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S-band
Beam Position Monitor

User's Manual

Rev. 3.3

Record of updates

Version	Date	Updates performed
1.0	12/2008	Initial version derived from LR-BPM User's Manual v. 2.2.1 S-BPM 111.3.1
1.1	01/2009	Layout change
1.3	02/2010	Layout change S-BPM CONNECTORS PINS ALLOCATION change
1.4	03/2010	T&H; S&H Timing change T&H; S&H graphs added p. 44 TRG.IN.AUX negative edge correction p. xx Pin ALLOCATION correction DB9, 9 => TRG.ADC.OUT
2.0	04/2011	S-BPM new release: 111.3.2. Main changes: S-BPM layout change (switch positions) Track Continuous reptition rate up to 10MHz instead of 5MHz Sample & Hold 400ns processing time instead of 470ns Sample & Hold repetition rate 5KHz instead of 2MHz due to trigger inhibition SUMOUT positive value instead of negative TRG.AUX.IN on rising edge > 0.4V instead of negative > 2V Ortho. / Rot. jumpers positions as LR-BPM Track Continuous traces Track & Hold and Sample & Hold traces Resolution improvements CONNECTORS PINS ALLOCATION Rev. 1.2 (TRG.ADC.OUT DB9 pin5)
2.1	04/2011	p.43 "Agreement on axes & signs", schematics and annotations corrections.
2.2	05/2011	Correction T / T&H S&H mode switch position p.12, 13 & 15
2.3	03/2012	Reaction Time to Beam Position Change p.28 => updated
3.0	02/2019	Review of the full manual. Obsoletes all previous versions
3.1	01/2020	Correction T/T&H S&H mode description
3.2	11/2020	Correction T/T&H S&H mode pictures Correction of chapter “Agreement on Axis & Signs”
3.3	03/2021	Modification of the TRG.ADC.OUT switch name from “Edge” to “Pulse”. All related references were modified in the manual. “Triggering Out” chapter added

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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.

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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 S-band BPM only: S-BPM 111.3.2
Other models, e.g. MX-BPM, LR-BPM, VF-BPM, BB-BPM, BPM-AFE are described in other manuals.

The S-band BPM system includes:

Description	*Order code*
S-band BPM electronics module	S-BPM/X.XXXGHz
Sample & Hold on X and Y, option	S-BPM-SH
Beam Trigger, option	S-BPM-TRG
Sum of logs, option	S-BPM-SUM
Direct A, B, C, D wideband outputs, option	S-BPM-ABCD

The options are factory-installed onto the S-BPM electronics module.

Accessories

Filter/Amplifier Front-end (1 channel)	S-FEFA/X.XXXGHz
19" chassis with power supply	BPM-RFC/X X = number of BPM stations
Table-top test kit	BPM-KIT
3U-Card extender with coaxial contacts	BPM-XTD
RF service module with four front-panel BNC	BPM-SERV/RF

Check that the Table-top Kit power supply voltage corresponds to the 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 the 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 the 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 one 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 S-BPM model you received

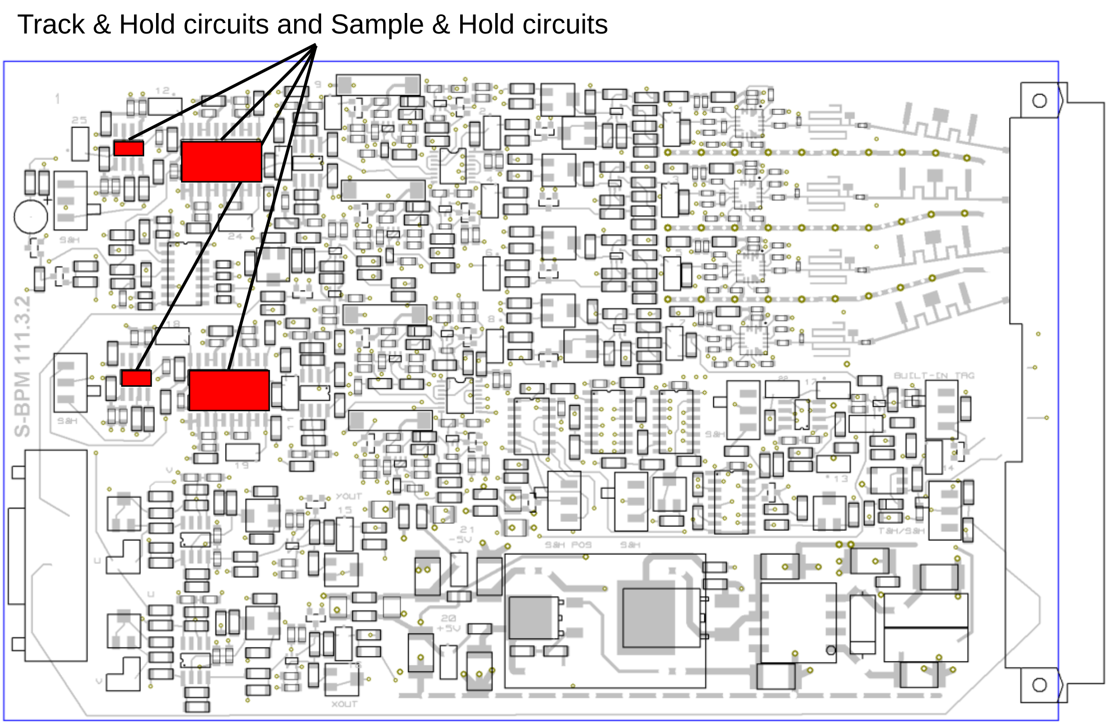
At the time of writing this User's Manual, only one version has been shipped to users: S-BPM revision number 111.3.2

The circuit revision number 111.3.2 is engraved on the printed circuit board.

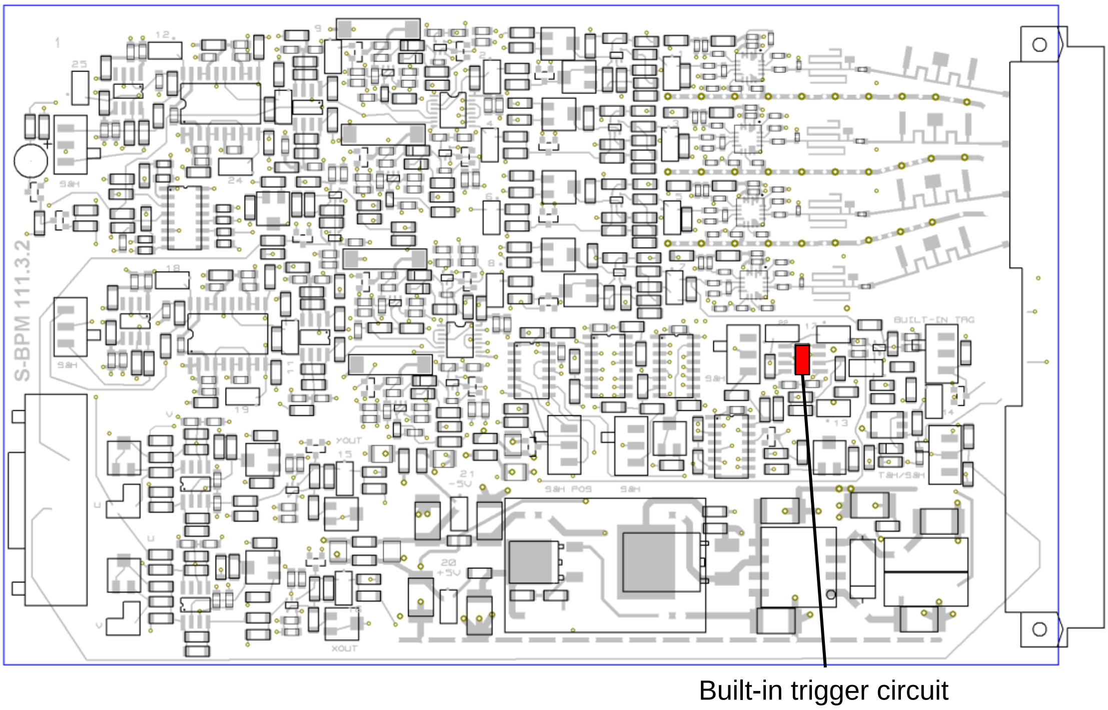
Determine which options are installed onto S-BPM

S-BPM with option Sample & Hold i.e., S-BPM-SH can be recognized by:
The printed circuit is equipped with Track&Hold + Sample&Hold circuits:

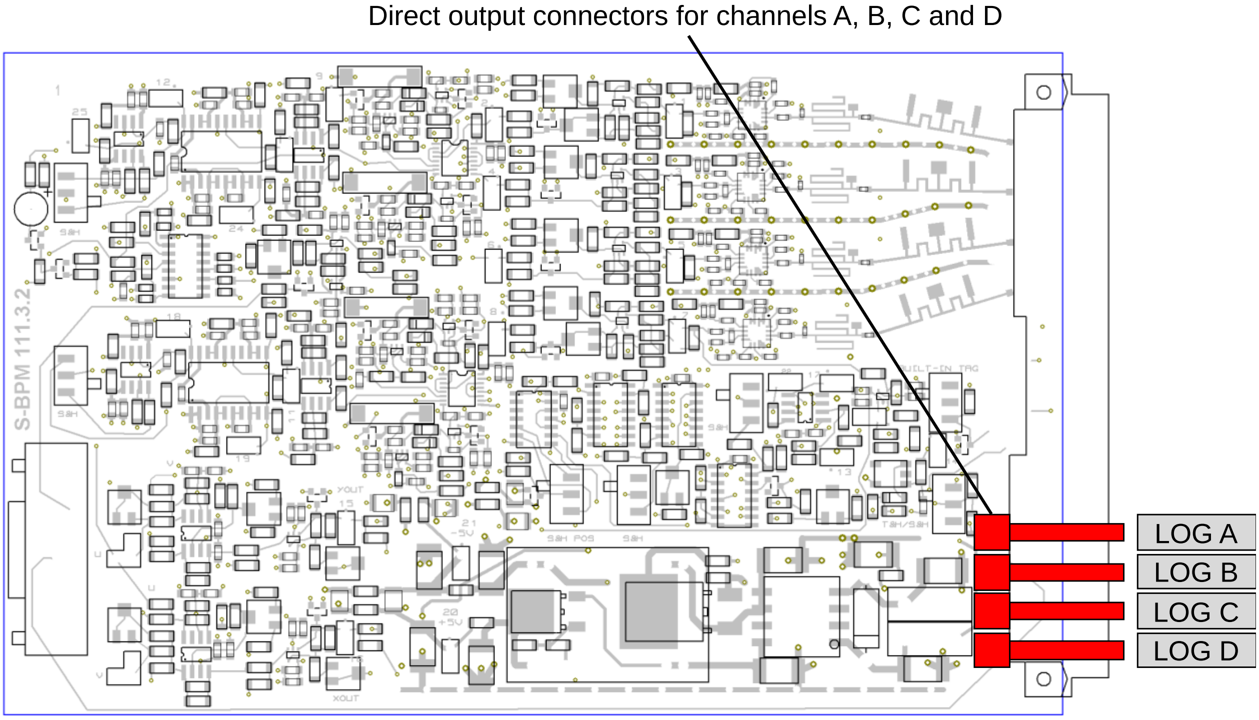
To remove the shield cover, refer to Chapter ACCESS TO JUMPERS and SWITCHES.



S-BPM with Built-in Trigger option S-BPM-TRG can be recognized by having the printed circuit board equipped with a built-in trigger circuit:



S-BPM with A, B, C and D direct outputs option S-BPM-ABCD can be recognized by having the printed circuit board equipped with A, B, C and D output connectors.



MODES OF OPERATION FOR VARIOUS BEAMS

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

Track-Continuous (T) Mode

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

Output bandwidth DC to 10 MHz

T-mode is indicated whenever fast beam motion must be observed:

- CW beams in general
- Linacs and synchrotrons with bunch repetition rate up to 3 GHz
- Betatron oscillation monitoring in boosters and storage rings
- Cyclotrons, microtrons
- Ion and proton synchrotrons with f_{rev} > 1 MHz

Note: Track & Hold can also be used up to 5 MHz f_{rev}.

Macropulse beams:

- Linacs with micropulse RF structure up to 3 GHz
- Transfer lines with micropulse RF structure up to 3 GHz
- Cyclotrons, microtrons

The Track Continuous mode is NOT suitable for single bunch beams, i.e. beams of short pulses at low repetition rate. E.g., pulses at 10 Hz repetition rate. To measure these beams, the Sample & Hold mode must be used.

Refer to "Sample & Hold Mode" chapter for switch settings.

Sample & Hold (S&H) Mode

Requires Sample&Hold option S-BPM-SH to be mounted on the printed circuit board

Processing time	~ 400 ns
Hold time	Up to 100 ms.
ADC measurement time	At maximum repetition rate, at least 100 ns "good signal".
Repetition rate	Limited to 5kHz by on-board trigger inhibition.

Note that T&H Mode can be used, up to 5 MHz, when the pulse or macropulse repetition rate is higher than 1 MHz.

Linacs: single bunch, macropulses, bunch trains
Transfer lines: single bunch, macropulses, bunch trains
Synchrotron first turn
Synchrotron single bunch turn-by-turn
Synchrotron multi-single bunch turn-by-turn, using trigger gate.

Refer to "Sample & Hold Mode" chapter for switch settings

Track & Hold (T&H) Mode

Requires Sample&Hold option S-BPM-SH to be mounted on the printed circuit board

Processing time	~ 60 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 whenever the single pulse or macropulse repetition rate is faster than 2 MHz.
Note that T&H Mode cannot be used when the pulse or macropulse repetition rate is higher than 5 MHz.

Indicated for:	Linacs, Synchrotron f_{rev} < 5 MHz, Single bunch turn-by-turn Synchrotron multi-single bunch turn-by-turn, using trigger gate.

Refer to " Track & Hold Mode" for switch settings

Triggering In

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

Triggering can be provided:

a) by the built-in Beam Trigger, if installed on S-BPM (order code S-BPM-TRG).
To use the built-in Beam Trigger, it must be enabled by its switch. See built-in Beam Trigger switch p.12.

b) by an external signal applied to TRG.IN.AUX input.
To use the external trigger, the built-in trigger –if installed– must be disabled. See built-in Beam Trigger switch p.12.

Triggering Out

In Sample&Hold (S&H) and Track&Hold (T&H) modes, S-BPM outputs a trigger for the external ADC (TRG.ADC.OUT).

