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Log-ratio Beam Position Monitor User's Manual

Rev. 3.0

Record of updates

Version	Date	Updates performed
2.2.1	04/2008	CONNECTORS PINS ALLOCATION Rev. 2.1 Optional output signals: LogA, LogB, LogC and LogD pin assignment on DIN41612M LR-BPM module rear connector has been corrected to resp. b31*, b223, b28* and B25*. Note to users of BPM-RFC chassis with BPM-RFC/ABCD option: The locations of chassis rear panel SMA output connectors LogA, LogB, LogC and LogD are unchanged.
3.0	01/2020	Review of the full manual. Obsoletes all previous versions

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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

This manual applies to the Log-ratio BPM only: LR-BPM
"MX-BPM", "S-BPM" and "BB-BPM" are described in other manuals.

The Log-ratio BPM system includes:

<i>Description</i>	<i>Order code</i>
Log-ratio BPM electronics module	LR-BPM-XXXMHz
Sample & Hold on X and Y, option	LR-BPM-SH
Beam Trigger, option	LR-BPM-TRG
Sum of logs, option	LR-BPM-SUM
Direct A, B, C, D wideband outputs, option	LR-BPM-ABCD

The options are factory-installed on the LR-BPM electronics module.

Accessories:

Beam-Based Center determination module	BPM-BBC
19" chassis with power supply	BPM-RFC/X, X = BPM stations number
Table-top test kit with power supply	BPM-KIT
3U-Card extender with coaxial contacts	BPM-XTD
RF service module with four front-panel BNC	BPM-SERV/RF
TTL controls service module	BPM-SERV/CMD with front-panel DB9 and DB15 connectors

Check the power supply voltage, that it corresponds to your mains voltage.

On some table-top kit BPM-KIT older models, an AC/DC power supply block is installed. Its AC input voltage range is indicated on the power supply block. If it does not correspond to your AC mains, use a transformer or contact the manufacturer to get another power supply.
In the 19" chassis BPM-RFC: The power supply is autoranging from 98V...264V.

Check the fuse configuration, that it corresponds to your national regulations.

The table-top test kit does not have any fuse.

The 19" BPM-RFC chassis fuse compartment is configured at the time of shipment according to its destination:

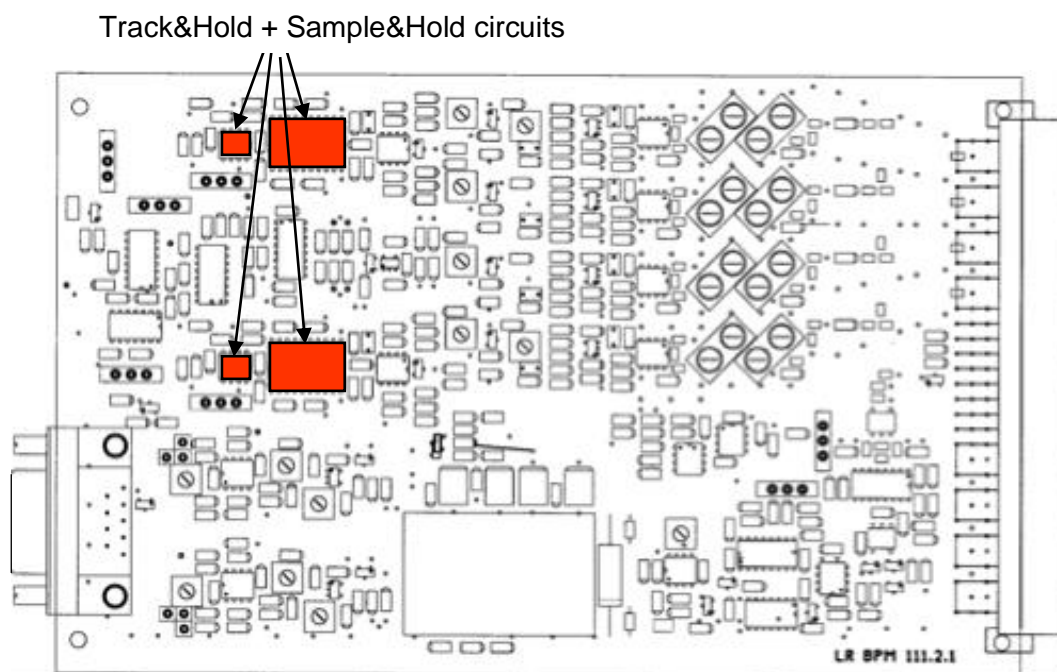
- North America: mains ground wire unfused.
- All other destinations: both mains wires are fused.
To verify which fuse configuration is installed on your chassis, pull out the removable fuse block, using a small screwdriver.
- The unfused ground configuration has a shorting bar and a 2A 6x32 fuse.
- The configuration with both AC lines fused is equipped with two 2A 5x20 fuses.
To change this configuration, unscrew the fuse holder off the fuse block, flip the holder over and screw it back onto the fuse block. Insert the following fuses:
- For unfused ground configuration: one 2A 6x32 fast fuse.
- For both AC lines fused configuration: two 2A 5x20 fast fuses.

Determine which LR-BPM model you received

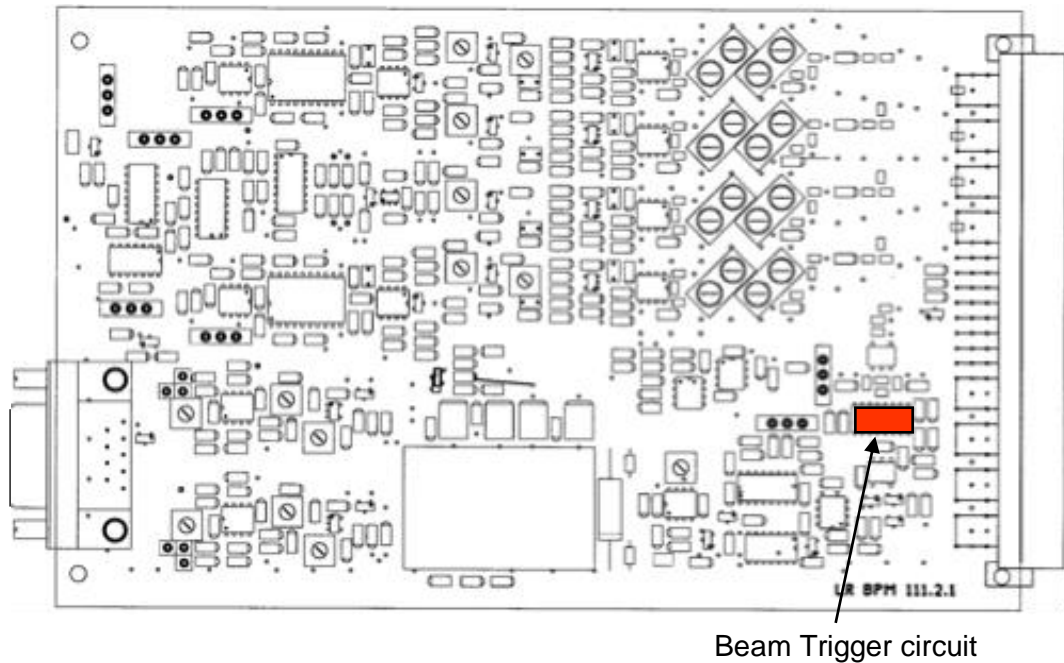
LR-BPM version-1 have serial numbers $< \#955$. They are described in another manual.
If you have a Version-1 unit, please ask Bergoz Instrumentation or your distributor to send the LR-BPM User's Manual version 1.x.

LR-BPM version-2.0 have serial numbers $\#956 \leq \text{SN} \leq \#1074$
The circuit revision number 111.2.0 is engraved on the printed circuit board "solder side".
LR-BPM version-2.0 are the object of this User's Manual.

LR-BPM version-2.1 have serial numbers $\#1092 \leq \text{SN} \leq \#xxx$
The circuit revision number 111.2.1 is engraved on the printed circuit board.
LR-BPM version-2.1 with Sample & Hold option LR-BPM-SH can be recognized by:
The printed circuit is equipped with Track&Hold + Sample&Hold circuits.

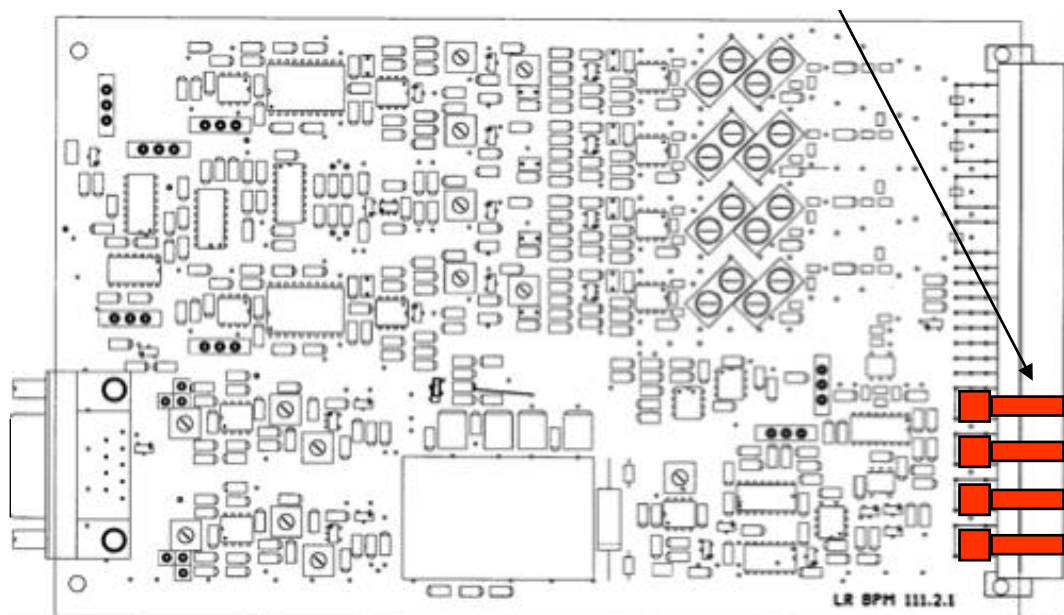


LR-BPM version-2.1 with Beam Trigger option LR-BPM-TRG can be recognized by:
The printed circuit board is equipped with a log amplifier limiter circuit:



LR-BPM version-2.1 with A, B, C and D direct outputs option LR-BPM-ABCD can be recognized
The printed circuit board is equipped with A, B, C and D output connectors:

Direct output connectors for Channels A, B, C and D



MODES OF OPERATION FOR VARIOUS BEAMS

LR-BPM can be equipped with many options, then further configured by the user to support many modes of operation:

Sample & Hold (S&H) Mode

Note: Requires Sample&Hold option LR-BPM-SH to be mounted on the printed circuit board.

Processing time	~450 ns
Hold time	Up to 100 ms
ADC measurement time	At maximum repetition rate, at least 100 ns "good" signal
Repetition rate	Up to 2 MHz

Indicated for: Linacs: single bunch, bunch trains, prebunched S-band/X-band
Transfer lines
Synchrotron first turn
Synchrotron single bunch turn-by-turn
Synchrotron multi-single bunch turn-by-turn, using trigger gate.

Refer to "Sample & Hold Mode" for switch settings

Track & Hold (T&H) Mode

Note: Requires Sample&Hold option LR-BPM-SH to be mounted on the printed circuit board.

Processing time	~110 ns
Hold time	~70 ns
ADC measurement time	At maximum repetition rate, at least 50 ns "good" signal
Repetition rate	Up to 5 MHz

Indicated for: Synchrotron $2 \text{ MHz} < f_{\text{rev}} < 5 \text{ MHz}$, single bunch turn-by-turn
Synchrotron multi-single bunch turn-by-turn, using trigger gate.

Refer to Track & Hold Mode" for switch settings

Track Continuous (T) Mode

Note: Does not require Sample & Hold option. Does not require Built-in Beam Trigger option

Output bandwidth	5 MHz
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Indicated for: CW beams in general:

- Linacs and synchrotrons with bunch repetition rate up to 500 MHz
- Betatron oscillation monitoring in boosters and storage rings
- L-band, S-band, X-band linacs prebunched up to 500 MHz
- Smaller-size ion and proton synchrotrons with $f_{\text{rev}} > 5 \text{ MHz}$.

Refer to "Track-Continuous Mode" for switch settings.

In Sample&Hold (S&H) and Track&Hold (T&H) modes, LR-BPM must be triggered.

Triggering can be provided:

- a) by the built-in Beam Trigger, if installed on LR-BPM (order code LR-BPM-TRG).
To use the built-in Beam Trigger, it must be enabled by its switch.
See TRG switch below.
- b) by an external signal applied to TG.IN.AUX input.
To use the external trigger, the built-in trigger –if installed– must be disabled.
See TRG switch below.

OPTIONS

In addition to the Sample & Hold option described in the preceding chapter, other options are available:

Built-in Beam Trigger “LR-BPM-TRG” option

Note: Requires Built-in Beam Trigger option LR-BPM-TRG to be mounted on the printed circuit board.

Particle polarity	LR-BPM version 2.1 operates with positive and negative particle polarity
Minimum detected charge	100 pC bunch seen by four pickups of 5 pf capacitance and width = 1/8 of circumference.
Maximum repetition rate	5 MHz.

Sum of logs Output “LR-BPM-SUM” option

Note: Requires Sum-of-Logs option LR-BPM-SUM to be mounted on the printed circuit board.

Value	$SUM = \text{Log}(A) + \text{Log}(B) + \text{Log}(C) + \text{Log}(D)$
Bandwidth	5 MHz
See typical Log(A) output from a single bunch on preceding page timing diagram	

Direct log outputs for A, B, C and D “LR-BPM-ABCD” option

Note: Requires Direct A, B, C, D Outputs option LR-BPM-ABCD to be mounted on the printed circuit board.

Outputs	Log(A), Log(B), Log(C) and Log(D)
Bandwidth	5 MHz
Connectors	1.0/2.3 output connectors

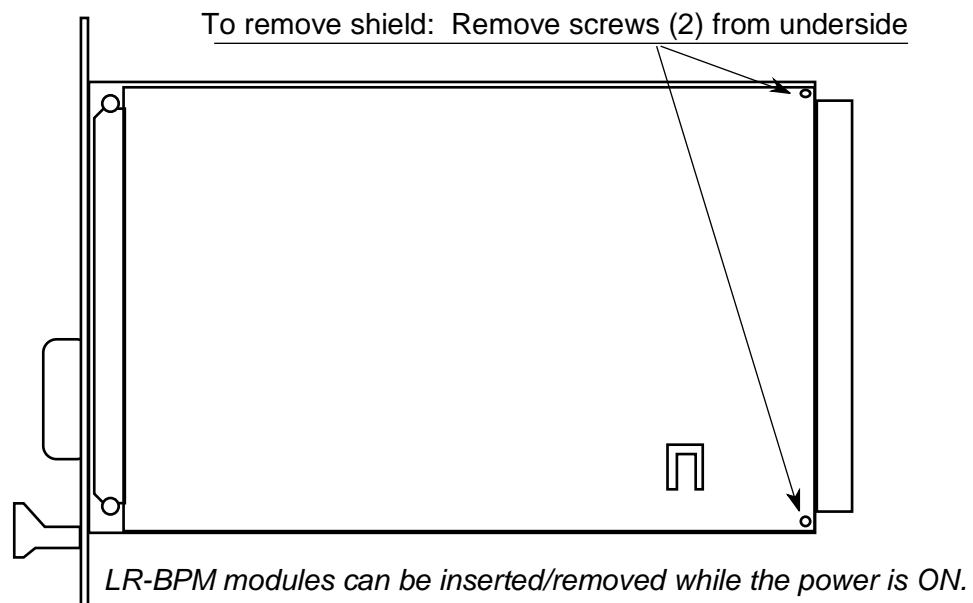
Note: Mating connectors are not installed in chassis BPM-RFC or BPM-KIT. Users of option LR-BPM-ABCD must provide these connectors. Refer to “BPM MODULE REAR CONNECTOR”.

