A KU-BAND DUAL-POLARIZATION RADAR WITH SIMULTANEOUS RECEPTION - SYSTEM -

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1. Introduction

We have developed a Ku-band dual-polarization radar, and made some rainfall observations to test rainfall rate estimates with Zdr observation. Our system adopted a FM-CW radar with two small offset parabolic antennas, and can obtain horizontal and vertical components of rain echo using a slow polarization switching mechanism [1]. From these rainfall observations, we confirmed that measured Zdr by this dual-polarization radar correlates two independently estimated Zdrs, one is calculated from raindrop size distributions obtained by a disdrometer, and the other is estimated from a vertically pointing C-band Doppler radar observation [2]. The fluctuation of measured Zdr values is, however, so large that it prevented the rainfall rate estimate by Zdr values. The fluctuation comes from the loss of a correlation between two polarizations during the polarization switching time. To reduce the fluctuation of measured, we have been developing a new system which enables to receive horizontal and vertical polarization of rain echo simultaneously. The system consists of a large Cassegrain antenna (13 m diameter) with one transmitter and a small offset parabolic antenna (60 cm diameter) with two coherent receivers. We made some experiments for a test of the performance of the system. In this paper, we introduce the new system and preliminary data.

2. System for simultaneous reception

In our new system, polarized transmission at 45° to the horizontal is used, and the backscattered echo is received at both horizontal and vertical polarizations simultaneously[3]. The block diagram and parameters of this system are shown in Fig.1 and Table 1, respectively.

A function generator is used to produce a triangle waveform that modulates the transmitter carrier frequency. Modulated wave around 140 MHz (IF) is up-converted to the transmitted frequency, the center of which is 14.3625 GHz. Amplified radio wave by a high power amplifier (HPA) up to 300 w is transmitted with a large Cassegrain antenna. The polarization plane of transmitted wave, which is easily changed by a polarizer, is set at 45° to the horizontal to have the same horizontal and vertical components [3].

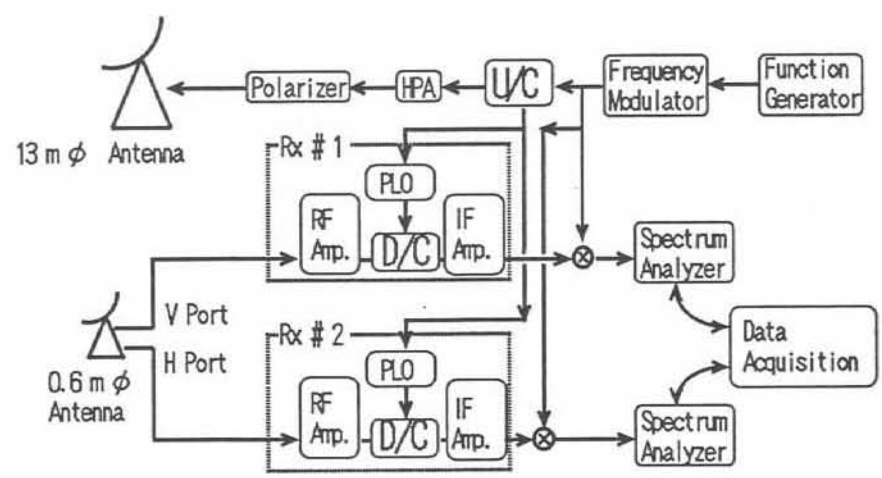

Figure 1 Block diagram of the dual-polarized radar for simultaneous reception.

A returned signal from rain is received with a small offset parabolic antenna, and is divided into the horizontal and vertical components at the antenna port. Two polarization signals are down-converted with the same reference signal to the IF frequency (140 MHz), and mixed with the current modulated IF signal. The output signals of mixer are led to two spectrum analyzers, and the frequency spectra are recorded by a personal computer with the GP-IB interface.

Table 1 **Specification of the dual-polarization radar**

Type	FM-CW
Center frequency	14.3625 GHz
Bandwidth of sweep	7.5 MHz
Sweep frequency	300 Hz
Sweep waveform	triangular wave
Transmitting power	300 W
Transmitting antenna gain	63.2 dB
Receiving antenna gain	37.3 dB (H) / 37.2 dB (V)
cross polarization	below −23 dB (within 3dB beam width)
Receiver gain	more than 40 dB

One of the features of our system is that used radio wave frequency is 14 GHz (Ku-band). S-band or C-band are mostly used for dual-polarization radars. At Ku-band, as well as its rain reflectivity and attenuation increase, an effect of Mie scattering appears. These characteristics may be utilized for acquiring more information about raindrops, especially its deformation. On the other hand, rain echo fluctuates more rapidly as used wavelength is shorter, since rain echo is a sum of signal backscattered by a number of raindrops which are randomly arrayed and moving. Therefore, it is difficult to get Zdr with enough accuracy with an alternative reception by a polarization switching,. This weak point will be removed by an simultaneous reception.

