Artificial Cloud Target (ACT) for Weather Radar Data Generation for Cumulus Clouds

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ABSTRACT

Design and development of Artificial Cloud Target for Radar (ACTR) to artificially generate radar data for simulating growth/decay and motion of cumulus clouds based on Quadratic Growth Hypothesis (QGH), has been presented. ACTR simulates the variation of reflectivity and horizontal motion of actual convective clouds. Along with ACTR, X-Band radar has to be used to generate data from the ACTR and spontaneously process the same for the nowcasting. Short range X-band radar which can be used for this purpose has been described. It can track the objects in the range of 70m to 200m and has the resolution of 1m. Outputs of any software thus developed, could be spontaneously disseminated without loss of time, which is crucial in hail suppression mission in particular and all weather modification campaigns in general.

Keywords: *Artificial Cloud Target for Radar (ACTR), Hailstorm, Hail suppression and X-Band Radar.*

1. Introduction

This research is motivated to alleviate the constraints encountered by meteorologists the world over, to obtain actual radar data for any scientific analysis or mathematical modeling. Weather radar data sets are comprised of 'Cloud-Reflectivity vs. Time' matrices for various levels of weather radar scans. Further, as clouds move; more conspicuously in case of cumulus clouds, information on motion of clouds should be inherent in each data set. Hence, before making any scientific enquiry based on weather radar observations, one needs these data matrices for different levels for the region of interest. Moreover, after the British Chemist Luke Howard (1802) made lasting contribution to the field of meteorology by proposing cloud classification based on shape and texture during his presentation to Askesian Society, unfortunately till date, even after more than 200 years later, no further attempt has been made to classify clouds in such way that they have direct bearing on modern weather forecasting tools. Keeping this aspect in mind, Kumar and Pati (2019 a&b) had classified cumulus clouds based on their rate of growth (r) as slow (r≤.2dBZ/min), moderate (0.2dBZ/min< r < 0.8dBZ/min) and fast (r≥.8dBZ/min). They also presented Quadratic Growth Hypothesis (QGH) for predicting hailstorms. In their analysis, they found that QGH is 100 % true for slow cumulus and 64% true for moderate growth. For example, to validate the QGH, 'Cloud-Reflectivity vs. Time' data from Patna, Mumbai and Nagpur had to be collected in the following format:

Matrix 1.

Time	Cloud Reflectivity
t_1	dBZ_1
t_2	dBZ_2
t_3	dBZ_3

Actual radar data in Matrix 1 have the following characteristics:

(a) Column 1 is comprised of time which increases monotonically with each row.

(b) Time interval between any two rows in column 1 is equal to scan interval of radar.

(c) Column 2 is comprised of reflectivity values of cumulus clouds.

(d) Cloud reflectivity values in column 2 may change randomly with rows.

Extraction methodology of reflectivity values from the raw radar data was presented by Kumar and Pati (2015).

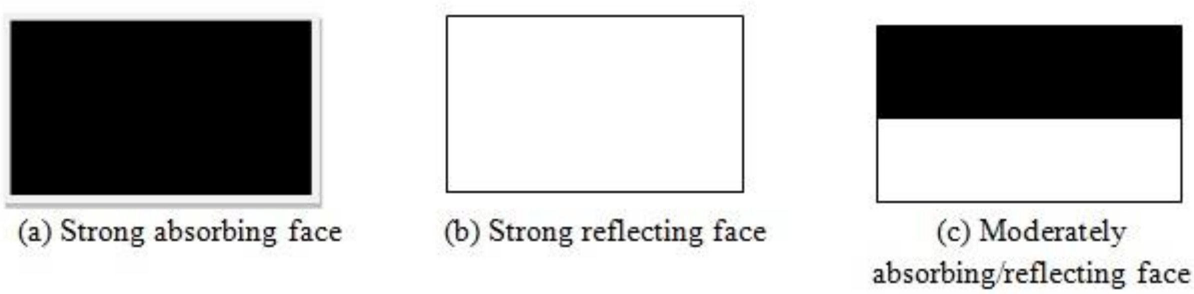


Figure 1(a) to (c): It shows three different faces of prism. (a) has minimum reflectivity as it is pasted by Radio Wave Absorbing Material (RWAM), (b) has maximum reflectivity as it is pasted with shining white aluminum foil and (c) is having moderate reflectivity – in between (a) and (b) - as it is pasted with half RWAM and half shining white aluminum foil.

