS

| | |
|---|---|
| NWRT-ATP-HDD-001 | ATP Hardware Design Description |
| NWRT-ATP-SUM-001 | ATP Software User's Manual |
| ATP_InstallationNotes_05282009 | ATP Installation Notes finalized May 28, 2009 |

# 3. SYSTEM DESCRIPTION

## 3.1 Mission Review

The ATP tracks aircraft and allows weather surveillance with a single radar system. Thus, the relative location of aircraft and hazardous weather will be measured precisely, eliminating positioning errors due to calibration and mapping differences. This improved data quality in the national airspace will improve aviation safety, reduce accidents, and minimize delays and reroutes because of hazardous weather.

An additional aviation benefit of ATP is that it will track aircraft in all three dimensions. The ATP system is capable of obtaining an aircraft's altitude in addition to its range and azimuth location and displaying targets alongside weather. The ATP is useful in tracking aircraft without transponders and aircraft with malfunctioning, or powered off transponders, and there is no detrimental impact on the environmental processor collecting weather data.

### 3.2 Test System Configuration

The installation of the ATP is based on the premise that it will not interfere with the existing installed Environmental Processor used by NSSL to collect weather data. In order to achieve this, a variant of the Systran Exchange fiber optic card was used to receive the data from the radar system. This design is a "passive" tap into the radar data that is accomplished concurrently and in parallel. The ATP does not send any message traffic to the Real Time Controller (RTC) system or load the radar resources in any manner. The basic configuration for the ATP Installation is shown below in Figure 3.2-1.

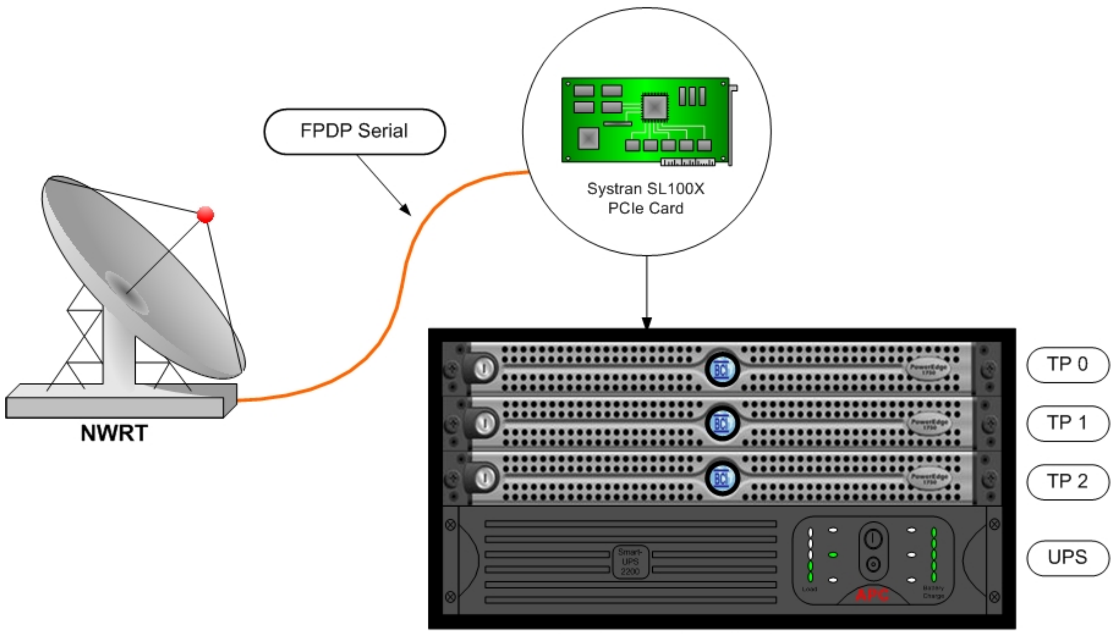


**Figure 3.2-1 NWRT Configuration for the ATP**

An important consideration is that this version of the ATP is designed and built from readily available COTS servers from DELL and the Operating System is COTS Red Hat Linux version 5, prevalent throughout the computing industry today. Except for the proprietary Systran FibreXtreme card purchased from Curtis Wright, the entire system is readily available from commercial vendors, very scalable, and relatively inexpensive. Successful installation and test of the ATP will prove that a COTS solution is a viable, cost effective solution for the Signal Processing required to track targets of opportunity in the NWRT.

