UNIVERSITY OF OSLO
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UWB Impulse Radio for RFID

Master thesis

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Contents

1 Introduction

In recent years RFID has become more and more widespread and is being used in an ever growing number of applications. Current RFID technology does however face some difficulties in several possible new applications. A change in technology is needed and in this thesis we will examine a very promising candidate, namely Ultra wide band Impulse radio (UWB-IR). To verify the viability of this technology a test chip has been made in 90 nm CMOS[1] process.

This thesis begins with a description of RFID, its history, how it works and some of the problems the current RFID technology faces. It then moves on to describe UWB and outlines how this technology might solve some of the problems. This thesis then presents the chip constructed before the final words in the conclusion.

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[1] Complementary Metal Oxide Semiconductor

2 RFID

RFID[1] is a term used to describe various wireless identification processes. RFID devices comes in a large amount of different configurations, ranging from simple devices sending a serial number to devices with cryptographic capabilities. In this chapter we will examine RFID. Much of this chapter is based on [Shepard 05, Finkenzeller 99, Landt 01].

2.1 History of RFID

The first use of an RFID system, was the IFF[2] used during World War II. Invented by the British in 1939, the IFF was a simple identification system for airplanes. The IFF was attached to aircrafts and sent back a response to certain radar signal, identifying the aircraft as friendly.

The first work exploring RFID was the paper “Communication by Means of Reflected Power” by Harry Stockman, published in 1948. It would however take 30 years before technology was able to realise his ideas. In the meantime, a lot of research took place in the 1950s and 1960s. Some important papers include R. F. Harrington’s “Field measurements using active scatterers” and “Theory of loaded scatterers” in 1963–1964, Robert Richardson’s “Remotely activated radio frequency powered devices” in 1963, Otto Rittenback’s “Communication by radar beams” in 1969, J. H. Vogelman’s “Passive data transmission techniques utilizing radar beams” in 1968 and J. P. Vinding’s “Interrogator-responder identification system” in 1967.

The first RFID systems deployed during the early 1970s was electronic article surveillance systems used to protect stores against theft. It is the same type of systems that are used in stores today. In 1973 the first general RFID patent was granted to Mario Cardullo. But chiefly, the 1970s was characterized by developmental work.

The 1980s saw implementation and commercial deployment of RFID systems. Examples include animal tracking and toll collection, with the first commercial electronic toll collection application in Ålesund, Norway, October 1987.

In the 1990s large scale deployment of RFID begun, particularly the large roll outs of electronic toll collection systems all over the world. As technology evolved and matured, new RFID applications are mostly limited by fantasy and very little by technology.

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[1] Radio frequency identification

[2] Identification, friend or foe

2.2 The RFID device

2.2.1 Energy

An RFID device needs energy to function. How this energy is obtained is detrimental to its price, functionality, size and range. Most RFID devices are powered by energy provided by the reader, however some devices has an on-board battery. This battery can either be used to completely power the device, or it is used to boost the energy of some particularly energy demanding part of the device, usually the transmitter. It would also be possible to use solar energy or energy gathered from environmental vibrations, but this is as of yet very uncommon. In [Calhoun 05] a table of the energy potential of these different kinds of alternative energy sources is given. This table is reproduced in table 2.1.

Technology	Power Density (μW/cm^2)
Vibration — electromagnetic	4.0
Vibration — piezoelectric	500
Vibration — electrostatic	3.8
Thermoelectric (5° difference)	60
Solar — direct sunlight	3700
Solar — indoor	3.2

Table 2.1: Example Power Densities of Energy Harvesting Mechanisms

The most common method of providing power to a RFID device is by using magnetic induction. The reader and the device forms a transformer, the workings of which is well known. Although an effective method of energy transfer at short ranges, due to the high loss of magnetic signals, it is unsuitable for long range transfer of energy.

A related method of power transfer to magnetic induction more suited for long range is electromagnetic waves, usually operating at one of the unlicensed ISM[3] bands. With the increasing propagation of wireless networks and other equipment operating in the unlicensed ISM bands, using these frequencies for energy transfer can give an additional boost.

The energy is picked up by the antenna and a voltage multiplier is then used to generate a suitable operating voltage. To see how this is done, we will take a look at two voltage multipliers.

The Dickson multiplier

The most used on-chip voltage multiplier is the Dickson multiplier [Dickson 76], or a modified version of it. The basic Dickson multiplier is shown in 2.1. C_s is the parasitic capacitor associated with each node. clk and $\overline{clk}$ are in antiphase.

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[3] Industrial, scientific, and medical

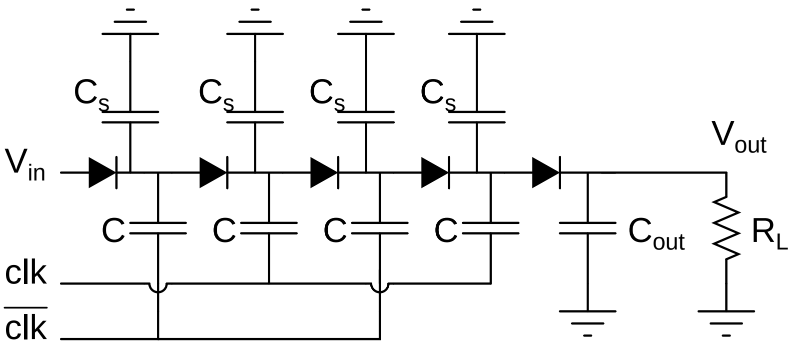

Figure 2.1: The basic Dickson multiplier, 4 stages

The multiplier works like a bucket-brigade, pumping charge from one node to the next. The voltage difference between each node is given as

$$V_\Delta = V'_{clk} - V_t - V_L \tag{2.1}$$

where V'_{clk} is the voltage gain due to capacative coupling from the clock, V_t is the diode threshold voltage and V_L is the charge and discharge voltage when the multiplier is supplying an output current I_{out}. Using capacitance division gives us

$$V'_{clk} = \frac{C}{C + C_s} \cdot V_{clk} \tag{2.2}$$

Since the total charge pumped by each diode per clock cycle is $(C + C_s)V_L$, the output current supplied by the multiplier at a frequeny f is

$$I_{out} = f(C + C_s)V_L \Rightarrow V_L = \frac{I_{out}}{(C + C_s)f} \tag{2.3}$$

Substituting, the voltage gain per stage is

$$V_\Delta = \frac{C}{C + C_s} \cdot V_{clk} - V_t - \frac{I_{out}}{(C + C_s)f} \tag{2.4}$$

For N stages we get

$$V_{out} - V_{in} = N \left[\frac{C}{C + C_s} \cdot V_{clk} - V_t - \frac{I_{out}}{(C + C_s)f} \right] \tag{2.5}$$

which gives us

$$V_{out} = V_{in} + N \left[\frac{C}{C + C_s} \cdot V_{clk} - V_t - \frac{I_{out}}{(C + C_s)f} \right] - V_t \tag{2.6}$$

The extra V_t is due to the additional diode at the output to prevent clock breakthrough.

From these equations we can see that the limiting factor is the threshold voltage of the diodes. In order for the voltage multiplier to work, we need

$$\frac{C}{C + C_s} \cdot V_{clk} - \frac{I_{out}}{(C + C_s) f} > V_t \tag{2.7}$$

In integrated circuits the diodes can be replaced by low threshold diode connected transistors. This gives us a much lower threshold voltage, which enables us to work with much smaller input voltages. However, in case we do not have a twin well process, we will get an additional body effect due to difference between source and body. This gives us an increased effective threshold voltage, thereby reducing the input span of the voltage multiplier.

