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A Subnanosecond Pulsed Electric Field System for Studying Cells Electropermeabilization

Njomza Ibrahimi, Graduate Student Member, IEEE, Leslie Vallet, Franck M. Andre, Member, IEEE, Laurent Ariztia, Marc Rivaletto, Antoine Silvestre de Ferron, Bucur Mircea Novac, Senior Member, IEEE, Lluis M. Mir, and Laurent Pécastaing, Senior Member, IEEE

Abstract—This article presents an experimental arrangement which, using 3-D numerical modeling, aims to study biomedical effects using subnanosecond pulsed electric fields (PEFs). As part of a major effort into developing contactless technology, the final aim of this study is to determine conditions of the applied PEFs (number of pulses, strength, pulse repetition frequency) able to produce electropermeabilization. The arrangement uses a pulsed power generator producing voltage impulses with an amplitude of up to 20 kV on a 50-Ω matched load, with a rise time of 100 ps and a duration of 600 ps. During the preliminary study reported here, samples containing E. Coli were exposed to PEFs in a 4-mm standard electroporation cuvette, allowing the application of a peak electric field strength of up to 60 kV/cm. The studies were facilitated by detailed 3-D electromagnetic modeling of the electric field distribution generated by voltage impulses inside the system. Due to the nature of tests, the numerical analysis played an essential role in the interpretation of results. Preliminary biological results reported in this study are very encouraging, showing that trains of 5000 to 50 000 pulses applied at a pulsed repetition frequency of 200 Hz (maximum PRF) can efficiently induce E. Coli electropermeabilization.

Index Terms—Biological cells, electropermeabilization, pulsed electric fields (PEFs), pulsed power, subnanosecond pulses.

I. INTRODUCTION

THE use of narrow-band electromagnetic fields for application to medicine and biology has received significant attention by the scientific community over the last few decades [1]. Electroporation (electric pore formation) is a phenomenon which increases the permeability of the cell membrane when exposed to pulsed electric fields (PEFs) of high intensity and short duration. The pore formation generates openings in the cell membrane, allowing for the transfer of therapeutic molecules across the cell membrane [2], [3]. Thus, the electroporation phenomenon contributes to the efficiency of electrochemotherapy, when used with drugs [4] and electrothergometry, when used with DNA plasmids [5].

PEFs can cause reversible electroporation, i.e., a temporary permeabilization of the cell membrane [6], but they can also produce irreversible electroporation, i.e., cell death, for eradicating cancerous or other unwanted cells [7].

There are basically two types of PEF techniques applied in vivo: invasive, where metallic pairs of penetrating electrodes are used to apply the electric field and noninvasive, where the electric field is generated through electrodes brought in contact with the skin, without penetration of the body. In addition, the contactless term refers here to the approach dealing with the generation of electric fields remotely from the metallic structure of a PEF source (antenna).

The electrode-based contact technology is already successfully applied in the treatment of various cancers including, but not limited to, kidney, liver, lung, and bone cancers [8]. Pulses having hundreds of ns duration applied for cancer treatment are still under clinical trials and as such are not part of regular treatments. PEFs of about 100 μs are widely used, depending on the type and the evolution of cancer while ms pulses are not used for cancer treatment. The outcome effect depends not only on the magnitude and duration of the PEFs delivered, but also on the pulse repetition frequency (PRF) and on the characteristics of the tissue, in particular, its conductivity. Irreversible electroporation using microsecond very high intensity PEFs in the tissues is widely considered in many hospitals. An advantage of this technique is that the thermal effects are considerably lower, when compared to other ablation techniques [9]. Cancer treatment techniques, which include but are not limited to chemotherapy and surgery, are unfortunately accompanied by adverse side effects imposed on the patient [10], [11]. The future of the PEF-based cancer treatment techniques is therefore closely related to the identification of new ways to avoid the challenges imposed by the existing invasive surgical procedures. The pathway toward a contactless technology, a nonsurgical procedure, which aims at overcoming some of the issues mentioned above, was studied in very few research laboratories worldwide. The reason for the very limited number of publications published in this domain is perhaps due to the fact that, depending on their output voltage, the highly specialized HV subnanosecond pulsed...
power generators required are either extremely expensive or
only available at military related research centers. Even more
difficult, the focusing of electromagnetic radiation with very
high precision in a volume around 1 cm³, or preferably even
lower, is possible only using highly sophisticated impulse
antenna techniques.

