Research Activity on Synthetic Aperture Radiometry in CSSAR/CAS

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Abstract

Interferometric synthetic aperture radiometry is a relative new technique in the area of microwave earth observation to measure the brightness temperature distribution of the earth. It can enhance the spatial resolution of the passive microwave remote sensing effectively. Steady progress of this technology have been achieved in both one dimensional and two dimensional cases since 1990’s. The typical instruments are ESTAR and MIRAS, developed by NASA (and umass) and ESA respectively.

Relative research has also been conducted in China, mainly by National Microwave Remote Sensing Laboratory (NMRS Lab), Center for Space Science and Applied Research (CSSAR), Chinese Academy of Sciences (CAS), since the middle of 1990’s. A C-band and an X-band instrument has been developed. In this paper, research activities on synthetic aperture radiometry in CSSAR/CAS will be reviewed and summarized, including the development of the instruments. Finally, further plans in synthetic aperture radiometry in CSSAR/CAS will also be prospected.

Introduction

As a passive remote sensor, microwave radiometer is one of the most important earth observation instruments for many applications [1]. The conventional radiometer is essentially a high sensitive superheterodyne receiver designed to measure the brightness temperature distribution of the earth, by scanning its real aperture antenna across the field of view (FOV). It is obvious that the spatial resolution is directly determined by the physical antenna size. Since the applicable antenna size is always limited, especially in the satellite-borne use, the spatial resolution of the traditional total-power microwave radiometer is also limited. The application fields of traditional microwave radiometer are restricted by low spatial resolution.

Since the middle of 1980’s, the concept of interferometric aperture synthesis technique in radio astronomy is introduced in passive microwave observation to solve this problem [2][3]. Unlike the traditional radiometer, the synthetic aperture radiometer maps the brightness temperature distribution of the earth indirectly, by measuring the Fourier transform of the brightness temperature distribution over the FOV. This kind of measurement in Fourier frequency domain is accomplished by the complex correlation among a set of antennas/receivers arranged in particular positions.

ESTAR, developed by NASA and the University of Massachusetts, is the first airborne instrument designed to demonstrate this technology [3][4]. It operates in L-band and uses aperture synthesis only in the cross-track dimension. ESTAR had done many flying experiments in 1990’s, most of which were made to measure the soil moisture and ocean salinity [5]∼[8]. All of these experimental results provided convincing proof to support the feasibility of the synthetic aperture radiometer.

MIRAS is much more complicated and ambitious, using aperture synthesis in two dimensions, containing 69 antenna/receiver units arranged in Y-shape arms and more than 5000 correlators in central hub. MIRAS is the only payload for the SMOS mission proposed by ESA, which planned to be launched in 2007 [9]. To ensure the success of the space mission, several universities participated in the research under the support and coordination of ESA. UPC has done lots of work on imaging algorithm research, system performance analysis (such as spatial resolution, radiometric resolution, etc), and end to end system simulation [10]∼[13]; HUT has developed a NIR for calibration, and a U-shape airborne demonstrator [14][15]. All of these detailed research work drive the development of synthetic aperture radiometry effectively.

In China, under the support of the National High Technology Research and Development Program of China (863 Program), NMRS/CSSAR/CAS started its own preliminary research on this topic from the middle of 1990’s. A C-band instrument was developed for demonstrator in 2001, which can achieve 4 degree spatial resolution with 6 channels and 11 analog correlators [16][17]. Experiences and lessons were both achieved in this progress. After that, NMRS/CSSAR/CAS developed an airborne X-band 8 channel synthetic aperture
radiometer during 2002~2004, which can achieve higher spatial resolution about 2 degrees. Both analog and digital correlation schemes were adopted in the X-band system design to permit the direct comparison between them. The X-band instrument performed well in its first flying experiment in April, 2004 [18]. Furthermore, by utilizing different antenna array arrangement and digital correlation design, this one-dimensional X-band instrument can even be switched to a two-dimensional experimental system.

**Fundamental Research on Imaging Principle**

As mentioned above, the imaging principle of synthetic aperture radiometer is totally different from traditional radiometer. Since the raw measuring results of synthetic aperture radiometer are a set of frequency domain samples of the scene, transform algorithms are needed to produce the original brightness temperature image. Fourier transform is the most common method to image retrieving. But it often does not perform well enough on real application occasions. NMRS/CSSAR/CAS started its research on image retrieve algorithm in the early term of C-band system developing. The most general situation of aperture synthesis was considered, and corresponding numerical image retrieving algorithm rather than Fourier transform was investigated [19][20][21].

