Available online at www.sciencedirect.com
SCIENCE DIRECT®
Fusion Engineering and Design 74 (2005) 191–198
Fusion Engineering and Design
www.elsevier.com/locate/fusengdes

Matching to ELMy plasmas in the ICRF domain

J.-M. Noterdaeme [a,b,*], Vl.V. Bobkov [a], S. Brémond [c], A. Parisot [f], I. Monakhov [e], B. Beaumont [c], Ph. Lamalle [d], F. Durodié [d], M. Nightingale [e],

the ASDEX Upgrade Team [a], the Tore Supra Team [c], and the JET-EFDA contributors

[a] *Max-Planck IPP-EURATOM Assoziation, MaxPlanck Institute for Plasmaphysik, Boltzmannstraße 2, D-85748 Garching, Germany*
[b] *Gent University, EESA Department, Belgium*
[c] *Association EURATOM-CEA, CEA-Cadarache, France*
[d] *Association EURATOM, Belgian State, LPP-ERM/KMS, TEC*
[e] *EURATOM/UKAEA Fusion Association, Abingdon, UK*
[f] *Plasma Science Fusion Center, MIT, Cambridge, USA*

Available online 2 August 2005

Abstract

An ICRF antenna coupled to the plasma presents a load impedance different from what the generator requires for optimal power transfer. The required matching must be able to accommodate changes in coupling impedance due to varying plasma conditions. The changes occur on a timescale varying between particle confinement time and MHD events. In ELMy plasmas, the latter can be as fast as 50 μs. Several methods are in use, but only a few can cope with this most challenging condition: hybrid couplers and conjugate-T. Hybrid couplers have been implemented on ASDEX Upgrade, Double-III-D and will be on JET, while Alcator C-mod, JET, Textor and Tore Supra have been outfitted with conjugate-T.

Keywords: ICRF; RF generators; Matching; Hybrid couplers; Conjugate-T; JET; ITER

1. Introduction

The ICRF generators (typically operating in the 20–180 MHz region, with single-unit power in the 2 MW range, see Table 1) are designed to operate into a constant matched load. The antennas, which couple the power to the plasma, present a loading impedance different from that needed by the generator for optimal power transfer (30 or 50 Ω). The mismatch is overcome by a matching system that transforms the antenna impedance to that required by the generator. Since the antenna impedance depends on varying boundary conditions in front of the antenna, dynamic matching methods, or passive load isolation, are needed to cope with the variations. Different approaches [1] can handle diverse timescales. The choice has a substantial impact

* Corresponding author. Tel.: +49 89 32991336; fax: +49 89 32992558.
E-mail address: noterdaeme@ipp.mpg.de (J.-M. Noterdaeme).

0920-3796/$ – see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.fusengdes.2005.06.071

Table 1
Major ICRF systems worldwide

	Frequency range (MHz)	Installed generator power	Matching system	System response
ASDEX Upgrade	30–120 (30–60 used)	4 × 2 MW	Double stub Hybrid coupler	Between shots Fixed
C-Mod	80 40–80	2 × 2 MW 4 MW	Trombone Stub	Between shots Between shots
D-III-D	60 60–120	2 MW 1 MW at 120 MHZ	Hybrid couplers	Fixed
JET [8]	23–57	16 × 2 MW	Trombone Stub Frequency	16.5 cm/s 5 cm/s ±200 kHz in 1 ms
JT-60 U	102–131 (112)	8 × 1.5 MW	Trombone Stub Frequency	0.5 cm/s 2 cm/s 400 kHz 10–80 ms
NSTX [54]	30	6 × 2 MW	Trombone Stub	Between shots Between shots
TEXTOR	25–38	2 × 2 MW	Stub Trombone Capacitors	Between shots Between shots 20–30 ms
Tore Supra	35–80	3 × 2 × 2 MW	Resonant double loop (capacitors)	200 ms

on the flexibility of the system, its efficiency and operational reliability.

2. Sources and types of variations

The antennas consist of one or more current carrying conductors, connected to transmission lines with characteristic impedance Z_0. Z_0 is often, but not necessarily, the same as the loading impedance required by the generators. The antenna load, defined as the equivalent complex impedance terminating a transmission line with the characteristic impedance Z_0, depends on the antenna geometry and on the boundary conditions for the electromagnetic fields excited by it. In contrast to antennas radiating in an infinite and stable medium, as is the case for broadcasting antennas, the changing boundary conditions for the fields in a plasma physics experiments lead to a changing load. In many cases, the field pattern is dominated by an exponential decay up to the location where the plasma density is high enough for the wave to start propagating. Consequently, the loading is sensitive to changes of the plasma density, and the density gradient in front of the antenna. The fields, and thus the antenna loading can also be affected by changes in absorption of the wave inside the plasma, or by variations of the fields excited by neighboring straps.

Changes occur in the real and imaginary part of the antenna impedance, while the ratio between both is not constant. For JET [2] the value range typically from 1 to 10 Ω in the real part with changes in electrical length of up to 35 cm. Similar values are found for ASDEX Upgrade [3].

The timescale of the density variation splits naturally into two types depending on the cause. Slower timescales are related to particle/thermal confinement time and are depending on machine (size, confinement properties) in the range millisecond–second. An L to H transition, which changes suddenly the confinement properties of the plasma edge on the millisecond timescale, is the fastest of this type [4]. Faster timescales result from MHD events, such as ELMs (rise time in the range 50–200 μs) [2,3,5].