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Avian Radar Maintenance: Magnetron Replacement Requirements

November 2013

DOT/FAA/TC-TN13/47

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16. Abstract

Magnetrons are a critical component of current avian radar technologies, providing avian radar systems with the energy that is transmitted and received to identify targets. The current avian radar systems used in an avian radar performance assessment uses X-band marine radars that are based on magnetron technology. Manufacturers recommend regular replacement of magnetrons to maintain radar detection effectiveness. The University of Illinois Center of Excellence for Airport Technology (CEAT) examined the issue of operational effectiveness for magnetrons with short and long operational histories. CEAT found that magnetrons with long operational histories performed at a level consistent with new magnetrons. CEAT recommends that magnetron replacement be based on performance criteria rather than on a fixed schedule or replacement period. Replacement should be made when a magnetron fails to produce consistent detection results when evaluated as part of a regularly scheduled radar health assessment program.

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LIST OF ACRONYMS

AR1-M	Accipiter Radar Single Unit at a midfield location
AR2-1	Accipiter Radar Dual Unit, Radar 1
AR2-2	Accipiter Radar Dual Unit, Radar 2
ARTI	Accipiter Radar Technologies, Inc.
CEAT	University of Illinois Center of Excellence for Airport Technology
DRP	Digital radar processor
FAA	Federal Aviation Administration
PPI	Plan Position Indicator
RCS	Radar cross section
SEA	Seattle Tacoma International Airport

EXECUTIVE SUMMARY

In a previous study, the University of Illinois Center of Excellence for Airport Technology (CEAT) evaluated the operational life of magnetrons using maintenance records for operational radars. The study determined that, when used in avian radar systems, a replacement life of 12,000 to 15,000 transmitting hours (or 18 to 24 months) of continuous operation was appropriate for maintenance planning. This was far above typical manufacturer recommendations for magnetron replacement, which is between 2000 and 4000 transmitting hours. To further evaluate the need for magnetron replacement, the current study was conducted to determine if detection performance was degraded in magnetrons with long operational histories. For the avian radar systems installed at Seattle Tacoma International Airport, magnetrons with a service life of more than 11,000 transmitting hours were replaced with new magnetrons. Assessments revealed no significant differences in the performance parameters between the old and new magnetrons. This finding supports the use of magnetron-based radars for periods beyond the manufacturer's recommendation for replacement and the use of archived radar data with some confidence that the data are not biased by the age of the magnetron. The data suggest an alternate to service-time-related magnetron replacement strategies in radar maintenance programs. CEAT recommends replacing magnetrons when they fail or when a radar health assessment indicates reduced performance.

INTRODUCTION

In 2006, the University of Illinois Center of Excellence for Airport Technology (CEAT) was tasked to develop a performance assessment program for commercially available avian radar systems by the Federal Aviation Administration (FAA) Airport Safety Research Program at the William J. Hughes Technical Center. The deployment of avian radar systems began in 2007, with installations at Seattle-Tacoma International Airport (SEA), Chicago O'Hare International Airport, New York John F. Kennedy International Airport, Dallas/Fort Worth International Airport, and the Naval Air Station Whidbey Island in Oak Harbor, WA.

As part of the overall performance assessment, CEAT has maintained records on the maintenance performed on avian radar systems, which includes a radar unit and a radar digital processor (DRP). In total, CEAT has operated 19 radar systems for time periods ranging from several months to more than 4 years. Fourteen of these radar systems have been deployed at civil airports to assess their contribution to wildlife management and overall safety of operations at airports. The avian radar systems deployed by CEAT are commercial off-the-shelf marine X-band radars that use magnetrons to generate the necessary microwave radiation for target detection and tracking. Magnetrons use strong magnetic fields and high voltages to excite and release electrons within the device, which produces energy. That energy is then emitted as microwave radiation, which is transmitted via the radar scanner antenna. An inevitable result of operating magnetrons is a loss of cathode material and a depletion of available electrons from the cathode section of the magnetron over time. When the available electrons decrease, so does the transmitted power of the system, which produces degradation in detection performance. To ensure that sufficient performance capability exists in this critical safety technology, marine radar manufacturers recommend replacing magnetrons at intervals ranging from 2000 to 6000 transmitting hours. Although this replacement interval may be appropriate for shipboard operation where radar transmissions are not continuous, the requirement may not be realistic in an avian radar system that operates continuously. Using maintenance records for operational radars, CEAT evaluated the operational life of magnetrons and determined that replacement was not required at the manufacturer's recommendations, but rather after 12,000 to 15,000 transmitting hours (or 18 to 24 months) of continuous operation.

Further analysis considered that typical avian radar systems operate 24 hours a day, 7 days a week, and exceed 9000 total transmitting hours annually. A replacement every 4000 hours (i.e., 166 days of continuous operation) would require a minimum replacement of two magnetrons per year per radar unit. The average cost of a magnetron replacement, including associated labor, is approximately $1500, assuming the repair technician is located within an hour of the radar site. Clearly, if magnetron performance is acceptable with long operational history, then maintenance costs can be reduced.

To further evaluate the need for magnetron replacement, a study was conducted on the SEA avian radar systems to determine if the magnetrons' detection performance was degraded with long operational histories. Two CEAT-designated avian radar systems were used in this study: an Accipiter Radar Single Radar Unit at a midfield location (AR1-M) and an Accipiter Radar Dual Unit with collocated radars on the roof of the terminal building (AR2-1 and AR2-2). These

units were functioning with magnetrons that had operated between 11,000 and 15,000 transmitting hours. The AR2-1 and AR2-2 units' performance parameters were assessed, the magnetrons were replaced, and the same performance parameters were reassessed. This report provides a summary of CEAT's findings related to this maintenance exercise with the X-band avian radars used in the FAA-supported performance assessments. The objective of this study was to contribute to the development of maintenance requirements for avian radar systems that could be deployed at civil airports, specifically to support recommendations on when to replace magnetrons as part of preventative maintenance.

METHODS

CEAT personnel reviewed the operational and maintenance logs from three radar units deployed in avian radar systems at SEA. Magnetron transmission time was determined from the radar units' operations meters, which indicate the magnetron's hours of operation. The avian radar systems were supplied by Accipiter Radar Technologies, Inc. (ARTI), using a Furuno FR8252 X-band marine radar. With operational histories of 11,000 to 15,000 transmitting hours, a study was planned to evaluate the operational effectiveness of the radar units. A radar health assessment was performed on the operating radar units, and then the magnetrons were replaced. A radar health assessment was performed again, and the results were compared to determine the influence of magnetron operational history on radar performance.

