Methods of the use for capacitive touch keys on RL78G13 Renesas microcontroller

Application note

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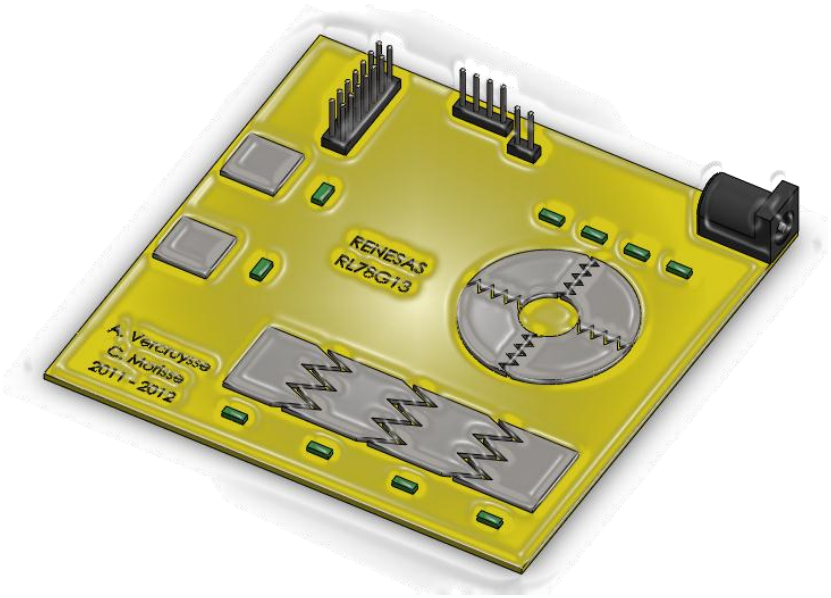

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Chapter 1 Introduction

The capacitive touch keys[1] have been on the market for several years. They are used in many electronic applications and particularly in the household appliance.

However, the main problem of this type of capacitive touch keys is the detection and the use for these keys, when the used microcontroller is not equipped with a dedicated port.

This application note was realized for the project "Development a software library for capacitive touch keys on RL78G13 Renesas microcontroller" at Polytech'Clermont-Ferrand in 2011. The purpose of this project, submitted by Renesas Electronics Company, aims at the realization of an electronic board, which will be able to handle the capacitive touch keys of the new corporate microcontroller, the RL78G13. In concrete terms, the challenge is to develop a library while implementing the low power consumption of this new microcontroller, which does not have a dedicated port in order to handle capacitive touch keys.

On the first part, this application note will deal with the physical principle and the design of capacitive touch keys. A second part concerns the algorithms of the detection of capacitive touch keys, including a square key, a slider, and a touch wheel.

[1] In order to facilitate the comprehension of this note, we use the abbreviation ”key” as “ capacity touch key”

Chapter 2 Operating principle of capacitive touch keys

The main advantage of keys is as follows: the system works like a switch without a mechanical contact. Consequently, the major drawback is the detection of contact on these keys.

A key is realized as follows:

- A protective surface which protects the surface of the keys (1),
- A layer of copper which represents the shape of the keys (2),
- The thickness of the electronic board (3),
- A ground area (4).

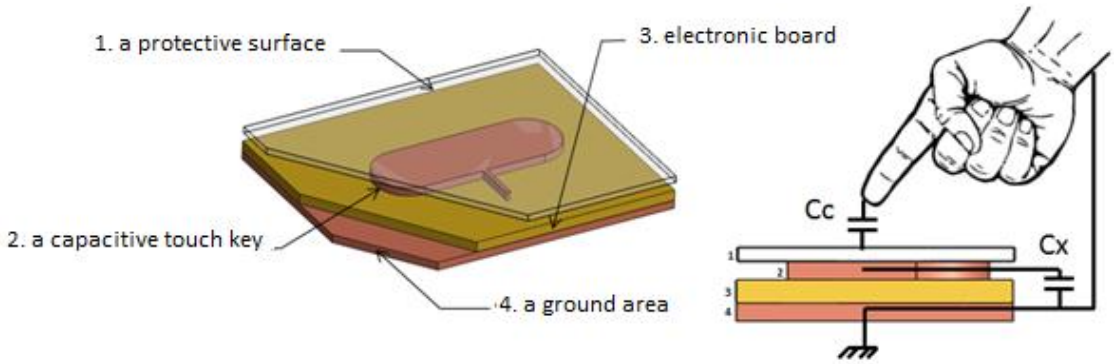
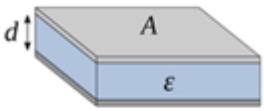


Figure 1 : illustration of capacitive touch key

The structure of a key is equivalent to a capacity. The value of this plane capacity can be calculated by the following formula:

$$C = \varepsilon o \,.\, \varepsilon r \,.\frac{A}{d}$$



εo represents to the permittivity of vacuum,
εr represents to the relative permittivity of the dielectric
A is the area of drivers vis-à-vis,
d is the distance between the two conductors.

