Flash-over evaluation on large solar panels - EMAGS3 study - ESA Co. 22771

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2. Objectives of EMAGS3 study
3. Main tasks
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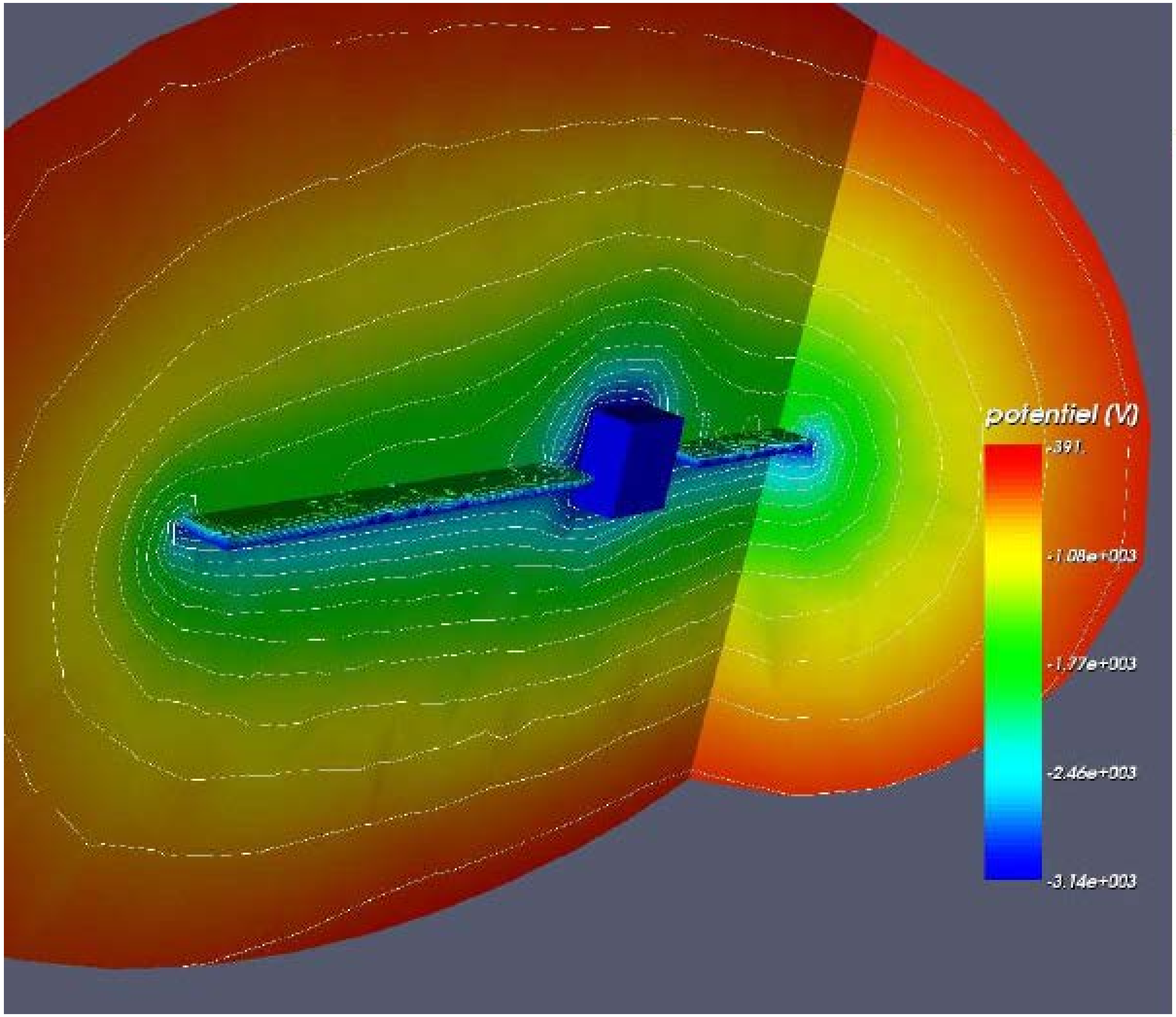
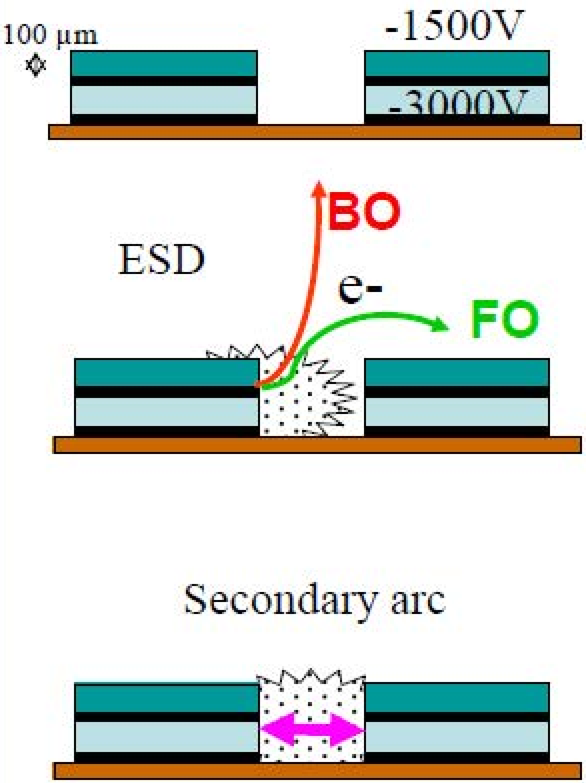
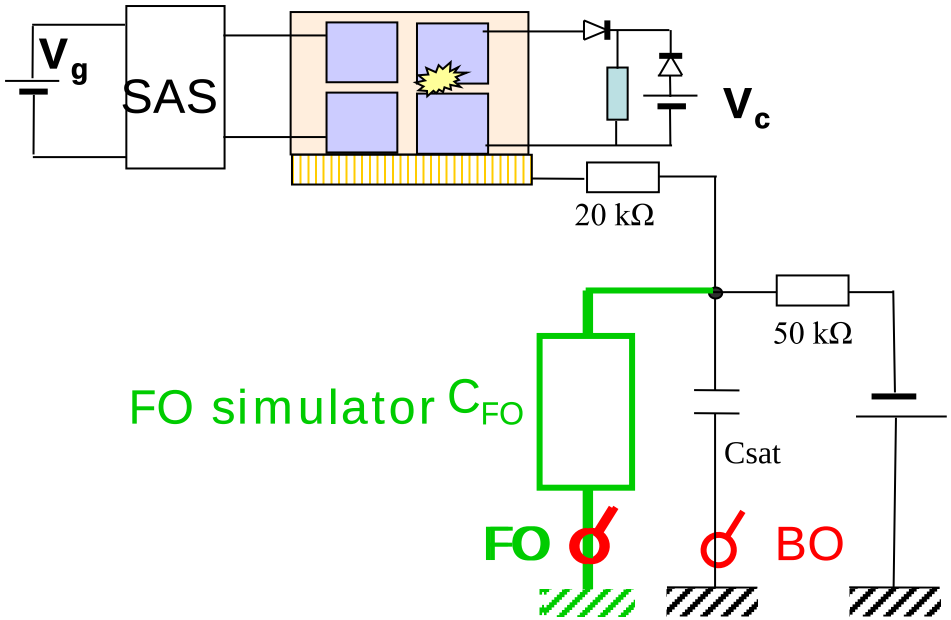
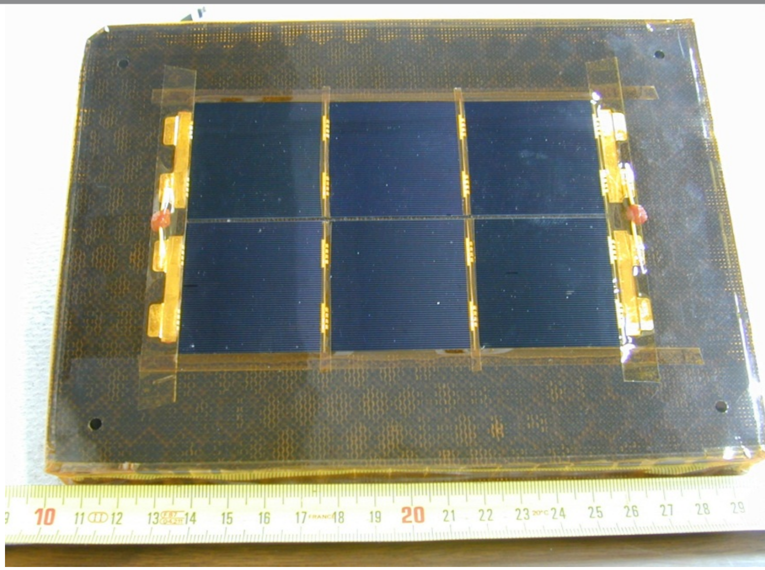
BACKGROUND


potentiel (V)
-391.
-1.08e+003
-1.77e+003
-2.46e+003
-3.14e+003


100 µm
-1500V
-3000V
BO
ESD
e-
FO
Secondary arc

BACKGROUND





FO simulator :
- which characteristics??