S-BPM provides two complementary signals:

- A square positive pulse ("Positive" mode)
- The complementary pulse to the square positive pulse ("Complementary" mode)

An on-board switch allows to choose the output trigger shape.
Refer to " Track & Hold Mode" or "Sample & Hold Mode" for switch settings.

Switching between modes

In principle, the Mode of Operation is set by the on-board switches, permanently.

Yet, it is possible during operation, to switch to Track-Continuous Mode to ease the timing adjustment of an external trigger. The control line TRACK-CONTINUOUS (pull down) is available on the front panel DB9 pin 7.

OPTIONS

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

Built-in Beam Trigger "S-BPM-TRG" option

Requires Built-in Beam Trigger option S-BPM-TRG to be mounted on the printed circuit board

Particle polarity	S-BPM 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 "S-BPM-SUM" option

Requires Sum-of-Logs option S-BPM-SUM to be mounted on the printed circuit board

Value	SUM = +[Log(A) + Log(B) + Log(C) + Log(D)]
Bandwidth	10 MHz

Note: When the beam is on center of the BPM pickup, Log(A) = Log(B) = Log(C) = Log(D), thus SUM is proportional to +Log(beam current).

Direct log outputs for A, B, C and D "S-BPM-ABCD" option

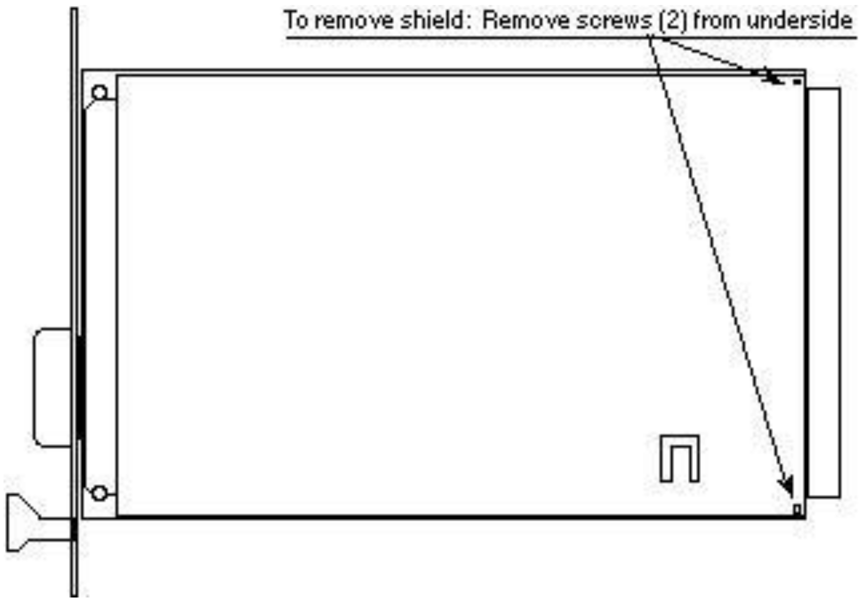
Requires Direct A, B, C, D Outputs option S-BPM-ABCD to be mounted on the printed circuit board

Outputs	Log(A), Log(B), Log(C) and Log(D)
Bandwidth	10 MHz
Connectors	1.0/2.3 output connectors Note: Mating connectors are not installed in chassis BPM-RFC or BPM-KIT. Users of option S-BPM-ABCD must provide these connectors. Refer to "BPM MODULE REAR CONNECTOR".

Note: Accessories are described in chapter p.48 "ACCESSORIES".

ACCESS TO JUMPERS AND SWITCHES

To access jumpers and switches, remove the module shield:



Note: S-BPM modules can be inserted/removed from their chassis or BPM-KIT while the power is ON.

The S-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.

S-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.

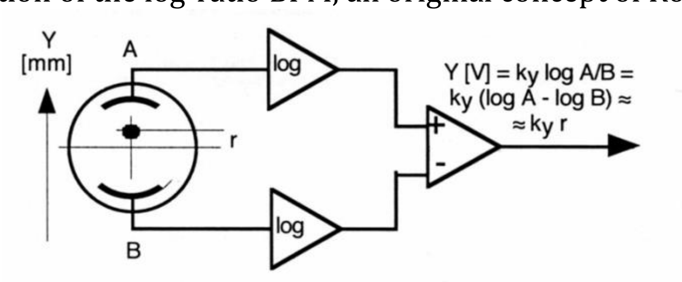
Each amplifying chain produces a signal which peak amplitude is proportional to the log of the input signal, be it a single pulse, a pulse train, or a continuous wave.

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

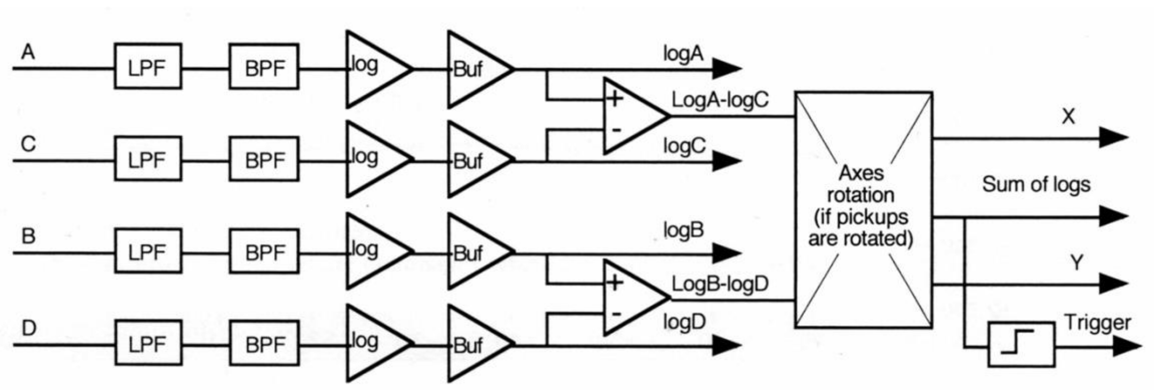
If the pickup electrodes are placed along the axes in which the beam displacement is to be measured, the displacement $X = K_x$ Log(A/C), directly. The K_x gain is obtained by an amplifier with adjustable gain. The same goes for the Y axis.

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:



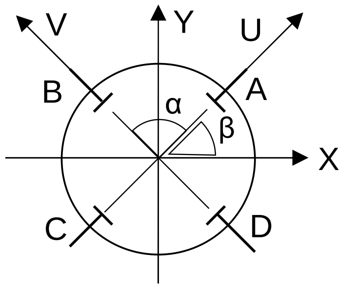
BLOCK DIAGRAM



AGREEMENT ON AXES & SIGNS

X, Y: User's orthogonal axes
U, V: S-BPM pickup axes AC and BD
K_X, K_Y: gain obtained by an amplifier with adjustable gain

ROTATED PICKUPS

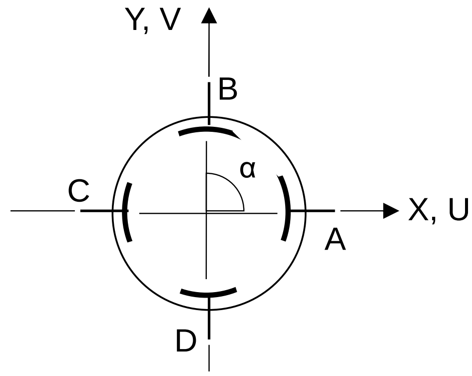


$\alpha = 90°$
$\beta \neq 0$
Note: α may be ≠ 90°. S-BPM is factory-set for equal X and Y gains, i.e., α= 90°

U = Log(A/C)
V = Log(B/D)
Note: U and V are signals of positive polarity

$X = K_x \cdot (U \cdot \cos\beta - V \cdot \sin\beta)$
$Y = K_y \cdot (U \cdot \sin\beta + V \cdot \cos\beta)$

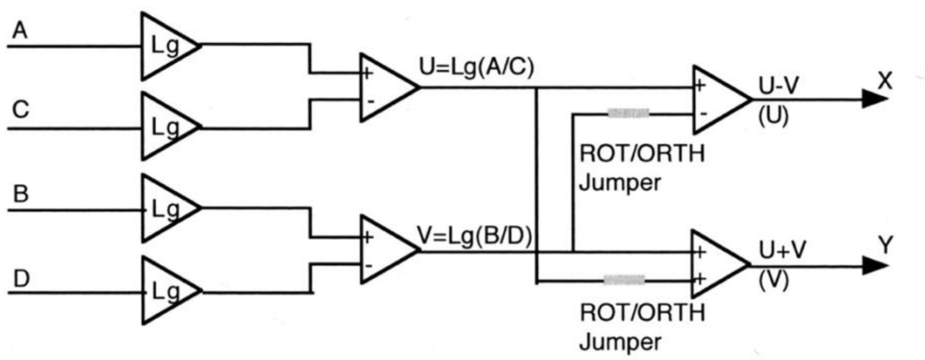
ORTHOGONAL PICKUPS



$\alpha = 90°$
$\beta = 0$

U = Log(A/C)
V = Log(B/D)
Note: U and V are signals of positive polarity

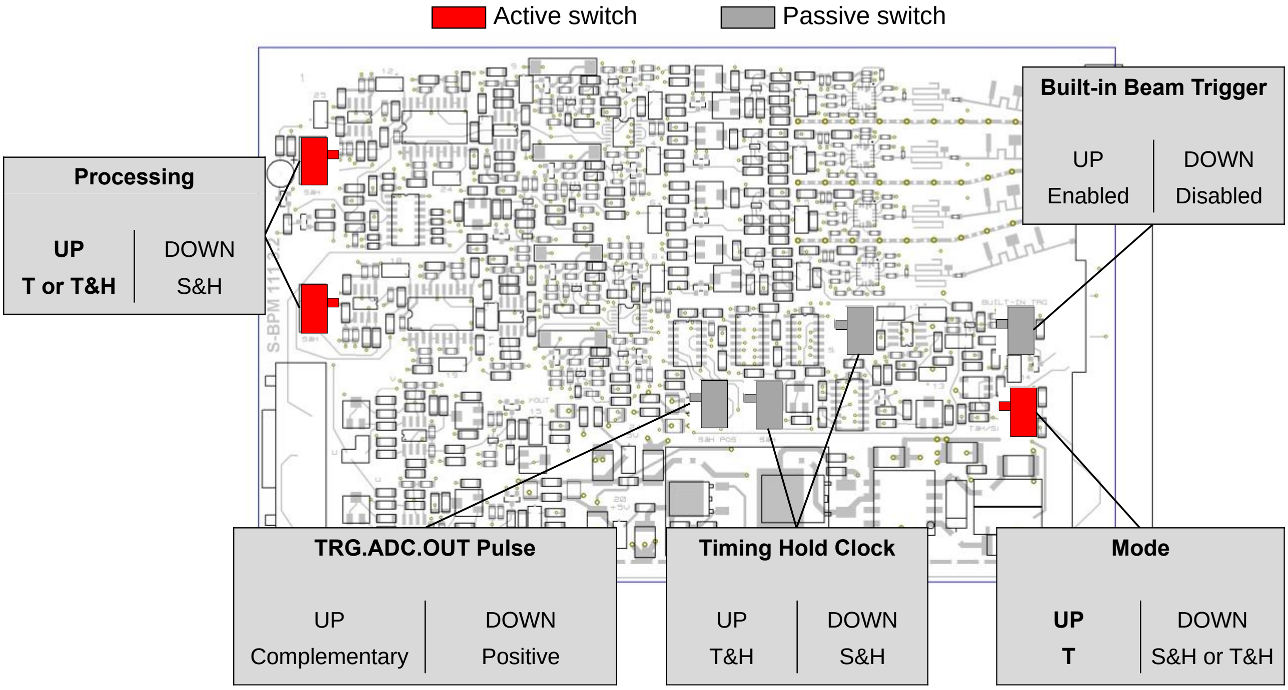
$X = K_x \cdot U$
$Y = K_y \cdot V$



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.

TRACK-CONTINUOUS MODE

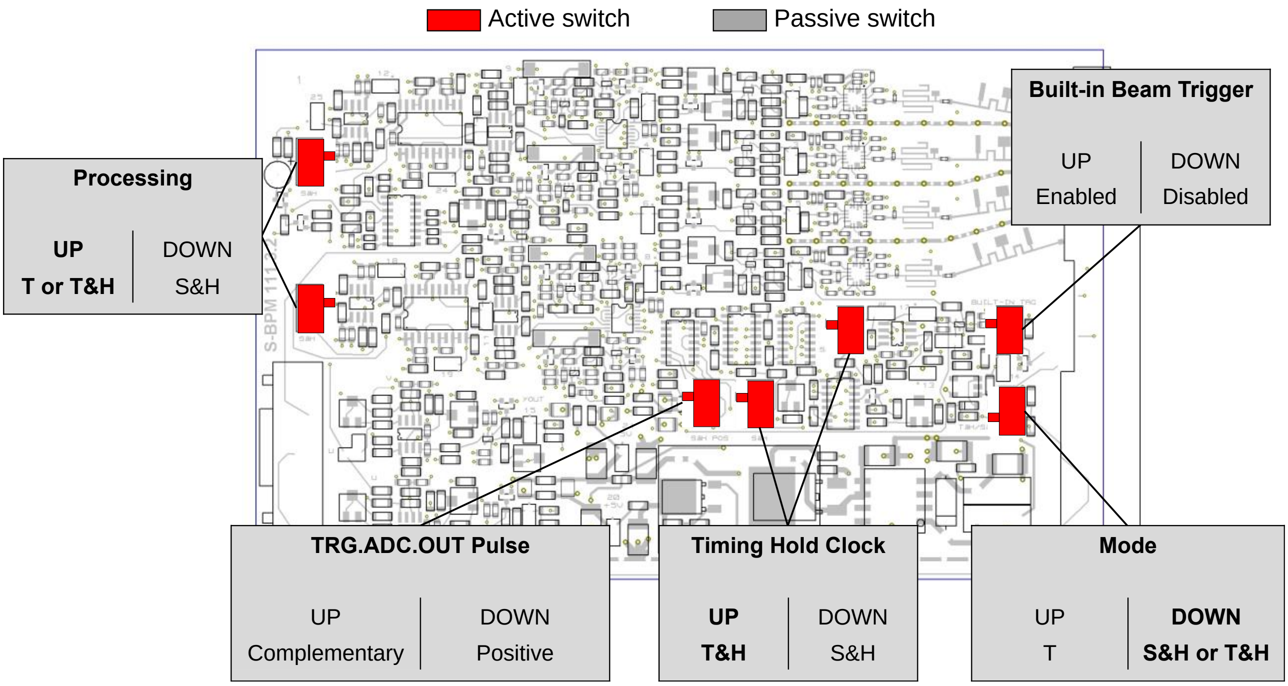
Set switches to: Mode: Track-Continuous (T) => UP
Processing: Track-Continuous (T) => UP
Timing: Inactive
Built-in Beam Trigger: not available in this mode
TRG.ADC.OUT Pulse: not available in this mode



