KRAS - A Danish High Resolution Airborne SAR

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ABSTRACT

The Electromagnetics Institute, the Technical University of Denmark, is presently constructing a C-band high resolution airborne SAR. The main purpose of the project, which is called KRAS, is to develop the knowledge base required to build advanced coherent radars. The paper will present the design rationale. The design of the radar is based on digital technology to the largest possible degree. This results in a very flexible radar system, with most of the system parameters being software controlled. Variable waveforms of bandwidths uarger than100 MHz and durations up to 20 µs can be generated. Calibration of the system has also been given much consideration, and design principles usually applied in radiometers have been implemented. The significant flexibility and the calibration is of major importance since the system is intended for applications ranging from medium resolution wide swath mapping, i.e. sea ice mapping or oil pollution surveillance, to high resolution narrow swath mapping for cartography or reconnaissance .

I INTRODUCTION

The Electromagnetics Institute has been involved in the development of specialized radar systems for nearly 30 years. It all started when the Institute undertook the development of a 60/300 MHz radar sounder for measuring the thickness of the inland ice of Greenland and Antarctica [Gudmandsen,1980]. In cooperation with a number of foreign institutes such as the Scott Polar Research Institute, U.K. and with the support from the National Science Foundation, U.S.A., the ice sounder has surveyed more than 200,000 km. of bed-rock under the two major ice caps of the world, and a thickness of up to 3.2 km was measured in Greenland and 4.8 km was measured in Antarctica.

Since then, a number of special purpose radars have been developed at the Electromagnetics Institute e.g. a number of weather radars for measuring both horizontal and vertical distribution of rain. Other studies have involved marine radar systems and sea clutter studies [Maaløe,1982], a coherent 1.5 GHz earth penetrating radar system, and design studies for the European Space Agency of planetary radars. Simultaneously passive microwave radiometers were developed.

Ten years ago the Institute modified a conventional incoherent marine radar so that it could be used as an X-band SideLooking Airborne Radar (SLAR). This system was improved a number of times and it was successfully used in a number of field experiments. In one of these experiments the system was modified to acquire HH and VV polarized images simultaneously. The system is today commercially available.

The Electromagnetics Institute´s activities within the Synthetic Aperture Radar field started in 1977, where the breadbording of a real-time digital processor for a medium resolution airborne SAR was initiated [Søndergaard,1977]. In 1982 a study of the basic properties of SAR images was initiated. This study involved speckle theory, procedures for estimating the power transfer function of the SAR system as well as postprocessing algorithms for edge detection and adaptive speckle filtering [Madsen,1986], [Madsen,1987].This study also resulted in the development of digital off-line processors for both the airborne SAR-580 system and the SEASAT satellite SAR system. Since 1984 the Institute has also conducted a number of studies of the feasibility of using SAR for scientific and commercial sea ice mapping [Skriver et al.,1986].

The project that will be described in this paper was officially commenced in January 1986. Its title is Coherent Radar Techniques and Advanced Signal Processing (KRAS). The formal goal of the project is to establish a Danish research group with a solid knowledge base within the field of advanced coherent radar technology and high speed digital electronics. The concrete goal is to fly an experimental high resolution airborne C-band SAR in 1989. However, the system holds so much flexibility, that it can accommodate more general experiments with coherent radars. Flexibility is given high priority in the design. It is expected, that the applications of the system will span from geophysical science, which require wide swath but only medium resolution, to mapping experiments that calls for the highest achievable resolution. It is also considered important, that the radiometric fidelity of the images is the highest achievable. Hence, special attention has been given to build in calibration loops in the radar and to some extent radiometer design techniques has been used to obtain the best possible component stability.

II THE KRAS SAR SYSTEM

The radar is a single frequency system operating at 5.3 GHz. It is designed to obtain a resolution down to 2 m by 2 m. The maximum range of the system is 80 km and the swath width is between 10 and 50 km depending on the resolution. Both maximum range and swath width are prepared for later upgrading. It is expected that the initial experiments will involve an installation on a Gulfstream G-3 aircraft from the Royal Danish Air Force.

