Project Report
ATC-222

TDWR Scan Strategy Implementation

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16. Abstract

The Terminal Doppler Weather Radars (TDWRs) installed at major airports around the country are intended to enhance the safety of air travel by the detection and timely warning of hazardous wind shear conditions in the airport terminal area. To meet these objectives, scan strategies to efficiently cover the protected airspace were developed after extensive testing at several sites with different meteorological environments.

Since the topology and geometry differ at each TDWR location, special considerations were necessary to define the specific scan sequences for each site. This report describes the criteria used to establish these scan sequences, including the determination of the lowest practicable elevation angle for each site — the "surface scan," which is used to detect microburst surface outflows, and other special scans such as the "MTS scan," which is used to illuminate the remote Moving Target Simulator (MTS).

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1. INTRODUCTION

This report describes the specific scan strategy implementation for the Terminal Doppler Weather Radars (TDWRs) to be installed at the major airports in the U.S. This network of radars is intended to enhance the safety of air travel by the timely detection and warning of hazardous wind shear conditions in the airport terminal areas. It will also aid in the management of air traffic through the early detection of gust fronts, storm cores, and the accompanying wind shifts.

The scan patterns employed at each site are unique and designed to optimize the radar coverage at each location. The criteria employed and the rationale behind the selected scan patterns are described. These include selection of scan sequences to efficiently cover the terminal area volume, determination of the surface scan elevation angle (the lowest elevation scan employed), and selection of an appropriate "MTS Tilt" to illuminate the Moving Target Simulator (MTS) which monitors the performance of the unattended TDWR facility.

2. SCAN MODES

Campbell and Merritt [1] established the fundamental TDWR scan strategy requirements. These were initially tested at the FL-2 testbed in Denver, CO during the summer of 1987 and 1988. The scan design objectives were to detect hazardous meteorological phenomena in an efficient manner while minimizing possible data contamination resulting from range and velocity folding effects. The scans were divided into two principal modes of operation:

1. Monitor Mode Scans, used when there are no significant weather returns within 45 km of the airport, and

2. Hazardous Weather Mode Scans, employed when significant weather returns are detected within 45 km of the airport.

2.1 Monitor Mode Scans

2.1.1 Description

Monitor Mode is a surveillance scan sequence consisting entirely of 360 degree azimuthal scans at various elevation angles. These scans cover the volume of space from the Earth's surface up to an elevation angle of about 60 degrees and out to the maximum processing range of the radar (96 km). The antenna operates continuously in the same azimuth direction in order to minimize the acceleration forces on the antenna pedestal. The volume scan sequence is repeated every five minutes.

A typical scan sequence is shown in Table 1. The monitor mode scans are basically the same for all sites, with perhaps two or three individual scans differing from site to site to account for local topographical differences. A total of 17 scans are required during the five-minute interval in order to cover the required volume of space and to perform certain dedicated measurements. The dedicated measurement scans include:

1. An initial "Low PRF" scan at a low tilt intended to unambiguously measure the distance to all storms within detection range (km). This information determines the extent to which long range storms will be aliased into the first-trip detection region and enables the calculation of appropriate PRFs to minimize obscuration by these returns during the subsequent volume scan.

2. A consecutive pair of "GF" scans carried out at two different PRFs to provide unambiguous velocity measurements. These are typically performed at 0.3 degree elevation but may be slightly higher at sites where there is blockage by surrounding terrain. In addition, a 1.0 degree elevation scan is included to complement the 0.3 degree scans.