See typical Log(A) output from a single bunch on preceding page timing diagram

Note: Accessories are described in a specific chapter “ACCESSORIES”.

ACCESS to STRAPS and SWITCHES

To access switches or straps, remove the module shield:



The LR-BPM module is equipped with many on-board potentiometers to adjust the log amplifiers gain, slope and intercept point. They require precise instruments, tools and procedures for their adjustment.

LR-BPM PRINCIPLE OF OPERATION

The signals from the pickup electrodes are processed simultaneously thru four independent channels. Each channel consists of an input band-pass filter, followed by an amplification chain with logarithmic response.

When a single short pulse is applied to the band-pass filter, it will oscillate at its own resonant frequency for about 250 ns, allowing enough time for the logarithmic amplifier to detect the log of its envelope.

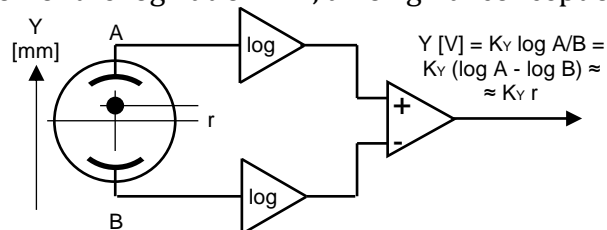
Each amplifying chain produces a signal which peak amplitude is proportional to the log of the input signal, be it a single pulse, a pulse train, or a continuous wave.

Log signals from opposite pickup electrodes are deducted from one another to obtain $\text{Log}(A) - \text{Log}(C) = \text{Log}(A/C)$ which is said to be a very faithful representation of beam displacement between two pickup electrodes.

If the pickup electrodes are placed along the axes in which the beam displacement is to be measured, the displacement $X = K_x \text{Log}(A/C)$, directly. The K_x gain is obtained by an amplifier with adjustable gain. The same goes for the Y axis.

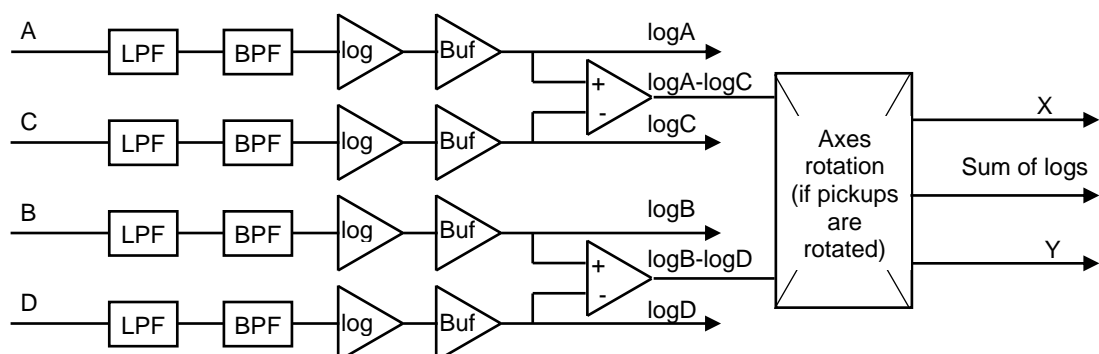
If the pickup electrodes are placed along axes rotated as compared to the beam position measurement axes, the A-C and B-D axes must be rotated to obtain the beam displacement values along X and Y. The rotation is done wideband with >5 MHz response applying the algorithm hereafter:

Schematic representation of the log-ratio BPM, an original concept of Robert E. Shafer:



Position measured by this method is more linear, over a wider range, than difference-over-sum.

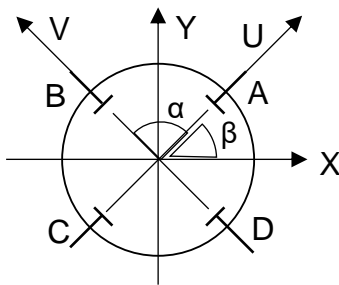
BLOCK DIAGRAM



AGREEMENT ON AXES & SIGNS

X, Y: User's orthogonal axes
U, V: LR-BPM pickup axes AC and BD

Rotated pickups



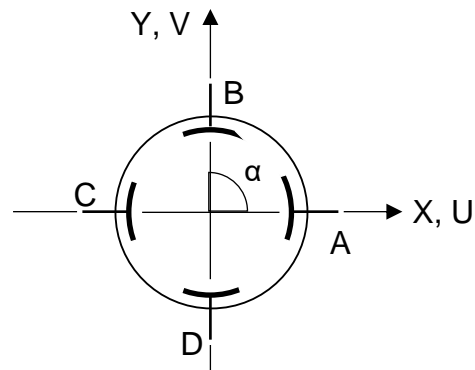
$$\beta \neq 0$$

General case: α may be $\neq \pi/2$

Note: LR-BPM is factory-set for equal X and Y gains,
i.e. $\alpha = \pi/2$

$$\begin{aligned} U &= \text{Log}(A/C) \\ V &= \text{Log}(B/D) \quad \text{Signals of positive polarity} \\ X &= K_X \cdot (U-V) \cos \beta \\ Y &= K_Y \cdot (U+V) \sin \beta \end{aligned}$$

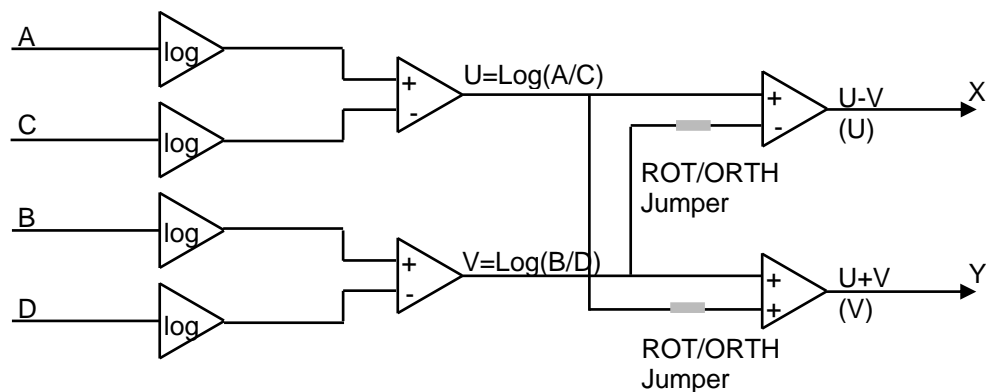
Orthogonal pickups



$$\alpha = \pi/2$$

$$\beta = 0$$

$$\begin{aligned} U &= \text{Log}(A/C) \\ V &= \text{Log}(B/D) \quad \text{Signals of positive polarity} \\ X &= K_X \cdot V \\ Y &= K_Y \cdot U \end{aligned}$$

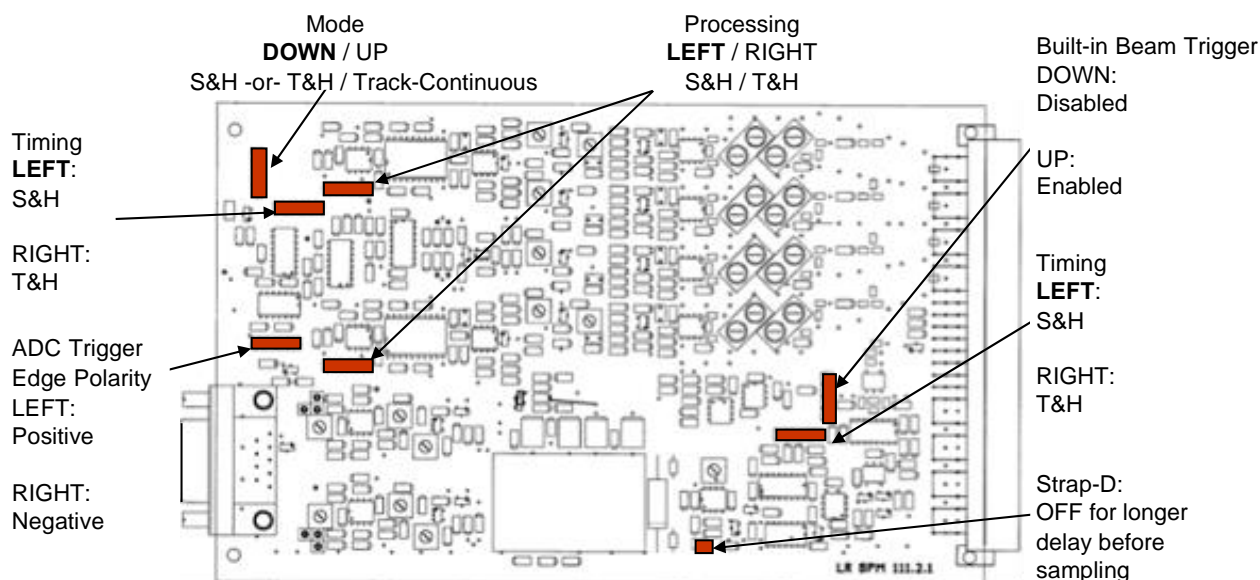


For details on pickup sensitivity and log-ratio, consult:
Log-ratio Signal-Processing Technique for Beam Position Monitors, Robert E. Shafer,
Proceedings of the Fourth Accelerator Instrumentation Workshop, Berkeley 1992.
AIP Conf. proceedings No. 281, pages 120-128.

SAMPLE & HOLD MODE

Set switches to:

Mode: Sample&Hold (DOWN)
Processing: Sample&Hold (LEFT position)
Timing: Sample&Hold (LEFT position)
Built-in Beam Trigger: As desired
ADC Trigger Output Edge: As desired



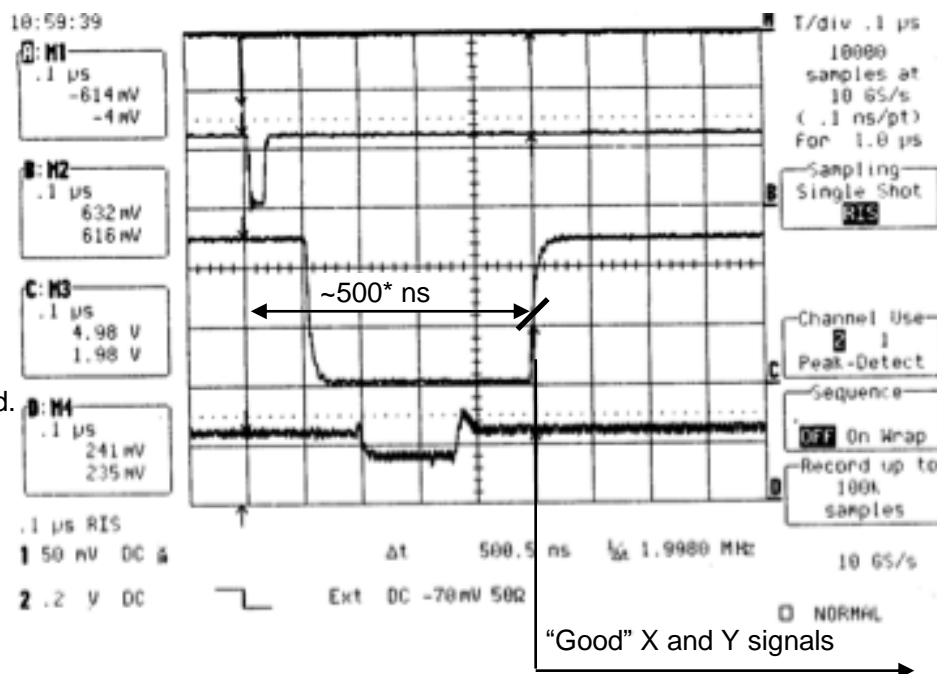
Signal timing in Sample & Hold mode

Input signal from pickup

Trigger output
TRG.AUX.OUT
from Built-in Beam Trigger
or External Trigger

Trigger output for ADC
TG.ADC.OUT
from Built-in Beam Trigger
or External Trigger
Note: Positive edge selected.
*600 ns when Strap-D
removed

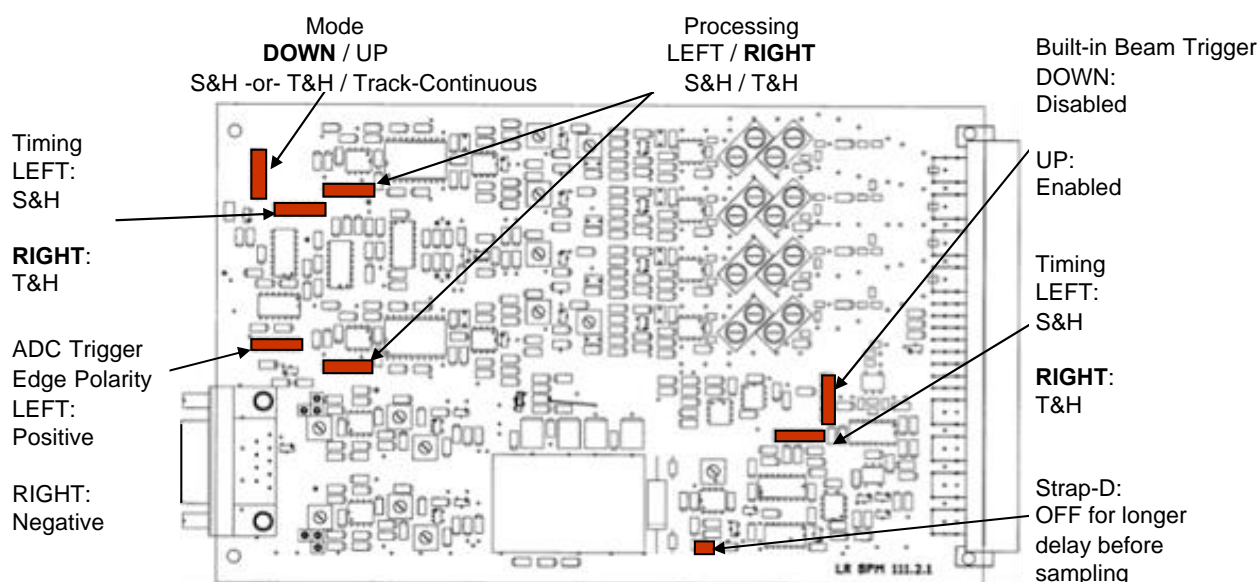
Position output signal
XOUT or YOUT



TRACK & HOLD MODE

Set switches to:

