3.1.1 ANTENNA AND RECEIVER SYSTEM

By

Noriyuki KURIHARA[*1], Hiroshi TAKABA[*2], Akihiro KANEKO[*3],

and Koichi SEBATA[*4]

(Received on)

Running title: Antenna and receiver system

[*1] Kashima Space Research Center

[*2] Gifu University

[*3] Standards and Measurements Division

[*4] Keystone Project Research Team

ABSTRACT

The Communications Research Laboratory (CRL) has been developing the Crustal Deformation Monitoring system for the Tokyo Metropolitan Area since 1993. This project is ca11ed the "Key Stone Project (KSP)". The antenna and receiver system is used in the KSP VLBI data acquisition terminal. The antenna and receivers must have high sensitivity for continuous data production that is both high-quality and reliable. This antenna is an AZ-EL mount and has an 11-m modified surface parabolic dish. It is equipped with a Frequency Selective Sub Reflector (FSSR) in order to give it high aperture efficiency in both the S and X bands. We designed the antenna's reference position (geodetic VLBI reference point) to be fixed within 3 mm during a year. So the foundation of the antenna pedestal is firmly connected to the hard ground by long pilings. The receivers are equipped with FET-type low-noise pre-amplifiers and an optical fiber IF signal transmission system for the S and X bands.

Keywords: VLBI, antenna, receiver

1. Introduction

The Communications Research Laboratory (CRL) started the Key

Stone Project (KSP) dedicated to monitoring crustal deformation around the Tokyo metropolitan area in 1993[1]. The KSP consists of four stations equipped with VLBI (Very Long Baseline Interferometer) and SLR (satellite laser ranging) facilities around the metropolitan area, and it aims to monitor crustal deformation using space geodetic techniques. The project started with the construction of VLBI stations. All four stations at Koganei, Kashima, Miura, and Tateyama have been completed and regular operation's have been started. The antenna and receiving system described in this paper are part of the important observation hardware used to acheive high-precision geodetic VLBI. That is, the antenna aperture efficiency, system noise, and the performance of the antenna drive serve as important parameters to limit the observation accuracy. In other words, the performance of the antenna and receiver will affect the sensitivity of the detection of crustal deformation. Here we describe the characteristics and the functions of the antenna and receiving system developed for the KSP VLBI system.

2. The design concept of the antenna and the receiving system for VLBI observation

The antenna and receiving system described here are used as part of the VLBI observation system for carrying out a highly precise VLBI experiment in a metropolitan area to monitor crustal deformation. It was designed to operate for five hours every day. Thus it need to be reliable for such a routine operation. It also need to be remotely controllable from the Koganei central station to enable unmanned operation(2).

Furthermore to achieve highly accurate measurement, we needed to incorporate the following into the design concept; a highly efficient antenna that could receive weak radio sources, a low-noise preamplifier, wide pointing capability, an easily controlled antenna drive, IF signal transmission using a wide band optical transmitter, and a stable antenna foundation and reference point.

From a practical view point, we emphasised the need to avoid trouble with the antenna mechanism. Problems were notified by alarm to the Koganei central station through the internet when they occurred.

3. Antenna for VLBI observation

The antenna for VLBI observation consists of an antenna foundation, an antenna structure, an antenna drive part, a weather measurement system, and other equipment. We will describe the functions and features of each part. A block diagram of the antenna and the receiving system for VLBI observation is shown in Figure 1.

3. 1 Antenna foundation

The stratum composition of each observation site in a metropolitan area differs. A geological survey of each antenna was therefore carried out at each site using a rotary-hand-feed boring machine. We measured the N value, which is an index used to display ground strength and is defined as the number of blows needed to attain a depth of 30 cm with a standard hammer, samples of soil extracted were analyzed. On the basis of this geological survey result, base concrete piles were laid as a support layer (base exceeding the N value of 50), and their heads were connected to the antenna foundation. The length of the base stakes are 11 m, 32 m, 15 m and 11 m, for Koganei, Kashima, Miura, and Tateyama, respectively. Figure 2 shows the driving work of the base piles. Figure 3 shows the frame work of steel rods which combines the base stake head and the antenna foundation.

3.2 Antenna mechanical system

The antenna mechanical system consists of antenna equipment and a feeder.

3. 2. 1 Antenna

This is an 11-m-diameter Cassegrain antenna that has an AZ-EL mount which receives weak radio signals from celestial sources at S (2 GHz) and X (8 GHz) bands with very low noise and high efficiency. To ensure the antenna, can do this it has an accurate main reflector, a sub reflector, and three pillars which support the sub reflector. The antenna can be turned around the AZ-EL axes. The main reflector consists of ten inner panels and twenty outer panels, and a back structure supporting it. There is a small room called “the center hub”, at the core of the main reflector framework structure, and this contains the receiving system.

