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Solid-state weather radar which reached the practical use stage

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Abstract—. **The purpose of this paper is to describe the characteristic and performance of X-band solid-state weather radar and to show the solid-state radar has the equivalent or higher performance to other klystron radars using the data of these new radars in operation (provided by the "Technical Development Consortium Related to X-Band MP[1] Radar" which was established by MLIT Consortium).**

I. Introduction

With a rush of disasters in recent years caused by unusual weather, especially localized torrential downpours and gusts, weather radar plays a more and more important role in weather observation.

To deal with these phenomena, we have developed the latest model of weather radar (manufactured by TOSHIBA corporation) and installed it under management of MLIT[2] in 2010. This is the first X-band solid-state weather radar in service in Japan, which adopted new technologies including multi-parameter observation and solid-state transmitter to enable very accurate observation of precipitation and to achieve drastic reduction of its size and life cycle cost. This year, 9 units of X-band solid-state weather radars have installed by TOSHIBA corporation.

The new weather radar will provide us with useful weather observation data and contribute significantly to improvement of safety and security of our society.

II. Solid-state transmitter

Figure 1 shows the process of evolution of weather radar in Japan. The weather radar in the initial stage started its operation as an analog radar which displayed the intensity of back scattering of radio wave from rain as the intensity of brightness on a display. Later, the observation values were digitalized to enable the observation of rainfall quantitatively. In the 1990's, the weather radar in Japan was divided into two radar types: Doppler radar and dual polarization radar. The transmitter type changed from magnetron to klystron.

Today, MLIT tries to deploy dual polarization radars. Solid-state transmitters are employed for most of these radars.

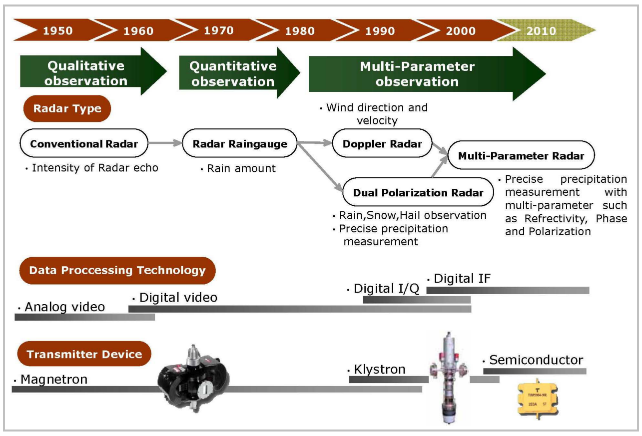


Figure 1. Evolution of Weather Radar in Japan

III. X-band Solid-state weather radar

A X-band Solid-state weather radar

The X-band solid-state weather radar which was first put into service in Japan employed solid-state transmitter and small and high-performance digital signal processor to enable wide-area and high-precision observation with small power.

Figure 2 shows the first solid-state weather radar and Figure 3 shows the major components. The major components were accommodated in the radome at the top of a steel tower by making them compact and light weight. Thus, the attenuation of radio wave by the length of wave guide was minimized to allow sufficient observation

[1] MP:Multi-Parameter

[2] Ministry of Land, Infrastructure, Transport and tourism

performance with small power. The size was reduced by approximately 1/4 (based on Toshiba products) compared with the conventional weather radars and the consumption power was reduced by approximately 1/10 (based on Toshiba products). TABLE I. shows the major specification of this weather radar.

Figure 2. X-band solid-state weather radar (outward appearance)

Figure 3. X-band solid-state weather radar (installed in a radome)

TABLE I. TYPICAL SPECIFICATION OF SOLID-STATE WEATHER RADAR

Item	Description
Observation range	80 km or more in radius
Frequency	One of the waves in the frequency range from 9.7 to 9.8 GHz
Pulse width	1 μ sec; 32 μ sec
Peak power	200W or more (horizontal polarization)
	200W or more (vertical polarization)
Receiver dynamic range	95 dB or more
Radome diameter	4.5 m or less
Antenna diameter	2.2 m or less
Antenna gain	41 dB or more
Beam width	1.2 deg or less
Range resolution	150 m or less
Elimination of ground clutter	Coherent MTI system
Output data	Received signal power (Ph, Pv) (dB)
	Doppler velocity V (m/s)
	Spectrum width W (m/s)
	Differential phase φDP (deg)
	Correlation coefficient (ρ HV)

B. *Frequency separation of short and long pulses*

The pulse compression is performed by giving linear FM modulation to the long transmitting pulse of 32μs in this weather radar to achieve the range resolution of 150 m. As radars cannot transmit while receiving, the observation in a short range is not possible while transmitting long pulses. To solve this problem and to enable full coverage from short range to long range, the observation by short pulse for short range observation is also performed. Figure 4 shows the time sequence of transmitting pulse.