The methods and procedures for the radar health assessment were developed by ARTI and CEAT personnel. CEAT's radar health assessment was initially performed, recording all data and capturing screen images. This information was then provided to ARTI for further processing. The CEAT radar health assessment procedures were as follows:

1. Capture a radar display image.

2. Capture a DRP-generated plan position indicator (PPI) image.

3. Capture a DRP Status Tab image.

4. Record 1 minute of raw data.

5. Compare the captured radar display image with the DRP image; confirm the radar returns are in expected locations with similar intensities.

6. Observe live feeds; confirm operation.

7. Examine automatically generated track history images; confirm the histories are sequential and complete.

8. Play back a sample of recorded plots/tracks from the previous month's dataset to observe tracks and track dynamics; ensure the displayed tracks match known vehicle locations and are consistent with expected speeds.

9. Play back raw data; confirm the radar returns match the environmental features on the underlying radar map.

For the study, CEAT personnel collected their health assessment information and provided it to ARTI radar engineers who conducted their own review and analysis. This analysis included replaying raw data to assess each radar's calibration and tuning results as a basis for comparison with previous radar health assessment studies.

The ARTI review was based on (1) calibration procedures that ARTI radar engineers developed for initial deployment of radars and (2) the company's periodic quality assurance checks of operational avian radar systems. The ARTI radar calibration procedure included the following steps:

1. Review PPI images captured from the ARTI DRP display to provide a basis for comparing these two displays. In this analysis, emphasis was placed on fixed clutter conditions.

2. Review the Rutter digitizing board A-scope data display to assess changes in noise level and bias, providing information on analog-to-digital signal mapping levels.

3. Review recorded raw radar data that were reprocessed by DRP software. Screen captures of the scan-converted PPI data were made to assess changes in the transmit/receive levels or indications of change in the radar hardware settings.

4. Determine radar cross section (RCS) values for known targets from recorded data, plotting RCS-versus-range.

The ARTI avian radar systems deployed at SEA used a Furuno FR8252 X-band marine radar that was modified to allow remote control through ARTI hardware and to feed analog radar data to the ARTI DRP. ARTI engineers provided the capability to record an unmodified Furuno data stream, termed "raw data." In the DRP, the analog data from the Furuno data stream was converted to digital data using a Rutter digitizing system that supports analysis of the radar data stream, termed "A-scope analysis." With digitization, ARTI software performed additional processing. In the DRP, ARTI engineers provided multiple options for radar data analysis, including

- a digital PPI image generated from digitized, but unprocessed, data so the image is similar to a native radar console PPI.

- data on radar input to the DRP (A-scope data).

- a DRP-generated PPI based on scan-converted digital data.

- raw data recording capability that supports replaying recorded data using full DRP capabilities.

For this study, CEAT and ARTI personnel took advantage of the long operational history of the SEA radars. CEAT personnel performed a radar health assessment on SEA's three radar units and supplemented the assessment with extended raw radar data recordings. The radar health assessment results and raw data were shared with ARTI technicians, who completed a full calibration and tuning exercise for each radar. After the old magnetrons were replaced with new ones, a similar process was followed, which provided a dataset on the three radars before and after magnetron replacement.

RESULTS SUMMARY AND DISCUSSION

The magnetrons in the SEA radar units had slightly different operational histories. At replacement time, the magnetron in the AR1-M had operated for 15,517 transmitting hours, the AR2-1 operated for 11,888 transmitting hours, and the AR2-2 operated for 12,869 transmitting hours. This analysis compared performance from the AR2-1 and the AR1-M before and after magnetron replacement. Due to technical issues not associated with the magnetron, the AR2-2 radar was not operating immediately before this study, and data were not collected for the AR2-2 before replacement, so no comparisons could be made. Because CEAT's radar health assessment is generally qualitative, the primary resource for comparison data was the ARTI recalibration and tuning analysis conducted on the AR2-1 and the AR1-M.

THE AR2-1.

ARTI engineers completed several analyses, each comparing aspects of the radars before and after magnetron replacement. The first analysis compared the PPI images from before and after magnetron replacement. The PPI images provided a sense of radar operation unmodified by radar settings or DRP processing. These PPI images included all radar reflections and, thus, provided impressions (blips) of fixed targets as well as moving targets. When comparing radar performance from before and after magnetron replacement, the detailed ARTI analysis focused on fixed-target detections. In figure 1, AR2-1 example before and after images show the radar image consistency. Although a slight change in the manual display gain setting was required for the new magnetron, the surface clutter returns were approximately the same size, position, and intensity.

A second analysis examined the radar data stream using the digitizer's diagnostic application, which provides a live A-scope display of radar returns associated with given digitizing settings for the radar. The settings included trigger delay, trigger threshold, video gain, and video offset. Because the antenna was rotating, the A-scope display details were constantly changing; but, it was still possible to immediately determine if the settings had been changed and to qualitatively assess whether the signal levels had shifted due to hardware changes. Figure 2 shows the before and after diagnostic displays. The differences in the A-scope trace details are associated with the normal variation of antenna rotation. The consistency in the nominal magnitudes of the strong clutter returns and the noise floor indicates that, with the same settings before and after magnetron replacement, the radar showed similar performance results.

