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Tevatron Beam Position Monitor Upgrade Offline Software Specification

Rob Kutschke
Fermilab, Computing Division, EXP Department

Mike Martens
Fermilab, Accelerator Division, Tevatron Department

Brian Hendricks
Fermilab, Accelerator Division, Controls Department

Abstract

This document contains the specification for Beam Position Monitor (BPM) offline software sub-project within the project to upgrade the Tevatron BPM system. An important part of the BPM offline software sub-project is to develop a system for tracking changes to the calibration. The interfaces between the offline software sub-project and other sub-projects will be described.

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1 Introduction

This note defines the work which falls under the Beam Position Monitor (BPM) offline software sub-project within the project to upgrade the Tevatron BPM system. It also identifies work for which co-ordination with other sub-projects is important and it identifies work which is explicitly not part of the project.

The specifications presented in this document are driven by the project requirements document, [Beams-doc-554](#), and it is informed by the specification documents for the front end software, [Beams-doc-860](#), and the online software sub-project, [Beams-doc-1060](#).

The BPM system is being upgraded in parallel with the Beam Loss Monitor (BLM) system. No work related to the BLM system is included in this sub-project.

1.1 Stakeholders in this Sub-project

1. The Tevatron Department, who are the end users of the upgraded BPM system.
2. Those who will have a role in the long term maintenance of the upgraded system. This includes the Controls, Instrumentation, Operations and Accelerator Integration Departments.
3. The members of the upgrade team, including those working on the electronics, the front end software, the online software and the offline software.
4. The management teams of the:
 - a. Tevatron Department
 - b. The BPM upgrade project
 - c. The Tevatron Luminosity upgrade project..

1.2 Definition of Offline Software

For purposes of this document, the BPM offline software is defined to be software which uses BPM data but which can neither read from the live accelerator complex nor control the BPMs. Most of this software is privately maintained and privately operated; usually it is not available from the VAX consoles or the JAVA web pages. Mike Martens, for example, has private codes for doing orbit studies and Valeri Lebedev has private codes which study coupling. Martens' software reads orbit data from one of the supported databases; these databases will be discussed in section 3. Lebedev's software reads BPM data from an ASCII file. This ASCII file is written by online software which is privately maintained by Brian Hendricks. The one supported offline BPM application is the JAVA browser which views BPM data stored in the Sequence Data Acquisition (SDA) database.

Online software, in contrast, is defined to be software which is capable either of reading BPM data from the live accelerator complex or controlling the live BPMs.

Some of the online software is capable of reading both from the live accelerator complex and from one or more of the AD supported databases. For purposes in this document, these applications are considered to be online software.

The newly available antiproton information will be made accessible and used in many online and offline applications. Appendix A gives an overview of this work.

1.3 Time Dependence of Calibration Data

Over the past few years Jean Slaughter lead an effort to improve the accuracy of the old BPM system. This involved redoing some calibrations and updating calibration constants. This work exposed a weakness of the old system that should be improved in the upgraded system: the old system did not keep a history of the time evolution of calibration information. In many ways, this made it difficult to develop, study and deploy improved calibration. The upgraded offline software will expect that calibration data may be time dependent and its design will include support for time dependent calibration data.

1.4 Compatibility with Other Upgrade Efforts

Simultaneously with the upgrades to the BPM system, other parts of the accelerator controls and monitoring software are being upgraded. The BPM upgrade project must remain aware of these efforts and be prepared to coexist with them, so that the various improvements interact constructively, not destructively. Two such efforts have an impact on the offline software, the effort to build a JAVA based controls system and the effort to migrate the VAX-C based controls system to a Unix-C based system.

2 Scope of the Offline Software Sub-project

2.1 Work Expected from Others

This section discusses deliverables on which the offline software project depends and which will be delivered by others. In particular the deliverables from the online software sub-project and from the JAVA group will be discussed.

2.1.1 BPMUTI

The VAX library BPMUTI provides access to the BPM data for all online and offline applications. It can return data either from the live accelerator complex or from one of the supported databases. The online software project includes the work to upgrade the

BPMUTI library. This includes porting BPMUTI to use the upgraded low level data structures, without any changes to the public interface seen by application software, either online or offline. It also includes extending the public interface to provide access to the new information provided by the upgraded instrument.

