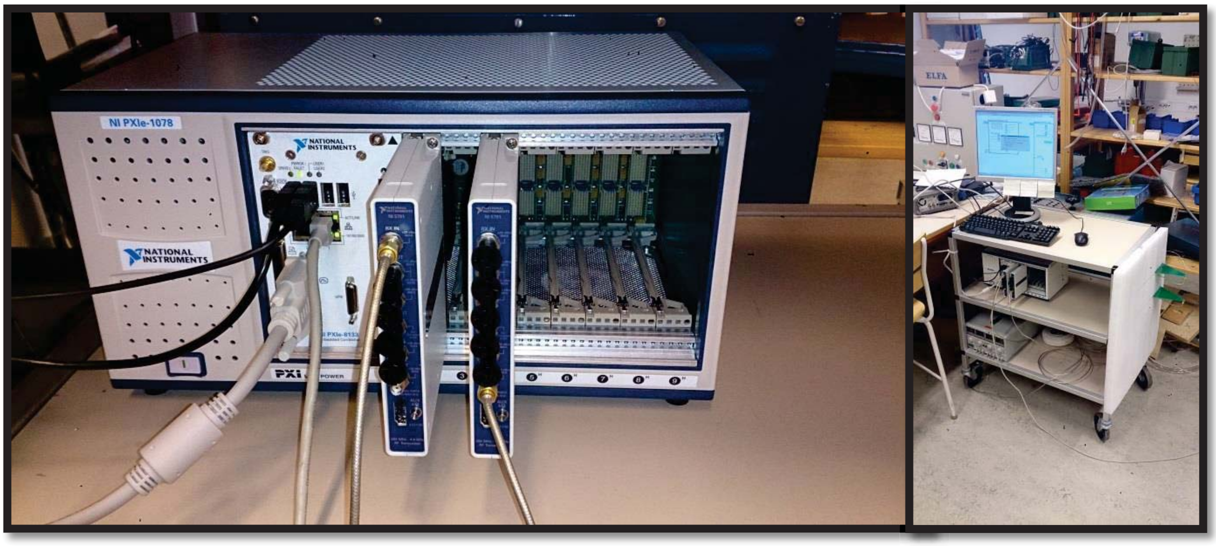

Software Development For a Radar Application Based on SDR Technology

Examensarbete inom högskoleingenjörsprogrammet Elektroingenjör

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STATEMENT BY THE AUTHORS

We hereby declare that this submission is our own work and to the best of our knowledge, it contains no material previously published or written by another person, nor material which to a substantial extent has been accepted for the award of any other degree or diploma at any educational institution, except where due acknowledgement is made in the thesis.

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ABSTRACT

Radar systems have been around since the thirties, in the beginning they were stationary, needed a lot of energy and were not that precise. Today's radar systems are much more efficient, more precise and can be mounted on most vehicles. Still there is more development to be made, due to the advancement in computer technology there is a new way of constructing a radar system. By converting analog parts of a radar system and implementing them into software you will get a smaller and more flexible system. A system like this is called, software defined radar (SDR Radar). This thesis is investigating the possibilities and limitations of such a system.

The tests were carried out on National Instruments development platform flexRIO, it includes a chassis with two 7966R FPGA cards, each mounted with the 5791 RF module and a host computer. The whole project was divided into two projects were this report focuses more on the software development for the host computer. During the project a radar system was successfully created and could detect large objects with high cross section from maximum 75 meters. A transmitter- and receiving application were developed in LabVIEW. The FPGA cards were programmed by the other thesis group.

The project was made in cooperation with SAAB Electronic Defense (EDS) and all tests and development was made there and at Chalmers University of technology, Lindholmen. Support, hardware and the programming platform LabVIEW were provided from National Instruments.

ACKNOWLEDGEMENTS

We would like to thank Sakib Sistek from Chalmers University of Technology for all the help and making this thesis possible. We also have our advisor Manne Stenberg and examiner Bertil Thomas to thank for the help and useful input. The last one to thank from Chalmers is Arto Heikkilä for his help regarding antennas and electromagnetic waves. From National Instruments we would like to express our gratitude to Jonas Mäki who has been giving us great support on LabVIEW and the hardware. Last but not least we want to thank all personal at SAAB EDS in Kallebäck for the help and for making us feel welcome at their work. We also want to give a special thanks to Lennart Berlin who has been our advisor at SAAB, he has been a great support.

TABLE OF CONTENTS

1 Introduction

1.1 Background

Radar systems were first applied in the military field in the 1930´s and were used to detect German fighters invading Great Britain. However, the area of use has rapidly expanded since then; today it is still used in the military but also for commercial use such as, air traffic, weather forecasts, industrial measurements and in many other areas [1]. These radar systems are mostly built up by analog parts which make them unilateral and expensive for small commercial use. To broaden the market and answer to the growing demand of cheaper and more versatile systems the most promising solution is software designed radar (SDR Radar). These systems implement most if the analog parts to software which make them very versatile and also reduces costs, which makes them good for testing and prototyping. This is why SAAB electronic defence system (EDS), one of the world´s leading manufacturers of surveillance systems, wanted to see what different solutions could be realized with SDR Radar, focusing on efficient signal processing.

1.2 Purpose

The purpose of this thesis is to investigate if it is possible to create a radar system with the given development equipment. With a focus on smart software designed application in the programming platform LabVIEW.

1.3 Deliminations

This project will focus on detection of nonmoving targets. The systems maximal and minimal distance will be delimited depending on the systems performance and stability.

1.4 Definitaion of task

Is it possible to create a software based radar system with the following hardware?

- 1078 chassis
- Two 7966R FPGA cards
- Two 5791 RF modules
- PC-host

Suggest business cases for SAAB EDS with different area of use.

2 Technical background

2.1 Radar

Radar stands for ”Radio Detection and Ranging”, there are many different ways of constructing a radar depending on what purpose it shall have. However, the main principal for a radar system is to detect and measure objects using electromagnetic waves. A common type of radar is pulse radar; this system is transmitting pulses of electromagnetic waves in a narrow direction. When a pulse is transmitted it will bounce around on anything in its path, how much of the energy that is bounced back to the receiver depends on the conductivity and shape of the object. The receiver takes the signals in and then they need to be processed, otherwise there will be too much noise to be able to make anything out of the received information. After the information has been processed the time between the transmitted pulse and received echo is measured, since EM waves propagation velocity is constant, the distance to the objects can be calculated.

2.1.1 Radar equation

The radar equation gives a good summary of what is affecting the maximum range. Take notice that PRF is not included in the equation which sets a limit to the minimum and maximum range as well (*Read more about PRF in the duplexer part)*. The equation can be calculated linearly or in decibel.

$$R_{max} = \left(\frac{P_t G_t G_r \sigma \lambda^2 L_s}{(4\pi)^3 N(SNR)} \right)^{1/4}$$

P_t is the peak power of the transmitter [W].
G_t and G_r is the antennas transmitting and receiving gain.
σ is radar cross section (RCS) and is a measure of how detectable a target is.
λ is the wavelength of the transmitted signal.
L_s is all the inevitable inefficiencies of a radar system putted together as a system loss factor.
N is the average noise and SNR signal to noise ratio.

Each part in the radar equation will be explained further in chapter 4. [1]

2.1.2 The pulse radar

A pulse radar can be scaled down to a few important parts as showed in the Fig. 1

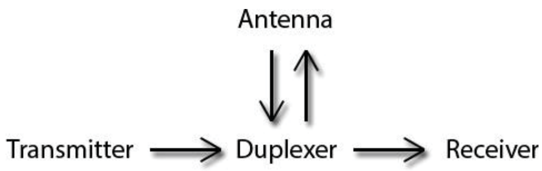

Figure 1. A radar system simplified and scaled down.

2.1.3 Duplexer

Usually, a pulse radar has only one antenna, this means that the antenna has to be able to transmit and receive. It cannot do both things at the same time, if the receiver is on at the same time as the transmitter, it would be destroyed by the high output. This is why there is a duplexer controlling whether the antenna is sending a pulse or receiving. How frequently a pulse is transmitted is called Pulse Repetition Frequency (PRF), this is important because it sets the limits of the distances that the radar is able to unambiguously detect objects.

