Development of the ultra-wideband LORA SAR operating in the VHF/UHF-band

Conference Paper · August 2003

DOI: 10.1109/IGARSS.2003.1295485 · Source: IEEE Xplore

12 authors, including:

L.M.H. Ulander
Swedish Defence Research Agency
234 PUBLICATIONS **4,237** CITATIONS

Peter Follo
Swedish Defence Research Agency
5 PUBLICATIONS **70** CITATIONS

Per-Olov Frolind
Swedish Defence Research Agency
53 PUBLICATIONS **651** CITATIONS

B. Larsson
Swedish Defence Research Agency
25 PUBLICATIONS **411** CITATIONS

Development of the Ultra-wideband LORA SAR Operating in the VHF/UHF-band

L.M.H. Ulander, M. Blom, B. Flood, P. Follo, P.-O. Frölind, A. Gustavsson, T. Jonsson, B. Larsson, D. Murdin, M. Pettersson, U. Rääf, and G. Stenström.

Department of Radar Systems
Swedish Defence Research Agency (FOI)
P.O. Box 1165, S-581 11 Linköping, Sweden
Phone: +46-13-378000, Fax: +46-13-378100, E-mail: ulander@foi.se

***Abstract* – LORA (low-frequency radar) is a new airborne VHF/UHF-band radar which has both synthetic-aperture radar (SAR) and ground moving target indication (GMTI) modes. The main motivation for the system is to facilitate detection of man-made objects in a variety of conditions, *i.e.* stationary or moving, located in open terrain or in concealment under foliage. The LORA system will operate in several configurations extending from 20 MHz to 800 MHz. Initial flight trials during 2002 were successfully conducted using the 200-400 MHz band. SAR image examples are shown including both forested areas and man-made objects. A second band, 400-800 MHz, has also been completed but not yet flight tested. A third band, 20-90 MHz, is being added and will be completed during 2003.**

I. INTRODUCTION

The Swedish Defence Research Agency - FOI (formerly known as FOA) – has performed research since the mid-80´s in the area of airborne ultra-wideband VHF-band synthetic-aperture radar (SAR) [1-3]. The work has resulted in two airborne CARABAS systems operating in the 20-90 MHz band. The prime application is for detection of man-made objects concealed by foliage or camouflage. Results have also shown that CARABAS is capable of accurately mapping forest stand volume (m^3/ha), or biomass (ton/ha), up to about 1000 m^3/ha, which is of high interest for environmental and commercial applications [4-6].

LORA (low-frequency radar) is FOI:s new airborne radar which will succeed CARABAS. It will operate from 20 MHz to 800 MHz and will be used for demonstrating new defence and civilian applications. The main application is expected to be detection of man-made objects in a wide range of operating conditions, *i.e.* both stationary and moving objects located in the open or under concealment.

II. BACKSCATTERING PHENOMENOLOGY

Backscattering is a complicated function of the geometry of the scattering object and its dielectric and magnetic properties. Large variations with angle are encountered when the object is large compared to the wavelength due to interfering scattering centers. Another important effect is the interaction between the object and its background, e.g. reflection off the ground surface. This reduces backscattering for lower frequencies since the direct and reflected wave tend to cancel each other. The effect becomes more significant for grazing angles and for small object heights above the ground compared to the wavelength. The net result is that backscattering falls significantly when the radar wavelength is larger than about $8h\varphi$, where h is the object height above the (smooth) ground and φ ($<< 1$) is the grazing angle.

Radar backscattering from the object background is related to dielectric properties and, in particular, to surface roughness. The roughness needs to be a significant fraction of the radar wavelength, *i.e.* approximately $> \lambda/10$, in order to give a substantial backscattering contribution. The backscattering from the object background is thus small when its surface roughness is small compared to the wavelength, and vice versa.

The radar wavelength should be carefully chosen to give a maximum object-to-background ratio in order to maximize detection performance. The mechanisms discussed above suggest using as large wavelength as possible without significantly reducing object backscatter for low grazing angles.