An elevation stowing is equipment to fix antenna toward the zenith direction by inserting a pin into the mount of the main reflector. This enables the antenna to withstand the winds up to 60 m/s (instantaneous value). Figure 4 shows the rear view of the antenna at Kashima. Figure 5 shows the antenna at Koganei mounted on a tall pedestal to ensure a clear view over trees around the antenna. Figure 6 shows the antenna and observation building at the Miura station.

3. 2. 2 Feeder

The feeder portion consists of a sub reflector, a feed horn, 2/8 GHz discriminator, and a polarizer. The basic function of the feeder portion is to separate receiving signals into 2/8 GHz band signals and circular polarization components. They are then fed to each wave guide circuit. Wide-band and highly efficient electrical components are used in the circuit. The feeder is therefore designed so that its circuit has low loss and wide band performance. Table 1 shows the performance of the antenna and the feeder portion adopted by KSP.

3. 3 Antenna drive part

Each axis (azimuth and elevation) is equipped with two sets of driving mechanisms, which applies opposite rotation torque in order to avoid a backlash from the gears. This system is conventionally called an anti-backlash drive system. Adopting this system improves the antenna tracking accuracy. In a usual KSP-VLBI observation, the observation schedule created at the Koganei central station is sent to the observation control computer at an observation station in advance by a communication network, and program tracking starts automatically.

The motor is a sealed DC motor with a power of 3.7 kW; it is designed for outdoor use. An absolute-type rotary encoder is used for angle detection. An angle resolution of 0. 005 degrees was attained.

3. 4 Weather observation system

The precise temperature, pressure, and humidity of the atmosphere needs to be measured to calibrate the excess delay time due to the atmosphere. Furthermore, the wind velocity is required to limit the operation of the antenna when a strong wind is blowing. Thus, the weather measurement system is fixed and acquires data on the weather every minute. The performance of the weather observation system is summarized in Table 2.

3. 5 Other equipment

The center hub located on the back of the main dish, contains equipment sensitive to environmental temperature changes, such as a low-noise amplifier, a frequency converter, an optical transmitter, and an antenna unit of the delay calibration system. Therefore, an air-conditioner is used to maintain a relatively constant environmental temperature. Currently the temperature is kept at 25 +/- 3 degrees centigrade.

A 1.5 m standard pillar and a stone marker corresponding to the fourth-grade triangulation point defined by the Geographical Survey Institute are placed near each antenna. These are used to compare GPS and SLR observations. Figure 7 shows a photograph of the GPS receiver being attached to the top of the standard pillar at the Kashima station. Corner-cube-reflector attachments are also fixed at the antenna mount and at the back structure of the main dish in preparation for a future SLR collocation experiment.

A TV camera was installed to monitor the 11 m antenna. Pictures taken by this camera are transmitted to Koganei through a communications network. Thus real-time monitoring is always available at Koganei central station. The mechanical specification and performance of the antenna for VLBI observation are summarized in Table 3.

4. Receiving system for VLBI observation

The receiving system for VLBI observation consists of a low-noise amplifier, a frequency converter, an optical transmitter, and an IF signal distributor. We will describe the functions and features of each block.

4. 1 Low-noise amplifier

Both S-band and X-band low-noise amplifiers are contained in the center hub located behind the main dish reflector. Regarding selection of low-noise amplifiers, we focused on low-noise performance and reliability rather than pursuing the best performance and freshness as described in section 2 on the design concept. Consequently, we chose a normal-temperature-type low-noise amplifier. As it is not equipped with a cooling system, it can be operated without any special maintenance for long periods.

A GaAS FET low-noise amplifier with four stages is used for the S-band and one with six stages for the X-band; they have a gain of 50 dB or more at each frequency band. Furthermore, the amplifiers are contained in airtight aluminum cases, which makes it easy to keep high circuit stability. The noise temperature of the low-noise amplifier used at Kashima and Koganei was measured, and we confirmed that it was lower than 50 K for the S-band and lower than 80 K for the X-band(Table 4). Table 4 also lists the other performance factors of the low-noise amplifier.

