Development of Reflectometry for Plasma Density Measurements at JET

A E Costley

JET Joint Undertaking, Abingdon, Oxon, OX14 3EA.

"This document is intended for publication in the open literature. It is made available on the understanding that it may not be further circulated and extracts may not be published prior to publication of the original, without the consent of the Publications Officer, JET Joint Undertaking, Abingdon, Oxon, OX14 3EA, UK".

"Enquiries about Copyright and reproduction should be addressed to the Publications Officer, JET Joint Undertaking, Abingdon, Oxon, OX14 3EA".

DEVELOPMENT OF REFLECTOMETRY FOR PLASMA DENSITY MEASUREMENTS AT JET

A E Costley

JET Joint Undertaking, Abingdon, Oxon, OX14 3EA, UK

1. INTRODUCTION

Although the basic physics of millimetre wave reflectometry has been known for many years, it is only recently that reliable measurements have been obtained with the technique in applications on tokamak plasmas. This is primarily because for these plasmas the electron density is a rapidly fluctuating parameter and these fluctuations generate broad-band 'noise' in the measurement systems. Also, several important experimental requirements were not originally realised. Recently, special techniques and hardware for processing the signals have been developed, and appropriate care taken in designing and implementing the measurement systems. As a result, reliable measurements are now being obtained routinely and are being used extensively in plasma physics studies.

Reflectometry has the potential to provide measurements of the spatial dependence of the electron density, ie. the electron density profile, during quasi-stationary periods of the plasma. It can also provide measurements of the movement of specific density layers during fast phenomena, ie. density transients. In principle, information on the broad band density fluctuations can also be obtained.

Extensive use is made of reflectometry at JET where substantial systems have been developed. In this paper, we discuss the principles of the technique and describe the instrumentation on JET. Results demonstrating the performance of the reflectometers are presented.

2. PRINCIPLES OF REFLECTOMETRY

Millimetre wave radiation is directed at the plasma along the gradient of the electron density and reflected at the layer where the electron density equals a critical value ($n_e = n_c(\omega)$) at which the plasma refractive index has fallen to zero. Usually the launched radiation has its electric vector parallel to the magnetic field (o-mode) and in this case the reflection occurs when the source frequency $\omega = \omega_p = (n_e e^2/\varepsilon_0 m_e)^{1/2}$ where ω_p is the plasma frequency. Phase changes in the reflected radiation are measured by mixing it with a reference beam in a detector. The frequency of the source is swept and the corresponding change of phase (ϕ) measured. Different frequencies are reflected at different density layers with higher frequencies being reflected at higher densities which are located towards the centre of the plasma. $d\phi/d\omega$ is determined at each frequency in the range of interest and the spatial profile of the electron density ($n_e(R)$) is determined by an inversion technique [1].

Alternatively, the source frequency can be held constant and movements of a single density layer determined by measuring $\phi(t)$. By combining data from two or more reflectometers it is in principle possible to determine the spatial extent and movement of the density perturbations which generate the broad-band fluctuations in the reflectometer signals. The data are analysed using correlation techniques and the method is known as Correlation Reflectometry [2].

3. IMPLEMENTATION AT JET

The main reflectometer on JET is a multichannel system. The outputs from twelve Gunn oscillators operating in the range $18 < f < 80$ GHz are multiplexed into an oversized (WG 12A) waveguide (figure 1). A combiner employing band branching/channel filtering systems was developed specifically for this purpose [3]. The waveguide has a length of 25 m and employs reduced height E-plane bends to minimise mode conversion. The radiation is launched and received using separate antennas mounted in the JET vacuum vessel. The separation of the reflected signals is effected with a second band branching/channel filtering system, and the signals are detected using sensitive heterodyne receivers. The data acquisition includes automatic fringe counting electronics to give ϕ.

The system can operate in both the swept frequency and fixed frequency modes. In the swept mode, the frequency of each source is swept over a narrow range, typically 100 MHz, in a time of $\lesssim 3$ ms. $d\phi/d\omega$ is determined by interpolation at all frequencies in the measured range and $n_e(R)$ obtained by inverting the data. A typical result is shown in figure 2. In the fixed frequency mode, fractions of a fringe can be measured and so very small movements, typically < 1 mm, in the positions of the density layers can be determined with recording bandwidths up to 100 kHz.

