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7.6.1 MONITORING OF THE MU RADAR ANTENNA PATTERN BY SATELLITE OHZORA (EXOS-C)

Toru Sato[1], Yasuhiro Inooka[1], Shoichiro Fukao[2], and Susumu Kato[1]

18974

[1]Radio Atmospheric Science Center
Kyoto University
Uji 611, Japan
[2]Department of Electrical Engineering
Kotot University
Kyoto 606, Japan

INTRODUCTION

As the first attempt among MST type radars, the MU radar features an active phased array system (KATO et al., 1984; FUKAO et al., 1985a,b). Unlike the conventional large VHF radars, in which output power of a large vacuum tube is distributed to individual antenna elements, each of 475 solid-state power amplifiers feeds each antenna element. This system configuration enables very fast beam steering as well as various flexible operations by dividing the antenna into independent subarrays, because phase shift and signal division/combination are performed at a low signal level using electronic devices under control of a computer network. The antenna beam direction can be switched within 10 μsec to any direction within the zenith angle of 30°.

Since a precise phase alignment of each element is crucial to realize the excellent performance of this system, careful calibration of the output phase of each power amplifier and antenna element has been carried out. However, it is necessary to confirm the total performance by measuring the radiation pattern of the whole array from distant places where the antenna far field condition is satisfied.

Among various aircrafts which may be used for this purpose, e.g., airplanes, helicopters or balloons, artificial satellites have an advantage of being able to make a long-term monitoring with the same system. An antenna pattern monitoring system for the MU radar has been developed using the scientific satellite OHZORA (EXOS-C) which was launched on February 14, 1984. OHZORA has an almost circular orbit with the apogee of 815 km, perigee of 350 km and a high inclination of 74.6°, which are quite suitable for the purpose of monitoring.

A receiver named MUM (MU radar antenna Monitor) on board the satellite measures a CW signal of 100-400 watts transmitted from the MU radar. The received signal strength is transferred to the tracking station (Kagoshima Space Center of ISAS; KSC) through a telemetry channel. The overall antenna pattern is synthesized by integrating the data over many passes with different zenithal and azimuthal angles.

PRINCIPLE OF THE MEASUREMENT

The received signal strength is affected not only by the transmitting antenna pattern, but also by height and attitude of the satellite, the receiving antenna pattern and its radiation impedance. In order to remove these factors, a small omnidirectional reference antenna is installed at the MU radar site, which transmits a CW signal of a frequency of 50 kHz offset from the MU radar frequency. The level of this reference signal is compared with the MU radar signal on the satellite, and the MU radar antenna pattern is determined as the relative gain to that of the reference antenna. A turnstile antenna with a ground plane in a grid structure of 5 m x 5 m is located as the reference antenna on the top of the control building of the MU radar. Figure 1 illustrates the scheme of the measurement.

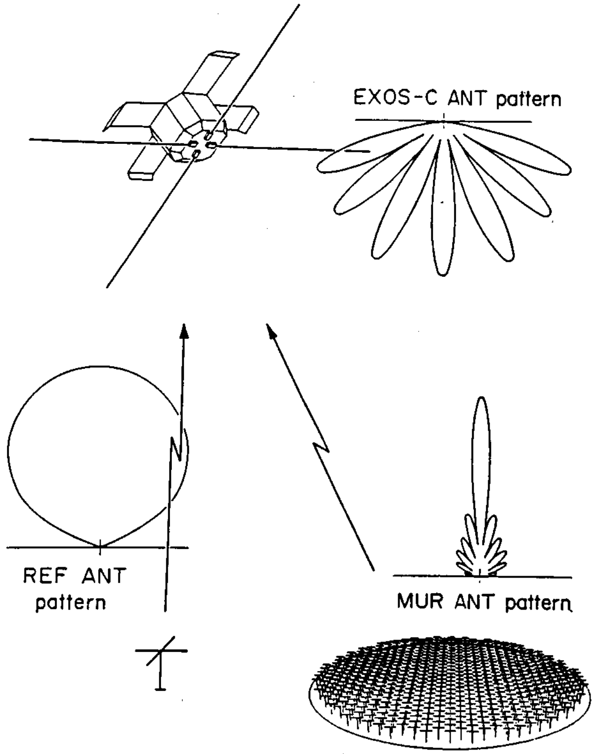

Figure 1. Principle of the MU radar antenna pattern measurement.

