Adv. Space Res. Vol. 10, No. 10, pp. (10)151–(10)154, 1990
Printed in Great Britain.

0273–1177/90 $0.00 + .50

EQUATORIAL RADAR SYSTEM

Shoichiro Fukao, Toshitaka Tsuda, Toru Sato and Susumu Kato

Radio Atmospheric Science Center, Kyoto University, Uji, Kyoto 611, Japan

ABSTRACT

A large clear air radar with the sensitivity of an incoherent scatter radar for observing the whole equatorial atmosphere up to 1,000 km altitude is now being designed in Japan. The radar will be built in Pontianak, West Kalimantan, Indonesia (0.03°N, 109.29°E). The system is a 47-MHz monostatic Doppler radar with an active phased array configuration similar to that of the MU radar in Japan, which has been in successful operation since 1983. It will have a PA product of $\sim 3 \times 10^9$ Wm^2 (P = average transmitter power, A = effective antenna aperture) with a sensitivity of approximately 10 times that of the MU radar.This system configuration enables pulse-to-pulse beam steering within 20° from the zenith. As is the case of the MU radar, a variety of operations will be made feasible under the supervision of the radar controller. A brief description of the system configuration will be presented.

INTRODUCTION

An international equatorial radar is planned to be constructed at Pontianak in West Kalimantan, Indonesia (0.03°N, 109.29°E), under the co-operation between the Indonesian National Institute of Aeronautics and Space (LAPAN) and the Radio Atmospheric Science Center (RASC) of the Kyoto University, Japan. It will be a powerful VHF Doppler radar with a capability of observing the entire depth of the earth's atmosphere. It is an enlarged version of the MU radar at Shigaraki, Shiga, Japan, and succeeds most of its flexibility such as the fast and continuous antenna beam steerability. Readers are referred to Fukao *et al.* /1, 2/ for the details of the MU radar system.

The radar is a monostatic pulsed Doppler radar with an active phased array system. The operational frequency is 47 MHz and the maximum peak and average radiation powers will be 1.1 MW and 55 kW, respectively. The antenna is a quasi-circular array with an aperture of $\sim$60,000 m^2. The nominal beam width is 1.2°. The shortest 1 μs pulse width will be available in the 2 MHz bandwidth which will be reserved exclusively for the radar. Figure 1 is an artist's conception of the radar, and Figure 2 gives its general block diagram.

The basic parameter of the radar are given in Table 1. This system is composed of $\sim$2,500 array elements and an identical number of transmitter-receiver (TR) modules. The TR modules are accommodated in seven TR booths located within and around the antenna array. The whole system can be subdivided into $\sim$40 groups. The exact number of the elements and groups, and hence the outer shape of the array are subject to change in the course of the final system design. Each array element is driven by its own TR module. The main constituents of the TR module are a solid state transmitter, a receiver preamplifier, a T/R switch, and a digital phase shifter.

An antenna element consists of two orthogonally crossed Yagi antennas with 3 or 4 subelements. A numerical optimization procedure, which takes the effect of mutual coupling between elements into account, is employed in designing the array element. A circular polarization is synthesized by combining these two antennas with 90° phase difference.

The overall operation of the radar is supervised by a programmable radar controller linked with TR module controller of each group. Flexible operations are made possible by the software control of the entire system. For instance, it is possible to switch the antenna beam direction every inter-pulse-period (IPP), virtually to any direction within 20° of the zenith.

Received signal from each group can be connected to any of four receivers, enabling various interferometric uses of the radar. Output of each receiver is processed by digital demodulator/integrator, and then by an supermini computer with an array processor.

ANTENNA

The largest concern in designing the antenna of this type of radars are the sensitivity and the maximum beam steerability. The former is proportional to the effective area A, and the latter increases as the spacing d between array elements (with independent phase shifter) decreases. The effective area A of a large array antenna is approximated by a product of the number of array elements N and the effective area of each array element $A_{\rm elm}$ with the effect of the mutual coupling between elements taken into account. Since $A_{\rm elm} \propto d^2$, increasing A by increasing $A_{\rm elm}$ conflicts with the requirement to reduce d. As a consequence, the total performance of the antenna is limited mostly by N, which is the dominant factor of the construction cost.

