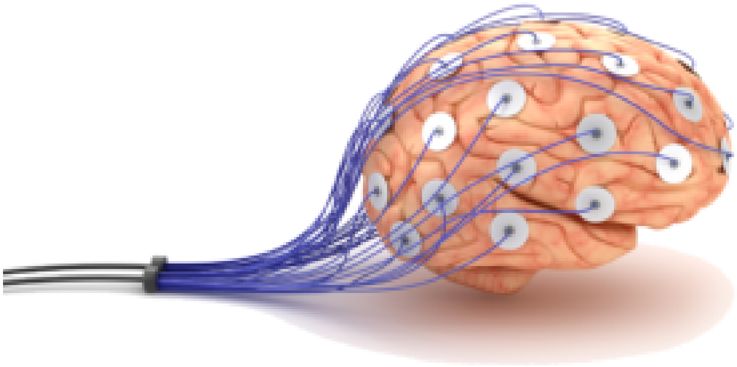

Spike Detector using an LC Oscillator

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Thesis to obtain the Master of Science Degree in

Electrical and Computer Engineering

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November 2022

To my grandparents…

I declare that this document is an original work of my own authorship and that it fulfills all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

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I would like to thank to my supervisor Prof. Jorge Fernandes for all the support and orientation throughout the thesis, and for sharing his knowledge and experience with me.

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Abstract

Spike detectors are important components and can be used as data compression or data reception mechanisms. Advances in microtechnology have developed various applications for spike detectors, whether at the neural level, in communications, in the UWB domain, and in other areas.

In this thesis, a very sensitive spike detector based on a LC oscillator is proposed, which can amplify the input signal at time and amplitude levels. A study of its ability to detect small energy spikes is presented. The study concludes with a circuit that is not only capable of correctly detecting energy or current spikes, but also of detecting them wirelessly, i.e., inductively.

This type of detector is impressive for its simplicity, for its high sensitivity, and finally for the variety of possible applications, since it can operate over a wide range of signal amplitudes, from 100 μA to 2mA.

Keywords

Analog Integrated Circuit Design; CMOS Technology; Spike detector; LC oscillator; inductive receiver.

Resumo

Os detetores de impulsos são componentes importantes, e podem ser utilizados como mecanismos de receção ou descodificação de dados. Os recentes avanços a nível da microtecnologia têm desenvolvido diversas aplicações para detetores de impulsos, sejam a nível neuronal, comunicações, no domínio da banda ultra larga ou noutra áreas.

Nesta tese é proposto um detetor de impulsos muito sensível, baseado num oscilador LC, que pode amplificar o sinal de entrada tanto a nível temporal como de amplitude. É realizado um estudo relativo à sua capacidade de detetar impulsos de dimensões muito reduzidas. O estudo conclui que o circuito não só é capaz de detetar impulsos de corrente ou energia, mas também é capaz de os detetar sem recurso a fios, ou seja, indutivamente.

Este tipo de detetor impressiona pela sua simplicidade, pela alta sensibilidade e, finalmente, pela variedade de aplicações possíveis, uma vez que pode operar numa ampla gama de amplitudes de sinal, de 100 μA a 2mA.

Palavras Chave

Projeto de Sistemas integrados Analógicos; Tecnologia CMOS; Detetor de Impulsos; Oscilador LC; Recetor Indutivo.

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Acronyms

CMOS - Complementary metal–oxide–semiconductor

DC - Direct current

LC - Inductor Capacitor

LFP - Local Field Potential

RF - Radio Frequency

RFID - Radio Frequency Identification

UWB - Ultra Wide Band

WSN - Wireless Sensor Networks

1

Introduction

Contents

1.1 Motivation

A spike detector can have several applications. We will focus here on three of these main applications, namely a neuron firing detector, Ultra Wide Band (UWB) spike detector, and at other communication levels.

Starting with neurological signals, the human body and anatomy have been subject of studies in the most varied areas. In the 1920's, a German scientist named Hans Berger was the first to show that the human brain was producing electrical currents. Such currents reflected brain activity and could be measured on the scalp using electrodes. [1] Since then, many developments in the area have appeared and Electroencephalography, Brain-Computer Interfaces or even the Thought Translation Device have become topic of interest for various scientists all over the world.

Brain signals are electrical signals and can be divided into two sections, the Local Field Potential (LFP), and the spikes or Action Potential. Both signals are superimposed on an offset associated with the electrodes. LFP are transient electrical signals generated in nervous and other tissues by the summed and synchronous activity of the individual cells in that tissue, and those are slowly varying signals (300 Hz). The Action Potential signals, have higher frequencies (300 Hz – 10 kHz), and those signals are associated with the firing of individual neurons in the immediate proximity of the electrode. [2]

For our receiver, the action potential signals are the ones we are interested on detecting. To do that, our main challenge is to separate the desired action potential signal, from the large offsets and low-frequency disturbances.

In recent years, neural signal decoding has been studied and has been shown to have several benefits to health care, in areas such as paralysis, blindness or deafness. Neural data acquisition can be done with extracellular multi-electrode recording systems that provide raw data signal including neural action potentials (spikes) mixed with noise originated from surrounding neurons (neural noise) and from the acquisition system itself (electrical noise). [3]

A neuron firing detector can have numerous advantages at medical and biomedical level. By detecting a neural signal, or a neural communication on our brain, it can help us to understand how the human brain works, how and when the communications occur between the neurons. By receiving a neural signal, we can react to that stimulus, and make something happen when the stimulus occurs, being able to develop actuators controlled by those signals. Those actuators can vary from controlling a robotic arm or leg, send some wireless signal to a device or even a muscular or nerve stimulation and many other hypotheses that would bring a great benefit for the user.

