Scoping Study of RWM on NSTX

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- Purpose: 1) identify the design issues, 2) develop the design concepts and 3) outline the tasks

- GA/PPPL collaboration already deployed an RWM system on DIIID, so a starting point for this study is to determine to what extent the GA coil and power supply designs can be adopted for NSTX duty.

• Concluded:

- DIIID internal coil design can be adopted on NSTX, but there are many challenges to in-vessel installation.

-As an alternative, external coils can formed from power cables (preferably 2 turns), but installation will again be challenging due to small available space and many obstructions

-Further study is necessary to 1) quantify the performance difference (VALEN code) and 2) quantify the cost/schedule difference between internal and external coils.

- Robicon Switching Power Amplifiers (SPAs) appear to be suitable for the NSTX application.

-one or more DC source power supplies need to be identified. The PPPL Transrex power supplies could be used, but their voltage does not match.

-appears that the SPAs and DC source can be installed at FCPC without excessive DC line impedance. However, this needs to be confirmed.

-more effort to estimate the costs, but some information already in hand....

>GA style coils, assembled in-vessel, would cost $100K-$150K per coil, so 6 coils would cost $600K-$900K.

>If they could be assembled ex-vessel and passed through a port then the cost could be significantly less, but this needs to be determined.

>External coils formed from cable would be less expensive, but their performance and feasibility needs to be demonstrated.

>SPA costs approximately $150K. New DC source @ 1.5MW $175K. For the SPA/DC source combination, ultimately three units would be required, but initial operations could commence with one unit. So, the initial cost for the power supplies, might be of order $325K, and for the final system, $975K.

- Reduced cost option:

-external coils formed from power cables
-initial power supply via 1kV Transrex (fmax ~ 30Hz)
-add 1kV SPA later

- Cost not yet estimated (non-labor ~ $150K???

-mostly PPPL labor
-new power cabling NTC to FCPC
-new CLR
-new Disconnect/grounding systems
-new current transducers
-new control/protection

Requirements

Number of Coils	6
Coil Location	Centered about midplane
Coil Connections	Diametrically opposite coils connected in anti-series forming 3 independently controllable circuits
Coil height	Approximately equal to gap between passive plates ~ 1 m.
DC Field at r=R0+0.6*a	50 gauss
AC Field at 1kHz, r=R0+0.6*a	10 gauss
Maximum Ripple	+/- 2% of full load DC
Pulse Length	5 sec
Repetition Period	300 sec

DIIID System

External Coils

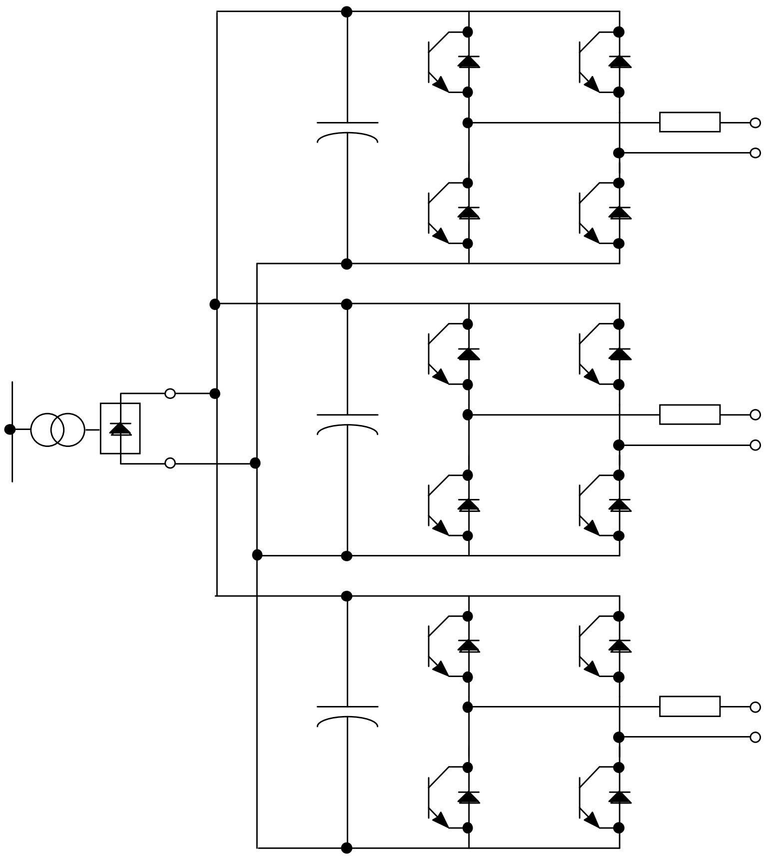
Internal Coils

• Cost associated with the internal coils themselves was of order of $1.5-$1.8M or approx. $100K-$150K per coil.

