Examensarbete

LITH-ITN-ED-EX--03/002--SE

Design of a transmitter for Ultra Wideband Radio

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Titel
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Sammanfattning
Abstract

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The major difference with UWB compared to other RF systems is that UWB sends information with pulses instead of using a carrier wave. The technique is from the nineteenth century and was first developed by Heinrich Hertz (1857-1894), which led to transatlantic communications 1901.

This Master thesis presents a proposal of a transmitter for Ultra Wideband Radio using multiple bands. The proposed transmitter is implemented on system level in Simulink, Matlab. The frequency generation in the transmitter is also implemented at component level in a 0.13 um IBM process. The thesis begins with an introduction of UWB theory and techniques.

Nyckelord
Keyword

UWB, Ultra Wideband Radio, Transmitter, Multiple bands, RF, pulses, Frequency generation

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Ultra Wideband Radio (UWB) is an upcoming alternative for wireless communications. Since the Federal Communication Commission in the USA allowed UWB for unlicensed usage in April 2002, more and more companies have started developing UWB systems.

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I would especially like to thank my supervisor Pär Svalänge at Bluechip IC Design AB for all the technical ideas and knowledge he has given me. I am also grateful to my examiner Shaofang Gong at the University of Linköping, Campus Norrköping for support. I would also like to thank the rest of the staff at Bluechip for technical knowledge and support.

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List of Abbreviations

BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
CF	Center Frequency
DFT	Discrete Fourier Transform
DTC	Divide by Two Circuit
EIRP	Effective Isotropic Radiated Power
FCC	Federal Communication Commission
IEEE	Institute of Electrical and Electronics Engineers
IM	Inter Modulation
PRF	Pulse Repetition Frequency
RF	Radio Frequency
UMTS	Universal Mobile Telecommunication System
USB	Universal Serial Bus
UWB	Ultra Wideband Radio
VCO	Voltage Controlled Oscillator
WPAN	Wireless Personal Area Network

1 Introduction

Background

The need for speed, mobility and flexibility in electronic media products has increased the interest in wireless alternatives. In April 2002, the federal communication commission (FCC) allowed unlicensed use of an old technique for communication. Heinrich Hertz and Marconi developed the first transceiver in the late nineteenth century before the carrier wave was invented. Today it is called Ultra Wideband Radio (UWB) and send information with pulses instead of the commonly used carrier wave. UWB has for many years been used in radar systems and in army communication but has not been allowed on the open market before 2002. The advantage with UWB is its potential to send high data rates (480 Mbps) over short distances making it favourable in e.g. wireless personal area network (WPAN) systems.

Task

The task of this master thesis was to develop a transmitter for UWB. The work started with an analysis on UWB and existing UWB systems. Then a transmitter on system level should be designed in appropriate software thereby finding the bottlenecks of the system and finally designing a crucial part of the transmitter at component level.

Outline of the report

The report begins with an overview of UWB with two different pulse techniques used in existing UWB designs. Then a proposal for a UWB transmitter is developed on system level and finally, a part of the transmitter is designed at component level. Considerations for the receiver are not accounted for in this thesis.

2 Ultra Wideband Radio

UWB differ significantly from other wireless communication standards. UWB systems, here after called UWB, send series of pulses instead of using a carrier wave. The pulse can be seen as an intense burst of RF energy where each pulse carries one symbol of information. In contrast to a carrier wave, which has narrow bandwidth, the pulses have large bandwidth, giving the system potential for high data rates. Another advantage is that UWB can operate simultaneously with other RF products in the same frequency band. This gives UWB several areas of operation, e.g. in imaging systems, vehicular radar systems and communication and measurement systems. A drawback when operating in the same frequency bands as other systems is that the pulses must be adapted not to disturb these systems.

Since the FCC passed a proposal concerning unlicensed usage of UWB, several companies started developing and manufacturing products in the areas mentioned above. Notice that no standard has been set, but for product compatibility, several parties are cooperating to develop one, e.g., the IEEE 802.15 working group.

2.1 Theory and Techniques

As mentioned before, UWB send information through pulses. The pulses are sent one by one, after each other with a given pulse repetition frequency (PRF). The pulses have large bandwidth, which means that the energy of a pulse is spread over a wide frequency band whereas a carrier wave system concentrates the energy on a specific frequency. Comparing these two alternatives, it can be seen that a pulse based system can have a lower average output power per MHz than a carrier wave based system and hence does not disturb the carrier wave under simultaneous operation.

The pulses can be created in different ways and have different characteristics. The Gaussian pulse (Appendix I), which has a relative pulse width and the Hermite based pulses (Appendix II), which are based on polynomials are two alternatives for UWB pulses. The first order Hermite based pulse and the Gaussian monocycle are the same, Figure 1.

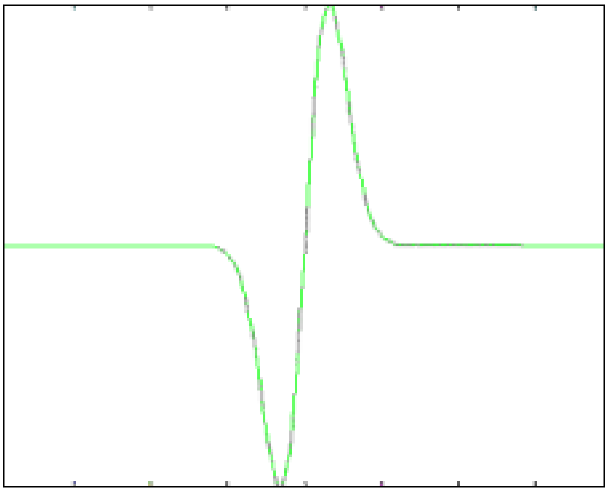


Figure 1. A Gaussian monocycle and a first order Hermite based pulse

Increasing the order of the Hermite polynomial and the number of cycles in the Gaussian, the pulses begin to differ. While maintaining the same pulse width for both pulses, the amplitude is modulated differently and the Hermite does not sustain a consistent center frequency, Figure 2. Due to the mentioned differences of the pulses, the Gaussian pulse is more attractive for UWB use.

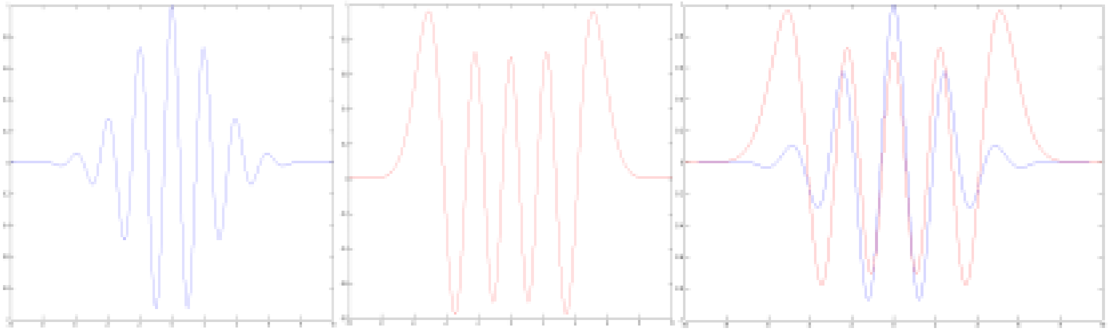


Figure 2. A Gaussian pulse, an eight order Hermite polynomial and the two pulses overlapped.

The relationship, pulse width versus bandwidth is displayed in Figure 3. Notice that the center frequency sets the position of the pulse in the frequency domain and the pulse width sets the bandwidth. A small pulse width sets a large bandwidth.

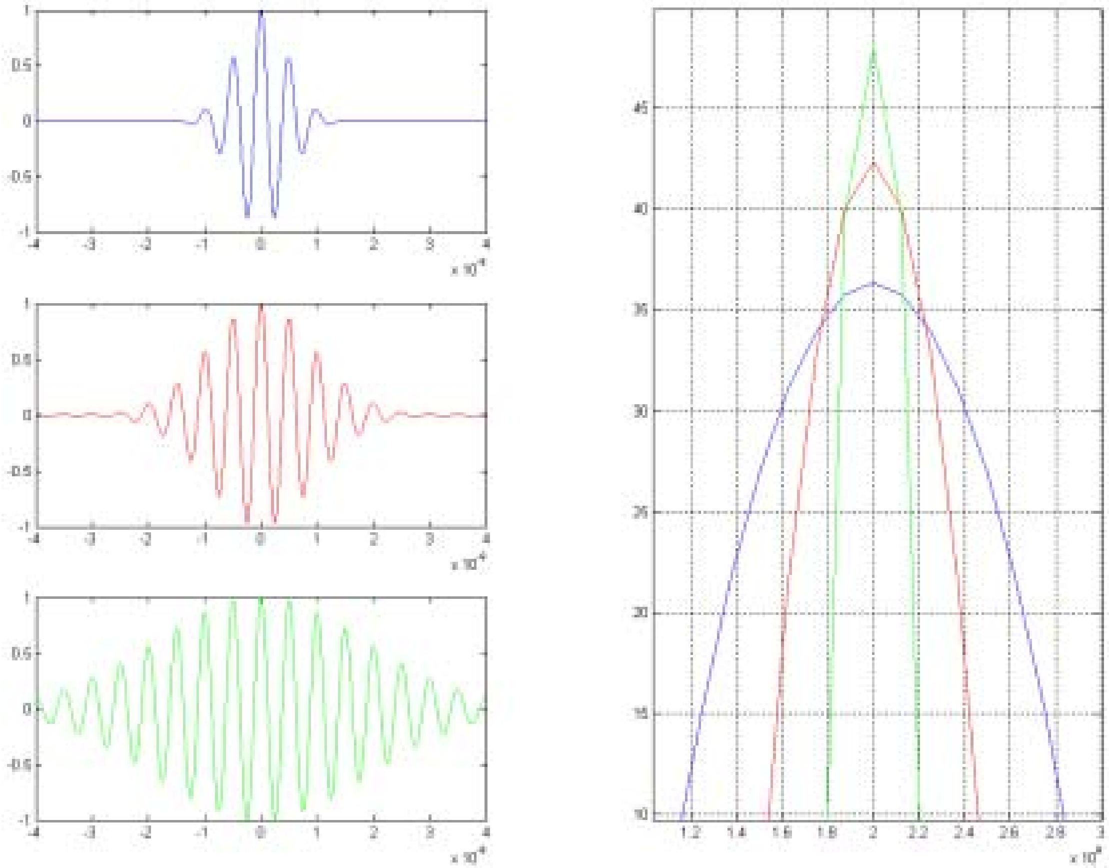


Figure 3. Pulse width versus bandwidth, small pulse width set a large bandwidth. The center frequency is the same for the three pulses while the pulse width differ.

There are two different techniques used when optimizing a system for a given bandwidth, called “single band” and “multiple bands”. The single band technique uses one pulse with very large bandwidth while a set of pulses with different center frequencies is used in the multiple bands technique.

2.1.1 Single band

Transmitting on a single band, as the PulsON technology developed by Time Domain [1], the pulses have the same center frequency and a short pulse width is used to obtain large bandwidth, Figure 4 and Figure 5. Sending data with pulses based on the same center frequency works well for one user and requires only one frequency source. Due to the large bandwidth, a high data rate is achieved but the system will be sensitive to interferers because most RF systems operate in the same band as the single band technique for UWB. For data modulation, a pulse position modulation can be used where the position of the pulse in a given time frame sets the symbol of the pulse.

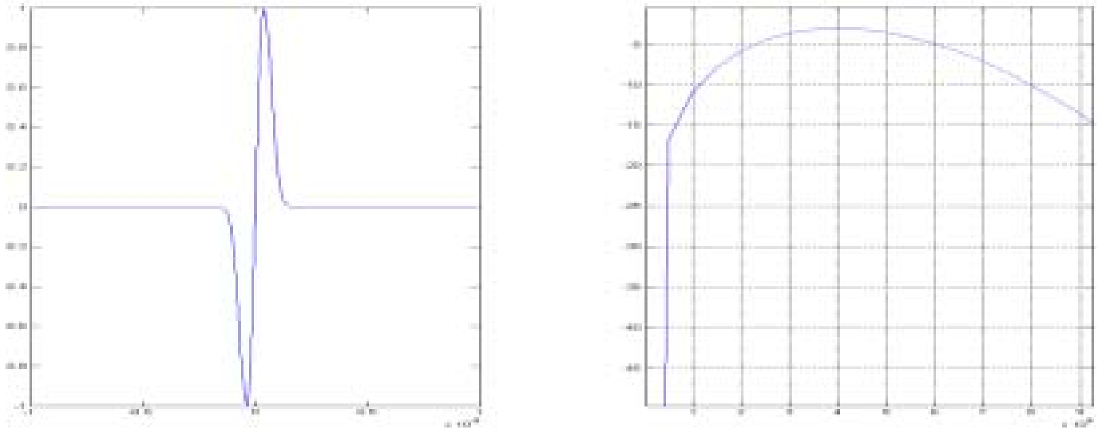


Figure 4. A Gaussian monocycle displayed in the time plane and the frequency response.

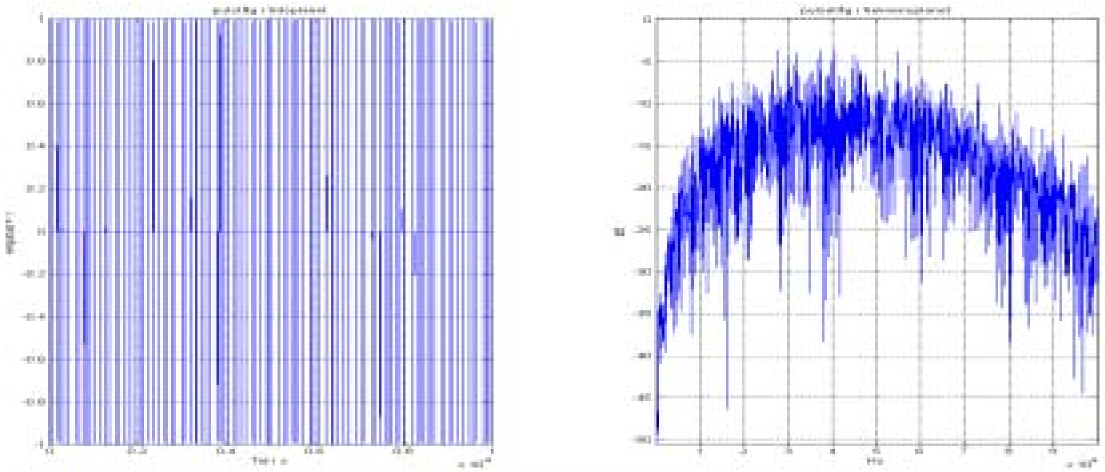


Figure 5. 100 monocycles with DFT cf = 4GHz, PRF= 100MHz placed randomly within a frame. The frequency response is similar to the response that of one pulse.

2.1.2 Multiple bands

An alternative to increase the flexibility and reduce the sensitivity to interferers is to split the frequency spectrum into bands or channels. The pulses have different center frequencies but have the same pulse widths, Figure 6 and Figure 7. A company using this technique is General Atomics who is developing a wireless USB 2.0 replacement [2] based on the multiple bands technique.

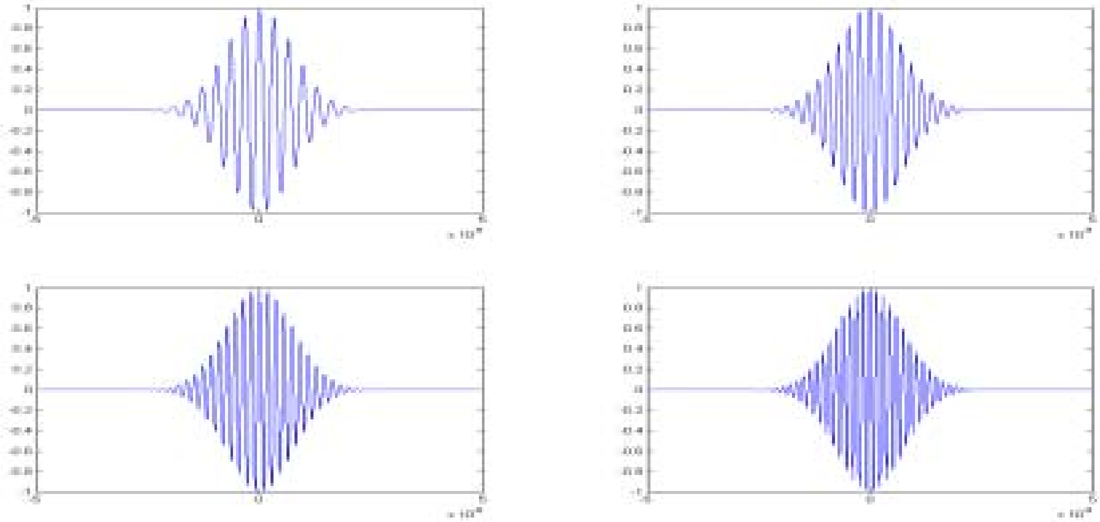


Figure 6. Four Gaussian pulses with different center frequencies.