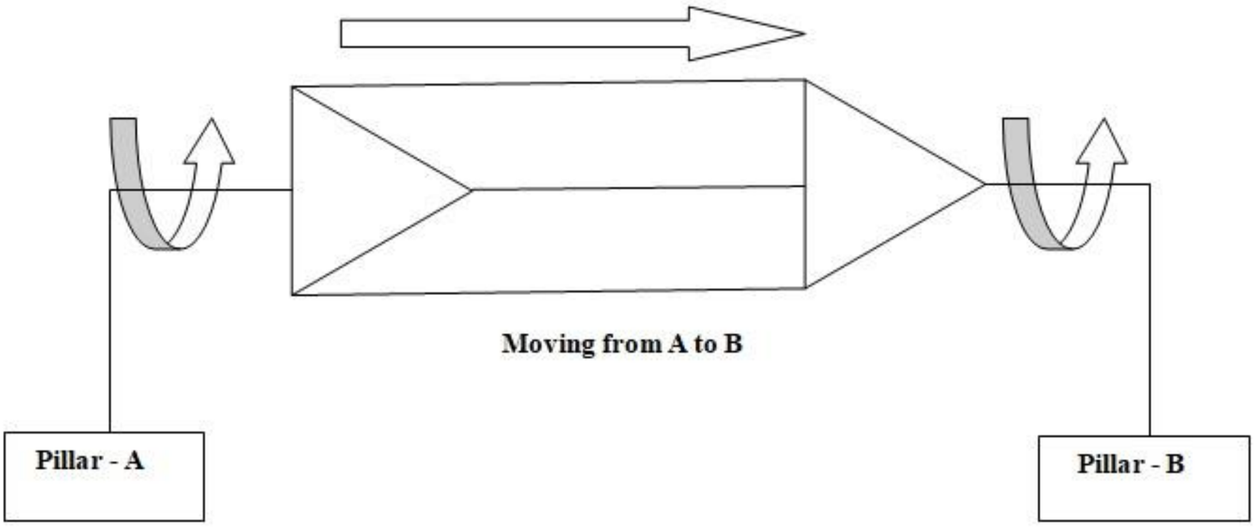


Figure 2: Schematic description of artificial target hanging over a wire tied up on two pillars A and B.

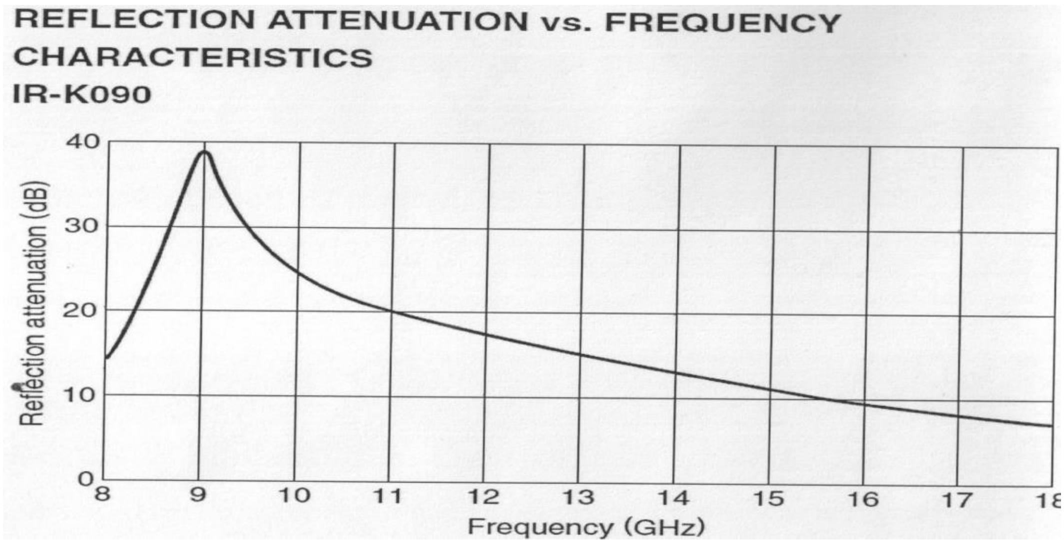


Figure 3: Reflection Attenuation vs. Frequency Characteristics for IR-K090 as RWAM.