FO :
- maximum surface/distance ?
- propagation speed ?
- Can jump over a gap between panels?

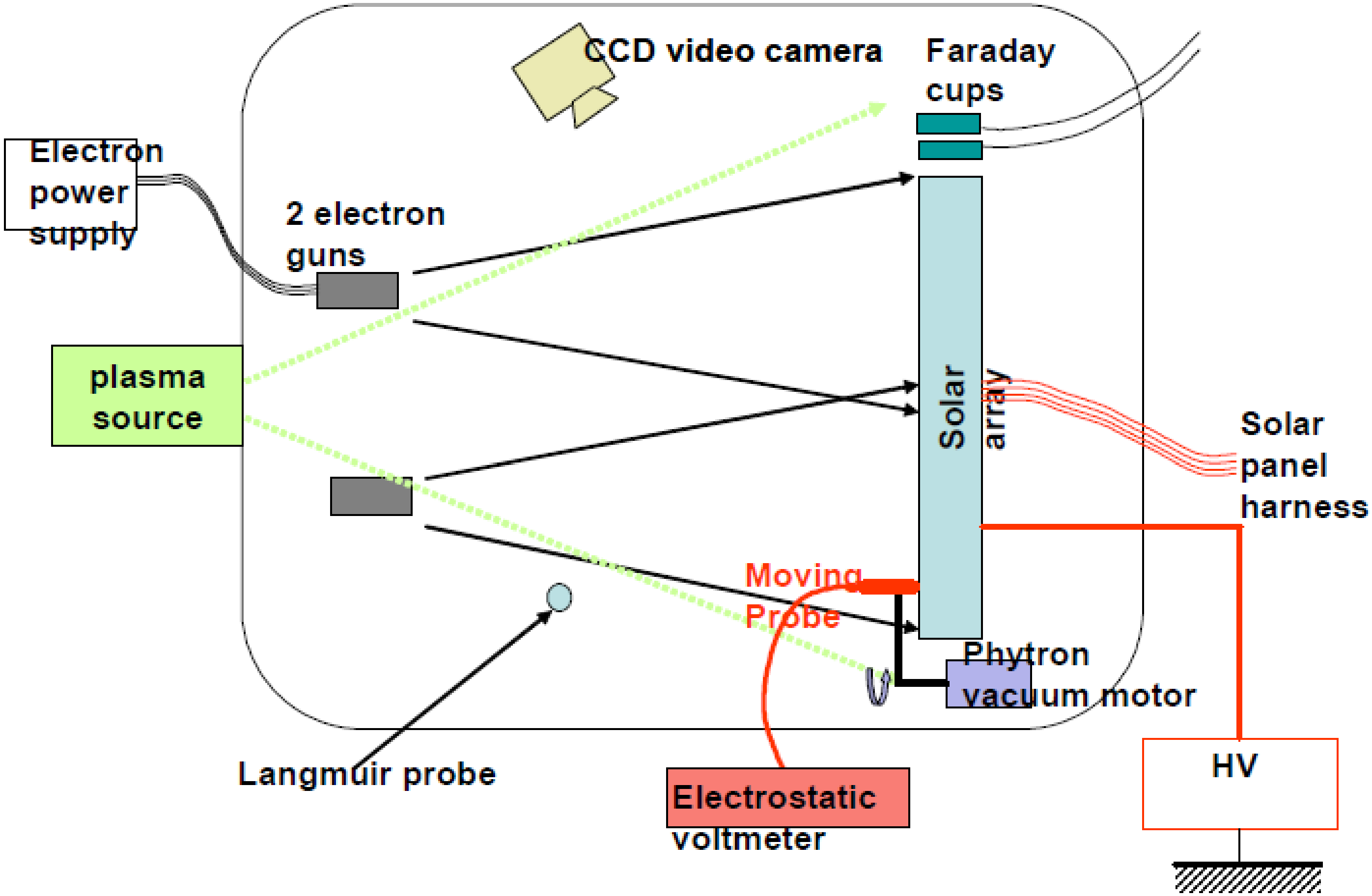
OBJECTIVES

1. Perform tests on a large solar panel to measure FO propagation
   a. Maximum discharged area
   b. Velocity
   c. Effects of different parameters
      – Plasma/Electrons IVG (inverted voltage gradient)
      – Temperature
      – Dielectric capacitance
   d. Jump over gap
2. Proposal of an updated ESD/arcing qualification test setup for solar array coupons

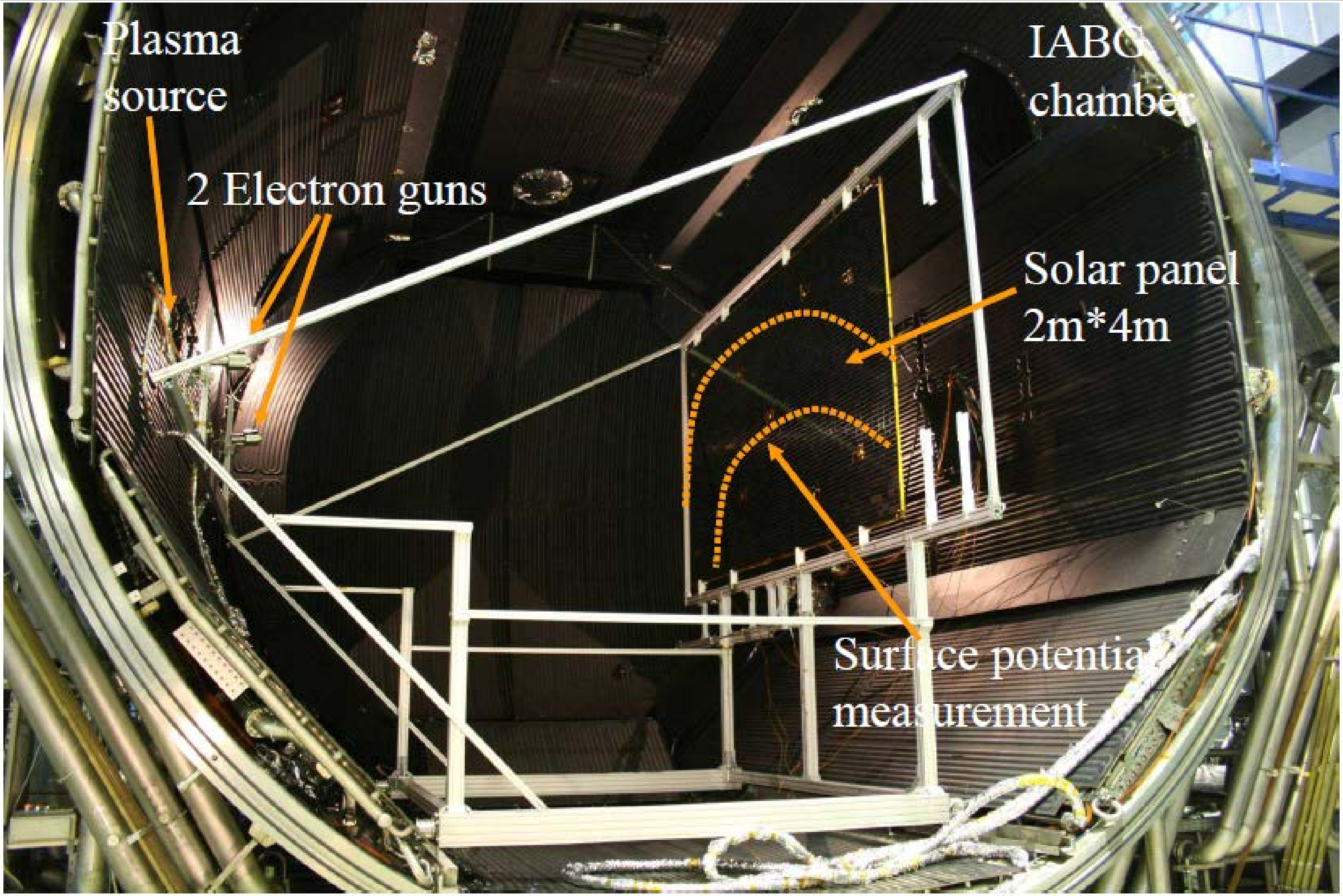
INDUSTRY TEAM

1. Prime: ONERA
2. Subcontractors:
    a. Astrium Germany (panel supplier, modification of harness)
    b. Astrium France
    c. Thales France
    d. IABG (Test facility)
3. Observer: CNES