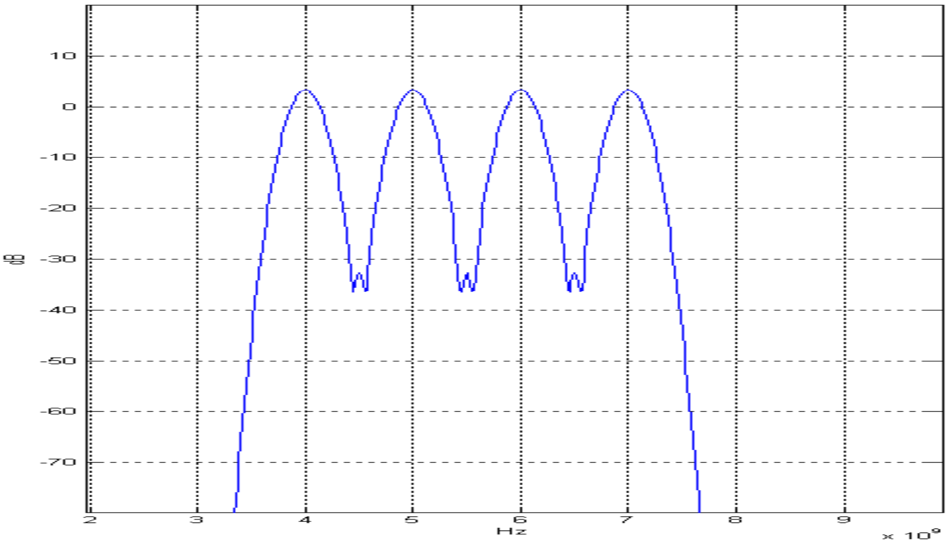


Figure 7. Frequency response for the pulses in figure 6.

The multiple bands technique allows many users to operate simultaneously by giving users different bands. In environments with high RF interferers, there is also the alternative to temporarily close a band containing an interferer to reduce the bit error rate (BER), Figure 8. For data modulation when transmitting with Multiple Bands, Binary Shift Keying (BPSK) can be used giving each pulse one bit of information.

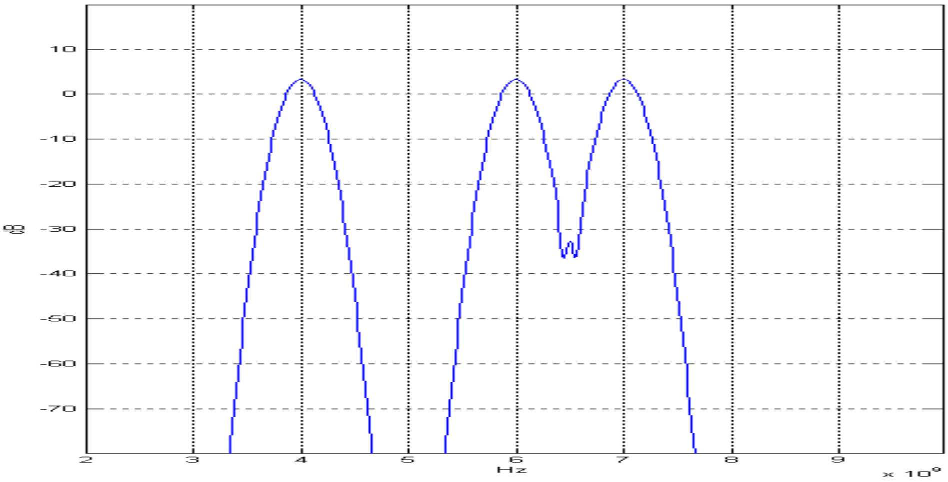


Figure 8. The frequency response when a band is unused to avoid an interferer.

2.2 Restrictions & Regulations

In April 2002 the FCC finished the “Report and Order” on UWB [3]. It contains the policy for UWB and states restrictions and regulations on the different types of UWB products. Some important restrictions and regulations for indoor and handheld systems are presented here.

There is 7.5GHz available spectrum to use between 3.1GHz and 10.6GHz. The bandwidth must be larger than 500MHz or the fractional bandwidth must be larger than 20% at –10 dB. The transmitter must also be in contact with a receiver in 10-second intervals. In Table 1, there is a diagram representing the emission limits for indoor and handheld systems measured in Effective Isotropic Radiated Power [EIRP].

Emission limits for UWB:	***Handheld***	***Indoor***
Frequency [MHz]	EIRP [dBm]	EIRP [dBm]
960-1610	-75.3	-75.3
1610-1900	-63.3	-53.3
1900-3100	-61.3	-51.3
3100-10600	-41.3	-41.3
Above 10600	-61.3	-51.3

Table 1. Emission limits for handheld and indoor systems in EIRP.

2.3 The Situation of UWB today

In UWB communication, many parties now see the advantages with multiple bands and several companies are developing WPAN chipsets. The IEEE 802.15 working group for WPAN are pushing for a standardization that is scheduled to come in 2004. In April 2003, Intel presented a prototype with a data rate at 220 Mbps, which is twice the data rate achieved in 2002 [4]. The use of UWB is not legalized in Europe yet. In April 2003 Ultrawidebandplanet published an article stating that UWB could cause interference with 3G headsets based on the universal mobile telecommunication system (UMTS). This result is confusing since UMTS operate in the 2 GHz band and UWB has lower emission in that band than several other systems e.g. Bluetooth and 802.11 according to Robert Aiello at Discrete Time Corporation [5]. The study was done by the Radiocommunications agency in the U.K. with a single band system. The results should not become a problem regarding the legalisation in Europe anyhow, because multiple-bands is now considered a better technique.

3 Transmitter Design

A UWB transmitter can be made with a rather simple architecture. A sinusoidal source is needed, as are a pulse shaping block, a modulation block and an antenna. This chapter deals with the transmitter on system level, the antenna excluded, and presents a solution for pulse transmission.

Two types of software with the required tools for realising a transmitter on system level are Simulink in Matlab with its different toolboxes and Agilent ADS. The toolboxes in Simulink are extensive and each contains blocks meant for a certain application. Using a combination of blocks it is possible to create very different systems. In ADS it is possible to create a system combined of blocks and real transistor circuits, giving a more real system. In this thesis, Matlab was chosen due to earlier experiences and availability.

3.1 Requirements and restrictions

For handheld devices the need for power efficiency is always important, the less power needed the better. To be able to successfully design a system on block level it is crucial to understand the current consumption of each block. Knowing this, some blocks can be avoided and the total number of blocks is minimized. The filters used in the system were restricted to a Q-value (Appendix III) of 12 due to physical characteristics of on-chip inductors. Another requirement was that the "Multiple bands" technique should be used with eight bands. The center frequency of the eight bands was chosen to be at 500 MHz intervals, ranging from 3.5 GHz to 7 GHz and the pulse width was set to 4ns which gives a bandwidth of approximately 500 MHz. In this thesis, much effort has been spent on minimizing the number of frequency sources.

3.2 Modelling and Simulation

There are a number of ways to implement the transmitter model. A fast tuneable synthesizer can be used to implement the eight band frequencies. The frequency is then tuned between the different bands between pulse transmissions. A problem is to get a synthesizer with short enough settling time. Better then is to switch eight sources where a switch controls band selection. For pulse shaping, a filtered square wave can be used where the filter sets the pulse shape. An alternative is to multiply a square wave with a sinusoidal wave giving a round pulse shape. Having these considerations and the restrictions in chapter 3.1 in mind, the outlines of a transmitter model was investigated which resulted in the first transmitter model.

3.2.1 The First Model

The first approach to a transmitter model, Figure 9, is based on eight frequency sources. A pulse generator, a Bessel filter and a multiplier were chosen for the pulse shaping, a sign converter and a multiplier to phase modulate the data read from file. Figure 10 show the pulses this model creates. Each pulse has a different center frequency and they are sent at 4ns intervals.

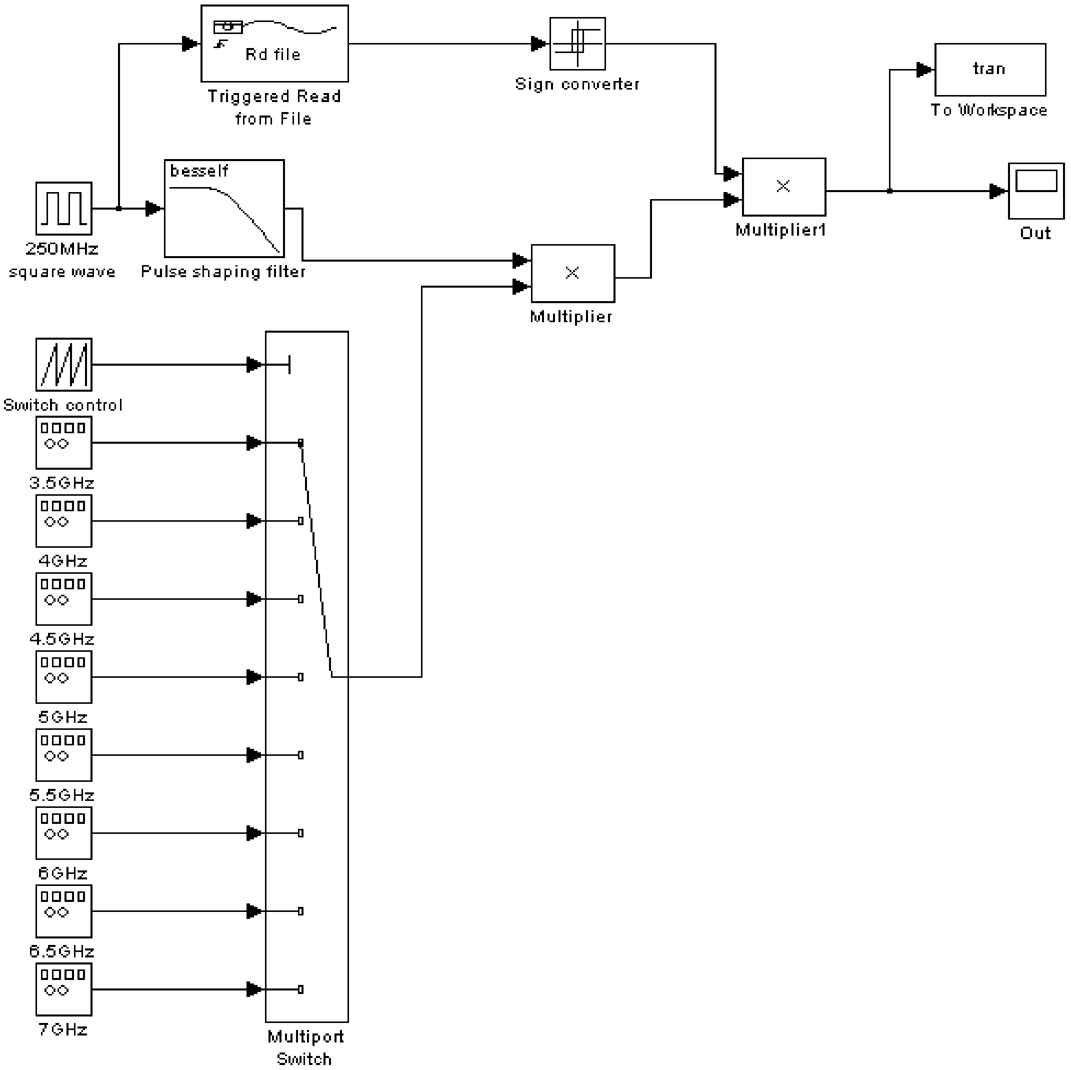


Figure 9. First model of a transmitter for UWB

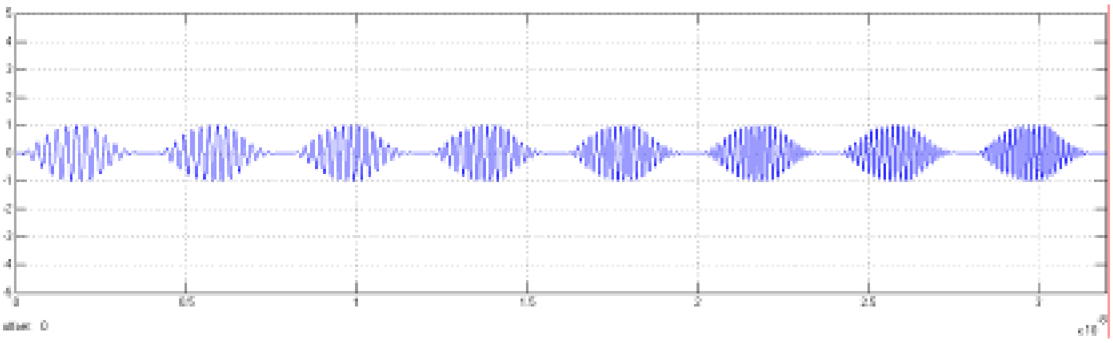


Figure 10. Eight pulses, each in a different band.

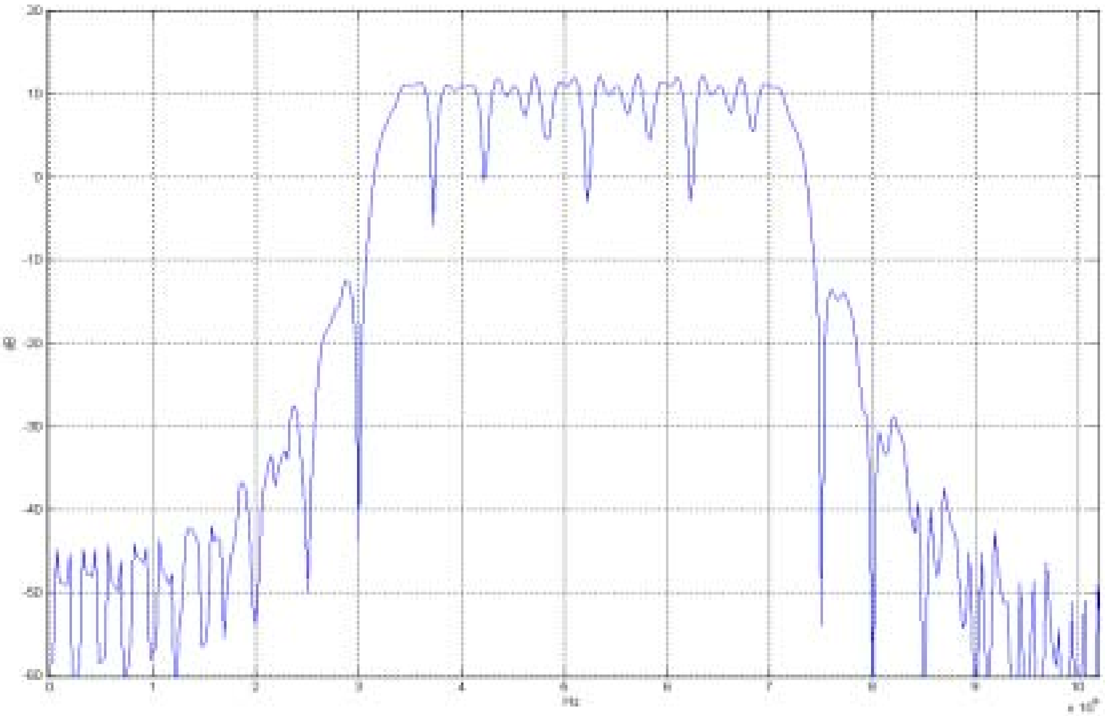


Figure 11. Frequency response (DFT) of the eight pulses in Figure 10.

As can be seen in Figure 11, a 4.3 GHz total bandwidth from 3.1 to 7.4 GHz measured 10 dB below peak amplitude is used, which passes the requirements in the “Report and Order” from the FCC. Keeping the pulse shaping in this model, further work on the frequency generation is needed.

3.2.2 Mixers and Filters

The frequency generation is a major part in the transmitter. Optimizing the frequency generation is therefore important for system performance and power efficiency. In the first model, Figure 9, eight frequency sources were used. A reduction of sources would reduce the power consumption. An alternative with mixers (Appendix IV) and filters was therefore designed, Figure 12, reducing the number of sources by four.