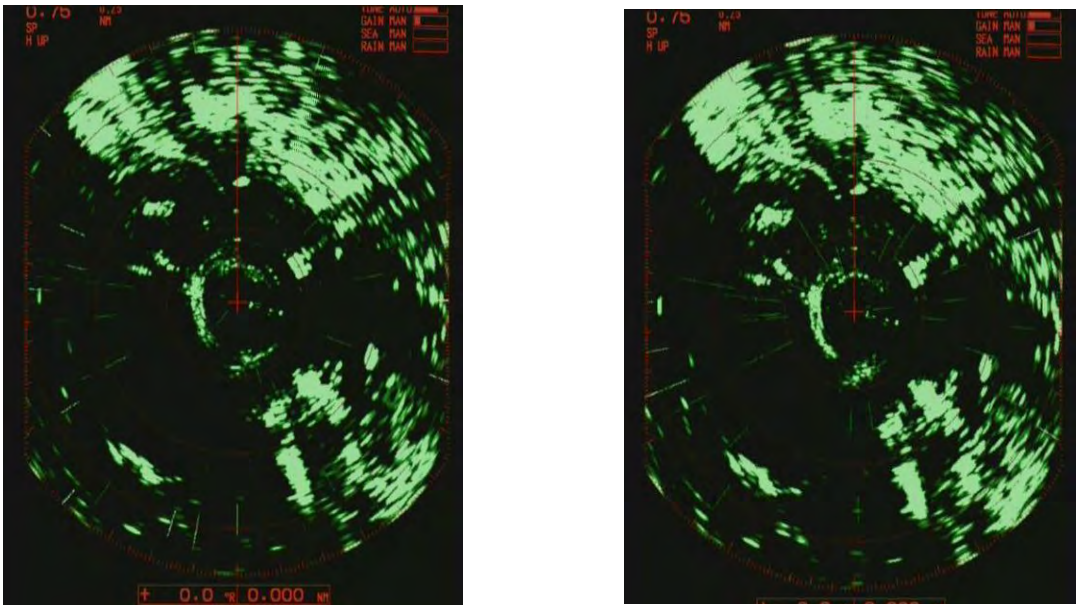

Figure 1. Radar Displays (PPI Images) From the AR2-1 Shows Consistency Before (left) and After (right) Magnetron Replacement

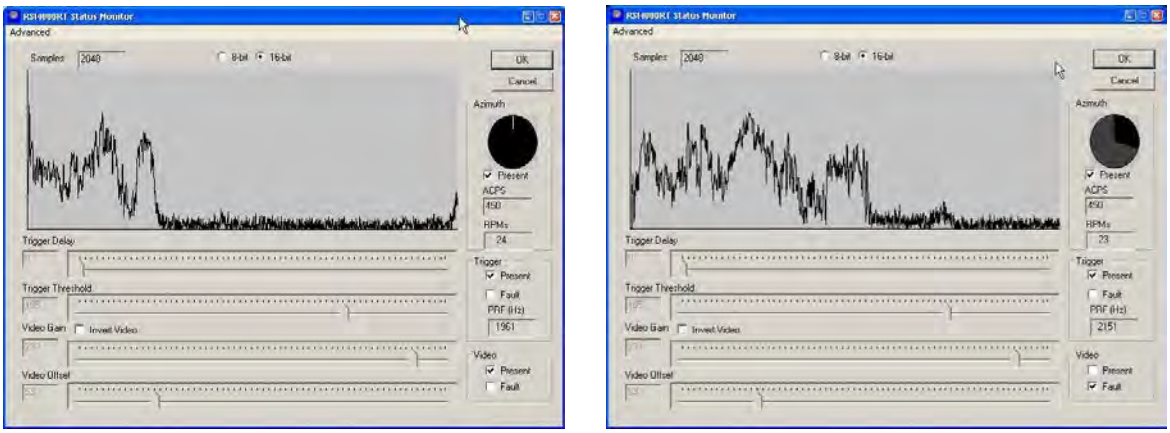

Figure 2. The A-Scope Display From the AR2-1 Before (left) and After (right) Magnetron Replacement

A DRP-processed, scan-converted image can be generated, which is similar in appearance to the PPI images generated by a marine radar unit (such as the AR2-1 shown in figure 1). However, the digital-processing effect from the DRP provides a basis for more complete image control. Raw data recordings were used as inputs for DRP processing. In this analysis, screen captures of the scan-converted PPI data were taken, and no changes were observed in transmit/receive levels or any other radar aspects (figure 3).

For another analysis procedure, the DRP processed the recorded raw data using a set of options for detecting fixed (ground clutter) targets. In this analysis, it was possible to estimate an RCS for some persistent fixed targets. These targets are circled in the “before” image in figure 4.