According to this system, the reflection wave of long pulse from precipitation area which is outside the observation range is also received at the same time and the reflection waves of short and long pulses are mixed in the radar of its own station. To avoid this problem, the frequencies of short and long pulses are detuned in this radar as shown in Figure 5.

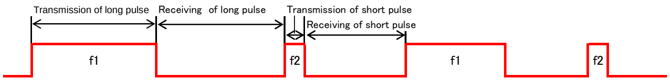


Figure 4. Transmission and receiving schedule of solid-state radar

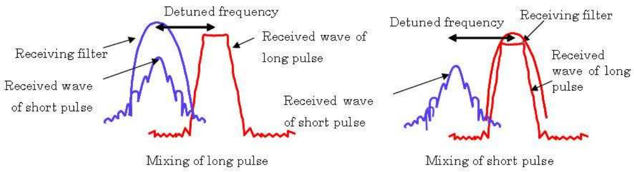


Figure 5. Separation of frequencies of long and short pulses

Figure 6 shows the calculation result of received level when the frequencies of transmitting and receiving waves of long and short pulses are detuned (when the frequencies are separated). For example, if the frequencies of transmitting and receiving waves are detuned by 2.5 MHz, the received level is reduced by 35 dB for short pulse and the received level is reduced by 50 dB for long pulse.

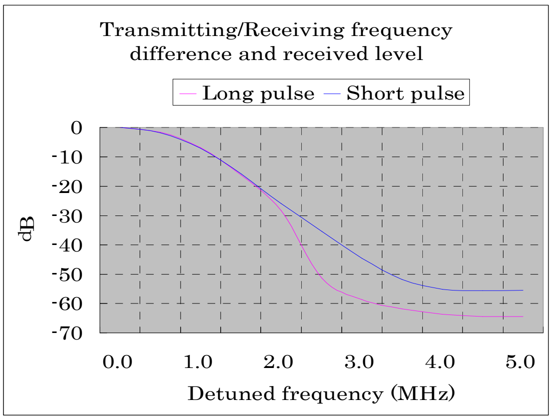


Figure 6. Suppression of received level by frequency detuning

Figure 7 shows the relationship between the intensity of the mutually interfered secondary echo and the intensity of the primary echo. If the frequency is not detuned, it is observed that the received power is reduced approximately by 15 dB when the secondary echo of long pulse interfered in the short pulse area. The received power is reduced by approximately 35 dB when the short pulse interfered in the long pulse area. As the received level is further reduced by

50 dB for long pulse and by 35 dB for short pulse when the long and short pulses are detuned by 2.5 MHz, the precipitation intensity of the secondary echo is reduced to 0.01 mm/h which is a negligible level.

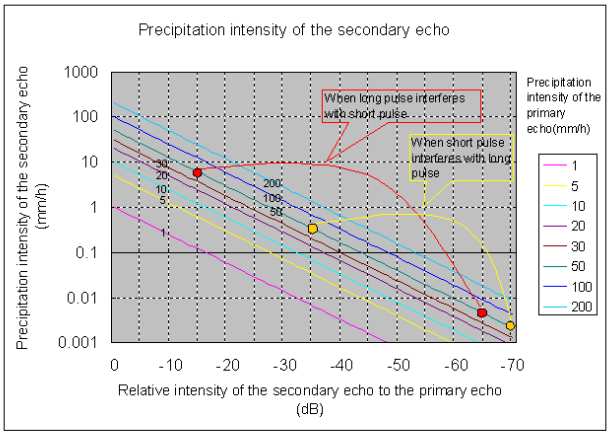


Figure 7. Effect of interference suppression

IV. OBSERVATION DATA

A X-band MP Radar of Kinki area network(MLIT)

As shown in Figure 8, Ministry of Land, Infrastructure, Transport and Tourism has installed 4 units of X-band MP radars in Kinki Area. The one installed in Jyubusan is a solid-state radar while the other three are Klystron radars.