In electronics, the capacity of capacitor reveals its ability to store the electrical charges on his frames. However, the main feature of a capacitor is its charge curve and its discharge curve through a resistor.

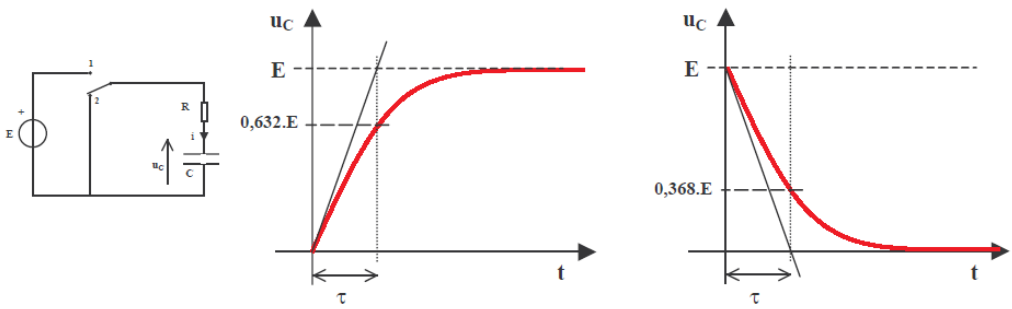


Figure 2 : charge curve and discharge curve of a capacitive through a resistor

When the human finger is in contact with a key, the impact of the finger changes the appearance of the charge curve together with the one of the discharge curve of capacity through a resistor. Indeed, there is a transfer of electrical charges between the finger and keys, which enables to distinguish two cases:

- A press on the key
- No key is pressed.

2.1. No key is pressed

In the case where there are no human actions on a key, we only have a plan capacity named Cx[2].

2.2. A press on the key

When there is a human action on a key, we have another plan capacity whose the value is different from the Cx capacity. The action creates a Cc capacity in parallel with the Cx capacity. This new capacity changes the appearance of the charge curve together with the one of the discharge curve of capacity through a resistor.

When there is a contact on the keys, the appearance of the discharge curve of capacity will discharge more slowly in comparison with the discharge curve without human contact.

Thus, the detection of a key press will be realized by measuring the discharge time.

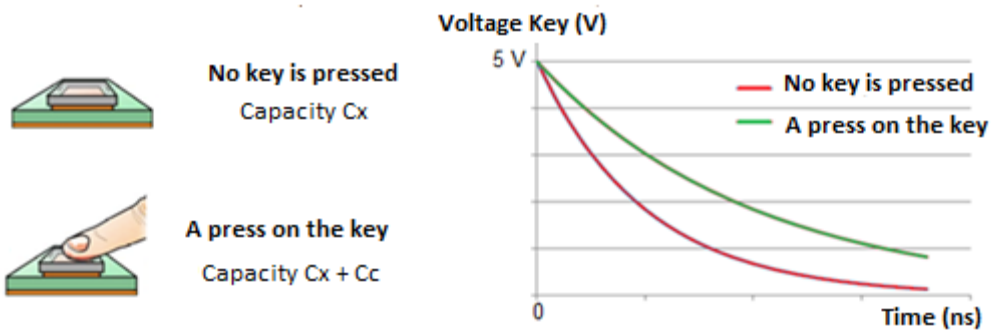


Figure 3 : illustration of working

[2] Cf. Figure 1 : illustration of capacitive touch key page 4

Chapter 3 Design of capacitive touch keys

3.1. Circuit diagram

In order to detect a contact, a RC parallel circuit connected on a programmable port of the RL78G13 microcontroller has been realized. The detection of contact is performed by the failing edge of the keys. The charge/discharge process consists in charging the keys by setting a high level on the output pin and then by putting the pin in input. This time of charge is instantaneous due to the used unit of measurement of keys, the nano Farad (nF).

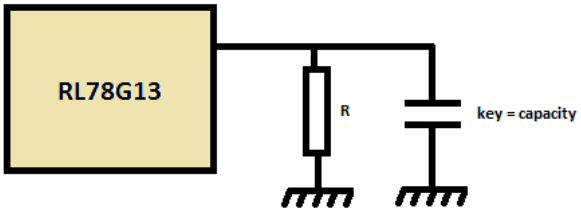


Figure 4 : circuit diagram of a key

3.2. Ground area

The ground area is not necessary. The input pins of RL78G13 microcontroller go from a high level '1' to low level '0' when the voltage of the input pins reaches the threshold of the half of the supply voltage (Vdd) of the microcontroller, either Vdd / 2.

Subsequent to different performed tests, with an electronic board without ground area, the result is a difference of time more important between the times separating the appearances of the discharge curves (Vdd/2).

Basis of the performed test:

- Resistor of discharge : 2.2 Meg-ohm,
- Square key,
- Size of square key: 20 mm x 20 mm.