Output signals XOUT and YOUT track the position given by A, B, C and D inputs with DC to 10 MHz bandwidth

TRACK and HOLD MODE

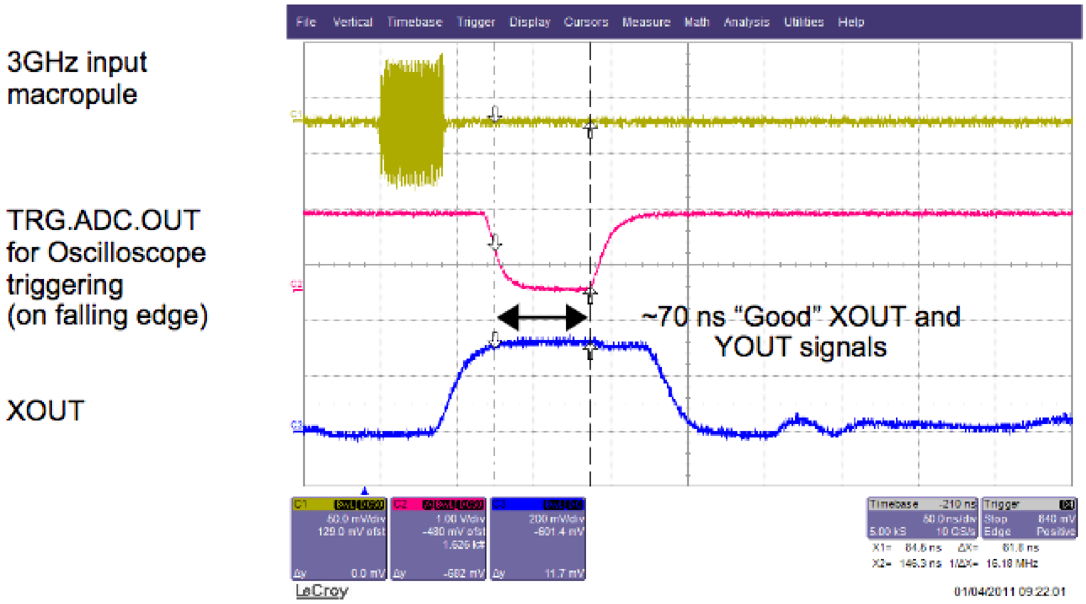
Set switches to: Mode: T&H => DOWN
Processing: T&H => UP
Timing Hold Clock: T&H => UP
Timing Trigger: Inhibition Trigger to avoid bad trigger during processing. 200ns in T&H mode => UP
Built-in Beam Trigger as desired. Disable for external trigger.
ADC Trigger Output Pulse as desired



If TRG.ADC.OUT Pulse is set on "Positive", XOUT and YOUT must be read from the trigger rising edge.

If TRG.ADC.OUT Pulse is set on "Complementary", XOUT and YOUT must be read from the trigger falling edge.

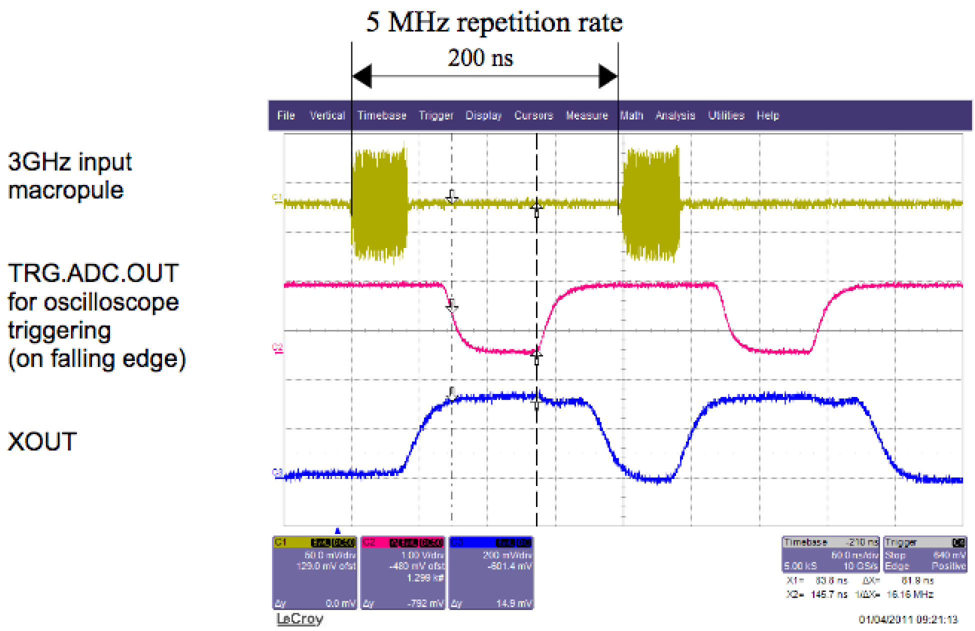
In Track & Hold Mode, the output signals timing looks like this:



TRG.ADC.OUT Pulse is set on "Complementary" on the picture above.

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

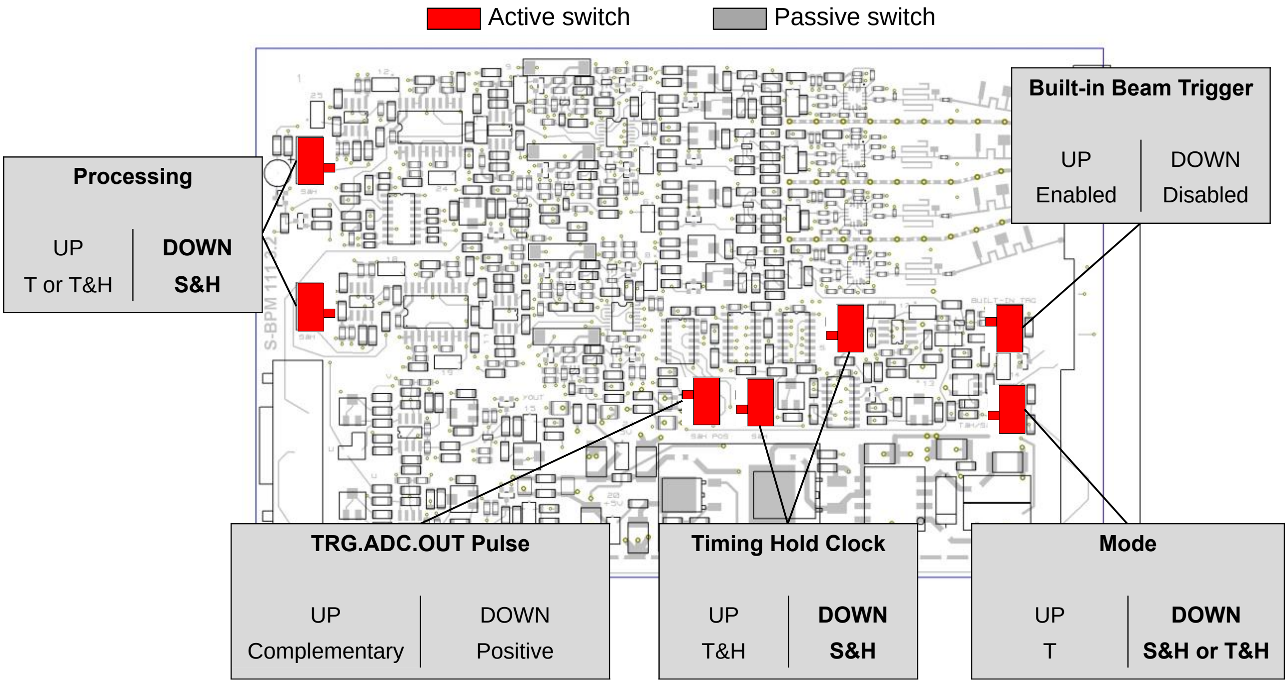
With 5MHz macropulse repetition rate, the output signals look like below:



SAMPLE & HOLD MODE

Set switches to:

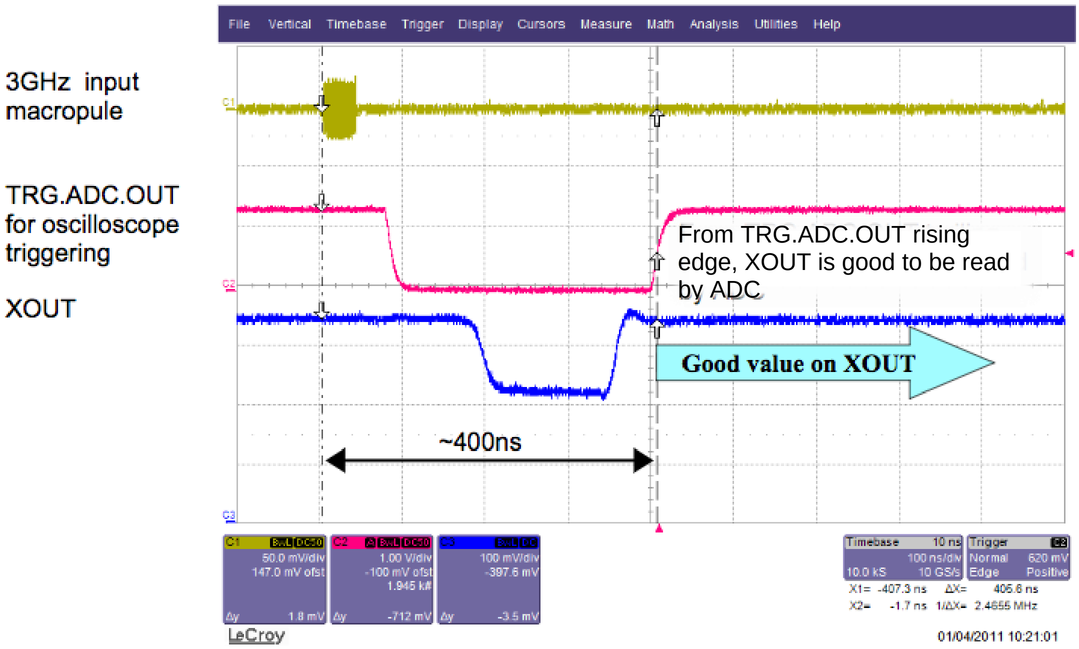
Mode: Sample&Hold => DOWN
Processing: Sample&Hold => DOWN
Timing Hold Clock: Sample&Hold => DOWN
Timing Trigger: Inhibition Trigger to avoid bad trigger during processing. 200µs in S&H mode => DOWN
Built-in Beam Trigger: As desired
ADC Trigger Output Edge: As desired



If TRG.ADC.OUT Pulse is set on "Positive", XOUT and YOUT must be read from the trigger falling edge.

If TRG.ADC.OUT Pulse is set on "Complementary", XOUT and YOUT must be read from the trigger rising edge.

In Sample & Hold Mode, the output signals timing looks like below:



TRG.ADC.OUT Pulse is set on "Complementary" on the picture above.

Rising edge of TRG.ADC.OUT occurs about 400ns from the time when TRG.IN.AUX was applied to S-BPM.

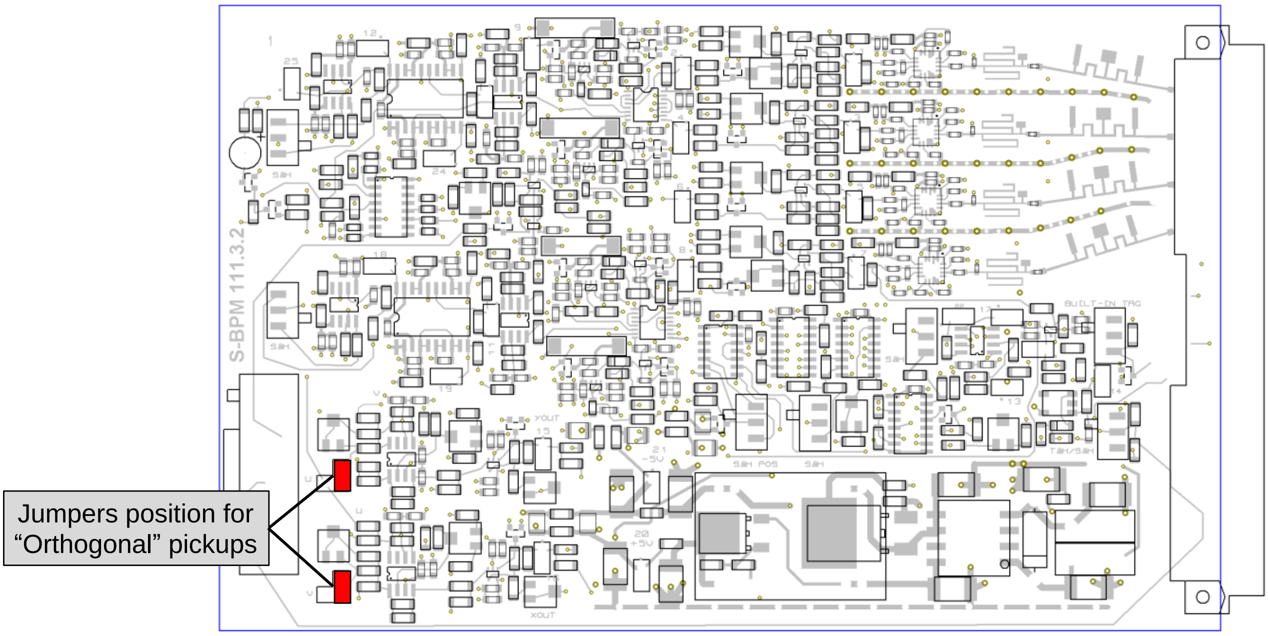
XOUT (and YOUT) are good to read by ADC at the time of TRG.ADC.OUT rising edge.
Note that TRG.ADC.OUT shape can be changed. See TRG.ADC.OUT description p.10.

The timing is explained in more details in
QUICK CHECK: S-BPM in Sample & Hold Mode: Timing for macropulse beam p.33

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:

Orthogonal pickups, position of jumpers



Rotated pickups, position of jumpers

QUICK CHECK: S-BPM in Track-Continuous Mode

Track-Continuous mode can be used on CW beam or macropulse (burst) mode. A Quick Check is described for both modes, successively.