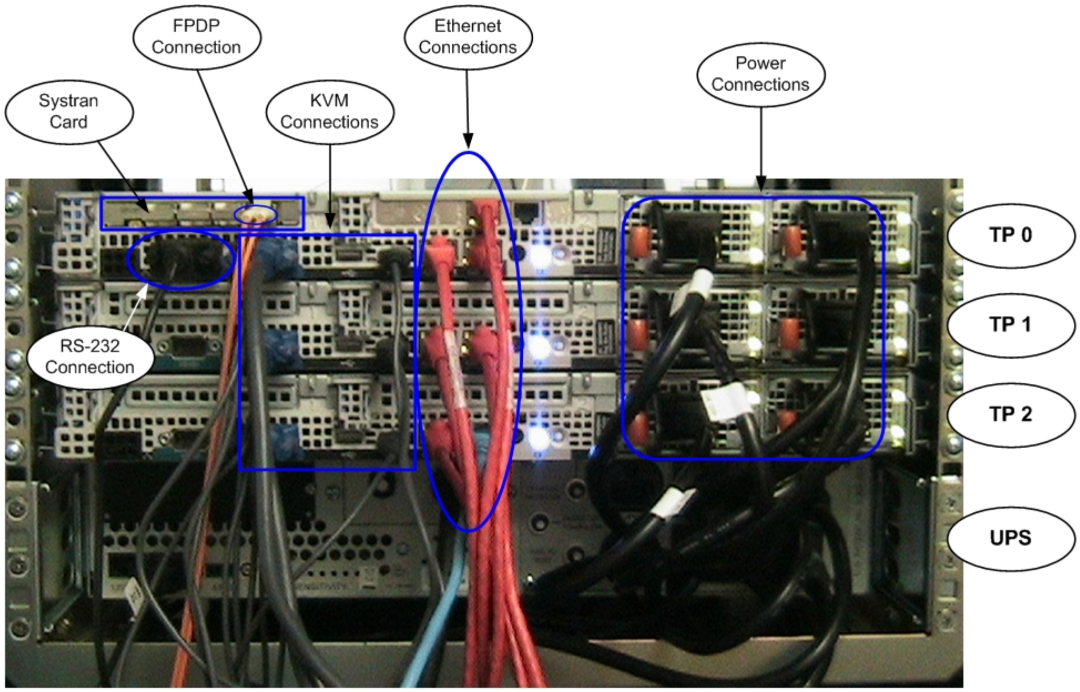


**Figure 3.2-2 ATP Enclosure with COTs Servers(rear view)**

| Interface | NWRT TP0 | NWRT TP1 | NWRT TP2 |
|---|---|---|---|
| eth 0 | 192.168.1.130 | 192.168.1.134 | 192.168.1.138 |
| eth 1 | 192.168.1.131 | 192.168.1.135 | 172.22.0.116 |
| eth 2 | 192.168.1.132 | N/A | N/A |
| eth 3 | 192.168.1.133 | N/A | N/A |

Ext Network Connection

**Figure 3.2-3 ATP Ethernet Addresses and Port Assignments**

# 4. TEST DESCRIPTIONS/RESULTS

## 4.1 Power-up Test

### 4.1.1 Test Objective/Criteria

The Power-up Test will be performed to verify the ATP's ability to be properly powered up after shipment and installation. This test will verify that all components of the ATP were installed correctly and operating efficiently. It will also verify that the ATP is an independent, non interfering signal processor that operates transparently and seamlessly with the NWRT. The connection of the ATP to NWRT will not interfere with NSSL's operation of NWRT.