3. A Terminal Area Precipitation (TA Precip) scan intended to detect precipitation levels near the arrival/departure gate aircraft altitudes. This particular tilt is not fixed but varies somewhat from site to site because various airports have different arrival/departure gate altitudes and the scan is selected to correspond to one of the regular scans computed for the Hazardous Weather mode for that site. (see 2.2, Hazardous Weather Mode)

Table 1.
Typical TDWR Monitor Mode Scans

Scan No.	Scan Type	Elev. Angle (deg.)	Total Azimuth Angle (deg.)	Nominal Duration	Cumulative Time
1	Lo PRF	0.6	360	18	
2	GF (PRF 1)+MB+MTS	0.3	360	18	
3	GF (PRF 2)+MB	0.3	360	18	
4	TA Precip	2.6	360	18	
5	GF	1.0	360	18	
6		6.1	360	18	
7		11.0	360	18	
8		15.9	360	18	
9		20.8	360	18	
10		25.7	360	18	
11		30.6	360	18	
12		35.5	360	18	
13		40.4	360	18	
14		45.3	360	18	
15		50.2	360	18	
16		55.1	360	18	
17		60.0	360	18	306 sec
DPHYNEK 3/23/94					

4. An MTS scan which is intended to illuminate the Moving Target Simulator located on a remote tower. If the geometry permits, the MTS tilt is selected to match (and to be included in) the Gust Front scans (typically at 0.3 degree elevation angle). If the geometry does not allow this because of tower height or distance limitations, a special MTS scan is inserted in the scan sequence replacing the highest (60 degree) elevation scan.

The monitor mode sequence is repeated continuously until the onset of significant precipitation, at which time the TDWR automatically enters the Hazardous Weather Mode.

2.2 Hazardous Weather Mode

2.2.1 Description

Hazardous Weather Mode scans consist primarily of sector scans in the direction of the airport. A selected number of special purpose 360 degree azimuthal scans is also included in the sequence, and the entire set is repeated every five minutes. Unlike monitor mode scans, the Hazardous Weather scans differ almost completely from site to site. This is because of the difference in topology and geometry at each location and the requirement to cover a fixed region of space directly over the airport.

Table 2 gives a typical hazardous mode scan sequence. In addition to the higher elevation scans intended to detect features aloft, special 360-degree scans are inserted to perform functions similar to those described in monitor mode. These include:

1. A Low PRF scan for unambiguous range determination of distant weather.

2. Gust Front detection scans.

3. Terminal Area Precipitation scans. Depending on the type of aircraft, these gates are traversed at altitudes between 2,500 and 20,000 feet. The scan selected to be the "TA Precip" scan is taken somewhat arbitrarily to be one of the regular hazardous mode scans that falls in the elevation interval between 2.5 and 4.5 degrees. This nominally covers the region of interest without requiring a special scan dedicated to this measurement. (At 3 degrees elevation, for example, the beam would point to approximately 10,000 feet altitude for gates 30 nmi away).

The hazardous mode also includes a "surface scan" (0.2 degree in the Table 2 example), which is designed to view the 100 to 200 meter altitude region above the Airport Reference Point (ARP) where strong microburst outflows occur. This is an important low elevation viewing scan which is carefully determined using procedures described in Section 2.2.3.

Table 2.
Typical TDWR Hazardous Weather Mode Scans

Scan No.	Scan Type	Elev. Angle (deg)	Total Azimuth Angle (deg)	Nominal Duration (sec)	Cumulative Time	Time from End of Last MB Scan
1	Lo PRF	0.6	360	20		
2	GF (PRF 1)+MB+MTS	0.3	360	20	40s	40s
3	GF (PRF 2)+MB	360	20	1m00s	20s	20s
4		2.6	105	7		
5		5.1	105	7		
6		7.7	105			
7		10.2	105	7		
8		12.7	105	7		
9		15.0	105	7		
10		17.9	105	7		
11	MB	0.2	105	7	1m56s	
12	GF	1.0	360	20		
13		21.2	105	7		
14		25.0	105	7		
15		29.3	105	7		
16		33.9	105	7		
17		38.1	105	7		
18	MB	0.2	105	7	2m58s	56s
19	TA Precip	2.6	360	20		
20		5.1	105	7		
21		7.7	105	7		
22		10.2	105	7		
23		12.7	105	7		

Table 2.
(Continued)