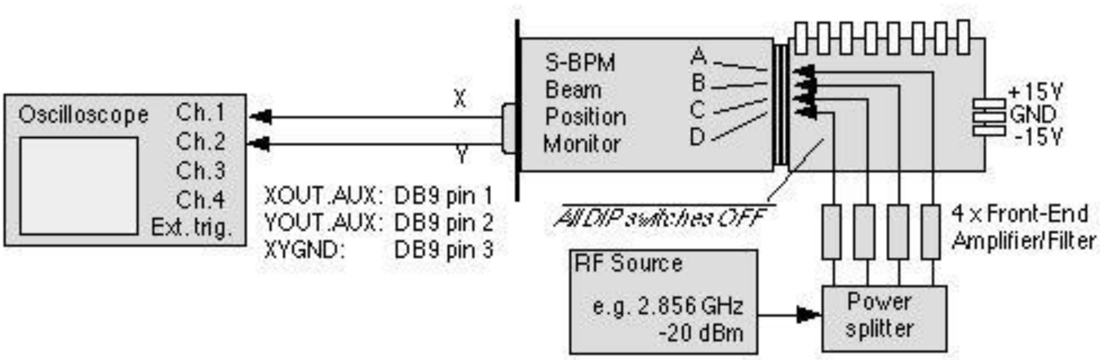
For CW beams

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

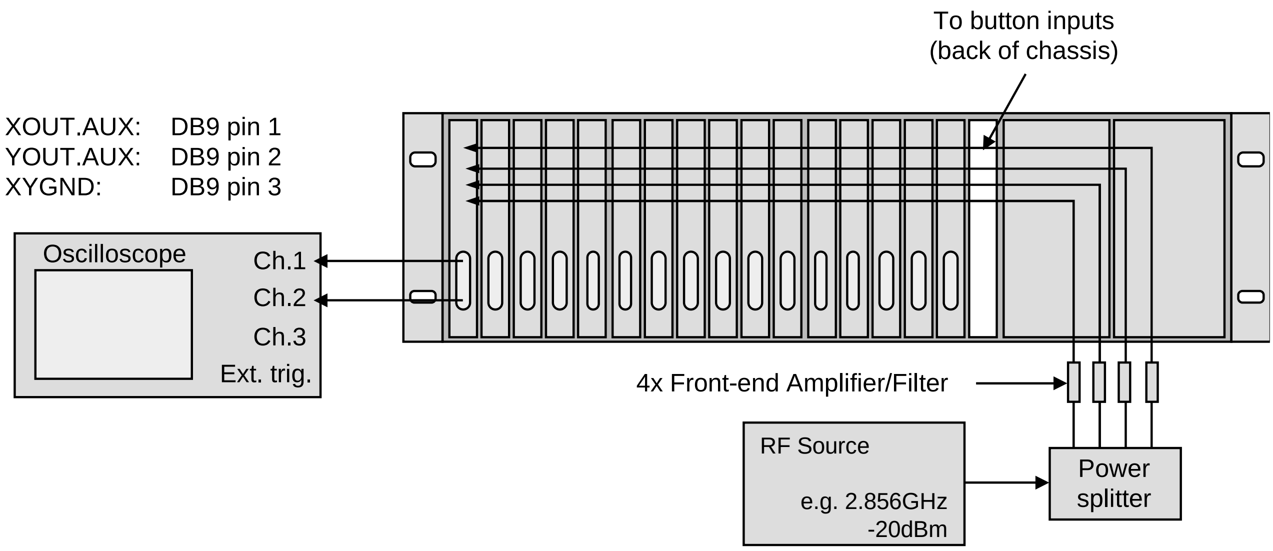
- Orthogonal pickups
- Mode: Track-Continuous
- Built-in trigger: Disabled
- ADC Trigger output: positive edge

Setup, to check immediately that your S-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, use an oscilloscope.
Attach the equipment together as shown above.

Oscilloscope setup:

Time base	1 µs/div.		
CH1	0.2 V/div.	DC-1 Mohm	XOUT
CH2	0.2 V/div.	DC-1 Mohm	YOUT

Trigger: free running

Set the RF source to the S-BPM operating frequency. E.g. Set to 2856 MHz to test S-BPM/2856MHz. Amplitude about -20 dBm

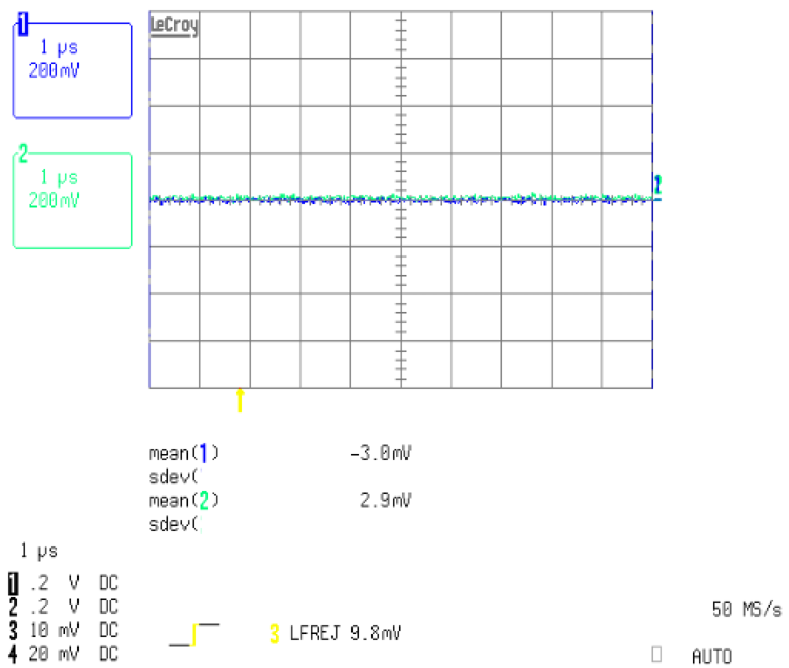
Please note that signals applied to S-FEFA inputs will be attenuated by the 4-way splitter:
Inductive-type 4-way splitters typically attenuate by 7dB,
4-way resistive splitters or cascaded 2-way splitters attenuate by 12dB.

Connect Test Kit to DC supply or BPM-RFC chassis to AC mains; the oscilloscope will display X and Y values.

XOUT signal from either Front Panel DB9 pin 1 or BPM-KIT XOUT BNC

YOUT signal from either Front Panel DB9 pin 1 or BPM-KIT YOUT BNC

Note : XOUT and YOUT signals overlap. Observe RMS signal noise (sdev).



If the RF signals applied to all four S-FEFA inputs were exactly equal, and if the S-FEFA and S-BPM modules were perfect, the XOUT and YOUT voltages would be exactly 0 Volt. This is generally not the case, X and Y will be many 10s of millivolts off.

To determine how much of this offset is caused by power splitter imbalance:
Instead of connecting S-FEFA "A" to power splitter output 1, connect it to output 3.
Do the same for S-FEFA B and D with power splitter outputs 2 and 4.

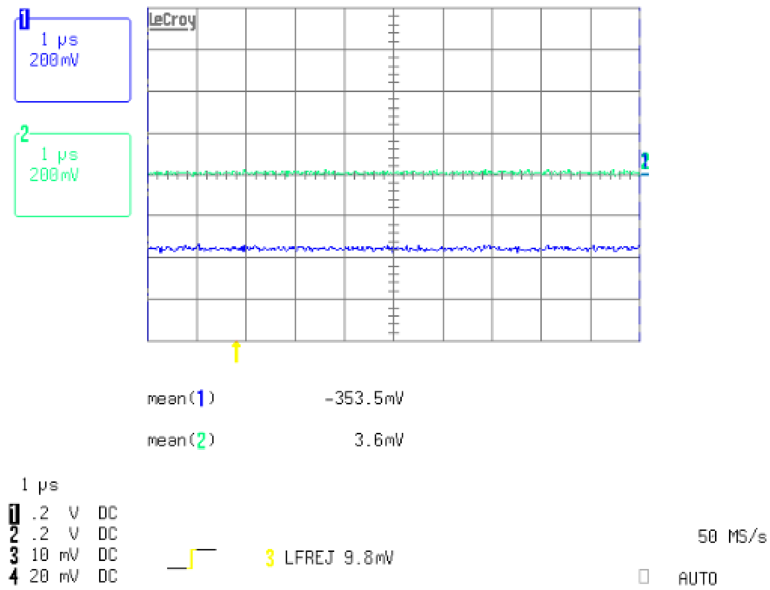
The next tests consist of simulating beam displacements.

Insert a 6-dB attenuator at any power splitter output (e.g., signal to input A)
The RF source output power should be in the range -10dBm ... -35 dBm

XOUT signal from either Front Panel DB9 pin 1 or BPM-KIT XOUT BNC

YOUT signal from either Front Panel DB9 pin 1 or BPM-KIT YOUT BNC

Note :
Observe XOUT signals is shifted to above -347mV due to the 6dB attenuator in input A.



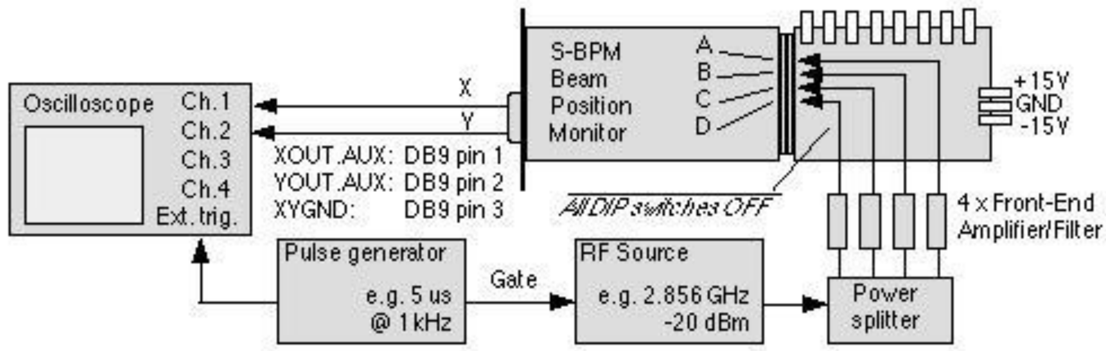
Further tests can be performed:

- Beam displacement
  - Simulating beam displacements along the X or Y axes (or both) with various attenuator values.
  - Refer to BEAM DISPLACEMENT chapter.
- Dynamic range
  - The dynamic range can be tested: Simulate a higher or lower beam current by varying the RF source output power.
  - Also refer to DYNAMIC RANGE chapter.

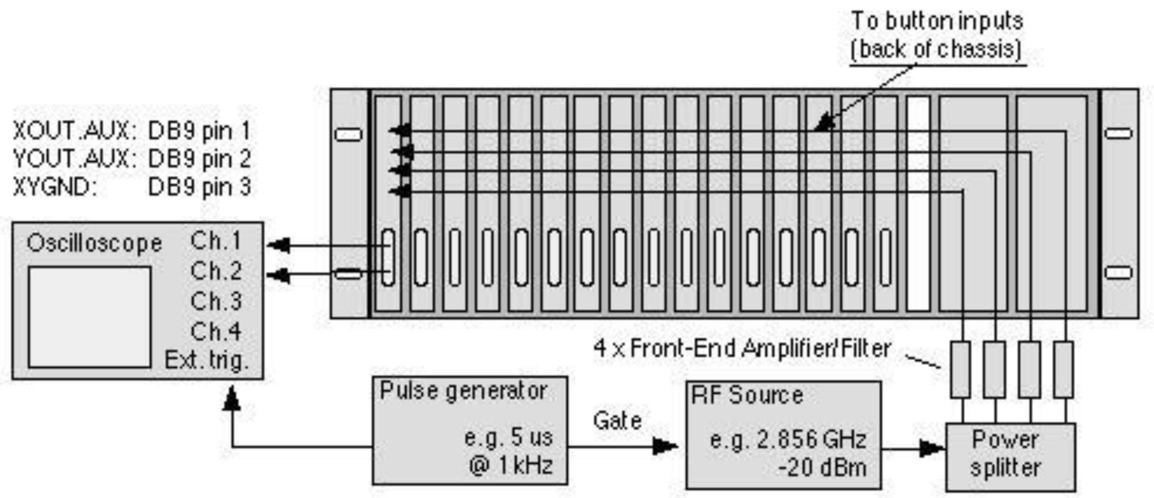
For macropulse beam

If the RF power source can be gated, apply a gate to the RF source to simulate macropulses. Apply the same gate signal to the oscilloscope trigger input.

Setup. 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:



The Gate duration is set to 5 µs. The gating frequency is set to 1 kHz.
Try faster gating frequency: The macropulse repetition rate can be very high.

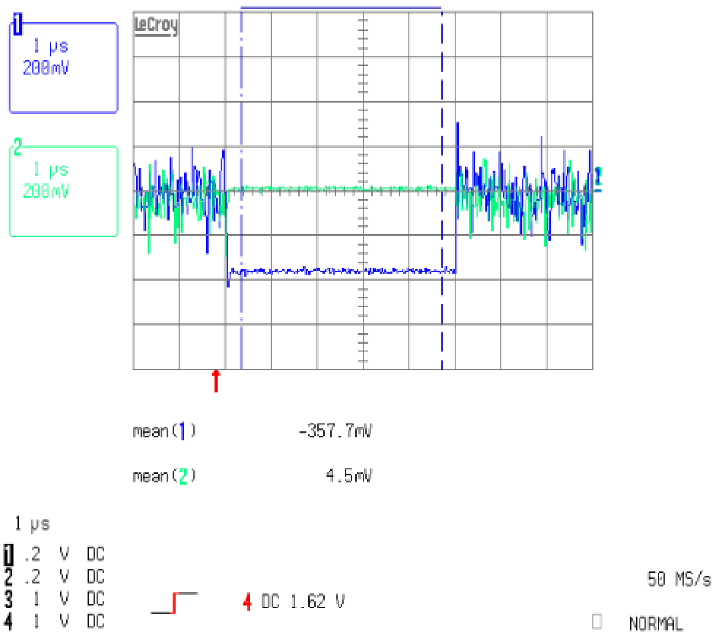
The following screen shot does not show the macropulse. It shows the S-BPM output signals XOUT and YOUT.

Observe high amplitude output noise on XOUT and YOUT before and after the 5-µs macropulse. This high noise is caused by the amplifiers going into high gain when there is no input signal.

