Design of Microstrip Array Antenna with Three-Element Sequential-Rotation Subarray for DBS

Kyung-Soo Jin[1] · Hye-Jung Shin[2] · Byong-Woo Park[2]

Abstract

The LHCP circularly polarized antenna operating at DBS band is developed by employing the sequential-rotation technique in which each subarray is comprised the three truncated-corner patch square element. Antenna designed with sequentially-rotated technique whose $M=3$, $p=2$ has the effect of improved axial-ratio bandwidth, cross-polarization etc. And it is proved that the degradation of radiation pattern can be reduced significantly by minimizing the radiation loss of feeding line structure. Antenna designed shows extremely low side lobe level of below -25 dB in the diagonal plane and cross-polarization level of below -20 dB in the all plane. And these performances comply with the array antenna specification for DBS.

Key words : microstrip array antenna, sequential-rotation technique, DBS, circularly polarized antenna.

Ⅰ. Introduction

The sequential rotation of elements is an interesting technique for the design of circularly polarized array antenna which was proposed originally to improve the main beam polarization purity and bandwidth of microstrip arrays[1]. This primary advantage of sequential rotation is particularly important in small satellite earth station antennas. For example, the cross-polarization rejection of 20 dB for direct broadcast reception is difficult to achieve without rotation. Cross-polarization rejection is improved by the element to element rotation reinforcing the wanted hand of polarization.

Generally, a sequential-rotation array is composed of a group of identical elements which are physically rotated by multiples of a defined basic angle and are excited with equal amplitudes and phase offsets corresponding to their individual rotation angles. Though a large variety of sequential-rotation configuration is possible, as summarized in [2].

In the design of the DBS antennas, there are the problems of reducing the size and weight, and yet it must have a gain high enough to be competitive with the popular parabolic reflector antennas. A number of flat antennas using microstrip antenna elements have been developed so far with the features of light weight and ease of installation on the walls of a house or a building, location inside a room. Several planar antennas for satellite broadcasting reception using circularly polarized printed arrays have been proposed[3]~[6].

In 1985, Haneishi designed a circular-patch array antenna which utilized the paired elements as the fundamental element of the antenna. It has 1024-elements(size of the antenna is 48 cm × 64 cm) and has a about 33 dBi gain[3]. In 1986, Murata and Ohmaru designed a square-patch planar array which has 512-patch elements(size of the antenna is 32 cm × 64 cm) and its gain is 34 dBi[4]. However, there are some disadvantage of these two antennas : 1) their size is relatively large, 2) they have a large number of patch element, and 3) they are heavy because the main feeding line has a rear-mounted rectangular waveguide.

In 2000, Joo-Seong and Yun-Hyun designed a circular polarized microstrip 16 × 16 array which consisted of sequential rotation 2 × 2 array and its gain is 30.5 dBi[5]. However, this antenna has a disadvantage of complexity configuration because its adapted the dual-feeding.

Such antennas all have been designed by using the sequentially rotated technique of 2- or 4-group subarray.

In 2000, Kyung-Soo Jin *et al.* also first proposed that a circularly polarized planar array can be designed by employing the sequential rotation technique of 3-group subarray[6]. They also convinced that if the DBS reception antenna were designed by adapting the 3-group radiator, the side lobe level of below -25 dB in the diagonal plane and the cross-polarization level of below -20 dB in the all plane can be achieved. However, its disadvantage is a shortage of the gain which is 20.8 dB at the center frequency of DBS band.

The microstrip array developed here for DBS was designed by employing the sequential rotation technique of 3-group

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subarray, resonates at 11.85 GHz, and radiates a broadside beam with left-handed circular polarization. It provides a peak gain of about 28.5 dB at center frequency and achieve the input return loss bandwidth of greater than 1 GHz and the 3 dB axial ratio bandwidth of 7.34 %.

This antenna designed has a small size, light weight, less element number, which can be used the reception antenna for DBS. Also, it is confirmed that the performances of this microstrip array can be improved to the level up similar to that of the parabolic antenna.

Ⅱ. Patch-element and Subarray Design

Three major steps were taken to develop this microstrip array for direct-broadcast signal reception. These are the single patch element design, the subarray design, and the full array design. Since the microstrip radiator is a narrow band device, the designs of the single patch and the subarray are generally necessary prior to the design of the full array. This is to assure that the array will have the correct resonant frequency, polarization purity, bandwidth, etc.

For an array to generate CP(circularly polarization), its element is generally required to be circularly polarized. A CP array can be composed of LP elements[7],[8] if the radiation efficiency is not a concern. The circularly polarized patch element is used here to take into account the radiation efficiency. Since the insertion loss of microstrip array is mostly incurred in the power distribution transmission lines, the length and complexity of these lines should be minimized. For this reason, the single-feed patch is selected for the array.