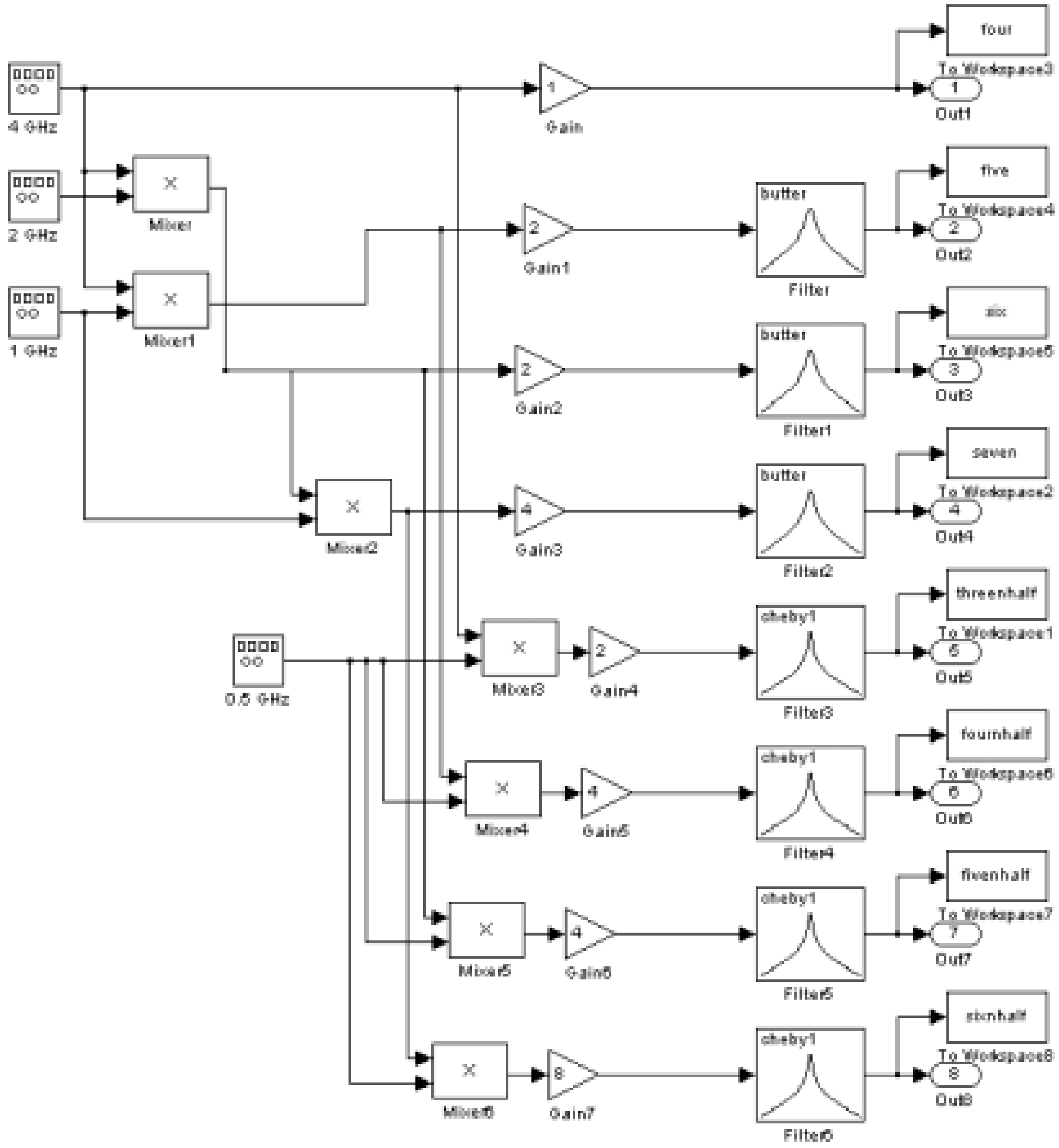


Figure 12. Frequency generation with four sources, seven mixers, eight amps and seven filters.

Simulating mixers in Simulink, multipliers can be used. Gain blocks are used as amplifiers and in this model, third order Chebyshev and Butterworth filters are used to filter the mixed signals. The eight outgoing frequency bands are shown in Figure 13, which shows that a delay is added by the filters, causing the amplitude for some of the signals to saturate after 8 ns. This adds a start up time for the frequency generation. The mixers add more interferers, which require the complex filters used in Figure 12. With the mentioned filter restriction in mind, these filters cannot be used. Therefore another alternative was investigated.

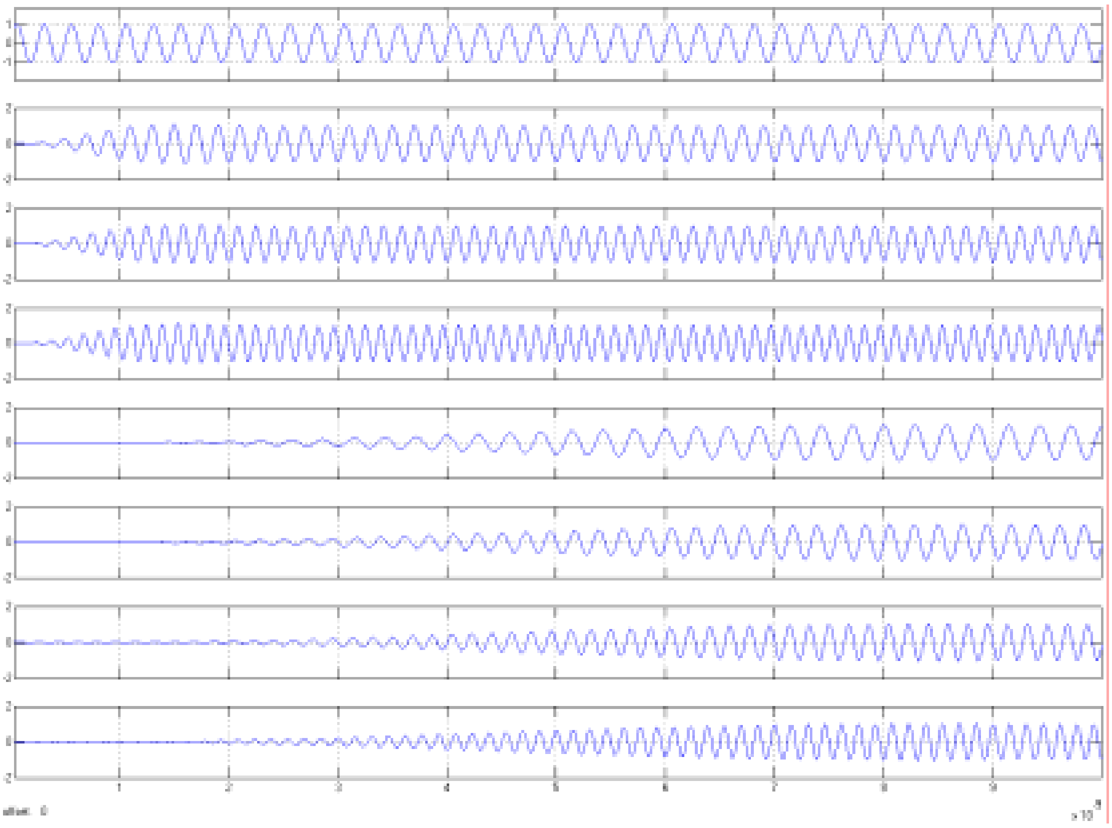


Figure 13. Output from the frequency generation based on mixers and filters. The frequencies 4, 5, 6, 7, 3.5, 4.5, 5.5 and 6.5 GHz respectively. A delay comes with mixing.

3.2.3 Divider

The frequency sources used are at 4, 2, 1, and 0.5 GHz. Introducing a divider to the model, dividing the 4 GHz source with divide by two circuits three times, the four frequencies are created. A Divide-By-Two circuit (DTC) consists of two D-latches (Appendix V) in master and slave configuration. The DTC can be designed as in Figure 14.

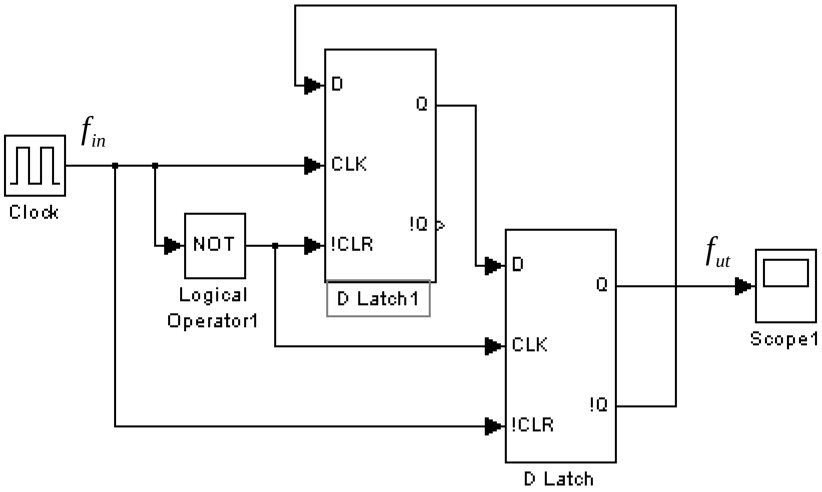


Figure 14. A divide by two circuit (DTC)

Due to a constraint in Simulink, logical blocks and latches cannot be feedback coupled without a time delay. A simpler circuit based on a D latch with a time delay can be used instead as in Figure 15, showing three DTCs, creating the frequencies used as sources in the frequency generation of the transmitter, Figure 16.

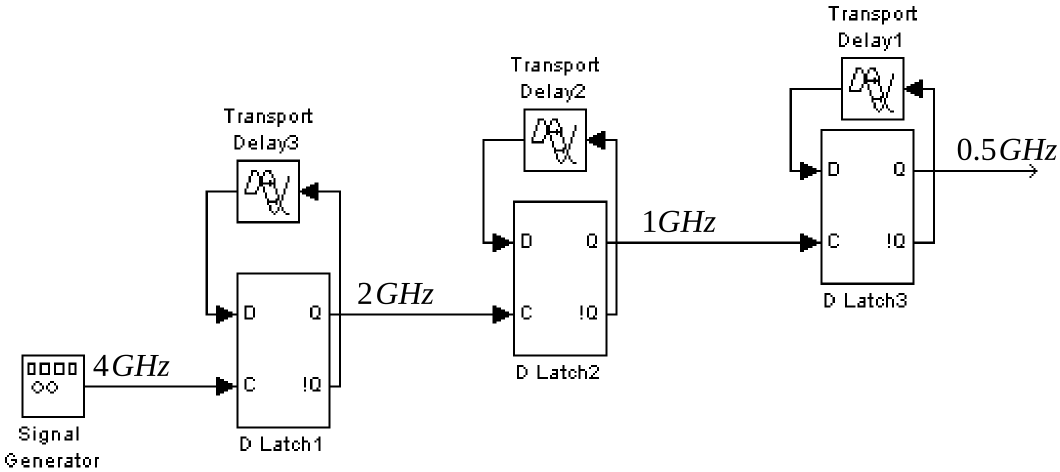


Figure 15. A divider containing three DTCs and a signal generator giving the four frequency sources used for frequency generation.

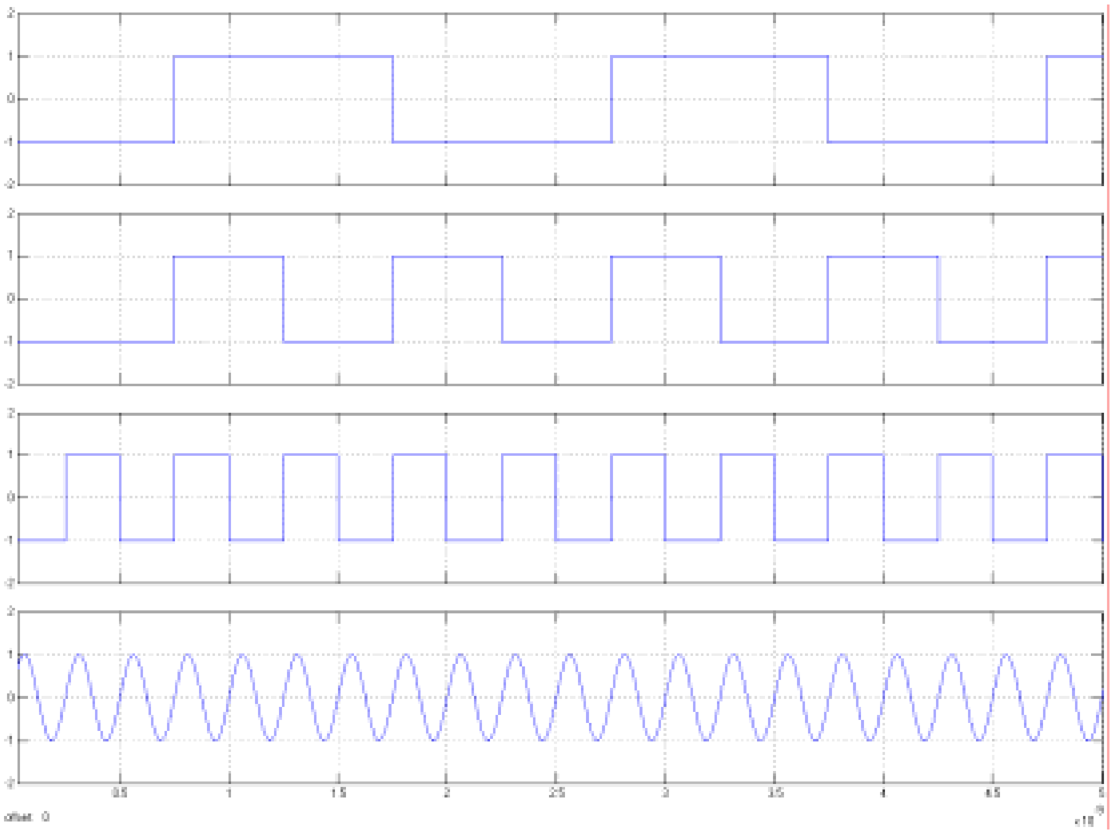


Figure 16. Output from the divider in Figure 15, 0.5, 1, 2 and the 4 GHz source respectively.

3.2.4 Harmonics

Since the wanted frequency bands are multiples of the four source frequencies, an alternative is to use the harmonics (Appendix VI) from the sources. The benefit with this idea is that the mixers can be discarded, and the number of blocks reduced. The wanted center frequencies for the eight bands and from what sources they can be given are shown in Table 2. If the need for more bands arises, there is more than 3 GHz of bandwidth left unused.

Wanted f_c [GHz]	***Fundamental frequency [GHz]***	***Order of the harmonic used***
3.5	0.5	7
4	4	1
4.5	0.5	9
5	1	5
5.5	0.5	11
6	2	3
6.5	0.5	13
7	1	7

Table 2. Each band frequency with the source giving the harmonic and the order on the harmonic used.

Using the harmonics of the four source frequencies increases the demand on the filters. As mentioned in the chapter concerning demands and restrictions, the filters were constrained to a maximum Q-value of 12. Replacing the Chebyshev and Butterworth filters with an s-function representing an LC tank with a q-value of 12 and using the harmonics as in Table 2, the frequency generation block before switching is finished, Figure 17.

