Innovative project

# CRA

## FOR SHARK RISK REDUCTION

**Results of experimental tests on personal protective devices with electric impulse repellents**

April 2019

***Keywords:***

*In the bibliography, this report will be quoted as follows:*

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# SOMMARY

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# 1 BACKGROUND AND EXPERIMENTAL APPROACH

## 1.1 CONTEXT OF THE APPROACH

This study corresponds to phase 2 of the draft study on the efficacy of PPE (personal protective equipment) for the repulsion of sharks at sea. This project was validated by the administrators of the shark risk reduction resource and support center (CRA) in September 2017.

It takes place in three phases:

### PHASE 1: STATE OF THE ART

- **OBJECTIVES :**
  - ➢ Informing sea users of PPE to avoid dangerous practices;
  - ➢ Sharing experience with users.
- **MEANS :**
  - ➢ Listing of existing systems;
  - ➢ Bibliographic research: senses/perceptions/ sharks predation;
  - ➢ State of the art on the analysis of the efficacy of PPE (independent studies);
  - ➢ Restitution to users: public meetings + website (documentary dissemination).
- **STATE OF PROGRESS:**

A State of the art on the efficacy of PPE was carried out and returned to the users of the sea, after validation of its contents by the Maritime Safety Commission of the CRA on November 20, 2017. Three public meetings were held in St Leu, St Gilles and St Pierre to restore the State of the art to the users of the sea. These reunions allowed meeting 70 people. Communication activities were held with press articles in the JIR, the daily, as well as an interview radio (RTL) and a report aired on Antenne reunion.

The workshops were used to distribute a questionnaire to users in order to raise the knowledge of the field. These elements were forwarded to the researchers at the University of Reunion for analysis.

Chapter 1.2 of this report proposes a synthetic restitution of this state of the art on the efficacy of PPE.

## PHASE 2: TESTING OF PPE ON TEST BENCH

- **OBJECTIVES :**
  - Comparative analysis of the size of the electric field between several devices
- **MEANS :**
  - Construction of a test bench: pond + devices + instrumentation oscilloscope / Multimeter;
  - Measuring the electric field in a pond;
  - P Technical partnership with the students of senior scientist of the high school Bois d'olive.

This report is a restitution of the work carried out in phase 2 of the project.

## PHASE 3: COMPLEMENTARY TESTS IN SITU

The content and objectives of phase 3 of the project are discussed at the conclusion of this report, taking into account the results obtained.

- **OBJECTIVES :**
  - Establishment of a sea test bench and an PPE efficiency verification service for sea users;
  - Carry out tests in situ of certain PPE on Bulldog sharks, a species mainly responsible for attacks in Reunion Island.
- **MEANS :**
  - Fabrication of a test bench;
  - International collaboration (Australian/South African) ;
  - Tests and Protocol to be adapted in Reunion Island conditions.

# 1.2 SYNTHESIS OF THE STATE OF THE ART OF KNOWLEDGE ON THE EFFICACY OF PPE

## 1.2.1 General considerations

When looking for information on the effectiveness of marketed equipment, it is very easy to find testimonials from test users filming in the natural environment, and in the presence of sharks of various species, the protective effect or not of these Devices. These testimonies remain isolated information that does not make it possible to conclude one way or another on the effectiveness of these devices.

In order to be able to bring consolidated information, it is important to compile many experiments whose Protocol is mastered and corrected by possible bias. The data thus collected can be processed according to statistical methods allowing to give, or not, tendencies on the repulsive effect of each device. It is on this principle that scientific studies are resting in order to consolidate their conclusions. For this reason, the State of the art rendered in this document relied mainly on the scientific studies known at the time of its drafting.

Before entering into the details of the restitution of these studies, it should be noted that to date, no shark attack in the world has occurred on a person equipped with PPE using the principle of electric field pulsed in water. However, given the fact that shark attacks remain relatively rare events, and that the number of people with PPE in the world is also limited and unknown, it is not possible to rely on this result to conclude a protective effect of these devices.

However, it may be noted that in December 2016 a shark attack occurred with a person equipped with a SharkBanz1 device. It can be remembered here that this bracelet is based on the principle of a static (non-pulsed) electric field, different from the PPE tested in the context of this study. The particular circumstances of the attack could perhaps explain the accident despite wearing the PPE by the user.

It may also be noted that none of the promoters of these equipment asserts absolute protection against shark attacks. They indicate at most a more or less significant reduction in the risk to the.

[1] https://surf-me.com/se-attaquer-requin-bracelet-anti-requin/

## 1.2.2 State of the art synthesis

At the first State-of-the-art review carried out at the end of 2017 (phase 1 of the project), only 3 independent scientific publications were identified on devices available on the market, and based on a repulsion principle by creating a field Electric pulsed.

In 2018, an additional publication and a study of a private office came to complement these documents. In March 2019, a final publication came to complement this art. It is therefore logically on these publications and studies that this report will be based.

A synthesis of these different studies is proposed in the following table 1 page. Full scientific publications are available in the annex to this report.

The principle used to carry out all these experiments is to stimulate the feeding behaviour of the shark using bait or an olfactory stimulus, and to quantify the extent to which the presence of a lighted PPE in the vicinity can allow this behavior and thus decrease the number of shark interactions with this bait or stimulus.

**In summary, the bibliographic evidence suggests that the SharkShield FREEDOM demonstrates real efficacy on the white shark. Although the device is not effective at 100%, the probability of bait bite is going from 81% to 11% activated device nearby (KEMPSTER et al, 2016).**

This activation also decreases, the time of presence of sharks while increasing the limit distance of repulsion. **Studies also indicate that even if the repulsive effect is demonstrated, the repulsion distance remains low: about 80cm**.

In 2018, for the first time, a study (Huveneers 2018), allowed to compare and test several devices of the market under identical and controlled conditions (notably the devices SharkShield FREEDOM + SURF and RPELA-v1). This study confirmed the repellant effect of SharkShield in its FREEDOM + SURF version adapted to surfers.

**On the other hand, this study indicates that the presence of an activated RPELA-v1 has no significant effect on the number of bait interactions and bites compared to an extinct RPELA-v1. This information is important to integrate for the holders of this device in Reunion Island.**

At the end of the year 2018, the company RPELA launched a new version of its PPE (called the RPELA-v2 here), and commissioned a private Design Office to evaluate it.

**This study, released in December 2018, appears to demonstrate this time the presence of a measurable and quantifiable effect of the decrease in the number of interactions in the presence of the activated device (the probability of bite going from 75% to 25%, device activated).**

In March 2019, a scientific publication (Egeberg CA, Kempster RM, Hart NS, Ryan L, Chapuis L, Kerr CC, et al. (2019)) relates the results of tests carried out by the electronic shark defense system (Electronic Shark Defense System ESDS) on the great white shark.

The results appear to indicate a limited efficacy of the device: a very low repulsion distance (less than 15.5 cm), decreasing but not preventing, at this distance, the number of bites, without being able to decrease the number of interactions total (grouping a bite or physical contact).

It should be noted that this device no longer appears to be marketed at the present time, and has been replaced by the NoShark device, whose technical characteristics have visibly evolved.

### 1.2.3 Use of Pulsed electric field PPE as a public risk reduction policy

In the world so far, the only known public policy measure based on individual Pulsed electric field equipment comes from the State of Western Australia.

Since 2017, the State of Western Australia has taken the political decision to subsidize, as a result of its scientific and independent evidence of effectiveness on the ocean guardian SharkShield (FREEDOM + SURF and FREEDOM) devices. the State of Western Australia has made the political decision to subsidize, as an individual, the purchase of these devices up to 176 €/person for the inhabitants of his State (200 US $).

It is a strategy that allows them to act on the reduction of shark risk at the level of all the practitioners equipped, and on the entire coastline of the State.

| Authors | SITE | SHARK SPECIES | TYPE OF TEST | PROTOCOL | TEST CONDITIONS | DISTANCE APPAT/REPULSIF | % OF BAIT BITE (NB) (PPE OFF) CONTROL | % OF BAIT BITE (NB) (EPI ON) active | CONCLUSION/REMARKS |
|---|---|---|---|---|---|---|---|---|---|
| **PEDDEMORS ET SMITH** 2003 | **South Africa** | **White shark Carcharodon carcharias** | **Static bait** | **Static bait attached to SharkPod Center all attached to a buoy** | 98 tests (19 min) | 0 m (milieu) | **85% (after 5min)<br>97% (after 10min)** | **0 % (5 and 10min)** | |
| **HUVENEERS ET AL**<br>2013 | **Australia**<br>Neptune island group (South Australia) | **White shark Carcharodon carcharias** | **Static bait** | | 116 tests (15 min)<br>49 with SS OFF<br>67 with SS ON<br>314 approaches<br>527 interactions | 2.3m | **Bait bite in 77.6% of trials (38/49)** | **Bait bite in 79.1% of trials (53/67)** | Results very uncertain and contrary to those expected |
| **HUVENEERS ET AL**<br>2013 | **South Africa**<br>Seal Island, False Bay, Cape Town | **White shark Carcharodon carcharias** | **Towed seal lure** | | 190 tests (15 min)<br>98 with SS OFF<br>91 with SS ON<br>314 approaches<br>61 interactions | 2.3m | **Bait bite in 16% of trials (16/98)** | **No bait bites during testing (0/91)** | Hypothesis: very strong energy cost -> deterrence + easy if risk of failure |
| **KEMPSTER ET AL**<br>2016 | **South Africa**<br>Seal Island, Mossel Bay | White shark Carcharodon carcharias | **Static bait** | | 4 simultaneous sites::<br>2 active, 2 non-active (300m distance)<br>90 minutes of ENR. /session 4 days of experimentation-> 44 recorded sessions (of which 22 inactive)<br>Observation by stereoscopic cameras | ~0.2m | **Bait bite for 81% of sharks (26/32)**<br>**Time presence: 1min 42s**<br>**Average approach distance: 24cm** | **Bait bite for 11% of sharks (1/9)**<br>**Time presence: 58 s average**<br>**approach distance: 81cm** | If repulsion, repulsion distance measured between 0.2 and 1M<br>Measured habituation effect |
| **HUVENEERS ET AL**<br>2018 | **Australia** | **White shark Carcharodon carcharias** | **Static bait** | | 6 tested devices<br>5 trips on site bait: tuna (2kg)<br>300 tests carried out (50 per device) - 15 min each observation from boat + stereoscopic cameras | 0.3m sous la planche | **% bite of bait/Board: 96% of sharks (48/50)** | **% bite of bait/Board:**<br>**SharkShield: 38% of sharks (19/50)**<br>**RPELA-v1:89% of sharks (44/59)** | SharkShield surf + effectiveness confirmed<br>Effect of undetectable RPELA-v1 |
| **CARDNO**<br>**2018** | **Salisbury Western Australia** | **White shark Carcharodon carcharias** | **Static bait** | | RPELA v2 tests<br>21 test device active 27 test device idle 15 min for each test | 0.45m sous la planche | **% of bait/plank interaction: 80% of sharks**<br>**% bite of bait/Board: 75% of sharks** | **% of bait/plank interaction: 50% of sharks**<br>**% bait/plank bite: 25% of sharks** | Unknown shark interaction distance<br>Decreased interactions and bites. |
| **Egeberg CA, Kempster RM, Hart NS, Ryan L, Chapuis L, Kerr CC, et al. (2019)** | **South Africa**<br>Seal Island,<br>Mossel Bay | **White shark Carcharodon carcharias** | **Static bait** | | ESDS tested<br>90min tests<br>17 active device testing<br>17 idle device testing<br>51hours of video | 0.15m | **% of bait/Board interaction: 96% of sharks**<br>**% bite of bait/Board: 87% of sharks**<br>**Average approach distance: 24cm** | **% of bait/Board interaction: 86% of sharks**<br>**% bite of bait/Board: 52% of sharks**<br>**Average approach distance: 23cm** | Low and no approach distance modified by active device<br>% unmodified interaction<br>% decreased bite |

*Table 1: synthesis of independent scientific studies carried out on the evaluation of Pulsed electric field PPE*

## 1.3 TESTED DEVICES

Four devices implementing an underwater Pulsed electric field were evaluated in the test pool at the CRA premises:

- ➢ The ESharkForce
- ➢ The NoShark
- ➢ The ocean guardian SharkShield FREEDOM + SURF (which will be called SharkShield for convenience thereafter)
- ➢ The Rpela in two separate versions: v1 and v2 (the latter being available from the beginning of 2019)

### 1.3.1 ESharkForce

The E-shark force is the latest model of the electronic repulsion device that Mr. Wilson Vinano invented in Hawaii in 2005. E-shark force is intended for divers, surfers, swimmers and stand up paddlers.

Website: http://www.e-sharkforce.com/

The CRA exchanged with Mr. Wilson Vinano (CEO and President) and Ms. Amanda toy (Director of operations) in May 2017 via a Skype interview. The company sent 8 E-shark force units to the reunion for repulsion tests if validated and undertaken by the CRA.

#### SEVERAL MODELS ARE MARKETED:

| MODEL | PHOTO | PRICE (WEBSITE) |
|---|---|---|
| E-Shark Force Dive unit: |  | 325 € (365 US$) |
| E-Shark Force PaddleBoard unit |  | 325 € (365 US$) |

*Table 2: marketed E-SharkForce products*

No information was found, either on their website or in the scientific bibliography, regarding the structure and intensity of the electric field generated by these devices.

The E-SharkForce enclosure is closed by a bolted watertight plate. The charging of the battery is done by induction using a circular platform on which the device is installed, which avoids the problems of sealing.

In particular, the E-SharkForce "swim unit" has two square-shaped electrodes spaced each other by 13cm. The surface of each electrode is 6.8 cm ².

The E-SharkForce "paddle unit" presents two rectangular electrodes spaced each other by 25.5 cm. The surface of each electrode is 19.8 cm ².
Surfers and body boarders therefore have the choice to use the "swim unit" as a bracelet at the ankle or wrist, or a "paddle unit" at the hang out of its Board.

The electrodes are made of conductive wire kinked on it and flattened and compacted in the form of a parallelepiped. This may be a way to increase the Exchange area of the driver with the medium.

As part of this study, it is the E-sharkforce model "swim unit" that has been tested, but the user has the choice of a use at the ankle on the wrist, or at the hang out at the back of his surf, his paddleboard.

To our knowledge, these devices are little known and little used on the island of la Réunion.

## 1.3.2 NO SHARK

The NoShark is a wristband device that has two electrodes inserted into the clamping ring.

The product is sold online on the website: http://www.noshark.com/

There are two versions of the NoShark: the first single bracelet, the second with a Leach to attach to the surfboard.


