Spike Detector using a LC Oscillator

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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.

1. Introduction

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

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).[4]

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 Ultra Wide Band (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.[5] 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. [1]

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.

2. Background

2.1. 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.

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.

2.2. LC Oscillator

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.[2] Its frequency can be obtained by the following equation:

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

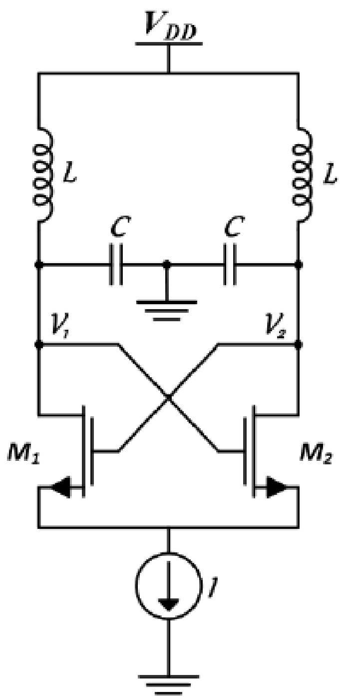

Figure 1: LC Oscillator.

3. Implementation

The starting point of this project was to design an LC oscillator based on the circuit shown on Figure 1. 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 µm, I = 2mA, L/2 = 10nH, 2C = 420fF, making an oscillation frequency of 2.4GHz.[3]

3.1. Initial oscillator

The oscillator was designed with the previously mentioned values, and it was made with the circuit sown in Figure 1. Some simulations were made to test if the results of the initial oscillator correspond to the expected. 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:

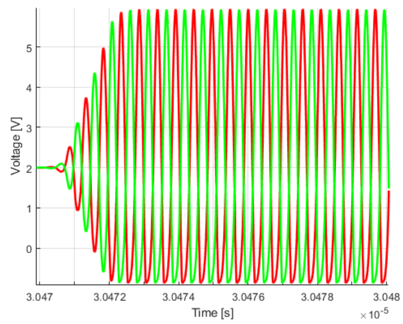

Figure 2: Working Oscillator.

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, it 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.

3.2. Signal input

Using the oscillator on the steady point preveasly found, we tried to input a signal in voltage and in current, obtaining the best results with the last one. Later we chose to change that input to a energy input in the coil, that could be received inductively.

After some tests, our sensor is starting to oscillate when a current spike of just 100 µA is received as an input. As we can se in the following graph:

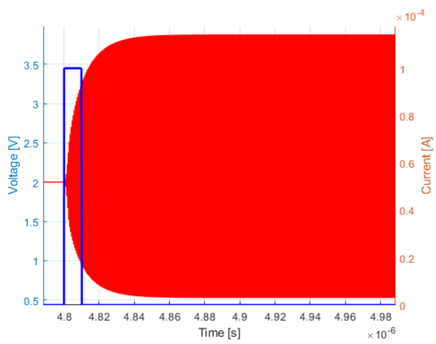

Figure 3: Detector not stopping oscillating.

We are now facing a plausible current of a neurological or UWB 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.

3.3. 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. The obtained results can be seen in the following graph:

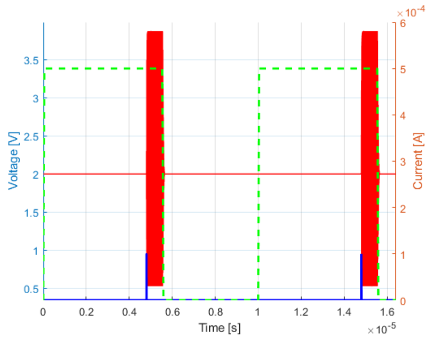

Figure 4: Working Detector.

3.4. Inductive Input

Now that we have the receiver working as we planned, we 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 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.

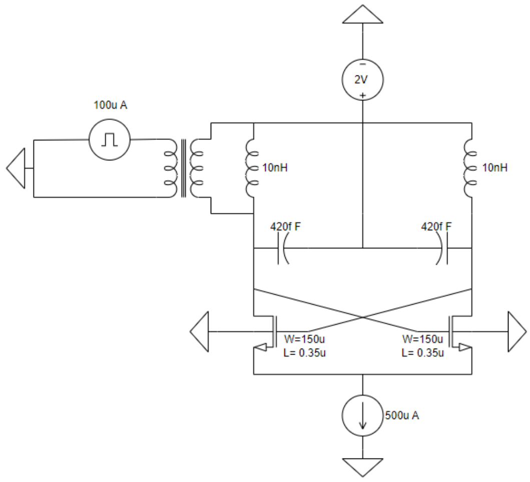

Figure 5: Circuit with transformer.

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.

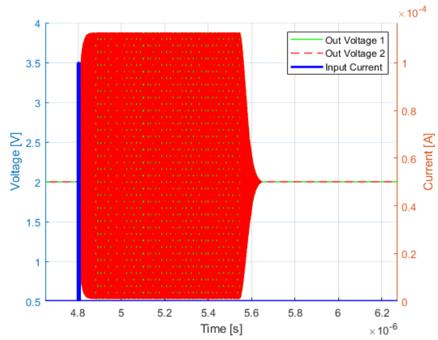

Figure 6: Output with inductive input.

As it is possible to see in Figure 6, 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 and UWB signals but also any other type of spikes, without the need of a wired contact.

4. Results

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.

4.1. Circuit Results

The final version of our receiver can be seen in Figure 5, on the previous chapter. Analysing the obtained graph, in Figure 6, 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 the 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 an electrical spike. 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.

4.2. 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.

4.3. Spike detector

Through the previous results, we can conclude that our circuit may have other applications besides the detection of neurological 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.

5. 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.

5.1. 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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