XOUT signal from either Front Panel DB9 pin 1 or BPM-KIT XOUT BNC

YOUT signal from either Front Panel DB9 pin 1 or BPM-KIT YOUT BNC

Note :
Observe XOUT signals is shifted to above -347mV due to the 6dB attenuator in input A.
Observe high noise before and after macropulse due to amplifiers going to highest gain when there is no input.

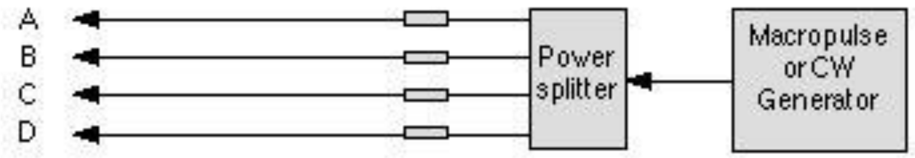


Simulating beam position changes

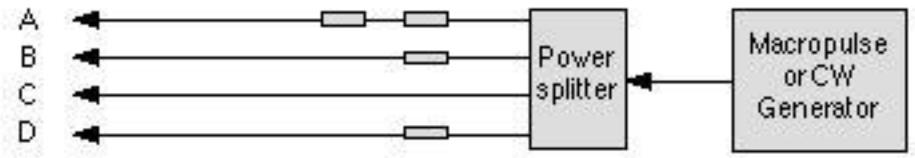
To simulate beam position changes, the input signal power is changed by 6 dB, 10 dB and 14 dB, hence simulating position changes up to 1/3 of BPM pickup radius.

The S-BPM on-center sensitivity is factory-set to 55.5 mV per dB of signal difference between opposite pickups. For pickups with small subtending angle (e.g. Buttons), 6 dB corresponds to beam displacement equal to 1/6 of BPM pickup radius. As the beam goes far off center, this sensitivity becomes lower due to the algorithm X = 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, write down the XOUT and YOUT 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 <=> C, and B <=> 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).

S-BPM modules are factory preset:

- For orthogonally placed pickups: up, left, down 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. Please 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, assuming the pickup subtending angle is infinitely small.

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			
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			
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			
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			
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			

Please note these are displacements. Take into consideration the zero offsets due to power splitter imbalance and attenuators inequality.

Note: The above voltages are representations of the algorithms:

For Orthogonal pickups:
$X = K_x \cdot \mathrm{Log}(A/C)$
$Y = K_y \cdot \mathrm{Log}(B/D)$

For Rotated pickups:
$X = K_x \cdot [\mathrm{Log}(A/C) \cdot \cos\beta - \mathrm{Log}(B/D) \cdot \sin\beta]$
$Y = K_y \cdot [\mathrm{Log}(A/C) \cdot \sin\beta + \mathrm{Log}(B/D) \cdot \cos\beta]$

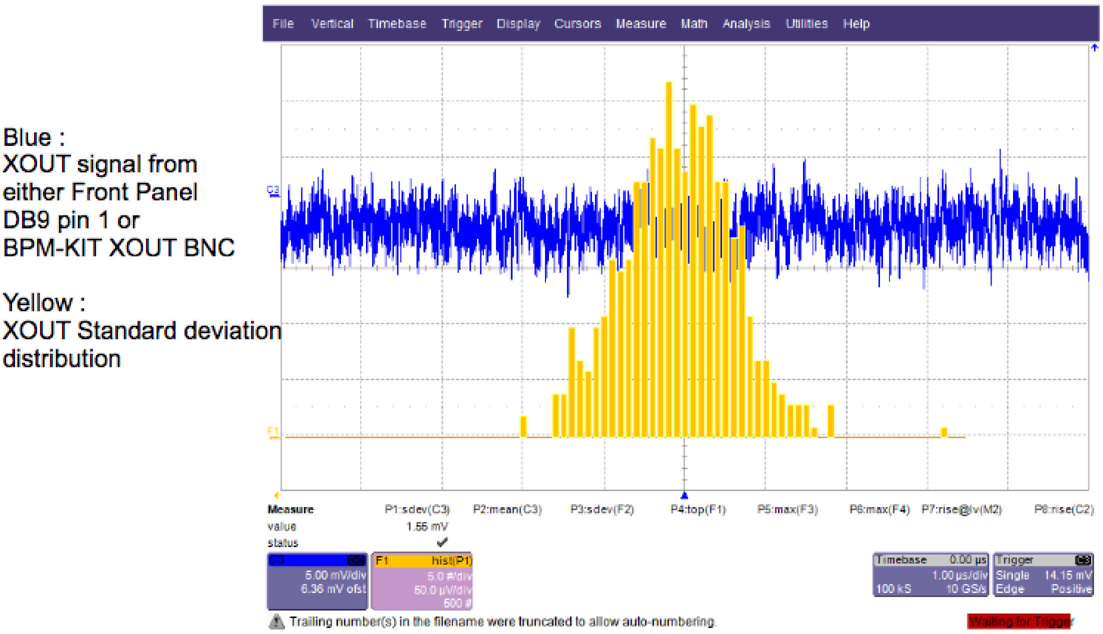
Where: β is the tilt angle of the pickup axes. Refer to AGREEMENT on AXES and SIGNS.

Resolution

The noise spectrum of XOUT (or YOUT) indicates the resolution attainable by S-BPM.

Connect an oscilloscope to XOUT (or YOUT).

Plot in histogram mode (e.g., Lecroy SDA11000)



The noise is about 1.6mVrms.

To translate this rms voltage noise in beam position resolution, let's assume a 25mm vacuum chamber radius and pickup electrodes width < vacuum chamber radius. In this case, a beam displacement by 1/6 of the pickup radius equals to 347mV.

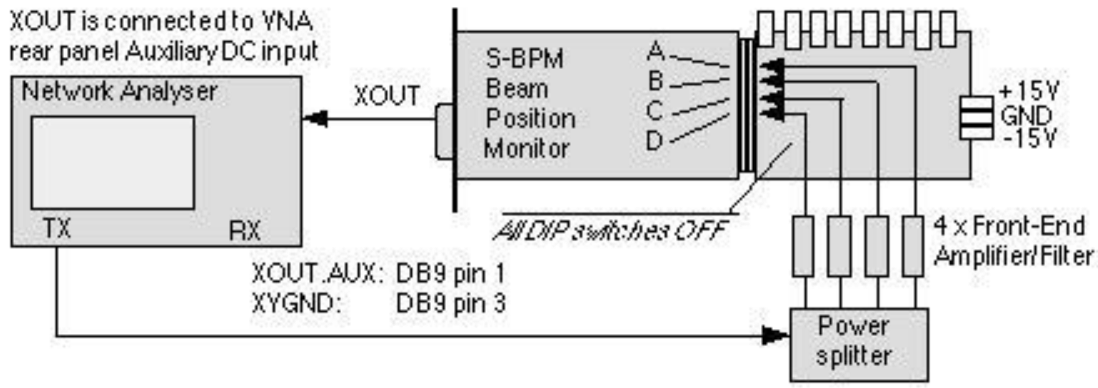
Hence, in the example above, 1.6 mVrms = 24 micrometers rms.

Dynamic range

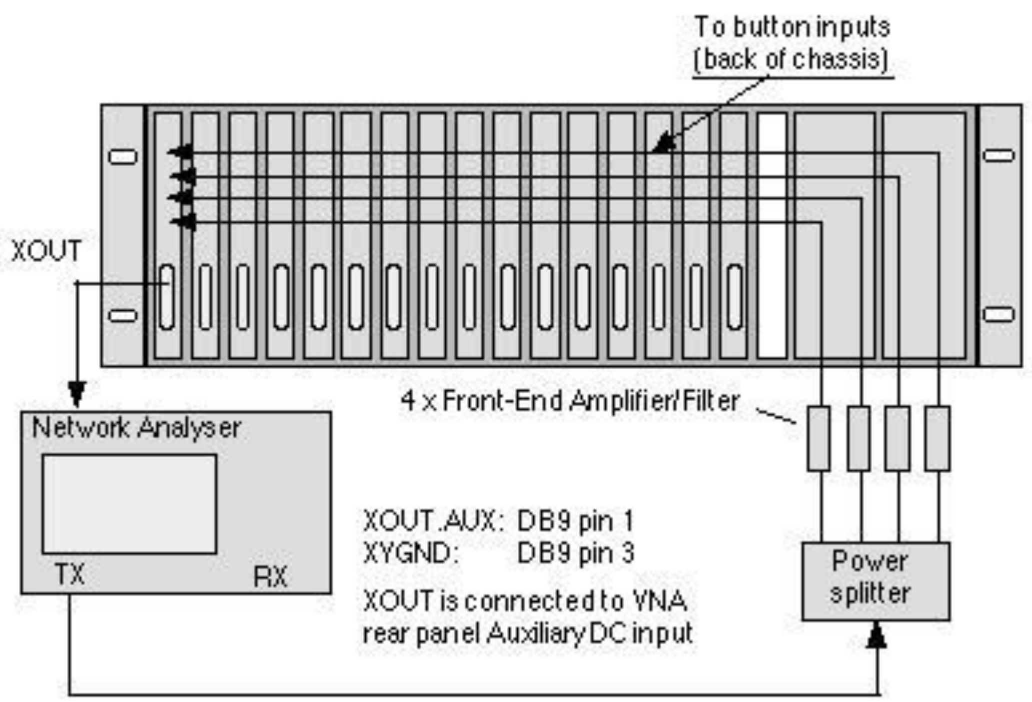
Observe S-BPM dynamic range with a vector network analyzer (VNA).
The measurements hereafter require a VNA equipped with an Auxiliary DC input, usually placed at the rear. Some known models to feature such a DC auxiliary input are: Agilent 8357D, E and ES, Agilent 5071C.

Setup

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



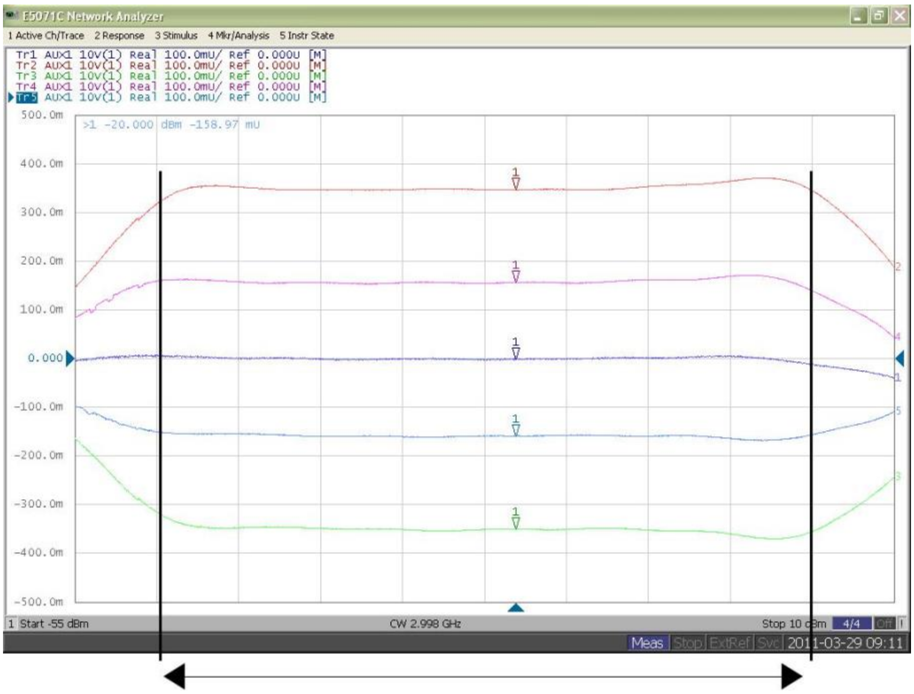
If you have a 19" chassis (BPM-RFC/X), use the following set-up:



Set the VNA in power sweep mode, over the widest possible range.
To cover the full S-BPM dynamic range, the VNA must be capable of >50dB power sweep.
Successive power sweeps may be needed if the VNA has a more limited sweep range.

Perform several sweeps with various input attenuators combinations in such a way that X and Y off center linearity is tested.
Explore the range from +7 dBm down to -70 dBm.

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



Useful dynamic range about 52 dB

The plot above shows the dynamic range of S-BPM with 11-meter long input cables.
The 1/4" cables used attenuate ≈100dB/100m at 3 GHz (Huber+Suhner GX03272).

A subjective evaluation would indicate a useful dynamic range of 52dB from Marker-1 to Marker-2.

Operating limits with 11-meter cables: -50 dBm to 0 dBm (after adding 7dB to the markers value in consideration of the 4-way inductive splitter insertion loss).

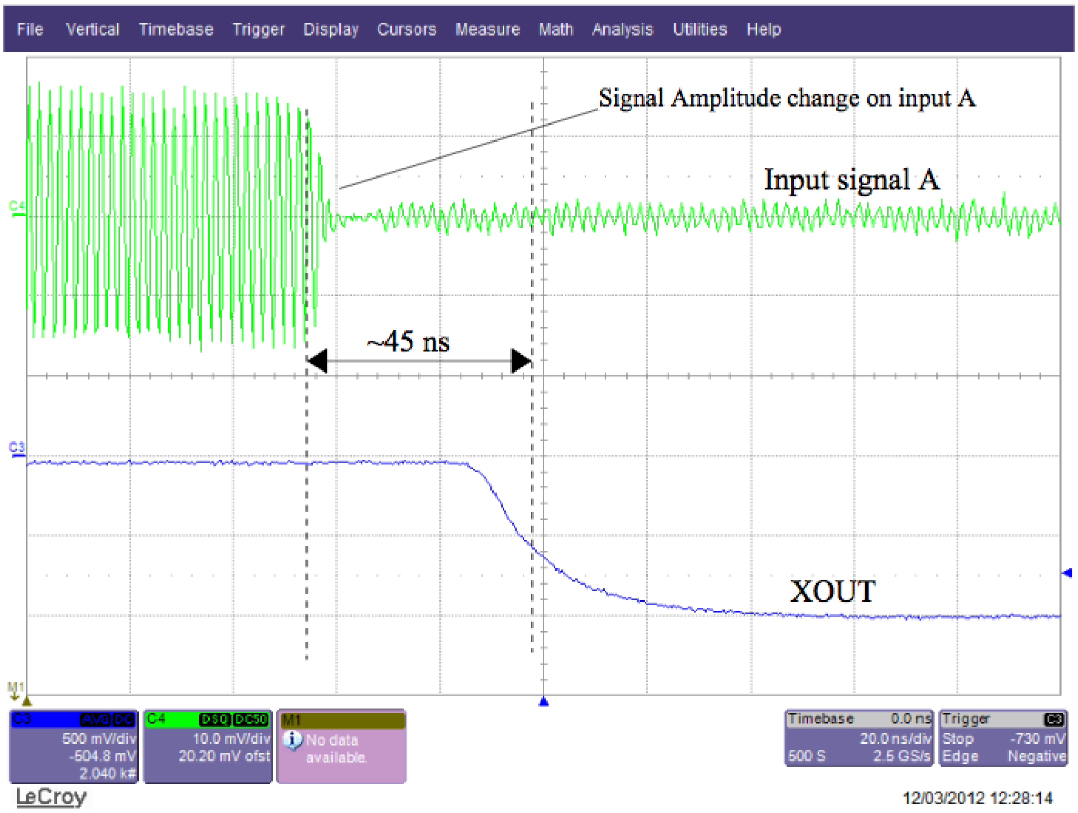
Note: -50 dBm is –approximately– the signal collected by a BPM electrode whose subtending angle is 45 degrees, passed by a 100-uA CW beam. Scale up the beam current lower limit if the electrode subtending angle is smaller.

