INTERFEROMETRIC SYNTHETIC APERTURE MICROWAVE RADIOMETERS: AN OVERVIEW

Andreas Colliander[1], Darren McKague[2]

1) Jet Propulsion Laboratory, California Institute of Technology

2) University of Michigan

INTRODUCTION

This paper describes 1) the progress of the work of the IEEE Geoscience and Remote Sensing Society (GRSS) Instrumentation and Future Technologies Technical Committee (IFT-TC) Microwave Radiometer Working Group and 2) an overview of the development of interferometric synthetic aperture microwave radiometers as an introduction to a dedicated session.

IEEE GRSS IFT-TC MICROWAVE RADIOMETER WORKING GROUP

The Microwave Radiometer Working Group (MRWG) of the IEEE GRSS IFT-TC addresses issues related to passive remote sensing in the microwave, millimeter wave and sub-millimeter wave portions of the electromagnetic spectrum [1].

One of the currently on-going actions of the working group is to summarize the current state-of-the-art and future trends of microwave radiometry for remote sensing in a white paper. Special sessions were organized in the 11th Specialist Meeting on Microwave Radiometry and Remote Sensing of the Environment, MicroRad 2010, on current interesting technologies, and in the IEEE International Geoscience and Remote Sensing Symposium 2011, IGARSS'11, on calibration of microwave radiometers, in order to increase the awareness of the community of these technologies and calibration of the instruments, and to gather relevant material for the white paper. The papers in these sessions cut through the spectrum of relevant new technologies and calibration approaches. This presentation summarizes the novel developments in the field of microwave radiometry addressed in MicroRad 2010 and IGARSS'11. Another action of MRWG is to foster the extension of standardized radiometer terminology to interferometric synthetic aperture microwave radiometers. Currently, [2] covers terminology for general radiometry, real aperture conventional radiometers and polarimetric radiometry.

Furthermore, this paper opens another Working Group session. This session complements the previous sessions by devoting itself to the interferometric synthetic aperture microwave radiometers.

INTERFEROMETRIC SYNTHETIC APERTURE MICROWAVE RADIOMETERS

The development of radiometers for remote sensing is considered to have been initiated by Dicke et al. in the 1940's [3]. The concept of interferometric microwave radiometry was conceived not long after that for radio astronomy in the 1950's [4], and the interferometric technique has remained as an essential part in that field [5]. For Earth science the application of interferometric synthetic aperture started in the 1980's [6] for solving the

large aperture problem of L-band remote sensing. The difference between the astronomical application and Earth science application is that in astronomy the target is point-like, whereas in Earth science extended, and in astronomy the receivers are separated by a long distance from each other, whereas in Earth science a compressed receiver configuration is called for. These differences presented a number of challenges that required solution before the technique was ready for deployment.

Interferometric synthetic aperture radiometers use several receivers to electrically form an image of a target. The benefit is the fact that the spatial resolution can be enhanced without introducing a respective large scanning antenna aperture, but spreading small antenna apertures with receivers over a non-scanning array [7]. The pair-wise correlations between the receivers are combined through the so-called visibility function to produce the brightness temperature image [8].

Application of interferometric synthetic aperture radiometers is beneficial when the measurement geometry calls for aperture size not practical to implement. For the L-band measurement of geophysical parameters, such as soil moisture and sea surface salinity (SSS), the low frequency together with spatial resolution requirement requires a relatively large aperture size which initiated the application of the technique to Earth observation [9]. Other proposed applications include, for example, atmospheric microwave observations from geostationary orbit, where the distance to the target imposes a requirement for large aperture size, even at frequencies significantly higher (50 GHz and more) than L-band [10], and hurricane wind measurements from airborne and low Earth orbit platforms at C-band [11].

The energy distribution in the measurement of extended targets is very different in comparison with point-like targets of radio astronomy and the antenna patterns of individual antennas have also respectively wider beam-widths to capture the emission from the extended scene. This sets quite difference design criteria for the antennas, receivers and processing. Additionally, for making successful and accurate measurements with compressed interferometer arrays, as opposed to sparse arrays utilized for astronomy, the visibility function required addition of correction terms to account for the coupling between the correlated antenna pairs [12]. Furthermore, the calibration of the instrument array requires establishment of the critical parameters for all individual receivers, their phase relationship and de-correlation of the signal over the distance between element-pairs [13]. Significant progress has been made on these calibration issues over the years: for example, phase and amplitude calibration using a noise injection network has been developed [14], [15] and very beneficial utilization of a cold homogeneous targets has been established [16].