The UWB is a technical of radio transmission which consists of using signals whose spectrum is spread out over a broad frequency band, typically ranging from MHz to several GHz frequencies. [4] Impulse Radio-UWB is actively being researched as low-cost wireless technology for Ultra Low Power, low data-rate, short-range wireless links in tagging, sensing and medical applications. [5]

An UWB spike detector can be very useful nowadays, it can detect UWB pulses, for short range Wireless Sensor Networks (WSN) or Radio Frequency Identification (RFID), among other applications.

The majority of communications takes place via electrical signals, and these signals must be detected and received. With a spike detector, the reception of the signals can be improved, because it is possible to detect the beginning of the signal, or the signal itself. In this and other ways, a spike detector can play an important role in the treatment of signals in communication systems.

1.2 Objectives

The purpose of this work is to propose a different way to detect energy spikes. It is proposed the hypothesis of developing a spike detector, using an CMOS cross-coupled LC oscillator, studying the possibility of having the oscillator in a resting state, very close to the oscillation threshold for it to start oscillating when the spike signal is received as a kick off signal.

The main objectives for our work were defined: (1) Finding background and theoretical information in the topics covered, namely (A) neural and UWB signals, how they work, and how we could detect them, and (B) Oscillators in general, and the CMOS cross-coupled LC oscillators in particular. (2) Understand and explain the circuit to be used, how it works and how it can be used to receive energy spikes. Estimate possible and intended results. (3) Design, simulate and analyse the final circuit to be implemented. And finally, (4) analyse and discuss the obtained results.

1.3 Outline of the Thesis

The thesis is splitted into five main chapters.

On the first and second chapters it is done an introduction and motivation to the topic, it is explained the foundations of neurological signals, and some basic concepts about UWB. And it is done an overview of existing work and the state of the art of the topic.

The third chapter consists of the receiver architecture, a brief introduction to oscillators is given, speaking about oscillators in general and of CMOS cross-coupled LC oscillator in particular. And at the end, a plan is made on how we implement our receiver.

On the fourth chapter of the thesis, it is done the project and development of the receiver itself. Making all the necessary calculus and simulations to obtain the desired receiver. And taking the reader through the entire process of development of the circuit.

On the fifth chapter, we are able to analyse the results obtained in the simulations performed and compare them with the expected ones.

On the final chapter of the thesis, all the necessary conclusions are drawn, resulting from the results obtained, and from the final result of our circuit.

2

Background and state of the art

Contents

2.1 Neural Signals

Human brain produces electrical signals. In the study of the synaptic function of a human brain, the hippocampus is the most important structure in our memory, for that reason it's also the more studied one. In recent years, field potential techniques have been used to perform high-resolution recording from hippocampus slices. These measurements provide valuable information about the electrical potential produced by neurons outside of the cell. [6]

The recording of brain signals provides valuable information for physiologists and neuroscientists to understand the brain. The recording of those signals has been done using extracellular microelectrode systems, either on the brain surface or deep within the brain [7], MOS transistors have also been successfully used to record neuronal signals. Each one of the two techniques measure the voltages produced by ionic current flow originated from neuronal interactions, as neurons cell membranes depolarize as the result of inputs received from other cells. [7], [8]

The neurological signals we are interested in detecting in this project consist of the neural potentials or "spikes" and represent the electrical half of an electrochemical system, those pulses can be interpreted as coming from action potential currents and have an amplitude around 20μV, a pulse length of 20 to 30 ms, and a frequency content extending up to perhaps 10 kHz. [6], [7]

In 1966, the Stanford University began recording signals from the nervous system using integrated circuit technology to create dense arrays of thin-film electrodes. These first recordings were made using probes that had the general structure shown in Fig. 2.1.

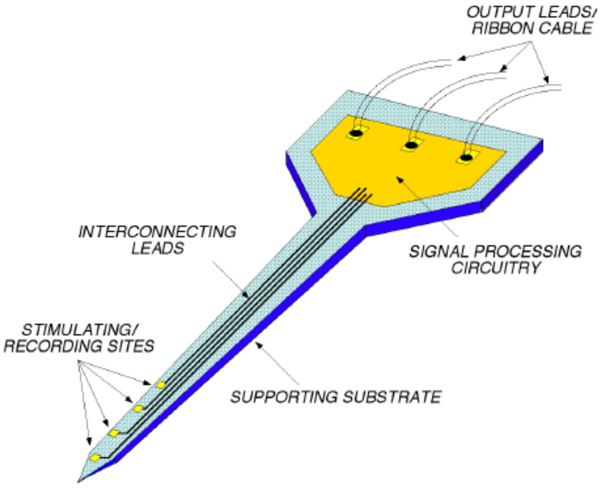

Figure 2.1: Basic structure of a central nervous system probe from [7]

This basic structure of probe is typical of practically all lithographically defined electrode arrays reported since that time. The probe structure consists of a micromachined substrate, with conducting leads insulated above and below by inorganic dielectrics. The recording sites are made by an area of exposed metal. [7]

The acquisition of neurological signals has been the subject of several studies, and different results have been achieved. On Table 2.1 we can see a summary of the performances previously achieved with designs from industrial and academic researchers: [2]

Table 2.1: Neurological receivers

	JSSC '09	ISSCC '10	VLSI '11
Power [hμW]	15	0.64	43
IRNoise (μV), Spike	7.0	14	2.2
Spike Bandwidth	5kHz	6.2kHz	10kHz
NEF	4.6	6.5	5
Vdd [V]	3	0.8	1.2
Area [mmˆ2]	0.04	0.4	0.2
Technology	0.35 μm	0.13 μm	0.13 μm

2.2 UWB

UWB, is a short-range RF wireless communication technology that can be used in multiple fields, be it high-precision location of people or devices with great precision. Like other communication protocols, UWB can be used to transfer data between devices over radio waves. This happens over an extremely wide frequency range.

