DOT/FAA/NR-92/4

Project Report
ATC-188

The Terminal Doppler Weather Radar (TDWR) Moving Target Simulator (MTS) at Orlando, Florida

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20 August 1992

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Prepared for the Federal Aviation Administration,
Washington, D.C. 20591

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TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. ATC-188	2. Government Accession No. DOT/FAA/NR-92/4	3. Recipient's Catalog No.
4. Title and Subtitle The Terminal Doppler Weather Radar (TDWR) Moving Target Simulator (MTS) at Orlando, Florida		5. Report Date 20 August 1992
		6. Performing Organization Code
7. Author(s) William H. Drury, John M. Frankovich		8. Performing Organization Report No. ATC-188
9. Performing Organization Name and Address Lincoln Laboratory, MIT P.O. Box 73 Lexington, MA 02173-9108		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DTFA-01-89-Z-02033
12. Sponsoring Agency Name and Address Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington, DC 20591		13. Type of Report and Period Covered Project Report
		14. Sponsoring Agency Code

15. Supplementary Notes

This report is based on studies performed at Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology under Air Force Contract F19628-90-C-0002.

16. Abstract

Monitoring the performance of Doppler weather radars presents special problems since target returns cannot be verified by reference to other systems (e.g., as ASR-9 aircraft reports can be compared with beacon replies). The Terminal Doppler Weather Radar (TDWR) system includes a Moving Target Simulator (MTS) which provides a point target equivalent to a 50 dBZ reflectivity weather return with an apparent radial velocity of 5 m/s.

This report describes the installation and initial operational results for a prototype MTS using the TDWR testbed radar in Orlando, FL. Procedures were developed for improved aiming of the MTS, using azimuth and elevation adjustments, which are recommended to be incorporated in the production MTS installation procedure. Initial data analyses indicate that the MTS returns from a typical radio tower would be useful for integrity monitoring in fair weather using typical TDWR filters. The use of the MTS when high-reflectivity weather or anomalous propagation (AP) is present needs further study.

17. Key Words Moving Target Simulators (MTS), Lucas Aerospace, Raytheon, TDWR, Bell South, Orlando	18. Distribution Statement This document is available to the public through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	35	

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

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ACKNOWLEDGMENTS

The authors would like to express appreciation to Lucas Aerospace and Raytheon for their help in obtaining the prototype unit of the MTS for use by Lincoln Laboratory. The authors also would like to thank Skip Copeland for his work with Bell South Mobility to obtain a lease for space on their tower in Taft, Florida and a subcontract for the MTS installation. Maurice Couture developed the modifications for the addition of an optical telescope and for adjusting the elevation of the MTS on the tower. Nat Fischer, Mark Isaminger, Ben Stevens, Sen Lee, and Leonie Henshaw provided valuable help in collecting and analyzing the MTS data.

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1. THE TDWR MOVING TARGET SIMULATOR AT ORLANDO

A. Introduction

The Moving Target Simulator (MTS) is a test target mounted on a local tower such that the Terminal Doppler Weather Radar (TDWR) scans past it at least once per volume scan (five minutes). It is positioned from 2 to 20 kilometers from the radar, and preferably in the hazardous weather coverage sector.

The MTS (figure 1) consists of a 36-inch diameter antenna with a small box containing microwave and electronic circuitry mounted behind it. The antenna beamwidth of the MTS antenna is three degrees. The only active (power consuming) component in the box is a digital phase shifter used for frequency translation. The transmitted C-band pulse from the TDWR is received, translated upwards in frequency by 187 Hz, attenuated to a predetermined threshold, and then re-radiated back to the radar. The attenuator is normally adjusted to provide a return signal equivalent to a 50 dBZ reflectivity at the TDWR site. The frequency translation causes the return at the TDWR to appear as a target moving away from the radar with a velocity of 5 meters per second (m/s).

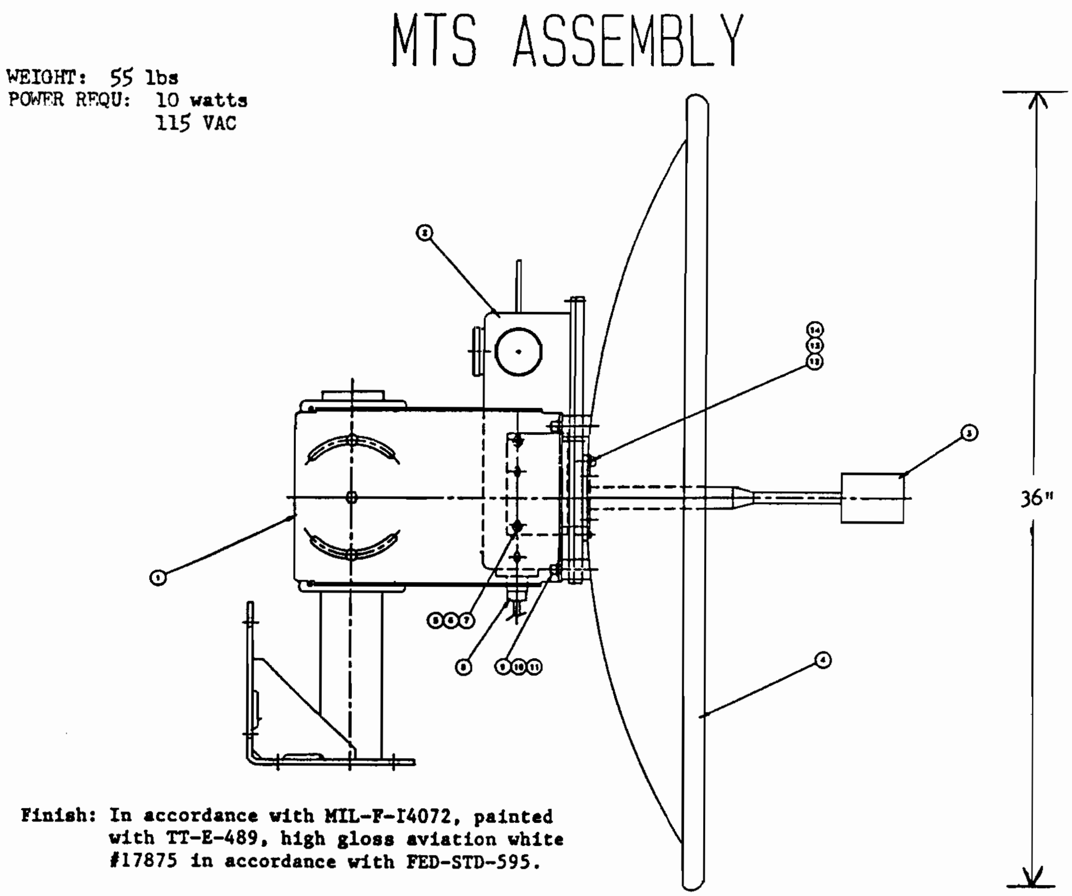

Figure 1. Schematic of moving target simulator assembly (drawing by Lucas Aerospace, Hopkinton, MA).

The MTS unit weighs 55 pounds and consumes 10 watts at 115 volts AC. The manufacturer is Lucas Aerospace of Hopkinton, MA. The unit under test at Orlando is the prototype version of the units that Lucas is supplying to Raytheon for installation at all the TDWR sites. This unit is identical to the production units in all respects except for the arrangement and certification of some of the components in the electronics box.

Radar meteorologists currently evaluate the integrity of a Doppler radar (i.e., NEXRAD) by observing the return from "clear air"* in the presence of a known uniform wind field. In an unmanned system such as TDWR, this subjective evaluation is not practical. The MTS will verify radar transmitted power to within ±1 dB and velocity processing to within ±1 m/s, provided that the MTS return is at least 10 dB greater than the radar return from the tower on which it is mounted and that there is no significant weather occurring along the path between the TDWR and the MTS or at second trip return distances.

The proposed algorithm for use of the MTS selects and evaluates the frequency translated return from the device whenever the TDWR antenna scans past it. An additional internal test procedure at the TDWR verifies the integrity of the entire radar system, with the exception of the waveguide and antenna assemblies, by using built-in hardware test capabilities. (A sample of the transmitted pulse is delayed for several microseconds and then injected into the receiver for evaluation.) Although the MTS algorithm provides a test of the complete system, it is subject to local meteorological conditions and can on occasion give a false indication of failure. Therefore, a failure alarm will be given only when both the internal test signal and the MTS so indicate.