Following facts emerge about the actual weather radar reflectivity data and horizontal speed of natural cumulus clouds.

(i) In any cumulus cloud reflectivity changes randomly.

(ii) It may randomly increase or it may randomly decrease or in exceptional cases it may randomly increase then decrease and again increase.

(iii) The average hourly growth of growing cumulus clusters may be 19.1 dBZ per hour (Std. Dev. ± 3.9) and that for decaying cumulus it may be 18.0 dBZ per hour (Std. Dev. ± 8.1). However, in exceptional cases reflectivity may grow as fast as 0.9 dBZ per minute (≈54 dBZ per hour) (Kumar, 2017).

(iv) Horizontal speed of the cumulus clouds shows wide variability. Normally average speed of the clusters could be 10.6 m/s (Std. Dev. ± 4 m/s). However speed could be as high as 19 m/s and as low as 5 m/s in exceptional cases (Kumar, 2017).

In the present paper, an attempt has been made to develop an artificial cloud target which simulates all the above characteristics.

2. Artificial Target Prism made of Radio Wave Absorbing Material

A prism whose three different faces are having different Radio Wave Absorbing Material (RWAM) can simulate the criteria mentioned in Section 1. To ensure random increase or decrease or both, one after the other, a prism with three faces (area of each face =1.25mx1.0m) of different reflectivity was taken. With reference to Figure 1(a-c), each rectangular face of the prism is having different reflectivity as one face is fully pasted with Radio Wave Absorbing Material (strong absorbing face), one face is fully pasted with shining white aluminum foil paper (strong reflecting face) and one face is pasted with half shining white aluminum foil paper and half RWAM (moderately absorbing/reflecting face). White shinning aluminum is strong reflector of the radio waves.

To enforce randomness in the reflectivity, as observed in natural cumulus clouds, the prism is made to rotate on its horizontal axis in steps of 1200 each time. Further, to simulate horizontal motion of the convective clouds, the prism is made to slide on horizontal axis with the help of a thin iron wire. As shown in Figure 2, for Radio Wave Absorbing Material (RWAM), the IR-K090 of TDK Corporation electromagnetic absorber sheet was used for X-band (8–12.5 GHz). Frequency vs. Reflection attenuation graph is shown in Figure 3. It may be noted that reflection attenuation is high in X band. It is 2.5 mm thick flexible sheet and is composite of synthetic rubber and Ferrite material. Different RWAM are briefly discussed in Section 4.

3. Radar Specifications

ACTR's dimension, speed and distance must be within the tracking limits of any radar. Hence, X-Band radar was selected for the purpose. Radar picture is shown in Figure 4. This small radar is foldable and can be carried on shoulders. For tracking targets, it looks only in selected directions ie. horizontally and vertically. Its tracking range is 70-200 meters. It has mounting tripod.

The radar operates on two rechargeable 24 V batteries which are carried separately. The radar can also be operated from AC supply. The batteries are usually suspended from the tripod to provide extra stability to the radar, although they can be kept separately. Its display unit can be connected to any computer. At 100 m it can resolve a target of 1 m width and 50 cm height.

Radar's general tracking specifications are mentioned below:

(i) Elevation Coverage: -40 to +15° (remotely settable).
(ii) Azimuth sector scan: Sector scanning.
(iii) Azimuth accuracy: 0.5° rms.
(iv) Azimuth resolution: better than 4°.
(v) Track while Scan: Multiple targets.

Other hardware details of the radar are mentioned in appendix-A of this paper.

4. Artificial Cloud Target for Radar (ACTR)

4.1 Design of Prism

For receiving optimum back scatter at the fixed point where radar antenna is located, each reflecting surface of the prism is given with minor convexity.

