A comparison of internal vs external matching for the JET-EP antenna

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R. Walton (UKAEA)

Workshop on Outstanding Issues in ICRF Technology
Oxnard, California
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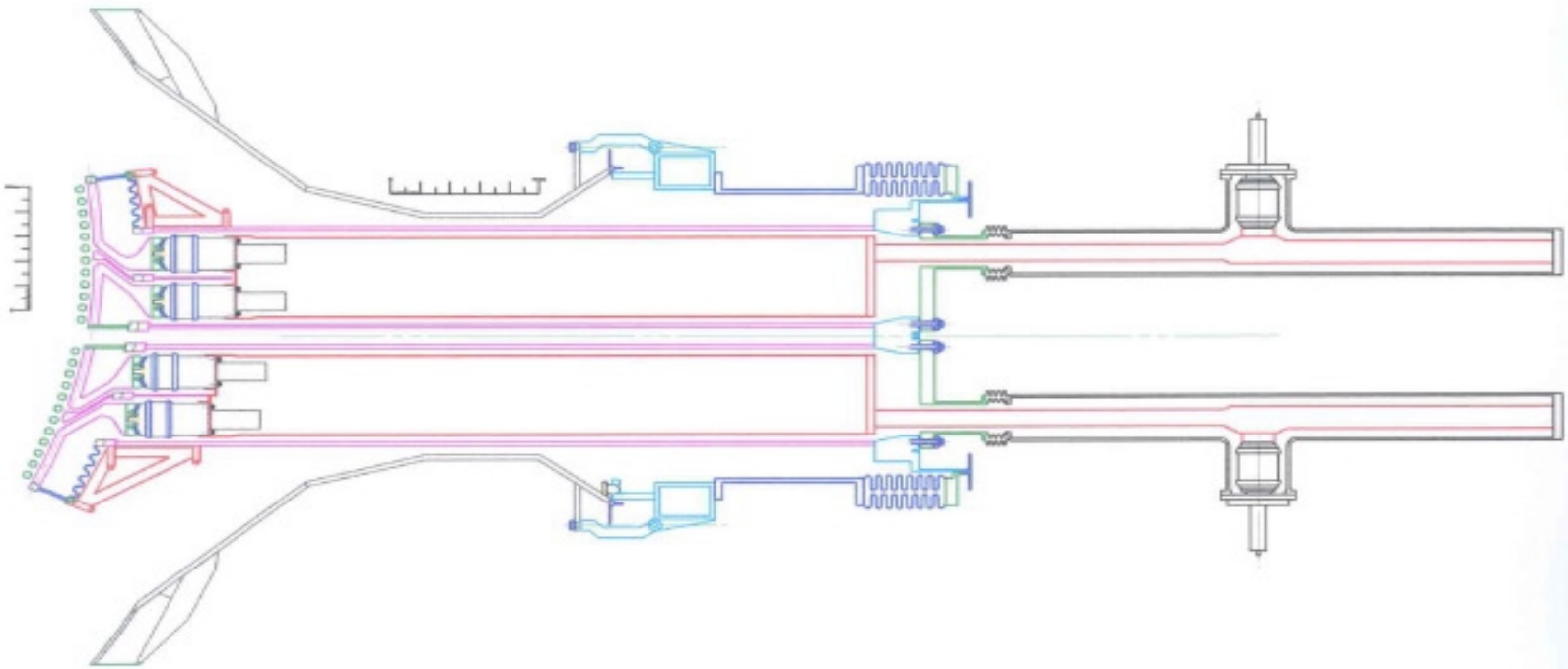
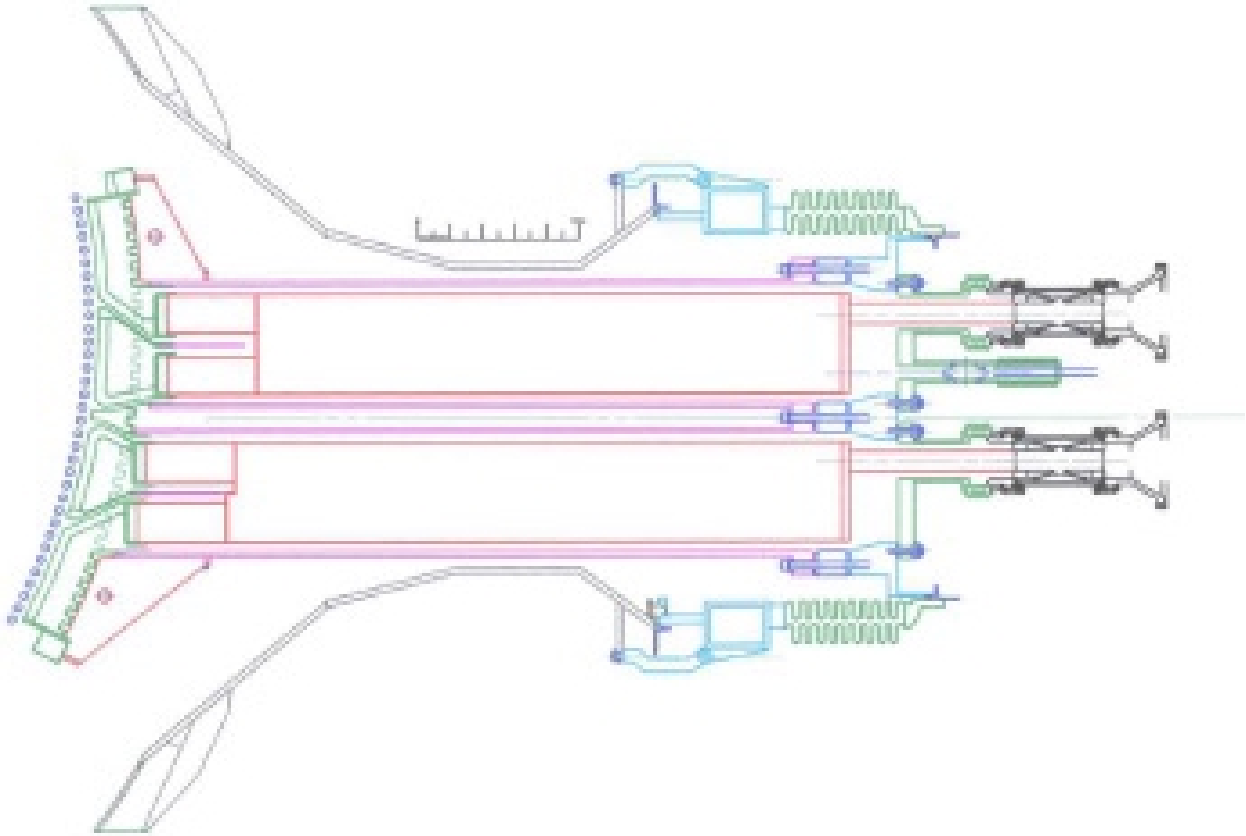
Baseline Option