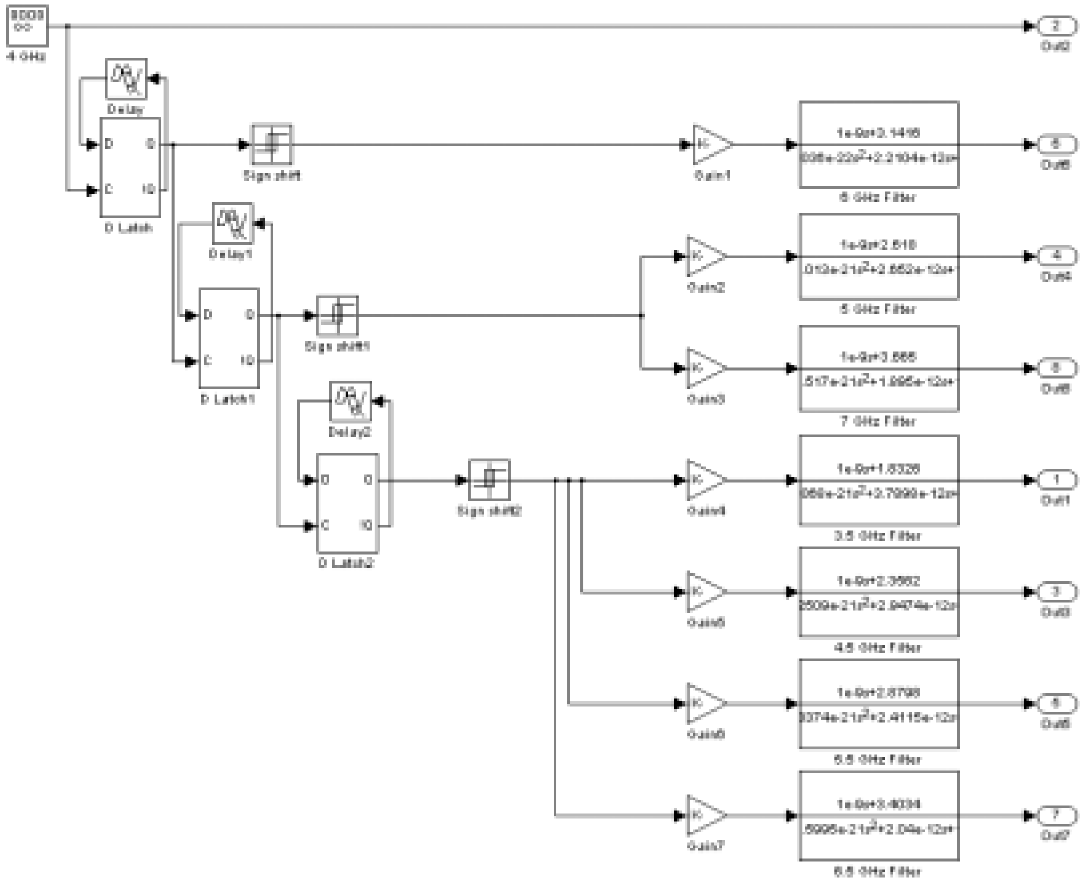


Figure 17. The frequency generation with one source, three dividers 7 gain stages and seven filters.

The output frequencies are amplitude modulated by the surrounding harmonics due to the restriction for the filters. This is shown in Figure 18.

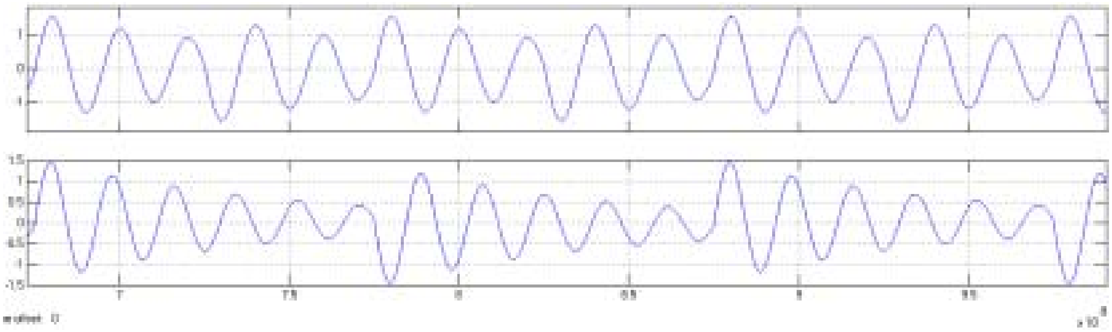


Figure 18. The 5 and 5.5 GHz bands after filtering respectively.

The closest harmonic is the strongest interferer for both signals, but the distance in frequency to the closest harmonic is different for the two signals due to the difference in fundamental frequency used. The interferer suppression for the 5 and the 5.5 GHz signals are 17 dB and 12 dB respectively, Figure 19.

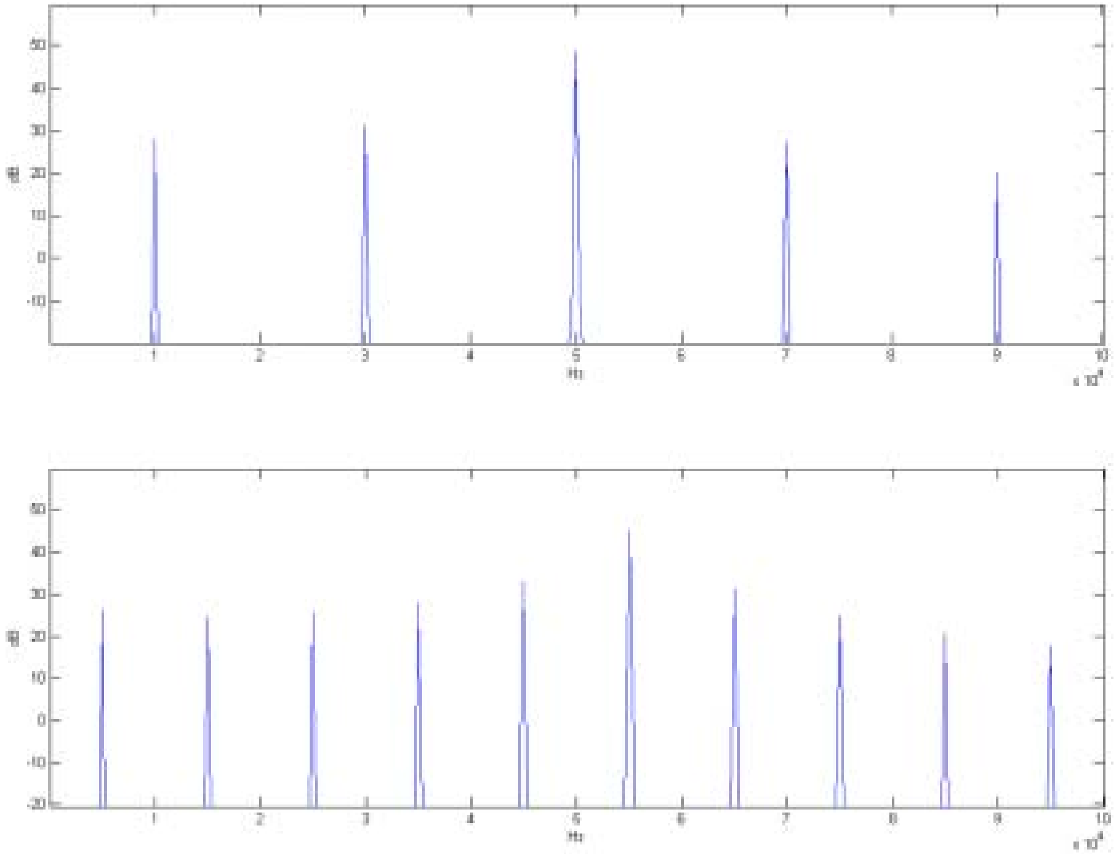


Figure 19. The frequency response of the 5 and 5.5 GHz signals in figure 18. The sideband rejection is 17 and 12 dB respectively.

3.2.5 Limiters

The suppression of the interferers is too small, because for pulse shaping, constant amplitude is needed, therefore the amplitude modulation must subside. Introducing a limiter, placed after the frequency generation block gives the desired effect. The limiter limits the signal to 1 and –1 respectively when it crosses zero, as seen in Figure 20, and improves the suppression by 15 dB to 32 dB and 27 dB for the 5 and the 5.5 GHz signals, as shown in Figure 21. The limiter reduces the closest interferers the most, making the fundamental frequency the strongest interferer.

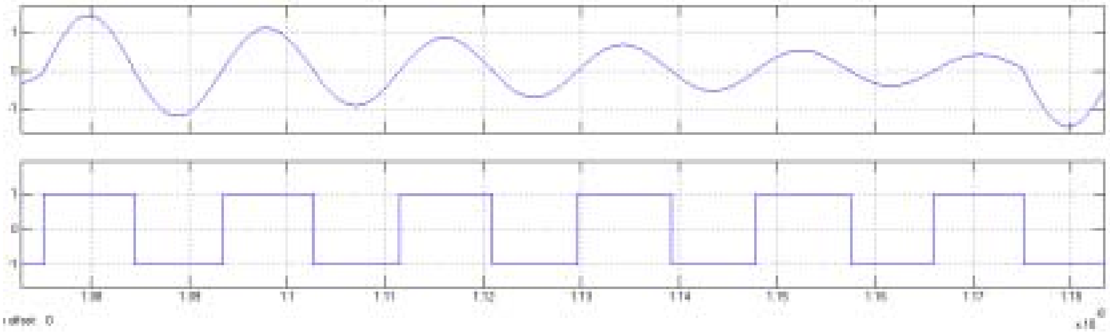


Figure 20. The amplitude modulated 5.5 GHz signal before and after limitation.

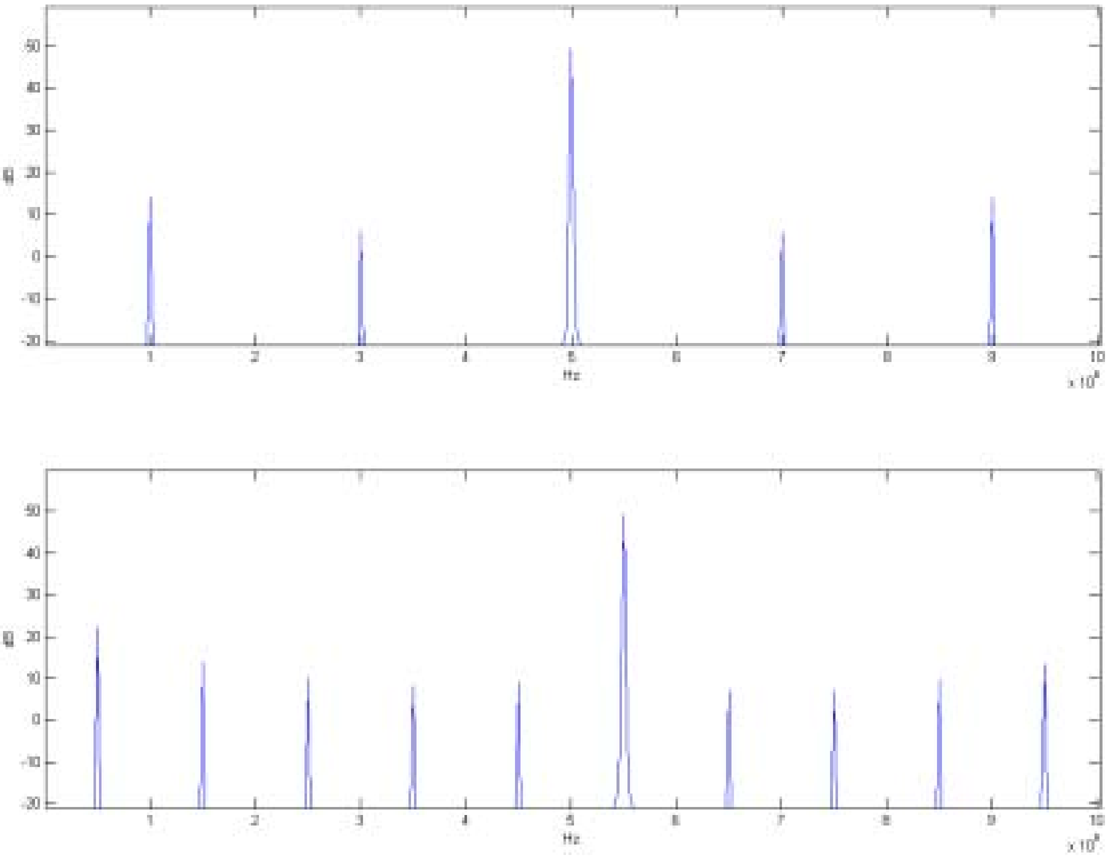


Figure 21. Frequency response for the limited 5 and 5.5 GHz signals.

3.3 Final Transmitter Design

The complete transmitter with frequency generation, pulse shaping and phase shift for data modulation is shown Figure 22, with the frequency generation block in Figure 23.

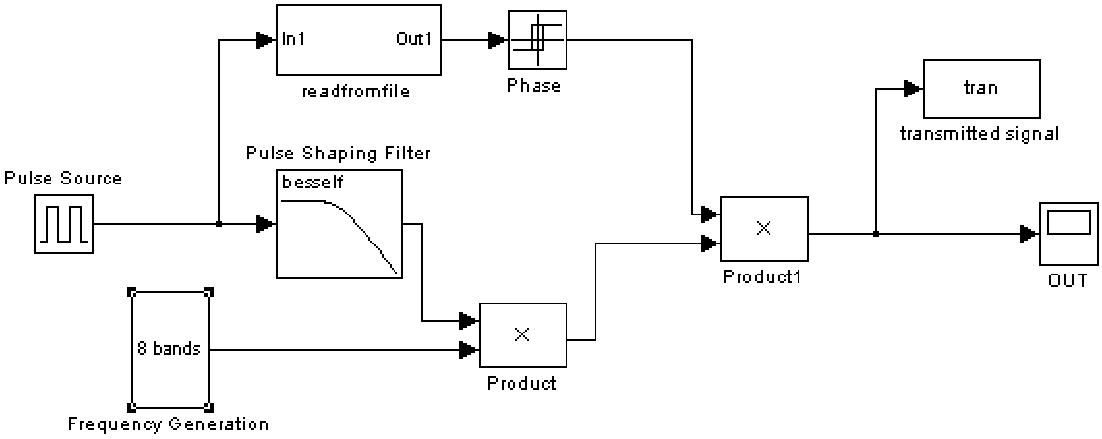


Figure 22. Transmitter Design

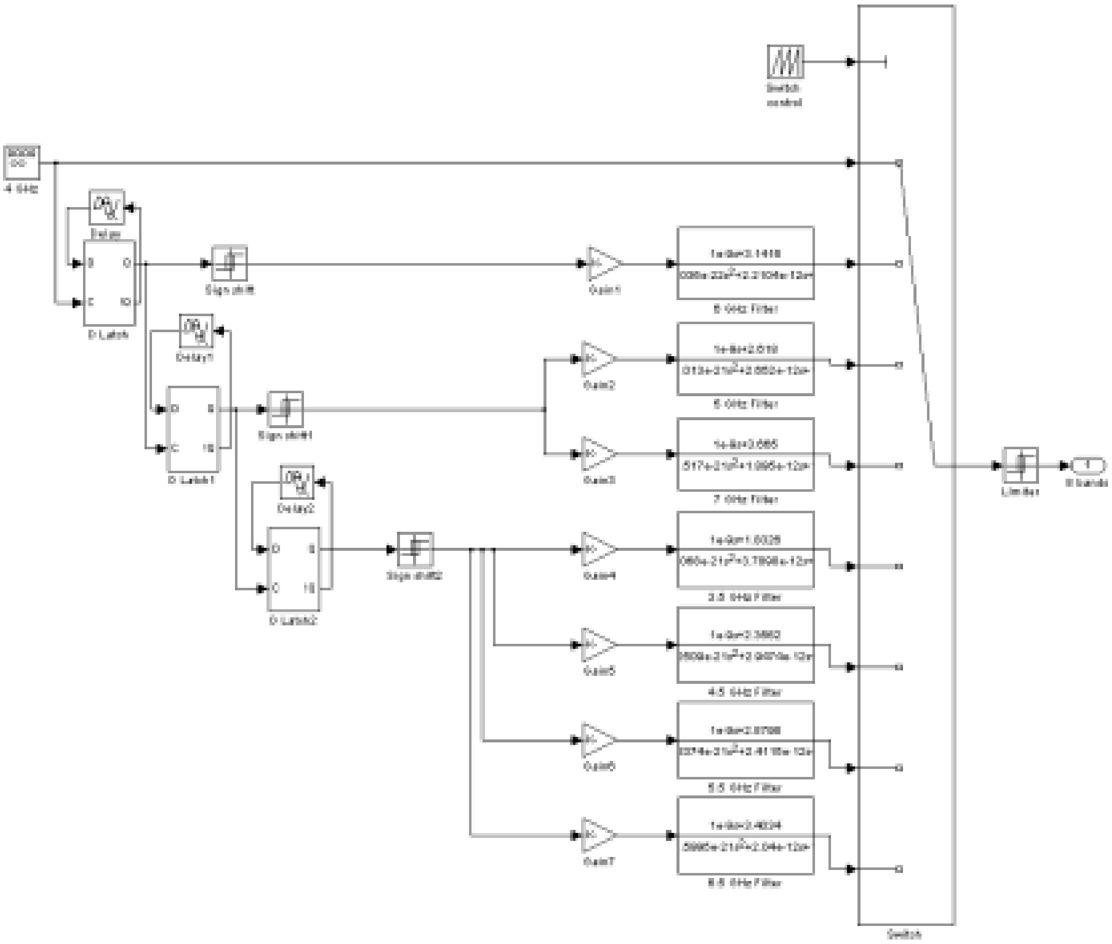


Figure 23. The Frequency generation based on one source, three dividers, seven gain stages, seven filters, one switch and one limiter. The three Sign shift blocks changes the zero out from the dividers to a minus one.