*Figure 1: NoShark – surf version (left) and diver (right)*

## MANUFACTURER SPECIFICATIONS

- Depth: 45m maximum for the surf version or 60M for the diver version;
- Case dimensions: approximate 0067 width X 0058 height X 0.029 thickness;
- Weight: 198g;
- Battery: internal 3.7 V Li-ion;
- Charger: 5 VDC, 1.0 amp;
- Charging time: approx. 7 hours (new battery, evolves over time);
- Autonomy: approx. 6 1/2 hours (in water);
- Output: 120V to 200V. Proprietary pulsed waveform;
- Electrodes: 2 electrodes, each 2.7 mmX 2.7 mm stainless steel;
- A leash (surf version);
- A neoprene ring (optional for users without combination).

The NoShark has two square-shaped electrodes, spaced apart from each other by 12cm. the surface of each electrode is 7.29 cm ².

The case is plastic and sealed. An electrical wire comes out of the case and allows ensuring the connection of the device with the internal battery (via another wire entering the box) or the external charger.


*Figure 2: NoShark electrodes*

## SELLING PRICE

The product is sold €356 (399 US $) on the website, excluding postage, in its version "dive" (dive version) and €400 (449 US $) in its version "surf" (with integrated Leach). Both models differ by their immersion limit depth.

## 1.3.3 OCEAN GUARDIAN SHARKSHIELD©TECHNOLOGIE

The company OCEAN GUARDIAN sells a range of repulsion products with models designed for diving, swimming and surfing.

The first device was created under the name of SharkPod in 1990 by the KwaZulu Natal Sharks Board (KZNSB) in South Africa and was developed by an Australian company SeaChange technology and marketed by Shark Shield in October 2006, which became the Ocean guardian company today.

The devices marketed are based on SharkShield technology.

The company sells its products on the following website: https://sharkshield.com/

Three devices are marketed:

### • *1.3.3.1 FREEDOM7*

The FREEDOM7 is a device designed for scuba diver, the free diver or underwater fighter.

This is an ankle strap on which is connected a 2.2 m antenna. The power box powered by a lithium generation battery is located in the ankle strap while the antenna contains the two electrodes at each end.

When it was released in 2006, this device was used by some surfers, especially in La Réunion (some even using an earlier version: freedom 4). Their testimonies indicate that the weight of the power system (especially for the freedom 4 equipped with heavier batteries), as well as the presence of the antenna, greatly hindered their practice.


*Figure 3: FREEDOM7 of Ocean Guardian*

Today a special surf version has also been developed.

## MANUFACTURER SPECIFICATIONS

- Number of nominal battery charge cycle: 1000 loads;
- Storage temperature: 0 °c – 60 °c;
- Operating temperature between 12 °c – 40 °c. Lower temperature reduces battery life;
- Unit dimensions (without antenna): 80mm L x 140mm W x 35mm H;
- Maximum operating depth: 50m;
- Unit weight: 335g;
- Weight (full): 950g;
- Weight in water (complete): 69g;
- Battery operation time: 5 to 6 hours (depending on temperature);
- Predicted electromagnetic field strength: greater than 1V/m at 1M from the Centre of the electrodes.

## SELLING PRICE

The device is sold €394 (US $449) on the website, excluding postage.

A grant of €176 (US $200) is granted by the State of Western Australia for its resident citizens.

### *1.3.3.2 SCUBA 7*

The SCUBA7 is intended for military, scientific divers or recreational divers. The principle is to attach one electrode to the scuba tank, another to the end of a flexible antenna attached to the plunger's calf, while the power module is located at the plunger's hip. The electric field is generated by the two electrodes.

*Figure 4 : SCUBA7 of OceanGuardian*

## MANUFACTURER SPECIFICATIONS

- Storage temperature: 0 °c – 60 °c;
- Operating temperature between 12 °c – 40 °c. Lower temperature reduces battery life;
- Unit dimensions (without antenna): 80mm L x 140mm W x 35mm H;
- Maximum operating depth: 50m;
- Unit weight: 335g;
- Weight (full): 950g;
- Weight in water (complete): 69g;
- Battery operation time: 5 to 6 hours (depending on temperature);
- Predicted electromagnetic field strength: greater than 1V/m at 1M from the Centre of the electrodes.

## SELLING PRICE

The device is sold €525 (US $599) on the manufacturer's website, excluding postage.

### *1.3.3.3 FREEDOM + surf*

The FREEDOM + SURF is the surfing version of the device. The power box is attached to the top of the Board, in the form of a heel under the rear pad of the surf. The electrodes are in the form of stickers incorporating conductive layers that allow the current to be routed to the two electrodes positioned under the surfboard, at the front and at the rear.

The device can be installed on any surfboard, by slightly modifying the rear pad (recut) and pasting the elements (housings + electrodes). A kit to equip a second Board is also marketed. The power box can be used on either of the boards equipped with the.

*Figure 5: FREEDOM + SURF from Ocean guardian. Power box (left); rear electrode (Center); front electrode (right)*

## MANUFACTURER SPECIFICATIONS

- Number of nominal battery charge cycle: 1000 loads;
- Storage temperature: 0 ˚c – 60 ˚c;
- Operating temperature between 12 ˚c – 40 ˚c. Lower temperature reduces battery life;
- Unit dimensions (without antenna): 208mm L x 28mm W x 63mm H;
- Maximum operating depth: 50m;
- Unit weight: 250 g (case) + 225g (antenna and support);
- Battery operation time: 5 to 6 hours (depending on temperature);
- Predicted electromagnetic field strength: greater than 1V/m at 1M from the Centre of the electrodes.

## SELLING PRICE

The device is sold €438 (499 US $) excluding postage on the manufacturer's website.

A grant of €176 (US $200) is granted by the State of Western Australia for its resident citizens. The equipment kit of a second Board is sold €106 (169 US $).

# 1.3.4 RPELA

The Rpela, formerly known as surf safe, is a system positioned under the surfboard. The power box is positioned in an inlaid insert in the hull of the surf, at the rear. It also acts as an electrode. The second electrode is also positioned under the hull, but at the front of the surf. A conductive wire connects the front electrode and the rear box.

The product is marketed on the website: https://www.rpela.com/

To be installed, this system requires the intervention of a shaper or a minimum of know-how in order to modify the Board to:

- Install the power box insert;
- Install the electrode under the hull at the front of the surf;
- Install the conductive wire between the housing and the front electrode.

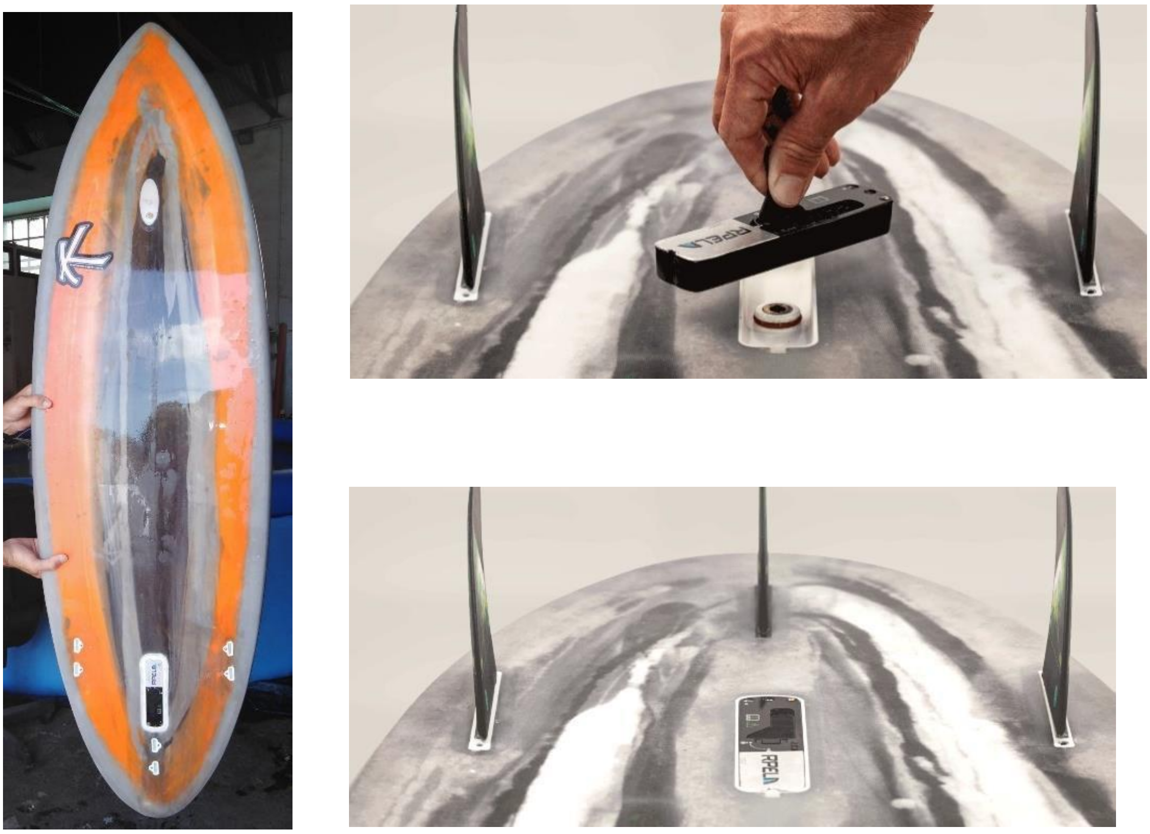


*Figure 6: Rpela system*

Once these elements are installed on the Board, the RPELA power box can be installed and removed easily and manually, thanks to a PIN system.

It can thus be removed at the end of use for the maintenance of the device and to recharge the battery.

Note that a kit allows equipping a second surfboard; the two boards can then be used with the same device, to the choice of the user.

Since December 2018, a new version of the RPELA has been commercialized: RPELA version 2.

This shows the following improvements compared to the previous version:

- ➢ Casing electrode made of aluminum and substantially enlarged;
- ➢ Additional sticker to extend the surface of the front electrode;
- ➢ The frequency and duration of electrical pulses have also been modified according to the manufacturer.


*Figure 7: enclosure of the Rpela version 2 – top: power box with aluminum electrode on its right part of the photo – bottom: additional sticker of the front electrode*

## MANUFACTURER SPECIFICATIONS

- Length: 147mm/width: 36mm height: 19mm;
- Weight 155g;
- Battery capacity: 1800mA;
- Charging time: 3.5 h;
- Autonomy: 6.5 h;
- Voltage: 200V;
- Frequency: 9.5 Hz;
- Weight of the Rpela insert: 56g.

## SELLING PRICE

The device is sold €314 (499 AU $) on the manufacturer's website, excluding postage

The equipment Kit for a second Board is sold €35 (55 AU $).

The installation made by a Shaper costs between 100 and €150.

# 1.4 Use of EPIS at La Réunion

At the public meetings held in Saint-Leu, Saint-Gilles and Saint-Pierre (cf. Chapter 1.1), questionnaires were distributed to practitioners and users of the sea in order to better understand their methods of practice, understanding and quantifying the events of user/shark interactions, to gather their opinions on shark risk management, and to better know the level of use of PPE in the context of La Réunion. These questionnaires were also disseminated via email and social networks to the sea users ' community. The dissemination, collection, processing, and analysis of data was carried out in partnership between the CRA and UMR Espace DEV
-University of Reunion (E. Lagabrielle), which has worked extensively on data processing and analysis. The complete results of these analyses will be the subject of a dedicated publication.

On the part specific to the use of PPE, the analysis shows that of the 124 practitioners in La Réunion who replied to the questionnaire, 69 people practice a wave activity (56%). Of these 69 persons, 26 use or used PPE over the period 2007-2017, i.e. about 38% of users engaged in wave activity.

The evolution of the use of PPE during the period (see Figure 8), reflects concretely the rise of the use of these devices from the year 2014. In 2017, of the 124 interviewees, 22 people use PPE in their activities.

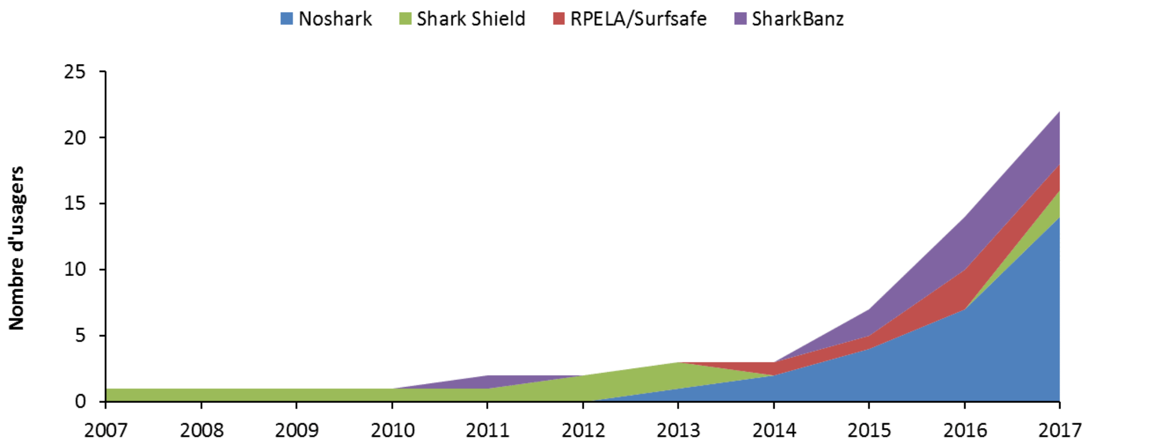



*Figure 8: evolution of the use of PPE at La Réunion over the period 2007-2017 to the users who replied to the questionnaire*

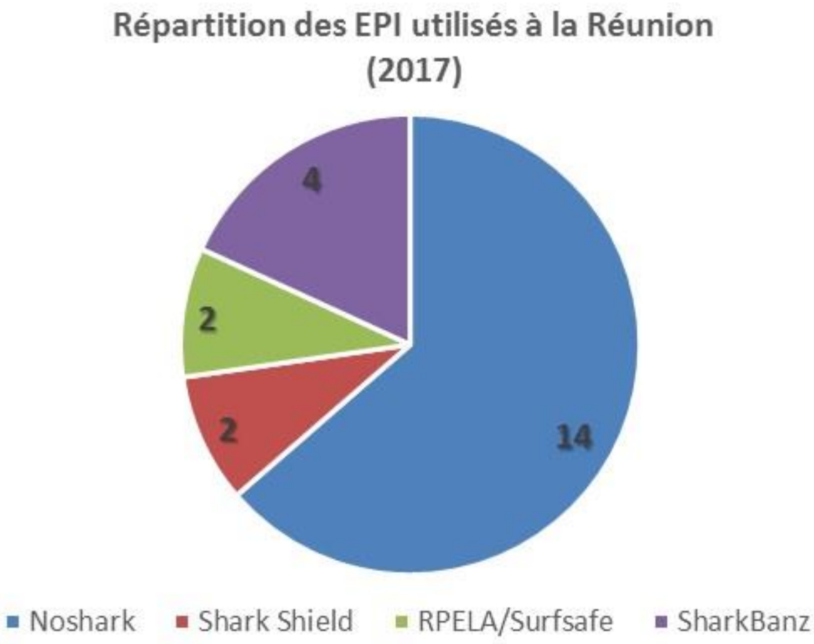



*Figure 9: distribution of PPE at La Réunion in 2017 among users who replied to the questionnaire*

According to the information from these questionnaires, it appears that the product NoShark was strongly praised by the practitioners of Réunion (64% of people equipped in 2017).