Scan No.	Scan Type	Elev. Angle (deg)	Total Azimuth Angle (deg)	Nominal Duration (sec)	Cumulative Time	Time from End of Last MB Scan
24		15.0	105	7		
25	MB	0.2	105	7	4m00s	62s
26		17.9	105	7		
27		21.2	105	7		
28		25.0	105	7		
29		29.3	105	7		
30		33.9	105	7		
31		38.1	105	7		
32	1.0 deg Sector	1.0	105	7		
33	MB	0.2	105	7	4m56s	56s
CENTER AZIMUTH 345 deg						
DPHYNEK 3/23/94						

2.2.2 Coverage Region

The TDWR is required to detect microbursts out to 6 nmi. from the ARP as specified in the TDWR System Requirements Statement. [2] Depending on the distance from the TDWR to the airport, this corresponds to an azimuthal sector of about 70 degrees for radars at the more distant sites, to in excess of 100 degrees for radars at short distances to the airport. To provide a measure of standardization, as well as a buffer region for additional warning time, a sector size of 105 degree minimum has been established as a practical compromise for all sites (some sites may have a somewhat wider sector where the TDWR is relatively close to the airport). This sector size provides more than the required volume coverage and still stays within the time requirements established for revisits and completion of scans. This is graphically depicted in Figure 1 using the Memphis TDWR as an example.