NCP-2

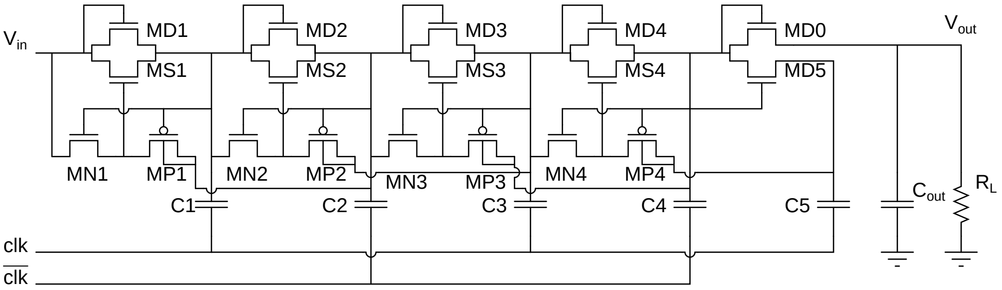

Figure 2.2: Four-stage NCP-2

In [Wu 98] an improved charge pump design is proposed using dynamic charge transfer switches. The circuit is shown in figure 2.2.

As previously explained, due to the diode connection of the transistors in the Dickson circuit, we both get a lower input voltage limit and a voltage drop over the diode connected transistors. But if we control the threshold voltage by another voltage, we can reduce these problems. This is the idea behind the NCP-2 circuit. As the transistors MS1 to MS4 is connected to a higher voltage node, we can make sure the gate to source voltage is higher than the source to drain voltage, thereby reducing the effective threshold voltage. This enables the circuit to operate at even lower input voltages.

The transistors MD1 to MD4 is included just to initialize the circuit. They work just like the diodes in the Dickson circuit, making the initial charge transfer so that the transistors MS1 to MS4 can begin to operate. The transistors MN1 to MN4 and MP1 to MP4 makes sure the transistors MS1 to MS4 is properly turned on and off as the clock turns on and off, thereby avoiding charge leakage.

2.2.2 Communication

The purpose of the RFID device is communication. Usually this is simply the transfer of an identification number or in the case of anti-theft devices the confirmation of presence. Some devices, such as smart cards used in public transport, feature more advanced communication, using cryptography to verify identity and transactions. The method of communication is often related to how the device is powered.

On most devices powered by magnetic induction, simple load modulation is used. By changing the load impedance in the device, the amount of energy drawn from the reader is changed. This leads to a change in voltage at the reader, which can be read and used as a means of communication.

The other prevalent form of communication is the use of electromagnetic waves. If the device is powered by electromagnetic waves, electromagnetic back scatter can be used to transfer information. If not using electronic back scatter, the device may use regular radio transmission. This may allow for greater range of operation of the device compared to load modulation and electromagnetic back scatter. However, as this demands quite a lot of energy, it usually requires more power than what can be delivered by the reader, thereby requiring a battery. In many devices using normal radio transmission, the main circuit is powered by battery, while the radio transmission is powered by the energy provided by the reader.

2.2.3 Multiple access

Outside of controlled test environments several RFID devices are often present in the interrogation field at the same time. This can lead to interference, which can produce devastating results if not handled properly.

Multiple access is a well known field in communication theory and there are four methods of dealing with it, SDMA[4], FDMA[5], CDMA[6] and TDMA[7].

SDMA handles multiple access by dividing up access based on spatial coordinates. This can be done by using narrow directional antennas or by using a very short range. However this method of multiple access is not well suited for RFID as the only way to guarantee spatial diversion in most RFID applications is by having only one RFID device, in which case multiple access is not required. Even the short range option may not guarantee only one device in the interrogation zone. One example is RFID smart cards used in public transport. Even though they have a very short range, there is no guarantee that you do not have several smart cards in your wallet as you sweep it past the reader.

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[4] Space division multiple access

[5] Frequency division multiple access

[6] Code division multiple access

[7] Time division multiple access

FDMA handles multiple access by giving each device its own communication frequency. This requires the reader to be able to listen on all the available frequencies, something which complicates the reader and makes it more expensive. But guaranteeing that two devices using the same frequency enters the interrogation zone at the same time is impossible, unless the total number of devices and the number of frequencies is the same or you have a very controlled environment.

CDMA handles multiple access by spreading the data in time or frequency or both using a orthogonal code, making sure that interference is minimized or constructive. This can be a viable option for some RFID applications. However the use of CDMA increases the complexity of the transponder, as it need additional logic to generate the CDMA codes. For many devices this makes them too expensive.

TDMA handles multiple access by giving each device a separate slice of time to send data. This is perhaps the most used method of multiple access for RFID devices. There are several methods that can be used to achieve TDMA communications. In reader initiated methods the reader selects RFID devices one at a time and tell them when to communicate. In transponder initiated methods the transponder picks the time to send data, possibly aided by a synchronisation signal from the reader. Usually an protocol like the Aloha is used.

2.3 Problems in current RFID implementations

For many RFID applications, the current state of RFID sufficiently covers the needs of the application. One example of this is anti theft devices, which has remained more or less unchanged since the 1970s. However some new applications is limited by the current RFID technology. The ever increasing use of RFID also entails non-technical problems concerning privacy and security. This is however out of the scope of this thesis.

Current RFID implementations with ranges of more than one meter communicate using electromagnetic narrow band communication. This requires the generation of a base band signal on which to modulate the information. This is a energy hungry endeavour which can create problems for passively powered devices. Because the amount of energy required is high, they may need to use a long time to gather enough energy for communication. In addition destructive interference is highly likely when several devices communicate at the same time. This also increases the time needed to transfer information.

One possible RFID application where this is very problematic is the automatic registration of merchandise as the customer walks through the cash register. The high time needed means that the possibility of items not being registered increases. This is totally unacceptable for this application as the business will loose a significant amount of money.

In the next chapter we will examine an alternative communication method, UWB-IR, which offer a solution to these problems, as well as opening up for new possibilities.

3 Ultra wide band

Traditional electromagnetic communication has used a narrow band carrier based signal to send information. However, in February 2002 the FCC[1] opened up the band from 3.1 GHz to 10.6 GHz for unlicensed Ultra wide band (UWB) communication. Traditionally UWB[2] refers to what is now called UWB-IR[3]. UWB now has been redefined to include all communication using a minimum of 500 MHz band width.

Unlike traditional base band communication, in UWB-IR information is sent using very short pulses in time, which occupy a large bandwidth. The shorter the duration of the pulse is, the larger the bandwidth. This usage of short pulses instead of traditional carrier based communication means simpler and more efficient circuits can be used.

Much of the information in this chapter is based on [Oppermann 04, Siwiak 04, Rappaport 01].

3.1 The regulations

The 3.1 GHz to 10.6 GHz band is already populated by several applications and the use of this band for UWB would therefore seem a strange choice. However the intended use is for short range devices which can and must send with such low power as to avoid interference for existing applications. The regulations is given as the maximum EIRP[4] per MHz and is split in two, one set for indoor applications and one for hand held applications. The FCC regulations as defined in [FCC 02] is shown in table 3.1.

Frequency	Indoor EIRP (dBm/MHz)	Hand held EIRP (dBm/MHz)
960 MHz – 1.610 GHz	-75.3	-75.3
1.610 GHz – 1.990 GHz	-53.3	-63.3
1.990 GHz – 3.1 GHz	-53.3	-63.3
3.1 GHz – 10.6 GHz	-41.3	-41.3
Above 10.6 GHz	-51.3	-61.3

Table 3.1: FCC UWB regulations

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[1] The Federal Communications Commission

[2] Ultra wide band

[3] Impulse radio

[4] Effective Isotropic Radiated Power

The FCC only has mandate in the United States of America and these regulations therefore only applies there. In Europe the regulation process is more complicated as ETSI[5] does not have the mandate to define regulations. They can only recommend and propose, but it is up to the regulatory authorities in each country to set regulations. An unified UWB regulation has as of yet not been set in Europe, but it is expected that European regulations will be very close to the FCC regulations.

