External Stimulation of Edge Modes

Alan Binus, Willy Burke, Ambrogio Fasoli, Theodore Golfinopoulos, Robert Granetz, Martin Greenwald, Jerry Hughes, Yijun Lin, Brian LaBombard, Rick Leccacorvi, Ronald R. Parker, Miklos Porkolab, Rui Viera, Paul Woskov, Steve Wukitch

PSFC@MIT, JET

September 8, 2010

Motivation

Why are we *excited* about *exciting* fluctuations in the pedestal?

- EDA H-Mode and Quasi-Coherent mode [6]
- Quiescent H-Mode and Edge Harmonic Oscillation [1]
- I-Mode and Weakly-Coherent mode [10]

Pedestal-localized modes: "knob" to control particle confinement independently of energy confinement?

QCM Spectrogram

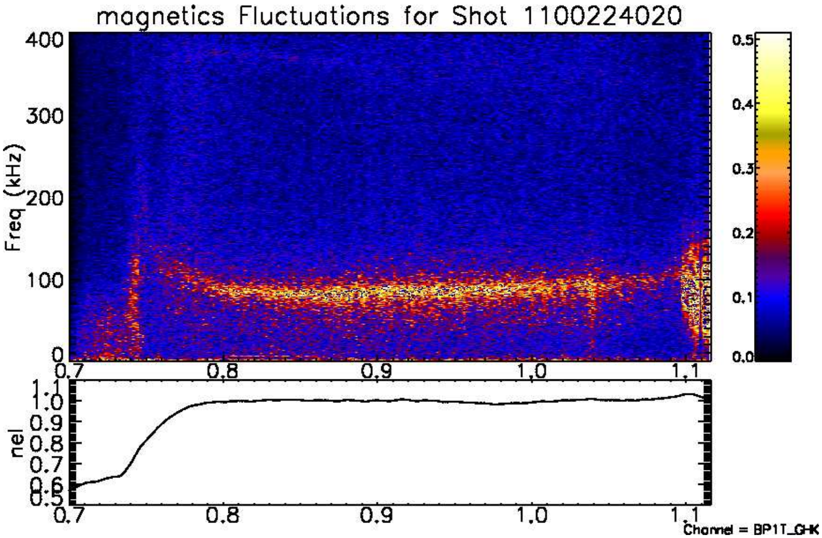


Figure: Example of quasi-coherent signature as seen in spectrogram of magnetics fluctuation diagnostic signal. Downward frequency spin likely due to the Doppler shift from change in plasma rotation velocity [8].

WCM Spectrogram

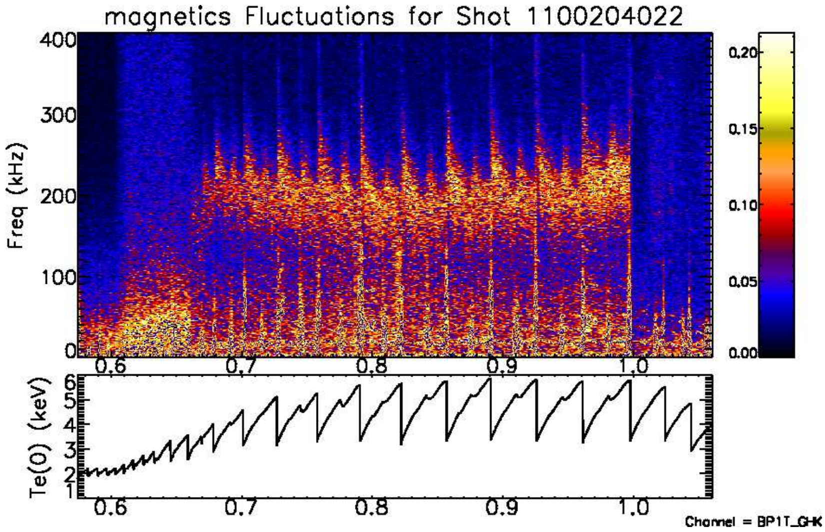


Figure: The I-Mode operating regime's "Weakly-Coherent Mode" or "Heavy Impurity Mode", visible in a magnetics fluctuation spectrogram as a fairly broad band of activity around 200 kHz.

Goals

Short-term:

- proof-of-concept: determine conclusively whether external excitation methods are capable of coupling to the QCM.