BPMUTI will be upgraded so that the information from the full Tevatron is always available, even in the commissioning period, during which part of the ring will be instrumented with the old BPM system and part of the ring will be instrumented with the upgraded BPM system.

According to Brian Hendricks, there is no functionality of BPMUTI which is present in the old system but which will be absent in the upgraded system. Therefore, after BPMUTI has been updated, all code, whether online or offline, which access BPM data using BPMUTI should continue to work without modification.

2.1.2 The Orbit Database

The orbit database holds information about a collection of BPMs from around the ring and will be described in more detail in section 3. This database can be read and written by online applications via calls to BPMUTI. The upgrade of this database and the associated parts of BPMUTI are within the online software subproject.

2.1.3 Device Names

In the upgraded system, some ACNET devices will return information which has the same format as that returned by old system. This includes the devices read by the fast time plot and the data logger. In order to simplify the transition, the upgraded system will use the same device names for these devices as were used in the old system.

There are other ACNET devices for which the upgraded system will return information that has different format than that returned by the old system. In order to avoid configuration confusion, the upgraded system will use new names for these devices. See the online software requirements, [Beams-doc-1060](#), for a description of these names. This includes the devices that will be logged for SDA.

2.1.4 Moving Calibration Information to the Front End Computers

The online software project is generally responsible for passing configuration information to the front end computers. This includes calibration constants.

2.1.5 Tasks to be Performed by the JAVA Group

According to Timofei Bolshakov there are three tasks required to upgrade the JAVA software:

1. Modify the tables that control what data is stored by the SDA system
2. Port the upgraded VAX BPMUTI library to JAVA.
3. Add the new ACNET device names to the list of known devices in the data browser.

Because the plan is to create new ACNET devices whenever the old and upgraded systems have format differences, the job of operating during the commissioning period is greatly simplified. Bolshakov has agreed to do both of these jobs and he estimates that duration will be of order several days.

2.2 Work Included in the Offline Software Sub-project

The upgraded BPM system is capable of much greater resolution (precision) than the old BPM system and it has the potential for much greater accuracy. While the full resolution will be available both online and offline, it is likely that the best accuracy will only be available offline. The reasons for this have to do with the complexity of applying some of the corrections needed to obtain the best accuracy. Because the primary function of the online system is robust monitoring of changes to the orbits, not the absolute determination of the orbits, corrections which only affect the accuracy, but not the stability or the resolution, will, at least initially, be reserved for offline use. This will be discussed further in section 4 and 5.

The offline sub-project team will work with the electronics team to develop a calibration which meets requirements specified in [Beams-doc-554](#). This includes the development of algorithms and an understanding of which calibration constants may be time dependent. The offline software sub-project team will work with the online software team to develop a database¹ to hold the time dependent calibration constants. As experience is gained with the system, the calibration algorithms and the format of the calibration information may change. Therefore the database will be designed with the flexibility to allow such changes. The sub-project team will work with the online software team and the front end software team to ensure that the appropriate parts of the calibration software and calibration constants are available at the front end computers.

An integral part of the project is the development of documentation targeted at end users of the system, including the maintainers of the system. This effort needs to be started well before the end of the project so that the transition to operations is smooth.

2.3 Work Not Included in the Upgrade Project

¹ *The word database is used in a generic sense. The solution may be as simple as a set of files which live in a predefined directory. Or a more complex solution may be appropriate.*

2.3.1 Offline Code which Uses Unsupported Access Methods

Offline applications which access BPM data via the supported methods of BPMUTI should continue to work following the upgrade. On the other hand, applications which access BPM data via unsupported methods may break after the upgraded BPM system is deployed. In the general case, these applications use software, such as lattice functions, with which the BPM project team has no expertise. The project team, therefore, will not be able to port code and to certify that the ported code is working correctly. The project does include the preparation of documentation which will describe to the maintainers of the private offline codes how properly access data using the supported methods in BPMUTI.

2.3.2 Final Optimization of Calibration

This project does not include any calibration work beyond that required to deliver a commissioned system which meets the requirements given in [Beams-doc-554](#). However the project does anticipate that such work will eventually be done and the calibration infrastructure will be designed with evolution in mind. The project does involve the preparation of adequate documentation so that it is possible for others to continue work on improved calibrations at a later date.