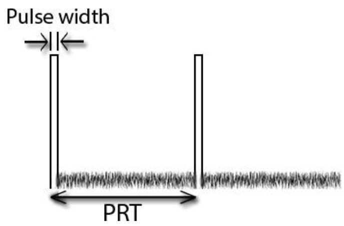

Fig. 2, PRT stands for Pulse Repetition Time.

$$PRF = \frac{1}{PRT}$$

The minimum range is determined by the transmitted pulse duration τ, the pulse has to propagate to target and back to the antenna in between pulses, otherwise the receiver is off. The maximum range is given by the following equation.

$$R_{max} = \frac{C_0}{2 * PRF}$$

Where C_0 is the velocity of electromagnetic propagation. [1]

2.1.4 Transmitter

The transmitter is important for the range and reliability of the radar. It must produce a steady, easily modulated, high output radio frequency (RF) pulse. Not only the power of the output P_t is important for the range but also which frequency the radar is transmitting on. As seen in the radar equation, the wavelength is affecting the radar range. RF are divided into different bands as shown in table 1. Today, many frequencies are occupied by other standards, both military and commercial use, for example WIFI that is working on 2,4 GHz and 5 GHz. This is why it is important for the transmitter to be stable and hold the sidebands to a minimum; otherwise it would intervene with other neighboring bands. Therefore there are a few frequencies that are more common than others when using radar. [2]

Band Designation	Frequency Range	Assigned Radar Frequency Ranges	Common Radar Frequency	Common Radar Wavelenght
HF	3-30 MHz			
VHF	30-300 MHz	138-144 MHz 216-225 MHz	220 MHz	1,36 m
UHF	300-1000 MHz	420-450 MHz 890-942 MHz	425 MHz	0,71 m
L	1-2 GHz	1,215-1,4 GHz	1,3 GHz	23 cm
S	2-4 GHz	2,3-2,5 GHz 2,7-3,7 GHz	3,3 GHz	9,1 cm
C	4-8 GHz	4,2-4,4 GHz 5,25-5,925 GHz	5,5 GHz	5,5 cm
X	8-12 GHz	8,5-10,68 GHz	9,5 GHz	3,2 cm
Ku	12-18 GHz	13,4-14 GHz 15,7-17,7 GHz	16 GHz	1,9 cm
K	18-27 GHz	24,05-24.25 GHz 24,65-24,75	24,2 GHz	1,2 cm
Ka	27-40 GHz	33,4-36 GHz	35 GHz	0,86 cm
V	40-75 GHz	59-64 GHz		
W	75-110 GHz	76-81 GHz 92-100 GHz		

Table 1, Radio frequency bands

The wavelength is affecting range and precision of a radar system, therefore the different bands have different area of use. The lower bands, VHF, UHF and L are used for long distance search radars. While the middle bands X, Ku and K are used for more precise tracking radars. Higher frequencies results in signal attenuation due to atmospheric absorption which leaves the higher frequencies for other use. [2]

2.1.5 Receiver

When echoes return to the antenna they are much weaker and shrouded in background noise, the noise comes from the sun and movements of electrons in the circuit of the receiver. [3] To be able to distinguish the echo from the noise it needs to be amplified and filtered out, that is what the receiver is for. There are numerous ways of amplifying the signal, a typical amplifier is a Low Noise amplifier (LNA). It amplifies with the minimum Signal to Noise Ratio (SNR) and is often the first stage of the receiver. [2]

$$SNR = \frac{Energy\ in\ signal}{Energy\ in\ noise}$$

After the LNA the signal is filtered out and processed before being sent to the indicator. The filter and signal process differs from system to system depending on which purpose the system has and how the signal is to be shown to the user.

2.1.6 Antenna

Radar antennas comes in many different sizes and shapes, most pulse radars only has one antenna whilst other has an array of antennas. The main purpose of the antenna is to launch the signal and receive the incoming echoes, it also has to propagate the transmitted energy in the right direction. Otherwise it would be impossible to determine the direction of the object.

The gain of an antenna varies with the size and wavelength; the gain can be estimated with following equation.

$$G_r = \frac{4\pi A_e}{\lambda^2}$$

$A_e$is the area of the antenna, a larger antenna means that a larger amount of the returning power can be intercepted. [1] λ is the wavelength and is related to its frequency by the following equation.

$$\lambda = \frac{C_0}{f}$$

As shown by antenna gain equation, a long range, high gain antenna needs to be big. That is also why radars do not go below 1 MHz in frequency; the antenna would be too big

A radar system that uses one antenna has to rotate it to change the direction of the beam, changing its search area. An array of antennas takes advantage of the electromagnetic waves interference with each other to change the beam´s direction. So instead of changing the antennas direction, the pulses from each antenna is transmitted with a phase shift, resulting in a steering of the main lobe. [4] What also needs to be taken into consideration is that the wavelengths of the transmitted pulses are affecting how the waves propagate in space. This makes the placement of the antennas in relation to transmitting frequency very important. A rule of the thumb is to place the antennas half a wavelength from each other.

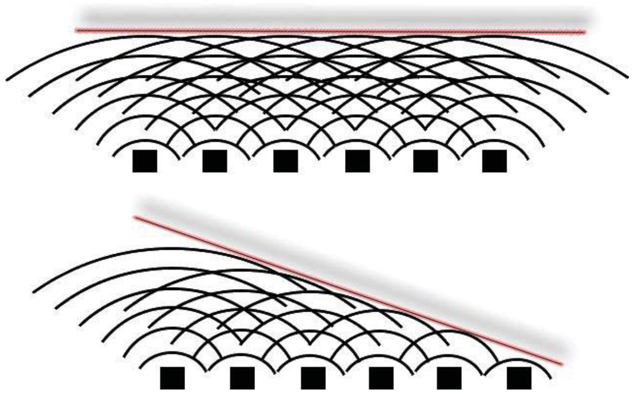

Fig 3, Main lobe direction change through phase shift.

2.2 Sampling

The analog to digital- A/D and digital to analog conversion is handled by the hardware in this thesis so it is not so important to understand the theory behind the process. However, sampling itself is very important because it controls how much data that is being processed which determines the stress level on the hardware. It also controls signal quality and a higher sampling improves the SNR [1]. It is important to find a balance in the sampling rate, if the sampling rate is too high, the hardware will not be able to process the incoming data and this will cause the program to either crash or start dumping data. If the sampling rate is too low the signal will be in poor quality. Another problem with low sampling rate is that echoes can slip through in between samples.

In systems where high accurate measurement is required there is not enough to satisfy the Nyquist theorem. The sampling rate must be set high enough to prevent aliasing, which is recommended to be about 5 to 10 times the highest frequency component in the signal. [5]

2.2.1 Aliasing

If a signal is sampled at a sampling rate less than twice the Nyquist theorem frequency, there might appear false lower frequency components in the sampled data, this phenomenon is known as Aliasing.

As figure 4 shows, a false sine curve appears when the sampling does not fulfill the Nyquist theorem.

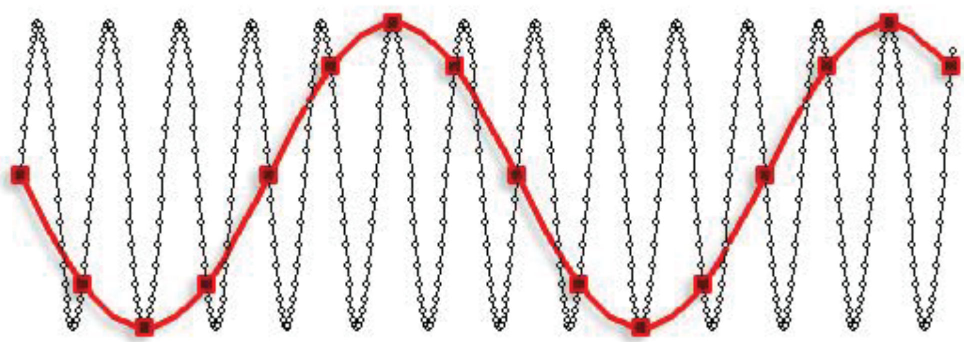

Figure 4, A false sine curve appears

To prevent aliasing, it is beneficial to remove any frequency components above half the programmed sampling rate. This is called an antialiasing filter and is mostly performed by an analog or digital filter or a combination of them. In figure 5 there is shown the effects of various sampling rates. In case A, a sine wave with frequency f is sampled at the same frequency f. The result is a waveform as an alias as DC. If the sampling rate is increased to 2f, the waveform has the correct frequency but will appear as a triangle waveform as in case B. In case C, the sampling rate is at 4f/3 which reproduces as an alias waveform of incorrect frequency and shape. [5]

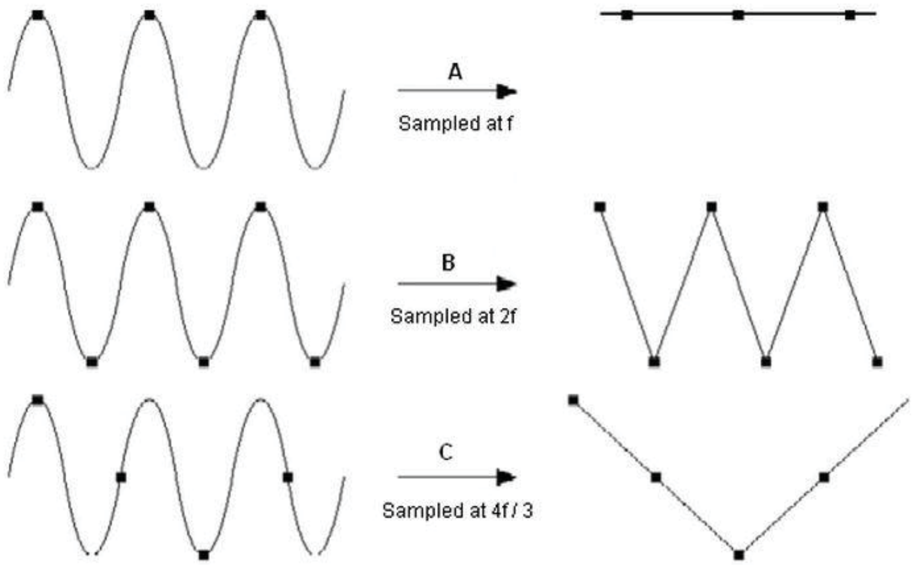

Figure 5, three alias waveforms[5].

