EUROfusion

WP15ER-CPR(17) 16843

O. D'Arcangelo et al.

# New receiving line for the remote-steering antenna of the 140 GHz CTS diagnostics in the FTU Tokamak

Preprint of Paper to be submitted for publication in Proceeding of
2nd European Conference on Plasma Diagnostics (ECPD)

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

# New receiving line for the remote-steering antenna of the 140 GHz CTS diagnostics in the FTU Tokamak

PUBLISHED BY IOP PUBLISHING FOR SISSA MEDIALAB

RECEIVED: *June 30, 2017*
ACCEPTED: *December 14, 2017*
PUBLISHED: *January 10, 2018*

2ND EUROPEAN CONFERENCE ON PLASMA DIAGNOSTICS (ECPD2017)
FROM 18TH TO 21ST APRIL 2017
BORDEAUX, FRANCE

# New receiving line for the remote-steering antenna of the 140 GHz CTS diagnostics in the FTU Tokamak

**O. D'Arcangelo,[a,1] W. Bin,[b] A. Bruschi,[b] M. Cappelli,[a] F. Fanale,[b] G. Gittini,[b] F. Pallotta,[b] G. Rocchi,[a] O. Tudisco,[b] S. Garavaglia,[b] G. Granucci,[b] A. Moro,[b] and A.A. Tuccillo[b]**

[a] *ENEA, Fusion and Nuclear Safety Department, C. R. Frascati, Via E. Fermi 45, 00044 Frascati (Roma), Italy*

[b] *Istituto di Fisica del Plasma, Consiglio Nazionale delle Ricerche, Via R. Cozzi 53 Milano, Italy*

*E-mail:* ocleto.darcangelo@enea.it

ABSTRACT: A new receiving antenna for collecting signals of the Collective Thomson Scattering (CTS) diagnostics in FTU Tokamak has been recently installed. The squared corrugated section and the precisely defined length make it possible to receive from different directions by remotely steering the receiving mirrors. This type of Remote-Steering (RS) antennas, being studied on FTU for the DEMO Electron Cyclotron Heating (ECH) system launch, is already installed on the W7- X stellarator and will be tested in the next campaign. The transmission of the signal from the antenna in the tokamak hall to the CTS diagnostics hall will be mainly realized by means of oversized circular corrugated waveguides carrying the hybrid HE11 (quasi-gaussian) waveguide mode, with inclusion of a special smooth-waveguide section and a short run of reduced-size square-corrugated waveguide through the tokamak bio-shield. The coupling between different waveguide types is made with ellipsoidal focusing mirrors, using quasi-optical matching formulas between the gaussian-shaped beams in input and output to the waveguides. In this work, after a complete study of feasibility of the overall line, a design for the receiving line will be proposed, in order to realize an executive layout to be used as a guideline for the commissioning phase.

KEYWORDS: Nuclear instruments and methods for hot plasma diagnostics; Plasma diagnostics - probes

[1] Corresponding author.



https://doi.org/10.1088/1748-0221/13/01/C01012

2018 JINST 13 C01012

## Contents





## 1 Introduction

The Collective Thomson Scattering (CTS) was initially introduced in plasma physics as a diagnostic tool able to evaluate the ion temperature; the developments arose during the years widen the possible applications of this diagnostic. Today it is being used to investigate plasma main parameters (ion temperature, fuel ratio) as well as unexpected regime that can affect the efficiency of the diagnostic itself as well as the Electron Cyclotron power deposition. The CTS system at FTU has been deeply improved during last years [1, 2], in order to meet the requirements to investigate these unexpected plasma regimes. In particular it is being exploited to study possible anomalous phenomena originating from the interaction of the probe beam with the plasma, as already noticed in different experiments [3, 4]. It has been observed that the anomalous phenomena can be driven by the inversion of the density profile induced by the presence of a well-developed magnetic island [5, 6]. Since we are interested in effects of the magnetic islands on the EC beams, in order to verify the conditions for such low-threshold PDIs and their link with an inversion of the density gradient in islands, we stimulate with various techniques the growth of a MHD rotating island, and observe the effects of its passage through the crossing region of the probe and receiving beams. Thus, a new fast data acquisition system has been installed in order to obtain a very high sample rate acquisition, essential to follow possible fast emission correlated with rotating islands. Moreover a second radiometer has been installed, increasing the flexibility of the FTU CTS system: up to now, the two front ends were used to collect linearly perpendicularly polarised radiation, with the signal coming from the scattering volume. The recent installation of a new remote steering antenna further increase this flexibility, allowing the possibility to detect signals coming from a different position in the plasma with respect to the scattering volume. This signal will be used as reference and the direction of the line of sight will be selected by means of moving mirrors to be placed outside the vessel. The transmission line for the new antenna will be discussed in this work.