Backscattering from forests should also be considered in order to enable detection of targets under foliage. The main mechanism for lower frequencies is direct and ground-reflected dihedral backscattering from the stems whereas branches as well as leafs/needles is a secondary effect due to their smaller size. Typically, stems have a diameter up to about half a meter which implies that their backscattering drops significantly when the radar wavelength is larger than about five meters. This mechanism suggests that the optimum radar wavelength for detection of a vehicle-sized target under foliage is in the VHF-band with a weak dependence on stem diameter. The optimum wavelength in terms of the object-to-background ratio therefore seems to be in the low VHF-band for most forests except young forests for which high VHF- or UHF-band is adequate.

0-7803-7929-2/03/$17.00 (C) 2003 IEEE

II. LORA SYSTEM DESIGN

LORA has been designed as a multi-function VHF/UHF-band radar system which can simultaneously operate in both SAR and ground moving target indication (GMTI) modes [7]. It operates in two basic configurations: 1) Ultra-wideband SAR/GMTI 200-800 MHz, and 2) Ultra-wideband SAR 20-90 MHz. The latter will be a replacement for the CARABAS system which will be completed during 2003. In the present paper, we focus on the SAR/GMTI-mode operating over the 200-800 MHz band.

One of the most problematic issues when designing an ultra-wideband radar below 1 GHz is the challenging radio-frequency environment. The radar system must be able to share the frequency bands with a large number of other services, i.e. without causing harmful interference. Furthermore, the system must not saturate due to external interference which requires a receiver subsystem with very large dynamic range and out-of-band suppression. The dynamic range requirement is in direct conflict with the large bandwidth in order to achieve high resolution SAR. Receivers with large analogue and digital dynamic range have a rather narrow bandwidth. Our solution to this problem is to use a stepped-frequency waveform so that the instantaneous bandwidth is much smaller than the full bandwidth [8]. The latter is reconstructed by stitching together frequency bands in the signal processing. Each pulse in the waveform has a large time-bandwidth product (typically, a chirp) to meet average power requirements.

LORA is built around an eight-channel ultra-linear receiver. Each channel has a bandwidth of 10 MHz and provides 12-bit digital output data at a rate of 25.6 MHz. The local oscillator (LO) is retuneable from pulse-to-pulse and provides the necessary agile frequency generation for the stepped-frequency waveform. Pulse modulation is generated by an arbitrary waveform generator. The digital output from the receiver is fed into the data control unit where the signal is processed in real time to reduce the data rate before storage onto hard disks. Range windowing and Doppler filtering are used to reduce the data rate, and each frequency band can be filtered with different filter kernels to facilitate maximum data reduction. The radar data is complemented by precise antenna positions measurements from an integrated GPS/INS system.

The GMTI mode on LORA has ten physically separated antennas arranged so that five antennas are available for each frequency band. They are used in a bistatic arrangement with two for transmission and three for reception housed in each push-boom structure – the same as used in CARABAS.

III. FIRST LORA RESULTS

LORA made its first airborne trials on 16 and 30 October 2002. A number of different modes were used including SAR, GMTI-2 and GMTI-3. In these first tests, the system bandwidth was restricted to 219-420 MHz since only the antenna for the lower band had been completed. SAR images have been formed using the factorised backprojection (FBP) algorithm which provides accurately focused SAR images for wide beamwidth antennas and non-straight flight tracks [9]. It operates in the time domain and achieves computational performance in parity with frequency-domain methods but without the inherent limitations of the latter for wide beamwidth systems.

Results from the SAR mode are shown in Figs. 1-3 where a comparison is made with CARABAS images over the same area but acquired two years earlier. Note the differences visible in the images. It is an effect of different resolutions but also of different radar wavelengths used. The higher frequencies used in LORA respond more quickly to sparse vegetation whereas man-made structures are less pronounced. The LORA image also has a much higher resolution (0.6 m) compared to CARABAS (2.5 m), which provides more details of the imaged structures on ground.

