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Design Of A Dedicated ECE Diagnostic For Feedback Control Of Instabilities By ECRH

J.W. Oosterbeek, W.A. Bongers(1), I.G.J. Classen(1), I. Danilov(2), J.A. Hoekzema, R. Heidinger(2), M.F. Graswinckel(1), S.B. Korsholm(3), A.Kramer-Flecken, O.G. Kruijt(1), J. Scholten(1), C. Tito(1), E. Tsakadze(3), B.C.E. Vaessen(1), E. Westerhof(1) and the TEXTOR team

Forschungszentrum Jülich GmbH, Institut für Plasmaphysik,
*Association EURATOM-FZJ, 52425 Jülich, Germany**
(1) FOM-Institute for Plasma Physics Rijnhuizen,
*Association EURATOM-FOM, PO Box 1207, 3430 BE Nieuwegein, The Netherlands**
(2) Forschungszentrum Karlsruhe, Institut für Materialforschung I,
Association EURATOM-FZK, P.O. Box 3640, D-76021 Karlsruhe, Germany
(3) Risø National Laboratory, Association EURATOM-Risø National Laboratory,
Optics and Plasma Research Department, 4000 Roskilde, Denmark
** Partners in the Trilateral Euregio Cluster*

Abstract. Efficient stabilisation of tearing modes is achieved by placing the ECW deposition profile exactly over the spatial profile of the mode. Therefore the location of the island with respect to the ECW deposition profile needs to be known accurately, while this information also needs to be available quickly in order to respond timely to the growth of the NTM. A scheme to suppress NTMs is under development that utilises the ECW transmission line as an ECE receiver thus eliminating the need to compute the coordinates of the island. The receiver needs operate in an extreme dynamic range in the power spectrum as the ECE components are in the order of nWs while the gyrotron component is at hundreds of kWs.

Email: of J.W. Oosterbeek: J.W. Oosterbeek@fz-juelich.de

LINE OF SIGHT PRINCIPLE

The "Line of Sight" scheme [1] exploits the gyrotron transmission line in the reverse direction as an ECE antenna thus ensuring that the ECE observed originates from the same location as where the ECW is deposited. In case a NTM is detected [2] in the observed ECE spectrum the steerable ECW launcher is moved such that the mode is located exactly in the centre of the observed ECE profile, which in turn will ensure that the ECW deposition profile is placed exactly over the mode.

The situation is sketched in figure 1. The plate shown in the transmission line is the first section of the Frequency Selective Coupler that is required to be transparent at the gyrotron frequency, but reflective at frequencies just adjacent of it. These reflected frequencies compose the ECE spectrum and are guided towards a radiometer.

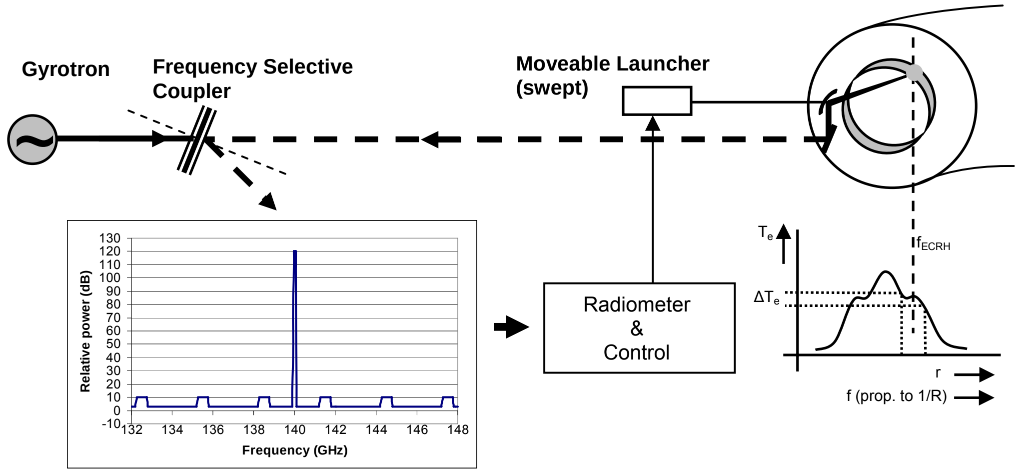

FIGURE 1. Sketch of the principle of "Line of Sight" system for detection and localisation of NTMs.

