Paper

A dedicated computer system for FM-CW radar applications

Silvester H. Heijnen, Jaques S. van Sinttruijen, Fred W. van der Zwan, and Leo P. Ligthart

Abstract — In this paper, a DSP based computer system for FM-CW radar applications is described. Besides data acquisition and storage, the computer system will also be used for front-end data processing and system control. Processing includes filtering and clutter suppression. The radar for which the computer is designed is a multi parameter atmospheric profiler capable of doing Doppler and polarimetric measurements. The computer system will allow for a measurement of the full polarimetric scattering matrix over 512 range cells and 512 Doppler cells in 2 s. Radar system control includes the timing and the settings of the radar system together with linearity correction of the sweep oscillator.

Keywords — radar, data processing, system control, filtering and clutter suppression.

1. Introduction

At the International Research Centre for Telecommunications-transmission and Radar (IRCTR, a department of the Delft University of Technology in the Netherlands) a new transportable atmospheric radar system (TARA) [1], is under construction. The main area of application of the system will be in the field of atmospheric remote sensing. Transportability will allow for studies of the atmosphere at different geographical location, but imposes severe constrains on the construction of the system. Being a research tool, the system has to be as flexible as possible to adapt the system to the measurement conditions. Therefore, the FM-CW principle is used allowing for easy changes in system settings. FM-CW also has the advantage of low peak power allowing for an all solid-state design. A consequence is the need for two antennas to isolate the transmitter from the receiver. In atmospheric remote sensing the targets usually have a low radar cross-section. On the other hand obstacles like trees and buildings have a high radar cross-section giving rise to large clutter contributions. One way to reduce clutter contributions is to reduce the antenna sidelobes in the direction of the obstacles. Clutter can also be removed in the Doppler domain as it has a low to zero Doppler velocity. The transmit frequency is chosen to be 3.3 GHz allowing for studies of clear-air turbulence as well as studies of clouds and rain. The bandwidth of the system can be changed between 2 and 50 MHz. The TARA system has Doppler and polarisation capability. For 3D wind field measurements, off-axis beams are available in two orthogonal directions. In Table 1 a summary of the system specifications is given. A technical drawing can be found in Fig. 1. Clearly visible is the dual antenna system with large shields. The shields will reduce the far sidelobes of the antennas. TARA is constructed in a twelve-meter long standard container. The front part of the container is used as measurement chamber. During the construction phase, new developments were found in the field of antenna research and real-time data processing.

In a FM-CW system, range dependent reflectivity information is contained in the frequency spectrum of the beat signal, which is generated by comparing the received signal with the transmitted signal using a mixer. Doppler information is contained in the reflective phase differences between successive measurements of the same target. Multiple Fourier transforms are used to retrieve information from the raw data. The computer system described in this paper is capable of doing these multiple Fourier transforms in real-time. The other functionality of the computer system is radar-system control. This includes beam switching and polarisation switching but also linearisation of the frequency sweep. It will be shown that in a FM-CW system, nonlinearities of the frequency sweep will limit the achievable resolution. The linearisation scheme used in the TARA system is discussed as well as the realised linearity.

2. Computer architecture

The primary function of the computer is the front-end data processing. As was explained before, processing involves multiple FFT's. They are implemented in hardware using the PDSP16510 from Plessey. This chip is capable of doing a 1024-point 16-bits complex FFT in 96 μs. DATA is digitised with a 16-bit 2-MHz ADC and stored into a local memory before down loading into the first FFT chip. The output of the FFT chip is loaded into the memory of a DSP that is used for correction of shifts occurring in the FFT process for each individual sweep. The information in the output data of the first FFT contains the reflectivity per range resolution cell. A total of 512 sweeps is stored and, subsequently, a second FFT is calculated now per range resolution cell. The output data of this second FFT contains the Doppler spectrum. Each Doppler spectrum is filtered and the clutter is suppressed. This is done in the Doppler domain by omitting the zero velocity Doppler resolution cell. After clutter suppression, the first three moments of the Doppler spectra, being the reflectivity, the averaged Doppler speed and the Doppler spectral width, are

