A phase calibration method of active phased array antennas for satellite communication

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Abstract: An active phased array antenna consists of many channels. Each channel has a different initial phase shift and gain because of the inequality in the active circuits themselves, interface between radiators and active circuits, and beam-forming circuits and other antenna system configurations. This raises an inherent problem in active phased array antennas. To compensate for this problem, the initial phase and gain of each channel should be calibrated. This paper presents an efficient calibration method for an initial phase variation of each channel in active phased array antennas. We tested our method in an active phased array antenna, and obtained good results in the radiation pattern and beam direction of antenna.

1. Introduction

An active phased array antenna consists of many channels including radiators and active circuits that contain amplifiers and phase shifters. Each channel has a different initial phase shift and gain because of the inequality in the active circuits themselves, interface between radiators and active circuits, and beam-forming circuits and other antenna system configurations. This raises an inherent problem in active phased array antennas. To compensate for this problem, the initial phase and gain of each channel should be calibrated to obtain the desired radiation pattern and gain [1,2].

Most of large active phased array antennas have their own calibration method inside. For example, THHAD(Theater High Altitude Area Defense) has six reference horn antenna for channel calibration and the calibration should be performed before operation[3]. AMSAR(Airborne Multi-roll Solid-state Active-array Radar) has its own unique routine for calibrating T/R modules[4]. Recently, there are many researches on the efficient calibration algorithm for adaptive beam forming antennas[5].

An active phased array antenna, which consists of a great number of channels, is not much effect by the unequal channels, because the imbalances of each channel are canceled. But the antenna presented in this paper has only sixteen channels. Therefore we must compensate gains and phases deviation of active channels to improve a performance of the antenna.

Generally we need much time and effort to calibrate an active phased array antenna, which is one of major defects of an active phased array antenna. In this paper, we propose an efficient phase calibration method. If gains of all active channels are uniform, the method is convenient, and moreover, it improves largely the performance of an antenna by compensation for the deviation of initial phases on an active phased array antenna. To prove this fact, we really applied to the developed active phased array antenna for satellite communication. We obtained good results in the radiation pattern and beam direction of antenna.

2. Structure of Array Antenna

The array structure of the active phased array antenna designed in this study is shown in Fig. 1. Each radiator subarray of the antenna consists of 4 circular microstrip patches. And the whole antenna system consists of 16 radiator subarrays and 16 active channels.

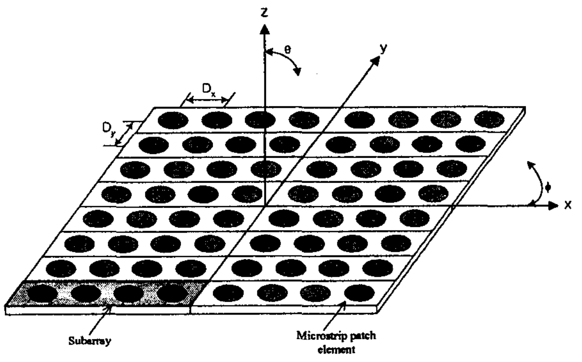

Figure 1. Structure of an active phased array antenna for satellite communication.

The gain pattern of a single radiator subarray is given by

$$G_0 = \left| 5.01 \cdot \left[\sqrt{(1-u^2-v^2)} \right]^{1.4} \cdot AF_1 \cdot AF_2 \right|^2 \qquad (1)$$

Where

$$AF_1 = \cos(k \cdot \frac{D_x}{4} \cdot \frac{u}{2})$$

$$AF_1 = \cos(k \cdot \frac{D_x}{4} \cdot u)$$

$$u = \sin\theta\cos\phi, \quad v = \sin\theta\sin\phi .$$

In Eq.(1), the radiation pattern of a single microstrip patch is approximated by cosine $(x)^{1.4}$ and the absolute magnitude of a single patch gain was measured by experience.

The whole array antenna gain pattern is calculated from the subarray gain pattern as follows.

$$G_T = G_0 \cdot \frac{\left|\sum_{m=1}^{M}\sum_{n=1}^{N} S\right|^2}{\sum_{m,n}\left|A_{mn}\right|^2} \qquad (2)$$

$$S = A_{mn}\cdot \exp\left[-jk\{(m-1)D_x\cdot u + (n-1)D_y\cdot v\} + j\Psi_n\right]$$

$$\Psi_n = E\left[\frac{0.5 + k_0\{(m-1)D_x\cdot u_0 + (n-1)D_y\cdot v_0\}}{\Delta\Psi}\right]\cdot\Delta\Psi \qquad (3)$$

Where M(=2), N(=8) is the number of radiator subarrays in x or y direction, A_{mn} is a coefficient of incident power to each radiator subarray. In Eq.(2) and (3), Ψ_n is a phase shift value and $\Delta\Psi$ is the minimum discrete phase variation of the used phase shifter.