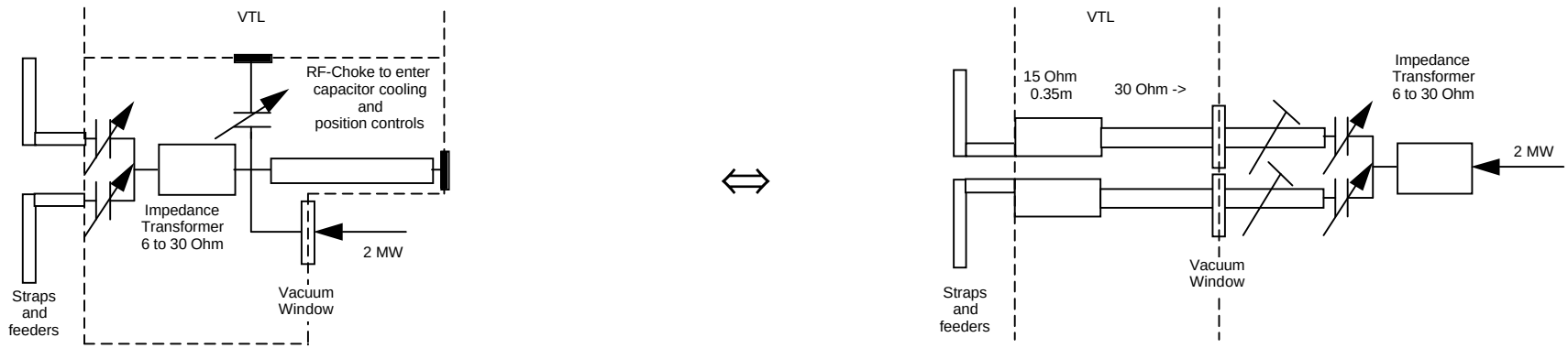
Fallback option (earlier drawing)



Fall-back Ex-Vessel Matching Option

- If the insertion of the water-cooled capacitors inside the JET vessel turns out to be problematic for what concerns reliability, safety, achievable pulse length and or mechanical assembly a fall back option is considered placing reactive matching elements outside the torus vacuum. **The maximum system voltages** are estimated to be slightly about 30 kV at the end of the feeders for the reference option (with 35 kV across the capacitors) and the fallback option alike and **35 kV along an optimised VTL for the fall back** option. **Electric fields** are kept in both options to be **below 2 kV/mm**.

- It has to be noted that the present ITER-FEAT ICRF launcher design in which JET-EP's in-vessel matching (series) capacitors are replace by (tri-axial) coaxial elements is quite challenging. The fall-back ex-vessel matching option is therefore provide an alternative for ITER-FEAT.



Reference In-Vessel Matching Solution

Fall-back Ex-Vessel Matching Solution

JET-EP External/Internal Matching Considerations

External

+ Reliability
– **35 kV at feedthrough**
– **Extended high voltage region**
– **Additional space needed for external matching components**
– **Requires phase shifters**
– **Double number of feedthroughs?**

Internal

- Performance (Power Handling)**?**
  + **11 kV at feedthrough**
  + **Limited high voltage region**

- **Capacitor issues**
  – **Reduced diameter 18 →14 cm**
  – **High current (920 A rms)**
  – **Stainless steel bellows**
  – **Mechanical alignment**
  – **Contacts - fingerstock**
  – **Cooling fixed end**
  – **Thermally insulated cooling lines**
  – **Capacitor drives**

Will power handling be reduced in fallback design?

- Does limiting region of high voltage, and voltage at feedthrough correlate with higher strap voltage (and current)?
- Are harmonics and line resonances important, and how do the two designs compare in this respect?
- How does tolerance to load variations compare?
- Does the baseline design already lose by having a real instead of a virtual ground?

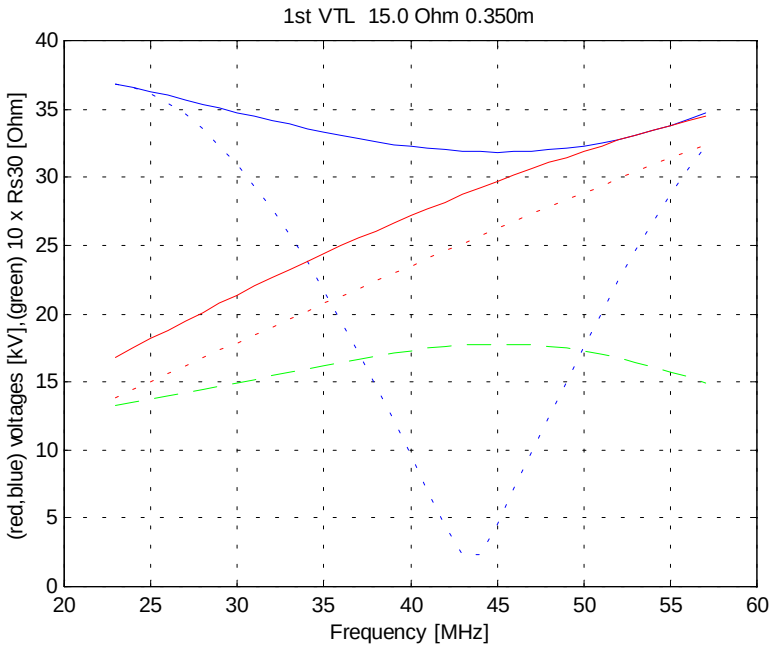


Figure 6 : Voltages for the fallback solution : (solid blue) maximum voltage on the 30 Ohm part of the VTL, window and feeding transmission line to the matching capacitors, (dashed blue) voltage at the window at 2.20m from the 15 Ohm VTL, (solid red) maximum voltage on the 15 Ohm part of the VTL, (dashed red) maximum voltages at the end of the 20 Ohm antenna feeder (same as blue curve of figure 1), (green dashed) 10 x Rs on 30 Ohm of the single strap.

