In the present work, the resolution of a 4-channel pulsed radar being built at Rijnhuisen for RTP tokamak is analyzed. The achievable resolution depends mainly on the accuracy of the time-of-flight measurements and the number of sampling frequencies; since the technological solution and the configuration have already been set, the emphasis is laid on the interpretation of the measured data (inversion problem) and minimization of the overall error. For this purpose, a specific neural network — Multi Layer Perceptron (MLP) — has been successfully applied.

The central density in the range $0.2-0.6 \times 10^{20} \text{ m}^{-3}$ was considered, i.e., above the critical density for all four frequencies but not too high to restrict the measurements just to the edge of plasma. For a wide class of density profiles, by balancing the inversion error and the time measurement error, the overall error in estimating the reflection point position between $0.72 \text{ cm}$ (for the lowest frequency) and $0.52 \text{ cm}$ (for the highest frequency) root mean square was obtained, assuming an RMS error of 70 ps in the time of flight measurements. It is probably much better than what could have been obtained by Abel transform. Moreover, the mapping by MLP is incomparably faster and should be considered for routine multichannel pulsed radar data processing.

1. Introduction

The use of subnanosecond pulses for measurements of plasma density profiles in tokamaks has been proposed in [1-3]. The proclaimed advantages of pulsed radar over classical instruments such as interferometers and reflectometers are the speed of measurements (allowing for the time resolution in the $\mu$s range), the simplicity of arrangement and good stability against the source frequency variations. The obvious drawback, on the other hand, is the necessity of very accurate time measurements in the subnanosecond range.

The purpose of this paper is twofold. Firstly, it is the analysis of the global resolution of the 4-channel pulsed radar proposed for RTP tokamak [4] which depends both on the accuracy of measurements and the interpretation method. Secondly, the applicability of a Multi Layer Perceptron (MLP) [5] to this purpose is "tested by using", and the advantages of this method over the traditional use of Abel transform are demonstrated.

The paper is organized as follows. In Section 2, basic principles of a pulsed radar are briefly summarized. In Section 3, the problems connected with the application of Abel transform as a standard inversion method are pointed out and the spatial
resolution is discussed in terms of the measurement and inversion errors. Section 4 introduces a neural network approach and presents some results obtained by a 1-hidden layer perceptron (MLP-1). The conclusions are drawn in Section 5.

2. The principles of the pulsed radar

A pulsed radar, in regimes with the maximum plasma density above the cut-off density, relies on the total reflection of electromagnetic waves by plasma. The underlying physics is similar to that of a reflectometer, but the time of flight (the time necessary for a transmitted narrow pulse to complete a round trip to the critical layer in the plasma and back to the antenna),

$$\tau(f_i) = \frac{1}{2\pi} \frac{d\Phi(f)}{df} \bigg|_{f=f_i} = \frac{2}{c} \int_{r_c(f_i)}^{a} \left[ 1 - \left( \frac{f_p(r)}{f_i} \right)^2 \right]^{-1/2} \, dr \quad (1)$$

is directly measured. In this formula, $\Phi$ is the phase shift, $f_i$ the applied frequency, $f_p(r)$ is the plasma frequency,

$$f_p(r) = 89.79 \times \sqrt{n_e(r)} \quad [\text{GHz}; 10^{20} \text{ m}^{-3}], \quad (2)$$

$n_e(r)$ the plasma density, $r$ the radius and $a$ the small radius, $r_c(f)$ the point of reflection where $f = f_p$ so that the refractive index becomes zero.

For density profile measurements, pulses at several different frequencies have to be launched to get a set of samples of the function $\tau(f)$. Additional information about $\tau(f)$ can be in principle obtained by measuring the reflected pulse width. It can be shown that for a Gaussian shaped transmitted pulse, within the validity limits of WKB approximation, the reflected pulse is also Gaussian and the relation between the transmitted ($W_t$) and received ($W_r$) pulse widths is

$$W_r = W_t \sqrt{1 + \left( \frac{2 \ln 2 f''(f)}{\pi^2 W_t^2} \right)^2}. \quad (3)$$

From Eq. 1 it follows that $W_r$ is related to $\tau'(f)$. However, for RTP sized tokamak and the transmitted pulse width of 0.5 ns, the broadening is too small to be of much help at the accuracy of time measurement given below. Therefore, the measurement of $W_r$ will not be considered here.

If the frequency $f_i$ of the launched pulse is above the highest plasma frequency $f_{p, \text{max}}$, or, in other words, the critical (cut-off) density

$$n_c = \left( \frac{f_i}{89.79} \right)^2 \quad [10^{20} \text{ m}^{-3} \text{ GHz}] \quad (4)$$

is higher then the maximum plasma density, the pulse penetrates through the plasma column and gets reflected but from the inner wall. Equation 1 still holds.