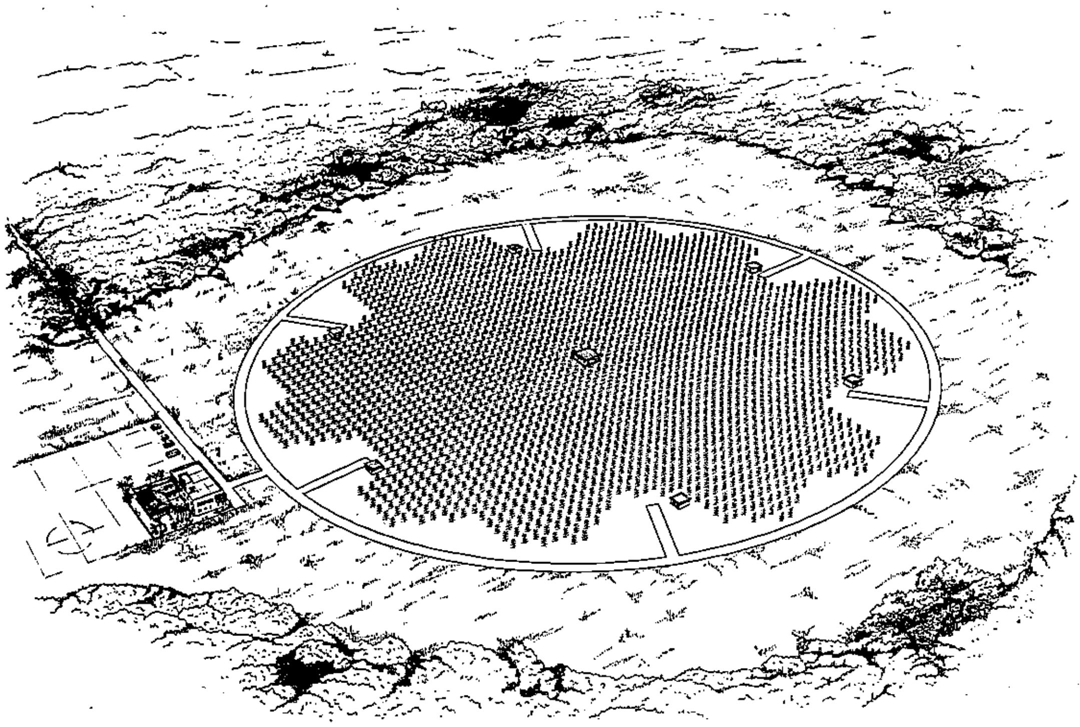

Fig. 1. Artist's conception of the equatorial radar.