2.2.2 Nyqvist theorem

The Nyquist theorem says that the sampling rate must be at least double the highest frequency component of interest in the measured signal. Otherwise the high-frequency content will alias at a frequency inside the spectrum of interest. An alias is a false lower frequency component that appears in sampled data caused by a too low sampling rate. [5]

2.3 FPGA

FPGA (Field Programmable Gate Arrays) is a digital circuit that contains programmable blocks of logic that the programmer can program to perform different kind of tasks. A FPGA device does not have an operative system which makes it a very high performance device that can run its program without interrupts from other programs. [6]

Newer FPGA devices provided by National Instruments can be programmed directly in LabVIEW. This high level programming in LabVIEW makes it easier and more efficient to create programs.[11]

2.4 LabVIEW

LabVIEW (Laboratory Virtual Instrument Engineering Workbench) is the tool that has been used to program both the host and the FPGA cards. LabVIEW is a graphical programming platform from National Instruments that provides possibilities for making digital measurement and control applications.[11]

The program the user create is based on different Virtual Instruments (VI:s). A VI have two parts, a front panel and a block diagram. The front panel is what the end-user will see and where it's possible to control and configure the program. In the block diagram is where all the logic and functions is located and is mostly only visible for the developer.

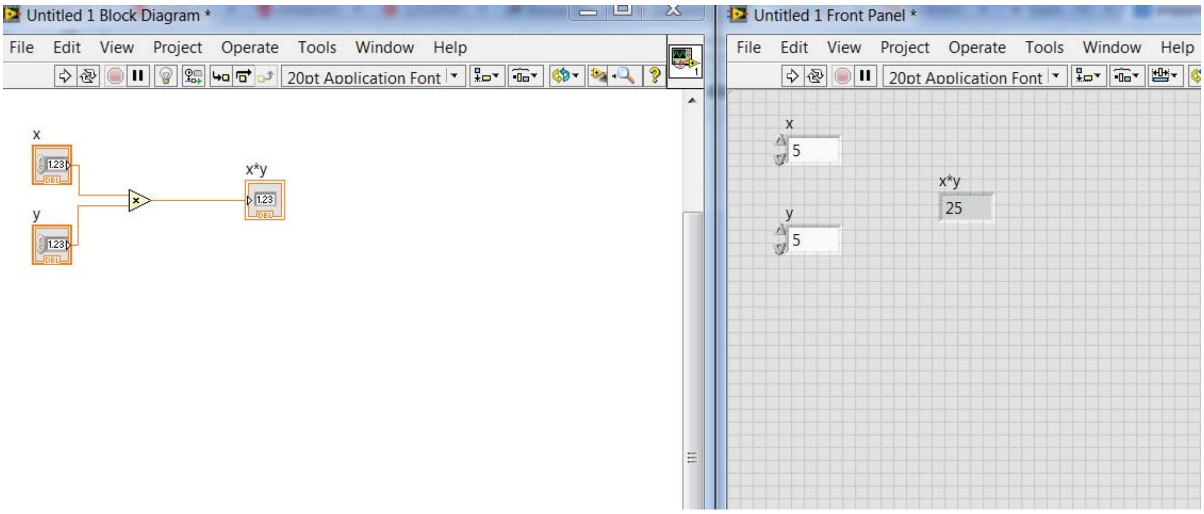

Figure 9. A simple example of a LabVIEW application

As seen in the example in figure 9, the application has one block diagram view and one front panel view. The block diagram to the left views the logic for the multiplier program and the front panel to the right is where the user can enter values.

2.5 IQ Data

The signals that are being received will be converted to I/Q data. I/Q data is a simple format to work with when you are working with signal processing. The I/Q data are complex number that shows amplitude and phase changes in a sinus carrier. If these changes happens predetermined it is possible to code information into the carrier, also known as modulate a signal. [12]

There are different ways to modulate the signal. Frequency, amplitude and phase can be changed to create data. I/Q data is a combination of amplitude and phase modulation where "I" represents the real axis and "Q" represents the imaginary axis.

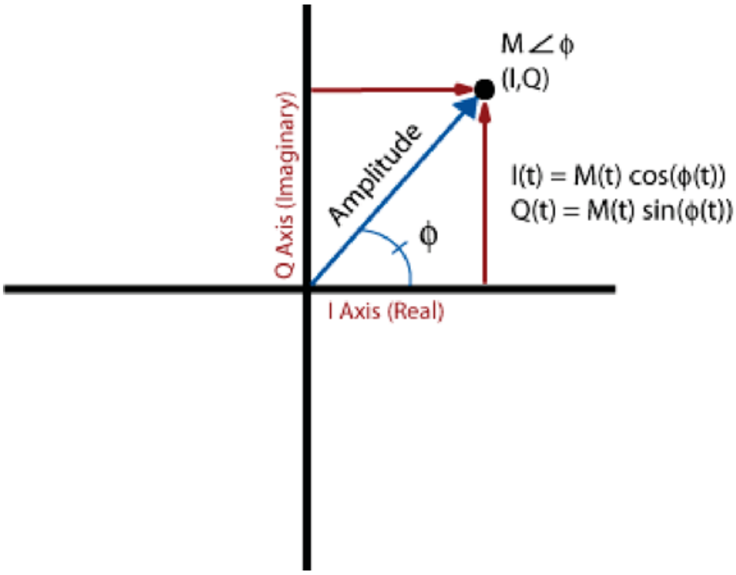

Figure 10. I and Q Represented in Polar Form[12]

If a change on "I" or "Q" occurs, the angle Φ and the amplitude of the carrier will change. This makes I/Q data relatively simple to implement in hardware comparing to changing the amplitude and phase.

With help of trigonometry it is possible to see that "I" is a cosine function and "Q" is a sinus function. This results in a phase shift of 90 degrees between them that has to be compensated when reading and creating the signals[12].

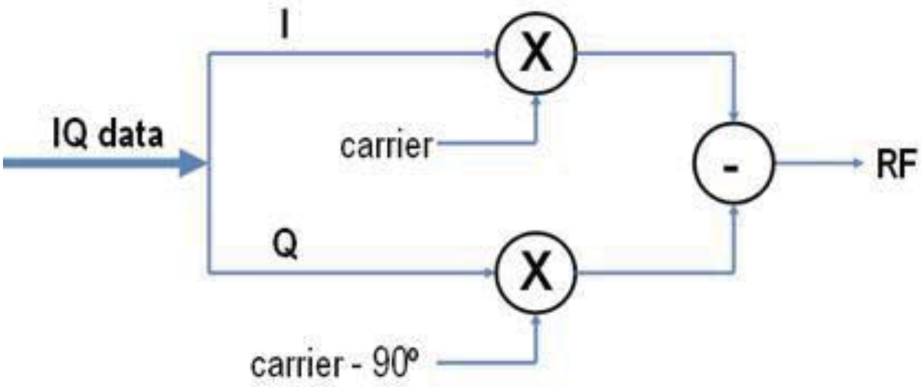

Figure 11. Hardware Diagram of an I/Q Modulator[12]

In figure 11 it is described how a RF signal is generated. The “I” data is combined with the carrier wave and the “Q” data is combined with a 90 degrees phase shifted carrier to compensate. At last the modulated signals are combined to a complete RF signal [12].

2.6 Hardware specification

2.6.1 1078 chassis

PXI (PCI eXtension) is a PC-based platform made for measurement and testing. The platform is developed by National Instruments and mainly consists by three parts.

- The chassis
- The controller
- Modules

The advantage with the chassis is that it provides a high bandwidth between the components and a low response time. The controller could be a PC with ether a Windows operative system or National Instruments own Real-time Operating System installed and connected to the high performance bus with the modules. The chassis have slots where it’s possible to connect different kind of modules to the bus.[7]

Another advantage with using only National Instruments equipment is that drivers to all modules is easy to find and works good with each other.

