EXPERIMENTS OF INTERFEROMETRIC AND SUPER-SYNTHESIS MICROWAVE RADIOMETER

Koji KOMIYAMA
Electrotechnical Laboratory
Agency of Industrial Science and Technology, MITI
1-1-4, Umezono, Tsukuba, Ibaraki, Japan 305-8568
Phone:+81-298-61-5637, Fax: +81-298-61-5640, E-mail:komiyama@etl.go.jp

1. Introduction

The super-synthesis technique is ordinarily used in radio astronomy as a method to make microwave maps of a celestial body with high angular resolution. The technique utilizes interferometers fixed on the ground moving together with the rotating earth facing to the celestial body. Such a technique of the moving interferometer may be applied to other moving platform smaller than the earth. A space platform in a low earth-orbit(LEO) quasi-linearly moves over the local ground. Therefore, the same technique as radio astronomy may also be applied to the passive microwave imaging of the earth surface from such a platform as a LEO satellite.

We proposed a super-synthesis technique [1] for the remote sensing of the earth on the basis of such an idea as in radio astronomy. Imaging process of the super-synthesis radiometer was shown by one-dimensional imaging experiments in an EM anechoic chamber [2]. Some results of the experiments included the retrieved images of point-targets, each of which is composed of a noise source and an antenna. In the paper, an idea of two-dimensional super-synthesis radiometer was also related. Two-dimensional(2D) images of point noise sources were shown as a result of the demonstration experiments of 2D radiometer [3]. These planer images were obtained by an X-band interferometric radiometer in the anechoic chamber. A conceptual design of 2D radiometer for field experiment was presented [4]. The frequency band of 6GHz was chosen to the radiometer design for easy operation of the imaging experiments. Rotational scanning was also testified for simple operation of the radiometer. The off-nadir angle of the interferometer base-line was evaluated and the problem of the retrieved brightness temperature was also examined [5]. Retrieved brightness temperature of the super-synthesis radiometer was evaluated numerically by a thermal emission model of the ground with the Fresnel reflection coefficient [6]. A radiometer system was under development for the 2D passive microwave imaging experiments. For evaluating the super-synthesis technique and sensitivity of the radiometer, one-dimensional imaging experiments were made using an interferometer in 6GHz frequency band by rotary scanning [7].

In this paper, the behavior of the super-synthesis radiometer is numerically evaluated. The developed radiometer is used for the experiments of imaging from over the ground. The results of the experiments are expressed including the radiometer hardware, configuration of imaging experiments and retrieved images.

2. Super-synthesis technique

The super-synthesis technique is a kind of the aperture synthesis for passive imaging and it is effective only along the platform track, because the platform usually moves quasi-linearly over the ground. Therefore the super-synthesis is restricted along the track. So, the radiometer configuration is expressed only in the vertical plane including the platform track as shown in Fig.1. The synthesis is possible utilizing the phase variation of the interferometer output, namely, a visibility function. Two antennas are aligned with an angle α. The phase change is attributed to the variation of the incidence angle of the surface emission from ground target into the base-line of the interferometer. With the assumption that the ground is composed of infinite number of point noise sources, a point target at the origin in the coordinate system is considered to illustrate the performance of the image retrieval. Since the path difference to these two antennas is the product of two vectors shown in Fig.1, the phase of the visibility function is expressed as the next equation,

$$f(t) = \frac{kd(h \cdot Cos\,a - x \cdot Sin\,a)}{\sqrt{x^2 + h^2}} \qquad (1),$$

where k, d, h and x are the wave number, the length of interferometer base-line, the altitude of platform and the horizontal position of the interferometer. With the assumption of zero off-nadir angle and small x relatively to h, the phase $\phi(t)$ is approximated to

$$kd\left[1 + \frac{1}{2}\left(\frac{x}{h}\right)^2\right] \qquad (2).$$

Since the platform position x is proportional to time in the case of constant velocity, the phase is a time quadratic function. Consequently the frequency is a time linear function. Therefore, matched filtering technique can be used for the synthesis. It is an analogy to the imaging process of the synthetic aperture radar (SAR).

