Lab session 1. Morse

Generating and detecting Morse signals.

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In this lab session, we will generate a Morse code signal and study some of the steps required to receive and decode Morse code signals.

> ATTENTION: Remember that paragraphs like this one indicate work you must complete individually as previous work. Also note that to access the lab and carry out the session, it is mandatory to submit the preliminary report via Atenea before the lab session.
> For this lab session, you must bring all the necessary lab materials: a protoboard, cables (banana-banana, BNC-banana, and BNC-BNC), and the required tools (wire cutters, wire strippers, tweezers, etc.). As always, the lab will provide the required components, and rigid wire will also be available for your use.

1 The Morse Code

Morse code is a method of transmitting textual information using a signal that is turned on and off over predefined time intervals. It generates sequences of short and long signals, separated by spaces, known as *dots* i *dashes*, respectively. A significant feature of Morse code is its encoding system. The duration of each symbol is approximately inversely proportional to its frequency of occurrence in English. For example, the most frequent letter in English, "E", has the shortest code: a single dot.

Morse code was used to transmit information via radio waves before it was possible to transmit voice. Moreover, Morse code remains highly effective in long-distance radio communications, where signals arrive with very low amplitude and are affected by noise: it is relatively easy to distinguish the presence or absence of a high-pitched tone within noise, much more so than identifying full spoken words.

The international Morse code defines five elements:

- The *dot*, which has a duration of one time unit. This can be symbolized with `1`.
- The *dash*, with a duration of three time units. Symbolically, `111`, that is, a length three times longer than the dot.
- The gap between the elements of a character (letter or number), with a duration of one time unit. The symbol can be `0`.

- The gap between characters, lasting three time units, and represented as `000`.
- The gap between words, with a duration of seven time units, `0000000`.

> *Previous Work* 1. Search for information about Morse code and encode your first name and surname using this code, following the rules described above. As always, it is not only about giving the answer, but also about commenting on it!

2 Generation of Morse signals

Morse signals can be generated in the laboratory by adjusting a function generator to produce a periodic signal, at a frequency that we consider most pleasant to the ear. By using a push button, we can control whether this signal reaches its destination or not.

The model of this setup is represented in Figure 1. The operator activates the push button or switch, which causes the output voltage to be a fraction of the input voltage. Considering that $R_G = 50\Omega$ is the resistance of the generator and that the element receiving the signal—such as an amplifier—often has a very high resistance, the signal loss is therefore almost negligible.

In order to experiment comfortably and in a controlled way in the laboratory, it would be useful to have a system capable of generating the Morse signal automatically, without requiring one of the two team members to operate the push button. For this purpose, we have developed a Morse signal generator that produces the call `SOS`, which could even be useful on certain occasions.

This generator, shown in Figure 2, is controlled by a clock signal of approximately 1 kHz. A first counter outputs a signal every 100 pulses, which corresponds to the duration of a dot. A second counter counts the number of dots or spaces, and a decoder block, which is a combinational block (LUT), outputs a signal equal to 1 or 0 depending on the current value of the counter. In fact, it is a ROM where each position stores whether the Morse signal should be 1 or 0. You will notice that the cycle repeats every 34 pulses.

With this configuration, the signals shown in Figure 3 are generated. The signal `PIN_4`, whose name indicates the pin where it can be found in the laboratory, is the Morse code signal, which could be used, for example, to light up an LED. On the other hand, the signal `PIN_5` is used to drive a loudspeaker directly: a signal with the same frequency as the input clock is generated during the dots and dashes, while during the gaps the signal is 0.

With the described system, a change in the clock frequency produces a change in the tone generated at `PIN_5`, but it also modifies the time duration of the dots and dashes.