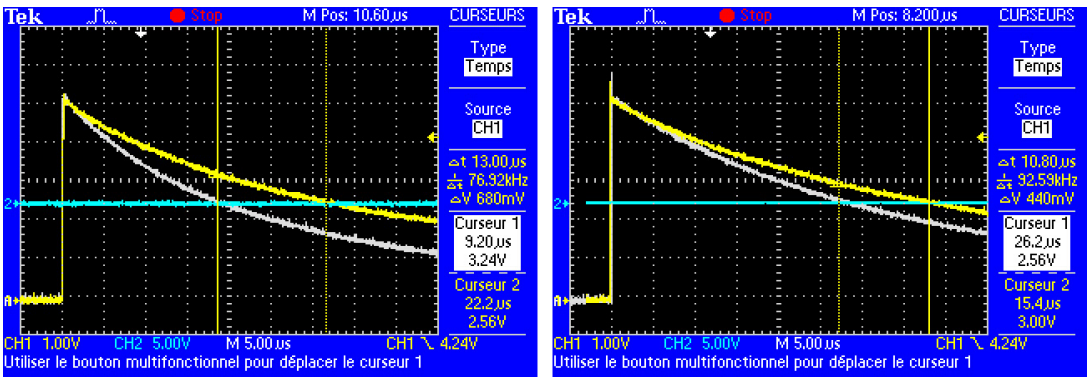


Figure 5 : measures of the time of a discharge without ground area (left) - measures of the time of a discharge with ground area (right)

Remark:
In order to working the different algorithms of detection, these algorithms were tested on keys. The design features of different keys were calculated by the formula page 4 with:

- the permittivity of vacuum = 8,86 pF/m,
- area of human contact = 78 mm²
- the distance between the two conductors = 1 mm,
- the relative permittivity of copper = 3,5
- the relative permittivity of Plexiglas = 3,3
- Vdd = power supply of microcontroller.

3.3. Size of square keys

10 x 10 mm is the dimension of a square key.

	capacity of key	time of charge until Vdd/2
A press on the key	3,1 pF	2,76 µs
No key is pressed	2,27 pF	2,03 µs

3.4. Size of slider's keys

The slider has 4 keys whose its dimension is 15 x 58.2 mm. The area of two end keys is 180 mm ². The area of interior keys is 210 mm ².

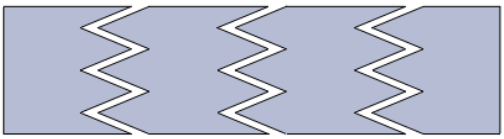
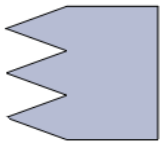
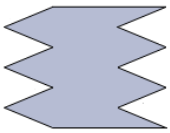


Figure 6 : représentation of slider



	capacity of key	time of charge until Vdd/2
A press on the key	5,56 pF	4,9 µs
No key is pressed	2,27 pF	2,03 µs



	capacity of key	time of charge until Vdd/2
A press on the key	6,51 pF	5,6 µs
No key is pressed	2,28 pF	2,1 µs

3.5. Size of first wheel's keys

This wheel owns 4 identical keys. The area of each key is 149 mm². The interior diameter is 10 mm and the outdoor diameter is 30 mm.

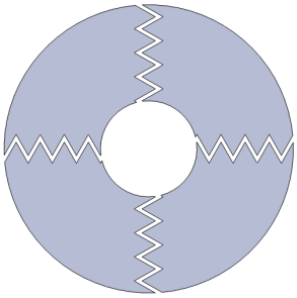
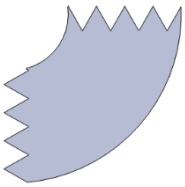


Figure 7 : représentation of first wheel



	capacity of key	time of charge until Vdd/2
A press on the key	4,6 pF	4,11 µs
No key is pressed	2,27 pF	2,025 µs

3.6. Size of second wheel's keys

This wheel owns 3 identical keys. The area of each key is 184 mm². The interior diameter is 10 mm and the outdoor diameter is 30 mm.

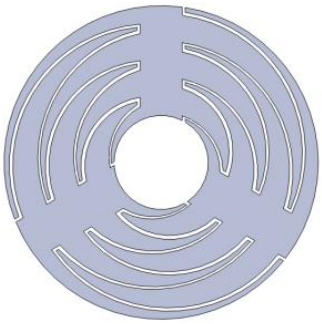


Figure 8 : représentation of second wheel

	capacity of key	time of charge until Vdd/2
A press on the key	5,7 pF	5,08 µs
No key is pressed	2,28 pF	2,04 µs

Chapter 4 Detection of a contact on the square keys

The purpose is to detect a human action on the square keys.