3.4 Summary

Designing the transmitter model in Simulink Matlab, the task was to get an overview of the system and finding the bottlenecks. The result is a transmitter with a frequency generation ready for transistor implementation based on one frequency source, three dividers, seven gain stages, seven filters and a switch. Sending pulses as in Figure 24, on the same band, the frequency response will be as in Figure 25 and when using eight bands the frequency response will be as in Figure 26. Bottlenecks in the system are the filters due to the Q-value. Furthermore, it will probably be hard to achieve a limitation at component level similar to that achieved in chapter 3.2.5.

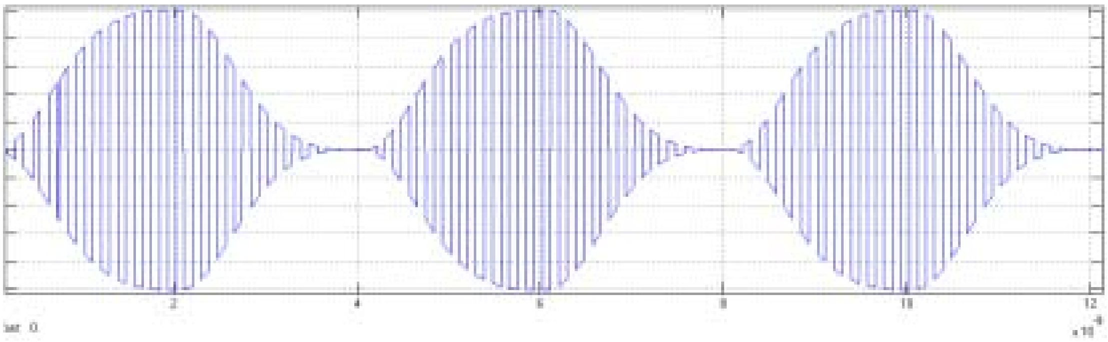


Figure 24. Three 5.5 GHz pulses

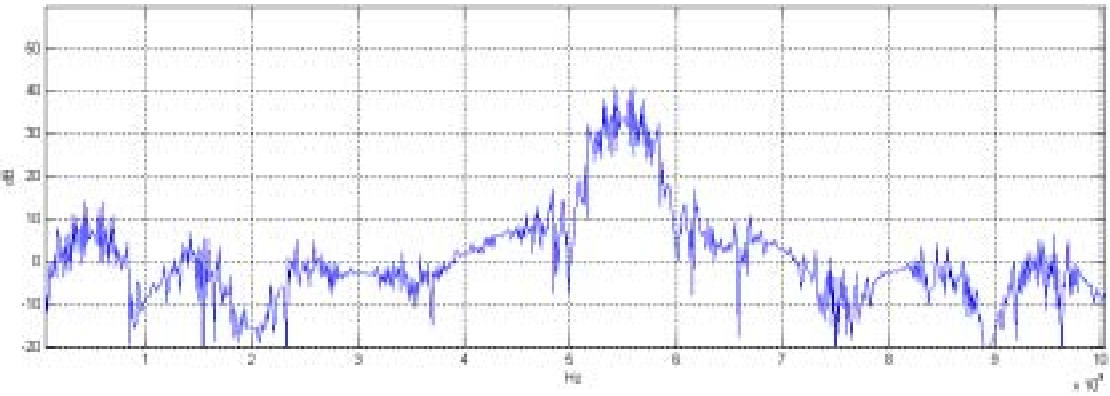


Figure 25. Frequency response on a serie of 5.5 GHz pulses. The bandwidth is approximately 500 MHz.

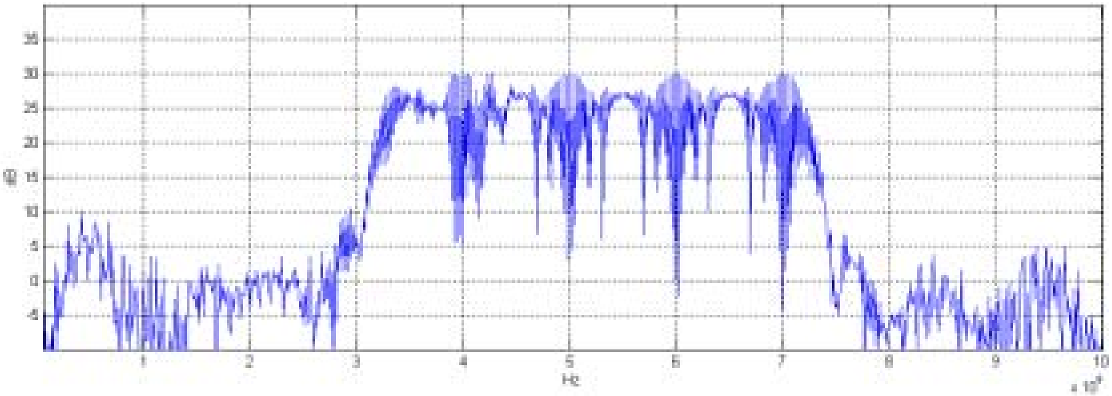


Figure 26 Frequency response on a serie of pulses containing all eight frequency bands

4 Circuit implementation

An emphasis on the frequency generation has been made in this thesis and in the summary of chapter 3, it was concluded that the bottlenecks of the system arises there. Therefore, that part was selected for implementation at component level. First, a divider was designed, then a filter, an amplifier and a limiter were designed. Finally, the total frequency generation was designed with transistors. In the filters, the inductances and the capacitances were tuned for the different bands.

Cadence was used for the circuit design. Alternative UNIX based software's are Mentor Graphics and Hspice. A PC alternative is Orcad. Cadence was chosen due to earlier experiences and availability.

The process used is an IBM, 0.13 um RF CMOS process.

4.1 Divider design

The DTC consists of two D latches, Figure 27, master and slave. Notice that the signals are differential, e.g. the clock signal consists of clock and clockinv.

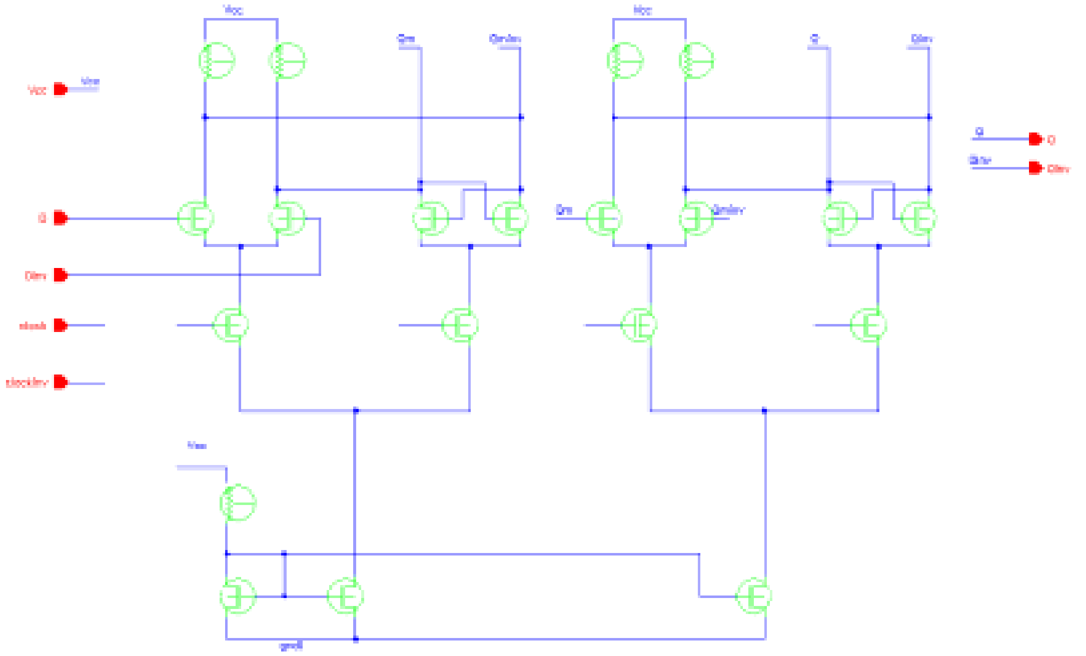


Figure 27. A DTC constructed of two D latches, each based on a current source.

The switching transistors were first set to their minimal size with two fingers. The current was set to 60 uA in the current mirror, giving an output signal as in Figure 28. The frequency is divided by two, but given the small current and the size of the transistors, the load has to be small to maintain functionality of the circuit.

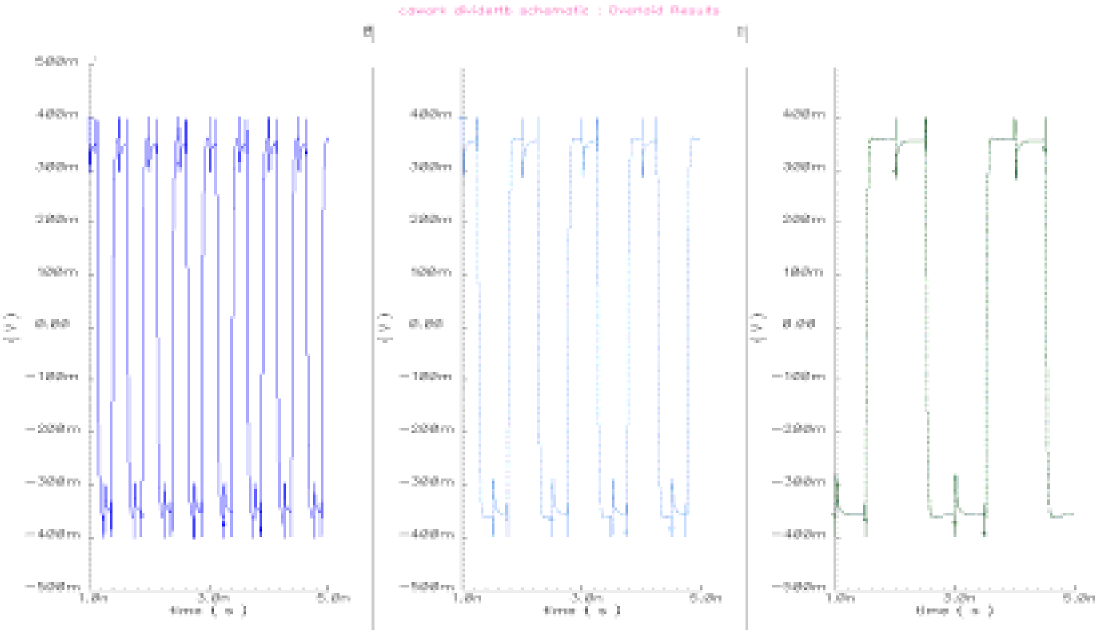


Figure 28. Transient output from the DTC with an input signal at 4, 2, 1 GHz, respectively.

Designing a divider based on three DTC circuits has been done as in Figure 29, with source followers on the output of each DTC. The divided frequency outputs with a 4 GHz square wave as input are shown in Figure 30.

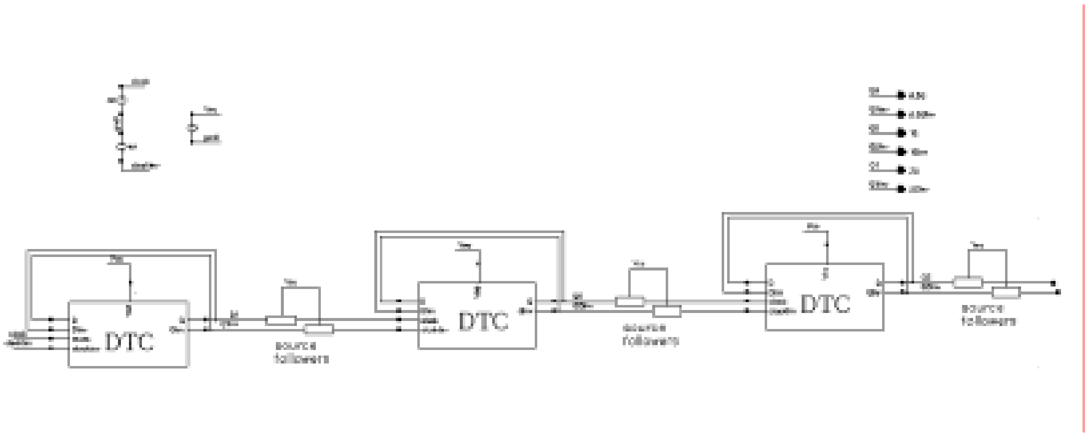


Figure 29. Divider based on three DTC with source followers in between and as a load.

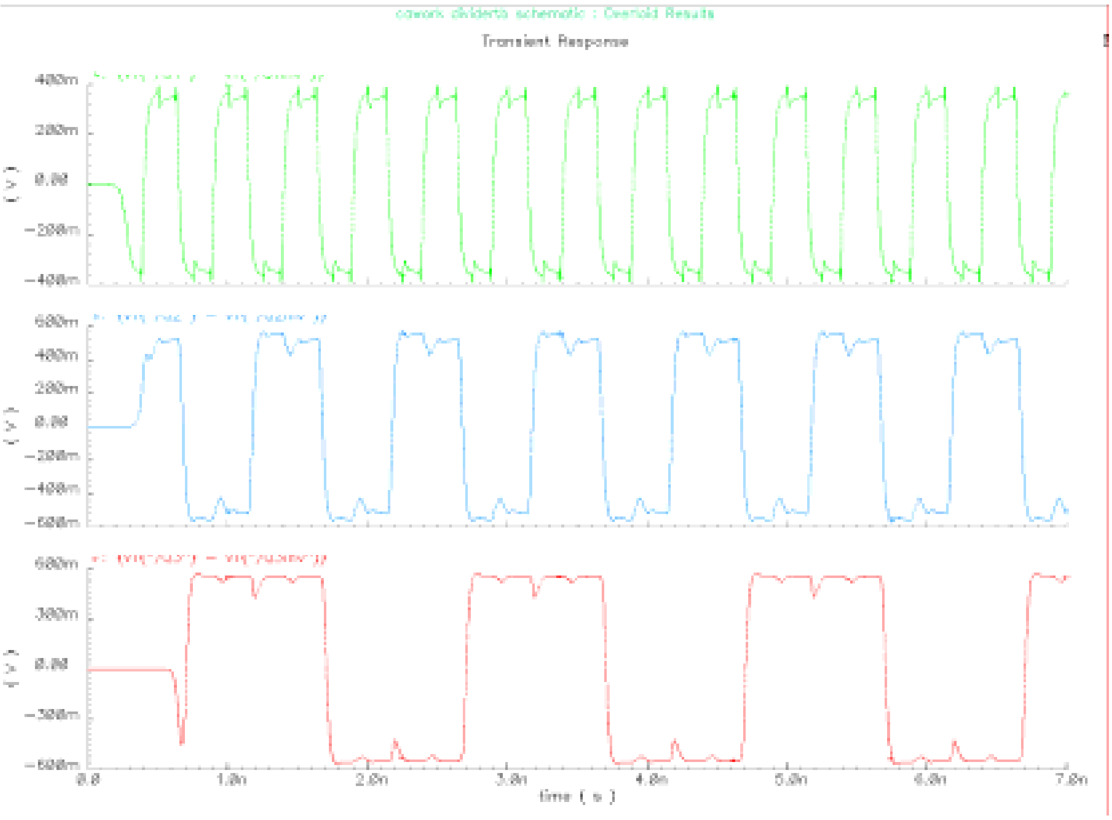


Figure 30. Output signals from the divider. Frequencies 2, 1 and 0.5 GHz respectively.

4.2 Filter Design

Before implementing the LC tank as a filter, the components were swept for optimum Q-value, Figure 31 and Figure 32. For a capacitor at 103fF, it was possible to get a Q-value of 40 at 3.5GHz, which is usable. The inductor has in general a lower Q-value and a maximum of 14 was obtained with one turn and the outer dimension at 200um at 7 GHz.