Long-Term:

- determine whether high performance EDA H-Mode operation can be made more accessible, appear in previously-unseen parameter ranges;
- attempt to either reinforce or stabilize the spontaneous QC mode in normal EDA H-Mode via feedback;
- explore the physics of the QC mode spectrum;
- determine whether other modes besides the spontaneously-arising QCM may still accomplish same particle transport;
- optimize particle transport/antenna power efficiency;
- attempt to excite other edge or near-edge modes, including the Weakly Coherent (Heavy Ion) mode associated with the I-Mode regime, EHO of QH regime, etc.

Methods

Methods we have employed in allied field, Active MHD Spectroscopy (see early work at JET, e.g. [2, 4, 5], etc.)

- Direct excitation: build external antenna excited directly at mode frequency
- Parametric excitation: use three-wave process or other nonlinear effect to couple power from (most likely) higher-frequency drives (e.g. beating ICRF antennas, amplitude-modulated ICRF, etc.) into lower-frequency mode

Methods

Requirements:

- Resonance cond.: match Doppler-shifted mode frequency, k
- Variable frequency desirable: allows robust techniques for resonance ID, overcomes uncertainty in mode frequency, allows to map spectra
- "Two-color": desirable to drive weakly at off-resonance level for noise rejection
- Perturbation from drive accesses location where mode is localized (simpler for edge modes than core modes)
- (Rule of thumb) Match magnetic perturbation observed in mode

Direct Excitation

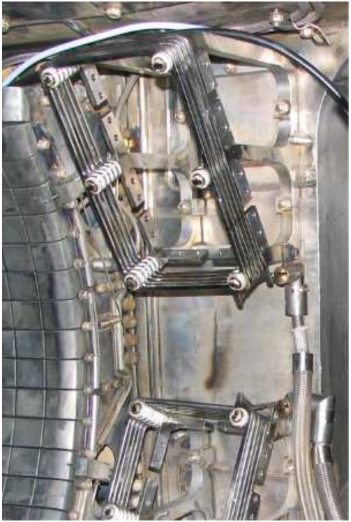


Figure: Photograph of Active MHD antennas currently installed in Alcator C-Mod. Antennas are 15 cm $\times$ 25 cm, and are symmetric above and below the midplane.

Spectrogram of Active MHD Run

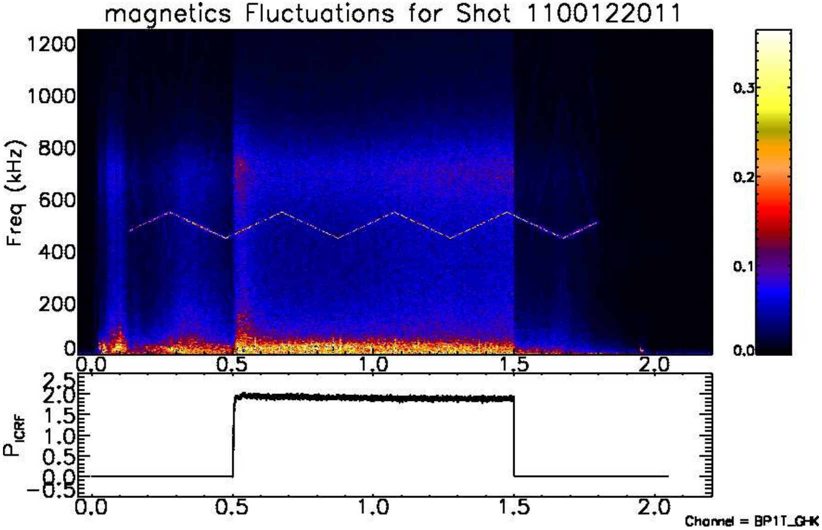


Figure: Spectrogram of fast magnetics fluctuations for Shot 1100122011, for which Active MHD antenna was energized. Resonance detected from 1.68-1.78 s.

