4-10 Development of the CRL Okinawa Bistatic Polarimetric Radar

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Communications Research Laboratory (CRL) has developed a new C-band multi-parameter Doppler radar system with a bistatic Doppler network to establish a next-generation technology of rain observation for meteorological and hydrological applications such as weather forecasts and run-off analysis in predicting floods. This new radar is named COBRA (CRL Okinawa Bistatic polarimetric Radar). COBRA has polarization, monostatic Doppler, and bistatic Doppler observation functions. The targets of this system are typhoons, Baiu-frontal rainfall, meso-scale precipitation in subtropical zones, and clear air turbulence. To measure the polarization characteristics of rainfall, the main radar can select one of six kinds of polarizations for every transmitting pulse, and then both the horizontal and vertical polarizations are measured simultaneously by two receiver systems.

Keywords
Polarization observation, Bistatic radar network, Signal processing, Stokes parameters

1 Introduction

Each year in Japan, precipitation phenomena—such as localized torrential rain, typhoons, and heavy snow—inundate homes, cause mudslides, and damage crops. These natural disasters lead to loss of life and valuable property. These precipitation events are typical examples of meso-scale atmospheric phenomena, occurring on scales of several km to several 100 km and lasting from several minutes to several days. The precipitation radar is a remote-sensing instrument that can make both instantaneous and continuous observation from a single point on the ground of an extremely wide area (with a radius of several 100 km), and therefore, it represents an effective tool in monitoring and resolving the mechanisms of such meso-scale phenomena. A normal precipitation radar emits radio waves from the ground toward the sky and then receives the backscattered signals. The precipitation intensity can be measured by measuring the intensity of the received signal.

A polarimetric precipitation radar (the COBRA, or CRL Okinawa Bistatic polarimetric Radar) has been under development since FY 2000 at the Okinawa Subtropical Environment Remote-Sensing Center of the Communications Research Laboratory (CRL Okinawa), as part of a project to develop subtropical environmental measurement technologies[1]. The COBRA is a next-generation precipitation radar capable of high-precision measurements of subtropical meteorological phenomena such as typhoons, meso-scale precipitation, and 3-D wind-speed structures. Our goal is to utilize COBRA in the development of meso-scale meteorological and hydrological observation applications to support commercial weather forecasting and data collection for disaster prevention purpose.

2 COBRA System

The COBRA features a main radar with

polarization observation functions to enable detailed observation of the polarization characteristics of precipitation particles. It also employs a bistatic radar network—specifically, a network of receivers for observation of oblique scattering from precipitation particles. Fig.1 shows the location of the main radar and the two bistatic receivers. The main radar is installed at the Nago precipitation radar facility in Nago City, Okinawa (CRL Nago), and the bistatic receiver stations are located at the Ogimi wind profiler facility (CRL Ogimi) and CRL Okinawa. The two bistatic radar stations and CRL Nago are connected by a dedicated line of 128 kbps, and CRL Nago and CRL Okinawa are linked by a dedicated line of 1.5 Mbps. CRL Nago is unmanned, and is remotely controlled and monitored from CRL Okinawa.

COBRA features three observation modes: steady observation mode, detailed observation mode, and campaign observation mode; these modes are used in combination during experimental observations with COBRA. In steady observation mode, observation is made at two angles of elevation—0.4 deg. and 1.0 deg.—at intervals of 5 or 10 minutes, to allow for statistical analysis (such as time series analysis). In detailed observation mode, observation is performed within a limited range (such as detailed polarization observation), as required. Data collected in steady observation mode will be used to determine the time at which to switch over to detailed observation mode and to determine the range of observation. Campaign observation mode is used for continuous observations of typhoons or for extended observations in the context of joint projects.

2.1 Main Radar

COBRA's main radar is a ground-based monostatic pulse Doppler radar that uses a single wave (5,340 MHz) in the C-band. The main specifications are listed in Table 1. The antenna has a diameter of 4.5 m, a beam width of ≤ 1.1 deg., and a radome diameter of 8 m. The antenna scan speed can be adjusted in increments of 0.1 rpm between 0.5 - 10 rpm in