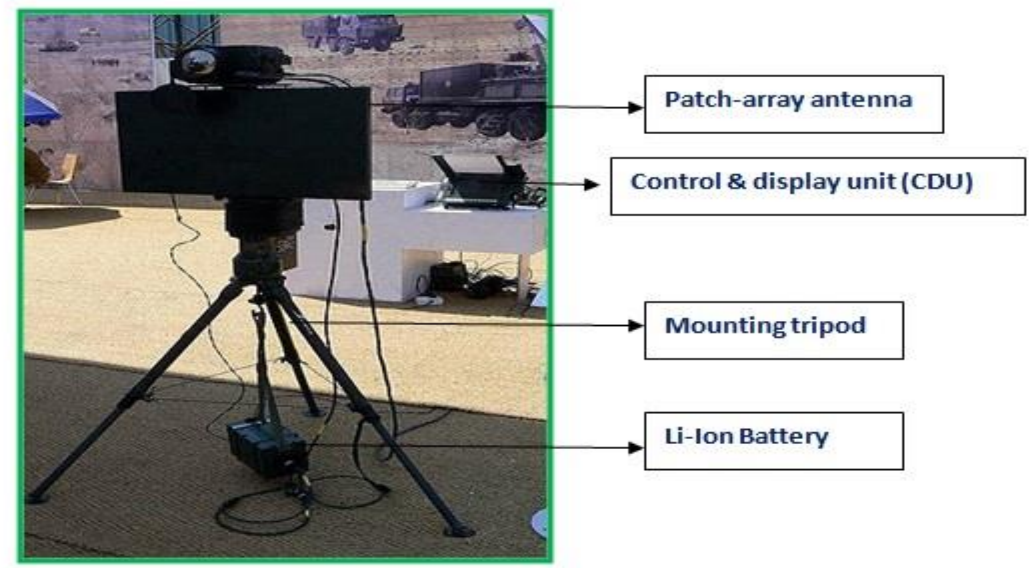
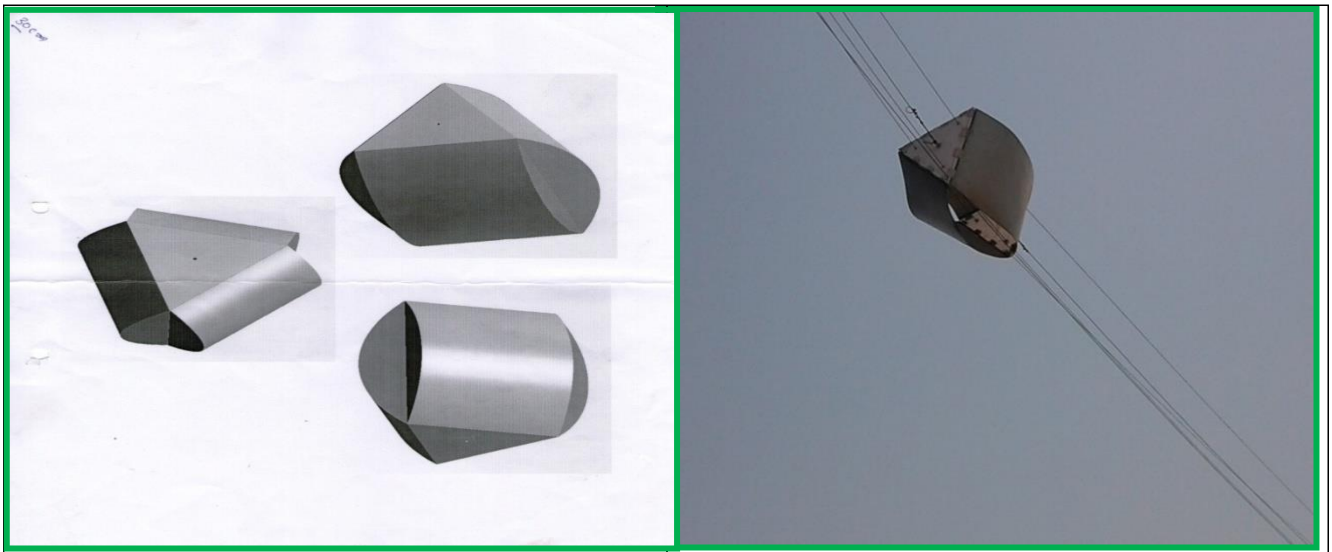


Figure 4: Portable X-band short range Radar.



