USER MANUAL

# S-BPM

## S-band

## Beam Position Monitor

Rev. 4.0

www.bergoz.com

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INSTRUMENTATION

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## Record of updates

| Version | Date | Updates performed |
|---|---|---|
| 1.0 | 12/2008 | Initial version derived from LR-BPM User's Manual v. 2.2.1<br>S-BPM 111.3.1 |
| 1.1 | 01/2009 | Layout change |
| 1.3 | 02/2010 | Layout change<br>S-BPM CONNECTORS PINS ALLOCATION change |
| 1.4 | 03/2010 | T&H; S&H Timing change<br>T&H; S&H graphs added<br>p. 44 TRG.IN.AUX negative edge correction<br>p. xx Pin ALLOCATION correction DB9, 9 => TRG.ADC.OUT |
| 2.0 | 04/2011 | S-BPM new release: 111.3.2. Main changes:<br>S-BPM layout change (switch positions)<br>Track Continuous reptition rate up to 10MHz instead of 5MHz<br>Sample & Hold 400ns processing time instead of 470ns<br>Sample & Hold repetition rate 5KHz instead of 2MHz due to trigger inhibition<br>SUMOUT positive value instead of negative<br>TRG.AUX.IN on rising edge > 0.4V instead of negative > 2V<br>Ortho. / Rot. jumpers positions as LR-BPM<br>Track Continuous traces<br>Track & Hold and Sample & Hold traces<br>Resolution improvements<br>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<br>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.<br>"Triggering Out" chapter added |
| 4.0 | 07/2024 | Manual layout update |

## DISTRIBUTORS

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GMW Associates
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## TABLE OF CONTENTS

## 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. 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, disassembly, neglect, use of faulty part, accident or abnormal conditions, repair made by the customer, 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: The purchaser/customer must ask for a RMA (Return Material Authorization) number to Bergoz Instrumentation or its local distributor before return of goods. Bergoz Instrumentation will repair or replace any product under warranty at no charge.

For products in need of repair after the warranty period, Bergoz Instrumentation will assess the technical issue and send a quote to the purchaser/customer. The purchaser/customer must provide a purchase order before repairs can be initiated. Bergoz Instrumentation can issue fixed price quotations for most repairs.

## RETURN PROCEDURE

All products returned for repair should include a detailed description of the defect or failure as well as name, phone number and email of a contact person to allow further inquiry. Contact Bergoz Instrumentation or your local distributor to determine where to return the product. Returns must be notified by email prior to shipment.

The shipment of a product under warranty or out of warranty back to the factory is paid by the user/customer, including the customs fees. The return of this repaired product under warranty back to the customer is paid by Bergoz Instrumentation.

Return of product out of warranty should be made prepaid or will be invoiced. Bergoz Instrumentation will not accept freight-collect shipments. Shipments should be made via UPS, FedEx or DHL. Within Europe, the transportation services offered by the national Post Offices can be used. The delivery charges or customs clearance charges arising from the use of other carriers will be charged to the customer.

## SAFETY INSTRUCTIONS

This instrument is operated from the mains power supply. For safe operation, it must be grounded by way of the grounding conductor in the power cord. Use only the fuse specified. Do not remove cover panels while the instrument is powered. Do not operate the instrument without the cover panels properly installed.

Chassis originally shipped to U.S. or Canada feature AC mains power entry modules where the Phase is fused and the Neutral unfused, as is the rule.

Chassis to other destinations but U.S. and Canada feature AC mains power entry modules where both Phase and Neutral are fused.

When a chassis with unfused Neutral shall be used outside the U.S. and Canada, fuse configuration must be modified so that both Phase and Neutral will be fused:
The Power entry module must be opened, the Phase fuse must be removed, the fuse holder must be flipped; its reverse side presents two slots where two new fuses must be inserted, one in each slot. The fuses rating must be same as the Phase fuse that was removed.