TEST SETUP – IABG CHAMBER



TEST SETUP – IABG CHAMBER

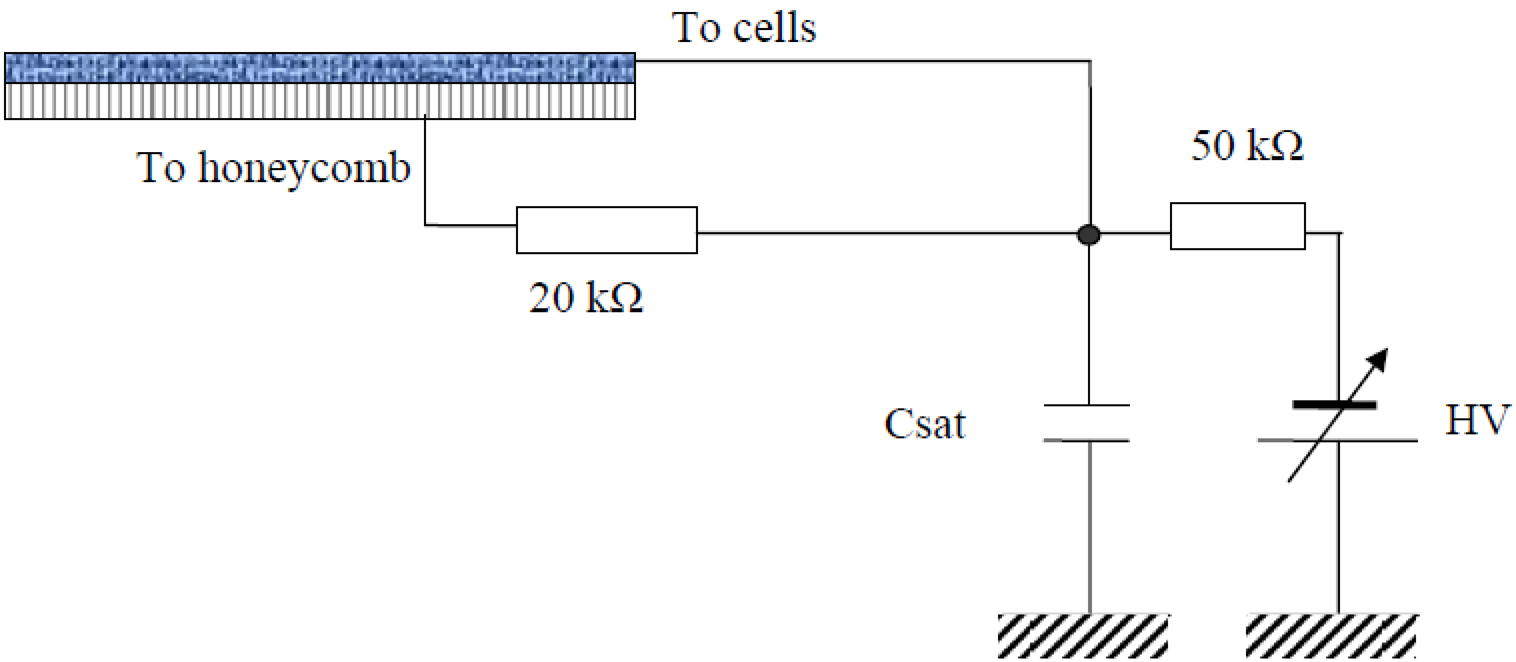


TEST PLAN IN IABG FACILITY

1. IPG (inverted potential gradient) with electron gun
2. IPG in plasma
3. Effect of low temperatures
    a. Electron gun
    b. Plasma
4. Effect of capacitance (by adding dielectric foil – two different values)
    a. Electron gun
    b. Plasma
5. Simulation of gap between panels (by adding a 1m^2 panel at a distance of 10cm)