The second device appears to be the SharkBanz (18% of people equipped in 2017).

In the last position come the Rpela and the SharkShield (9% and 9% respectively of the persons equipped in 2017).

However, these results should be relativized in view of the limited size of the sample (124 total practitioners, of which only 26 used PPE over the period 2007-2017).

These figures remain to be considered as trends allowing a first approach to the problematic.

# 1.5 THEORETICAL APPROACH

## 1.5.1 General terms and conditions

The devices tested in this study all use the same principle of the emission of a pulsed electric field.

The principle of these devices is to generate an electric dipole by relying on the two electrodes.

At each impulse of the devices, each electrode will charge positively for one and negatively for the other, for a limited time.

This difference in polarity is then an electric dipole that creates an electric field in all the surrounding conductive space (salt water).

It is this electric field that is perceived by sharks through their Lorenzini bulbs.

The effectiveness of each device, namely the potential repulsion distance of a shark, will depend directly on the size, shape, and intensity of the electric field thus created, which will depend directly on the following parameters:

- **The size and shape of each electrode.** One can see from the above pictures presented that these are very variable on the different devices tested;
- **The load of each electrode.** The intensity of the load will depend on a choice of the manufacturer: compromise between the frequency and duration of the pulses, their intensity, and the autonomy of the devices;
- **The distance between each electrode.** Depending on the spacing of the electrodes and their positions in the space, the electric field can be deformed, the protected volume enlarged in an axis, and positioned differently from the practitioner.

## 1.5.2 Calculating an electric field

The calculation of the electric field of a dipole is known and derives from the laws of electromagnetism.

The electric field created by an electrical charge is expressed according to the distance of the measuring point (r), the electrical conductivity of the medium (ε _0 ε _ r) and the electrical load (q). The expression of the electric field is written :

$$\vec{E} = \frac{q}{4\pi\varepsilon_0\varepsilon_r} r^{-2}\vec{U}_r$$

In the presence of a dipole, i.e. two loads of opposing signs (as is the case for each device tested), and positioned at a distance 2A from each other, the electric field created can be described by the following formulation:

$$\vec{E} = E_r\vec{U}_r + E_\theta\vec{U}_\theta$$

$$= K\left[\frac{r - a\ \cos\theta}{(a^2 + r^2 - 2ar\cos\theta)^{3/2}} - \frac{r + \ \cos\theta}{(a^2 + r^2 + 2ar\cos\ \theta)^{3/2}}\right]$$

$$= K\left[\frac{a\ \sin\theta}{(a^2 + r^2 - 2ar\cos\theta)^{3/2}} + \frac{a\ \sin\theta}{(a^2 + r^2 + 2ar\cos\theta)^{3/2}}\right]$$

With $K = \frac{q}{4\pi\varepsilon_0\varepsilon_r}$

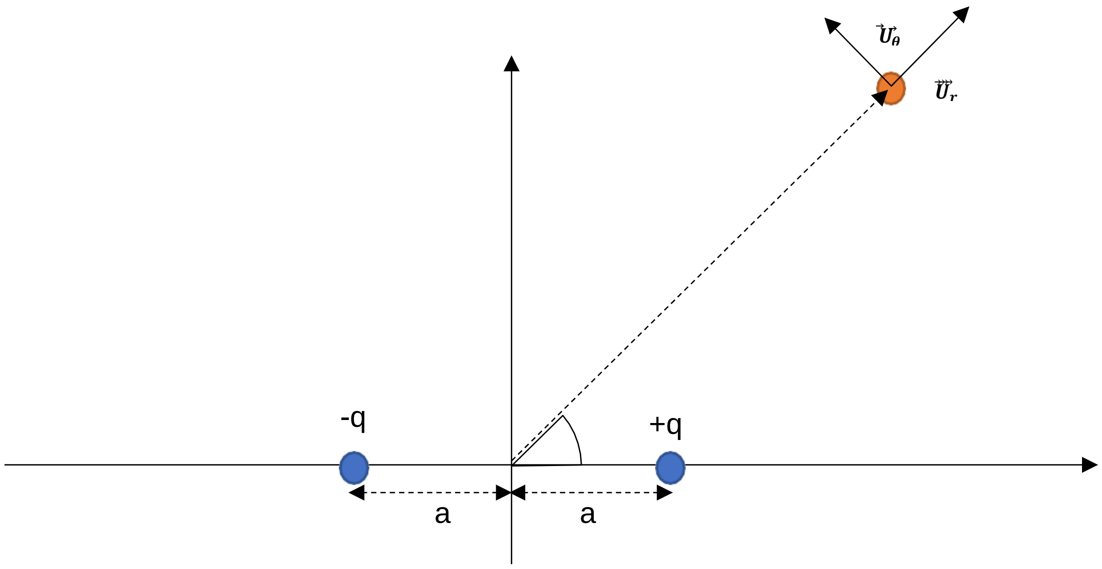



*Figure 10: decomposition of the electric field vector in the space surrounding the device*

The theoretical vector field of the electric field can thus be represented in a plane passing through the two electrodes. Two examples are shown in Figure.

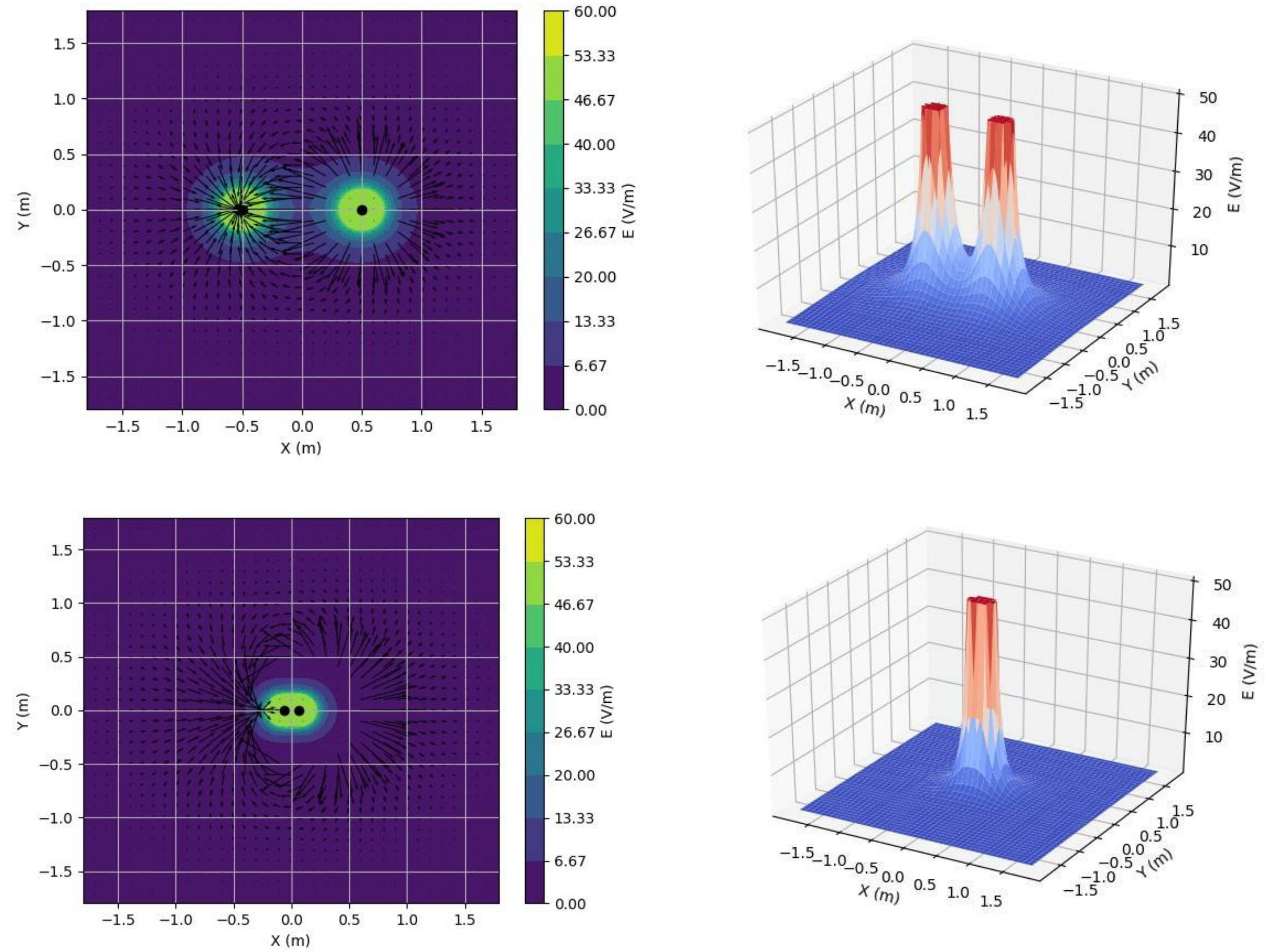



*Figure 11: General form of an electric field generated by a dipole – above: electrodes spaced 1M (plane and 3D view) – below: 0.25 m spaced electrodes (plane view and 3D)*

Each of the dipole electrodes locates a peak of electric field strength.

When the distance between the two electrodes is large, the two peaks are clearly isolated from each other, and the electric field has an elongated shape with two distinct lobes: a configuration close to the SharkShield and the RPELA.

When the two electrodes are closer to each other, the two lobes partially merge and the field becomes more symmetrical (radial symmetry): configuration close to the NoShark and the E-SharkForce.

The repulsive devices tested in this study all present an electrical dipole device that emits an electric field in the water as an impulse. By knowing the distance between the electrodes, the conductivity of the medium, and the point load generated by the device, one can thus reconstruct the theoretical form of the field of each device.

This theoretical approach allows a first analysis and a better understanding of the geometric form of the electric field in space by assuming a continuous, homogeneous and isotropic medium. The consideration of a number of parameters remains to be incorporated into this theoretical approach in order to have a complete description of the field in a real context of use:

- ➢ The effect of the presence of the surface of the water near the electrodes;
- ➢ The effect of the presence of the Board (insulating medium) in the immediate vicinity of the electrodes (case of Rpela and SharkShield).

# 1.6 EXPERIMENTAL METHOD

In order to carry out these tests, an experimental test bench was manufactured with the support of the technical high school of olive wood of Saint Pierre in reunion.

This test bench is made up of:

➢ a basin filled with water in which the measurements of the electric field have been carried out;
➢ a positioning system;
➢ an electrical field measuring device (measuring electrodes +wiring + oscilloscope).

## 1.6.1 pool

The basin is a self-supporting swimming pool in circular PVC of 4m in diameter and 1.20 m in height. The choice was made on an insulating material (PVC) in order not to disturb the electric field near the edge of the pond, thus spreading any option of swimming pool with metal structure. This basin is placed in a covered workshop that limits the temperature variations.

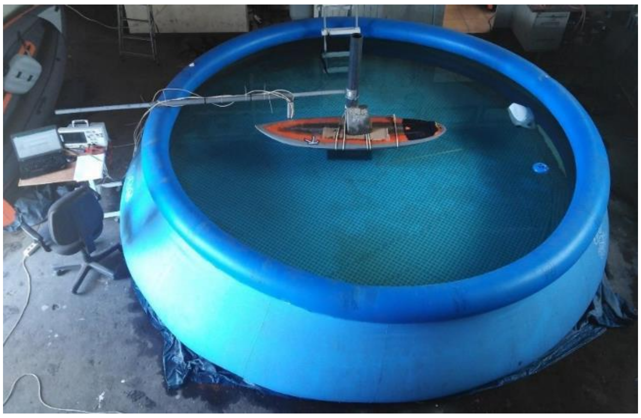


*Figure 12: CRA experimental basin for PPE testing (basin; PC/oscilloscope; Measuring electrodes)*

The water in the basin comes from the drinking water system. Pool salt has been added to obtain water of the same conductivity as water from the sea. To ensure proper calibration of the water conductivity of the pond, conductivity measurements are performed at each start of a test run.

Conductivity measurements are carried out systematically on:

- a water sample from the pond;
- a sample of seawater.

In order not to disturb the measurement, the two samples are at the same temperature: the seawater can is permanently left in flotation in the pond in order to standardize the temperatures.

The conductivity measurement is carried out from a Hanna instruments™ device. Before each use, the device is calibrated using a calibration solution at 6.44 ppm.

## 1.6.2 Positioning system

The intensity of the electric field is very spatially variable, in the first tens of centimeters around the repulsive devices.

A precise positioning system of the repellents and measuring electrodes in the basin is therefore necessary to achieve precise and reproducible measurements.

The developed positioning system is based on a benchmark in polar coordinates. The repulsive device is positioned in the center of the marker.

The position of the measuring electrodes is marked in relation to the distance in the Centre of the mark (the radius r), and the angle of incidence relative to the electrodes of the PPE (angle $\theta$).


*Figure 13 : Polar positioning system in the arc test basin*

## 1.6.3 Measuring electrode

A measuring electrode plate has been used to measure the electrical potential differential in the water.

The turntable has 4 electrodes that work by torque:

- ➢ 2 electrodes in the radial axis $\vec{U}_r$;
- ➢ 2 electrodes in the tangential axis $\vec{U}$.

For each couple, the electrodes are spaced 10cm apart.

By working on one of the two electrode pairs of choice, the potential difference can therefore be measured on the two axes $\vec{U}_r$ and $\vec{U}$.
The electric field can thus be reconstituted in the horizontal plane. Each electrode is welded to a coaxial cable.
The choice of coaxial cable allows a reduction of the noise by insulation of the electric field inside the core of the cable (Faraday cage principle).

Before starting the tests, many improvements were made to the electrode plate, aiming at the quality of the measurements.

## 1.6.4 Measurement and acquisition

Measurement and data acquisition is accomplished using the Agilent DSO-X-2002A technology oscilloscope.

This device allows a maximum sampling of 2Gsa/s and has an internal storage memory of 1Mpts.

The maximum temporal resolution is therefore of the order of the nanosecond, which is sufficient to characterize the electrical impulses of the PPE tested in the context of this study whose width varies between 19 µs and 1000 µs.