Two possible solutions were suggested theoretically by Carl
Baum, as part of a major research effort undertaken by the
Frank Reidy Research Center for Bioelectronics at Old Domin-
ion University (USA); an impulse radiating antenna (IRA)
operated in air [12], [13], in combination with a complex
many layer dielectric lens [14] and another prostate-spheroidal
reflector, operated underwater [15]. More recently, at the same
research center, a dielectric rod antenna was also suggested
as a candidate for generating subnanosecond PEFs for the
stimulation of neurological tissue [16]. All the three tech-
niques have been theoretically investigated using CST software
[15]–[17], with detailed numerical studies being reported.
In contrast, very limited experimental work has been pub-
lished, and only using rather low voltage subnanosecond
pulsed power generators, with the resulting PEFs having
extremely low peak values when compared with the values
required for electroporation [18]–[20], the latter work re-
presenting an effort made at University of Limoges (France).
For stimulating deep inside a tissue, say at 8 cm [17] using
intense PEFs of some tens of kV/cm, published work suggest
a subnanosecond pulsed power generator with a peak output
voltage in excess of 250 kV is required [17]. Such a generator
is technically extremely challenging.

Another aspect is that when using such innovative contact-
less delivery systems, the characteristics of the subnanosecond
PEFs are different when compared with those of the existing
PEF processing. A logical step is therefore to understand their
action on cells by firstly using standard electrode-based PEFs
driven by subnanosecond pulsed power generators. Results
published by the Old Dominion team and also by a research
group at Chongqing University (China), demonstrated that
subnanosecond PEFs can indeed produce: permeabilization
[21] followed by the transfer of molecules inside the cell [22],
cell stimulation with calcium mobilization (through VGCCs
activation) [23], and apoptosis (cell death) [24]–[27]. The main
issue with these results however is that they suggest a very
low efficiency of processing for a PEF having a relatively
low peak value, say around 25 kV/cm, as it is expected to
be generated in a deep tissue by a contactless reflector-based
system. Under such conditions, to obtain the effect on a
significant percentage of cells, it was necessary to apply an
extremely large number of pulses, of the order of a few
millions [22].

The development of contactless PEF technologies has been
a major research theme in the long history of an ongo-
ing collaboration between Pau University and Loughbor-
ough University and two major works have been already
published discussing a novel technique for food process-
ing [28] and a subnanosecond driven prolate antenna operated
underwater [29]. The latter work reports the first practi-
cional demonstration of generating underwater a peak PEF
of 50 kV/cm at 8 cm away from any metallic structure,
i.e., fulfilling the conditions required for contactless deep
tissue permeabilization [17].

The arrangement reported here is using a standard
electrode-based approach. In the preliminary phase of this
study, it was decided to apply PEFs on the E. Coli DH5α
bacteria, which are very small cells with a diameter in the
range of 1 μm.

First, the pulsed power generator will be introduced,
together with its corresponding diagnostics.

Second, a detailed 3-D model is presented, based on the
CST Microwave Studio, a 3-D finite integral time-domain
(FITD) electromagnetic simulation software [30]. As the direct
measurement of the PEF generated inside a cuvette containing
the cell culture is technically challenging, a comprehensive
3-D modeling and numerical electromagnetic analysis were
essential during the experimental studies.

Third, we report encouraging preliminary results that
demonstrate that a high percentage of permeabilized bacteria
can be achieved using the described arrangement.

This conclusion ends with conclusions and a brief presen-
tation of the way ahead.

II. EXPERIMENTAL ARRANGEMENT

For the present studies, a pulsed power generator similar to
that described in [31] was adapted for use as a subnanosecond
transient source capable of producing high voltage pulses
with an amplitude of up to 20 kV and having a 100-ps
rise time on a 50-Ω matched load, with a duration of about
600 ps. The generator is connected to the PEF processing
load through a 2.5-m-long RG214-U type coaxial 50-Ω cable,
having an insulator made of polyethylene with relative per-
mittivity of 2.26. A simplified scheme of the pulsed power
arrangement is shown in Fig. 1. The generator is constructed
as a fast pulse forming line, with the closing switch operated
under high-pressure hydrogen. To obtain a 20-kV peak voltage
output, the product of the hydrogen pressure and the gap
distance of the electrode system was held to 22 bar · mm.
This value was then adjusted to obtain other values for the
output peak voltage. The output voltage is measured using a
capacitive voltage divider, the main voltage probe, attached
to the RG214-U coaxial cable [Fig. 1(b)]. The transmission
coefficient for this probe is equal to −46 dB all over the
frequency bandwidth and the reflection coefficient is lower
than −12 dB while the cut-off frequency is close to 6 GHz.