4. 2 Frequency converter

All S-band and X-band signals output from the low-noise amplifier are fed to a six-stage Tchebycheff band-pass filter to suppress unnecessary signals. S-band signals are converted into one wide-band IF signal while X-band signals are converted into two wide-band IF signals (XL, XH). We used two IF signals for the X-band to further extend the frequency band so as to improve observation accuracy. The local signals for frequency conversion are generated from a PLO (Phase Locked Oscillator) of which reference signals (5 MHz) are supplied through a coaxial cable from the Hydrogen maser frequency standard located in an observation building(3). The frequency of the local oscillator is 3000 MHz, 7200 MHz, and 7600 MHz for the Sband, XLband, and XHband, respectively. The performance of the frequency conversion part for VLBI observation are summarized in Table 5.

4. 3 Optical transmission part

Optical transmission equipment sends the IF signals of the S-band (500-900 MHz) and X-band (500-1000 MHz) to a back-end part in an observation building. This equipment consists of a transmitting unit (E/O) for optical transmission contained in the antenna center hub and the receiving unit (O/E) for optical transmission installed in the observation building. These units are connected by optical fiber. Although a delay calibrator to compensate for the delay change within the IF signal transmission cable is separately prepared in the VLBI system, it is desirable to keep such a delay change and inferiority in frequency characteristics to a minimum. We therefore adopted a wide-band optical transmission system that uses single-mode light transmission at a wavelength of 1.3 micrometers which does not need a cable equalizer. Since the optical transmission part is installed in the center hub, it is affected by slight vibrations caused by the antenna drive or air-conditioner. It is important to take measures to prevent such vibrations. The performance of the light transmission part for VLBI observation is shown in Table 6.

4.4 IF Signal distribution part

All IF signals output from the receiving unit for optical transmission (O/E) are amplified and divided into three lines through this part, which are fed to the back-end part[4], to a spectrum analyzer to monitor interference, and to a power meter for measuring system noise temperature, respectively. Furthermore, the signal route to the VLBI back-end is equipped with a programmable attenuator for level adjustment. The optimum signal level can therefore be adjusted and controlled by computer.

5. Conclusion

The antenna and receiving system for VLBI observation dedicated to the KSP have been developed. In this development, high sensitivity and high reliability were thought to be important considering the purpose of the project, that is, routine crustal deformation monitoring using a VLBI technique. The antenna and the receiving system at Koganei, Kashima, Miura, and Tateyama for VLBI observation have now been completed. We have obtained a variety of data during development including adjustment data at each station. The antenna efficiency measured at the time of completion and the system noise temperature are summarized in Table 7. We started daily observations on the Kashima-Koganei baseline at the end of January, 1995. On April 1, 1996, we started regular observation using the four stations, one each at Kashima, Koganei, Miura, and Tateyama. An unmanned operation was also started simultaneously. So far the antenna and the receiving system have not exhibited any serious problems. We are currently monitoring regular crustal deformation by VLBI as planned.

Acknowledgments

The antenna and receiving system for VLBI observation was developed with the help of many individuals. Especially, in the antenna construction, we would like to express our gratitude to the Kanto Regional Bureau of Telecommunications (Miura station) and the NTT Long-Distance Communications Sector (Tateyama station) for their assistance. We would also like to thank NEC Corporation for constructing the antenna and the receiving system. Many thanks also go to our colleagues for their encouragement and stimulating discussions.

References

(1) T. Yoshino, “2. Oberview of the Key Stone Project,” J. Comm. Res. Lab. in this issue, 1999.

(2) Y. Koyama, T. Iwata, and H. Takaba, “3.1.4 Ovservation and System Management,” J. Comm. Res. Lab., in this issue, 1999.

(3) Y. Hanado, M. Imae, N. Kurihara, M. Hosokawa, H. Kiuchi, K. Sebata, M. Sekido, and T. Goto, “3.1.2 Frequency Standards and Instrumental Delay Calibration System,” J. Comm. Res. Lab., in this issue, 1999.

(4) H. Kiuchi, J. Amagai, S. Hama, and M. Imae, “3.1.3 KSP Data-Acquisition System,” J. Comm. Res. Lab., in this issure, 1999.