Table 1
Specifications of the TARA system

Parameter	Value	Additional remarks
Type	FM-CW	
Central frequency	3.3 GHz	
Transmitted power	100 W	can be attenuated in 10 dB steps
Dynamic range	$80-90$ dB	
Noise figure	~ 1 dB	
Sweep bandwidth	$2-50$ MHz	computer controlled
Sweep shape	triangular, saw tooth	can be arbitrarily
Sweep time	> 1 ms	can be staggered
Sampling	< 2 MHz	16-bits ADC
Samples per sweep*)	1024	
Sweeps per Doppler spectrum*)	512	
Polarisation (linear)	HH, HV, VH, VV	antennas controlled independently; central beam only; offset beams are single linearly polarised
Resolution aspects		
Max. range	38 km	@ 2 MHz bandwidth
Min. range resolution	3 m	@ 50 MHz bandwidth
Unambiguous Doppler speed	~ 22.7 m/s	max. @ 1 ms sweep time
Doppler resolution	~ 8.9 cm/s	@ 1 ms sweep time
Sensitivity*)	@ 5 km	@ 1 km
Reflectivity	$\leq 2.3 \cdot 10^{-14}$ m^{-1}	$\leq 0.9 \cdot 10^{-15}$ m^{-1}
Radar cross-section	$\leq 1.8 \cdot 10^{-8}$ m^2	$\leq 2.8 \cdot 10^{-11}$ m^2
*) SNR = 0 dB, resolution = 40 m		

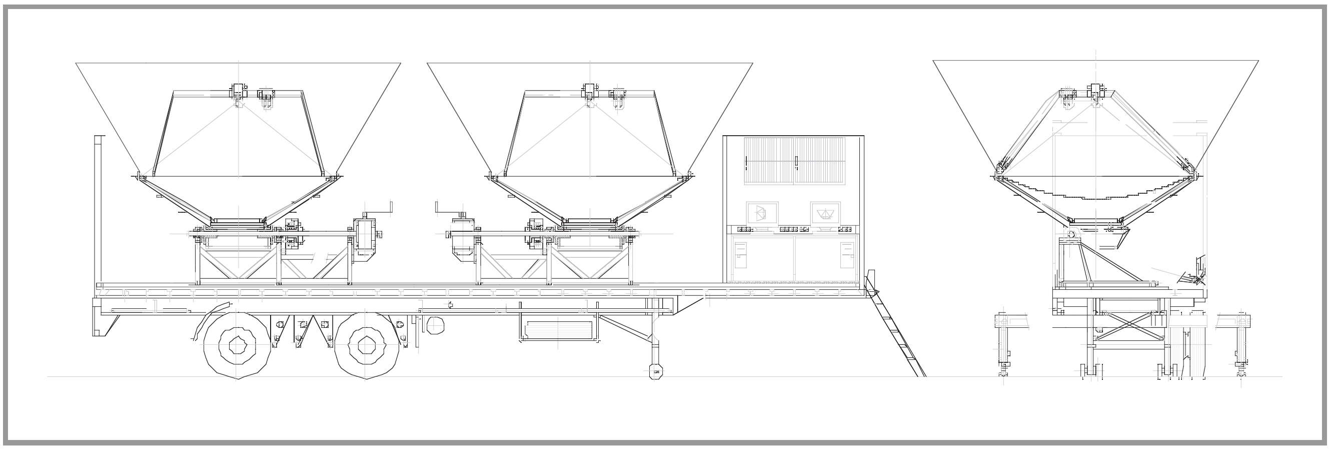

Fig. 1. Technical drawings of the TARA radar system. Clearly visible is the dual antenna system with large shields.