### 4.1.2 Test Descriptions

Visual inspection of all components and connections of the ATP will be performed on the DELL servers, Systran FibreXtreme card, etc. When the inspection is completed, the ATP will be powered up. The internal board connections will also be validated by this start up test.

### 4.1.3 Data Collection and Analysis Method

Visual inspection of all power lighting and alarm indications. The host computer control screen will be properly booted up and logon completed. The NWRT operational status will be verified to validate the proper devices are connected and online. The operating system will display hardware and OS status information on the system monitor.

### 4.1.4 Results/Discussion

After shipping some items in the Dell Servers became dislodged and were reseated before the power up. The system was powered up and the boot sequence occurred, however the monitor for TP1 was relocated to the front display port because the rear display on the server was not operable. System boot up was successfully verified.

### 4.1.5 Conclusions

System power up was successfully accomplished after shipping to NSSL. The ATP was powered up and online for further testing and use and not interfering with operation of the NWRT.

## 4.2 Interface Installation and Functionality Test

### 4.2.1 Test Objective/Criteria

The Interface Installation and Functionality Test will be performed to verify the ATP's ability to interface with digital data from the NWRT Digital Receiver (DR), received from the Link Exchange output interface to the Systran FibreXtreme card. The test also validates the proper network setup and communications on both the fiber channel and the Ethernet network connections.

### 4.2.2 Test Descriptions

The ATP will be placed in operational mode. The interface to the Link Exchange and operation of the Systran card will be verified using the Systran administrative tools. The operator will test the communication paths and validate the IP settings for all external communications and output paths.

### 4.2.3 Data Collection and Analysis Method

The operator will verify there is a physical connection (Link Light) between the Systran card and Link Exchange, and that the Systran card is receiving data with no errors. Also the operator will verify that the servers in the ATP can Ping each other, necessary mounts are accomplished, and that the system can be accessed from an external computer on the same network.

### 4.2.4 Results/Discussion

There were link lights present on the Systran card and the Link Exchange box in the computer room. Running the utility "nsl_mon –u 0 –p 1000 –V" on TP0 verified the collection and interoperability of the serial FPDP data transfer. All TP servers were able to "ping" each other and necessary mounts between TP2 and TP0 were accomplished. Data files were able to be accessed from TP2 from the old "TP Server" which resides on the same local network as the ATP.

### 4.2.5 Conclusions

All of the System interfaces were installed correctly and the communications established to support operation of the ATP.

## 4.3 Input Processing and Control (STIM and I/Q Data) Test

### 4.3.1 Test Objective/Criteria

The Input Processing and Control Test will be performed to verify operation of the ATP and generation of products.

### 4.3.2 Test Descriptions

The ATP will be placed in operational mode. The raw radar data (I/Q), and radar stimulus header data received by the ATP is processed by the ATP front end and distributed to multiple beam processors across multiple CPUs, facilitating simultaneous beam processing of the data. The system logging function will be turned “On”, the log will be reviewed, and the proper operation of the ATP and generation of products will be verified.

### 4.3.3 Data Collection and Analysis Method

The data analysis for this system will require visual inspection of the logs to verify that the processing occurs with no errors and that tracking files are created.

### 4.3.4 Results/Discussion

The radar interface data was received as expected on the fiber interface on the FPDP. System logging was turned “On” in the adaptation file, and operation of the ATP created the “/var/log/WEC/nwrt.log” which indicated proper operation of the ATP software. In addition, track files were created.

### 4.3.5 Conclusions

The radar data was correctly received, processed by the track processor, and track files were created. This also validated proper operation and interface to BCI’s radar simulator which is used to support additional off-site testing.

## 4.4 Track Processing and Displays Test

### 4.4.1 Test Objective/Criteria

This test evaluates the continuous operation of the ATP and its ability to generate XML track data files that are compatible with the NSSL WDSS-II system.