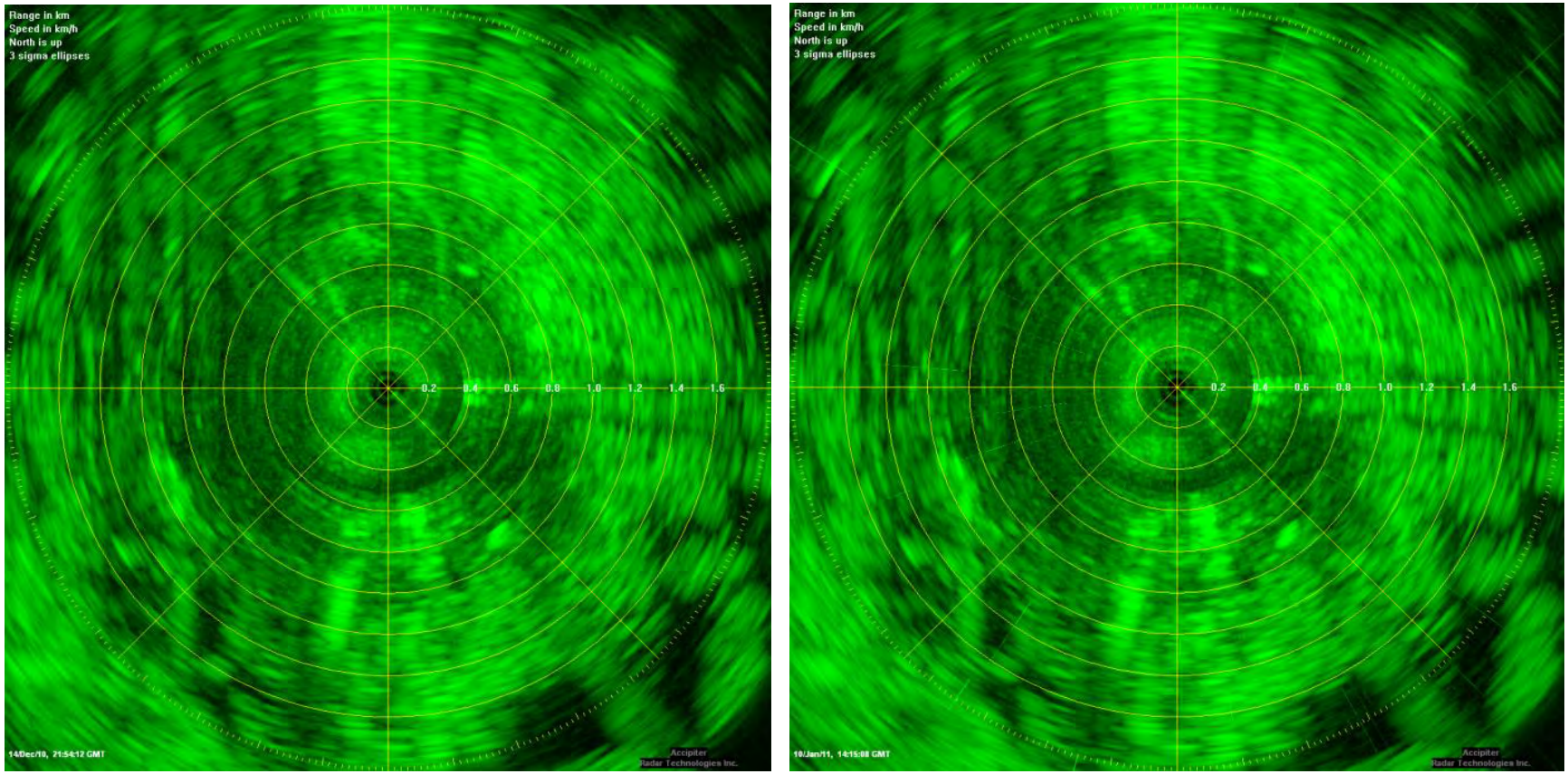

Figure 3. Scan-Converted PPI of Raw Radar Video From the AR2-1 Before (left) and After (right) Magnetron Replacement

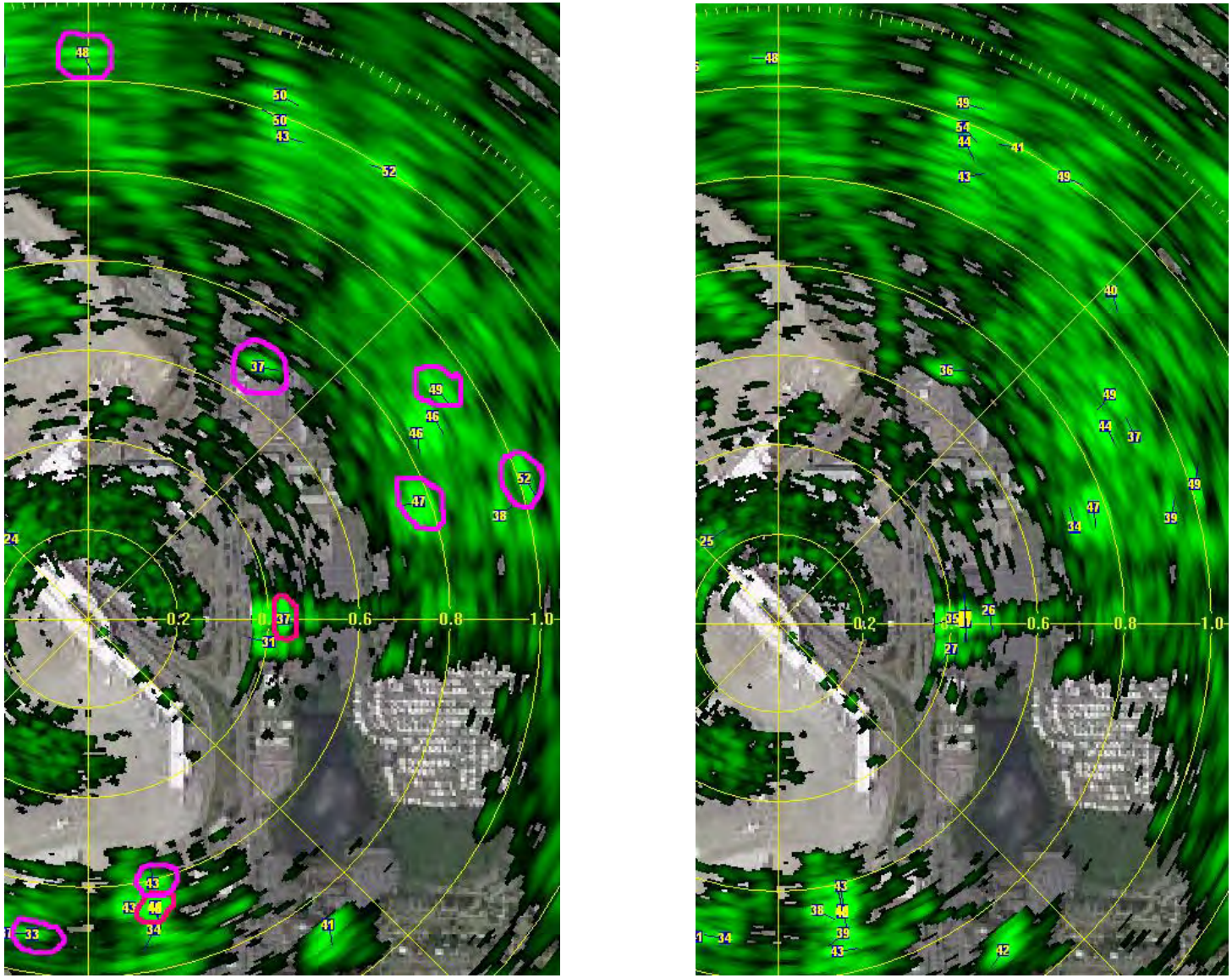

Figure 4. Fixed Targets Tracked Before (left) and After (right) Magnetron Replacement in the AR2-1

The RCS values for the circled fixed targets (figure 4) were consistent before and after magnetron replacement. The average difference in RCS value was -0.33 dBsm/target, as shown in table 1.

Table 1. The RCS Values and Differences for Circled Fixed Targets in the AR2-1

RCS Value Before Magnetron Replacement	RCS Value After Magnetron Replacement	Difference
48	48	0
37	36	-1
49	49	0
52	49	-3
47	47	0
37	37	0
43	43	0
48	48	0
33	34	+1
Average Difference		-0.33

An analysis of RCS values from moving target detections was conducted using 12 hours of data from the AR2-1 and the AR1-M radars (6 hours before and 6 hours after the magnetron replacement). The ARTI DRP software detects and tracks targets as they move. The target tracks are shown on the DRP display as well as recorded to disk. Because target tracking occurs continuously as the radar data are streamed to the DRP, each track consists of a time-evolving sequence of position, velocity, and RCS estimates (updates), in which each track update provides a snapshot of the radar-derived knowledge about the tracked target at that time. The track data were analyzed, and the RCS-versus-range was plotted for the first 32,000 track updates from each 6-hour dataset. In figure 5, track updates from before the magnetron replacement are shown in blue, and track updates from after the magnetron replacement are shown in red. Although the basic data are not exactly the same (e.g., different targets and target densities and movements were present before and after magnetron replacement), the curves from before and after appear to have the same general shape, as indicated by the logarithmic trend lines in the scatterplot. The results for the AR2-1 are shown in figure 5.

