Oscillatory Technique for T$_e$-Measurements by Langmuir Probe on the CASTOR Tokamak

Stöckel J., Kryška L., Žáček F.
Institute of Plasma Physics, Czech Academy of Sciences,
Za Slovankou 3, P.O.Box 17, 182 11 Prague 8

The experimental data about the local electron temperature T_e in the tokamak edge plasma are of the fundamental importance to determine the transport coefficients in this region. The Langmuir probes are used often for this purpose. The standard Langmuir probes techniques as swept probe or triple probe, however, have some principal disadvantages. The first technique is rather cumbersome for routine measurements and moreover, processing of the data has to be performed to obtain T_e. For this reason the method has limitation in the temporal resolution. The later, triple probe technique, allows to determine the electon temperature on line, but the value of T_e is averaged over the distance between the probe tips. Moreover, an existence of poloidal non-uniformities in the plasma potential complicate interpretation of the measurement.

The oscillatory probe method, described in this contribution, overcomes these disadvantages. It was originally developed for measurement in mirror machine [1], however, it has been used recently in tokamak TEXTOR [2] as well. The principle of the method is based on the rectifying properties of the Langmuir probe immersed in the plasma. Namely, if the harmonic RF signal with the amplitude $V_o \leq T_e$ is applied to the probe being on the floating potential V_{fl}, a negative shift ΔV_{fl} of the averaged floating potential arises. This shift ΔV_{fl} is related to the electron temperature T_e through the simple expression:

$$T_e = \frac{1}{4} \cdot \frac{V_o^2}{\Delta V_{fl}}.$$

Here T_e is expressed in eV.

There are two possibilities how to measure the potential difference ΔV_{fl}:

1. Two very near placed floating probes are used. The RF signal is applied to one probe only, while the second serves as a reference one. In this case it is possible to measure the difference ΔV_{fl} on line.

2. Only one probe is used and the RF signal is alternately switched on and off (square modulation). In this case the value of V_{fl} in both phases are compared.

The second method has been used for measurement of T_e in the edge plasma of tokamak CASTOR ($R = 0.4m$, $a = 0.085m$, $B = 1T$, $I = 10 - 20kA$). The results have been compared with the triple probe technique. Experimental set-up of the oscillatory technique used is given in Fig. 1. The results of the measurement are shown further in Fig. 2. The more negative values of V_{fl} (y

axis) in this figure correspond to the phase with zero RF signal. Interpolated values of V_{fl} in corresponding phases of the modulation are given in the figure as well. In the lower part of the figure, the time evolutions of $< T_e >$ obtained by this oscillatory technique are compared with the triple probe data. It may be seen that the agreement is very good. This is an indication, that oscillatory technique may be used in the edge plasma as a convenient, strictly local method of electron temperature measurement.

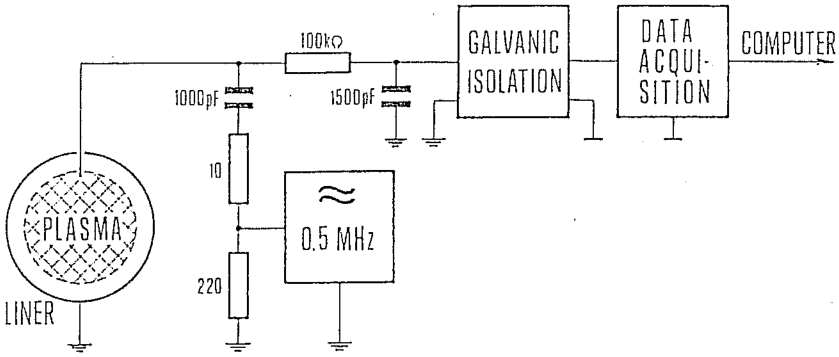

Figure 1: Schematic diagram of electric circuit used in the oscillatory probe technique.

As a further application of the oscillatory technique the mapping of electron temperature in both radial and poloidal directions is envisaged. For this purposes the multiple tip probes will be used.