### 4.4.2 Test Descriptions

The ATP will be placed in operational mode. The ATP will be initialized and the Track Processing software operated to generate track files that will be ingested into the NSSL WDSS-II system and displayed on the NSSL display. This will prove the functionality of the ATP and its integration into the NSSL WDSS-II system.

### 4.4.3 Data Collection and Analysis Method

The operator will initiate the ATP software application and monitor the NSSL display to verify that aircraft tracking data are displayed.

### 4.4.4 Results/Discussion

The ATP system operated for a few hours and several aircraft tracks were displayed and continuously updated on NSSL's display. A picture of the test results on the WDDS-II System are shown in figure 4.4.4-1 below.

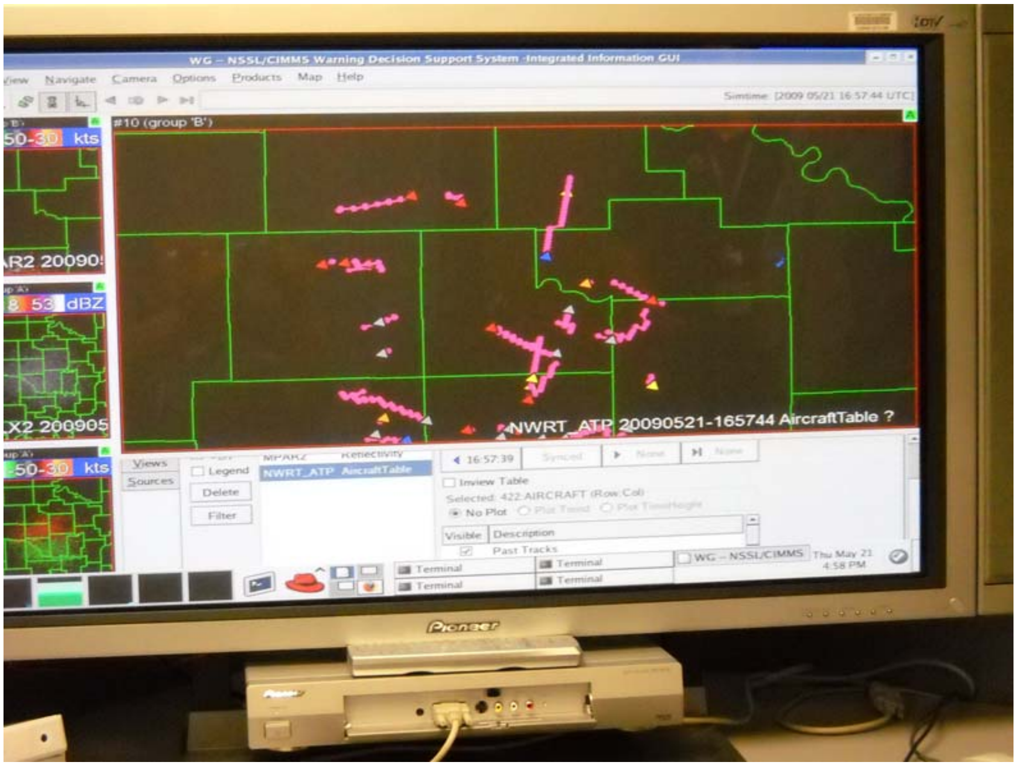


**Figure 4.4.4-1 ATP Track Data on the NSSL WDSS-II System**

### 4.4.5 Conclusions

The initial data presented on the display demonstrated that the ATP operates as expected; it is detecting tracks and maintaining track paths for multiple targets of opportunity. The track products have also been successfully integrated into NSSL's WDSS-II system.

## 4.5 Track Processing Validation with External Radar Test

### 4.5.1 Test Objective/Criteria

The purpose of this test is to compare track data from the ATP of the NWRT with data collected from the operational ASR-9 radar system at Will Rogers International airport in Oklahoma City, OK, and verify that the ASR-9 target tracks correlate with the target tracks generated by the ATP.

