

# **Multiplexed Beam Position Monitor**

## **User's Manual**

Rev. 2.0

**Record of updates**

Version	Date	Updates performed
2.0	01/2020	Review of the full manual. Obsoletes all previous versions

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[www.gmw.com](http://www.gmw.com)  
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## **INITIAL INSPECTION**

It is recommended that the shipment be inspected immediately upon delivery. If it is damaged in any way, contact Bergoz Instrumentation or your local distributor. The content of the shipment should be compared to the items listed on the invoice. Any discrepancy should be notified to Bergoz Instrumentation or its local distributor immediately. Unless promptly notified, Bergoz Instrumentation will not be responsible for such discrepancies.

## **WARRANTY**

Bergoz Instrumentation warrants its beam current monitors to operate within specifications under normal use for a period of 12 months from the date of shipment. Spares, repairs and replacement parts are warranted for 90 days. Products not manufactured by Bergoz Instrumentation are covered solely by the warranty of the original manufacturer. In exercising this warranty, Bergoz Instrumentation will repair, or at its option, replace any product returned to Bergoz Instrumentation or its local distributor within the warranty period, provided that the warrantor's examination discloses that the product is defective due to workmanship or materials and that the defect has not been caused by misuse, neglect, accident or abnormal conditions or operations. Damages caused by ionizing radiations are specifically excluded from the warranty. Bergoz Instrumentation and its local distributors shall not be responsible for any consequential, incidental or special damages.

## **ASSISTANCE**

Assistance in installation, use or calibration of Bergoz Instrumentation beam current monitors is available from Bergoz Instrumentation, 01630 Saint Genis Pouilly, France. It is recommended to send a detailed description of the problem by email to info@bergoz.com.

## **SERVICE PROCEDURE**

Products requiring maintenance should be returned to Bergoz Instrumentation or its local distributor. Bergoz Instrumentation will repair or replace any product under warranty at no charge. The purchaser is only responsible for transportation charges.

For products in need of repair after the warranty period, the customer must provide a purchase order before repairs can be initiated. Bergoz Instrumentation can issue fixed price quotations for most repairs. However, depending on the damage, it may be necessary to return the equipment to Bergoz Instrumentation to assess the cost of repair.

## **RETURN PROCEDURE**

All products returned for repair should include a detailed description of the defect or failure, name and fax number of the user. Contact Bergoz Instrumentation or your local distributor to determine where to return the product. Returns must be notified by fax prior to shipment.

Return should be made prepaid. Bergoz Instrumentation will not accept freight-collect shipment. Shipment should be made via UPS, FedEx or DHL. Within Europe, the transportation service offered by the Post Offices "EMS" (Chronopost, Datapost, etc.) can be used. The delivery charges or customs clearance charges arising from the use of other carriers will be charged to the customer.



## BEAM POSITION MONITOR SYSTEM

The BPM system includes:

### *Description*

### *Order code*

BPM electronics module  
19" chassis with power supply  
number  
Table-top test kit with power supply  
3U-Card extender with coaxial contacts  
RF service module with four front-panel SMA  
TTL controls service module  
with front-panel DB9 and DB15 connectors

BPM-XXX.XXMHz....  
BPM-RFC/X, X = BPM stations  
  
BPM-KIT  
BPM-XTD  
BPM-SERV/RF  
BPM-SERV/CMD

This delivery may include:

Option: Single button sampling  
Option: Fast NIM gate

BPM-SBS  
BPM-FG

If included, these options are mounted on the BPM electronics module.

### **Check that the voltage of the power supply corresponds to the mains voltage.**

On the table-top kit: The voltage is indicated on the power supply module.

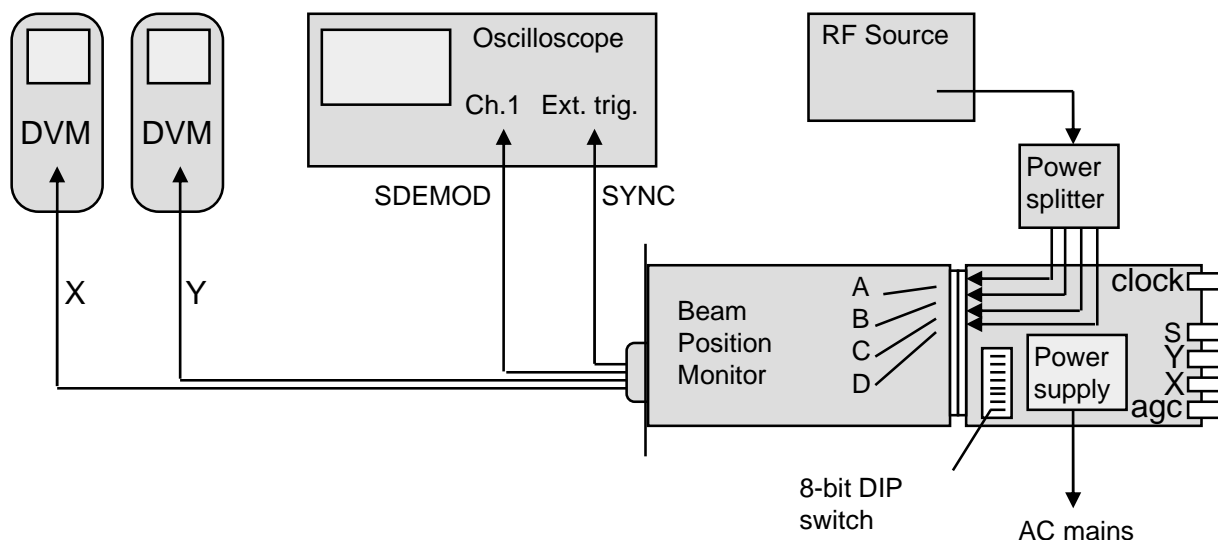
If it does not correspond, use a transformer or contact the manufacturer to get another power supply.

In the 19" chassis: The power supply is autoranging (98V...264V) and does not need any adjustment.

## QUICK CHECK

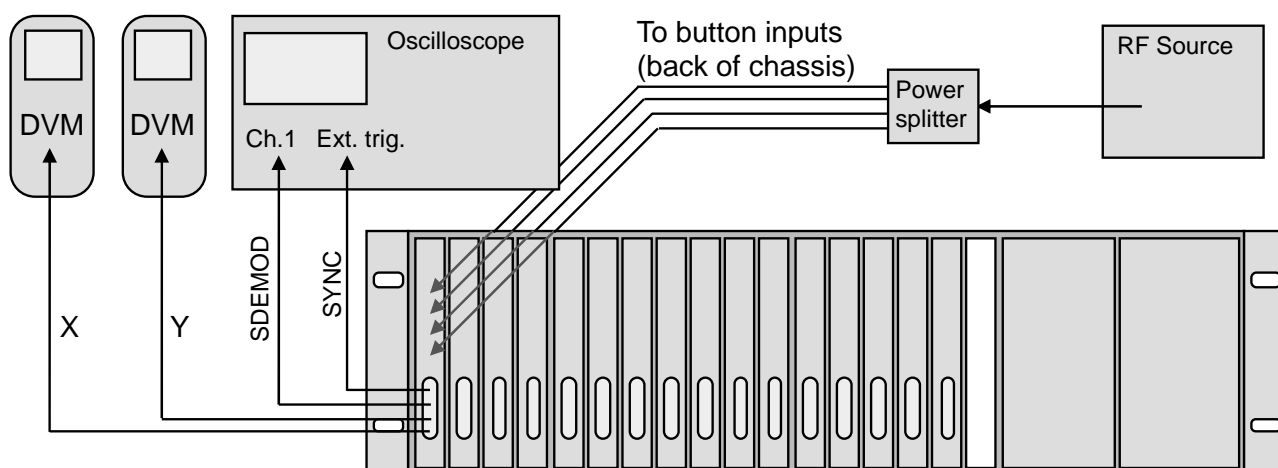
You can check immediately that your BPM system is working.

If the table-top test kit (BPM-KIT) is part of the MX-BPM set, use the following set-up:



**Place all DIP switches to the left: OFF**

If a 19" chassis (BPM-RFC/X) is part of the MX-BPM set, use the following set-up:



Attach the equipment together as shown above.

Set the oscilloscope time base on 0.2 ms / div.

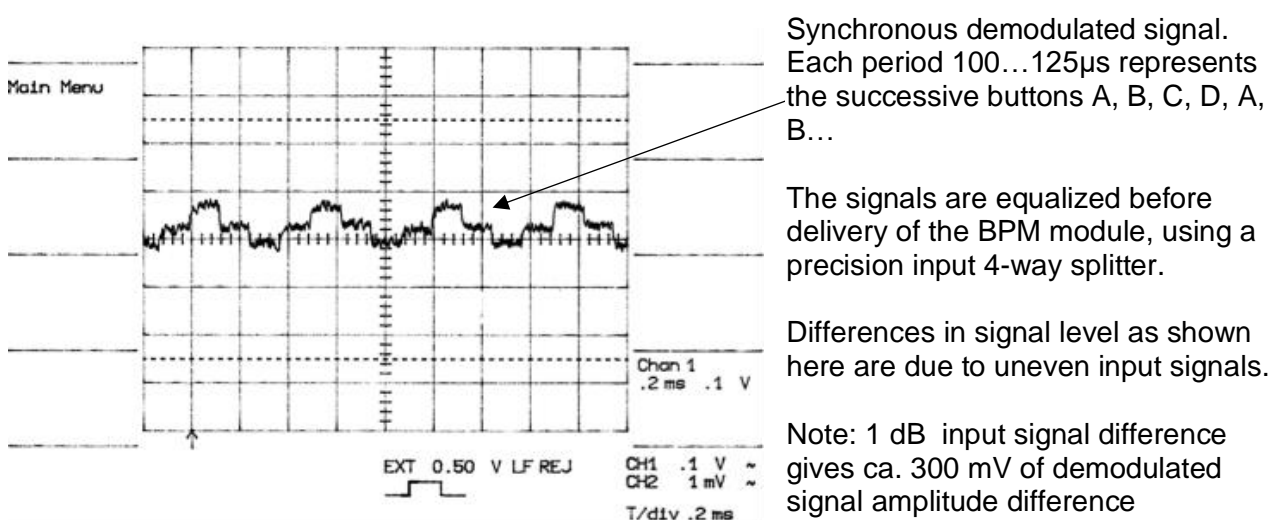
Ext. trigger connects to SYNC signal, trigger level 0.2V, 1 M $\Omega$  AC coupling