**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 |

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<br>X = number of BPM stations |

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

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

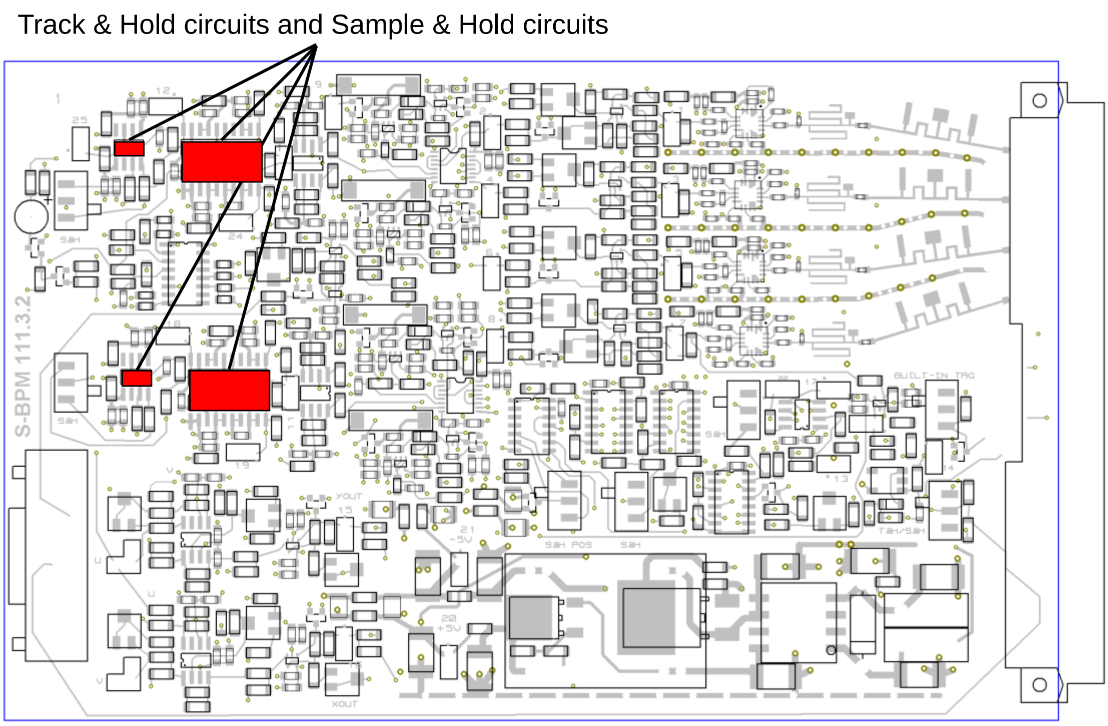
At the time of writing this User's Manual, only one version has been shipped to users: S-BPM revision number 111.3.2

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:


Built-in trigger circuit

## 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:

### 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,<br>Single bunch turn-by-turn<br>Synchrotron multi-single bunch turn-by-turn, using trigger gate. |

Refer to " Track & Hold Mode” for switch settings

**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

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.