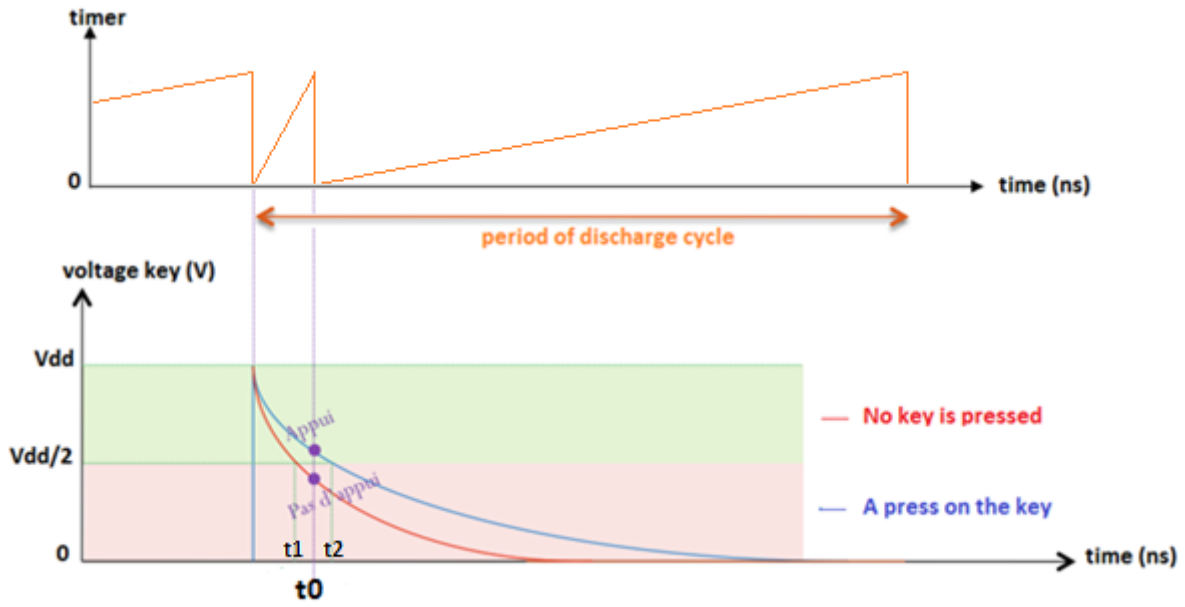


Figure 9 : illustration of detection of contact on the square keys

This method consists in

- running the discharge of the keys,
- waiting for a definite time t0.
  This value of this time is defined by

$$t0 = \frac{t1 + t2}{2}$$

- reading the value of the port to check if there is some contacts or not.
  If the reading of a pin is a high level '1', there is human contact on the square key. Otherwise, there is no human contact.
- After the reading of the state of the key, the value of the timer is changed in order to have a regular scanning. This value corresponds with rest of a scanning where we know that the state of keys has a low level. This time is adjusted by the value of timer.

This method is able to read states of several keys at the same time.

Chapter 5 Detection of the direction of linear movement on the slider

The purpose is to detect a linear movement on the slider. Two methods of detection can be implemented.

5.1. First method of movement detection

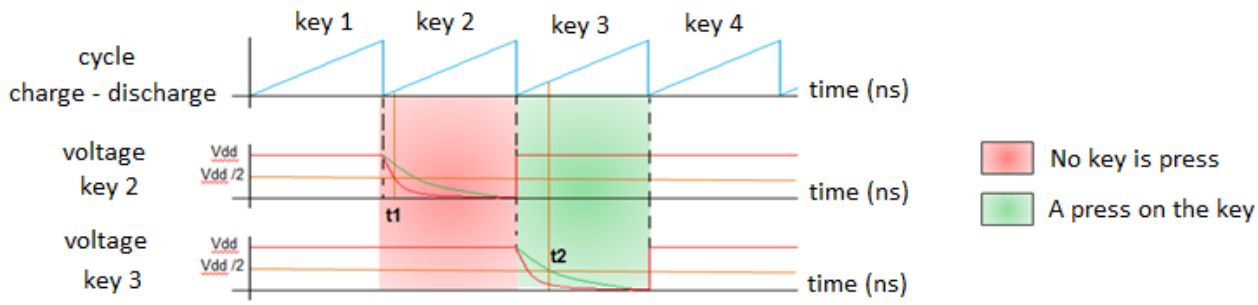


Figure 10 : illustration of the first method – slider

This method consists in programming a timer in order to charge and discharge the keys periodically. The use for a timer permits to measure the elapsed time after a discharge of key until the detection of failing edge.

The failing edge of the key is detected by an interruption when the state of pin of microcontroller from a high level '1' to a low level '0'. Subsequent to the generation of this interruption, the reading of the discharge time (t1 and t2) determines the state of the key. The reading of time t1 means the key is inactive[3]. The time t2 means the key is active[4]. However, this method does not allow the reading of several keys at the same time.

In order to detect the falling edge of the capacity, the "Key Interrupt" block has been implemented. This design feature is able to generate a single interruption in the microcontroller for multiple input pins. The "Key Interrupt" block is often used to handle keyboards.