Reaction Time to Beam Position Change

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

Time delay from a beam position change to Output signal half-height rise is ~45 ns Output risetime is ~30 ns.

Signal shown is taken from an S-BPM at 3GHz.



Example from Orthogonal pickups configuration.

QUICK CHECK: S-BPM in Sample&Hold Mode

This Quick Check works only if Sample & Hold S-BPM-SH option is installed

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

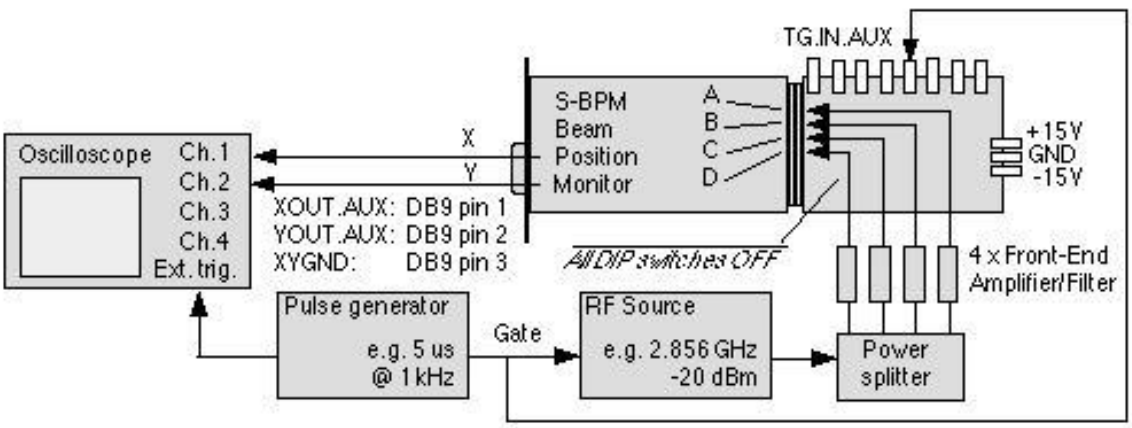
- Orthogonal pickups
- Built-in Beam Trigger
- Mode, Timing and Processing: S&H
- Built-in trigger: Disabled
- ADC Trigger output: Complementary.

S-BPM in Sample & Hold Mode can measure macropulse beams or single pulse beam.
Quick Check setups for both types of beams are given hereafter:

- QUICK CHECK: Sample&Hold Mode for macropulse beam
- QUICK CHECK: Sample&Hold Mode for single pulse beam.

For macropulse beam

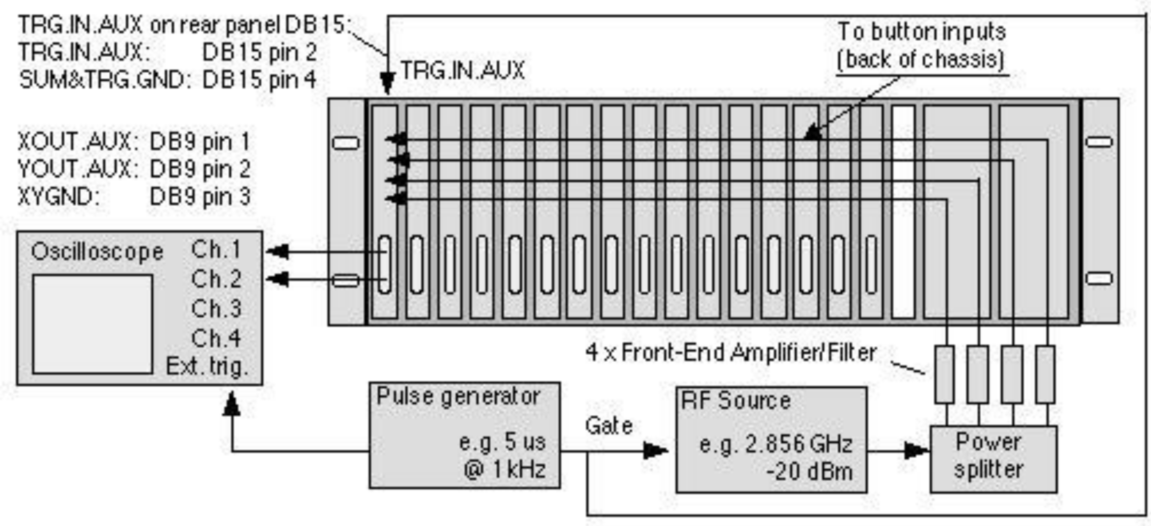
Setup, to check immediately that your S-BPM system is working in Sample & Hold Mode.
If you have the table-top test kit (BPM-KIT), use the following set-up:



Note: The cable to TRG.IN.AUX must be same length as input cables to compensate delay.

If you have a 19" chassis (BPM-RFC/X), use the set-up on next page.

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



Set the RF source to:

- Gated mode
- The S-BPM operating frequency e.g. 2856 MHz
- -20dBm output power

Set the Gating pulse generator to:

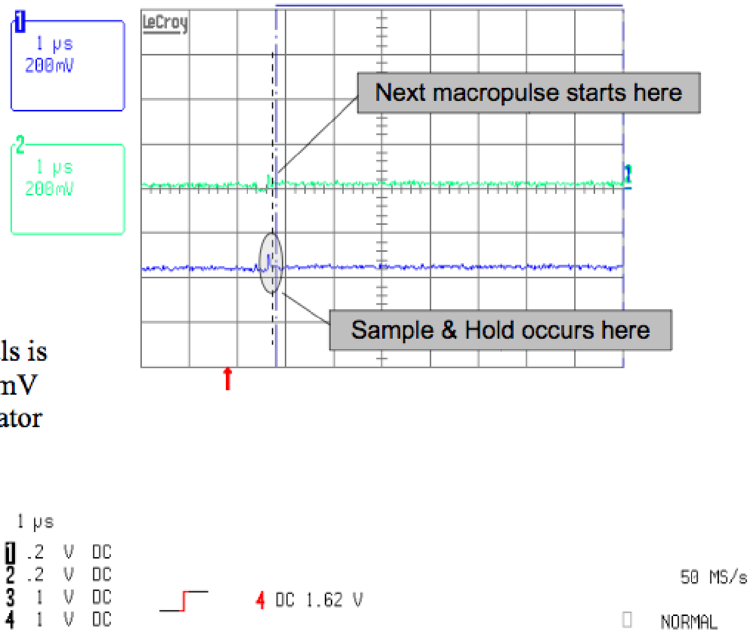
- 5 µs pulse duration
- Slow repetition rate, e.g. 500 Hz

Note: Some oscilloscopes External trigger delay is not long enough to view the signal on the oscilloscope screen. When that is the case, add a cable delay line to delay the "Gate" of the RF source until the gated pulse is in the screen.

Insert an attenuator in one of the inputs, e.g. 6 dB in Input A.
Trace 1 XOUT and Trace 2 YOUT show the held X and Y positions of the macropulse:

XOUT signal from
either Front Panel
DB9 pin 1 or
BPM-KIT XOUT BNC

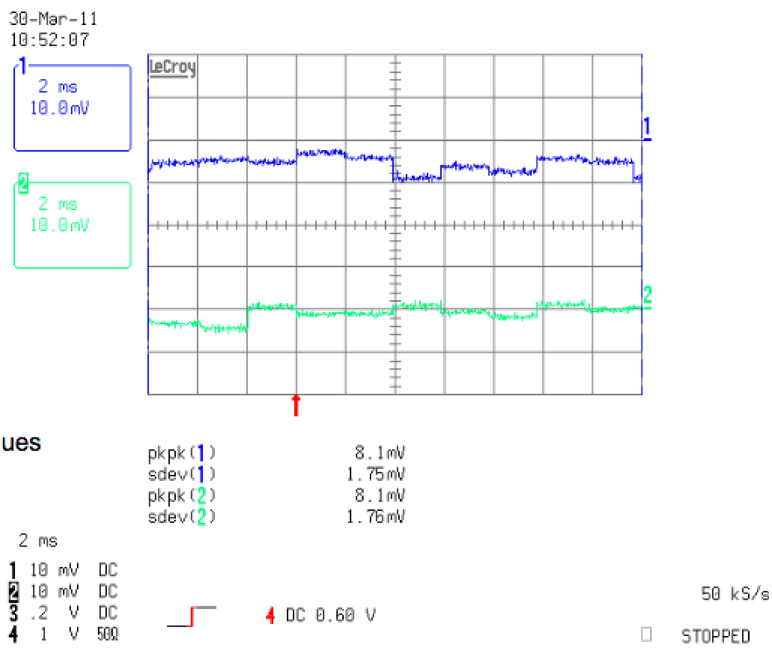
YOUT signal from
either Front Panel
DB9 pin 1 or
BPM-KIT YOUT BNC



Note :
Observe XOUT signals is shifted to above -347mV due to the 6dB attenuator in input A.

XOUT signal from
either Front Panel
DB9 pin 1 or
BPM-KIT XOUT BNC

YOUT signal from
either Front Panel
DB9 pin 2 or
BPM-KIT YOUT BNC



Note :
Observe the pkpk or sdev values for trace 1 and trace 2.

Using the same setup, observe the same signal on a slower oscilloscope time base:

The pkpk() value is the macropulse-to-macropulse S-BPM peak-peak noise
The sdev() value is the macropulse-to-macropulse S-BPM rms noise or resolution.

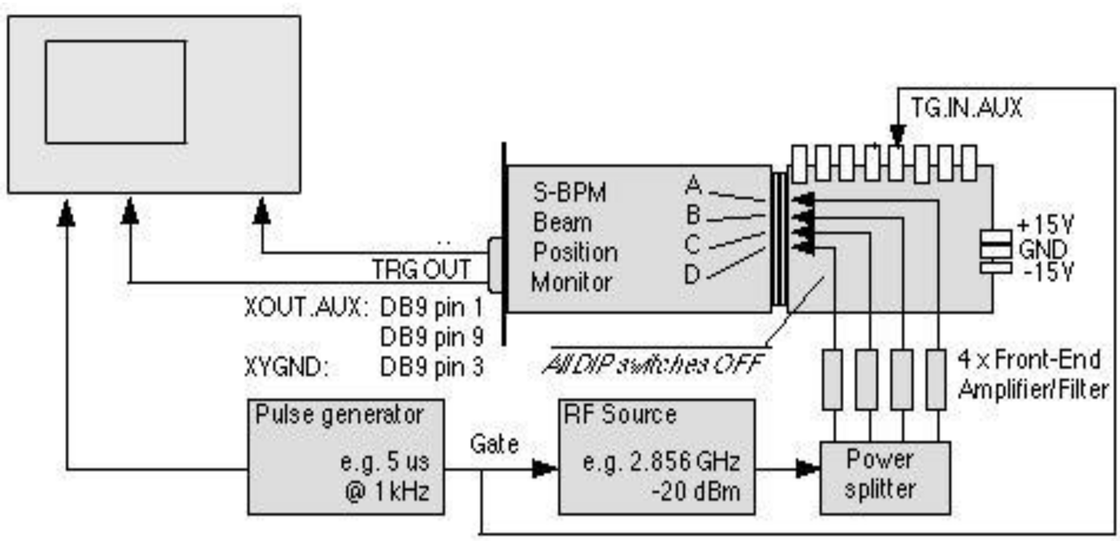
Observe sdev(1),the macropulse-to-macropulse S-BPM rms noise or resolution of XOUT: 1.8mVrms.

To translate this rms voltage noise in beam position noise, let's assume a BPM pickup aperture of 25mm and pickup electrodes subtending angle infinitely small. In this case, a beam displacement by 1/6 of the pickup radius equals to 347mV.

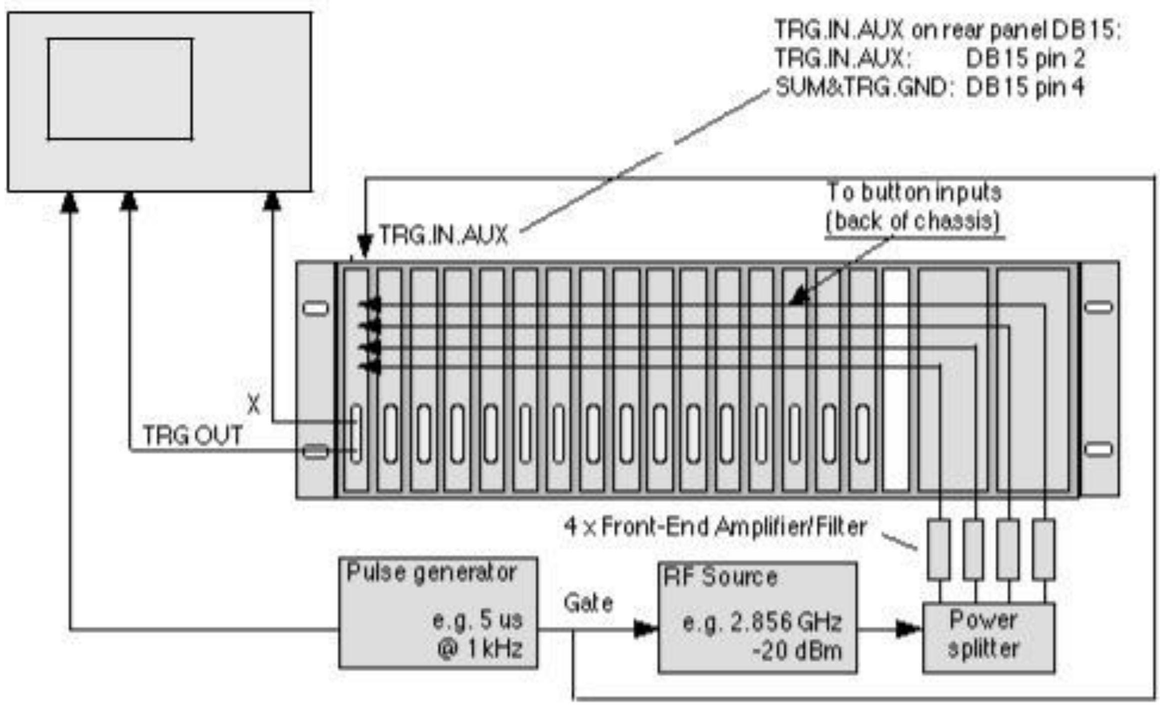
Hence, in the example above, 1.8 mVrms = 43 micrometers rms.