• NSTX coils could be cheaper if they could be assembled outside and brought in from top or from future NBI port

• Feasibility (clearances to antenna and NBI protective plate) not certain

Robicon SPA



Pulse Current per Module	1.667kA
Pulse Current (3 parallel module)	5kA
Pulse Duration	10 sec
Pulse Period	180 sec
Input Voltage	300Vdc
Switching Frequency	3.5kHz (first version) 7.0kHz (second version)
Input Filter Capacitance (3 parallel module)	0.2835 millifarad, 800V
Output Filter Inductor (per module)	11 microhenry
Output Filter Inductor (3 parallel module)	3.67 microhenry
Cabinet Footprint Dimensions	6’ wide x 6’ deep x 8’ tall

- 300V probably based on surplus LLNL DC supplies

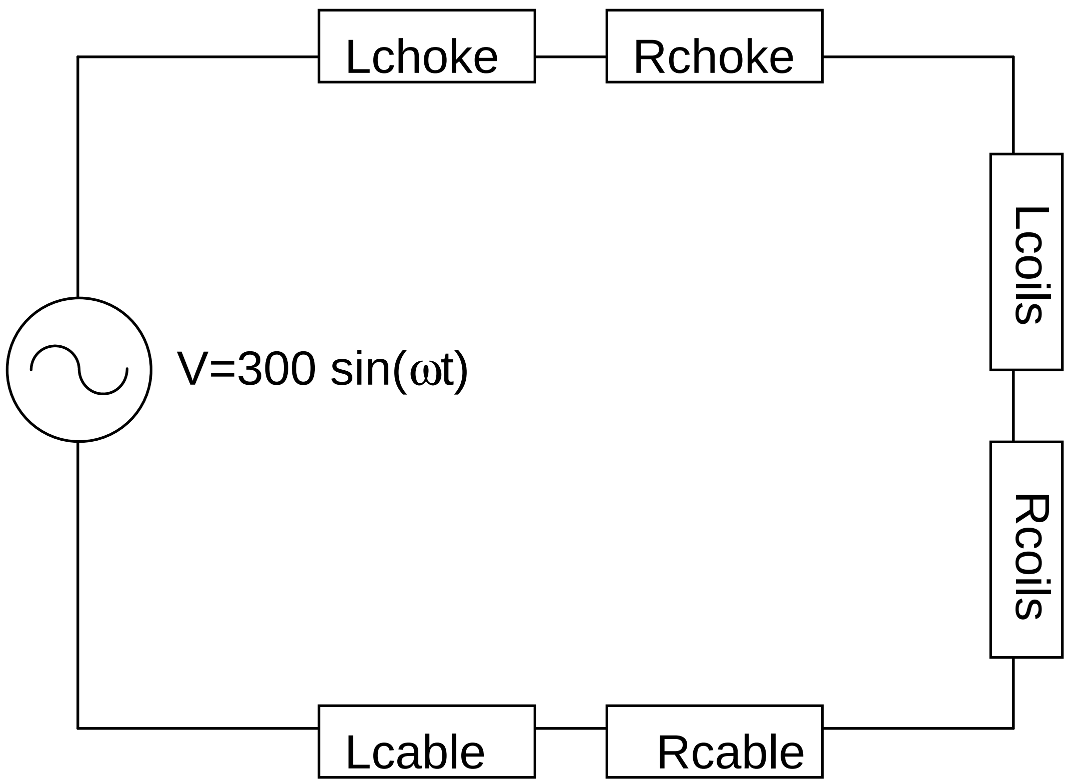
- Magnetic Analysis

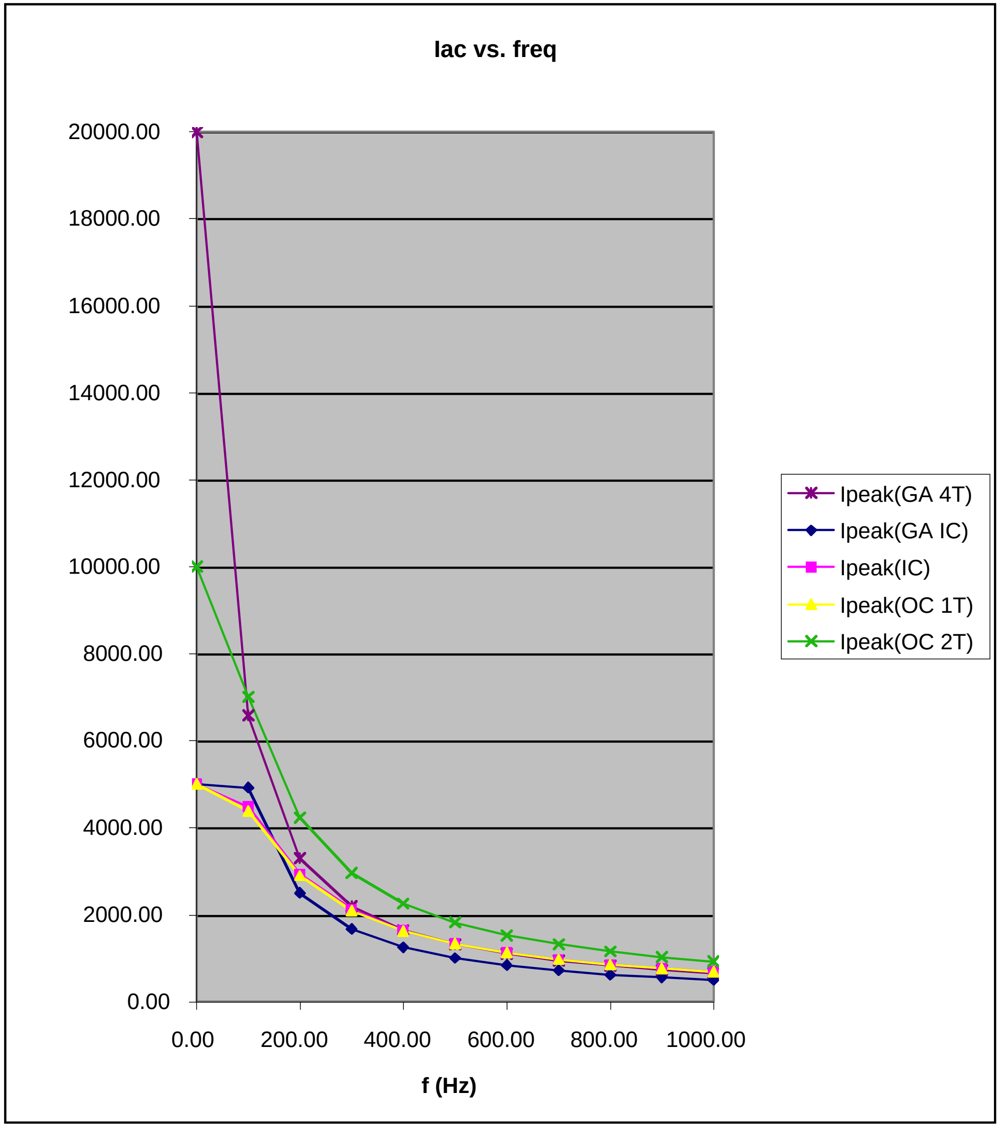
-planar picture frame coil centered about midplane
-DC field at midplane due to one coil pair
-DC field at midplane due to three coil pairs