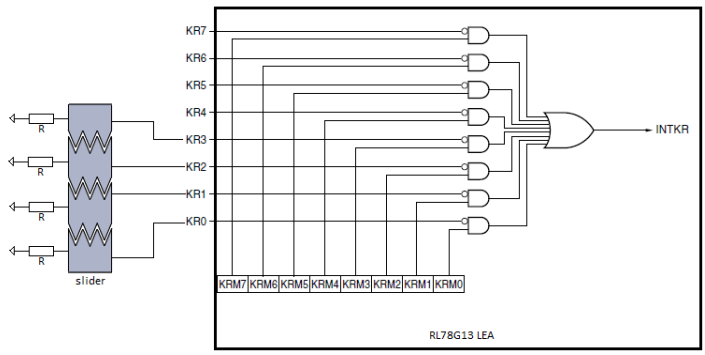


Figure 11 : illustration of "Key Interrupt" block

[3] *Inactive means that there is not contact on the key.*
[4] *Active means that there is a contact on the key.*

The detection of linear movement on the slider is based on the difference between the position of the active key[5] and the position of the next active key.

In order to determine the position of the active currently key, it is obligatory to have an initialization step of all keys. The storage of the discharge time of keys without human contact (t1) is guaranteed. The memorized time of each key will be compared with the value of the time of discharge of keys (t2), when the algorithm will work.

t2 > t1 : a key is active
t2 ≤ t1 : no action on the key [6]

Moreover, a margin of adjustment was introduced. Indeed, the rough idea of the resistor of discharge is Meg-ohm. This large value can introduce noise in the electronic board. This margin will avoid that a key is active whereas there are no human actions on the keys.

5.2. Illustration of the algorithm of detection

We have chosen that the direction "up" represents a movement from left to right on the slider. The direction "down" is the opposite movement.

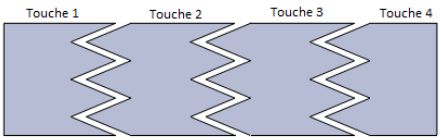


Figure 12 : position of keys

Active key	Next Active key	Direction on the slider
no direction	1	no direction
1	2	1 – 2 = -1 direction up
2	3	2 – 3 = -1 direction up
3	4	3 – 4 = -1 direction up
4	3	4 – 3 = 1 direction down
3	2	3 – 2 = 1 direction down
4	2	no direction
2	3	2 – 3 = -1 direction up

In conclusion, this first method needs a timer and a "Key Interrupt" block to be implemented on a RL78G13 microcontroller. The time of discharge of all keys can be adjusted by the value of timer.

[5] *The term "active touch" means there is a human action on one of the slider's keys. In this case, the value of discharge time of an active key is the time t2 at least.*
[6] *This comparison will permit to know the active currently key. A key will be active if the timer of discharge of the key is higher than initialization time t1. Otherwise, there are no human actions on the keys.*

5.3. Second method of movement detection

This second method consists in scanning the states of keys on the slider periodically. A finite-state machine has been implemented to detect the movement on the slider.

The detection of support is identical to the square key.[7]

The human action can introduce a contact with several keys simultaneously by this method. This means that keys can be active simultaneously. The finite-state machine is designed to "filter" these particular cases and to detect the linear movement.

5.4. Finite state machine: movement detection

This finite state machine is synchronous with the cycle of discharge of all keys.

The detection of movement is not affected in a state of the machine, but the passage of transitions only when the direction "up" or "down" is detected. Otherwise, there is no detection of movement on the slider.

The finite state machine will return to its original position (step 0) when it will detect the following combinations:

- Three keys and more are active at the same time,
- No key is active.

On the following figure, the initialization step is step 0. For reasons of readability, the combinations, which are able to have an access of the initialization step, do not appear on the following diagram.

Meaning of transitions:
The transition "T1 actif" means that the key T1 is only active.
The transition "T2 actif" means that the key T2 is only active.
The transition "T3 actif" means that the key T3 is only active.
The transition "T4 actif" means that the key T4 is only active.

Meaning of affectation
The term “sens = up” means that the direction of contact on the slider is the direction “up”.
The term “sens = down” means that the direction of contact on the slider is the direction “down”.

[7] Cf. Chapter 4 Detection of a contact on the square keys page 7.

