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CARABAS - An UWB Low Frequency SAR

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ABSTRACT.

The significance of low frequency ultra wide band radar imagery has been investigated at FOA for several years. In order to verify the theoretical predictions, an airborne SAR radar system, operating over the frequency band 20 - 90 MHz has been developed. A first data collection campaign took place in January 1992. Initial data are still in the phase of evaluation. In the wavelength interval adopted, vegetation is transparent and radiation penetrates the ground to a significant degree. The system is considered capable of mapping structures and objects obscured by vegetation or buried into the ground.

§1. Introduction.

CARABAS is an acronym for "Coherent All Radio Band Sensing", an airborne synthetic aperture radar concept, which has been under development at our institute for some time.

CARABAS adopts a major part of the short wave radio band for the transmission and reception of ultra wide band signals. As a result, the system has a high geometric resolution, in particular in relation to the emitted wavelengths. The CARABAS system has involved a considerable effort, both as regards wide band low frequency SAR processing and hardware design. Initial baseline flights with this new system were conducted in January 1992. Collected data are presently in the state of evaluation. We shall in this short account only point at the motivation for the system and some of its unique design features.

§2. Motivation.

Conventional microwave SAR yields an image where speckle severely impairs its usability. Speckle in radar images is explained as due to the existence of several elementary scatterers within each resolution cell. However, the elementary scatterers can never be smaller than some sizeable fraction of the wavelength, set by the Rayleigh limit. Ideally, a *diffraction limited* SAR, viz. a SAR with a geometric resolution equal to this limit, would produce speckle free images. This situation can be approached in practice using large *relative* bandwidth, i.e. UWB, radar signals, covering an octave or more of signal bandwidth.

A suitable way to optimize SAR relative bandwidth is to transpose the transmitted signal spectrum to a frequency interval, as low as is technically feasible, keeping the absolute bandwidth at a convenient size. A drastic reduction of speckle enables entirely new procedures for information extraction from SAR data. As will be evident, a low frequency SAR system also possesses other properties, not shared by conventional SAR or indeed any other form of surveillance. Within the frequency range adopted (below 100 MHz), vegetation is highly transparent, while the SAR processing procedure developed for CARABAS provides a 3-D contour image of the ground underneath the vegetation canopy. In addition, due to the low frequencies, the radiation penetrates into the ground. Because imaging is diffraction limited, it

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becomes possible to discriminate between surface and subsurface structures.

Low signal frequencies are of course less practical for real aperture radar, because the radar beam from a reasonably large antenna at low frequencies will be very wide and angular resolution correspondingly low. Low frequency narrow band systems have been produced previously, though the low resolution attained has been a severe limitation. CARABAS seems unique in its combination of low frequencies, very large bandwidth, and SAR.

A noticeable restriction of the CARABAS technology is that the length of the synthetic aperture approximately must equal the surveillance range. It is not known how far the synthetic aperture may be extended ultimately, or what surveillance range possibly can be reached with this type of system.

§3. Diffraction limited imaging.

A microscope is an example of diffraction limited imaging. The optics of a microscope is highly complex, while the telescope is a very simple imaging system. Similarly, increasing the relative bandwidth, the SAR processing becomes more complex. The view adopted in CARABAS is that, as the relative bandwidth tends to unity both in range and azimuth, the SAR measurement becomes *complete* as regards the geometry down to the resolution set by the maximum frequency. Thus data are best utilized by a *deterministic* SAR processing scheme, solving the corresponding inverse scattering problem. The scattering model relies on physical optics. Surprisingly, the physical optics inverse scattering problem posed by the SAR configuration, can be solved analytically *[1]*. The resulting algorithm resembles to a certain extent existing SAR algorithms.

A very broad bundle of rays is required in diffraction limited image formation. This makes the requirements for focusing very delicate, while the depth of field of the image will be extremely small (one may again compare with the microscope). The CARABAS processing scheme will "autofocus" to a surface consistent with wave propagation along rectilinear rays and with constant speed of light. For CARABAS the small depth of field means that subsurface reflexes become significantly defocused, because they travel along rays bent and slowed down several times by refraction (the dielectric constant of the ground is generally fairly large at the frequencies considered). Assuming Snell's law of refraction, re-focusing routines are quite feasible, actually looking for underground reflexes at different dielectric depths. The situation is very different from that of conventional SAR, where the underground reflex affects just one single resolution cell, and therefore is inseparable from the surface reflex. The presence of speckle in conventional SAR data diminishes the possibility of detecting underground reflexes even further.

Using a broad bundle of rays, one must take into account the dependence of the variations of the ground reflectivity with aspect angle, as the ground is sensed from different directions. Processing narrow band SAR data, one simply assumes the ground reflectivity to be a scalar complex function. The aspect angle dependence in CARABAS requires a vector or even a tensor valued expression for the ground reflectivity.