3.2 Channel capacity

The theoretical maximum information rate of an analog communication channel is given by the Shannon–Hartley theorem. For a channel subject to only additive, white noise this is given by

$$C = BW \cdot \log_2 \left(\frac{S + N}{N} \right) \tag{3.1}$$

where C is the channel capacity in bits per second, BW is the bandwidth of the channel, S is the total signal power over the bandwidth and N is the total noise power over the bandwidth. For a channel where the noise is not white, the more generalized equation is

$$C = \int_0^{BW} \log_2 \left(\frac{S(f) + N(f)}{N(f)} \right) df \tag{3.2}$$

From these equations we see that what most influence the channel capacity is the bandwidth. The capacity has a linear relationship with the bandwidth, whereas only logarithmic with regard to the SNR[6]. This means that even though we have a relatively low SNR in UWB because of the low effect demanded by regulations, the very high bandwidth gives us a very high channel capacity.

3.2.1 Signal to noise ratio factors

The SNR is, as the name implies, dependant upon two factors, the received signal and the received noise. The received signal is dependant upon the following factors

Transmitted power The signal received can of course not be greater than what is sent out.

Antenna gains The antenna gain in the transmitter and the receiver determines how much of the power sent to the transmitter antenna can be received by the receiver antenna. Higher gain means more power, but this comes at the expense of reducing directionality.

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[5] European technical telecommunications administration

[6] Signal to noise ratio

Path loss The transmitted energy is not concentrated in a infinitely thin ray beamed directly to the receiver, but is spread over an increasing area as distance increases. The received power is therefore inversely proportional to the distance. Additionally the signal often needs to take detours to reach its destination. These detours includes traveling through objects, reflecting off objects and scattering.

The noise is also dependant upon several factors

Thermal noise Thermal noise is a constant background noise dependant upon bandwidth and the temperature.

Multipath interference The signal often can take several different paths to reach its target. These signal copies arrives at different times dependant of the distance they need to travel. Often these multiple copies is unwanted an increases the noise level. However, in UWB-IR these additional copies can be used constructively, increasing SNR instead of reducing it.

Multiple access The simultaneous use of the channel by several different applications decreases SNR. This is perhaps the most important noise source and will be treated in more detail in the next section.

3.2.2 Multiple access

Very seldom exclusive access is given to a communication channel and the channel capacity must be shared, which of course reduces the channel capacity for each user. Normally this problem is alleviated by the fact that all the users are coordinated, like for instance in cellular phone networks. In an unlicensed band like the UWB band there is no regulations of protocol and modulation in the band, and each application may use what it deems appropriate. This makes the use of FDMA, TDMA and CDMA impossible on an application independent scale.

However, since the UWB band is intended to be used by short range devices, something which is clear from the low transmitting power allowed in the regulations, the multiple access problem is greatly alleviated. This short range effectively makes the UWB band a SDMA system, at least for high speed devices. In order to get the SNR needed for high speed communication, distance between the communicating devices need to be short. But low speed devices like RFID devices do not need a high SNR and by lowering the speed greater distance can be achieved.

This might seem a contradiction. By increasing range in RFID devices, the SDMA properties is lost and multiple access seems problematic. There are three tings that alleviates this problem.

Firstly, low speed requirements means that the number of pulses each device needs to send is also low. The reduced number of pulses sent by each device significantly reduces the probability of collision. In RFID the speed requirements is often no more than a few hundred bytes per second.

Secondly, in UWB-IR fading is a constructive property. The receiver uses the multipath copies of a signal to boost reception of the pulses. So even if a pulse is lost, the probability of other multipath copies reaching the receiver is still high.

Thirdly, the use of pseudo random sequences makes the UWB-IR behave as a TDMA system. If we sent a sequence of pulses spaced equally apart with a time t_d, this would cause a spike in the power specter at $\frac{1}{t_d}$ which would violate the regulations as the energy is no longer equally distributed over the UWB band. This means that the pulses need to be sent spaced by a random sequence of delays. By doing this the pulse train creates a pseudo noise signal, appearing in the specter as white noise. As the pulses must be spaced unevenly in time, the probability of to pulses from two different devices colliding is therefore very low as long as the number of pulses to be sent is low. But as the number of pulses goes up, so to does the collision probability. This means that the low speed UWB-IR devices works as an unsynchronized TDMA system, efficiently sharing the capacity of the UWB band.

3.3 Pulse shapes

Selecting a proper pulse shape is of great importance to UWB-IR. By using the appropriate shape better efficiency and lower energy usage can be achieved.

There are three methods of generating an UWB-IR pulse. A simple short pulse, like a square pulse, spanning the entire frequency range from zero to 10.6 GHz or more can be used. This pulse is then high pass or band pass filtered to make it fit the UWB regulations.

The second method is to generate a pulse with the desired bandwidth and then shift it up in frequency to fit the regulations.

The third option is to generate a pulse that is shaped such that it fits the regulations.

Obviously the first two options are less attractive as they waste energy in the filter and on creating the frequency shifting. Frequency shifting involves multiplying the signal with a sinus wave. This requires a high frequency oscillator which complicates the circuit and requires a lot of energy. Creating a pulse that is shaped to fit the regulations may however also need complicated circuitry and may therefore be less suited.

Even though energy is wasted in a low pass filter, using a square signal is an attractive option. Creating a square pulse requires no more than an inverter. But if we look at the Fourier transform of the square pulse which is

$$\frac{1}{|\tau_p|} \operatorname{sinc}\left(\tau_p f\right) \tag{3.3}$$

we see that this is the sinc functions. The sinc function has very high sidelobes, which means that much of the energy in the pulse is wasted. In figure 3.1 the specter of an 100 ps square pulse is shown to illustrate this.

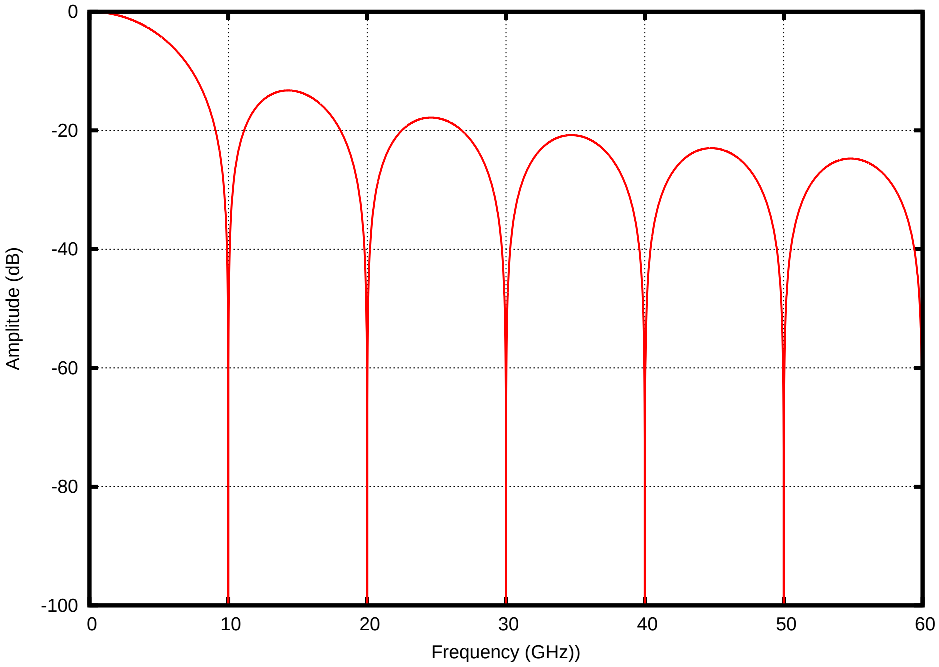

Figure 3.1: The specter of a 100 ps square pulse

So, what pulse shape should we use to create a pulse that fits the regulations? The by far most popular pulses is a derivative of the Gaussian pulse

$$p(t) = e^{-2\pi \frac{t}{\tau_p}} \tag{3.4}$$

where τ_p is the pulse length. In figure 3.2 the second, fourth, sixth and eight order Gaussian pulses is shown in addition to their spectral properties.

