EUROPEAN FUSION DEVELOPMENT AGREEMENT

EFDA–JET–CP(03)03-05

I. Monakhov, T. Blackman, A. Walden, M. Nightingale, A. Whitehurst,
F. Durodie, P. U. Lamalle and JET EFDA Contributors

New Techniques for the Improvement of the ICRH System ELM Tolerance on JET

New Techniques for the Improvement of the ICRH System ELM Tolerance on JET

I. Monakhov[1], T. Blackman[1], A. Walden[1], M. Nightingale[1], A. Whitehurst[1],
F. Durodie[2], P.U. Lamalle[2] and JET EFDA Contributors*

[1]*EURATOM/UKAEA Fusion Association, Culham Science Centre, Abingdon, OX14 3DB, UK*
[2]*LPP-ERM/KMS, Association Euratom-Belgian State, Brussels, B-1000, Belgium*
** See annex of J. Pamela et al, "Overview of Recent JET Results and Future Perspectives", Fusion Energy 2000 (Proc. 18th Int. Conf. Sorrento, 2000), IAEA, Vienna (2001).*

Preprint of Paper to be submitted for publication in Proceedings of the
15th Topical Conference on Radio Frequency Power in Plasmas
(Moran, Wyoming, USA 19-21 May 2003)

ABSTRACT.
Two complementary improvements to the ELM tolerance of the existing A2 antennas on JET are being assessed. The use of external conjugate-T matching of straps of adjacent antenna arrays could reduce the VSWR levels at RF amplifier output during fast load perturbations. The scheme under consideration uses coaxial line-stretchers (trombones) for tuning the conjugate-T to low resistive impedance (3-6Ohm) with subsequent stub/trombone circuit impedance transformation to 30Ohms. Another technique is to modify the RF plant protection system logic to reduce the high VSWR trip duration to an absolute minimum corresponding to a typical ELM response (~1-2ms) without compromising the plant safety. Both projects are presently being tested and could increase the average power delivered by RF plant into ELMy plasmas at JET.

1. INTRODUCTION

The capability of RF plant to inject high power levels into ELMy H-mode plasmas is essential both for the JET research program and successful ITER operations. The main research in this field involves the new ITER-like antenna being developed on JET [1,2]. Two complementary approaches to improve the ELM tolerance of the existing JET A2 antennas [3] are underway and discussed below.

The present-day JET ICRH system [4] comprises 16 "similar" circuits for independent energising of four straps of four existing antenna arrays, each using a stub/trombone matching and real-time frequency control to track slow evolutions of plasma loading. Because of insufficient speed and load tolerance of the present matching system, the amplifier output VSWR reaches high values during ELMs. The plant VSWR protection system, being unable to distinguish between arcs and ELMs, then produces relatively long RF power trips with slow post-trip recovery, resulting in impaired RF plant performance and significantly reduced average power delivered into ELMy plasmas. Two ICRH system modifications are under consideration to overcome this loss in average coupled power: an external conjugate-T matching system has been modelled and is now proceeding to prototype test; modifcations to the existing trip management system have been implemented and are ready for testing.

2. EXTERNAL CONJUGATE-T MATCHING AT JET

2.1. PRINCIPLES

Conjugate matching comprises the parallel connection of two complex conjugate impedances, tuned to make the resulting impedance purely real (Fig.1). The main advantage of such a system is that the simultaneous resistive load increase in both legs of the circuit does not cause a severe transmission line mismatch. Simple analytical treatment shows that the load tolerance quickly improves with increasing the value of unperturbed loading R_0, which is favourable for the A2 antenna case as compared with short-strap antenna design [1,2]. Load tolerance optimisation also dictates the necessity to tune the T-junction to low impedances ($R_T << Z_0$) and, hence to use an additional impedance transformer $R_T \to Z_0$. The conjugate-T matching reactance $X_0^2 = R_0 (2R_T - R_0)$ dependence on R_0 and R_T implies adjustments for variable loading R_0 and enables load-tolerance fine-tuning via RT control.

2.2. FEATURES

The proposed conjugate-T system involves four amplifiers and two antenna arrays. The power from each amplifier (Fig.2) is split between two straps of different arrays, to retain array-phasing flexibility. With the existing ~1 MW per strap power limit of A2 antennas the maximum values of delivered power remain unaffected.