Acknowledgement

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References

[1] Godjak V.A. et al.: ZHTF 37 (1967), 1063

[2] Ivanov R. S. et al.: Textor Report Jul-2432, January 1991

[3] Kanaev B.I. et al.: ZHTF 46 (1974), 2302

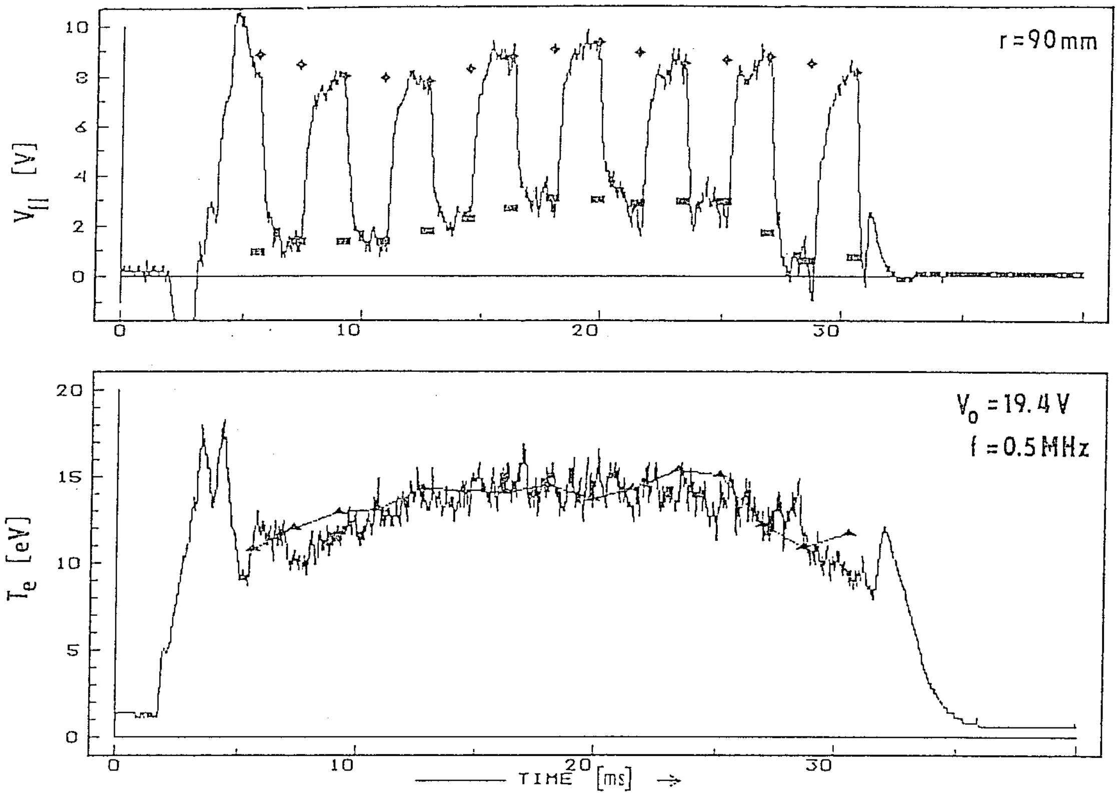

Figure 2: Floating potential picked up from the probe with a harmonic disturbance which is modulated by rectangular signal. Sign ◇ means interpolation of the non-modulated phase and □ means interpolation of the modulated phase (upper part of the figure). Evaluated T_e by the triple probe (line) and average T_e evaluated by the oscillatory probe are given in lower part of the figure.

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J. Stöckel, L. Kryška, F, Žáček, K. Jakubka

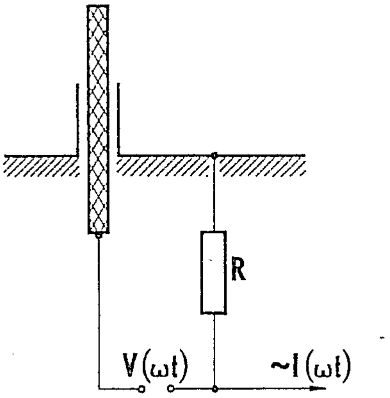
Institute of Plasma Physics
Czech Academy of Sciences
Za Slovankou 3, P.O.B.17, 182 11 Praha 8,
Czechland

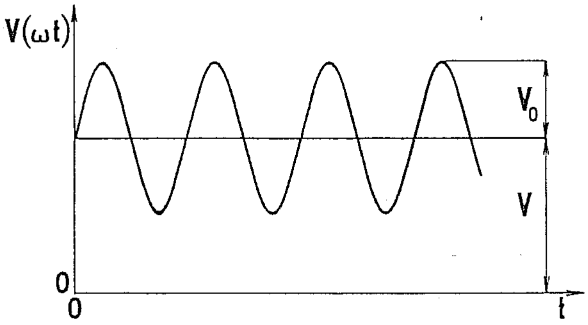
- Motivation
- Review of the single Langmuir probe
- Oscillatory technique - basic equations
- Experimental arrangement
- Results
- Future applications on the CASTOR tokamak
- Summary

A copy of poster presented at 19th Sym. on Plasma Physics and Technology,
Praque, 27.-29.4.1993

Ref:
[1] Godjak V.A. et al: ZHTF, 37,1967, No.6, p.1063
[2] Kanaev B.I. et al: ZHTF, 46,1974, No.11,p.2302
[3] Ivanov R.s. et al: Textor Report Jul-2432, January 1991

Oscillatory probe





Sinusoidal voltage is applied to the probe:

$$\mathrm{V}(\omega \mathrm{t}) = \mathrm{V} + \mathrm{V}_0 \sin \omega \mathrm{t}$$

Consequently, the electron current is modulated:

$$\mathrm{I_e}(\omega \mathrm{t}) = \mathrm{I_e^0} \mathrm{e}^{-(\phi_\mathrm{s} - \mathrm{V} - \mathrm{V}_0 \sin \omega \mathrm{t})/\mathrm{T_e}}$$

where $\mathrm{T_e} \equiv \mathrm{kT_e/e}$, $\mathrm{I_e^0}$ is the electron saturation current, ϕ_s is the space potential.

