Evaluation of Imaging Performance for Sub-Y-type Interferometric Synthetic Aperture Radiometer

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Abstract

The two-dimensional interferometric synthetic aperture radiometer measures the brightness temperature distribution using two-dimensional antenna array without scanning. It has been reported that Y-type array configuration with equally spaced antennas is optimal in terms of a narrow 3dB beamwidth and wide synthesized field-of-view (FOV). The sub-Y-type array was suggested to improve the spatial resolution than that of conventional Y-type array with the same number of antenna elements. To evaluate it, 37 GHz two-channel interferometric radiometer demonstration model is implemented. The angular resolution of sub-Y-type array was compared with that of Y-type array with the same number of antennas. In this paper, the performance of sub-Y-type is evaluated under the some two-dimensional targets such as the contiguous square objects. The images of sub-Y-type and Y-type array were simulated. The imaging features were compared. The sub-Y-type has higher spatial resolution than Y-type in case of the contiguous target as well as a single point source.

Introduction

Interferometric synthetic aperture radiometer was suggested in the 1980s for earth observation at low microwave frequency with an advantage of high resolution [1]. It was proposed as an alternative to the real aperture radiometer. It can obtain high resolution images without mechanical scanning. In two-dimensional interferometric radiometer, an antenna configuration is one of the important design considerations. It settles the sampling type of visibility function and the minimum number of visibility samples required for a determined aliasing level. It has been reported that Y-type array with equally spaced antennas is optimal in terms of a narrow 3dB beamwidth and wide synthesized field of view [2]. This is applied to develop MIRAS (Microwave Imaging Radiometer by Aperture Synthesis) by the European Space Agency. MIRAS has large Y-type array with 43 antennas per arm spaced 0.89\(\lambda\) (\(\lambda\): wavelength) at 1.4 GHz in order to obtain 3dB beamwidth of 0.77\(^\circ\). The requirement for many antennas to get a high spatial resolution is one of the controversial points, because it causes problems such as system complexity and system cost.

A new type of array configuration, the sub-Y-type array is proposed by SSL(Sensor System Laboratory) at GIST [3][5]. The 37 GHz two-channel interferometric radiometer demonstration model was implemented to evaluate the performance of sub-Y-type array configuration. The visibility samples for interferometric aperture synthesis are measured by spacing two antenna elements sequentially in required pairs of positions. Using the reference noise source, the radiometric characteristics of sub-Y-type array configuration were examined. To compare the theoretical results of proposed type, two contiguous noise sources were tested with sub-Y-type and Y-type. The detailed architecture and experimental results are discussed in the following sections.

Figure 1: Sub-Y-type array with 136 antennas.

Figure 2: Visibility samples for sub-Y-type.
Sub-Y-Type Array Configuration

In this section, the sub-Y-type array configuration is explained. This configuration is suggested to achieve the two dimensional high angular resolution images. The antenna array configuration is important because the array shape affects the synthesized beam pattern of the interferometric synthetic aperture radiometer. Several array types have been proposed such as T-, L-, and Y-type array. Among these, Y-type array has been evaluated as the most efficient configuration that has a large alias free field of view and a narrow synthesized beamwidth compared with other array types under the same number of antenna elements[2]. The sub-Y-type array configuration is devised to obtain the wider visibility coverage area than the Y-type array keeping the hexagonal sampling characteristic under the fixed number of antenna element. However, it is at the expense of incomplete spatial sampling. It is based on sub-array groups where four antenna elements are arranged by \( d_1 \) like Y shape. It is based on antenna groups, which consist of two sub-arrays spaced by \( d_2 \). The distance \( d_2 \) is set to 4\( d_1 \) to obtain a complete sampling on the principle axes. The grouping of sub-arrays in Fig.1 is intended to extent the arm of sub-Y-type array keeping a complete sampling on the principle axes. The spacing between two groups is represented by \( d_3 \). The detailed description of sub-Y-type array antenna configuration is presented in [5].

The antenna array configuration of interferometric radiometer affects on the imaging characteristics because the brightness temperature image is reconstructed from the sampled visibility functions by the inverse Fourier transform [1][4]. The visibility function is

\[
V(u, v) = \iint_{\xi^2 + \eta^2 \leq 1} T_B(\xi, \eta) \exp[-j2\pi(u\xi + v\eta)]d\xi d\eta
\]

where \( u = D_x/\lambda \), \( v = D_y/\lambda \), \( \xi = \sin \theta \cos \phi \), and \( \eta = \sin \theta \cos \phi \). The reconstructed brightness temperature is

\[
\hat{T}_B(\xi, \eta) = \sum_u \sum_v V(u, v) \exp[j2\pi(u\xi + v\eta)]
\]

The wider the sample coverage of the visibility function is, the narrower the synthesized 3dB beamwidth is. The visibility sample coverage is shown in Fig.2. The visibility samples are not completely sampled.

Simulation

The simulation is performed as following conditions:

1. Antenna configuration: the Y-type array with 136 antenna elements and the sub-Y-type array with 136 antenna elements are used.
2. Test input images: a single point source target, contiguous square targets are used.