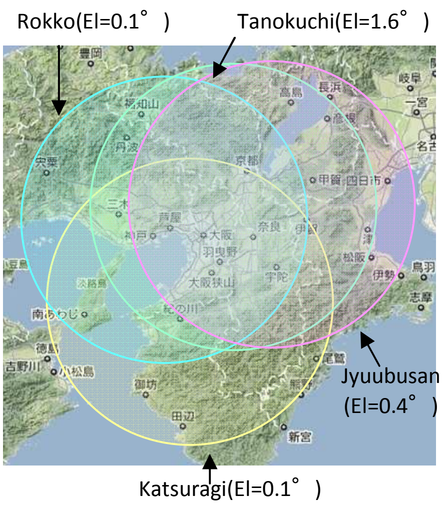
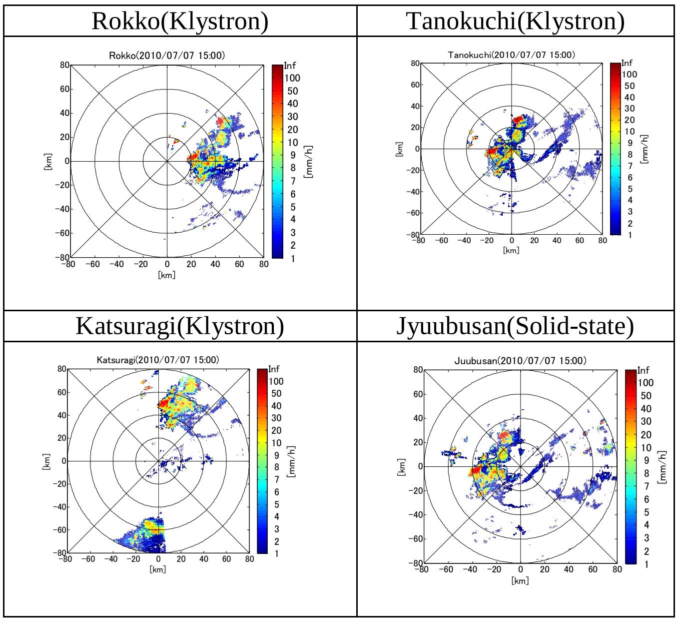


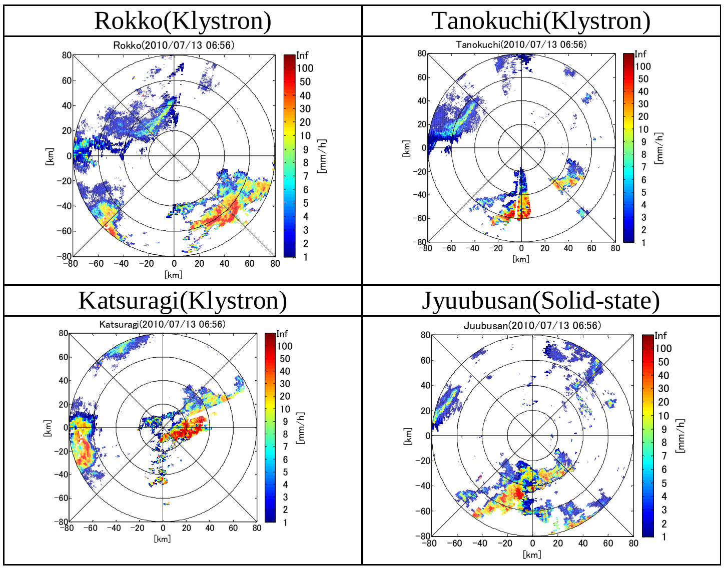
Figure 8. X-band MP radar of Kinki area network (MLIT)

B Observation examples by X-band MP Radar

Figure 9 shows the result of two observation examples by these 4 radars. As shown in Figure 9, the results of radar observation are very similar and no conspicuous difference is found among the radars.



(a) 2010/07/07 15:00



(b) 2010/07/13 06:56

Figure 9. Radar echo observed by the solid MP radar and Klystron MP radars

C Comparison of observation data among the radars.

Figure 10 shows the scatter diagram of precipitation intensity observed by each radar and TABLE II. shows the correlation coefficient of precipitation intensity among the radars.

