THE AVERAGE ORBIT SYSTEM UPGRADE FOR THE BROOKHAVEN AGS[*]

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INTRODUCTION

The flexibility of the AGS to accelerate protons, polarized protons and heavy ions requires average orbit instrumentation capable of performing over a wide range of beam intensity (10^9 to $6x10^{13}$ charges) and accelerating frequency (1.7MHz to 4.5MHz). In addition, the system must be tolerant of dramatic changes in bunch shape, such as those occurring near transition. Reliability and maintenance issues preclude the use of active electronics within the high radiation environment of the AGS tunnel, prompting the use of remote bunch signal processing. Recently renovated electrostatic beam position detectors will be used to provide both radial and vertical bunch signals from 72 locations around the AGS. The high dynamic range requirement is addressed by using a narrowband *implicit normalization* scheme to provide a linear output with beam position. This paper will describe the basic objectives and design concepts for the AGS Average Orbit system upgrade.

SYSTEM OBJECTIVES

It is desired to build an average orbit measurement system using the recently modified PUE (Pick Up Electrode) detectors currently used for orbit acquisition. The original internal signal wiring in these detectors has been replaced with radiation-hard shielded cable, and new vacuum flanges with coaxial connectors have been installed. These electrostatic detectors exhibit a linear differential response with beam position.

The improved BPM system should be able to operate with one or more bunches in the AGS, over a wide range of bunch lengths (typically 10 nsec to 300 nsec). Since the detectors are electrostatic, the peak amplitude of the bunch signals will vary over a wide range. Although intensities from 10^9 to $6x10^{13}$ charges appear to imply a dynamic range of ≈95 dB, actual peak PUE voltage variations can add another 20dB to this requirement, when the effects of non-zero beam position and bunch signal shape are taken into account.

Concurrent with the dynamic range requirement, the system operates over an RF sweep of 1.7MHz to 4.5 MHz, with PPM (Pulse to Pulse Modulation) compatibility. [PPM would allow the AGS to accelerate alternate types of particles on a pulse by pulse basis]. In addition, maintenance and reliability issues dictate that there be no active electronics located inside the high radiation environment of the AGS ring.

Augmenting its use as an average orbit monitor, the upgrade can also be used to instrument the radial control loop function, adding the flexibility to choose any combination of BPM locations for horizontal position feedback.

DESIGN STRATEGY

The upgrade for the AGS Average Orbit system is divided into three areas; 1.A new PUE signal delivery system; 2.New average orbit processing electronics; and 3.Centralized peripheral and data acquisition hardware. Figure 1 indicates the locations and functionality for the upgraded hardware. A distributed processing architecture was chosen to minimize the PUE signal cable lengths, the group of four from each detector location being phase matched to within ±5°.

The design of remote electronics with >95dB dynamic range implies isolation and filtering requirements calling for a "closed" processing front end to minimize corruption of the low level bunch signals. As such, inputs and outputs other than the PUE signals are fiberoptically coupled for maximum isolation. Processing will be done in the frequency domain, operating on only a single spectral component of the PUE signals. Localized BITE (Built In Test Equipment) circuitry functions to verify proper operation of the remote processing electronics. RF calibration and Local Oscillator (LO) signals are provided by the existing AGS LLRF system, and are shipped to the remote service buildings for distribution. The BITE circuitry provides: 1.Swept-frequency calibration signals and LO; 2.Common-mode amplitude control of the test signals to verify system dynamic range; 3.Differential-mode amplitude control of the test signals to simulate several different beam positions and 4.A zero position reference prior to the start of each AGS cycle.