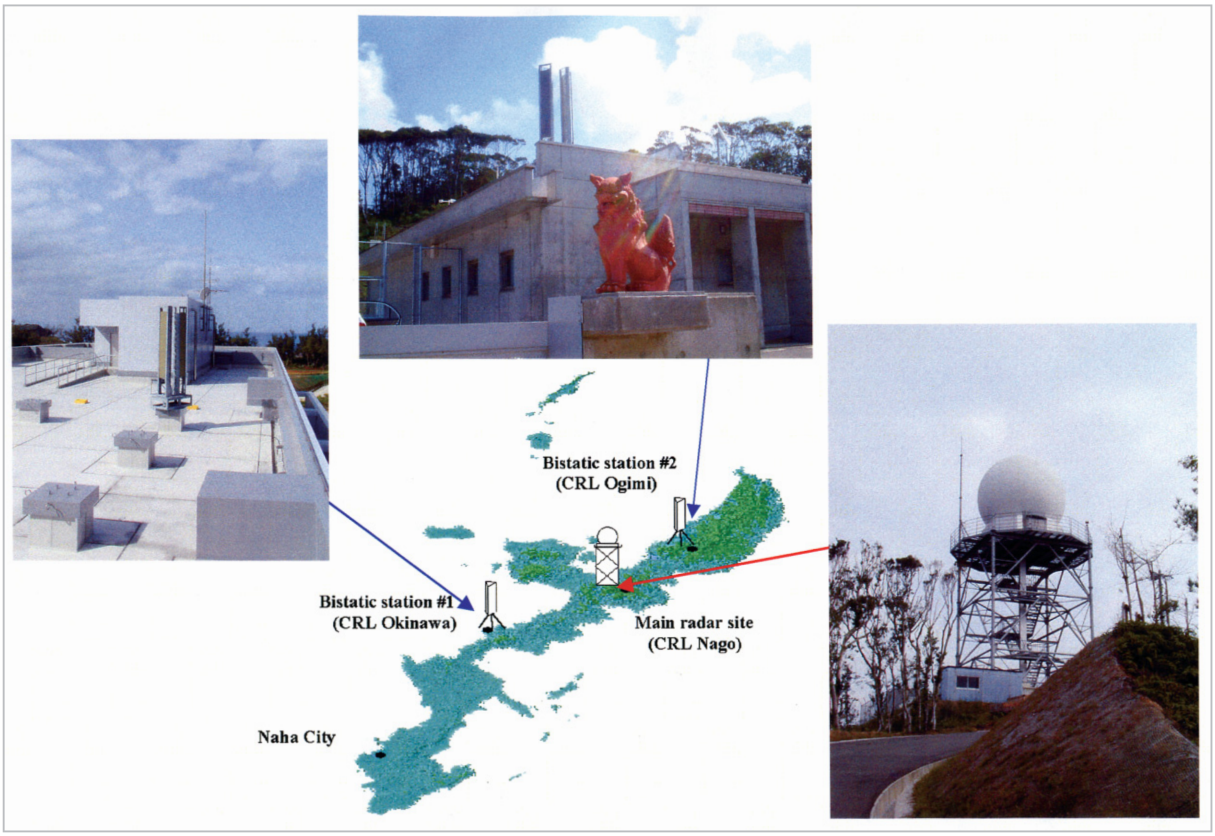


Fig.1 Locations of the COBRA system

Table 1 *Main specifications of the COBRA main radar*

Antenna	
Antenna diameter	4.5 m parabolic
Cross polarization ratio	> 36 dB (Integrated value in a beam)
Antenna gain	> 42 dBi (including radome)
Beam width:	< 1.1 degree
Sidelobe	< -25 dB (one way)
Antenna scan speed	0.5-10 rpm(PPI), 0.1-3.6 rpm(RHI), 0.1 rpm step
Transmitter	
Frequency	5340 MHz (one frequency)
Peak power	> 250 kW
Transmitter tube	Dual Klystron
Pulse width	0.5 μs, 1.0 μs, 2.0 μs
PRF	250 Hz - 3000 Hz, 1 Hz step (staggered PRF)
Polarization	H, V, +45, -45, LC, RC (pulse by pulse)
Receiver (H and V)	
Noise figure	< 3 dB at the input of LNA
Dynamic range	> 90 dB
Data acquisition	
Doppler sift estimation	Pulse pair / FFT
Integration hits number	16, 32, 48, 64, 80, 96, 112, 128, 256, 512, 1024
Range bin number	>2000
Level-1	Stokes parameter, Complex mutual correlation(PPP), Doppler spectrum (FFT), and noise level of receivers.
Level-2	Z, Ze, ZDR, LDR, PhiDP, KDP, RhoHV(0), NCP, Vel, Wid, etc.

the horizontal direction, and between 0.1 - 3.6 rpm in the vertical direction, in accordance with the observation conditions set by the user. The maximum observation range is approximately 300 km in radius, although this depends on the repetition frequency and transmitted pulse. The spatial resolution is 37.5 - 600 m, depending on the pulse width and oversample rate. Furthermore, an antenna with good side-lobe characteristics and a radome with little attenuation were selected, in order to enable detailed polarization observations.