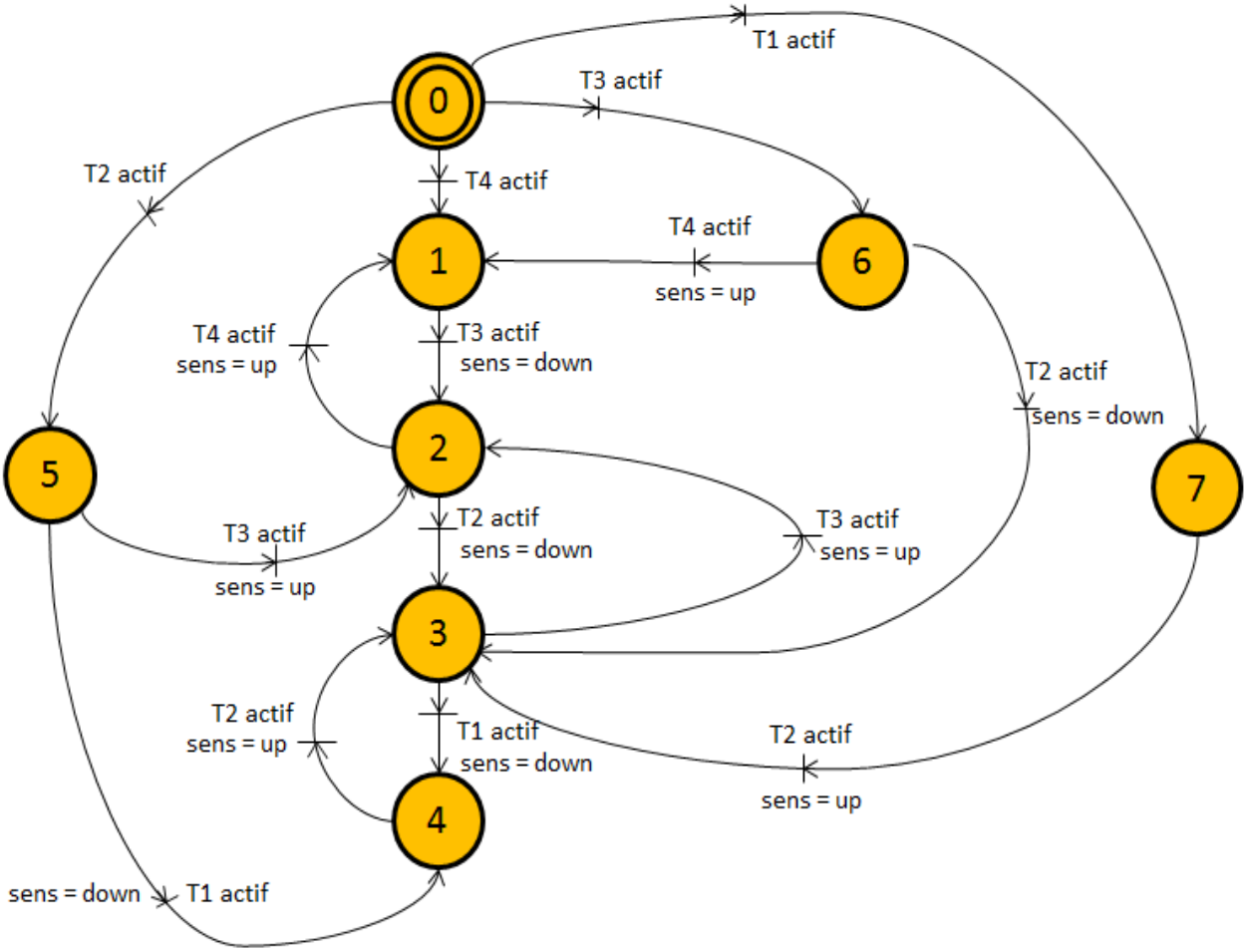


Figure 13 : finite state machine - slider

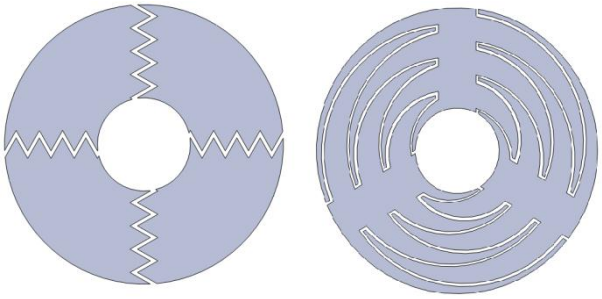
To sum up, this method uses I / O standards and a timer to set the time of the discharge of keys. The main advantage of this method is to read more keys simultaneously. The main drawback is the power consumption by the continuous scanning of all keys. The time of discharge of all keys can be adjusted by the value of timer.

Remark for the two method of movement detection

For a reactive response, the cycle of the charge and discharge of the keys must be between 10 ms and 20 ms.

Chapter 6 Detection of the direction of movement on the wheel

The purpose is to detect a circular movement on the wheel. Two methods of detection can be implemented in accordance with the shape of wheel.



The first wheel has a shape where the keys are fitted together, in contrast to the second wheel. For this wheel, the detection of movement can be realized by the same technique than the first method of detection of the movement on the slider.

However, this method cannot be implemented with the second wheel. When there is a human contact on the second wheel, this contact can activate several keys. In order to overcome this constraint, a finite state machine can be realized to detect the direction of movement.

6.1. First method of movement detection[8]

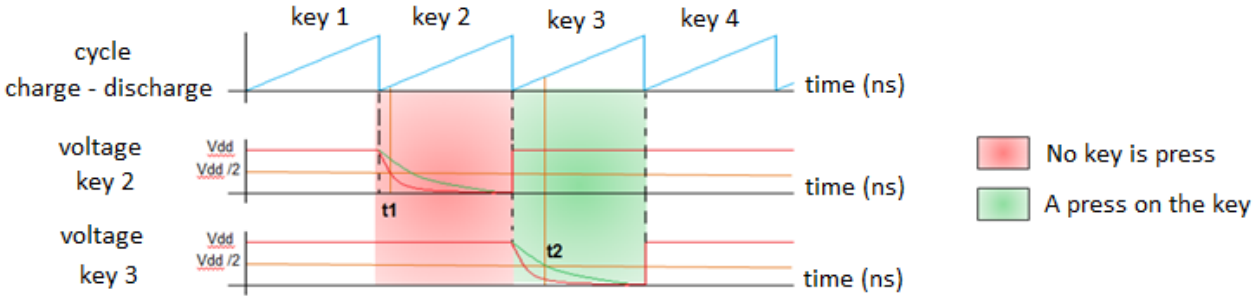


Figure 14 : illustration of the first method – first wheel

This method consists in programming a timer in order to charge and discharge the keys periodically. The use for a timer permits to measure the elapsed time after a discharge of key until the detection of failing edge.