The PEF processing load connected at the end of the
RG214-U coaxial cable [Fig. 1(b)] consists of two
parallel-plate electrodes made of copper. The distance between
copper electrodes is fixed to 12 mm to allow mounting
between them a standard electropropagation cuvette, having a gap
distance of 4 mm between its internal aluminum electrodes.
The volume of the sample which contains the deionized water
to be tested was kept at 100 μL for two reasons. First,
to obtain the desired PEF in water in terms of amplitude,
rise time, and duration and second to reduce the impedance
mismatch. To avoid any possible electric breakdown, the upper
part of the cuvette was additionally filled with 1.6 mL of
paraffin oil, having a relative permittivity 2.33. It is important
to note that the dielectric strength of the present experimental arrangement, when subnanosecond electric pulses are applied, is much higher compared to cases when 50-Hz ac, microsecond or longer duration pulses are applied. The complete experimental configuration is presented in Fig. 2. An SMA-type V-dot probe is mounted just a few millimeters below the cuvette with the connector’s body attached to the ground plate electrode. This probe is used to control the voltage across the cuvette, with the electric field in the cuvette obtained using the numerical technique described in the following.

III. NUMERICAL TECHNIQUES

A detailed 3-D modeling and EM analysis were carried out for the PEF system. To shorten the time required for numerical analysis of the 50-Ω (RG214-U) coaxial cable, only a length of 101 mm was considered, corresponding to a propagation time of 0.5 ns. The 3-D CST model of the coaxial cable (3), two parallel-plate electrodes (4), 4-mm electroporation cuvette (5), and SMA-type V-dot probe (6).

The electric field distribution inside the cuvette was studied numerically, using the CST Electrostatics solver. The cuvette behaves like a collection of two parallel plate capacitors mounted in parallel, one containing paraffin oil and the other water. Because of this, the electric field strength is the same in the two media, but the displacement fields are different. CST calculations indicate for the impedance starts to increase to a value of 70 Ω. This effect is due to the mismatch between the coaxial cable and the PEF processing load. At around 1.2 ns the impedance starts to decrease and at 1.4 ns attains a minimum value of 32 Ω.

1. Nomenclature

Fig. 1. Pulsed power arrangement for subnanosecond PEF. (a) Subnanosecond generator (adapted after [31]) and PEF processing load. (b) Overall schematic.

Fig. 2. Experimental arrangement for subnanosecond PEF processing. The numbers 1–6 represent the generator (1), capacitive voltage divider (main voltage probe) (2), RG214-U 50 Ω coaxial cable (3), two parallel-plate electrodes (4), 4-mm electroporation cuvette (5), and SMA-type V-dot probe (6).

Fig. 3. Complete CST model for the PEF processing chamber, including the RG214-U coaxial cable, the two parallel-plate copper electrodes with the SMA-type V-dot probe attached and the electroporation cuvette, with various compartments filled with paraffin oil and water sample, which may contain bacteria. The two CST ports are highlighted.
the cuvette a total equivalent capacitance of 5.95 pF, a value allowing voltage pulses having about 258-ps rise time to be delivered to the PEF processing load.

IV. DETERMINATION OF THE TIME VARIATION OF THE ELECTRIC FIELD IN THE PROCESSED WATER SAMPLE

Because of the very small size of the water sample to be processed, there are no available techniques that can be used to directly measure the electric field generated inside. The only way to determine this essential parameter, which allows the correct interpretation of the biological results, is to use a combination of numerical modeling predictions and experimental evidence. Firstly, a detailed 3-D CST electromagnetic analysis of the load was carried out, including the SMA-type V-dot probe mounted near the cuvette (Fig. 7). The input signal applied to the processing load (see Fig. 8) was accurately measured using the main voltage probe attached to the RG214-U coaxial cable described above. This experimentally obtained voltage signal, with a rise time of about 258 ps and FWHM about 434 ps, was then used as an input (or excitation signal) for the CST Port 1 situated at the coaxial cable input (Fig. 3). To check the model, the predicted reflected signal was then successfully compared with the experimentally recorded reflected signal (see Fig. 9). To allow this comparison, the time delay of the signal due to the 2.5-m coaxial cable (see Fig. 8) was adjusted to the corresponding shorter time delay of only 101-mm length of cable considered by the CST model (see Fig. 9). A second comparison between CST predictions and the experimental data was performed for the CST Port 2 situated at the V-dot probe output (Fig. 3). Fig. 10 demonstrates the very good similarity between the predicted and the measured signal.