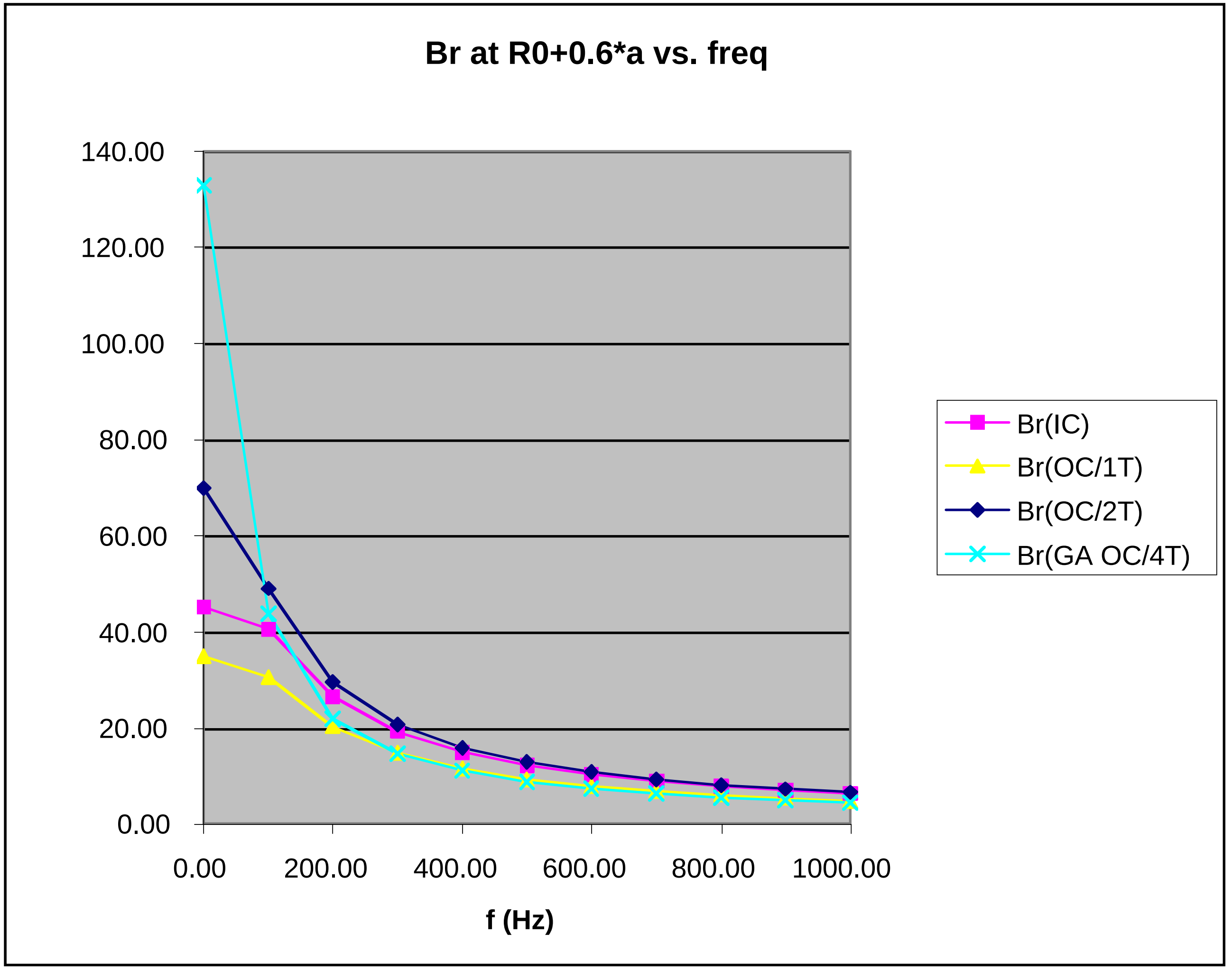
- Electrical Analysis

-self-inductance and resistance of simple picture frame coils
-inductance and resistance of cable run
-inductance and resistance of additional choke