There are several configurations[9]~[11] of the single-feed patch to generate CP, such as a square patch with two truncated corners as shown in Fig. 1, a square patch with a tilted center slot, and a circular patch with two indented edges. The truncated corners configuration is selected here because it has only one parameter(the depth of truncation) to deal with, while the other two approaches each has two parameters(width and length) to concern with. The CP bandwidth of all these single-feed patch is generally about 1 %. This narrow bandwidth, not only will not meet the system requirement, but also will cause the perfor-

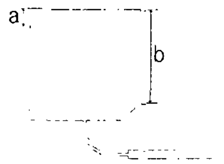


Fig. 1. Circularly polarized square patch with two truncated corners and a single input feed.

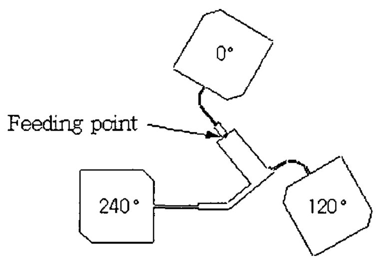


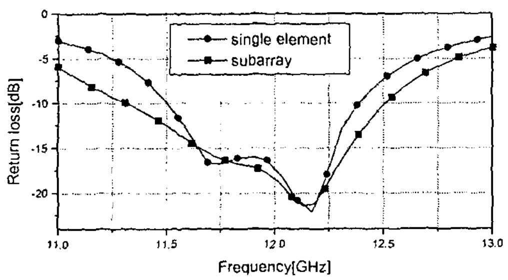
Fig. 2. Circularly polarized subarray with three sequentially arranged patches.

mance to be very sensitive to fabrication tolerance temperature change, etc. One technique to increase the CP bandwidth is to arrange three neighboring elements sequentially in orientations and in phase[1](see Fig.1). This 3-element subarray forms the basic building block for the entire array.

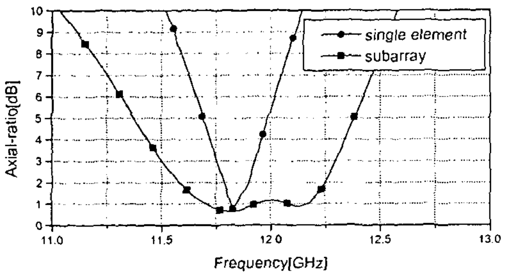
The truncated corner square patch was designed with the following parameters (see Fig. 1) ; a = 6.427 mm, b = 1.172 mm, relative dielectric constant = 2.5, dielectric thickness = 0.7874 mm. Fig. 3(a) shows the simulated results of the single-element as shown in Fig. 1. It shows that the 10 dB bandwidth of the input return loss is 11.5 GHz~12.4 GHz (7.59 %) and the 3 dB bandwidth of the axial-ratio is 11.75 GHz~11.93 GHz (1.52 %). The fabrication tolerance, manufacture's material specification tolerance, and the inaccuracy of the tools are all contributors to the poor axial-ratio bandwidth. Nevertheless, it was expected that relatively narrow CP bandwidth of the perturbed single-feed patch can be reduced significantly by the sequential rotation subarray technique.

The three truncated corner square patch, each being a narrow band CP element, are arranged sequentially in orientation and in phases as shown in Fig. 2 to construct the subarray. This configuration provide the improved CP quality and bandwidth. Also, the high diagonal lobes are significantly reduced when the sequential subarray is placed in a large array environment. In Fig. 2, the three elements are arranged in 0 degrees, 120 degrees, 240 degrees fashion to achieve purer polarization and the element spacing(distance between center point of any patch and one of another) is $0.78\lambda_o$, where λ_o is free-space wavelength. The required differential phases between elements are achieved by designing different length transmission lines.

Fig. 3(b) shows the simulated results of the circularly polarized subarray with three sequentially arranged patches (M=3, p=2) as shown in Fig. 2. It shows that the 10 dB bandwidth of the input return loss is 11.3 GHz~12.5 GHz (10.13 %) and the 3 dB bandwidth of the axial-ratio is 11.5 GHz~12.3 GHz (6.75 %). From the this results, the axial ratio of the three-elements subarray, as expected, is significantly better than that of the single-element.



(a)



(b)

Fig. 3. Simulated results of single element and $M=3$, $p=2$ subarray ; (a) input return loss, (b) axial-ratio.

Ⅲ. Full Array Design

The sequentially arranged three elements as shown in Fig. 2 are used as the building block subarray in the full array where all the subarrays are identical and are combined by Wilkinson power divider. Fig. 4 shows the photograph of the full array which has 192-elements and the characteristic of left-handed circularly polarization. The SMA connector(CDI-5762) located at the side of the full array feeds the microstrip transmission line with a Wilkinson power divider which splits the power parallel to the left and right identical halves.