Time average value of the electron current

$$< \mathrm{I_e} >= \frac{1}{2\pi} \int_0^{2\pi} \mathrm{I_e}(\omega \mathrm{t}) \mathrm{d}(\omega \mathrm{t})$$

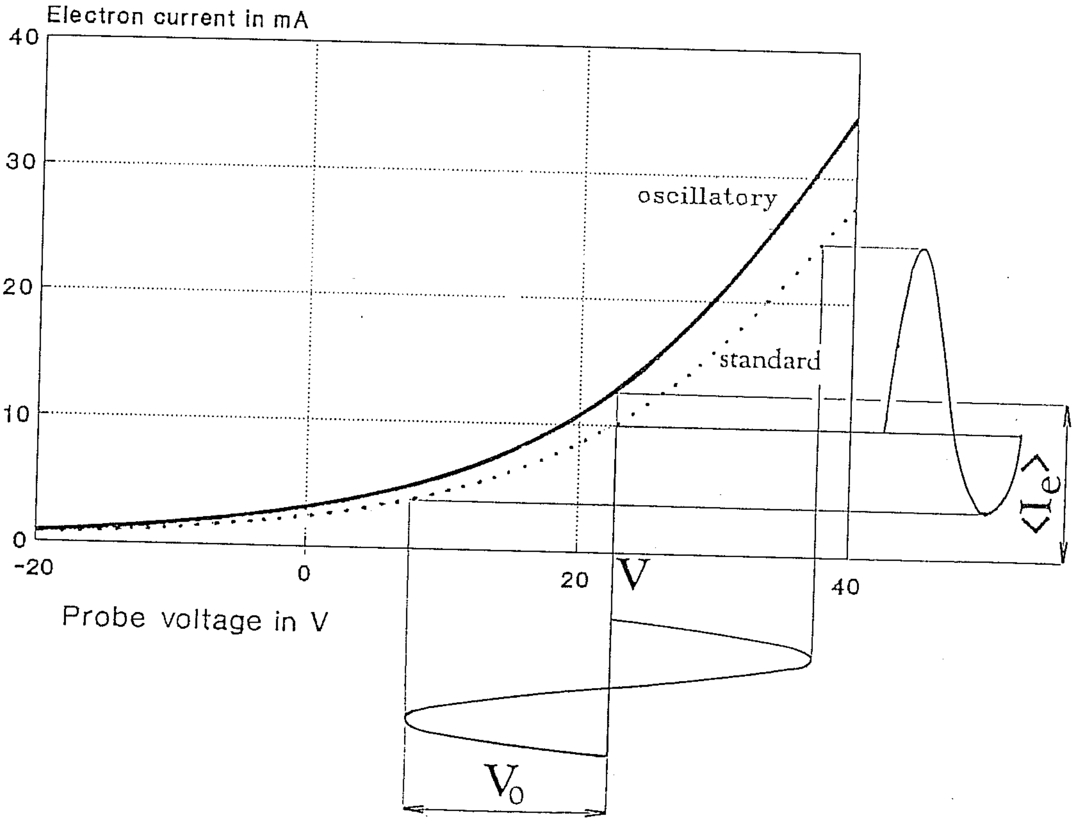
is always higher than the electron current of a standard single Langmuir probe:

$$< \mathrm{I_e} >= \mathrm{I_e^{stand}} \cdot \mathcal{J}$$

where
$\mathcal{J} = (1/2\pi) \int_0^{2\pi} \mathrm{e}^{\mathrm{V}_0 \sin \omega \mathrm{t}/\mathrm{T_e}} \mathrm{d}(\omega \mathrm{t})$ is the modified Bessel function,

$\mathrm{I_e^{stand}} = \mathrm{I_e^0} \mathrm{e}^{-(\phi_\mathrm{s} - \mathrm{V})/\mathrm{T_e}}$ is the electron current of the standard single Langmuir probe.

Electron Current of Oscillatory Probe



Approximation for $V_0 < T_e$:

We expand the argument of integral $\int_0^{2\pi} e^{V_0 \sin\omega t/T_e} d(\omega t)$ (as $e^x = 1 + x + x^2/2 + ...$). Then

$$< I_e >= I_e^{\text{stand}} \cdot \frac{1}{2\pi} \int_0^{2\pi} [1 + \frac{V_0}{T_e} \sin\omega t + \frac{1}{2} (\frac{V_0}{T_e})^2 \sin^2 \omega t + ...] d(\omega t)$$

and finally

$$< I_e > \doteq I_e^{\text{stand}} \cdot [1 + (\frac{V_0}{2T_e})^2]$$

Floating Potential of Oscillatory Probe

Floating potential $< V_{fl}^{osc} >$ of the oscillatory probe is evaluated using condition $< I >= 0$ (electron current equals to ion saturation current I_i^0):