## 1.6.5 Protocol evolution and measurement optimization

Since the initiation of the project, the test pond has improved according to the following planning:

- **January 2018**: design and manufacture of the positioning system by the Lycée Bois d'olive/installation of the basin at the CRA premises;
- **February 2018**: first tests and measurement tests with 2 radial electrodes;
- **March-May 2018**: first period of data acquisition by students of the Bois d'olive high school;
- **May-June 2018**:1st data processing chain set up;
- **August 2018**: manufacture of a 4-electrode plate allowing simultaneous measurement of the two components of the electric field vector;
- **September-October 2018**:
- Replacement of wiring by coaxial wires to reduce noise;
- Setting up a potential differential measurement procedure between two separate analogue inputs. ;
- Optimization of the oscilloscope setting for reliability of the measurement (acquisition mode, analysis time resolution, data export).
- **November 2018-February 2019**: final acquisition of data on the 4 devices, including the Rpela version 2.

At the end of this optimization process, the methodology and measurement technique of the test bench is now perfectly mastered, reproducible and comparable.

## 1.6.6 Discussion of the experimental method

The measurement of the electric field in the basin is a physical limit that is specific to the limited size of the pelvis.

Contrary to the conditions that can be found at sea, the propagation of the electric field in a confined medium can be distorted due to the heterogeneity of the medium (water/air interface) at the perimeter of the pool as well as at the bottom level. The experimental basin therefore has a measurement bias compared to the reality of the electric field that could be measured in the open sea.

It can also be noted that these devices are generally used at shallow depths, sometimes in water with currents and charged with insulating air bubbles (surge areas).

Knowingly, the experimental protocol is conducted in such a way that this bias is identical for all devices: each of them is positioned perfectly in the Centre of the basin, so that they are all exposed strictly to the same conditions Experimental.

These conditions have been set to reproduce the typical use of the devices without looking for any advantage for one device rather than another.

In phase 3 of the project, it is proposed to carry out an experimental test bench deployable directly at sea, in order to measure directly the electric field in the marine environment.

# 2 ANALYSIS OF THE RESULTS

## 2.1 E-SHARK FORCE

### 2.1.1 Temporal description of the signal

The E-SharkForce emits an electric field following a time sequence organized into "bursts of pulses". The overall cycle frequency is 4.1 s. On each complete cycle, the device emits the following two sequences:

- ➢ 1 emission sequence 20 pulses during 2.46 s;
- ➢ 1 resting sequence of 1.64 s.

After 4.1 s, the cycle resumes. Figure 12 below allows you to view 3 consecutive burst emission sequences.

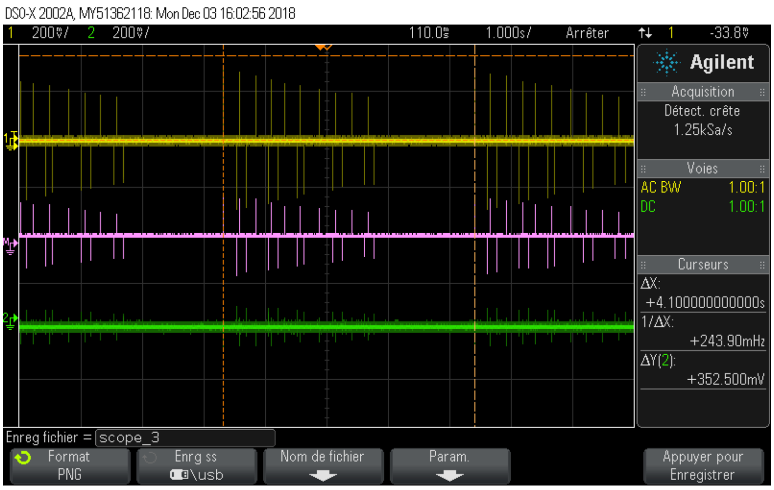



*Figure 14: General overview of the E-SHARKFORCE periodic emission cycle – pink curve: signal of the electrical potential measured between the two electrodes of the Platinum (yellow and green signals)*

During the transmission sequence, 20 pulses are emitted with an alternating polarity (the pulses are alternately positive and negative). Pulse intensity is decreasing in absolute value.


*Figure 15: Sequence of the 20 pulses of the E-SHARKFORCE of alternating and decreasing intensity (in absolute value)*

| Impulse n ° | time (s)/first impulse | voltage %/first impulse |
|---|---|---|
| 1 | 0.000 | 100% |
| 2 | 0.200 | -96% |
| 3 | 0.260 | 95% |
| 4 | 0.366 | -92% |
| 5 | 0.522 | 85% |
| 6 | 0.728 | -86% |
| 7 | 0.782 | 80% |
| 8 | 0.888 | -82% |
| 9 | 0.990 | 80% |
| 10 | 1.200 | -77% |
| 11 | 1.250 | 71% |
| 12 | 1.302 | -72% |
| 13 | 1.564 | 67% |
| 14 | 1.770 | -63% |
| 15 | 1.824 | 61% |
| 16 | 1.928 | -62% |
| 17 | 2.090 | 61% |
| 18 | 2.300 | -58% |
| 19 | 2.350 | 57% |
| 20 | 2.460 | -57% |

*Tableau 3: Detail of the characteristics of the 20 pulses of the ESF*

The last impulse therefore has a lower intensity, corresponding to 57% of the intensity of the first impulse.

Thereafter, in order to characterize the level of intensity of the bursts produced by the apparatus in the basin space, the measurement of the electric field was systematically carried out on the first impulse of the series.

The other pulse intensities may, if necessary, be deducted from the values presented in table 3.

## 2.1.2 Pulse characteristic

By improving the temporal resolution of the analysis, one can accurately describe the shape of each impulse produced.

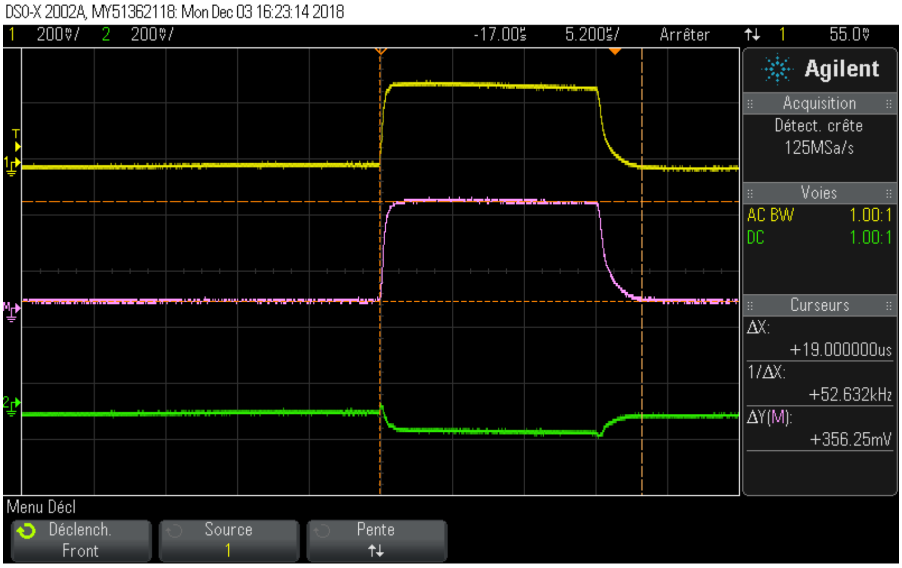



*Figure 16: Form of a ESF pulse – pink curve: difference in electrical potential measured between the two electrodes of the Platinum (yellow and green signals)*

The ESF pulses have a total width of 19µ s.

The shape of an impulse presents:

- A rapid rise of 1.5 µ s to reach the plateau;
- A horizontal tray of 13 µ s in length;
- A slower descent of 3 µ s.

## 2.1.3 Spatial measurement of the electric field

In order to characterize the intensity of the electric field of a pulse burst, it was chosen to measure the intensity of the first impulse (the most energetic).

The intensities of the other pulses may be inferred from this measure using table 3.

In order to validate the measurement operations and reproducibility of the experimental approach, the electric field of the E-SHARFORCE was measured on 3 sets of different measurements.

The intensity of the electric impulse was measured at a distance from the center of the device varying from 0.3 to 1.7 m, and with increments of 10 to 25cm for directions θ = 0 ° and 90 °.

The other θ values were also explored in one of the three measurement series, in order to be able to represent the field in the space around the device.

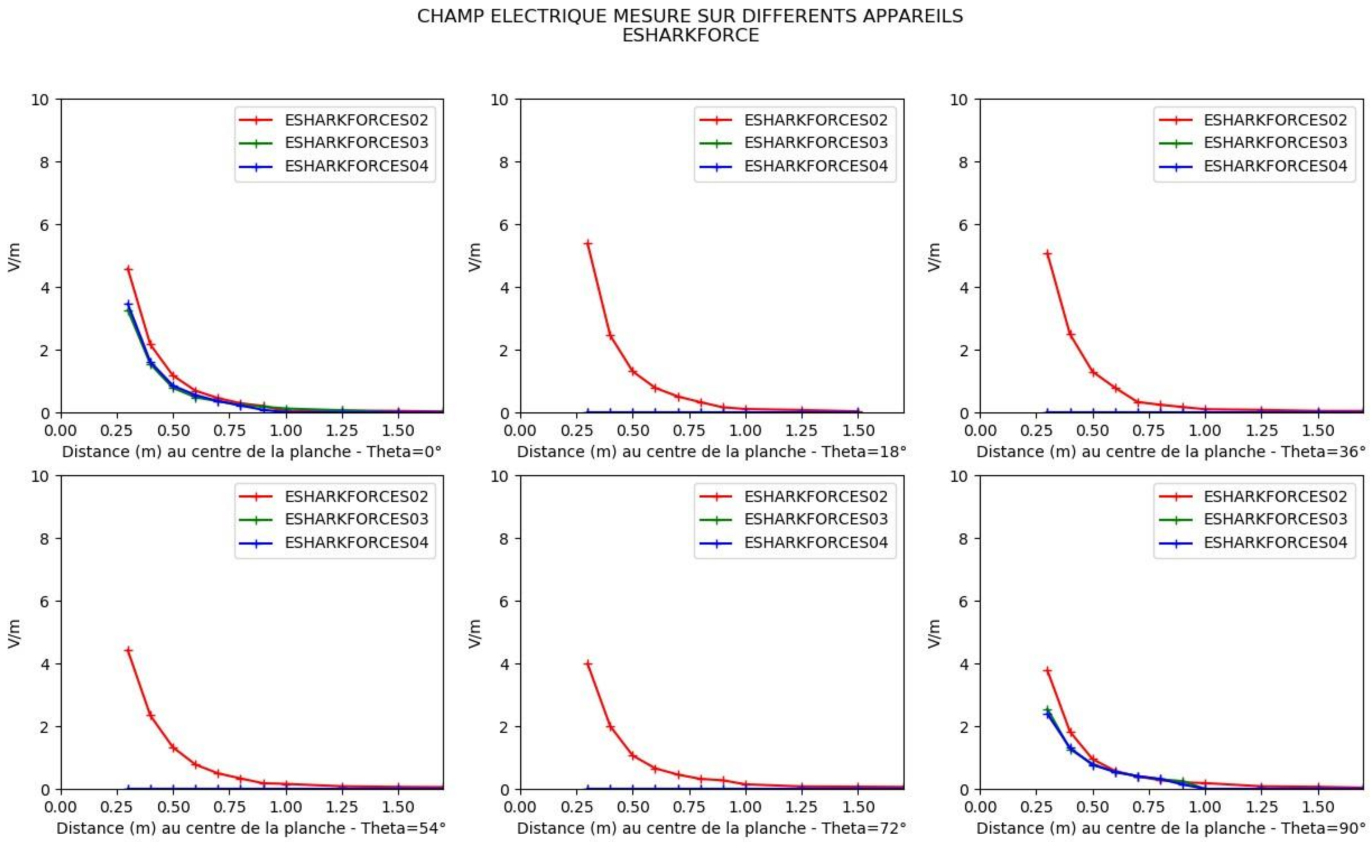



*Figure 17: Electric field measured in the horizontal plane of the E-SHARKFORCE (theta from 0 ° to 90 °)*

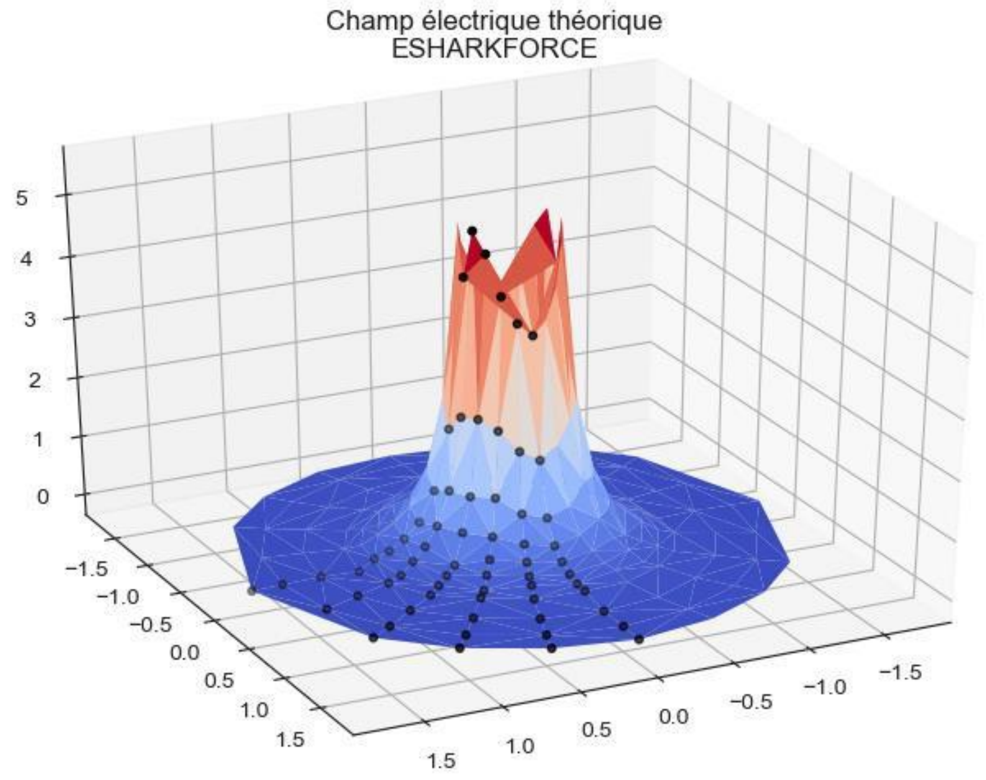



*Figure 18: 3D representation of the electric field measured on the E-SHARKFORCE in the horizontal plane – black point: measuring points achieved.*

The results obtained on measurement series n ° 3 and n ° 4 are perfectly identical.

The No. 2 series is coherent in the far field with the other two series, and very slightly majoring in the near field

## 2.2 NOSHARK

### 2.2.1 Temporal description of the signal

The NoShark emits an electric field following a time sequence organized into "bursts of pulses". The overall periodicity of the cycle spreads over 4.68 s. On each complete cycle, the device emits the following two sequences:

- 1 emission sequence 17 pulses during 2.33 s;
- 1 resting sequence of 2.35 s.