Task 1. In the laboratory, you will be given a properly programmed CPLD. Power it up with 3.3 V, adjusting the laboratory power supply accordingly. Limit the current to a reasonable value that allows the CPLD to operate correctly (around 30 mA or 40 mA). Once the CPLD

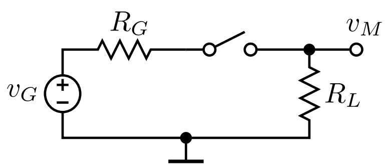

Figura 1: Basic generation of a Morse signal.

is working properly, connect it to CH3 of the laboratory power supply, making sure to set it to 3.3 V.

Please remember that the CPLD is mounted on a printed circuit board. Below we provide the correspondence between the CPLD pin number (as indicated in the instructions) and the pin number on the board where you will need to make the connections.

Power supply:	PIN 32 of the board
Ground:	PIN 16 of the board
Clock:	PIN 10 of the board
CPLD PIN 4:	PIN 6 of the board
CPLD PIN 5:	PIN 5 of the board
CPLD PIN 6:	PIN 1 of the board
CPLD PIN 12:	PIN 31 of the board

Task 2. With the function generator, we will produce the required clock signal. Use the TTL output. You can adjust the frequency to a value close to 16 kHz.

Task 3. Verify in different ways that the generator is working correctly.

3 More flexible generation

To easily experiment with variations of the signal, one option is to use a laboratory function generator and adjust it to provide a *sinusoidal* signal with the desired frequency and amplitude

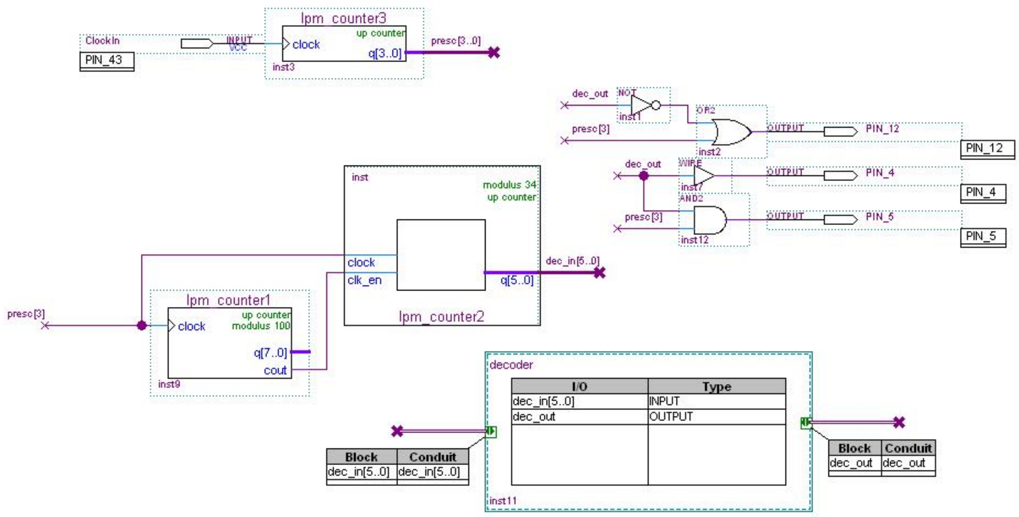

Figura 2: Block diagram of the generator

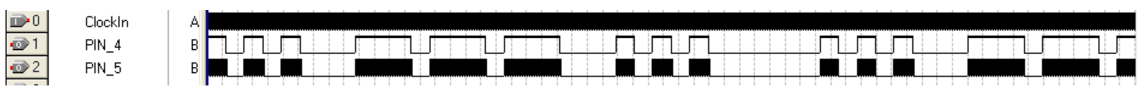

Figura 3: Timing diagram corresponding to the SOS signal.

(audible and pleasant to the ear). Then, by means of an analog switch controlled by the CPLD, we could implement the circuit shown in Figure 1, obtaining the signal we are looking for.