Mode: Track&Hold (DOWN)
Processing: Track&Hold (RIGHT position)
Timing: Track&Hold (RIGHT position)
Built-in Beam Trigger: As desired
ADC Trigger Output Edge: As desired



Signal timing in Track & Hold mode

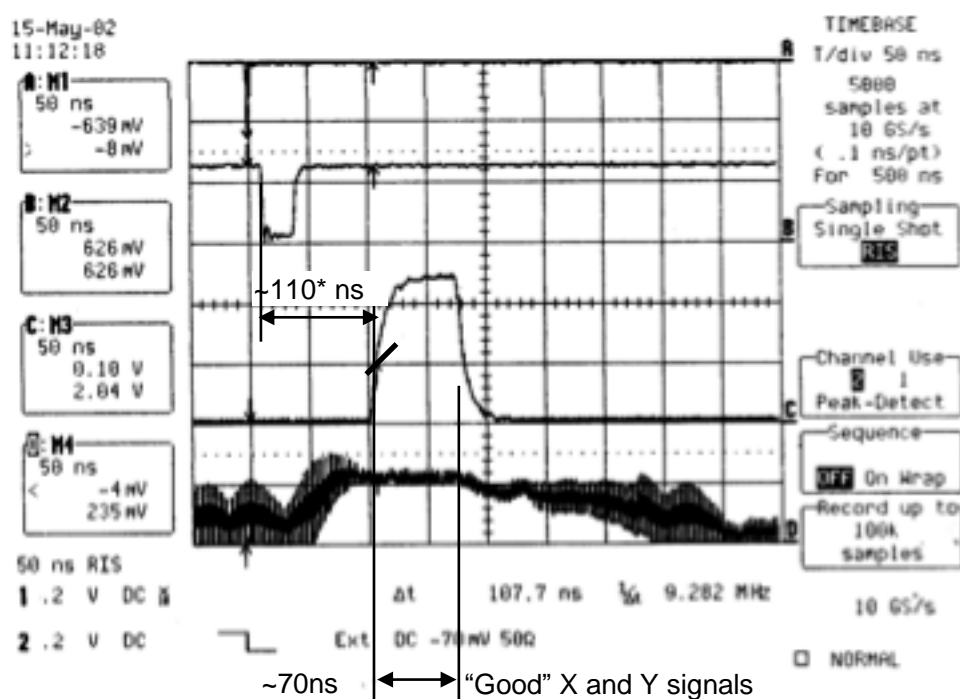
Input signal from pickup

Trigger output
BT.G.BT.AUX.OUT
from Built-in Beam Trigger
or External Trigger

Trigger output for ADC
TG.ADC.OUT
from Built-in Beam Trigger
or External Trigger
+ Track&Hold delay

Note: Positive edge
selected. *600 ns when
Strap-D removed

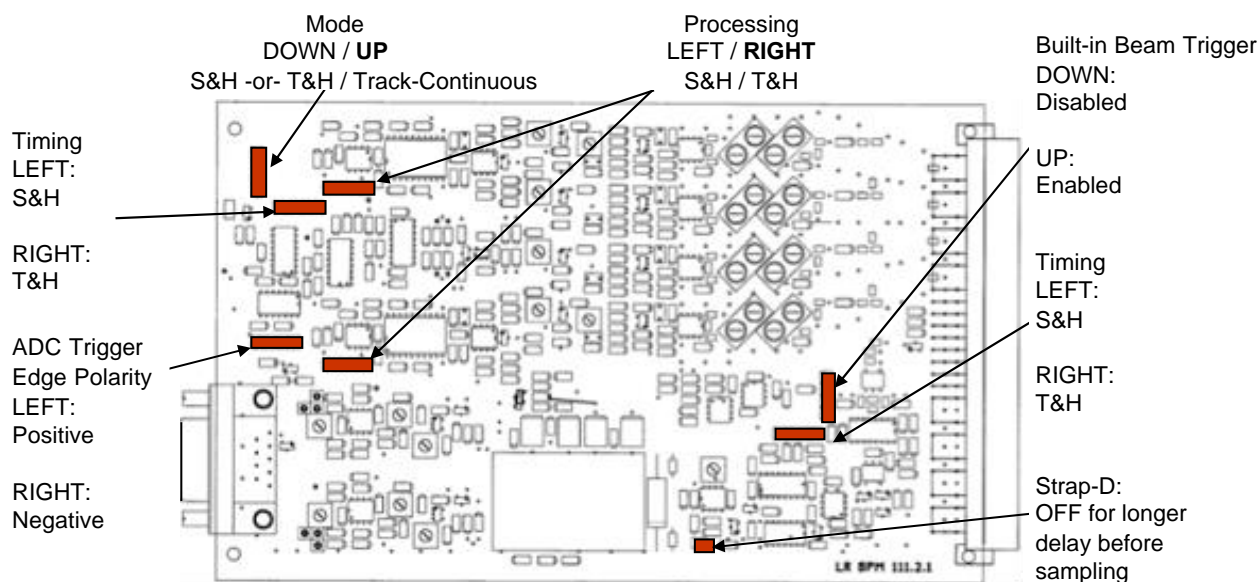
Position output signal
XOUT or YOUT



TRACK-CONTINUOUS MODE

Set switches to:

- Mode: Track-Continuous (UP)
- Processing: Track&Hold (RIGHT position)
- Timing: Choose suitable position according to ADC
- Built-in Beam Trigger as desired
- ADC Trigger Output Edge as desired



Note: Built-in Beam Trigger (Option LR-BPM-TRG) will not operate above 5 MHz bunch repetition rate

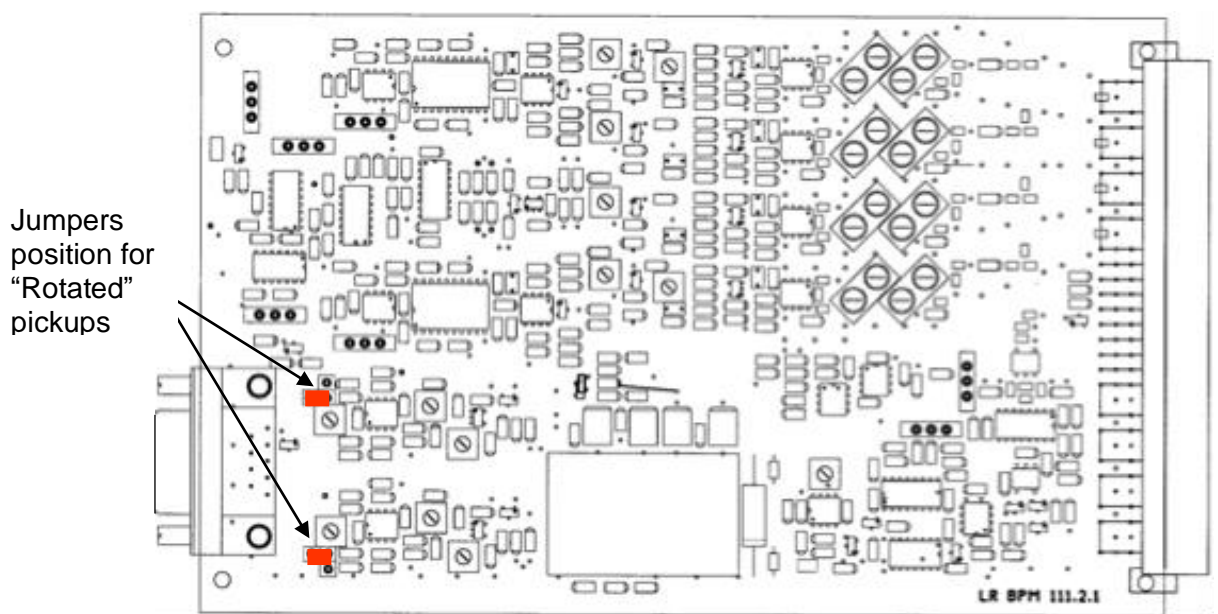
Output signals XOUT and YOUT track the position given by A, B, C and D inputs with 5 MHz bandwidth.

CHANGING PICKUP CONFIGURATION

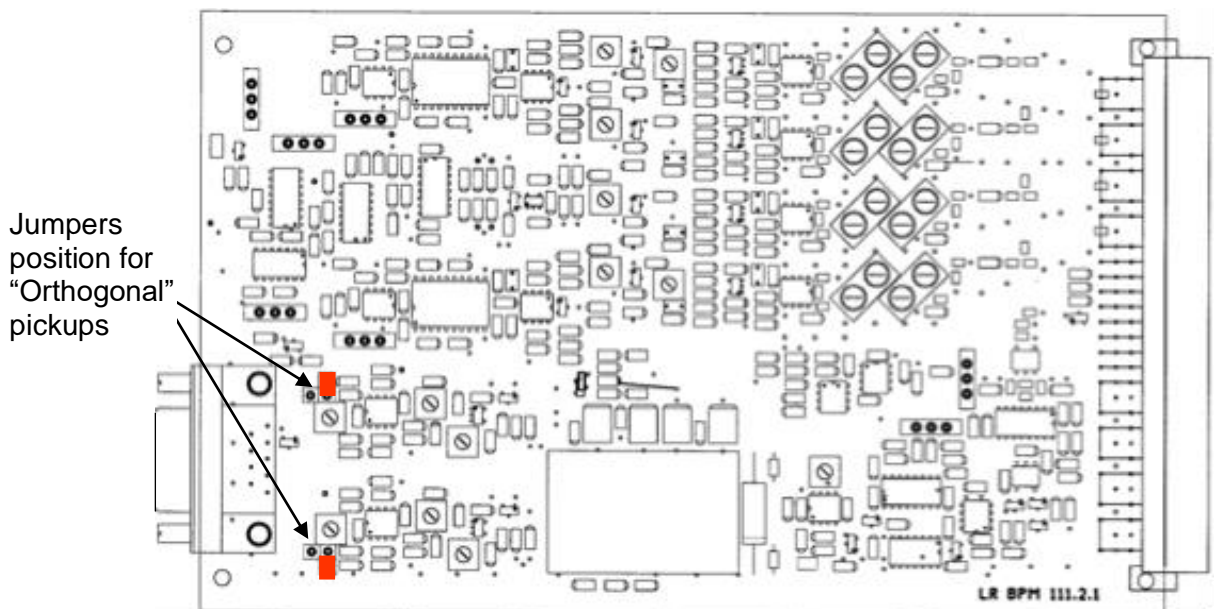
The pickup configuration is set with two jumpers.

To change the configuration from “Rotated” to “Orthogonal” or vice versa, change the jumper position:

Rotated pickups, position of jumpers



Orthogonal pickups, position of jumpers



QUICK CHECK: LR-BPM IN SAMPLE&HOLD MODE

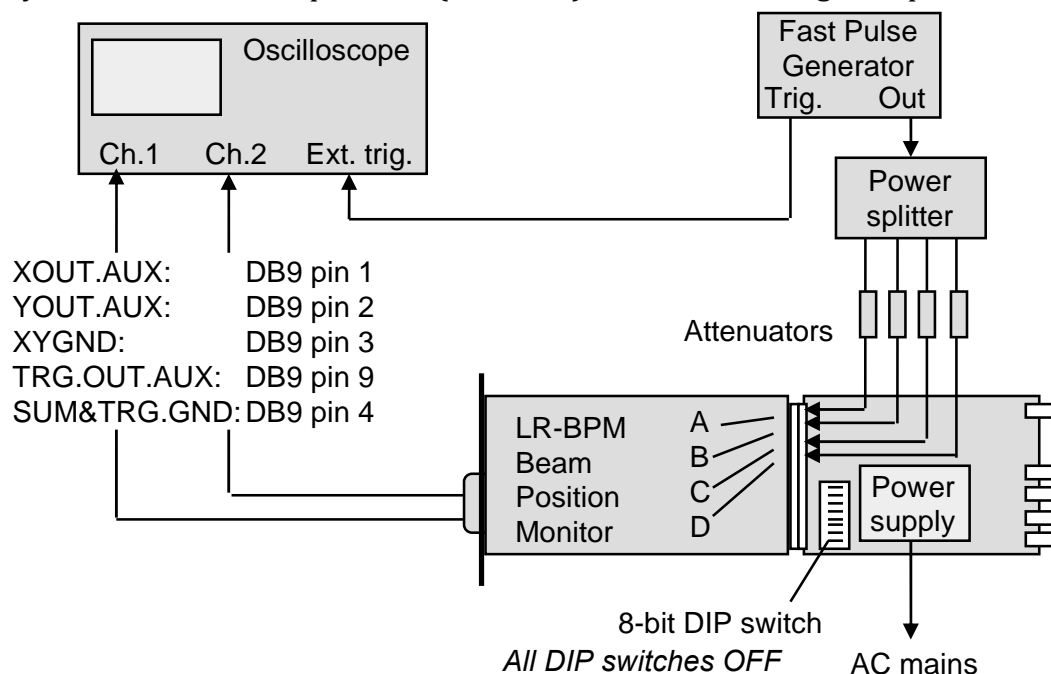
Note: This Quick Check works only if Sample & Hold LR-BPM-SH option is installed

Unless otherwise specified on the Certificate of Calibration, LR-BPM with Sample&Hold option has following ex-factory settings:

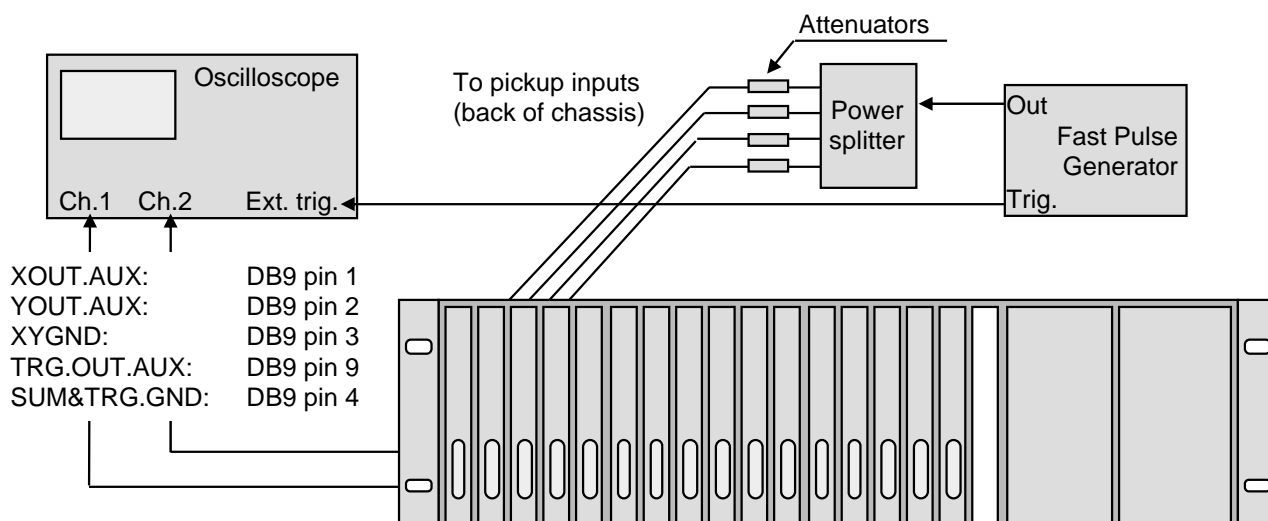
- Rotated pickups
- Built-in Beam Trigger
- Mode, Timing and Processing: S&H
- Built-in trigger: Enabled
- ADC Trigger output: Positive edge

Setup: to check immediately that your LR-BPM system is working.