3 The Supported Saved Data Formats

There are several saved data format that are supported:

1. The Lumberjack database.
2. The Sequenced Data Acquisition (SDA) database.
3. The orbit databases used, for example, by applications T39 and C50 (TOP).

The Lumberjack database holds data which has already been scaled from raw data to engineering units. In the old BPM system, the front ends were not able to perform calibration and returned only raw data. The data logger read raw data from the BPM and used the scaling service to convert the raw data to engineering units. The scaling service is a library of simple, and general, transformations which can be applied to raw data; one can, for example, evaluate a polynomial with the raw data as the argument. The scaling service does not contain the full information about calibration and the full calibration can only be achieved by accessing BPM data using BPMUTI.

In the upgraded BPM system, the front end computers will be able to return calibrated positions and intensities. It will also be able to return raw data when that is requested. The data logger can be configured to read the calibrated data and apply the null transformation² from the scaling service. Therefore the Lumberjack database will continue to work without any changes to offline software.

² *The null transformation returns its input as the output.*

The SDA database holds an image of the raw data for an ACNET device and data in the database should be accessed via the library BPMUTI, or its JAVA clone. Therefore, once BPMUTI has been upgraded to deal with the upgraded data formats, offline code which accesses the SDA database should continue to work.

The code which writes the SDA database is driven by a configuration table which has the flexibility to accommodate the upgraded data formats. No new code will be needed but the tables will need to be updated as each house is commissioned with upgraded BPMs.

In the old system, the orbit database contains only calibrated positions, without a copy of the raw data; the orbit database is read and written using BPMUTI. In the new system the orbit database will also contain the raw data, which will make it easier to develop new calibrations, particularly those which use information from more than one BPM. As was discussed in section 2.1.2, the work to upgrade the orbit database and the associated parts of BPMUTI are part of the online software-subproject. This task is mentioned here because the offline software sub-project includes the development of the calibration system, which will influence the design of the upgraded orbit database.

Some privately maintained offline code accesses the orbit database without going through BPMUTI and instead makes SQL calls. The authors of this code will be encouraged, and helped, to port their code to use BPMUTI.

4 Features of the Upgraded System

4.1 Improved Resolution and Accuracy

One of the main purposes of the upgrade is to deliver measurements of beam positions which are both more precise and more accurate than those delivered by the old system. The work to date, using a modified version of the Recycler Echotek board, shows that the requirement for improved resolution will be achievable. See, for example, [Beams-doc-1076](#) and [Beams-doc-1124](#).

It is less clear what work will be required to meet the accuracy requirements. Because the instrument is much more precise than the old one, it may be sensitive to systematic effects to which the old system was not sensitive. Moreover, some of these effects may be time dependent. It is important, therefore, that the capability of tracking time dependent calibrations be designed into the upgraded system from the start. This capability should prove particularly useful during the final commissioning and early operation of the system, during which time improvements to the calibration procedures can be expected to evolve rapidly.

4.2 Simultaneous Measurements of Protons and Antiprotons

Another of the main purposes of the upgrade is to simultaneously measure the positions of both protons and antiprotons. Although the old BPM system is blind to antiprotons, a

previous version of the system was capable of sequential measurements of protons and antiprotons. It did not, however, have the capability to deal with simultaneous measurements.

The simultaneous measurement of both species requires that one work around the imperfect directionality of the pickups. The signal on the antiproton cable is contaminated by the non-directional component of the signal from the proton bunches. Similarly, the signal on the proton cable is contaminated by the non-directional component of the signal from the antiproton bunches. At the present time, the former effect is much more important because there are about 10 times as many protons per bunch as antiprotons per bunch. As the antiproton intensity increases, however, the importance of the second effect will also increase.

The upgraded system has two modes for separation of protons and anti-protons, the long gate mode and the short gate mode. In the former mode, the Echotek board integrates over many turns. Because of the long measurement time, and consequent narrow resolution bandwidth, the cross-contamination can be well characterized by measurements taken when only a single beam species is present. Using the knowledge of the cross-contamination, the measured signals can be deconvoluted to yield the separated proton and anti-proton signals. In the latter mode, Echotek board is gated to acquire data only when the signal from a single species is present. This cannot be achieved on all BPMs for all cogging states of the Tevatron. These two modes are also referred to, respectively, as separation in the frequency domain and separation in the time domain.

