RF-based diagnostics of discharges in high gradient accelerating structures

plans for measurements at SLAC

Andrea Palaia

Department of Physics and Astronomy
Uppsala University

12 January 2011

Overview

RF reflected during a discharge keeps the memory of the interaction of the incoming RF with whatever object is created during the discharge itself.

Strategy

1. model of an object (plasma, a cloud of neutrals or electrons) and its interaction with RF;
2. RF measurement (incoming, reflected, transmitted) and extrapolation of the properties of the object it interacts with;
3. direct measurement of emitted charges (electrons, ions) to invalidate the model of the assumed interacting object.

Interacting objects

If a **plasma**, it has to be “expanded” in order to reflect RF (low density)

A simple model:

- thermodynamic equilibrium (Boltzmann and Maxwell distributions);
- quasi-neutrality (only ions and electrons);
- full ionization (same number of ions and electrons);

- temperature (kinetic energy) defined using direct ions measurements;
- number of charges given by direct measurement of ejected ions;
- plasma size is assumed (free parameter).

If **electrons** are removed from the plasma before it expands they rapidly fill the structure and are the source of RF reflection

Reflection on ions is not likely to happen since they are ejected much later than the RF pulse length

Interaction with RF

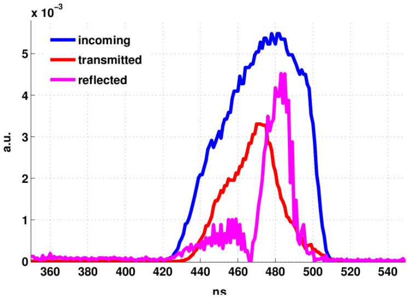
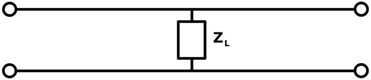


Figure: Power signals during a breakdown as seen at CTF3, during conditioning of a 30 GHz structure (December 2007).

Circuit formalism for the interaction



reflection coefficient

$$\Gamma = \frac{P^*_{reflected}}{P^*_{incoming}} = \frac{1 - \sqrt{\epsilon^*_r(\omega, n)}}{1 + \sqrt{\epsilon^*_r(\omega, n)}} \quad (1)$$

where $Im(\epsilon^*)$ would give information on missing energy

Layout

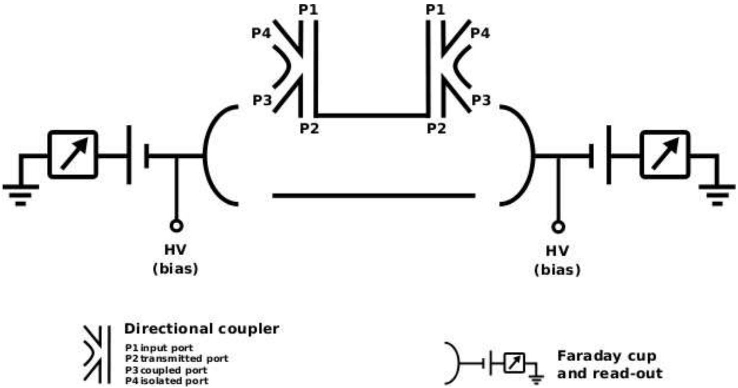


Figure: a high-gradient structure is fed with RF which is measured both at its input and its output by directional couplers. Two Faraday-cups (one per side) measure ions and electrons emitted after breakdowns. The Faraday-cups are biased in order to reject secondary electrons.

Hardware

- data available from experiments with a travelling-wave structure (T18) in resonant ring at ASTA;
- running standing-wave structure experiments

Requirements

- measurement of incoming, reflected and transmitted RF;
- IQ demodulators for each RF measurement (2x3 channels);
- measurement of ejected electron and ion currents;
- possibly HV bias on the ions detector (Farday-cup or antennae) to avoid secondary electrons.

Ion and electron currents measurements (2007)

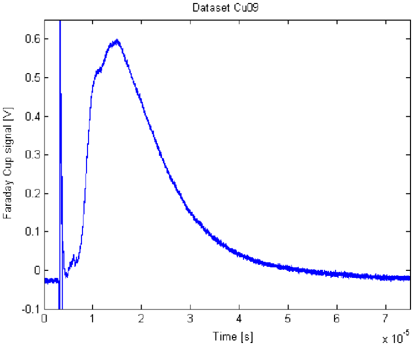


Figure: Faraday-cup signal as seen at the high-gradient 30 GHz test stand at CTF3 (2007)[1].

- electron current $< \mu s$
- ion current $> 10\ \mu s$

Fit to a Coulomb explosion model[1]:

- temperature $\sim\ 10^6$ K
- detected charges $\sim 10^{10}$ (total initial number $\sim 10^{15}$ considering a spherical distribution and the limited geometrical acceptance)

[1] M. Johnson et al., Arrival time measurements of ions accompanying RF breakdown, Nucl. Instr. Meth. A595 (2008) 568

If plasma caused reflection

Extrapolation of the density of a plasma causing the measured RF reflection

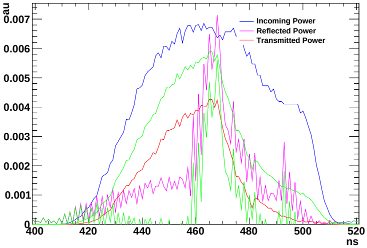


Figure: A breakdown event.

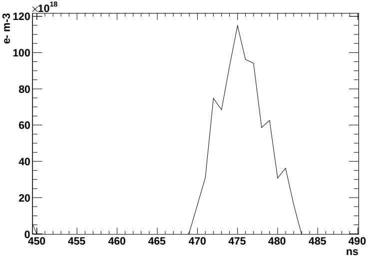


Figure: Extrapolated plasma density.

Summary and comments

- it is difficult to define where and what exactly causes RF reflection;
- a simplified model might anyway work (if charge and RF measurements agree);
- such a model can be used to predict the interaction of an electron beam "with" the breakdown (emittance, kick)

1. falling time of the transmitted signal
   $\longrightarrow$ information on the development time of whatever reflects RF;
2. missing energy measurement to relate to beam kick;
3. longitudinal breakdown position measurement using ion currents signals;
4. a detailed resolution/error estimation is missing;
5. a dedicated low-power RF diagnostics would avoid non-linear effects (as described here, the RF used for the diagnostics is the same triggering and sustaining the discharge).