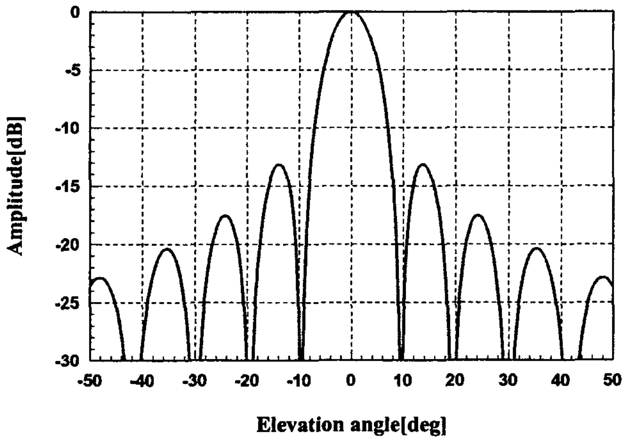

Fig.2. Calculated antenna pattern in the elevation plane.

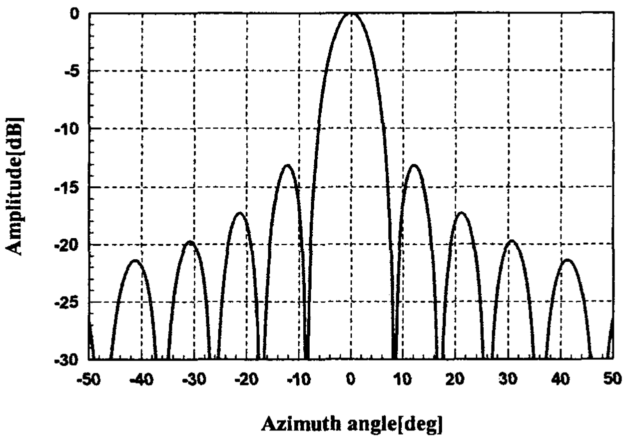

Fig.3. Calculated antenna pattern in the azimuth plane.

The antenna pattern can be calculated from the Eq.(2). Fig.2 is the normalized antenna pattern in the elevation plane and Fig.3 is the normalized antenna pattern in the azimuth plane.

3. Antenna system configuration

The antenna system configuration for satellite communication calibrated using the proposed method is presented in Fig.4. In Fig.4, sixteen radiator subarrays and sixteen active channel blocks (including a low noise amplifier, a 4bit phase shifter an amplifier) are connected in series and then connected with four column combiners and one beamforming block in series or parallel. The functions of each block are as follows:

- Radiator subarray is a microstrip patch array antenna to receive the satellite signal.
- Active channel block amplifies the signal and makes beam in the direction of satellite
- Column Combiner combines signals from 4 active channel blocks.
- Beam forming block combines all signals and divides the signal into one main beam signal and one tracking beam signal.
- Tracking signal converter converts the tracking beam signal to DC voltage for satellite.

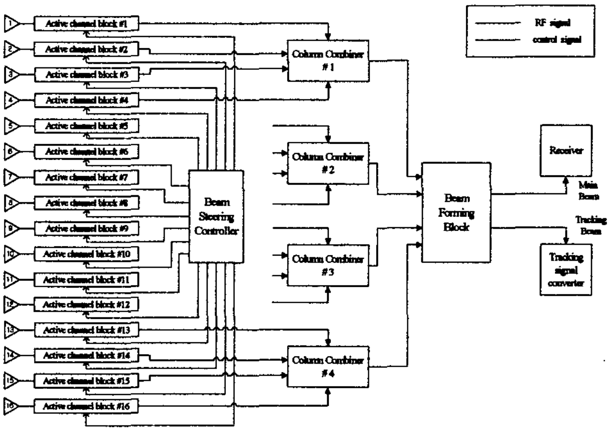

Figure.4. Antenna system configuration.

4. Calibration of Active phased array antenna

4.1 Calibration Method

As previously stated, the initial phases of the channels of active phased array antennas are unequal because the antenna system combines the complicated active circuits with other circuits. To solve this problem, we calibrate the phase shifters using the proposed method.

In our method, we perform the calibration using a near field measurement system. The procedure is as follows.

1. The developed antenna is set at a constant distance from a source antenna.

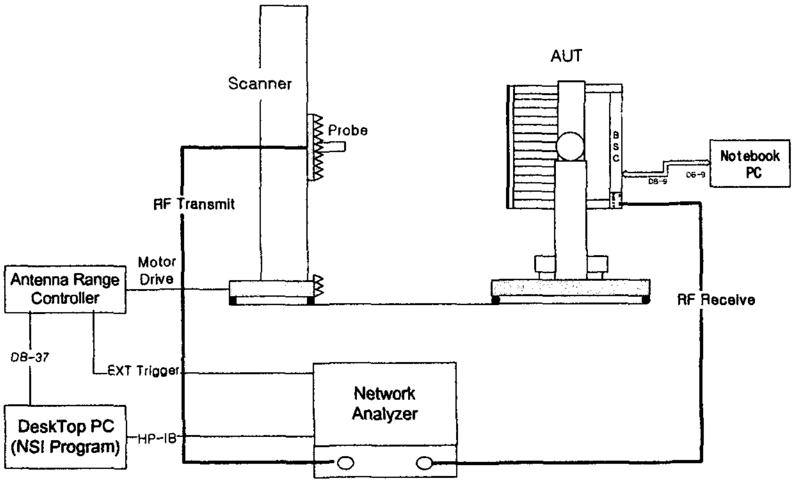

Figure.5. Test environment of the active phased array antenna calibration

2. After the center of each subarray in this antenna and the center of source antenna is arranged in a horizontal line, the phase shifters' phase values are set to 0° using a program connected to the beam steering controller.
3. We extract the initial phase values displayed on the monitor of a near field measurement system.
4. After measuring the initial phase values, The compensated beam steering data for the array antenna could be calculated and the data for phase shifters are as follows.