If you have the table-top test kit (BPM-KIT), use the following set-up:



If you have a 19" chassis (BPM-RFC/X), use the following set-up:



Attach the equipment together as shown above.

Set the fast pulse generator to:

- Output voltage: 50V (in 50-ohm)
- Pulse polarity: negative
- Pulse width ≤ 1 ns fwhm
- Pulse repetition: slow (in the Hz to kHz range)

Note: Signals applied to LR-BPM inputs will be attenuated by the 4-way splitter:

- Transformer-type 4-way splitters typically attenuate by 7dB,
- 4-way resistive splitters or cascaded 2-way splitters attenuate by 12dB.

This 50V pulse, after splitting in a transformer-type 4-way splitter (-7 dB) is about equivalent to a 10-nC bunch seen by four pickups of 5 pf capacitance and width = 1/8 of circumference.

Use 4 similar attenuators, each 3 dB. The same test can be done with 5 and 10 dB.

Note: Attenuators are seldom more precise than ± 0.1 dB. This will be reflected upon the LR-BPM X and Y zero readings.

Connect to Test Kit or 19" BPM-RFC chassis to AC mains.

Auxiliary trigger output

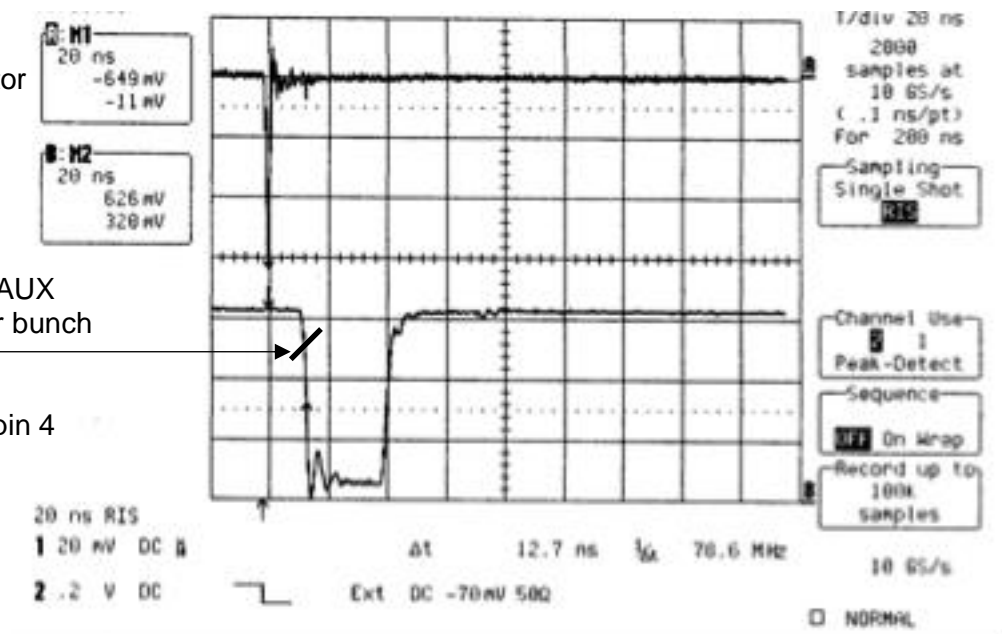
Observe the Auxiliary trigger from LR-BPM. This trigger is used for oscilloscope triggering.

Input signal from
Fast Pulse generator
(50 Ω):

Output DB9 pin 9
TRG.OUT.AUX
(1-M Ω):

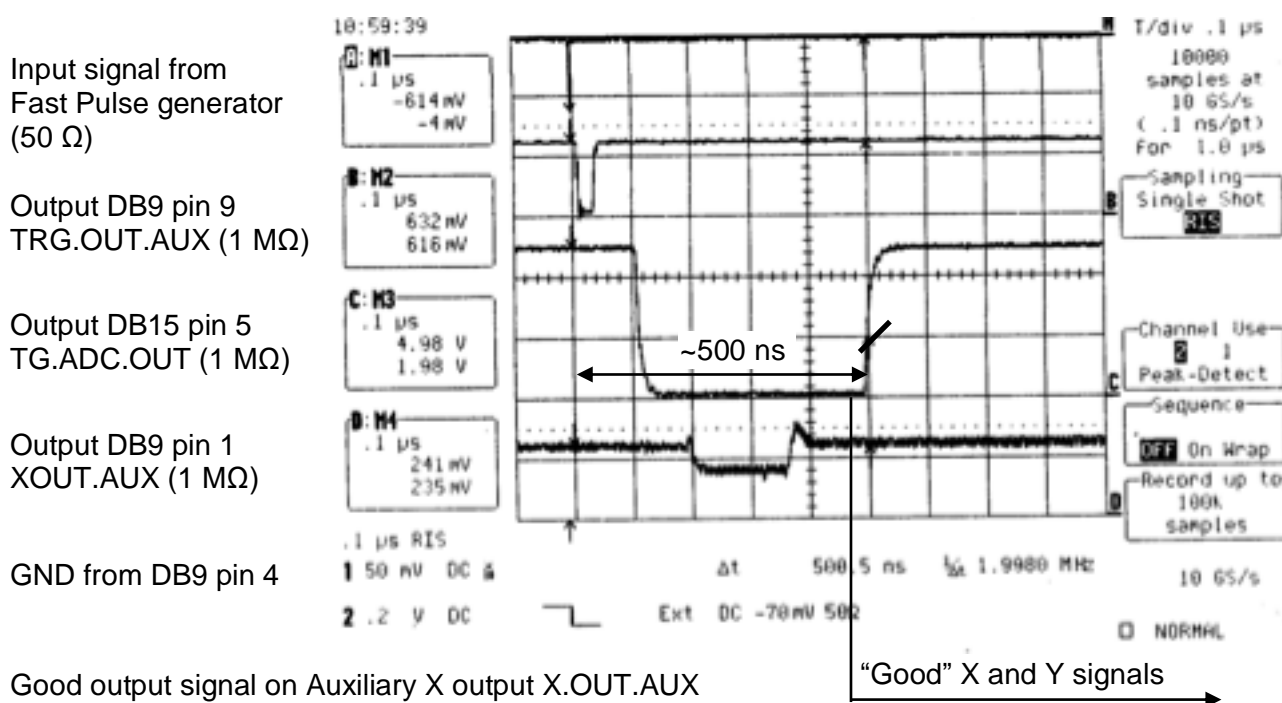
Trigger TRG.OUT.AUX
comes ~13 ns after bunch

Ground from DB9 pin 4



ADC Trigger output and Auxiliary X or Y outputs

Observe ADC Trigger output, available from the DB15 connector pin 5, either at side of BPM-KIT or at rear of BPM/RFC chassis.



Good output signal on Auxiliary X output X.OUT.AUX
DB9 pin 1, starts with TG.ADC.OUT downswing, ~500 ns after
beam bunch. Output signal is held more than 100 milliseconds

Note: Your ADC can be triggered from DB15 pin 5 output signal TG.ADC.OUT:

- First edge is ~ 120 ns after the beam bunch
- Second edge is ~ 500 ns after the beam bunch.

Polarity of edge is determined by ADC Trigger Edge Polarity switch.

Auxiliary outputs X and Y are available on DB9 pin 1 and pin 2 respectively.

XOUT and YOUT Zero Offsets

If the signals applied to all four LR-BPM inputs were exactly equal, and if the LR-BPM module were perfect, the values of X and Y would be exactly 0 Volt.

This is generally not the case, X and Y will be many tens or even hundreds of millivolts off.

You can determine how much of this offset is caused by attenuator inequality: Swap the attenuators A and C, then B and D and observe the offset change.

You can determine how much of this offset is caused by power splitter imbalance: Instead of connecting attenuator A to power splitter output 1, connect it to output 3 and connect attenuator C to output 1. Do the same for attenuators B and D with power splitter outputs 2 and 4.

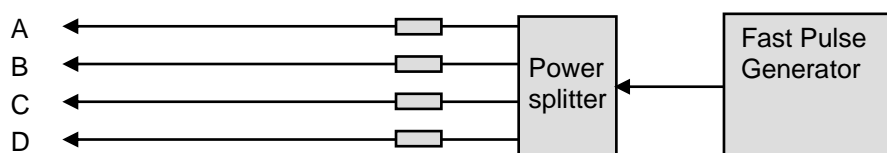
Simulating beam position changes

To simulate beam position changes, the input signal power is changed by 6 dB, 10 dB and 14 dB, hence simulating position changes up to 1/3 of vacuum chamber radius.

The pulse generator output amplitude should be in the range 5V...50V

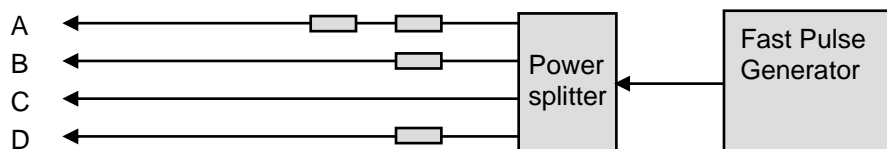
The LR-BPM on-center sensitivity is factory-set to 55.5 mV per dB of signal difference between opposite pickups. For pickups with small angle (e.g. buttons), 6 dB corresponds to beam displacement equal to 1/6 of vacuum chamber radius. As the beam goes far off center, this sensitivity becomes lower due to the algorithm $X = \text{Log}(A/C)$. Please consider that the pickup sensitivity becomes higher as the beam goes off center, and one non-linearity tends to compensate the other.

Before simulating a beam displacement, start by noting the X and Y zero offsets, using four equal attenuators:



Then simulate the displacement by removing an attenuator from one input and inserting it in the opposite input: A \leftrightarrow C, and B \leftrightarrow D.

Example:



Attenuator C is removed from input C, and added to input A, thus simulating a displacement of the beam towards C (stronger signal on C pickup).

LR-BPM modules are factory preset:

- For orthogonally placed pickups: up, down, left and right
or,
- For rotated pickups: upper-right, upper-left, lower-left and lower-right.

The combinations on the following table can be tried, yielding the X and Y values listed.

Note: These are displacements. Take into consideration the zero offsets due to power splitter imbalance and attenuators inequality.

Table of X/Y output voltage vs. input amplitude

Input	Attenuators	Equivalent displacement	Rotated pickups	Orthogonal pickups
A	3 + 3	1/6 of radius towards C		
B	3		X = -0.245 V	X = -0.347 V
C	0		Y = -0.245 V	Y = 0 V
D	3	(button pickups << chamber diameter)		
A	3 + 3	1/6 of radius towards C		
B	3 + 3	1/6 of radius towards D	X = 0 V	X = -0.347 V
C	0		Y = -0.490 V	Y = -0.347 V
D	0	(button pickups << chamber diameter)		
A	5 + 5	1/4 of radius towards C		
B	5		X = -0.407 V	X = -0.576 V
C	0		Y = -0.407 V	Y = 0 V
D	5	(button pickups << chamber diameter)		
A	5 + 5			
B	5 + 5		X = 0 V	X = -0.576 V
C	0		Y = -0.814 V	Y = -0.576 V
D	0	(button pickups << chamber diameter)		
A	10 + 7	1/3 of radius towards C		
B	10		X = -0.570 V	X = -0.806 V
C	3		Y = -0.570 V	Y = 0 V
D	10	(button pickups << chamber diameter)		

Note: These are displacements. Take into consideration the zero offsets due to power splitter imbalance and attenuators inequality.

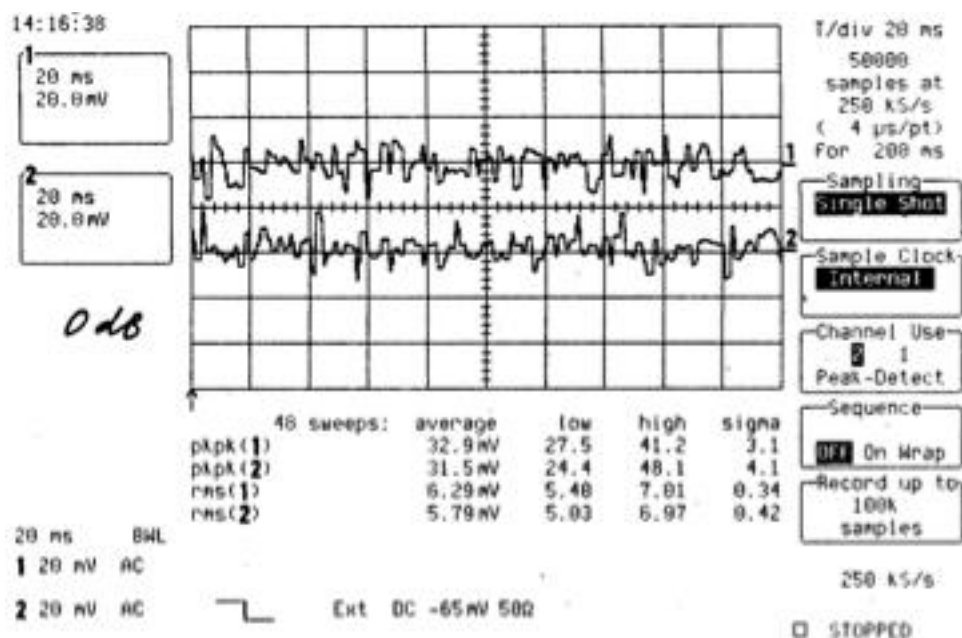
Noise measurement

X and Y outputs exhibit noise. The following test gives a feel of the noise, without the need for a sophisticated data acquisition system.

An oscilloscope takes a single sweep of Xout and Yout. Its timebase is set to display –in a single sweep– the outputs corresponding to ~200 input pulses:

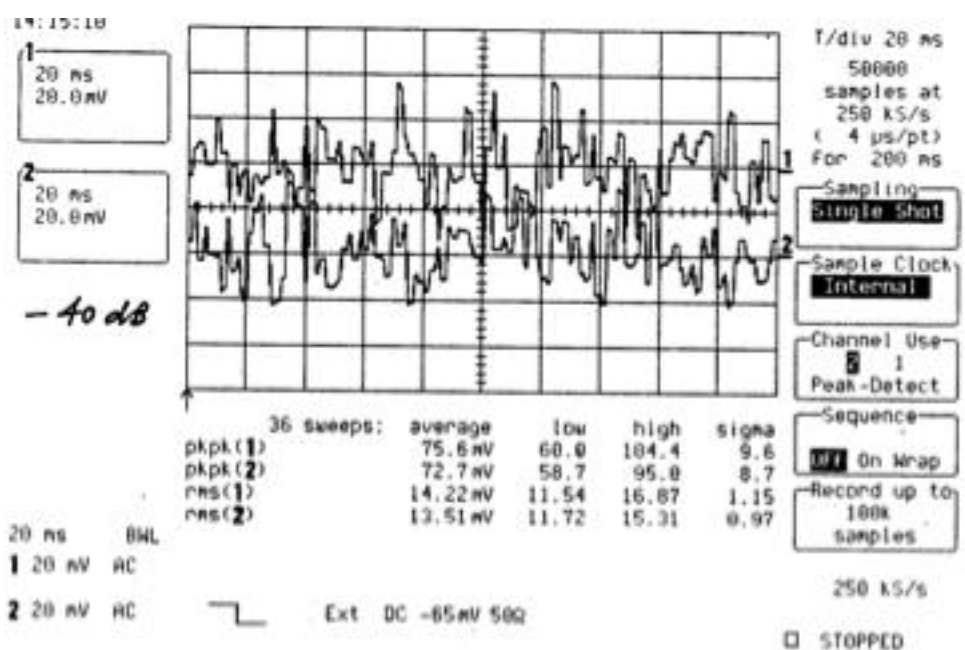
X and Y outputs corresponding to a bunch ~10nC “seen” by four pickups, ea. 5 pf capacitance and width = 1/8 of circumference.