Channel 1 to SDEMOD signal, sensitivity 0.1 V / div., 1 M $\Omega$  AC coupling

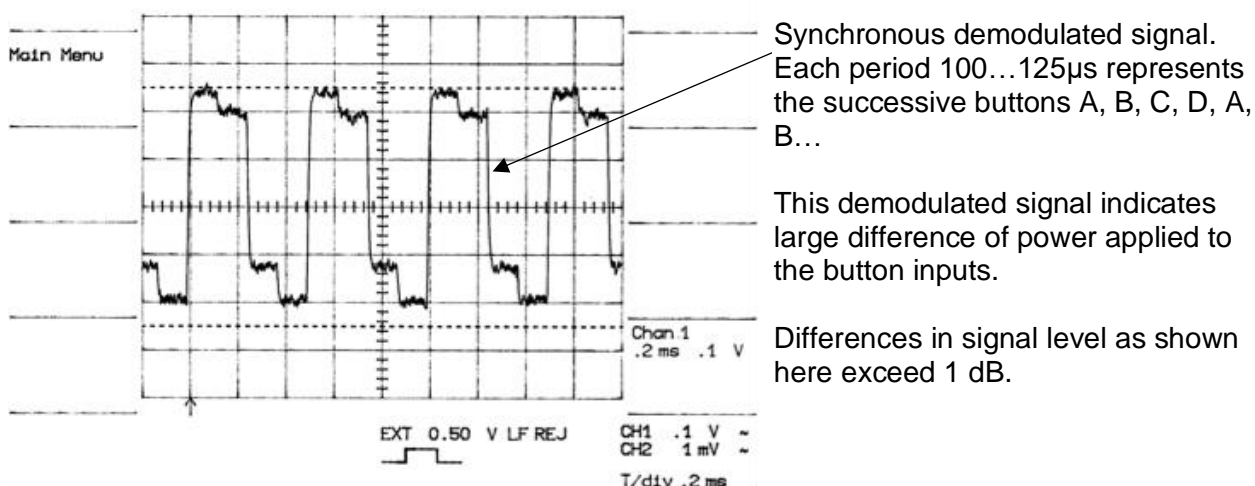
Set the RF source to the operating frequency.  
Amplitude ca. -13 dBm

Note: The BPM module operating frequency is written on the F-Key daughter board.  
To access the F-Key, remove the BPM module shield.

Set the X and Y voltmeters range in such a way that millivolts are readable.  
Connect to AC mains, the oscilloscope should display:



It may be that the demodulated button signals are uneven, like this:



The on-board button attenuators could be adjusted to compensate for the input power difference, therefore equalize the signals, but..  
Do not readjust the on-board attenuators before you are familiar with the BPM behavior.

### **What if the display does not look as shown**

Check that all DIP switches of the table-top test kit are set OFF (left position).  
Check that all cables are properly connected.  
Check that the RF source gives the required frequency and amplitude.

If you have more than one BPM module, try another one.

### **Getting familiar with the BPM**

Vary the power from the RF source to simulate beam intensity variations.  
Explore the range from 0 dBm down to -90 dBm.  
Remember that the 4-way power splitter absorbs some power: adjust for it!

While the RF source output power is changed, observe the intensity dependence of X and Y outputs on the voltmeters. If the BPM electronics gain has been set for 1 V/mm, each mV is equivalent to 1  $\mu\text{m}$  beam displacement.

Measure the rms noise at various signal levels.  
Observe the noise spectrum with an FFT or baseband spectrum analyzer, at various signal levels.

## ON-BOARD ATTENUATORS ADJUSTMENT

### Introduction

The BPM module is equipped with four on-board adjustable attenuators. Each attenuator adjustment range exceeds 1 dB. We recommend that all BPM modules are adjusted on center for equal power applied to the four button inputs. The on-center condition is satisfied when the amplitude variation of SDEMOD is below 20mV at -10 dBm input power. Then,  $X \approx 0$  and  $Y \approx 0$ . The remaining X and Y zero offsets can be eliminated (within  $\pm 20\text{mV}$ ) by fine tuning the attenuators.

The BPM electronics has best performance, i.e. more linearity over the dynamic range, when the power difference between input signals is kept to a minimum. This is obtained for a centered beam and cables with equal attenuation.

The on-board attenuators can be used –within their limited 1 dB range– to compensate for an off-centered beam or unequal cable attenuations.

### Procedure

The table-top test kit (BPM-KIT) is the easiest setup to adjust the attenuators. Extract the BPM module and proceed as described in “Quick Check”.

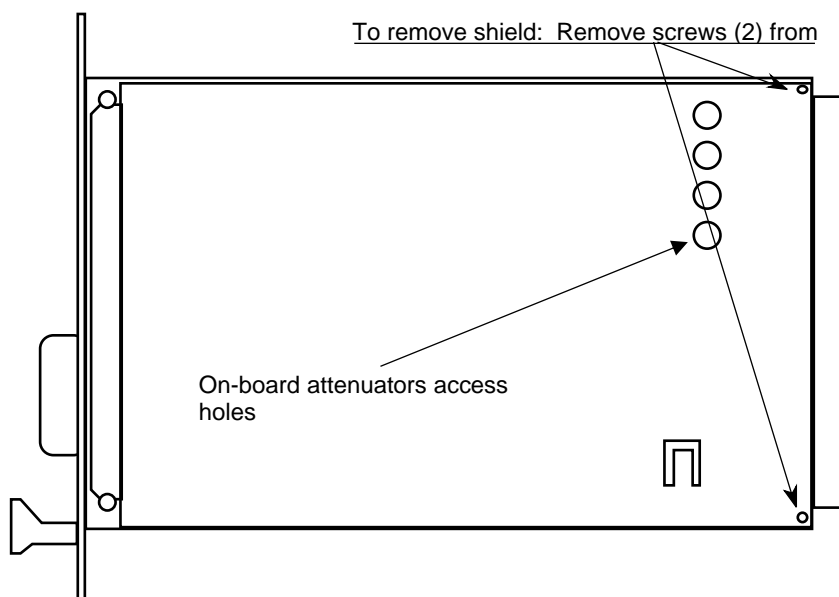
Note: BPM modules can be removed and inserted while the power is on.

The card extender (BPM-XTD) allows a BPM module to be extended out of its chassis slot.

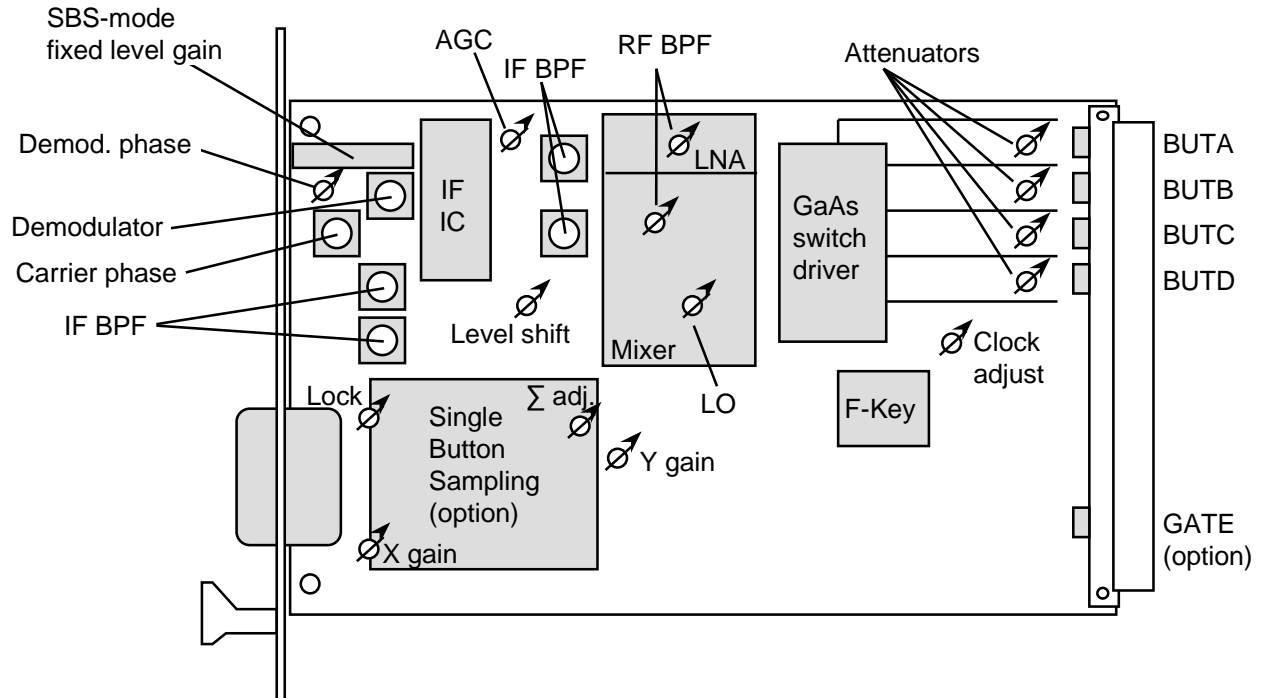
Extract the BPM module, install the extender and proceed as in “Quick Check”.

Note: The card extender has unequal button-to-button attenuations. It introduces an offset in X and Y. The card extender offset was measured at the time of shipment. To recheck it, measure the X and Y offsets with and without extender.

To adjust the on-board attenuators, it is recommended to remove the shield:



## Beam Position Monitor board



To adjust the attenuators, use a screwdriver with a ceramic tip. A metal tip changes the signal!

Set all four on-board adjustable attenuators  $\frac{1}{4}$  of a turn clockwise. One turn is ca.  $\frac{3\pi}{2}$ .

Set the RF source to the BPM operating frequency. Set power level such that -10 dBm is applied to each button, taking the 4-way power splitter attenuation into account.

Adjust progressively A, B, C and D attenuators until the SDEMOM signal has minimum level differences.

Note: The BPM module adjustment must be done by observing SDEMOM to minimize the button-to-button power differences. It cannot be done by simply adjusting X=0 and Y=0: There is an infinite number of A, B, C, D combinations satisfying X=0 and Y=0; i.e. A=1, B=2, C=1, D=2 yields X=A-B-C+D=0 and Y=A+B-C-D=0.

## BUTTON SAMPLING

The BPM module has an on-board clock to drive the input multiplexer. The internal clock frequency is adjustable by the "Clock adjust" potentiometer from 8 to 10 kHz.

Each button is thus sampled during 100 to 125  $\mu$ s, and a complete scan is made in 400 to 500  $\mu$ s.

The beginning of each scanning cycle is available as output signal SYNC rising edge (See "Connector Pins Allocation", this manual). SYNC frequency is  $\frac{1}{4}$  of sampling frequency.

The internal clock can be overridden by an external clock.

## EXTERNAL CLOCK

An external clock can be applied to the BPM module to drive the input multiplexer.

It must be applied to CLK\* (See "Connector Pins Allocation", this manual).

Amplitude  $\geq 6V_{p-p}$ , or  $\geq 3V$  positive-going, pulse length  $\geq 10\mu s$ .

It overrides the internal clock after a few milliseconds.

The BPM module operates properly up to an external frequency of 40 kHz. Therefore, the sampling of each button input can be made in  $25\mu s$ , the four buttons can be sampled in  $100\mu s$ . As a result, the beam position can be effectively sampled up to a frequency of 10 kHz.