In 2002, the UWB frequency range was released in USA, defined by the federal communications commission as any wireless transmission scheme that occupies, at least, a fractional bandwidth of 20%, i.e, (BW/ fC) $\geq$ 20%, where fC is the carrier frequency, or more than 500 MHz of absolute bandwidth. [9]

One of the advantages of UWB is that it allows information transfers at higher data rates, while dissipating less power, thus requiring less complex circuitry. With the increasing integration of UWB sensors in consumer electronics like phones or watches, UWB technology is poised to take over the localization market.

In IR-UWB, short pulses are generated for sending data, and for that reason, a spike detector can be used to detect and decode these spikes. That way it can be used in location, communication, and other types of systems. [10]

On Table 2.2 we can see a summary of the performances previously achieved in UWB receivers: [11]

Table 2.2: UWB Receivers

	JSCC 2007	ESSCC 2008	ICUWB 2010
CMOS Process	90 nm	0.18μm	0.13 μm
Frequency	3 - 5 GHz	3 - 5 GHz	3.1 - 10.6 GHz
Sensitivity for 10^{-3} BER	-99 dBM @100 kb/s	-101 dbM @100 kb/s	-78 dbM @ 100 kb/s
Power	36 mW	31.5 mW	25 mW
Modulation	PPM	OOK	OOK
Size	2.2 mm^2	2.8 mm^2	0.7 mm^2

3

Receiver Architecture

Contents

3.1 Oscillators

Oscillators are a key element for most of the circuits nowadays, it's difficult to find any application that doesn't require a periodic signal, whether RF circuits with mixers, digital circuits with clocks, or even analog circuits. This makes oscillators a very important component on many systems at all levels.

An oscillator generates a periodic signal at the output from a DC power at the input, it can be a sine, a square or any other wave form. As such, the circuit must involve a mechanism that is self-sustaining, and that allows its own noise to grow and eventually become a periodic signal. [12]

A good oscillator design requires to have in consideration some aspects like the frequency range, the spectral purity, the amplitude stability or even the phase for the oscillator to have a good response and behaviour.

Another key attribute of oscillators is that these circuits can produce an accuracy and resolution that is much better than an analog output voltage circuit.

Designers are often reluctant to use oscillators due to their lack of familiarity with these circuits. A negative feature with oscillators is that they can be difficult to troubleshoot and may not oscillate under all conditions.

3.1.1 Barkhausen Criteria

Most oscillators can be seen as feedback systems, with a zero or negative phase margin.

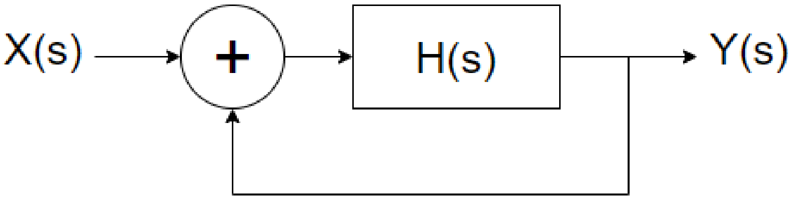

Figure 3.1: Feedback System.

Obtaining the transfer function of the simple feedback system previously shown:

$$\frac{Y(s)}{X(s)} = \frac{H(s)}{1 - H(s)} \tag{3.1}$$

The Barkhausen stability criterion is a mathematical condition to determine when a linear system will oscillate, it establishes two conditions necessary for a steady-state stable oscillation with a ω_0 frequency. The first one is the gain condition, and it says that the loop gain must be unitary:

$$|H(j\omega_0)| = 1 \tag{3.2}$$

The second one is the phase condition, and it says that the open loop phase shift must be $2k\pi$, where k is an integer:

$$Arg(H(j\omega_0)) = 2k\pi, k \in \mathbb{Z} \tag{3.3}$$

The two conditions mentioned above are necessary but not sufficient for the system to oscillate. For the system to oscillate, we need to ensure that there is a loop gain greater than one at the start:

$$|H(j\omega_0)| > 1 \tag{3.4}$$

This condition allows for the system to begin the oscillation, originated by the noise and the positive feedback, until it reaches the steady-state frequency.

3.1.2 Types of Oscillators

There are different types of oscillators, the three most common ones at circuit level are Ring Oscillators, Relaxation Oscillators and the LC Oscillators. This last one will be the one we will use in our circuit.

3.1.2.A Ring Oscillators

A ring oscillator consists of an odd number of inverters, connected in series. Each inverter inputs a propagation delay time (tp). The frequency of oscillation depends directly on the number of inverter stages (N): [13]

$$f = \frac{2}{2 * N * tp} \tag{3.5}$$

The biggest advantage of the ring oscillator is its simplicity and his small dimensions. It takes a small area, and it's a circuit of simple implementation. In terms of behaviour, it can be compared to LC and Relaxation oscillators, but in the other hand, it has a worst phase noise then the LC oscillators referred.