At most BPMs there are some cogging states for which separation in the time domain does not work – there are no times at which one beam species passes through the BPM in isolation from the other species. In this case one might consider modifying the short gate technique to use a deconvolution scheme similar to that used in the long gate sampling mode. It is believed, however, that the resolution bandwidth of this method is too broad and the measurement would be too contaminated by noise at other frequencies to provide good separation. As yet no studies have been made to confirm this speculation.

The upgrade project will implement both modes of operation, long and short gate sampling, and will support switching between the modes. This will allow the Tevatron Department to choose the mode which it finds most useful for each application.

5 Calibration

5.1 Combining Horizontal and Vertical Data

The old BPM system computed the position of the beam in one co-ordinate, either horizontal or vertical, using only the information available from a single BPM. It has long been known that this procedure produces a biased measurement. For example, the

response of a horizontal BPM depends on the vertical position of the beam as it passes through that horizontal BPM. Similarly, the response of a vertical BPM depends on the horizontal position of the beam as it passes through that vertical BPM. These effects are of order of a few hundred microns when the beam is moved from +6 mm to -6 mm in the orthogonal coordinate. In the old system these effects were at the threshold of the resolution of the BPMs and were generally ignored.

When the BPM is used solely as a stability monitor, these considerations can safely be ignored and it remains sufficient to report a position computed using only the information from one BPM. If, on the other hand, one wishes to fully exploit the resolution of the instrument, one must simultaneously use data from several BPMs along with knowledge of the lattice functions.

The plan of the BPM upgrade project team is that the correction for the beam position in the orthogonal coordinate will be used by offline applications but that it will not be used by software which runs in the front end computers. It is also expected that, at least initially, online applications will not use this correction.

5.2 Effect of Non-Parallel Beams

The BPM response depends on the angles which the beam makes with the nominal symmetry axis of the pickup plates. There has been a request from Lebedev to correct for this effect, if possible. This is under investigation but, as yet, no commitments have been made.

5.3 Calibration of the Beam Position

Understanding how to calibrate the upgraded BPM system is still underway. The issues under study include the resolution of the measurement, the stability of the measurement with respect to changes in the Tevatron operating conditions and the absolute accuracy of the system. There are limitations on the absolute accuracy which are outside of the scope of this project. For example, the alignment of each pair of pickup plates relative to the magnetic center of the corresponding quadrupole was measured many years ago. The project team can only trust the manufacturing tolerances and the surveys of the completed components which were done 20 years ago. Therefore most of the work on calibration has gone into understanding how the response of the instrument depends on changes in the Tevatron operating conditions. These studies include,

1. For a single species of beam in the machine:
 - a. What is the algorithm to convert raw data to a beam position?
 - b. What measurements are needed to calibrate the system and to test the quality of the calibration?
 - c. What is the best way to define zero of position?

- d. What is the residual error in all of the above and how does it depend on beam intensity and beam position?
 - e. At an x measuring BPM, if the beam moves in the y direction, but not the x direction, how much does the x measurement change?
 - f. How does the position measurement depend on the slope of the beam through the BPM? The question holds for both x and y slopes of the beam, for both x and y measuring BPMs.
2. When two species of beam are in the machine.
- a. What is the best method to cancel the proton contamination on the anti-proton cables?
 - b. What measurements are needed to obtain and test this calibration?
 - c. How large is the residual error from this technique?
 - d. How does the residual error change as properties of the proton beam change?
 - e. There is also contamination of the signal on the proton cables due to contributions from the anti-protons. How large is the error on the proton position if this effect is ignored? Is it necessary to cancel this contamination? If not now, will it be necessary later?

In all cases, it is necessary to understand the size of the effect, to decide if it needs to be calibrated out and to understand the size of the residual effect after calibration. Moreover it is important to understand which effects require a time dependent correction.

It must also be determined how the calibration depends on the fill pattern of the Tevatron. For example, what is different, if anything, about batch mode compared bunch mode; similarly for a single bunch compared to 12 x 0 or 36 x 0?