## 2 CTS Layout

The CTS system exploits the transmission lines of the 140 GHz gyrotron: one of these lines could be used either as electron cyclotron power deposition in the plasma or as line transmission for the signal arriving from the plasma. Both lines are equipped with front steerable mirrors and are symmetrical with respect to the equatorial plane. The detected signal is guided to the radiometers hall, where it is collected by two front ends fed by the same transmission line. The polarisation of the incoming signal can be selected rotating the two corrugated mirrors ($\lambda/4$ and $\lambda/8$ depth) and the two pure linear polarisations are finally coupled to the radiometers by means of a grid acting as beam splitter (figure 1). Data are acquired at the same time with two filter banks (32 channels each, 1.2 GHz maximum frequency band) and with the fast data acquisition at extremely high sample rate, up to 12 Gs/s for a single channel acquisition, 6 Gs/s for two channels in parallel, providing up to 4.2 GHz band around the local oscillator frequency, variable in a range centred at 140 GHz. During the 2016 experimental campaign, the backscattered radiation from the scattering volume has been acquired for the O and X mode during the same shots [7, 8]

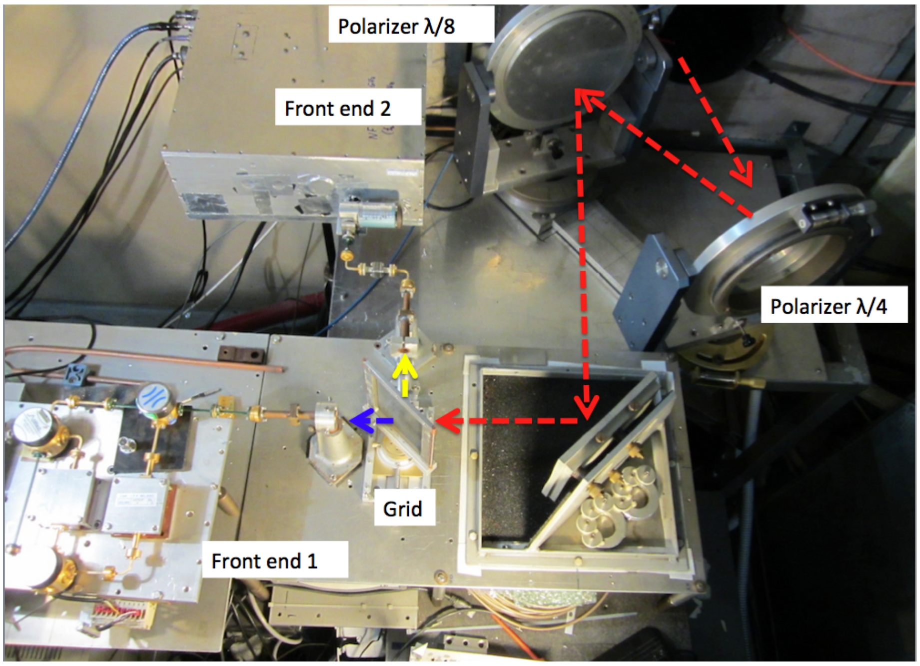


**Figure 1**. The front ends of the two CTS radiometers: the two polarising mirrors deviate radiation over a focusing mirror and the grid acts as beam splitter.

Recently, a new Remote Steering Antenna (RSA) has been installed [9], providing a new access to the plasma. Feeding the second receiver, this antenna allows the possibility to receive the signal from different positions in the plasma, even outside of the scattering volume, thus storing a signal that could be used as reference.