As can be seen in the figure, these pulse shapes have suitable spectral shapes. In addition to this, they are also easily detectable, which means simple circuitry can be used in the receiver. In the next chapter we will see how they can be generated by very simple circuits.

In [Hu 05] the Gaussian pulse is compared to two other pulse shapes, pulses based on PS functions and modified HP pulse. The Gaussian pulses were found to hold up to these more advanced pulse shapes in spectral properties, but the Gaussian pulses are much easier to generate, requireing just a simple circuit. A Gaussian pulse therefore seems to be a good design choice for UWB-IR devices.

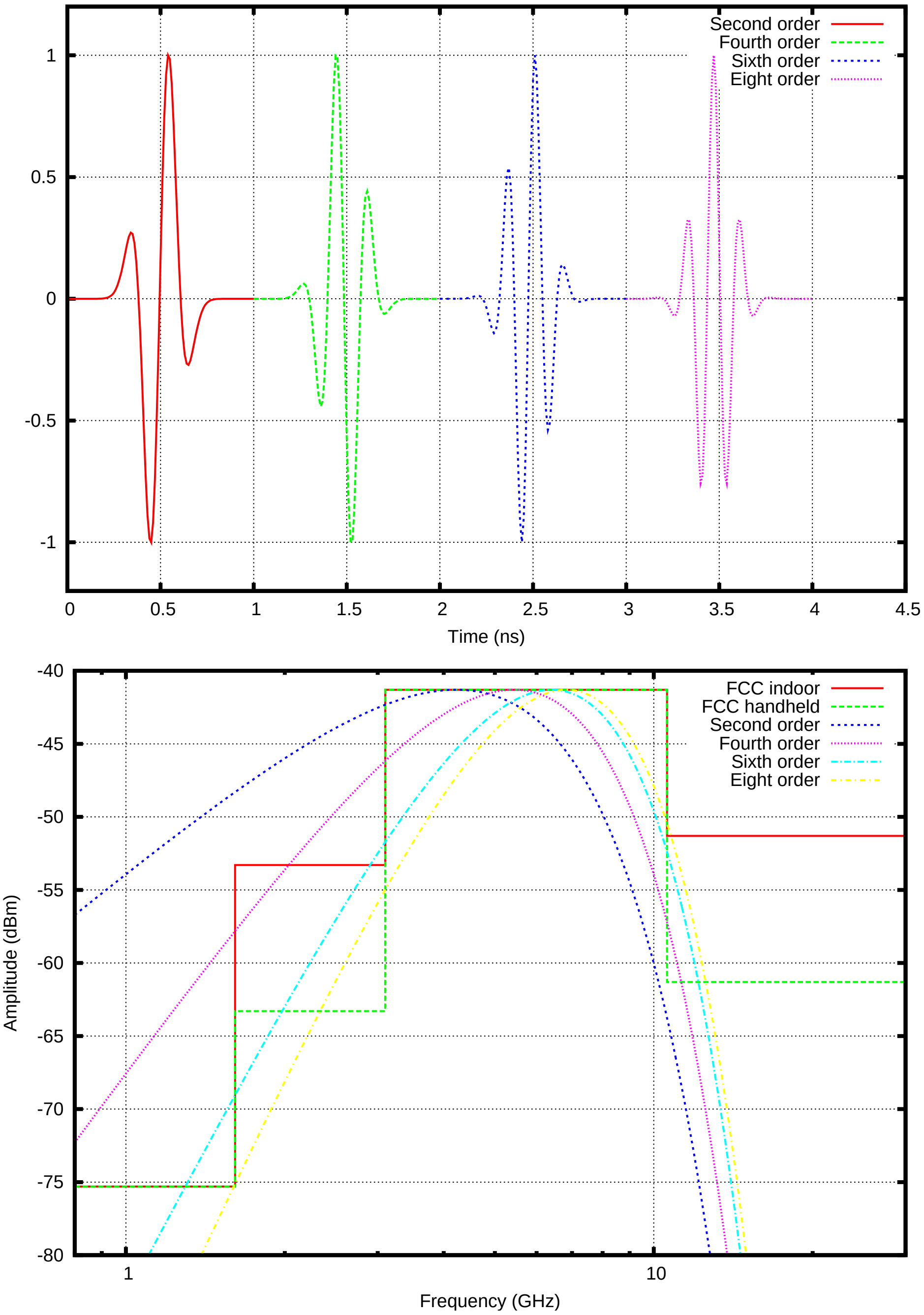

Figure 3.2: The Gaussian pulses

3.4 What UWB-IR can contribute to RFID

As already mentioned, the usage of UWB-IR significantly reduces collision problems when several devices try to send information at the same time. This means that the time required to transfer information is significantly reduced, allowing for higher device densities. In addition, the usage of pulses instead of base band communication means lower energy requirements. The effect of this is that the time needed to transfer information is reduced, as well as increasing operating distance.

UWB-IR also offers new possibilities. The very short pulses gives us a high spatial resolution. This means that simple trackers can be made with no modification to the transponders. Some possible usages of this is the ability to locate merchandise in a store or warehouse or a simple device to help find lost keys.

4 Pulse generator

This chapter describes the design of a UWB-IR pulse generator suitable for small, cheap and remotely powered RFID devices. One of the key usages for this type of device is in merchandise as a replacement for bar codes. This means we have the following design requirements:

Low power consumption Given that these devices will be given power remotely by the reader, power consumption is a key factor. Lower power consumption means longer range and less sensitivity to spatial placement relative to the reader.

Small and simple circuitry The smaller and simpler the circuit is, the less power it consumes and the cheaper it gets. The price is especially important if these devices are to replace bar codes.

Use of standard CMOS process Using standard CMOS is important to price as CMOS is a well developed and cheap manufacturing process. By also using only standard components the devices can be manufactured at any plant which also drives prices down.

Given these requirements, we were able to find an article, [Marsden 03], that described a programmable CMOS Gaussian pulse generator which seemed to provide a good starting point for our generator construction. The main circuit of this programmable generator is depicted in figure 4.1. This circuit consists of four transistors, A to D, one inductor and one capacitor. By turning the four transistors, A to D, on and off in different sequences, the common node is pulled up and down, which creates the Gaussian pulses. The pulse generator is capable of generating both positive and negative first and second order Gaussian pulses.

4.1 Modified generator

The programmability of the pulse generator came at a cost, namely that it required a big and complex state machine. For our purpose however, the ability to generate more than one type of pulse was not necessary and we could simplify the pulse generator. We went for creating a pulse generator able to generate the second order Gaussian pulse. This gives a good compromise between circuit complexity and spectral power distribution.