Indication of Resonance During AMHD

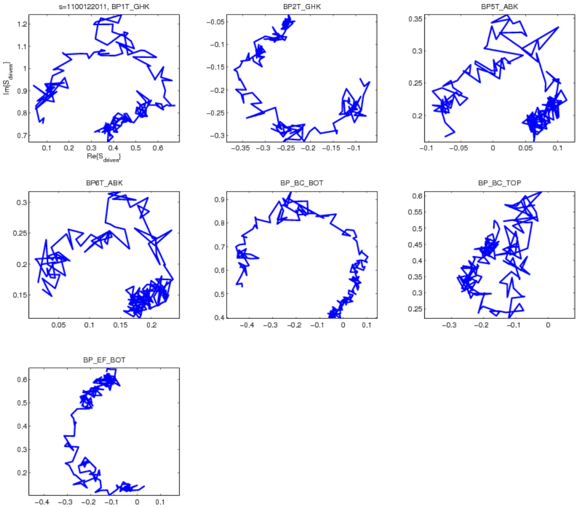


Figure: Shot 1100122011, plot of transfer function in complex plane from several probes, 1.68 s-1.78 s, $f = 453 - 504$ kHz (rampdown). Resonance centered at 466 kHz.

Direct Excitation: "Shoestring" Antenna

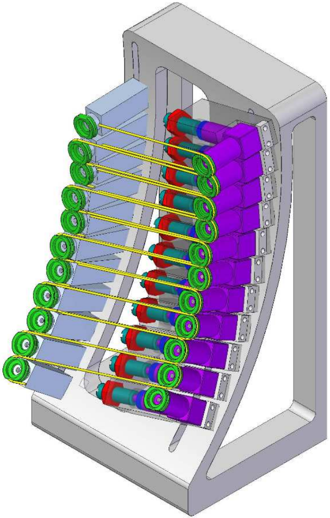


Figure: Isometric view of antenna design (late Aug.). Mo ML wire (Mo doped with La) is strung back and forth across antenna. Source: Rick Leccacorvi, PSFC engineer.

Parametric Excitation

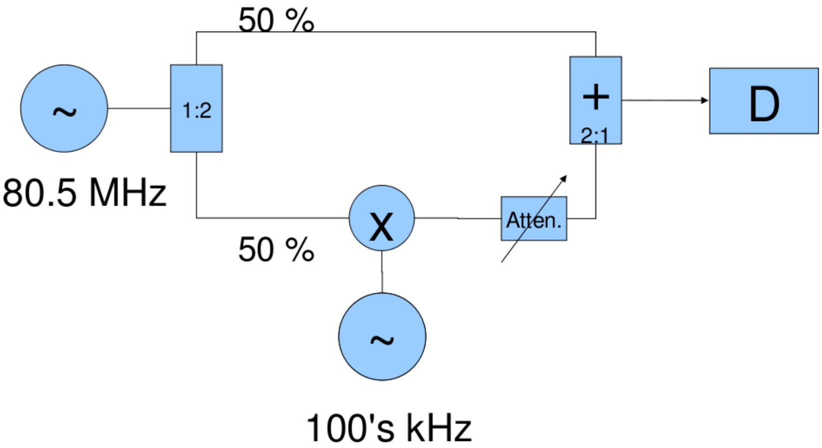


Figure: Simple schematic of our amplitude modulation system. Employed during Run 1100122 and half of Run 1100226 under MP590 and MP432.

Parametric Excitation

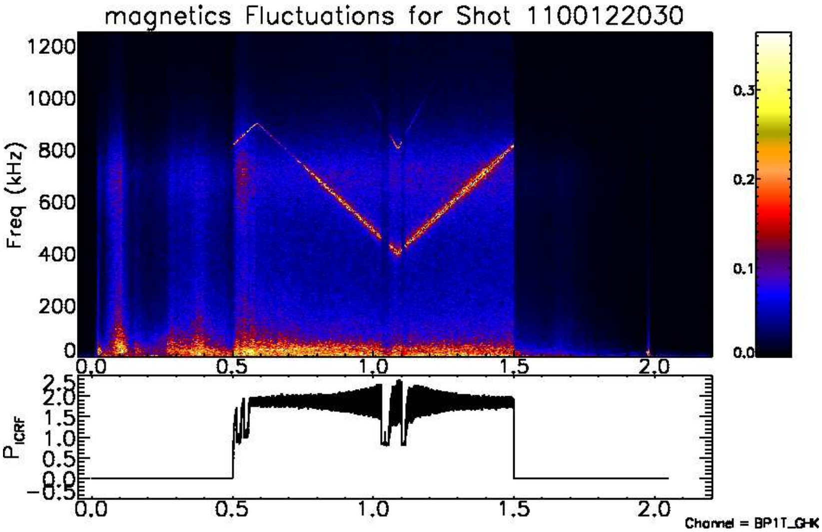


Figure: Spectrogram of fast magnetics signal from Shot 1100122030, for which ICRF amplitude modulation was run. Resonances may have occurred around 0.838-1.025 s and 1.15-1.33 s.