2018 JINST 13 C01012

## 3 Remote steering antenna (RSA)

An aluminium square corrugated waveguide, 1245 mm long and formed by two pieces joined together, has been installed in the ECH port. The choice to install a RSA in between the two existing lines of the launcher has been made due to the lack of space in the very narrow CTS port. The RSA will be equipped with a mirror system for collecting radiation at different angles between ±12 degrees in the toroidal direction. The antenna is under vacuum, with a DN40-CF fused silica window of selected thickness for maximum transmission around 140 GHz (figure 2).

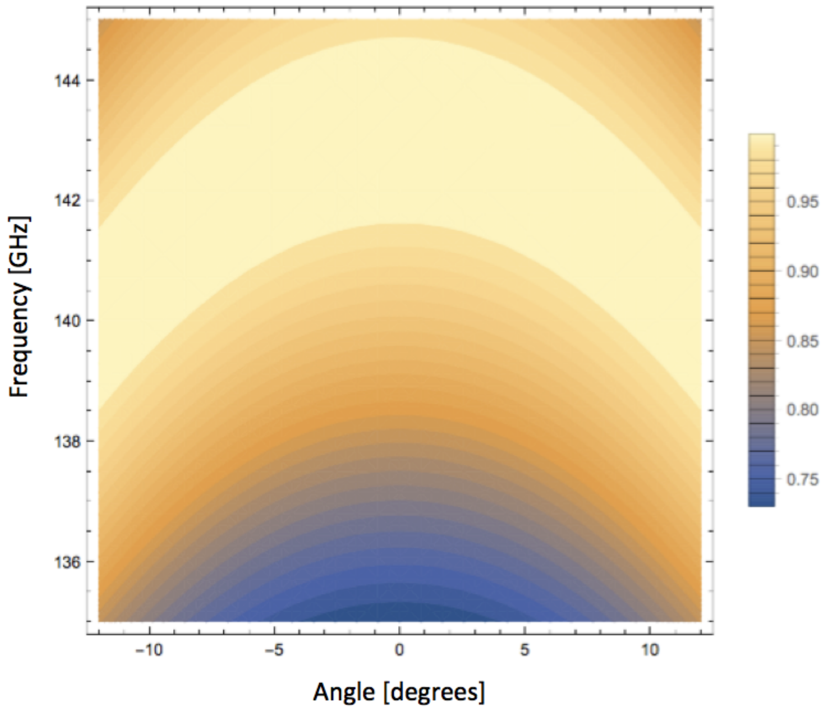


**Figure 2**. Transmission efficiency of the fused silica window as function of the angle of incidence and frequency for the selected width.

The antenna exploits an equatorial access already integrated in the launcher design, between the two lines used to send the gyrotron power (lower line) and collect the scattered signal (upper line, figure 3). The aim of the second line is mainly to receive a reference signal from the plasma, including positions outside the scattering volume, simultaneously with the primary signal detected with the main CTS line. The steering mechanism presently under study is designed to allow a limited range of scattering geometries, with line of sight crossing or not crossing the probe beam, in order to provide for cross-calibration and reference signals of background radiation from the plasma. It will allow steering capabilities on different planes, including vertical and horizontal ones, even if with limitations in performances. The beam quality will decrease rapidly out of the design frequency and increasing steering angle, but the coupling of the output beam with the one launched in input is considered sufficient to use the collected radiation as reference in the range of frequencies ±1.5 GHz around the probe (figure 4).