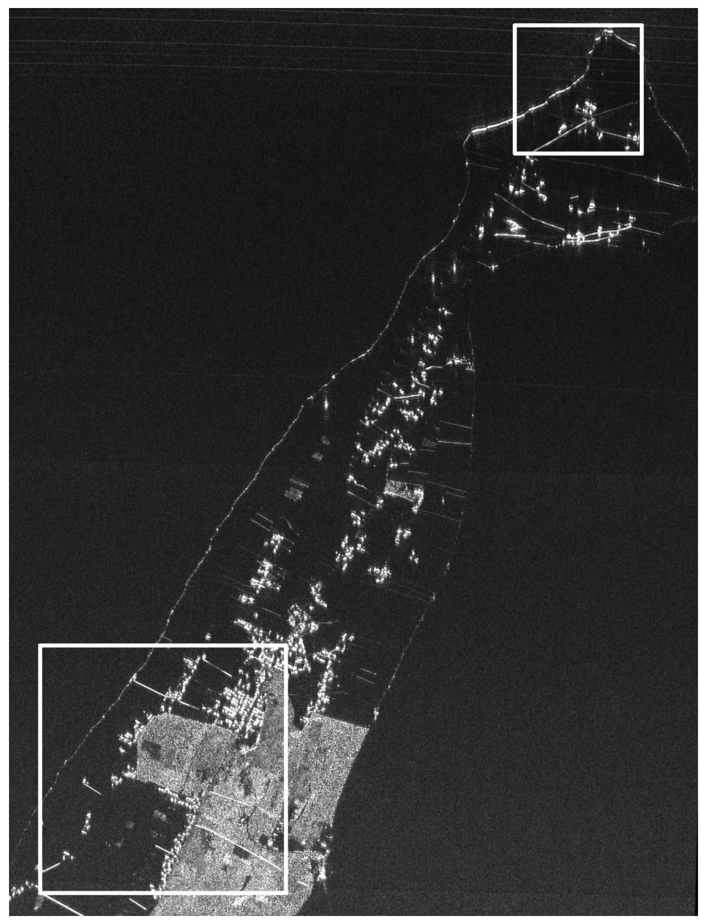

Figure 1. CARABAS image (7 x 9 km^2) of Visingsö in Lake Vättern. The southern part is largely forest covered whereas the northern part is farming land. Images from CARABAS and LORA corresponding to the indicated boxes are shown in Figs. 2 and 3.

IV. FUTURE WORK

Future work with the LORA SAR/GMTI system will focus on processing data from the various GMTI modes. During 2003, LORA is also being upgraded with a 20-90 MHz VHF-band SAR mode which will succeed CARABAS-II.

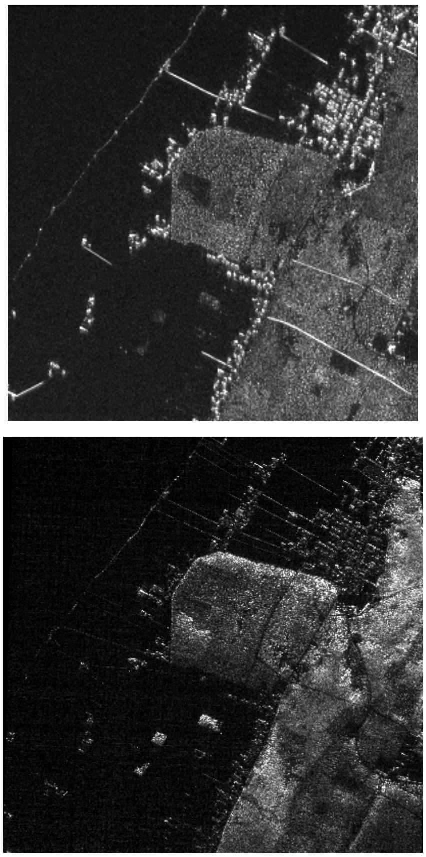

Figure 2. CARABAS 22-82 MHz (upper) and LORA 219-420 MHz (lower) images of the lower box in Fig. 1. Note the enhanced brightness which often occurs at the top forest boundary in the LORA image. This is probably an effect of reduced attenuation through the canopy since the radar look direction is from the top.