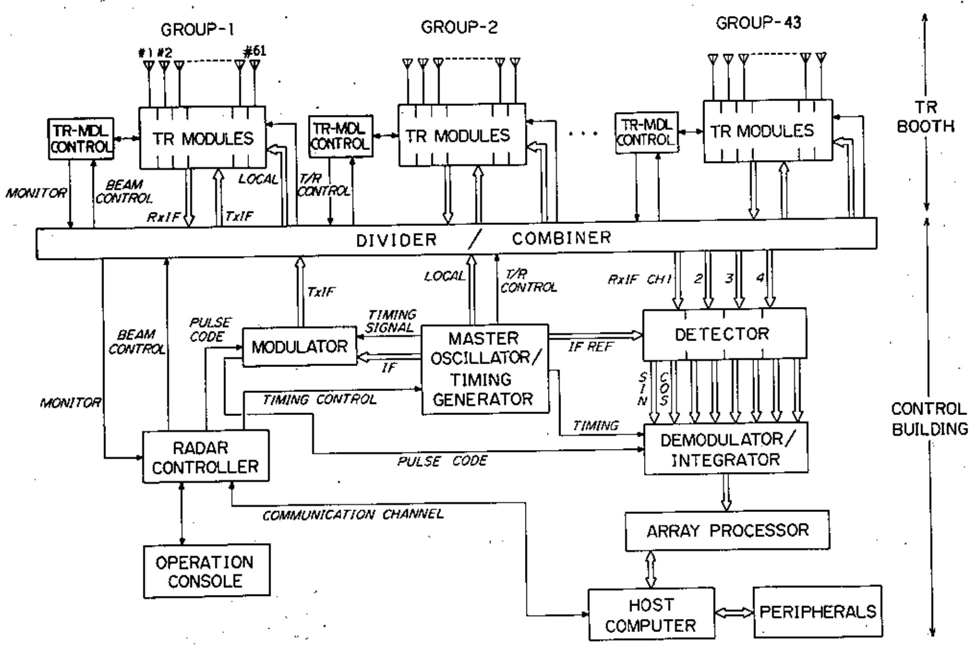

Fig. 2. General block diagram of the equatorial radar.

TABLE 1 Basic parameters of the international equatorial radar.

Parameter	Value
Location	Pontianak, West Kalimantan, Indonesia (0.03°N, 109.29°E)
Radar system	monostatic pulse radar; active phased array system
Operational frequency	47 MHz
Antenna	circular array of ~2,500 crossed Yagi's
aperture	~60,000 m^2 (~280 m in diameter)
beam width	1.2° (one way; half power for full array)
steerability	steering is completed in each IPP
beam directions	~2,000; 0°–20° off zenith angle
polarizations	circular
Transmitter	~2,500 solid state amplifiers (TR modules; each with output power of ~500 W peak and ~25 W average)
peak power	~1.1 MW (maximum)
average power	~55 kW (duty ratio 5%)(maximum)
bandwidth	~2 MHz(maximum) (pulse width: 1–512 μs variable)
IPP	200 μs to 65 ms (variable)
Receiver	
bandwidth	~2 MHz (maximum)
IF	5 MHz
A/D converter	12–16 (not fixed) bits × 8 channels
Pulse compression	binary phase coding up to 32 elements; Barker and complementary codes presently in use

Here the upper limit of N is set to be ~2,500 from economical considerations. From scientific requirements, including the one that the radar should be able to observe a direction perpendicular to the earth's magnetic field, the maximum beam steering angle is set to 20°. Theoretical considerations based on computations of the array factor led to the arrangement of the elements to be an equilateral triangular grid with $d = 0.83\lambda$, where λ is the radar wavelength (6.4 m). This spacing set the upper limit of A as 61,000 m^2, which corresponds to a circular array with a diameter of 280 m.

The spacing also determines the upper limit of the gain of the array element as 8.7 dB. An element design of 3–subelement Yagi is already made by a numerical optimization technique, yielding an element gain close to this upper limit, and acceptable element pattern, bandwidth, and impedance characteristics. However, further search for 4–subelement Yagi is necessary to examine whether a better performance can be obtained by increase the number of subelements.

TR MODULE

Both the up-conversion and down-conversion are conducted in the remote booths, so that the IF (5 MHz) and local (42 MHz) signals are transferred between the booths and the control building. Upon arrival at the booth, the signals are divided into groups by the TR module divider (TX IF divider and local divider, respectively) and distributed to TR modules in each of the groups.

On the other hand, the received IF signals from each TR module are combined into one by the TR module combiner, and sent directly to the control building. The timing signals for T/R switching and initial set pulse (ISPL) are split in the same way. Figure 3 is a block diagram of one group of TR modules.

The main constituents of the TR module are a mixer (MIX) unit and a power amplifier (PA) unit. Frequency conversion is performed in the MIX unit. The 42 MHz local signal (LO) fed to the MIX unit passes through a digital phase shifter for beam steering and TX/RX phase correction. This phase correction takes overall care of individual phase differences of MIX and PA modules, cables, and connectors.

The PA unit amplifies the RF (47 MHz) signal supplied from the MIX unit up to ~500 W, and feeds it to an array element. An exciter consisting of a three-stage amplifier operates in A class with a gain of ~40 dB.

A T/R switch consists of a combination of two 3-dB hybrids and high-power PIN diodes /3/. Three additional diode switches are inserted in the RX channel in order to obtain a total isolation of 100 dB between TX and RX signals. Switching requires ~10 μs, limiting the interval between the end of the TX and the start of sampling.

A band pass filter is inserted after T/R switch to prevent transmission of undesired harmonics. The second and third harmonics are reduced by more than 85 dB in comparison with the fundamental frequency.