2018 JINST 13 C01012

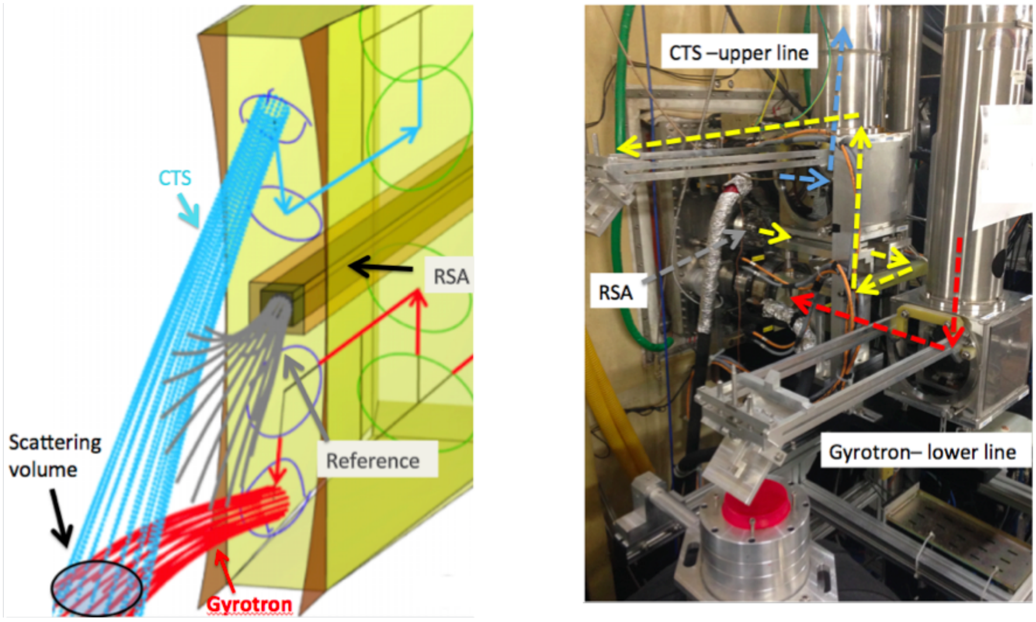


**Figure 3**. Left: sketch of the front side of the FTU launcher, with the new remote steering antenna integrated between the two front steering lines: probe (lower, red), CTS (upper, blue) and reference (middle, grey) beam are shown (taken and modify from picture 2 in ref. [9] [http://dx.doi.org/10.1063/1.4955478], with the permission of AIP publishing). Rigth: the back side of the launcher installed in the FTU port. The probe (lower, red), CTS (upper, blue) and remote steering output. The path of the output signal from the RSA foreseen by the present design is shown with the yellow arrows.

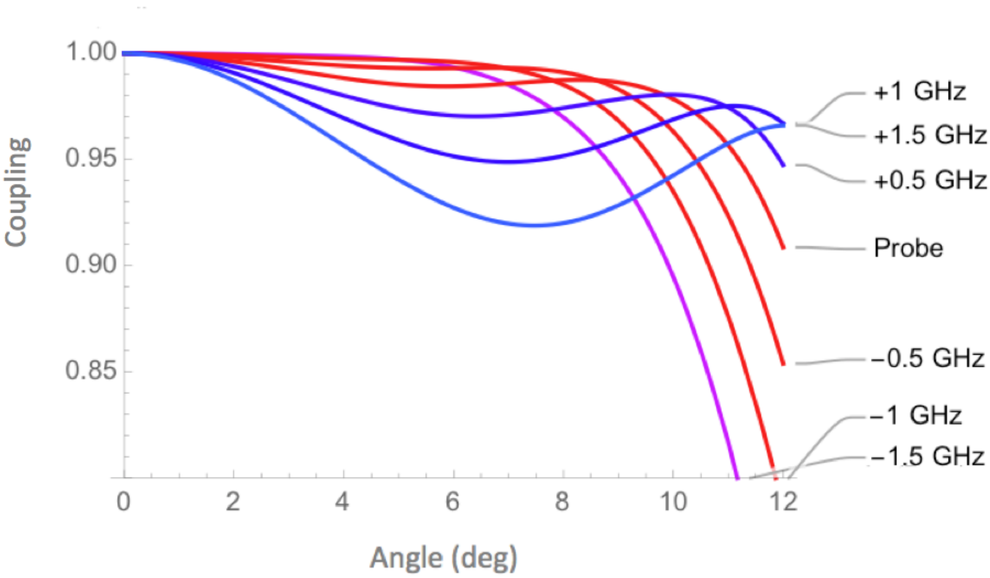


**Figure 4**. Expected power coupling with ideal gaussian beam at various frequencies away from the probe (nominally at 140.25 GHz) as a function of the steering angle.