TEST SETUP – IABG CHAMBER

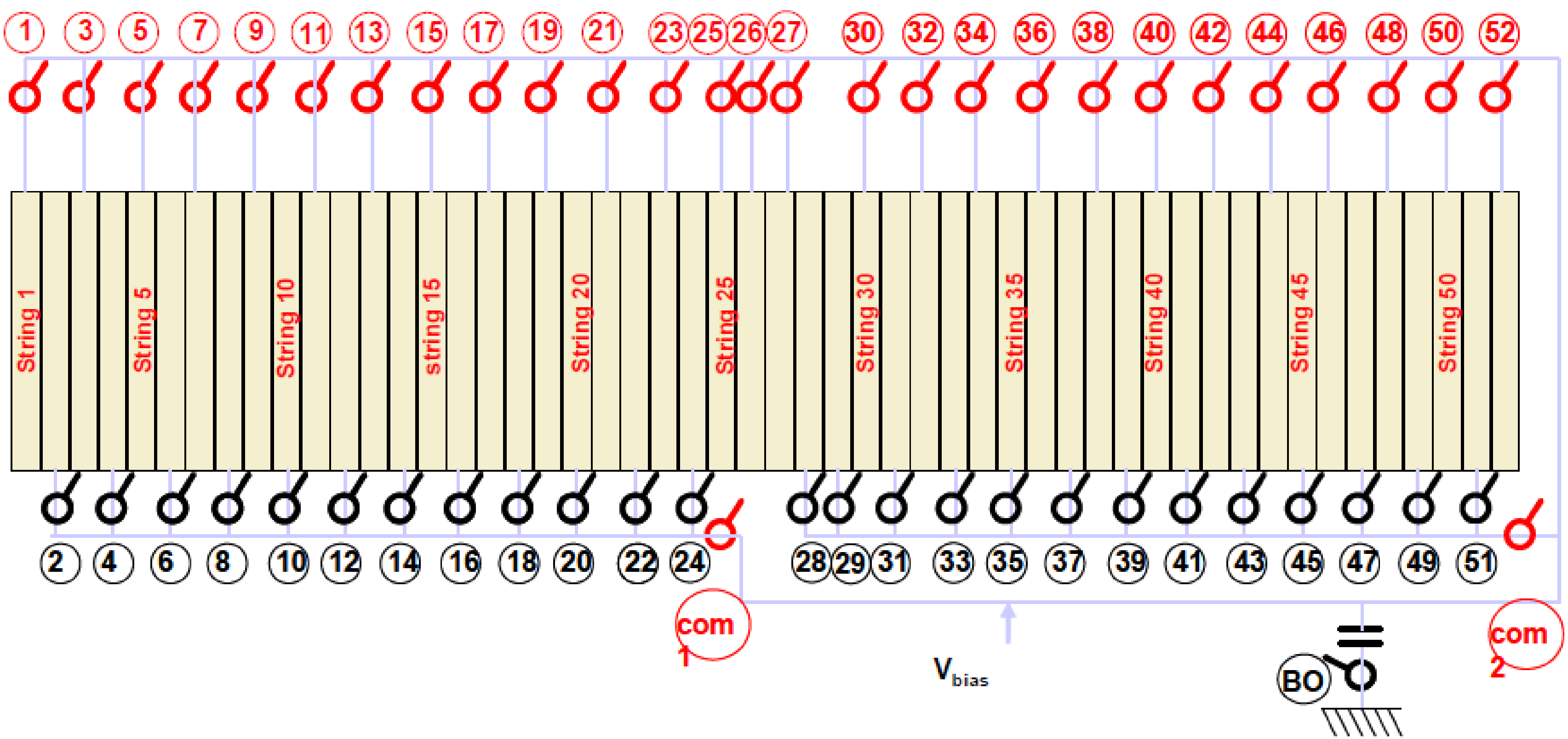
ELECTRICAL CIRCUIT DIAGRAM



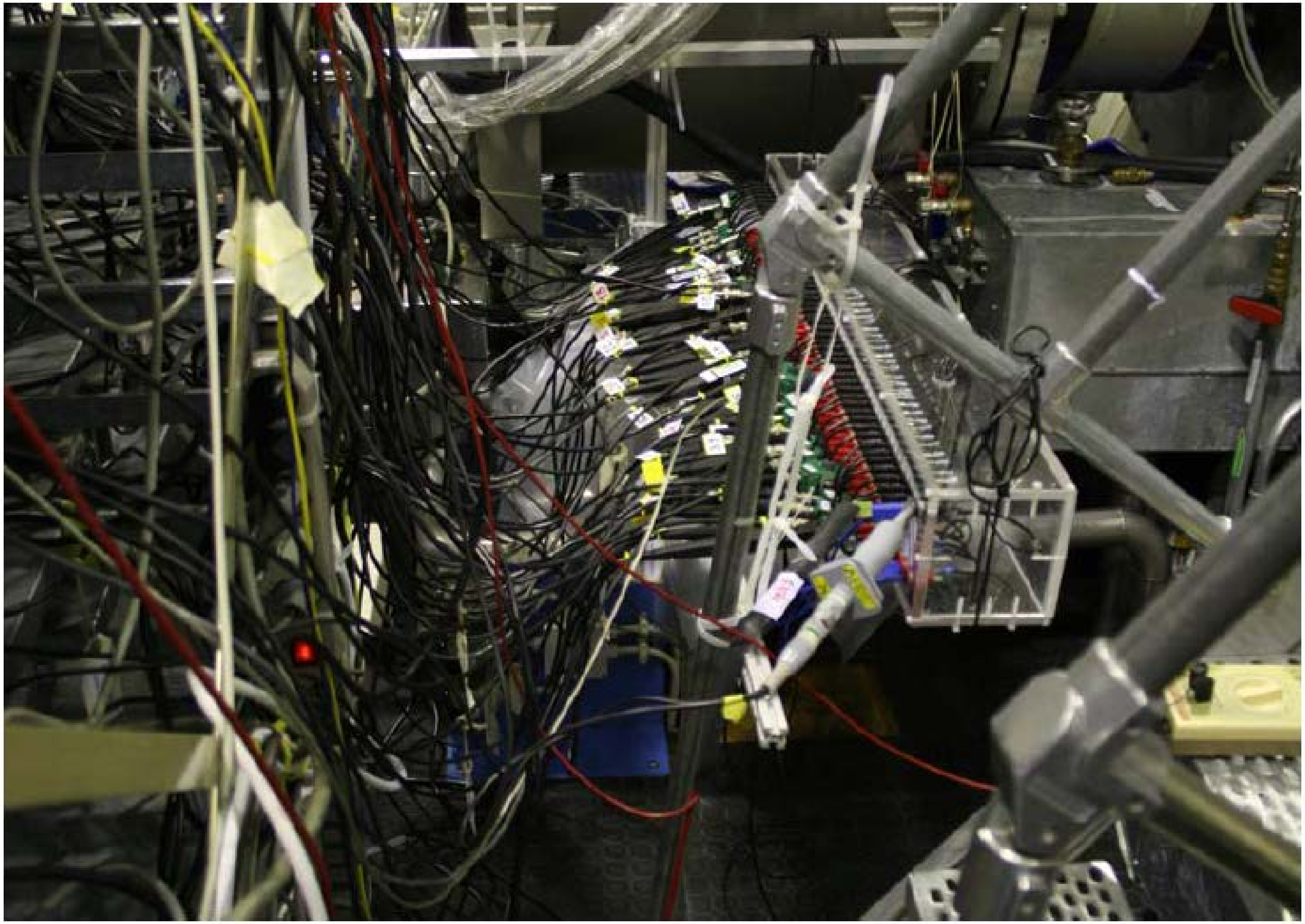
DATA ACQUISITION

Low level measurements (collected Flash Over + BO) : Pearson 2877 probes

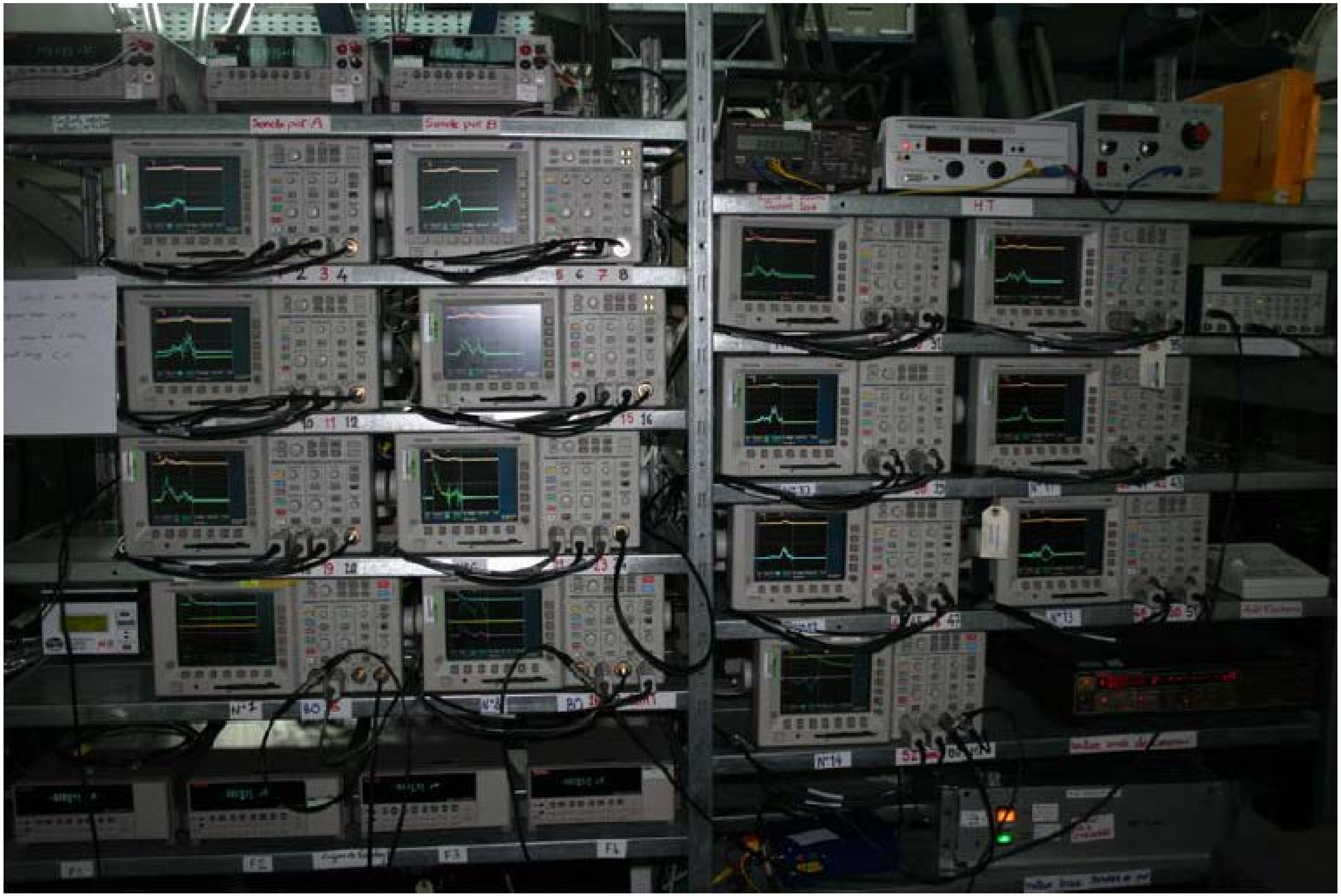
High level measurements (emitted Flash Over + com) : Tektro TCP202 probes



DATA ACQUISITION



DATA ACQUISITION



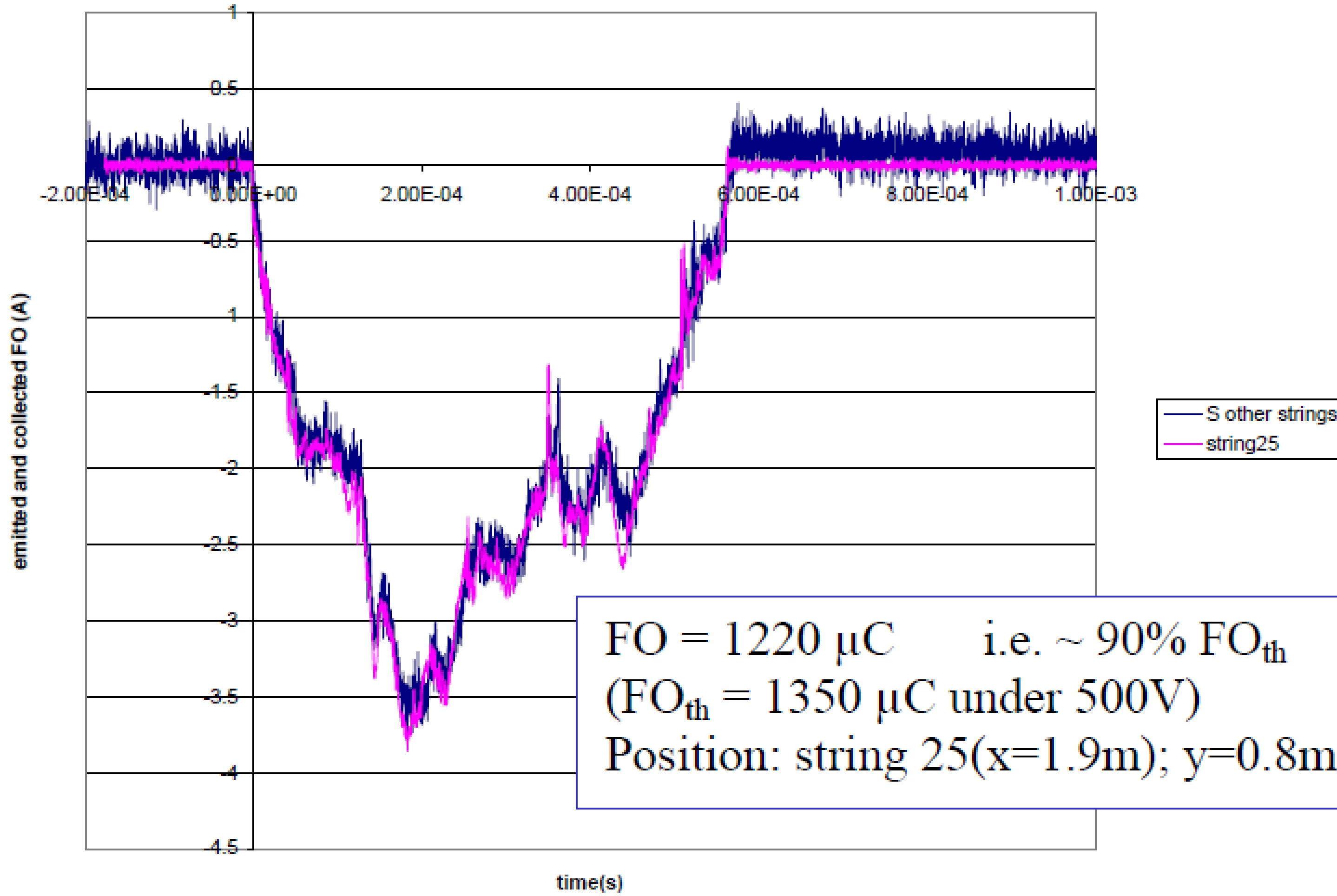
RESULTS

step	configuration	Nb ESD	comment
Step 1	Electrons Room temperature	199	12 ESDs have discharged more than 75% of the theoretical stored charge in the coverglasses.
Step 2	Plasma Room temperature	106	12 have discharged more than 75% of the theoretical stored charge including 2 that discharged completely the panel
Step 3	Electrons low temperature (-120°C)	>300	No potential measurement, no camera from time to time Very high rate of ESDs even at low flux and even without irradiation
Step 4	Plasma low temperature (-120°C)	104	No potential measurement
Step 5	Electrons Go back to room temperature	150	Confirmation of first results at low temp (step 3) and at room temp (step 1)