Timing for macropulse beam

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



Note: The cable to TRG.IN.AUX must be same length as input cables to compensate delay.



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

Note: The cable to TRG.IN.AUX must be same length as input cables to compensate delay.

Observe the relative timing of

- CH1: input macropulse.
- CH2: output trigger TRG.ADC.OUT for the ADC on rear panel DB15 or front panel DB9 pin 9.
- CH3: X output XOUT.

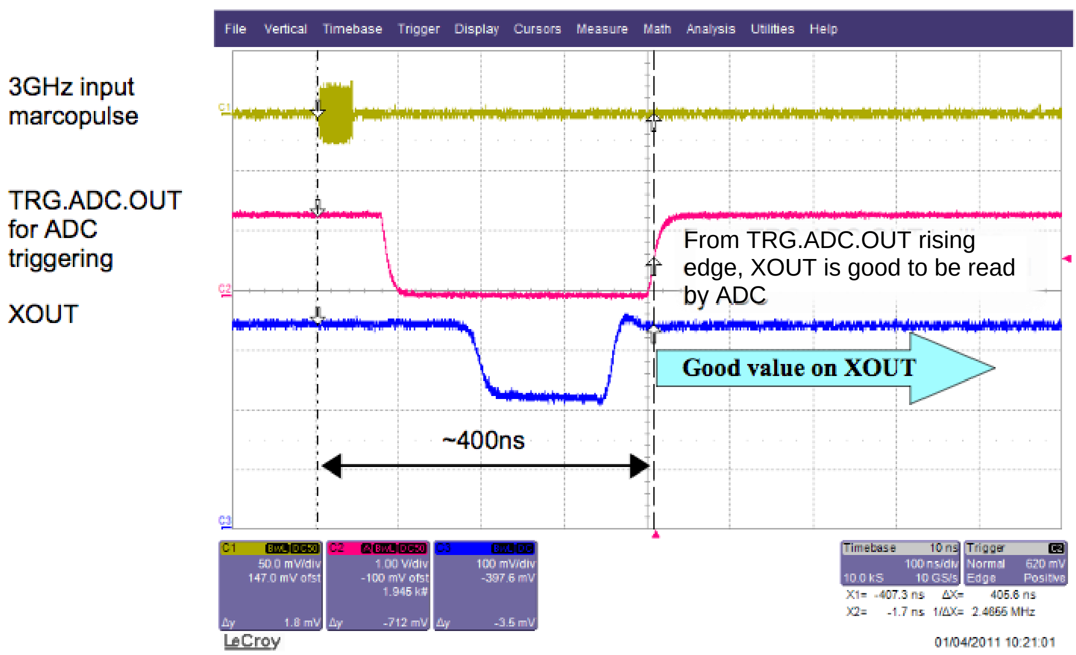
Pulse generator setup:

- Gate duration 40ns
- Gate frequency: Slow, e.g. 500 Hz

Oscilloscope setup:

Time base	100 ns/div.		
CH1	50 mV/div.	DC-50 ohms	S-band input macropulse
CH2	1 V/div.	DC-50 ohms	TRG.ADC.OUT to trigger ADC & oscilloscope
CH3	100 mV/div.	DC-1 Mohm	XOUT

Trigger on CH2 (TRG.ADC.OUT)



Rising edge of TRG.ADC.OUT occurs about 400ns after TRG.IN.AUX was applied to S-BPM.

XOUT (and YOUT) are good to read by ADC after TRG.ADC.OUT rising edge.
Note that TRG.ADC.OUT shape can be changed. See TRG.ADC.OUT description p.10.

Resolution

With same setup as above, observe the noise on XOUT (or YOUT) output:

Set the oscilloscope persistence ON, say 10 seconds persistence:

Sdev(C3) is the rms noise or resolution of XOUT measured in the measurements window, when the output signals are "good-to-read". The trace thickness is the noise of all successive macropulses over a 10-second period.

To translate this rms voltage noise in beam position resolution, let's assume a 25mm vacuum chamber radius and pickup electrodes width < vacuum chamber radius. In this case, a beam displacement by 1/6 of the pickup radius equals to 347mV.

Hence, in the example above, resolution 1.9 mVrms = 45 micrometers rms.

For single pulse beam

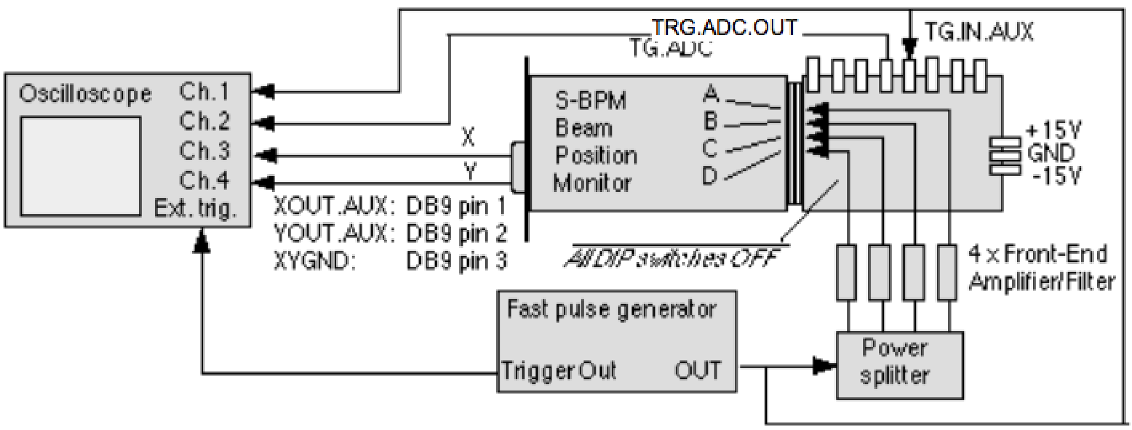
This Quick Check works only if Sample & Hold S-BPM-SH option is installed

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

- Orthogonal pickups
- Built-in Beam Trigger
- Mode, Timing and Processing: S&H
- Built-in trigger: Disabled
- ADC Trigger output: Complementary.

Setup, to check your S-BPM working in Sample & Hold Mode with single pulses.

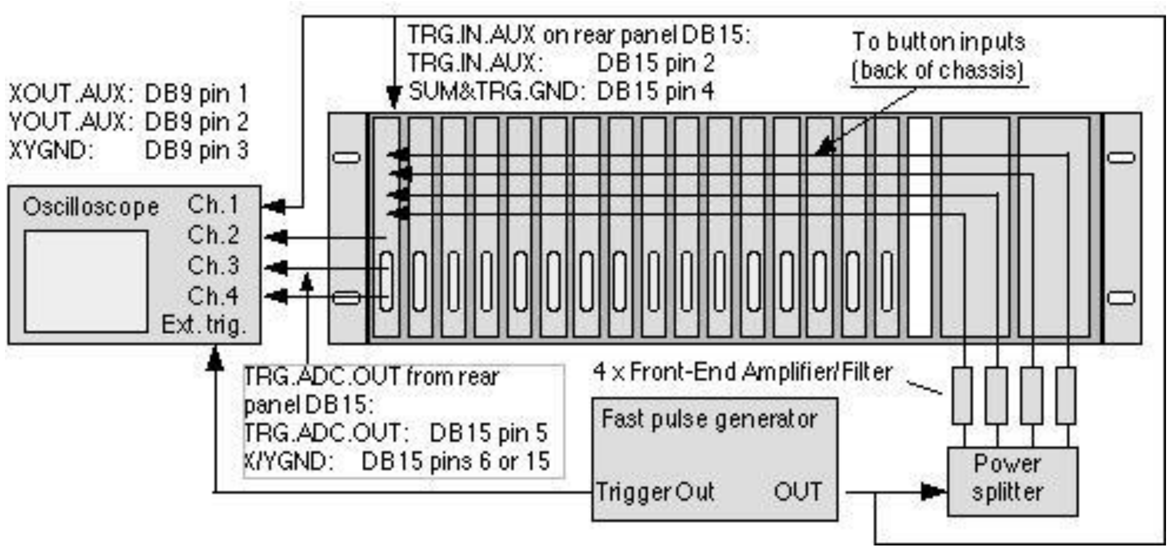
If you have the table-top test kit (BPM-KIT), use the following set-up:



Note: The cable to TRG.IN.AUX must be same length as input cables to compensate delay.

If you have a 19" chassis (BPM-RFC/X), use the set-up on next page

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



Note: The cable to TRG.IN.AUX must be same length as input cables to compensate delay.

Set the Fast Pulse Generator to:
- < 160ps risetime
- 50 V
- Slow repetition rate, e.g. 1 kHz

Please note that signals applied to S-BPM inputs are attenuated by the 4-way splitter:
Inductive-type 4-way splitters typically attenuate by 7dB,
4-way resistive splitters or cascaded 2-way splitters attenuate by 12dB.

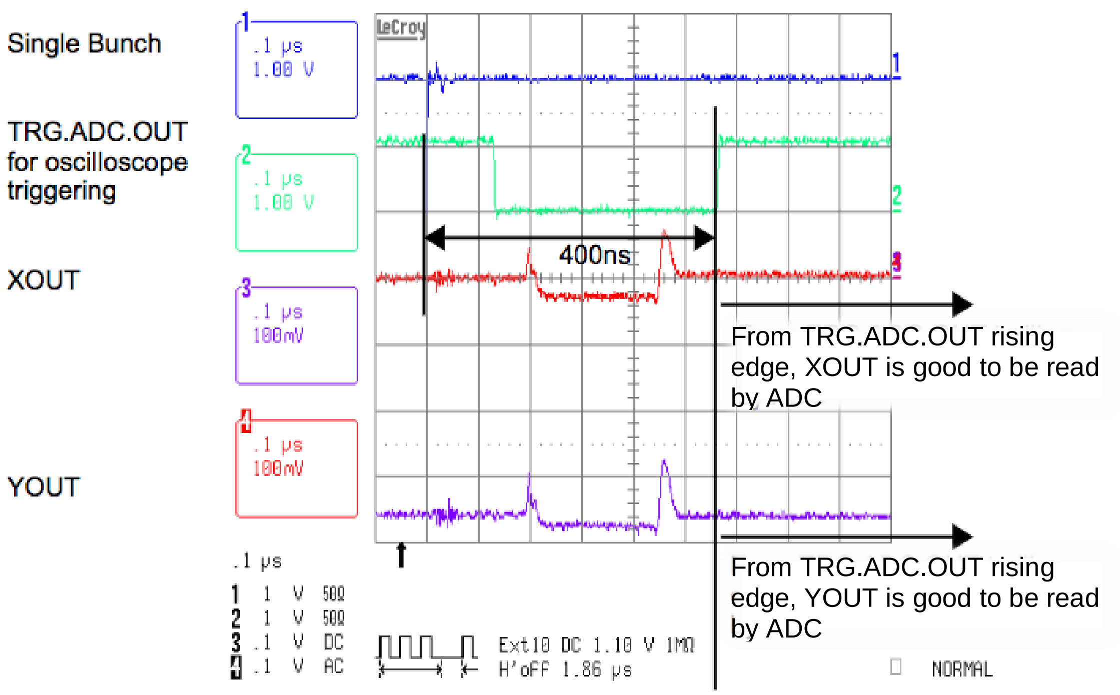
This 50V pulse, after splitting in an inductive-type 4-way splitter (-7 dB) is about equivalent to a 500-pC bunch seen by four pickups of 5 pf capacitance and subtending angle = 45 degrees.

Set the oscilloscope to:

Time base	100 ns/div.		
CH1	1 V/div.	DC-50 ohms	"Beam" Pulse
CH2	1 V/div.	DC-50 ohms	TRG.OUT
CH3	0.1 V/div.	DC-1 Mohm	XOUT
CH4	0.1 V/div.	DC-1 Mohm	YOUT

External trigger from Fast Pulse Generator.

Note: Some oscilloscopes External trigger delay is not long enough to view the signal on the oscilloscope screen. When that is the case, add a cable delay line to delay the Fast Pulse output until the signals appear on the oscilloscope screen.



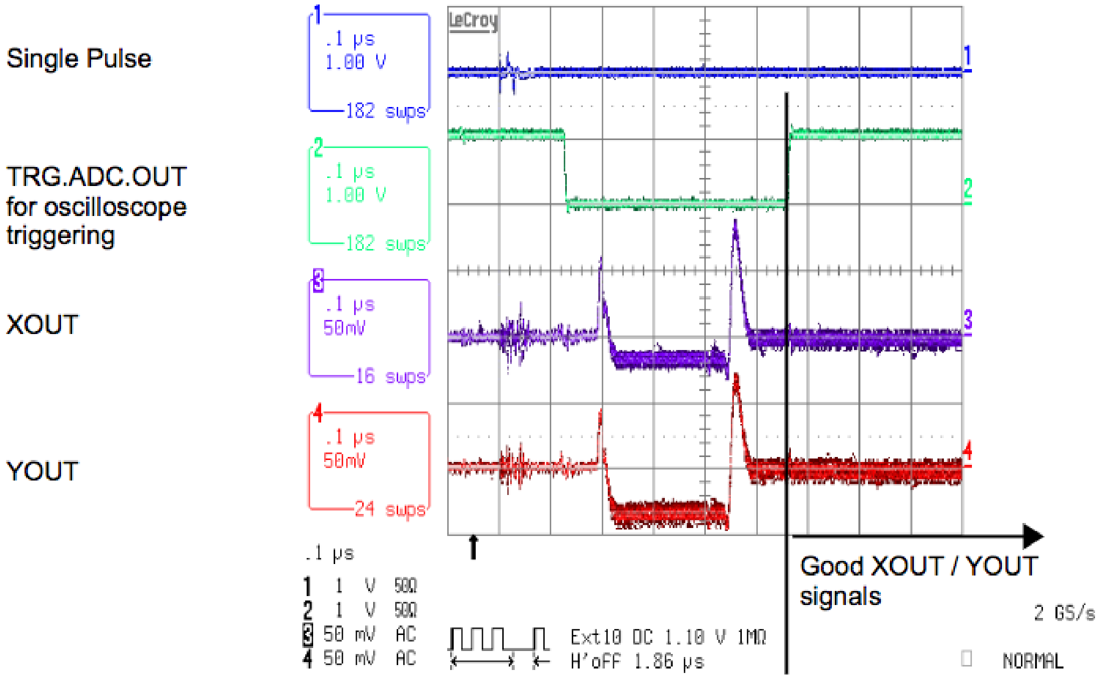
Rising edge of TRG.ADC.OUT occurs about 400ns from the time when TRG.IN.AUX was applied to S-BPM.