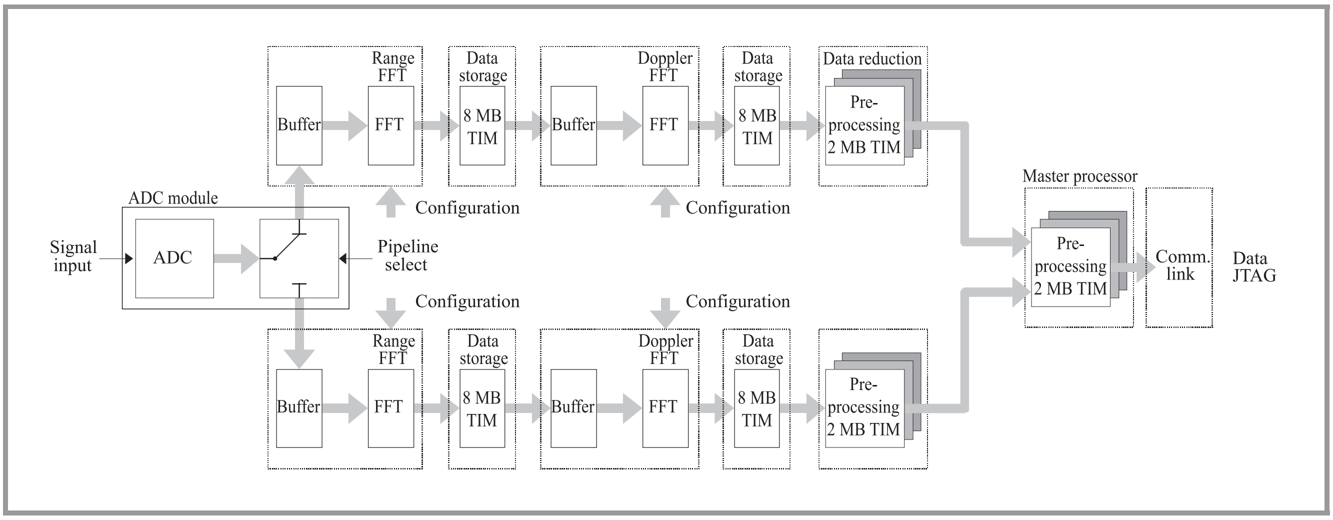

Fig. 2. Block diagram of the spectrum processor for the TARA system.

calculated. To remove noise contributions in the reflectivity, the Doppler spectra are clipped before the calculation of the moments is executed. All these calculations are done in a single DSP. After processing, data is transferred into a last DSP were data displaying and archiving is handled. The minimum sweep time in the system is 1 ms. To guarantee continuous data throughput, a dual pipeline architecture is used, see Fig. 2. A photograph of the system is shown in Fig. 3.

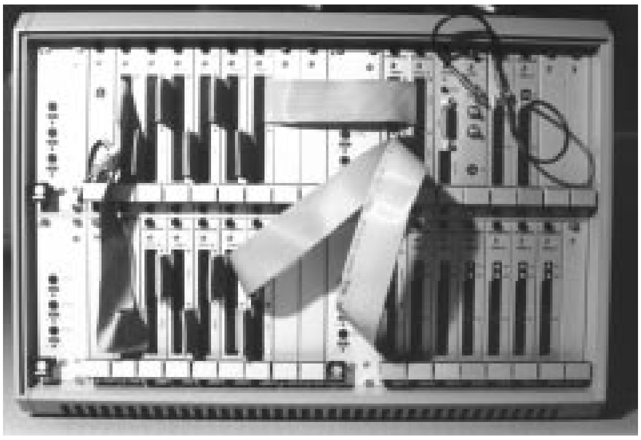

Fig. 3. Photograph of the computer system. The left upper quadrant contains the ADC and one pipeline of the spectrum processor. The second pipeline is placed in the left lower quadrant. The right upper quadrant contains the master processor and the linearisation module. The right lower quadrant contains the I/O modules for system control.

The second function of the computer system is control of the radar hardware. This includes, but is not limited to, polarisation and beam switching, bandwidth and frequency agility. All settings can be changed on a sweep to sweep base. Delayed sampling is used to allow the system to relax after switching such that stability during the measurements is guaranteed. This means that of a sweep of 1 ms only 875 μs are used for sampling.