After 4.68 s, the cycle resumes. During the transmission sequence, 17 pulses are emitted with an alternating polarity (the pulses are alternately positive and negative).

Pulse intensity is decreasing in absolute value.

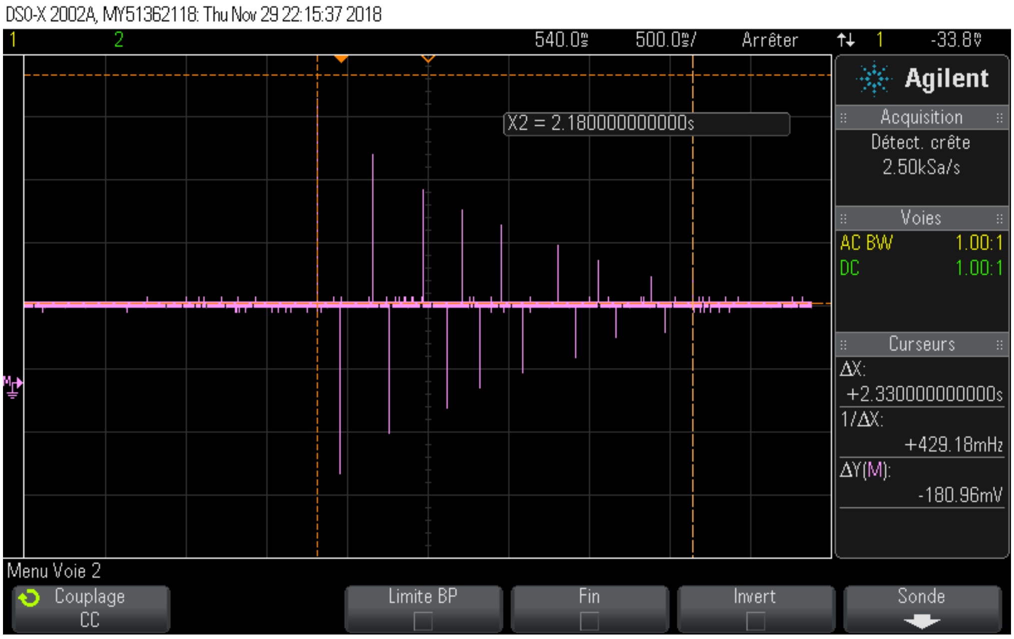



*Figure 19: sequence of the 17 NoShark pulses of alternating and decreasing intensity (in absolute value)*

The last impulse has a very low intensity: 14% compared to the first of the series.

| Impulse n° | time (s)/first impulse | voltage %/first impulse |
|---|---|---|
| 1 | 0 | 100% |
| 2 | 0.14 | -83% |
| 3 | 0.35 | 73% |
| 4 | 0.45 | -63% |
| 5 | 0.66 | 56% |
| 6 | 0.81 | -50% |
| 7 | 0.9 | 46% |
| 8 | 1.01 | -40% |
| 9 | 1.14 | 38% |
| 10 | 1.27 | -34% |
| 11 | 1.49 | 29% |
| 12 | 1.61 | -26% |
| 13 | 1.75 | 21% |
| 14 | 1.86 | -17% |
| 15 | 2.07 | 14% |
| 16 | 2.16 | -14% |
| 17 | 2.33 | 14% |

*Tableau 4 : Detail of the characteristics of the 17 pulses of the NoShark*

## 2.2.2 Pulse characteristics

By improving the temporal resolution of the analysis, one can accurately describe the shape of each impulse produced.

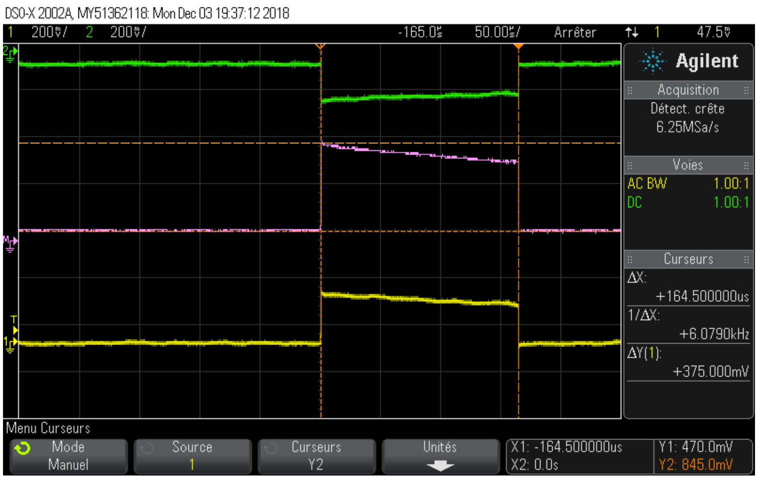



*Figure 20: Shape of a NoShark pulse – pink curve: the signal of the electric field measured between the two electrodes of the Platinum (yellow and green signals)*

The NoShark pulses have a width of 164 μs. The climb as well as the fall are sharp, and the plateau is slightly descending.

## 2.2.3 Spatial measurement of the electric field

In order to characterize the intensity of the electric field of a pulse burst, it was chosen to measure the intensity of the first impulse (the most energetic). The intensities of the other pulses can be inferred from this measure using table 4.

In order to make the measurement operations and the reproducibility of the experimental procedure reliable, the electric field of the NoShark was measured on 3 different sets of measurements. The intensity of the electric impulse was measured at a distance from the center of the device varying from 0.3 to 1.7 m, and with increments of 10 to 25cm for directions θ = 0 ° and 90 °.

The other θ values were also explored in one of the three measurement series, in order to be able to represent the field in the space around the device.

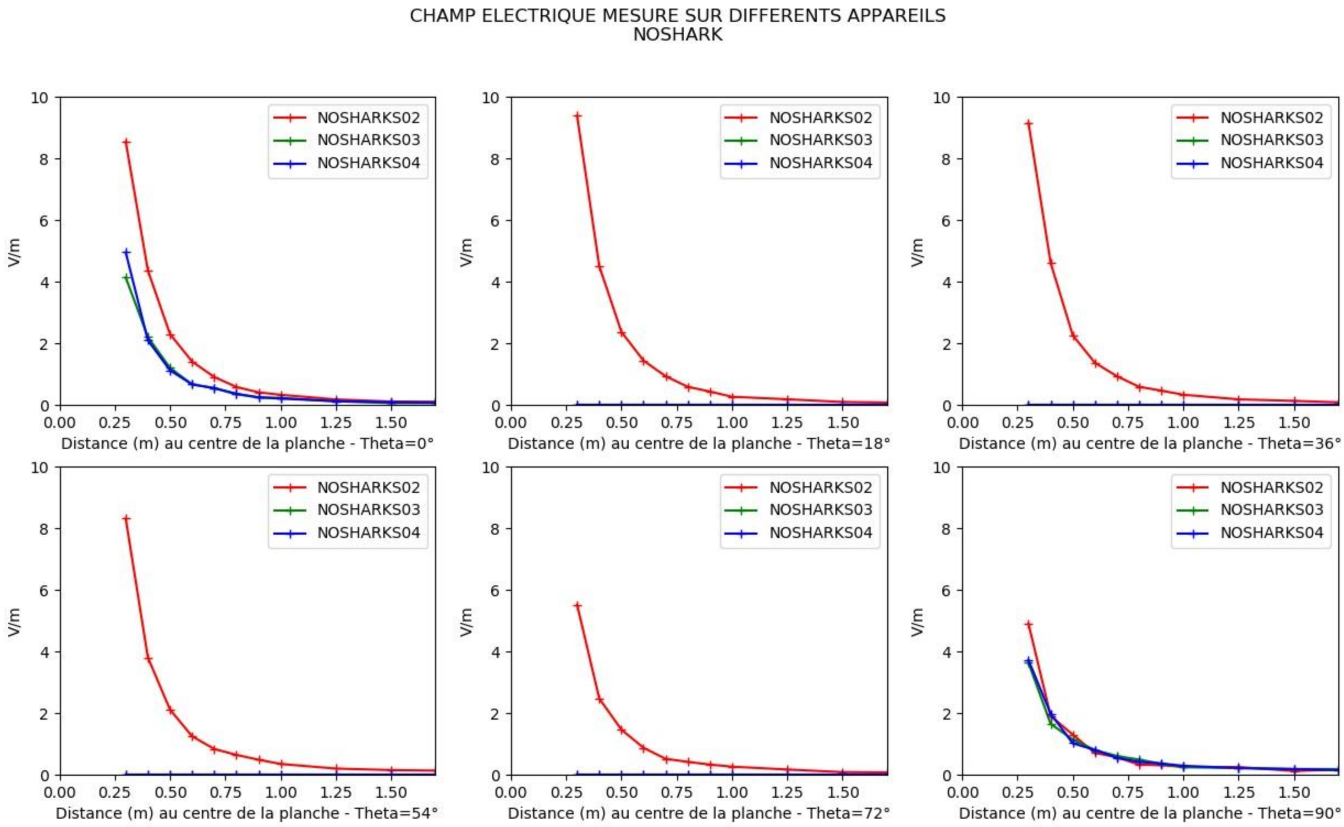



*Figure 21 : Electric field measured in the horizontal plane of the NoShark (theta from 0 ° to 90 °)*

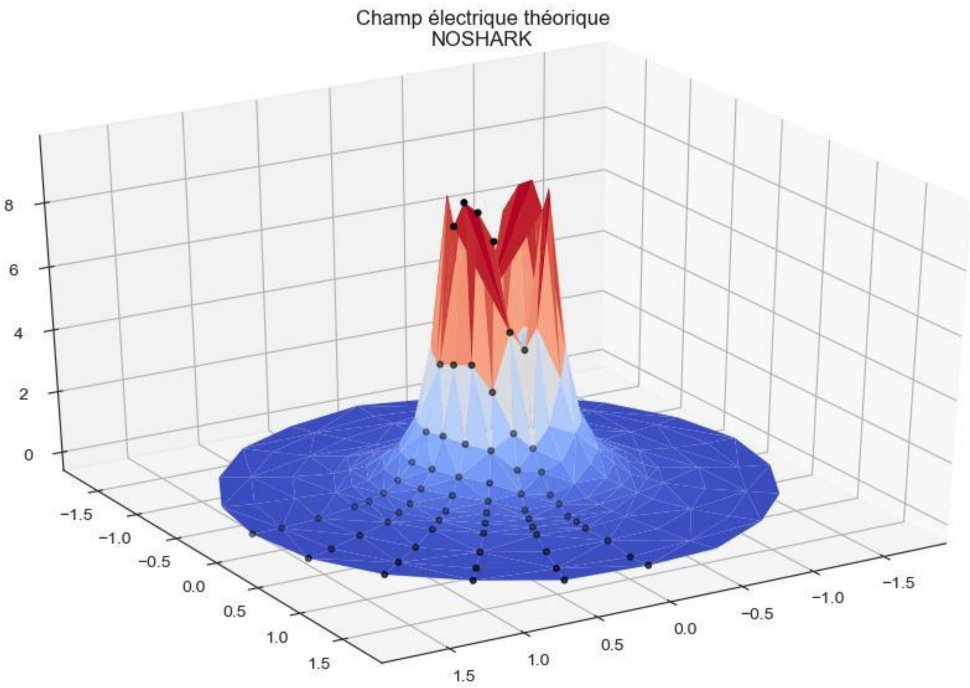



*Figure 22: 3D representation of the electric field measured on the NoShark in the horizontal plane – black point: measuring points achieved.*

Series n ° 2, 3 and 4 are in coherence. Only the series n ° 2, in the electrode axis (θ = 0), is slightly increased in the near field (d < 1M)

# 2.3 OCEAN GUARDIAN – FREEDOM+SURF

## 2.3.1 Temporal description of the signal

FREEDOM + SURF emits a field of electrical pulses in water at a frequency of 1.5 Hz, a pulse every 666ms.

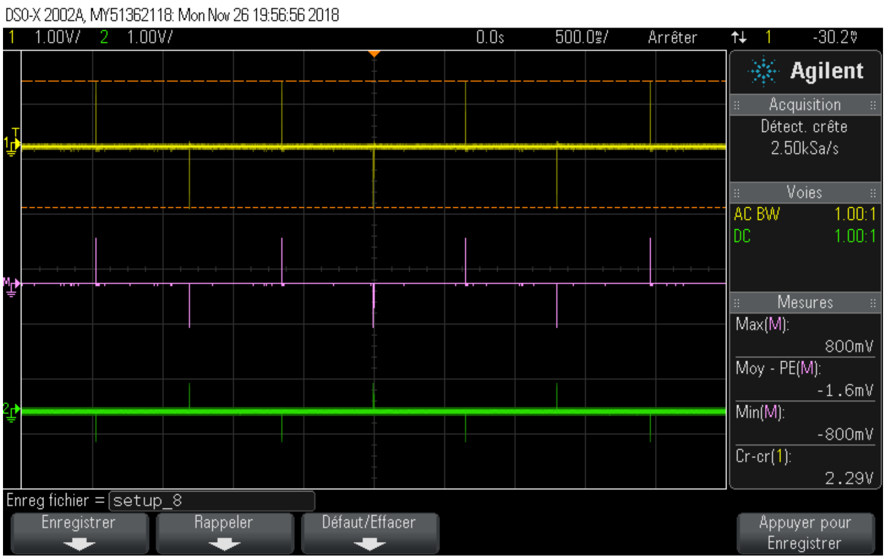



*Figure 23: General overview of the SHARKSHIELD's periodic emission cycle – FREEDOM + SURF – pink curve: signal of the electric field measured between the two electrodes of the Platinum (yellow and green signals)*

The polarity of the pulses is alternative (change of polarity at each impulse), but the intensity of the pulses is constant in absolute value.

## 2.3.2 Pulse characteristic

By improving the temporal resolution of the analysis, one can accurately describe the shape of each impulse produced.