Quick Comparison of Methods

Direct Excitation:

- Good control of frequency, k-matching for QC mode
- Antenna must be very close to mode due to rapid decay of field away from antenna (since large k_θ); estimates show acceptable for pedestal modes
- (Perturbation of BC's may allow coupling to core modes)
- We have amplifiers in the range of 1-1.5 kW; expected to be sufficient - more power is more expensive.
- Another drive option: capacitor banks, LC circuit at res. freq. since antennas are inductive; lose capability for variable frequency
- Impedance matching to the amplifier has proven challenging in AMHD experiments, though we expect improvement in next round of experiments.
- Perhaps analysis of direct antenna-plasma interaction is simpler than that of parametric excitation
- Antenna may be installed and ready for operation for spring 2011 campaign

Quick Comparison of Methods

Parametric Excitation:

- Equipment is largely in place already and relatively inexpensive; requires one day setup with appropriate advanced notice
- Start with high power, but limited by Manley Rowe relations, $|P_1/\omega_1| = |P_2/\omega_2| = |P_3/\omega_3|$ ($\omega_3 = \omega_1 - \omega_2$, $\omega_1 \approx \omega_2 \gg \omega_3$).
- Expect better access to core than external inductive antenna, but remains to be seen how edge access compares.
- Can good k-matching be achieved? We believe operating at low absorption may help; our ICRF antennas have variable frequency, 40-80 MHz.

Summary and Future Work

- Actively exciting pedestal fluctuations is “exciting” topic
- One goal: find a new way to control particle transport across pedestal
- We have gained experience in coupling to MHD modes from Active MHD spectroscopy
- Currently developing direct and parametric drive methods for exciting QC mode; if successful, will attempt other modes subsequently, including WCM (may or may not be a pedestal mode; ref. Prof. Bruno Coppi)
- QCM antenna may be ready for spring 2011 campaign, parametric method can be ready sooner.

K. Burrell, M. Austin, D. Brennan, J. DeBoo, E. Doyle, et al.
Quiescent H-mode plasmas in the DIII-D tokamak.
Plasma Physics and Controlled Fusion, 2002.

A. Fasoli, J. Dobbing, C. Gormezano, J. Jacquinot, J. Lister, S. Sharapov, and A. Sibley.
Alfvén eigenmode excitation by ICRH beat waves.
Nuclear Fusion, 36(2):258–263, 1996.

A. Fasoli, D. Testa, S. Sharapov, H. Berk, B. Breizman, A. Gondhalekar, R. Heeter, M. Mantsinen, and contributors to the EFDA-JET Workprogramme.
MHD Spectroscopy.
Plasma Physics and Controlled Fusion, 44:B159–B172, 2002.

J. Goedbloed, H. Holties, S. Poedts, G. Huymans, and W. Kerner.
MHD spectroscopy: Free boundary modes (ELMs) & external excitation of TAE modes.
Plasma Physics and Controlled Fusion, 35:B277–B292, 1993.