The use of an external clock –and faster beam position sampling– may be required to eliminate aliasing of certain beam motions.

The performance of the BPM module is not affected by a higher sampling frequency:

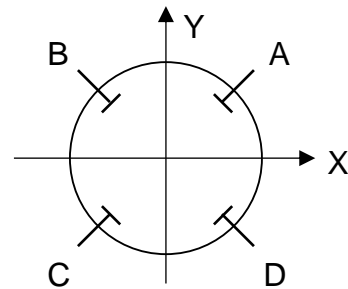
- The X/Y output noise increase is not noticeable
- The X/Y zero (on-center) dc values are slightly shifted, but stable at each particular frequency.

## ALGORITHM & POLARITY CONVENTION

### 45° buttons

$$X = K_x \frac{V_A - V_B - V_C + V_D}{V_A + V_B + V_C + V_D}$$

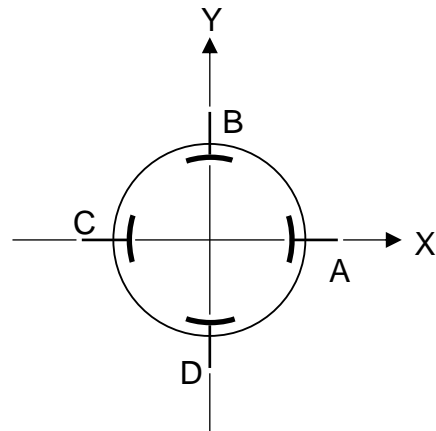
$$Y = K_y \frac{V_A + V_B - V_C - V_D}{V_A + V_B + V_C + V_D}$$



### Orthogonal buttons

$$X = K_x \frac{V_A - V_C}{V_A + V_B + V_C + V_D}$$

$$Y = K_y \frac{V_B - V_D}{V_A + V_B + V_C + V_D}$$



## PRINCIPLE OF OPERATION

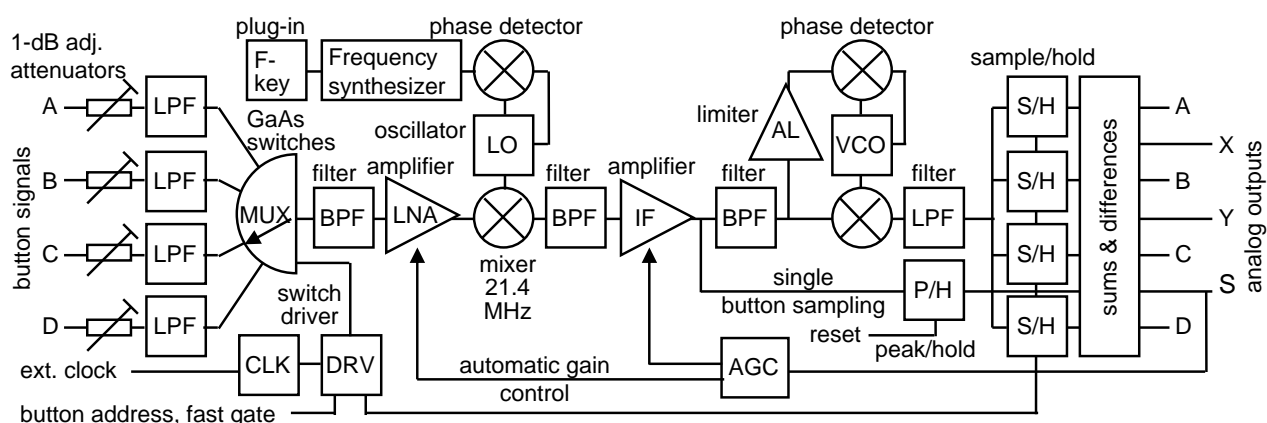
The signal from the BPM buttons are time-multiplexed into a single signal applied to a superheterodyne receiver. The demodulated signal is demultiplexed into four button values stored in analog memories. The four signals are summed, and the sum is maintained constant by an automatic gain control. The sum of all buttons being equal, the beam position is obtained by the analog summations  $X=A-B-C+D$  and  $Y=A+B-C-D$  for  $45^\circ$  buttons, and  $Y=D-B$  and  $Y=A-C$  for orthogonal buttons.

Papers giving more details can be found on our website:  
www.bergoz.com :: MX-BPM :: Downloads :: Papers

- Precision Analog Signal Processing for Beam Position Measurements in Electron Storage Rings, J.A. Hinkson and K.B. Unser, Proceedings of the 2nd DIPAC, Travemünde 1995
- New Generation Electronics Applied to Beam Position Monitors, Klaus B. Unser 1996 Beam Instrumentation Workshop, Argonne National Laboratory.

Many of the fundamental principles of our BPM module were developed by John W. Bittner and Richard W. Biscardi for the National Synchrotron Light Source at Brookhaven National Laboratory. U.S. Patent 5,001,416 was granted to them on March 19, 1991.

## BLOCK DIAGRAM





## PERFORMANCE

BPM electronics for closed orbit measurement are characterized by:

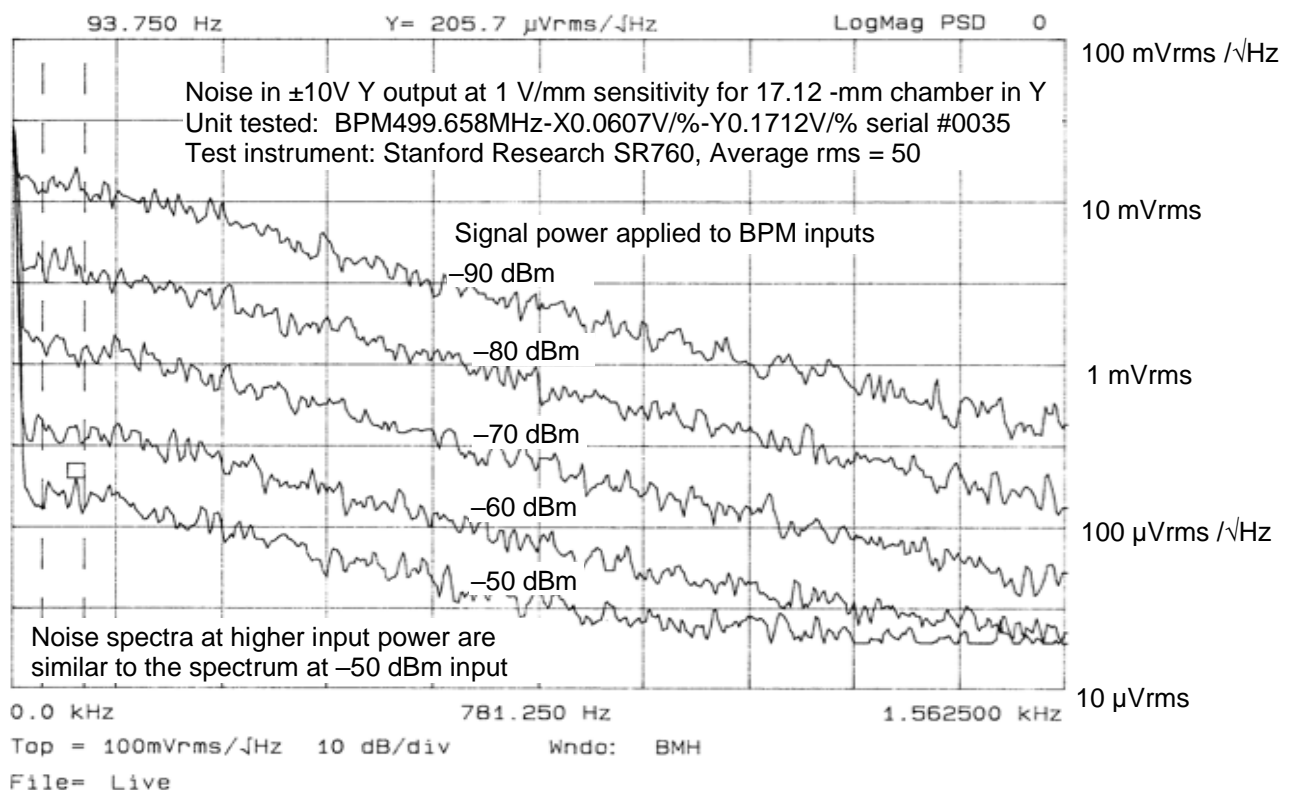
- Sampling frequency of the button signals
- Output signal noise (resolution) vs. input signal strength
- Dynamic range of signals that may be applied to the unit, itself characterized by:
  - Position error (linearity) vs. input signal strength for equal signals (on-center beam)
  - Position error (linearity) vs. input signal strength for unequal signals (off-center beam)
  - Drifts caused by environmental changes

The performance of the first regular production units is given hereafter:

### Sampling frequency

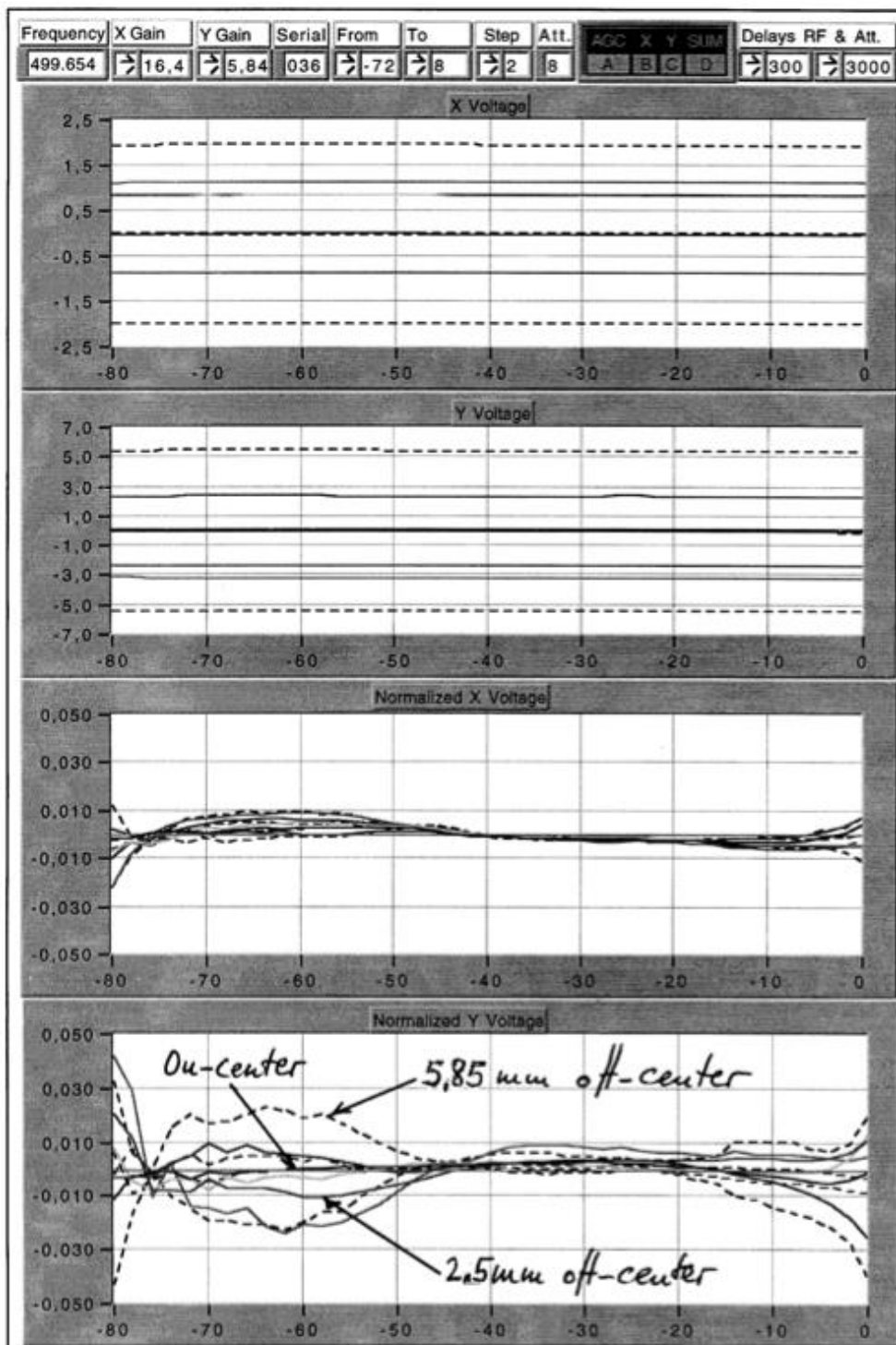
Up to 40 kHz. X and Y are updated at the rate up to 10 kHz. With the internal (default) clock, the sampling frequency is 2...2.5 kHz.