APPLICATION OF THE SCHEME AT TEXTOR

TEXTOR (R = 1.75 m, r = 0.46 m) is a very suitable facility for investigating mode suppression. An ECRH system (800 kW, 140 GHz, 10 s gyrotron [3]) is available with moveable launcher and narrow focus, while a set of perturbation coils on the high field side (Dynamic Ergotic Divertor [4]) allows triggering of a reproducible m=2, n=1 tearing mode. Suppression of such a mode using a radial deposition scan has been demonstrated [5].

ECW deposition at TEXTOR is at the 2-nd harmonic X-mode, with B_t on axis typically 2.25 T. For implementation of the Line of Sight system six channels are planned for the ECE receiver ranging from 132.5 GHz to 147.5 GHz. This will cover approximately 1/3 of the normalised radius at any position of the steerable launcher [1], while by moving the launcher over a vertical angle of 20 º the full plasma can be scanned.

At TEXTOR Electron temperatures around 700 eV are measured around the q = 2 surface. In order to positively identify the NTM from the phase relations between adjacent ECE channels, a minimum detectable temperature fluctuation of around 100 eV is required. To find the ECE power, the Plack expression for black body radiation is approximated to *kTB* (*k* = Boltzmann's constant, *T* is electron temperature and *B* is the observed bandwidth.) Taking 500 MHz wide ECE channels the ECE power per channel per mode of radiation is ~ 8 nW. Allowing for losses from the plasma back via the quasioptical transmission line to the FSC, the ECE power at the 1-st plate is estimated to be in the order of several nW.

The ECE power travelling in the reverse direction of the transmission line will contain a large gyrotron component caused mainly by reflection of the tokamak window and surroundings. Measures have been taken to reduce such reflections but it is estimated that 100 W could still be present at 1-st plate of the FSC. The overall receiver thus needs to be capable of suppressing the gyrotron component by at least 11 orders of magnitude.

FREQUENCY SELECTIVE COUPLER

The Frequency Selective Coupler is in fact a window that has been made resonant at the frequency of the gyrotron, and anti-resonant at the ECE frequencies. The resonance condition is based on the Fabry-Perot principle of summing multiple reflections [6,7]. If the incoming wave fronts are plane, the window is lossless, and has infinite transverse dimensions the frequency spectrum shows maxima with full transmission, and minima with zero reflection. The location and modulation of the minima and maxima are a function of the thickness of the window, the angle of incidence, the relative permittivity and the polarisation (except for normal incidence). This is illustrated in figure 2.

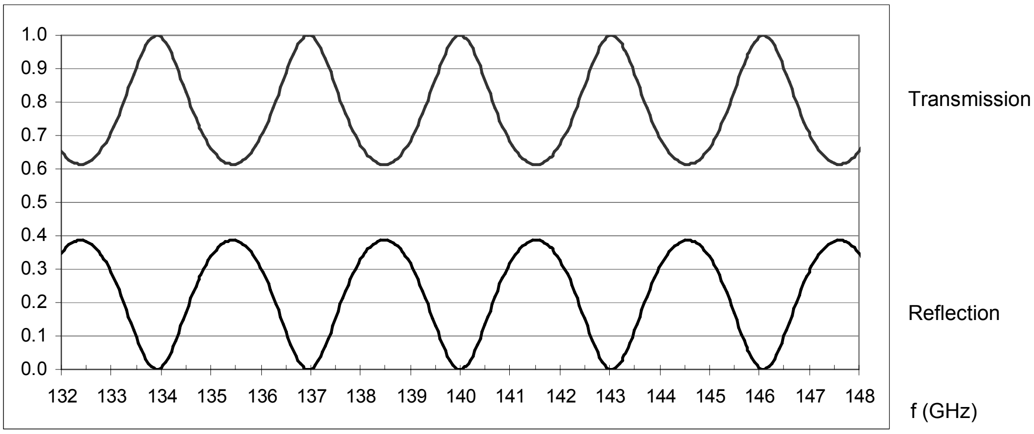

FIGURE 2. Minima and maxima in transmitted and reflected intensity through a lossless quartz window. The relatively narrow spacing between the minima and maxima is obtained by using a thick window (d = 25.75 mm, ε_r = 3.805, angle of incidence of 22.5 º, perpendicular polarisation).