Left is the side view of the prism. Right (above) is the side and bottom view of the prism and right (below) is the top view of the prism.	**ACTR on wire. By 2 HP a motor it moves left to right or right to left with controlled speed and also it rotates on horizontal axis in steps of 120^0 each.**

Figure 5: It shows the convexity of each surface of prism and mounted ACTR on wire.

This is to ensure that incoming radar beam towards the surface of moving prism makes least possible angle with the normal to the surface of prism. The lesser is the angle to the normal the higher is the back scatter towards the radar antennae. The prism design its mounting on rope is shown in the Figure 5. Each rectangular face of the target is of dimension 1.25m /1m in length and breadth respectively and the total weight is about 25-30 KG. Each face is made in such a manner so that it forms a convex plane.

4.2 Support system

Entire ACTR with support system is shown in Figure 6. Entire arrangement consists of two poles of height 10 m and 50 m apart. A triangular prism is hanging on two wires through it. These wires are fixed on two pulleys – one on either pole. Each rectangular convex face of the prism is of dimension 1.25m x 1m. These pulleys are made to

Figure 6: A live picture of the Artificial Cloud Target for Radar (ACTR) on wire supported by two yellow pillars on either side.

rotate by 2 HP motor to spin the prism on horizontal axis. Each rotation is in the steps of 120^0, so that after every one step different face of the prism faces radar antenna. Either end of the prism is also hooked up to separate wires; other ends of these wires are connected to geared pulley devices attached on the pole facing the side. If prism has to move to right then right side pulley pulls it and left side pulley relaxes the rope similarly if prism has to move to left then left side pulley pulls it and right side pulley relaxes the rope. To avoid the impact by the prism on extreme ends there are sensors installed on either side so that motor will switch off one meter short of extreme end of the rope.

Some more features with their photos are described below:

Poles, Ladder arrangement with platform: To make the aerial arrangements of the target 10 meter above the ground, this is required as support on either side. Higher location of prism helps remove the ground clutter while tracking by the Radar. Refer picture in Figure 7. To make any changes in the target, wires, pulley etc. Also to lubricate the entire chain, wire system.

Electrical Motor, toothed gear chain arrangement: Figure 8 shows the tooth gear chain at the bottom of the pillar. Chain connects to the other tooth gear on the top of the pillar in line with the horizontal motion of the prism. Also a spring lock is provided on the gear so that is can be locked after 120^0 rotation of the toothed structure. Arrangement is made to manually fix the rotation after each 120^0.

Figure 7: Pole with ladder and platform.

For rotating the prism, one 2 HP Electric motor is also fixed with the gear on top of the pole to rotate in steps- refer Figure 9(a). Normally motor is used for the rotation. Manual arrangement is only standby device in case of power failure. Another 2HP electrical motor (Figure 9b) is fitted on the top of the platform which provides the required driving power to move the target both in forward and reverse direction. It is a both forward/reverse geared motor.

Control panel: This is the heart of entire structure which controls the entire operation of the ACTR.

Entire operation is achieved by microcontroller programming. Main controls consist of (i) Forward and reverse motion of the target, (ii) Speed of the target, (iii) Load capacity of the motor and (iv) Operating frequency as displayed in Figures 10& 11.

Figure 8: Toothed wheel with handle for manual rotation.

Figure 9: Two-HP forward/reverse geared motor.

Figure 10: Some parts of Control Panel

Figure 11: Other parts of Control Panel

Table 1. Data collected from the artificial cloud target tracking by X-band radar.

Sl .No.	Track ID	Range (m)	Azimuth (degree)	Speed (m/s)	Strength	Date	Month	Year	Time (Hour:Min:Sec)
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	1	119	314.22	-1.93	24	3	4	2013	18:41:00
2	1	111	317.11	-3.97	53	3	4	2013	18:42:00
3	1	101	323.13	+5.46	61	3	4	2013	18:47:00
4	2	108	325.11	+7.56	126	3	4	2013	18:53:00
5	2	113	335.92	+7.25	82	3	4	2013	18:55:00
6	2	126	342.44	+1.77	151	3	4	2013	18:59:00

Table 2. Derived data or Range, Azimuth, Speed and Direction of motion from Table 1.