A pair of long wire dipole antennas of 40 m tip-to-tip installed for another physical instrument is utilized as the receiving antenna of MUM. As the length of this antenna corresponds to 6-wave dipoles at the frequency of the MU radar, the receiving antenna pattern becomes quite complicated. Also, the range of the satellite from the MU radar site varies from about 300 to 3000 km. In order to adapt to the expected wide dynamic range of the received signal due to these effects, an automatic gain control (AGC) is applied relative to the reference signal level.

The angular velocity of the satellite seen from the MU radar is 1.5°/sec at most, which is fairly slow considering the main beam width of 3.6° of the MU radar antenna. Therefore, a received-signal sampling rate of 100 msec is sufficient to make a detailed measurement of the antenna pattern. Since a sampling rate of as fast as 2 msec is available for the data processing unit of OHZORA, the MU radar antenna beam can be pointed up to about 10 different directions switched periodically during one pass of the satellite, still allowing for several contiguous samples in each beam direction. Figure 2 schematically shows this sequence.

RESULTS

In the example shown below, the MU radar antenna beam is pointed to 6 directions switched every 15.2 msec alternately when the satellite passes above the antenna. Among these directions, five directions are pointed to different

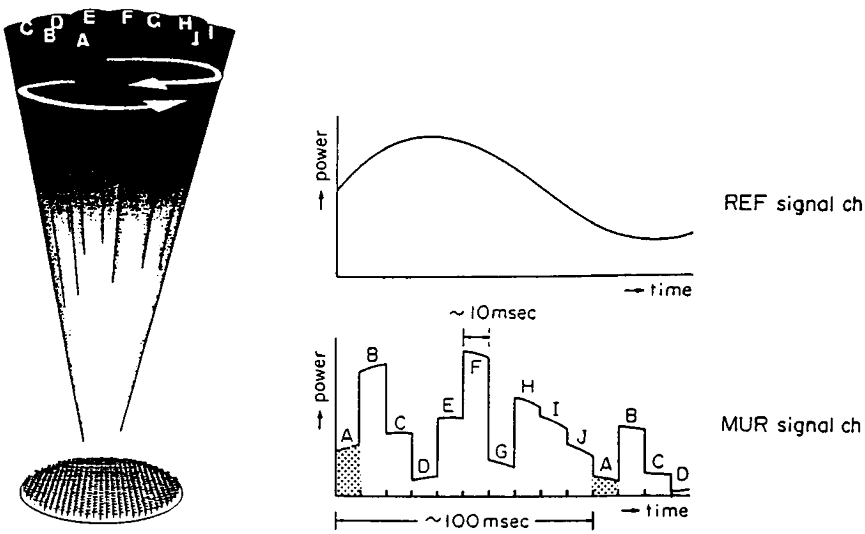

Figure 2. Schematic diagram of the temporal variation of the received signal levels. The antenna beam switched in a sequence of A, B, C,...J in this example. In practice, one of these beam direction (A) is used as a timing marker by shutting down the transmitter.

points on the expected path of the satellite, and the transmitter is shut down for the period of the remaining direction. This shut-down period is used as a timing marker to distinguish different beam directions in the off-line data analysis.

Figure 3 shows an example of unprocessed data of such measurement. The horizontal line around 150 digit is the reference signal level. Figure 4 gives the theoretical (thin line) and measured (thick line) relative gains of the MU radar antenna over the reference antenna for one of these five directions separated from the data in Figure 3. Since the reference antenna has almost constant gain of 6-8 dB for the elevation angles shown in this figure, this figure is regarded as the directivity pattern of the MU radar antenna if the above-mentioned gain of the reference antenna is added.