The KRAS system parameters are listed in Table 1 and the system block diagram is shown in figure 1.

Frequency:		5.3 GHz
Transmitter peak power:		2 kW
Receiver noise figure:		2.5 dB
Total system losses (estimated):		3 dB
Pulse length:		from 0.64 to 20 μs
Maximum bandwidth:		100 MHz
Antenna	gain:	27 dB
	azimuth beamwidth:	2.7 °
	elevation pattern:	20° section of cosec sqr. pattern
	polarization:	VV
Resolution	range:	Variable 2, 4, 8 m
	azimuth:	Variable 2, 4, 8 m
Slant range mapping width:		Variable 9.3, 21.6, 46.2 km
Range:		80 km

Table 1: KRAS system parameters

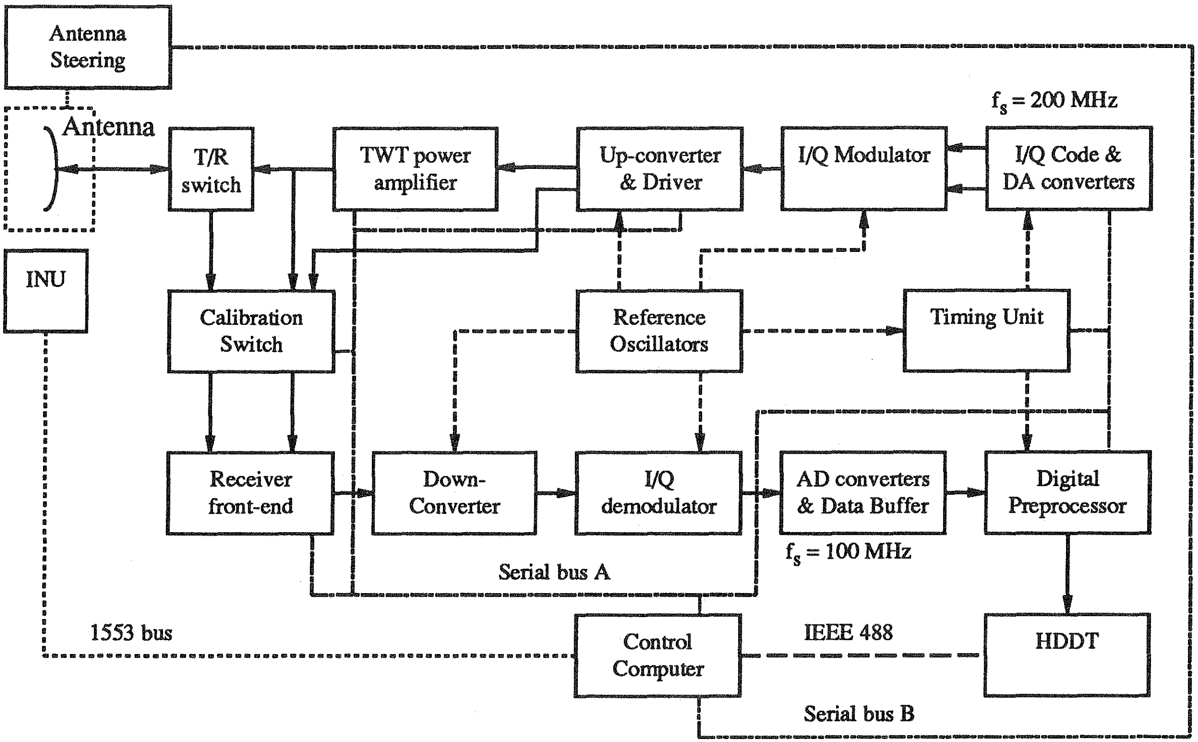

Figure 1: Block diagram of KRAS radar.