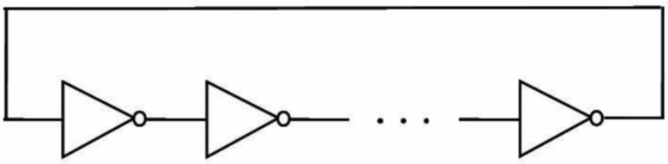

Figure 3.2: Diagram of a Ring oscillator.

3.1.2.B Relaxation Oscillators

Relaxation oscillators are referred to as a first order oscillator, they use passive elements as resistors and capacitors. When compared with the LC oscillators, they are worst on the quality factor, on the phase noise and have a higher power consumption. In the other hand, they are smaller and come at a lower cost.

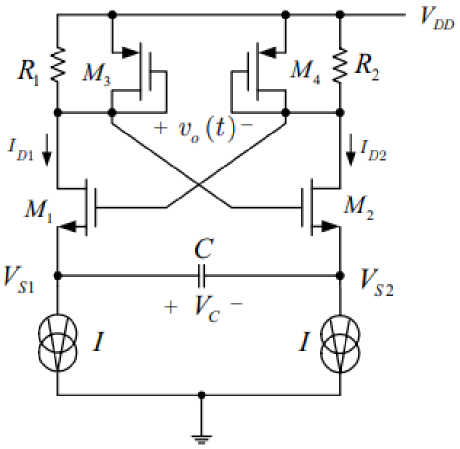

Figure 3.3: Circuit of a CMOS relaxation oscillator from [14]

The above circuit works by charging and discharging a capacitor between two predefined threshold voltage levels, and its frequency can be obtained by:

$$f = \frac{1}{8RC} \tag{3.6}$$

In this case, the Barkhausen criterion cannot be applied, because this is not a linear oscillator.

3.1.2.C LC Oscillators

An LC Oscillator is a circuit with a differential pair, that compensates the losses of an inductor-capacitor network. These oscillators are commonly used in radio-frequency circuits because of their good phase noise characteristics. Other advantages of this type of oscillator are the good quality factor, and the low power consumption.

On the other hand, because these oscillators work with inductors, their implementation occupies a considerable amount of die area. [15]

Its frequency can be obtained by the following equation:

$$f = \frac{1}{2\pi\sqrt{LC}} \tag{3.7}$$

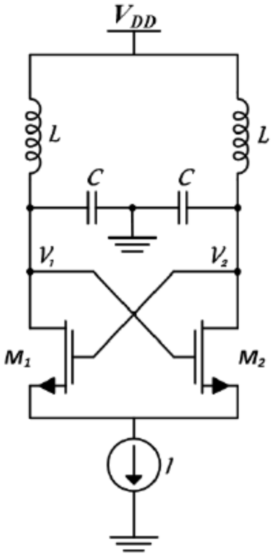

Figure 3.4: Circuit of a LC oscillator
from [16]

The cross-coupled LC oscillator contains a tank circuit and a cross-coupled pair. The cross-coupled pair serves as a negative resistance or a negative impedance in a small signal operation that allows the oscillation to start. In large signal operation, the cross-coupled pair also acts as a regenerative circuit.

CMOS differential cross-coupled LC oscillators have a superior phase noise performance, and this reason makes them widely used. Its designs process is not trivial, although the small number of components, it is necessary to consider the trade-off between the phase noise and power consumption. Cross-coupled oscillator can be constructed by using only PMOS or only NMOS devices or using both (CMOS). The selection of which topology to use is made based on the application, and on theoretical and simulation models.

Tail noise filtering or sinusoidal tail shaping have been part of the different attempts to improve the phase noise response, yet the cost-performance effectiveness of such techniques has not been well-discussed in the literature. [17]

A conventional Cross-coupled oscillator is shown in Fig.3.4 This oscillator can operate in two regimes related to the dc value of Itail: Current limited regime and voltage limited regime.

3.2 Planning

By analysing the three oscillators referred, we realize that our best option is the LC oscillator. Because with the LC oscillator we can have a linear oscillator, and we can obtain the best phase noise. Those characteristics are important, even if we must consume a larger circuit area.

We start to propose a development of an CMOS cross-coupled LC oscillator, with the objective of receiving a enrgy spike. To achieve that objective, the oscillator will work in a state very close to the oscillation threshold, so close that a very small spike can serve as a kick-off and make the oscillator turn ON, while ensuring a consistent start-up behaviour.

The start of the oscillation will be the indication that a energy spike has occurred, that oscillation will work as an amplifier for the spike signal both in time and in amplitude.

The base plan for our project will start from the circuit shown in Figure 3.5:

