Progress towards implementation of a digital Mirror Langmuir Probe diagnostic on ASDEX Upgrade

MAX-PLANCK-INSTITUT FÜR PLASMAPHYSIK

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MOTIVATION

Problem:

- Langmuir probes effectiveness limited to the voltage range and frequency sweep
- Plasma properties vary radially across the SOL
- Filamentary transport dominant in the SOL, important for future devices
- ✗ Outside of swept voltage range, reducing accuracy
- ✗ Fast fluctuations, i.e. filaments, are missed by slower swept probes

Solution:

- FPGA-based, digital Mirror Langmuir probe
- Inspired by the original transistor-based mirror probe at Alcator C-mod [1, 2]
- ✓ Dynamically adjusts the probe bias in response to plasma parameters [3–6]
- ✓ Capable of ultra-fast sweeping ($\sim$ MHz)
- ✓ Allows high time resolution of measurements in SOL

BACKGROUND

Starting from the planar Langmuir probe model:

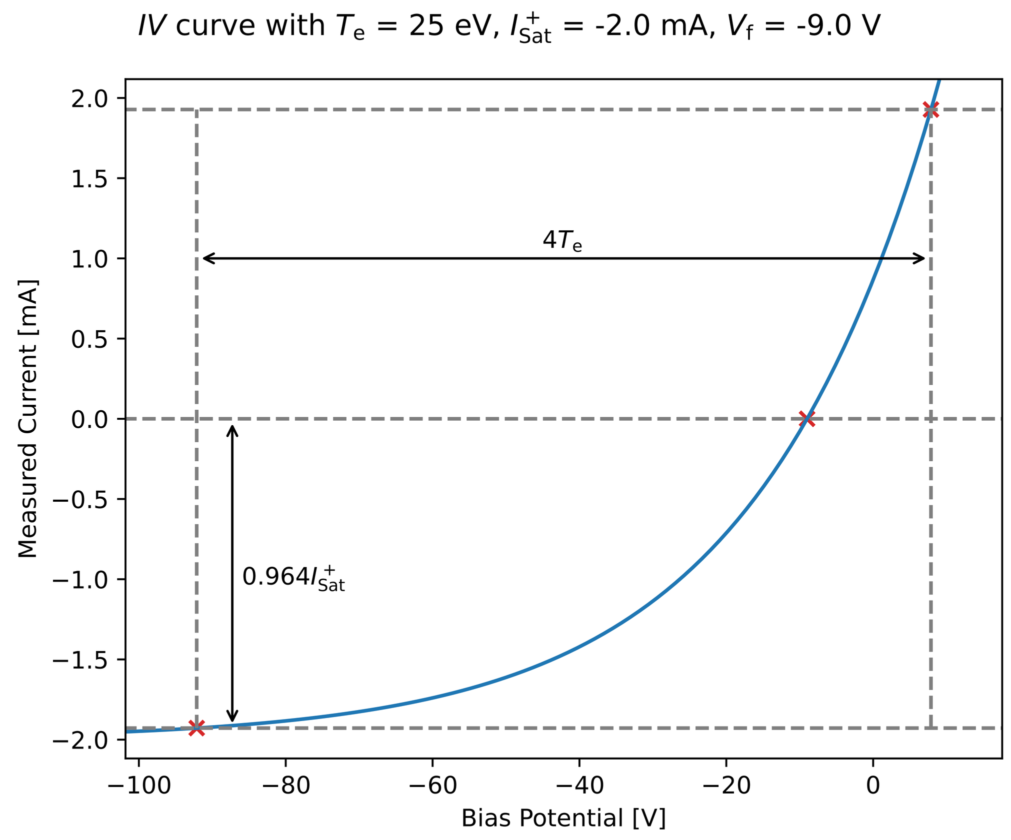
$$I_{pr}(V) = I^+_{Sat}\left[1 - \exp\frac{(V_{pr}-\phi_f)}{T_e}\right]$$