Much work has already been done on many of these issues. [Beams-doc-1161](#), for example, proposes the plan for converting raw data to position when only a single species of beam is present. Other examples include the measurements summarized in [Beams-doc-988](#), [Beams-doc-1076](#), [Beams-doc-1124](#) and [Beams-doc-1149](#), which were made using the modified Recycler Echotek board connected to VA15 and HA15. These measurements have demonstrated the resolution which can be obtained using both the long gate sampling mode and the short gate sampling mode. They also illustrate some of systematic effects discussed above and find, qualitatively, that there are many effects which cause position errors of order a few hundred microns. In some cases, the natural scale of the effect is a few hundred microns, which can be corrected to a much smaller size, if required. In other cases the size of the effect, after all corrections is of order a few hundred microns. This work is still in progress.

There also remain some open issues on how to implement a closed orbit measurement in short gate sampling mode. This is discussed in [Beams-doc-1167](#).

5.4 Calibration of the Intensity Signal

When the energy of the Tevatron increases the bunch length decreases, which increases the power at the RF frequency that is coupled from the beam to the pickups. As a result the BPM sum signal increases during the energy ramp-up of the Tevatron, even though the intensity of the beam is essentially constant during the ramp. This is about a 15% effect.

The old BPM system ignored this effect and the raw signal was scaled to a nominal intensity without regard for the beam energy. This was acceptable because the sum signal was never used as a precise measurement of the beam intensity, only as a threshold for validity of the position data and as an on/off indicator.

The default action of the upgrade will be to reproduce this behavior.

5.5 Deployment of Calibration to the Front End Computers

The front end computers of the upgraded BPM system will have ACNET devices which return raw data and other ACNET devices which return calibrated positions and intensities. Therefore the relevant information from the calibration databases must be moved to each front end. In the ACNET model, the front end computers have ACNET devices which can be written to and which can be used to receive calibration information. One of the features of ACNET is a mechanism to persist this information across power failures and other events which cause the front end computers to reboot. When an ACNET device is written to, ACNET records the information in a database which holds the current configuration of all ACNET devices. When a device reboots, ACNET will restore that device to its previous state.

Using this facility it will be straightforward to deploy calibration information to the front ends. One needs to write an online application which will read the appropriate information from the calibration database and write it to the appropriate ACNET devices. The calibration system must be designed so that this software does not require maintenance when the format or other inner details of the calibration information changes.

Whenever possible, when a front end computer returns calibrated data, it should return the database ID of the calibration which was current when the data was taken.

6 Specification of the Offline Software Sub-Project

6.1 Tasks that are Part of the Offline Software Sub-project.

6.1.1 Support Porting of Offline Applications

The online software sub-project team will be available to work with the maintainers of the offline code to ensure that their applications continue to work. It is not possible at the

present time to say how much time this will take and when it will occur. Most likely this will involve little work at random times.

6.1.2 Complete Calibration Studies

Section 5 discussed the work done so far to learn how to calibrate the upgraded electronics. In conjunction with those working on the upgraded electronics, the offline software team will continue with this work until it has reached a conclusion. The deliverables from this work are:

1. A report which identifies,
 - a. What are the calibration algorithms?
 - b. What calibrations parameters are required and how are these to be determined?
 - c. Which of these parameters are time-dependent?
 - d. Which parameters belong in the calibration database even if they are not now believed to be time dependent?
 - e. What are some scenarios for future upgrades to calibration? This is needed to inform the design of the database.
 - f. What calibrations information needs to be moved to the front end computers so that they can report calibrated positions and intensities.
 - g. Which calibrations do not need to be performed until some other, larger, effect is controlled.
2. Prototype code to implement the algorithms.

6.1.3 Develop Calibration Database

The offline software team will work with the online software team, to design and implement a database to hold the calibration information. The database also needs to be accessible from the JAVA applications. This task includes writing of utility routines that write data to and read data from the database.

The design of this database should anticipate that the details of the calibration algorithms and the calibration constants may change with time. In particular the data structures held in the database should be sufficiently self describing that code which copies a data structure from the database to the front end computers does not need to be modified when the structures change.

6.1.4 Code to Apply the Calibrations

Write utility library code which can apply the calibrations to raw data. This includes both code which implements a partial calibration, such as might be done on the front end computers, and code which implements the full calibration.

This code should understand some notion of a default calibration, perhaps the calibration which was current when the data was taken. It should also be possible override the default and ask that a specific calibration be applied.

After discussion with Hendricks it was decided that, because this code is of general interest, it should live in BPMUTI. The code will be developed in this sub-project but will have to be compatible with all requirements for BPMUTI code, as specified by the online software sub-project.