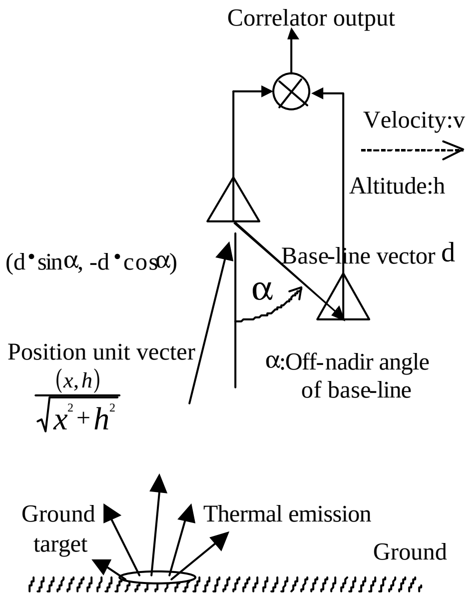

Fig.1 Concept of super-synthesis for surface remote sensing

3. Response to continuous radiation distribution

The response of the radiometer to a continuous radiation distribution is important for the earth remote sensing. The imaging process can be evaluated using a model shown in Fig. 2. This model is a simple interferometer whose antennas are aligned up and down. As each antenna is sticky and the fan beam is spread along the track, the emission only from the inside the slim foot print is received. The correlator output respecting an ideal point target is simply expressed by

$$f_1(x) = e^{jkd(1-\cos q)} \qquad (3), \text{ and}$$

$$q = \tan^{-1}\frac{x}{h} \qquad (4).$$

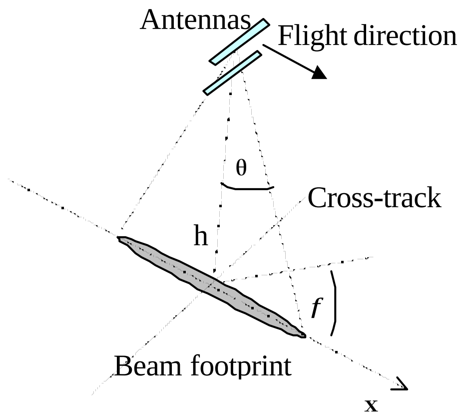

Fig.2 Model of numerical evaluation

The antenna power pattern along the track is assumed as belows.

$$g(x) = \cos^2(3q), \qquad -\frac{p}{6} \le q \le \frac{p}{6} \qquad (5)$$

$$= 0 \quad , \qquad outside$$

The correlation output can be calculated by the integration of the product of the brightness distribution and the antenna response inside the beam. The output respecting a point source is shown in Fig. 3. The parameters of all the calculations are the same as those of the field experiments. The signal is undulating with a varying frequency and the integration of multiple or continuous source may be cancelled down to small values. Resultantly, the retrieved image using the reduced values also may become small. This prediction is verified by numerical evaluation. Two kinds of brightness distributions are adopted. They are a point-like distribution and a step one. The calculated correlations are normalized by the total-power images, respectively, by the same antenna beam as the interferometer, as it is written in (6).

$$C(x_s) = \frac{\int_a^b h(x,-x_s)g(x)f(x)dx}{\int_a^b h(x,-x_s)g(x)dx} \qquad (6)$$

The total-power images used for the normalization are shown in Fig.4 (a) and (b). The brightness images are retrieved from these correlations and are shown in Fig.5(a) and (b). They are remarkably sharp with high spatial resolution by super-synthesis, but the retrieved

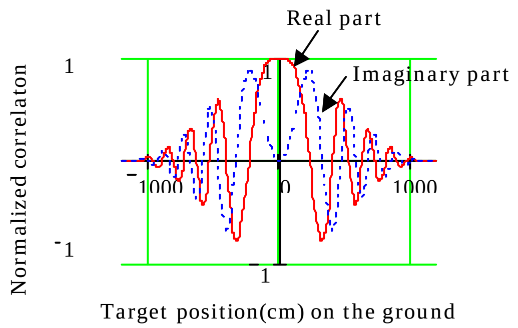

Fig.3 Correlation from an ideal point target

intensity becomes smaller than the total power images, paticularly, in the case of continuous distribution like step function.

Further, the case of 2-dimensionally broad beams is evaluated. Two antennas with conical beams are used instead of sticky antennas in the model of Fig.2 and the resultant correlator output from uniform distribution is obtained by the next double integral.

$$f_2(d) = \int_0^{2\pi} \int_0^{\frac{\pi}{2}} g(\theta)\, f_1(\theta, d) \tan\theta \quad d\theta \quad d\phi \quad (7)$$

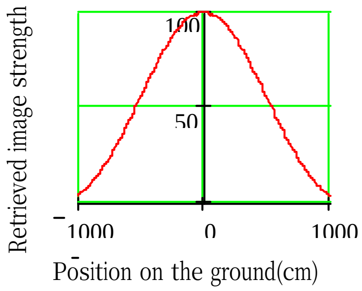

Fig.4(a) Image of point-like target by total power radiometer

The correlator signal of the interferometer becomes small by the 2D cancellation of the undulating signals. The complex output is shown in the case of the experimental 6.6GHz interferometer with the parameter of the length of the baseline in Fig.6. The real part becomes extremely small in the case of longer baseline than 50cm. It may be a weak point of the synthesis under the curcumstance with large noise and error in the hardware, though the image can be retrieved for ideally small noise and error.