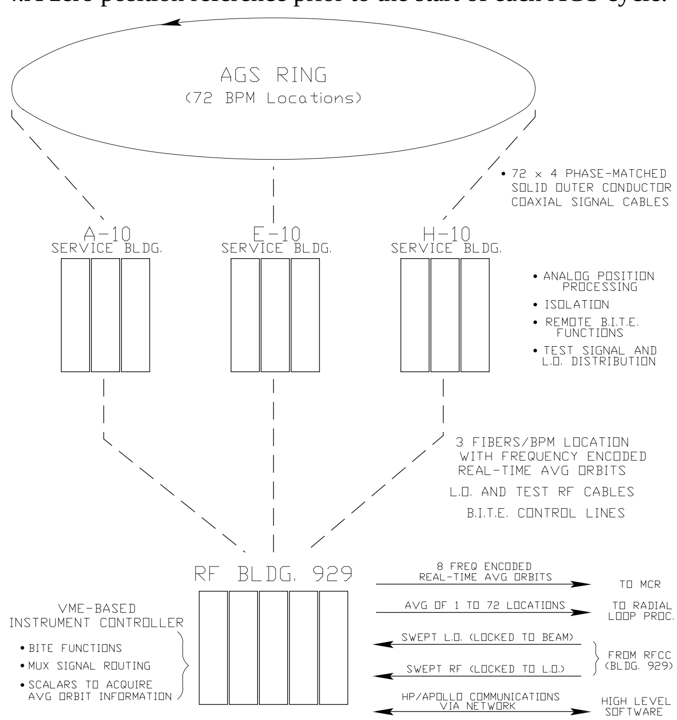

Figure 1. System Overview.

NEW HARDWARE

Design Of A New PUE Signal Delivery System

Figure 2 illustrates the "extended Faraday cage" concept used by the upgrade, necessary to satisfy the contradictory requirements of operating on very low intensity PUE signals using only passive

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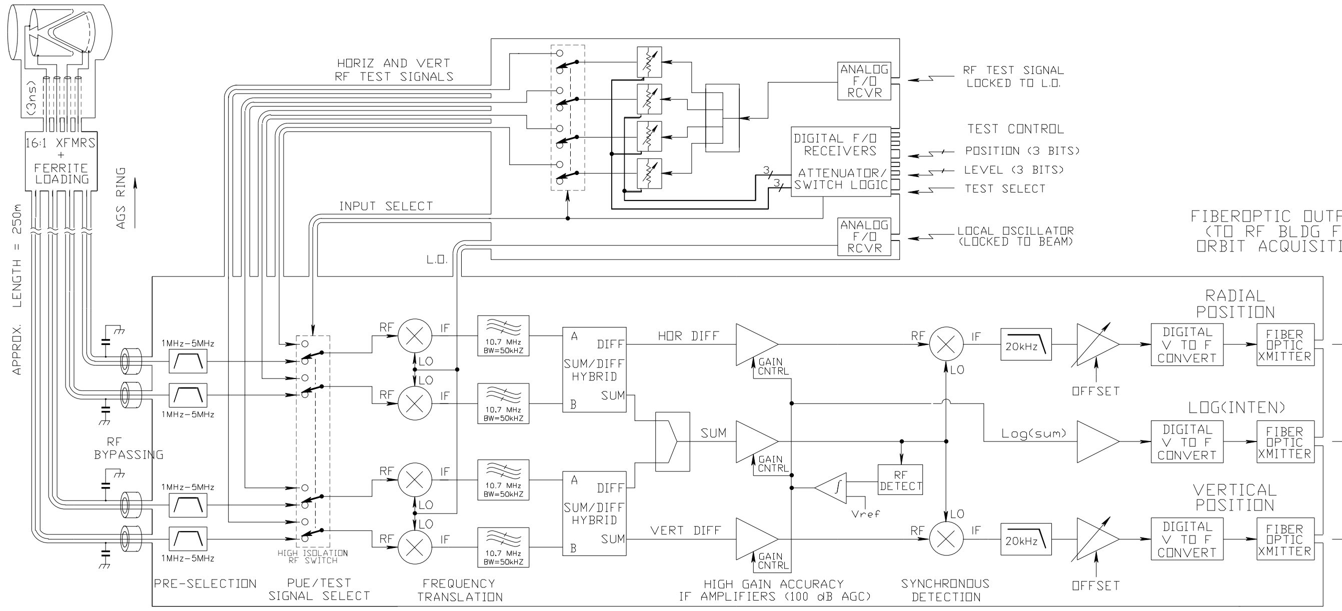

Figure 2. Block Diagram Showing "Extended Faraday Cage" Topology and Implicit Normalization Technique.

electronics in the ring. Of paramount importance is the use of high quality (i.e., low loss, solid shield) coaxial cable, which serves as an extended electrostatic shield from the beampipe to the electronics. Four phase-matched cables from each detector location bring the PUE signals out of the AGS, into three remote service houses for analog processing. All other inputs or outputs to the processing electronics are coupled via fiberoptics to minimize the number of breaks in this "closed system" topology (see Figure 2). Power supplies are "floated" to allow the electronics to be referenced to beampipe potential.

