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DEVELOPMENT OF PHASED-ARRAY WEATHER RADAR SYSTEM FOR 3D OBSERVATION OF CUMULONIMBUS CLOUDS

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1. INTRODUCTION

In Japan especially in urban areas, natural disasters caused by extreme weather are recently increasing and the lives of citizen are at risk. Severe weather phenomena such as localized heavy rainfalls, gusts and tornadoes are mainly caused by the rapid growth of cumulonimbus clouds which grows to more than 10 km altitude. Generally, the lifecycle of a cumulonimbus cloud is as short as 10 to 30 minutes. However, conventional weather radar systems with parabolic antenna requires approximate 5 to 10 minutes for full volume scanning to observe the three dimensional structure of a cumulonimbus cloud, which has an inadequate capability in temporal and spatial resolution for observing the behavior of cumulonimbus clouds. [1] In order to achieve precise three dimensional observations of cumulonimbus clouds for predicting severe weather, weather radar is expected to observe the full volume of meteorological phenomena within 1 minute. Figure 1 shows a conceptual image of Phased-Array Weather Radar Operation.

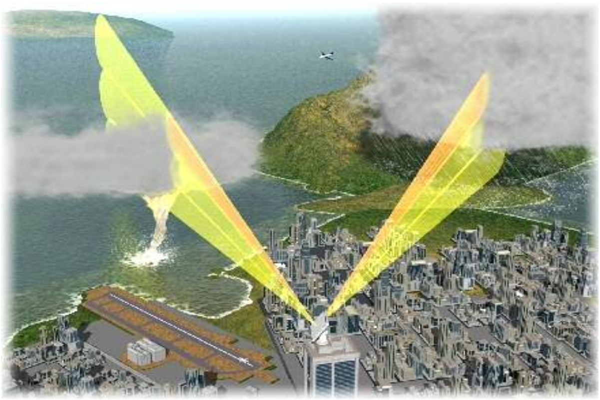

Figure 1: conceptual image of PAWR

2. SYSTEM OVERVIEW

Toshiba's newly developed X-band Phased-Array Weather Radar (PAWR), shown in Figure 2 has the capability to observe cumulonimbus clouds within 1 minute. PAWR is already installed at Osaka University (Japan) under a grant of NICT, has a 128-slotted array antenna and applied Digital Beam Forming (DBF) technique to simultaneously generate the multiple vertical beams for covering the elevation angle from 0 to 90 degrees. PAWR antenna is mounted with a mechanical drive for azimuth angle and electronic scanning for elevation angle. For the elevation angle, the transmitted beam is formed as a fan beam, and the received beams are formed as multi-beam using DBF technology. Tilt angle of the antenna was set to 30 degrees in elevation, transmitted and receiving by time-division radio wave from -30 degrees to +60 degrees, to observe without a gap from 0 degrees to 90 degrees in elevation. The main feature of PAWR is to perform dense 3-D volume scanning within 10 to 30 seconds without gaps between each beam.

Figure 2: X-band PAWR installed at Osaka University

Table 1 describes the major specifications of PAWR. This system has two observation modes. One is “Rapid Mode” which able to update the full volume scanning in 10 seconds with the 20 km radius range. Another is “Wide Range Mode” which observes a 60 km radius range in 30 seconds. Compared with conventional parabolic antenna weather radar, PAWR in “Wide Range Mode” has 100 elevation angles which is 10 times more numerous than conventional radar, and scanning time has been reduced to 30 seconds compared to 5 minutes for conventional radar. In total, performance is 100 times improved by PAWR. Typical observation range for rapid mode is shown in Figure 3. Comparison of PAWR and conventional radar are shown in Figure 4.