B. Installation in Orlando

An initial temporary installation of the MTS was made on the air traffic control tower at the Orlando International Airport (MCO) in order to check out the mounting and operational procedures. Two modifications to the MTS were necessary in order to complete this installation and test. To aim the antenna accurately, an optical telescope was mounted on a section of channel stock bolted to the electronics package. After adjustment, the channel stock was left in place and the telescope removed. It was also noted that the elevation adjustment was very difficult because of static friction. This was overcome by adding a lead screw in the elevation adjustment hardware such that the adjustment could be made smoothly. Both of these modifications can be seen in figure 2. The end of the screw appears just behind the channel bar. It is strongly suggested that these two modifications be applied to all production MTS units.

The vertical component of the MTS mounting bracket is shown in figure 3. Note that there are four holes for attaching hardware, permitting attachment to either a horizontal or vertical member. Figure 4 shows an aluminum bracket (1 of 4) fabricated by Lincoln Laboratory. When used in pairs, these brackets will accommodate a round tower structure component between three and five inches in diameter. Figure 2 shows the position of the upper pair of brackets. In this photo, the lower set has not yet been mounted.

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* "Clear air" is defined subjectively as containing no perceptible contaminants.

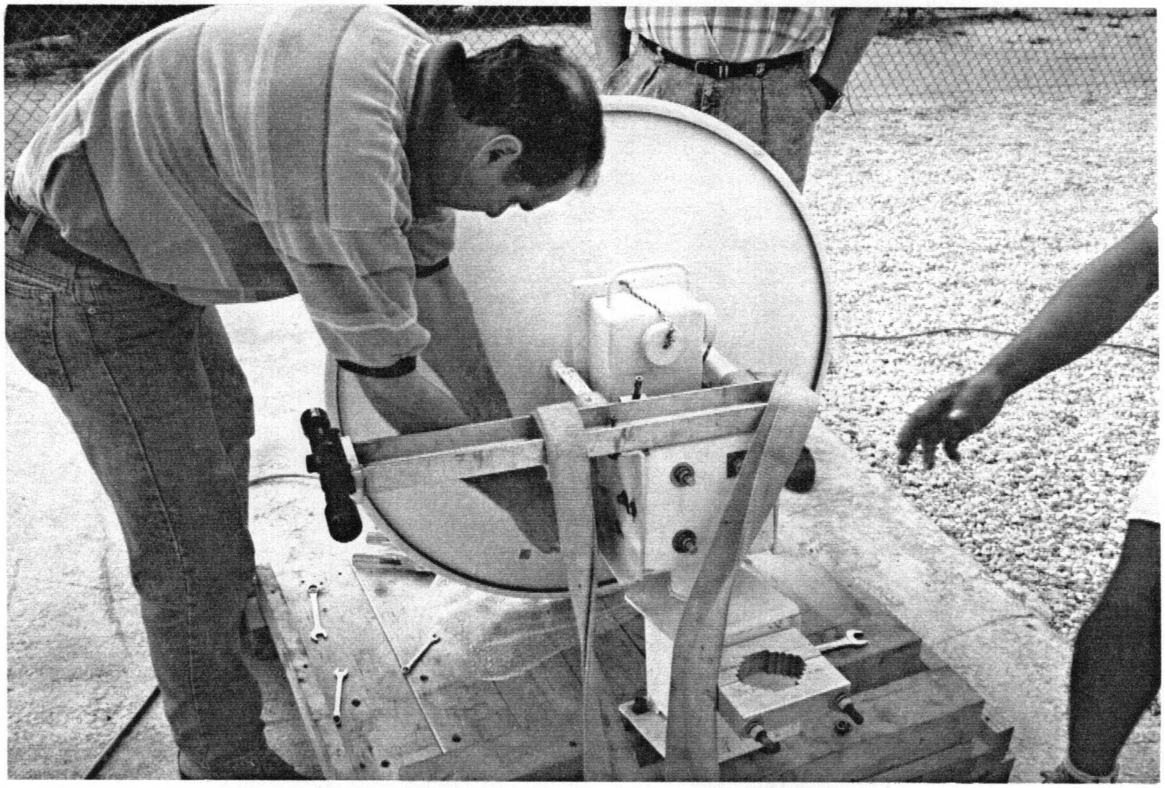


Figure 2. Modifications being made to adjust the elevation angle of the antenna.

The final operational installation was accomplished on 2 December 1991. The MTS was bolted to a Rohn self-supporting tower owned by Bell South Mobility in north Taft, Florida. This tower is located approximately 6 km west of MCO and 11 km northwest of the TDWR site. The MTS was lifted to the 170-foot level on the tower where it was bolted to one of the upright legs of the structure. Figure 5 shows this process, and figure 6 shows the MTS being bolted in place. After aiming, the telescope was again removed and a power cord was connected. A surge protector made by Transtector was installed between the power plug and the utility outlet at the base of the tower

The MTS is located exactly at an azimuth of 339.7 degrees from the TDWR. The radar feedhorn is 137 feet above mean sea level (AMSL), the MTS is 265 feet AMSL, and the distance between them (range) is 11.075 kilometers. Using a 4/3 earth approximation at that distance reduces the apparent height of the MTS to 240 feet AMSL. The radar thus must point at an elevation angle of 0.16 degrees to center the radiated beam on the MTS.

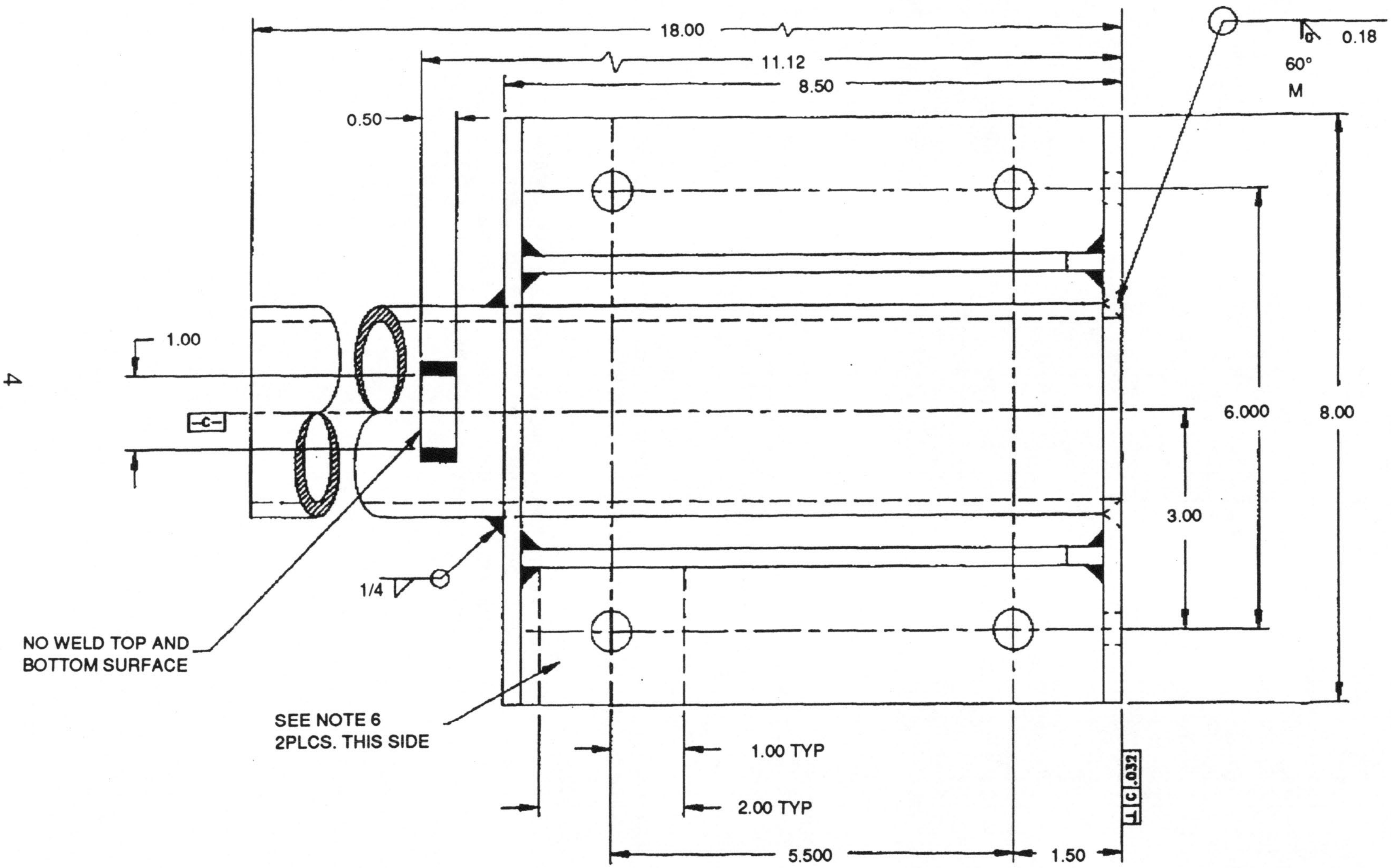


Figure 3. MTS mounting bracket, vertical portion (drawing by Lucas Aerospace, Hopkinton, MA).

