

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

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Abstract. Efficient stabilisation of tearing modes is achieved by placing the ECRH deposition profile exactly over the spatial profile of the mode. Therefore the location of the island with respect to the ECRH deposition profile needs to be known accurately, while this information also needs to be available quickly in order to respond in time within the growth of the NTM. A scheme to detect NTMs is under development that utilises the ECRH transmission line as an ECE receiver thus eliminating the need to compute the coordinates of the island. The receiver needs to 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 kW.

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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 ECRH is deposited. In case a Neo Classical Tearing Mode (NTM) is detected [2] in the observed ECE spectrum, the steerable ECRH 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 ECRH deposition profile is placed exactly at the mode centre.

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

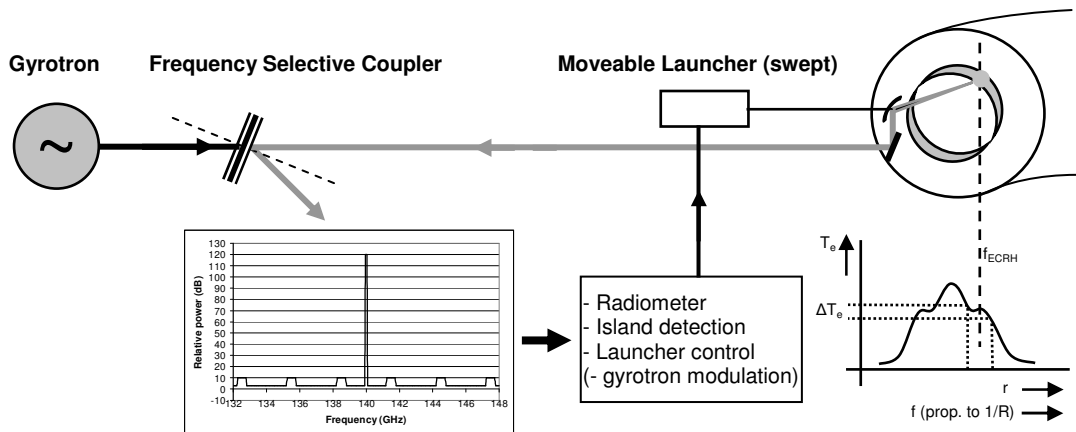


FIGURE 1. Sketch of the “Line of Sight” system for detection and localisation of NTMs.

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].

ECRH deposition at TEXTOR is at the 2nd 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° 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, temperature oscillations of around 100 eV need to be detected. To find the ECE power, the Planck equation for black body radiation is approximated to kTB (k Boltzmann’s constant, T electron temperature and B 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 quasi-optical transmission line to the FSC, the ECE power at the 1st 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 which is 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 the 1st 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 FSC 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]. Assuming 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.

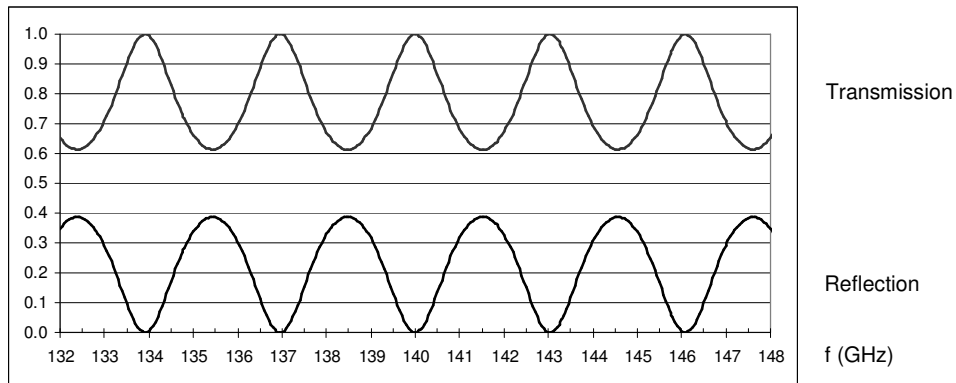


FIGURE 2. Minima and maxima in transmitted and reflected intensity through a lossless quartz window. The relatively narrow spacing between the minima and maxima is obtained by using a thick window ($d = 25.75$ mm, $\epsilon_r = 3.805$, angle of incidence of 22.5° , perpendicular polarisation).

Referring to the geometry of figure 1, the problem would now be solved as approximately 40 % of the ECE power at the selected frequencies 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: $\gamma = \alpha + j\beta$. ($E = E_0 \exp(j\omega t - \gamma z)$). 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 modifies the 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°C 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 off 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 the reflection coefficient is more serious: the loss tangent of $2.9E-4$ modifies the coefficient of reflection such that at the minima the reflection is 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 relatively steep thermal gradient will induce significant thermal stress in the dielectric, which is presently being analysed.

ii) The plate is placed under an angle which means that the expression for the resonance condition [6,7] is not valid for curved wave fronts. 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 radius of curvature of the wave fronts incident on the plate is very large which means that the wave fronts can be considered plane.

iii) The diameter of the plate is 450 mm (4 x waist and corrected for the 22.5° 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 $100 \text{ W} * \exp(-8) \sim 30 \text{ mW}$ [15]: 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.