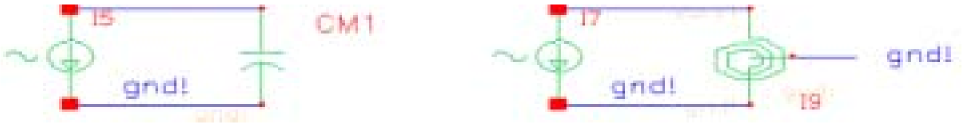


Figure 31. Schematic used for optimization of the capacitors and the inductors. A current source connected to respective passive component.

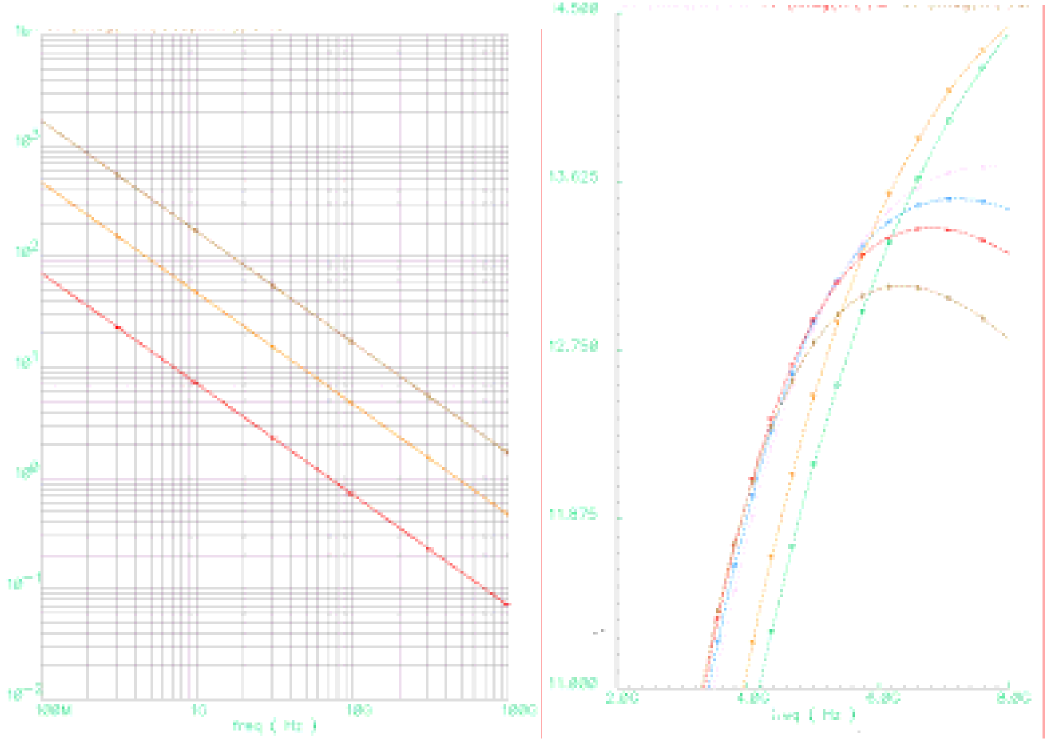


Figure 32. AC analysis of the Q-values of three capacitors and six inductors. Notice that the Q-value increase with the frequency for inductors while it falls for the capacitors.

These components are then used in the differential filter, Figure 33. Since the inductors have lower Q-values than the capacitors, an inductance for each frequency band was chosen and the tuning was done with the capacitor. Several capacitors in parallel were used instead of one large due to better Q-values in small capacitors.

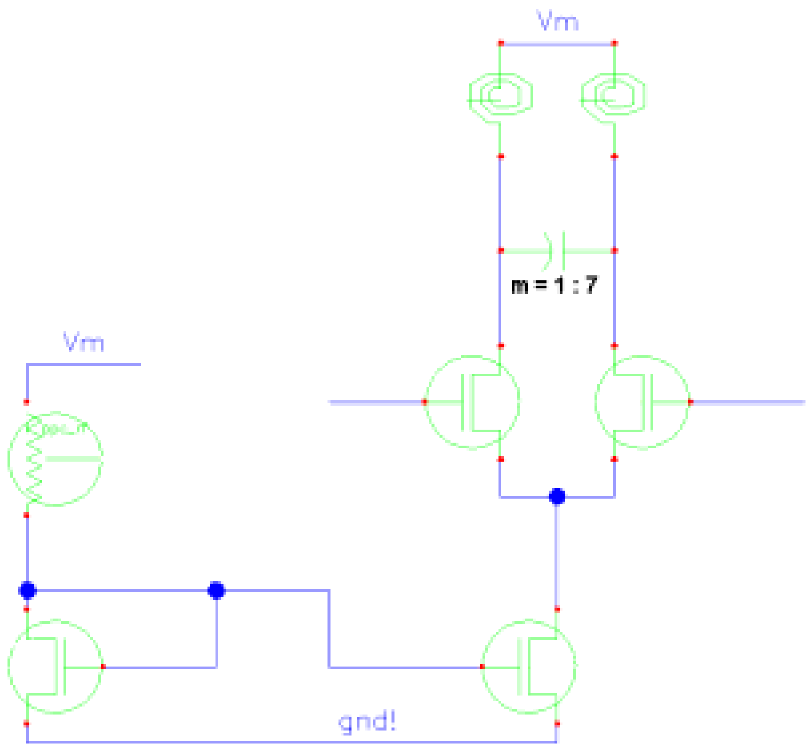


Figure 33, Differential filter with a current mirror. This filter contains seven capacitors and two inductors tuned for 6.5 GHz.

Simulating the filter with a square wave input, the differential output over the capacitors, Figure 34, is nearly the same as the output from the s-function block in chapter 2, Figure 18. Notice that the input signal to the filter is an ideal square wave and not the output from the divider.

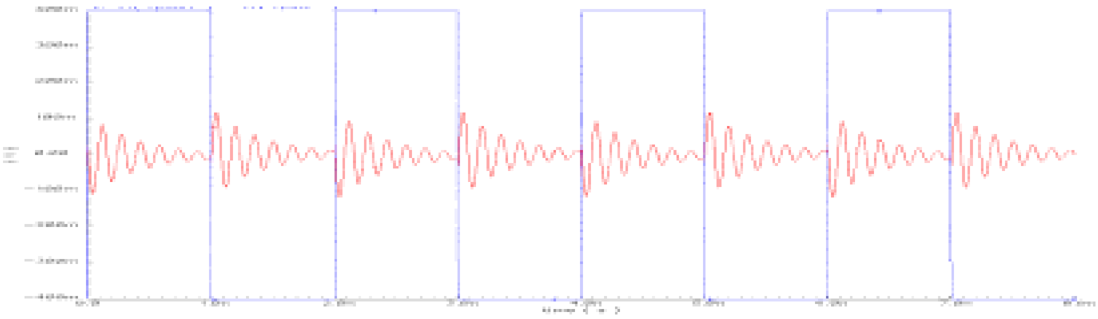


Figure 34. Output signal from a 6.5 GHz filter and a 0.5 GHz square wave input.

4.3 Amplifier design

Since the signal from the filter is small and amplitude modulated, it needs to be amplified and limited before pulse shaping. Here, the amplification and the limitation were separated and a single ended approach for amplification was investigated to obtain high gain, also giving the signal more headroom. The gain stage in Figure 35 is used for amplification and is based on one transistor with an AC coupling at the gate. A 6 dB gain was achieved for the gain stage, requiring twelve stages for the bands with the largest amplitude modulation. Figure 36 shows the differential output for the 6.5 GHz frequency band. Notice that the strongest parts of the signal are limited at this stage.

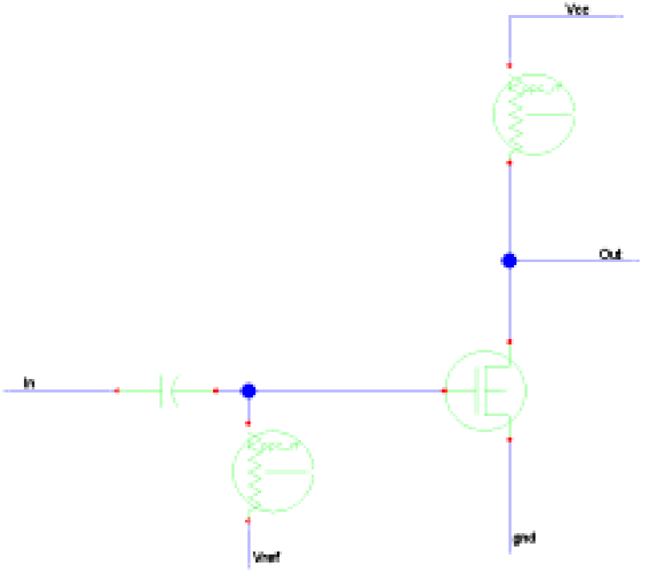


Figure 35. A single ended gain stage used for amplifying the filtered band frequencies. Several are used in series to obtain desired amplification.

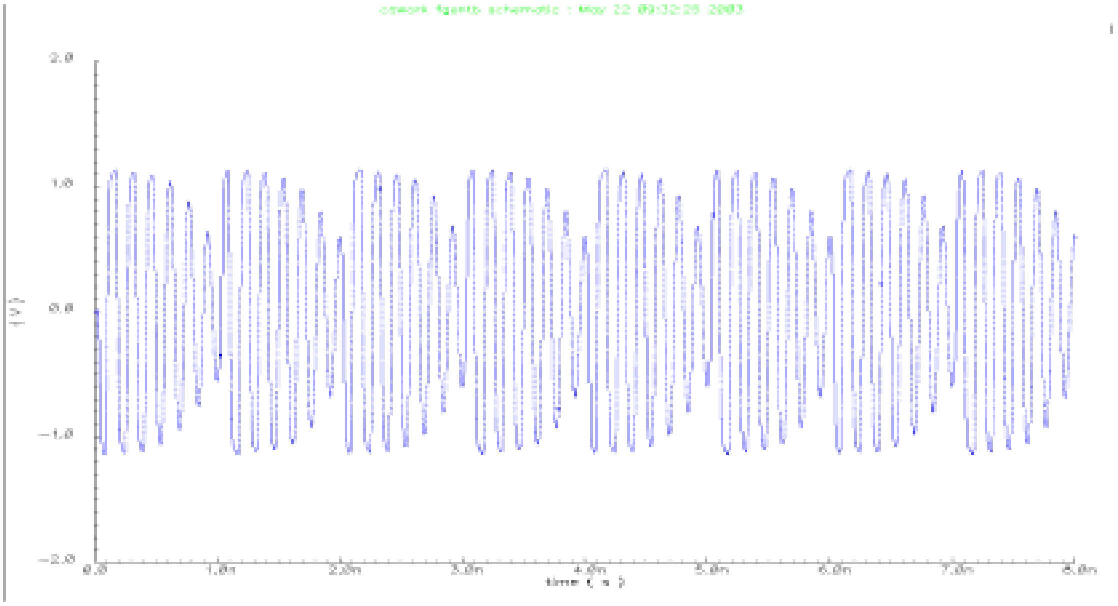


Figure 36. Differential output signal from the coupled gain stages. The weakest part of the signal has the amplitude of 0.6 V.

4.4 Limiter Design

After amplifying the signal, a differential stage is used to obtain constant amplitude for the signal, Figure 37. Setting the amplitude level to 0.25 V peak to peak, the closest harmonic are suppressed –24 dB, Figure 38. Decreasing the current, reduces the amplitude level, but increases the rejection. Increasing the current, the amplitude rise and the rejection subside. A drawback is that a trace of the amplitude modulation remains despite the reduction in amplitude level to 0.25 V.

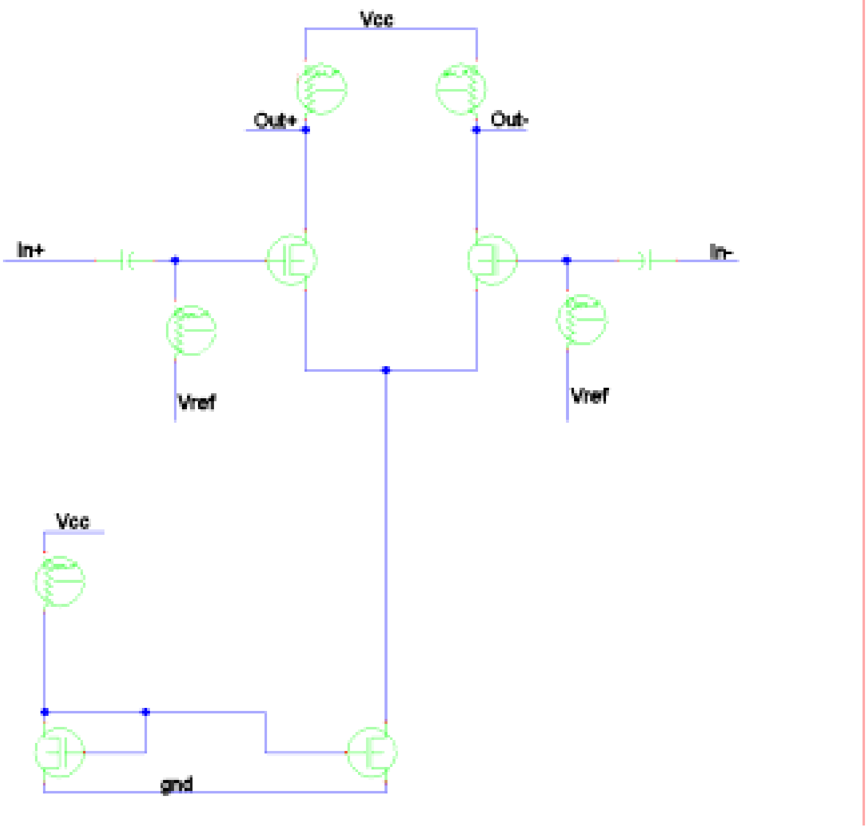


Figure 37. A differential limiter with an AC coupling at the input and a current source.

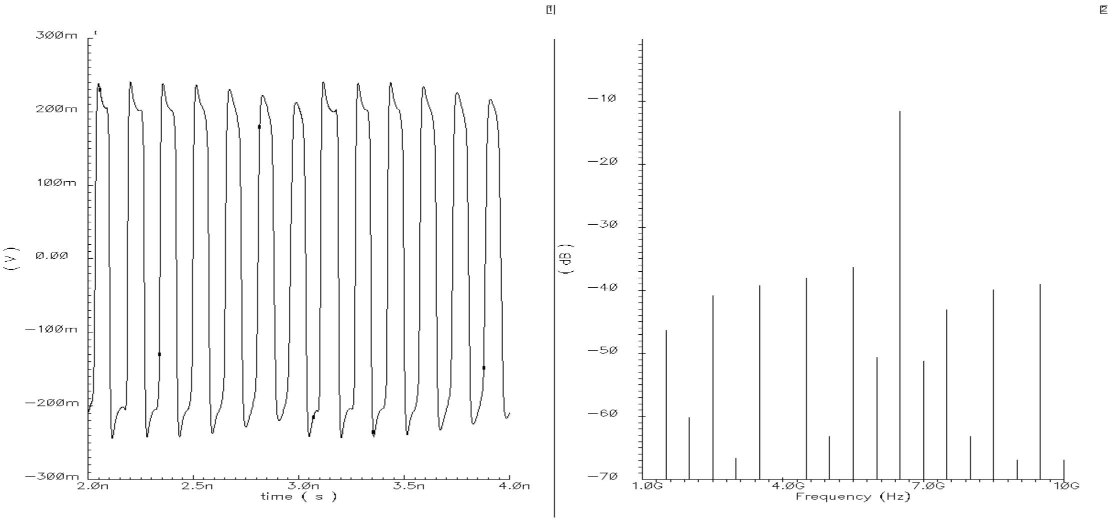


Figure 38. Output signal from a limiter with 0.25V peak amplitude. The current is set to 1 mA for the limiter and the frequency used in simulations is the 6.5 GHz band.

4.5 Pulse shaping and switching

Ideal circuits are used for pulse shaping and switching between the bands. The pulse shaping signal is realized by multiplying a square wave with a sinusoidal wave. The pulses are then created by multiplying a band frequency with the pulse shaping signal, Figure 39, creating the output in Figure 40.