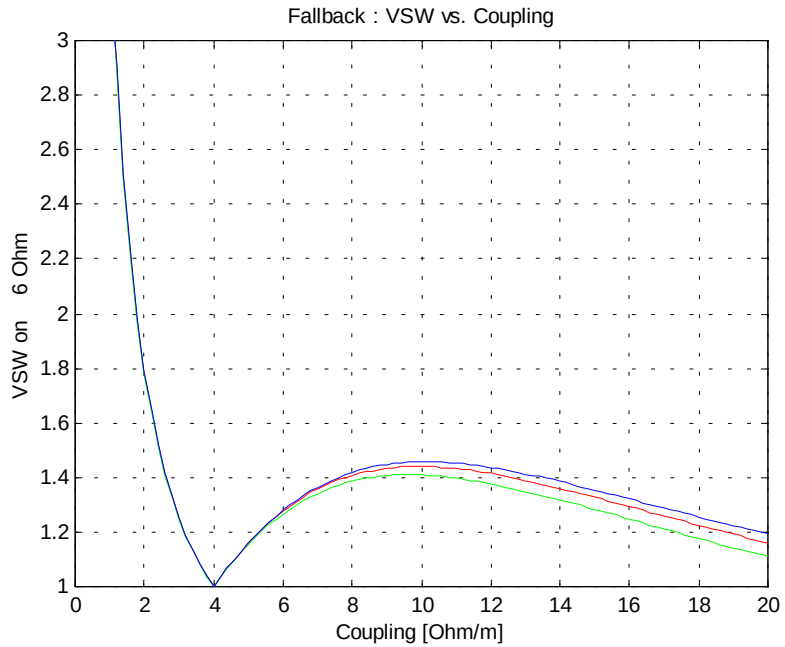
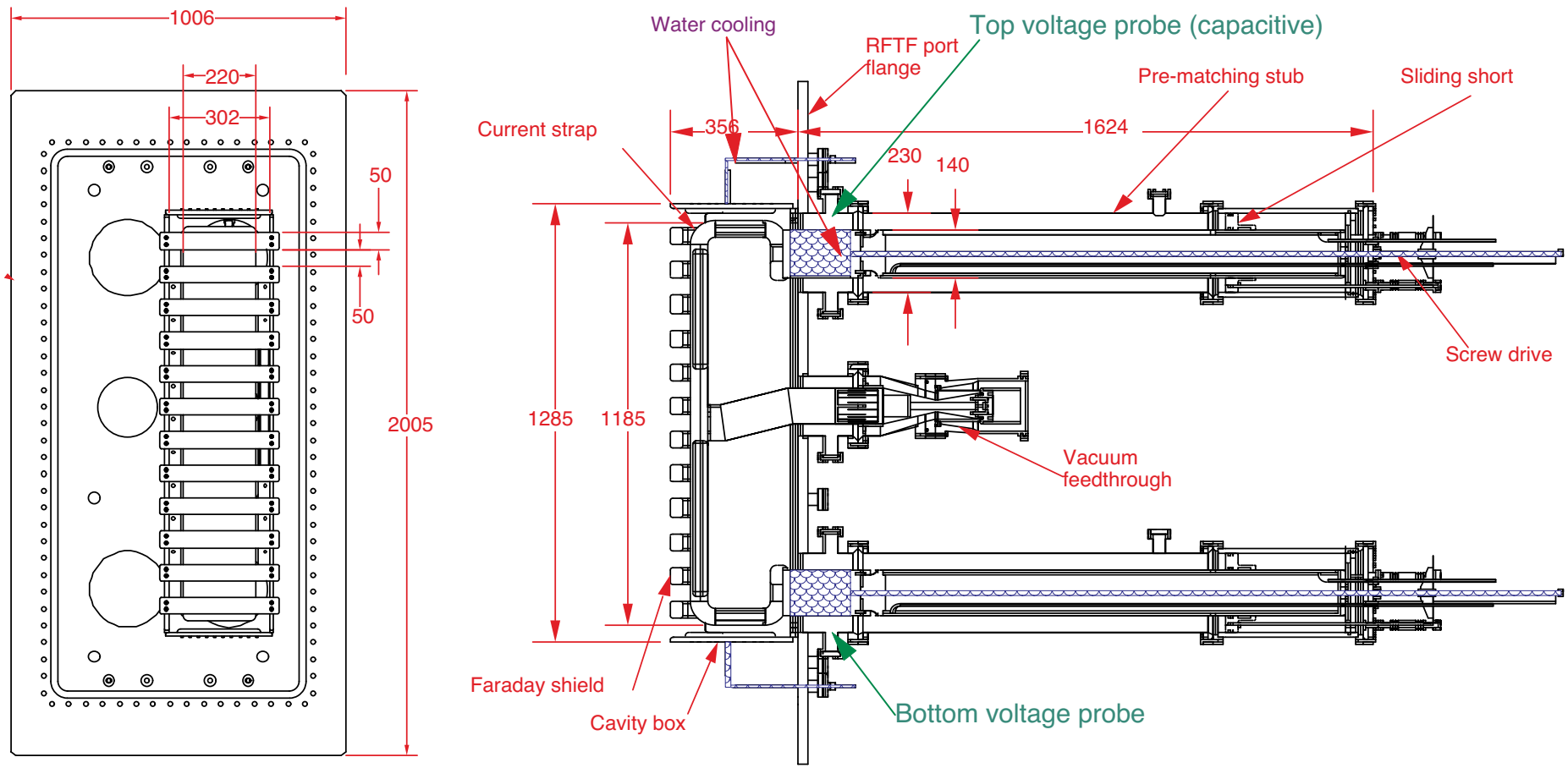