With this setup, TRG.IN.AUX is applied at the same time as the pulse.

XOUT and YOUT are good to read by ADC from the time of TRG.ADC.OUT rising edge.

Note that TRG.ADC.OUT shape can be changed. See TRG.ADC.OUT description p.10.

With same setup as above, observe the noise on XOUT and YOUT outputs:



Set the oscilloscope persistence ON:

Observe the XOUT and YOUT trace thickness. It is the peak-peak dispersion –or noise– of all successive pulse position measurements during the oscilloscope persistence time.
On the plot above, about 20 mVpp after TRG.ADC.OUT rising edge, when XOUT and YOUT are "good" to read.
The rms noise –or resolution– is about 3.2 times lower than the peak-peak noise, i.e. 6.25mVrms.

To translate this rms voltage noise in beam position resolution, let's assume the BPM pickup aperture is 25mm and the pickup electrodes subtending angle is infinitely small. In this case, a beam displacement by 1/6 of the pickup radius equals to 347mV.

Hence, in the example above, resolution 6.25 mVrms = 37.5 micrometers rms.

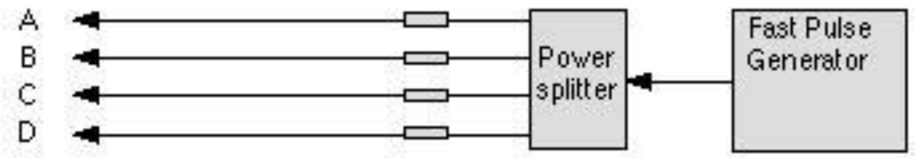
Simulating beam position changes

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.

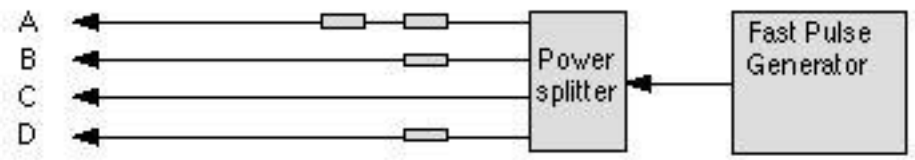
If an inductive-type 4-way splitter is used, the pulse generator output amplitude should be about 50V with risetime < 160ps. If a resistive-type pickup is used, 100V is required.

The S-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 = 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 <=> C, and B <=> 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).

S-BPM modules are factory preset:

- For orthogonally placed pickups: up, left, down 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. Please 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, assuming the pickup subtending angle is infinitely small.

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			
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			
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			
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			
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			

Please note these are displacements. Take into consideration the zero offsets due to power splitter imbalance and attenuators inequality.

Note: The above voltages are representations of the algorithms:

For Orthogonal pickups:
$X = K_x \cdot \mathrm{Log}(A/C)$
$Y = K_y \cdot \mathrm{Log}(B/D)$

For Rotated pickups:
$X = K_x \cdot [\mathrm{Log}(A/C) \cdot \cos\beta - \mathrm{Log}(B/D) \cdot \sin\beta]$
$Y = K_y \cdot [\mathrm{Log}(A/C) \cdot \sin\beta + \mathrm{Log}(B/D) \cdot \cos\beta]$

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

SIGNALS

Input signals

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

Output signals for ADC

XOUT	X displacement. Bipolar signal up to ±2V (0 Volt represents pickup center) Output impedance: 100 Ω
YOUT	Y displacement. Bipolar signal up to ±2V (0 Volt represents pickup center) Output impedance: 100 Ω
XGND	Analog ground for XOUT
YGND	Analog ground for YOUT
SUM.OUT	+ (Log(A) + Log(B) + Log(C) + Log(D)) signal Signal range 0...+2V Output impedance: 100 Ω
TRG.ADC.OUT	Trigger for external ADC TTL pos./comp. Pulse (See QUICK CHECK: Sample&Hold Mode -and- Track&Hold Mode) Output Impedance 100 Ω.
SUM&TRG.GND	Ground for SUM.OUT -and- TRG.ADC.OUT
VPHOUT	Phase angle output ±9V = ±90° RF to Phase reference angle (S-BPM with BPPM option only, not available at time of writing)

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 > 0.4 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 S-BPM circuit, i.e. 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

TRACK.CONTINUOUS	TTL signal. To set Track-Continuous mode. High state (default) sets Track&Hold mode. Pull down for Track-Continuous mode. Pullup resistor to 5V is 4K7.
GND	Ground for above signals.

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

None are handled by S-BPM

S-BPM CONNECTORS PINS ALLOCATION Rev. 1.2

		DB9 female connector on S-BPM front panel	DIN41612M S-BPM module rear connector	DB15 female connector on BPM-RFC rear panel (one connector per BPM station)
INPUT SIGNALS				
Input A	BUTA		b2 *	
Input B	BUTB		b5 *	
Input C	BUTC		b8 *	
Input D	BUTD		b11 *	
Phase reference (BPPM 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	5	c20	3
ADC Trigger TTL output pos/comp pulse	TRG.ADC.OUT	9	b20	5
AUXILIARY OUTPUT SIGNALS				
X auxiliary output	XOUT.AUX	1		
Y auxiliary output	YOUT.AUX	2		
X and Y auxiliary outputs analog ground	XYGND	3		
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
** Default value: High, no inhibiting	SUM&TRG.GND	4	b19	4
OPTIONAL OUTPUT SIGNALS				
Log A	LOGA		b22 *	
Log B	LOGB		b25 *	
Log C	LOGC		b28 *	
Log D	LOGD		b31 *	
* Coaxial insert 1.0/2.3 type				
EXTERNAL CONTROLS				
Reserved	RESERVED	8	a13	1
Track-Continuous mode, Low	TRACK.CONTINUOUS	7		
GND	GND		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 ±1ns. Yet, unlike most BPM electronics, the S-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 or even better: nanocrystalline cores.

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 6 GHz for 3 GHz operating frequency.

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

ACCESSORIES

Font-End Filter/Amplifier (S-FEFA)

The Front-End Filter/Amplifier S-FEFA is tuned to the beam RF frequency.
The filter is a bandpass with very high Q-factor, thus narrow bandwidth.
Therefore, an S-FEFA cannot be used at another frequency than the frequency it is tuned to.

Every S-FEFA is matched to one S-BPM input channel A, B, C or D.
When BPM pickup cables BPM-C-XX are delivered by Bergoz Instrumentation, they are matched to a specific S-FEFA and S-BPM input channel A, B, C or D.

S-FEFA is powered from the S-BPM module thru the coaxial cable.
Therefore, no filter, no attenuator can be inserted in the cable from S-FEFA to S-BPM.

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.
- BB-BPM, Baseband BPM for medical ramped accelerators.
- LR-BPM log-ratio BPM.
- S-BPM, S-band BPM.

BPM-KIT currently delivered must be powered by a laboratory +/- 15V 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 DIN41612M 24+8 mating connector
- Four coaxial cables connected to the button inputs, terminated by SMA plugs
- Eight BNC jacks to enter signals like triggers and view output signals.
- Four DIP switches to simulate external control signals.

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.

The RF Service module BPM-SERV/RF 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.

Power Supply module

AC mains voltage	Autoranging 98…132Vac and 185…265Vac
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

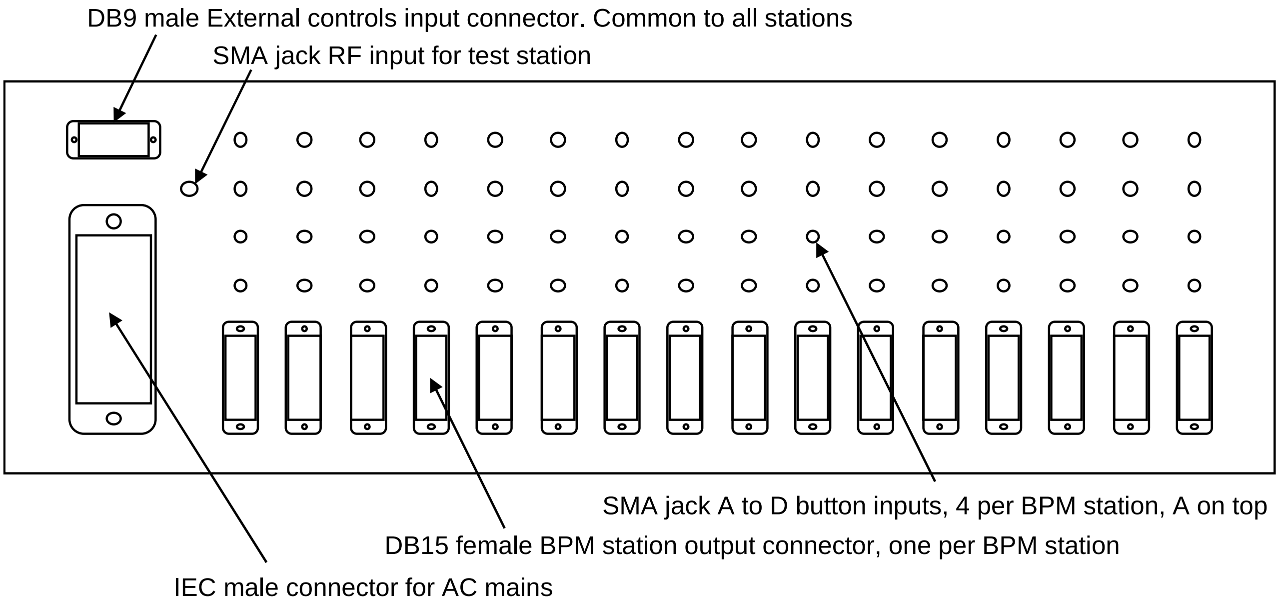
BPM Chassis BPM-RFC/X

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

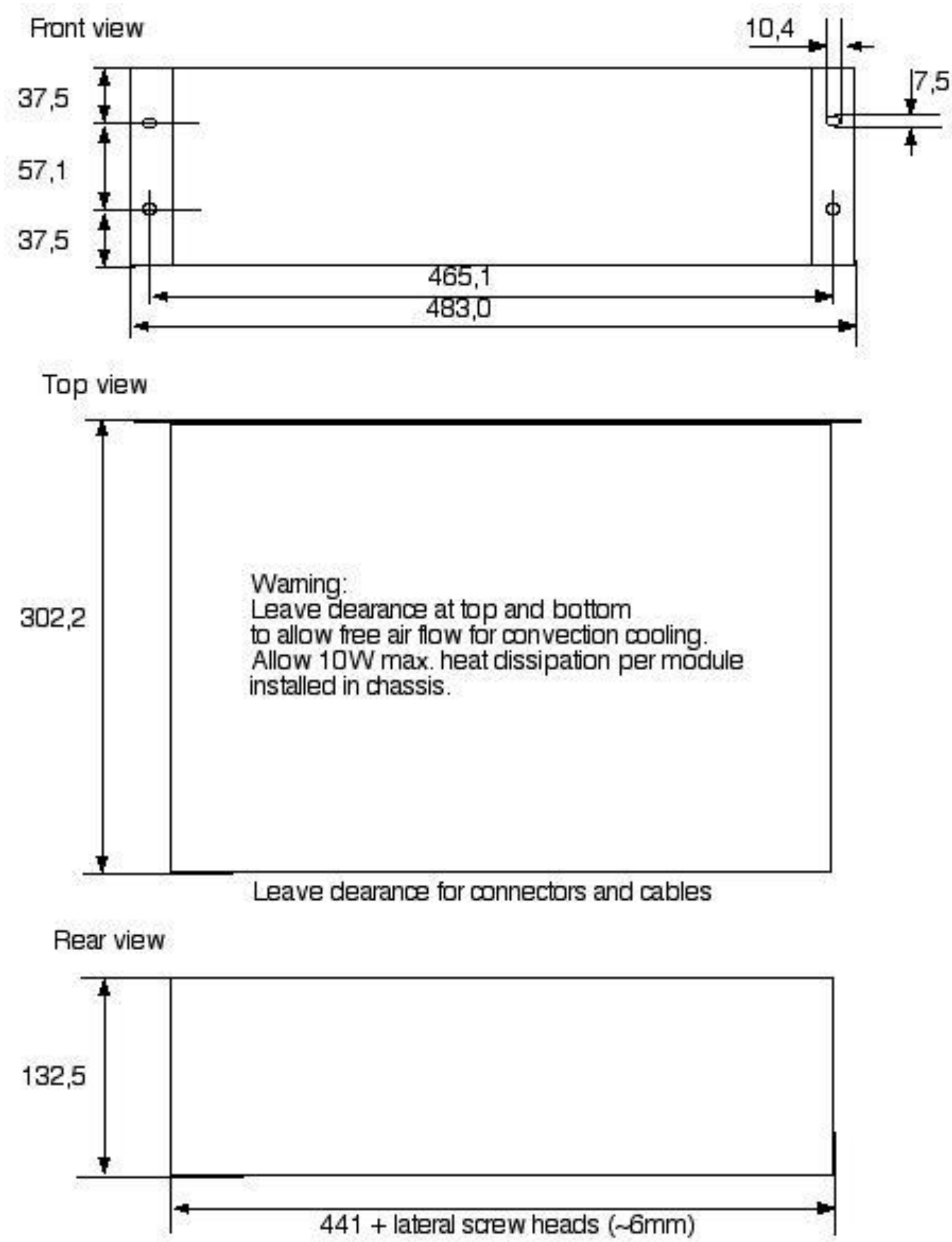
The BPM-RFC/X is available equipped for 1 up to 16 BPM stations. X being the number of stations.

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



BPM Chassis BPM-RFC/X Outer dimensions



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 fax, 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: ....

ACKNOWLEDGEMENTS

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

Our S-BPM module was developed by Sebastien Artinian, based on the earlier LR-BPM design of Alexander Kalinin.

Last revised: Saint Genis Pouilly, March 2021