The following action items emerged from the Tune Feedback Workshop, held March 9-11 at BNL

1. Tune – all action items were related to the '60Hz problem'. It has been clearly demonstrated that the beam in RHIC is excited at the betatron frequency by high harmonics of the 60Hz mains frequency that appear on the main dipole bus. This excitation has also been seen at the PS and SPS at CERN, and in the Tevatron at FNAL. The amplitude of coherent oscillations seen in RHIC is estimated to be ~5 microns. This excitation contributes uncorrelated phase information to the PLL tune tracker, and has been observed to cause loss of lock.
    a. 720Hz balancing - Hardware exists in RHIC for balancing the 12-phase converters. Due to the fact that this has previously not been identified as a problem, that hardware has never been commissioned. It is urgent that the hardware be commissioned and the amount of suppression gained be quantified as soon as possible.
    b. It is urgent to determine the magnitude of expected mains ripple at LHC, and what means will be available to suppress this ripple. The problem is potentially much more severe at LHC. Due to the ~x7 lower revolution frequency much lower (and consequently stronger) harmonics of the mains frequency will excite the beam at the betatron line.
    c. Operation without filtering - The first choice is obviously to have the 60Hz harmonics suppressed at their source. It is likely that balancing and filtering will not result in complete suppression of the 60Hz harmonics. In that case, successful operation may yet be possible by adjusting loop gains to increase dither sufficient to adequately sample the beam response on both sides of a given mains harmonic. This approach is potentially perilous, and must be quantitatively investigated with beam.
    d. filtering without tune feedback - If operation with increased dither is not robust, then filtering must be considered. The PLL will inevitably see the phase shift of any filter as the tune crosses the mains harmonics. Loop stability will also be diminished by the time delay introduced by the filter. It is possible to digitally implement zero phase shift filters, at the expense of doubling the time delay. With knowledge of the mains frequency, it is also possible to digitally compensate the phase shift introduced by a mains filter. Just the same, parking a filter in the middle of a PLL bandwidth is tricky business, and if seriously considered will require substantial investigation.
    e. filtering with tune feedback - The filtering problem might be simplified with tune feedback on, by parking the tune midway between two mains harmonics, and lowpass filtering just below the mains frequency. This is in some sense a simple and elegant solution, but has the dual disadvantages of limiting PLL loop bandwidth to something significantly less than the mains frequency, and permitting reliable operation of the PLL only with tune feedback on (an undesirable constraint at any time, and particularly damaging when one is commissioning).
    f. 60Hz frequency fluctuations - mains frequency fluctuations of 0.1% have been observed in machine operations, and twice that or more may be expected in the long term. The two previously mentioned options will require real-time

measurement of line frequency, and the communication of that measured frequency to any algorithm that seeks to control or compensate the effects of the mains harmonics.

2. Chromaticity - Repeatable and reliable chromaticity measurement during ramping has been demonstrated in RHIC, by observing the tune modulation resulting from a 1Hz 100 micron radial modulation.
    a. Effect of chromaticity on PLL operation – evaluation at RHIC showed that 245MHz PLL operation was very weakly dependent on chromaticity. While this is also expected to be true for the baseband PLL, it needs to be verified.
    b. Orbit feedback at 1Hz will be implemented in LHC, and is essential for successful operation of the collimation system. Obviously, radial modulation at 1Hz for chromaticity measurement will fight with the orbit feedback. One possibility is to modulate the radius at a multiple of the orbit feedback frequency, say at 2Hz. Detailed investigation of the effect of a 2Hz radial modulation on both the orbit feedback and collimation systems must be accomplished.
    c. chromaticity feedback - beam time was requested during RHIC run 5 to test implementation of chromaticity feedback at injection. To the best of our knowledge, this feedback has never been implemented via the PLL tune measurement method, and requires testing. Critical path item is magnet control. It is essential that this test be accomplished asap.
    d. chromaticity feedback 'runaway' scenario – In the presence of tune modulation, the PLL always has a finite phase error while tracking, the actual amplitude of tune modulation is greater than what is measured, and similarly actual chromaticity is greater than what is measured. When a feedback loop is closed on chromaticity, the resulting correction value will be less than what is actually required, and in the presence of rapidly changing chromaticity (for instance, at snapback) the resulting under-correction of chromaticity will result in greater tune modulation in the next measurement interval, greater phase error in the PLL tracking, greater error in the tune and chromaticity measurements, greater under-correction of the chromaticity by the chromaticity feedback loop,…. This runaway might be alleviated by adjusting the parameters of the chromaticity loop, at the expense of stability. A more reliable approach would be to correct for the PLL phase error in calculating the depth of the tune modulation. This requires investigation with beam at RHIC.
    e. effect of non-linearities - In RHIC operations we see that it is not unusual for non-linear chromaticity to be larger than the linear chromaticity. This requires that linear chromaticity be comparatively small. In this case, chromaticity feedback would be unstable, and could be driven to the wrong sign. More detailed investigation of the actual quantitative situation is needed.
    f. The Bruning method - It has been proposed to measure chromaticity by fast (ie faster than synchrotron frequency) phase modulation of the RF, rather than by slow radial modulation. Earlier, it was thought that this method required that the PLL loop bandwidth extend up to the phase modulation frequency, an unrealistic requirement. Recent investigation suggests that this is not true, that