For this, we would need an integrated circuit of the 4066 type, which includes 6 analog switches, but this would add one more integrated circuit to the setup. An alternative way to obtain a Morse signal, starting from a sinusoidal signal provided by an external function generator, is the one shown in Figure 4, where $v_G(t) = A\cos 2\pi f_0 t$, R_G is the internal resistance of the generator (50 Ω), and R prevents excessive current from flowing each time the switch is closed.

The advantage of this configuration is that, to implement the switch function, we can use a CPLD output configured in tri-state mode (Figure 5). You will recall that tri-state outputs have a control signal that allows the output to be placed in high-impedance mode, where the output node is isolated.

> *Previous Work* 2. Within the CPLD, a tri-state buffer can be routed to the output. When the control signal is high (1), the buffer is active: a 0 or 1 at the input is passed through as a 0 or 1 at the output, respectively. When the control signal is low (0), the output is in high-impedance state. Based on the signals shown in Figure 3, design the input signal and the control signal for the tri-state buffer.

Task 4. Knowing that `PIN_6` performs the switch function, build the circuit corresponding to Figure 4. Your function generator will be occupied generating the CPLD clock. Therefore, the sinusoidal signal $v_G(t)$ will come from the common line that runs across all workstations. We will have adjusted it to 100 mV. We will use a value of $R = 1$ kΩ. Check the output by viewing the signal on the oscilloscope and by listening to it with a loudspeaker. Note the difference when you change the frequency.

Note: The voltage $v_G(t)$ will be centered around zero. This means that it will take positive and negative values. According to the CPLD manufacturer, the voltages cannot be more negative than -0.5 V. This means that the technique in Figure 4 can only be applied to signals with sufficiently small amplitude, as is the case with the laboratory signal line.

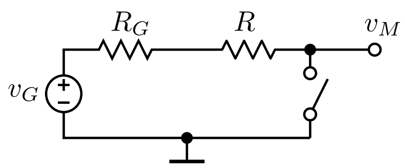

Figura 4: Generation from a sinusoidal signal and a switch.

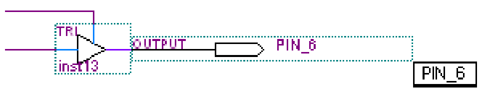

Figura 5: Tri-state buffer.

4 Detection

The Morse signal can be decoded by a person who knows the code (and is sufficiently trained!). However, we could think of building an electronic detector: a circuit that, from the signal captured by a microphone, would be able to present the transmitted message in a human-readable form. This could be a task to carry out with a microcontroller such as an Arduino...

In this laboratory exercise, we will perform some of the steps needed to achieve this goal: amplification and envelope detection.

The envelope detector is a circuit that, from the signal $s(t) = A(t)\cos 2\pi f_0 t$, with $A(t) \geq 0$, is able to reconstruct $A(t)$. This is illustrated in Figure 6.

A circuit that can achieve this objective is shown in Figure 7 and consists of a diode and a parallel RC combination. If we consider the diode as ideal, it can be in two states, ON and OFF. More precisely, it is characterized by a constitutive relation that is:

$$\begin{array}{ll} \text{State ON:} & v(t) = 0 \text{ if } i(t) > 0 \\ \text{State OFF:} & i(t) = 0 \text{ if } v(t) < 0 \end{array} \tag{1}$$

Then, the operation of the circuit in Figure 7 can be more easily understood by first considering the case $R \to \infty$, that is, replacing the resistor with an open circuit. In this case, we can follow the reasoning below:

- Let us assume that the capacitor is initially discharged.
- When V_G begins to become slightly positive, we must consider the state of the diode:
  - If it were OFF, then the voltage across its terminals would be positive, contradicting the hypothesis that $v(t) < 0$.
  - If it were ON, then there would be no voltage across its terminals and the current would be positive: this is reasonable, since this is the current required by the capacitor to charge. Therefore, it is ON.