The main radar is capable of estimating the precipitation intensity (R) based on measurements of the reflection intensity (radar reflectivity factor: Z) from precipitation particles (a procedure that is normally performed by meteorological radar) and is also capable of detailed polarization observation of precipitation using the polarization characteristics of the precipitation echo. Two transmitter (klystron) units are used for the polarization observation. Transmission is switched between six types of polarizations for each pulse—horizontal polarization, vertical polarization, ±45-degree tilt linear polarization, and right-and left-handed circular polarizations (Fig.2); the precipitation echo is observed simultaneous by two receiver systems for horizontal and vertical polarizations (Fig.3). The precipitation radar conducts a full polarimetric observation using the polarization characteristics of the received waves. Observation using six polarizations is performed in detailed observation mode. Furthermore, to conduct polarization observations under optimal conditions, the system is designed to analyze the temperature characteristic of the two systems by monitoring the output for each pulse to minimize inter-system differences.

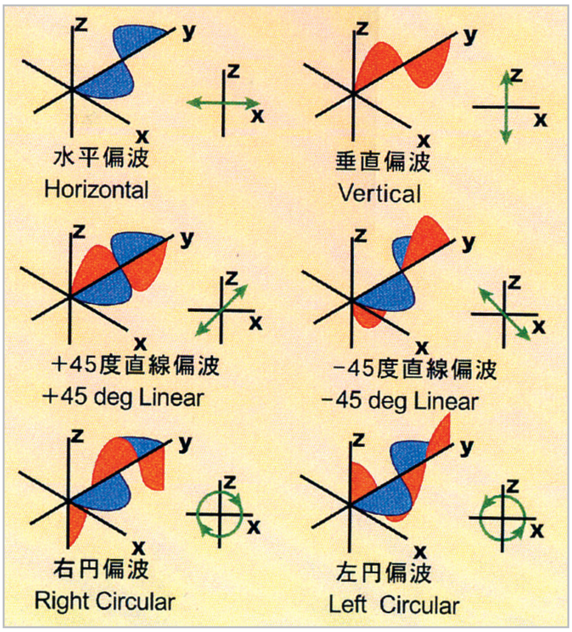


Fig.2 *Six types of transmitted polarizations*

In Doppler observation, the user may select either measurement of the Doppler velocity and spectral width using the pulse pair method or Doppler spectrum measurement using the FFT method[2]. To correct the Doppler velocity folding, settings can be made to switch the double PRF between pulses.

Antenna pattern measurements were made twice—once at the COBRA system construction factory and once at the radar site—to confirm the level of antenna performance required for detailed polarization observations. Fig.4(a) and (b) show the antenna patterns on the H port and the V port on the horizontal plane, respectively. The blue line in the figure shows the results of measurements taken in the factory without the radome, and the red line indicates the results at the radar site with radome cover. The results of antenna pattern measurements show that even at the radar site with radome, the side-lobe level is -29.5 dB in the worst case, and that the cross-polarization ratios to the horizontal and vertical polarizations are -36.3 dB and -39.3 dB, respectively. The beam width was approximately 0.95 deg., satisfying the goals for the initial stages of development. Based on the above, the COBRA main radar was confirmed to display sufficient antenna performance to conduct detailed polarization observations.

2.2 Bistatic Radar Network

Doppler observations will be made with the COBRA main radar to observe the background winds with precipitation. By combining this information and the results of Doppler-shift measurements made by the two bistatic receiver units to receive oblique scattering from precipitation particles, it will be possible to make a speedy and precise observation of the 3-D wind speed field over a wide area[3]. Fig.5 outlines the applicable principles of observation. The bistatic receivers consist of dual-plane linear slot array antennas for observing the regions to the right (antenna R) and left (antenna L) facing the main radar (Fig.1). The results of measurement of the beam width of the antennas of the bistatic receiver showed that antenna R of the bistatic receiver installed at CRL Okinawa had horizontal and vertical beam widths of 14.6 deg. and 3.3 deg., respectively, while those of antenna L were 15.7 deg. and 3.2 deg., respectively. For the bistatic receiver installed at CRL Ogimi, the horizontal and vertical beam widths for antenna R were 16.0 deg. and 8.4 deg., respectively, and for antenna L, they were 17.9 deg. and 7.9 deg., respectively. These beam widths satisfied the goals for the initial stages of development.