### Output signal noise (resolution) vs. input signal strength



## Position error (linearity) vs. input signal strength

Front Panel



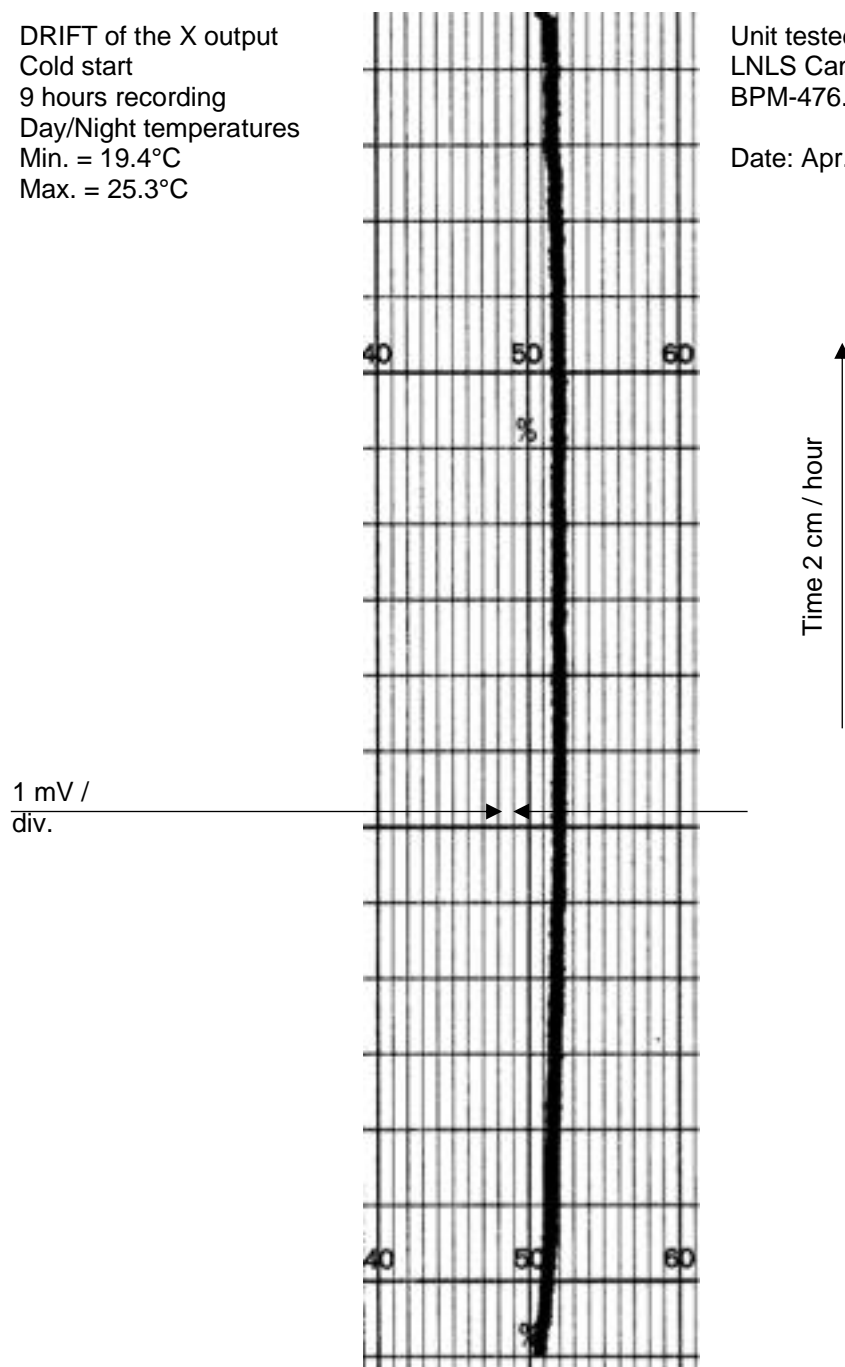
LabVIEW data acquisition virtual instrument using NB-MIO-16XH sampler, by Karen Scott

## Temperature drift

DRIFT of the X output  
Cold start  
9 hours recording  
Day/Night temperatures  
Min. = 19.4°C  
Max. = 25.3°C

Unit tested:  
LNLS Campinas, serial #020  
BPM-476.003MHz-X0.21V/%-Y0.21V/%

Date: Apr. 29, 1996, by Alain Charvet



## CLOSED ORBIT OPERATING MODE

This is the simplest operating mode. It is the default mode, i.e. when no external control signals are applied to the BPM module.

In the default mode, the internal clock controls the button sampling frequency (8...10 kHz).

The average beam position is available as:

**XOUT** X output. Analog output. (See Algorithm & Polarity Conventions, this manual)  
Voltage range: -10V...+10V. Zero is centered beam.

**YOUT** Y output. Analog output. (See Algorithm & Polarity Conventions, this manual)  
Voltage range: -10V...+10V. Zero is centered beam.

The value of each individual button A, B, C and D is also available. They can be used to compute -externally- the beam position with algorithms other than  $\Delta/\Sigma$ :

**AOUT** A output. Analog output.  
Voltage range: 0...+10V. Pedestal ca. 1 V.

**BOUT** B output. Analog output.  
Voltage range: 0...+10V. Pedestal ca. 1 V.

**COUT** C output. Analog output.  
Voltage range: 0...+10V. Pedestal ca. 1 V.

**DOUT** D output. Analog output.  
Voltage range: 0...+10V. Pedestal ca. 1 V.

In closed orbit mode, the BPM module performance can be monitored with:

**PLLOCK** PLL demodulator in lock & good signal level. TTL output.  
High = PLL in lock and signal level OK  
Low = PLL out of lock or signal level poor

The DB9 female front-panel connector allows the observation of the multiplexed demodulated signal:

**SDEMODO** Synchronous demodulator output. Analog output. For oscilloscope viewing.

**SYNC** Synchronization pulse. TTL output. Positive-going. For oscilloscope trigger.

## FIRST TURN CAPABILITY

When the Single Button Sampling option (BPM-SBS) is installed on the BPM module board, the BPM module has a limited capability of monitoring the first turn(s) after beam injection.

The BPM-SBS option consists of a small piggy-back plug-in board which installs on the BPM main board.

The first turn capability offered when BPM-SBS is installed consists of measuring four successive injections, first with button A, second with button B, third with button C and fourth with button D.

The value of each button is given by the BPM module on the X analog output XOUT. It corresponds to the highest signal received by the selected button, until it is reset by the user. A peak and hold (P/H) circuit on the BPM-SBS piggy-back board implements it.

The value of each button must be measured, and the position must be calculated by an external computer.

When the SBS mode is enabled, the Automatic Gain Control (AGC) is disabled. The amplifiers gain is controlled by a 20-turn potentiometer "Gain Adjust" located on the BPM module front panel. The potentiometer must be roughly adjusted so that the amplifiers gain is sufficient in relation to the injected charge and the pickups sensitivity.

Note: The gain may be different among BPM modules.

The Single Button Sampling mode is enabled by pulling down:

**SBS\***            Single Button Sampling mode. TTL input.

The button is designated by a 2-bit address:

**BADD0\***            Button addresses. TTL input. Active only when SBS mode is enabled.

**BADD1\***

	BADD1	BADD0
Button A	high	low
Button B	low	low
Button C	high	high
Button D	low	high
Default value: Button C		

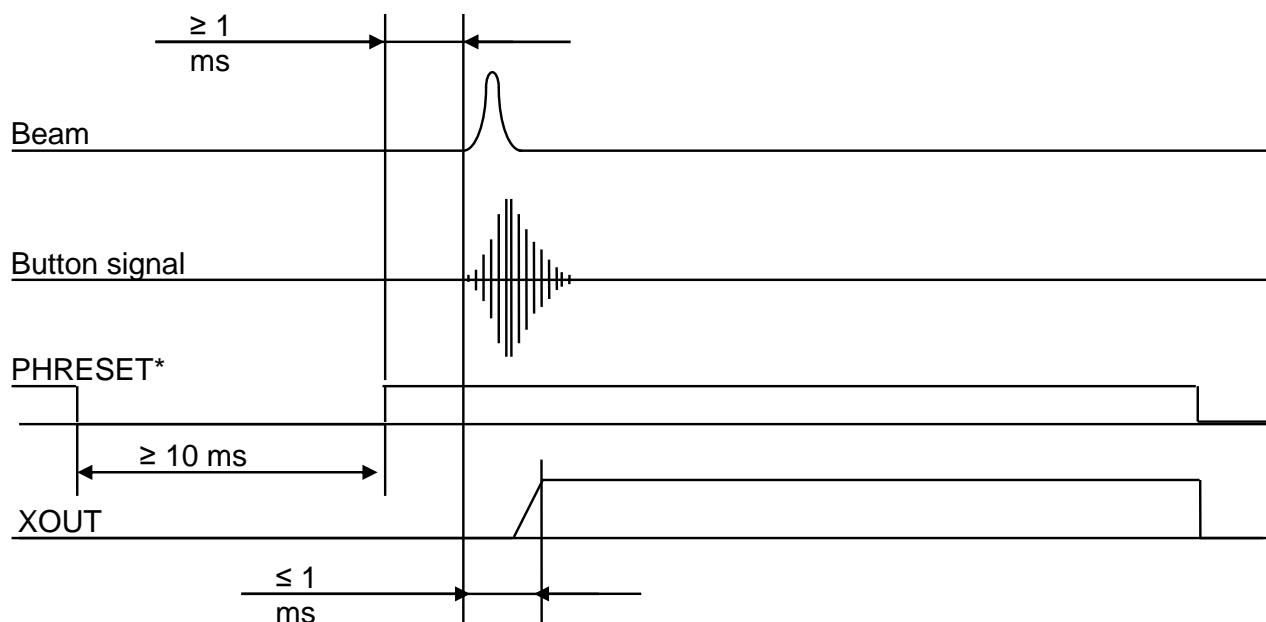
The output is obtained on:

**XOUT**      Analog output value of button addressed, from P/H circuit  
Voltage range: 0...+5V, pedestal  $\approx 0.5V$ .  
Settling time < 1 ms  
Signal droop negligible up to 100 ms

The Peak and Hold circuit is reset by pulling down:

**PHRESET\***    Peak and Hold Reset. TTL input.  
This input has no internal pull-up.  
Pull up to reset (min 5 ms).  
Pull down to measure bunch, at least 1 ms before bunch. Keep down to hold.  
But don't pull down too early, or SBS will measure peak ambient noise!