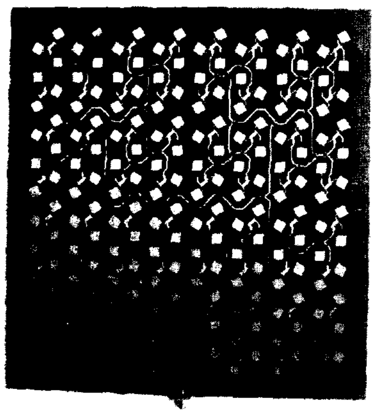
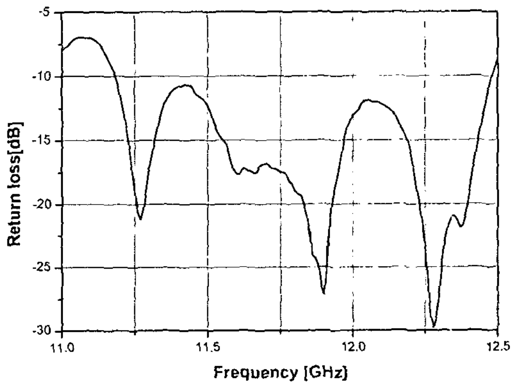


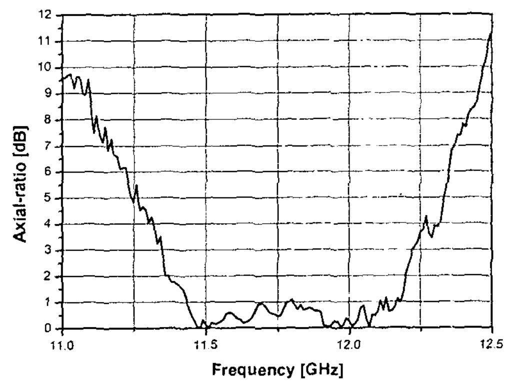
Fig. 4. Photograph of the DBS band full microstrip array with 192-elements.

The microstrip line changes width at each power division point of three-element subarray in Fig. 4. This was uniquely designed to achieve uniform power distribution throughout the array with proper impedance matches. The microstrip lines are also impedance matched at every junction point throughout the array so that multiple reflection of the signal are nearly eliminated to reduce insertion loss. The reflections from element input mismatched will result in some power distribution within the feed network unless isolating splitters are used. Therefore, the power distribution of each subarray is designed using the Wilkinson power divider to protect the array excitation errors and to provide the uniformity of power distribution. The degradation of radiation pattern can be reduced significantly by minimizing the radiation loss of feeding line structure.

The spacing between two adjacent patch elements becomes approximately 0.74 free-space wavelengths. In the array, 3/6-group subarray was arranged to 8 in columns and 4 in rows. Therefore, there are a total of 48 sequentially arranged subarrays with a total of 192 patch elements. This array has a radiating aperture size of 29 cm×27 cm. The microstrip patches and lines



(a)



(b)

Fig. 5. Measured results of the full array ; (a) input return loss, (b) axial-ratio.

are etched on a 0.7874 mm thick dielectric substrate(Taconic TLX-9) having a relative dielectric constant of 2.5.

The measured input return loss and axial ratio of the array is shown in Fig. 5. The input return loss in Fig. 5(a) was measured by using the vector network analyzer HP-8740C. The 10 dB return loss bandwidth is about 11.19 GHz~12.48 GHz (10.89 %), which is wider than the 3-elements subarray's bandwidth of 10.13 %. This is partly because the full array's input match is better designed and partly due to the fact that the full array has a Wilkinson power divider to lower the returned signals due to mismatches.

In Fig. 5(b), it shows that the 3 dB axial-ratio bandwidth is 11.35 GHz~12.22 GHz (7.34 %), is wider than the 3-element subarray's bandwidth of 6.75 %.

The antenna gain of the full array as shown in Fig. 6 was measured across DBS frequency band. It show that the antenna gain is approximately 28.5 dB in the center frequency (11.85 GHz) and is above 20 dB in DBS frequency band.

The radiation patterns measured at 11.85 GHz in the two principal planes (horizontal and vertical plane cuts) of the 192-elements sequentially rotated array in Fig. 4, as well as in

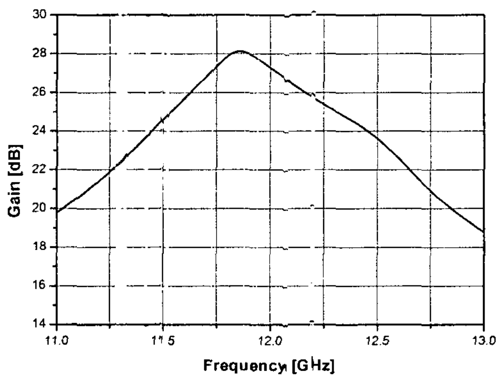


Fig. 6. Measured gain of the of the full array.