Another feature of our new system is a capability of LDR (Linear Depolarization Ratio) measurement. In our system, the polarization plane of transmitted wave can be easily altered. For example, it takes a few minutes to change from a horizontal to a vertical polarization with manual operation. LDR is measured as the ratio between two received powers at two polarizations, when a horizontal (or vertical) polarization wave is transmitted. The small offset Cassegrain antenna for reception was designed to suppress a cross-polarization component below −23 dB (within 3 dB beam width). We expect that this ability of LDR measurement will distinguish hydrometeors, and that it will be available for a study of melting layer.

3. Preliminary results

In Fig.2, observed spectra of the horizontal and vertical polarizations are shown. The upper thick line is the horizontal component of rain echo, and the lower thin line is the vertical one. The horizontal axis represents frequency, which corresponds to the range of the scatters. The vertical axis represents the power of received rain echo. Since we have not done the complete calibration of this system, the absolute values of these graphs are unreliable. However, the relative variations of those are reliable.

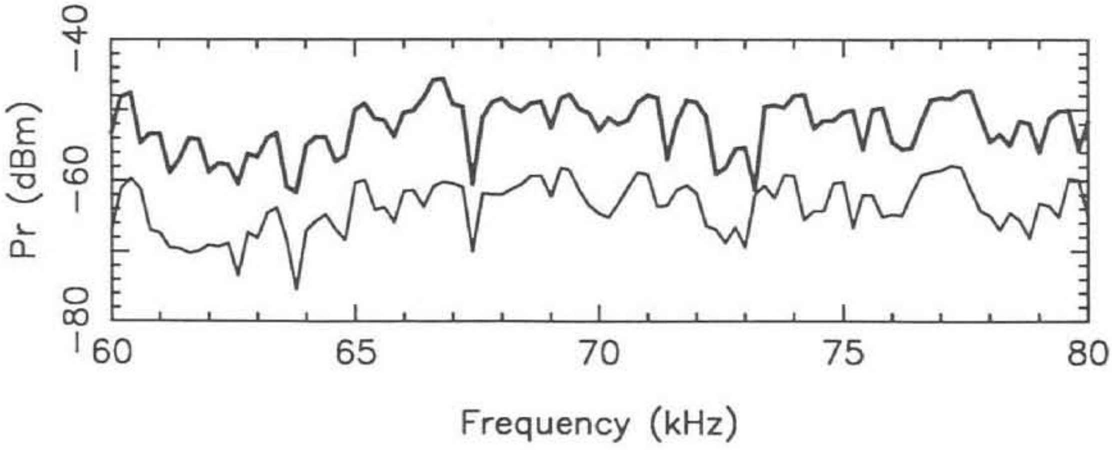

Figure 2 **Observed spectra of the horizontal (upper thick line) and vertical (lower thin line) polarizations.**

It is also noted that the variations in Fig.2 reflect fluctuations of rain echo in time domain rather than rainfall rate variations in space. This means that since frequency spectrum obtained by normal type of spectrum analyzer needs a sweep time, rain echo, which is a sum of numerous backscattered signals by randomly arrayed and moving raindrops, has a rapid fluctuation during the sweep time. In the case of the data in Fig.2, a sweep time, approximately 10 msec, was much larger than the typical correlation time of rain echo estimated about 3 msec for 14 GHz.

These observed spectra were obtained in a very light rain of less than 1 mm/h, which may mean that most of returned echo comes from signals backscattered at small radius raindrops. Small raindrop keeps sphere owing to little air resistance. Therefore, the difference between the horizontal and vertical components was thought to be very small, which is consistent with the similarity of two spectra.

To investigate the cause of fluctuation in received power, the same range data as in Fig.2 were gathered for several minutes, and shown as a scatter plot in Fig. 3. The horizontal and vertical axes means the received power of the horizontal and vertical polarization. The distribution has a good correlation, with a tendency that the extent of scatter is larger as the received power is smaller. This tendency cannot be explained by receiver noise alone, since two receivers' noise levels at that time were estimated −68 dBm and −77 dBm for the horizontal and vertical components, respectively. We considers that the tendency is a manifestation of rain echo consisting of numerous backscattered signals by randomly arrayed and moving raindrops. For a comparison, the pair of Z factor in simultaneous reception are simulated, and plotted in Fig.4.