### Timing



### Gain setting

In Single Button Sampling mode (SBS\* pulled down), the automatic gain control (AGC) is disabled. The circuit gain is set by the front panel potentiometer labelled "Gain Adjust".

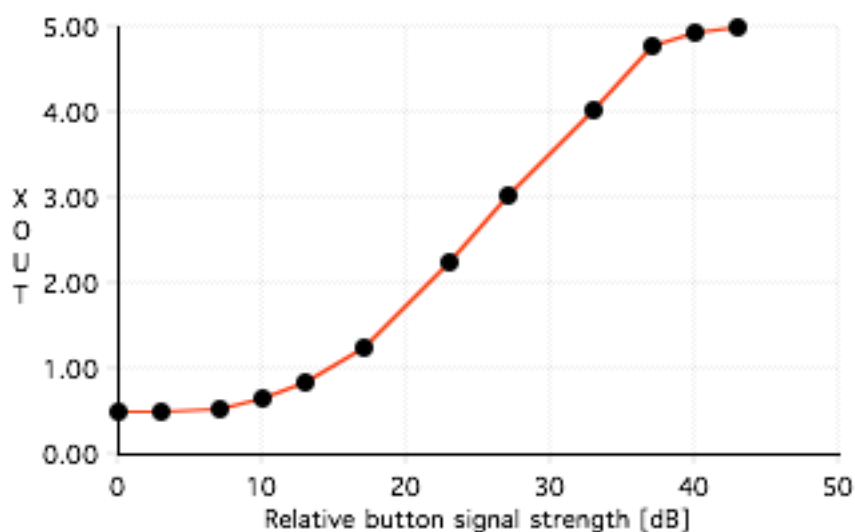
The potentiometer must be set so that the injected bunch causes the X output XOUT to be ca. +2.5V. In practice, if the beam is not on center, it might be necessary to read successively all four buttons and set the 4-buttons average output value to ca. +2.5 V.

After setting the gain potentiometer, the setting can be recorded, in order to reset it to the same value whenever needed: while the BPM is in Single Button Sampling mode, measure the AGC voltage and record it. The AGC voltage is a reliable indication of the potentiometer gain setting.

The AGC voltage (VAGC) is available from the front panel DB9 connector (pin 3) and from the DIN41612 rear connector (pin c19). On the BPM chassis ref. BPM-RFC/xx, it is available from the DB15 connector (pin 2).

### Button value readout

The output signal XOUT is (in first approximation) proportional to the logarithm –or dB value– of the button signal strength. The signal has a pedestal  $\approx 0.5V$ , it has the same value for all four buttons.



The pedestal must be read in the absence of beam and deducted from the button value reading.

The phase relationship between the beam bunch and the superheterodyne receiver local oscillator (LO) is arbitrary. As a consequence, the down-converted signal varies in amplitude, depending on the phase angle. Amplitude variations from bunch to bunch (i.e. from conversion to conversion) can be as high as 20%. These variations are purely statistical and can be eliminated by averaging a series of readings.

## SINGLE BUNCH / SINGLE BEAM MODE

The Fast Gate option (BPM-FG) allows to monitor the position of a single bunch out of a beam, or to separate beams in colliders, provided the selected bunch can be fitted in the gate of 20 ns minimum width. The BPM-FG option consists of a modified GaAs switch driver –with a NIM pulse control– replacing the standard switch driver, and the addition of the GATE input connector.

The Fast Gate may be used with the Closed Orbit mode and with the Single Button Sampling mode.

- In Closed Orbit mode, the Fast Gate allows to monitor the average position of a single bunch, or selected bunches.
- In First Turn mode, the Fast Gate allows to capture the first turn only, or any other subsequent turn.

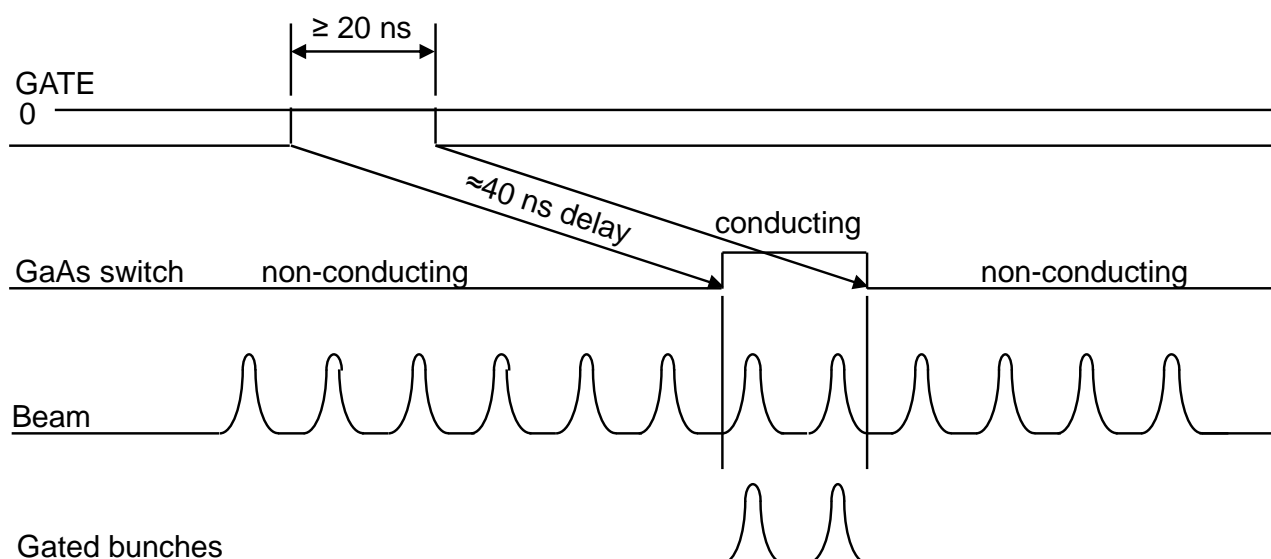
The gate is defined by:

**GATE** External fast NIM gate. Only with option BPM-FG.  
 Gate width  $\geq 20$  ns.

The Fast Gate feature works like this:

- When no signal is applied to GATE (disconnected), the Fast Gate feature is not active.
- When GATE is pulled down by a NIM (-20 mA) signal, all multiplexer GaAs switches remain open (non-conducting).
- When GATE is released high (0 mA), the GaAs switch addressed by the button address lines BADD0 and BADD1 closes (conducting).

### Fast Gate timing



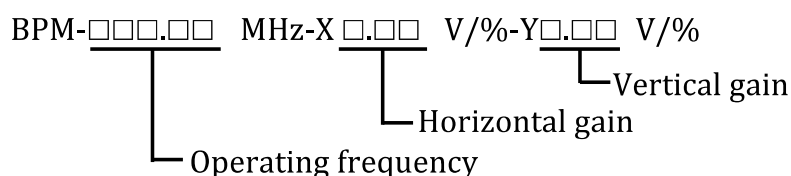
To display the above signals in their correct time relation, the service module BPM-SERV/RF can be inserted in place of a BPM module. It provides the RF signals BUTA, BUTB, BUTC, BUTD and the delayed GATE signal.



## X AND Y GAIN ADJUSTMENT

### Conventions

BPM modules are referenced in terms of operating frequency and X / Y gains as they appear on the order code:



The BPM module X / Y gain units are V/%.

The BPM buttons sensitivity is -depending on the laboratory- expressed as:

- Vacuum chamber calibration factor [mm]
- Vacuum chamber Sensitivity [mm-1] or [%/mm] or [dB/mm]

The overall gain of the BPM buttons and electronics system is expressed in V/mm.

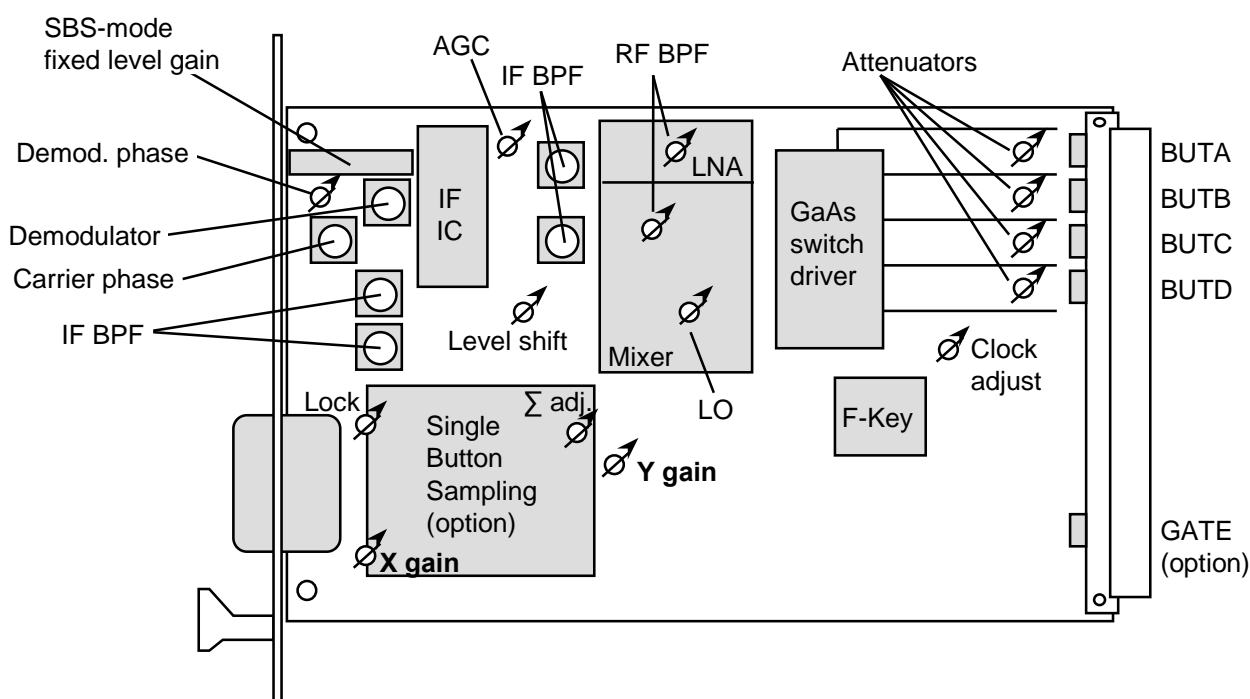
It is the product:

Gain [V/mm] = Vacuum chamber Sensitivity [%/mm] x BPM module gain [V/%].