The above presented preliminary work had two important consequences.

1) Following [32], the SMA-type V-dot probe could be calibrated, with the voltage \( V(t) \) calculated from the
probe output voltage signal $V_{signal}(t)$ as:

$$V(t) = \frac{1}{\tau} \int_0^t V_{signal}(t') dt$$ \hspace{1cm} (2)

where $\tau = Z_0 \cdot C_1$, with $Z_0 = 50 \ \Omega$ being the impedance of the cable connecting the probe to oscilloscope and $C_1 = 2.9 \ \text{fF}$ the probe coupling capacitance [32], [33], as shown in Fig. 7 was obtained using CST calculations.

2) The following procedure was established. During testing, the electric field generated inside the water sample is calculated by CST, using an input voltage Port 1 based on the experimentally measured input voltage signal. However, as a precaution, the CST predictions for Port 2 are always checked against the experimental signal generated by the V-dot probe housed inside the load. If the two are identical, the CST results are most likely correct. If the two are different, a possible explanation could be that electric breakdowns are present inside the processing load.

As an example, Fig. 11 presents the calculated time variation of the electric field strength inside the water sample for the experimental conditions of Fig. 9, i.e., when the peak transient voltage input reaches a peak of 20 kV. The corresponding peak electric field strength reaches 58 kV/cm, with a rise time of 303 ps and an FWHM of 773 ps. This is shown in Fig. 12. It is important to note two essential characteristics: 1) the electric field is mainly concentrated inside the cuvette and 2) inside the cuvette the electric field is highly homogeneous, allowing a simple interpretation of the results obtained after PEF processing.

When performing a large number of tests at a high PRF, one important question is related to the possible temperature increase of the water sample. The variation of temperature $\Delta T$ during $N$ consecutive shots is given by

$$\Delta T = \frac{W}{m C_p} N$$ \hspace{1cm} (3)

where $W$ is energy deposited in the water during one shot, $m \approx 100 \ \text{mg}$ is the mass of the water sample and $C_p = 4188 \ \text{J/kg/K}$ is the constant-pressure heat capacity of water at 25 $^\circ$C [34]. The energy is calculated as

$$W = R \int_0^t I^2(t') dt'$$ \hspace{1cm} (4)

where $R$ is the water sample resistance while the current integral was performed using data from a CST virtual current sensor. As the water sample has a conductivity of about $\sigma = 300 \ \mu\text{S/m}$ and a relative permittivity $\varepsilon_r = 78.4$ at 25 $^\circ$C [35], the time constant $\tau_0 = 140 \ \mu\text{s}$ is much larger than the pulse duration ($\approx 2 \ \text{ns}$) and therefore the conduction
current can safely be ignored. In such conditions the water
series equivalent resistance can be estimated as
\[ R = \frac{\tan \delta}{2\pi f C_w} = 1.28 \, \Omega \]  
(5)
where \( \tan \delta = 0.005 \) [35] is the water loss tangent at a
frequency \( f \) estimated as \( f = 0.35/t_{rise} = 1.35 \, \text{GHz} \), where
\( t_{rise} = 258 \, \text{ps} \) is the rise time of the impulse. The equivalent
capacitance \( C_w \) of the water sample was calculated using CST
as \( C_w = 4.6 \, \text{pF} \). As a typical result, after applying \( N = 50,000 
\) consecutive shots, the estimated water sample temperature
increase is only \( \Delta T = 0.00615^\circ \text{C} \) and therefore negligible.