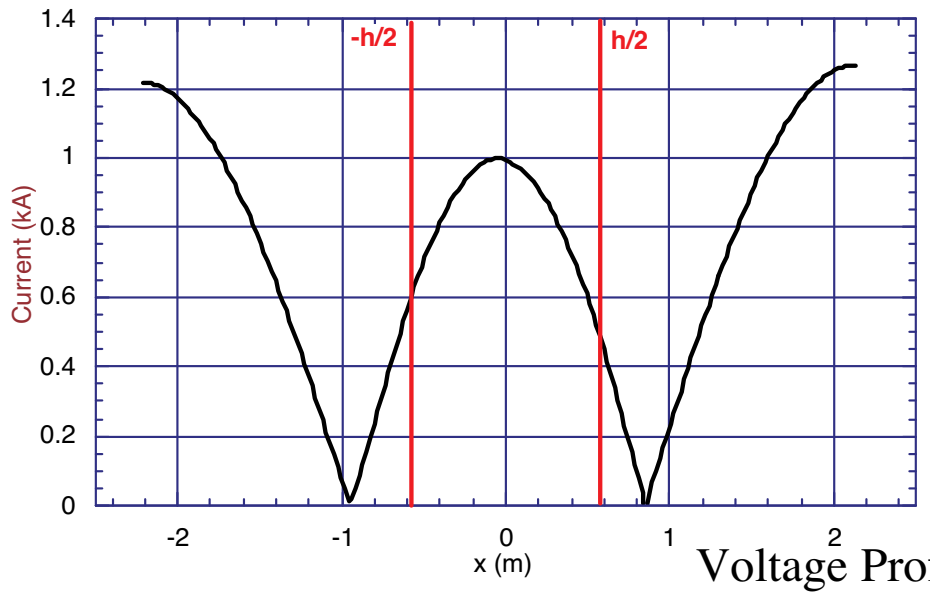
Figure 7 : Load tolerance performance of the fallback solution for 30, 43 and 55 MHz (resp. red, green, blue curves). The total length of the 30 Ohm VTL/TL feeding line from the straps to the matching capacitors is resp. 4.50m, 5.79m* and 4.23m* (* shifted by an extra half wavelength).

ICRF Antenna Parameters

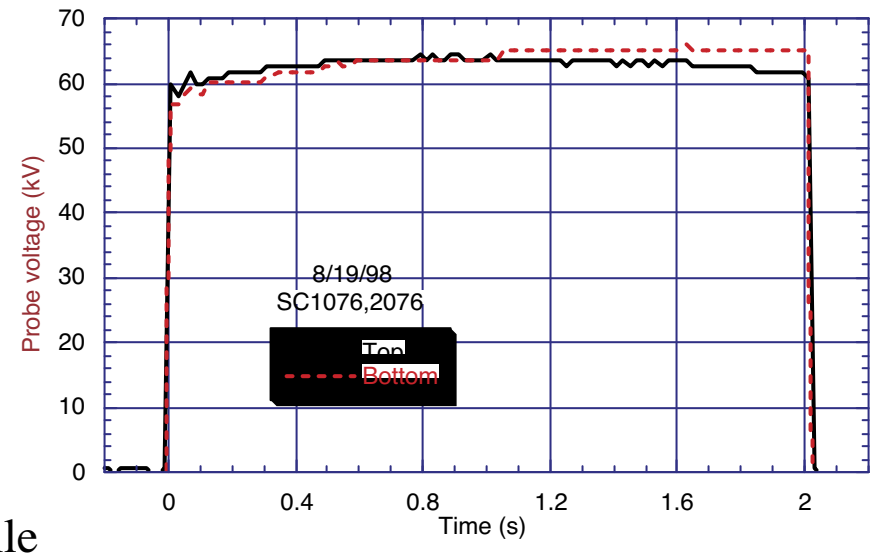
	Coupled Power (MW)	*Power Density (MW/m^2)*	*Max Voltage (kV peak)*	*Frequency Range (MHz)*
JET (A2)	8-14	2.5	35	25-55
JT-60 U	7	6	35	102-131
AUG	4-6	2.4	25	30-60
Tore Supra	9.5	10	45-50	35-80
DIII-D	3.6	3	25	30-60
C-Mod	3.5	10	45	80
TEXTOR	3.6	5-10	35	25-38
TFTR Bay-M	5		40-50	


1006
220
302
50
50
2005
Water cooling
Top voltage probe (capacitive)
RFTF port flange
Pre-matching stub
Sliding short
Current strap
356
1624
230
140
Screw drive
1285
1185
Vacuum feedthrough
Faraday shield
Cavity box
Bottom voltage probe