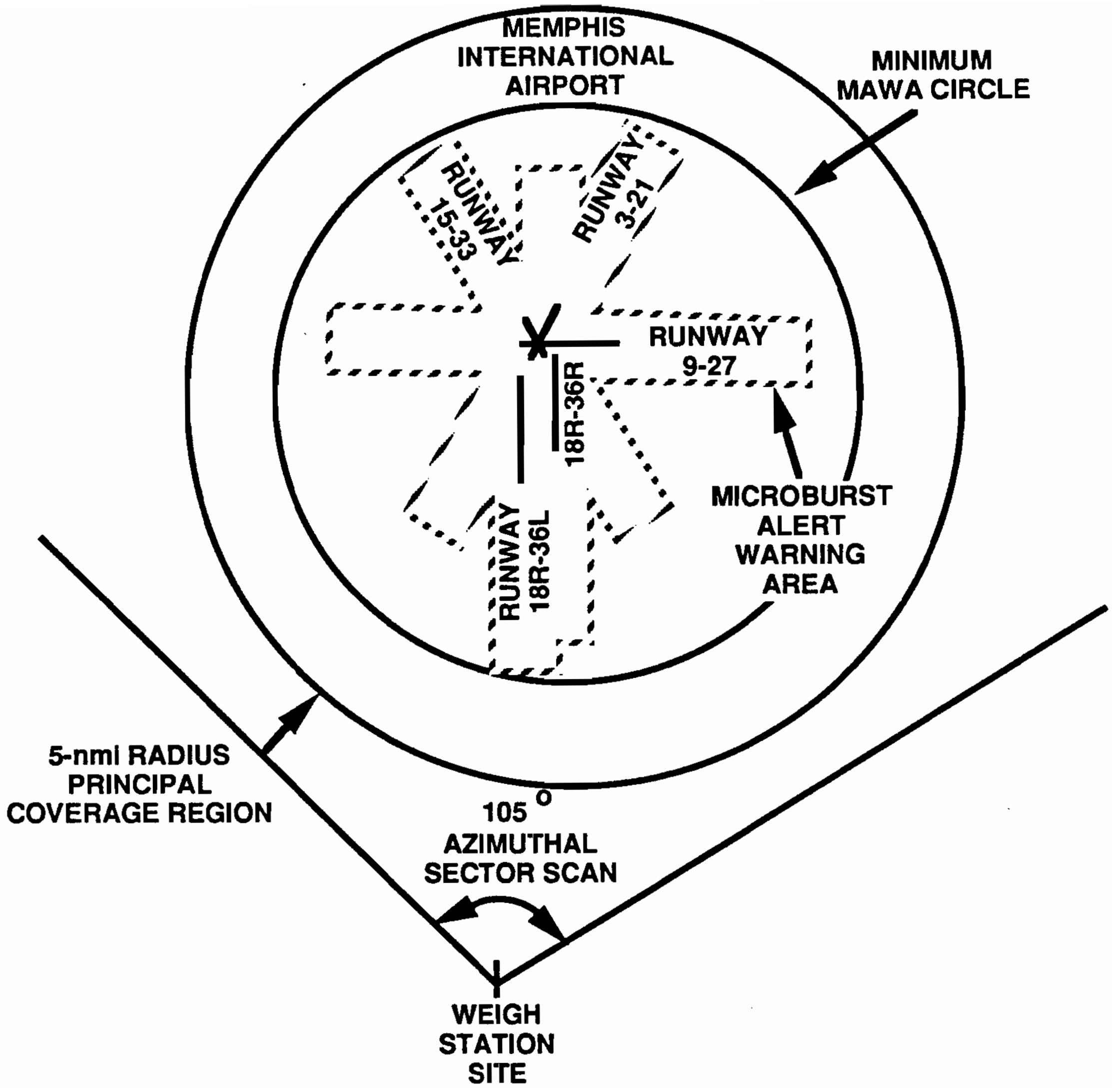


Figure 1. Azimuthal sector scan geometry for Memphis TDWR.

Vertically, the coverage region extends to 6 km altitude. It has been found [1] that in a typical scenario, microburst features aloft develop at about the 6 km level before descending and reaching the surface. Since microbursts develop rapidly and are short-lived (typically, features aloft precede initial surface outflow by about 5-10 minutes), it is important that these features do not fall between elevation scans as the TDWR scans from the surface to the 6 km level. To minimize this possibility, the scans are designed so that the worst case scan-to-scan vertical spacing does not exceed 1 km (see Figure 2), at least over the region encompassing the Microwave Alert Warning Area (MAWA). To further minimize the chances of fall-through, the scans are performed in an ascending elevation order. A sequence of decreasing elevation angles could potentially miss a descending core for an entire cycle by scanning just below the core as it came down. To further minimize the chances of fall-through, the scan aloft sequence is performed twice in the five-minute period.