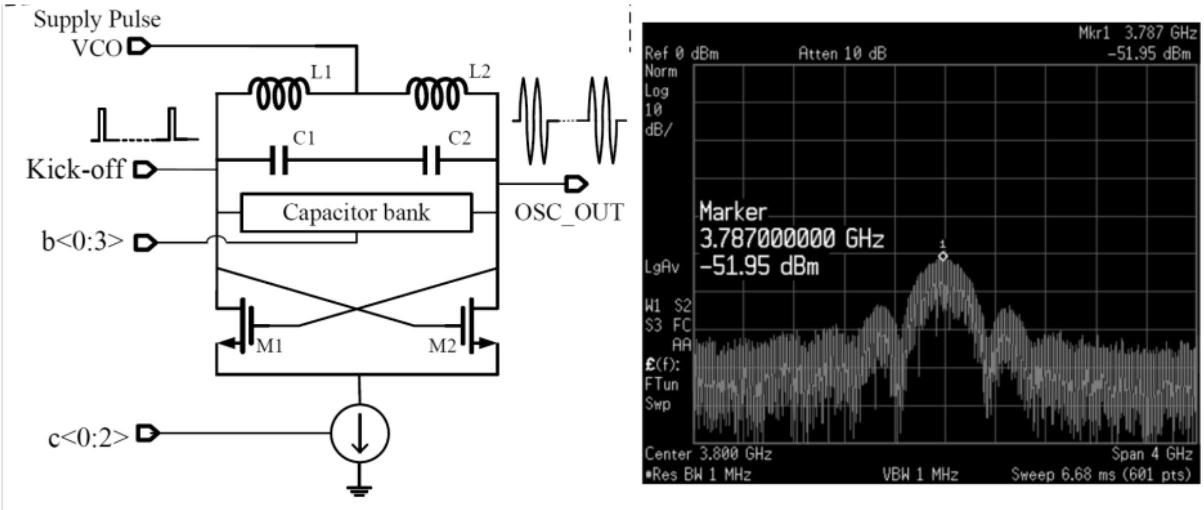

Figure 3.5: Receiver architecture and measured waveforms from [5]

4

Circuit Implementation

Contents

4.1 Oscillator Design

The starting point of this project was to design an LC oscillator based on the circuit shown on Figure 3.5. We started by looking for a functional oscillator, and we found an LC oscillator in AMS 0.35 μm, with a supply voltage of 2V with the circuit parameters $(W/L) = 50\mu m$, $I = 2mA$, $L/2 = 10nH$, $2C = 420fF$, making an oscillation frequency of 2.4GHz through the following equation: [16]

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

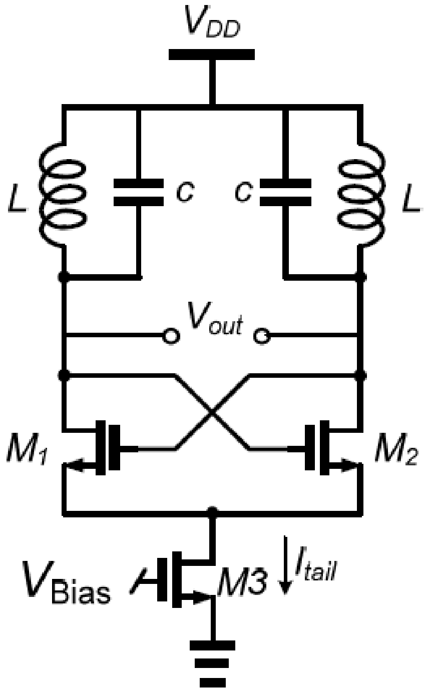

Figure 1. Conventional Cross-Coupled Oscillator.

Figure 4.1: Basic LC Oscillator
from [16]

The oscillator was designed with the previously mentioned values, and it was made with the following circuit:

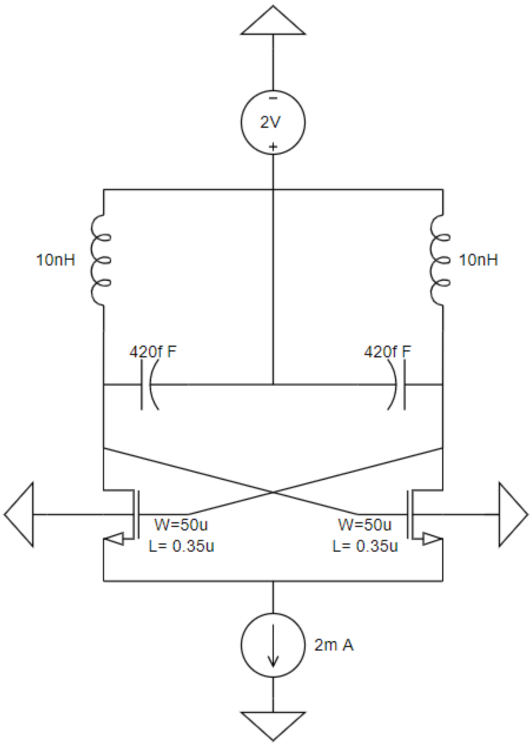

Figure 4.2: LC Oscillator circuit

Some simulations were made to test if obtained results of the initial oscillator correspond to the expected ones. A noise signal had to be generated to create some instability that causes the oscillator to start. The obtained results can be seen in the following graph:

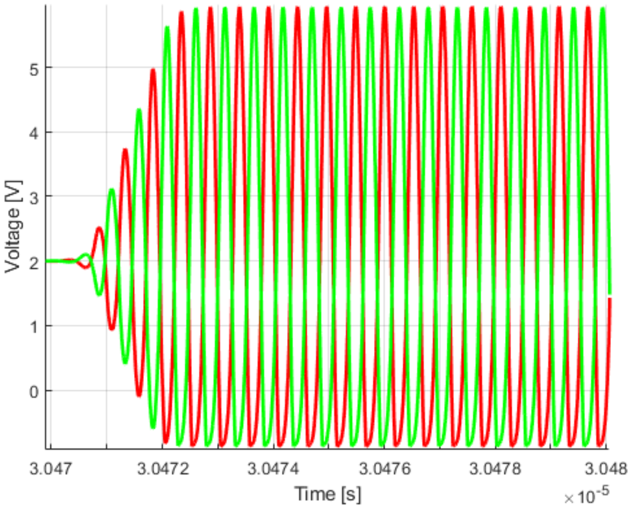

Figure 4.3: Oscillator output

When the LC oscillator was working with the desired frequency and characteristics, we started to reduce its Tail current until it stopped oscillating, that way, we ensure that by the point the oscillator no longer starts, we will be as close as possible to the oscillation threshold, and that any disturbance in the circuit will be the sufficient for the circuit to start oscillating. We can then create that disturbance with our input signal.