ARTI engineers conducted a final test of radar operation using a recurring, scheduled flight to SEA as a basis for comparing radar performance. This analytical approach takes advantage of commercial airport schedules in which flight schedules are similar for months or longer. Using a single flight, in this case an Airbus A320 aircraft (flight number DAL 1807), ARTI engineers examined the radar records from before and after magnetron replacement to determine if there was a difference in RCS. The A320 was retracked from recorded radar plot data before and after magnetron replacement. For the AR2-1, similar RCS values were observed in both tracks, as shown in the RCS-versus-range plot in figure 6.

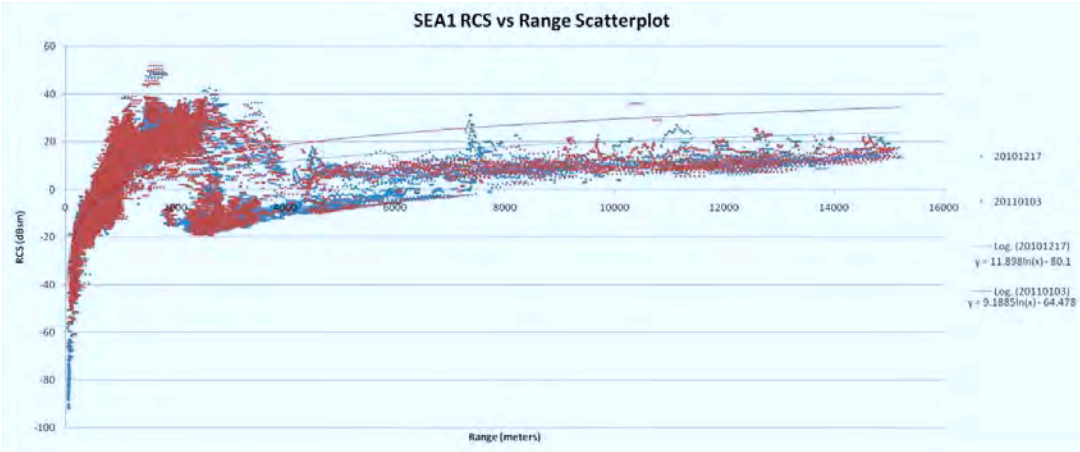

Figure 5. Logarithmic Trend Lines Before and After Magnetron Replacement in the AR2-1

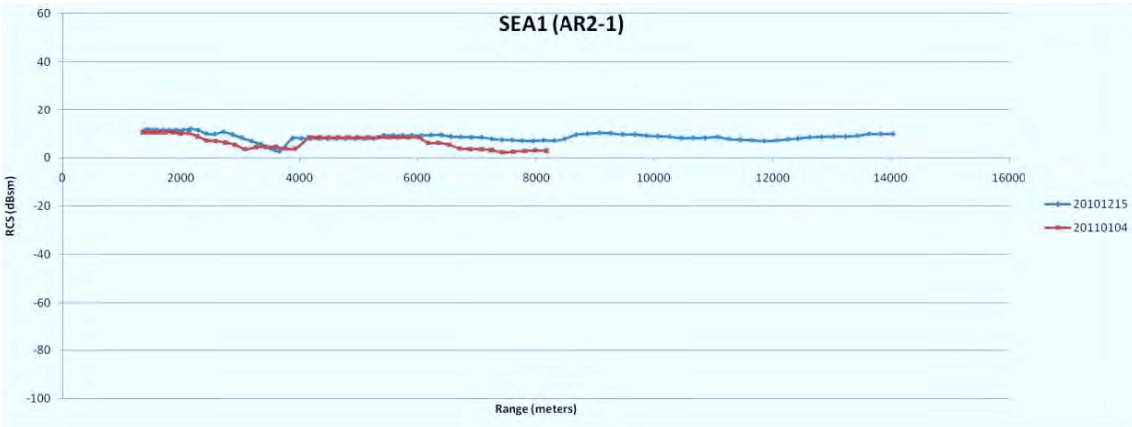

Figure 6. The RCS vs Range Plot From the AR2-1 for a Single SEA Aircraft Flight

<u>SUMMARY FOR THE AR2-1</u>. The comparative analysis of the AR2-1 showed that the baseline operational state of the magnetron with over 11,000 transmitting hours suggested little change on overall performance.

<u>THE AR1-M</u>.

ARTI engineers conducted the same analyses of the AR1-M that showed similar results to the analyses conducted on the AR2-1.

In figure 7, AR1-M example radar images show consistency before and after magnetron replacement. Before the magnetron replacement, the radar was set to trails mode, resulting in the persistent blue image in the PPI. Before and after comparisons indicate that the surface clutter returns were approximately the same size, position, and intensity.

The A-scope display from the Rutter digitizing system showed consistent results before and after magnetron replacement, see figure 8.