Referring to the geometry of figure 1 the problem would now be solved as approximately 40 % of the ECE power is coupled towards the radiometer while the plate is transparent for the gyrotron frequency. In practice there are, however, a number of complications.

i) The plate has a finite loss, accounted for by adding a real part to the propagation constant: $\gamma = \alpha + j\beta$. The losses are expressed by the loss tangent [8] which directly allows computation of α. The loss tangent of the material used (Infrasil301) is 2.9E-4 at 90 GHz [9]. The effect on the angle of refraction in the dielectric is negligible due to the small ratio of α/β, however, absorption in the plate causes a rise in temperature and, crucially, also modified coefficients of transmission and reflection [10, 11, 12]. The absorbed fraction of power [13] is expected to raise the temperature in the centre of the plate (a cylinder with 10 mm radius) to 150 ºC over a 3 seconds gyrotron pulse at 800 kW. The change in permittivity for quartz [14] is expected to be less than 0.5 % but the subsequent deviation from the resonance ($\Delta f \sim 250$ MHz) gives rise to up to 5 % reflected forward power. This could still be handled. The effect of loss on reflection is more serious: the loss tangent of 2.9E-4 modifies the coefficient of reflection such that the minima at the 140 GHz resonance are no longer zero, but 10^{-3}

to 10^{-4} (-30 to -40 dB). A slight deviation, such as a 1 degree difference in angle of incidence or the mentioned change in permittivity, increases the reflection coefficient to almost 10^{-1}! Finally, the effect of stresses - due to the relatively thick plate - are of concern and are presently being investigated.

ii) The plate is placed under an angle which means that the expression for the resonance condition [6,7] is only valid for plane waves. The plate will be placed in a waist of approximately 100 mm in the transmission line. The confocal distance is large (~ 15 m) [15] and thus the curvature of wave fronts incident on the plate is very large and no detrimental effects are expected.

iii) The diameter of the plate is 450 mm (4 x waist and corrected for the 22.5 º angle of incidence). As a result a limited number of reflections can contribute to the resonance condition, in particular at oblique incidence as the number of reflections is reduced by "walk-off". But, manual summing of the first 5 reflections at the resonance (no losses) results already in a coefficient of reflection of only 10^{-4}, while in practice many tens of reflections will occur. A problem of greater concern is stray radiation by scattering off the edges of the plate. At a diameter of 4 times the waist, the reflected gyrotron power is still 100x(1 - 0.9997) = 30 mW: very much larger than the ECE power. Careful shielding of the plate and radiometer horn antenna will be required.

RECEIVER

The biggest challenge in the receiver is the large gyrotron component. In order to reduce the gyrotron power even further a second dielectric plate and a notch filter [16] are included. The overall design is shown in Figure 3.

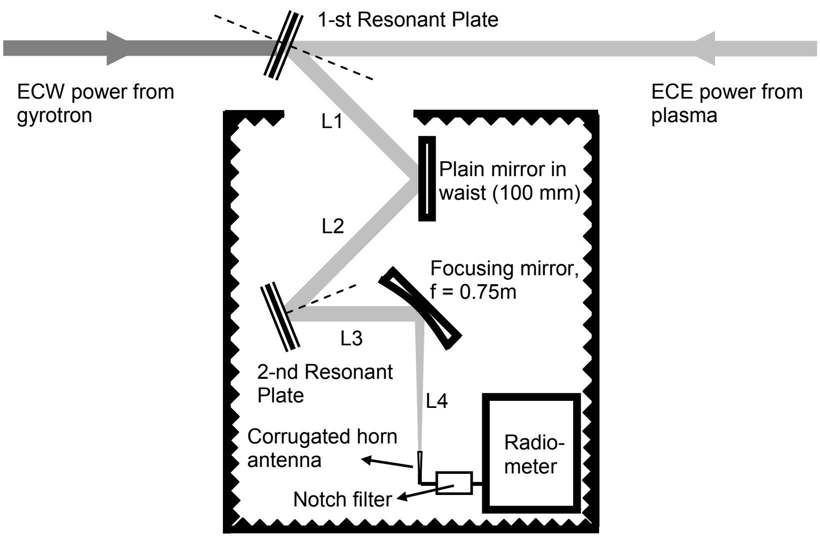

FIGURE 3. Sketch of the planned overall receiver to scale. The waist of the beam (100 mm) is placed at the plain mirror; the divergence is low and both dielectric plates are still approximately in a waist (101 mm). The receiver is shrouded in a box padded with eccosorb. Symmetry in the quasioptical design (L1 = L2 = 1.06 m, L3 = L4 = f = 0.75 m) make the receiver response less frequency dependant.

