APS, IPNS, ISIS, AND KEK COLLABORATION ON A LOW OUTPUT IMPEDANCE AMPLIFIER AND SECOND HARMONIC BEAM STUDIES ON THE ISIS RAPID CYCLING SYNCHROTRON

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INTRODUCTION:

An informal collaboration between the scientists at Argonne, KEK, and ISIS was initiated in 1996 on a prototype 2nd harmonic, low-impedance amplifier system for test on the ISIS synchrotron. The intent was to pool limited R&D funds to pursue a mutually beneficial study of interest to all three laboratories. The prototype low–output-impedance system was built and tested in Japan during the period from October 2000 to July 2002. The KEK laboratory provided the amplifier and cavity supply, the ISIS laboratory provided the cavity, and Argonne National Laboratory provided the power supply for the final tube. Preliminary tests of the fully assembled system have been successfully completed. Output impedances of less than 30 ohms have been achieved. The amplifier was tested in fixed frequency mode at several frequencies over the operating band. It was also tested in swept mode, but not yet at full cavity voltage. The cavity has been sent back to the UK and the other components are to be shipped before March 2003.

A plan for follow on installation and tests at ISIS is under development. Although tests with beam on the ISIS synchrotron were part of the original agreement, sufficient time has passed since the start of the collaboration that it would be worthwhile to review the benefits to the partner laboratories of the experimental program. It is the intent of this note to identify the benefits, outline the estimated schedule of activities, and identify the incremental costs in completing the program.

LOW-OUTPUT-IMPEDANCE SYSTEM

The three participating laboratories, at which, in early 1980's, facilities were built using spallation neutrons as a fundamental probe for material research, have their on-going projects and/or the future plans to increase the beam power to the neutron production target. In order to capture and accelerate higher beams without beam losses, compensation techniques for heavy beam loading are essential. The beam loading for the accelerating mode cavity has been overcome successfully by the beam-feed forward system combined with the beam-phase loop to damp the dipole oscillations. A 2nd harmonic system is used to control the beam density distributions. Although a 2nd harmonic system is operated in the non-accelerating mode, i.e. beam-cavity phase is

nearly zero, a large 2nd harmonic component of the beam would distort the cavity voltage, resulting in unstable control of the density. The low-output-impedance amplifier can provide a method to control the beam distribution more effectively because the beam loading to the system is negligibly small.

BENEFITS TO PARTICIPATING LABORATORIES:

ARGONNE NATIONAL LABORATORY:

There are two facilities at Argonne considering second, or higher, harmonic RF systems, the Intense Pulsed Neutron Source (IPNS) and the Advanced Photon Source (APS).

IPNS is building a 3rd amplifier and cavity system for the Rapid Cycling Synchrotron (RCS). The amplifier and cavity will act as a spares for the main accelerating system for the RCS. It will also be configured to be able to operate at the 2nd harmonic to test capture efficiency with the addition of a higher harmonic RF system. It will not be possible to operate this system over the full acceleration cycle because the frequency range of the ferrite for the existing system is too low for the higher 2nd-harmonic frequencies. A proposal has been presented to DOE to build a new 2nd harmonic system for IPNS. Funding for this proposal has not yet been approved.

The prototype program at ISIS will be of considerable value to both stages of the IPNS 2nd-harmonic program because of the close similarity of the two systems. The operation of the low-output-impedance amplifier used in the prototype for ISIS will be of considerable value for IPNS. A similar type amplifier could lead to more stable operation and less beam loss during acceleration because beam loading is more effectively handled by a low-output-impedance amplifier. This might be even more valuable for a 2nd harmonic system since the amplifier is operated at a non-accelerating phase angle.

APS is considering a higher harmonic RF system for the 7-GeV storage ring. The goal would be to stretch out the bunches longitudinally which would result in an increase in the lifetime of the stored beam and an increase in the single bunch current instability limit. This would allow operation of the storage ring with smaller emittances that would result in higher x-ray production from the undulators.