The point where the oscillator stopped, occurred when the Tail current was reduced to around 500 μA, so that was the starting point on the development of our spike detector.

4.2 Signal Input

The first tests on the oscillator were made creating a voltage input. To do that, an impulse with 20 μV was generated and was inputted on the left side of the oscillator, simulating a neural spike. With that spike we were able to obtain some oscillation from the reaction of the oscillator to that small voltage pulse, those oscillations had a good aspect, as the oscillator starts and then it reduces by itself, but we had no gain on the obtained signal, and almost no duration as we can see in Figure 4.4. So, although it was a good starting point, that was not what we were looking for. We started to realize that the 20 μV could not be enough to create a good reaction on the oscillator, and there for our sensor would not be able to receive and amplify the voltage spike.

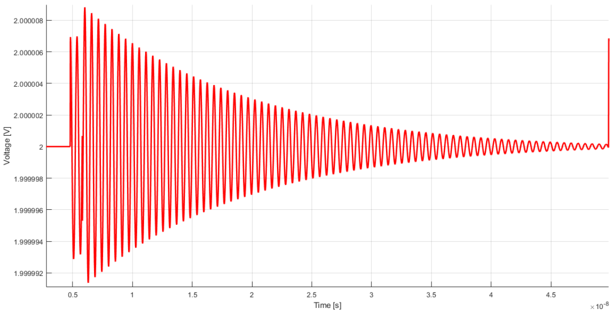

Figure 4.4: Output of voltage input

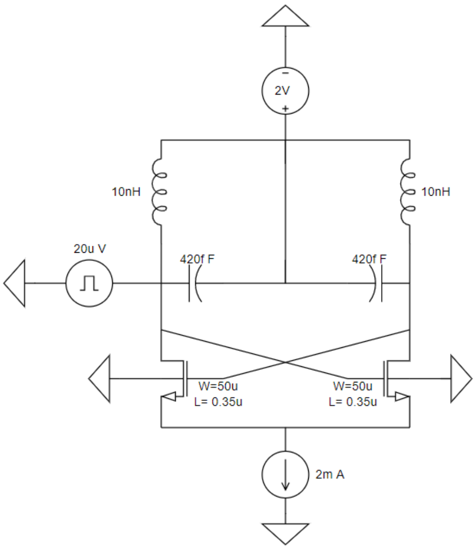

Figure 4.5: Voltage input circuit

As an alternative method to the voltage input, the possibility of the spike being received as a current has been studied.

With that came the idea of have an input of energy on the inductor. That way the signal could be received by the magnetic field of another inductor, creating a receiver that could work without contact. By transmitting energy inductively through the coils. The energy transmitted on the coil would depend on its size, and on the current that passes through it:

$$Energy = \frac{1}{2}LI^2 \tag{4.2}$$

The way to simulate this method would be to input a signal through a transformer.

But in order to avoid the use of transformers for this first part of the development, we opted to use an input signal as a spike of current at the end of the inductor. With the current being inputted that way, we were also inputting energy through the inductor.

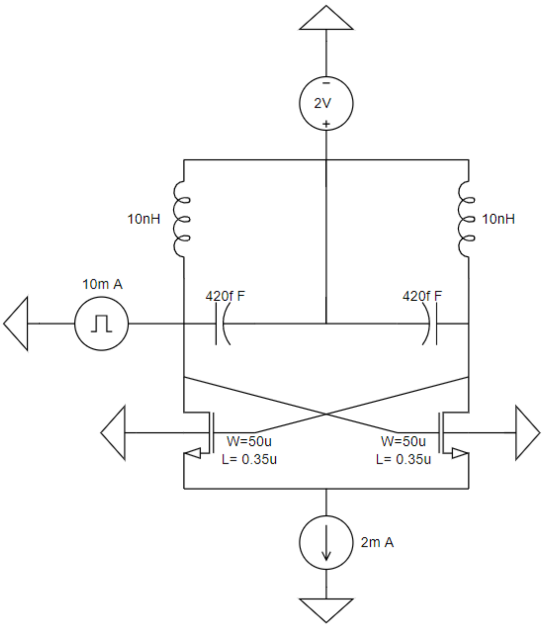

Figure 4.6: Current spike input circuit

In our first experiments, we could only detect a current spike of about 10 mA, while the sensor had a tail current of 2 mA. These were first good results, but still very far from our goal, because we had to detect much smaller signals than these 10 mA.

The process continued, and with some changes on our circuit, like increasing the transistors size to 150 μm, we were able to detect current spikes smaller than 1 mA. Some more fine tuning and we were able to reduce the tail current to 500 μA again, and our sensor was reacting to signals as small as 100 μA.