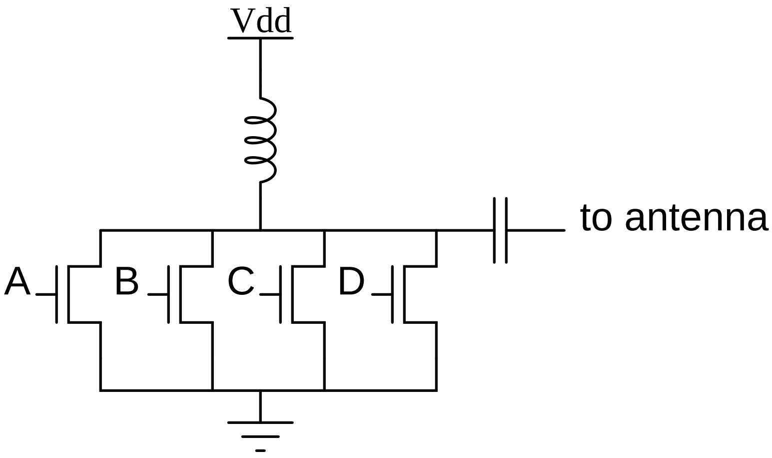

Figure 4.1: Original pulse generator

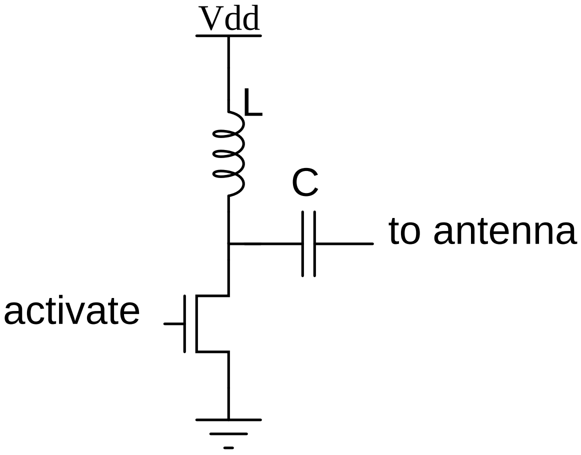

Figure 4.2: Modified pulse generator

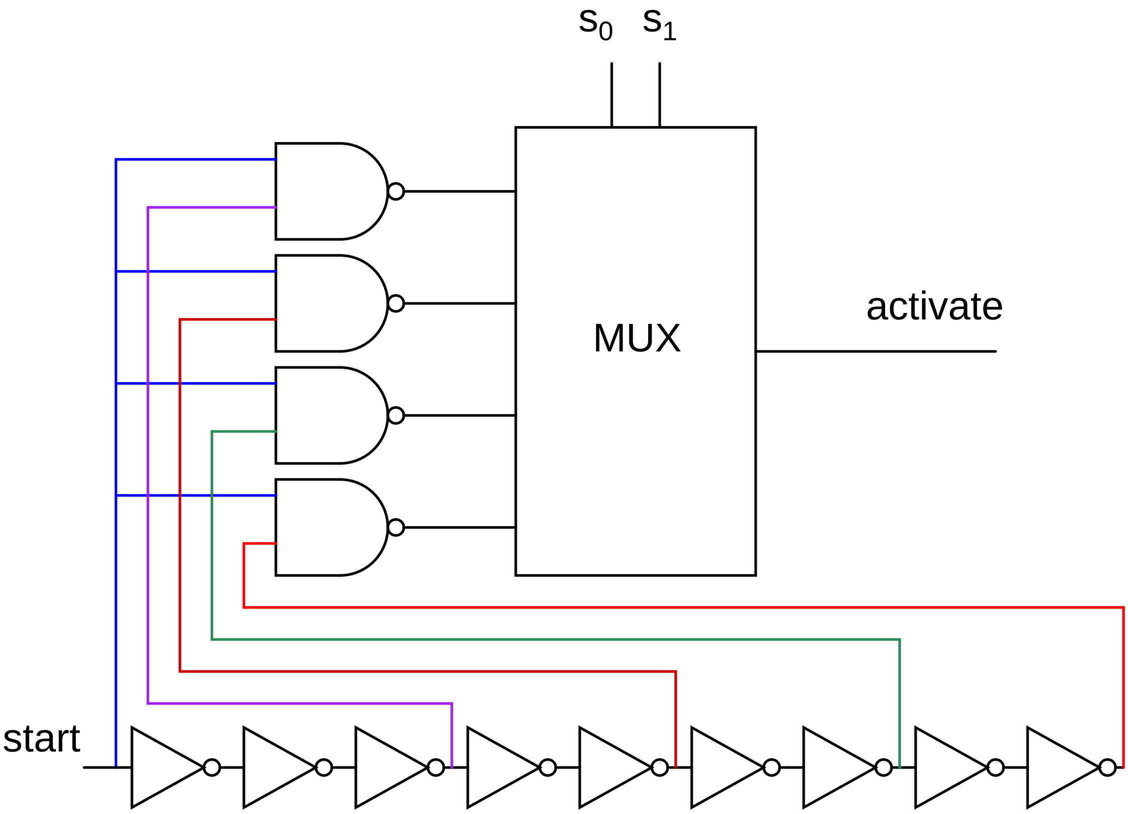

Figure 4.3: Pulse width controller

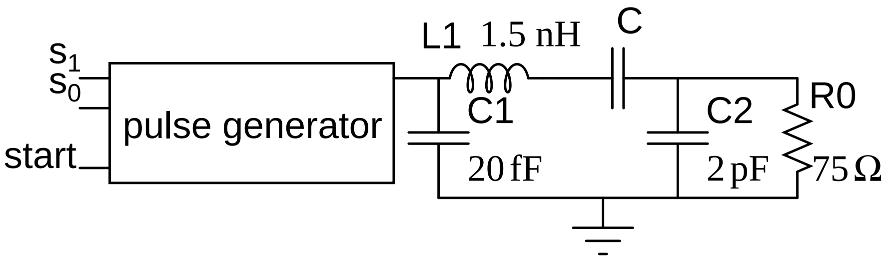

Figure 4.4: Test bench

If we take a closer look at the shape of the second order Gaussian pulse, we see that it resembles the ringing of a LC-configuration. In the original design there is such an LC-configuration, where the inductor is used as a bleeder and RF-choke, while the capacitor is used as a DC-block and high pass filter. By carefully tuning the inductor and capacitor as to avoid oscillations, we might be able to use this LC-configuration to reduce the circuit down to one transistor as shown in figure 4.2.

Initial simulation verified the viability of this solution.

4.1.1 Pulse width controller

The spectral width of the Gaussian pulses are proportional with the length of the pulses and as the width, and as the frequency width increases so to does the center frequency. This means the length of the pulse is a very important characteristic and we need to create a mean to control it. The length of the pulse is determined by the time the transistor is turned on or the time it is turned off for reversed polarity. We therefore need to make sure the gate voltage of the transistor is properly controlled. For this reason a simple control circuit was designed. This circuit is shown in figure 4.3.

The signal generator is made up of an delay line made of an odd number of inverters and a NAND-port. In the off state the first input to the NAND is 0 and the second input is 1. This means the output of the NAND is 1, the transistor is turned on and the output voltage is 0. To generate the Gaussian pulse the start signal goes to 1. When this voltage crosses the switching point of the first inverter, the inputs to the NAND is both 1 and the transistor is turned off. The output is going up towards the supply voltage. The rise time of the start signal is unimportant as the only parameter that matters is that the voltage crosses the switching point of the inverter. The inputs to the NAND is both 1 until the signal switch has propagated down the delay line. When this happens, the inputs to the NAND is 1 and 0, meaning the transistor is turned on again and the output voltage goes to 0 again. It now does not matter how long the start signal is kept at 1, or the delay of the fall down to 0, as the NAND-input will not be 11 before the start signal has returned to zero and is then risen to 1 again. The delay in the NAND-port is of no significance, as this will just be relative to the delay line transitions and the width of the pulse is purely controlled by the delay in the delay line.