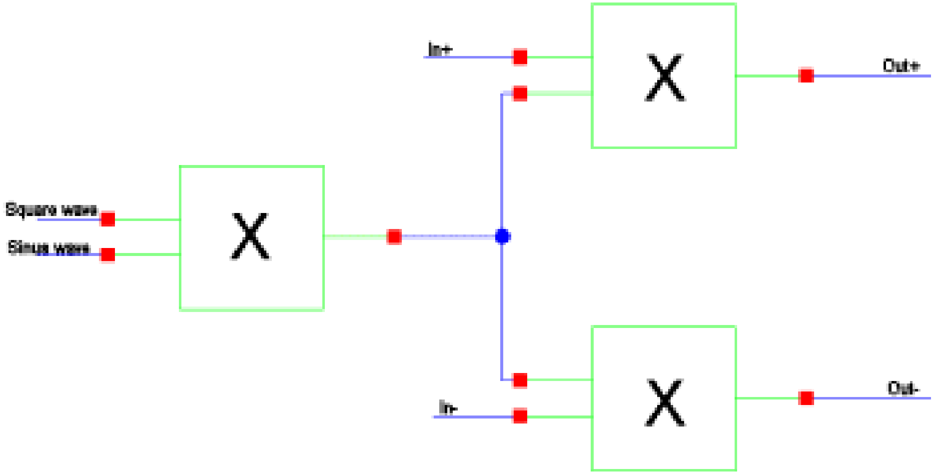


Figure 39. Pulse shaping block based on three multipliers with a square and a sinusoidal wave as control inputs.

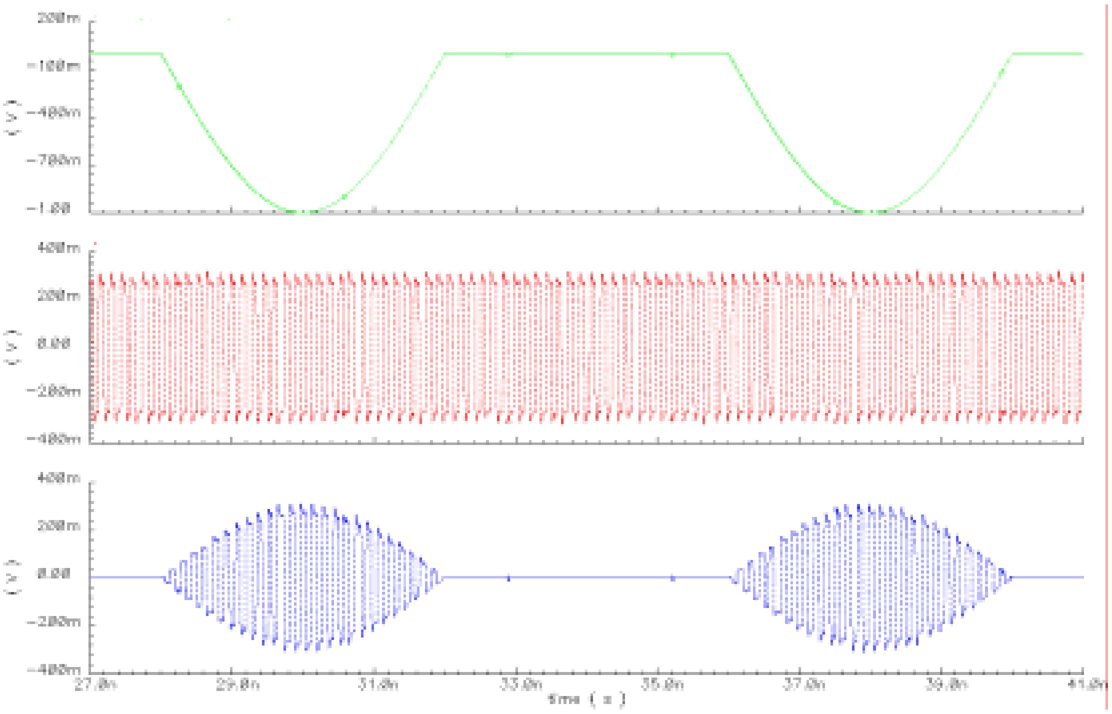


Figure 40. Pulse shaping. On top is the pulse shaping signal and in the middle is the 6.5 GHz input frequency. At the bottom are two pulses with 6.5 GHz center frequency.

The switching block is based on clocked multipliers, letting the bands through at different intervals, Figure 41.

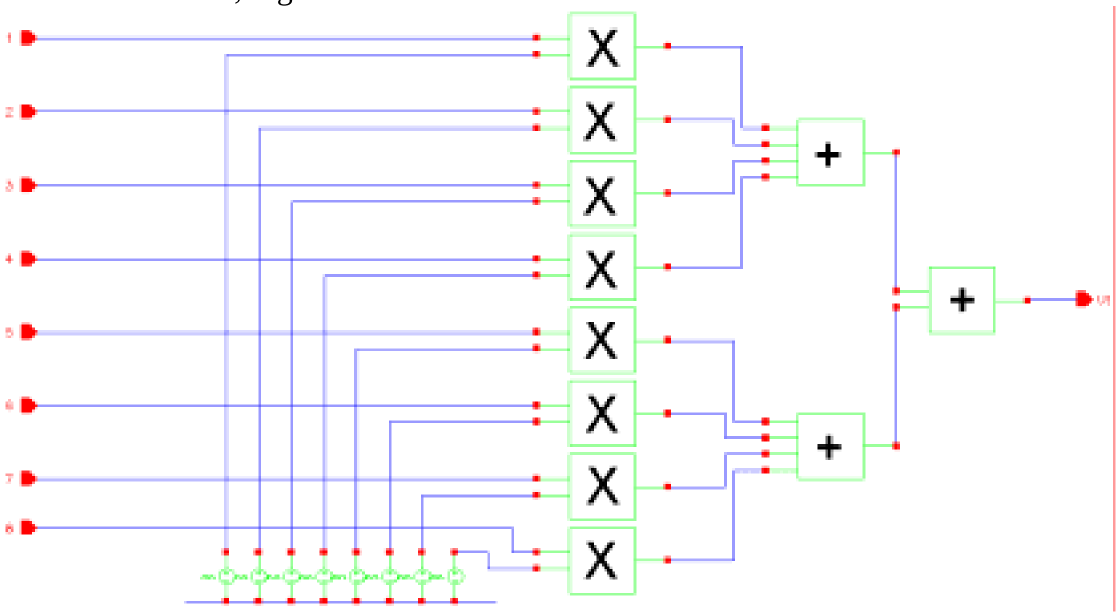


Figure 41. Switching circuit consisting of eight multipliers, three adders and eight square wave sources for multiplier timing.

4.6 Final IC design

The final IC design is shown in Figure 42 and contains a divider, buffers, filters, amplifiers, limiters, pulse shapers and switches.

The input impedance of the filters is too big for the divider to drive, so buffers, Figure 43, are needed. There are also six DTC used in the divider, Figure 44, instead of three as in the divider in chapter 4.1. One circuit is used for each wanted frequency instead of one circuit for all three wanted frequencies, minimizing the load to the DTC.

The amplifier block is based on six gain stages from chapter 4.3. The 5.5 and 6.5 GHz signals needed more amplification due to the high order of the harmonic used for the signals. Therefore, two amplifier blocks are used for these bands.

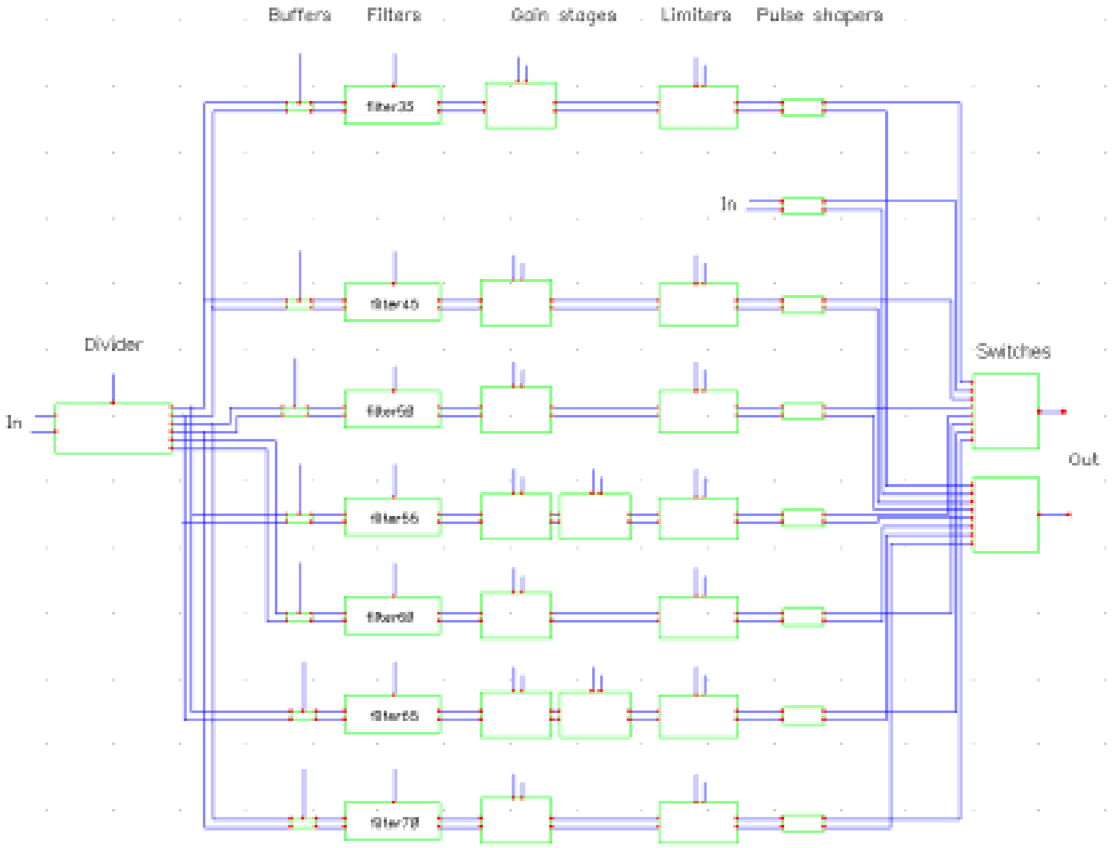


Figure 42, the final IC design, containing a divider, buffers, filters, amplifiers, limiters, pulse shapers and switchers. The 4 GHz input source is used for the 4GHz band giving the system no need to generate that band.

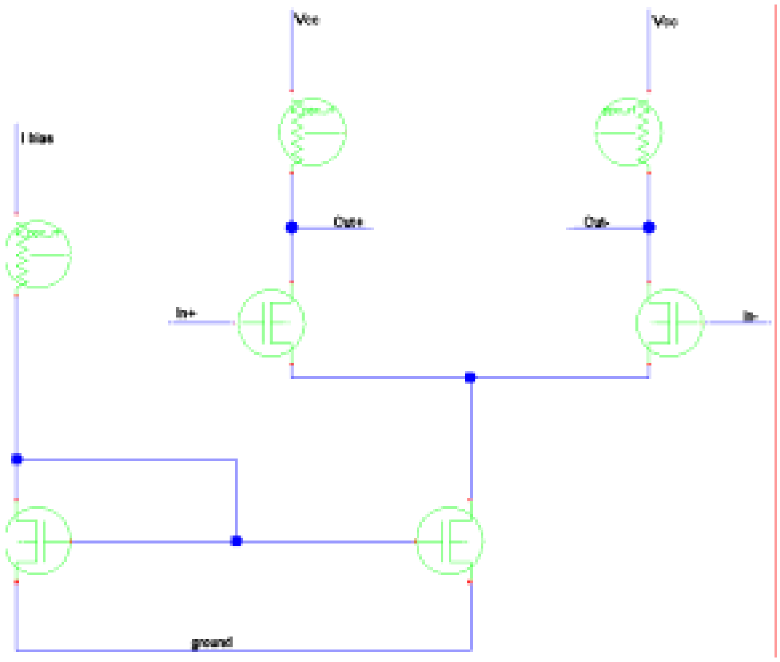


Figure 43, Differential gain stage used as a buffer with a current mirror.

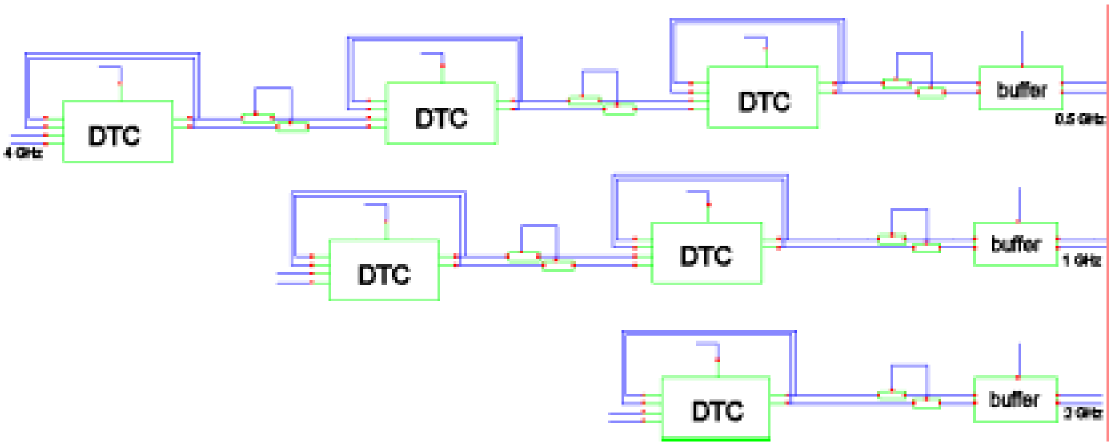


Figure 44, The divider based on six DTC with source followers after each DTC and a buffer before each output

4.7 Summary

The major work when implementing the circuits at component level has been to achieve functionality for the system. No consideration of noise has been made, except for intermodulation products (IM) and harmonics, which in contrary are used for functionality. A problem has been to filter and limit the 6.5 GHz signal due to the high order of the harmonic used, which require a high rejection of the fundamental frequency and the other harmonics.

The result is eight frequency bands implemented with transistors with ideal circuits for pulse shaping and switching. The pulses created are shown in Figure 45, where the pulses contain one band each. The frequency response for the pulses in Figure 45, is shown in Figure 46. Notice the similarity with the frequency response in Figure 26.

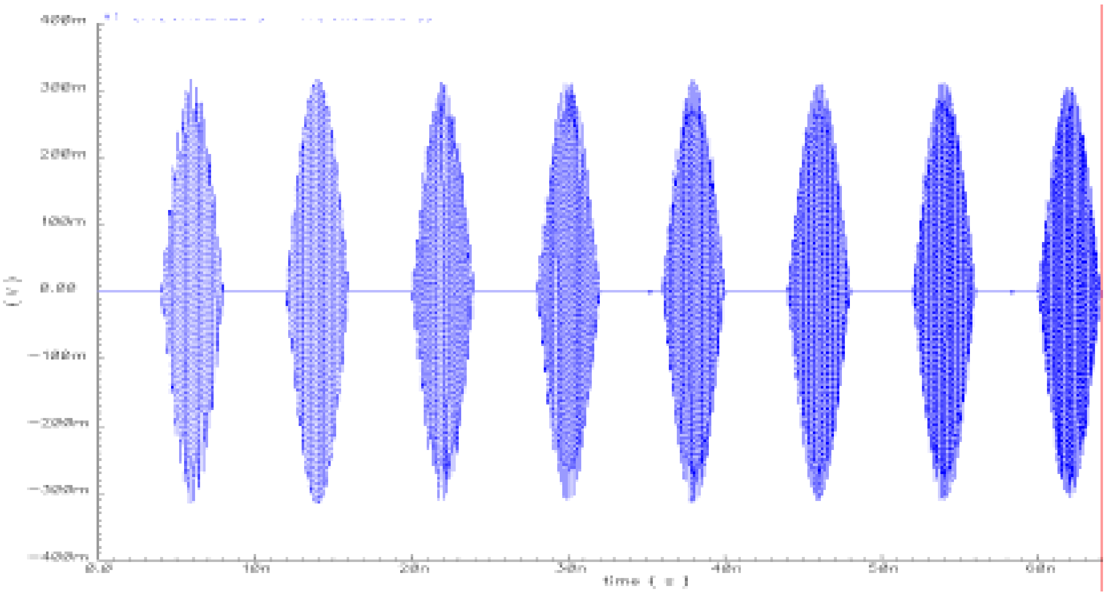


Figure 45, Output from the final IC design. Eight pulses representing one band each

Figure 46, frequency response on a transmission of the pulses in figure 45.

A drawback with the system is the high current consumption in the amplifier block, especially for the two frequency bands using two amplifier blocks. In Table 3., the current consumption of one band is presented where it can be seen that the amplifier block consumes more than half of the total current consumption.