Using the above layout of the receiver the expected performance can now be accessed by referring the power levels of the ECE and the ECW to the input of the mixer in the radiometer. Using decibels for convenience

ECE power: -57 dBm (2 nW) - $\text{Reflection}_{\text{plates}}$ - $\text{Reflections}_{\text{mirrors}}$ - $\text{Losses}_{\text{(Horn + Notch filter)}}$: P_{ECE} at input of mixer estimated at **-72 dBm**.

ECW power: + 50 dBm - 30 dB (first plate) - 30 dB (second plate) - 60 dB (notch filter): P_{ECW} at input of mixer estimated at **- 70 dBm**.

Using these estimates the ECW power at the input of the mixer is comparable to the ECE power and should cause no saturation or compression in the receiver. Note that the quoted ECE power refers to the relatively small fluctuations on the Electron temperature at the q=2 surface ($\Delta\ T_e \sim 100$ eV), and not to the overall Electron temperature of ~ 700 eV.

To assess whether the ECE signal level can still be detected the Signal to Noise ratio of the radiometer is required. This is found by considering a typical noise temperature of an ECE radiometer of 10.000 K [17], video bandwidth 20 kHz (the 2/1 NTM at TEXTOR rotates at ~ 2 kHz), and IF bandwidth 0.5 GHz. Using a SSB receiver the minimal detectable power is ~ **-82 dBm**.

MOCK UP

To assess the performance of the resonant plates a mock up experiment has been set up. See figure 4.

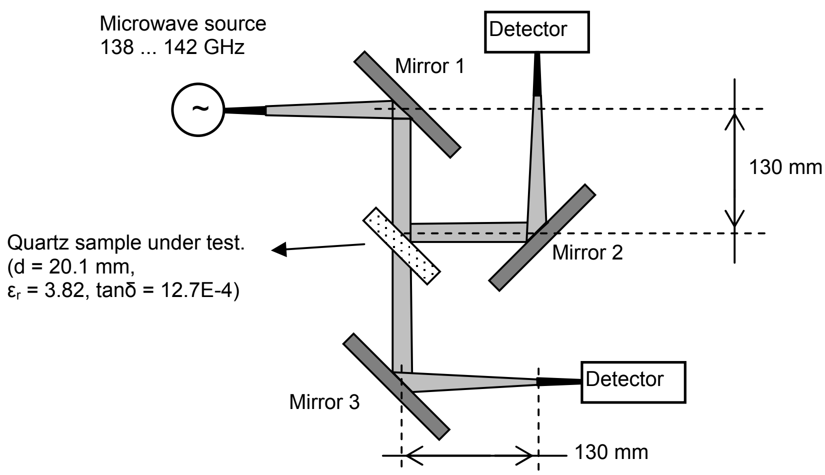

FIGURE 4. Mock up experiment to verify the quality of a quartz plate as resonator. The sample is illuminated with a swept source over a frequency range of 138 … 142 GHz while simultaneously the reflected power and the transmitted power are measured. The mirrors (f ~ 130 mm) ensure plane wave fronts at the sample (beam radius = 20 mm) and focus the beam in the horn antennae.

At the time of writing only one initial measurement could be performed. A resonance of several dB in transmission, and ~ 10 dB in reflection was observed, however, more measurements and analysis is needed as the models use and resonance frequency and modulation depth cannot be matched properly yet.

CONCLUSION AND RECOMMENDATIONS

The design of the receiver for the Line of Sight system for suppression of NTMs at TEXTOR is in an advanced stage. Difficulties are expected reducing the ECW power levels sufficiently at the input of the horn antenna of the receiver, in particular tuning and retaining a 30 dB attenuation in each plate. However, a steeper notch filter, or to use two cascaded notch filters, could give an additional attenuation of the gyrotron component of 30 to 60 dB at the expense of a few dB insertion loss, which could still be accommodated with respect to the Signal to Noise ratio.In addition a strategy of using modulated ECW and - closing the receiver with a pin switch during the gyrotron ON period - could be applied.

A mock up experiment has been built to assess the quality of the quartz plate as resonator. Very initial measurements show resonance, work on improving the set up and modelling the results are ongoing.

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