Rearrange for the three variables we measure:

$$I^+_{Sat} = \frac{I(V_{pr})}{\left[\exp\frac{(V_{pr}-\phi_f)}{T_e} - 1\right]}$$

$$T_e = \frac{(V_{pr}-\phi_f)}{\ln\left(-\frac{I(V_{pr})}{I^+_{Sat}} + 1\right)}$$

$$\phi_f = V_{pr} - T_e \ln\left(-\frac{I(V_{pr})}{I^+_{Sat}} + 1\right)$$

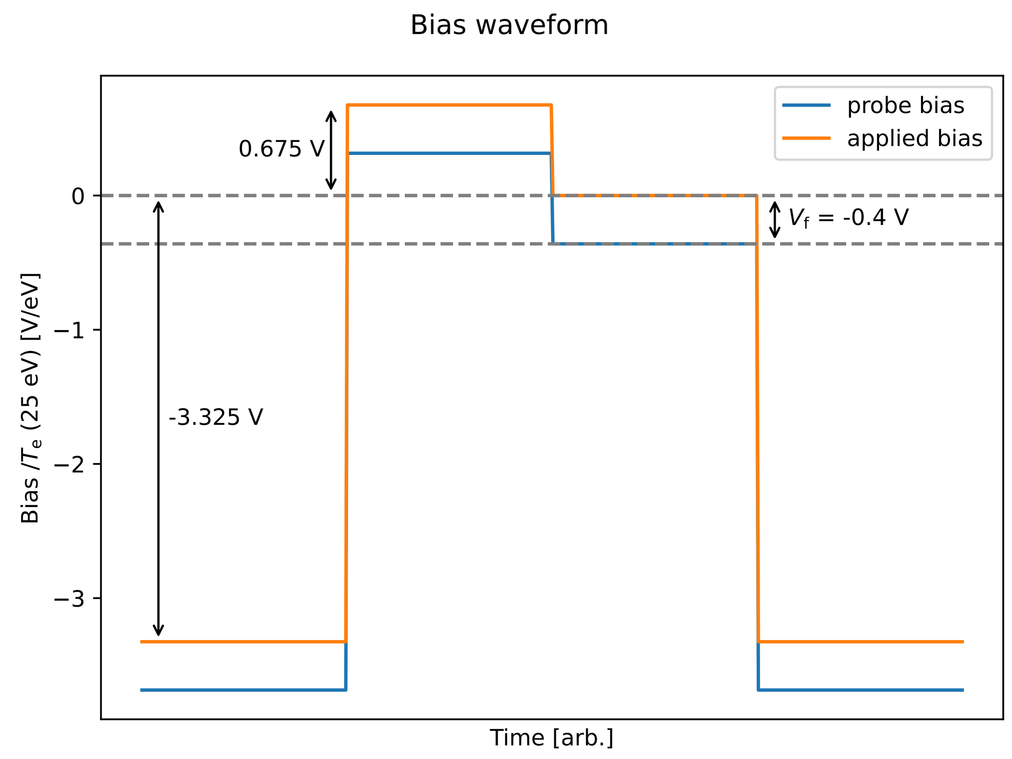


If $V_{pr} \ll 0$, model converges to $I^+_{Sat} = -I(V_{pr})$,

Need symmetric currents for circuit to float, applied bias is $V_{pr} = V_{+,-,0} \cdot T_e + \phi_f$. IV curve scales with T_e, limit bias range (thus current) [3, 5] by $V_{pr} = 4T_e$.