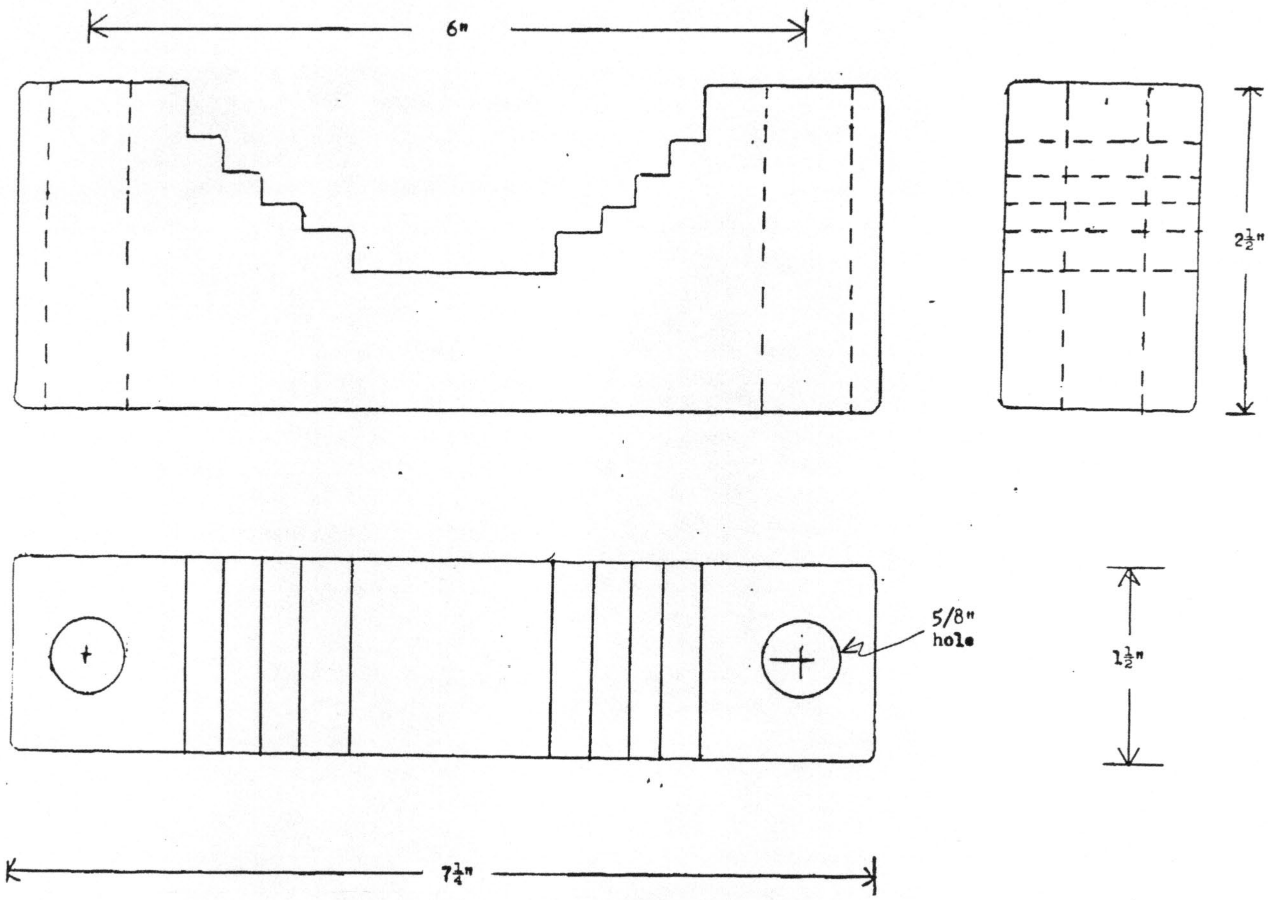


Figure 4. Aluminum bracket, 1 of 4.

Figure 5. MTS being hoisted to the 170-foot-high tower.

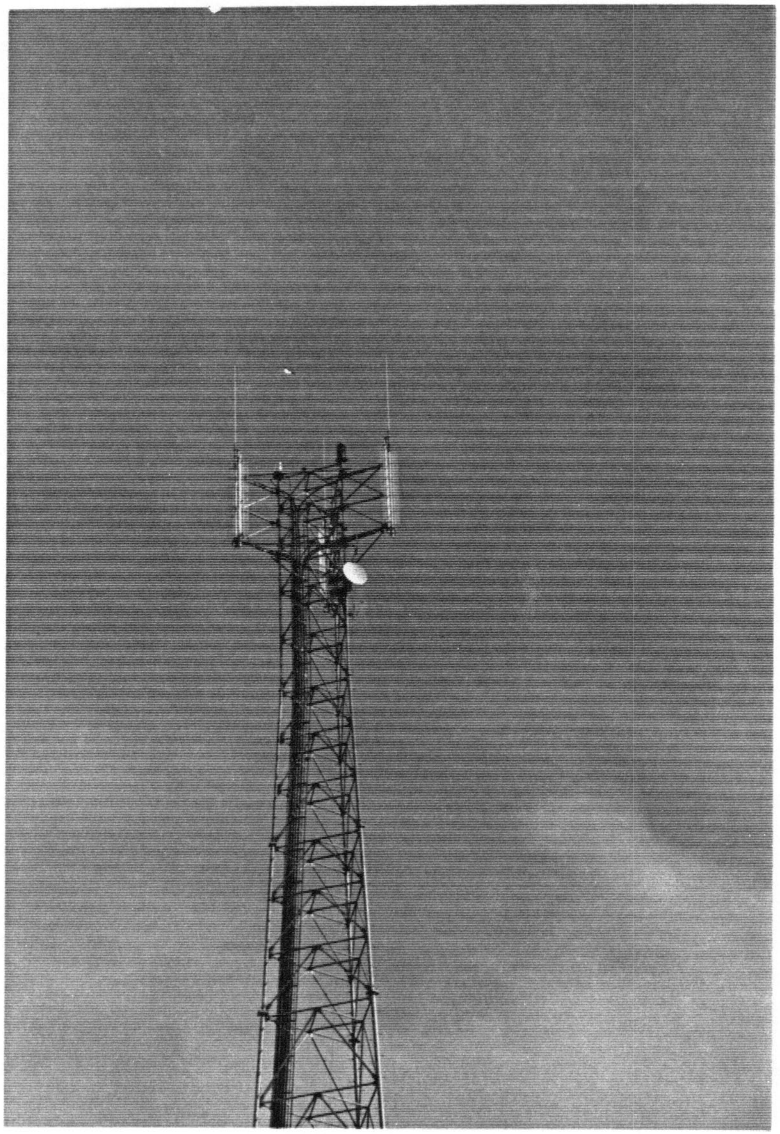


Figure 6. MTS on tower.

C. Processing MTS Returns

1. Initial Results

MCO Control Tower

The attenuator in the MTS was adjusted for minimum attenuation in order to have as strong a return as possible for test purposes. (In the final configuration, the MTS adjustable attenuator should have enough range to provide an equivalent 50 dBZ target return at the TDWR when the MTS is located at any range between 2 km and 20 km.) With the TDWR antenna pointed directly at the MTS (spotlighted), a spectral analysis of the returned signal was performed using a fast Fourier transform software package, known as the Single Gate Processor (SGP) program, that runs on the original FL-2C SP and DAA computers. The return from the MTS appeared as a five-meter-per-second moving target, as expected, but the return from the control tower was some 20 dB higher than that from the MTS. Therefore, when scanning the TDWR antenna past the MTS, the tower return completely masked the return from the MTS, and the antenna scanning portion of the test was not possible while the MTS was mounted on the MCO control tower.

Bell South Tower

Before installation of the MTS the TDWR return from the Bell South Tower was measured at approximately 30 dB lower than the return from the MCO control tower. With the minimal setting of the MTS attenuator and a range of about 11 km, the MTS return was expected to be 5.1 dB stronger than the 50 dBZ expected at 20 km. In actual fact, the MTS return is almost evenly split between two range bins in the receiver digitizing system, causing each bin to present a return that is 3 dB lower than would be expected if the return were centered in a single bin. The result is that the reflectivity return seen by the radar is between 52 and 53 dBZ, with zero attenuation inserted from the internal attenuator.