A preliminary design (16:1 and 36:1) for a wideband monofilar autotransformer is currently being tested in the AGS to match the high impedance electrostatic PUEs to commercially available 50Ω coaxial cable. The minimum impedance ratio of this transformer is 16:1 (800Ω to 50Ω), determined by the low end of the rf frequency sweep (1.7MHz). The maximum impedance of the primary is a trade-off between the -3dB response at the low end and signal reduction due to transformer action. The device must be located outside the high B field of the bending magnets (where the vacuum flange of the detectors are located), making necessary a small amount of additional cabling. The capacitance of this extra cable, when added to that of the 3nsec internal BPM lead-out cables, results in a voltage attenuation of approximately 10dB. In addition, these cables are not terminated in their characteristic impedance, and collectively respond to the beam with quarter-wavelength peaking at ≈85MHz. The transformer assemblies include lossy ferrite beads on the high impedance side to help damp this resonance without increasing the PUE capacitance load.

At the remote end of the cable, a decoupling network is formed by wrapping several turns of the signal cable around a ferrite toroid, then capacitively coupling the shield to earth ground. This helps to suppress any stray rf traveling on the outer conductor of the coax from reaching the electronics housing.

Design Of New Position Processing Electronics

The processing electronics located in the AGS service houses provide localized gain and average orbit processing for 72 BPM detectors, each with dual-plane measurement capability. Average position calculation is carried out using a modified form of sum/difference processing, used in conjunction with a high sensitivity AGC (Automatic Gain Control) circuit. In addition to an uninterrupted flow of average orbit information, this architecture also provides a "comfort" output (the AGC error voltage) which roughly relates to the beam current. Observation of this output gives an indication of whether or not the PUE signal level is sufficient for successful instrument operation. All three analog outputs (horizontal position, vertical position and LogI) are isolated using fiberoptic links with digital frequency modulation. The digital links provide dc and rf signal isolation, very high noise immunity, and protection against the amplitude variations normally associated with fiberoptic linearity and attenuation.

Standard heterodyne techniques are used to translate the swept RF component of the bunch signals to a fixed Intermediate Frequency (IF). There are several advantages to doing this; First, position information can be processed narrowband (i.e., at a bandwidth equal to twice the frequency response of the overall BPM system), providing the opportunity to filter wideband noise and f_{rev} frequency components. Secondly, the rf devices used to carry out the position processing need not be broadband. In addition, if the IF is chosen to be an "RF industry standard" frequency (e.g. 10.7 MHz), commercial availability of related rf components increases, significantly reducing their cost.

A block diagram of the implicit normalization technique is included in Figure 2. Due to their somewhat Cos^2 bunch shape, the PUE signals are rich in harmonics of f_{RF}. Since f_{RF} is continuously swept from 1.7MHz to 4.5MHz, some of these harmonics will present themselves as image frequencies and mix back down to the IF, causing interference to the processing circuitry. To remedy this, the IF is chosen to be *above* f_{RF} , and the PUE signals are low pass filtered to reject frequencies above 4.5MHz. This also limits the peak amplitude of the bunch signals as the machine approaches transition; The PUE signal harmonics (which increase dramatically as the bunch length shortens) are suppressed without affecting f_{RF}, the spectral component used to determine the beam position.

The PUE signal spectrum also includes sidebands at f_{rev}, the AGS revolution frequency. The magnitude of f_{rev} can be relatively large as compared to f_{RF}, especially when the ring is not completely "filled". Since f_{rev} is in close proximity to f_{RF} at the low end of the RF sweep ($f_{rev} \approx 371$kHz and f_{RF} sweeps from 1.7MHz to 4.5MHz), it is necessary to reduce the revolution frequency component to avoid saturating the front end amplifiers and confusing the AGC. This is accomplished with the use of a high-pass filter whose passband includes f_{RF} but not f_{rev}.

Following pre-selection, the bunch signals are upconverted, where crystal bandpass filters are used to select the 10.7MHz IF. This passband must be narrow enough to attenuate the revolution frequency sidebands (±371kHz; strongest when the machine is not full), but wide enough to pass the AM sidebands due to beam position movement (±20 kHz). The sum and difference of the IF signals are then taken, resulting in three distinct channels; Horizontal difference, vertical difference and the sum of all four PUE signals.

The amplitude of the SUM channel is maintained at a constant level via 100dB of dynamic gain control. The AGC error signal is used as common feedback to the gain controlled amplifiers of all three channels, dividing the horizontal and vertical differences by the detected sum. The phase of the normalized positions (and hence their sign) are recovered through synchronous detection with the SUM signal. After being low pass filtered and scaled, the analog positions and LogΣ are used to FM modulate three digital fiberoptic transmitters.