A culmination point in the development of the interferometric synthetic aperture microwave radiometers for Earth science applications was the launch of European Space Agency's SMOS (Soil Moisture and Ocean Salinity) satellite [17]. It deployed a two-dimensional interferometric array for the determination of soil moisture and SSS at L-band [18]. The first results from the mission have proven that the interferometric synthetic aperture

microwave radiometry can be applied to spaceborne observation of geophysical parameters [19]. While working towards the launch of SMOS, several significant L-band airborne demonstrators were developed [20]-[23].
And at the same time demonstrators for the other application have been developed, and are being developed [25]-[28], which increases the expectation that more interferometric synthetic aperture microwave radiometers will be deployed for Earth science research.

ACKNOWLEDGEMENT

This abstract was prepared in part at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

BIBLIOGRAPHY

[1] IEEE GRSS Instrumentation and Future Technologies Technical Committee web site: http://www.grss-ieee.org/IFT/IFTWorkingGroups.

[2] J. Randa et al., "Recommended Terminology for Microwave Radiometry", NIST Technical Note 1551, National Institute of Standards and Technology, August 2008.

[3] R. H. Dicke, "The measurement of thermal radiation at microwave frequencies", Rev. Scientific Instruments, vol. 17, no. 7, pp. 268-275, July 1946.

[4] J. D. Kraus, "Radio Astronomy", New York: McGraw-Hill, 1966.

[5] P. J. Napier et al, "The very large array: design and performance of a modern synthesis radio telescope", Proc. IEEE, vol. 71, no. 11, pp. 1295-1320, November 1983.

[6] C. Ruf et al., "Interferometric Synthetic Aperture Microwave Radiometry for the Remote Sensing of the Earth", IEEE Trans. Geosci. Remote Sens., Vol. 26, No. 5, September 1988.

[7] D. M. Le Vine, "Synthetic aperture radiometer systems", IEEE Trans. Microwave Theory Tech., vol. 47, no. 12, pp. 2228-2236, December 1999

[8] I. Corbella, N. Duffo, M. Vall-llossera, A. Camps, F. Torres, "The visibility function in interferometric aperture synthesis radiometry", IEEE Trans. Geosci. Remote Sensing, vol. 42, no. 8, pp. 1677-1682, August 2004

[9] D. M. Le Vine, M. Kao, C. T. Swift, A. Griffis, A. B. Tanner, "Initial results in the development of a synthetic aperture microwave radiometer", IEEE Trans. Geosci. Remote Sensing, vol. 28, no. 4, pp. 614-619, July 1990

[10] B. Lambrigtsen, S. T. Brown, T. C. Gaier, L. Herrell, P. P. Kangaslahti, A. B. Tanner, "Monitoring the Hydrologic Cycle With the PATH Mission", Proc. IEEE, Vol. 98, No. 5, May 2010.

[11] W. L. Jones, J-D. Park, J. Zec, C. Ruf, M. C. Bailey, J. W. Johnson, "A Feasibility Study for a Wide-Swath, Airborne, Hurricane Imaging Microwave Radiometer for Operational Hurricane Measurements", Proc. IEEE Int. Geosci. Remote Sens. Symp. 2002, IGARSS'02, pp. 786-789, 2002.

[12] I. Corbella, F. Torres, A. Camps, N. Duffo, M. Vall-llossera, K. Rautiainen, M. Martín-Neira, A. Colliander, "Analysis of Correlation and Total Power Radiometer Front-Ends Using Noise Waves", IEEE Trans. Geosci. Remote Sensing, vol. 43, no. 11, pp. 2452-2459, November 2005.

[13] A. Tanner, C. Swift, “Calibration of a Synthetic Aperture Radiometer”, IEEE Trans. Geosci. Remote Sens., Vol. 31, No. 1, January 1993

[14] I. Corbella et al., “Analysis of Noise-Injection Networks for Interferometric-Radiometer Calibration”, IEEE Trans. Microwave Theory and Tech., Vol. 48, No. 4, April 2000.