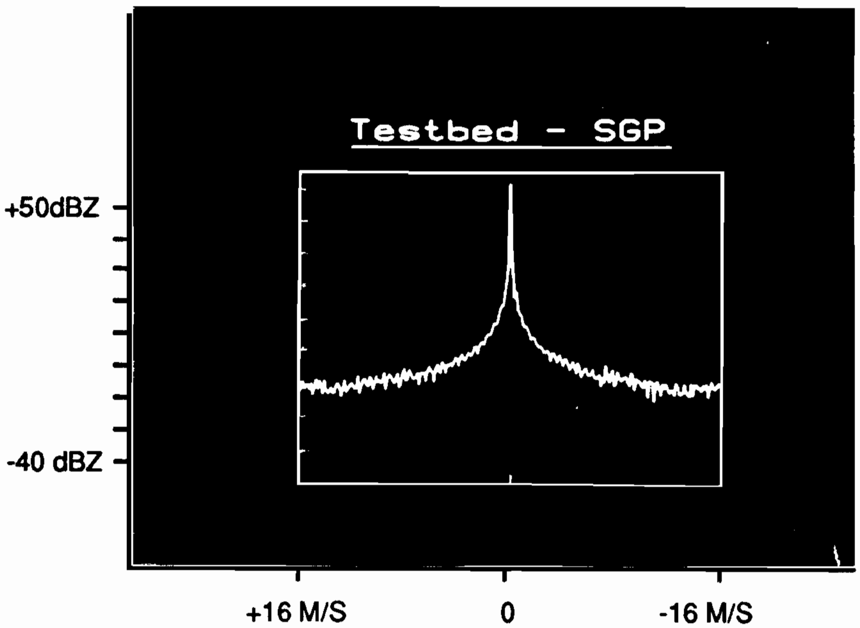
2. Parametric Effects

The four photos in figure 7 are outputs from the SGP program with the antenna pointing at the MTS at the Taft site. Figure 7 (a) is the return from the Bell South tower before installation of the MTS, and 7 (b) is the same signal processed through a clutter rejection filter. Figure 7 (c) is the return from the MTS and the tower combination, while figure 7 (d) is the same signal processed through a clutter filter.

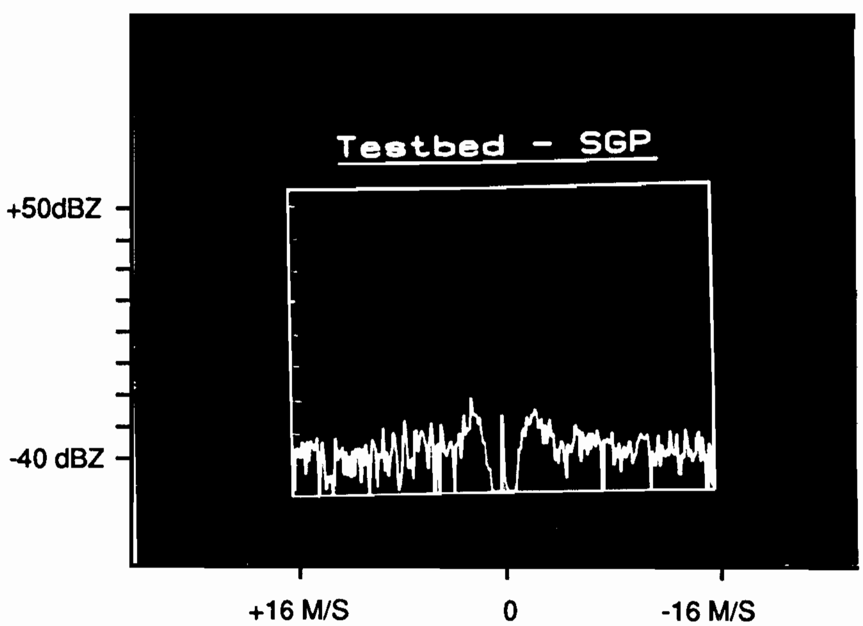
Additional results are shown on the plots in figure 8 using an A-Scope presentation program that runs in the new Programmable Signal Processor (PSP). Figure 8 (a) is the signal power in range with the antenna pointing at the MTS. The target return straddles gates 81 and 82. Figure 8 (b) is the same return calibrated in dBZ, while figure 8 (c) is the velocity in meters per second. The PRF in these measurements is approximately 1000, and the antenna elevation is 0.2 degrees. No clutter filter was used in this processing. Since the reflectivity of the radio tower is close to that of the MTS return, the pulse-pair processing yielded a velocity value of about 4 m/s.

There are two real-time indications from the pulse-pair processed moment data that both the radar and the MTS are working properly when the TDWR antenna scans past the MTS. The first is when the color displays are adjusted for moderate resolution (5 dB/color in reflectivity and 2 dB/color in velocity) and the clutter filters are enabled. The MTS then shows up in both the reflectivity and velocity presentations each time the antenna scans past it. Figures 9 and 10 are examples of these presentations in PPI mode, and figures 11 and 12 in RHI mode. The PPI scan at 0.3 degrees elevation and the RHI at 339.6 degrees azimuth are intended to produce maximum values. The reflectivity appears as 55-60 dBZ and the velocity as 4-6 m/s due to quantization effects.

The second real-time output is a report on one of the status screens each time the MTS is viewed by the radar. Figure 13 shows these reports for a scan strategy that consists of alternating PPI scans at 0.3 degrees and 0.5 degrees on a clear day. Note that the reflectivity (DZ) and velocity (V) are extremely consistent for each elevation. At an elevation of 0.3 degrees the MTS return is between 52 and 53 dBZ.

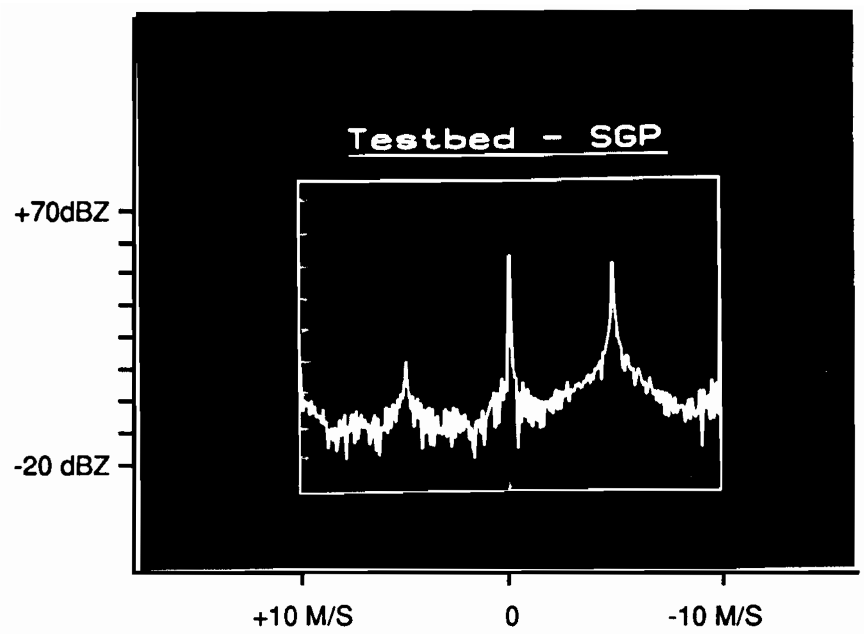


(a) Unfiltered
Tower alone

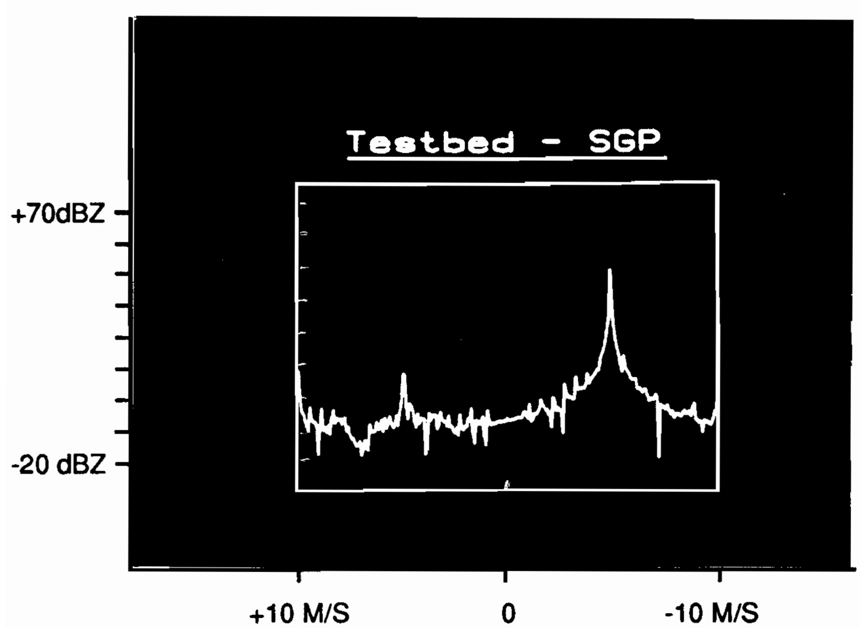


(b) Filtered
Tower alone

Figure 7. SP SGP plots of Bell South tower.