APS also would benefit from tests of the solid state Buck-Regulator (BR) element of the plate power supply that was supplied by Argonne National Laboratory. This device regulates the voltage and provides fast shutoff protection of the vacuum power tube in the event of an internal arc. The APS has five 1-megawatt klystron stations that currently have voltage regulation and arc protection provided by an SCR regulated power supply and a mercury-ignitron tube crowbar circuit. The mercury in the ignitrons, although small in volume, still represents a waste disposal problem and a potential environmental risk if the ignitron's ceramic envelope should break. Successful operation of the BR during the ISIS tests would effectively be a test bed for a BR on the APS klystron systems. Also, if the solid state switching technology of the buck regulator is utilized at the APS, the level

of power line related sidebands on the RF are significantly reduced. This, in turn, will reduce APS beam motion.

KEK LABORATORY:

The KEK and JAERI laboratories in Japan are jointly pursuing an interdisciplinary facility based on a high intensity proton accelerator complex known as J-PARC for Japan Proton Accelerator Research Complex. One element of the accelerator complex is a RCS with an average power of about 1 megawatt of beam power that would be a larger and more robust version of the ISIS RCS. The higher beam power and higher bunch density that will be required puts a heavy burden on the RF systems. The prototype low-output-impedance amplifier could provide the robustness needed to capture and accelerate the intense beams in the J-PARC RCS. A second harmonic system would also increase the ability of the J-PARC RCS to accelerate the beams that are required. Testing the 2^{nd} harmonic, low-output-impedance amplifier system on the ISIS accelerator will relate directly to the J-PARC program and will provide important experience on which the future accelerator complex will be based.

RUTHERFORD-APPLETON LABORATORY (RAL):

The ISIS facility at the RAL currently has a funded upgrade program in progress to add a 2^{nd}-harmonic RF system to their RCS. The goal is to increase captured and accelerated beam for delivery to the neutron production target. Since the 2^{nd}-harmonic RF system is already under construction, the prototype, low-output-impedance amplifier system will not have any direct impact on the current program. However, the results of testing the prototype might influence future programs at RAL, for instance, the addition of a higher energy synchrotron to extend the power of the present facility to match that of the SNS facility under construction at the Oak Ridge National Laboratory in Tennessee.

There will be an additional benefit to RAL from participation of the ANL and KEK scientists in the 2^{nd} harmonic studies program. Scientists from the collaboration laboratories will increase the intellectual manpower base helping to take data and analyze the results of their preliminary studies program that are planned using some of their existing RF systems at the 2^{nd} harmonic during injection and early acceleration.

MAJOR ACTIVITIES AND ESTIMATED SCHEDULE OF ACTIVITIES:

Hardware and data collection will be taking place at KEK and RAL. Analysis of data and experiment preparation activities are planned at all three collaborating laboratories. Specifically;

At the KEK Laboratory:

October 2002– July 2003:

Completion of low-output-impedance (LOI) amplifier tests at the KEK laboratory.

Ship LOI amplifier to ISIS.

At the Rutherford Appleton Laboratory:

October 02 – Jan 03

- Build first HPD, test and install in SP5 location in Dec
- Complete installation of cables and services to SP5 and SP6 cavities,

Jan 03 – Sept 03

- Prepare site utilities and installation space for LOI amplifier installation at ISIS

[Installation depends on space in building R5.2 being available if the 'MICE' experiment is given the ok (Decision Jan) and manpower and funding approved].

- First experiments on 2nd Harmonic capture on ISIS accelerator
- Install 2nd HPD

Oct 03 – Feb 04 long Shutdown

- Installation of two more cavities in SP4 and SP8
- Complete services to all four cavities
- Install LOI amplifier in SP8 cavity if results from first two cavity operations are successful.

March 04 - onwards

- Establish ISIS beam, 1 cycle
- Studies with LOI amplifier on ISIS

It is understood that this schedule will depend on the operation periods of ISIS and could be drastically changed as operational necessity demands. These dates are the best estimates at the present time.

Incremental costs to complete program:

The remaining significant costs are: shipping remaining LOI equipment from KEK to ISIS; installation of utilities and amplifier; modification of LOI control system to be compatible with ISIS control system; travel for participants from Argonne and KEK laboratories; and miscellaneous equipment and data handling systems for running the experiments.