### 4.5.2 Test Descriptions

The ATP will be operational and the NWRT aimed at the sector (315 degrees to 45 degrees) covering the Will Rogers International Airport area and the data, both processed and raw, recorded and saved. Meanwhile, during the same time period, raw data will be recorded at the ASR-9 facility. The main difference in the data is the ASR-9 raw data are recorded in Range, Azimuth (referenced to Magnetic North), and Altitude, and the ATP is recorded in x,y,z, then converted to Latitude and Longitude.

### 4.5.3 Data Collection and Analysis Method

The ASR-9 data will be processed by a software utility for conversion to Latitude and Longitude, then a common 5-minute time frame of data from both radars plotted in geodetic latitude and longitude for comparison.

### 4.5.4 Results/Discussion

The following figure 4.5.4-1 shows a comparison of data during the same 5 minute time frame. The ASR-9 data (Beacon only) are plotted in Red and the ATP in Blue. Although there is a slight bias in the data, the plot shows a definite correlation (overlapping tracks) between the two separate radars.

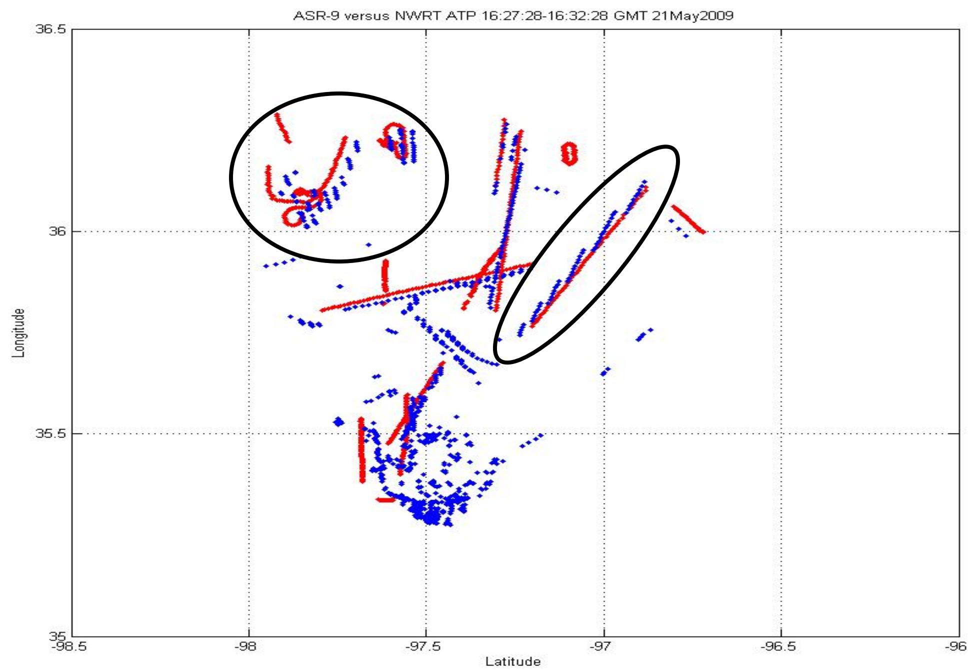


**Figure 4.5.4-1 ASR-9 vs. ATP / May 21, 2009 16:27:28 – 16:32:28 GMT**

Addressing some of the differences - the ATP also shows additional tracks in blue that were not plotted from the ASR-9. These tracks were shown on the WRTADS tool as surveillance (non Beacon) tracks detected by the ASR-9. The Track While Scan limitations are evident where the ATP has trouble tracking tight circular tracks identified in the upper left hand corner of the plot, and the "stepped" track in the upper right hand corner which shows the resolution limitation in differentiating the exact position of targets in a 1.7° beamwidth.

### 4.5.5 Conclusions

The above plot (Figure 4.5.4-1) shows the ATP is capable of target detection with tracks that correlate with the ASR-9 Radar and Beacon tracks. The ATP displays noticeable "stepped" tracks, the lesser correlated "circular" tracks, and some noticeable clutter.