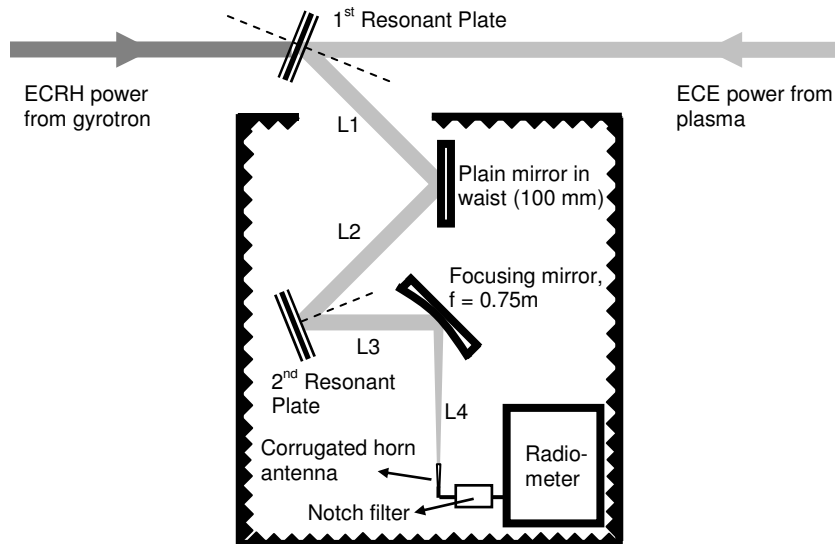


FIGURE 3. Sketch of the planned overall receiver to scale. The waist of the beam (100 mm) is placed at the plain mirror; the divergence is low and both dielectric plates are still approximately in a waist (101 mm). The receiver is shrouded in a box padded with microwave absorber. Symmetry in the quasioptical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

Based on the above layout of the receiver, the expected performance can now be accessed by comparing the power levels of the ECE and the ECRH to each other at the input of the mixer in the radiometer. Using decibels for convenience:

Element of the antenna	ECE	ECRH
Power level at 1 st plate (dBm)	-57	50
Reflection two dielectric plates (dB)	$10 * \log(0.4 * 0.4) \sim -10$	-60
Losses mirrors + horn + notch filter (dB)	-5	-5
Suppression notch filter (dB)	-0	-60
Power at input of mixer	-72 dBm	-75 dBm

Using these estimates the ECRH power at the input of the mixer is comparable to the ECE power and should cause no saturation or compression in the receiver.

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 *minimum detectable power is ~ -82 dBm*.

MOCK UP

To assess the performance of the resonant plates a mock up experiment is under construction. See figure 4.

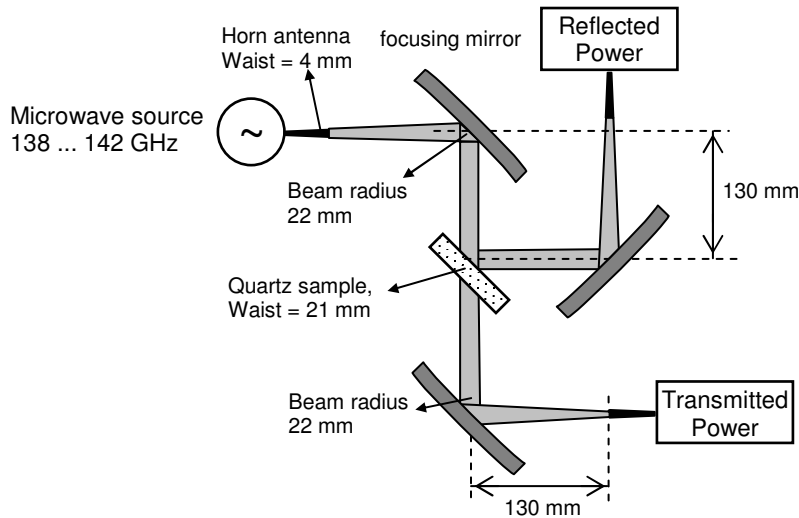


FIGURE 4. Mock up experiment to verify the quality of a quartz plate (10 x 10 cm, thickness 2 cm) as resonator. The sample is illuminated with a swept source over a frequency range of 138 ... 142 GHz, while simultaneously the reflected power and the transmitted power are measured.

At the time of writing, an initial set of measurements showed resonances of a few dB. There are difficulties matching the data to the model, but note that the mock up is

not optimised yet, and that the model does not include walk-off yet which in this case is particularly relevant due to the small sample and the large angle of incidence [18].

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 ECRH 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 the 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 ECRH - closing the receiver with a pin switch during the gyrotron ON period - could be applied.

A mock up experiment is under construction to assess the quality of the quartz plate as resonator. Preliminary measurements show resonance, work on improving the set up and modelling the data is ongoing.

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This work, supported by the European Communities under the contract of Association between EURATOM/FOM, was carried out within the framework of the European Fusion Programme. The views and opinions expressed herein do not necessarily reflect those of the European Commission.