As this is such a simple design, we added three more delays and a MUX so that we could select between four different delays to measure the impact on the Gaussian pulse. For the delay line we used minimum inverters, with the number of inverters 3, 5, 7 and 9 respectively. The delay of just one inverter would have been to short for the transistor, therefore the shortest delay is 3 inverters. The different delays is shown in table 4.1. Unfortunately, the design kit did not allow extraction, so we were unable to measure the delay on the layout. Therefore only the schematic delay is shown.

Number of inverters	Delay
3	41 ps
5	73 ps
7	104 ps
9	132 ps

Table 4.1: Delay line measurement

4.1.2 Sizing of the elements

The largest hurdle when sizing the elements was the inductor. Our process kit does not have support for creating on-chip inductors nor does it have the ability to extract a drawn inductor and simulate on it. We found a free program to help us with our efforts, namely Asitic from Berkeley (`http://rfic.eecs.berkeley.edu/~niknejad/asitic.html`). Using this we were able to create inductors, but as mentioned we could not simulate on it. This meant we that we had to use ideal inductors in our simulations.

The inductor and capacitor forms a LC-configuration which has a resonance frequency of

$$\frac{1}{2\pi\sqrt{LC}} \tag{4.1}$$

which should be at 6.85 GHz, the center frequency of the UWB band.

The regulations gives the maximum EIRP as -41.3 dBm/MHz, which means that the pulses should be at approximately 500 mV peak to peak. To provide this voltage while at the same time being fast enough, the transistor was sized at a length of 90 nm and a width of 20 µm.

These parameters gave us some rough estimates at which we could find appropriate values to use for simulations. Tuning by means of simulation we ended up using a square inductor at 5.5 nH measuring 100 µm times 100 µm using 6 metal layers. The capacitor was set at 155 fF. This gives us a resonance frequency of 5.45 GHz.

We decided to make the capacitor external in order to have an extra tuning parameter during measurements.

4.1.3 Test bench

The test bench is shown in figure 4.4. The inductor L1 represents parasitic inductance in the bonding wire, the capacitor C1 parasitic capacitance in the pad, the capacitor C2 parasitic capacitance due to the package and soldering and finally the resistor R0 represents the antenna. As mentioned, we decided that the capacitor of the pulse generator, as shown in figure 4.2, was to be put outside of the chip in order to have an extra tuning parameter during measurements. This capacitor is the capacitor labeled C in the testbench.

4.2 Simulation

In figure 4.5 the schematic simulation results can be seen. The pulses resemble the Gaussian pulse shown in figure 3.2 as expected. The length of the pulses are however longer than anticipated, closing in to 400 ps. The main cause of this problem seems to be that the transistor is struggling to keep up with the speeds required. This can clearly be seen by the lower amplitude and actually somewhat longer duration of the 3 inverter delay pulse. The consistency of the other pulses implies that this is at the edge of what the transistor is capable of handling. The constructive usage of ringing can be clearly seen in the 9 inverter delay pulse, which is very close to oscillating. The amplitude of the pulses must be said to be very good, almost 200 mV, especially considering that the pulse transistor is connected directly to the antenna through the capacitor without buffering. The peak frequency of the pulses is close to the resonance frequency at 5.45 GHz.

Due to the lengthening of the pulse widths, the pulses are placed lower in the frequency spectrum than they should be, but all the pulses do have their lower -20 dB point at approximately 1 GHz. The band width of the pulses are however satisfactory. Due to the extra amount of ringing in the two longest pulses, they have varying degrees of upper side lobes. This is however probably alleviated when the added parasitic effects of the layout comes into play.

When looking at the layout simulation in figure 4.6, the circuit still holds up faced with the extra parasitics added to the simulation, except for the 9 inverter delay pulse which started oscillating and has therefore been left out of the plots. The peak frequency also has fallen somewhat.

The ringing is more dampened due to the extra parasitics and the pulses resembles the Gaussian pulse very much. As predicted, the parasitics also reduces the upper side lobes in the frequency specter.

4.3 Measurements

A very simple PCB[1] test board was made and the pulse generator was connected to a high frequency oscilloscope through a SMA[2] connector. A 0.5 pF capacitor was used, as we were unable to get smaller capacitors.

When looking at the measurements depicted in figure 4.7, the circuit seems to work very well. The amplitude of the pulses are actually higher than predicted by simulations, slightly more than 300 mV. The downside is that the pulses are slower than anticipated by the simulations. This can clearly be seen by the reduced bandwidth. Once again we se that the transistor is struggling to deliver the shortest pulses, as seen by the reduced amplitude. The lower -20 dB point is also lower in frequency as a result of the increased pulse length.

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[1] Printed Circuit Board

[2] SubMiniature version A

Due to the larger capacitor, the resonance frequency should be at 3 GHz. The peak frequency in the measurements is close to this.

The power consumption of the pulse generator was measured to be 0.45 pW/Hz of pulses sent, meaning that this number needs to be multiplied by the number of pulses sent per second to get the effect used.

Using two bowtie antennas we also measured the pulse when sent between two antennas. The pulse output was directly connected to one of the antennas, while the recieving antenna was connected to the oscilliscope through a 15 dB LNA[3]. The measurements is shown in figure 4.8. The pulses have switched polarity, but this is as anticipated as the antenna to antenna transfer derives the signal. What is interesting is that even connected directly to an antenna without any buffering, the pulse generator still holds up. The spectral properties are about the same, although the edges are a bit steeper because of the higher order of the received pulse.