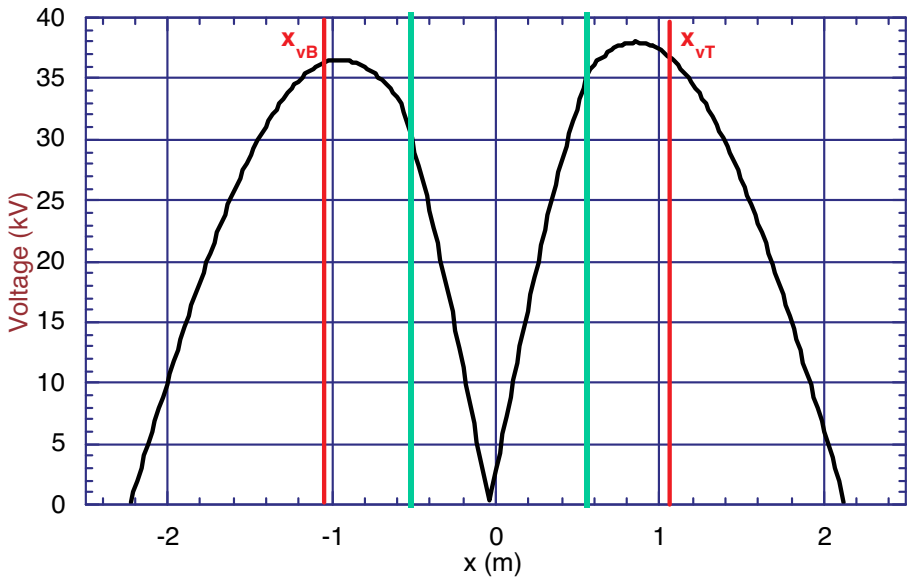
Current Profile

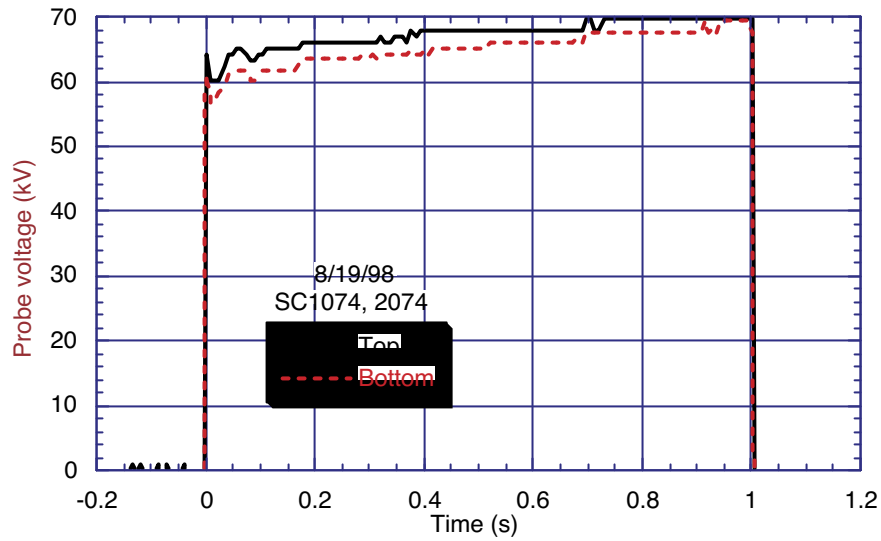


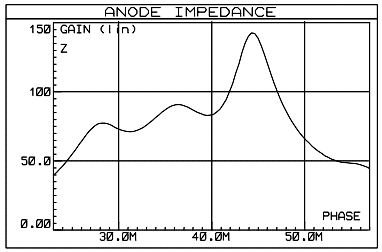
Test Pulses

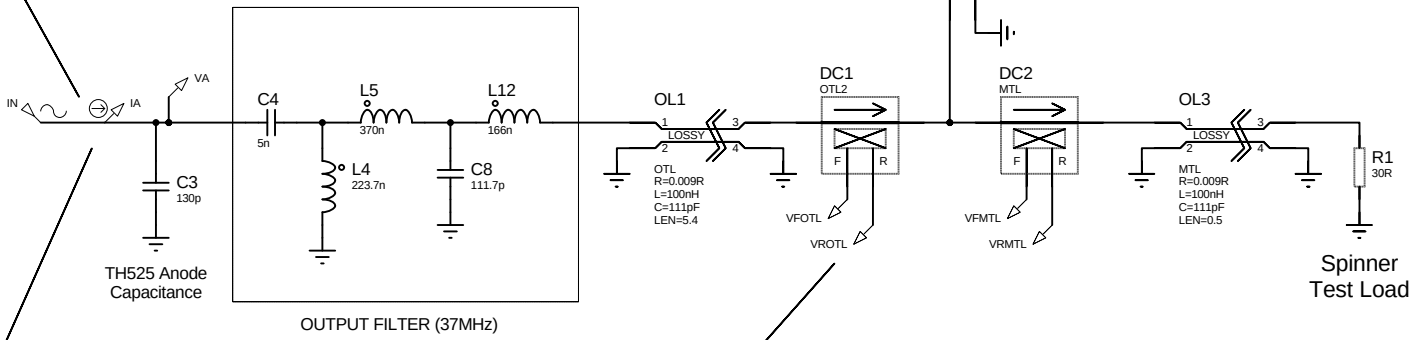


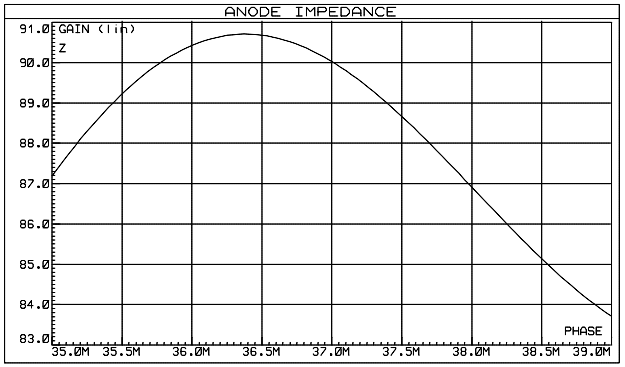
Voltage Profile

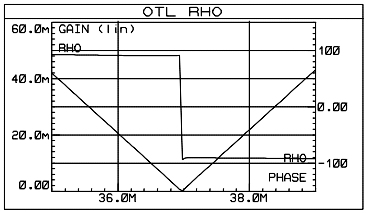












Connected to Test Load

Typical operation at 37MHz into 30 Ohm test load showing little variation of anode impedance over the frequency range.

Over the entire frequency range, there's little variation away from the 90 Ohm working point.

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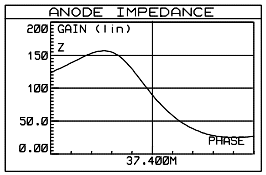
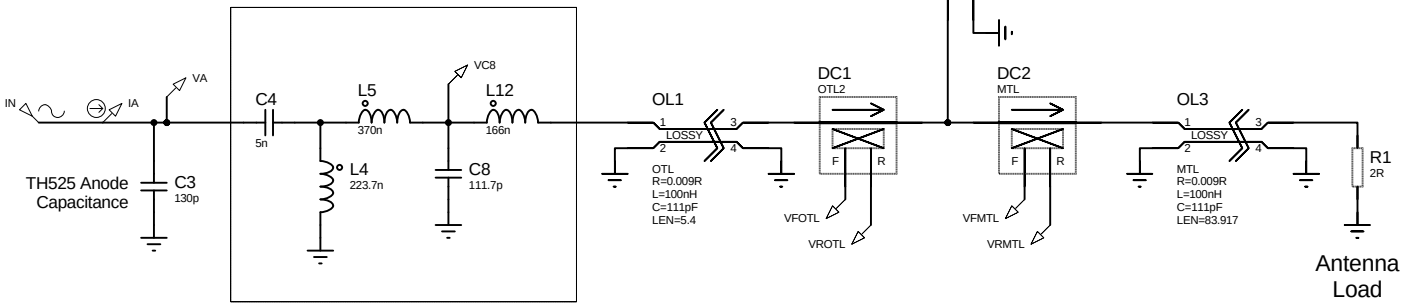
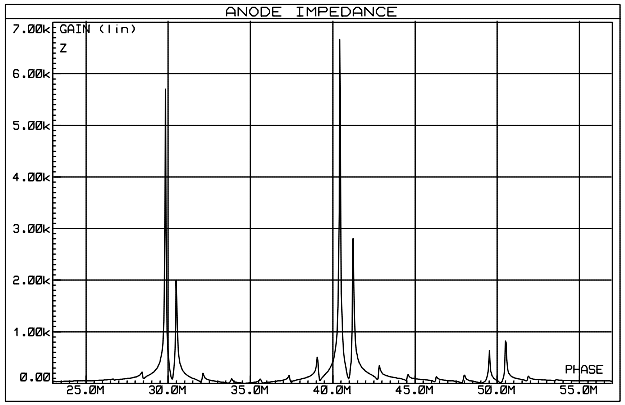
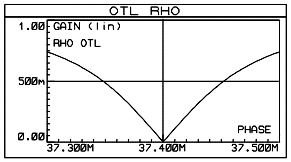
BY: AGH Sibley	DOC: Figure1.DSN		PAGE: 1/1





OUTPUT FILTER (37MHz)





2 Ohm Load

Shows the effect of connecting a 2 Ohm load to the system. High anode impedances ~7k now appear at ~30 MHz and ~40MHz. These are dependant on the length OTL and also the tuning of the endstage components.