The failing edge of the key is detected by an interruption when the state of pin of microcontroller from a high level '1' to a low level '0'. Subsequent to the generation of this interruption, the reading of the discharge time (t1 and t2) determines the state of the key. The reading of time t1 means the key is inactive[9]. The time t2 means the key is active[10]. However, this method does not allow the reading of several keys at the same time.

[8] Please notice that the principle of the first method is the same as one for the slider.
[9] *Inactive means that there is not contact on the key.*
[10] *Active means that there is a contact on the key.*

In order to detect the falling edge of capacity, the interrupt input pins (INTP) were implemented. These pins are able to generate an interrupt further to the detection of a rising and/or falling edge.

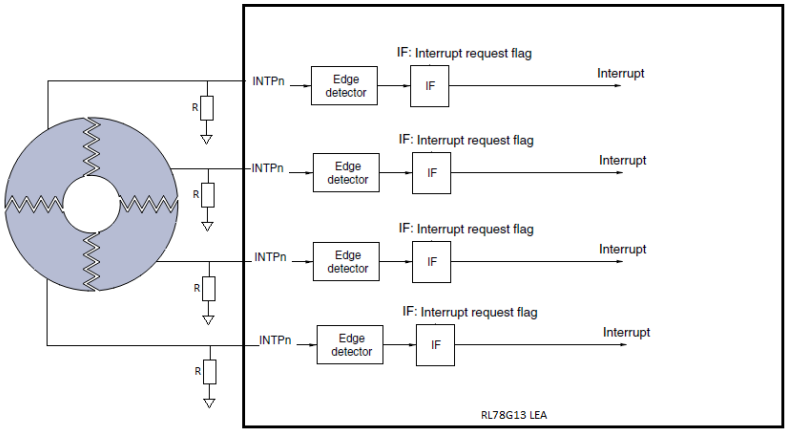


Figure 15 : illustration of INTP bloc

The detection of linear movement on the slider is based on the difference between the position of the active key[11] and the position of the next active key.

In order to determine the position of the active currently key, it is obligatory to have an initialization step of all keys. The storage of the discharge time of keys without human contact (t1) is guaranteed. The memorized time of each key will be compared with the value of the time of discharge of keys (t2), when the algorithm will work.

t2 > t1: a key is active
t2 ≤ t1: no action on the key [12]

Moreover, a margin of adjustment was introduced. Indeed, the rough idea of the resistor of discharge is Meg-ohm. This large value can introduce noise in the electronic board. This margin will avoid that a key is active whereas there are no human actions on the keys.

6.2. Illustration of the algorithm of detection

It was arbitrarily chosen that the direction "up" represents a movement of the clockwise. The direction "down" is the opposite movement.

[11] *The term "active touch" means there is a human action on one of the slider's keys. In this case, the value of discharge time of an active key is the time t2 at least.*
[12] *This comparison will permit to know the active currently key. A key will be active if the timer of discharge of the key is higher than initialization time t1. Otherwise, there are no human actions on the keys.*

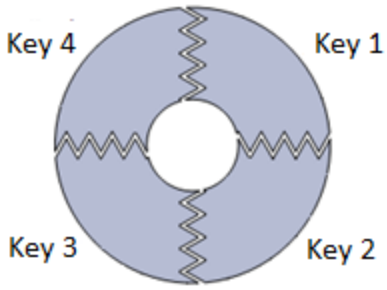


Figure 16 : position of keys

Active key	Next active key	Direction on the wheel
no direction	1	no direction
1	2	1 – 2 = -1 direction up
2	3	2 – 3 = -1 direction up
3	4	3 – 4 = -1 direction up
4	1	4 – 1 = 3 direction up
1	2	1 – 2 = -1 direction up
2	1	2 – 1 = 1 direction down
1	4	1 – 4 = -3 direction down
4	3	4 – 3 = 1 direction down
3	2	3 – 2 = 1 direction down
2	4	no direction
4	3	4 – 3 = 1 direction down

In conclusion, this first method needs a timer and the interrupt input pins (INTP) to be implemented on a RL78G13 microcontroller. The time of discharge of all keys can be adjusted by the value of timer.

6.3. Second method of movement detection

This second method consists in scanning the states of keys on the slider periodically. A finite-state machine has been implemented to detect the movement on the slider.