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[3] Low noise amplifier

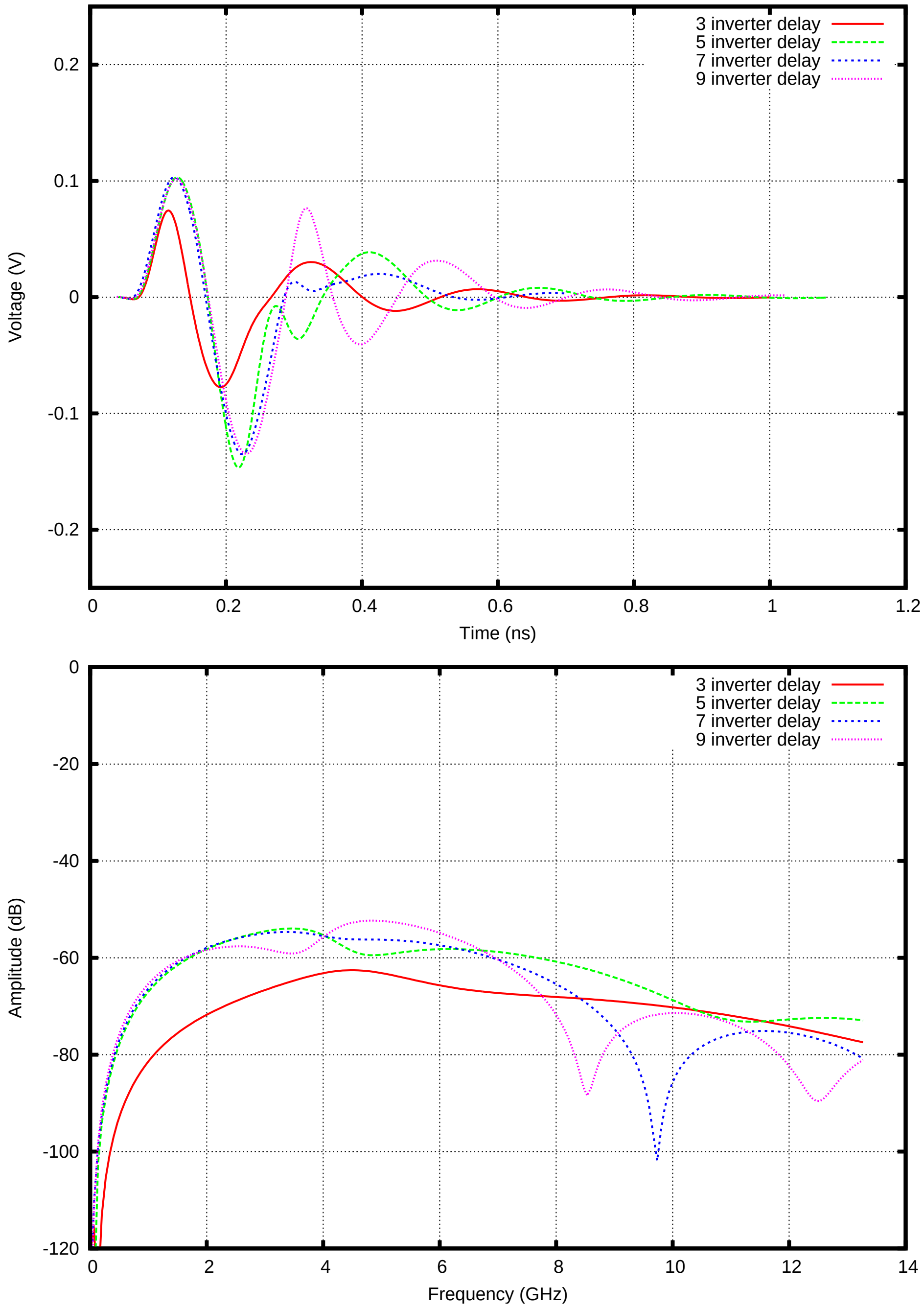

Figure 4.5: Schematic simulation

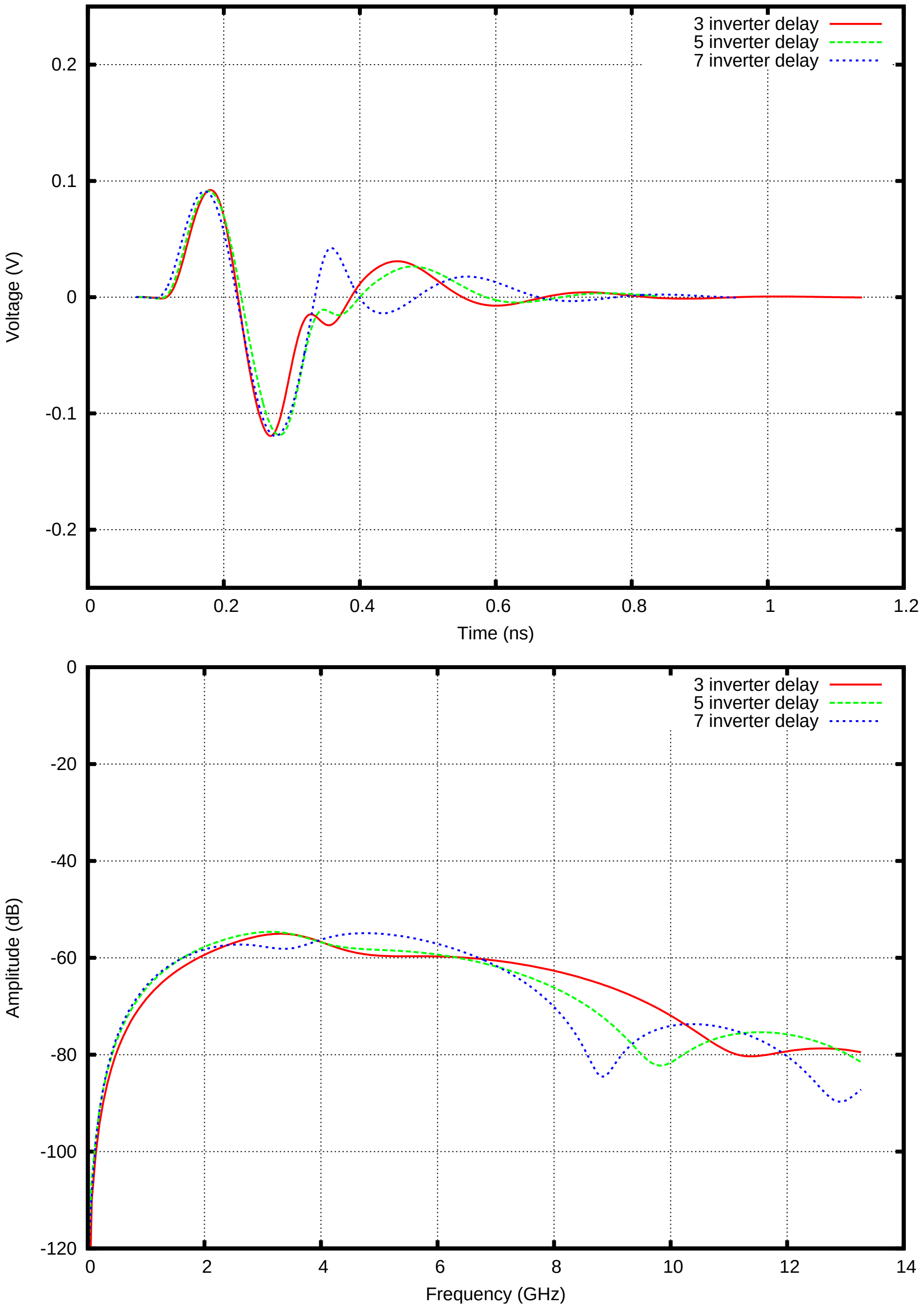

Figure 4.6: Layout simulation

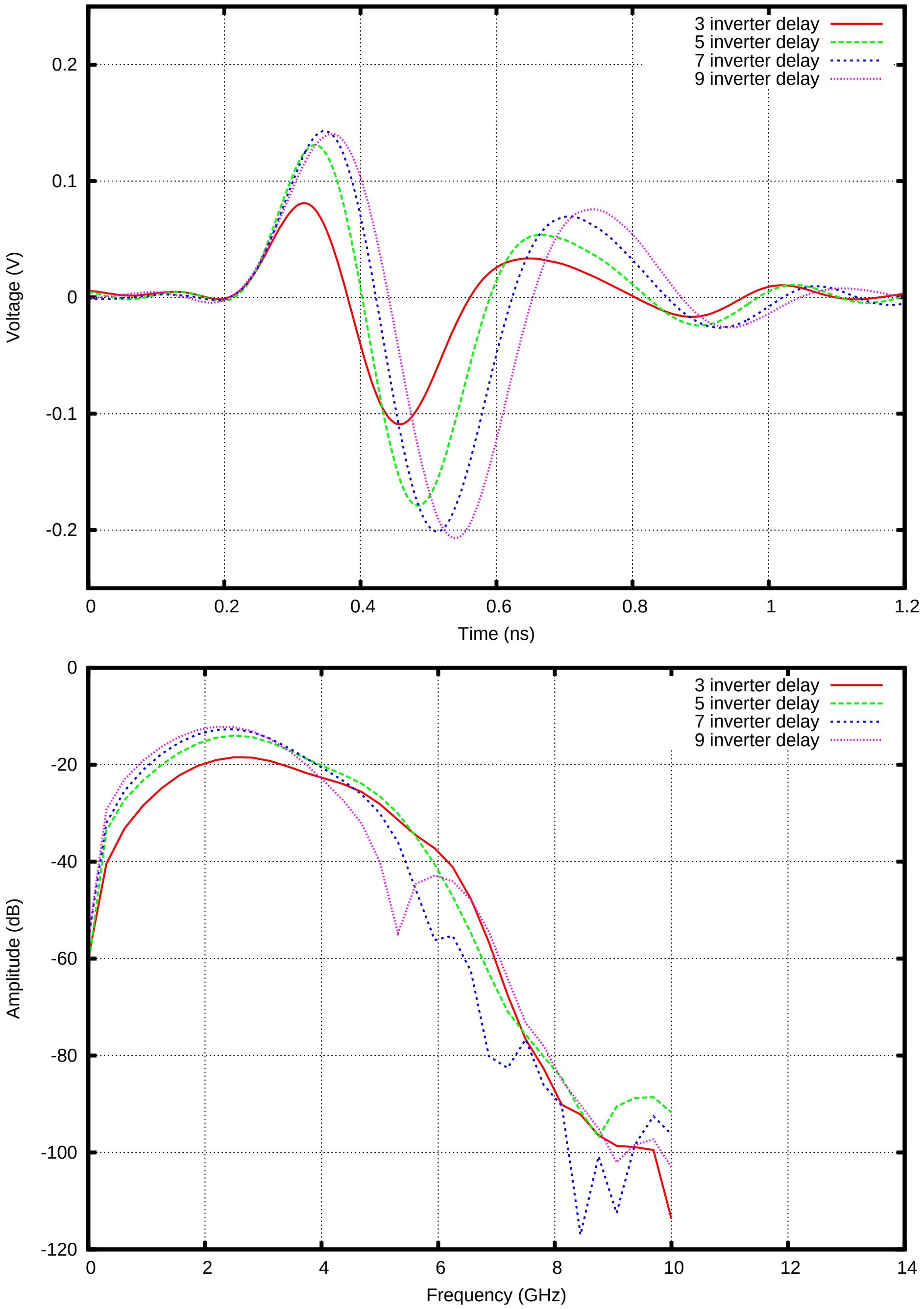

Figure 4.7: Measured pulse

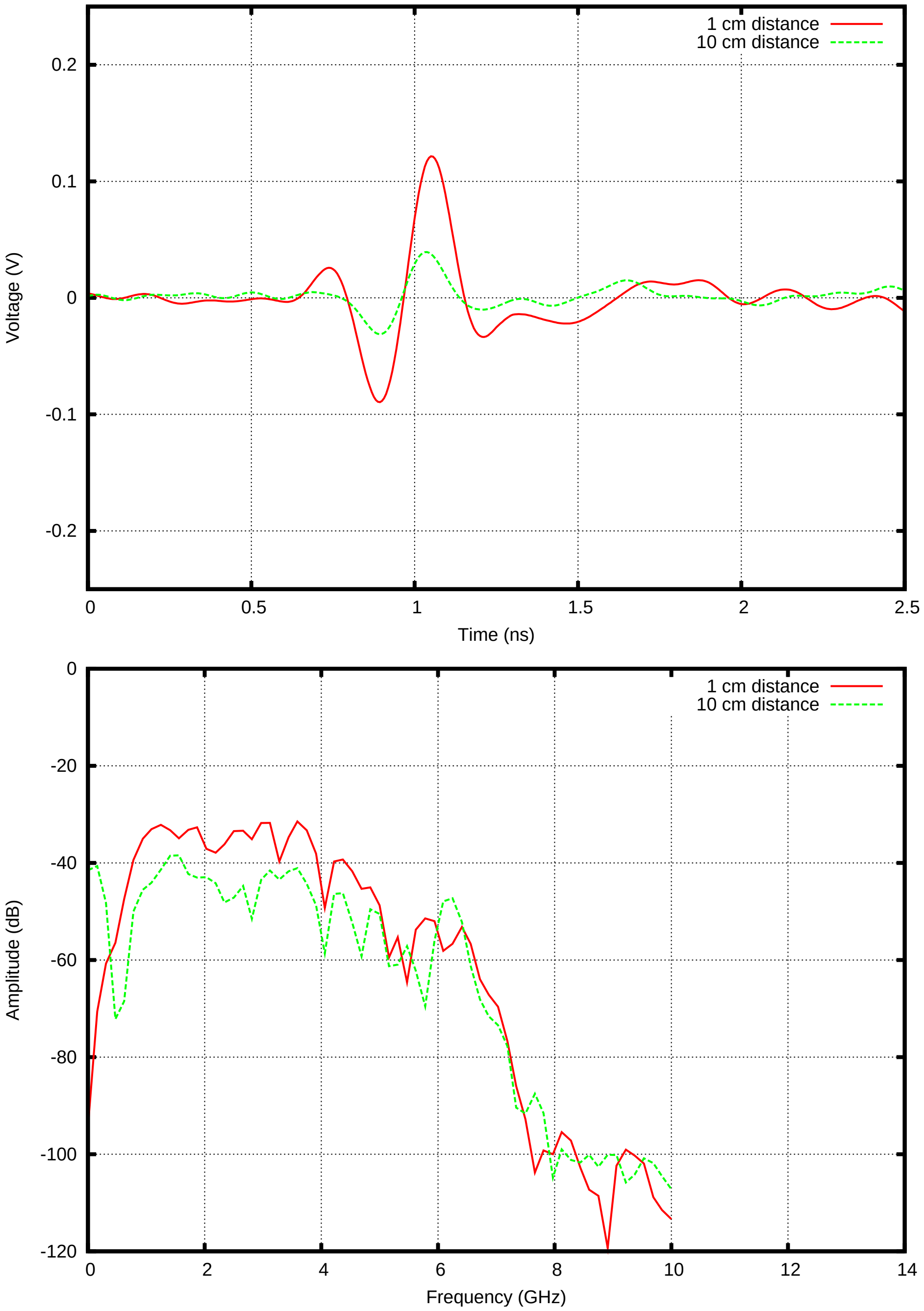

Figure 4.8: Measured pulse via antenna

5 Conclusion

During this thesis we have examined RFID and seen some of the problems the current RFID technology faces. We have then looked at the UWB-IR and seen how this technology can solve the problems outlined. To demonstrate the viability of this solution, a test chip was designed and manufactured in a 90 nm CMOS process which implemented a simple and energy efficient pulse generator. The pulse generator was shown to work satisfactory. The pulse generator was also used in a radar implementation on the same chip as described in [Hjortland 06]. There it functioned very well, adding to the viability of the pulse generator.

Even though the generator worked well, it does have improvement potential. The spectral power density of the pulse should have been shifted a bit upwards in frequency, thus complying completely with FCC regulations. It would also be interesting to design and test higher order Gaussian pulse generators and see how they perform.

This thesis only covers the actual physical information transportation mechanism. Further work would look at the proper modulation and multiple access parameters for a complete RFID transponder. More research into energy gathering would also be needed.

Acronyms

CDMA	Code division multiple access
CMOS	Complementary Metal Oxide Semiconductor
EIRP	Effective Isotropic Radiated Power
ETSI	European technical telecommunications administration
FCC	The Federal Communications Commission. FCC[1] is an independent United States government agency, directly responsible to Congress. The FCC was established by the Communications Act of 1934 and is charged with regulating interstate and international communications by radio, television, wire, satellite and cable. The FCC's jurisdiction covers the 50 states, the District of Columbia, and U.S. possessions.
FDMA	Frequency division multiple access
IFF	Identification, friend or foe
IR	Impulse radio
ISM	Industrial, scientific, and medical
LNA	Low noise amplifier
PCB	Printed Circuit Board
RFID	Radio frequency identification
SDMA	Space division multiple access
SMA	SubMiniature version A
SNR	Signal to noise ratio
TDMA	Time division multiple access
UWB	Ultra wide band

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[1] The Federal Communications Commission

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