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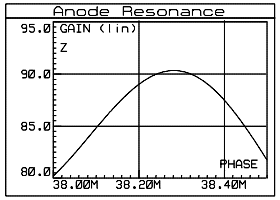
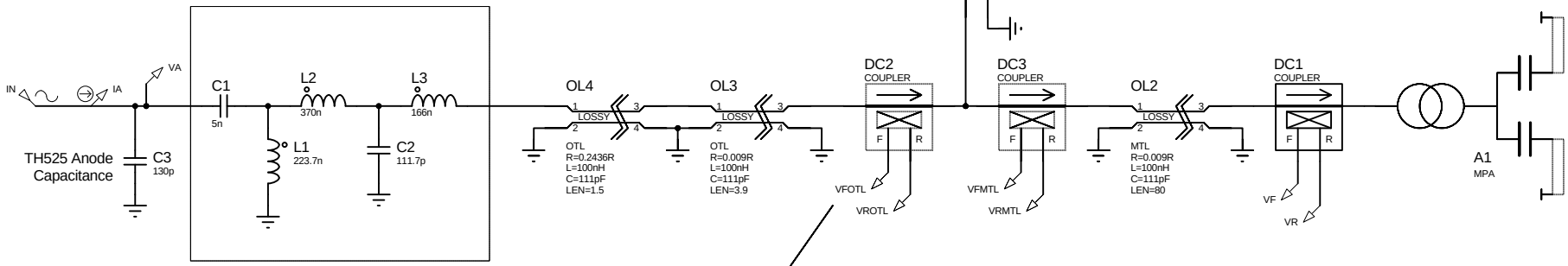
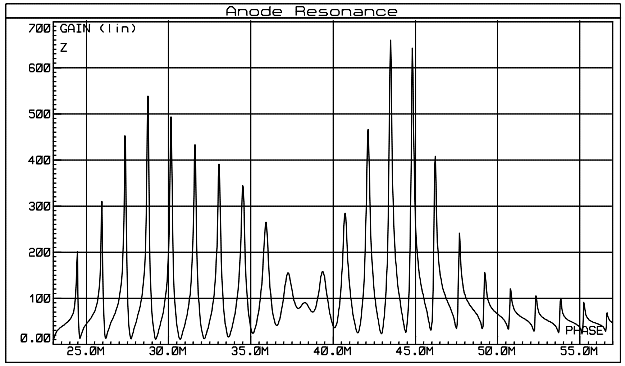
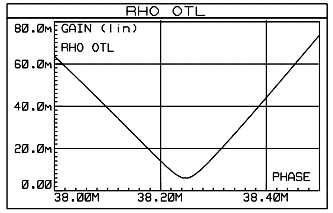
BY: AGH Sibley	DOC: Figure2.DSN		PAGE: 1/1









JET-EP Antenna

With the JET-EP antenna simulated by sections of lossy lines (P Lamalle), there are no resonances above ~1k to causing problems with spurious oscillations.

The length of the transmission line (MTL) is taken as 80m but this will depend on the final line layout. The most serious problem with not knowing the line length is the effect on the anode impedance under fault conditions.

As the MTL length is matched, it effectively becomes the OTL and therefore the overall length can be critical in determining the anode impedance under fault conditions.

See further layouts for fault analysis.

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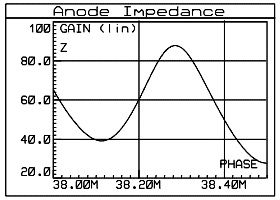
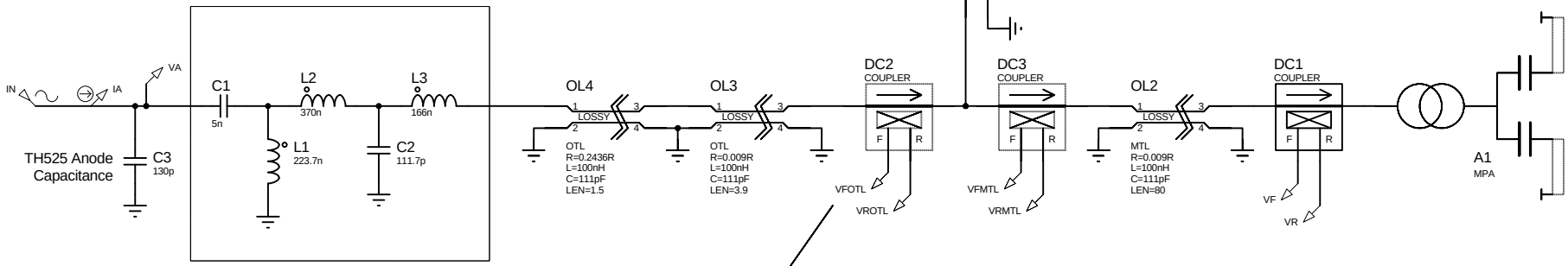
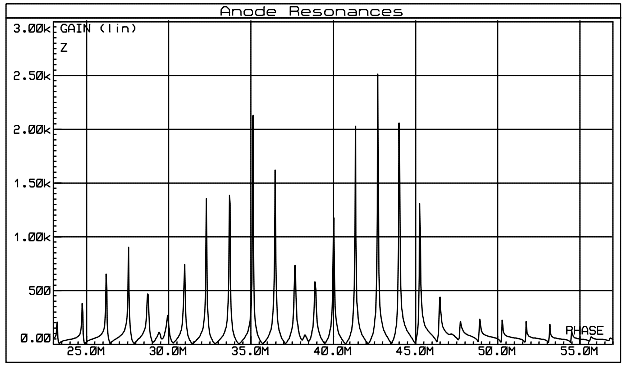
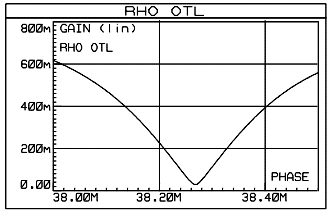
	BY: AGH Sibley	DOC: Figure6.dsn		PAGE: 1/2







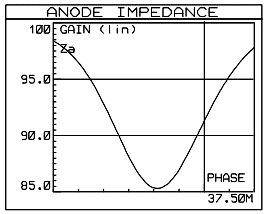


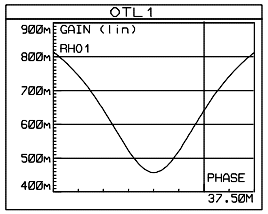
JET-EP Fallback Simulation

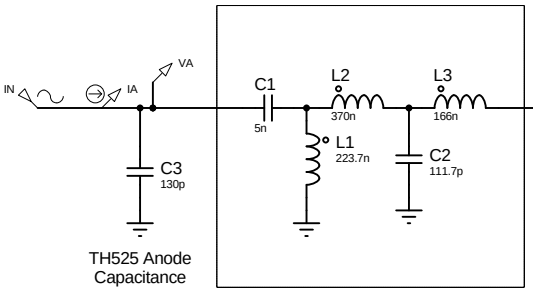
Capacitors are mounted outside of the vacuum envelope connected to the current straps by a section of 30 Ohm line. Resonance peaks are increased by this but are not thought to cause a problem with spurious oscillations.