### BPM module gain adjustment

The X and Y gains have been adjusted before shipment according to the order code.

Two on-board potentiometers allow a fine adjustment of the gain: X gain and Y gain:



The gain potentiometers are accessible via holes bored through the Single Button Sampling (option) piggy-back board.

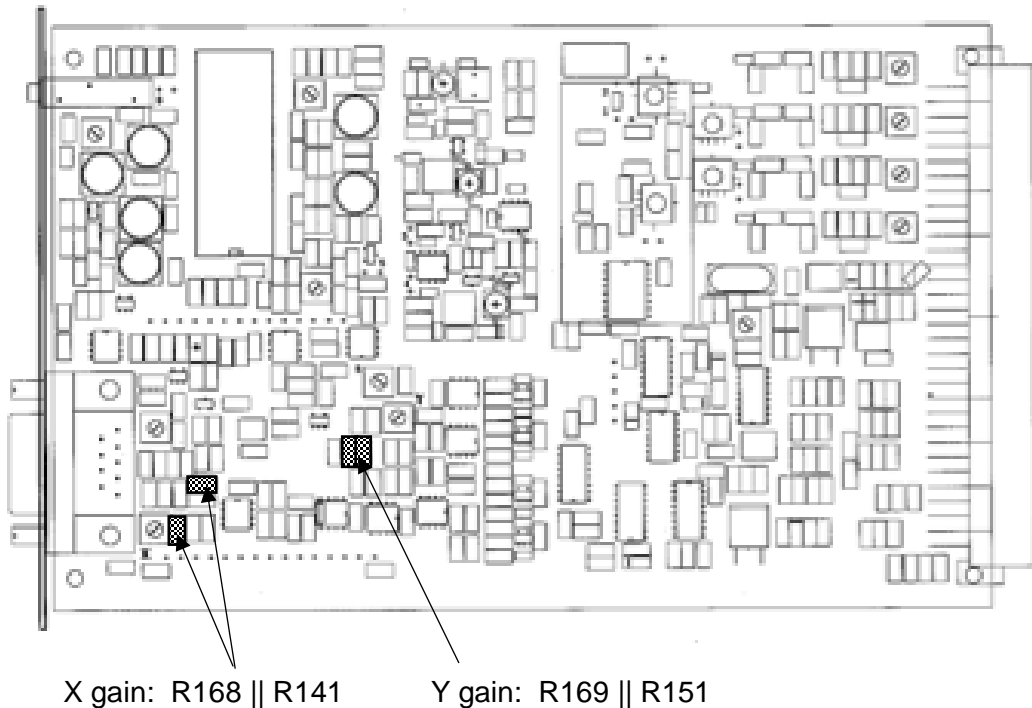
The gains can be adjusted over a wider range by changing a few components.

X gain is determined by the equivalent resistance of R168 in parallel with R141.

Y gain is determined by the equivalent resistance of R169 in parallel with R151.

The equivalent resistance as a function of the desired gain can be approximated by:

$$R_{\text{equ}}[\text{k}\Omega] = \frac{0.93}{\text{Gain} \left[ \frac{\text{V}}{\%} \right] - 0.034}$$



## LOCAL OSCILLATOR PROGRAMMING

### Introduction

The beam spectrum selected harmonic –called the “operating frequency”– is mixed with the Local Oscillator (LO) frequency to obtain the Intermediate Frequency (IF).

Mixing two signals produces many frequencies, one of which is of interest to us:  $|f_{op} - f_{LO}|$ . The BPM module uses 21.4 MHz as intermediate frequency. As a consequence, the LO frequency can have either of two values:

$$f_{LO} = f_{op} - 21.4 \text{ MHz}, \quad \text{or} \quad f_{LO} = f_{op} + 21.4 \text{ MHz}$$

The IF filters have a typical 3-dB bandwidth in excess of 500 kHz. However, BPMs made for very large machines may have narrower filters to reject their revolution frequency. The phase-locked synchronous demodulator tracks the carrier signal over a wide range:

$$21.25 \text{ MHz} \leq f_{IF} \leq 21.55 \text{ MHz}$$

The on-board local oscillator frequency synthesizer uses an MB87003A circuit from Fujitsu. It requires a 17-bit serial word for its programming<sup>1</sup>. The BPM module implementation of this circuit is described in an annex to this manual<sup>2</sup>.

### Changing the LO frequency

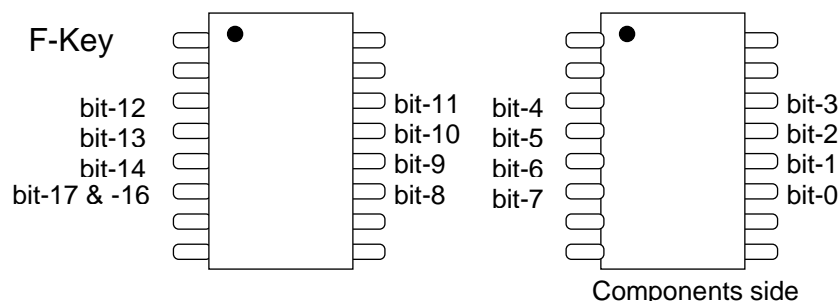
Note: It may be necessary to change the LO frequency if the difference between your beam chosen harmonic and the BPM operating frequency exceeds 100 kHz.

The 17-bit word is generated by a small daughter board plugged on the BPM module main board.

Each bit is programmed high or low by a solder bridge to either +5V or ground:

- Solder bridges on the F-Key components side are pull-ups.
- Solder bridges on the F-Key solder side are pull-downs.

Programming bits are numbered as follows:



Note: The synthesizer receives effectively 17 bits from the F-key. The first programmed F-key bit is sent twice, as bit17 and as bit16.

<sup>1</sup> Fujitsu Telecommunications Products, 1992 data book, Cmos PLL frequency synthesizer, page 2-3 thru 2-14

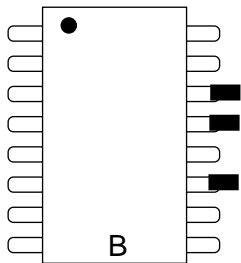
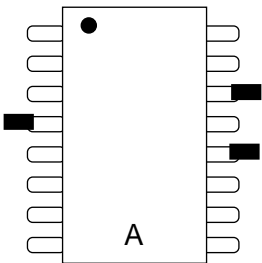
<sup>2</sup> New Generation Electronics Applied to Beam Position Monitors, K.B. Unser, page 4, Tbp.: proceedings of the 1996 Beam Instrumentation Workshop, Argonne.

Example:

APS RF frequency	351.94 MHz
Desired $f_{LO}$	$f_{RF} + 21.4 \text{ MHz} = 373.34 \text{ MHz}$
Modulus	$M = 64$
Ref. divider ratio	64
$f_{ref}$	69.275 kHz
Nearest synthesized $f_{LO}$	373.325 MHz
N	$84 = 00\ 0101\ 0100$
A	$13 = 000\ 1101$
f-code	(0) 0010 1010 0000 1101
$f_{in} = \text{synthesized } f_{LO} - 21.4 \text{ MHz}$	351.925 MHz (nearest programmable operating frequency)
Deviation	$(351.94 - 351.925) \text{ MHz} = 15.4 \text{ kHz}$
Condition	Deviation $\ll 150 \text{ kHz}$ PLL tracking range: accepted

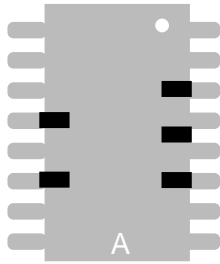
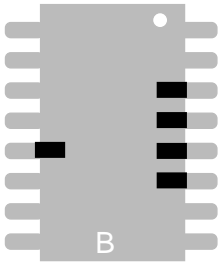
Top View

Pull-ups = "1"



Bottom View

Pull-downs = "0"



On request, the BPM manufacturer will send the solder bridges layout for a given LO frequency.

## SIGNALS

### Button Inputs

**BUTA** Button inputs A, B, C, and D. Impedance 50Ω.  
**BUTB** See Algorithms & Polarity Conventions, this manual, for buttons assignment.  
**BUTC**  
**BUTD**

### Auxiliary fast signals

**RFOUT** RF signal output. Reserved for future use.

**LOIN** Input for external Local Oscillator. On option only.  
 Nominal power 0 dBm, range -8 dBm...+6 dBm. Internally terminated in 50 Ω.  
 External Local Oscillator option not compatible with on-board LO.

**GATE** External fast NIM gate. Only with option BPM-FG.  
 Multiplexer GaAs switch closes only during GATE.  
 GATE is NIM signal -20mA in 50Ω load.  
 Gate width ≥ 20 ns.

### Common external controls

Common external controls are controls which are common to all BPM modules in a BPM chassis.

Note: When no external controls are applied, the BPM default mode is:

- Closed orbit measurement
- Sampling frequency as given by the internal clock
- Automatic gain control

**SBS\*** Single Button Sampling mode. TTL input.  
 Default value: high = SBS mode not enabled.

**BADD0\*** Button addresses. TTL input. Active only when SBS mode is enabled.  
**BADD1\***

	BADD1	BADD0
Button A	high	low
Button B	low	low
Button C	high	high
Button D	low	high
Default value: Button C		

**PHRESET\*** Peak and Hold Reset. TTL input.  
 pull down to reset  
 Reset pulse duration ≥ 10 ms  
 Reset pulse must terminate at least 1 ms before the bunch to be measured.  
 Default value: high

<b>AGCD*</b>	AGC disable. TTL input. Disables the Automatic Gain Control (on option only) Pull down to disable AGC. Default value: high.
<b>CLK*</b>	External sampling clock, input, overrides the internal clock after a few milliseconds when applied. Maximum frequency 40 kHz Amplitude $\geq 6$ Vpp, or $\geq 3$ V positive-going Pulse length $\geq 10 \mu\text{s}$ Default value: the internal clock is active.
<b>GND</b>	Ground for external controls.