(c) Unfiltered
Tower plus MTS



(d) Filtered
Tower plus MTS

Figure 7. (Continued)

Using various scan rates and PRFs, raw I and Q data were collected from the analog-to-digital converters for analysis at several elevations during antenna scans past the MTS. Figures 14 through 16 show plots of some of this data when the scan rate of the antenna was 5 degrees per second and the PRF was 1114. Figure 14 is the signal power of the return in range gate 81 over a 20-degree scan past the MTS, and figure 15 is an expanded view, four degrees wide, that is centered on the target. The MTS modulation can be seen clearly even when the FL-2C antenna is several degrees off from the MTS, whenever the ambient signal is more than 60 dB below the principal peak. This presumably reflects the sidelobe response of the TDWR antenna. In figure 16 a spectral analysis of a single one-second data window centered on the MTS shows the peak in the MTS return at 187 Hz, along with the DC return from the Bell South tower and surrounding stationary objects. The MTS return is about 5 dB lower than these zero velocity returns.

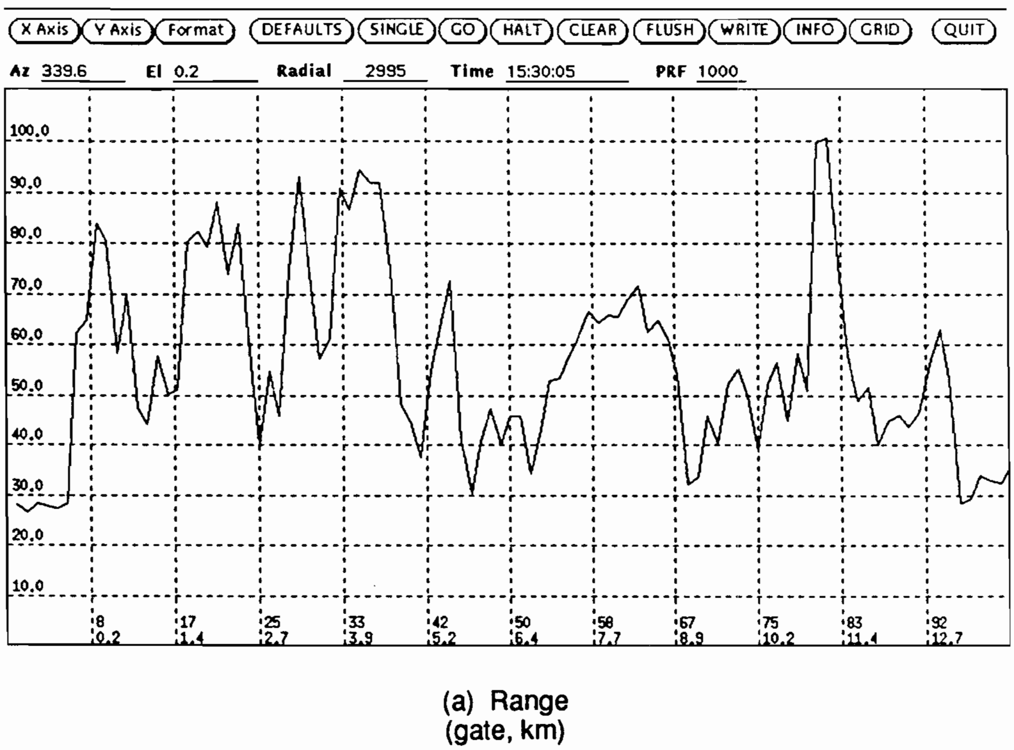
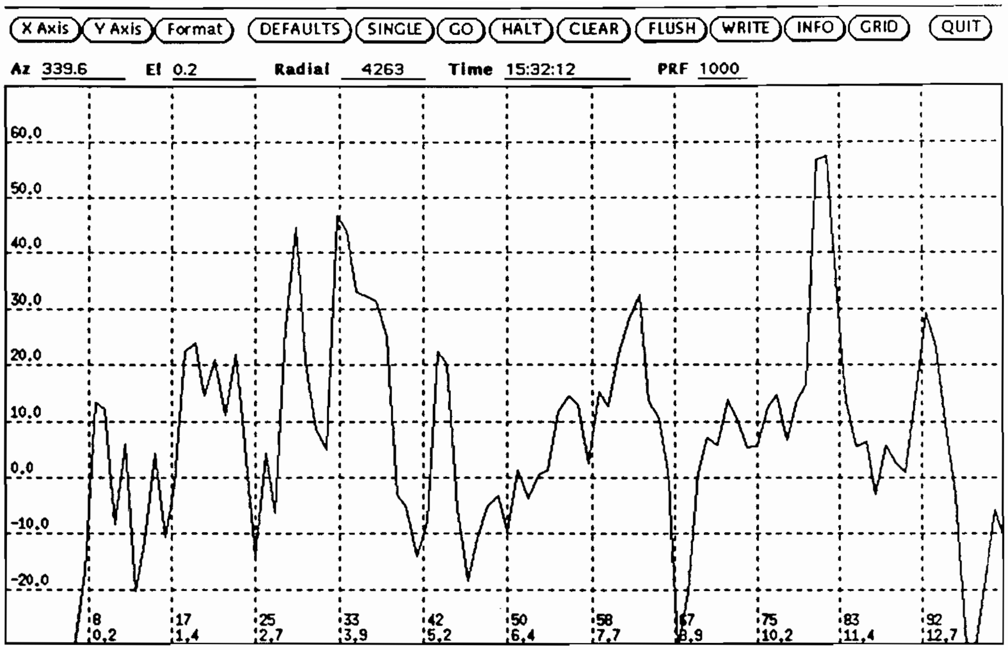
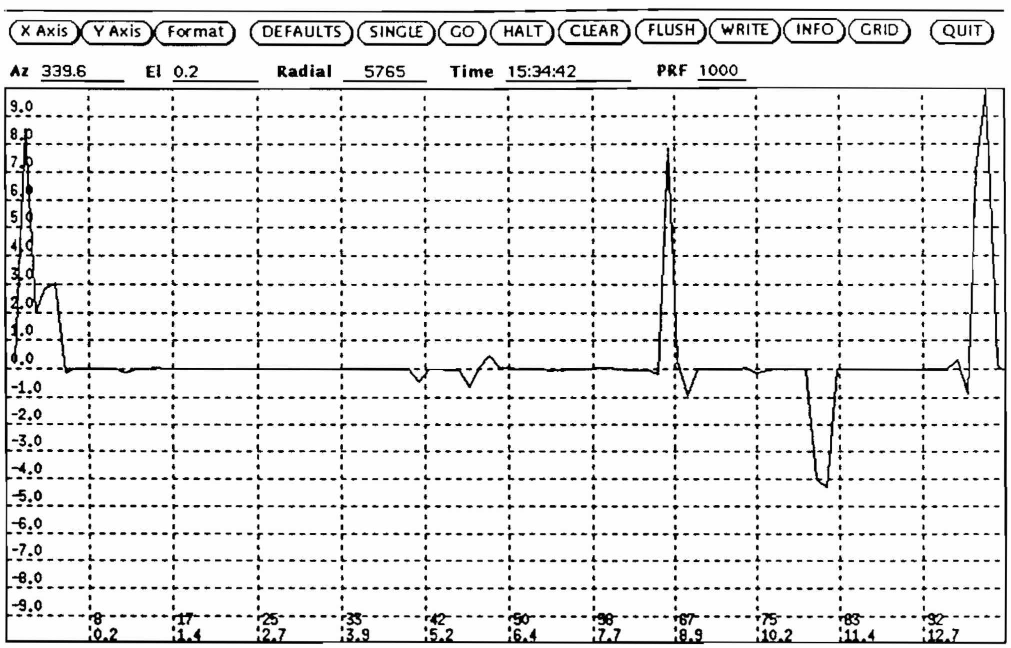


Figure 8. PSP A-scope plot of Bell South tower. Signal power in range with antenna pointing at MTS.