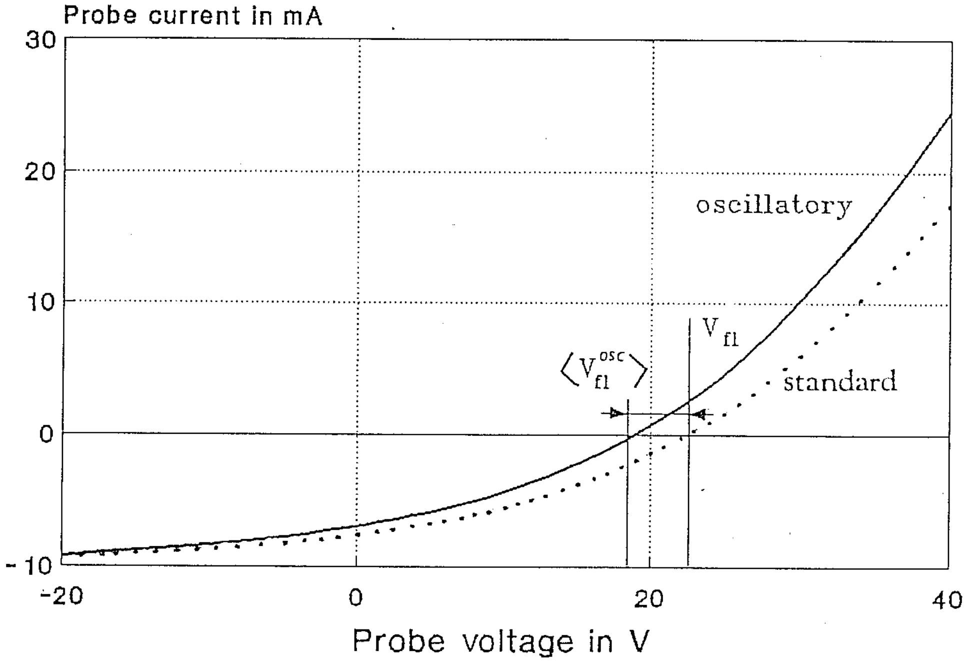
$$I_e^0 e^{-(\phi_s - < V_{fl}^{osc} >)/T_e} * \mathcal{J} = I_i^0$$

$$\phi_s - T_e \ln I_e^0 / I_i^0 = < V_{fl}^{osc} > + T_e \ln \mathcal{J}$$

Left hand side is the unperturbed floating potential $V_{fl} \Rightarrow$

$$\Delta V_{fl} = V_{fl} - < V_{fl}^{osc} > = T_e \ln \mathcal{J} \quad .$$

Note that the floating potential of the oscillatory probe $< V_{fl}^{osc} >$ is always lower than V_{fl}!



Approximation for $V_0 < T_e \Rightarrow$

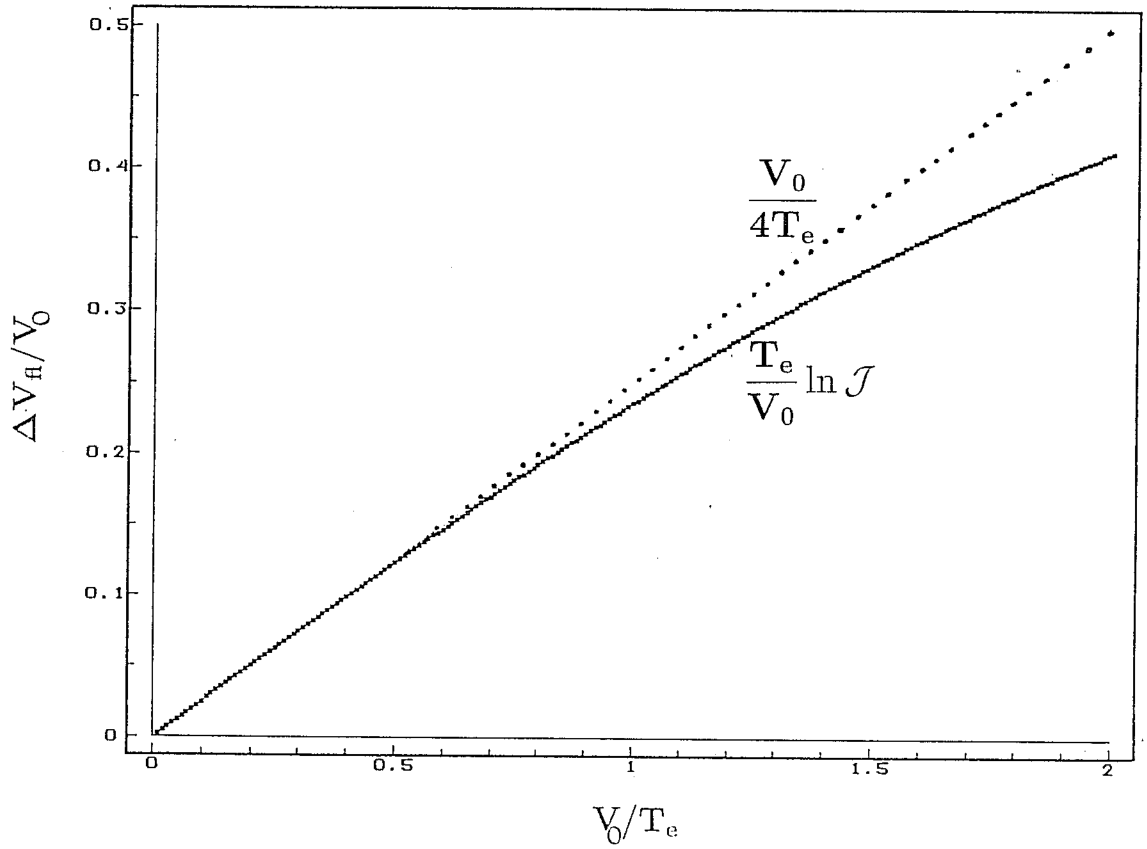
$$\Delta V_{fl} \simeq \frac{V_0^2}{4T_e}$$