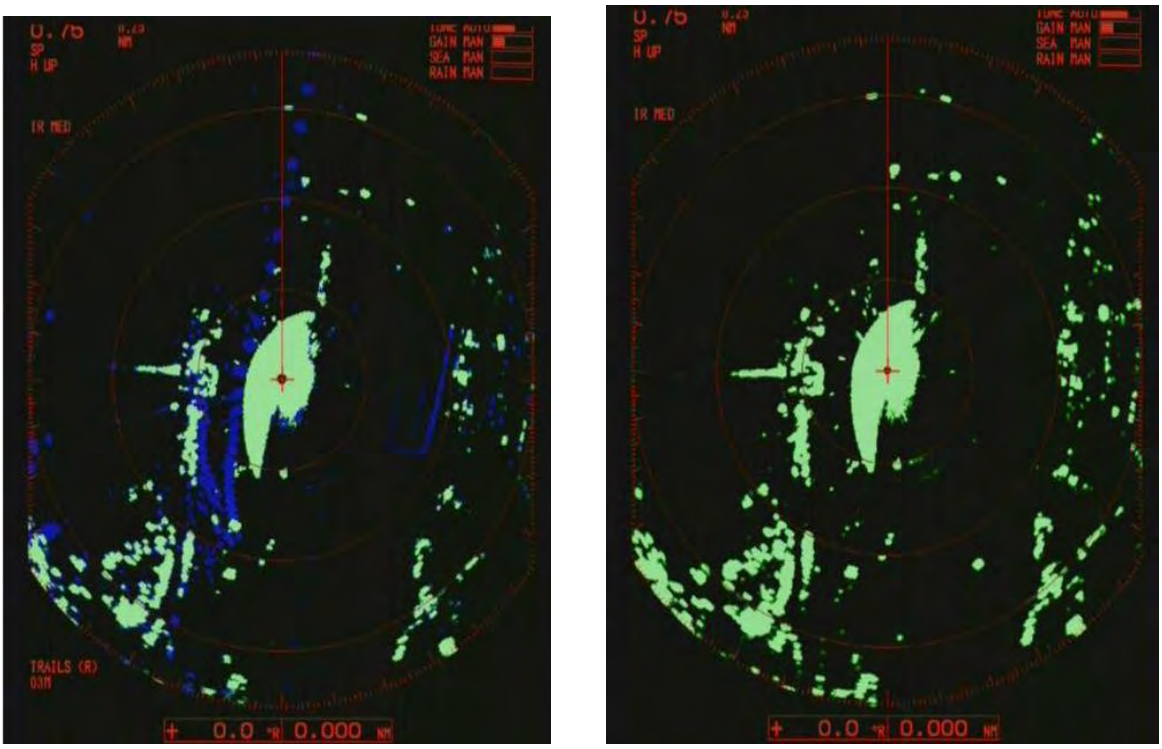

Figure 7. Radar Displays (PPI Images) From the AR1-M Shows Consistency Before (left) and After (right) Magnetron Replacement

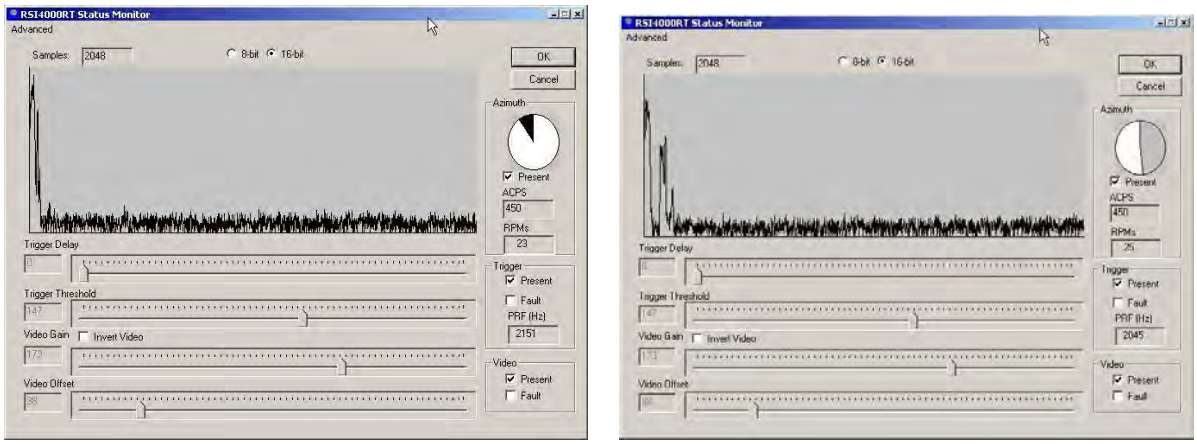

Figure 8. The A-Scope Display From the AR1-M Before (left) and After (right) Magnetron Replacement

From the comparison of PPI images from the scan-converted digitized data (DRP PPI), figure 9 shows consistent transmit/receive levels before and after magnetron replacement.

A comparison was performed of fixed-target RCS values before and after magnetron replacement. The DRP processed the recorded raw data using a set of options for detecting fixed targets (ground clutter). This data made it possible to estimate an RCS for some persistent fixed targets. These targets are circled in the “before” image in figure 10.