Voltages become:

$$V_- = -3.325T_e + \phi_f \rightarrow I_- = -0.964I^+_{Sat}$$
$$V_+ = 0.675T_e + \phi_f \rightarrow I_+ = +0.964I^+_{Sat}$$
$$V_0 = \phi_f \rightarrow I_0 = 0$$



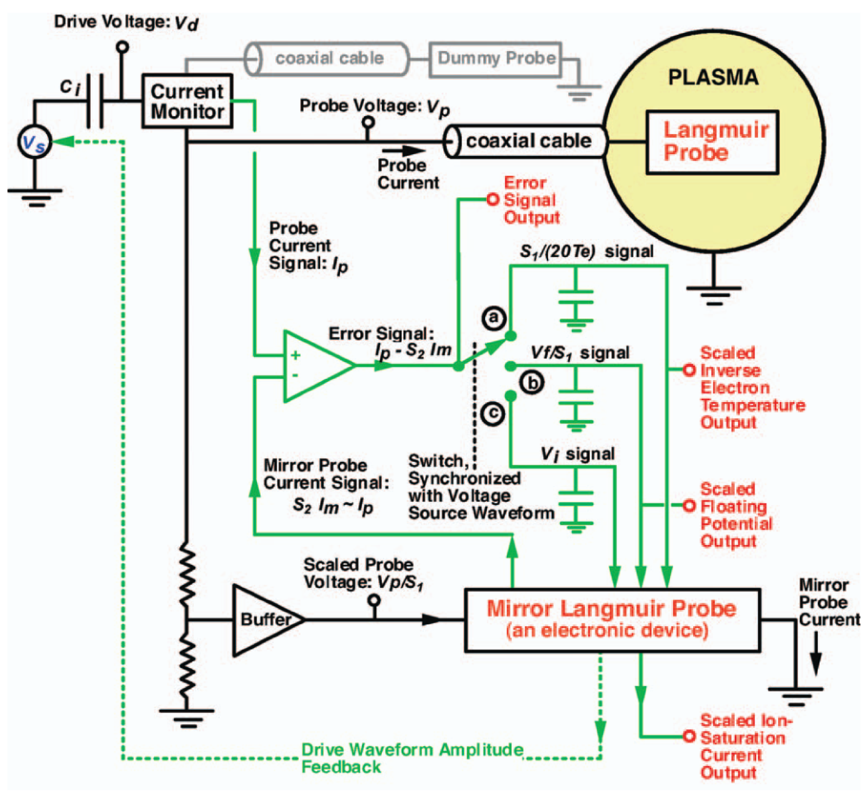
Algorithm loop:

1. Calculate $V_{-,+,0}$ from previous loop values (or initial guess)
2. Bias to V_-, calculate I^+_{Sat} from previous loop ϕ_f, T_e values
3. Bias to V_+, calculate T_e from previous loop/step ϕ_f, I^+_{Sat} values
4. Bias to V_0, calculate ϕ_f from previous steps I^+_{Sat}, T_e values

WHAT IS A MIRROR PROBE?

Original Mirror probe on Alcator C-mod by LaBombard et al. [1]:

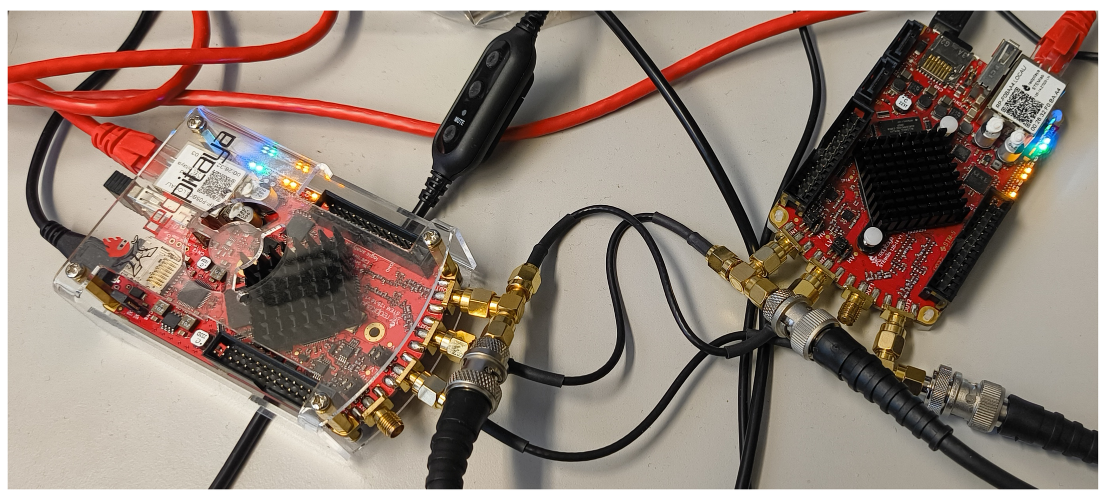
- Pair of RF bipolar transistors to mirror IV response of LP
- ✓ Single point measurement, $\sim$ MHz