An external (out of vessel) coaxial T-junction will be tuned to a low resistive impedance (R_T=*3-6* Ohm) by coaxial line-stretchers (trombones). The use of the external T-junction allows the whole system to be built from standard coaxial components and facilitates conventional strap loading diagnostics. Trombone-based conjugate-T tuning also offers a number of advantages for the system design: the elements readily provide the required reactances of both signs; they have no constraints on location along the line; the tuning accuracy is manageable and the line dispersion compensation is straightforward.

A prototype test of the proposed configuration has now been installed onto one pair of straps and is ready for testing.

3. SIMULATIONS

Computer simulations have been undertaken to analyse the circuit load tolerance, tuning accuracy and electrical strength under different loading conditions. Available A2 antenna loading data were used to provide the following input parameters [5]: the static (between ELMs) strap coupling resistance $R_0 = 1-3\Omega$; the perturbed (during ELM) coupling resistance $R \rightarrow 10\Omega$ and the ELM-related electrical length change $\Delta L = +2 \rightarrow -20$ cm. The transmission lines lengths between the T-junction and the strap (31m) and the T-junction and the stub (2.9m) were chosen to optimise the frequency coverage in the 31-57MHz band, assuming 0-1.5 m trombone length variation and 3 m maximum stub length.

The simulations demonstrate an excellent circuit tolerance to the resistive loading perturbations and a possibility to fine-tune the loading characteristics depending on strap loading between ELMs (Fig.3(a)). The circuit shows reasonable robustness with respect to asymmetry of resistive loading perturbation between straps (Fig.3(b)) and to the accompanying strap electrical length changes up to -20 cm (Fig.3(c)).

4. IMPROVED TRIP MANAGEMENT LOGIC

In parallel with the above developments, a trip management system is being updated on JET to improve the RF plant performance in situations where conjugate-T matching may not cope, in particular for ELMs involving a large strap electrical length perturbation [5]. At present, this system trips the RF power if a high VSWR is detected, with a trip threshold depending on RF power and ELM activity. This introduces a long trip ($5 \rightarrow 20$ms) and recovery ($10 \rightarrow 80$ms) duration, with both durations increasing with trip frequency. The result is that the average power delivered in ELMy plasmas is reduced, and in constant-power control setting the power feed-back loop increase forward voltage demand to maintain the requested average power level, causing even more trips.

Given these problems, the present system is being upgraded to include a check as to whether a high measured VSWR is accompanied by an ELM (Da signal increase rate is above the set threshold). If no ELM is detected, then the long trip & recovery time described above is applied to quench any arc. If an ELM is detected, the trip & recovery time is reduced to ~2ms only, to protect the amplifier during the ELM. If a high VSWR is re-detected immediately after the shortened (ELM-triggered) trip then the long trip & recovery time is applied, regardless of ELM detection, as ELM-related arcing is likely. This procedure should increase the average power delivered in ELMy plasmas without detriment to the RF plant protection.

CONCLUSIONS

A combination of external conjugate-T matching and modifications to the RF plant protection system logic should improve the performance of the JET ICRH system during ELMy plasma discharges.

ACKNOWLEDGEMENTS

This work was performed under the European Fusion Development Agreement. The work carried out by the UKAEA personnel was funded jointly by the United Kingdom Engineering and Physical Sciences Research Council and by EURATOM.

REFERENCES

[1]. Durodie, F., et al., “The ITER-like ICRF launcher project for JET”, this conference

[2]. Lamalle, P.U., et al., “Radio-frequency matching studies for the JET ITER-like ICRF system”, this conference

[3]. Kaye, A., et al., Fusion Engineering and Design **24**, 1-21, (1994).

[4]. Wade, T., et al., Fusion Engineering and Design **24**, 23-46, (1994).

[5]. Monakhov, I., et al., “Studies of JET ICRH antenna coupling during ELMs’, this conference