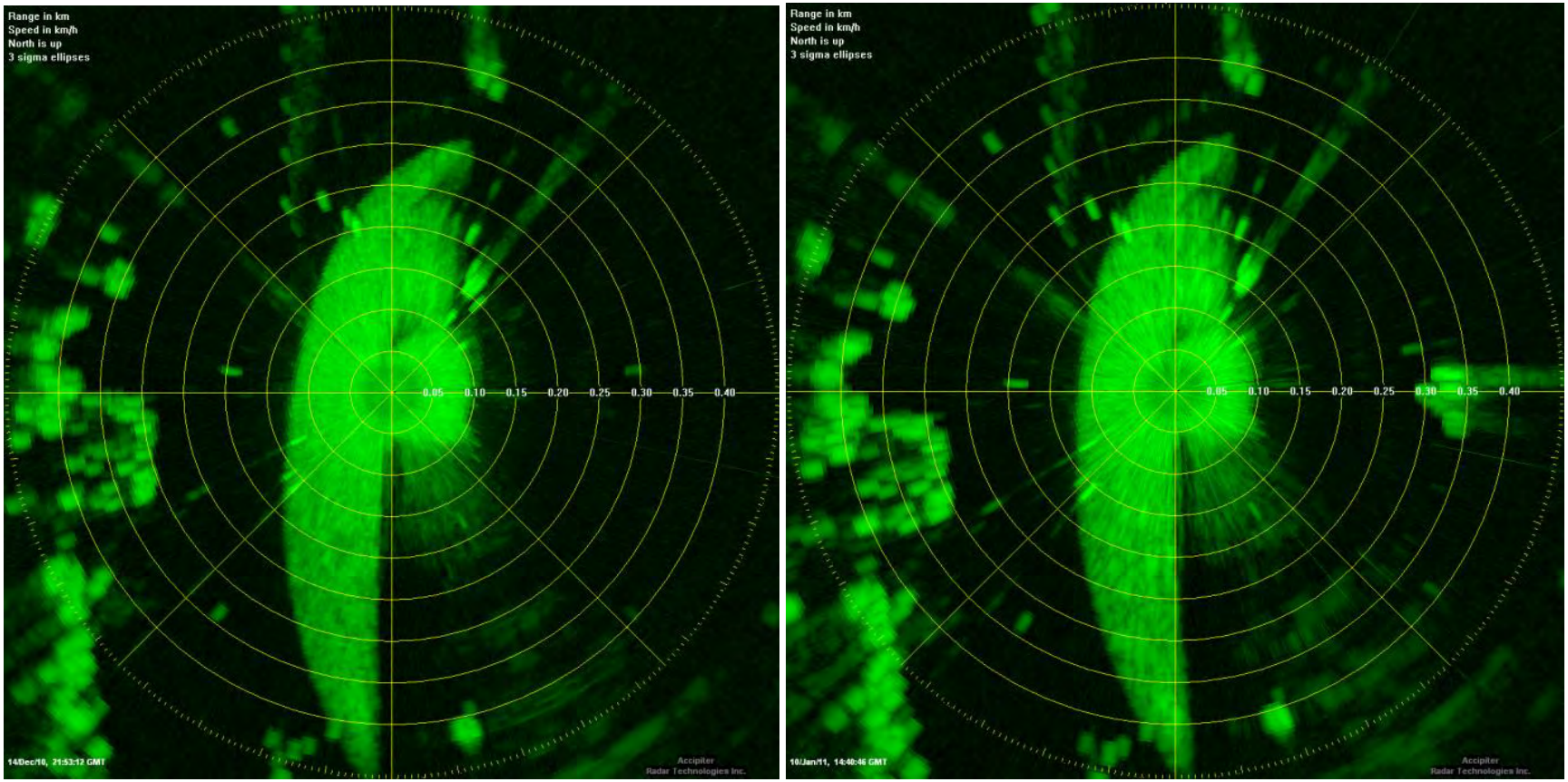

Figure 9. Scan-Converted PPI of Raw Radar Video From the AR1-M Before (left) and After (right) Magnetron Replacement

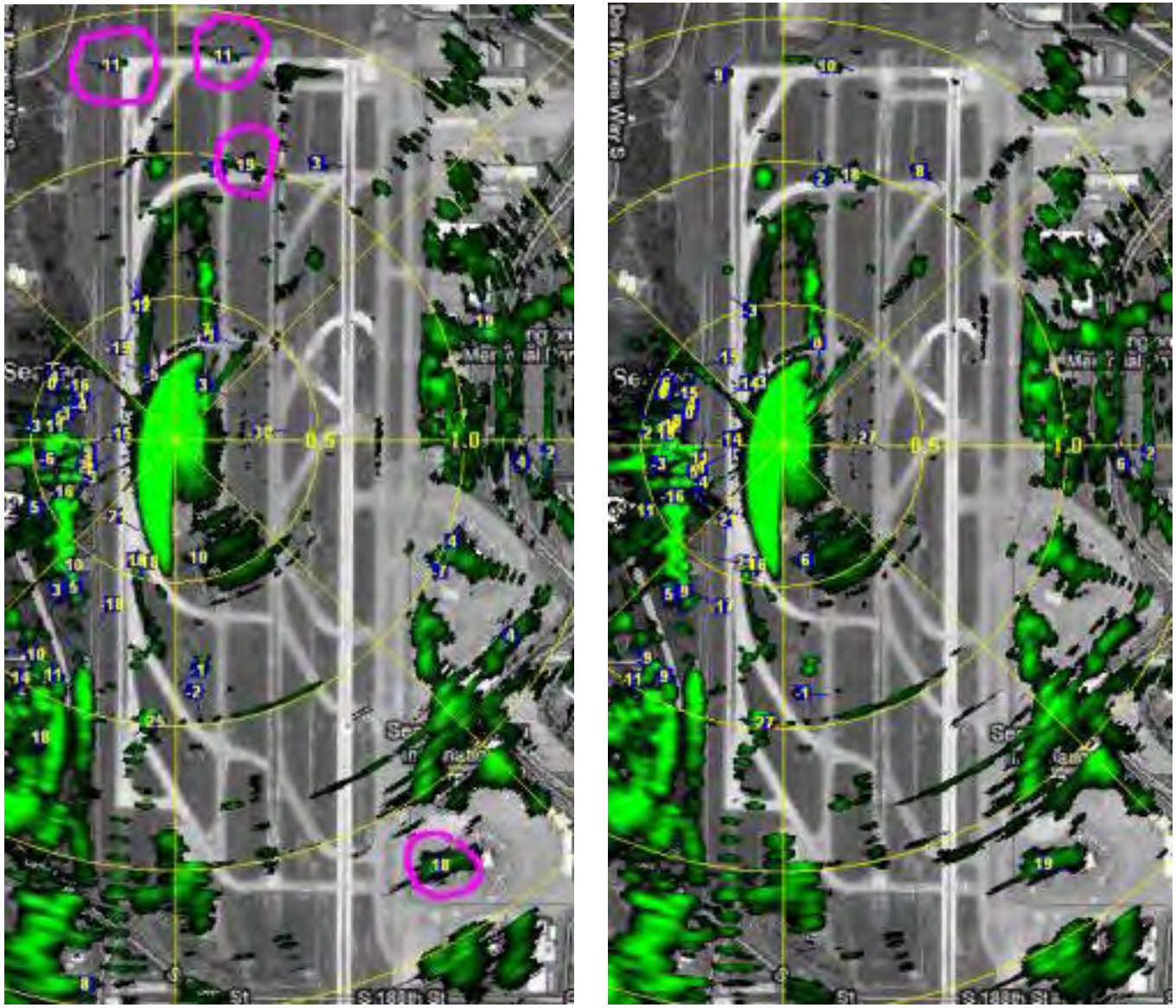

Figure 10. Fixed Targets Tracked Before (left) and After (right) Magnetron Replacement in the AR1-M

Reprocessing of raw data and comparison of the same fixed targets (figure 10) were consistent before and after magnetron replacement in the AR1-M. The average difference before and after magnetron replacement was less than -1 dBsm per target, as shown in table 2.

Table 2. The RCS Values and Differences for Circled Fixed Targets in the AR1-M

RCS Value Before Magnetron Replacement	RCS Value After Magnetron Replacement	Difference
11	10	-1
11	9	-2
19	18	-1
18	19	1
Average Difference		-0.75

The track updates from before magnetron replacement in the AR1-M were plotted, with blue indicating before replacement, and red indicating after replacement, see figure 11. As in the AR2-1 analysis, the basic data was not exactly the same, e.g., different targets, target densities, and movements were present before and after magnetron replacement. However, the curves from the before and after magnetron replacement appear to have the same general shape, as indicated by the logarithmic trend lines in the scatterplot in figure 11.