![Figure 1: Effects of Channel’s imbalance (left: amplitude imbalance, right: phase imbalance)](image1)

![Figure 2: Effects of Channel’s mutual coupling (a: original image; b: retrieved image with mutual coupling; c: retrieved image after calibration)](image2)

From the imaging principle of synthetic aperture radiometer, it is obvious that to retrieve the image of an extended target in FOV, the frequency domain must be sampled adequately and exactly. These frequency domain samples obtained by correlation of specific pairs of receiving channels are so called visibility functions. The ideal Fourier relationship between the complex visibility functions and the true brightness temperature distributions requires the balance and incoherence among all receiving channels. However, ideal channel properties
are impossible in practical implementation, imbalance (both amplitude and phase) and mutual coupling always exist among different channels. In this situation, numerical retrieving algorithm should be used, based on the calibration procedure measuring the real system response.

The effects of unideal channels on image retrieving are investigated in [22], where a calibration approach is also presented: using digital I-Q vector modulators to simulate the point source in the antenna range to get the system response G-matrix. Computer simulation results are presented here. Fig. 1 shows the different effects of amplitude and phase imbalance. Fig. 2(b) illustrates the retrieved image corrupted by mutual coupling effects, compared with Fig. 2(c), the retrieved image after calibration.

**Instrument Development: C-band and X-band**

Either of these two C-band or X-band synthetic aperture radiometer is one-dimensional ESTAR-like hybrid system. Some basic specifications of the C-band and X-band instruments are listed in Tab. 1. The X-band analog and digital correlation systems are listed separately.

<table>
<thead>
<tr>
<th>Center Frequency</th>
<th>9.398 GHz (analog correlation)</th>
<th>9.398 GHz (digital correlation)</th>
<th>6.6 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth</td>
<td>25MHz</td>
<td>25MHz</td>
<td>25MHz</td>
</tr>
<tr>
<td>Integration time</td>
<td>25ms</td>
<td>25ms</td>
<td>25ms</td>
</tr>
<tr>
<td>The least spacing between antenna elements</td>
<td>0.735λ</td>
<td>0.735λ</td>
<td>0.72λ</td>
</tr>
<tr>
<td>Antenna/Receiver elements</td>
<td>8</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Complex correlators</td>
<td>20</td>
<td>24</td>
<td>11</td>
</tr>
<tr>
<td>Weight</td>
<td>66kg</td>
<td>52kg</td>
<td>35kg</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>80w</td>
<td>85w</td>
<td>60w</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>2&quot;</td>
<td>2&quot;</td>
<td>4&quot;</td>
</tr>
</tbody>
</table>

Figure 3: Truck-borne experiment result: retrieved image of Baiyi Road, Beijing

Figure 4: The comparison of X-band synthetic aperture radiometer image (a, d) and SPOT multi-spectral image (b, d): (a) Jingpo Lake, Heilongjiang Province, 2004.04.16; (b) Jingpo Lake, 2004.04.14; (c) Songhua Lake, Jilin Province, 2004.04.14; (d) Songhua Lake, 2004.04.11;
The C-band system was developed during 1999–2001. Some initial imaging experimental results were achieved [17][24].

The X-band system was developed during 2002–2004. A series of ground-based, truck-borne and air-borne imaging experiments were conducted from the end of 2003. Fig. 3 and Fig. 4 show some imaging results of these experiments.

Prospect

The success of the X-band instrument’s flight experiments provides us a solid foundation to pave the way for future work. CSSAR/CAS is now investigating the space-borne application feasibility of the aperture synthesis technique in China, either in the area of micro/millimeter wave earth observation or radio space exploration. Several space-borne plans have been proposed, including the plan of Solar Polar Orbit Radio Telescope (SPORT).

Conclusion

After a long term development period of more than ten years, the aperture synthesis technology has become more and more mature and ready for practical applications in the world. NMRS/CSSAR/CAS had developed two synthetic aperture radiometers at C and X band for airborne use. The experiences and lessons achieved in the past will help us in the future.

REFERENCES