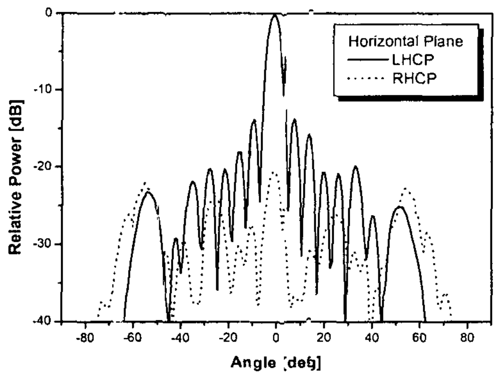


Fig. 7. Measured horizontal-plane ($\phi=0°$ cut) pattern of the array shown in Fig. 4.

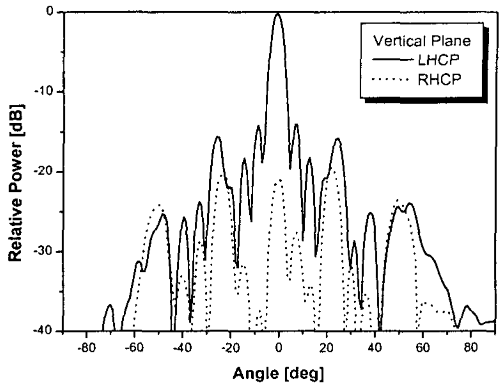


Fig. 8. Measured vertical-plane ($\phi=90°$ cut) pattern of the array shown in Fig. 4.

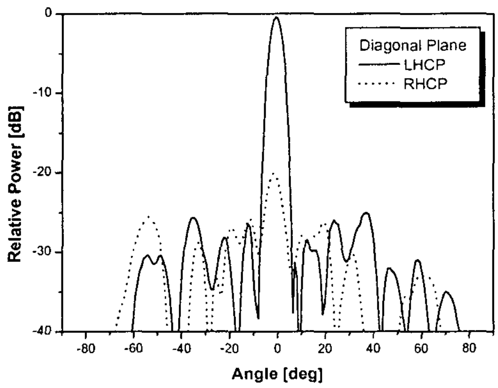


Fig. 9. Measured diagonal-plane ($\phi=45°$ cut) pattern of the array shown in Fig. 4.

the diagonal plane (45 degrees cut) are presented in Figs. 7, 8, and 9.

In Fig. 7, a peak side lobe level is -13.761 dB and a main beam peak cross-polarization level is -20.545 dB. Fig. 8 show a peak side lobe level of -14.124 dB and a main beam peak cross-polarization level of -21.067 dB. Fig. 9 is the radiation patterns measured at 11.85 GHz in the diagonal plane which show a peak side lobe level of -25.018 dB and a main beam peak cross-polarization level of -20.09 dB.

We consider that the cross-polarization produced on the main-lobe at the three radiation patterns is due to the element polarization error and/or feeding error. The cross-polarization level at all plane shows below -20 dB.

Ⅳ. Conclusions

The LHCP circularly polarized microstrip array antenna operating at the center frequency 11.85 GHz was developed by employing the sequential-rotation technique. The full array was comprised of 64 subarray with which $M=3$, $p=2$.

The axial-ratio bandwidth can be improved by employing the matched power divider to remove the mismatching between element and feeding point. Also, the degradation of radiation pattern can be reduced significantly by minimizing the radiation loss of feeding line structure.

The side lobe level is −13.761 dB in the horizontal plane and −14.124 dB in the vertical plane. In particular, it shows extremely low of −25.018 dB in the diagonal plane. The cross-polarization level is below −20 dB in the all plane. The gain is approximately 28.5 dB at the center frequency 11.85 GHz and above 20 dB within DBS bandwidth.

The $M=2$, $p=1$ sequential-rotation array antenna with 256-elements has a about 30.5 dB gain[14]. However, the gain of the $M=3$, $p=2$ array antenna designed here shows 2 dB less than it. For this reason, the array antenna designed here with 192-elements has 60-elements less than it. If the $M=3$, $p=2$ array antenna with 768-elements (size of the antenna is 50 cm×60 cm) is designed, it can be obtained gain comparable to parabolic antenna of 33 dBi gain for DBS. It can be expected that microstrip array antenna designed by using the proposed technique is compatible to receiving the satellite broadcast frequency band.

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