2.6.2 PXIe-8133

Mounted in the chassis is the PXIe-8133 module and was used as a controller. The module have a high performance Intel Core i7-820QM quad core processor, working together with a 2GB DDR3 RAM module. The module is connected with the other modules on a PCI-express bus. Addition to the PCI-e bus it also have four USB 2.0 ports and two Gigabit Ethernet connections. The module is delivered with a preinstalled Windows 7 operative system. [8]

Figure 6. PXIe-8133 controller module[8]

2.6.3 7966R FPGA

To be able to generate and receive signals in high resolution and speed, two 7966R FPGA cards was used for the data processing and conversion to I/Q data. This model is based on the Virtex-5 SX95 FPGA and have 512Mb onboard memory. This module have an adapter module interface on the front where it is possible to connect other cards directly to the FPGA module. [9]

Figure 7. PXIe-7966R FPGA module[9]

2.6.4 5791 RF modules

Connected to each of the FPGA modules is a PXIe 5791 RF-frontend. The module have one receiver and one transceiver and can generate and receive signals from 200MHz to 4.4GHz. The module require to be connected to a FPGA card to be able to operate, as seen in the upcoming figure. Together with the FPGA module it works as a high performance transceiver and receiver where one RF-module and one FPGA works with generating the signal and the other pair works with receiving signals and convert them to I/Q data. [10]

Figure 8. PXIe-5791 module connected to a PXIe-7966R FPGA module[10]

2.6.5 Low noise amplifier (LNA)

Two different LNAs were used for this thesis to increase the incoming signal and suppress the noise. They have the following specification:

Model	Frequency response	Gain [dB]	Noise Figure [dB] Typ/Max	Power output for 1 dB gain compression [dBm] min	Typ gain flatness [dB]	Typical third order intercept point [dBm]	DC power	Input powercurrent [mA]
AFT 4232	2-4 GHz	23	2,6/4,0	13	1	23	12-15	150
AMC 174	5-1000 MHz	15	- /3,8	2	0,3	14	15	16

Table 2. LNA specifications.

2 Method

This chapter reviews how all the tests were made to evaluate the system. The first part will tell about how the software application was built and tested. The second part will show how the system as whole was tested, it will also declare which parameters that was used.

2.1 The Process

The radar applications built in LabVIEW were divided into a transmitter and a receiver VI for the host computer. This was because it would be easier to develop and test them separately but also because the FPGAs were divided, one as transmitter and one as receiver. On the picture below is the whole system setup, mounted on a wagon, this setup was used when tests were performed outside. The 1078 chassis contains a host computer and two 7966R FPGAs which have the RF modules 5791 connected to them. From the first RF module there is a cable connected to the input “RX IN”, this is the receiver and in the application this FPGA is called RIO 0. From the second one, a cable is connected to the output “TX OUT”, this is the transmitter and this FPGA is called RIO 1 in the application.

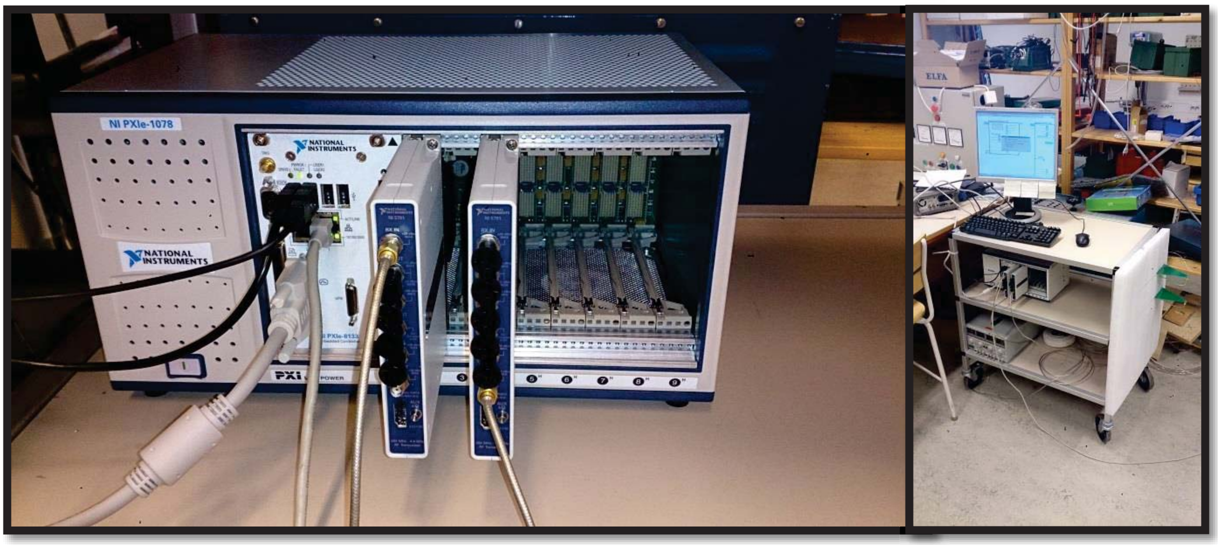

Fig 12. On the left is the 1078 chassis with all connections and on the right is the wagon setup.

The output TX is directly connected to the log periodic antenna which can be seen in figure 12. The other antenna is for the receiver, but instead of being directly connected to the RX input there is an LNA connected in between. Two different LNAs were used to boost the signals depending on which frequency that were used to transmit on.

2.1.1 Transmitter test

When designing the transmitter an indicator in the program was coded so that the correct wave could be confirmed in the software. When the desired wave was built and confirmed the output was directly plugged into an oscilloscope so that the real wave could be analyzed.

2.1.2 Receiver test

The receiver was first developed as a test version just to see that it would be able to process the incoming data. Later on the indicator was further developed so that it was designed for radar purposes. However, to test the receiver, a signal was sent out from the transmitter and then the receiver was turned on. In that way the signal could easily be recognized and confirmed.

2.1.3 System test

When both applications were working, tests were made to evaluate the whole system for different area of use. In each test different carrier frequency, sampling rate and PRF were tested to see what gave the best results. Some delamination had to be done during the tests because of limitations in the hardware. These limitations will be stated in the conclusion. All tests were on an object at known range with as high cross section as possible.

The first tests was made outdoors at a garage door at 15 meters and the following settings were made.

	Range [m]	Sample Rate [Ms/s]	PRF [KHz]	Frequency [GHz]	LNA
Test 1	15	40	1500	3,3	AFT 42-32
Test 2	15	50	1500	3,3	AFT 42-32
Test 3	15	60	1500	3,3	AFT 42-32
Test 4	15	70	1500	3,3	AFT 42-32

Table 3. Settings for the 15 meter tests.

The second test was made at 75 meters and was made with following settings. The radar object was still the same garage door.

	Range [m]	Sample Rate [Ms/s]	PRF [KHz]	Frequency [GHz]	LNA
Test 1	75	40	800	3,3	AFT 42-32
Test 2	75	50	800	3,3	AFT 42-32
Test 3	75	60	800	3,3	AFT 42-32
Test 4	75	50	800	1,3	None
Test 5	75	60	800	1,3	None
Test 6	75	50	800	0,9	AMC 174
Test 7	75	60	800	0,9	AMC 174

Table 4. Settings for 75 meter tests

The last test was targeting the side of a very large ferry at 750 meters. A broader test was made with the following settings.

	Range [m]	Sample Rate [Ms/s]	PRF [KHz]	Frequency [GHz]	LNA
Test 1	750	30	50	0,9	AMC 174
Test 2	750	40	50	0,9	AMC 174
Test 3	750	50	50	0,9	AMC 174
Test 4	750	60	50	0,9	AMC 174
Test 5	750	30	50	1,3	None
Test 6	750	40	50	1,3	None
Test 7	750	50	50	1,3	None
Test 8	750	60	50	1,3	None

Table 5. Settings for the 750 meter tests.

4 Review of results

In the previews chapter the measurement process was reviewed. But due to some limitations and other problems, the results from the tests were not as favorable as hoped. Different factors made various results. This chapter will reveal the factors that made some of the tests fail and some succeed. It will first review the tests; reveal the outcome and why the results showed what they did. In part two, the software will be reviewed.

4.1 System tests

The pulse width τ sets the minimum range for the system. This is because during the transmission of the pulse, the receiver is off. The pulse width is set by the PRF and the chosen duty cycle, therefore, when working at short ranges, a high PRF is required. The short range tests were made at 15 meters, but range parameters for 10 meters were used because a minor margin is good to have, which means that it takes 66,67 ns to propagate and back.

$$t = \frac{s}{v} => t = \frac{R * 2}{C_0} => \frac{10 * 2}{3 * 10^8} = 66{,}67 * 10^{-9}$$

When a high PRF is used by the system, the sampling rate must also be increased. Otherwise echoes can fall in between samples and be missed. If a pulse is as wide as in previous equation, a sample must at least be made in the same rate. This gives us a sampling rate at:

$$Sampling\ rate = \frac{1}{\tau} => \frac{1}{66{,}67 * 10^{-9}} = 15\ MS/s$$

This is the absolute minimum but it would not give any good results, as the Nyqvist theorem states, the sampling frequency must be at least twice as high as the highest frequency component to avoid aliasing. This results in a sampling rate at 30 MS/s. This did not give any good results either, it is because the sampling rate is also very important for SNR which increase the chance of finding an echo and distinguish it from the noise. A common guideline is to have five to ten times higher sampling rate than highest frequency component. The following table shows the relation between PRF, sampling rate and minimum and maximum range. The pulse width is 10% of the PRT, if the pulse width is increased, the minimum range will also increase.

PRF [KHz]	Pulse width [ns]	Range min [m]	Max range [m]	Sample rate [MS/s]
1500	66,67	10	100	90
1000	100	15	150	60
750	133,33	20	200	45
600	166,67	25	250	36
500	200	30	300	30
428,5714286	233,33	35	350	25,7
375	266,67	40	400	22,5
333,3333333	300	45	450	20
300	333,33	50	500	18
272,7272727	366,67	55	550	16,36
250	400	60	600	15
230,7692308	433,33	65	650	13,85
214,2857143	466,67	70	700	12,86
200	500	75	750	12
187,5	533,33	80	800	11,25

Table 6. Shows the relation between PRF. Sample rate and minimum and maximum range. Sample rate is three times the Nyqvist Rate.