Table 1 Performance of the antenna and feed system

	S band	X band
Frequency	2100 ~ 2500 MHz	7700 ~ 8600 MHz
VSWR	< 1.3 : 1	< 1.3 : 1
Polarization	RHCP or LHCP	RHCP or LHCP
Axial Ratio	< 2.0 dB	< 2.0 dB

Table 2 Performance of the weather observation system

	Measurement Range	Measurement Accuracy
・Temperature	−30 ℃ ~ 40 ℃	± 0.2 ℃
・Pressure	800 hpa ~ 1050 hpa	± 0.2 hpa
・Humidity	0 ~ 100 %	± 3 %
・Wind Direction	0 ~ 360 deg.	± 5 deg.
・Wind Velocity	0 m/sec ~ 60 m/sec	< 10 m/sec ; < ± 0.5 m/sec
		> 10 m/sec ; > ± 5 %

Table 3 Mechanical specification and performance of the antenna for VLBI observation

・Antenna Type ・Diameter of the Main Reflector ・Mount Style ・Receiving Frequency	Cassegrain type 11 m Az – El mount S band : 2100 – 2500 MHz, X band : 7700 – 8600 MHz			
・Driving System ・Driving speed	Anti-backlash gear drive (dual drive) Max. 3 deg/sec (Az, El)			
・Drive range (deg)	Azimuth		Elevation	
Hardware pre limit	-270 / +270		+2 / +90	
Hardware final limit	-273 / +273		+1 / +91	
Software limit	-265 / +273		+5 / +88	
・Angle Encoder	Mechanism : Absolute Rotary Encoder Resolution : 0.005 deg (19 bits)			
	Koganei	Kashima	Miura	Tateyama
・Antenna base concrete piles length (m)	11	32	15	11
・Reference Position of Antenna (m)	11.5	7.5	7.5	7.5
・Surface Accuracy (rms)	0.08	0.10	0.09	0.08
・Zenith Angle (arcsec)	17 (Az:194)	12 (Az:330)	13 (Az:350)	16.3(Az:150)
・Rectangularity accuracy (arcsec)	5	6	31	0.8
・Wind Velocity	Max. 17 m/sec (operable) Max. 60 m/sec (survival)			

Table 4 Performance of the low-noise amplifier in the S and X bands

	S band	X band
・Frequency	2100~2500 MHz	7700~8600 MHz
・Total Gain	> 50 dB	> 50 dB
・Amplitude Flatness	< 2dBp-p	< 2dBp-p
・Noise Temperature	< 50 K	< 80 K
・Input/Output VSWR	< 1.5 : 1	< 1.5 : 1

Table 5 Performance of the frequency converter in the S and X bands

	S band	X-low band	X-high band
· Input Frequency (MHz)	2100~2500	7700~8200	8100~8600
· Output Frequency (MHz)	500~900	500~1000	500~1000
· Local Frequency	3000 MHz	7200 MHz	7600 MHz
· Noise Figure	< 15 dB	< 15 dB	< 15 dB
· Conversion Gain	> 50 dB	> 50 dB	> 50 dB
· Flatness	< ±1 dB	< ±1 dB	< ±1 dB
· Image Rejection Ratio	> 50 dB	> 50 dB	> 50 dB
· Output Power	> +10 dBm	> +10 dBm	> +10 dBm
Local Oscillator			
· Input Reference Signal	5 MHz, +10dBm± 2 dBm		
· Output Signal Power	+10 dBm		
· Harmonic Ratio	< −20 dBc		
· Spurious Ratio	< −50 dBc		

Table 6 Performance of the optical transmission part

・Number of Input IF Channels	3 (S, X-low, X-high)
・Input/Output RF Connectors	SMA(F)
・RF Input Total Power	< ＋10dBm
・Optical Connectors	FC/PC
・Wavelength	1310 nm singlemode
・Frequency Response	0.5 ~ 1.0 GHz
・Amplitude Flatness(Total)	< 2 dBp-p
・Total Link Loss	< 20 dB
・Input/Output Impedance	50Ω
・Input/Output VSWR	< 1.5 : 1

Table 7 Aperture efficiency and system noise temperature of the antenna

	Koganei	Kashima	Miura	Tateyama
・Aperture Efficiency				
S band (2.30 GHz)	81 %	80 %	78 %	79 %
X band (8.15 GHz)	67 %	71 %	70 %	65 %
・System Noise Tempuretsure (EL Angle: 30deg., Clear Sky)				
S band (2.30 GHz)	76 K	71 K	70 K	71 K
X band (8.15 GHz)	95 K	99 K	112 K	103 K
・Measurement Date	24 Aug.1994	5 Aug.1994	14 May.1995	6 Jun.1996

Figure Captions (1/2)

Fig. 1 Block diagram of the antenna and the receiving system of VLBI observation.

Fig. 2 Drive work of the concrete piles of the VLBI antenna.

Fig. 3 Foundation of the VLBI antenna.

Fig. 4 Rear view of the VLBI antenna at Kashima station.

Fig. 5 VLBI antenna at Koganei mounted on a tall pedestal to ensure clear view over trees around the antenna.