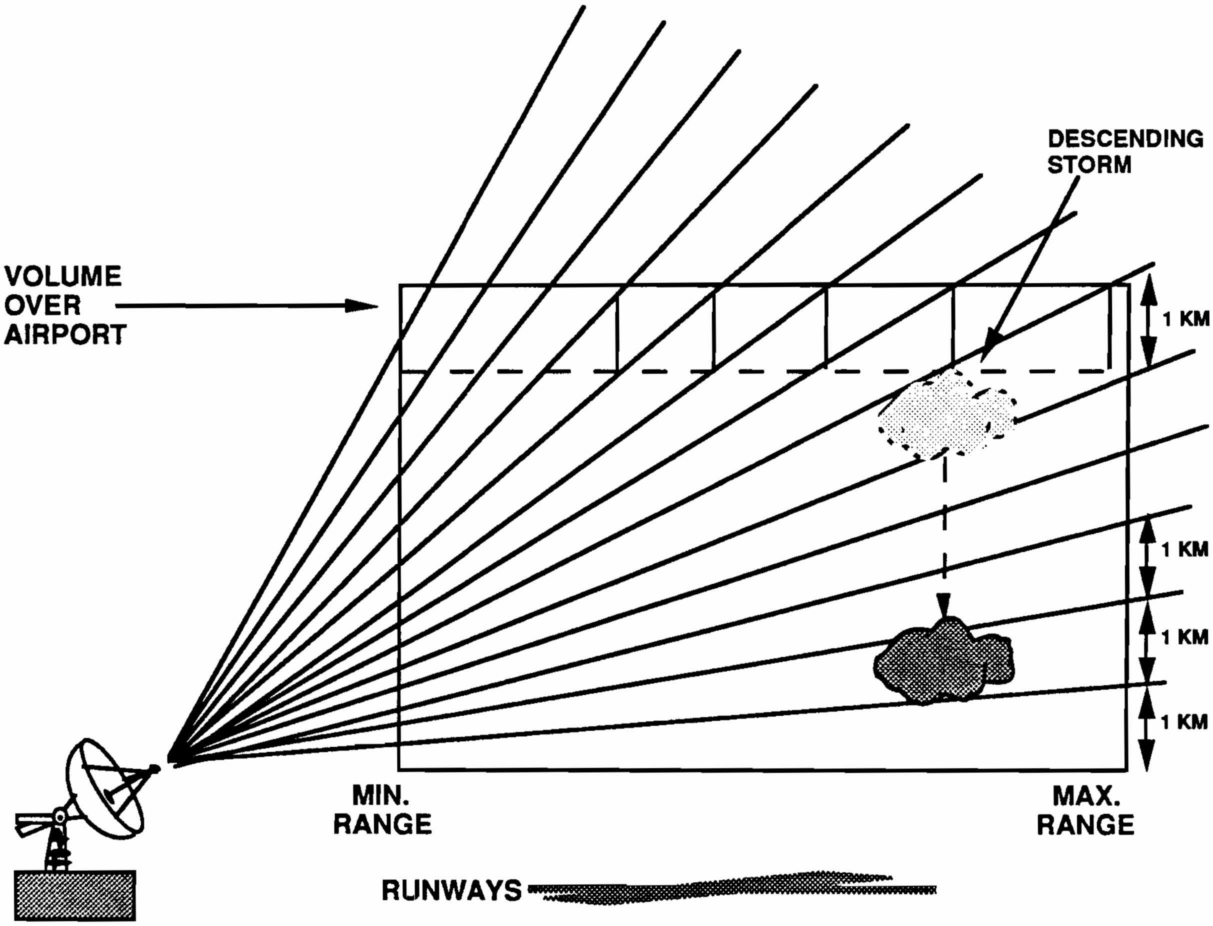


Figure 2. Hazardous weather scans coverage region.

In the calculation of the 1 km vertical separation, a minimum and maximum range for the coverage volume are set to be the ranges to the near and far MAWA. In practice these ranges are defined by the minimum and maximum distance to the smallest circle that encloses the entire MAWA and is centered at the ARP (Figure 1). This range definition (rather than a 6 nmi circle) results in a reasonable number of scans that adequately cover the required space in a time commensurate with the requirements. Generally, in hazardous weather mode, a total of 33 scans are completed during the five-minute cycle, with elevation angles typically extending up to about 40 degrees. This particular number of scans is appropriate to establish the correct time synchronization of the volume scans. If, as may be the case at certain locations, the coverage volume can be covered with a fewer number of scans, additional scans are added at higher elevation angles to obtain this number of total scans to maintain the correct time synchronization.