### Input and output signals

Input and output signals hereafter are specific to each BPM module, contrary to the above Common external controls which are shared by all BPM modules in a BPM chassis.

<b>GND</b>	Analog ground for outputs
<b>PLLOCK</b>	PLL demodulator in lock & good signal level. TTL output. High = PLL in lock and signal level OK Low = PLL out of lock or signal level poor
<b>VAGC</b>	Automatic Gain Control voltage. Analog output. Used for production tests. Voltage range +4V...+8V when PLL in lock.
<b>XOUT</b>	X output. Analog output. Voltage range: -10V...+10V. Zero is centered beam. Output impedance: $100\Omega$ Driving capability: 10 mA When BPM-SBS option is installed and SBS* is low, XOUT is analog output value of button addressed, from P/H circuit Voltage range 0...+5V, pedestal ca. 0.5 V. P/H circuit is reset by PHRESET* low.
<b>YOUT</b>	Y output. Analog output. Voltage range: -10V...+10V. Zero is centered beam. Output impedance: $100\Omega$ Driving capability: 10 mA
<b>SOUT</b>	Analog sum of A, B, C and D signals. Analog output. Used for production tests. Voltage is maintained by AGC at fixed value in range -3V...-4V

<b>AOUT</b>	A output. Analog output. Voltage range: 0...+10V. Pedestal ca. 1 V. Output impedance: 1k $\Omega$ Driving capability: 1 mA
<b>BOUT</b>	B output. Analog output. Voltage range: 0...+10V. Pedestal ca. 1 V. Output impedance: 1k $\Omega$ Driving capability: 1 mA
<b>COUT</b>	C output. Analog output. Voltage range: 0...+10V. Pedestal ca. 1 V. Output impedance: 1k $\Omega$ Driving capability: 1 mA
<b>DOUT</b>	D output. Analog output. Voltage range: 0...+10V. Pedestal ca. 1 V. Output impedance: 1k $\Omega$ Driving capability: 1 mA
<b>SYNC</b>	Synchronization pulse. TTL output. Positive-going. For oscilloscope trigger. Rising edge marks the beginning of button A sampling sequence. Remains high during button A sampling cycle; down during B, C and D. SYNC frequency is 1/4 of sampling frequency, also when external clock CLK* is active.
<b>SDEMODO</b>	Synchronous demodulator output. Analog output. For oscilloscope viewing.
<b>PDEMODO</b>	Peak demodulator output. Analog output. Reserved for future use.
<b>GAIN</b>	External gain setting. Analog input (on option only). Voltage range: >0...<+10V. Active only when optional signal AGCD* (AGC disable) is pulled down.

## BPM CABLES LAYOUT, INSTALLATION

**A button signal amplitude difference of 0.00043 dB ....**

**....changes the BPM output by 1 mV = 1  $\mu$ m.**

This is equivalent to 2.5m $\Omega$  change in connector contact resistance!

Conditions: 20-mm vacuum chamber calibration factor, 1 V/mm BPM system sensitivity, 50 $\Omega$  cable

### Cable layout

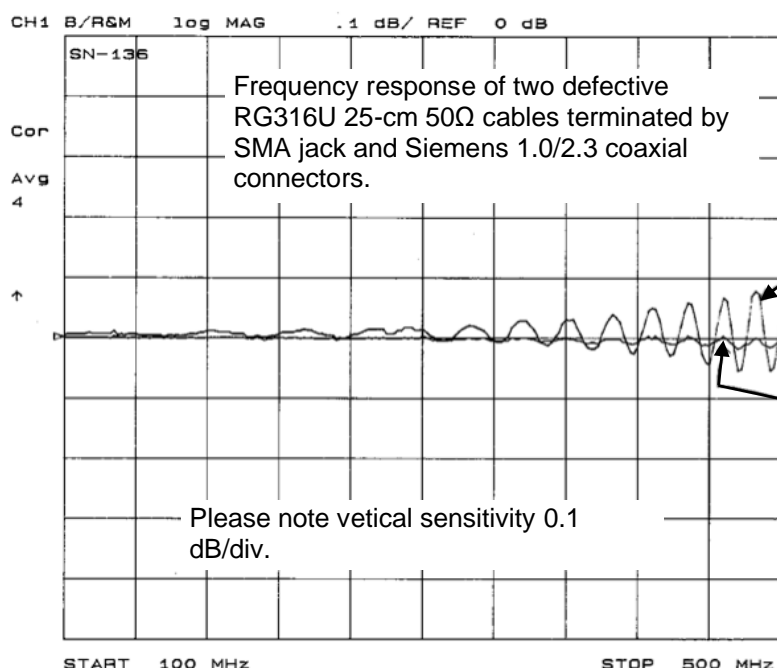
Unnecessary intermediate connectors should be avoided. When for practical reasons patch-panels must be used, the cables on either side of the patch-panel should be passed through tubular ferrite cores. Ferrite material must have high permeability at the BPM operating frequency.

The four cables pertaining to the same BPM stations must be laid side by side. Cables, BPM chassis and modules should be kept away –as much as possible– from RF equipment, klystrons, cavities.

Connectors must be chosen carefully to match the cable used. Connectors manufacturer's instructions must be followed meticulously. If cable layout is subcontracted, subcontractors must be informed of the extreme reliability expected from these cables. All cables with connectors must be checked before installation with a network analyzer, up to twice the operating frequency at least; i.e. up to 1 GHz for 500 MHz operating frequency.

BPM modules must be installed in an RF-shielded chassis.

Note: Unlike most BPM electronics, the BPM module does not require the button signal to be in phase. Cables do not need to be phase-adjusted. The BPM module tolerates any phase change, even 180°.



### Defective cables examples

A close examination of this cable showed that 7 wires of the cable braid had been cut when the SMA connector was fitted. The cable braid has a total of ca. 60 wires.

Close examination of this cable did not reveal anything suspect. Yet, 9 cables out of 302 exhibited this particular behavior

Good cables exhibit a frequency response within  $\pm 0.01$  dB up to 1 GHz



## OPERATING CONSIDERATIONS

### BPM aliasing of AM and FM modulations

Aliasing by the BPM can indicate nonexistent beam motions. Both FM and AM modulations of the RF signal can cause aliasing. No matter which button sampling frequency is chosen, aliasing will appear at a certain modulation frequency.

Aliasing occurs because the beam sampling frequency is lower than the other frequencies involved.

Some of the frequencies come from the beam:

- all harmonics of the revolution frequency, thus,
- the RF frequency extending to the full frequency spectrum of the bunches,
- the betatron and synchrotron frequencies.

More frequencies are produced by the BPM module itself:

- the local oscillator frequency and its harmonics,
- the original frequency of the quartz,
- the prescaling dividers of the frequency synthesizer.

These frequencies are voluntarily mixed together in the superheterodyne mixer and produce every possible sum and difference. Most of them will be eliminated by filters, but some of them are so close to the intermediate frequency that they cannot be eliminated.

Finally, the BPM sampling process –at the frequency of the clock– will produce signal aliasing. Any of these frequencies in the range 0 to 1 kHz will appear as a spectral line in the BPM outputs (X, Y, A, B, C and D).

### Identifying and eliminating aliasing

The BPM output (X, Y or both) must be observed with a low frequency spectrum analyzer or FFT analyzer in the 0 to 2-3 kHz bandwidth.

First, check the BPM with an RF generator. Apply the RF generator signal to the BPM module via a 4-way splitter (see page 4, this manual). The BPM noise spectrum should look as printed on the Noise vs. frequency hardcopy shipped with the calibration certificate.

Then, connect the BPM to the beam position pick-ups. If spectral lines (noise peaks) appear in the spectrum, several actions can be attempted to eliminate them.

Note: It is possible that one BPM module exhibits those spectral lines, while other BPM modules do not. This is because the local oscillator frequency and the clock frequency is not exactly the same for all BPM modules.

- a) The sampling clock frequency can be changed.
- b) The local oscillator frequency can be changed by a few thousand Hertz
- c) The local oscillator frequency can be changed in large steps by changing the synthesizer's F-key, yet this will generally not be necessary.  
(see "F-key" page 7, this manual, for its location, page 20 for its programming)

It is recommended to start with the sampling clock. The on-board clock generator frequency can be adjusted over a small range (ca.  $\pm 20\%$ ) with the "Clock adjust" potentiometer (see "Button Sampling", page 7, this manual). For a wider range, the on-board clock can be overridden by an external clock signal (see "External Clock", page 8, this manual).

By increasing the sampling clock frequency, it may be possible to "push" the spectral lines (noise peaks) out of the 0...1 kHz bandwidth of BPM response.

Note: When the external clock signal is applied to the BPM module thru the DB9 male connector (pin 8) at the rear panel of the BPM-RFC chassis, it overrides the clock for all the modules in the chassis.

If the spectral lines cannot be pushed out of the 0...1 kHz bandwidth, or if it is not desirable to change the sampling clock frequency, then the local oscillator (LO) frequency can be changed. This will work only if LO intermodulation is at the origin of the spectral line. To test this hypothesis, install the BPM module out of the chassis on a card extender (see "Procedure", this manual).

Put your finger on the quartz crystal oscillator (The quartz is located next to the "Clock adjust" potentiometer). The LO frequency will change by a few hundreds of Hertz. Observe the output spectrum: if the spectral lines (noise peaks) move up or down in frequency, it may be possible to "push" those lines out of the 0...1 kHz bandwidth of BPM response.

More than 2 kHz LO frequency change can be obtained by installing a few-pf capacitor (C94) on the BPM board.

Aliasing was observed on ALS at LBL<sub>3</sub> while using the LBL-built BPM prototype. Jim Hinkson suggests a diagnostic of aliasing and a cure: "We know the frequencies for synchrotron and betatron oscillations in our machine. These frequencies change with machine settings. It would be a simple matter to program a clock frequency based on tune measurements. This would allow us to avoid aliasing under all conditions. It's easy to see if aliasing is a problem.

Using a low frequency spectrum analyzer, coherent "beam" motion can be clearly seen in the sub-micron range. If aliasing is suspected, all one needs to do is change the clock frequency and see if the spectral line moves. If it does, it's aliasing."