RESULTS

step	configuration	Nb ESD	comment
Step 6	Electrons Kapton 125 µm	80	Quite good reproducibility 45/80 higher than 250µC
Step 7	Plasma Kapton 125 µm	25	Quite good reproducibility 14/25 higher than 250µC
Step 8	Electrons Kapton 25 µm	31	Measurements only on central strings (25 to 29) + patches 12 and 40 - $Q_{patch} = Q_{FO}/100$
Step 9	Plasma Kapton 25 µm	33	$Q_{patch} = Q_{FO}/100$
Step 10	Electrons Jump over	260	measurement of FO jumping over the gap of 10cm 5/16 selected are on small panel
Step 11	Plasma Jump over	58	measurement of FO jumping over the gap of 10cm 4/8 selected are on small panel
Total			~ 1400 ESDs 538 stored 223 selected in summary file

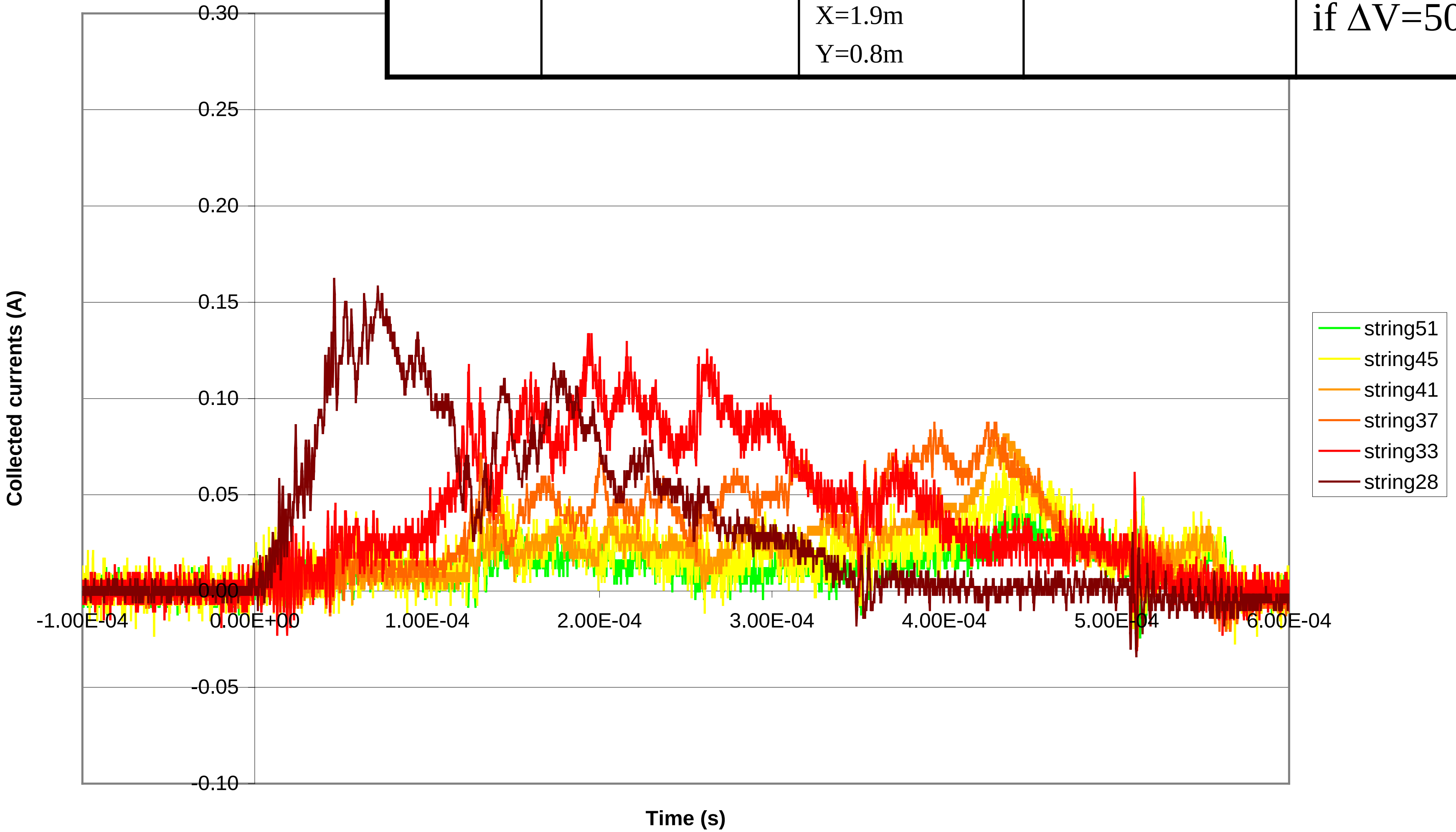
RESULTS



FO = 1220 µC i.e. ~ 90% FO_{th}
(FO_{th} = 1350 µC under 500V)
Position: string 25(x=1.9m); y=0.8m

RESULTS

#ESD	IPG	Position	FO integral	% of FO_{th}
184	electrons	String 25 X=1.9m Y=0.8m	1220 µC	90% (1345µC if ΔV=500V)