1) Single point source target

The first simulation is performed under a single point source target. The object is to get the radiometer system response. It represents the point spread function (PSF). It is important to analyze the imaging performance of the radiometer because its characteristics such as main beamwidth and sidelobe level are relevant to the imaging performance. In Fig. 3 and Table 1, the beamwidth of Y-type and sub-Y-type are different although the number of used antennas is same. Sub-Y-type array has narrower beamwidth than Y-type array. However, the sidelobe of sub-Y-type array is higher than that of Y-type.

2) Contiguous square targets

This simulation is executed under the contiguous square targets. Each target is spaced with different distances. The results of this are shown in Fig.4. Fig.4(a) is the contiguous multiple square targets image. The background value in the image is zero. Fig.4(b) is the reconstructed image using Y-type array with 136 antennas. Fig.4(c) is the reconstructed image using sub-Y-type array with 136 antennas. In the top left in Fig.4(b), targets seem like a big square with a hole. They are not distinguished clearly. Square images are blurred. In Fig.4(c), the targets are distinguished clearly. The edges of them are sharp. However, the background is brighter. It results from the high sidelobe level.
Table 1: Estimated characteristics of Y-type and sub-Y-type

<table>
<thead>
<tr>
<th>Antenna array type</th>
<th>Y-type</th>
<th>Sub-Y-type</th>
</tr>
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<tbody>
<tr>
<td>(136 antennas)</td>
<td></td>
<td>(136 antennas)</td>
</tr>
<tr>
<td>Beamwidth</td>
<td>0.74°</td>
<td>0.52°</td>
</tr>
<tr>
<td>Sidelobe</td>
<td>-7.62 dB</td>
<td>-5.54 dB</td>
</tr>
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</table>

Figure 3: One dimensional profile.

Figure 4: Simulation of the contiguous square targets. (a) Original image. (b) Reconstructed image using Y-type array. (c) Reconstructed Image using sub-Y-type array.

Experiment Results

37 GHz two channel interferometric synthetic aperture radiometer demonstration model was developed to experiment the performance of sub-Y-type array. The system specification and experiment environment are listed in Table 2. The visibility samples are measured by spacing the two patch antennas sequentially in required pairs of positions on the antenna mounting structure. A hot noise source is used as imaging target to evaluate the angular resolution of proposed interferometric synthetic aperture radiometer. This noise point source consists of a matched load, an amplifier, and a 4×4 linear polarization patch antenna. The point source is located at the center of the image plane. The sub-Y-type array is designed with 40 channels. The distance of two antennas, $d_1$ is fixed 0.89λ to compare with Y-type array and also $d_2=4d_1$ and $d_3=8d_1$ are decided to obtain optimum angular resolution [5]. The measured point response of sub-Y-type is affected by phase error because the measurement range is not satisfied with the far field region. In order to keep the same phase error for Y-type and sub-Y-type, the Y-type is constructed with 52 antennas for experiment so that the same visibility coverage of sub-Y-type with 40 antennas is achieved. The point source responses of Y-type array and sub-Y-type antenna configuration are reconstructed from visibility samples of 52 and 40 antennas respectively as shown in Fig.5. Although the antenna number of sub-Y-type array antenna configuration is reduced by 12 than that of Y-type antenna configuration, but their responses are similar. That is, the angular resolution is improved by 23%.

Table 2: System Specification and Experiment Environment.

<table>
<thead>
<tr>
<th>Measurement distance</th>
<th>3.6 m</th>
<th>Noise Bandwidth</th>
<th>96.65 MHz</th>
<th>Receiver gain</th>
<th>80 dB</th>
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<tr>
<td>Center frequency</td>
<td>37 GHz</td>
<td>I/Q demodulator</td>
<td>Software based</td>
<td>Channel isolation</td>
<td>&gt; 40 dB</td>
</tr>
<tr>
<td>Correlation bandwidth</td>
<td>100 MHz</td>
<td>Complex correlator</td>
<td>Software based</td>
<td>RF image suppression</td>
<td>&gt; 30 dB</td>
</tr>
<tr>
<td>Integration time</td>
<td>0.65μs</td>
<td>SNR</td>
<td>30 dB</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 5: Response of a noise source. (a) Y-type array. (b) sub-Y-type array.

Conclusion

First, the image performance of sub-Y-type array configuration with 136 antennas was evaluated by simulation. Compared with Y-type array with the same number of antennas, it has narrower 3dB beamwidth. However, since it has higher sidelobe level, the reconstructed image quality is degraded. 37GHz interferometric radiometer demonstration model is implemented to evaluate it. The performance of the angular resolution is evaluated by using a point noise source. As a result, the sub-Y-type array with 40 antennas has the same angular resolution with Y-type array with 52 antennas. It means that its performance is improved by 23% in terms of angular resolution. However, in the experiment result, its high sidelobe level affects the degradation of the reconstructed image quality.

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REFERENCES