Two types of correlation reflectometer have also been constructed. In one case, radiation from four Gunn oscillators at 75.5, 75.6, 76.15 and 77.75 GHz is multiplexed into one waveguide and the reflected radiation is detected

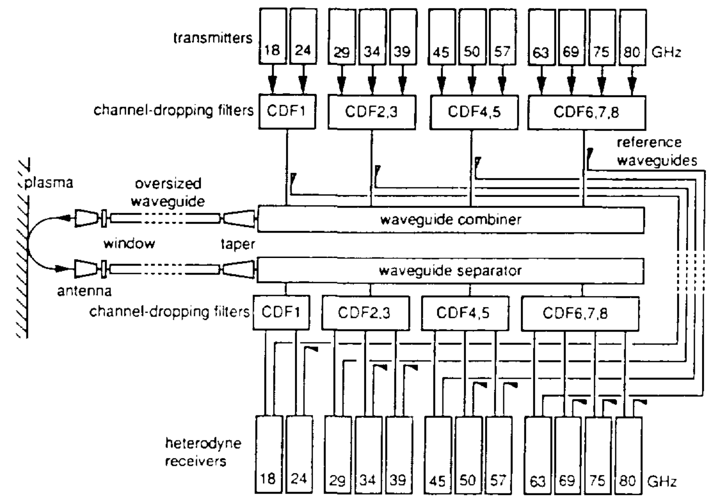

Figure 1. Schematic of the JET multichannel reflectometer system

by a broad-band heterodyne receiver. The different channels are separated by filtering at the IF stage. The fluctuating signals are recorded with a wide bandwidth (100 kHz) and the size of the density perturbations in the direction of the plasma radius is determined by a correlation analysis. In the second case, two reflectometers operating at the same frequency but probing the plasma at different toroidal locations are used to determine the toroidal motion of the perturbations.

The next phase of JET is aimed at improving the control of impurities and plasma exhaust by using a pumped divertor mounted inside the JET vacuum vessel. New diagnostic systems are being prepared for measuring the parameters of the plasma in the divertor region. In particular, a novel 'comb' reflectometer is being prepared. In this device radiation at several fixed frequencies is launched at the plasma along the same line of sight and the highest frequency in reflection is determined by observing both the amplitude of the transmitted beams and the level of fluctuations on the reflected beam. The peak density in the line of sight is therefore estimated. In addition, a swept frequency reflectometer for measuring the density profile in the extreme edge of the plasma (scrape-off-layer) in the mid-plane is being constructed. Possibilities exist for even more advanced systems utilising pulsed radar or pulse compression techniques and these are under consideration.

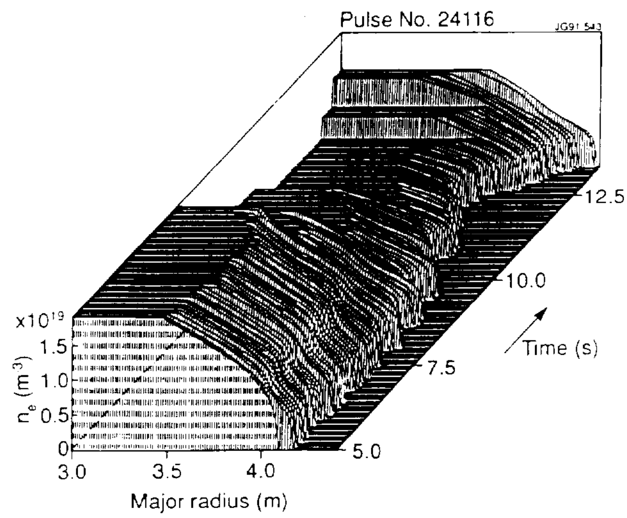

Figure 2: Typical measured electron density profiles.

1. I H Hutchinson, 'Principles of Plasma Diagnostics', 125-128 Cambridge University Press (1987).
2. A E Costley, P Cripwell, R Prentice and A C C Sips, Rev. Sci. Instrum. 61 (10), 2823-2838 (1990).
3. M Medeiros and N Williams, Conf. Digest Twelfth International Conference on Infrared and Millimetre Waves, IEEE Catalog No.87CH2490-1 (1987).