RESULTS

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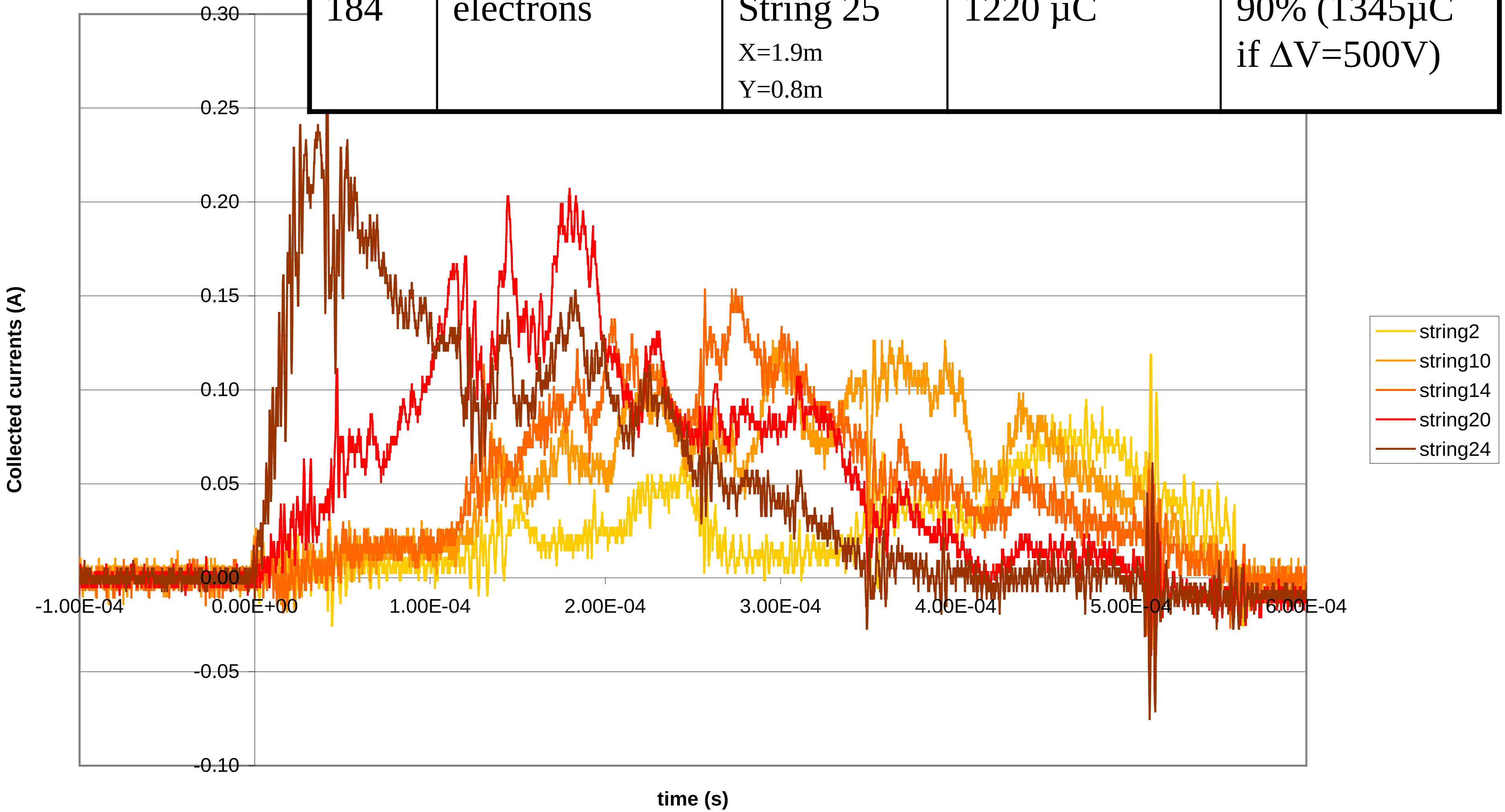
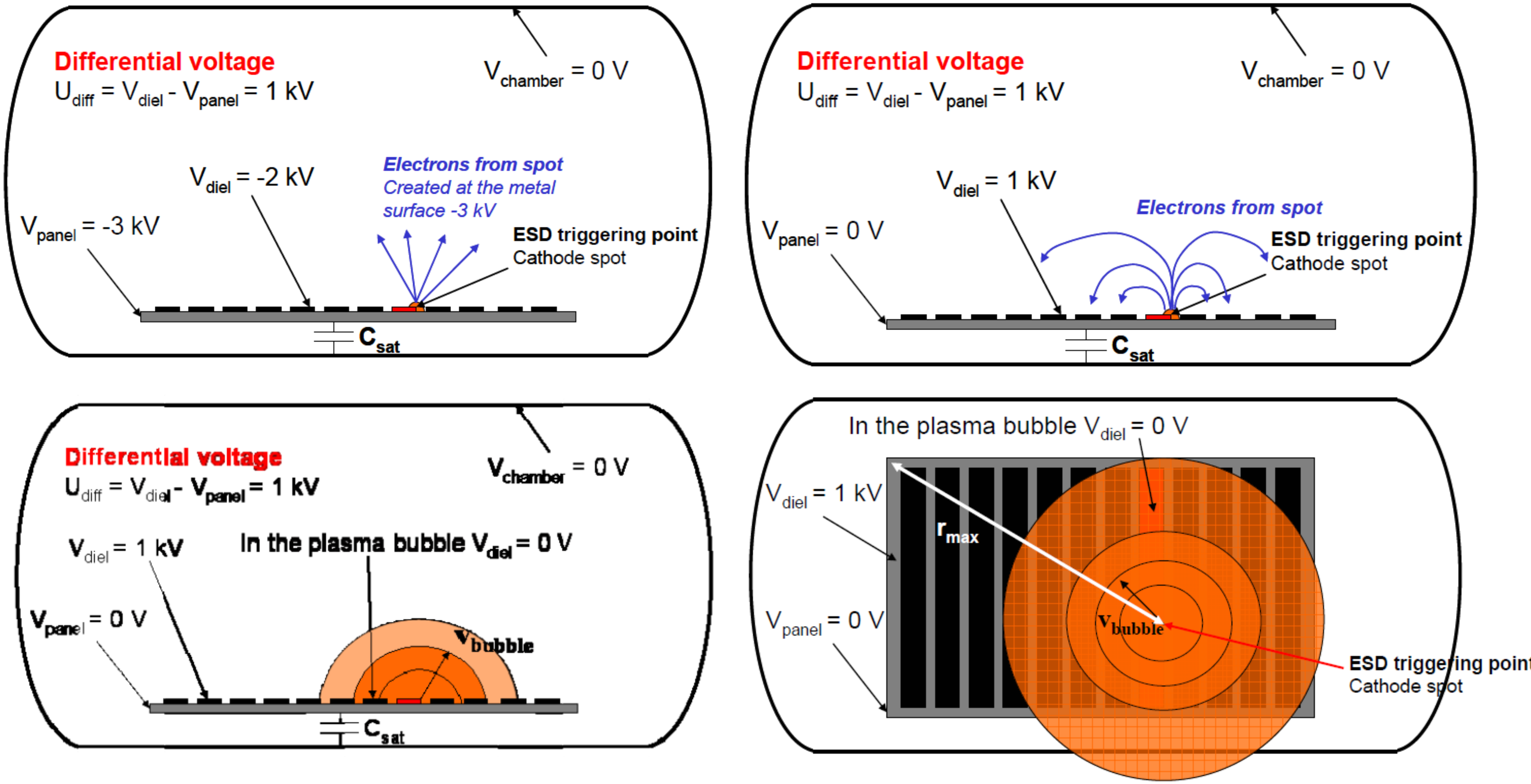


MODELLING OF THE RESULTS

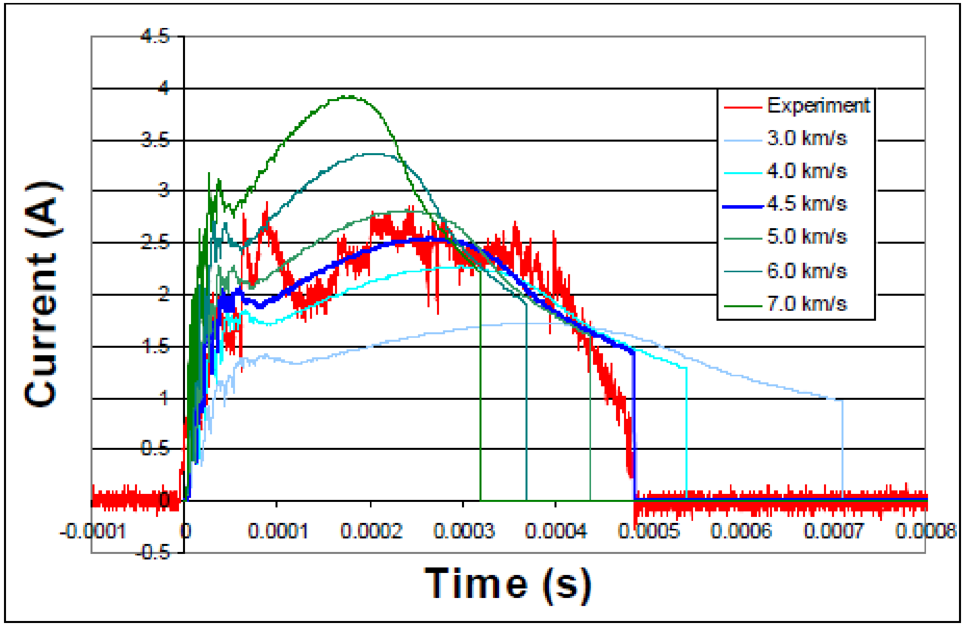


SIMPLIFIED MODEL

- Plasma bubble dynamic
  - Plasma bubble expansion is isotropic
  - Velocity of the bubble is constant
- Current collection by the solar panel in the bubble:
  - The plasma bubble neutralizes instantaneously the dielectric potential
- Electron current extracted from the bubble:
  - Collected by the solar panel
  - Space charge limited and uniform
  - Secondary electron emission is take into account
- Space and time variations of potential due to the current collection
  - Potential varies due to net current collected
  - The conducted current is neglected

PLASMA VELOCITY

ESD number reference: ESD267			
ESD position			
String number (X position):	48	Y position:	0.3m (+/- 0.1m)
Total charge collected: 0.995 mC			
Initial Potential Profile			
Neutralization source:	Plasma (uniform)	Differential voltage:	500V
Differential charging			
Panel capacitance:	2.69 µF	Maximum charge of the panel:	1.345 mC
String capacitance:	51 nF	Maximum charge by strings:	25.5 µC