Pulse
Generator:
50V - 0.75ns



X and Y outputs corresponding to a bunch ~100pC “seen” by four pickups, ea. 5 pf capacitance and width = 1/8 of circumference.

Pulse
Generator:
0.05V - 0.75ns



QUICK CHECK: LR-BPM IN TRACK&HOLD MODE

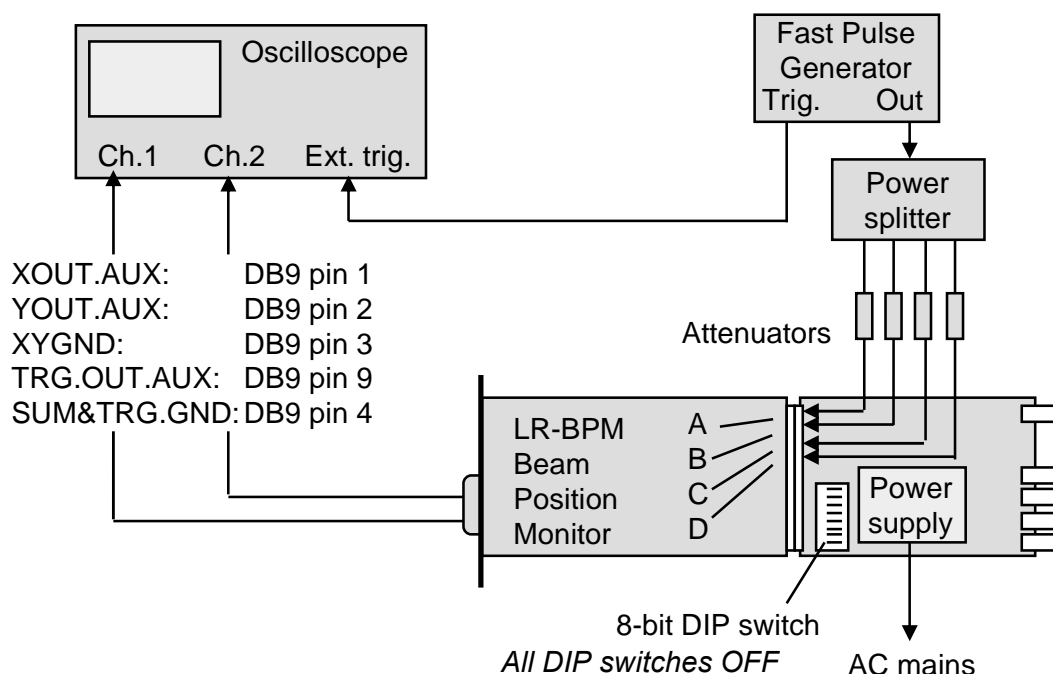
Note: This Quick Check works only if LR-BPM-SH (Sample & Hold) option is installed.

LR-BPM ordered specifically for Track&Hold operation has following ex-factory settings:

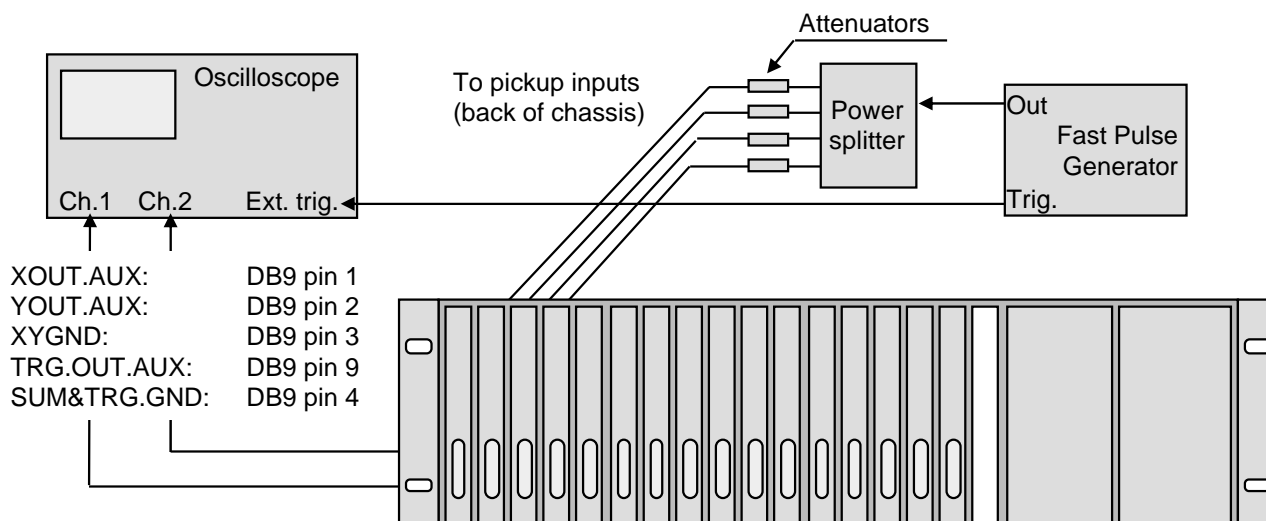
- Unless otherwise specified–
- Rotated pickups
- Built-in Beam Trigger
- Mode, Timing and Processing: Track&Hold
- Built-in trigger: Enabled
- ADC Trigger output: Positive edge

Setup: to check immediately that your LR-BPM system is working.

If you have the table-top test kit (BPM-KIT), use the following set-up:



If you have a 19" chassis (BPM-RFC/X), use the following set-up:



Attach the equipment together as shown above. Set the fast pulse generator to:

- Output voltage: 50V (in 50-ohm)
- Pulse polarity: negative
- Pulse width ≤ 1 ns fwhm
- Pulse repetition: slow (in the Hz to kHz range).

Note: Signals applied to LR-BPM inputs will be attenuated by the 4-way splitter:

- Transformer-type 4-way splitters typically attenuate by 7dB,
- 4-way resistive splitters or cascaded 2-way splitters attenuate by 12dB.

This 50V pulse, after splitting in a transformer-type 4-way splitter (-7 dB) is about equivalent to a 10-nC bunch seen by four pickups of 5 pf capacitance and width = 1/8 of circumference.

Use 4 similar attenuators, each 3 dB. The same test can be done with 5 and 10 dB.

Note: Attenuators are seldom more precise than ± 0.1 dB. This will be reflected upon the LR-BPM X and Y zero readings.

Connect to Test Kit or 19" BPM-RFC chassis to AC mains.

Observe the traces from:

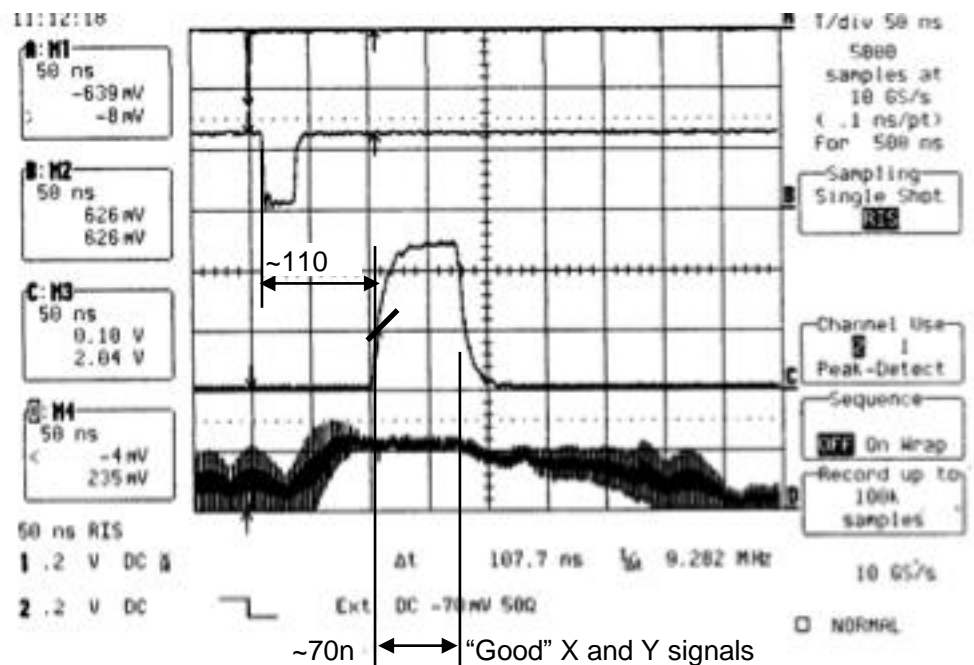
- Auxiliary trigger output: ~ 13 ns after bunch. This output is used for oscilloscope triggering.
- Trigger output for ADC: 110 ns after the bunch. This trigger is used to trigger ADC.
- X or Y output: signal can be measured; it is held for ~ 70 ns.
-

Input signal from pickup

Trigger output
BTG/BT.AUX.OUT
from Built-in Beam Trigger
or External Trigger

Trigger output for ADC
TG.ADC.OUT
from Built-in Beam Trigger
or External Trigger
+ Track&Hold delay
Note: Positive edge
selected

Position output signal
XOUT or YOUT



Next, proceed thru the same tests as "QUICK CHECK: LR-BPM in Sample & Hold Mode":

- XOUT and YOUT Zero Offsets
- Simulating beam position changes

Noise measurement cannot be performed as easily in Track&Hold mode, because the output signal is held only ~ 70 ns. For noise measurement, X or Y output must be sampled, using either Auxiliary Trigger, or ADC Trigger.

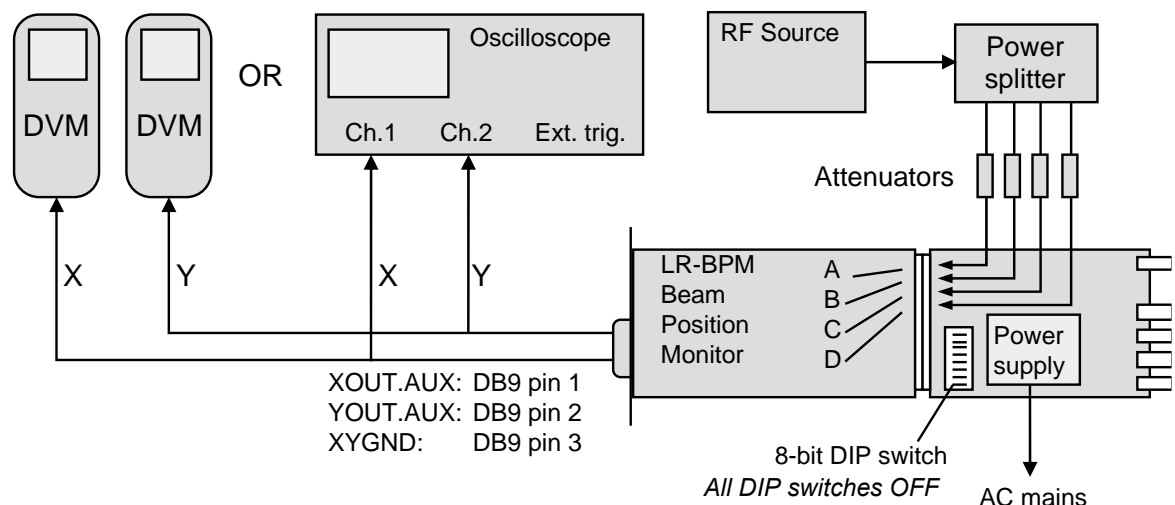
QUICK CHECK: LR-BPM IN TRACK CONTINUOUS MODE

If you wish to use an LR-BPM (whether or not it has the Sample & Hold option LR-BPM-SH), its switches must be set according to chapter TRACK-CONTINUOUS MODE. Unless otherwise specified, LR-BPM without Sample&Hold LR-BPM-SH option has following ex-factory settings:

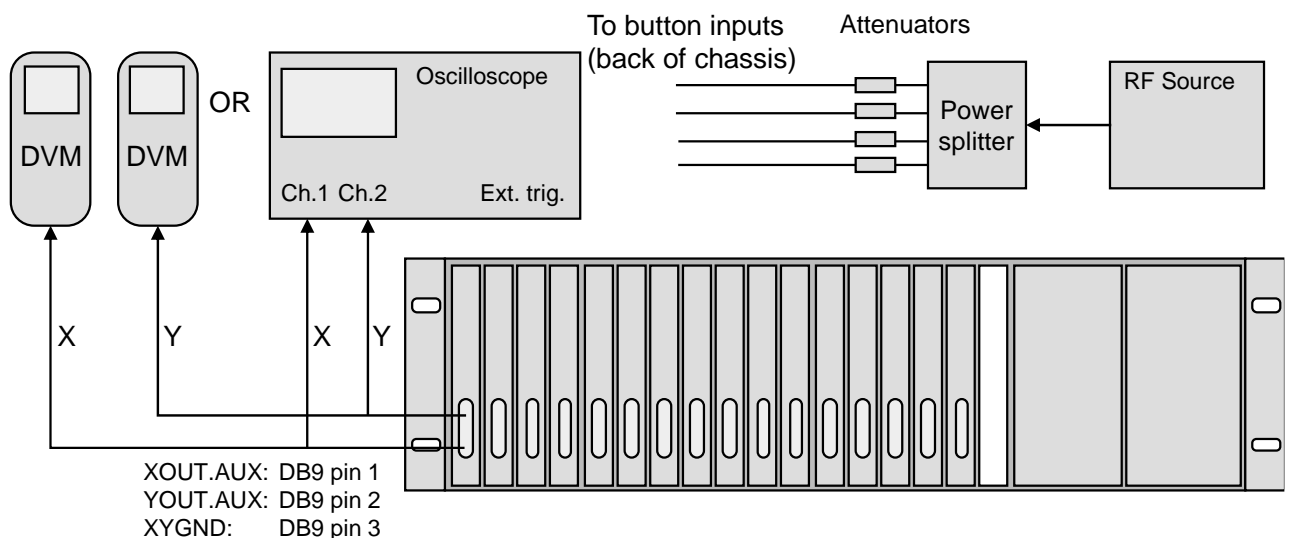
- Rotated pickups
- Mode: Track-Continuous
- Built-in trigger: Enabled
- ADC Trigger output: positive edge

Setup: to check immediately that your LR-BPM system is working.