As can be seen in table 6, the sample rate is quite high at close ranges. The system that was used could push itself up to 60 MS/s before the FIFO queue was overflowed. Still these high sampling rates did put quite a lot of stress on the computer. One way to avoid the stress levels on the host computer is to process the data even more in the FPGAs. A software trigger was used in the RX host computer application to find the incoming pulses. If this process was completed in the FPGA it would take away even more heavy calculation from the host computer, more about this in the next part.

At the 75- and 750 meter tests the sampling rates did not cause any major problems for the host computer. The sampling rates were still kept high because it increases the quality and suppresses the noise. However, another problem occurred, the power output was a bit weak. At 75 meter, echoes did return and could be confirmed from the indicator at some frequencies. But at the 750 meter test no echoes could be confirmed. The radar equation is a good way to evaluate how much each parameter affects the maximum range. But before making some calculation some of the parameters for the system must be reviewed.

$$R_{max} = \left(\frac{P_t G_t G_r \sigma \lambda^2 L_s}{(4\pi)^3 N(SNR)}\right)^{1/4}$$

P_t is output power, the 5791 RF signal output varies with the frequency as can be seen in the figure below. The figure shows output power at 0 dB gain from the system settings.

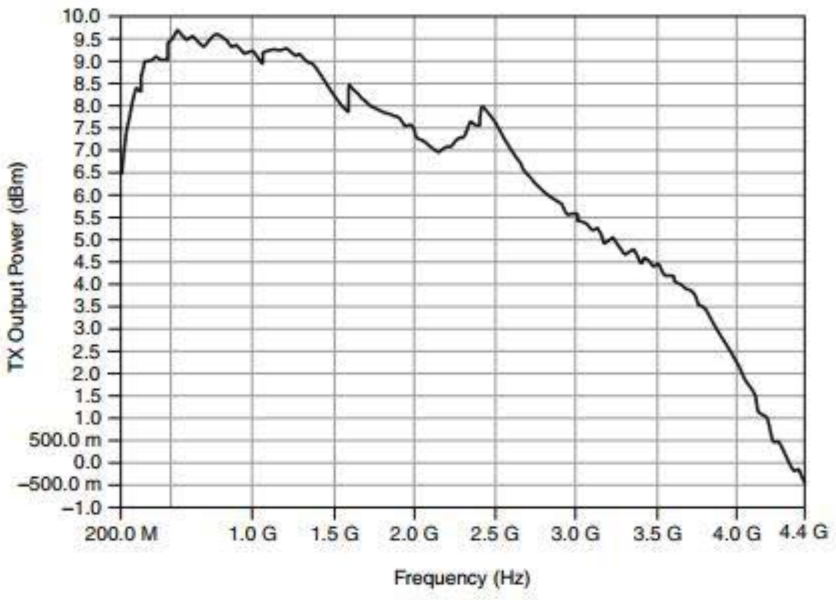

Figure 13. Output power from the 5791 RF module at different frequencies.[13]

In the system settings an internal amplifier can be set for TX up to 20 dB gain. If these are added up for the three different frequencies that were used during the tests the following power outputs can be estimated.

$$For\ 0{,}9\ GHz = 10^{9{,}5/10} * 0{,}001 = 8{,}91\ mW \Rightarrow 8{,}91 * 10^{-3} * 10 = 89{,}1\ mW$$

$$For\ 1{,}3\ GHz = 10^{9{,}3/10} * 0{,}001 = 8{,}51\ mW \Rightarrow 8{,}51 * 10^{-3} * 10 = 85{,}1\ mW$$

$$For\ 3{,}3\ GHz = 10^{5/10} * 0{,}001 = 3{,}16\ mW = 3{,}16 * 10^{-3} * 10 = 31{,}62\ mW$$

$G_t$and $G_r$is the antenna transmitter gain and receiving gain, the log periodic PCB antennas that were used gave an amplification at 6 dBi.

σ is the radar cross section and since it fluctuates with too many variables it was set to one. The measurements were also made so that the cross section would be as high as possible.

The chosen frequency also affects the maximum range directly through the wavelength λ.

L_s is the system loss factor and it is a variable that differs from system to system. In this case the value was set at 0,32 because it was a default value from an example calculation in the book, understanding radar systems [1]. The default value for N, the average noise factor and SNR, the signal to noise ratio, was also taken from this book.

Now that the different variables have been reviewed, calculations can be made to explain the results from the tests. Calculations for 0,9 GHz, 1,3 GHz and 3,3 GHz:

$$R_{\max\ 0,9\ GHz} = \left(\frac{P_t G_t G_r \sigma \lambda^2 L_s}{(4\pi)^3 N(SNR)}\right)^{1/4} = \left(\frac{0,0891 * 2 * 2 * 1 * 0,33^2 * 0,32}{(4\pi)^3 * 10^{-14} * (20)}\right)^{1/4} = 74,82\ m$$

$$R_{\max\ 1,3\ GHz} = \left(\frac{P_t G_t G_r \sigma \lambda^2 L_s}{(4\pi)^3 N(SNR)}\right)^{1/4} = \left(\frac{0,0851 * 2 * 2 * 1 * 0,23^2 * 0,32}{(4\pi)^3 * 10^{-14} * (20)}\right)^{1/4} = 61,75\ m$$

$$R_{\max\ 3,3\ GHz} = \left(\frac{P_t G_t G_r \sigma \lambda^2 L_s}{(4\pi)^3 N(SNR)}\right)^{1/4} = \left(\frac{0,0316 * 2 * 2 * 1 * 0,33^2 * 0,32}{(4\pi)^3 * 10^{-14} * (20)}\right)^{1/4} = 30,15\ m$$

As can be seen by the calculations above, 75 meters is on the edge of what the system can receive echoes. The low power output makes the radar system very sensitive to small changes. The frequency has a big impact on the maximum range, because it is affecting the power output and directly affecting wavelength in the radar equation. However, most parameters here not fixed and since some of them are estimated the results are just approximate. For example, if the sampling rate is changed the SNR will improve, the system loss factor could also be higher than estimated here and then the maximum range would improve. To put it into perspective, since the sampling rate is almost four times higher than the Nyqvist theorem maybe it improves the SNR with 50% and the system loss factor with 0,05 then the results would look like this.

$$R_{\max\ 0,9\ GHz} = \left(\frac{P_t G_t G_r \sigma \lambda^2 L_s}{(4\pi)^3 N(SNR)}\right)^{1/4} = \left(\frac{0,0891 * 2 * 2 * 1 * 0,33^2 * 0,37}{(4\pi)^3 * 10^{-14} * (20 * 50\%)}\right)^{1/4} = 92,27\ m$$

$$R_{\max\ 1,3\ GHz} = \left(\frac{P_t G_t G_r \sigma \lambda^2 L_s}{(4\pi)^3 N(SNR)}\right)^{1/4} = \left(\frac{0,0851 * 2 * 2 * 1 * 0,23^2 * 0,37}{(4\pi)^3 * 10^{-14} * (20 * 50\%)}\right)^{1/4} = 76,15\ m$$

$$R_{\max\ 3,3\ GHz} = \left(\frac{P_t G_t G_r \sigma \lambda^2 L_s}{(4\pi)^3 N(SNR)}\right)^{1/4} = \left(\frac{0,0316 * 2 * 2 * 1 * 0,33^2 * 0,37}{(4\pi)^3 * 10^{-14} * (20 * 50\%)}\right)^{1/4} = 37,18\ m$$

In the Tests at 75 meters, 0,9 GHz and 1,3 GHz did give the wanted results. Even though the returning echoes were weak they could be distinguished from the noise as can be seen in the figure below.

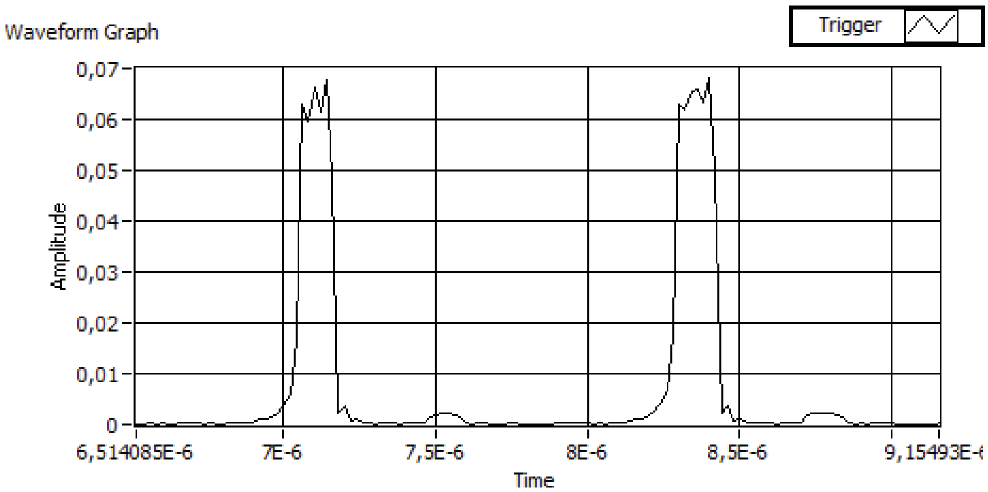

Figure 14. Echo from test 6 at 75 meter distance.