Normalized Drop of Floating Potential

$$\frac{\Delta V_{fl}}{V_0} = \frac{T_e}{V_0} \ln \mathcal{J} \quad .$$

Approximation for $T_e > V_0$:

$$\frac{\Delta V_{fl}}{V_0} = \frac{V_0}{4T_e}$$

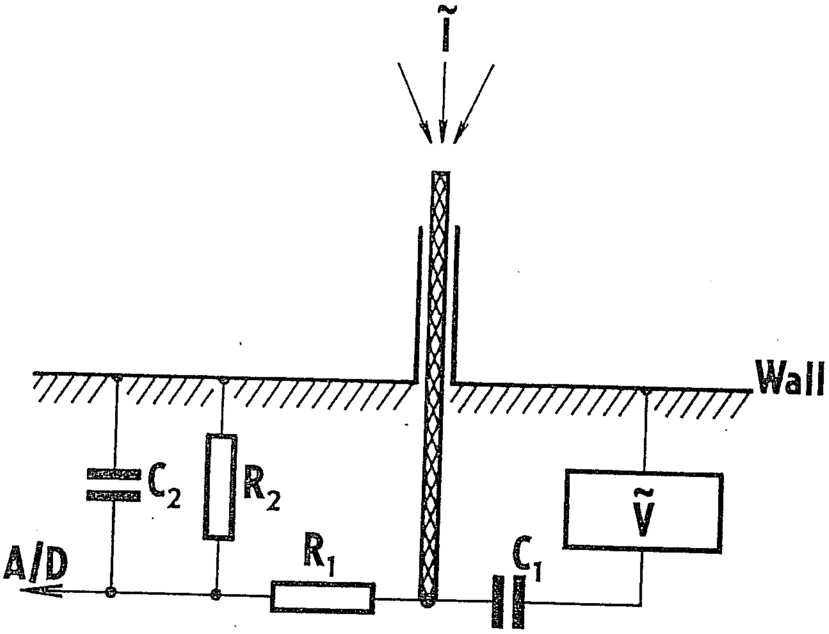


For $T_e > V_0 \quad \Rightarrow$

$$T_e \simeq \frac{V_0^2}{4\Delta V_{fl}}$$

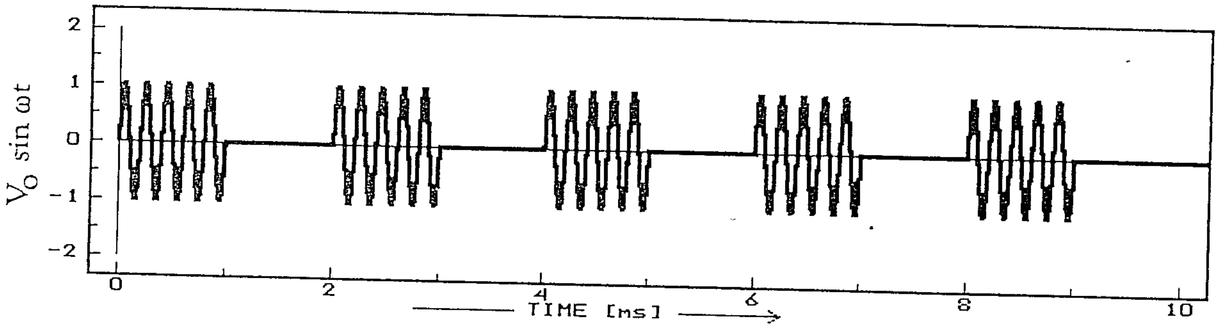
with accuracy better than $\sim 6\%$.