If you have the table-top test kit (BPM-KIT), use the following set-up:



If you have a 19" chassis (BPM-RFC/X), use the following set-up:



To display X and Y signals, you can use either two DVMs, or an oscilloscope. Attach the equipment together as shown above.

Set the DVMs on Volt-DC, or the oscilloscope on:

- Time base on 0.2 ms / div., free running,
- Channel 1 to Xout signal, sensitivity 0.2 V / div., 1 M Ω DC coupling
- Channel 2 to Yout signal, sensitivity 0.2 V / div., 1 M Ω DC coupling

Set the RF source to the LR-BPM operating frequency.

E.g. set to 500 MHz to test LR-BPM-500MHz.

Amplitude ca. -10 dBm

Use 4 similar attenuators, each 3 dB. The same test can be done with 5 and 10 dB.

Note: attenuators are seldom more precise than ± 0.1 dB. This will be reflected upon the LR-BPM X and Y readings.

Note: Signals applied to LR-BPM inputs will be attenuated by the 4-way splitter:

- Transformer-type 4-way splitters typically attenuate by 7dB, 4-way resistive splitters or cascaded 2-way splitters attenuate by 12dB.

Connect to Test Kit or 19" BPM-RFC chassis to AC mains, the DVM (or oscilloscope) will display X and Y values.

If the RF signals applied to all four LR-BPM inputs were exactly equal, and if the LR-BPM module were perfect, the values of X and Y would be exactly 0 Volt.

This is generally not the case, X and Y will be many 10s or even 100s of millivolts off.

You can determine how much of this offset is caused by attenuator inequality:

- Swap the attenuators A and C, then B and D and observe the offset change.

You can determine how much of this offset is caused by power splitter imbalance:

- Instead of connecting attenuator A to power splitter output 1, connect it to output 3 and connect attenuator C to output 1.
- Do the same for attenuators B and D with power splitter outputs 2 and 4.

The next tests will consist of:

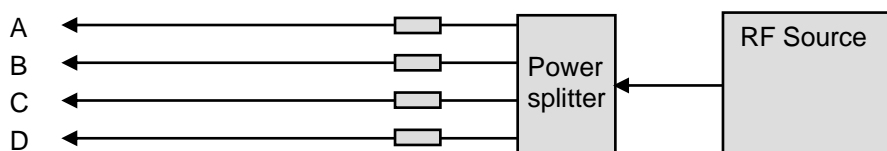
- Simulating beam displacements of 6 dB, 10 dB and 14 dB
- Exploring the LR-BPM dynamic range by varying the RF source output power.

Beam displacement

The RF source output power should be in the range -10dBm ... -35 dBm

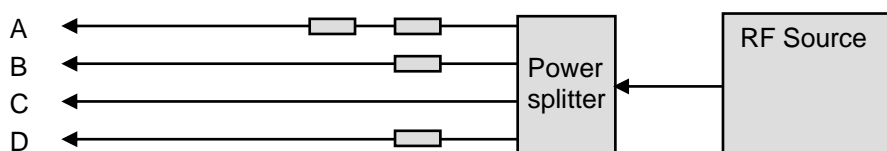
The LR-BPM on-center sensitivity is factory-set to 55.5 mV per dB of signal difference between opposite pickups. For pickups with small angle (e.g. buttons), 6 dB corresponds to beam displacement equal to 1/6 of vacuum chamber radius. As the beam goes off center, this sensitivity becomes lower due to the algorithm $X = \text{Log}(A/C)$. Please consider that the pickup sensitivity becomes higher as the beam goes off center, and one non-linearity tends to compensate the other.

Before simulating a beam displacement, start by noting the X and Y zero offsets, using four equal attenuators:



Then simulate the displacement by removing an attenuator from one input and inserting it in the opposite input: A \Leftrightarrow C, and B \Leftrightarrow D.

Example:



Attenuator C is removed from input C, and added to input A, thus simulating a displacement of the beam towards C (stronger signal on C pickup).

The following combinations can be tried, yielding the X and Y values listed here. Please note these are displacements. Take the zero offsets due to power splitter imbalance and attenuators inequality into consideration.

LR-BPM modules are factory preset:

- For orthogonally placed pickups: up, down, left and right
 Or
- For rotated pickups: upper-right, upper-left, lower-left and lower-right.

The combinations on the following table can be tried, yielding the X and Y values listed.

Note: These are displacements. Take into consideration the zero offsets due to power splitter imbalance and attenuators inequality.

Table of X/Y output voltage vs. input power

Input	Attenuators	Equivalent displacement	Rotated pickups	Orthogonal pickups
A	3 + 3	1/6 of radius towards C		
B	3		X = -0.245 V	X = -0.347 V
C	0		Y = -0.245 V	Y = 0 V
D	3	(button pickups << chamber diameter)		
A	3 + 3	1/6 of radius towards C		
B	3 + 3	1/6 of radius towards D	X = 0 V	X = -0.347 V
C	0		Y = -0.490 V	Y = -0.347 V
D	0	(button pickups << chamber diameter)		
A	5 + 5	1/4 of radius towards C		
B	5		X = -0.407 V	X = -0.576 V
C	0		Y = -0.407 V	Y = 0 V
D	5	(button pickups << chamber diameter)		
A	5 + 5			
B	5 + 5		X = 0 V	X = -0.576 V
C	0		Y = -0.814 V	Y = -0.576 V
D	0	(button pickups << chamber diameter)		
A	10 + 7	1/3 of radius towards C		
B	10		X = -0.570 V	X = -0.806 V
C	3		Y = -0.570 V	Y = 0 V
D	10	(button pickups << chamber diameter)		

Note: These are displacements. Take into consideration the zero offsets due to power splitter imbalance and attenuators inequality.

The above voltages are representations of the algorithms:

For Orthogonal pickups:

- $X = K_X \text{Log}(A/C)$
- $Y = K_Y \text{Log}(B/D)$

For Rotated pickups:

- $X = K_X [\text{Log}(A/C) - \text{Log}(B/D)] \cos(\beta)$
- $Y = K_Y [\text{Log}(A/C) + \text{Log}(B/D)] \sin(\beta)$

Where β is the tilt angle of the pickup axes. Refer to AGREEMENT on AXES and SIGNS.

$K_X \cos(\beta)$ and $K_Y \sin(\beta)$ are factory-set to 1.1513 Volts

Note: This value was chosen because it corresponds to a difference-over-sum ratio equal to 1 for small amplitude displacements off-center. E.g. 0.001 V for 0.005 x R.

Explore the dynamic range

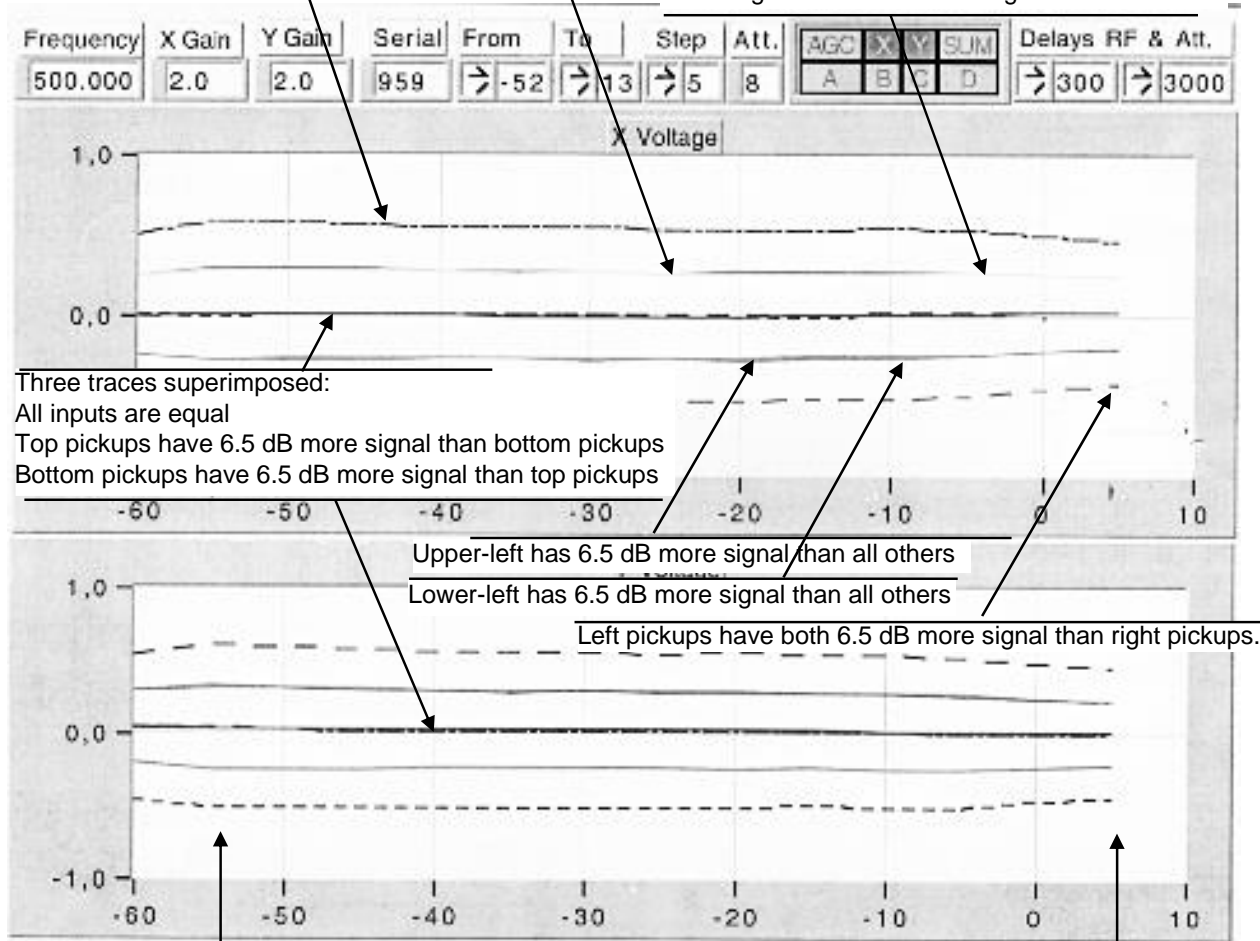
Set the input attenuators is such way that X and Y are off center.
Vary the power from the RF source to simulate beam intensity variations.
Explore the range from +7 dBm down to -70 dBm.

Remember that 4-way transformer-type splitters absorb typically 7 dB and resistive splitters absorb 12 dB.

Right pickups have both 6.5 dB more signal than left pickups.

Upper-right has 6.5 dB more signal than all others

Lower-right has 6.5 dB more signal than all others



This plot is taken with an LR-BPM configured for rotated pickups.

In a hypothetical 1-MHz f_{rev} synchrotron with
1-cm buttons in 4-cm dia. vacuum chamber...

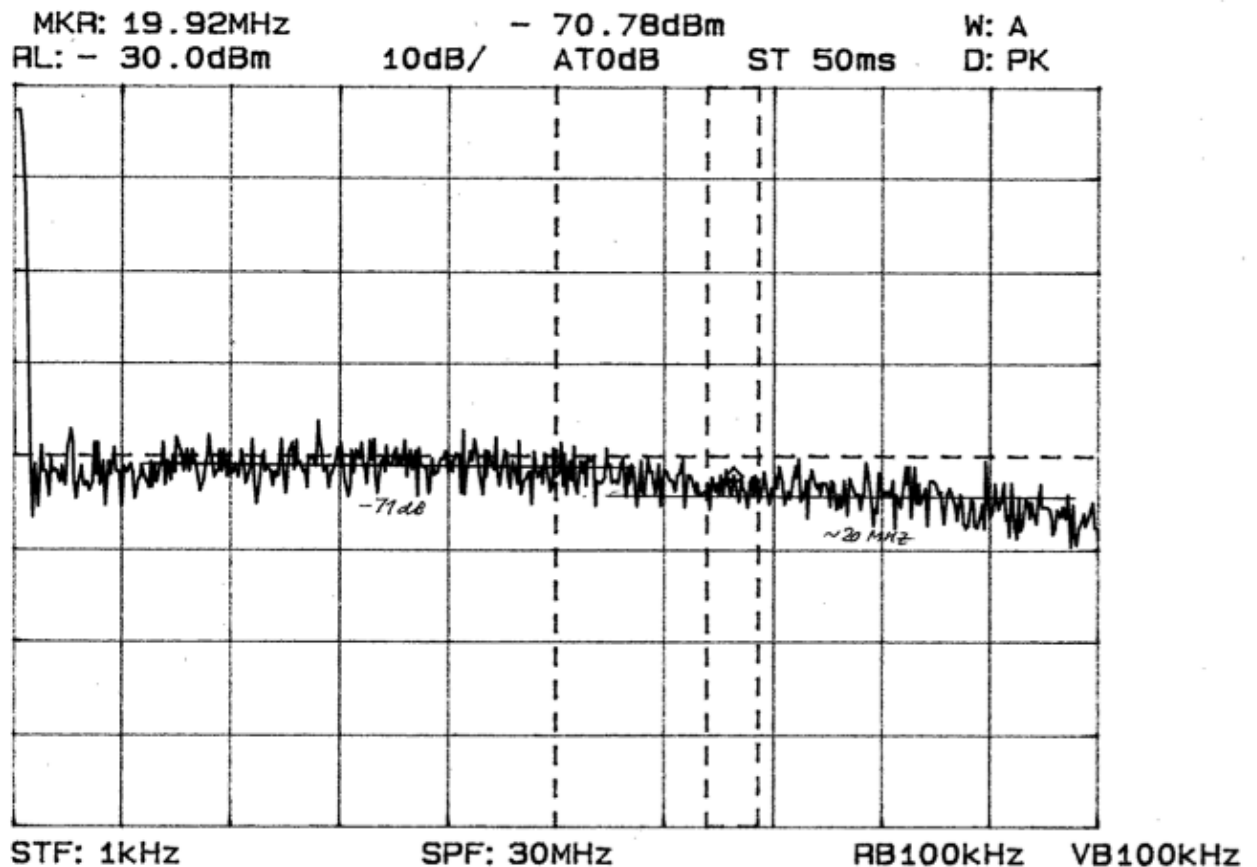
+5 dBm power level at inputs corresponds to ~200 mA stored beam

-55 dBm power level at inputs corresponds to ~200 uA stored beam

While the RF source output power is changed, observe the intensity dependence of X and Y outputs on the voltmeters. The X and Y output voltages vary with input power applied to the LR-BPM inputs.

Noise spectrum

Observe the noise spectrum with an FFT or baseband spectrum analyzer, at various input signal levels. The output noise spectrum looks like:



Noise over 1 kHz to 30 MHz bandwidth, with 100 kHz resolution bandwidth.

Plot taken with Anritsu 2601B Spectrum analyzer.

Probe -20 dB.

Input signal level -30 dBm.