2018 JINST 13 C01012

## 4 New transmission line

Up to now, the CTS radiometer could receive the signal only from a single line of sight in the plasma, the scattering volume. The new transmission line, dedicated to transmit the signal from the RSA to the receiver, has been designed and is being installed in the tokamak hall. The implementation of the new antenna transmission system will allow the possibility to receive the signal in parallel from a second line of sight, even outside of the scattering volume. Receiving signals from inside and outside of the scattering volume at the same time will help in discriminating between scattering signals from other emissions originated by different phenomena occurring in the plasma, along the transmission line or in the gyrotron cavity. One of the open points still under investigation in the analysis of our data is the origin of intense signals often appearing during some phases of the past shots. A possible interpretation is the breakdown of neutral gas in the launching port, during the passage of the probe beam in the line. Given the design of the FTU launcher, a significant quasi-optical cross-talk between the probe beam line and the main receiving line occurs. Therefore, signals originating from back-reflection due to breakdown in the probe line is expected to be detected by the main receiving line of the CTS apparatus. The design of the second line presented in this paper should not allow internal cross-talk with the power injection line and it should thus be more suitable for discriminating the real nature of signals. In particular, what is measured by this line should not be affected by back-reflected power in case of breakdown in the port. Only signals from the plasma should be detected. In case of PDIs process in the scattering volume, the emerging strong signals are expected to be detectable also in this secondary line, even though not crossing the scattering volume, under the form of stray power. Thus our expectation is that the new line will help us in determining the real nature of the observed signal. Moreover it will guarantee the detection of a reference signal for the ECE level. In fact, when working with extremely high sampling rate, it was possible to acquire the signal only for a limited time slice because of memory limit: obviously the detection was done during the gyrotron pulse and last for around 100ms at maximum sampling rate, thus only the scattered signal is acquired. With the new layout, the RSA could be dedicated to the detection of the ECE signal produced during the gyrotron pulse pointing the RSA outside the scattering volume, thus providing a reference also for the calibration of the spectra. The new transmission line of the RSA will incorporate the remote steering system. The transmission of the signal from the RSA to the CTS diagnostic hall will be mainly realised by means of oversized circular corrugated waveguides carrying the hybrid HE11 (quasi-Gaussian) waveguide mode, with inclusion of a smooth-waveguide ($TE_{11}$-$TM_{11}$ resonant [10]) section and a short run of reduced-size square-corrugated waveguide just outside the tokamak port. The foreseen design of the transmission line is shown in figure 5. The coupling between different line sections is made with flat and ellipsoidal focusing mirrors. An important constraints is given by the limited accessibility at the output of the FTU port, between the two vertical section of the gyrotron probe and CTS lines. Such mechanical constraints lead to the introduction of a waveguide section with reduced dimension and square cross section just outside the port (see RSWG1 and RSWG2 in figure 5), instead of quasi optical mirrors. In table 1 the principal parameters of the transmission line components are reported.