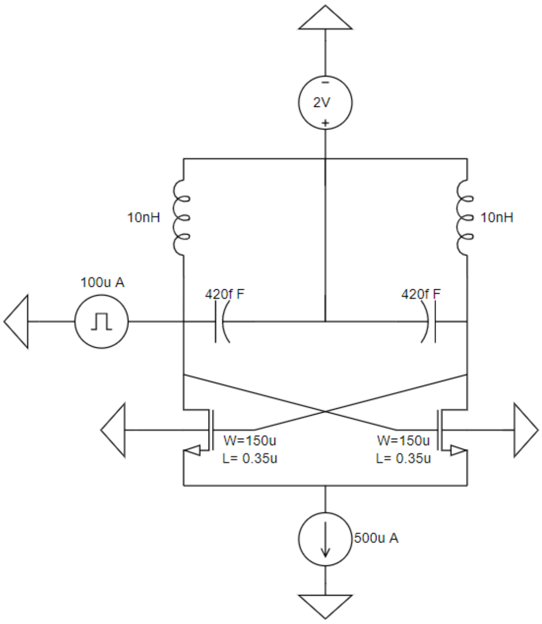

Figure 4.7: Low Energy input circuit

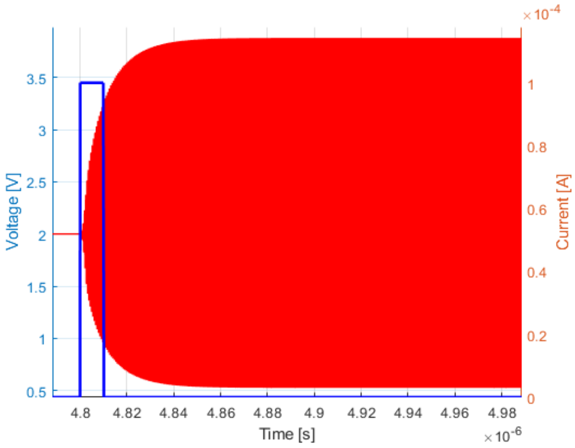

Figure 4.8: Oscillations start response

Like we can see in the image, our sensor was now starting oscillating when a current spike of just

100 μA is received. We are now facing a plausible current of a neurological signal. But the oscillation doesn't stop no more. Once it receives the signal, the oscillator stars and doesn't stop oscillating. So, we needed to find a way to stop the oscillation in order to be able to receive more than one signal over time.

4.3 Oscillation Stop

The best way to stop the oscillator, is to cut off its current. So, we changed its Tail current in order that it goes to zero sometime after the current spike that we generated had occurred.

That was made just by creating a pulse on the Tail current, synchronized with the input signal, making sure that the Tail current went to zero a few moments after the signal input ended, and the oscillator had started. In future work, this could be done with a comparator, being able to detect the start of the oscillation, and cut the current automatically after the oscillator had reacted to the signal. That way being able to receive more signals after the first one. With the setup used for this project, the circuit can also receive multiple signals over time, but those signals needed to be synchronized with the oscillator current.

After some tests and simulations, we were able to make the circuit work as we expected.

The obtained results can be seen in the following graph:

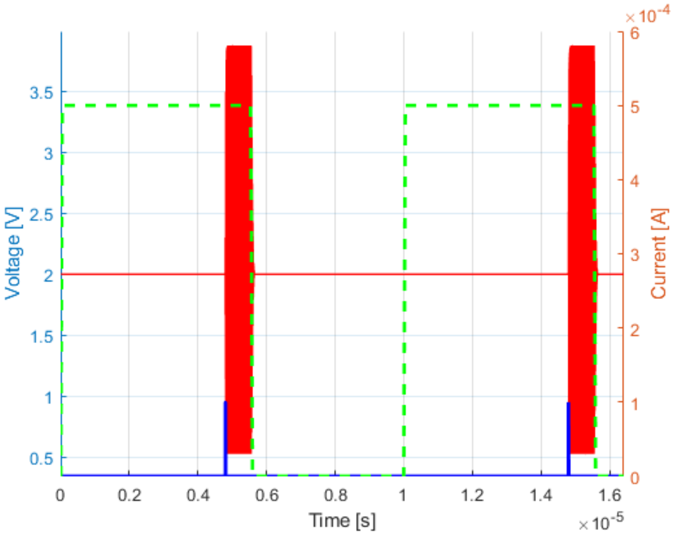

Figure 4.9: Output with current cutting

4.4 Inductive Input

Now that we have the receiver working as we planned, we can now test the same circuit, but with an inductive input. To check if we could have our circuit to operate in an inductive way.

Some research was made in order to find a model of a transformer that matched our needs, and that existed in Cadence libraries.

The best model we could find to use as a transformer was the one on analogLib, called xfmr.

The circuit was redesigned, to make the input impulse to be generated as energy, and being transmitted to the receiver by the transformer, simulating that way the reception of the signal inductively. That signal was generated as a current and inputed on the transformer, creating energy when the current passes by the coil, and transmitting that energy to the secondary coil on the transformer, that represents the inductor on the oscillator.

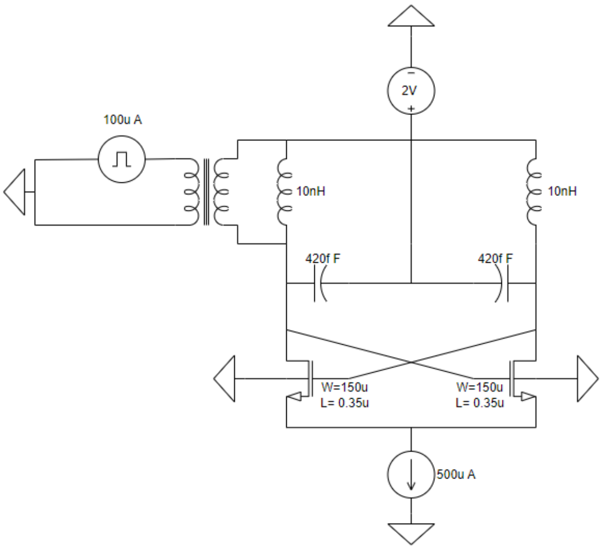

Figure 4.10: Circuit with transformer

After some tests, we were able to make our sensor to react to signals received inductively, and that way, our sensor is now able to detect signals through the magnetic field, without any contact.