Experimental arrangement



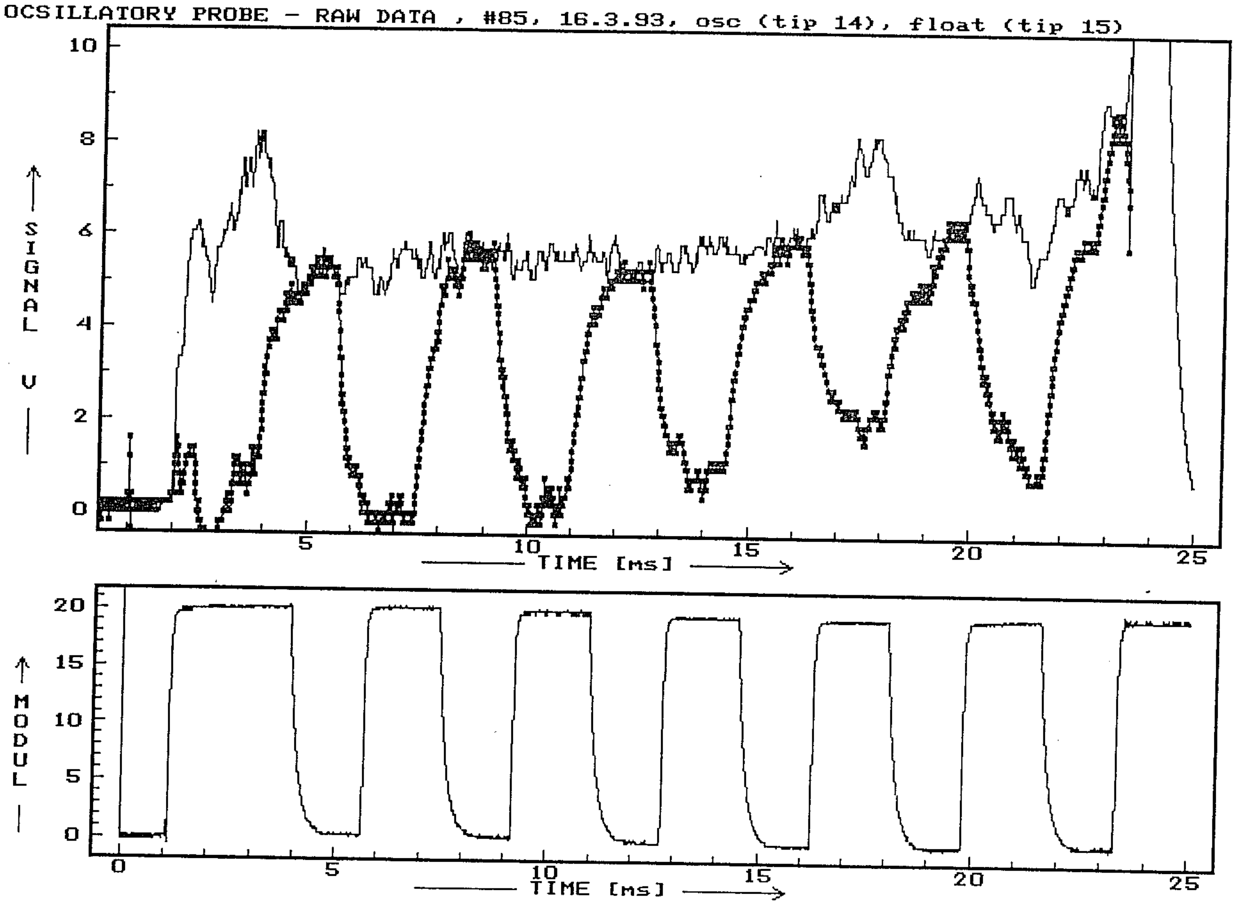
Modulation:
Amplitude ⇒ $V_0 \leq 20$ V
Frequency ⇒ f = 500 kHz
Impedance ⇒ R = 50Ω

Oscillatory voltage is periodically gated as shown schematically in the figure!



Test of the oscillatory probe on CASTOR tokamak

Amplitude of modulation:	$V_0 = 19.4$ V
Gating pulse:	$\tau_g = 1.7$ ms



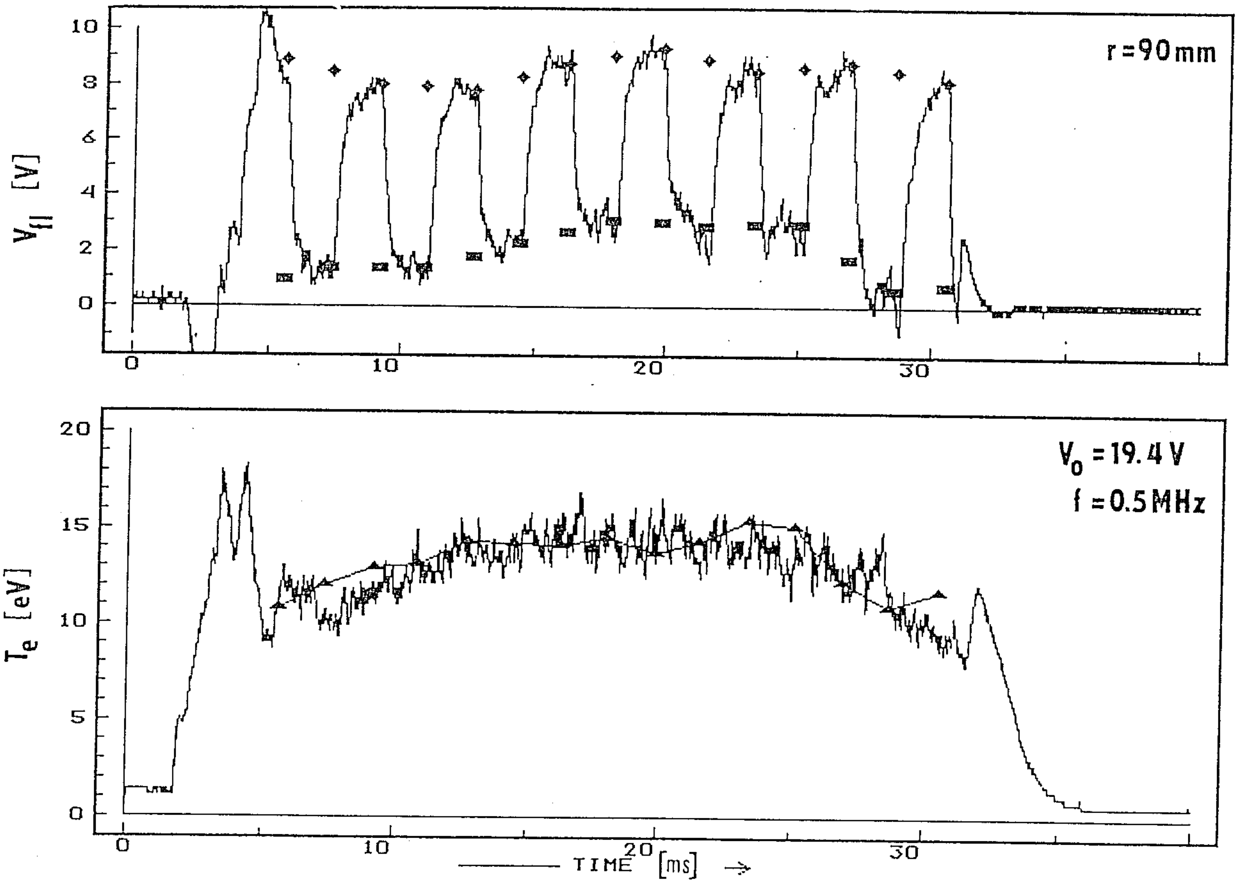
Thick line - signal of the oscillatory probe
Thin line - floating potential of the neighbouring tip