4.2 Review of software

4.2.1 Receiver front

In the receiver all data coming from the FPGA has to be processed and represented in a way so that the user can easily interpret the information. Different settings can also be made in the application, such as figure 15 shows.

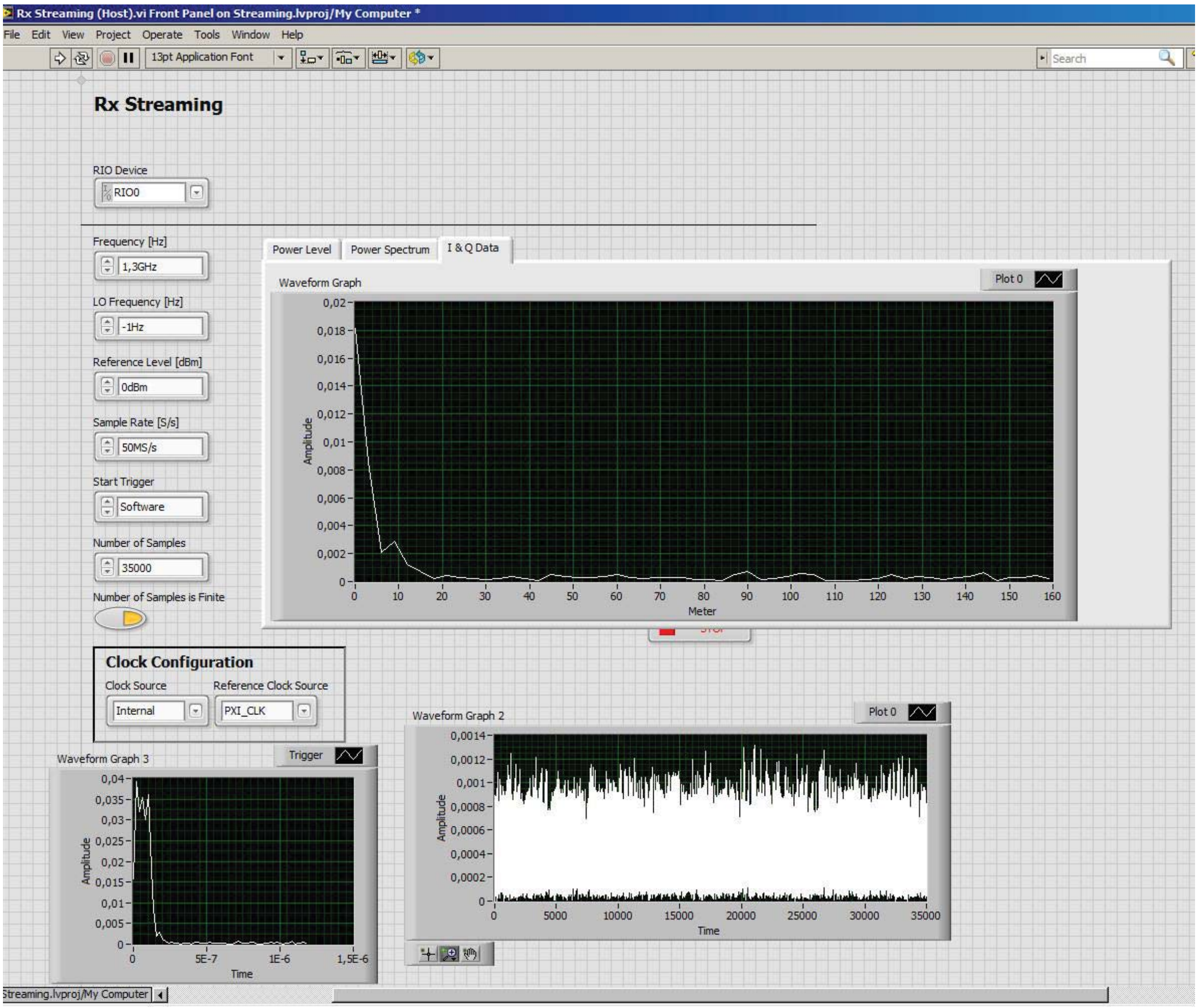

Figure 15. From the RX front panel.

The application interface shows the incoming signal in real time in the largest Waveform Graph up to the right in the figure 16 with amplitude as Y-axis and distance as X-axis. Tests were also made with two Waveform Graphs connected to a software trigger. Both graphs have amplitude as Y-axis, but one shows time on X-axis and the other shows distance in meters on the X-axis. The idea with a trigger is that it starts the viewing when a signal with a specific amplitude is received. This gives a better view of the signal when the trigger is configured to “listen” after the pulse.

The problem with the software trigger was that it processed data slower than the rate of new incoming data. This resulted in a queue that continued to increase until it became so overloaded that it resulted in a program crash.

This was solved with a counter that reset the trigger queue after a number of iterations. This code can be seen in figure 17 in chapter 4.2.2

4.2.2 Receiver block diagram

The RX application starts with setting up a connection to the FPGA card chosen as receiver. The first box named "PXIe-7966R" sets up the path to the bit file that will be loaded into the FPGA card which will make it possible to receive data from the RF modules. Box 2 "writes" the file to the FPGA before desired clock source is configured in box 3. In box 4, all the necessary info for the incoming signal will be configured depending on the choice of the user. The system will now be in a "stand by" mode where it is waiting for a trigger in box 5. When a trigger signal is detected. Box 6 will tell the main loop that it is time to start collect data.

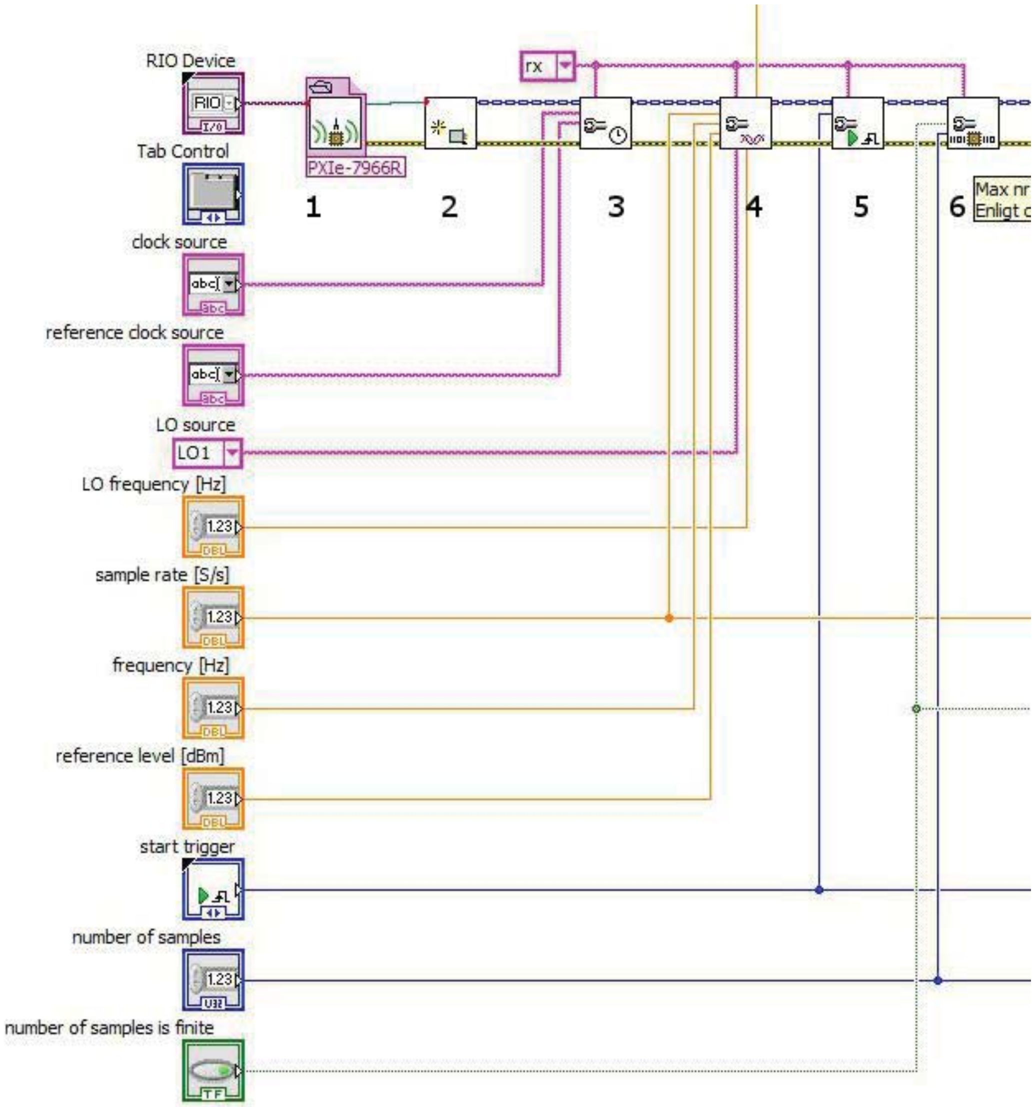

Figure 16. Receiver init

In the main loop, seen in figure 18, I/Q data will be converted to a waveform format in stage 1. During tests there was sometimes created a waveform with negative amplitude, so in stage 2 the amplitude was replaced with the absolute value for the amplitude to be sure that the trigger in stage

3 will find the pulse. In stage 4, a counter is counting iterations of the loop and in this case, it will send a reset signal to the trigger after 25 iterations to tell the trigger to drop its queue ensuring no overload on the system. The trigged signal is in stage 5 modified so the Waveform graph will show amplitude and meters instead of amplitude and time.