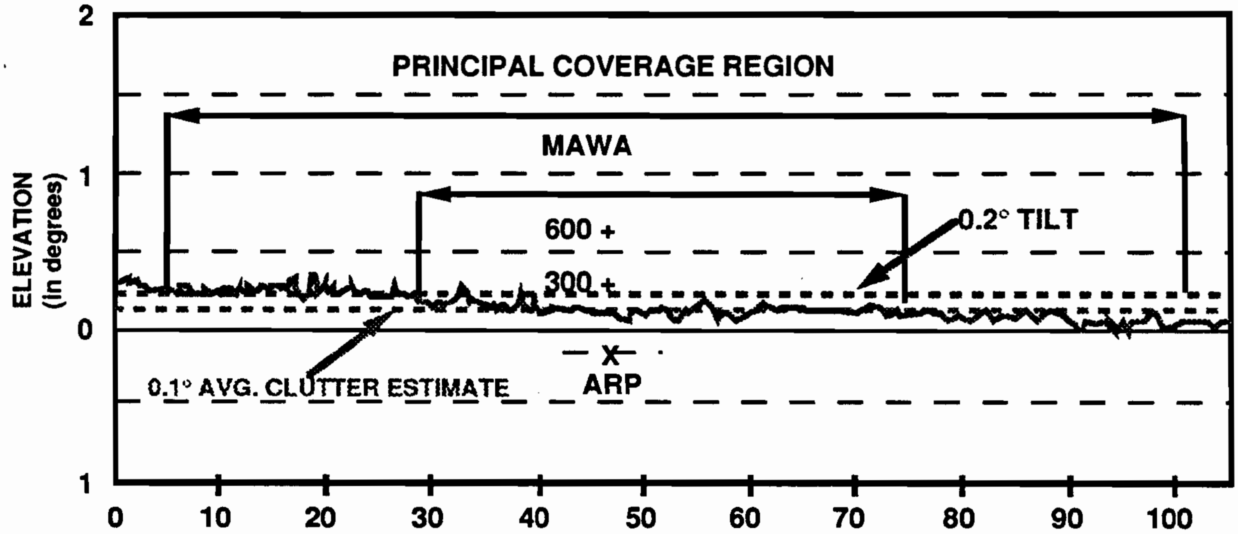
2.2.3 Surface Scans

From an aviation safety viewpoint, microburst outflows below about 300 meters above the ground are of greatest concern due to the limited altitude for recovery. The strongest winds associated with these outflows occur between the surface and approximately 100 meters above ground level (AGL). To detect these conditions the TDWR has been sited to have a clear view down to at least 200 meters, and preferably to 100 meters. Surface scans have been designed to be compatible with these requirements.

The ultimate lower limit of coverage is determined by the intervening terrain area and clutter characteristics. To establish this limit, the site selection process included optical measurements to determine the horizon profile as viewed by the TDWR at several antenna heights. Figure 3 shows such a typical horizon profile. To establish a surface scan tilt that is as low as possible and compatible with the horizon profile, the following semi-subjective procedure is followed:

1. Determine the average horizon angle over the MAWA region.
2. Add one-fourth beamwidth (0.1375 degree, approximately the 1 dB point on the beam) to the average horizon angle. The purpose is to point as low as possible yet not waste excessive beam energy below the average ridge line.
3. Optionally, add an upward bias if warranted by higher terrain in the Principal Coverage Region outside the MAWA (this region is included in the sector scans).
4. Round the angle to the nearest 0.1 degree.
5. If the resulting altitude over the ARP is less than 75 meters, increase the elevation angle in increments of 0.1 degree until the 75-meter minimum threshold is met (final angle is a multiple of 0.1 degree).

In the illustration given in the box in Figure 3, the calculation resulted in a surface scan elevation of 0.2 degree.



MICROBURST SURFACE SCAN TILT DETERMINATION

AVERAGE HORIZON ELEVATION IN MAWA	0.1	DEG.
ONE-FOURTH BEAMWIDTH	0.1375	
	0.2375	
ROUNDED TO NEAREST 0.1 DEGREE	0.2	DEG.

Figure 3. Surface scan determination from typical horizon profile.

Unavoidably, to detect low-altitude weather returns, the beam has to be placed close to the ground where ground clutter returns compete with the desired weather signals. In many cases ground clutter in the vicinity of the airport is minimized by nearby ridges which act as natural clutter fences and the siting process has attempted to take advantage of this, where possible. Ground clutter measurements were made during the siting process to obtain an estimate of clutter in the region; however, only the actual in-situ placement of the TDWR will show whether excessive clutter residue is a problem. The uniqueness of the terrain and differing clutter sources at the various locations could give rise to excessive clutter at the calculated surface tilt. In such cases the surface tilt may have to be modified slightly upward to reduce the clutter residue so as to obtain a clear view at the altitudes of interest.

2.2.4 Scan Timing Requirements

2.2.4.1 Hazardous Mode Scans

The primary requirement of the TDWR in regard to microbursts is the timely and reliable detection of the surface outflows. Since these phenomena evolve rapidly, it is necessary to perform frequent surface scans. The scan strategy requirements, [1] call for a surface scan at least once per minute. The last column in the Hazardous Mode scan sequence list (see Table 2), shows the elapsed time since the previous surface scan. Note that the lower Gust Front scans are also used as microburst surface outflow scans. All scan times given are based on nominal rotation rates and accelerations. The final times for each operational TDWR are established by Raytheon computer simulations which include pedestal dynamics.