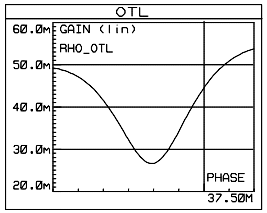
Under fault conditions, there are no appreciable resonances that would cause problems.

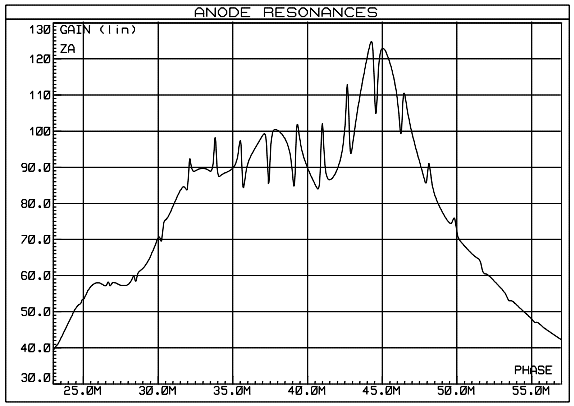
TITLE:	CREATED:	REV:	DATE:
Anode Resonance Simulation JET-EP Fallback	23/08/00		23/04/01
BY: AGH Sibley	DOC: Figure8.DSN		PAGE: 1/2