V. BIOLOGICAL TECHNIQUES

E. Coli DH5α were purchased from Invitrogen (Courtaboeuf, France). Cultures used for experiments
were grown from 80 \( \mu \text{L} \) of bacterial stock solution (saturated
bacterial broth mixed with glycerol in (1:1) ratio stored at
\(-80^\circ \text{C} \)) added to 8 mL of Luria Bertani (LB) medium
(Invitrogen LB broth base Lennox L) and incubated at 37 \( ^\circ \text{C} \)
under constant orbital shaking at 220 \( \text{r} / \text{min} \) for 8 h over day,
corresponding to an endpoint OD600 of approximately 0.9.
 Cultures were then placed at 4 \( ^\circ \text{C} \) overnight until used for
experiments on the next day. E. Coli permeabilization was
assessed using a cell-impermeant fluorescent nucleic acid
stain entering only permeabilized bacteria, the YO-PRO-1
iodide (\( \lambda_{ex} \) 491/ \( \lambda_{em} \) 509) (Invitrogen). E. Coli gating in flow
cytometry was validated using a cell-permeant fluorescent
nucleic acid stain entering all bacteria, permeabilized or not,
the SYTO 9 (\( \lambda_{ex} \) 485/ \( \lambda_{em} \) 498) (Invitrogen). Prior to PEF
exposure, bacteria were centrifuged at 2000 \( \times \) g for 20 min,
the supernatant was discarded and the bacterial pellet was
resuspended in the same volume of sterile deionized water
(same bacterial concentration than mother culture). Then,
ieither YO-PRO-1 iodide or SYTO 9 was added (working
concentrations of 30 and 50 \( \mu \text{M} \), respectively). A volume
of 100 \( \mu \text{L} \) of bacterial suspension with marker (YO-PRO-1
iodide or SYTO 9) was then placed in a 4-mm wide gap
commercial electroporation cuvette (Cell Projects Ltd., Kent,
U.K.) and covered with 1.6 mL of insulating paraffin oil
in order to prevent arcing between electrodes during PEF
exposure. Then, pulses were delivered at room temperature
by installing the electroporation cuvette in the applicator
presented in Fig. 3. Controls were sham exposures for which
all the steps of the exposure protocol were followed, except
for the PEF delivery. 5 min after PEF exposure, a volume
of 50 \( \mu \text{L} \) of the bacterial suspension was collected from
the cuvette and mixed with 50 \( \mu \text{L} \) of sterile deionized
water. On average 30 min after PEF exposure, and prior
to flow cytometry analyses, this bacterial suspension was
mixed with 600 \( \mu \text{L} \) of LB medium. Flow cytometry analyses
were performed using a BD Accuri C6 Flow Cytometer
(Bd Biosciences, le Pont-de-Claix, France). An excitation
laser of 488 nm and the FL1 bandpass filter 533/30 were used
to detect fluorescence of either YO-PRO-1 iodide and
SYTO 9 (the reason why these markers could not be used
simultaneously). For data processing, E. Coli were gated
and separated from debris based on FSC-A and SSC-A
morphological criteria. Nevertheless, a small proportion of
events was not SYTO 9 positive within this gating, meaning
that there was still debris. Thus, the specificity of the gating
was calculated as (6) and (7), shown at the bottom of the
page.

The specificity of the gating was evaluated for the different
experimental conditions (Sham or PEF exposures), and was
considered for further data processing. Finally, the percentage
of permeabilized bacteria was calculated using YO-PRO-1
iodide following (7).

VI. PRELIMINARY RESULTS

We assessed the ability of the subnanosecond pulses deliv-
ered by our system to induce electroporation on E. Coli DH5α,
applying trains of 5000 to 50000 pulses at a PRF of 200 Hz
at an electric field amplitude of 58 kV/cm (the top electric
field amplitude deliverable with the present arrangement). All
conditions tested efficiently generated electroporation of the
bacteria to YO-PRO-1 iodide, a fluorescent nucleic acid stain
and cell permeabilization marker of approximately 630 Da.
Moreover, under these conditions, we observed an additive
effect of the pulses, the percentage of permeabilized bacteria
increasing from 44.4 % to 89.3 % ± 4.7 % for 5000 to
50000 pulses applied, respectively (Table I). Importantly,
no increase of the temperature within the samples submitted to
PEF treatment was noticed under the conditions tested in this
study, in line with the estimated temperature rise presented
above under Section IV. Thus, the permeabilization of E. Coli
observed in response to PEF exposure performed in this study
cannot be attributed to thermal effects.