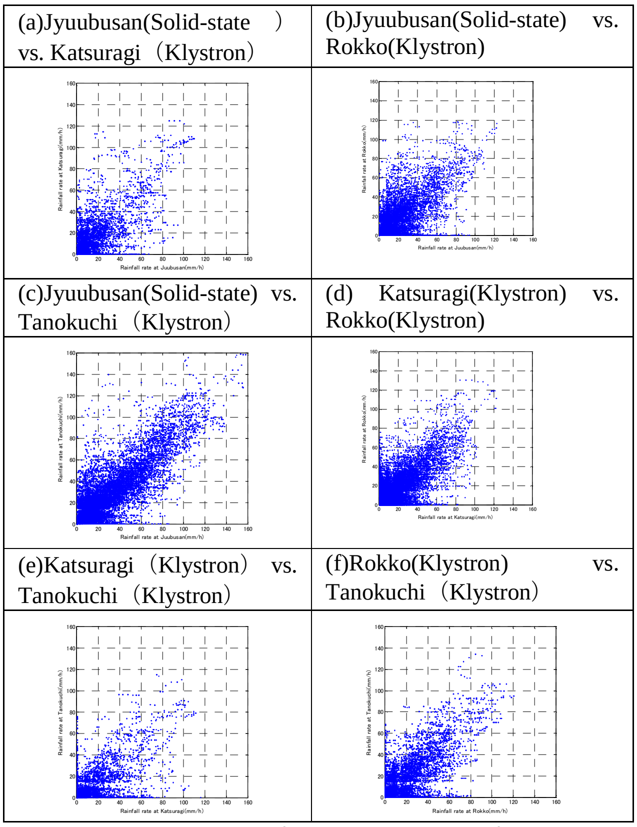


Figure 10. Scatter diagram of precipitation intensity of solid and Klystron radars

TABLE II. CORRELATION COEFFICIENT OF PRECIPITATION INTENSITY

		Klystron		
		Katsuragi	Rokko	Tanokuchi
Klystron	Katsuragi	–	–	–
	Rokko	0.808	–	–
	Tanokuchi	0.756	0.798	–
Solid-state	Jyuubusan	0.680	0.725	0.823

As shown in TABLE II. , the correlation coefficients of the solid radar in Jyuubusan and the Klystron radar in Tanokuchi are the highest(0.823) while the correlation coefficients of the Klystron radars in Tanokuchi and Katsuragi are the lowest(0.756).

Generally speaking, the correlation coefficient of radars are higher if the distance between sites are closer. Therefore, Figure 11 shows the relationship between the distance among the radar sites and the correlation coefficient.

As shown in Figure 11, the correlation coefficients of the radar sites are apparently dependent on the distance among the radar sites. It is evident that, if the distance among the sites is shorter, the correlation coefficient is higher. In comparison with this, the difference of transmission system, whether it is solid-state or Klystron, seems to have no effect on the result. This fact endorses the conclusion that the observation by solid-state radars is equivalent to that of the conventional Klystron radars.

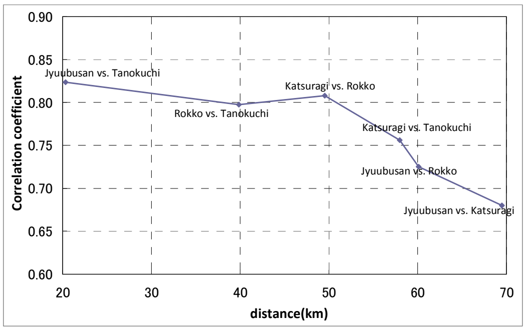


Figure 11. Relationship between the distance among the radar sites and the correlation coefficient

D Observation data by C band solid weather radar (provided by Meteorological Research Institute)

Figure 12 and Figure 13 show the stratiform precipitation observed by C band solid-satate weather radar and Figure 14 and Figure 15 show the observation result of convective precipitation. In the observation result of stratiform precipitation, the melting layer is clearly represented and the three dimensional structure of raindrop size can be inferred in the convective precipitation. From these results, we can conclude that solid-state weather radars allow us to obtain favorable result in the dual polarization observation.