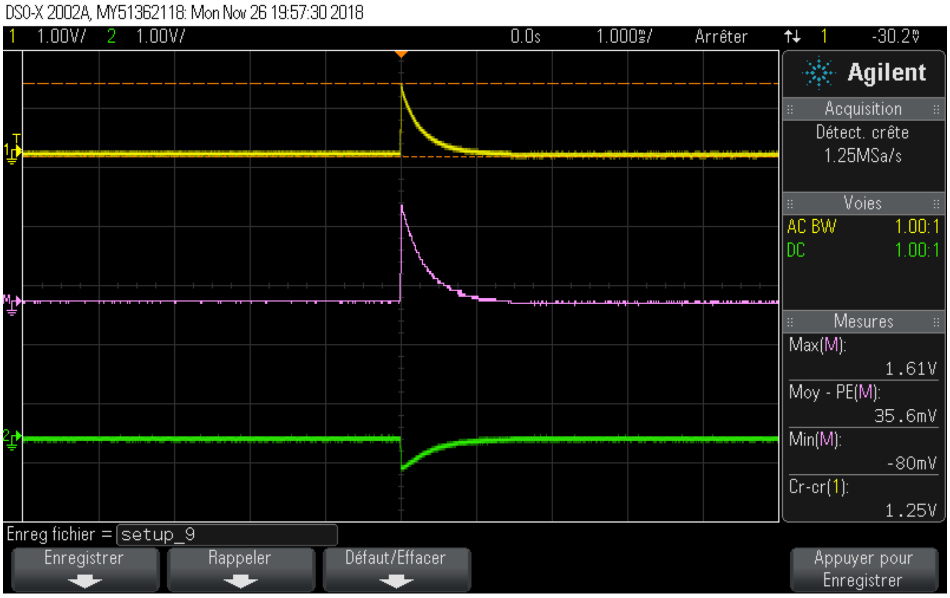



*Figure 24: Form of a pulse of the SHARKSHIELD – FREEDOM + SURF – pink curve: signal of the electric field measured between the two electrodes of the Platinum (yellow and green signals)*

The SHARKSHIELD FREEDOM + SURF pulses have the following characteristics:

- A rapid ascent in charge to reach the maximum at the beginning of the impulse;
- A descending logarithmic curve;
- The total duration of each pulse is 925 μs (5% of the maximum load)

The Max intensity is maintained for 107 μs (90% of the maximum load).

## 2.3.3 Spatial measurement of the electric field

In order to make the measurement operations and the reproducibility of the experimental procedure reliable, the electric field of the SHARKSHIELD/FREEDOM + SURF was measured on 4 different sets of measurements. The intensity of the electric impulse was measured at a distance from the center of the device varying from 0.3 to 1.7 m, and with increments of 10 to 25cm for directions θ = 0 ° and 90 ° (the other values of θ were also explored during one of the three measurement assignments, in order to be able to represent the field in the space around the device.

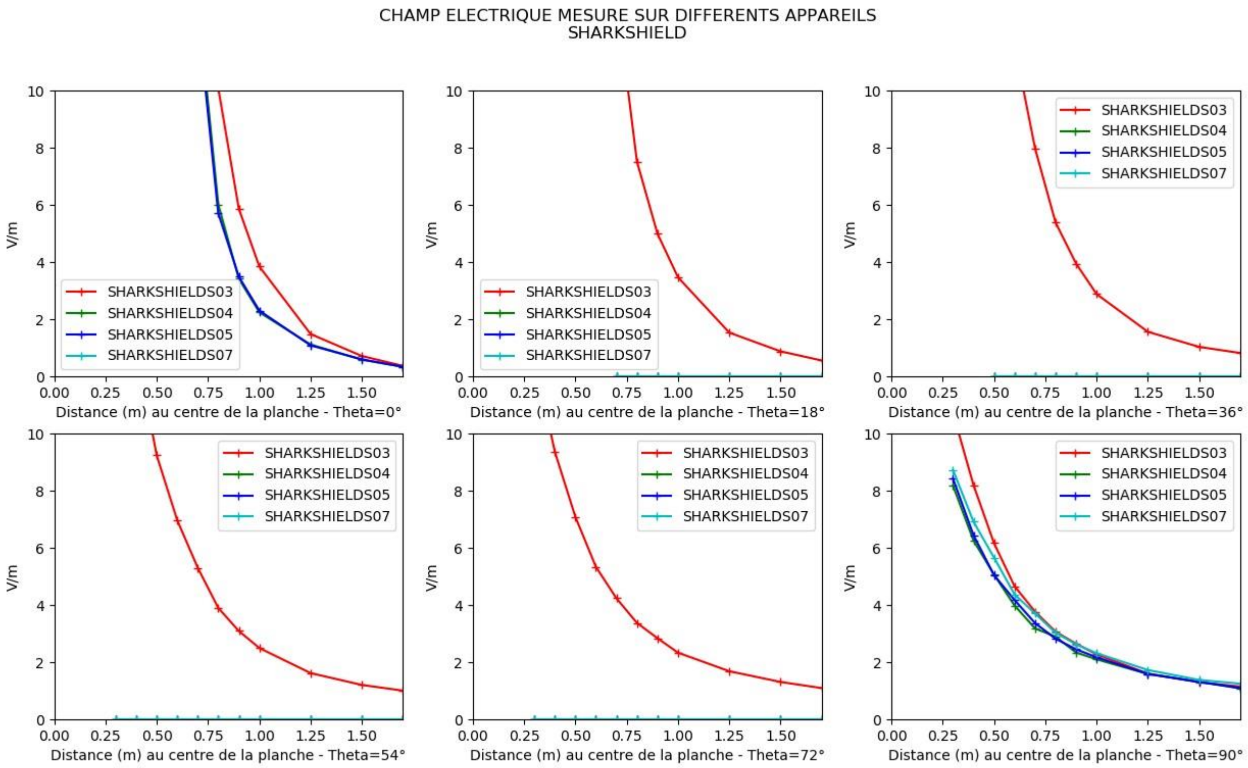



*Figure 25: Electric field measured in the horizontal plane of the SHARKSHIELD – FREEDOM + SURF (theta from 0 ° to 90 °)*

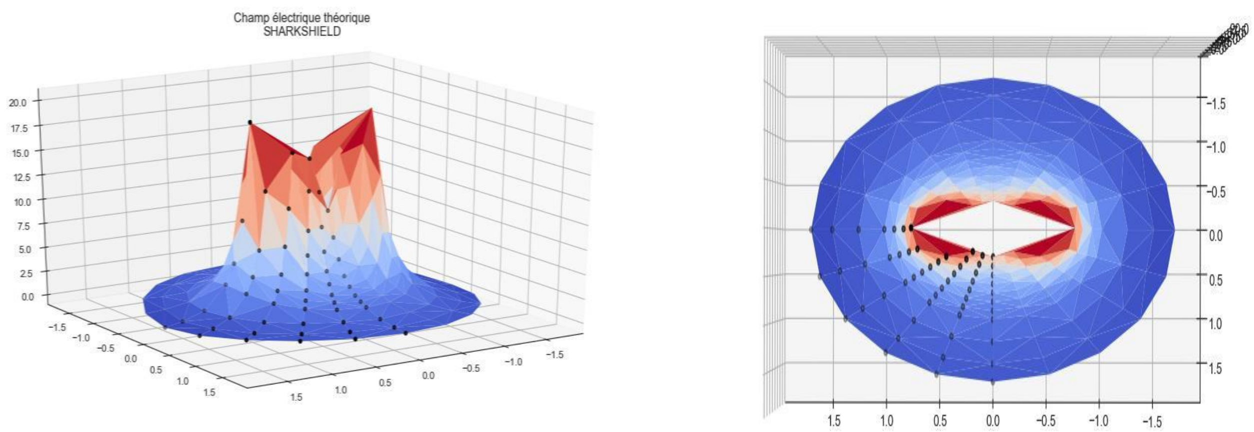



*Figure 26: 3D representation of the electric field measured on the SHARKSHIELD – FREEDOM + SURF in the horizontal plane – black point: measuring points achieved.*

## 2.4 RPELA

### 2.4.1 Temporal description of the signal

The RPELA emits a pulsed electric field in the water with a constant frequency.

This frequency is however dependent on the different versions of the devices tested in this study.

- RPELA v1 (version 2018): 10 Hz, i.e. one pulse every 100ms;
- RPELA v1 (version 2019): 14.7 Hz, i.e. one pulse every 68ms;
- RPELA v2 (version 2019): 13.9 Hz, one pulse every 72ms.

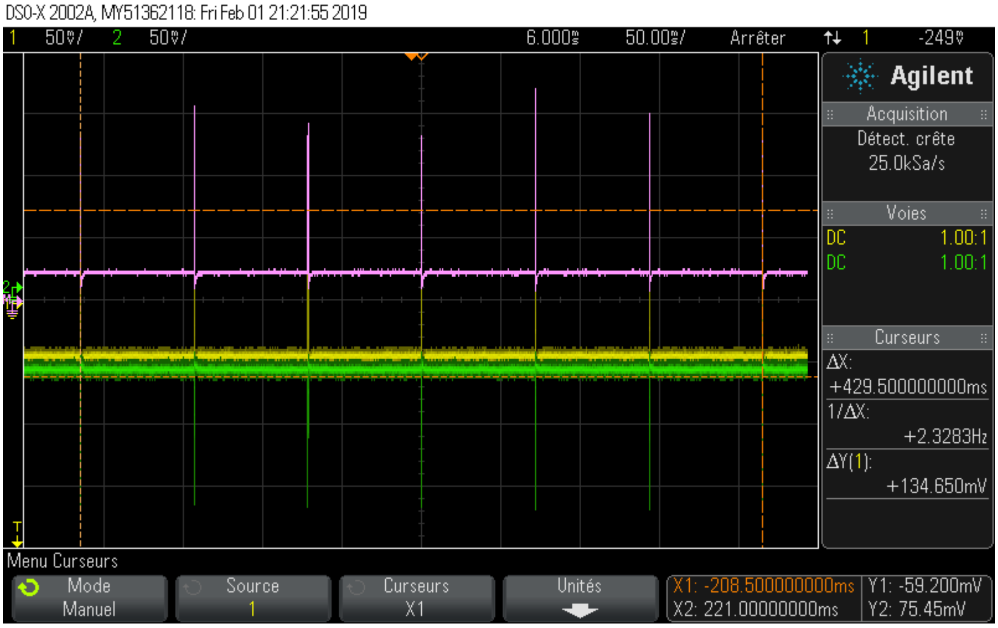



*Figure 27: General overview of the periodic emission cycle of the RPELA_V2 – pink curve: signal of the electric field measured between the two electrodes of the Platinum (yellow and green signals)*

The polarity of the pulses is not alternative as for the other devices.

The polarity of the electrodes remains unchanged during the tests. The load remains constant.

## 2.4.2 Pulse characteristics

By improving the temporal resolution of the analysis, one can accurately describe the shape of each impulse produced. The RPELA_V1 pulses have the following characteristics:

- A rapid ascent in charge to reach the maximum at the beginning of the impulse;
- A slightly decreasing slope;
- The total duration of each pulse is 92 µs.

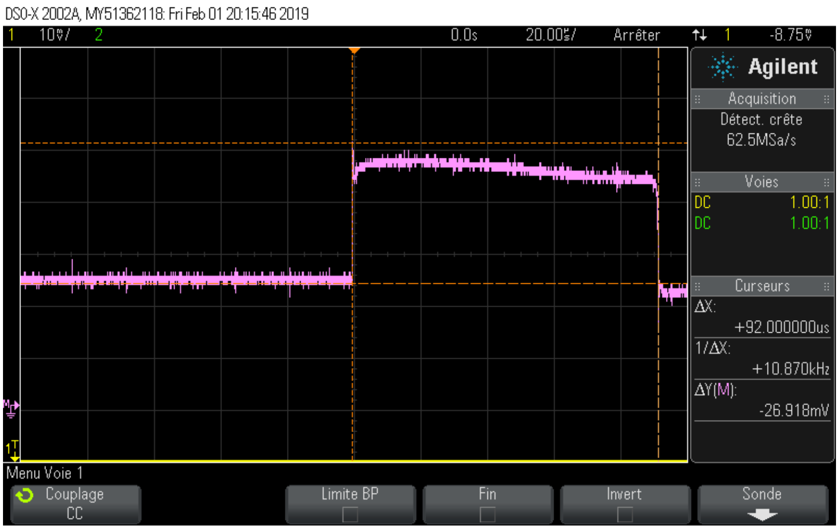



*Figure 28: Form of a pulse of the RPELA_V1 – pink curve: electrical potential measured between the two electrodes of the Platinum (yellow and green signals)*

The RPELA_V2 pulses have the following characteristics:

- A rapid ascent in charge to reach the maximum at the beginning of the impulse;
- A descending logarithmic curve;
- The total duration of each pulse is 193 µs;
- The Max intensity is maintained for 11 µs (90% of the maximum load).

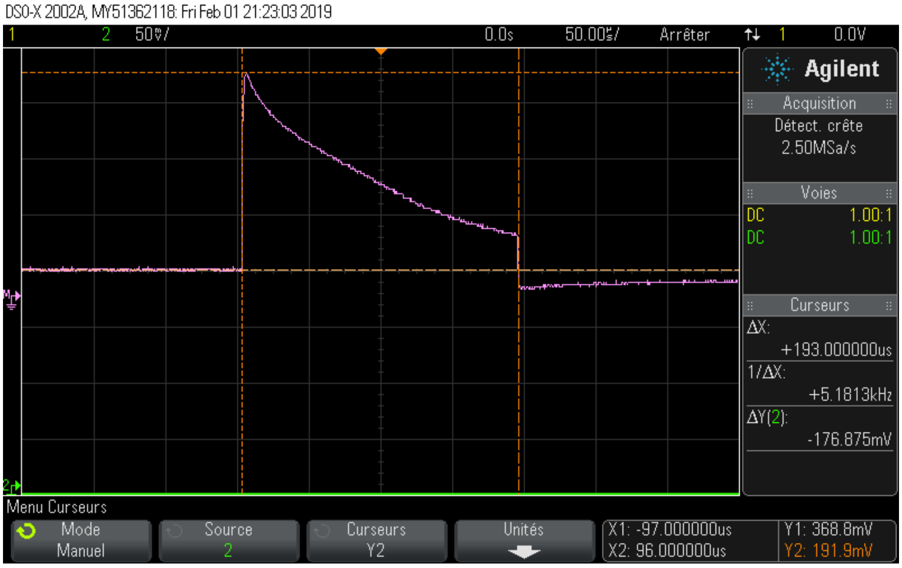



*Figure 29: Form of a pulse of the RPELA_V2 – pink curve: electrical potential measured between the two electrodes of the Platinum (yellow and green signals)*

## 2.4.3 Spatial measurement of the electric field

The objective here is to measure spatially the electric field around the device.

It should be noted here that the first RPELA-v1 device, purchased in 2018 for the purposes of experimentation, showed reliability problems that did not allow the correct characterization of the temporal spatial distribution of its signal.

In February 2019, during a passage on Reunion Island, Mr. Dave Smith was able to make two RPELA-v1 and RPELA-v2 aircraft available to the CRA. Both of these devices were tested in the CRA test pool in its presence.

However, unlike the other experimental devices, only a series of measurements could be performed for each device, not allowing characterizing the variability of the field measurement produced by these devices.

For each RPELA-v1 and RPELA-v2 device, the intensity of the electric impulse was measured at a distance from the Centre of the electrodes varying from 0.3 to 1.7 m, and with increments of 10 to 25cm for the directions θ = 0 ˚, 18 ˚, 36 ˚, 54 ˚, 72 ˚ and 90 ˚.