The Control Computer is based on a VME data bus. The main control CPU´s are based on the Motorola 68010 and 68020 processors. The Control Computer is linked to the individual subunits through two serial busses A and B. Bus A connects all "sensitive" units and is always shot down during echo reception. The Control Computer also includes IEEE-488, RS-232 and MIL-STD-1553 interfaces. Most of the radars subunits are also equipped with a number of BITE (Build In Test Equipment) facilities, which the Control Computer monitors. The Control Computer can initiate radar operation by down loading the code to be transmitted. The code can be up to 4096 samples long and each sample consist of 8 bit I and 8 bit Q data.

The digital codes are converted to analog signals at a 200 MHz sampling rate in dual DA converters and the analog I and Q channels are transformed to a 300 MHz IF signal in the quadrature modulator. In the up-converter the signal is converted to 5.3 GHz and the signal is amplified to a level sufficient to drive the TWT tube (22 dBm). 100 MHz, 300 MHz and 5 GHz local oscillator signals are generated in a reference oscillator unit, while 200 MHz is derived in the timing unit. Following the driver the signal is injected into the TWT power amplifier and a sample is directed into the Calibration Switch. The power level of the drive signal is controlled by a variable attenuator in a closed control loop. The power amplifier is a 2 kW Traveling Wave Tube amplifier with low phase noise. Following the TWT the signal is guided to the antenna. Both the power level of the signal injected into the antenna, and the signal reflected from the antenna is monitored using a -60 dB cross coupler. The reflected signal will shut down the TWT Electronic Power Conditioner (EPC) if the level is excessive.

The slotted waveguide array antenna consist of four separate panels to provide large bandwidth. Seven waveguides are stacked in elevation and the elevation pattern is shaped to give a modified cosecant squared illumination over a 40° sector, with sidelobes suppressed 24 dB. This is of major importance to insure that reflections from fuselage and wings will not give rise to two-way propagation, and thereby interference fringes.

The received signal is, after passing a solid state receiver protection unit, amplified by a low noise amplifier (LNA) with a noise figure of 2 dB, and following bandpass filtering a sensitivity time control (STC) is applied before the signal is down-converted to IF, hence limiting the dynamic range already at the RF level. At the IF level the signal is bandlimited and then the signal is down-converted to video in a quadrature I/Q demodulator. The I and Q signals are digitized to 8 bits per channel in dual AD converters running at a sampling rate of 100 MHz. The digitized echo is stretched to a high duty cycle signal in the data buffer, which holds 8192 complex samples, before the data flows into the digital preprocessor. The digital preprocessor performs Doppler tracking, initial motion compensation, and prefiltering of the data to reduce the effective pulse repetition frequency. A digital range filter that accepts complex data at a 100 MHz sampling rate facilitating programmable low-pass filtering and downsampling is presently being developed and this filter will be inserted between the AD converters and the buffers. Finally the signal is transferred to a HDDT system for later processing at the off-line facilities at the Institute.

III THE DIGITAL SIGNAL GENERATION SYSTEM

The purpose of coding the transmitted pulses is in short that thereby a good signal-to-noise ratio and a fine resolution can be achieved simultaneously. There are many different coding schemes of which phase and frequency coding are most relevant to radars using power amplifiers in their saturated power range.

Originally it was planned to use SAW (Surface Acoustic Wave) dispersive filters for generation of linear FM pulses in the KRAS radar as well as for pulse compression in the receiver. It was soon realized that to obtain resonable flexibility a number of pulse codes with different bandwidths and pulselengths were required. Likewise it was found that in situations where low sidelobes are required non-linear FM will give better performance than the usual linear FM chirp. However, since the SAW filters characteristics are fixed such flexibility can only be obtained by using a significant number of SAW devices. By using a digital data generation system it was found that the required flexibility could be supported by a single system.

Likewise the application of digital pulse compression in the receiver gives a number of advantages though at the expense of quite heavy processing requirements. The most important property is probably that the dynamic range measured as the ratio between the largest point target and the noise floor is improved by the processing gain relative to the dynamic range of the AD converters themselves.