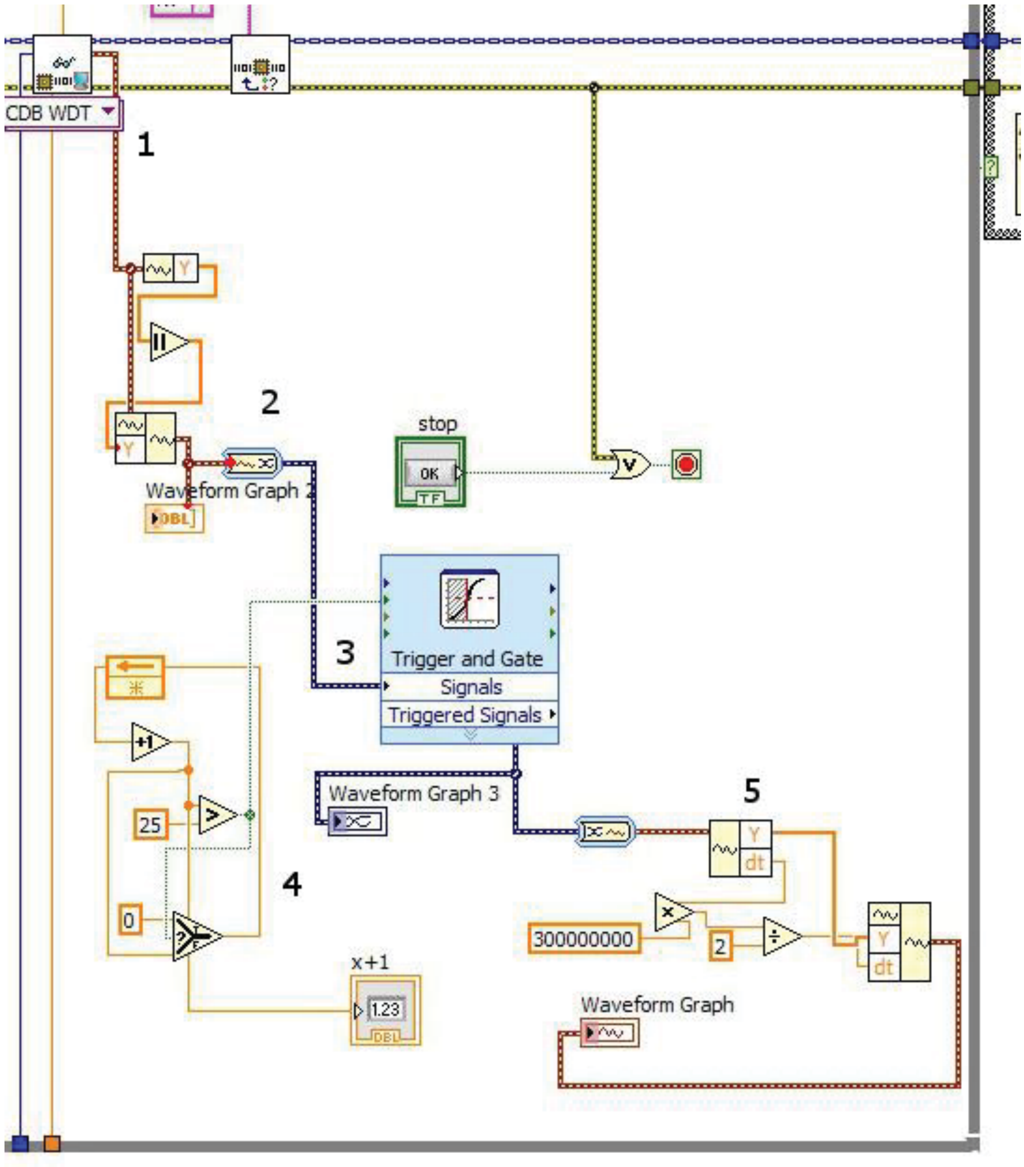

Figure 17. Receiver main loop

4.2.3 Transmitter front

The software implementation of the transmitter was successful. The modulation of the pulse was created entirely in the TX application. The Pulse was first shaped and then converted to I/Q data before being sent via the PCIe bus to one of the FPGA cards that will recalculate and forward the information to the RF-module.

The transmitter software is very flexible, as seen in figure 15, and designed so that every parameter of interest is possible to change to the desired value.

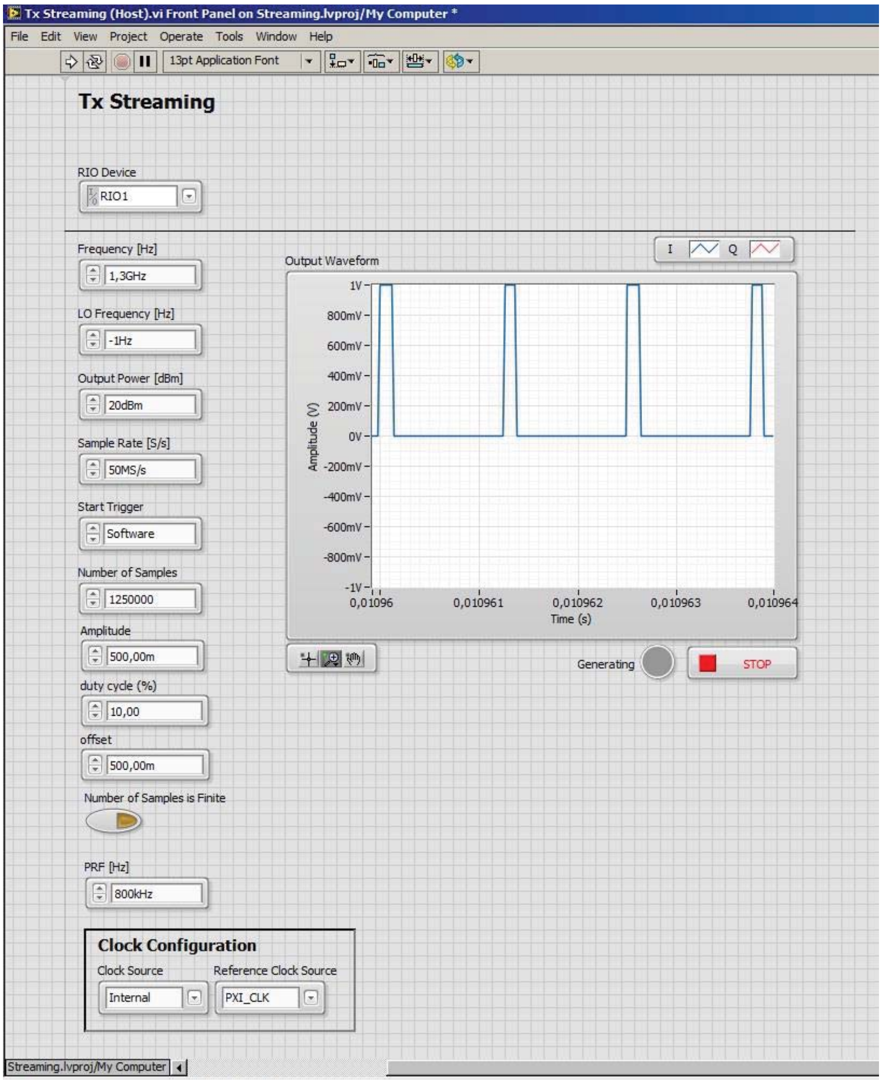

Figure 18. TX front panel.

4.2.4 Transmitter block diagram

As can be seen in figure 19, the TX block diagram contains an almost identical initialization as the RX block diagram. It differs just a little bit because now the initialization prepares the FPGA and RF module to transmit instead of receiving.