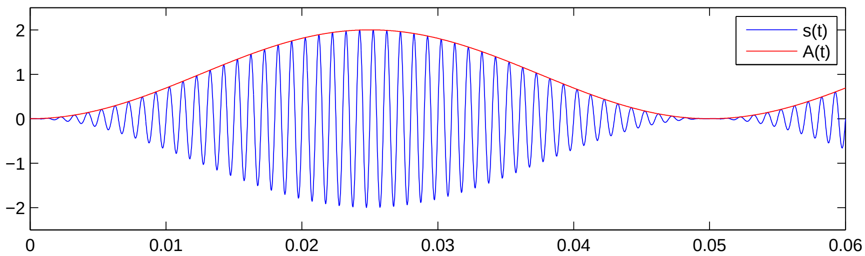

Figura 6: A signal and its envelope.

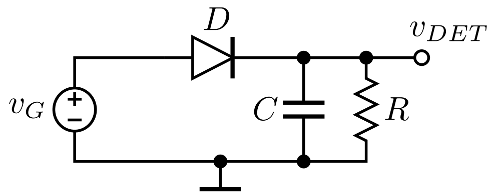

Figura 7: The envelope detector.

- The ON state is maintained until the input voltage begins to decrease. If it remained ON, then the capacitor voltage would also have to decrease, which would make the diode current $i(t) < 0$, contradicting the ON hypothesis.

- Therefore, while the input voltage continues decreasing, the diode remains OFF and the capacitor voltage does not change.

- The diode will return to the ON state when the input voltage rises above the voltage stored in the capacitor, and so on.

The result of this process is shown in Figure 8, where we can see that the circuit eventually behaves as a detector of the signal's maximum value.

A finite value of R causes the capacitor to discharge exponentially toward zero when the diode is OFF. The discharge process ends when the input voltage equals the capacitor voltage, at which point the diode switches to ON. The result can be seen in Figure 9. The discharge time constant, $\tau = RC$, must be chosen carefully. If it is too low, there will be excessive ripple. If it is too high, information is lost when the envelope decreases faster than the exponential.

Finally, Figure 10 shows how a real envelope detector would approximately reconstruct the envelope. The ripple present in the signal can be removed with circuits that we will study later on.

In practice, the diode will not be ideal, but the behavior of the overall circuit will not deviate much from what is expected.

Previous Work 3. Given the type of signal to be detected, choose values for R and C to achieve reasonably satisfactory detection. Provide any relevant considerations!

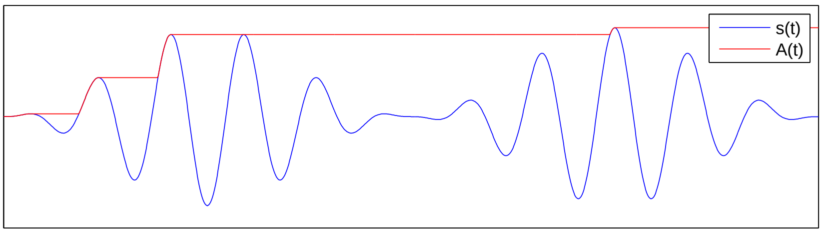

Figura 8: The circuit operating as a peak detector.

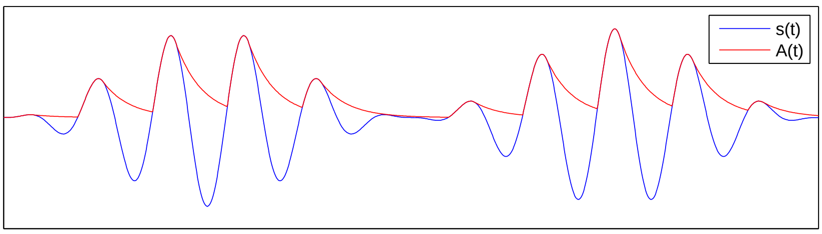

Figura 9: The resistor produces exponential decreases between peaks.