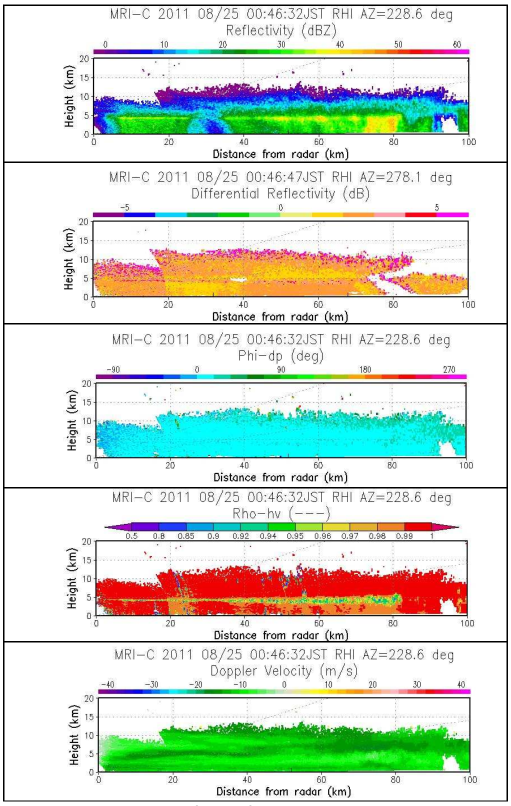


Figure 12. RHI display of stratiform precipitation(C-band)

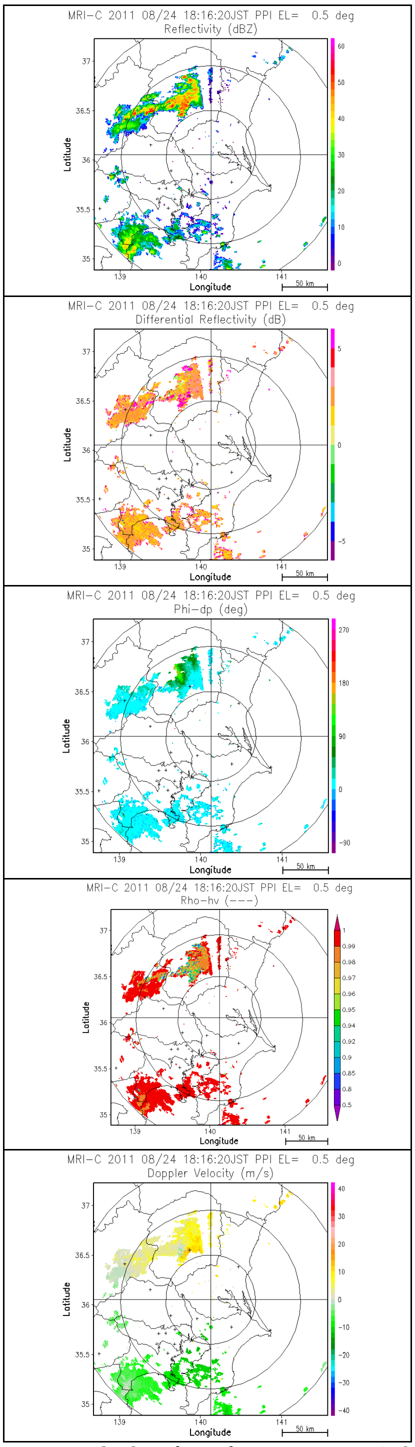


Figure 13. PPI display of stratiform precipitation(C-band)

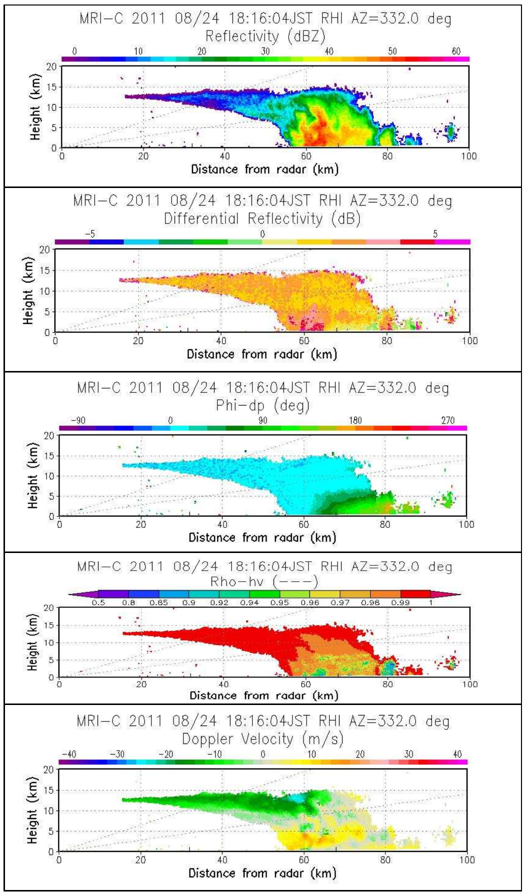


Figure 14. RHI display of convective precipitation(C-band)