Table 1: Major Specification of PAWR

Major Specification		
Tx Power	430 W or higher	
Tx Frequency	9,320 to 9,445 MHz (5MHz step)	
Beam Width (after DBF)	About 1 degree	
Range Resolution	100 m	
Doppler Velocity Measurement	60m/s (max); Dual PRF	
Doppler Velocity Accuracy	0.1 m/s	
Observation Mode	Rapid Mode	Wide Range Mode
Coverage Area (Radius)	20 km	60 km
Full Volume Update Time	10 sec	30 sec
Number of Hits	10 hits	20 hits
Simultaneous Elevations Scanned	100 angles	100 angles

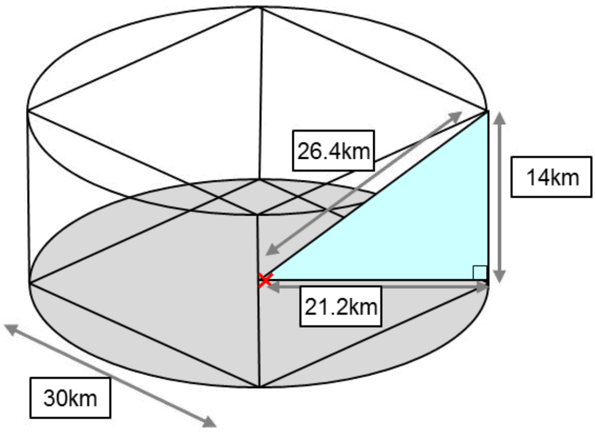

Figure 3: Typical observation range for rapid mode.

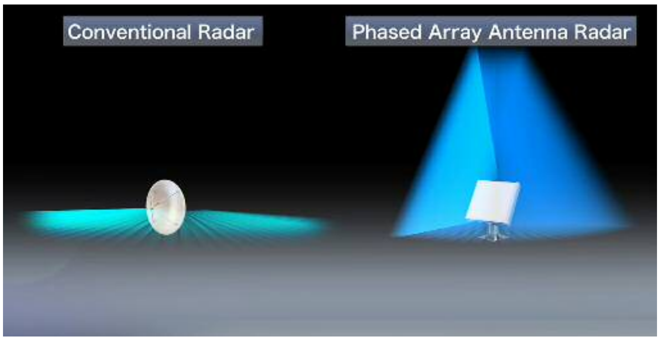

Figure 4: Comparison of conventional parabolic antenna radar and phased-array antenna radar

3. DEVELOPMENT AND EVALUATION OF ACTIVE PHASED ARRAY ANTENNA

Figure 5 shows the active phased array antenna used in PAWR which consisted of 128 slot antennas and its aperture length is 2 m by 2 m. This antenna has receiving and transmitting units, DBF units, and those units are located in the rear side of antenna. Figure 6 shows the Transmitting and receiving unit (TxRx unit). Each TxRx unit or Rx Unit has the capability of transmitting or receiving up to 8ch. This radar is able to transmit up to 24ch with 3 TxRx Units, and receive up to 128ch with 13 Rx Units.

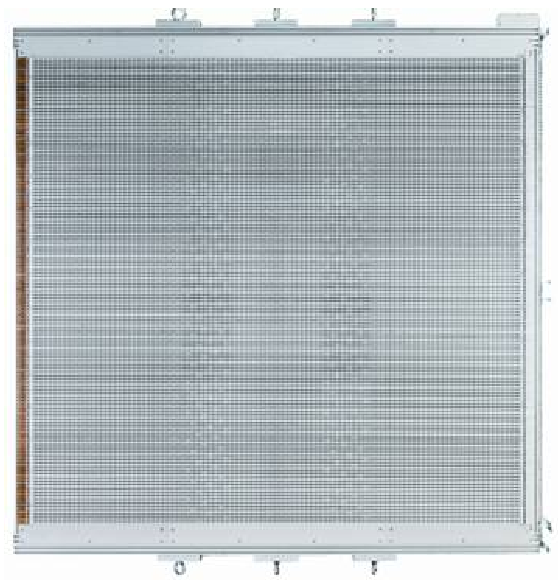

Figure 5: PAWR Antenna

Figure 6: Transmitting and receiving unit

The DBF Unit has the capability of processing 128ch synchronized A/D conversion and I/Q detection, and it has at least 60dB of dynamic range. The receiving multi beams at 1 degree from 128ch I/Q signals are formed by DBF technology. DBF Unit is capable of simultaneously handling 16 beams at same time. Actual measured antenna pattern is shown in Figure 7 and Figure 8. Azimuth beam width is about 1 degree and side lobe is less than -23 dB. Elevation beam width is about 4 degrees for transmitting by using 24 elements (24 slots), and about 1 to 1.2 degrees for receiving by DBF technique.[2]