Range (gate, km)

(b) Return signal calibrated in dBZ.



Range (gate, km)

(c) Velocity in meters per second.

Figure 8. (Continued)

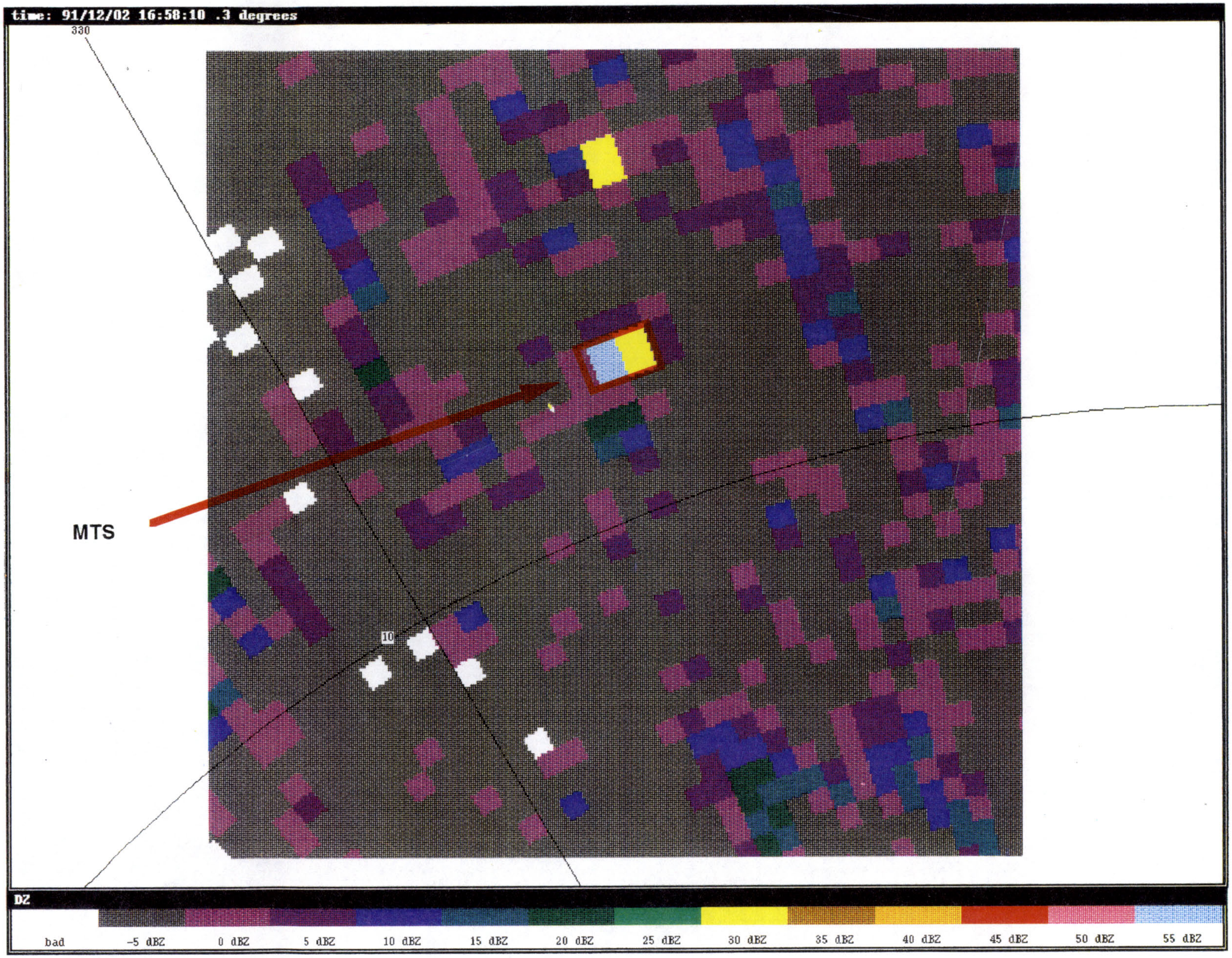


Figure 9. MTS reflectivity PPI scan.

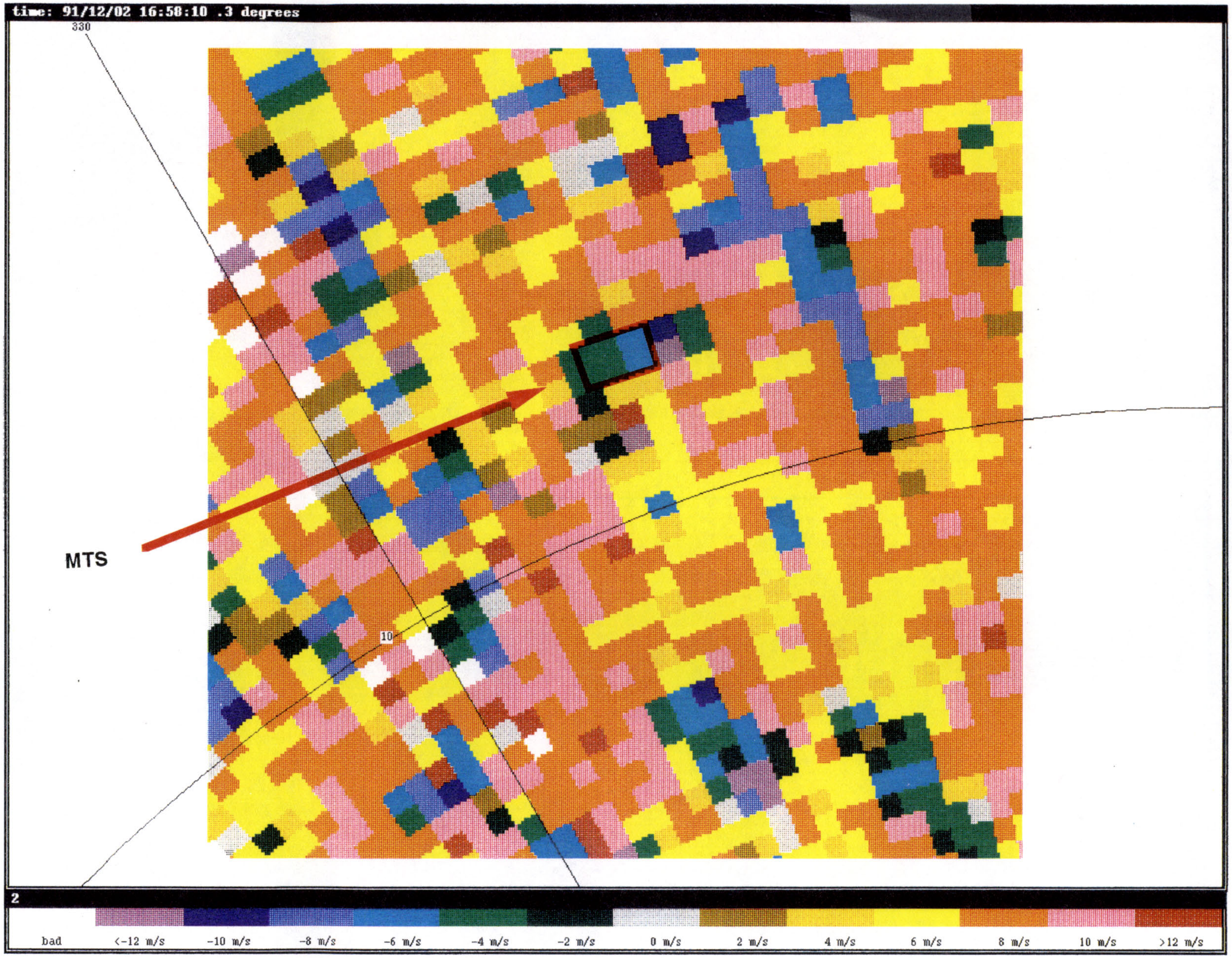


Figure 10. MTS velocity PPI scan.