<table>
<thead>
<tr>
<th>Number of pulses applied</th>
<th>Percentage of permeabilized bacteria (mean ± standard deviation)</th>
<th>Number of replicates*</th>
</tr>
</thead>
<tbody>
<tr>
<td>5000</td>
<td>44.4 ± 9.3</td>
<td>3</td>
</tr>
<tr>
<td>10000</td>
<td>65.4 ± 12.3</td>
<td>6</td>
</tr>
<tr>
<td>25000</td>
<td>81.0 ± 7.4</td>
<td>6</td>
</tr>
<tr>
<td>50000</td>
<td>83.3 ± 4.7</td>
<td>6</td>
</tr>
</tbody>
</table>

* The *number of replicates* is the number of times a given condition
was tested on bacteria coming from different independent bacterial
cultures.
VII. CONCLUSION AND THE WAY AHEAD

A relatively simple arrangement for PEF processing driven by a subnanosecond pulsed power generator has been developed and tested. The preliminary results show that subnanosecond processing can be highly efficient. The way ahead will require the development of a compact, high PRF and mobile subnanosecond 0.5-MV pulsed power generator that, when coupled with a probe reflector, will allow biomedical experimentation at (or near) a hospital.

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Antoine Silvestre de Ferron was born in Tarbes, France, in 1977. He received the master’s degree in electrical and electronic engineering from the University of Toulouse, Toulouse, France, in 2002, and the Ph.D. degree in electrical engineering from the University of Pau, Pau, France, in 2006.

From 2006 to 2008, he was a Researcher with the Atomic Energy Commission (CEA), a French government-fund technological research organization in Le Barp, France. He is currently an Engineer with the Electrical Engineering Laboratory, University of Pau. His research interests include pulsed power generation, with military and civil applications and the high-voltage transient probes associated.

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Dr. Novac is a Voting Member of the Pulsed Power Science and Technology Committee in the IEEE Nuclear and Plasma Science Society. He is also a member of the International Steering Committees for both the MEGAGAUSS Conferences and the Euro-Asian Pulsed Power Conferences. He is also the Co-Chairman of the U.K. Pulsed Power Symposium. He is a fellow of the Royal Academy of Engineering, and a Chartered Engineer and a fellow of the Institution of Engineering and Technology (IET), all in U.K.

Franck M. Andre (Member, IEEE) received the master’s degree in engineering (Science for Biological and Food Industries) from the Paris Institute of Technologies AgroParisTech (ex INP P-G), Paris, France, in 2002, and the Ph.D. degree for his research performed on in vivo gene electrot transfer from the ABIES Doctoral School, Paris Institute of Technologies AgroParisTech, in 2006.

During his postdoc (2007–2009) at the Frank Reidy Research Center for Bioelectrics, Old Dominion University, Norfolk, VA, USA, he investigated the effects of nanosecond pulsed electric fields on cell and nuclear membrane permeabilization. He is currently a Researcher with the French National Centre for Scientific Research (CNRS), Villejuif, France. For the last few years, his research has been mainly focused on electroporation-based gene transfer and drug delivery and on the use of electric pulses to manipulate the cytosolic calcium oscillations.

Lluis M. Mir graduated from École Normale Supérieure, Paris, France, and received the D.Sc. degree from the University of Toulouse, Toulouse, France, in 1983, and three Doctorate Honoris Causa degrees from the Universities of Buenos Aires (Argentina), Lima (Peru), and Ljubljana (Slovenia), in 2018.

As the DRCE at CNRS, he directed the Laboratory of Vectorology and Anticancer Therapies from 2010 to 2019 and the European Associated Laboratory for the applications of electric pulses in biology and medicine from 2011 to 2018. He published 238 peer-reviewed articles and 25 book chapters (H index = 70, WoS).

Dr. Mir is a fellow of the American Institute for Medical and Biological Engineering, the European Academy of Tumor Immunology, and the RadioScience International Union (URSI). He won several awards, including the URST’s 2017 Balthasar van der Pol Gold Medal. He is the present President of the International Society for the Electroporation Based Treatments and Therapies.

Laurent Arzitza received the B.Sc. and M.Sc. degrees from the Université de Pau et des Pays de l’Adour (UPPA), Pau, France, in 2017 and 2019, respectively.

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He is currently a Full Professor in pulsed power with the Laboratoire SIAME, UPPP. He is the Head of the High Voltage Power Team, Laboratoire SIAME, and he is also the Director of a Common Laboratory, CEA, Paris, France. His current research interests include high-power microwave sources, compact pulsed power systems, and ultrafast transient probes.

Dr. Pécastaing is the Chairman of the next EAPPC/BEAMS/MEGAGAUSS Conference to be held in France in 2021. He is also a member of the International Steering Committees for both the BEAMS Conferences and the Euro-Asian Pulsed Power Conferences.