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Author(s): W. A. Reass, P-24
G. A. Wurden, P-24

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OPERATIONAL PERFORMANCE OF THE TWO CHANNEL 10 MEGAWATT FEEDBACK AMPLIFIER SYSTEM FOR MHD CONTROL ON THE COLUMBIA UNIVERSITY HBT-EP TOKAMAK

W.A. Reass and G.A. Wurden
Los Alamos National Laboratory
Los Alamos, NM 87545
and
D.L. Nadle, M.E. Mauel, and G.A. Navratil
Columbia University
500 West 120th Street
New York, NY 10027

I. ABSTRACT

The operational characteristics and performance of the two channel 10 Megawatt MHD feedback control system as installed by Los Alamos National Laboratory on the Columbia University HBT-EP tokamak are described. In the present configuration, driving independent 300 uH saddle coil sets, each channel can deliver 1100 Amperes and 16 kV peak to peak. Full power bandwidth is about 12 kHz, with capabilities at reduced power to 30 kHz. The present system topology is designed to suppress magnetohydrodynamic activity with m=2, n=1 symmetry. Application of either static (single phase) or rotating (twin phased) magnetic perturbations shows the ability to spin up or slow down the plasma, and also prevent (or cause) so-called "mode-locking". Open loop and active feedback experiments using a digital signal processor (DSP) have been performed on the HBT-EP tokamak and initial results show the ability to manipulate the plasma MHD mode frequency.

II. INTRODUCTION

The electrical design off this system was thoroughly reviewed in the 95 SOFE conference record, in the paper titled "Design Construction, and First Operational Results of a 5 Megawatt Feedback Controlled Amplifier System for Disruption Control on the Columbia University HBT-EP Tokamak". In review, each of the two amplifiers are designed similar to a grounded cathode, push-pull, transformer coupled, tube type amplifier system. Each push-pull amplifier consists of 6 each Machlett ML8618 magnetically beamed triodes, 3 on each end of the (center tapped) coupling transformer. The transformer has .1 volt-seconds of core and a 1:1 turns ratio. The transformer is specially designed for high power, low leakage inductance, and high bandwidth. Each array of ML8618's is (grid) driven with a fiber-optic controlled 75 kW hotdeck with a 3CX10,000A7 high-mu triode. To linearize ML8618 grid drive, the hot deck utilizes a minor feedback loop with a 2 kW solid-state driver. The fiber optic coupling to the hotdecks also use amplitude modulated high-bandwidth links, with first order response, of Los Alamos design. Commercial FM links suffered poor signal-to-noise ratio's, excessive drift, and unusual phase shifts within their pass-band. These errors would make the choice of FM links difficult to operate the system with unconditional stability and reasonable fidelity. The over-all feedback system will not cancel the link induced noise. The Columbia system has the overall feedback system located at ground potential, with error signals coupled through the links (to the hotdecks). This methodology is different than what has been typically used for neutral beam modulators, where reference and gating signals are sent to the hotdeck. By closing the feedback loop at ground potential, the feedback loop may be broken during machine operation and loop parameters can easily be measured and adjusted to ensure system stability. This system topology is shown in Figure 1. The feedback compensation circuits obtain their inputs from the current viewing resistor in series with the saddle coils and an external reference input. An example of a 1000 Ampere test waveform is shown in Figure 2. The reference signal may be from a programmable generator to perform various "open-loop" (asynchronous) plasma response tests or derived from a Digital Signal Processor (DSP). The DSP would utilize measurements from various (e.g. magnetic) plasma diagnostics and then with the appropriate algorithm (yet to be determined!!), control the plasma response to inhibit plasma disruptions and/or control the plasma mode frequencies.