There are a number of ways to generate the digital codes and similarly there are several ways to transform the digital numbers to analog signals. Assume that the desired analog signal is:

$$s(t) = a(t)\cos(2\pi f_{RF}\,t+\phi(t))$$

(where a(t) will be an on-off keying and $\phi(t)$ is the phase modulation of the signal), then this signal can be generated by one of the systems outlined in figure 2.

The system shown in figure 2(A) implements a direct phase modulation on the RF carrier. Such a system is fairly simple and very attractive when phase codes with only few different phasors and moderate sidelobes are required. This coding process, however, introduces phase errors whose effect must be included in the design, [Iglehart,1978]. Both figure 2(B) and 2(C) use DA converters and low-pass filters to generate the modulation function, the main difference being that the one channel implementation (B) requires a digital carrier frequency which means that to generate signals of bandwidth B the sampling rate must be larger than 2 B. This implementation has been proposed for a simple pulse generator using a one bit DA converter [Johnston,1984]. The quadrature modulator shown in figure 2(C) generates the complex modulation function $m(t) = a(t)\exp\{j\phi(t)\}$ at baseband, and hence the DA converters need only a sample rate larger than B. The latter implementation is well suited for high bandwidth signals with low sidelobes and was therefore chosen for the KRAS signal generator.

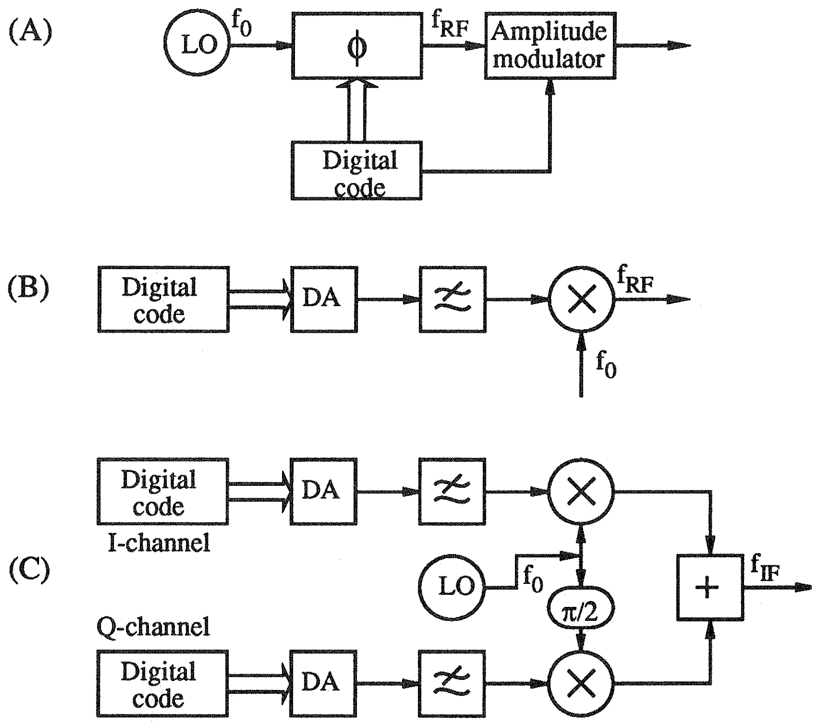

Figure 2: Digital signal generator mechanizations: (A) RF phaseshifter (B) Direct IF generator (C) Quadrature baseband modulator.

Also the digital codes can be generated in a number of ways. One method to generate the quadratic phase of a linear FM is for instance to implement a digital double integration of a constant, [Eber and Soule,1975],[Postema,1987]. By changing the constant the FM rate can be varied. Alternatively the pulsecode can be generated off-line and down loaded in a fast buffer memory. This approach gives significantly more flexibility and the software generating the codes can be designed to calculate non-linear FM with specified pulselength, bandwidth and sidelobe level. The price paid for this flexibility is that a fairly large and very fast buffer memory is required.

It is important to note that high quality signals with low sidelobes can only be obtained if the gain of the quadrature channels are equal and if the phase difference between the channels is 90°. Also the characteristics of the DA converted signals (i.e. digital signals have a periodic spectrum, and the "box" representation of the individual numbers in the code gives a $\mathrm{sinc}(\pi f/f_s)$ weighting of the spectrum) must be taken into account as well as other system components such as filters.