H. Holties, A. Fasoli, J. Goedbloed, G. Kuysmans, and

Backup Slide: Finding Resonances: ICRF Amplitude Modulation

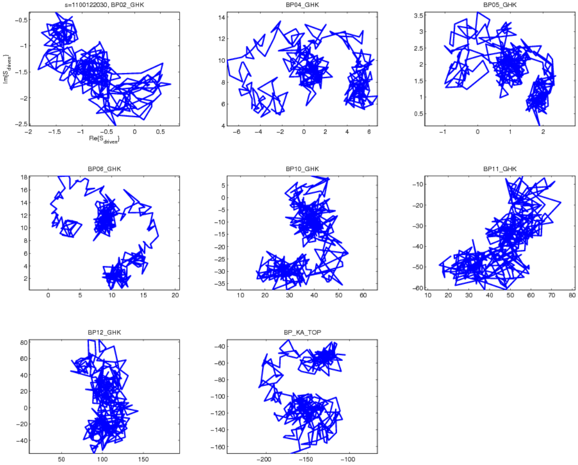
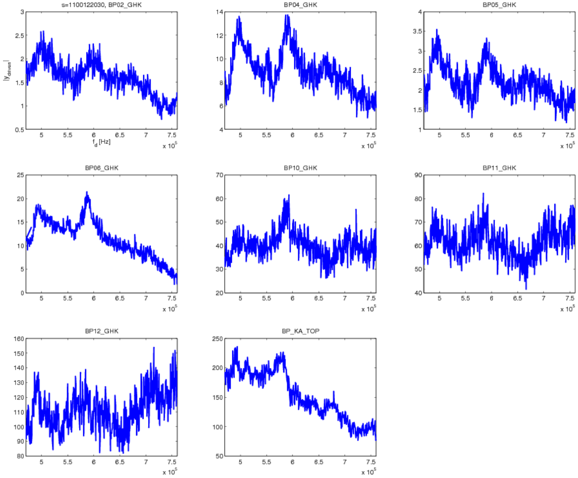


Figure: Shot 1100122030, Nyquist plot of transfer function from 0.838 to 1.025 s (650 kHz to 464 kHz).

Backup Slide: Transfer Function Magnitude



Backup Slide: Schematics of QC Antenna

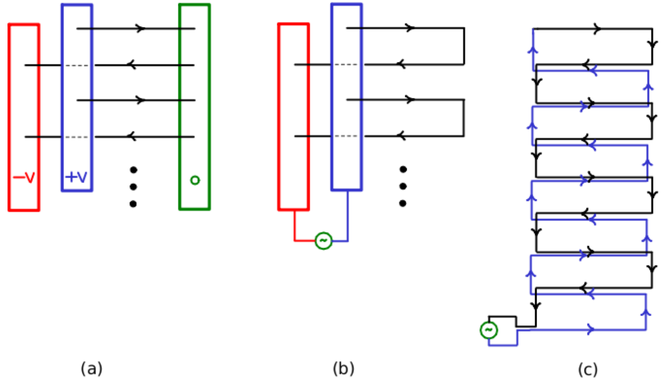


Figure: Different schemes for wiring antenna conductors. (a) "Pure parallel" - all wires are in parallel, and there are three common buses at voltages, $\{-V, 0, V\}$. (b) "Hybrid" - single-turn loops of wire are placed in parallel. (c) "Pure series" - all segments of wire are connected in series. Only one forward (blue) and backward (black) pass is shown, though multiple passes may be made. $N = 8$ turns are shown.

Backup Slide: Schematic of Active MHD System

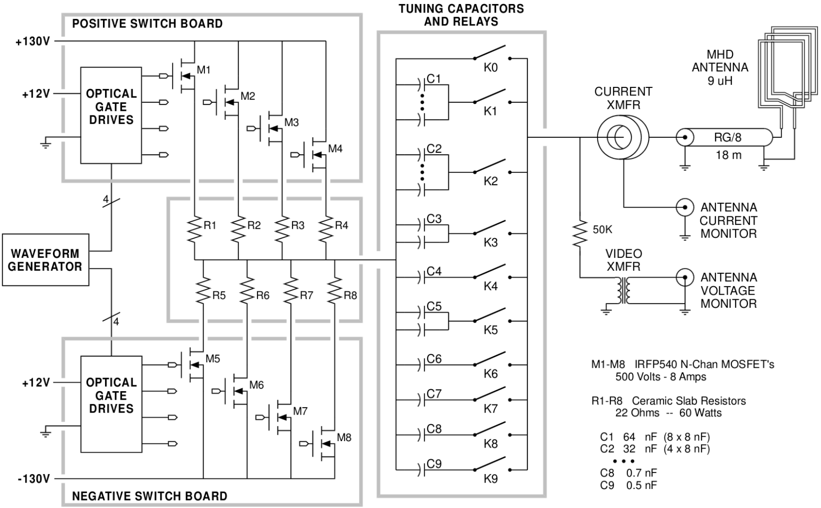


Figure: AMHD Block diagram, designed and built by Willy Burke.