Comments on measurement:

- Noise = -71 dBm + 20 dB (probe) = -51 dBm = 0.63 mVrms in 100 kHz
- Noise density = $0.63 \text{ mV} / \sqrt{100 \text{ kHz}} = 2 \text{ } \mu\text{V}/\sqrt{\text{Hz}}$
- Noise rms over 20 MHz = $2 \text{ } \mu\text{V}/\sqrt{\text{Hz}} \times \sqrt{20 \text{ MHz}} = \sim 10 \text{ mVrms}$

Putting the noise spectrum in perspective:

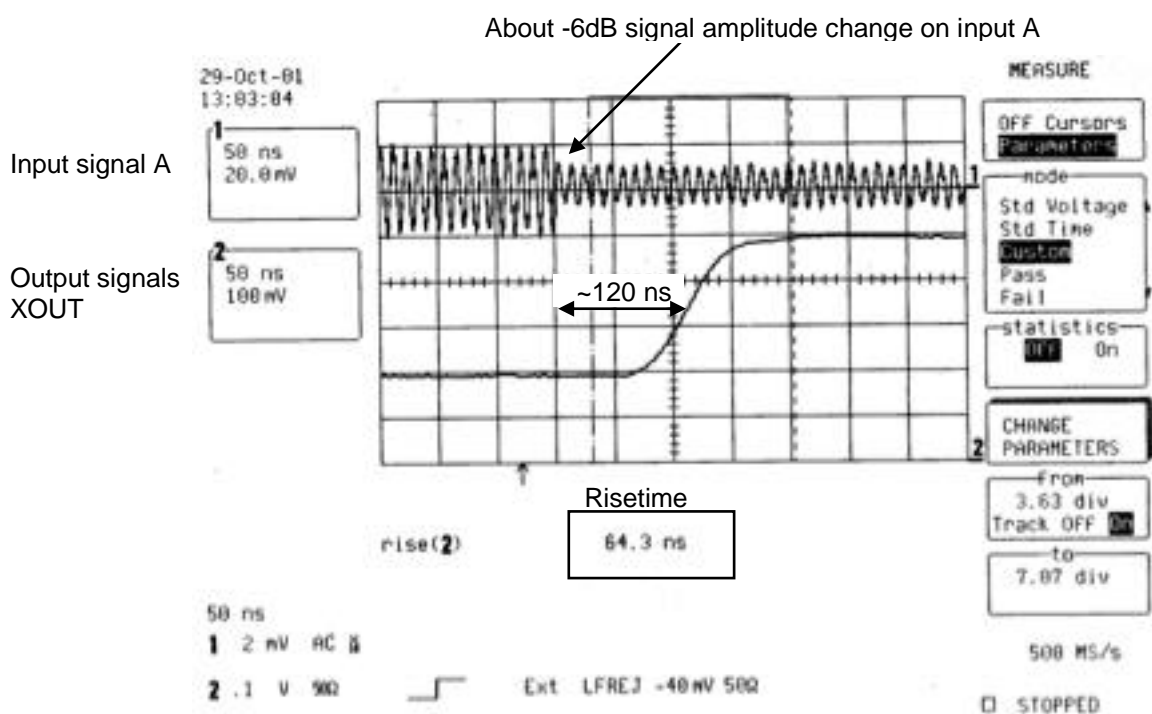
- On-center sensitivity is 39.2 mV/dB for rotated pickups.
- With XOUT and YOUT = 39.2 mV, the displacement is ≈ 0.03 of radius.

Thus 10 mV rms noise over 20 MHz is 1/140 of vacuum chamber radius. Say, 150 μm rms in a 20-mm radius vacuum chamber.

LR-BPM REACTION TIME TO BEAM POSITION CHANGE

LR-BPM can be used for fast interlock machine protection systems:

Time delay from a beam position change to Output signal half-height rise is ~ 120 ns
 Output risetime is ~ 65 ns

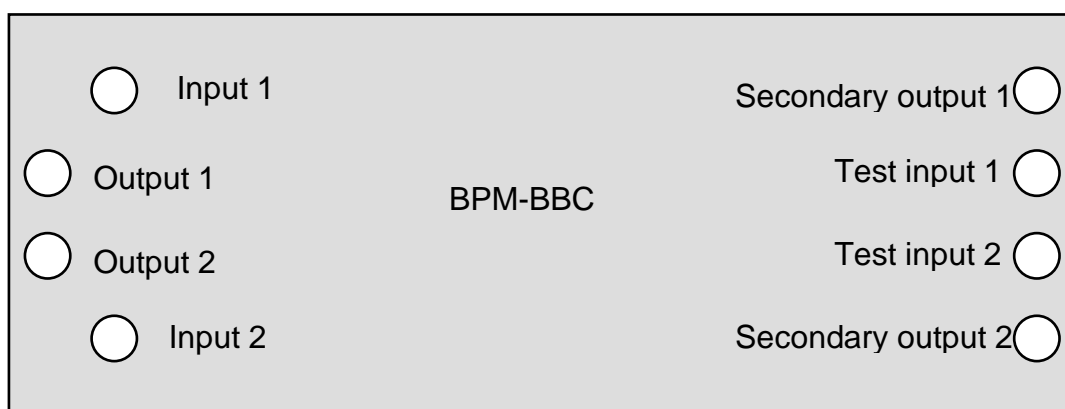


Example from Orthogonal pickups configuration.

QUICK CHECK: BEAM BASED CENTER DETERMINATION

Your shipment may include the product BPM-BBC, BPM Beam-Based Center determination device.

Each BPM-BBC consists of TWO boards. Each one looks like this:



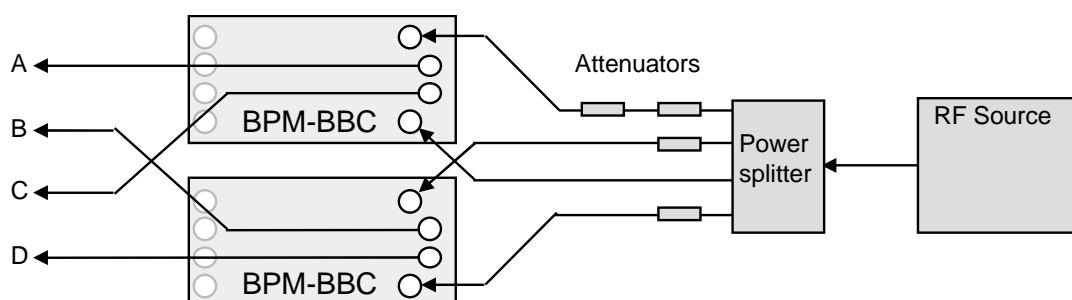
Each board handles the signals from two OPPOSITE pickups.

E.g. Pickups A & C, or pickups B & D, Up and Down, Left and Right.

Note: BPM-BBC has an insertion loss of 10 dB in each channel.

BPM-BBC will not fulfil its purpose of equalizing signals if connected to adjacent pickups. It must be connected to opposite pickups.

Connect the BPM-BBC:



All four unused SMA connectors (Secondary Outputs & Test Inputs) should be terminated by 50Ω.

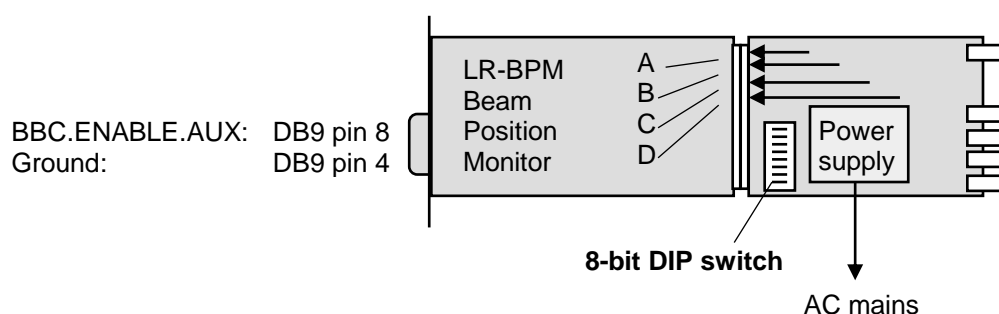
Connect the A, B, C and D signals to the BPM test kit or 19" BPM-RFC chassis, whichever you use.

Observe the effect of BPM-BBC on X and Y output signals. The pickup inputs must be unequal, so X and Y have non-zero values. Use asymmetrical configuration of attenuators to simulate off-center beam.

BPM-BBC can be enabled by the LR-BPM module, via the pickup coaxial cables. To enable BPM-BBC, the signal BBC.ENABLE/ON must be pulled down.

Enabling BPM-BBC will equalize the signals sent to LR-BPM, simulating beam-on-center. If you use BPM-KIT, pull down BBC.ENABLE by switching ON the DIP switch marked AGCD/BBC.ENABLE

Note: On BPM-KITs originally made for multiplexed BPMs, this switch is only marked "AGCD".



If you use a 19" BPM-RFC chassis, to enable BPM-BBC you have the alternative:

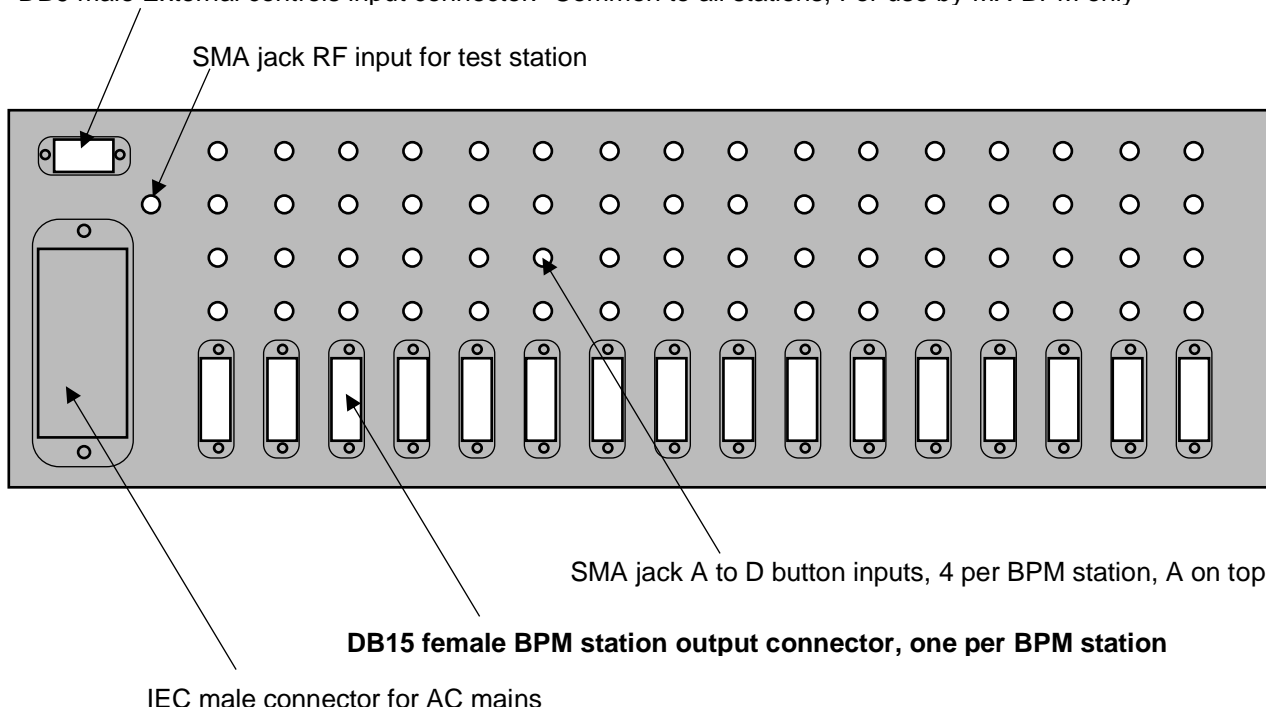
- Pull down to ground BBC.ENABLE.AUX on pin 8 of DB9 front panel connector of LR-BPM module

Note: Ground is on DB9 pin 4.

- Pull down BBC.ENABLE on pin 1 of the DB15 chassis rear panel connector which corresponds to the station you are using (refer to picture hereafter).

Note: Ground is on DB15 pin 10.

DB9 male External controls input connector. Common to all stations, For use by MX-BPM only



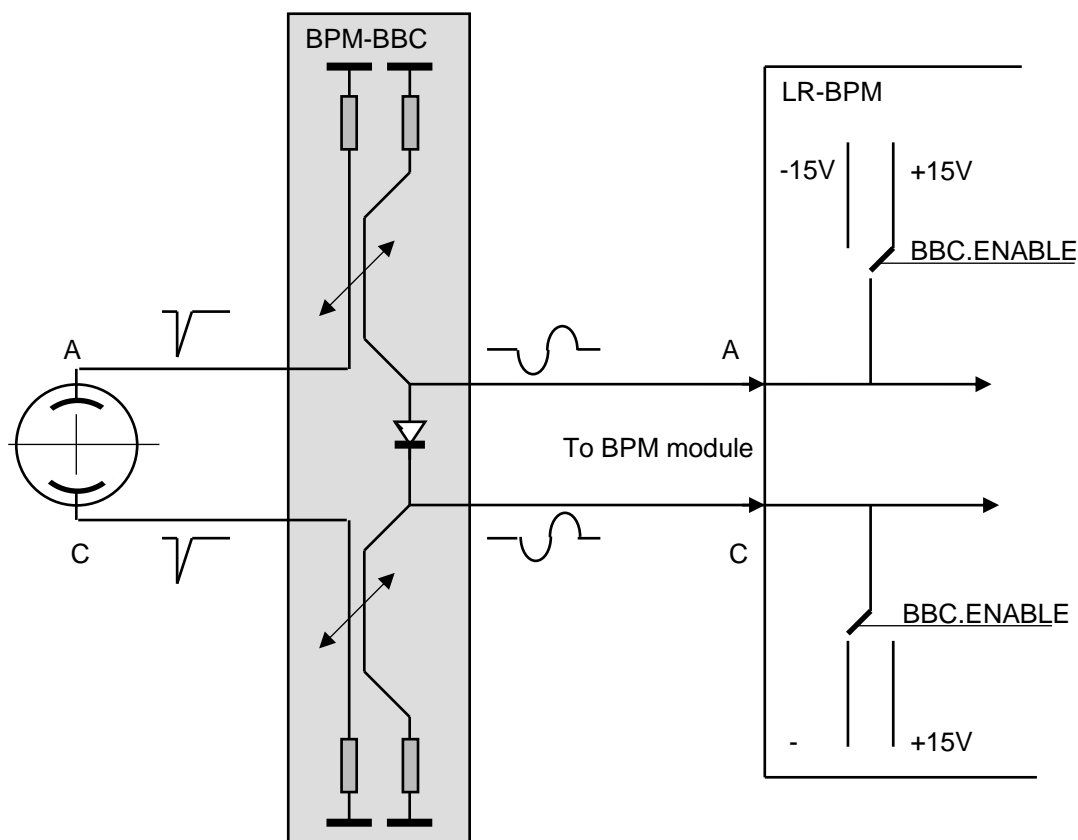
BPM-BBC PRINCIPLE OF OPERATION

The BPM-BBC circuit brings the user the possibility to measure the BPM X and Y zero offsets immediately, with beam, at the actual intensity of the beam.