-skin effect on resistance

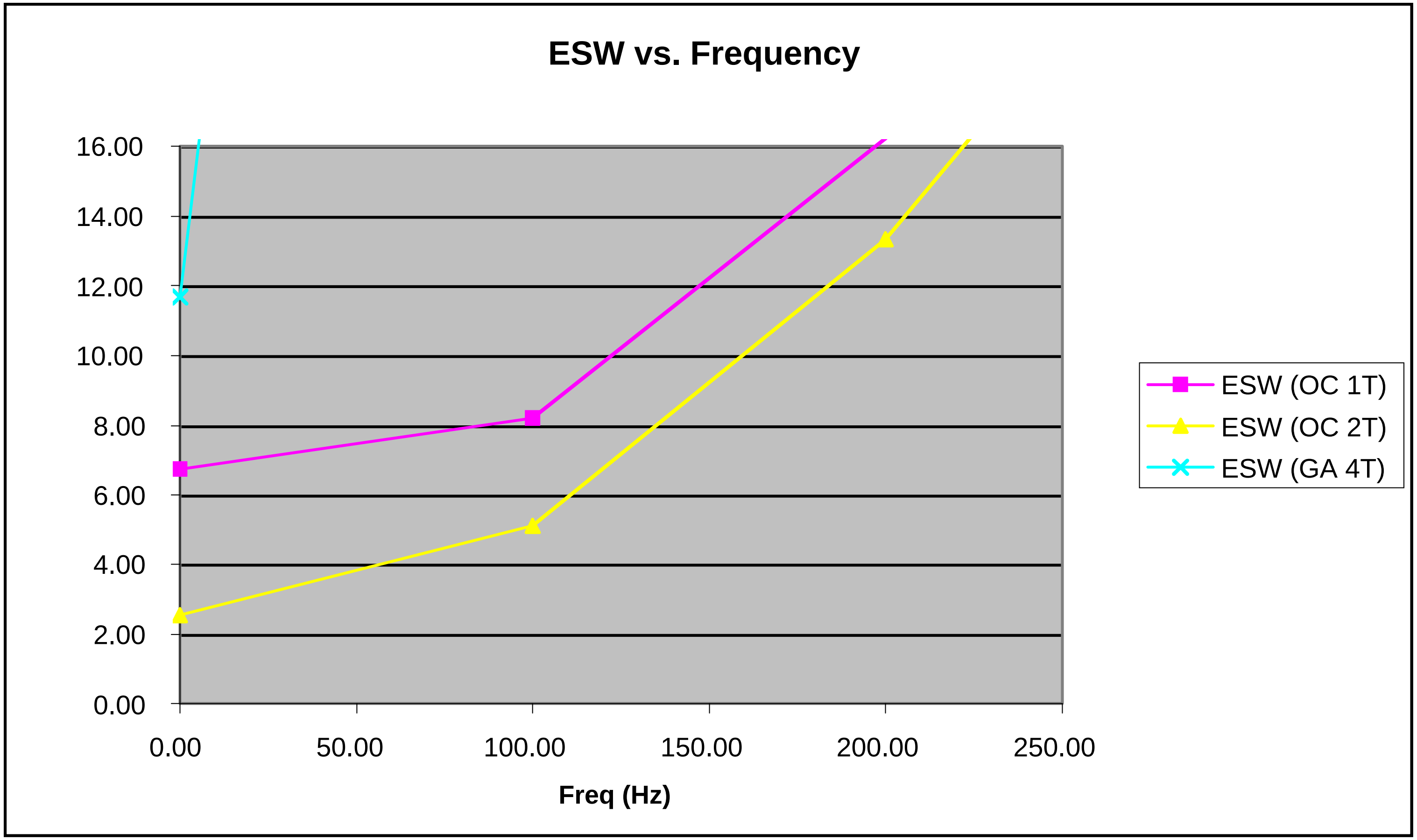
- R’s adjusted for frequency
- Inductive reactances $X = \omega L$
- Inductive impedance Z=sqrt(R^2+X^2)
- AC Current I=V/Z