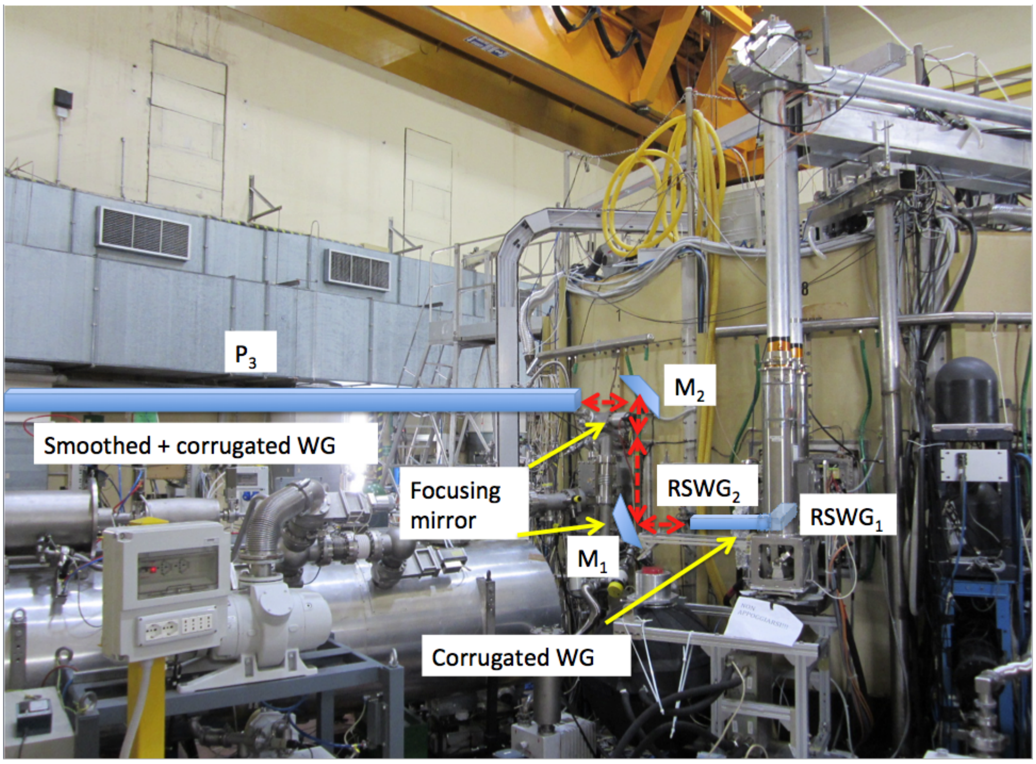


**Figure 5**. Sketch of the foreseen transmission system in the FTU hall.

**Table 1**. Component of the new RSA antenna transmission line and principal paramters.

| | Section | Length [mm] | Input dist. $D_1$ [mm] | Input dist. $D_2$ [mm] |
|---|---|---|---|---|
| $RSWG_1$ | Square corrugated WG | 360 | | |
| $RSWG_2$ | Square corrugated WG | 650 | | |
| $M_1$ | Focusing Mirror | | 351 | 585 |
| $M_2$ | Focusing Mirror | | 360 | 360 |
| $P_3$ | Square corrugated WG | 7500 | | |

## 5 Conclusion

A new receiving remote steering antenna has been installed in FTU in order to upgrade the CTS system. A dedicated optical system for collecting the radiation at different angles inside the plasma is presently under design. A new transmission line for this antenna is being installed in the tokamak hall. The transmission line will consist of an assembly of waveguides coupled by quasi-optical propagation coupling sections. The new reference line will allow the measurement of the background radiation from plasma and of the gyrotron stray radiation and will be used as a reference signal for the calibration of the CTS signal received from the scattering volume during the same plasma shot.



2018 JINST 13 C01012

## Acknowledgments

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

## References

[1] W. Bin et al., *The upgraded Collective Thomson Scattering diagnostics of FTU*, *Fusion Eng. Des.* **96-97** (2015) 733.

[2] W. Bin et al., *First operation with the new Collective Thomson Scattering diagnostic on the Frascati Tokamak Upgrade device*, 2015 *JINST* **10** P10007.

[3] E. Westerhof et al., *Strong Scattering of High Power Millimeter Waves in Tokamak Plasmas with Tearing Modes*, *Phys. Rev. Lett.* **103** (2009) 125001.

[4] S.K. Nielsen et al., *Experimental characterization of anomalous strong scattering of mm-waves in TEXTOR plasmas with rotating islands*, *Plasma Phys. Control. F.* **55** (2013) 115003.

[5] E.Z. Gusakov and A.Yu. Popov, *Theory of anomalous backscattering in second harmonic X-mode ECRH experiments*, *Phys. Plasmas* **23** (2016) 082503.

[6] E.Z. Gusakov et al., *Low-threshold parametric decay of the ordinary wave in ECRH experiments at toroidal devices*, *Plasma Phys. Control. F.* **59** (2017) 075002.

[7] A. Bruschi et al., *Observation of Short Time-scale Spectral Emissions at Millimeter Wavelengths with the New CTS Diagnostic on the FTU Tokamak*, *Nucl. Fusion* **57** (2017) 076004.

[8] B. Baiocchi et al., *Data analysis tools and coding activity in support of the FTU Collective Thomson Scattering diagnostic*, submitted to JINST (2017).

[9] W. Bin et al., *Advances in the FTU collective Thomson scattering system*, *Rev. Sci. Instrum.* **87** (2016) 11E507.

[10] F. Billé et al., *Optimization of an overmoded smooth-wall circular waveguide section for carrying strong MM-power in ECRH experiments*, *Proc. SPIE* **2104** (1993) 21048D.