Later on, we will consider receiving the signal with a microphone, which will require amplifying the signals. To approximate this situation, in this part of the lab we will work with relatively low amplitudes of the Morse signal, on the order of tens of millivolts.

Previous Work 4. Design a circuit capable of amplifying Morse signals to obtain volt-level amplitudes. This circuit will be followed by the envelope detector described above.

Task 5. Build the amplifier according to your preliminary design. Verify that it works correctly with a sinusoidal signal. Then connect it to the output of the circuit built in the previous task and check that the circuit amplifies it correctly.

Task 6. Build the envelope detector and verify that you are able to reconstruct a signal similar to `PIN_4`. What is the effect of the diode not being ideal?

5 Advanced questions

If you listen closely to the signal generated at `PIN_5` (Figure 3) through PC speakers, you will notice that the sound is accompanied by slightly unpleasant *clicks*. In fact, if we try to listen to the signal at `PIN_4`, we only hear *clicks*. On the one hand, our hearing is not able to interpret very low-frequency signals (such as those at `PIN_4`) as sound. On the other hand, the amplifier built into the speakers does not amplify very low frequencies either.

To fix this problem, we should be able to generate a signal without low-frequency components. Below we guide you toward a solution.

One of the advantages of people trained in both the analog and digital domains is that they are able to seek (and find!) mixed solutions.

The idea is as follows: if we were able to generate the signals shown in Figure 11, expanded in Figure 12, and obtain a signal equal or proportional to their analog sum, we would obtain a sufficiently interesting signal.

Previous Work 5. From the signals shown in the block diagram of Figure 2, how is the `PIN_12` signal generated? Consider other ways to generate it.

Previous Work 6. Draw the simplest possible circuit that produces a signal equal to (or proportional to) the analog sum of `PIN_5` and `PIN_12`. Sketch the resulting signal, indicating all the details you consider relevant.

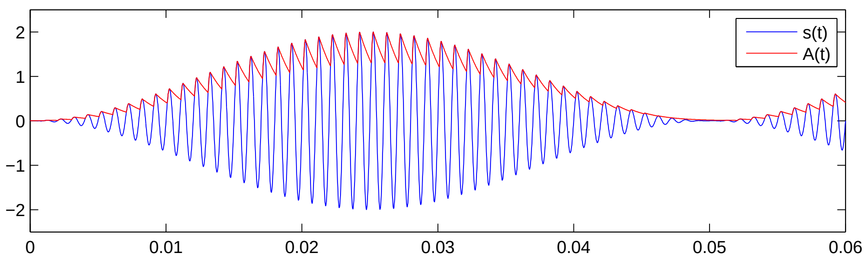

Figura 10: The signal recovered with the envelope detector.

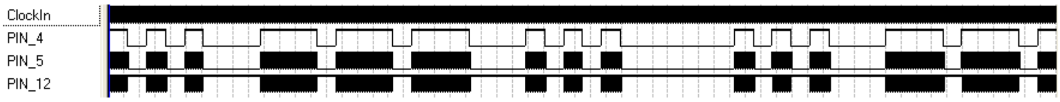

Figura 11: Generation of the auxiliary signal PIN_12.

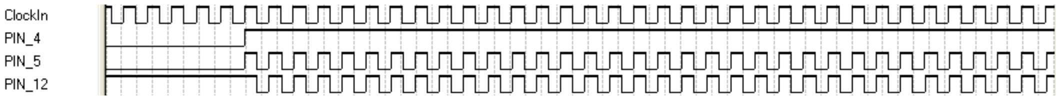

Figura 12: Detail of the auxiliary signal PIN_12.

Previous Work 7. Compare the sketch obtained with the `PIN_5` signal. Draw how the average value taken by the two signals over the 10 clock cycles immediately preceding each instant of time changes over time (the so-called moving average). Comment on the result!

Task 7. Listen to the `PIN_5` signal in the laboratory. Then build your solution, listen again, and note the difference.