The KRAS digital signal generator is based on a quadrature modulator with the converters running at a 200 MHz sampling rate. The low-pass filters have a cut-off frequency of 150 MHz and a nearly linear phase characteristic. 4096 complex code words are stored in a RAM buffer, hence supporting pulses of a length up to 20 µs. The codes are generated by a C-program that supports both linear and nonlinear FM codes. This program also hold the capacity for incorporating predicted or measured system properties, by generating predistorted signals, so that the signal that drives the TWT will be correct. It is also intended to use the calibration system described below to perform on-line measurements of transfer functions thereby enabling dynamic predistortion if required. How this can be implemented is presently subject to a Ph.D. study at the Electromagnetics Institute.

IV SYSTEM CALIBRATION

Calibration is a very important issue in modern remote sensing radars, especially when data from different radars or multitemporal data from one sensor are to be compared or if measurements have to be compared to models. Several precautions are taken in the KRAS radar design to enable fairly accurate system calibration. The main ingredients in the calibration of the KRAS radar are :

1) Design for maximum stability of the analog radar front end
2) Internal calibration loops
3) Accurate antenna calibration
4) Comparison with a 5.3 GHz noise scatterometer.

First of all the stability of the system is ensured by applying design techniques usually applied in radiometer systems. One of the important factors is that all RF components including the TWT+EPC will be temperature stabilized to an accuracy better than 1°C. Another important feature of radiometers is that of frequent automated calibration. This is implemented in the KRAS radar design by using a number of internal calibration loops. Both a sample of the TWT drive signal and the TWT high power output (sampled via a -60 dB cross coupler) is injected in the calibration switch. The calibration switch includes a programmable precision attenuator and an average power monitor, and the sample of the drive signal or the attenuated high power signal can be injected in the receiver either before or after the LNA. There is still some doubt whether the RF leakage can be kept sufficiently low to enable simultaneous calibration of the TWT and the LNA. All these measurement options are supported by the digital signal generator, that allow the transmission of extra calibration pulses concurrent with normal SAR operation.

The slotted waveguide antenna which is presently being developed will be calibrated in the Electromagnetics Institutes Radio Anechoich Chamber using spherical near field antenna measurement techniques. It will be attempted to include the antenna pod/radome in the measurements.

Finally the collected SAR data will be compared with data gathered with a C-band noise scatterometer that was recently developed at the Electromagnetics Institute , [Skou,1987].

V PROJECT STATUS

The project is presently in the construction and test phase. The RF generator/calibration switch and the receiver have been finished and have passed initial tests. The TWT+EPC system will be integrated and tested mid 1988. The antenna system is presently being developed at the institute and measurements on test samples show good results, so the antenna construction and test is expected before the end of 1989. The control computer is presently in the software development phase. Major parts of the high speed digital electronics have been finished already. Integration and test will take place in the first half of 1989, and the first flight test will be carried out in the summer 1989.

The subsequent phase of the project, which includes real-time processing is planned to be finished late 1990.

It is finally noted that the funding for the project including the real-time processing has already been granted.

Extensions of the project might include polarometric measurement.

VI CONCLUSION

This paper reports some features of the Danish KRAS radars design. The system is a C-band high resolution airborne SAR. The top level system parameters and system block-diagram are presented. Two subjects of main concern in the design is maximum flexibility and system calibration. The flexibility has been achieved by applying digital technology to the largest possible degree. The transmitted pulses are coded in a digital signal generator that can generate any pulse modulation up to a maximal length of 20 µs. It is presently being studied how predistortion of the pulses can be used to compensate for different system errors. The calibration efforts have led to the inclusion of radiometer design techniques such as temperature stabilization and internal calibration loops. Other calibration tasks includes precision measurements on the antenna and comparison with a scatterometer system. The first test flights are expected in the summer 1989.

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