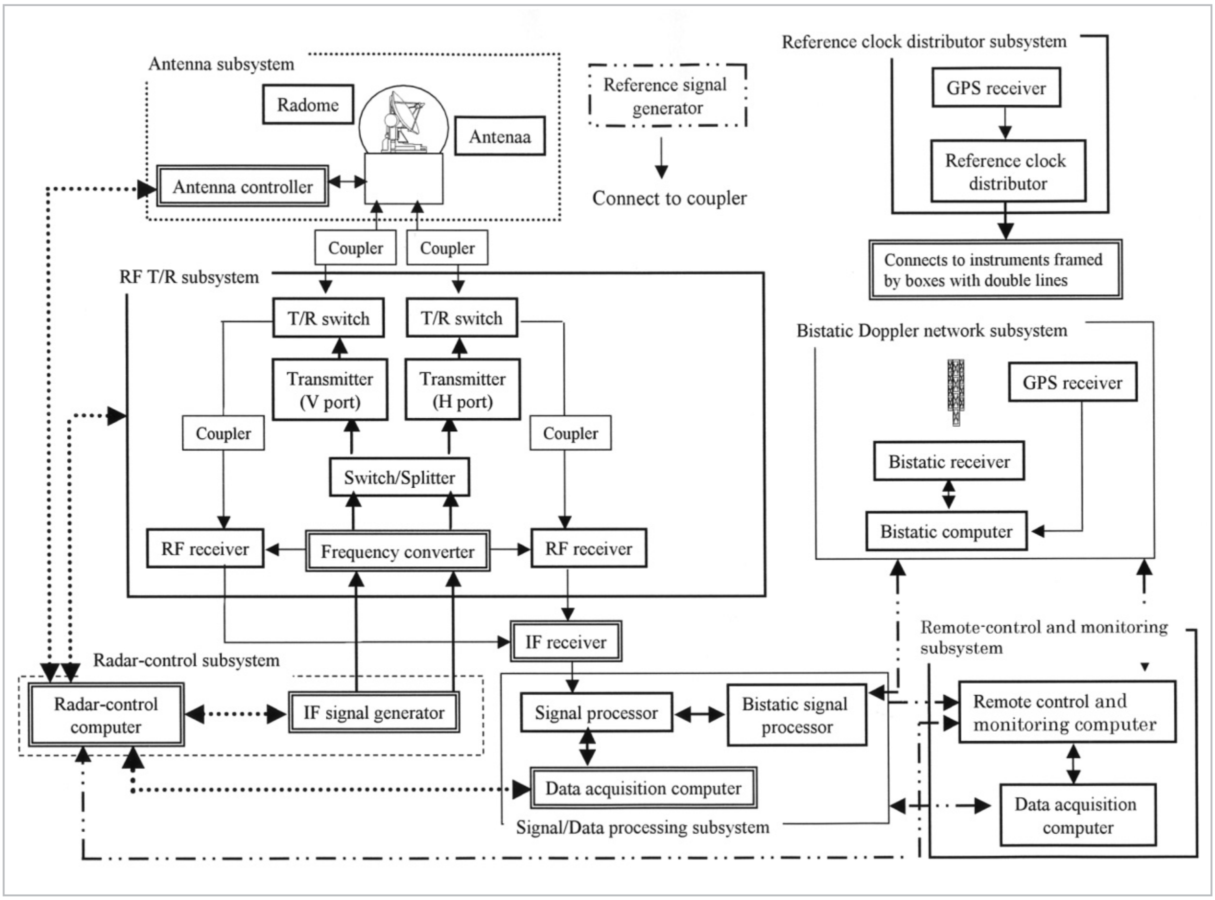
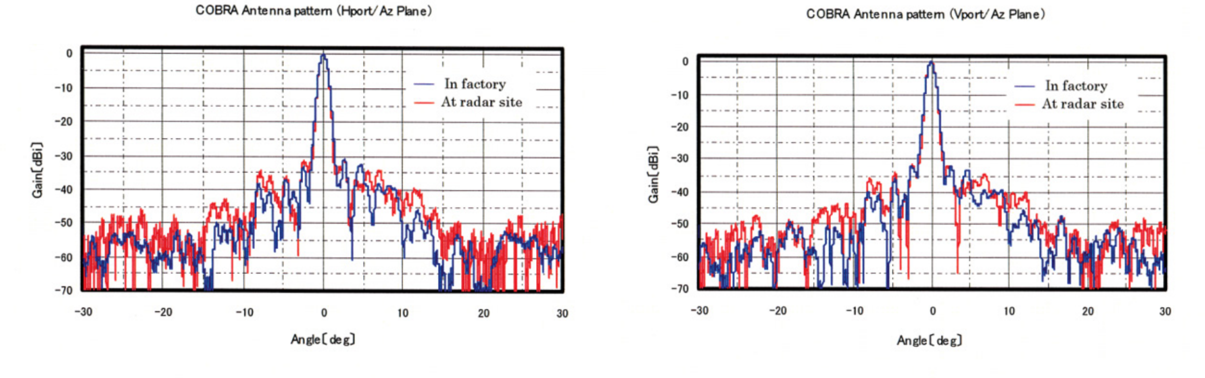