DATA ACQUISITION

The received signals, which is converted into IF and combined for each group, are transferred individually to the control building as stated above. The IF signals from all groups can be combined into one to four channels in an arbitrary combination. Only one channel is used for normal full power operation.

Four coherent detectors are available, corresponding to the four output channels of the combiner. The IF signal is split and

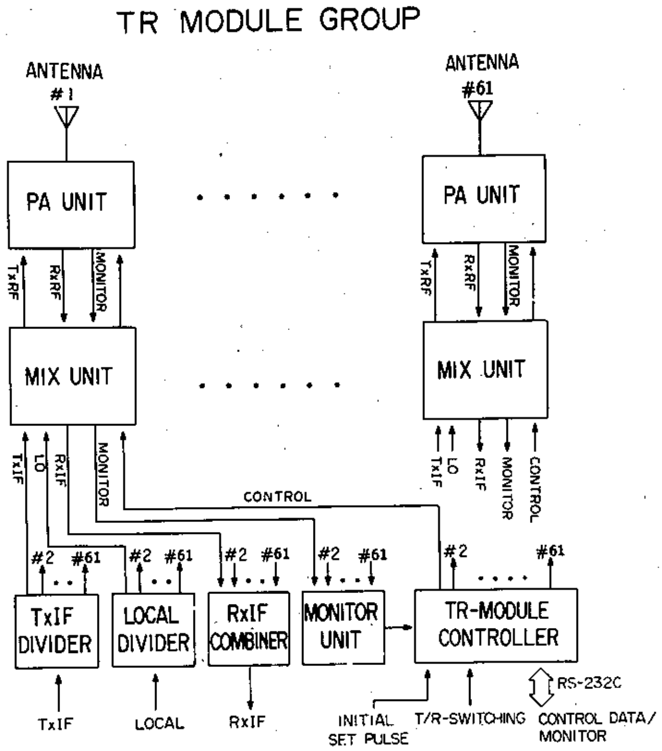

Fig. 3. Block diagram of one group of TR modules.

separately mixed with two phase-quadrature reference signals (5 MHz). This detection enables determination of the sign of the Doppler-shifted echo. The same low-pass filter as is used for the modulator is provided in each detector channel to match TX subpulse widths of 1, 2, 4, 8, 16, and 32 μs. The video amplifier in each channel matches the filtered signal to the desired input level of the analog-to-digital (A/D) converters in the demodulator/integrator.

Digitized signals are decoded for pulse compression and then coherently integrated. Coherent integration is possible only when the characteristic time of atmospheric refractive-index fluctuations is much longer than the period required for the integration. Since the equatorial radar incorporates pulse compression also for the purpose of observing the ionosphere with a characteristic time less than one IPP, decoding prior to/without coherent integration is required.

For MST (mesosphere, stratosphere and troposphere) observations, the output of the integrator is stored into a two dimensional buffer in the online data processing computer to constitute a time-height series. After a specified length of time series is obtained for each height, echo power spectra are calculated by an fast Fourier transform (FFT) algorithm. Spectra are then averaged further to reduce statistical fluctuations. For ionospheric observations, a multipulse technique is employed to obtain the signal auto-correlation functions (ACF's) instead of the power spectra.

Averaged spectra (or ACF's) are recorded on magnetic tapes, and stored in temporary buffers for a quick look in magnetic disc unit as well. The quick-look program provides a variety of visual outputs for the observer to check the data on the real time.

REFERENCES

1. S. Fukao, T. Sato, T. Tsuda, S. Kato, K. Wakasugi, and T. Makihira, The MU radar with an active phased array system: 1. Antenna and power amplifiers, *Radio Sci.*, *20*, 1155-1168, 1985a.

2. S. Fukao, T. Tsuda, T. Sato, S. Kato, K. Wakasugi, and T. Makihira, The MU radar with an active phased array system: 2. In-house equipment, *Radio Sci.*, *20*, 1169-1176, 1985b.

3. P. Czechowsky, G. Schmidt, and R. Rüster, The mobile SOUSY Doppler radar: Technical design and first results, *Radio Sci.*, *19*, 441-450, 1984.