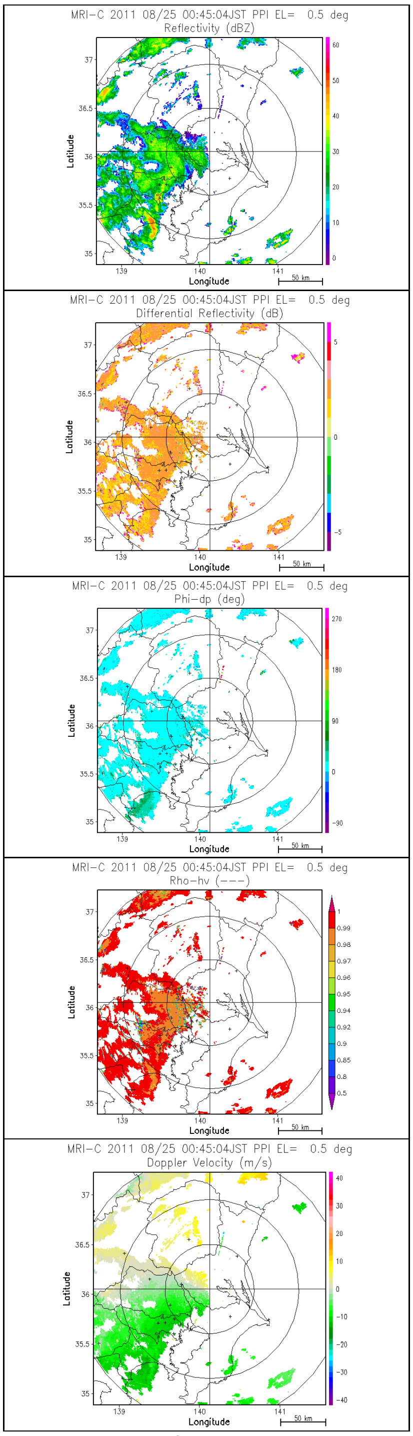


Figure 15. PPI display of convective precipitation(C-band)

V. Distribution of Observation Data Through the Web

The high-precision observation data obtained by X-band solid-state weather radar is distributed to public tentatively to be used for evacuation and disaster prevention activities when torrential rainfall occurs after going through a variety of processing together with observation data of other X-band multi-parameter radars provided by MLIT (Figure 16).

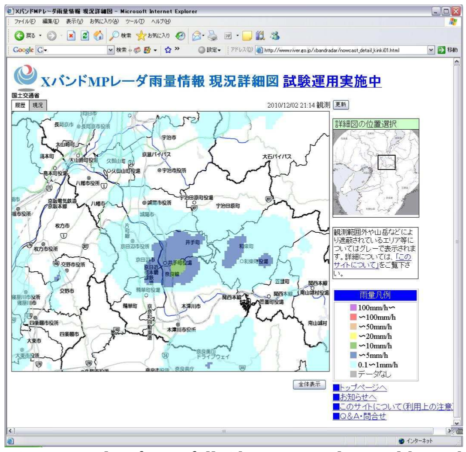


Figure 16. Example of Rainfall Observation detected by X-band MP Radar (provided by Ministry of Land, Infrastructure, Transport and Tourism)

*The title of this example should read "X-band MP radar precipitation information Under test

VI. Conclusion

10 units of solid-state weather radars have installed by TOSHIBA corporation for actual operation in Japan and the service is started for general public. Satisfactory results which are comparable to electronic tube radars are obtained. In addition, C-band solid-state radar has already been developed as well as S-band solid-state power amplifier.

We hope new X-band solid-state weather radar, which features the compact and light-weight design with its low running cost and low spurious level, will be used worldwide.

Acknowledgments

We would like to express our appreciation for the observation data of X-band MP radar which was provided as a part of activities of "Technical Development Consortium Related to X-Band MP Radar" established by MLIT.

We also express our sincere gratitude for the data provided by Meteorological Research Institute.