Fig.3 Block diagram of COBRA system

The solid and dotted lines represent the flow of radar signals and control signals, respectively. Lines of alternating dashes and double dots show the flow of data in the network.



(a) H port on the horizontal plane

(b) V port on the horizontal plane

Fig.4 Antenna pattern observed in factory and at the radar site for (a) H port on the horizontal plane, and (b) V port on the horizontal plane

The advantages of the bistatic radar network relative to conventional dual observation conducted with a combination of two or three monostatic Doppler radars lie in the lower cost and simplicity of the system. Furthermore, the acquisition of 3-D data for a wide area by perfect synchronous measurement using dual-mode observation was a time-consuming process, since measurements were made with narrow-beam radars. Measurements taken without complete synchronicity were not sufficiently reliable for observation of meso-scale meteorological phenomena displaying large temporal variations. With the bistatic method, perfect synchronicity is guaranteed, since signals from the irradiated part of the main radar are received simultaneously by all receivers, and so data acquisition can be performed in a short time. Furthermore, when using two or three monostatic Doppler radars for dual observation, two or three frequencies in the C-band will be required; however, the bistatic radar network requires only one frequency, contributing to the more effective use of frequencies.

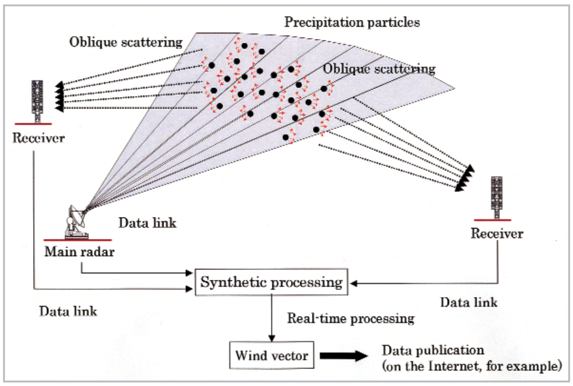


Fig.5 Schematic diagram of Observations by the Bistatic Radar Network

3 Signal Processing

The measured signals are categorized into four processing levels—Level 1, Level 2, and Level 3—and are processed in real time.

3.1 Level-1 Processing

In Level-1 processing, the horizontal and vertical polarization signals received (input) are processed to determine: (1) Stokes parameter of the transmitted and received signals for full-polarimetric polarization observation[4], (2) complex cross-correlation for the pulse-pair method, (3) Doppler spectrum obtained by FFT, and (4) noise level of the two receivers for both the horizontal and vertical systems. The results are stored as Level-1 processed data.

3.2 Level-2 Processing

In Level-2 processing, in addition to the precipitation intensity (R) calculated from the Z-R relationship with the radar reflectivity factor (Z), physical quantities are also calculated, such as the differential reflectivity factor (ZDR), the linear depolarization ratio (LDR), the correlation coefficient ($\rho_{HV}(0)$) between both polarizations, and their specific differential phase (KDP). Identification of the form of precipitation particles and estimations of raindrop size distribution are made based on these data[5][6]. Wind-speed vector data acquired by the bistatic radar network is processed, and precipitation intensity is estimated using the ZDR, KDP, and k-R relationships as well as the standard Z-R relationship[7][8]. These data are stored as Level-2 processed data.