As in the AR2-1analysis, to determine if there was a difference in RCS, ARTI used flight DAL 1807 and examined radar records from the AR1-M before and after magnetron replacement. The flight was retracked from recorded radar plot data before and after the magnetron replacement. Similar RCS values were observed in both tracks, as illustrated in the RCS-versus-range plot shown in figure 12.

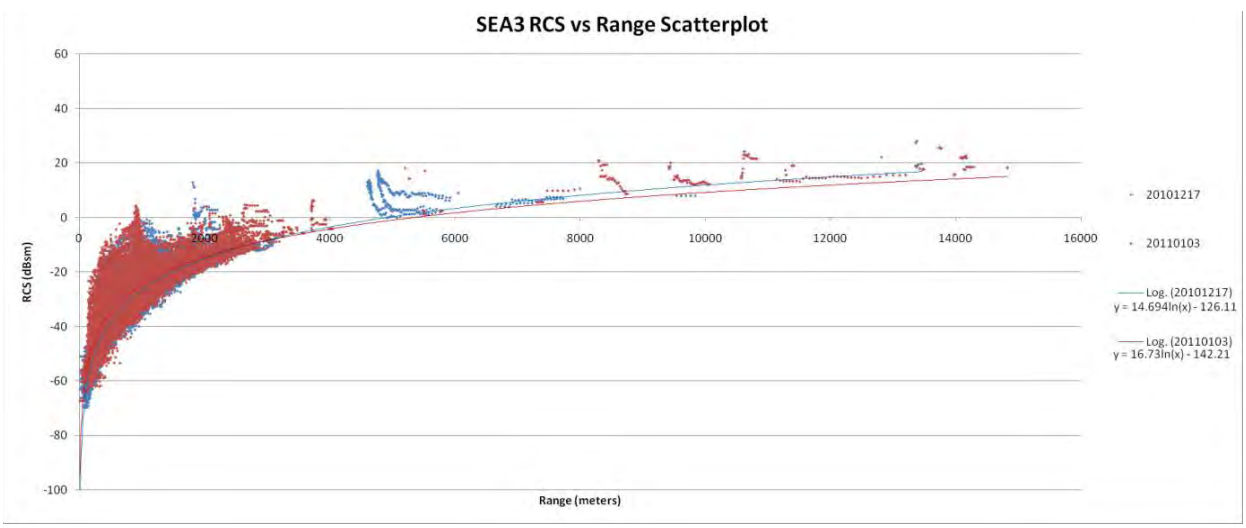

Figure 11. Logarithmic Trend Lines Before and After Magnetron Replacement in the AR1-M

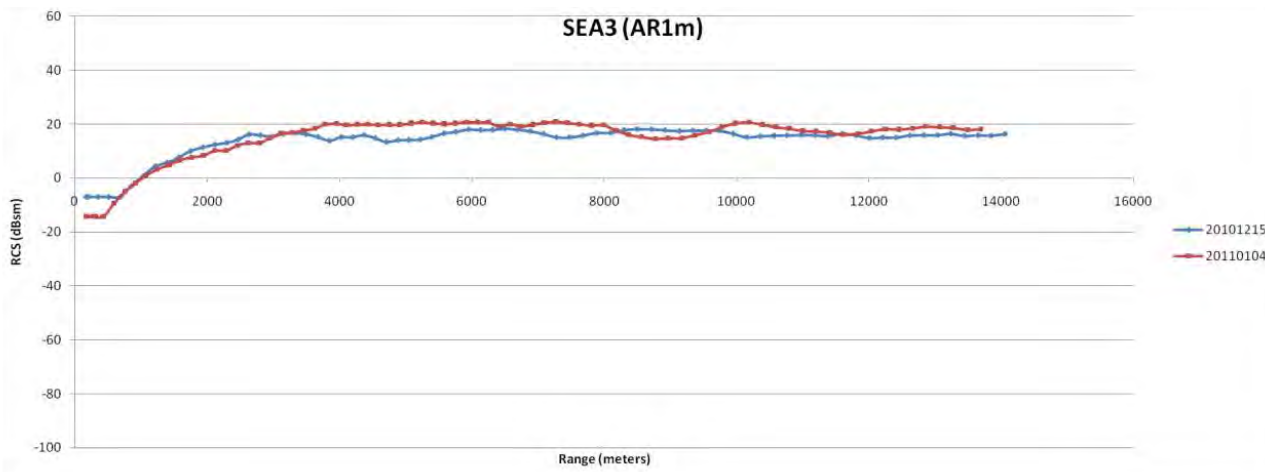

Figure 12. The RCS vs Range Plot From the AR1-M for a Single SEA Aircraft Flight

<u>SUMMARY FOR THE AR1-M</u>. The comparative analysis of the AR1-M showed that the baseline operational state of a magnetron with over 15,500 operational hours suggested little change on overall performance.

FINDINGS AND CONCLUSIONS

The results from the assessment of radar performance before and after magnetron replacement indicate that, in the ARTI avian radar system, there was little degradation in overall radar performance as the magnetrons aged.

This is an important finding that verifies that long-term, continuous use of avian radars can provide consistent performance over the entire life of the magnetron. Based on this result, avian radar users can be assured that the detection performance capabilities of an avian radar unit do not change with magnetron age and will provide a consistent level of detection over time. Irrespective of the magnetron's operational life in the radar unit, archival radar data is still comparable between old and new and magnetrons. These results also suggest that alternate approaches to magnetron replacement are available to the avian radar user. If old and new magnetrons exhibit similar performances, then a specific schedule for magnetron replacement is unnecessary. Based on out-of-service criteria, it is possible to allow a magnetron to fail with some assurance that detection capabilities are acceptable up to the time of failure. An alternate approach to scheduled replacement would be performance-based replacement. When used regularly, the health assessment procedures developed by ARTI and CEAT can provide a basis for magnetron replacement based on performance rather than magnetron life.

This study was performed to assess the detection performance of magnetrons with a long service life. This study revealed that there were no significant differences in the performance parameters assessed between old and new magnetrons. Avian radar systems provided similar performance between magnetrons operating for more than 11,000 transmitting hours and new magnetrons. This finding supports the use of archived radar data with some confidence that the data is not biased by the age of the magnetron. The data also suggest alternate magnetron replacement strategies in radar maintenance programs. Magnetrons should be replaced when they fail or when a health assessment indicates reduced performance.