it is only needed to measure the strength of the line generated in the spectrum by the modulation. This requires further attention to determine whether this method might overcome the radial modulation problems (orbit feedback, collimators) mentioned above.

3. Coupling - In the experience at RHIC, coupling has emerged as a show-stopper for tune feedback, driving the tune feedback loop (ie the system of PLL plus magnet control) unstable.
    a. the LHC specification - the specification does not adequately address the problem coupling poses for tune feedback. An improved coupling specification is required.
    b. robust PLL in presence of coupling - the possibility of developing a PLL architecture that is robust in the presence of coupling requires further investigation. This problem is presently viewed to be non-trivial.
    c. 6 parameter measurement - this measurement method (references available on Design Review web page) is viewed to be most favored, as it requires no perturbation to the machine beyond operation of the PLL (unlike the skew modulation method, which requires modulation of skew quads and the consequent additional stress on the PLL tune measurement). Further investigation of this method at RHIC, including tests of coupling feedback, is essential.
    d. additional receivers for coupling - operation of the PLL at baseband permits phase synchronization of PLL receivers at widely separated geographic locations. Installation of additional receivers as needed to measure coupling phase relative to the correction families appears desirable, and should be further investigated.
4. The Direct Diode Detection AFE
    a. the 3D AFE derives improved S/N by moving all the betatron lines in the beam spectrum to baseband. One might argue that coherent signal power adds as the number of lines n, whereas noise adds incoherently as root n, so that the overall S/N should improve as root n. However, one might also argue that if the primary source of noise in this system is beam noise, then the noise floor is the Schottky noise and S/N could improve as something better than root n. This requires further clarification.
    b. pre-filter evaluation - Conflicting results have been obtained by filtering the beam signals before the diodes. Significantly improved S/N has been observed in some cases, and not in others. This requires further evaluation.
    c. time constant evaluation - analytic modeling suggests that S/N can be significantly improved by proper selection of time constants. This requires detailed quantitative confirmation.
    d. the damper - PLL excitation must live beneath the damper sensitivity. Verify adequate resolution below 1 micron is available.
5. The DAB board
    a. delivery of DAB 64x - decision has been made to forego any further efforts on the DAB32 board, due to incompatibilities with gate array on the more recent board. Delivery of DAB 64x board is on the critical path, and must be expedited.

    b. vXworks drivers - requires communications between Larry Hoff and specialists at Triumf.
    c. DSP module in gate array - floating point available?
    d. Timing requires additional attention. Beam synchronous timing is not required, but the need for additional timing information (is there anything beyond time-stamping?) requires investigation
6. the FEC
    a. need spec from LHC, check compatibility with RHIC, order
    b. preliminary C code speed test - stripped down c-code from 245MHz system, needed to determine functional boundary between gate array and FEC
7. Interface to magnets and controls
    a. define memory map
    b. define ADO parameters
    c. define labview control parameters - compatibility with CERN?
    d. GPMs, archiving
    e. assure that hooks are in for feedforward for tune, chrom, coupling,…
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