The Hazardous Weather Scan mode is also required to perform a few 360 degree azimuthal scans in every five-minute period. These scans include the Low PRF scan, the Gust Front scans, and the Terminal Area Precipitation scan which were described earlier. A further requirement calls for the scan aloft sequence to be repeated every 2.5 minutes. This is intended to ensure that a descending core is scanned twice before reaching the ground. These timing considerations have been incorporated in the scan scenarios.

2.2.4.2 Monitor Mode Scans

As in the hazardous mode, 360 degree special azimuthal scans are required to be performed at least once in every five-minute period. These scans also include the Low PRF scan, the Gust Front scans, and the Terminal Area Precipitation scans. Also to be completed within a five-minute period are the 360-degree scans which cover the full volume of space around the airport, beginning at the base elevation and continuing up to a maximum elevation of 60 degrees.

3. MTS SCANS

In both the monitor and hazardous modes the TDWR is required to scan across, and receive a reflected calibration signal from the Moving Target Simulator (MTS). Since the TDWR operation is unattended, it is important that an accurate and reliable signal be obtained from the MTS to indicate any possible malfunction.

The MTS, which includes a three-foot-diameter dish and electronics, is mounted on a tower that is 2 to 20 km distant from the radar. The MTS reflects the incident TDWR signal after applying a phase shift, providing a point target equivalent to a 50 dBz weather return with an apparent radial velocity of five meters/second. If a signal return is not within prescribed tolerance bounds, a fault is indicated at the TDWR. Ideally, the MTS would be located so that (1), it is illuminated by the center of the radar beam; (2), that it returns a similar level signal whether in monitor or hazardous weather mode; and (3), that it is visible at an elevation angle that is included in the regular scan sequence. In the latter case, the MTS scan is able to "piggy-back" on an existing scan and thus will not require a separate scan.

In some cases, a limitation on mounting height causes the MTS to be viewed slightly off the beam center. Although a view of the MTS within 3 dB points of the main beam is deemed acceptable, in practice an offset of no more than 1 to 2 dB is typical. For these situations the reflected signal is restored to the nominal 50 dBz value by adjusting the internal MTS attenuator (the attenuator is adjusted at each site also to account for the differing ranges to the MTS tower).

Since it is preferred that the MTS be viewed at the same elevation angle in both hazardous and monitor modes, an attempt is made to select a regular scan that is common to both. The lowest elevation scan in monitor mode is the lower Gust Front scan (typically at 0.3 degree elevation). This tilt is also used in hazardous mode and therefore represents a suitable choice. If the geometry to the MTS tower permits, this offers the advantage of not requiring a special dedicated MTS tilt (which would preempt a weather monitoring scan). Where the distance and mounting height make this possible, this tilt is selected as the MTS scan. Where this condition cannot be met, a special MTS scan is added in monitor mode replacing the highest elevation scan (60 degrees). When a special MTS scan is necessary, it is selected to match the hazardous mode surface scan elevation. This choice imposes the added restriction that the MTS tower be located in the hazardous mode sector. An MTS scan that matches the Gust Front tilt provides added flexibility in that the tower need not be located in the hazardous scan sector.

GLOSSARY

AGL	Above Ground Level
ARP	Airport Reference Point
MAWA	Microwave Alert Warning Area
MTS	Moving Target Simulator
PRF	Pulse Repetition Frequency
TA Precip	Terminal Area Precipitation
TDWR	Terminal Doppler Weather Radar

REFERENCES

1. S.D. Campbell, M.W. Merritt, "TDWR Scan Strategy Requirements, Revision 1," M.I.T. Lincoln Laboratory, Lexington, MA, Project Report ATC-144, Revision 1, DOT/FAA/PM-87-22, 9 April 1990.

2. Terminal Doppler Weather Radar System Requirements Statement, Federal Aviation Administration, FAA Order 1812, 1987.