TESTING STRATEGY

Strategy outlined below:

1. ✓ Connect to function generator
   - ~ Dial in scales and offsets
2. ✓ Two boards duelling
   - ✓ One running mirror probe algorithm
   - ✓ One simulating plasma response
   - ✓ Tests algorithm
3. Test on glow discharge chamber
   - Slowly change parameters
   - Tests electronic and PSU setup
4. Install on MEM on ASDEX Upgrade
   - Vacuum test capacitive compensation
   - Far SOL tests ensure correct scales and offsets
   - Increase frequency



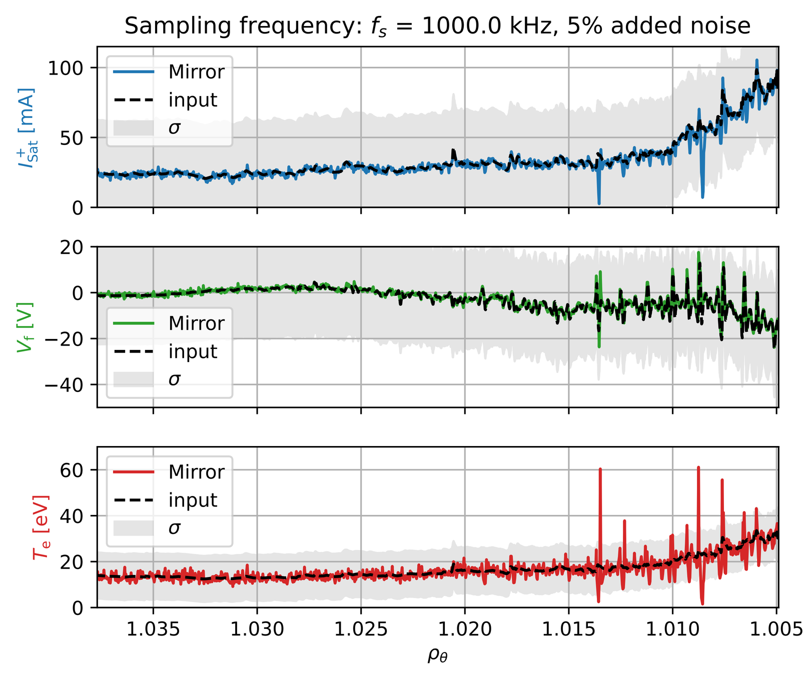
TESTING THE ALGORITHM

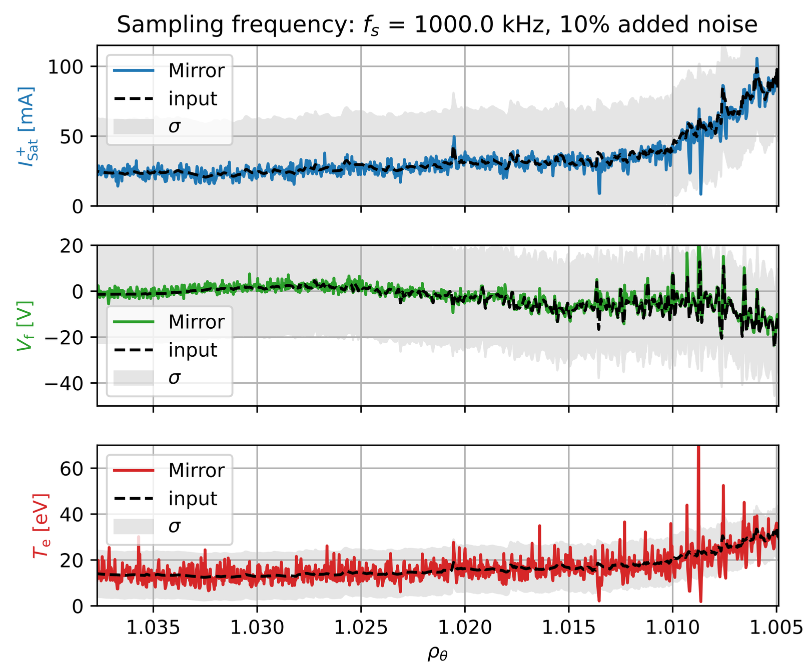