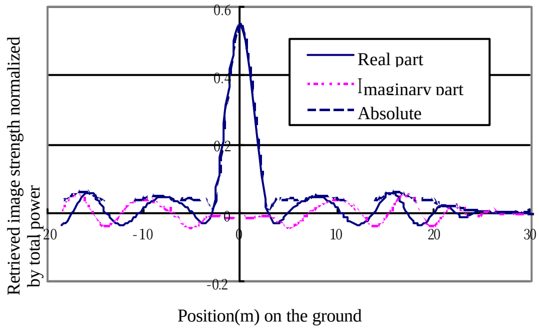

Fig.5(a) Retrieved image of point target by super-synthesis

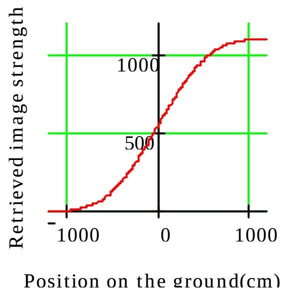

Fig4(b). Image of step distribution by a total power radiometer

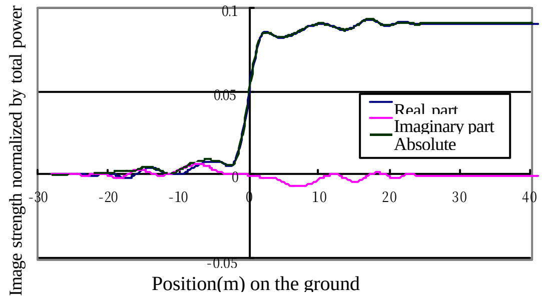

Fig.5(b) Retrieved image of step distribution by super-synthesis

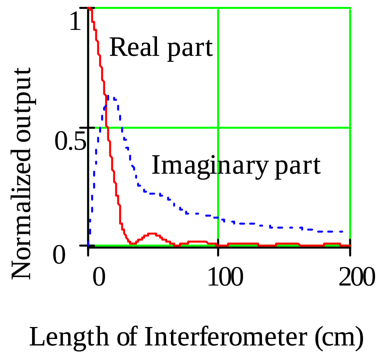

Fig.6 Interferometer output with a 2D broad antenna beam

4. Imaging experiments

The configuration of the radiometer for the imaging experiments is an ordinary microwave interferometer. The system has an antenna array composed of 17 antenna/front-ends, an independent antenna/front-end and 17 correlators with a common input channel. Each antenna is a four-patch array, whose beam width is about 30 degree. The receiving frequency and the band-width are 6.6GHz and 25MHz, respectively. The observation frequency is doubly down-converted coherently in receiver channels to 60MHz IF band with a common local signal. Analog correlators are used in the IF band with a common reference channel signal to generate complex outputs.

The place of experiments is an antenna site with a large ground plane of 50m by 30m. The radiometer is lifted to about 20m high over the ground by a construction crane. The radiometer observes the ground emission from over the ground. The metal ground plane is a large reflector and the emission is low, because the brightness temperature is almost same as the space temperature. Circular scanning is only available by the crane head movement. A point target is used for phase calibration and resolution evaluation. A noise source with a horn antenna is used as the point target.

The target ground is observed by a few kinds of the combination of antenna/front-ends and correlators. A total power radiometer is realized by supplying the same signals into both terminals of a correlator by using a directional coupler. An independent antenna/front-end is used with up and down configuration as shown by Fig.1 and its output is connected to the common channel of the correlator block for super-synthesis. Instead of the single antenna/front-end, the central antenna/front-end is used as the common channel for simple synthesis of multiple interferometers.

Two-dimensional images are made by synthesis from raw data. Fig. 7 shows the image intensity on the center line of the swath where the point noise source exists. The figure shows by the comparison between two 1D images. The super-synthesis image has higher sensitivity to an independent target but has less sensitivity to extended target of uniform brightness distribution as shown by numerical evaluation. Figure 8 shows the improvement of the spatial resolution to a point target depending on the length of synthetic aperture. The horizontal unit of these figures is degree, which means the position of the crane head.