III. ASYNCHRONOUS TESTS

Asynchronous tests have shown the ability to spin-up or spin-down the plasma mode frequencies as shown in Figure 3. Other experiments can determine the mode "lock-in" time, by performing "phase-flipping" experiments. An example of a 1000 Ampere phase-flipping test is shown in Figure 4. A measure of plasma mode lock-in time with amplitude and frequency may be of benefit in future control applications. Other tests have shown that with FM modulation of the mode frequencies, the plasma can avoid locking into degenerative modes (that cause disruptions) and extend the plasma discharge. Future asynchronous studies may include (and are not limited to!!) determination of wall-stabilization characteristics with accelerated or decelerated resonant surfaces and the ability to induce shear flow with rotating perturbations.

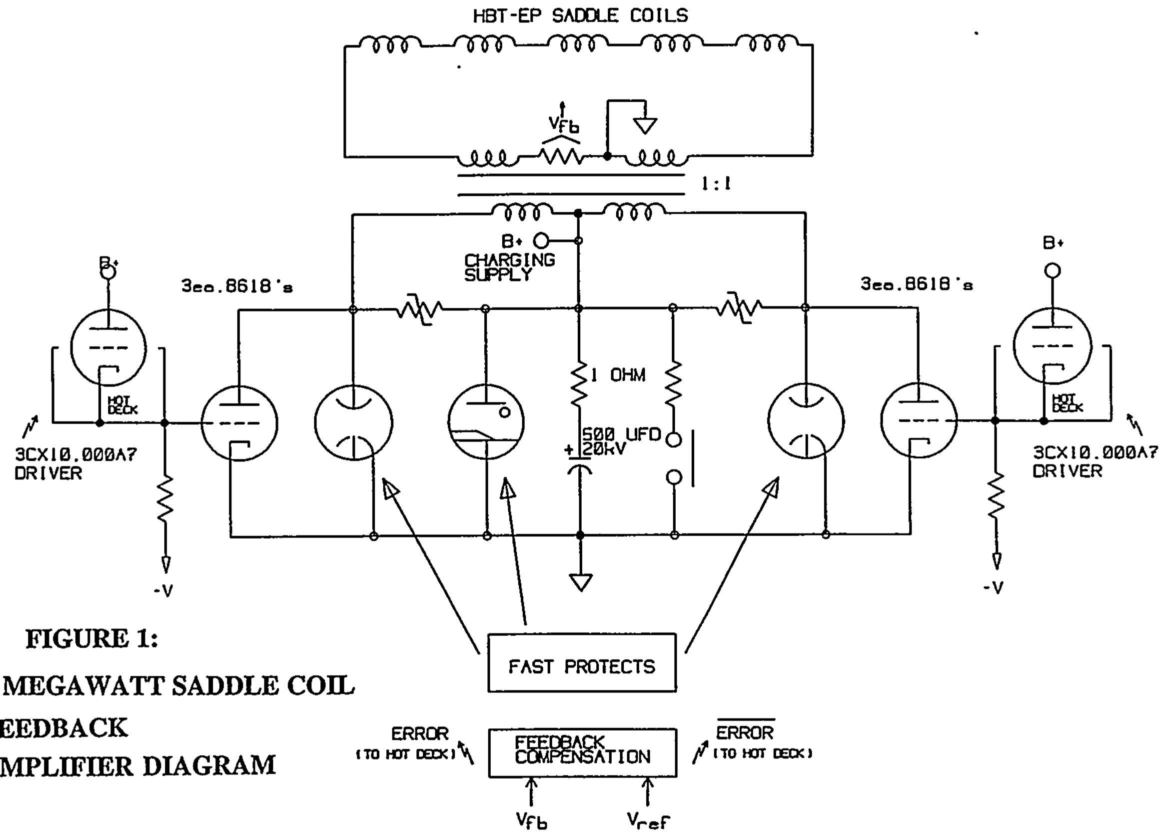

FIGURE 1:
5 MEGAWATT SADDLE COIL FEEDBACK AMPLIFIER DIAGRAM

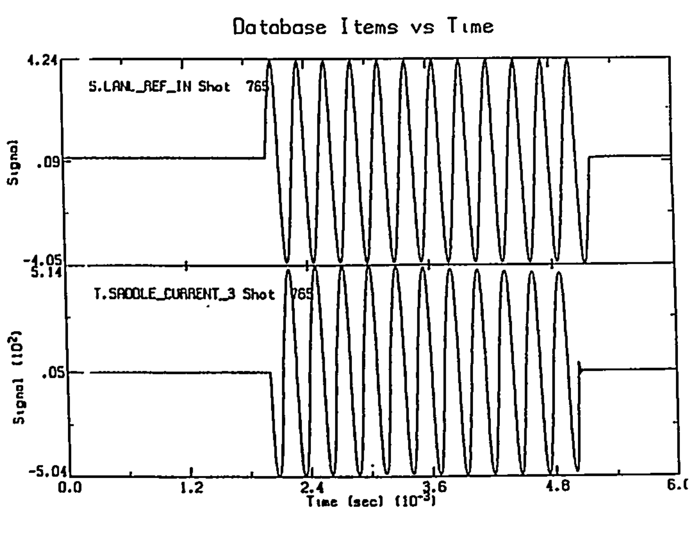

Figure 2. 1000 Ampere Test Waveform

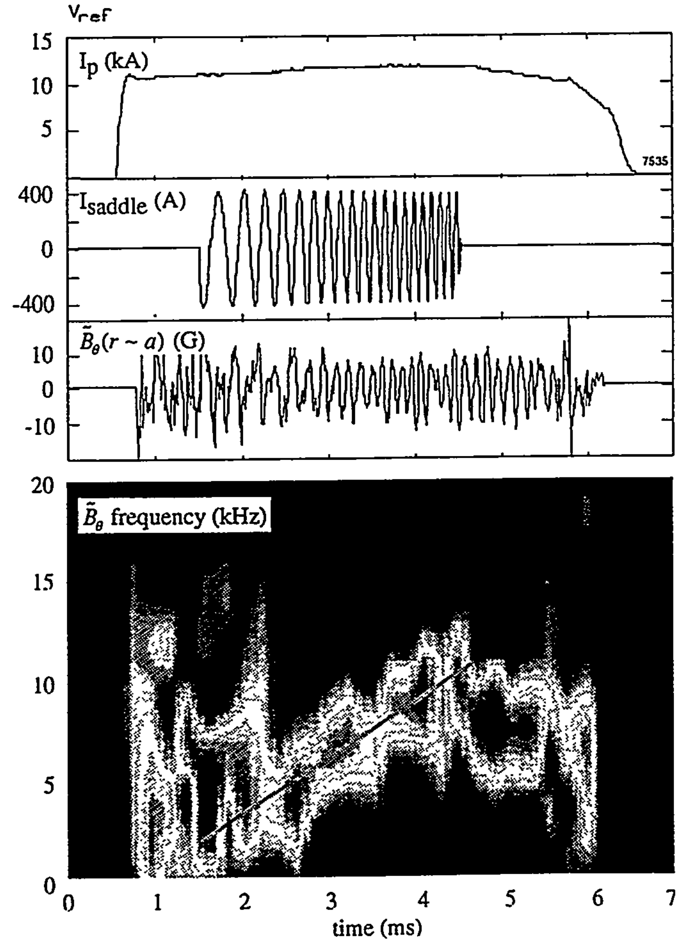

Figure 3. Application of a resonant magnetic perturbation of increasing frequency to a plasma with pre-existing magnetic fluctuations. The saturated instability (colored contours) locks to the applied field (solid line) over the range $f = 4$–11 kHz.