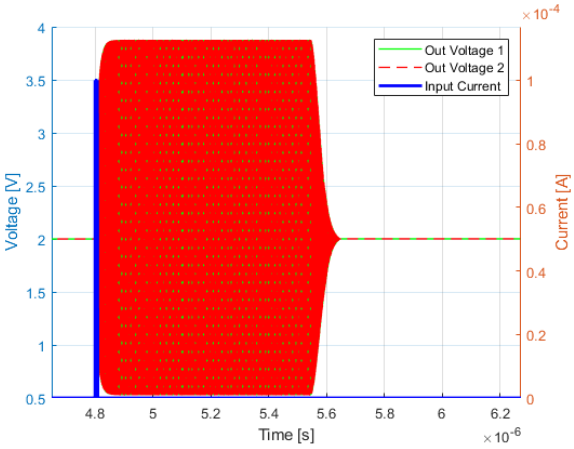

Figure 4.11: Output with inductive input

As it is possible to see in Figure 4.11, the obtained results with the transformer were very similar to the ones obtained previously, it means that the circuit works as we expected, and works just as well with the signal being introduced with a wire or inductively.

With this method to detect signals, our circuit can be used wireless, not just to detect neural or UWB signals but also any other type of spikes, without the need of a wired contact.

5

Results and Analysis

Contents

Having the circuit working as we wanted, we can now obtain and analyse the results from it. Some simulations were made to obtain the results presented in this chapter.

5.1 Circuit Results

The final version of our receiver can be seen in Figure 4.10, on the previous chapter.

Analysing the obtained graph, in Figure 4.11, it is possible to verify that our receiver is capable to detect very small signals, where neurological and UWB signals are included. A spike of just 100 μA can be enough to start the oscillator, and that way be amplified in both time and amplitude. The voltage amplitude of the amplified signal reaches values greater than 3V. At the time level, the current cut in the oscillator can be done with some kind of delay, allowing the signal to be prolonged for the necessary time. And the obtained signal, can be used as a result that informs the user of the occurrence of a spike signal.

When the detection is successfully done, it can be used to all kinds of applications. Either for medical purposes, detecting neural signals to control robotic prostheses. At UWb communications, or in any other way, to control other types of devices.

5.2 Shortest detectable spike

Knowing that the receiver can detect signals small as 100 μA, it's now time to test shortest signal in time that we can receive. After a few more tests and simulations, we were able to detect a signal as short as a picosecond. That spike is so short that it can almost be considered a Dirac.

This makes our detector to have a very high sensitivity, which can be very useful in the detection of fast signals.

5.3 Spike Detector

Through the previous results, we can conclude that our circuit may have other applications besides the detection of neurological and UWB signals. The ability to amplify current spikes can be used in many types of sensors.

And the fact that it can detect signals as small as 100 μA or as large as 2mA, gives us a wide variety of possible applications. Adding the possibility of the spike being detected by induction, without the need of a direct and wired connection to the circuit. This type of detector can be used to detect and send information about spikes in any type of signal, that the user may be interest in.

As a last aspect, we can observe that the receiver takes about 0.6 μs to reach its maximum oscillation. In this way, this would be the minimum gap between the detection of two spikes, in order to the detector have enough time to stop oscillating and be in a state where it can pick up a new signal.

6

Conclusion

Contents

6.1 Conclusions

This thesis shows the development of a spike detector using a LC oscillator. A brief review of the state of the art with respect to existing detectors is given, considering their characteristics and various applications.

A study is made of the different types of oscillators, with the conclusion that the LC oscillator is the best choice for our detector.

Starting from a simple LC oscillator, an input signal is generated, and it is tried that this signal is sufficient to start the oscillator. Some experiments have been done with the type and amplitude of the signal, and the final choice is an input signal in energy. When the oscillator is already started with the input signal, the current is interrupted to stop the oscillator and allow it to receive new signals.

After the circuit is working, a way to receive the input signal inductively through the coil without wires connecting the signal to the circuit is developed and tested using a transformer.

When the final circuit is ready and working, some testing is done, and the final conclusions are drawn.

The developed circuit is able to detect spikes from 100 μA up to 2mA. It can be used in various applications, such as neuron firing detector, UWB spike detector or communication level.

6.2 Future Work

In this thesis, ideal components were used, so in order to make sure that the circuit really works as described, it will be necessary to change its components to real ones. After the simulations are performed with the real components, the layout model can be developed, fabricated and tested, in order to test the circuit in practice.

A feature that could be added to the circuit would be a filter, in order to clean the signals received. That way, the receptor could be used to detect and amplify only spikes above a certain threshold.

The last thing to do in the developed circuit, would be the part that interrupts the current signal sometime after receiving a spike, so that the oscillator can stop and receive new spikes. This could be done with a comparator and some buffers. The comparator could analyse the output of the oscillator and, if it detects a signal, it interrupts the current for the oscillator bias.

When using the developed circuit for a specific application, it can be adapted and improved to better meet the required specifications.

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