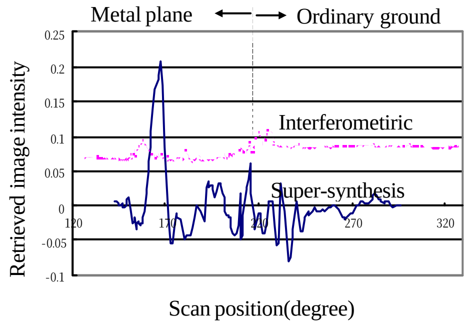

Fig.7 Comparison of 1D images of swath center

Two-dimensional super-synthesis images are shown in Fig.9 (a) and (b). Both images are the result of the fusion of different kinds of data. (a) is made by addiing a total power image and (b) is made by additon of an image by ordinary interferometric synthesis. By using the technique of data fusion, the radiometer can have the sensitivity to the area of constant brightness.

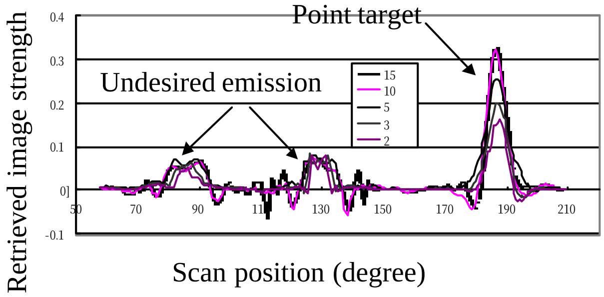

Fig.8 Spatial resolutions by super-synthesis

5. Conclusions

The behavior of the super-synthesis to extended targets is numerically evaluated for interpretation of the images of field experiments. It has a week point of reduced sensitivity of constant distribution. Two- dimensional imaging experiments are made using a microwave interferometer system in 6GHz band at an outdoor antenna site and the predicted phenomenon is shown. Data fusion technique in addition to the synthesis is presented to make a brightness map including smooth and large scale variation.

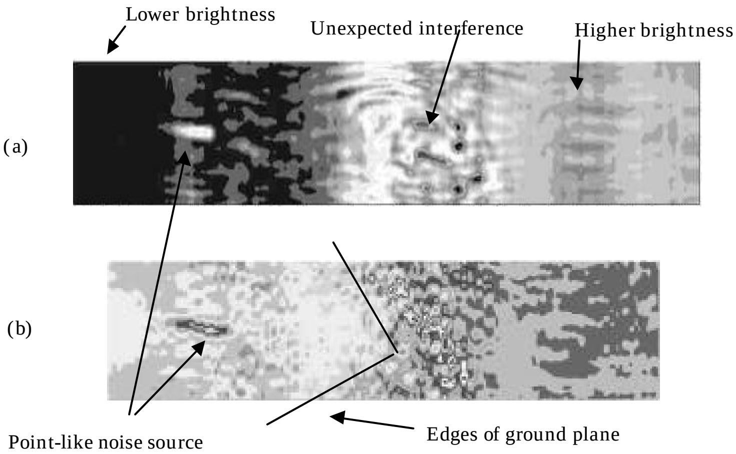

Fig. 9 2D images by super-synthesis with data fusion

References

[1] K. Komiyama, "Super-Synthesis Radiometer (SSR) for the Remote Sensing of the Earth," 44-2, APMC'90, Tokyo 1990.

[2] K. Komiyama, ”Supersynthesis radiometer for passive remote sensing,” Int. GRS Symposium (IGARSS’92) 1992.

[3] K. Komiyama, Y. Kato, and T. Iwasaki, “Indoor experiment of two-dimensional supersynthesis radiometer,” Int. GRS Symposium (IGARSS’94) 1994.

[4] K. Komiyama, Y. Kato, ”Two-dimensional supersynthesis radiometer for field experiment,” Int.GRS Symposium(IGARSS’95) 1995.

[5] K. Komiyama, Y. Kato, ” Characteristics of the baseline off-nadir angle of supersynthesis radiometer “, Int.GRS Symposium(IGARSS’96) 1996

[6] K. Komiyama, Y. Kato, K. Furuya, ” Interpretation of Brightness Temperature Retrieved by Supersynthesis Radiometer “, Int.GRS Symposium(IGARSS’97) 1997.

[7] K. Komiyama, ”Preliminary Experiment of One-Dimensional Imaging by Mocrowave Supersynthesis Radiometer”, Int.GRS Symposium(IGARSS’98) , pp1708,-1710, 1998.