Some of these issues can be addressed with additional post processing enhancements and optimizing STC, MTI, low velocity filtering, etc. The clutter can be improved by integrating NSSL's real-time clutter algorithm, developing a static clutter map for the ATP, or a combination of both. The tracking limitations can be improved with additional post processing in the tracking algorithms, and by integrating monopulse into the ATP. The FAA can work with NSSL to build and experiment with "optimized" STIMS that can be used for dual purpose tracking and weather, or interleave specialized STIMS utilizing the "Consumer Type" field to process their specific data set.

## 5. SUMMARY OF CONCLUSIONS

The ATP is operationally feasible. It demonstrates that the ATP COTS system architecture is a cost effective solution suitable for performing non-interfering tracking of commercial aircraft of opportunity around Will Rogers Airport utilizing “Track While Scan” techniques with NWRT. The test results show that it is functionally possible to do both weather processing and tracking of commercial aircraft using this specific radar system and that these data can be integrated into the WDSS-II system and simultaneously displayed on a common display at NSSL.

## 6. RECOMMENDATIONS

The ATP system, or a similar inexpensive COTS system designed and built by other agencies for their specific purpose, can be used in a development environment at NWRT to provide an experimental platform for future risk reduction of new technology and algorithms, and demonstrate the true multifunction capability of a MPAR system. Agency scientists, working with NSSL scientists, can use inexpensive COTS hardware solutions to implement, integrate, and test a variety of multifunctional capabilities of the NWRT while providing a solution for a specific requirement of their agency.

Addressing the ATP system specifically, the exhibited limitations can be investigated, and solutions provided and implemented, that will improve performance of the ATP and mitigate risk for future multifunction weather and tracking MPAR solutions. For example, the clutter can be reduced by integrating NSSL’s real-time clutter algorithm, developing a static clutter map for the ATP, or a combination of both. The tracking limitations can be improved with additional refinement of tracking algorithms, and certainly by integrating monopulse into the ATP. The FAA can work with NSSL to build and experiment with “optimized” STIMS that can be used for dual purpose tracking and weather, or interleave specialized STIMS utilizing the “Consumer Type” field to process their specific data set.

Again, the ATP COTS system architecture demonstrates an inexpensive hardware signal processing solution that performs non-interfering reception of radar data that is processed for aircraft tracking. The test results show that it is functionally possible to run multiple non-interfering signal processors on the NWRT and produce tracking data that is easily integrated into the WDSS-II system and simultaneously displayed on a common display at NSSL.

It’s likely that many government agencies can take an approach similar to the FAA. They can build an inexpensive COTS hardware system, integrate it into the NWRT then test the feasibility of their solution with phased array radar technology. The relatively inexpensive COTS technology as well as the non-interfering accessibility to the NWRT at NSSL promotes use of the NWRT as a national test bed while demonstrating the capability of MPAR technology.

# 7. GLOSSARY AND ACRONYMS

| | |
|---|---|
| ASR-9 | Airport Surveillance Radar-9 |
| ATP | Adjunct Track Processor |
| BCI | Basic Commerce and Industries, Inc. |
| CHI | Computer-Human Interface |
| COTS | Commercial of the Shelf |
| DR | Digital Receiver |
| EP | Environmental Processor |
| FAA | Federal Aviation Administration |
| FPDP | Front Panel Data Port |
| GUI | Graphical User Interface |
| I/Q | In-phase and Quadrature data (raw radar data) |
| MPAR | Multifunction Phased Array Radar |
| NSSL | National Severe Storms Laboratory |
| NWRT | National Weather Radar Testbed |
| OS | Operating System |
| PAR | Phased Array Radar |
| WRTADS | Windows Real Time Aircraft Display Software |
| RTC | Real Time Controller |
| STIM | Radar Stimulus Message |
| TSD | Track Processor Situation Display |
| WDSS-II | Warning Decision Support System |
| WJHTC | William J. Hughes Technical Center |