Current Consumption of one band [mA]	
Divider	0.75
Buffer	2.5
Filter	7.1
Amplifier	15 (33)
Limiter	1.8
Total	27.15 (45.15)

Table 3. Shows the current consumption of the different blocks that generates one frequency band. In the parenthesis is the consumption of a band using two amplifier blocks.

5 Conclusions and recommendations

Ultra wideband radio is here to stay. The need for a wireless alternative in high speed communication at short distances is large and UWB has a high potential in that area. The use of multiple bands is attractive, e.g. Intel and General Atomics are developing systems based on multiple bands. No standard is yet in place, but the IEEE 802.15 working group are developing WPAN consensus standards.

This thesis contains a preliminary study of UWB and a proposal on pulse generation for UWB transmission. The proposal is presented first on system level in Matlab and then at component level using Cadence. The multiple band technique is used with eight bands with a bandwidth of 500 MHz each. The center frequencies are created with a circuit based on one VCO where harmonics are used to obtain the eight bands of operation. The system has a current consumption of 27mA per band during operation, giving a consumption of 230 mA if all bands are generated simultaneously. This is unacceptable, but note that not all bands need to be on at the same time and the system has not been optimized for power primarily.

A recommendation for future work and enhancement is to improve the 6.5 GHz and 5.5 GHz band. A bottleneck in the system is the current consumption for amplification, which is over half of the total consumption. Enhancing the existing or investigating an alternative solution is therefore recommendable. The pulse shaping and band switching are ideal and has to be implemented with transistor circuits. Furthermore is the layout for the circuit yet to be done

Appendix I Gaussian Pulses

The Gaussian pulse has a wave form described by the Gaussian distribution. The amplitude can be described as:

$$V(t) = A \cdot e^{-\left(\frac{t}{\tau}\right)^2}$$

where A is the peak amplitude and τ is a time decay constant that sets the pulse width

A Gaussian pulse can be constructed as a monocycle or a polycycle. The monocycle is a wide bandwidth signal where the pulse width sets the bandwidth and the center frequency of the pulse[1].

The polycycle is a modulated sinusoidal pulse with a given center frequency and a variable bandwidth.

The Gaussian distribution has the interesting property that the Fourier transform of a Gaussian is also a Gaussian.

Appendix II Hermite based pulses

The Hermite based pulses are generated from modified Hermite polynomial functions. By applying some modifications to the polynomials, Mohammed Ghavami with colleagues propose in the article “Generation of Hermite Based Pulses for UWB Communications” [6], that it is possible to produce orthogonal pulses with specific pulse width and center frequency suitable for UWB communications.

The Hermite polynomial functions are defined as:

$$h_e\left(t\right)=1$$

$$h_{e_n}\left(t\right)=\left(-1\right)^n e^{\frac{t^2}{2}}\frac{d^n}{dt^n}\left(e^{-\frac{t^2}{2}}\right)$$

Where n = 1,2… and -∞ < t < ∞.

Examples of the polynomials are:

$$h_{e_2}\left(t\right)=t^2-1$$

$$h_{e_4}\left(t\right)=t^4-6t^2+3$$

$$h_{e_8}\left(t\right)=t^8-28t^6+210t^4-420t^3-105$$

They are related by the following equations:

$$h_{e_{n+1}}\left(t\right)=th_{e_n}\left(t\right)-h_{e_n}\left(t\right)$$

$$h'_{e_n}\left(t\right)=nh_{e_{n-1}}\left(t\right)$$

Combining these two, the differential equation, which is satisfied by Hermite Polynomials is derived as:

$$h''_{e_n}-th'_{e_n}+nh_{e_n}=0$$

Hermite polynomials are not orthogonal. For further information on making Hermite polynomials orthogonal, modifying and modulating them for use in UWB communication, see [7]

Appendix III Filter based on an LC tank

To achieve a realizable system for the frequency bands used, a conservative constraint was set on the filters in the frequency generation block. A LC tank was used consisting of a capacitance in parallel with an inductance, figure 1.

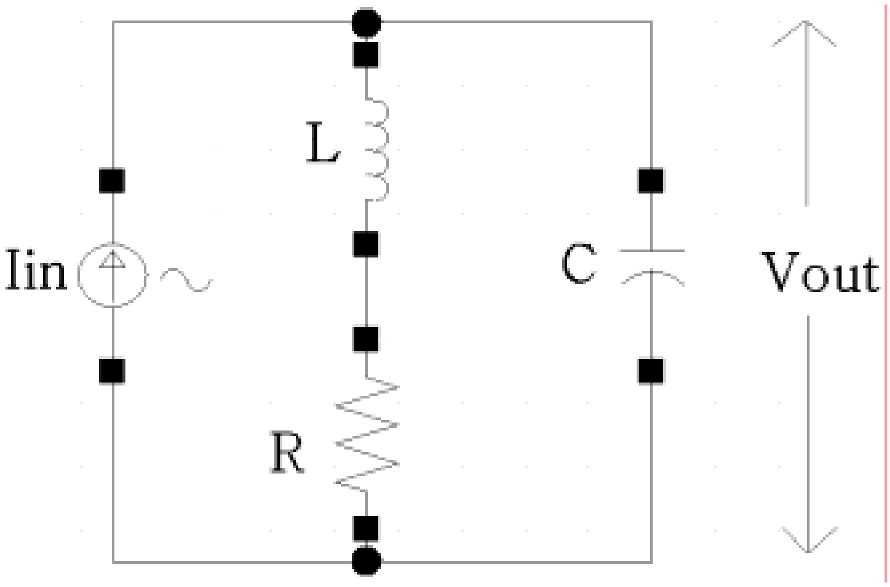


Figure 1, LC tank based on a capacitance in parallel with an inductance and its parasitic resistance, with a current input.

The transfer function of the LC tank is a transimpedence function, with a current input and a voltage output and can be represented in Fourier and Laplace transform as in equation 1. [8]

$$Z = \frac{V_{out}}{I_{in}} = \frac{R + j\omega L}{j\omega C(R + j\omega L) + 1} = \frac{R + sL}{1 + sRC + s^2 LC} \quad (1)$$

The q-value for this LC tank is set by equation 2.

$$Q = \frac{\omega L}{R} = 12 \quad (2)$$

Where ω [rad/sec] is given by equation 3.

$$\omega = \frac{1}{\sqrt{LC}} \text{ , thus } C = \frac{1}{L\omega^2} \quad (3)$$

Setting the inductance L to a fixed value, it is possible to calculate the capacitance C and the resistance R for the filters. For example,

$$\begin{matrix} \omega = 5{,}5\,GHz \\ L = 1\ nH \end{matrix} \quad \Rightarrow C = \frac{1}{10^{-9}(2\pi \cdot 5{,}5 \cdot 10^9)^2} = 0{,}84\ pF$$

Appendix IV Mixers

A mixer is often used to translate the frequency of a signal, either up in frequency or down, called upconversion and downconverison mixers [9].

Consider the two signals in equation 1.

$$\begin{aligned} x(t) &= A\cos\omega_1 t \\ h(t) &= A\cos\omega_2 t \end{aligned} \tag{1}$$

A mixer multiplies the signals as in equation 2.

$$\begin{aligned} y(t) &= x(t)h(t) \\ &= A\cos\omega_1 t \cdot A\cos\omega_2 t \\ &= \frac{A^2}{2}\left[\cos(\omega_1 - \omega_2)t + \cos(\omega_1 + \omega_2)t ...\right] \end{aligned} \tag{2}$$

Two signals at 3 respectively 4 GHz will generate output signals, intermodulation products (IM), at 1 respectively 7 GHz, figure 1.

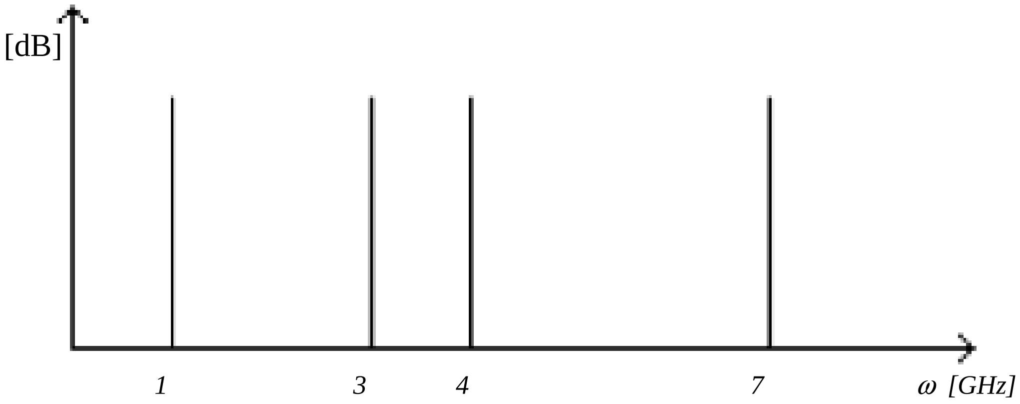


Figure 1, input and output signals for a mixer.

Appendix V Divide by two circuits (DTC)

A divide by two circuit, output a signal with half the frequency of the input. A linear DTC have a square wave as output. It is based on two D-flipflops connected as in figure 1.

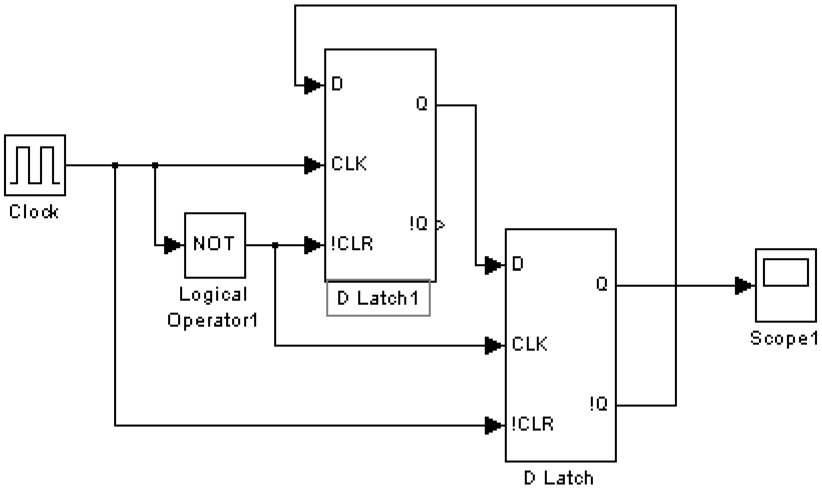


Figure 1, a DTC with a clock signal as input and the output connected to a scope.

A D-Flipflop is a logical block and can be constructed with nand gates [10], as in figure 2.

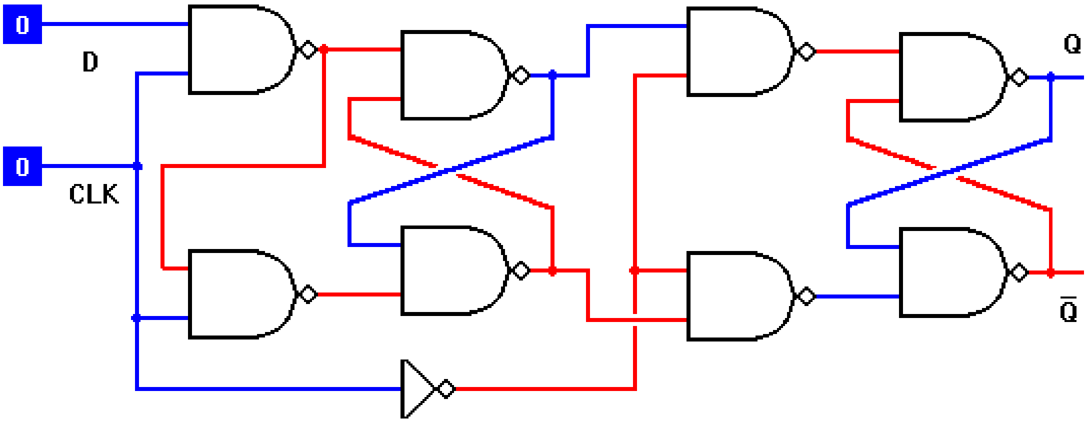


Figure 2, a D-flipflop based on nand gates.

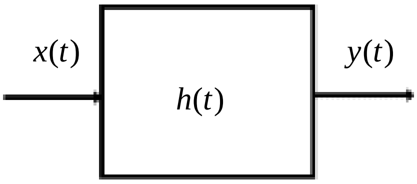
Appendix VI Harmonics

When a sinusoidal signal is applied to a nonlinear system, integer multiples of the input frequency are generated. The input frequency is called the fundamental frequency and the multiples are called harmonics [11].

With an input signal x(t),

$$x(t) = A\cos\omega t \tag{1}$$

applied to a nonlinear system h(t)



the output signal y(t) becomes,

$$y(t) = \alpha_1 A\cos\omega t + \alpha_2 A^2\cos^2\omega t + \alpha_3 A^3\cos^3\omega t\ \ldots$$

$$= \frac{\alpha_2 A^2}{2} + \left(\alpha_1 A + \frac{3\alpha_3 A^3}{4}\right)\cos\omega t + \frac{\alpha_2 A^2}{2}\cos 2\omega t + \frac{\alpha_3 A^3}{4}\cos 3\omega t\ \ldots \tag{2}$$

Harmonic distortion is defined as the ratio of the amplitude of a particular harmonic to the amplitude of the fundamental [9]. The harmonics of a 1 GHz signal are shown in figure 1 and the relation for the third harmonic can be derived from equation 2 as,

$$HD_3 = \frac{1}{4}\frac{\alpha_3}{\alpha_1}A^2 \tag{3}$$

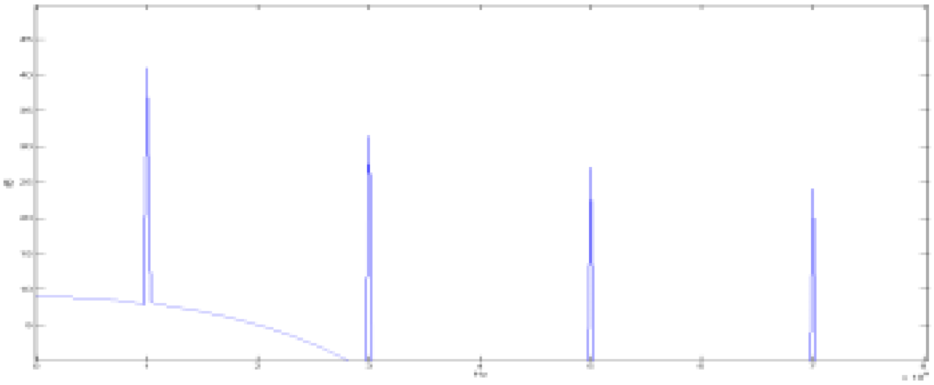


Figure 1, 1GHz frequency source with the third, fifth and seventh harmonic. Even order harmonics vanish due to symmetry.

References

[1]] PulsON technology Overview, Time Domain Corporation, 2001
http://www.timedomain.com/Files/downloads/techpapers/PulsONOverview7_01.pdf
2003-05-01

[2] General Atomics
http://web.gat.com/photonics/uwb/index.html
2003-05-01

[3] First Report and Order, Federal Communication Commission, 2002
http://www.uwb.org/files/new/FCC_RandO.pdf
2003-09-24

[4] Intel takes Ultra Wideband to 220 Mbps, Martyn Williams, Infoworld, 2003
http://www.infoworld.com/article/03/04/11/HNIDFUWB_1.html
2003-05-01

[5] UWB interference on 3G headsets by Vikki Likpset, Ultra wideband planet, 2003
http://www.ultrawidebandplanet.com/technology/article/0,,10850_2173501,00.html
2003-05-01

[6] Mohammed Ghavami, Generation of Hermite Based Pulses for UWB Communications, Sony computer science laboratories Inc. 2003

[7] Mohammed Ghavami, Hermite Function Based Orthogonal Pulses for Ultra Wideband Communications, Sony computer science laboratories Inc. 2003

[8] Passive filter characteristics and interstage matching networks for analog RF integrated circuits, Dr. John Choma, Department of Electrical Engineering-Electro physics, UCLA, August 2002

[9] VLSI for wireless Communication, Bosco Leung, Prentice Hall Electronics and VLSI series, 2002

[10] D-Flipflop, Ken Bigelow
http://www.play-hookey.com/digital/d_nand_flip-flop.html
2003-05-01

[11] RF Microelectronics, Behzad Razavi, Prentice Hall Communications Engineering and Emerging Technologies Series, 1998