Sl No.	Range (Meter)	Azimuth (Degree)	Position (x , y) (Meter)	Speed (m/sec)	Actual speed (m/sec)	Heading(θ) (Degree)	Actual Heading (degree)
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	119	314.22	(118.7,7.22)	6.12	6.0	79.62	78.00
2	111	317.11	(106.1,21.05)				
3	101	323.13	(90.7,55.69)				

5. Theory of Operation and Software Development

As the three faced prism horizontally moves on the wires from left to right and right to left at a controlled speed, it simulates horizontally moving convective cloud. Further, while moving horizontally as it randomly rotates in steps of 120^0 angle on the horizontal axis its different faces, successively would face the radar antennae, located at a fixed point at about ≥ 100m from the two poles of ACTR. And because each face of prism has different reflectivity radar would receive random change in reflectivity of the moving target. This would, therefore, simulate the moving convective cloud whose reflectivity is increasing or decreasing randomly, as noted in the actual DWR data presented in table-1. To identify the specific target of interest (TOI) i.e. prism among several of undesired targets filtering is done to spot out the same as follows:

(i) Identifying the target of interest (TOI) as anything within the range 90-140 m as the poles are about 100 m away.

(ii) Name out various targets IDs from 1, 2, 3 etc. ID no.1 is for TOI.

(iii) Radar information are stored in a text file that is already designed inside the receiver program to obtain all the information.

(iv) The text file is converted to a “MS –Access” database file where the above described filtering actions could be applied i.e. ID’s ≥ 2 are ignored in each sweep.

(v) Data related to Id 1 are only stored.

(vi) The software developed will fetch the “MS-Access file/excel sheet” to obtain the desired information and to automatically analyze the data.

Serial numbers of the observations are given in the first column of Table 1. Column 2 gives the Tack ID of the moving prism target of ACTR. As the radar can track multiple targets, each target is identified by its ID. Since any other target is noise for the study, Target ID's ≥ 2 are filtered from the display. They are not presented in the Table 2. These observations are recorded when the simulated cloud target (prism) is made to move from left to right (Fig.6) at an average speed of 5 m/s. Initially as the prism starts moving from its stationary position, its speed is < 5 m/s; thereafter it rapidly gains speed of >5 m/s. Once the prism reaches 1 m away from the left pole the speed rapidly drops down and becomes 0 m/s as it touches the left end. Radar is located 100 m away. Left pole is to the left of radar and right pole is to the right of radar. Column 3 shows the range of target i.e. distance of prism from the radar. Column 4 gives the azimuth of the target with respect to the radar. Column 5 epicts the radial speed of the target with respect to radar location point. Negative sign indicates the speed towards the radar and positive sign shows the speed away from the radar. Column 6 gives the strength of the received signal in normalized form. It is a dimensionless quantity computed by taking the ratio of strengths of back scatter signal power (reaching radar receiver) with that of transmitted power multiplied by a large constant and rounded to its nearest integer. Date, month, year and time are mentioned in col. 7 to 10 respectively. Computed values based on Table 1 (simulated cloud data) as observed from the X-Band radar, is presented in Table 2.

5.1 Development of software for computing the reaction time

Total Reaction Time (Kumar and Pati; 2015) may be defined as the time taken by any cumulus cloud with reflectivity 20 dBZ to grow till its reflectivity reaches 45dBZ; a threshold for occurrence of hails in thunderstorm (Witt et al, 1998; Singh et al, 2010; Srivastava et al 2011). Available Reaction Time (ART) is the time actually available within the TRT for action against the growing cumulus cloud growth. In the dimensionless unit form software was written assuming the 45 dBZ value as 100. Several observations of reflectivity in dimensionless form were recorded for three consecutive time intervals as for t_1, t_2 and t_3. Quadratic extrapolation (Kumar and Pati, 2019, a &b) was done to determine the time reaction time for 100. Having perfected the software, the units were replaced by dBZ values and 100 by 45 dBZ value (Fig. 12).

5.2 Development of software for computing the speed & direction

Kumar and Pati (2019) have presented the algorithm of position and speed computation. In Table 2, columns 2&3 indicate the range and azimuth of the TOI respectively. Column 4 shows the x and y co-ordinates. Columns 5&7 give the speed and heading (direction) respectively, calculated by the algorithms respectively. Columns 6&8 show the actual speed and heading (direction) respectively. It may be noted that the speed and heading are calculated with error of -0.12 m/s (column 6 – column 5) and -1.62^0 (column 8 – column 7) respectively.