The detection of support is identical to the square key.[13]

The human action can introduce a contact with several keys simultaneously by this method. This means that keys can be active simultaneously. By this type of wheel, there are always two active keys. The finite-state machine is designed to "filter" these cases and to detect circular movement. The detection of direction of movement on the wheel 2 will be realized by the combinations of two active keys at the same time.

[13] Cf. Chapter 4 Detection of a contact on the square keys page 7.

6.4. Illustration of the algorithm of detection

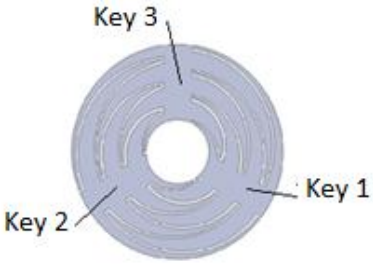


Figure 17 : position of keys

Active keys	Next active keys	direction
T1 : no active T2 : no active T3 : no active	T1 : active T2 : active T3 : no active	no
T1 : active T2 : active T3 : no active	T1 : no active T2 : active T3 : active	up
T1 : no active T2 : active T3 : active	T1 : active T2 : no active T3 : active	up
T1 : active T2 : no active T3 : active	T1 : active T2 : active T3 : no active	up
T1 : active T2 : active T3 : no active	T1 : active T2 : no active T3 : active	down
T1 : active T2 : no active T3 : active	T1 : no active T2 : active T3 : active	down

6.5. Finite state machine: movement detection

This finite state machine is synchronous with the cycle of discharge of all keys.

The detection of movement is not affected in a state of the machine, but the passage of transitions only when the direction "up" or "down" is detected. Otherwise, there is no detection of movement on the slider.

The finite state machine will return to its original position (step 0) when it will detect the following combinations: No key is active.

On the following figure, the initialization step is step 0. For reasons of readability, the combinations, which are able to have an access of the initialization step, do not appear on the following diagram.

Meaning of affectation
The term “sens = up” means that the direction of contact on the wheel is a movement of the clockwise.
The term “sens = down” means that the direction of contact on the wheel is a movement of the anti-clockwise.

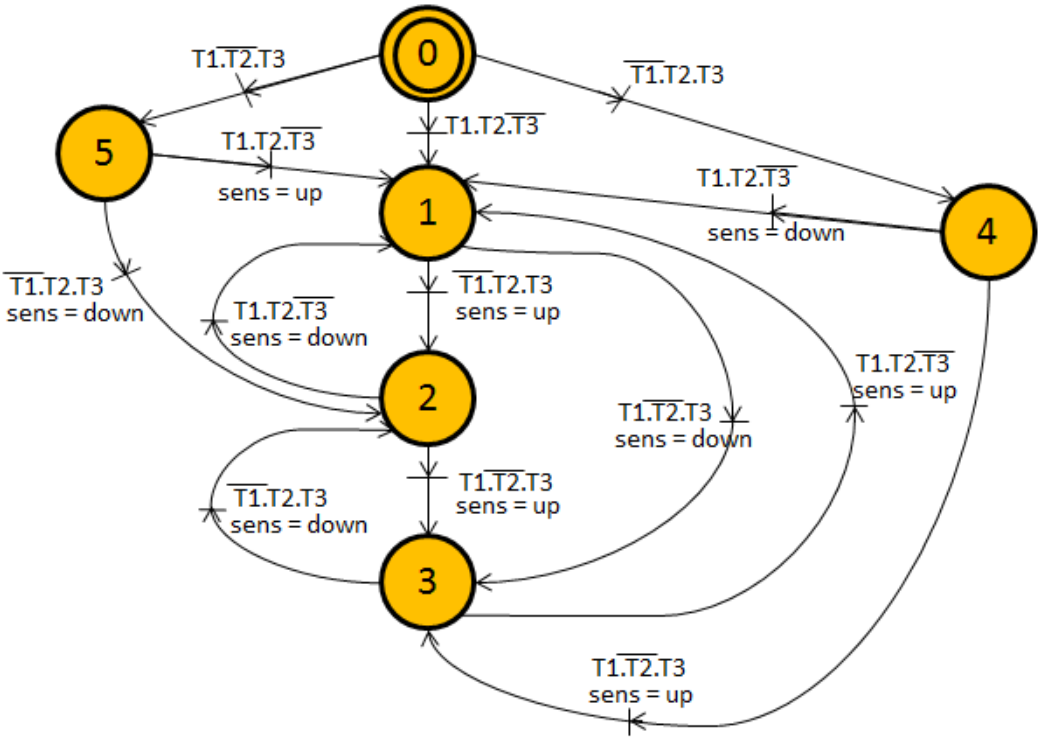


Figure 18 : finite state machine - wheel 2

To sum up, this method uses I / O standards and a timer to set the time of the discharge of keys. The main advantage of this method is to read more keys simultaneously. The main drawback is the power consumption by the continuous scanning of all keys. The time of discharge of all keys can be adjusted by the value of timer.

Remark for the two method of movement detection
For a reactive response, the cycle of the charge and discharge of the keys must be between 10 ms and 20 ms.