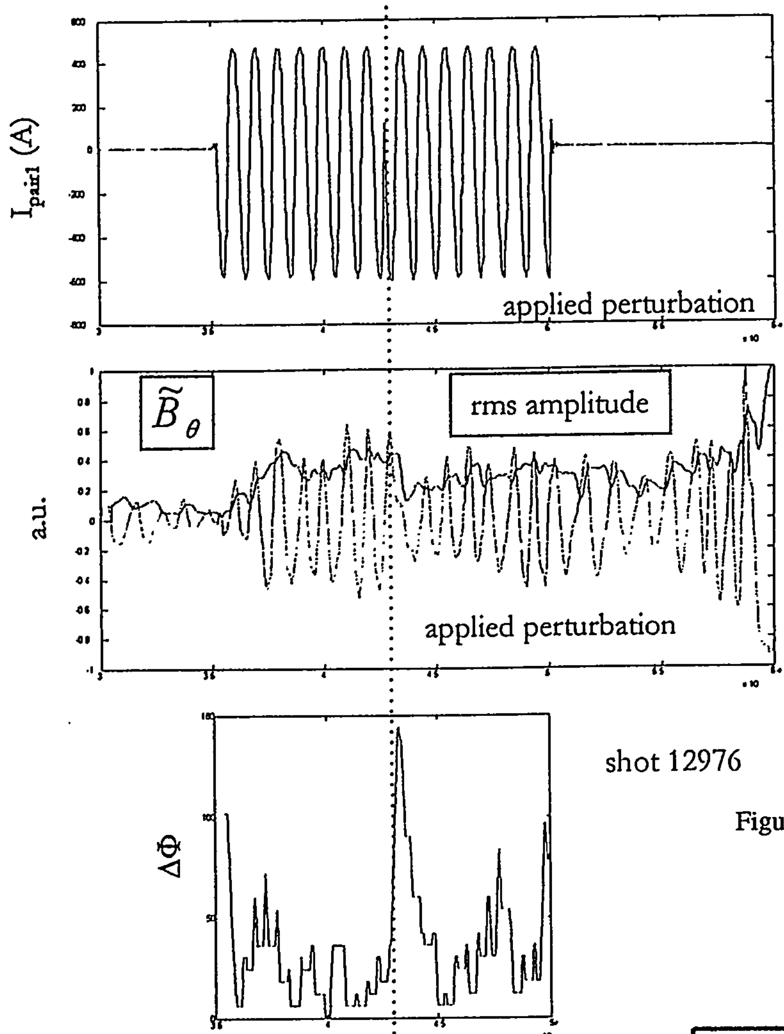

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Figure 4. 1000 Ampere Phase-Flip