- Signals of floating and oscillatory tips are comparable when $V_0 = 0$.
- Only a part of gating pulse can be used for evaluation of the electron temperature. Note the transient time (~ 1 ms) after the start and end of the gating pulse!

Evolution of the electron temperature (comparison of oscillatory and triple probes

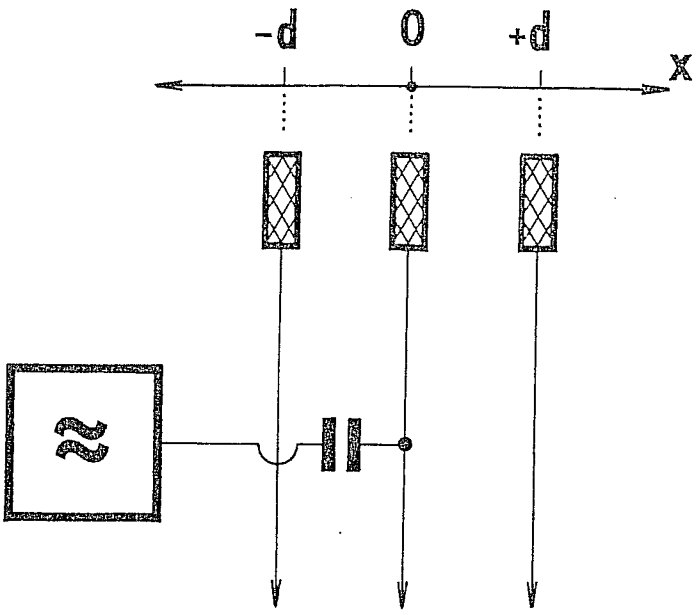
The raw signal is interpolated to reach a better temporal resolution.

◇ – interpolation of the floating potential period
□ – interpolation of the oscillatory period



- line — electron temperature by the triple probe
— △ — electron temperature by the oscillatory probe

Electron Temperature Fluctuations



$$T_e(0) = 0.25 \cdot \frac{V_0^2}{V_{fl}(0) - < V_{fl}(0)^{osc} >}$$

Floating potential in the origin (place of the oscillatory tip) is determined by interpolation of data measured at the points +d and −d, assuming $\partial V_{fl}^0 / \partial x = \text{const}$.

$$V_{fl}(0) \doteq \frac{V_{fl}(-d) + V_{fl}(+d)}{2}$$

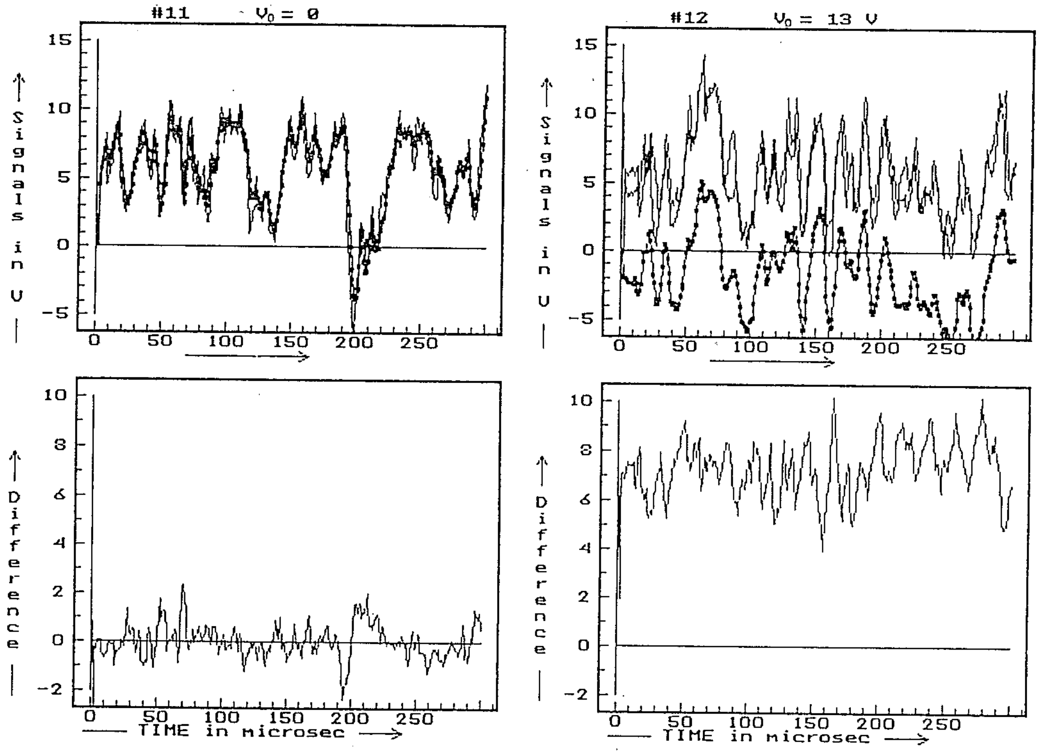
Frequency of the oscillatory voltage should be significantly higher than typical frequencies of fluctuations.