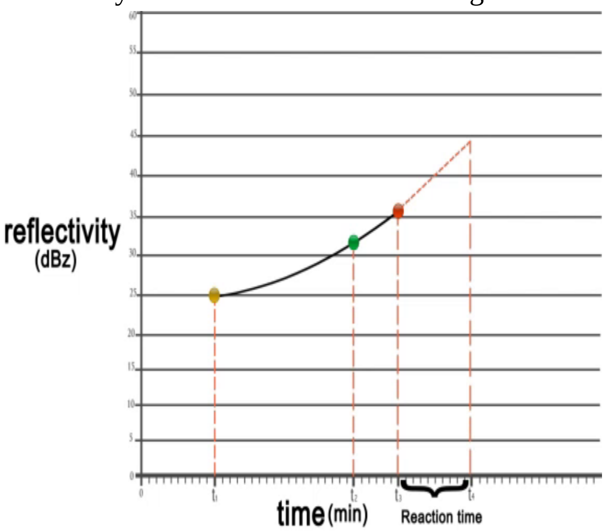


Figure 12: Reflectivity values for time t_1, t_2 and $t_3$are plotted. Best fit quadratic curve is extrapolated to cut 45dBz line at point. Corresponding time t_4 is known and t_4 - t_3 (Available Reaction Time) is computed by software.

As the methods described in Section 5 are based on linear extrapolation, the error would be large if the speed or directions are highly variable. Nevertheless, in short term predictions or in case of nowcasting, that possibility is unlikely.

6. Conclusions

(i) ACTR provides repeated data generation, even if there is no cloud.

(ii) As reaction time is limited for hail suppression, each second of Available Reaction Time is precious. ACTR provides instant processing of received data and spontaneous dissemination of processed data to cloud seeding activity without any loss of time.

(iii) Beside reaction time, ACTR can also be used for predicting the location, speed and direction of motion of the cloud with the same analogy as reaction time.

(iv) With known location and speed of moving prism, the resulting software outputs of location and speed prediction could be verified spontaneously.

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Appendix-A: X-Band Radar Hardware

Radar Array and Hardware: The radar array consists of:

(i) X-band Transmitter, receiver and processing modules within the single array block.

(ii) The signal processor is a single on-board -based chip, which consumes very less power.

(iii) The antenna array is made up of "microstrip (16*64)" patch array antennas.

(iv) The transmitter is a solid state transmitter module, while the separate receiver is "a super-heterodyne type receiver".

(v) The radar algorithm incorporates "Digital Pulse compression" Technology, which improves the LPI characteristics, as well as making the radar more accurate.

Display Unit: This is the most important part of the radar which the radar output unit.

(i) Our radar processing, display units and control functions are integrated on a single, touch sensitive, portable IBM PC, called the Control and Display Unit (CDU).

(ii) Some processing elements are also built into the radar.

(iii) The processed information is displayed on a high resolution 10.4" LCD colour display.

(iv) The PC operates on a Windows XP-based, menu driven user interface, which makes operating the Radar extremely simple.

(v) We can always visualize a high resolution, north oriented; colored radar picture is displayed on PC display.

(vi) The radar display can either be in a "Plan position indicators (PPI)" display or a "B-Scope" display.

(vii) A target position can be marked by means of a track ID for further investigation or to keep on tracking the same target for some time.

Radar interface

(i) The interface between the radar and the CDU can be either RS232C or LAN connectivity.

(ii) A light weight, rugged, standard 2-wire field cable is used for communicating between the radar and CDU. This allows the operators to be positioned up to 100 m away from the radar.

(iii) The use of wired interface also provides a better security from interception and lower noise, and does not require the radar and CDU to be within Line-of-Sight of each other.

Thermal Imager

(i) A third generation thermal imager has also been configured and integrated with it.

(ii) The imager has a single field of view (monocular sighting while operating in the Mid-wavelength Infrared (MWIR) spectrum (3-5 µm wavelengths), this gives the Radar day and night viewing capability.

(iii) All Radar data and images are combined and displayed on the common control and display unit (CDU). Thus, the radar can integrate its display with IR sensor output, which improves the overall efficacy of the system.

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