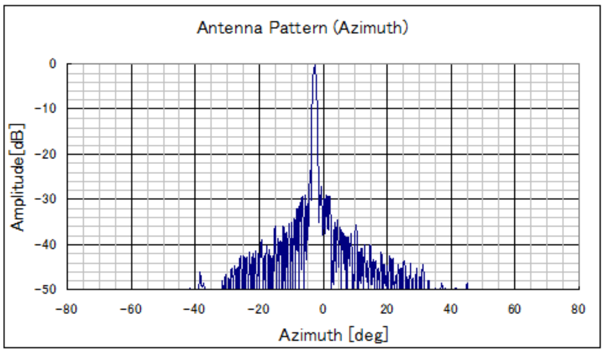

Figure 7: Antenna Pattern (Azimuth)

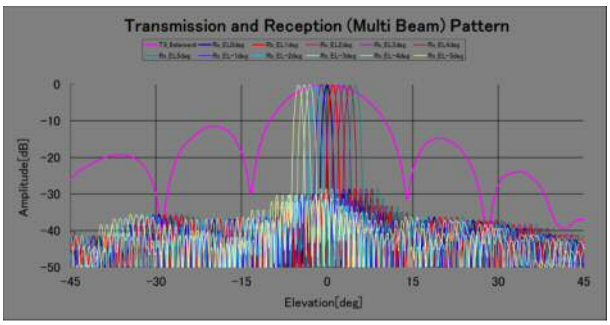

Figure 8: Antenna Pattern (Elevation)

For the reception pattern of elevation direction, we have achieved the reduction of the beam width to less than 1.2 degree at 0 degree elevation. Thus, the spatial resolution is about 500 m at 20 km, 1.3 km at 60 km; also able to observe all of the observation space and output 3D data such as radar reflectivity factor (Z) and Doppler velocity (V) within minimum of 10-second intervals.[3]

4. OBSERVATION RESULT

Figure 9 shows the three dimensional image of actual observation results observed in July 26, 2012. One cumulonimbus echo was about 3 km vertically and 8 km horizontally. Observation data showed a small indication of heavy rainfall (we call it an "a heavy rainfall in the making") of 4 to 6 km in altitude has exponentially grown and then became localized heavy rainfall within few minutes. By using PAWR, any changes in localized meteorological phenomena can be observed every 30 seconds or less. Our system is expected to use for preventing disasters by forecasting localized heavy rainfalls, gust and tornadoes.

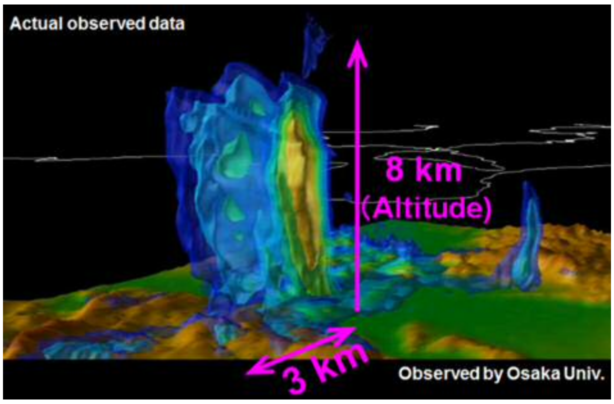

Figure 9: Localized heavy rainfall at East Osaka, view from Kyoto (North-East) direction (July 26, 2012,17:00:16)

5. FUTURE WORK

Continuing collaboration with Toshiba Corporation, NICT and Osaka University., we will work on the development of new signal processing techniques which adaptively forms antenna patterns, data archiving and the analysis of so-called "big data" and three-dimensional visualization.

ACKNOWLEDGEMENT

The authors wish to thank of Toshiba radar antenna engineers for their contribution to the measurement process of Active Phased-Array Antenna: M. Tanabe and Y. Masuda.
This research is supported by the National Institute of Information and Communications Technology (NICT), Japan.

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