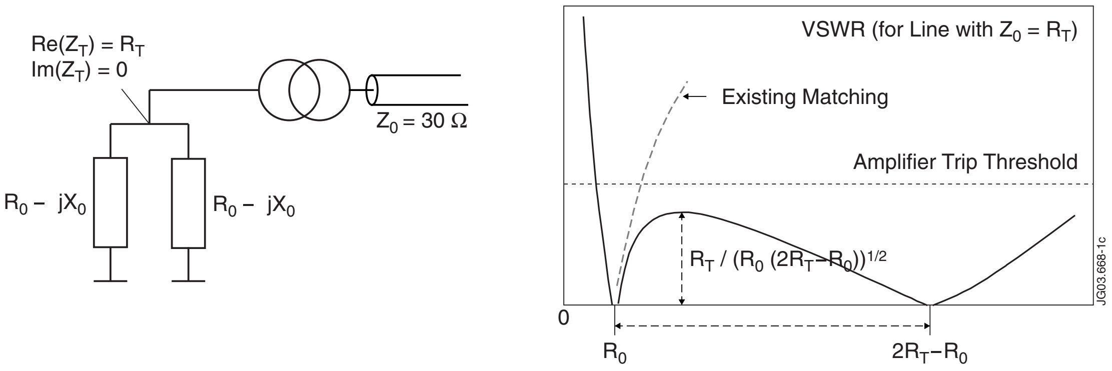

Figure 1: Generalised scheme (left) and loading response (right) of conjugate-T matching circuit

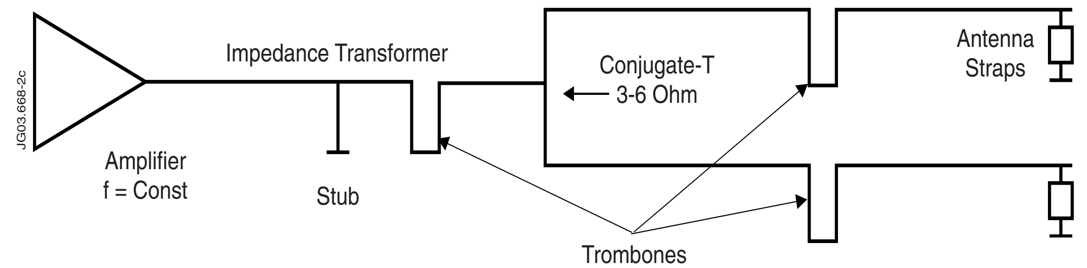

Figure 2: Schematic diagram of conjugate-T matching for JET A2 antenna straps (4 similar circuits)

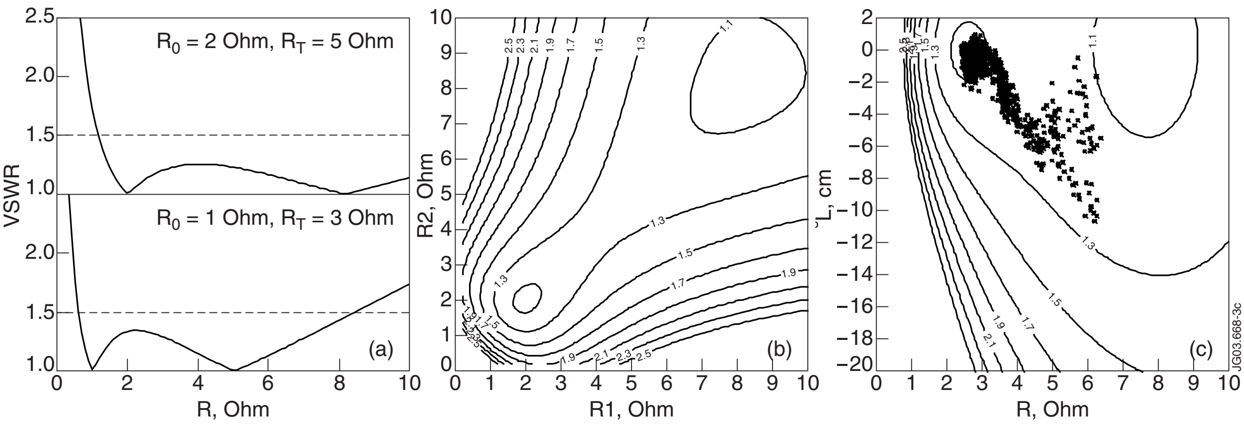

*Figure 3: Conjugate-T circuit load tolerance at f=42.5MHz. (a) - VSWR dependence on strap coupling resistance in case of symmetric resistive loading perturbation; two examples of the circuit tuning are shown corresponding to relatively high (top) and low (bottom) strap coupling resistance between ELMs; (b) - VSWR contours in case of asymmetric resistive loading perturbation (R_0 = 2 Ohm, R_T = 5Ohm), (c) - VSWR contours in case of symmetric resistive loading, accompanied by strap electrical length change (R_0=2.5Ohm, R_T = 5Ohm). Load tolerance domain VSWR=1.5 is shown by the bold line. The set of dots represents a **measured** "footprint" of a moderate ELM.*