Electron Temperature Fluctuations (raw signals)

Raw signals for determination of T_e-fluctuations. Three tips, denoted as No. 1, No. 2 and No. 3, are separated in poloidal direction by the distance $d = 2.5mm$.
The top figures are plots of the raw signals. The signal from the central tip No.2 is marked by dots. The bottom figure shows the differential signal

$$\Delta V_{fl} = \frac{V_{fl}(-d) + V_{fl}(+d)}{2} - V_{fl}^{osc}(0)$$

LEFT (# 11): All three tips are on the floating potential ($V_0 = 0$).
RIGHT (#12): The central tip (No.2) is modulated by oscillatory voltage ($V_0 = 13V$, $f = 1.4MHz$)



The differential signal without the oscillatory voltage (left) represents a noise for such arrangement of the tips. The fluctuations in the oscillatory case (right) are the highest estimate for the calculation of T_e fluctuations.

Electron Temperature Fluctuations (noise correction)

The differential signal in the oscillatory case

$$\Delta = \frac{V_{fl}(-d) + V_{fl}(+d)}{2} - V_{fl}^{osc}(0)$$

is a superposition of useful signal $V_0^2/4T_e(t)$ and of the noise $N(t)$:

$$\Delta(t) = \frac{V_0^2}{4T_e(t)} + N(t) \quad ; \quad < \Delta(t) >= \frac{V_0^2}{4T_e} \quad ; \quad < N(t) >= 0$$

The noise is caused by:

1) by an existence of short wavelength potential perturbations ($k_\perp > d$)

2) by an imperfect electronics.

To eliminate the noise, the fluctuating part of the differential signal is expanded as:

$$\delta\Delta = f_1 \delta T_e + f_2 \delta N$$

where $f_1 = \partial\Delta/\partial T_e = -V_0^2/4T_e^2$ and $f_2 = \partial\Delta/\partial N = 1$.

The mean square value of $\delta\Delta$ is then:

$$\tilde{\Delta}^2 =< \delta\Delta\delta\Delta >= f_1^2 < \delta T_e \delta T_e > + f_2^2 < \delta N \delta N > + 2 f_1 f_2 < \delta T_e \delta N >$$

The last term equals zero, if the temperature and noise fluctuations are not correlated.

$$\tilde{\Delta}^2 =< \Delta >^2 (\frac{\tilde{T}_e}{T_e})^2 + \tilde{N}^2$$

Finally,

$$\frac{\tilde{T}_e}{T_e} = \frac{\tilde{\Delta}}{< \Delta >}\sqrt{1 - \frac{\tilde{N}^2}{\tilde{\Delta}^2}}$$

Experimental data:

#11 (no modulation) $< N >= 0.04V \quad \tilde{N}^2 = 0.55V^2$

#12 (with modulation) $< \Delta >= 7.35V \quad \tilde{\Delta}^2 = 1.12V^2 \Rightarrow \tilde{\Delta}/\Delta = 0.15$

$$\tilde{T}_e/T_e = 0.12$$

The relative level of temperature fluctuations is comparable with values from TEXT tokamak, obtained with a different method.

Conclusions & Future plans

This contribution demonstrates application of the oscillatory technique for measurement of the local electron temperature on the CASTOR tokamak. A sinusoidal voltage is applied to the floating Langmuir probe. The electron temperature is then deduced simply from from a drop of the floating potential.

Two experiments were performed:

- simultaneous measurement of T_e by the oscillatory and triple probes demonstrated a reasonable agreement.
- measurement of the fluctuations of the electron temperature have shown that the relative level of T_e-fluctuations is $\tilde{T}_e/T_e = 0.12$ which well agrees with the value from TEXT tokamak, determined by another method.

In future, we try to use the oscillatory technique for mapping of the electron temperature both in radial and poloidal direction using a multiple tip Langmuir probe.

Ref:

[1] Godjak V.A. et al: ZHTF, 37,1967, No.6, p.1063

[2] Kanaev B.I. et al: ZHTF, 46,1974, No.11,p.2302

[3] Ivanov R.s. et al: Textor Report Jul-2432, January 1991