3.3 Level-3 Processing

In Level-3 processing, the precipitation intensity R(Z), which consists of Level-2 data, is processed statistically, to determine items such as 1-hr accumulated precipitation, 1-hr average precipitation, 24-hr accumulated precipitation, 24-hr average precipitation, 48-hr accumulated precipitation, and 48-hr average precipitation. Furthermore, in support of disaster-prevention activities, the 1-hr accumulated precipitation, 1-hr average precipitation, and 24-hr accumulated precipitation are determined for the drainage area around the dams in the main island of Okinawa.

The processed data are publicized in real time on the WWW as image data, including movies.

3.4 Data Distribution

The image data for Level-2 and Level-3 data will be displayed in real time on the CRL website. (The volume of Level-1 data is too massive to post.) The digital data will be stored as a subtropical environmental information database at the CRL[9], and will be distributed to scientists selected to participate in joint research efforts. The digital data will be stored in NetCDF format. (NetCDF is short for Network Common Data Form, developed by Unidata Program Center. For details, see http://www.unidata.ucar.edu/package/netcdf/)

4 Data Validation

The polarization observation data collected by the COBRA main radar will be validated using the 400-MHz wind profiler and the ground-based precipitation observation data at CRL Ogimi[10]. The 400-MHz wind profiler can perform simultaneous observations of the atmospheric turbulence echo and the echo from precipitation. Therefore, by analyzing the echo power spectrum of the received signal, it is possible to perform raindrop size-distribution measurements in which the effects of wind speed, intensity of atmospheric turbulence and background winds have been removed. Ground-based raindrop size-distribution measurements are made using a disdrometer. An optical rain gauge (which can measure 1-minute precipitation intensity) and a tipping-bucket rain gauge are used in observations of precipitation intensity (Fig.6).

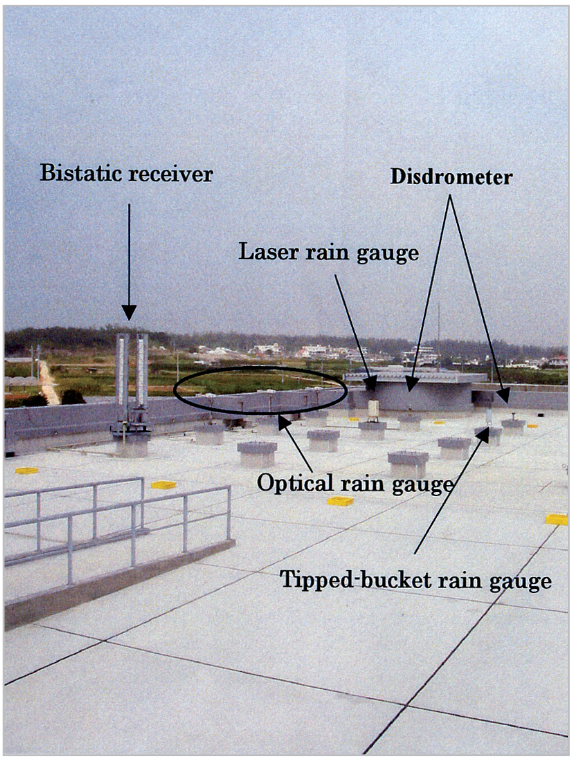


Fig.6 Ground-based precipitation measurement instrument for validation of COBRA observation data

The wind data are observed with the bistatic radar network and validated using wind data collected by the 400-MHz wind profiler and the airport Doppler radar at Naha Airport.

5 Conclusions

The installation of the COBRA main radar and its bistatic receivers in their respective stations has been completed, and currently, performance tests are being conducted of the main radar, as well as an operational check of the bistatic radar network and various system-performance tests. After confirming the performance of the overall system, experimental observations will be performed to validate the observed data.

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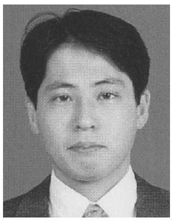

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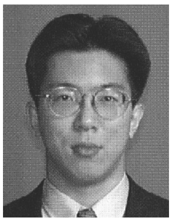

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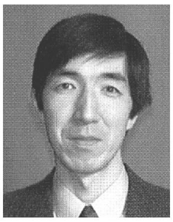

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