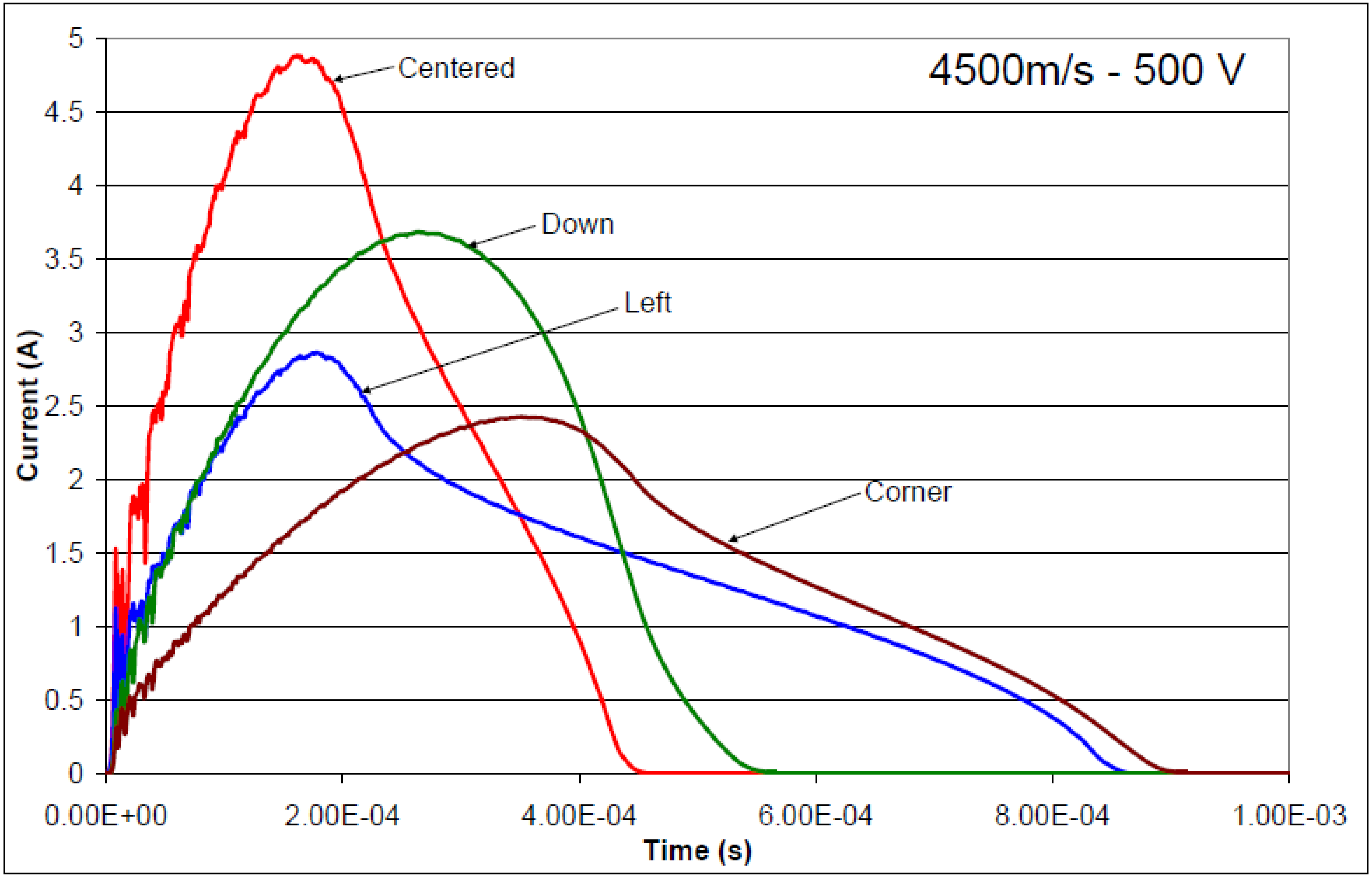


- The plasma bubble velocity proportional to the sound velocity of the plasma

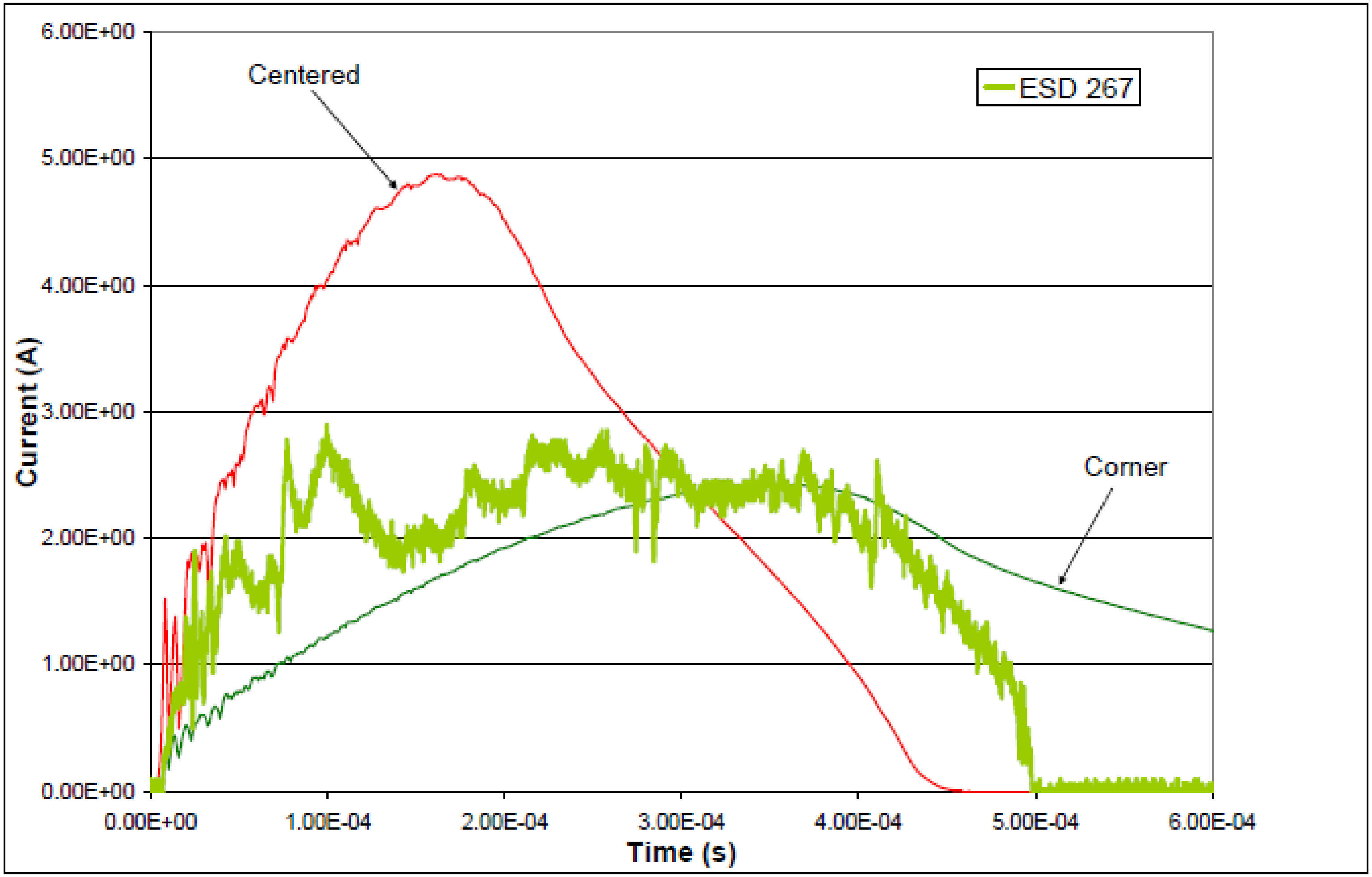
$$c_s = \sqrt{\frac{eT_e}{m_i}}$$

- Order magnitude of the bubble velocity for Te from 2 eV to 10 eV:
  - For silicon ions:
    - $m_{Si} = 4.8\times10^{-26}$ kg
    - 2580 m/s < c_s < 5768 m/s
  - For silver ions:
    - $m_{Ag} = 1.8\times10^{-25}$ kg
    - 1341 m/s < c_s < 3000 m/s

EFFECT OF ESD POSITION



EFFECT OF ESD POSITION



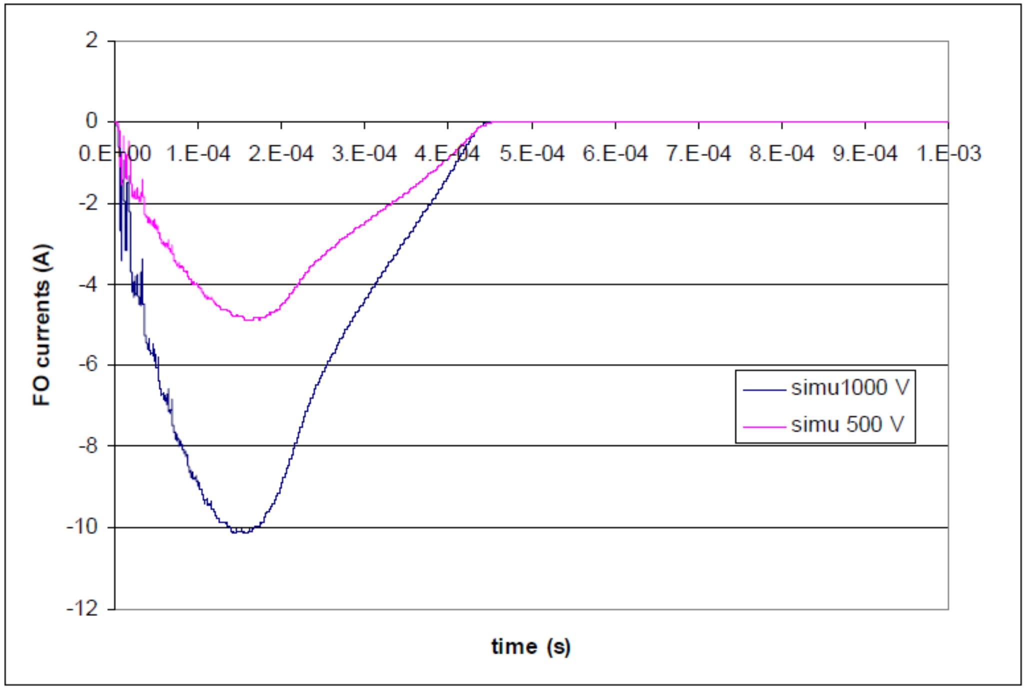
SUMMARY OF RESULTS

1. In principle it is possible to have the whole panel discharged by a flash-over
2. At low temperatures discharge rate increases (due to conductivity of materials such as adhesives decreases)
3. The flash-over can jump over a gap
4. The discharge duration is a function of the bubble expansion velocity (depending on the material of the plasma) and depends of course also on the location of the triggering ESD
5. Simplified model agrees very well with experimental results and thereby validates the hypothesis of the model