Figure 3 shows initial bench test results for the IF/detector section of this processing scheme. The plot assumes a detector sensitivity of 50mm, and illustrates the deviation from expected position due to 0dB and ±1dB IF input ratios (corresponding to 0mm and ±2.875mm, respectively).

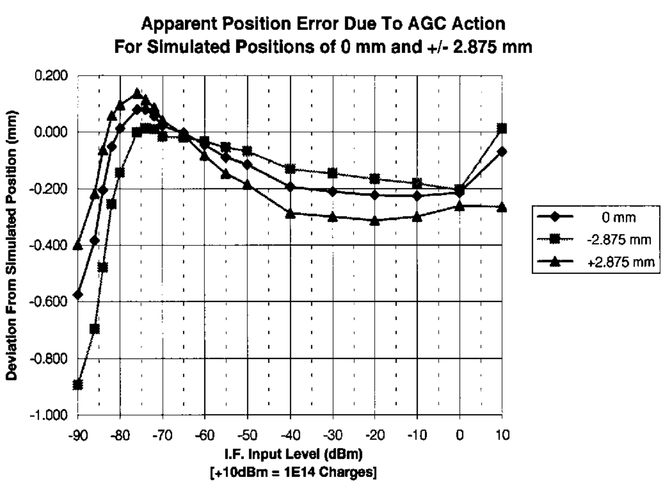

Figure 3. Bench Results For IF/Detector breadboard.

Preliminary results of the implicit normalization method using a pair of actual PUE signals via prototype 16:1 transformers are presented in Figure 4. Trace 1 shows the radial beam position for a full AGS cycle, and is in excellent agreement with the existing AM/PM based position monitor at this BPM location. Trace 2 is the LogΣ output, the AGC error voltage. Actual intensity in the AGS at the time this plot was recorded was 50TP (i.e., 12.5TP per batch), and the PUE signals were attenuated by 76dB before reaching the processing electronics. Note that in actual operation, the processing circuitry will operate on the sum of all four electrodes (rather than just one PUE pair), increasing the voltage to the SUM channel by 6dB.

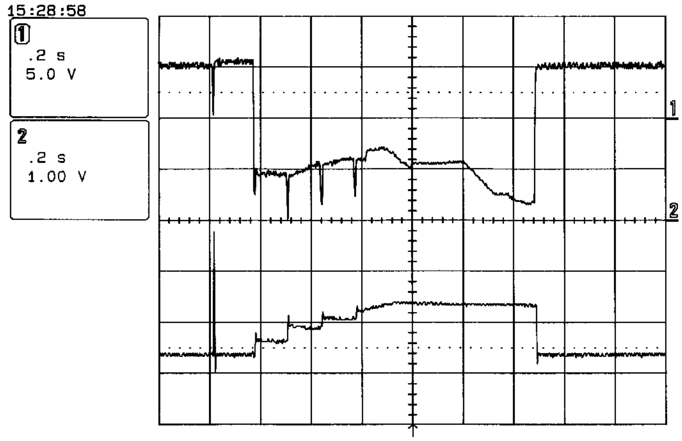

Figure 4. Radial Beam Position and LogΣ Outputs.

Centralized Support Hardware

Peripheral support hardware is centrally located in the RF building, and includes a digital multiplexer (mux) and VME-based Instrument Controller, as well as assorted rf and L.O. distribution amplifiers. The mux is a convenient "tie point" where orbit information from one or more BPM locations can be averaged for the radial control loop function, decreasing its sensitivity to loss of any one particular BPM location. The mux can also be used to route any combination of eight real-time average orbits or LogΣ outputs to the main control room. Finally, the mux provides test accessibility for system troubleshooting.

The Instrument Controller is used to acquire (and make available on the network) the position and LogΣ information from all 72 BPM locations in the AGS. Sample times will be specified as time line events via the high level software. To preserve signal integrety, the controller will receive digital FM orbit data directly, using gated counters (scalars) to input the data. The scalars can also provide additional filtering of the position data by varying the gating interval. In addition to gathering data from the remote processing electronics, the controller will provide control of the mux routing and of the BITE functions used for system test.

CONCLUSION

Initial requirements and design concepts for the AGS average orbit upgrade have been presented. The primary motivation is to seamlessly match the system's dynamic range to that of the AGS, without the need for hardware "changeovers" between runs. To accomplish this, a linear position processing technique based on the concepts of implicit division and AGC has been developed, and initial results presented. The proposed distributed system takes a "laissez-faire" approach to gain control, providing both acquired and real-time orbits.

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