Fig. 6 Photograph of VLBI antenna and an observation building at Miura station.

Fig. 7 Ground standard pillar with the GPS receiver on the top.

Figure Captions (2/2)

Table 1 Performance of the antenna and feed system.

Table 2 Performance of the weather observation system.

Table 3 Mechanical specification and performance of the antenna for VLBI observation.

Table 4 Performance of the low-noise amplifier in the S and X bands.

Table 5 Performance of the frequency converter in the S and X bands.

Table 6 Performance of the optical transmission part.

Table 7 Aperture efficiency and system noise temperature of the antenna.

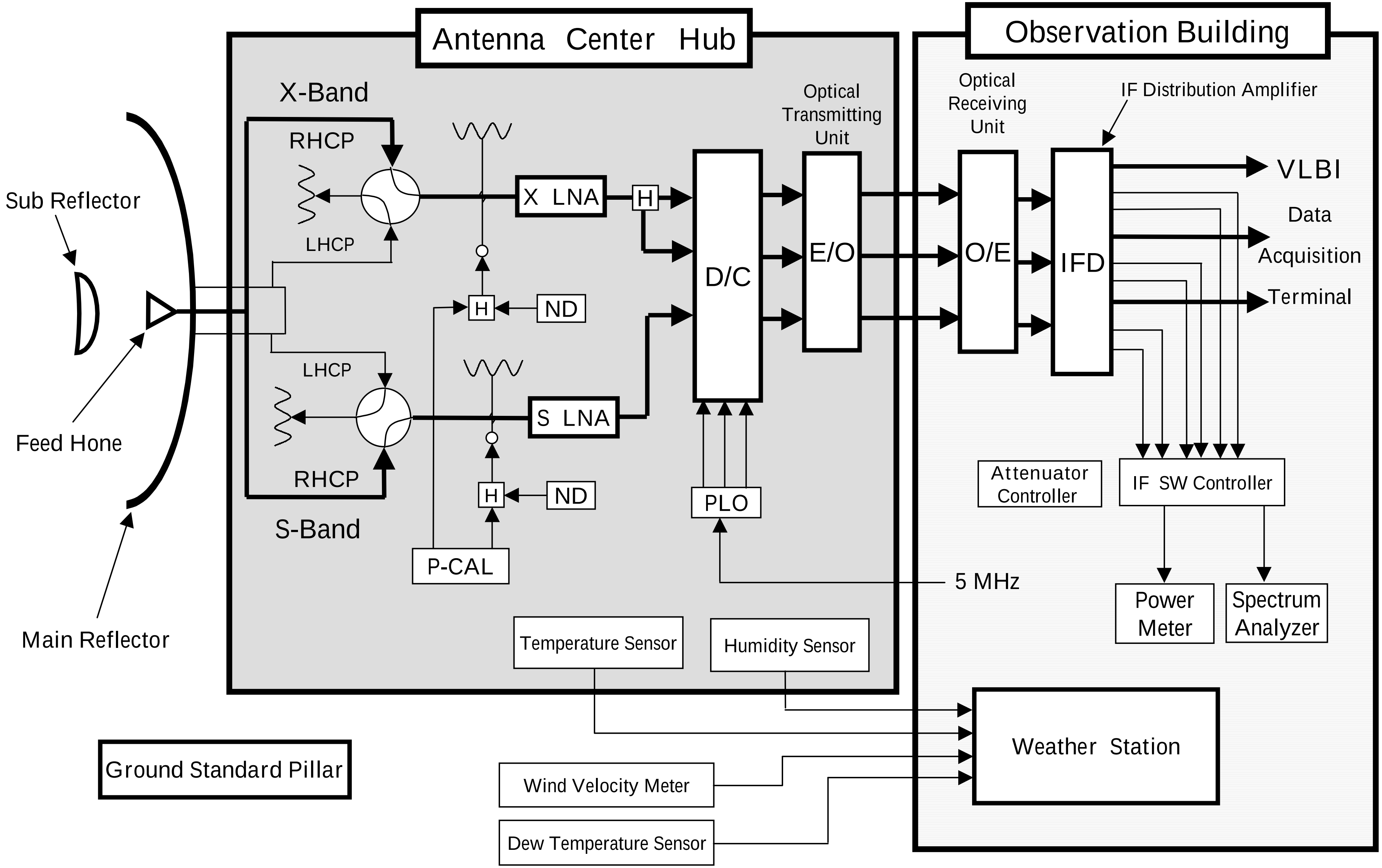

Fig. 1 Block diagram of the antenna and the receiving system of VLBI observation