The physical optics scattering model mentioned assumes the dominant source of radar reflectivity contrasts to be ground surface undulations. In fact the backscattering from any point on the ground is assumed proportional to the scalar product between the ground normal and the direction of the radar signal hitting that point. This vector expression will couple the ground topography to radar data. It turns out that radar data according to this model uniquely determine the divergence of the ground normal vector field or equivalently the ground surface curvature. An extra integration step produces the shape of the ground in the form of the contour map mentioned.

§4. Hardware implementation.

According to the previous discussion, the bottom frequency for CARABAS is set as low as practically possible. Limiting factors are the noise environment due to radio interference, and the size of the antenna, set by the longest transmitted wavelength. In practice this limits the bottom frequency to the interval 10 - 20 MHz. The highest emitted frequency is set by the absolute bandwidth, which together with the SAR swath width is limited by the transmission power available, and the amount of data which can be stored for later processing. There is, of course, the problem of achieving sufficiently good performance of the antenna system throughout a multi-octave frequency band. During the recent tests, CARABAS operated across the band 20-90 MHz, with a range resolution of about 2 meters.

It is impossible on the basis of the SAR principle alone to discriminate between ground reflexes from the right and left hand sides of the aircraft. For microwave SAR, antennas may be designed to radiate to one side of the aircraft only. At the low frequencies and large bandwidth presently intended, antennas can hardly be designed in this way. The alternative adopted is to rely on an interferometric technique for the required right/left discrimination. The antenna system consists of two broad band thick dipole antennas, displaced to the right and left of the aircraft centre axis, and trailing just behind the aircraft. Structurally the antennas are flexible sacks, suspended from the tips of a yoke fixed to the tail of the aircraft. When inflated by ram air and aerodynamically stabilized, the sacks obtain the shape of several meters long cylinders, co-linear with aircraft axis. Currently installed on a Rockwell Sabreliner business jet, the antennas are extremely stable in flight and the electromagnetic coupling between antennas and aircraft seems tolerably small.

Ultra wide band radars are often conceived as impulse radars in which case a large relative bandwidth is obtained by transmitting a sharp impulse. This technique is considered unsuitable for CARABAS. In order to use the transmitted energy in an optimal way, the sampling and data storing pace must be comparable to the bandwidth of the transmitted impulse. The movement of the aircraft puts restrictions on available integration time, which makes it important to reach the optimum (for e.g. georadar there are not the same time limitations). Due to the severe radio interference conditions met by an airborne HF radar, the dynamic range must also be very large. Existing A/D converters and data storing units are far below the level of performance required. The possibility left is signal shaping. Given limits for maximum range, the instantaneous transmitted bandwidth can be made correspondingly small. Adopting state of the art techniques for A/D-conversion and data storing, a surveillance range up to 10-15 km is thereby reached, corresponding to a time bandwidth product of the order 10^6.

§5. Future aspects.

Several tasks within the fields of military surveillance and civilian remote sensing suggest themselves for CARABAS.

Important civilian applications are environmental mapping, in particular as regards hydrology. Due to the penetration capability of the radar, mapping of sea ice thickness is another possible area of application. Because of the very large surface coverage capacity - typically in the range 2-5 km^2/s - mapping can be carried out on a national or even international scale. The area of Sweden - 450.000 km^2 - will for instance be covered after circa 100 h of registration.

The existing system is intended for demonstration purposes only and will even if quite successful not be available in its present form for more than a few years. After that period further developments must be based on dedicated units for civilian remote sensing or military systems.

The cost of this type of system in serial production, is expected to be less than that of conventional microwave systems. The low cost in combination with the limited surveillance range suggests that military application of this technique should be based on remotely piloted vehicles. Such an RPV is not required to carry onboard any data processing or even data storing capacity, but the system may rely on transmitting radar data back to a ground based or airborne command link, processing and distributing the data to its users.

A microwave surveillance system is inclined to expose a microwave target area, at least corresponding to the gain of the antenna. This would not be a problem presently, since the dipole type of antennas required exhibit a very small target area in the microwave region. A surveillance RPV would thus be capable of a very stealthy behaviour.

The time required for data analysis depends to a large degree on the application. Roughly, the computer burden for obtaining images from CARABAS data is of the same magnitude as for conventional high resolution SAR. Presently, work is on its way regarding real time CARABAS image processing, involving full motion compensa tion when flying along a curvelinear path *[2]*. A future possibility is however that in the absence of speckle, procedures for information extraction more intelligent than full image processing may be devised.

REFERENCES.

[1] Hellsten H. (1990): "Inverse Scattering Analysis of Diffraction Limited SAR"; *IEEE Trans. Ant. Prop.* **38**, 1517-1522.

[2] Hellsten H., Edberg E., (1991): "The Node Equation Approach to Wide Band SAR Image Reconstruction."; *European Trans. Telecom.* **2**, No. 6.