## CONNECTORS PINS ALLOCATION Rev. 4.0

Connectors on Table-top test kit BPM-KIT and Chassis BPM-RFC/X				
BPM Module rear connector				
DB9 female front panel connector				
BUTTON INPUTS				
Button A	BUTA		b2 *	
Button B	BUTB		b5 *	
Button C	BUTC		b8 *	
Button D	BUTD		b11 *	
AUXILIARY FAST SIGNALS				
Fast gate	GATE		b22	
Reserved (RF signal out)	RFOUT		b25	
Reserved (Local oscillator)	LOIN		b28	
Not allocated	free		b31	
COMMON EXTERNAL CONTROLS				DB9 male
Single button sampling mode	SBS*		b17	2
Button address	Upper bit	BADD1*	b16	3
	Lower bit	BADD0*	c17	4
Reset (single button mode)	PHRESET*		b15	5
AGC disable	AGCD*		b13	7
Sampling clock (inhibits on-board clock)	CLK*	6	c16	8
Reserved	free		a19	
Ground	GND		c14	9
Reserved			b18	1
				*Active low
INPUT AND OUTPUT SIGNALS				DB15 female
Ground (signal ground for all outputs)	GND	5	a20	15
PLL demodulator in lock output	PLLOCK		a13	1
AGC voltage output	VAGC	3	c19	2
X (also button value in single button mode)	XOUT	4	c20	3
Y output	YOUT	8	b19	4
Σ output	SOUT		b20	5
A button signal output	AOUT		a17	6
B button signal output	BOUT		a18	7
C button signal output	COUT		a15	8
D button signal output	DOUT		a16	9
Synchronization from sampling clock	SYNC	9	b14	10
Synchronous demodulator output	SDEMOD	7		
Peak demodulator output (single button mode)	PDEMOD	1		
External gain setting input	GAIN	2	a14	13
POWER SUPPLY				
+ 15 V	+15V		c13	
- 15 V	-15V		c15	
0 V (power supply ground)	GND		c14	

## ACCESSORIES

### Table-top test kit (BPM-KIT)

Three versions are available. Only difference is the power supply voltage:

- BPM-KIT-100V
- BPM-KIT-115V
- BPM-KIT-220V

The BPM-KIT includes:

- A power supply. Check AC mains voltage on power supply module before using
- A DIN41612M 24+8 mating connector
- Four coaxial cables connected to the button inputs, terminated by SMA plugs
- A DB9 male connector for External Controls input.  
Similar connector and pin-out as used on the BPM chassis BPM-RFC/X
- A DB15 female connector for Output signals  
Similar connector and pin-out as used on the BPM chassis BPM-RFC/X
- Five BNC jacks for:
  - X output XOUT
  - Y output YOUT
  - Sum output SOUT
  - AGC voltage output VAGC
  - External clock input CLK
- 8-bit DIP switch, to control (pull down):
  - PLL time constant. Reserved for future use
  - Single Button Sampling SBS\*
  - Button address BADD1 and BADD0
  - Peak and Hold Reset PHRESET\*
  - Peak Demodulator PDM. Reserved for future use
  - Fast Gate Enable ENGAT\*
  - Clock CLK. For production tests.

The BPM-KIT is very convenient. It allows the BPM module to be placed flat on the table. In this position, the shield can be removed, and the user can:

- a) Re-adjust the zero of the BPM. This is useful when the “normal” beam position is not at the geometric center of the button pick-ups.
- b) Re-adjust the X and Y gains, to change the sensitivity of the BPM. This is useful in two situations:
  - when the beam is very stable, the gain can be increased
  - when the beam has very large displacement from the center, the gain can be decreased.

- c) Re-adjust the local oscillator frequency. This is necessary when changes are made to the accelerator lattice. It could be useful also to change the working sideband, when one sideband is disturbed by a local television transmitter.
- d) Change the bandwidth of the intermediate frequency filters. It may be needed to have a narrower IF bandwidth to reject the revolution frequency on very large rings.

The adjustments above cannot be made when the BPM processing unit is in the chassis. They require a BPM-KIT or a card extender BPM-XTD.

### **Card Extender BPM-XTD**

The card extender allows access to the BPM module adjustments while it is connected to the chassis, thus to the readout and control system.

The BPM-XTD is not as convenient as the BPM-KIT for adjustments.

The coaxial connections extensions of the button signals cause an offset of the X and Y outputs when the extender is used. This is due to the difference in signal attenuation between the 4 extension cables. These differences are recorded on a label affixed to the extender.

### **TTL Controls Service module BPM-SERV/CMD**

Not available at the time this manual is written.

The TTL Controls Service module can be inserted in a BPM station of a chassis, in place of the BPM module.

It brings to the front panel:

- On a DB9 female connector, the External Controls applied by the control system to this station  
Similar connector pin-out as used on BPM-RFC/X and BPM-KIT, but reversed gender.
- On a DB15 male connector, the Output lines to which the BPM module would apply its Outputs.  
Similar connector pin-out as used on BPM-RFC/X and BPM-KIT, but reversed gender.

This module is useful because access to the cables at the rear of the chassis will be very difficult.

With this module, one can:

- a) Observe and debug the signals sent by the control system to a BPM station
- b) Feed known signals into the BPM readout system, to test it.

### RF Service module BPM-SERV/RF

The RF Service module can be inserted in a BPM station of a chassis, in place of the BPM module.

It brings to the front panel –on SMA jacks– the four signals applied to this BPM station by the BPM buttons.

For oscilloscope and spectrum analyzer viewing of the BPM button signals.

Very useful, because the RF cables at the rear of the chassis are too crowded to be disconnected.

### BPM Chassis BPM-RFC/X

The BPM-RFC/X chassis is built around a 19" Schroff rackable RF chassis.

Dimensions of the bin: 3U x 84F

Schroff reference: Europac Lab HF/RF #20845-283

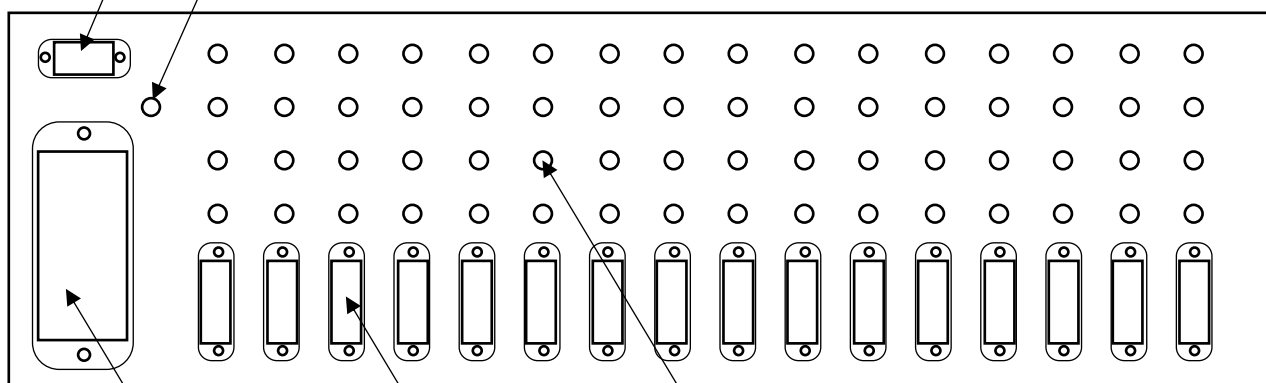
The BPM-RFC/X is available equipped for 1 up to 16 BPM stations. X being the number of stations.

BPM-RFC/X with less than 16 stations are partially equipped BPM-RFC/16. As a result, all BPM chassis are field-upgradable to the full 16-station chassis.

### Chassis rear view

DB9 male External controls input connector. Common to all stations

SMA jack RF input for test station



SMA jack A to D button inputs, 4 per BPM station, A on top

DB15 female BPM station output connector, one per BPM station

IEC male connector for AC mains

## SPECIFICATIONS

### BPM module

Beam intensity range	> 75 dB
Input signals	+5 dBm...-70 dBm, 50Ω
Operating frequency	According to order code
Noise rms	< 2mV [0...1 kHz] in ±10V @ +5 dBm < 5mV [0...1 kHz] in ±10V @ -35 dBm < 50mV [0...1 kHz] in ±10V @ -60 dBm
Linearity error	On-center: <5 mV [+5 dBm...-35 dBm] 2-mm off: <20 mV [+5 dBm...-35 dBm]
Sensitivity	User's choice. 1 V/mm recommended
X and Y gain	According to order code
Buttons sampling	2...2.5 ksamples/s with internal clock Up to 10 ksamples/s with external clock
Local oscillator	Factory-set frequency
Intermediate frequency	21.4 MHz or 10.7 MHz for narrow band IF
Outputs	X: ±10V, A-B-C+D, or A-C Y: ±10V, A+B-C-D, or B-D Σ: A+B+C+D, constant value (≈3V) A, B, C and D: >0...<+10V, ca. 1 V pedestal
Front panel LED	PLL in lock
Single button sampling	Enable and Reset TTL controls
Button address	Two TTL addressing lines
Single button output	Output on "X": >0...<+5V, pedestal ≈0.5V
Fast gate	NIM (50Ω negative-going -16mA pulse)
Power supply:	+ 15V, <200 mA (<250 mA with SBS option) - 15V, <40 mA (<60 mA with SBS option)

### Power Supply module

AC mains voltage	Autoranging 98...132Vac and 185...265Vac with automatic range changeover
Power derating	No derating down to 85 Vac (at full chassis load)
Output	± 15 V, unequal loading tolerant
Power	75 W
Efficiency	84% at 220Vac 81% at 110 Vac
Inrush current	limited to 10A max.
Dimensions	per DIN41494: 3U high, 8F wide, 160mm deep
Manufacturer	Delta Elektronika BV, the Netherlands
Model	75 SX 15-15

## **BPM MODULE REAR CONNECTOR DIN41612M 24+8**

Note: For connections, See Connector Pins Allocation, this manual.

BPM chassis for 1 up to 16 BPM modules are part of Bergoz Instrumentation sales program (BPM-RFC/X) and include the necessary mating connectors (See BPM chassis, this manual).

## **SCHEMATICS & BOARD LAYOUT**

Schematics and board layouts of our instruments remain the exclusive property of Bergoz Instrumentation at all times. They are protected by the copyright laws.

Schematics and board layouts are not delivered with our instruments. They can be obtained at the specific request of the instrument's user.

A request should be sent by email, worded in the following way:

*To: Bergoz Instrumentation*  
*From: \*User's name\**  
*Date: \*\*\*\*\**

*I am a user of instrument type xxx-xxx serial nr. xxx,xxx,xxx,xxx, etc.*

*Please send me one copy of the corresponding schematics and board layout.*

*I will use it for the instrument's maintenance only.*

*I will make copies only for my own use.*

*I will inform others who need these schematics that they should request them from Bergoz Instrumentation.*

*Signed: xxxxxxxx*



## **ACKNOWLEDGEMENT**

Many of the important –even fundamental– features of our BPM module were developed by John W. Bittner and Richard W. Biscardi for the National Synchrotron Light Source at Brookhaven National Laboratory. U.S. Patent 5,001,416 was granted to them on March 19, 1991. We sincerely thank them for their considerable contribution.

Our BPM module was developed on the basis of Jim Hinkson's Precision Analog Signal Processor for BPMs in Electron Storage Rings, designed for the Advanced Light Source at Lawrence Berkeley National Laboratory. His invaluable advice during the development of the industrialized version have decisively contributed to the quality of the present instrument. We thank him very sincerely.

Last revised: Saint Genis Pouilly, January 2020