Python implementation of algorithm using GRILLIX simulation data (courtesy of J. Pfennig-Bär, see also G. Grenfell poster on GRILLIX code validation)

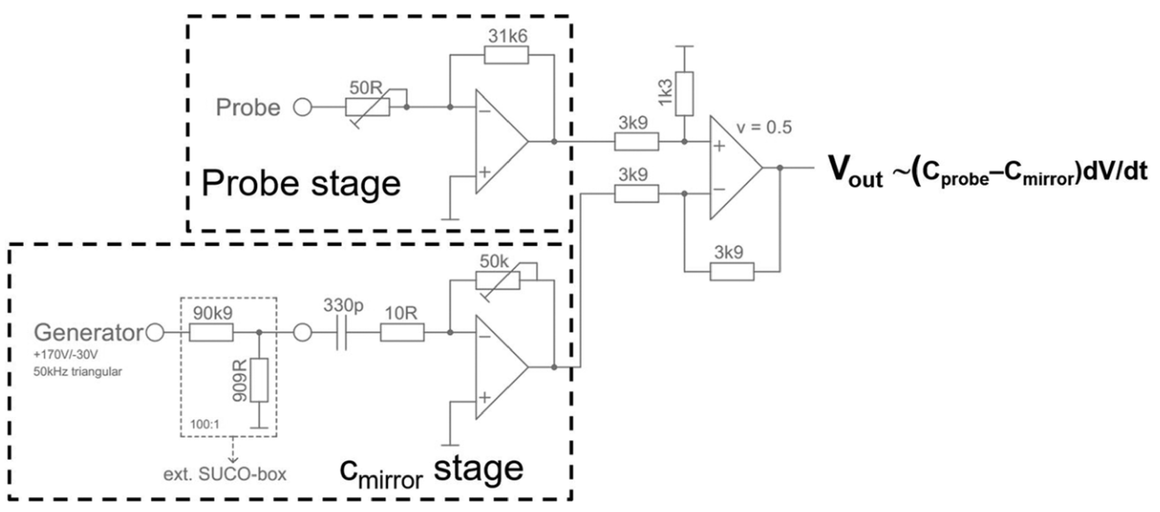
- ✓ Fast convergence
- ✓ Capable at high frequencies
- Voltage range approx. $50\,\mathrm{V}$ to $-250\,\mathrm{V}$
- Currant range approx. $1\,\mathrm{mA}$ to $500\,\mathrm{mA}$
- ✗ T_e strong sensitivity to noise.

solutions:

- mount close to the vessel to reduce cable length (capacitive noise)
- capacitive compensator circuit [7]
- Fast PSU(s) capable of $\pm 250\,\mathrm{V}, 1\,\mathrm{A}, f = 5\,\mathrm{MHz}$







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