When short bunch pulses are applied to the BPM-BBC two inputs, couplers produce two single sine wave signals on its outputs. The sine wave period is independent on bunch length. The amplitude of the two output waves are equal if the bunch is on center. If the bunch is off-center, the amplitudes are different.

When BPM-BBC is enabled, the PIN-diode is conductive. It unites the two outputs, equalizing their sine wave amplitudes if they were different. This simulates the conditions of a beam on center. Therefore, when the BPM-BBC is enabled, any non-zero X or Y output value given by LR-BPM is a zero offset. These offsets are caused the LR-BPM electronics, and by unequal attenuation of the BBC-to-LR-BPM cables.

To enable BPM-BBC, a TTL signal BBC.ENABLE must be applied to the LR-BPM module. It causes the PIN-diode to be biased, making it conductive.



Insertion loss: 10 dB per channel

The beam signals applied to BPM-BBC should be synchronous, otherwise the level of equalized signals diminishes. Thus, it is recommended to connect the BPM-BBCs to the pickups with short cables of equal length.

SIGNALS

Input signals

BUTA	Pickup inputs A, B, C, and D. Impedance 50Ω.
BUTB	See Agreement on Axes & Signs, this manual, for pickup assignments.
BUTC	
BUTD	

Output signals for ADC

XOUT	X displacement. Bipolar signal up to $\pm 2V$ (0 Volt represents pickup center) Output impedance: 100 Ω
YOUT	Y displacement. Bipolar signal up to $\pm 2V$ (0 Volt represents pickup center) Output impedance: 100 Ω
XGND	Analog ground for XOUT
YGND	Analog ground for YOUT
SUM.OUT	- (LogA + LogB + LogC + LogD) signal Signal range 0...-2V Output impedance: 100 Ω
TG.ADC.OUT	Trigger for external ADC TTL pos/neg. edge (See QUICK CHECK: Sample&Hold Mode -and- Track&Hold Mode) Output Impedance 100 Ω .
SUM&TG.GND	Ground for SUM.OUT -and- TG.ADC.OUT
VPHOUT	Phase angle output $\pm 9V = \pm 90^\circ$ RF to Phase reference angle (LR-BPM with BPPM option only)

Auxiliary Output Signals

XOUT.AUX	Same as XOUT, but 50- Ω output impedance
YOUT.AUX	Same as YOUT, but 50- Ω output impedance
XYGND	Analog ground for XOUT.AUX and YOUT.AUX

External Trigger Input and Trigger Gate

TRG.IN.AUX	Input for external trigger 50 Ω , positive edge > 2 V
TRG.GATE	Input for gating the beam trigger TTL, High-Low-High High state inhibits Built-in Beam Trigger Low state (default state) allows Built-in Beam Trigger.
SUM&TRG.GND	Ground for TRG.IN.AUX -and- TRG.GATE.

Optional Output Wideband Signals

Note: These optional output signals are made available to compute beam position when the algorithm implemented in the LR-BPM circuit, i.e. $\text{Log}(A/C)$ is unsuitable. This can be the case of 6-button BPM pickups, or asymmetric geometry of pickup electrodes.

LOGA	Logarithmic representation of BUTA input.
LOGB	Logarithmic representation of BUTB input.
LOGC	Logarithmic representation of BUTC input.
LOGD	Logarithmic representation of BUTD input.

External Controls

BBC.ENABLE	BPM-BBC Beam-Based Center determination Enable signal TTL signal. Pull down to equalize BBC output signals. Pullup resistor 4K7 to 5V.
TRACK.CONTINUOUS	TTL signal. To set Track-Continuous mode. High state (default) sets Track&Hold mode. Pull down for Track-Continuous mode. Pullup resistor 4K7 to 5V.
GND	Ground for above signals.

Common external controls

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

None are handled by LR-BPM

CONNECTORS PINS ALLOCATION Rev. 2.1

DB15 female connector on BPM-RFC rear panel (one connector per BPM station)				
DIN41612M LR-BPM module rear connector				
DB9 female connector on LR-BPM front panel				
INPUT SIGNALS				
Input A	BUTA		b2 *	
Input B	BUTB		b5 *	
Input C	BUTC		b8 *	
Input D	BUTD		b11 *	
Phase reference (BPM option only)	PHREF		b22*	
*Coaxial insert 1.0/2.3 type				
OUTPUT SIGNALS FOR ADC				
X output	XOUT		a15	8
Analog ground	XGND		a20	15
Y output	YOUT		a18	7
Analog ground	YGND		a17	6
Log (A, B, C, D) output	SUM.OUT		c20	3
ADC Trigger TTL output pos/neg edge	TRG.ADC.OUT		b20	5
Phase voltage output (BPPM option only)	VPHOUT	4	b19	4
AUXILIARY OUTPUT SIGNALS				
X auxiliary output	XOUT.AUX	1		
Y auxiliary output	YOUT.AUX	2		
X and Y auxiliary outputs analog ground	XYGND	3		
Beam/Ext. trigger output position edge	TRG.OUT.AUX	9		
EXTERNAL TRIGGER INPUT AND TRIGGER GATE				
External trigger input pos. edge	TRG.IN.AUX		c19	2
Trigger inhibit gate Low-High-Low**	TRG.GATE		b14	10
Trigger & Gate ground	SUM1TRG.GND	4	b19	4
**Default value: High, no inhibiting				
OPTIONAL OUTPUT SIGNALS				
Log A	LOGA		b31*	
Log B	LOGB		b22*	
Log C	LOGC		b28*	
Log D	LOGD		b25*	
*Coaxial insert 1.0/2.3 type				
EXTERNAL CONTROLS				
Beam-based Center (BBC) Enable, Low	BBC.ENABLE	8	a13	1
Track-Continuous mode, Low	TRACK.CONTINUOUS	7		
Ground	GND	6	a14	13
POWER SUPPLY				
+ 8 ... 15 V	+15V		c13	
- 8 ... 15 V	-15V		c15	
Common	COM		c14	

BPM CABLES LAYOUT INSTALLATION

Cable layout

Cables electrical length must be equal within $\pm 1\text{ns}$. Yet, unlike most BPM electronics, the LR-BPM module does not require the input signals to be in phase. It tolerates any phase change, even 180° .

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.

ACCESSORIES

Table-top test kit (BPM-KIT)

The table-top test kit "BPM-KIT" is an accessory which can be used to test the following modules made by Bergoz Instruments:

- MX-BPM multiplexed BPM, earlier called simply "BPM".
- VF-BPM multiplexed BPM for variable frequency (ramped) accelerators
- LR-BPM log-ratio BPM.

BPM-KIT currently delivered are all equipped with a universal mains voltage power supply. Yet, older units have been delivered to users with 100 Vac, 115 Vac and 220/230 Vac mains voltage. Check AC mains voltage on power supply module before using.

The BPM-KIT includes:

- A power supply
- 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 to view signals like XOUT and YOUT.

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 has access to all switches, Jumpers, filters and potentiometers.

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

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 can 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.

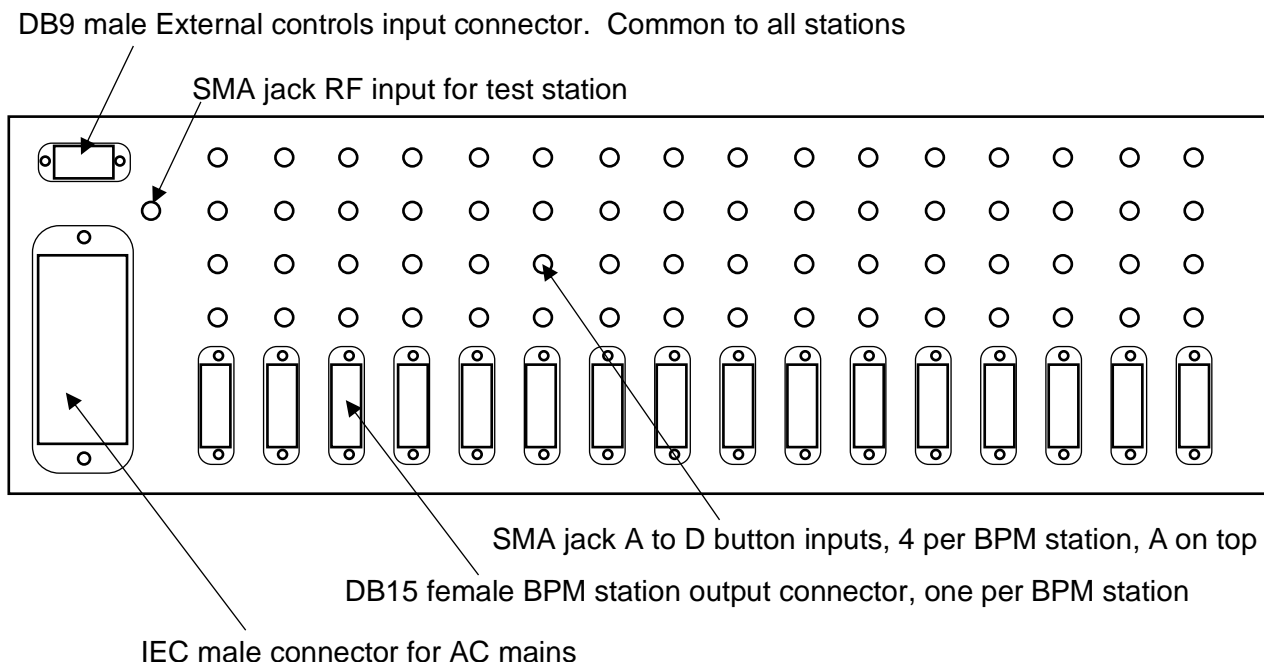
Dimensions of the bin: 3U x 84F

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.

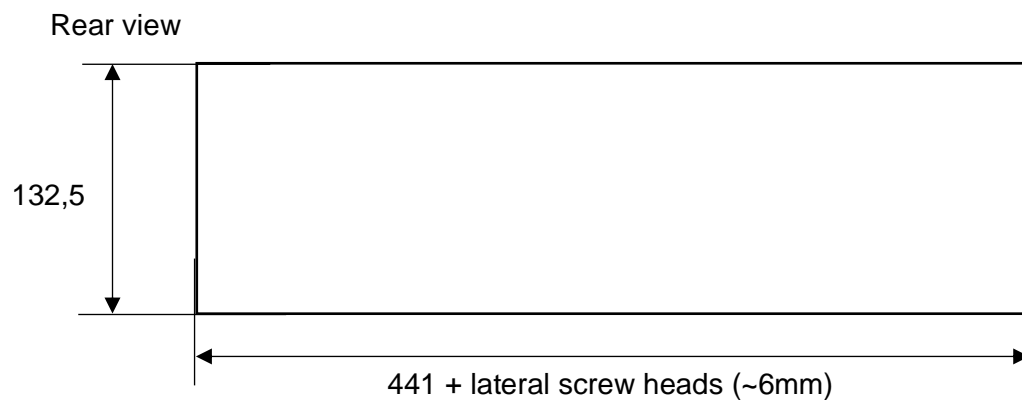
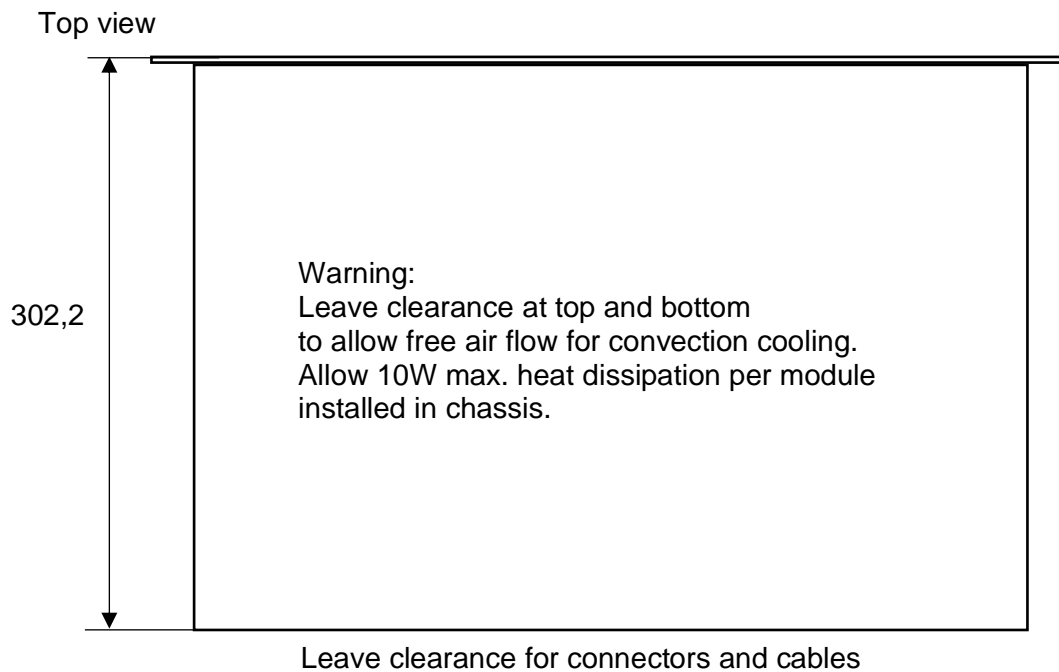
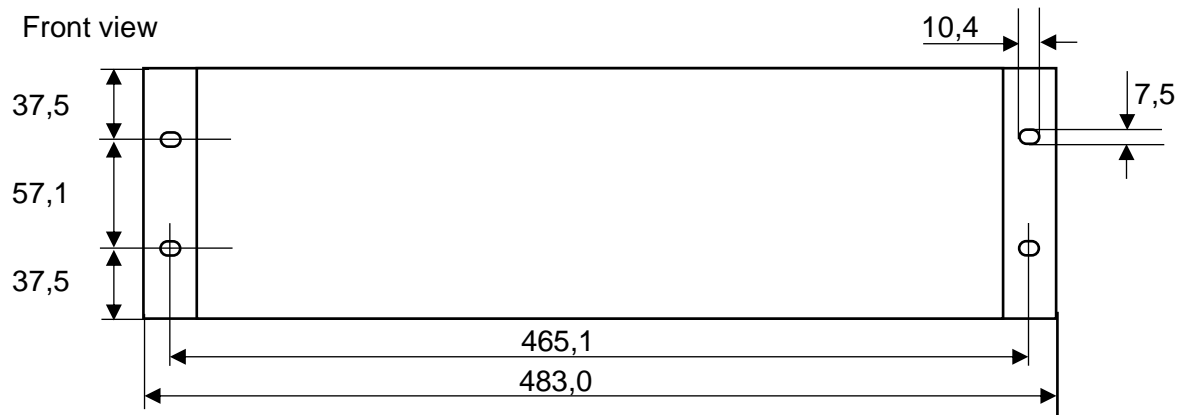
Chassis rear view



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 Chassis BPM-RFC/X Outer dimensions



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

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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:

ACKNOWLEDGEMENT

The fundamental principles of our Log-ratio BPM module were developed by Robert E. Shafer while at Los Alamos National Laboratory. We sincerely thank him for his considerable contribution.

Our LR-BPM module was developed by Alexandre Kalinin.

Last revised: Saint Genis Pouilly, January 2020