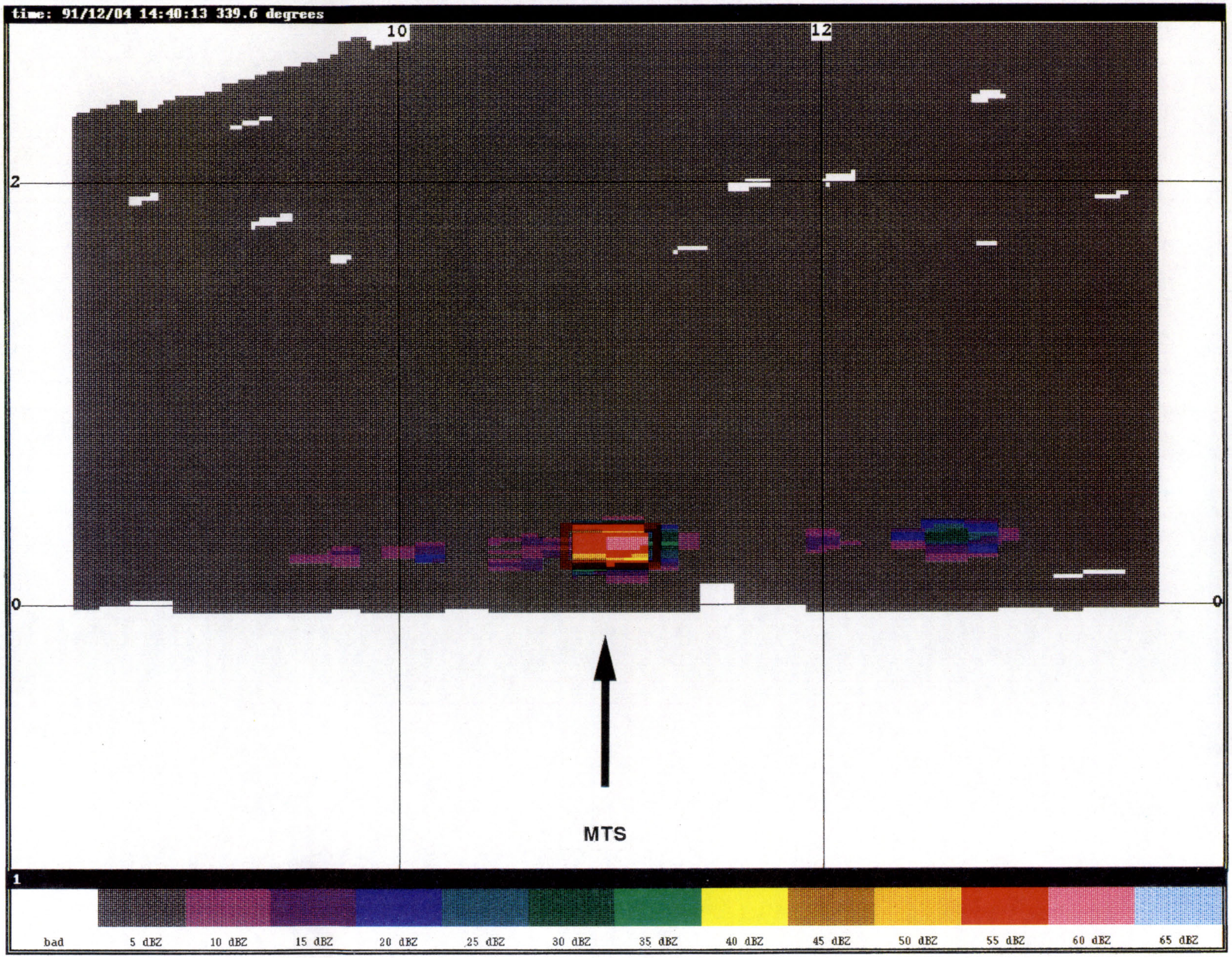


Figure 11. MTS reflectivity RHI scan.