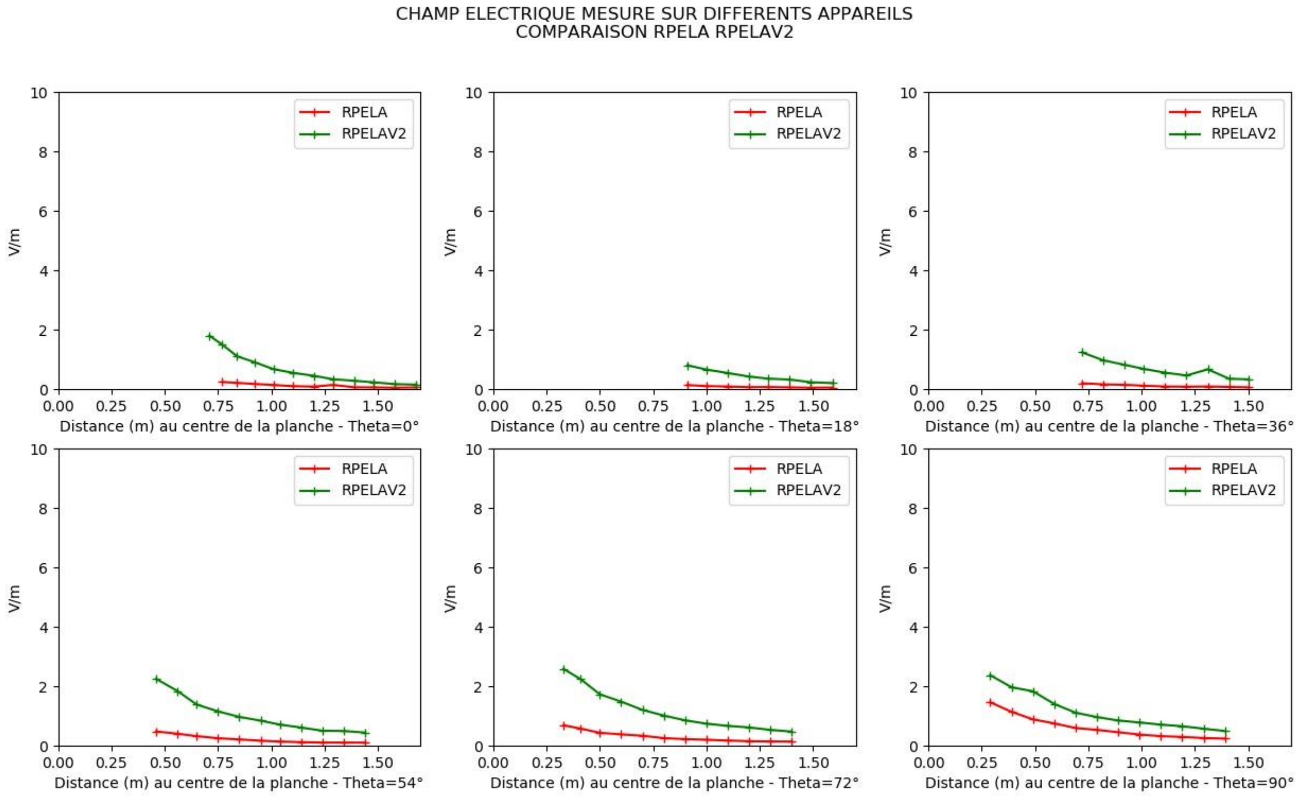



*Figure 30: Electric field measured in the horizontal plane of the RPELA version 1 (RPELA) and version 2 (RPELAV2) (theta from 0 ° to 90 °)*

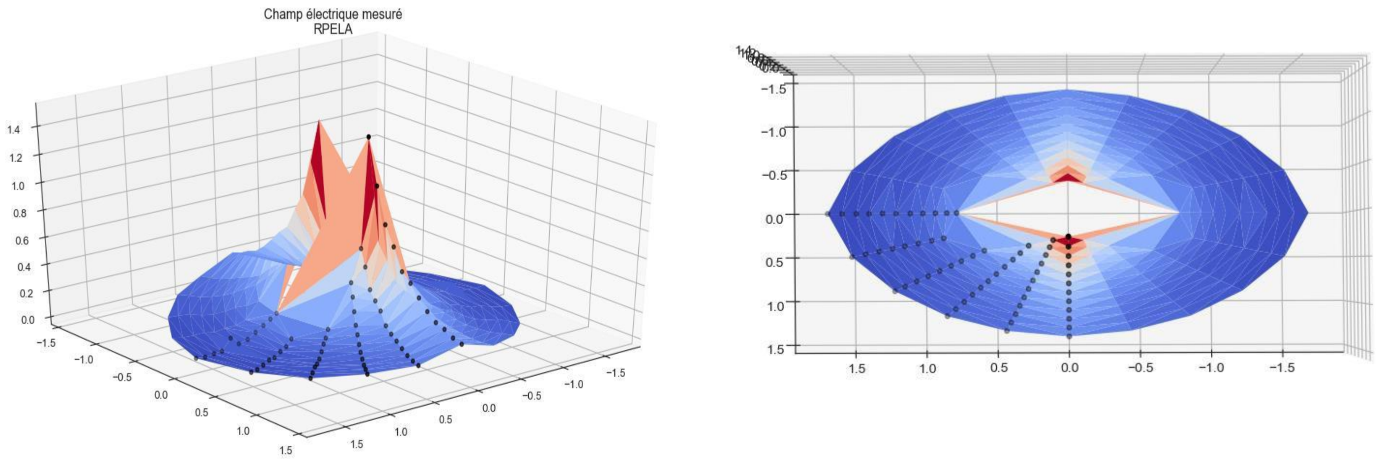



*Figure 31: 3D representation of the electric field measured on the RPELAV1 in the horizontal plane – black point: measuring points achieved.*

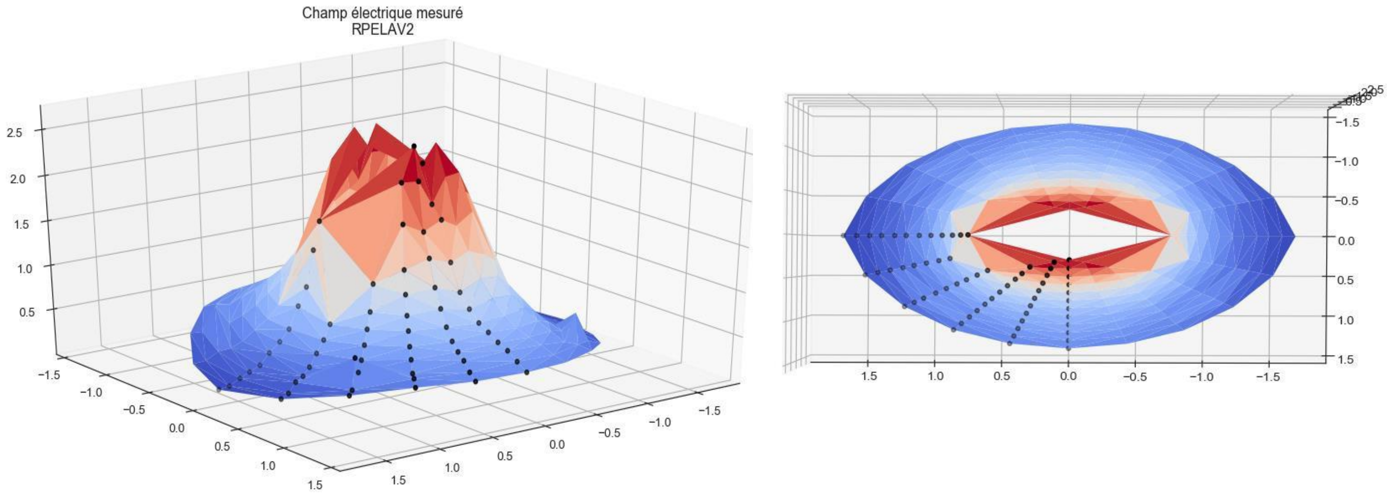



*Figure 32: 3D representation of the electric field measured on the RPELAV2 in the horizontal plane – black point: measuring points achieved.*

The results show a clearly distinguishable evolution between the two versions of the RPELA device. The increase in pulse intensity is observed in all directions of the measurement area.

# 3 COMPARATIVE ANALYSIS OF PPE

PPE can be compared and analyzed in two ways:

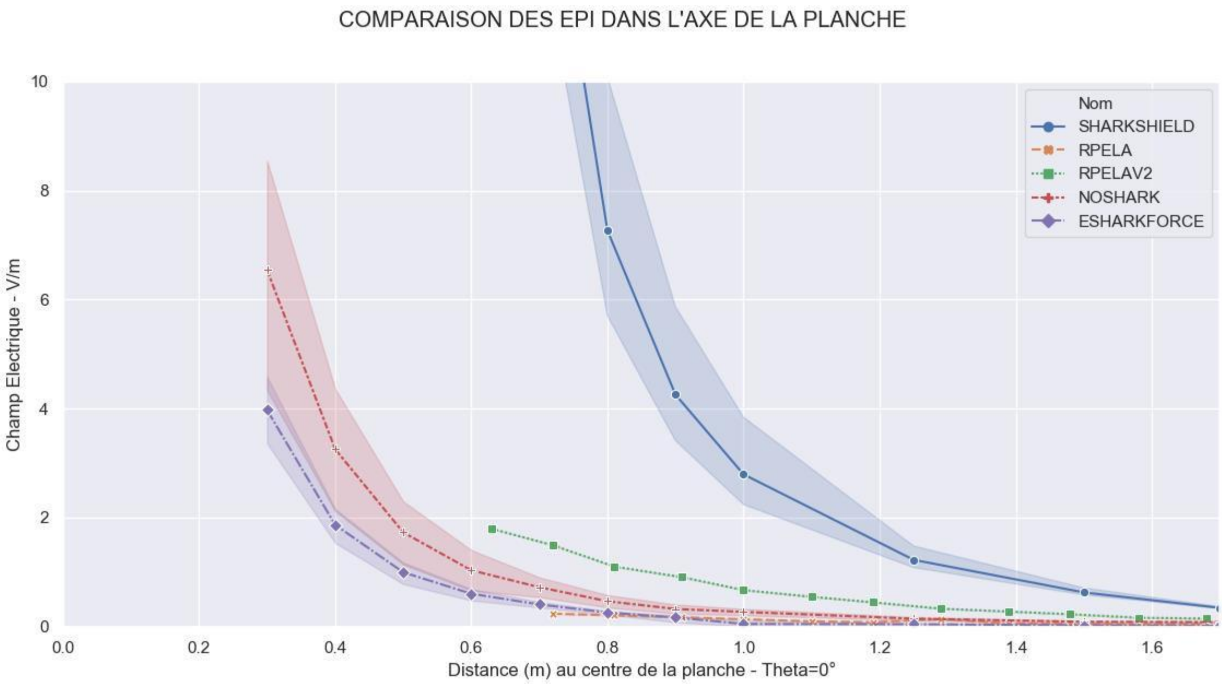
- From a spatial perspective by comparing the potential of the maximum field created by each device during an impulse. This spatial analysis consists of comparing the maximum intensity of the electrical pulses generated by each device, in several points of the space around the center of the two electrodes, and in the horizontal plane.

- From a temporal point of view by analyzing the time series generated by each device. This analysis allows to compare the evolution of pulses over time and to analyze the dynamics of the protection.

## 3.1 SPATIAL COMPARISON

For the NoShark and the E-SharkForce, the momentum for spatial comparison will be the most energetic, i.e. the first of the pulse bursts described in chapters 2.1 and 2.2. For Rpela and Sharkshield, pulses are of constant intensity over time.

Figure 31 next page allows a comparison of the pulse intensity of the different devices in both axes (perpendicular and longitudinal) relative to the electrode axis. For the Rpela and SharkShield, this axis corresponds to the axis of the surfboard.



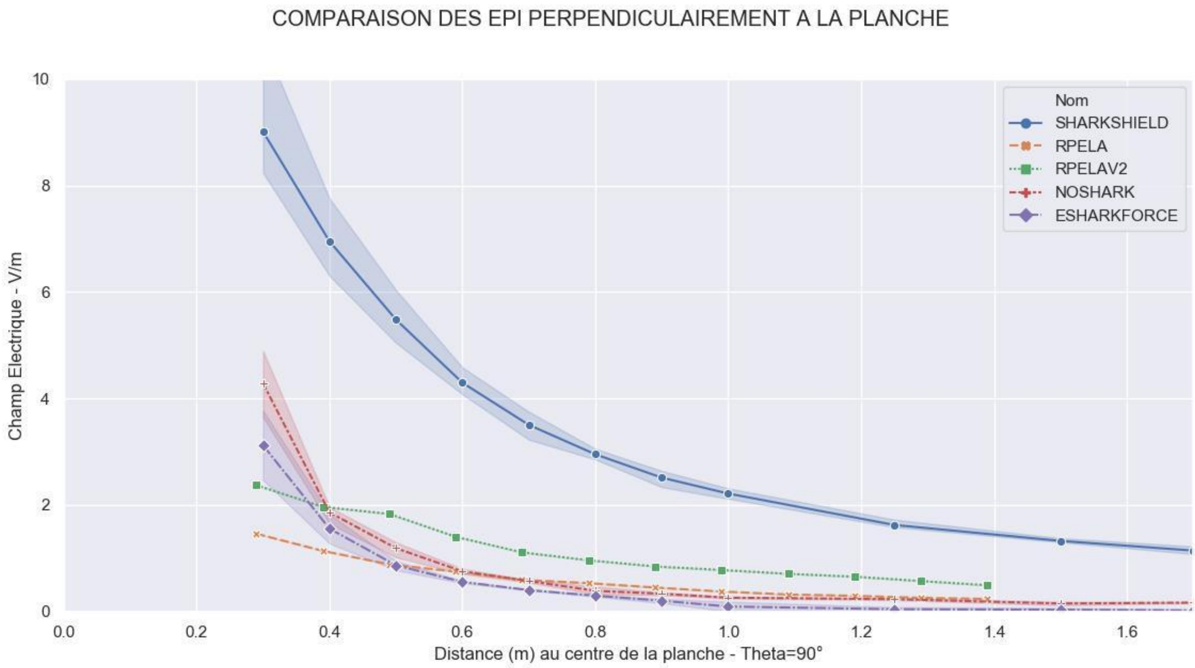




*Figure 33: Comparison of the electric field strength of different PPE in the axis (top) and perpendicularly (bottom) of the electrodes (CAD perpendicular to the Board for RPELA and SHARKSHIELD) – mean curve (color trait) and uncertainty range of results (colored surfaces)*

# 3.2 TIME COMPARISON

The temporal analysis proposes to compare the evolution in time of the electric field generated by 3 devices at 1M distance from the Centre of the electrodes, for θ = 90 ° (perpendicular to the Board for the Rpela and SharkShield).