$$\Phi_{ij}(\theta,\phi) = \varphi_{ij}(\theta,\phi) + \varphi_{ij}^{IPS} \qquad (4)$$

$$\varphi_{ij}(\theta,\phi) = \frac{2\pi}{\lambda_0}\{(i-1)D_x\cdot u_0 + (j-1)D_y\cdot v_0\}$$

$$u_0 = \sin\theta_0\cos\phi_0, \quad v_0 = \sin\theta_0\sin\phi_0$$

$$i = 1,2, \quad j = 1, 2, 3, 4, 5, 6, 7, 8$$

Where φ_{ij}^{IPS} is the measured initial phase value and $\varphi_{ij}(\theta,\phi)$ is the calculated phase one from array geometry.

4.2 Comparison of Radiation pattern before and after Calibration

Before and after calibration, the antenna radiation pattern is shown as Fig.6 and Fig.7. The solid patterns are measured results after calibration and the circular symbolic patterns are measured ones before calibration. In Fig.6 and Fig.7, we can know how calibrating the phase shifter for a real fabricated antenna system by the proposed calibration method improved the radiation pattern. When the scan angle is 0°, the antenna's main beam in the elevation plane is tilted about 3° and the radiation pattern is distorted before calibration, but after calibration, the main beam scan angle is precisely 0° and the radiation pattern is improved. In *addition, the sidelobe level in the beam pattern is improved* by about 3-5dBc after calibration.

By using this calibration technique, when the antenna scans in any direction, we can direct the beam in a desired direction. The radiation pattern shows a little difference between measured results and simulated ones. But the difference is caused by feedlines and substrate losses used radiator subarrays.

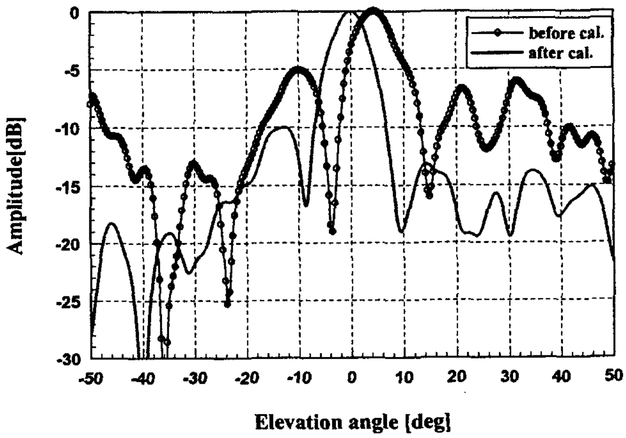

Figure.6. Calibrated radiation pattern in the elevation plane.

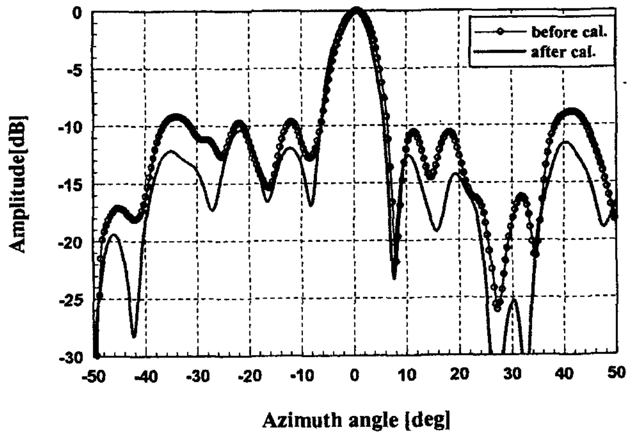

Figure.7. Calibrated radiation pattern in the azimuth plane.

5. Conclusion

In recent years, much research has focused on the effect of unequal channels on the active phase array antenna. However, research on the channel compensation method to reduce this effect is uncommon. Each channel of an antenna system has a different initial phase and gain. This raises an inherent problem in the active phased array antenna. One of a calibration method to solve this problem is as follows. While we receive the transmitted signal using our developed antenna, we change the phase shifter status for the antenna and simultaneously extract the phase values that give the strongest signal. The drawback of this method is that using more phase shifter costs much time. However, compared with the above method, the direct measurement method presented in this paper spends a little time and effort because we don't need to change the phase shifters status in all cases. Therefore, we don't need to spend more time, even if we use more phase shifter.

The proposed method is easily applicable to any kind of active phased array antenna.

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