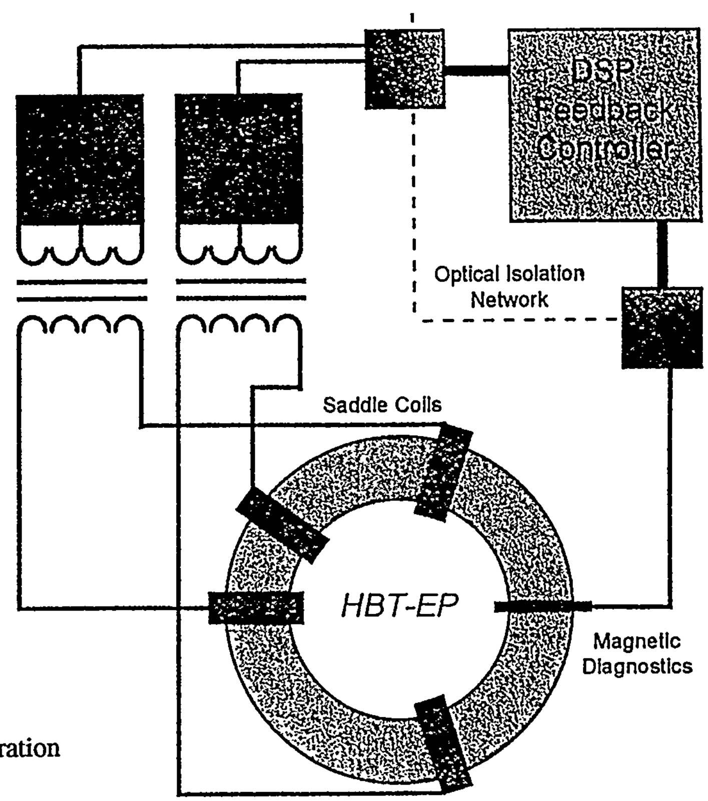

Figure 5. DSP Control Configuration

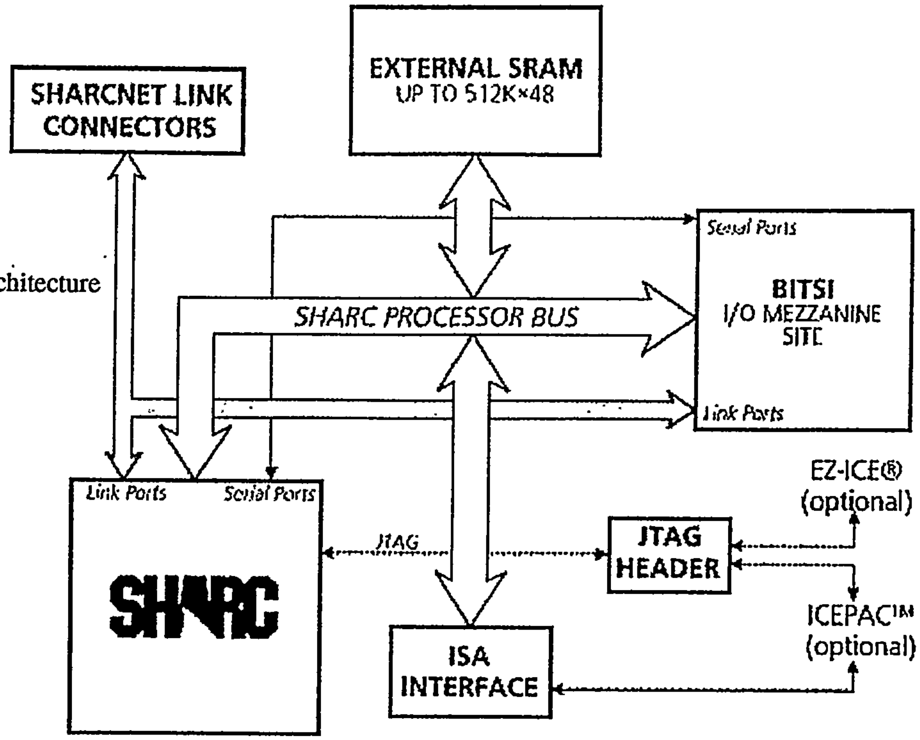

Figure 6. DSP Architecture

IV. SYNCHRONOUS TESTS

For synchronous testing, the two Los Alamos 5 Megawatt amplifiers are configured in the Columbia HBT-EP machine as shown in Figure 5. The DSP is located in the control room with amplifier and diagnostic I/O isolated by analog opto-couplers. The DSP is an Analog Devices SP-21060 operating at 40 MIPS, configured as shown in Figure 6. The present limitation is with the 100 kHz (12 bit) I/O daughter cards. As an additional clock cycle is needed for each read and write cycle, significant phase-shift occurs within the pass-band of interest. A 10 kHz waveform would have only 10 samples, less two for read & write. This would result in an additional 72 degrees phase shift in the closed loop system. Unfortunately, for the bandwidths of interest, stable system operation with the DSP's has not been attained. Once stable operation has been attained, either by reduced active bandwidth or with improved analog I/O, synchronous plasma control efforts will become very intensive.

V. CONCLUSION

Los Alamos delivered the first amplifier in July 1995 and the second amplifier in August 1996. Both units were delivered within schedule and budget. Both units have proven to be very reliable with only two unscheduled downtimes with 3 "amplifier-years" of operation. One was a blown interlock resistor (wrong value installed) and the other an "offset null" adjustment. This exciting experimental program continues with increased effort and understanding into disruption control physics. These results can have a very significant and meaningful impact on the overall fusion program.

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