REFERENCES

[1] H. Hellsten, P.-O. Frölind, A. Gustavsson, T. Jonsson, B. Larsson, G. Stenström, B.T. Binder, M. Mirkin, and S. Ayasli, "Ultra-Wideband VHF SAR - Design and Measurements," *Proceedings of Aerial Surveillance Sensing Including Obscured and Underground Object Detection*, held in Orlando, FL, 4-6 April 1994, SPIE vol. 2217, pp. 16-25, 1994

[2] H. Hellsten, L.M.H. Ulander, A. Gustavsson, and B. Larsson, "Development of VHF CARABAS II SAR," *Proceedings of Radar Sensor Technology*, held in Orlando, FL, 8-9 April 1996, SPIE vol. 2747, pp. 48-60, 1996

[3] L.M.H. Ulander, P.-O. Frölind, A. Gustavsson, H. Hellsten, and B. Larsson, "Detection of Concealed Ground Targets in CARABAS SAR Images using Change Detection," *Proceedings of Algorithms for Synthetic Aperture Radar Imagery VI*, held in Orlando, FL, 5-9 April 1999, SPIE vol. 3721, pp. 243-252, 1999

[4] G. Smith and L.M.H. Ulander, "A Model Relating VHF-Band Backscatter to Forest Stem Volume," *IEEE Trans. Geosci. Remote Sensing*, vol. 38, no. 2, pp. 728-740, 2000

[5] J.E.S. Fransson, F. Walter, and L.M.H. Ulander, "Estimation of Forest Parameters Using CARABAS-II VHF SAR Data," *IEEE Trans. Geosci. Remote Sensing*, vol. 38, no. 2, pp. 720-727, 2000

[6] G. Smith, L.M.H. Ulander, and X. Luo, "Low Frequency Scattering of Coniferous Forests on Sloping Terrain," *IEEE Trans. Geosci. Remote Sensing*, in press

[7] L.M.H. Ulander and H. Hellsten, "Low-frequency Ultra-Wideband Array-Antenna SAR for Stationary and Moving Target Imaging," *Proceedings of Radar Sensor Technology IV*, held in Orlando, FL, 5-9 April 1999, SPIE vol. 3704, pp. 149-158, 1999

[8] L.M.H. Ulander, "Performance of Stepped-Frequency Waveform for Ultra-Wideband SAR," *Proceedings of EUSAR'98*, held in Friedrichshafen, Germany, 25-27 May 1998, pp. 323-326, 1998

[9] L.M.H. Ulander, H. Hellsten, and G. Stenström, "Synthetic-Aperture Radar Processing using Fast Factorised Back-Projection," *IEEE Trans. Aerospace Electron Syst.*, in press

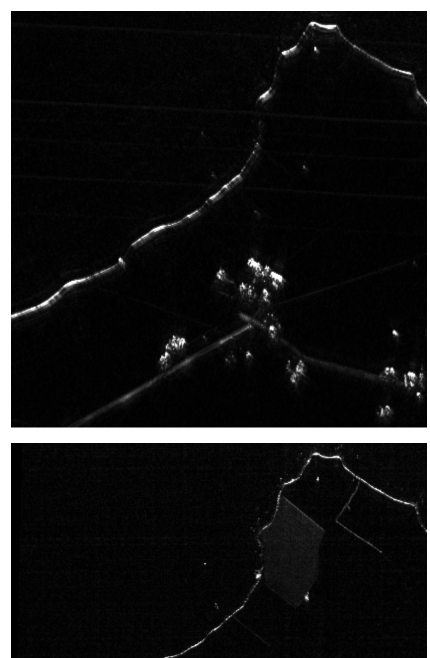

Figure 3. CARABAS 22-82 MHz (upper) and LORA 219-420 MHz (lower) images of the upper box in Fig. 1. Note that some fields are visible in the LORA image but not in the CARABAS images, probably due to the longer wavelength of the latter.