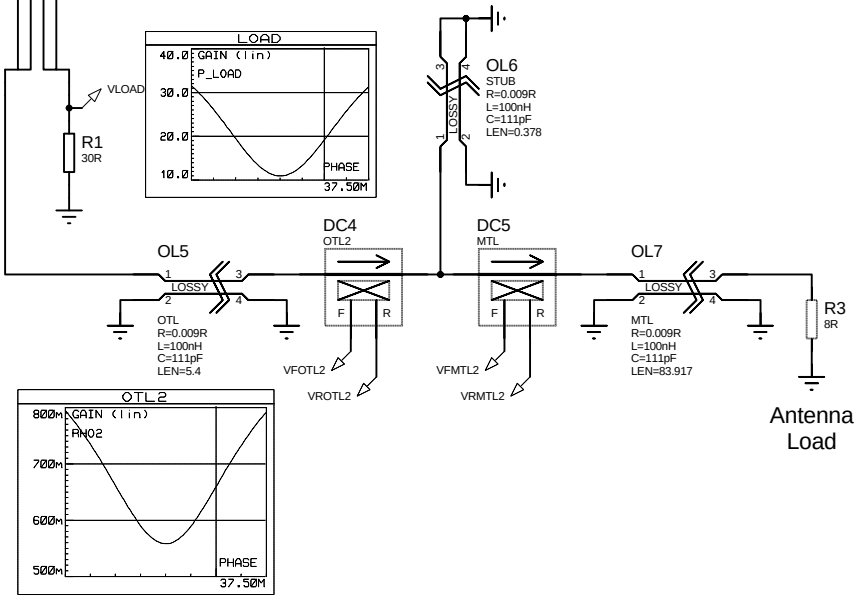


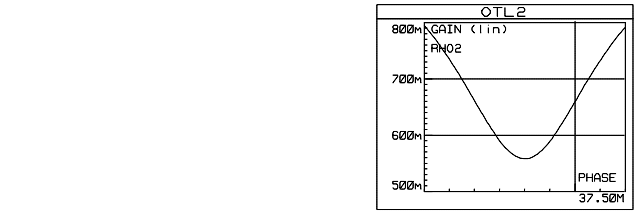








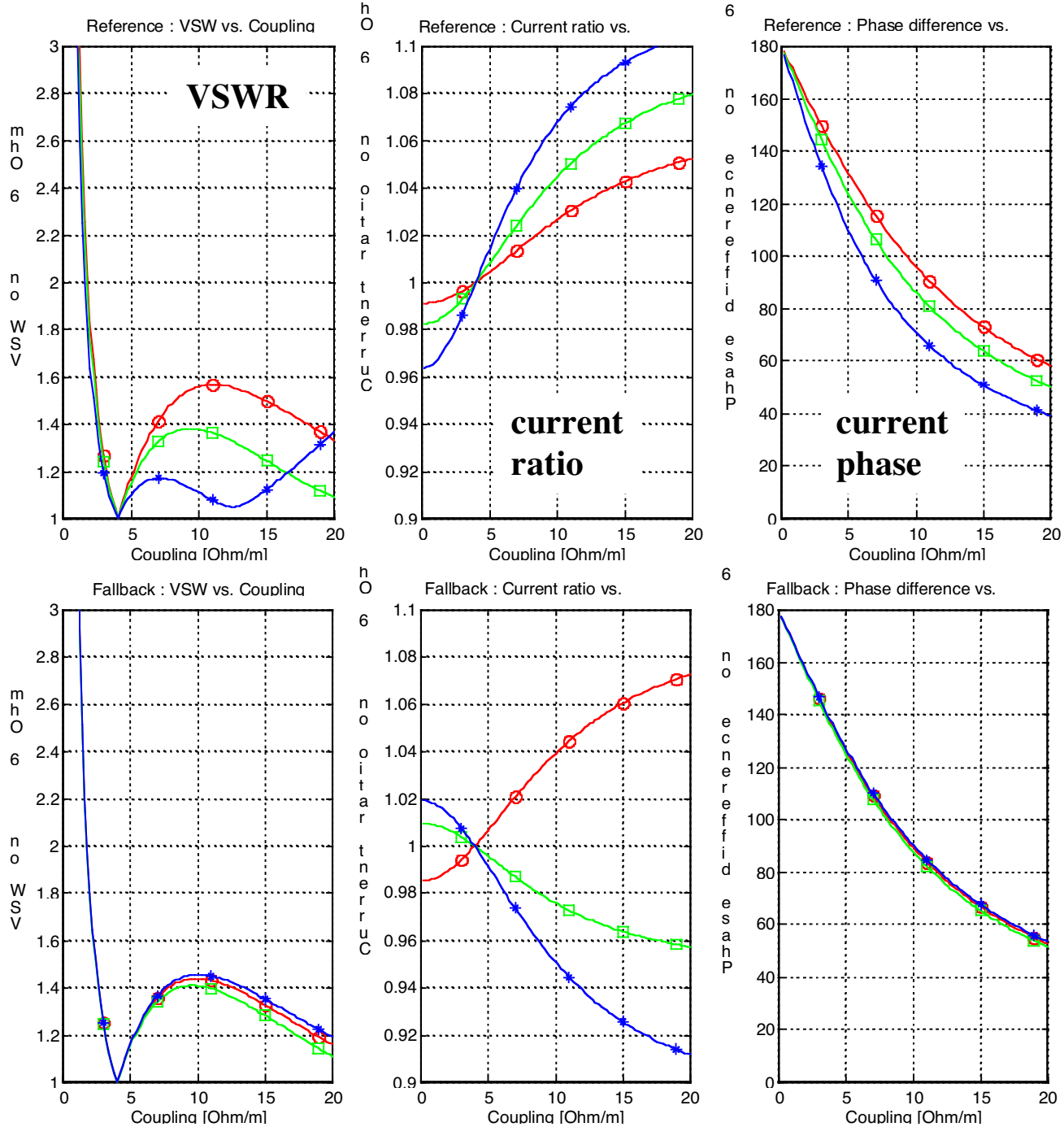




TITLE: 3dB Coupler Power Splitter	CREATED: 23/04/01	REV:	DATE: 24/04/01
BY: AGH Sibley	DOC: Figure99.DSN		PAGE: 1/2

Summary on Voltage Handling

- Best voltage handling seen on Tore Supra, C-Mod and TFTR launchers
- But high breakdown voltages also seen on ASDEX-U (and ORNL) breakdown testers, TEXTOR ceramic support at $\lambda/4$ point, and High Voltage R&D (ITER) antenna
- Suggests need for free electrons and/or gas to initiate breakdown - reducing voltages and/or electric fields in regions shielded from these may not be required
- Harmonics/resonances important? (External resonant loops also suppress additional resonances near drive frequency)
- One method for improving voltage handling is limiting voltage near current straps by internal matching (Tore Supra), but apparently not only way



Baseline

Fallback

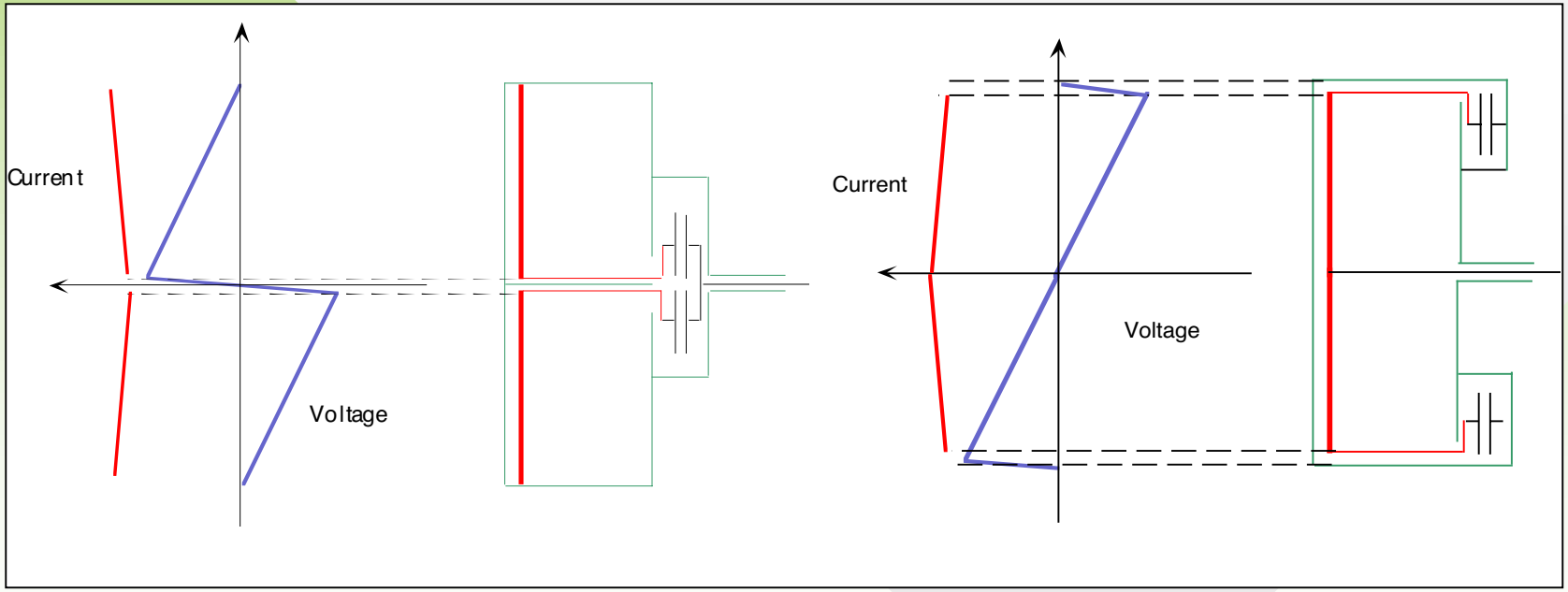
30 MHZ

43 MHZ

55 MHZ

Array Electrical Layout

The basic ICRF antenna layout is a modified version of the Resonant Double Loop (RDL) concept, which provides the highest power density performance in current systems (TS).



Additional Questions

- **Is it worth examining existing machine performance database in more detail?**
- **Can any other tests be done, e.g. convert High Voltage R&D (ITER R&D) antenna to end-fed with external resonant loop?**
  - **Voltage handling degradation due to feedthroughs in resonant line?**
  - **Voltage handling degradation due to extended region of high voltage?**

Conclusions

- Fallback design clearly preferable from the standpoint of simplicity and reliability
- However, also have a goal of 8 MW (~ 9 MW/m^2) launched power, so main question is, will the fallback design have significantly less power handling capability than the baseline design?
- Performance of C-Mod, TFTR launchers suggests that the required voltage handling can be achieved with external matching
- Other performance criteria such as load tolerance and resonance suppression also appear achievable with the fallback as well as baseline design