System control also includes linearisation of the frequency sweep. In FM-CW systems, range resolution is on the one hand determined by the bandwidth of the system and on the other hand by frequency-sweep linearity. Nonlinearities will lead to spectral leakage and thus deteriorate the resolution. It can be shown that the nonlinearities should be limited to less than 0.05% of the bandwidth for the spectral leakage to remain within acceptable limits. In general, a VCO does not comply with this specification and the frequency curve has to be linearised.

Linearisation of the sweep can be done in several ways. In the TARA system it is done in a feed-forward way. This means that off-line the voltage depending frequency in the system is measured. This measurement is done in a sta-

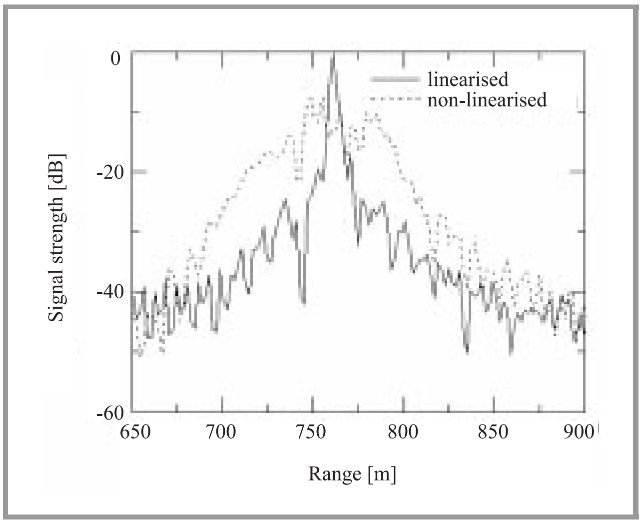

Fig. 4. Resolution of the TARA system with and without linearisation correction. Clearly visible is the dramatic improvement in resolution and the corresponding increase in signal strength.

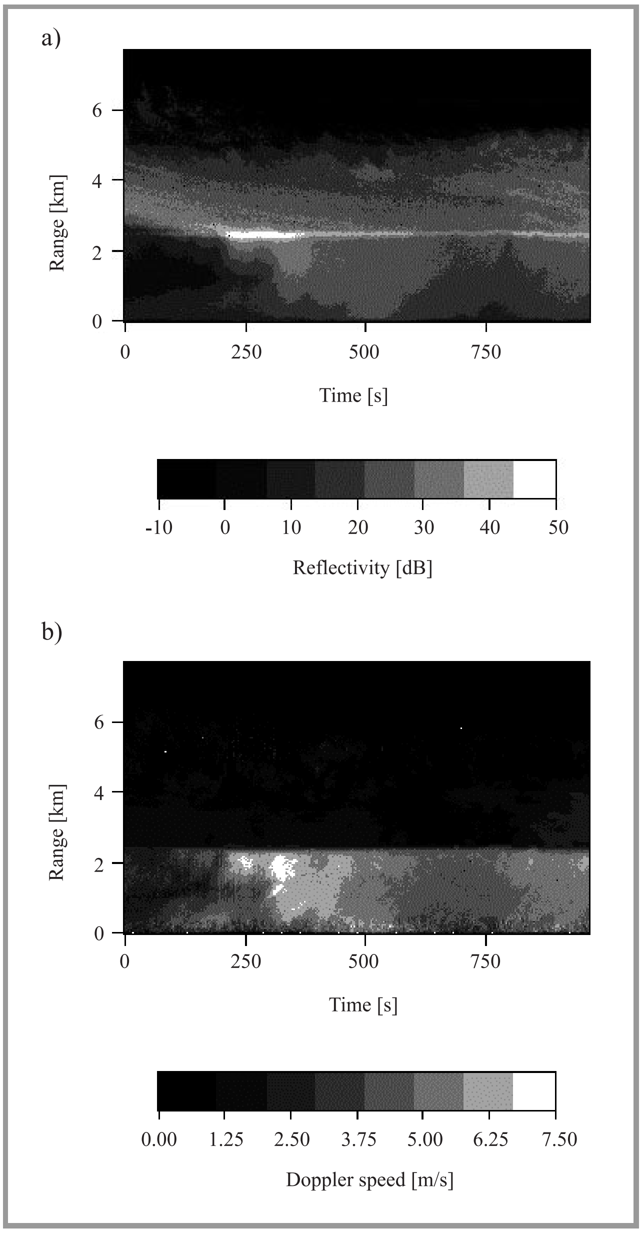

Fig. 5. Measurements with the TARA computer system: (a) the reflectivity and (b) the average Doppler speed. Sweep time: 1 ms, bandwidth: 15 MHz, 512 range cells and 512 Doppler cells. As the system is not calibrated, the reflectivity is given in dB.