Because the E-SharkForce does not generate any detectable electric field at this distance, it has not been included in the comparative analysis.

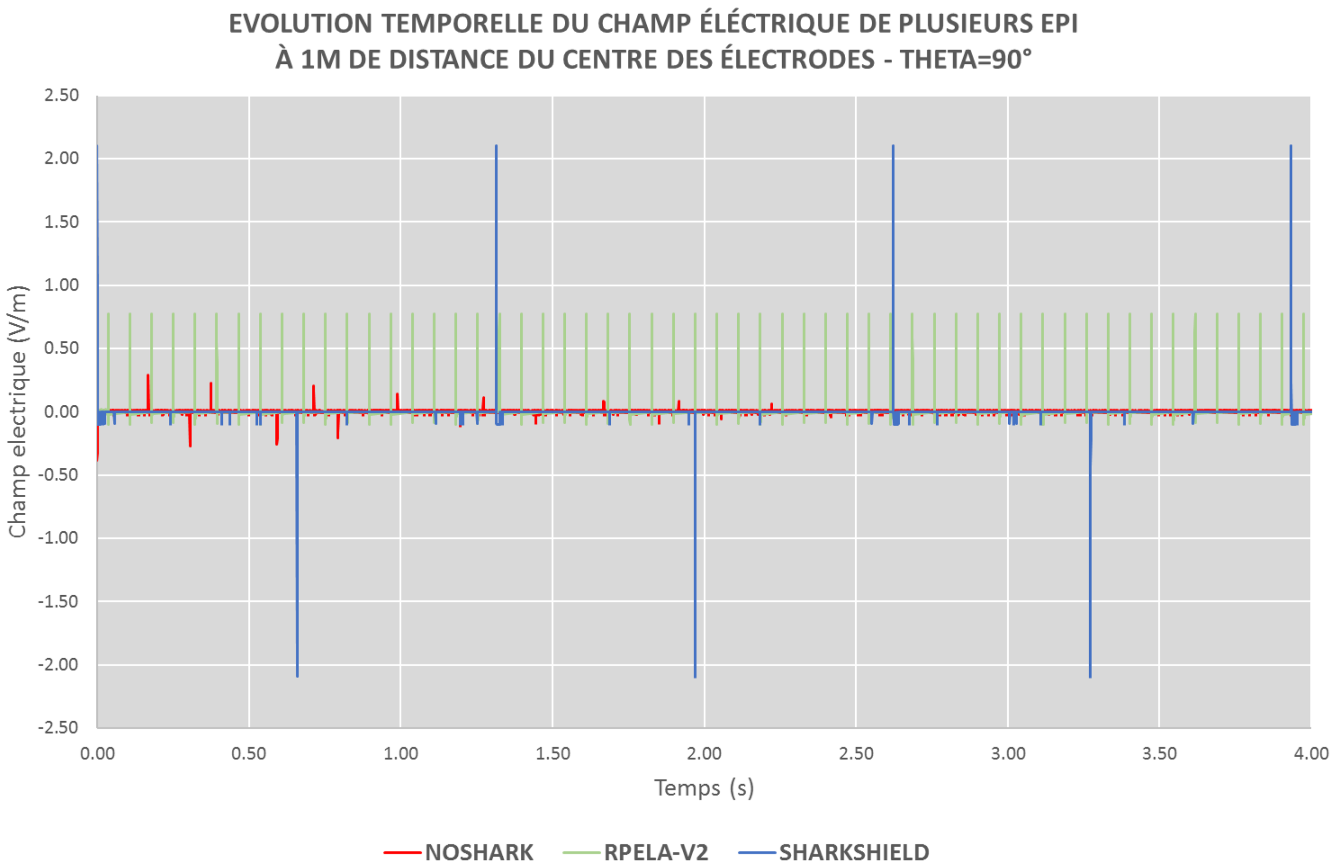



*Figure 34: Temporal evolution of the electric field of several PPE at 1M distance from the Centre of the electrodes-ϑ = 90 °*

## 3.3 DISCUSSION

The analysis of Figure 31 and Figure 32 shows very different strategies between the devices:

- The SharkShield clearly appears to be the device that emits the most energetic electric pulses. At 1M from the Centre of the electrodes, the pulses of the other PPE reach only 36% (RPela) and 18% (NoShark) of the pulse intensity of the SharkShield.

- In terms of distances, it can also be considered that in order to regain the intensity of the electric field produced by the SharkShield at 1M distance ($\theta = 90°$), it is necessary to approach about 0.4 m from the center of the electrodes for the other devices (Rpela, NoShark, E-SharkForce)

- On the other hand, the pulse emission frequency is the highest for the RPela-v2: about 14Hz, which is an impulse every 68ms. The SharkShield emits much more time-spaced pulses: all 666ms, approximately 10 times less often than the RPela-v2. The NoShark presents an intermediate strategy: it emits pulses every 150ms during 2.33 s, but nothing during 2.35 s before restarting a cycle.

The different PPE therefore all have more or less long "dead times" during which there is no electric field in the water between the pulses.

If these "dead times" are considered as temporal intervals of susceptibility of the PPE carrier, the limit speed of the animal in the approach that each device is potentially capable of deterring can be calculated.

For this reason, it is considered that the shark moving at a given speed will have to perceive at least an electric impulse in the last meter before interaction with the carrier of the PPE. The calculation gives the SharkShield a maximum movement speed of 1.5 m/s; for the RPELA-v2 15m/s; for the E-SharkForce, 0.6 m/s and for the NoShark 0.4 m/s. above this speed, the approaching shark can potentially traverse the last meter without perceiving an electric impulse. With the exception of the RPELA v2, these velocities are all below a shark speed in charge (about 5M/s for the Bulldog shark)

This analysis raises the question of the potential predation of Bulldog or Tiger sharks on sea users (bather, surfer, diver, etc.) and the dynamics of the attack: how fast does the shark approach its prey during an attack? And to what extent can PPE devices remain effective in the event of a rapid attack?

Regarding to this topic, the bibliographical analysis shows us the following elements:

- The experience of Huveneers (2013) was built to trigger fast loads (breaching) of white sharks on a moving lure towed behind a boat. Despite the high loading speed of white sharks and the significant distance between decoy and EPI (2.3 m), this experiment showed a very good rate of efficiency of the tested device (SharkShield freedom). The author explains this situation by considering the energy cost of such a charge for a white shark, which is indispensable to apprehend the prey given its speed of movement. Considering this important energy cost, it would be very easy to deter such a predator when deciding whether to trigger the load, or during its execution. The author indicates that there were sudden drop-outs of charge at very short distance from the lure, despite a high execution speed.

- KEMPSTER (2016) also assumes a perception of the electrical signal at a greater distance than the actual repulsion distance observed (0.8 m). His experience showed a sharp decrease in the number of people in a 3M radius around a SharkShield device when it was on. This assumption of a capacity to perceive the electric field at a greater distance (> 3M) could also explain the effectiveness of SharkShield to deter a load (demonstrated by Huveneers in 2013) at great distances despite a frequency of the device relatively low relative to the speed of the animal.

- In return, during the Kempster experiment (2016), the baits used are hung on a fixed Rod positioned in the water column. The approach of white sharks is accomplished rather in an exploratory mode, with several passages being necessary before a potential interaction occurs. Indeed, 4 passages at a distance of less than 1.3 m from the bait are necessary before a potential interaction occurs (25% probability when the device is switched on).

These elements suggest that on a stationary or slow target, the shark approach is potentially exploratory and slow because there is no justification for a fast energy-consuming approach.

In both cases (exploratory approach or fast load), SharkShield was able to demonstrate its ability to reduce the number of interactions. It can therefore be considered that the chosen strategy, which can be summed up by a couple [low frequency but high transmitting power], has proved its worth.

The strategy of other devices can be analyzed in the following way:

- The RPLEA-v2 offers a high transmission frequency (10 times greater than the SharkShield), but a much lower power than SharkShield (36%). The choice of a high frequency is conservative but it can be achieved at the expense of the power of impulses. According to the last study conducted by the private firm Cardno funded by RPELA, this strategy seems to have demonstrated its effectiveness in decreasing the likelihood of interaction. However, the experimental protocol was dimensioned to generate exploratory and not rapid approaches.

- NoShark and E-shark force provide a special "burst" impulse emission strategy, followed by a period of inactivity that can last 2.3 s and 1.7 s respectively for these two devices. This inactivity time may seem important, a shark swimming at a speed of 0.4 to 0.6 m/s having theoretically the time to traverse the last meter without being bothered by the emission of an electric impulse.

# 4 Synthesis

In the inventory of existing solutions to reduce shark risk, the solution of individual protective equipment is currently experiencing a boom with several industrial operators who invest the subject internationally.

Formerly reserved for a historical and unique operator (SharkShield, originally developed for scuba divers and underwater hunters under the name shark pod), several operators now offer protection devices whose strategies for design, protection, and market target may be different.

The PPE which has been the subject of this study consists of the equipment which emits an electric field in the water, in the form of pulses. 4 devices were the subject of this study which was carried out in several phases.

## PHASE 1: A BIBLIOGRAPHICAL REVIEW OF INDEPENDENT TESTS ON THE PPE OF THE MARKET REGARDING THEIR EFFECTIVENESS OF REPULSION ON SHARKS.

This review was carried out and returned to the users of the sea at 3 public meetings held in Saint Gilles, Saint Leu and Saint Pierre. In essence and in summary, the bibliographic evidence indicates that the SharkShield FREEDOM showed real efficacy on the white shark, although the device is not effective at 100%. Indeed, the rate of interaction with baits decreases from 81% to 11% when the device is activated. Studies also indicate that even if the repulsive effect is demonstrated, the repulsion distance remains low: between 80cm and 1M.

In 2018, for the first time, a study made it possible to compare and test several devices under identical and controlled conditions (notably FREEDOM + SURF and RPELA-v1). This study confirmed the repellant effect of SharkShield in its FREEDOM + SURF version adapted to surfers. On the other hand, this study indicates that no effects could be measured on the number of bait interactions and bite in the presence of the RPELA-v1. This information is important to integrate for the holders of this device in Reunion Island.

By the end of the year 2018, the company RPELA launched a second version of its device, and commissioned a private firm to evaluate its new PPE, the RPELA-v2. This study, released in December 2018, appears to demonstrate this time the presence of a measurable and quantifiable effect of the decrease in the number of interactions in the presence of the activated device (the probability of bite of the bait decreasing from 75% to 25% when device is activated).

Finally, it should be recalled that to date no shark attack in the world has been recorded on a person equipped with a pulsed electric field PPE device, even if this remark must be weighted in keeping with the low statistical representation persons equipped with PPE in relation to the number of attacks in the world.

## PHASE 2: CONDUCTING IN-SITU TESTS TO ANALYSE AND COMPARE THE STRUCTURE OF ELECTRICAL FIELDS GENERATED BY THE APPARATUS (PURPOSE OF THIS REPORT).

The results of these tests show the existence of very different strategies between the devices to repel the sharks. The main conclusions confirm the predominance of the SharkShield device in terms of the power of the electric pulses: at 1M from the Centre of the electrodes, the pulses of the other PPE correspond to 36% (RPela) and 18% (NoShark) of Pulse intensity of the SharkShield. In other words, to regain the same electric field strength produced by the SharkShield at 1M distance (θ = 90 °), it is necessary to approach about 0.4 m from the center of the electrodes for the other devices (Rpela, NoShark, E-SharkForce). These considerations confirm the findings made by Huveneers in 2018 concerning a significant difference in efficiency between the SharkShield and RPela-v1 devices on the repulsion of white sharks. The other two devices (NoShark and E-SharkForce) have never been tested in vivo on sharks.

The pond tests on the different versions of the RPELA devices show a noticeable evolution between v1 and v2 versions of this device. This finding is further corroborated by the positive tests carried out by the Cardno firm on the RPELA-v2 at the end of the year 2018, seeming to demonstrate some efficiency of this apparatus on the white shark.

Finally, the tests carried out at the CRA have revealed a number of problems of reliability of certain devices in erratic operation. To operate well and to be used for the duration, these devices require regular maintenance (rinsing, routine cleaning of the electrodes, etc.). In spite of this, failures or malfunctions can provide support. In view of the safety issue and the experience gained in this study, the CRA could propose a service to verify the integrity of the devices used by sea users in Reunion Island.

# EPI: AN ADDITIONAL TOOL FOR SHARK RISK REDUCTION AT THE REUNION ISLAND

Since 2017, the State of Western Australia has taken the political decision to subsidize, on an individual basis, a scientifically and independently proven efficacy on the ocean guardian SharkShield (FREEDOM + SURF and FREEDOM) devices. the State of Western Australia has made the political decision to subsidize, as an individual, the purchase of these devices up to 176 €/person for the inhabitants of his State. This is a public strategy that allows acting on the reduction of shark risk at the level of all the practitioners equipped, and on the entire coastline of the State.

The principle of this means of action to reduce risk has also been integrated by the reuniting practitioners who have massively equipped themselves with these devices in recent years, without having a good visibility on the level of efficiency of each of these PPE in terms of shark repulsion.

The choice has often been in support of secondary criteria such as price, weight, and ergonomics with regard to practice (surfing, Body boarding...) or simply the difference of attachment (on the user or on the Board of the user).

With the analysis of the tests carried out in the world and the tests carried out by the CRA, it is clear that:

- **Some PPE have clearly demonstrated their risk reduction effectiveness on large white sharks: SharkShield in a certain way, and the RPELA (only in its v2 version), to a lesser extent (non-independent study);**
- **These devices are equipment to reduce shark risk, but a residual risk is still present**;
- With the constant increase in battery efficiency (mobile solutions) and current technological developments, these devices are rapidly evolving towards further protection in the coming years;
- **With these findings, this risk reduction tool could be mobilized in the territory of Reunion Island in order to act on a wider public of sea users, still at present strongly exposed to shark risk because practicing outside the devices ZONEX, in addition to other tools such as the reunion fisheries prevention program**;
- It can be seen that to date, devices that have demonstrated their effectiveness are not the most prevalent among users in La Réunion. This risk reduction lever must be activated in an informed manner, communicating more broadly about good practices to remember and choosing a suitable, reliable and regularly controlled equipment;
- The erratic functioning of some devices makes the need to be able to control, in reunion, the devices purchased by users in the market, and to follow their evolution over time. To go in this direction, the CRA proposes to capitalize on the experience gained under this project, and to set up a mobile test bench that can be deployed at sea by its nautical team, near the surf areas, in order to provide an assessment free of charge for equipment for equipped users.

- To go further in the knowledge and reliability of these equipments in the context of reunion, tests remain to be carried out specifically on the Bulldog shark in order to accurately quantify the repulsive effects of PPE on this species. An experimentation project is planned, and is the subject of phase 3 of this project.