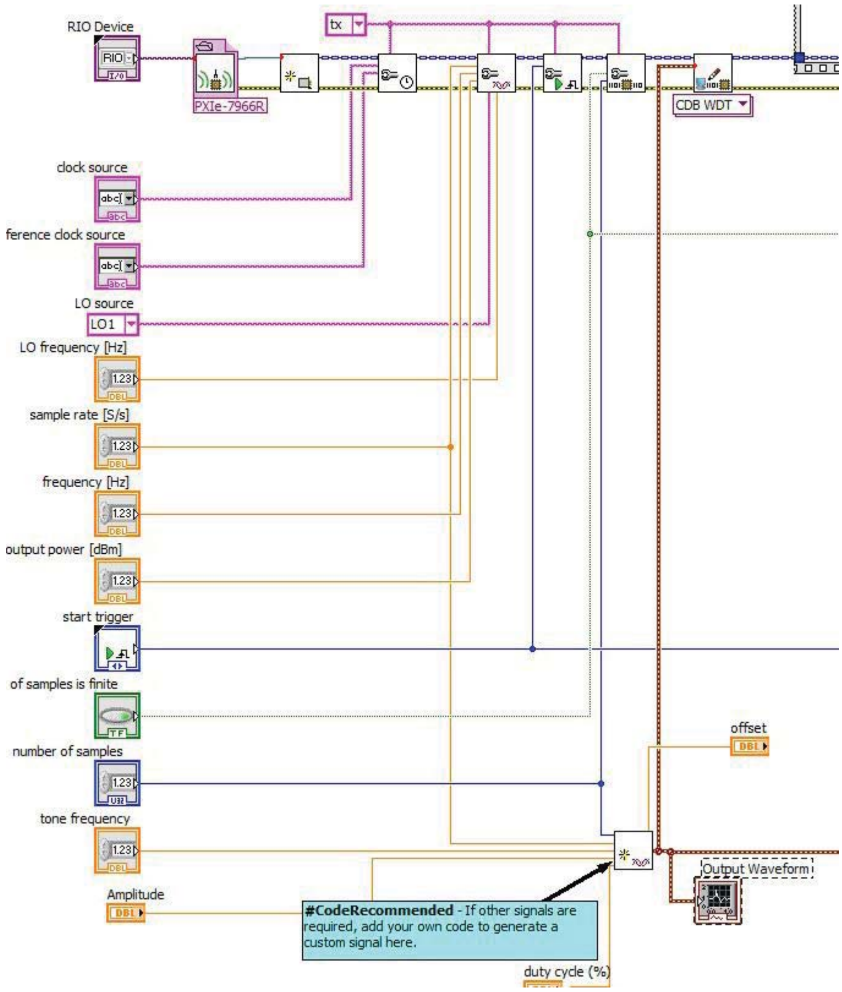

Figure 19. The initialization for the TX application.

One of the most important tasks of TX application is to modulate the wave. This happens in the VI shown in figure 20. What it does is creating a square wave defined by the user. The tone frequency decides the square wave frequency and the duty cycle decides how wide every pulse will be. In other words the PRF and pulse width are being created with an array where the transmitting time consists of 1: s and the listening time by 0: s. This is later converted to I/Q data before being sent to the FPGA.

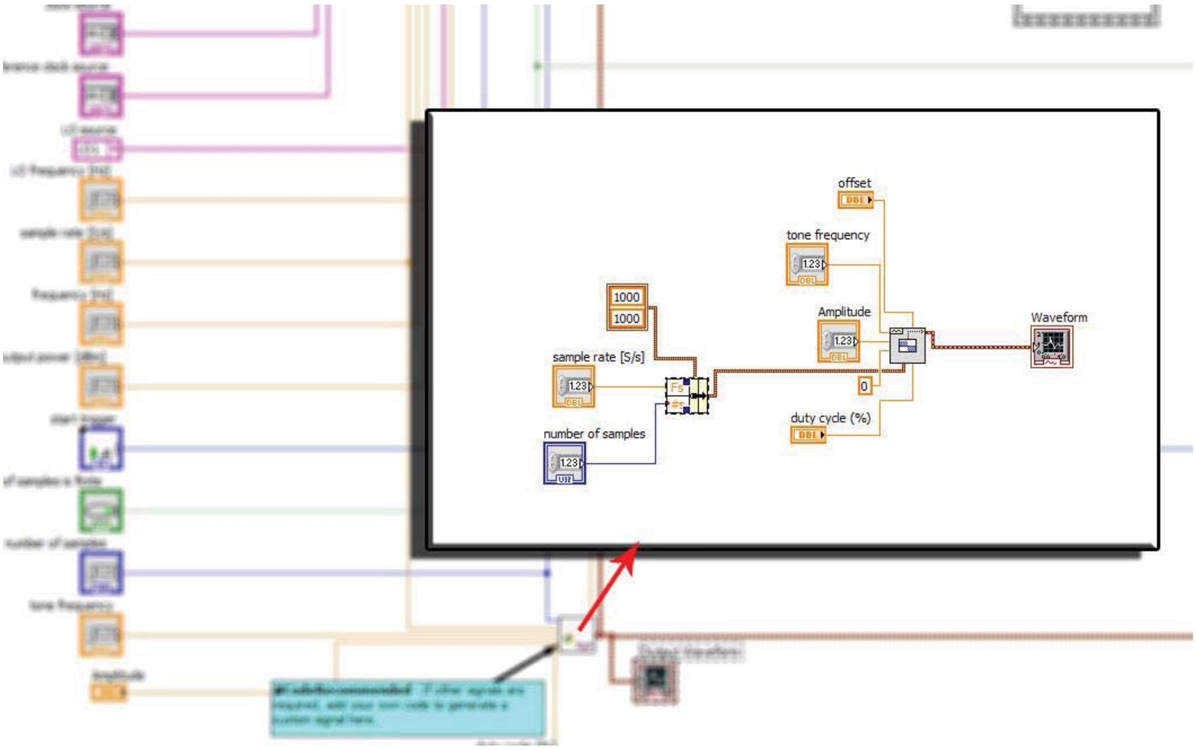

Figure 20. Shows how the modulation of the wave is created.

4.2.5 Duplexer

During the attempt to implement a duplexer, a lot of cooperation with the other group that coded the FPGA part was made. The conclusion of the cooperation and discussion was that there were two ways to implement a duplexer.

- On the host PC
- On the FPGA

It was decided that the best way to implement the duplexer was to program it as close as possible to the RF-module, on the FPGA-cards. The motivation for this was that a duplexer is very time critical and a FPGA is both closer to the RF-module and has better performance than the host computer. Unfortunately, due to a known critical bug in National Instruments driver for the FPGA-card, it was not possible to compile the FPGA code. The bug fix would not be released until after the end of the project, and due to the lack of time, no development on the PC-side was made. On the other hand, in this case, no external amplifiers were connected to transmitter and due to the low power output from the RF modules, it was possible to send and receive at the same time. If amplifiers were to be connected without implementing a duplexer, the high power output would most likely damage the sensitive receiver.

5 Conclusion

The purpose of this thesis was to investigate if it was possible to create a radar system with the given development equipment from National instruments. The thesis was successful though with some limitations. In this last chapter limitations of the system will be discussed. They will be divided into two parts, hardware limitations and software limitations. Further development and suggested area of use will also be discussed as well as environmental and ethical aspects.

5.1 Hardware limitations

The first limitation that caused problems in the development of this project was the antennas. Since the antennas aperture was too wide it gave a low power output at longer distances and bad precision. For example, a radar system that uses one antenna usually has a aperture of 1 -2 degrees, or 15 – 20 degrees; the PCB antenna used in this project had a 120 degree horizontal- and 160 degree vertical aperture [15]. Antennas with such aperture can be used as in a phased array system where it is possible to control the main lobe with phase shift.

The memory capacity did also put some limitation on the system. It is not crucial but an improved memory greatly enhances the performance.

5.2 Software limitations

Since the implementation of the duplexer was a failure the system will not be able to use an amplifier. This sets a quite low maximum range for the system as shown with the radar equation in chapter 4. Another minor software limitation is the software trigger that was used to ease the interpretation of incoming pulses. It is not an optimized solution, with a little more time and work it could be designed in a way so that the stress level on the computer was kept lower than the current solution.

5.3 Area of use

Due to the limitations of the complete system the area of use is limited. Today it could be used as a test system for educational purposes or as a platform for further development. For educational purposes the system gives a great understanding on how a radar system works and which parameters that is important for different area of use. As a platform for further development it can be used both as a platform for signal processing but also for further development for SDR Radar technology. Read more about this in 5.4.

5.4 Further improvement

If the duplexer would be implemented correctly in the FPGA, the system would be a lot easier to improve. Then it would be possible to connect amplifiers to be able to detect objects at greater distance. With the antennas connected to the system in this project, no good precision on the detected objects could be achieved due to the wide antenna aperture. One possible solution to this would be to add more antennas to achieve better precision, but that would result in adding more FPGA cards with RF-fronts, which is an expensive solution. Another solution could be to change to antennas with lower aperture and that are shielded from each other.

5.1 Environmental aspects

The environmental effect of this project is deemed to be positive in a long term perspective. Radar applications today can be very large in size and contains a lot of hardware. If it is possible to replace the components in software, there could be a positive environmental effect.

5.2 Ethical aspects

SAAB EDS is a defense and security company that provides solutions for military and civil defense. The company have signed United Nations Global Compact policy [14]. We believe that it is every country’s right to defend themselves and as long as a company follows ethical rules, we cannot see any ethical problems

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