Iac vs. freq
20000.00
18000.00
16000.00
14000.00
12000.00
10000.00
8000.00
6000.00
4000.00
2000.00
0.00
0.00
200.00
400.00
600.00
800.00
1000.00
f (Hz)
Ipeak(GA 4T)
Ipeak(GA IC)
Ipeak(IC)
Ipeak(OC 1T)
Ipeak(OC 2T)



Br at R0+0.6*a vs. freq
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0.00
200.00
400.00
600.00
800.00
1000.00
f (Hz)
Br(IC)
Br(OC/1T)
Br(OC/2T)
Br(GA OC/4T)


ESW vs. Frequency
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0.00
50.00
100.00
150.00
200.00
250.00
Freq (Hz)
ESW (OC 1T)
ESW (OC 2T)
ESW (GA 4T)

- Findings

1 – All of the designs come close to meeting the requirement for 50 gauss under DC conditions. However they all fall short of the requirement for 10 gauss at 1kHz. It appears that 10 gauss is only available up to around 500Hz.

2 – The need for the additional choke and higher switching frequency for the new GA internal coils to keep the ripple down, is clear

3 – The ripple requirement dictates the minimum allowable circuit inductance for a given driving voltage. This imposes, therefore, a fundamental limit on system performance. It may actually be advantageous to reduce the base DC voltage (nominally 300 volts) under certain conditions to reduce the ripple.

4 – The effect of the VV is probably very important in determining the ripple response. Considering that the NSTX VV is 5/8” (0.625”) thick 304SS, and the skin depth at 1kHz is only 0.550” in 304SS (resistivity = 7.7e-7 ohm-m), the VV may serve as an effective ripple filter, reducing or eliminating the need for external inductance (choke).

5 – If the VV does serve effectively as a ripple filter, then the noise pick-up on in-VV magnetic diagnostics would be reduced in the case of external RWM coils.

6 – It would appear that the resistive and inductive impedance of a cable run from the NTC to FCPC, assumed here to be 250’, can be tolerated, allowing the equipment to be installed at FCPC.

7 – For cable formed coils the available pulse length is a function of frequency. For the 500MCM and 750MCM conductors, the allowable pulse length at peak DC current exceeds 5 seconds with a 300 second rep rate. However a 250MCM cable is used (e.g. to conserve space and allow a 2 turn external coil to be formed) then the pulse length at the low end of the frequency range would be less than 5 seconds

8 – Since the water cooled GA conductor is designed for 7kA continuous then, as long as the DC feeds, etc., are 500MCM or larger, then the RWM could run at rated current for the full 5 second pulse.

9 – The net field available from 3 coil pairs will be higher than that available from one. Figure 7 shows the spatial variation of Br (at r=R0+0.6*a) on the mid-plane for the case of the 1 turn NSTX external coil when all three coil pairs are identically operated. The ratio of multi-coil to single coil field in this case is 2.37.