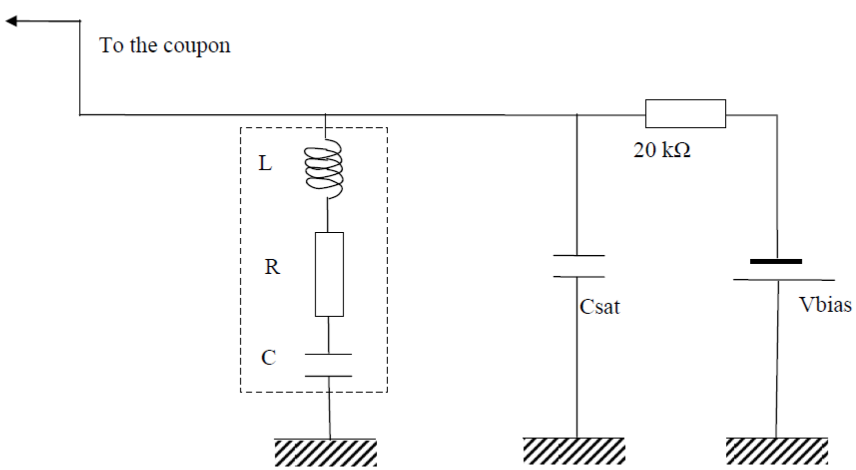
FO SIMULATOR

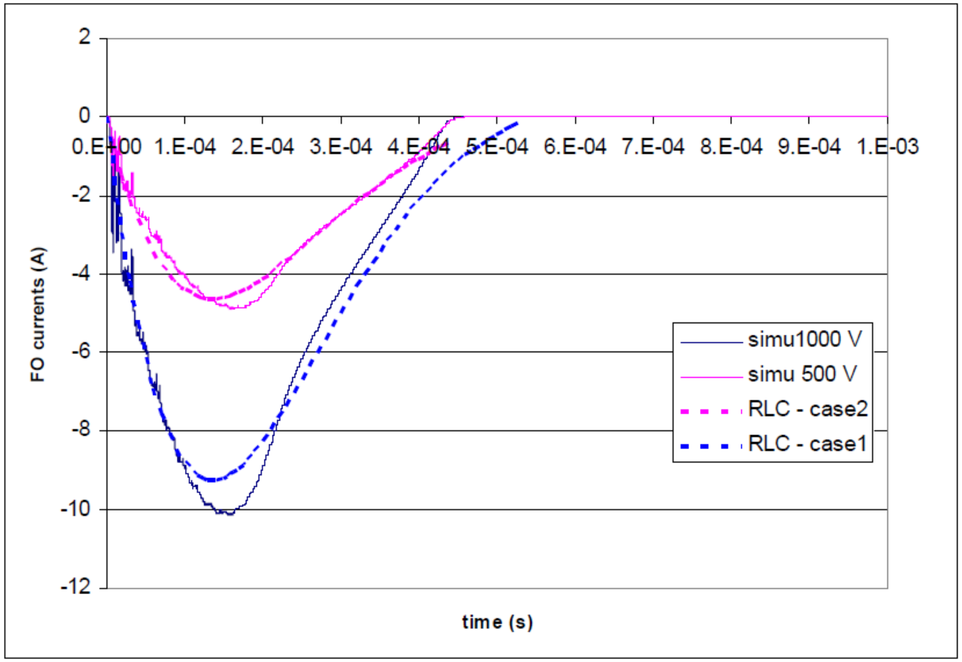
Maximum signals of FO simulated for a potential difference of 500V and 1000V (ESD occurs in the middle of the panel and the FO fully discharges the panel).

Rebuild characteristic signal with RLC circuit.



FO SIMULATOR



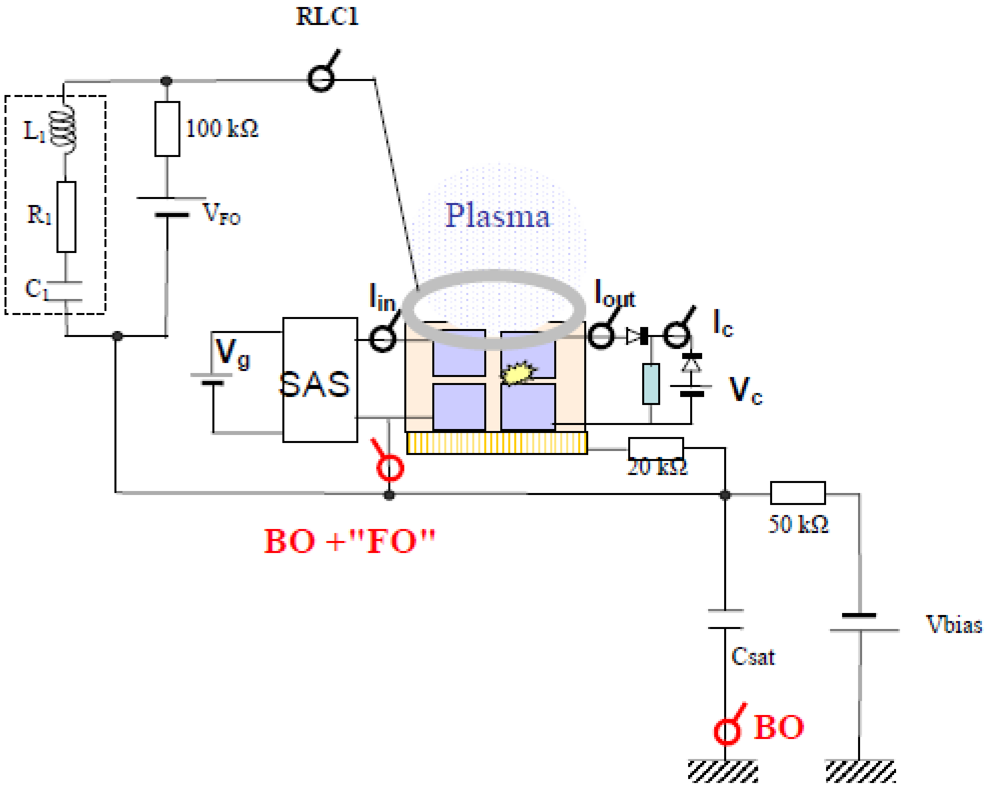


	R	L	C	Vbias
Case 1 (fits 500 V case)	70 Ω	6 mH	2.5 µF	-500 V
Case 2 (fits 1000 V case)	70 Ω	6 mH	2.5 µF	-1000 V

FO SIMULATOR

Initial tests have been performed using the flash-over simulator with the circuit diagram shown here.

More tests on actual coupons equipped with current state-of-the art solar cell technology would have to be performed.



CONCLUSIONS – NEXT STEPS

1. The test on the large panel has not shown any physical limit of the FO expansion
2. Tests are now needed to see the effect of the FO
    a. On solar cells
    b. On coupons (secondary arcing test)
3. A simple FO simulator has been developed and tested
4. What happens in flight? – probability of a „big“ FO? Note: at low temperature, ESD rate was very high (maybe no strong build-up of charge and thus no big FO?)
5. Effect of the solar array layout (including blocking diodes, etc.)

For further related information please refer to:

- V. Inguimbert et al., “Flashover measurement on a solar array – results of EMAGS3 experimental campaign”, Proc. 9th ESPC, 2011
- B. Boulanger et al., “Flashover current and solar array electrical architecture”, Proc. 9th ESPC, 2011
- V. Inguimbert et al., “Measurements of the flashover expansion on a real solar panel (EMAGS3 project), Proc. 12th SCTC, 2012
- P. Sarrailh et al., “Plasma Bubble Expansion Model of the Flashover Current Collection on a Solar Array – Comparison to EMAGS3 results”, Proc. 12th SCTC, 2012
- B. Boulanger et al., “Flashover current and sustaining arc current, is the flashover current flowing in the sustaining arc?”, Proc. 12th SCTC, 2012

THANK YOU FOR YOUR ATTENTION

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