[15] J. Lemmetyinen et al., “SMOS Calibration Subsystem”, IEEE Trans. Geosci. Remote Sens., Vol. 45, No. 11, November 2007.

[16] M. Martin-Neira et al., “The Flat Target Transformation”, IEEE Trans. Geosci. Remote Sens., Vol. 46, No. 3, March 2008.

[17] Y. H. Kerr, P. Waldteufel, J-P. Wigneron, S. Delwart, F. Cabot, J. Boutin, M. Escorihuela, J. Font, N. Reul, C. Gruhier, S. Enache Juglea, M. R. Drinkwater, A. Hahne, M. Martin-Neira, S. Mecklenburg, “The SMOS Mission: New Tool for Monitoring Key Elements of the Global Water Cycle”, Vol. 98, No. 5, May 2010.

[18] K.D. McMullan, M.A. Brown, M. Martin-Neira, W. Rits, S. Ekholm, J. Marti, J. Lemanczyk, "SMOS, the payload," IEEE Trans. Geosci. Remote Sens., vol. 46, pp. 594-605, Mar 2008.

[19] M. Martin-Neira, I. Corbella, F. Torres, F. Cabot, J. Closa, J. Kainulainen, R. Castro, J. Barbosa, A. Gutierrez, F. Martin-Porqueras, R. Oliva, E. Anterrieu, M. Brown, K. McMullan, “SMOS Payload Performance Assessment”, Proc. IEEE Int. Geosci. Remote Sens. Symp. 2010, IGARSS’10, pp. 3150-3153, 2010.

[20] D. M. Le Vine, A. J. Griffis, C. T. Swift, T. J. Jackson, “ESTAR: a synthetic aperture microwave radiometer for remote sensing applications, Proc. IEEE, vol. 82, no. 12, pp. 1787-1801, December 1994

[21] J. Kainulainen, K. Rautiainen, S. Tauriainen, T. Auer, J. Kettunen, M. Hallikainen, “First 2-D Interferometric Radiometer Imaging of the Earth from an Aircraft”, IEEE Geosci. Remote Sens. Letters, Vol. 4, No. 2, April 2007.

[22] D. M. Le Vine, T. J. Jackson, M. Haken, “Initial Images of the Synthetic Aperture Radiometer 2D-STAR”, IEEE Trans. Geosci. Remote Sens., Vol. 45, No. 11, November 2007.

[23] M. Martin-Neira et al., “AMIRAS – An Airborne MIRAS Demonstrator”, IEEE Trans. Geosci. Remote Sens., Vol. 46, No. 3, March 2008.

[24] A. B. Tanner et al., “Initial Results of the Geostationary Synthetic Thinned Array Radiometer (GeoSTAR) Demonstrator Instrument” IEEE Trans. Geosci. Remote Sensing, vol. 45, no. 7, pp. 1947-1957, July 2007.

[25] J. Christensen, A. Carlstrom, H. Ekstrom, A. Emrich, J. Embretsen, P. de Maagt, A. Colliander, “GAS: the Geostationary Atmospheric Sounder”, Proc. IEEE Int. Geosci. Remote Sens. Symp. 2007, IGARSS’07, pp. 223-226, 2007.

[26] J. Yan, J. Wu, M. Martin-Neira, H. Liu, H. Liu, J. Jiang, “FPIR: The Demonstrator and First Image”, Proc. IEEE Int. Geosci. Remote Sens. Symp. 2010, IGARSS’10, pp. 4298-4301, 2010.

[27] H. Liu, J. Wu, S. Zhang, J. Yan, L. Niu, C. Zhang, B. Li, “Development of a Three-Element Interferometer at 50~56 GHz for Geostationary Interferometric Microwave Sounder (GIMS)”, Proc. IEEE Int. Geosci. Remote Sens. Symp. 2010, IGARSS’10, pp. 554-557, 2010.

[28] C. Ruf et al., “The Hurricane Imaging Radiometer (HIRAD): Instrument Status and Performance Predictions”, IGARSS’09.