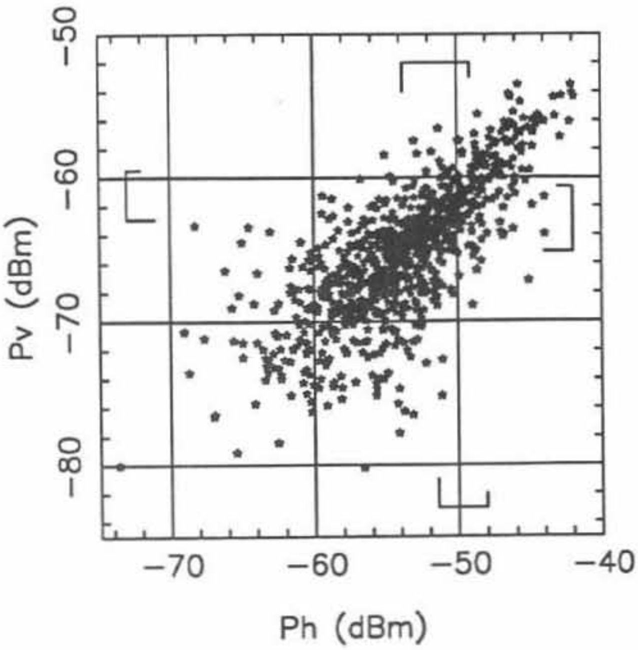

Figure 3 **Scatter plot of the observed horizontal and vertical polarizations.**

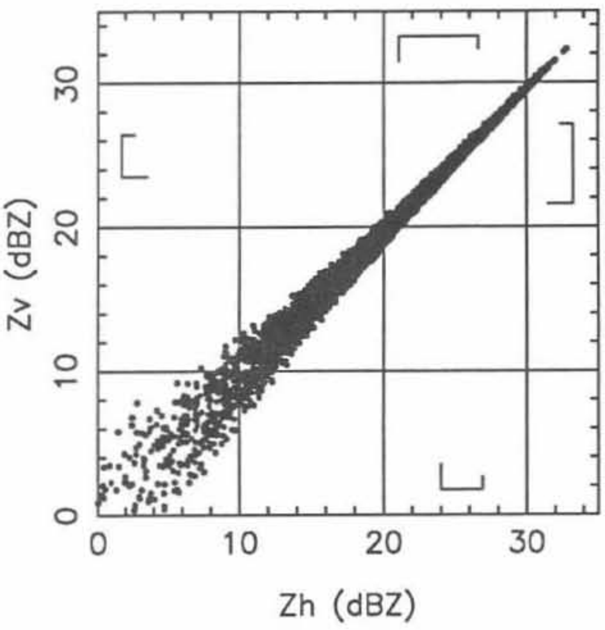

Figure 4 **Scatter plot of the simulated horizontal and vertical polarizations.**

Simulated raindrop size distribution corresponds to rainfall rate 1 mm/h. In this simulation, we assumed Marshall and Palmer raindrop size distribution, Gunn and Kinzer formula for raindrop terminal velocity, and radar reflectivity calculated by Oguchi's formulation for Prup pacher-Pitter form raindrop [4]. The received power is calculated as a sum of signals back-scattered at ten thousand raindrops, which fall with each terminal velocity, at an antenna elevation angle of 20°. The samples are from ten thousand-pulses with each interval 614 msec. Compared with that of Fig.3, the scatter of the simulated pair of Z factor has a similar tendency, but its magnitude is small. We think the difference explained by two reasons:
(1) The reference signals are supplied at 197 MHz from the up-converter to two receivers. Each receiver makes local frequency (14 GHz) separately with its own phase locked oscillator (PLO). Therefore, phase errors in PLO lose the coherence of the reference signals.
(2) Two spectrum analyzers are used for frequency analysis of two outputs of the mixers, and their differences on frequency response or sweep time result in the deviation of spectrum.

We now plan to down-convert with the same reference signals at 14 GHz by one PLO output divided two signals. To clarify a process of frequency analysis, digital processing will be useful. We prepare to record two outputs of the mixers in a personal computer, after A/D conversion. In this case, spectrum analysis will be done on the personal computer with on-line or off-line FFT. This upgrade will bring our system some good features: (a) flexibility in data processing, (b) shortening of data acquisition time, and (c) acquisition of phase information of rain echo. It is also feasible to add a Doppler function to the system, and to compensate effects of rain attenuation [5] and to get knowledge of hydrometeors' phase [6] by using differential phase shift.

4. Summary

A Ku-band (14 GHz) dual-polarization radar, which has a capability of simultaneous reception, has been developing. The system is a FM-CW type, and consists a transmitter, which radiates a linear polarization wave through a large Cassegrain antenna (13 m diameter), and two receivers, which receive two polarizations through a small offset parabolic antenna (60 cm diameter). It can receive the horizontal and vertical polarization simultaneously, with using polarized transmission at 45° to the horizontal. Another feature of the system, except simultaneous reception, is a capability of LDR observation with a transmit in horizontal or vertical polarization.

From preliminary results of the system, good correlations between horizontal and vertical polarizations were confirmed by comparison with each one sweep spectra. However, observed fluctuation in received power was larger than expected fluctuation from a simulation. After causes for the observed fluctuation are considered, two solutions: (1) usage of the same local frequency at 14 GHz, and (2) digital data acquisition system, are introduced.

References

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