This figure shows that both main beam direction and gain agree very well with the theoretical ones, indicating that both the MU radar and the MUM system are working properly.

The sidelobe levels, on the other hand, shows some discrepancy of $\sim$5 dB between the theoretical and measured patterns, although the positions of sidelobes agree fairly well down to low elevation sidelobes. The consistent offset in the gain throughout the sidelobe region seems to suggest that a slightly larger random phase error might remain in the individual power amplifiers and/or antenna elements of the MU radar, which are inseparably related in radars with an active phased array system. Apparently more detailed and continuous monitoring of the radiation pattern, as well as careful calibration of individual amplifiers and antennas, is necessary in order to establish the performance of this system.

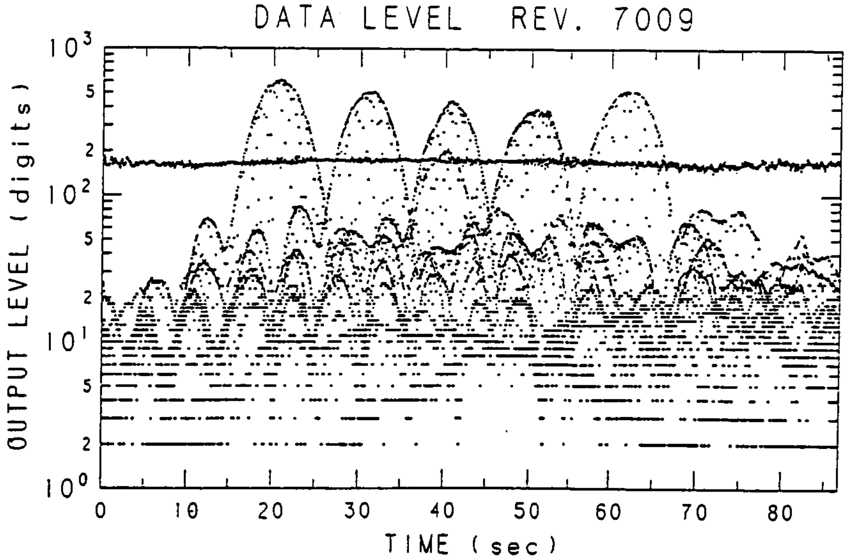

Figure 3. An example of unprocessed data which contains 5 different beam directions.

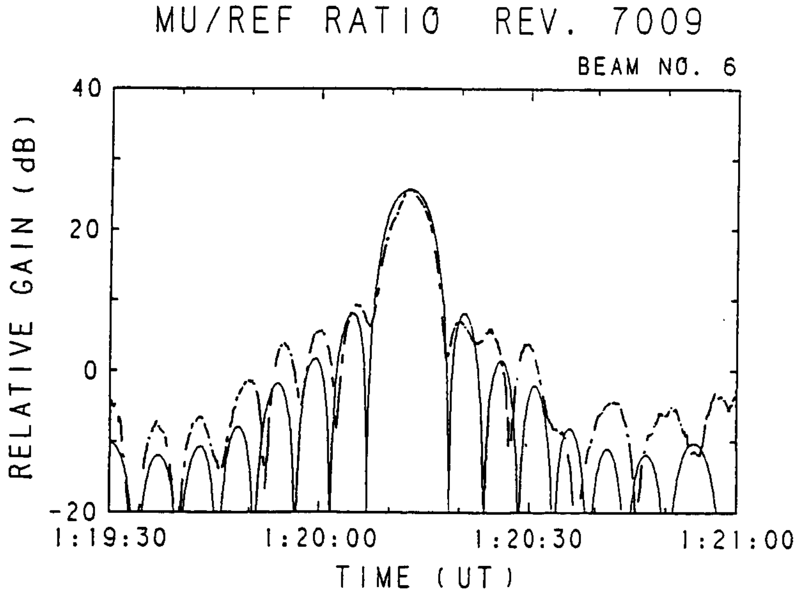

Figure 4. An example of the MU radar antenna pattern measured by MUM (thick line), and the corresponding theoretical antenna pattern (thin line).

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