6.1.5 Example Offline Code

The offline team will develop documented, example code which illustrates how to use the full calibration package in a variety of circumstances. This will include examples of how to access antiproton information and how to perform the corrections for the beam position in the orthogonal transverse coordinate. The exact form of these examples will be negotiated with the maintainers of the various offline applications.

6.1.6 Documentation

Prepare documentation on the final implementation of the calibration algorithms, the calibration database and the calibration code. The documentation will be targeted at two groups: users of the system and those who will maintain the system. This tasks includes documentation of the example code.

6.2 Prioritization, Milestones and Estimated Resources

The initial work is to complete the calibration studies, prepare the report and prototype code. This should be complete by July 16, 2004. The work will be done by Rob Kutschke, with some consulting from Jim Steimel, Bob Webber and Mike Martens, and is expected to take several weeks of full time effort.

The database design should be complete by July 23, 2004. A fully functional prototype of the database and the code to apply the calibration should be ready by August 13, 2004. This work should also include the first release of the example offline code discussed in section 6.1.5. At this time, the production database should be loaded with a set of calibration constants which is appropriate for the startup tests on the first crate. If the database is implemented as a collection of files in a predefined directory, this will be done by Kutschke, with consulting from Hendricks and Bolshakov. The above will require a steady state 50% effort from Kutschke and incidental time from the others. If, on the other hand, a formal database is needed the sub-project will need to identify people with appropriate skills to assist.

In the last weeks before the fall 2004 shutdown, it is expected that the first crate of the upgraded BPM system will be installed and will undergo its initial tests. At this time, the

goal of the offline software sub-project will demonstrate an end to end test of moving data from the front ends to the offline applications via SDA. The demonstration should show that offline software can work successfully with a mix of old and upgraded BPMs. Most of this work is to integrate work which will be performed in other sub-projects and, if all of that work is successful, will not involve a lot of effort. It will be done by Kutschke who will be available for 100% effort if needed.

During the fall 2004 shutdown, the lessons learned in the August crate tests will be incorporated into the offline software suite. The goal is to have a fully functional system ready to use when the main commissioning of the upgraded system begins following the shutdown. This will be done by Kutschke at the level of 33% effort.

During the rest of the BPM upgrade project, Kutschke will be available to trouble shoot problems which develop, to continue work on calibration and to finalize the documentation. It is expect that this will require less than 50% effort steady state but there may be short periods for which 100% attention is required.

7 Transition to Operations

The transition to operations needs to begin before the fall 2004 shutdown. Before the shutdown it is important to achieve an end to end demonstration of a prototype system, including the example offline code. During this time it will be important to get feedback from the end users of the system. Although it is unrealistic to expect detailed feedback at this time, a sanity check is critical.

This will be revisited a few times as the first houses are commissioned following the shutdown, hopefully with a more detailed level of feedback each time.

8 Appendix A: Access to Antiproton Information

There is no specific task to provide access to antiproton information; that work is embedded in many of the tasks described in the requirements documents for the front end, online and offline software. This appendix will give an overview of that work.

The offline software team and the electronics team will work together to develop the calibration procedures for the antiproton measurements, including the subset of the procedures which can be performed by the front end computers. The offline and online software teams will work together to store the calibration information in a database. The front end and online teams will work together to download the current calibration information to the front end computers. The front end team will write the code needed to apply the calibration.

The front end computers will be able to report calibrated antiproton positions and intensities for use by fast time plots and for storage in the Lumberjack database. In order to do this, the front end and online teams will work together to define new ACNET devices to return this information. The online software team will update the

configuration files to add the new ACENT devices to the list of devices known to the console menus.

The front end and offline software teams have proposed a data format for returning the full antiproton information, including the raw data for both the proton and antiproton plates. This data structure is designed so that it can be archived in the SDA database by adding it to the SDA configuration table. The front end and online software teams will define a new set of ACNET devices to return this information. The online software team and the JAVA group will add the new devices to the necessary configuration files.

The online software team will add code to BPMUTI to give access to the full antiproton information to any online or offline application which needs it.

The offline software team will develop the library functions, to be added to BPMUTI, that apply the full calibration these measurements. These functions may be called either by online or offline software. The offline software team will also develop examples of how to use these functions in a variety of circumstances.

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