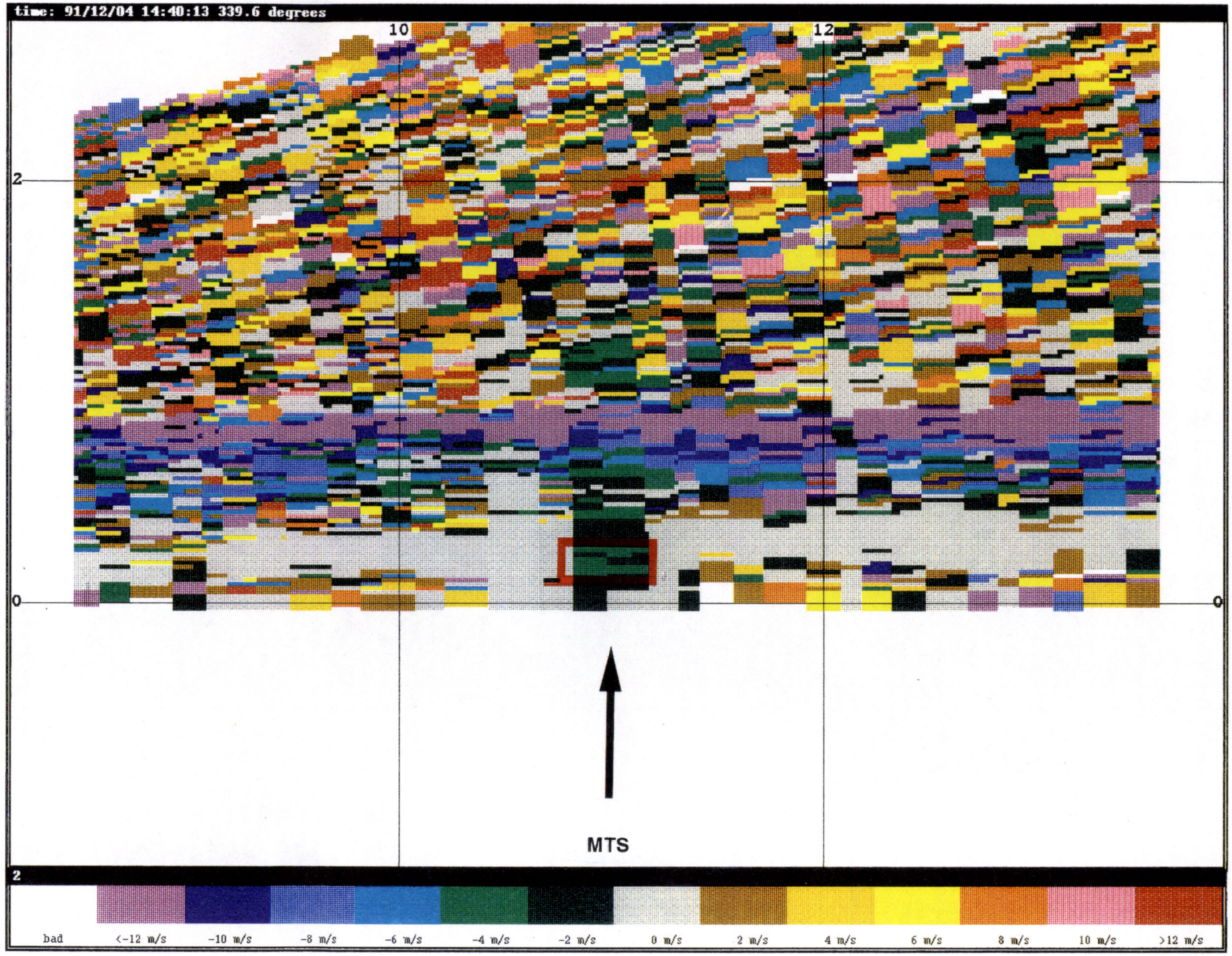


Figure 12. MTS velocity RHI scan.

```
09:30:24 BASEDATA: (MTS_XRAD) MTS report: AZ=339.5  EL= 0.3  DZ= 52.5  V= -5.0
09:30:25 BASEDATA: (MTS_XRAD) MTS report: AZ=339.5  EL= 0.5  DZ= 46.0  V= -5.0
09:30:27 BASEDATA: (MTS_XRAD) MTS report: AZ=339.5  EL= 0.3  DZ= 52.5  V= -5.1
09:30:37 BASEDATA: (MTS_XRAD) MTS report: AZ=339.5  EL= 0.5  DZ= 45.5  V= -5.0
09:30:41 BASEDATA: (MTS_XRAD) MTS report: AZ=339.5  EL= 0.3  DZ= 52.5  V= -5.0
09:30:53 BASEDATA: (MTS_XRAD) MTS report: AZ=339.5  EL= 0.5  DZ= 46.0  V= -5.0
09:30:57 BASEDATA: (MTS_XRAD) MTS report: AZ=339.5  EL= 0.3  DZ= 52.0  V= -5.1
09:31:08 BASEDATA: (MTS_XRAD) MTS report: AZ=339.5  EL= 0.5  DZ= 45.5  V= -5.0
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09:31:44 BASEDATA: (MTS_XRAD) MTS report: AZ=339.5  EL= 0.3  DZ= 52.0  V= -5.0
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09:32:00 BASEDATA: (MTS_XRAD) MTS report: AZ=339.5  EL= 0.3  DZ= 52.5  V= -5.1
09:32:11 BASEDATA: (MTS_XRAD) MTS report: AZ=339.5  EL= 0.5  DZ= 46.0  V= -5.0
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Figure 13. Status monitor display.

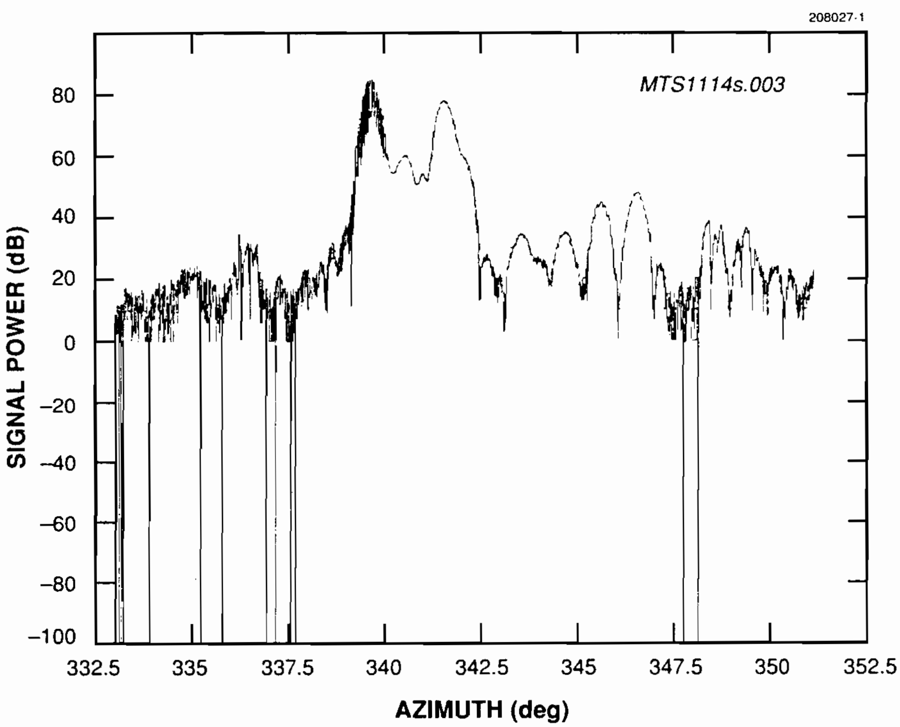

Figure 14. MTS PPI scan data [(gate 81) three-degree elevation, 1114 PRF, five degree per second scan rate)].

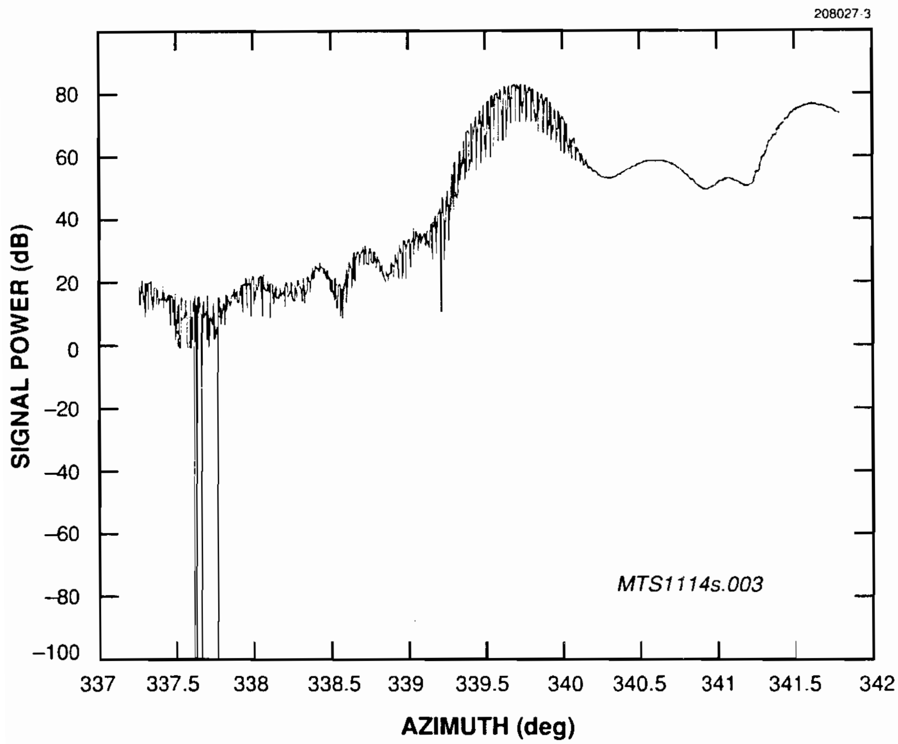

Figure 15. MTS PPI scan data - expanded.

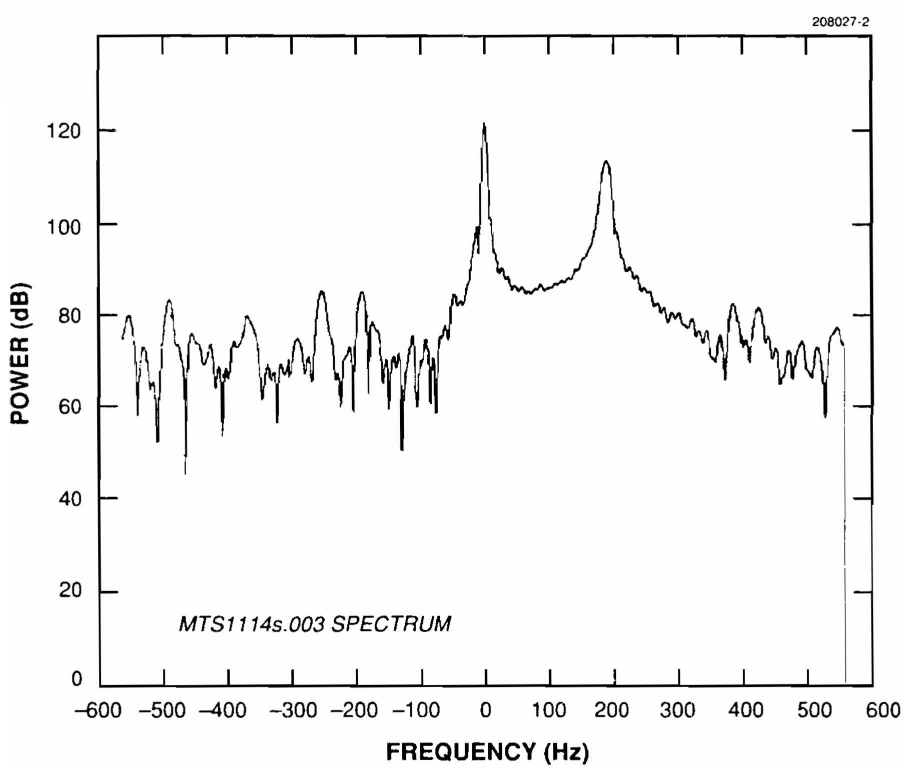

Figure 16. MTS PPI spectral data.

D. Conclusions

The MTS prototype unit produces a radar return that simulates a target moving away from the radar at a rate of 5 m/s when there is a clear weather path between the TDWR and the MTS. The specifications require that the return can be adjusted at the MTS to produce a 50 dBZ return at any range between 2 km and 20 km. In order to meet this specification, the prototype unit should have been able to produce a 55 dBZ return with the attenuator adjusted to zero at the 11.2 km range. This unit produced somewhat less than 53 dBZ, indicating that either the MTS had excess loss or that the TDWR testbed was out of calibration. Further tests will be conducted to resolve the issue.

As configured, the MTS gave accurate returns when the size of the mounting tower was considered. The unit has shown excellent reliability and stability. A series of algorithms will be tested to determine if the MTS return can be used to provide information concerning the weather conditions along the propagation path or at the MTS position.

LIST OF ABBREVIATIONS

AMSL	Above Mean Sea Level
AP	Anomalous Propagation
DAA	Data Acquisition and Analysis
DZ	Reflectivity
I and Q	In Phase and Quadrature
MCO	Orlando International Airport
MTS	Moving Target Simulator
PPI	Plan Position Indicator
PRF	Pulse Repetition Frequency
PSP	Programmable Signal Processor
RHI	Range Height Indicator
SGP	Single-Gate Processor
SP	Signal Processor
TDWR	Terminal Doppler Weather Radar
V	Velocity