tionary state. From the measured frequency characteristic, a correction table is calculated. Before starting measurements, a control signal for the VCO is calculated from the table and this is stored into a RAM-memory. During each sweep this memory is played back generating a linear frequency sweep. This set-up only works if two conditions are fulfilled. First, the VCO must be fast enough such that the sweep can be considered to be a sequence of stationary states. Second, the system must be stable and reproducible during very long times for the correction table to remain valid. To fulfil the first condition, a VCO is taken that can sweep over 200 MHz in less than 100 ns. As the sweep time for the TARA system is in all cases longer than 1 ms, while the bandwidth is less than 50 MHz, the first condition is met. To guarantee system stability, the VCO is temperature stabilised to within 1°C. In Fig. 4, the realised range spectrum is shown. For this measurement an internal delay line of 5 μs is used. The beat signal is Fourier transformed to give the reflected signal as a function of range. In the case of non linearisation correction, the delay line shows as a very broad peak extending over roughly 100 m in range. In the case the sweep is linearised, the delay line shows up as a very narrow peak within one resolution cell. This indicates linearity within the desired limits. As the spectral peak narrows, the signal strength increases. The correction table used for this measurement was more than two months old. New correction tables can easily be calculated every week or even more often making sure that linearity is not a limitation to the resolution.

3. Measurements

Although the TARA system is not yet fully operational, first measurements were done using an antenna set of a different radar system. These measurements were done during a day of light rain using a bandwidth of 15 MHz and a sweep time of 1 ms. The Doppler spectrum was calculated at 512 range cells using 512 sweeps. The first two moments of the spectrum, the reflectivity (un-calibrated) and the average Doppler speed (calibrated), are shown in Fig. 5. This typical example shows a sharp transition, the bright band or melting layer, at 2.5 km where the 0° isotherm is positioned. Above this melting layer the average Doppler speed is very low. Below this layer the velocities increase showing a downward movement towards the radar system. The quality of the measurement shows the real time possibility of the computer system and the validity of the linearisation scheme.

Acknowledgement

The work described in this article was done under financial support of the Dutch Technology Foundation "STW". The authors wish to thank the people from Prodrive in Eindhoven, The Netherlands, for helping in developing and building the computer system.

References

[1] S. H. Heijnen and L. P. Ligthart, "TARA: development of a new transportable atmospheric radar", in *5th Int. Conf. Radar Syst.*, Brest, France, May 1999.

Silvester Henri Heijnen was born in Geleen, the Netherlands, on July 15, 1964. He finished the University in 1983 with a degree in physics. His Ph.D. was done at a research institute for thermonuclear plasma physics research in Holland and culminated in a thesis on the application of short-pulsed radar for measuring electron density profiles in thermonuclear plasmas. After this he worked for one year in the Forshungs Anlage in Jülich, Germany. In 1995, he joined the International Reseach Centre for Telecommunications-transmission and Radar, IRCTR, Delft University of Technology, the Netherlands, to work on the realisation of the Transportable Atmospheric Radar, TARA. Currently, he is working in the remote sensing group of IRCTR on the interpretation of TARA data.

S.H.Heijnen@irctr.tudelft.nl
IRCTR
Delft University of Technology
Mekelweg 4
2628 CD Delft, The Netherlands

Jaques S. van Sinttruijen
IRCTR
Delft University of Technology
Mekelweg 4
2628 CD Delft, The Netherlands

Fred W. van der Zwan
F.Zwan@irctr.tudelft.nl
IRCTR
Delft University of Technology
Mekelweg 4
2628 CD Delft, The Netherlands

Leo P. Ligthart – for biography, see this issue, p. 6.