**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

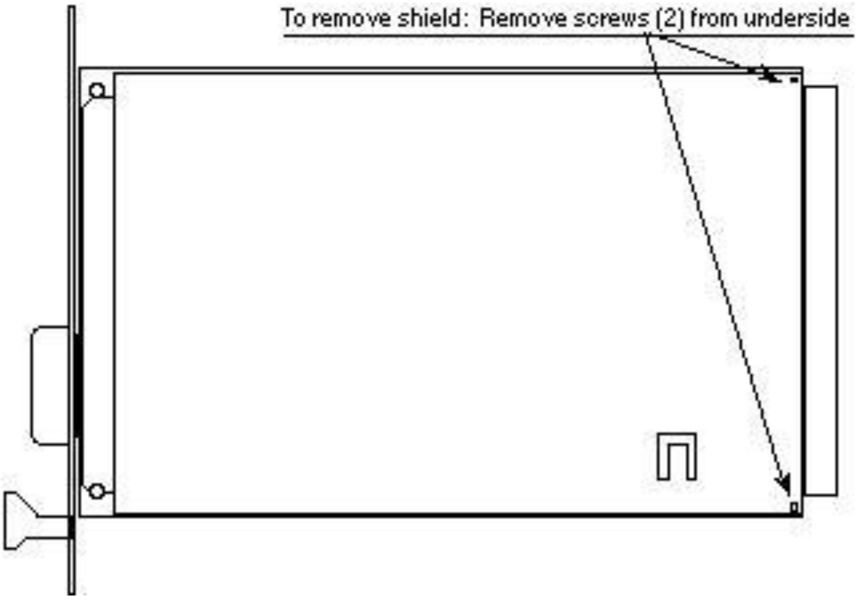
Requires Sum-of-Logs option S-BPM-SUM to be mounted on the printed circuit board

| | |
|---|---|
| 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).

## 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.

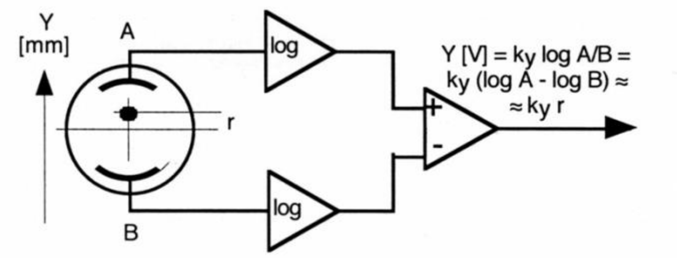
Each amplifying chain produces a signal which peak amplitude is proportional to the log of the input signal, be it a single pulse, a pulse train, or a continuous wave.

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.

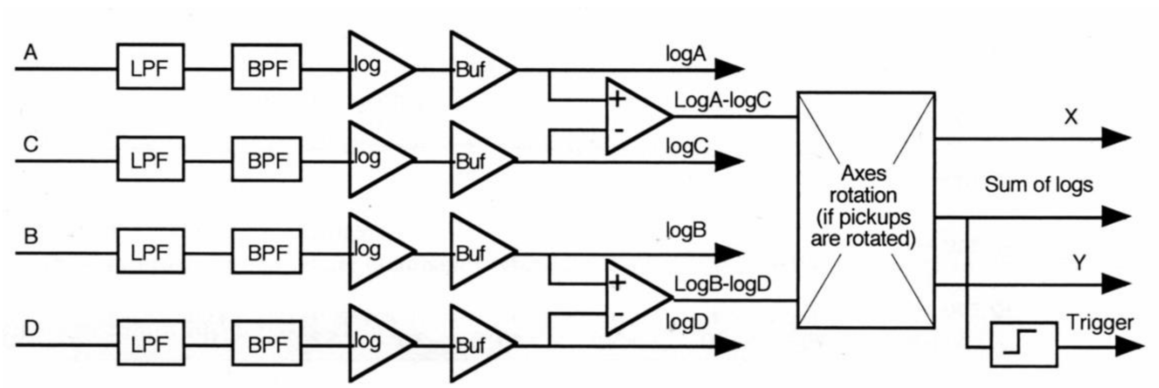
If the pickup electrodes are placed along the axes in which the beam displacement is to be measured, the displacement $X = K_x \, Log(A/C)$, directly. The $K_x$ gain is obtained by an amplifier with adjustable gain. The same goes for the Y axis.

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:



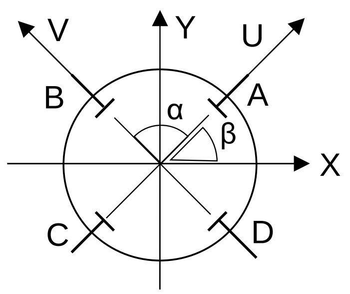

## BLOCK DIAGRAM



## 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

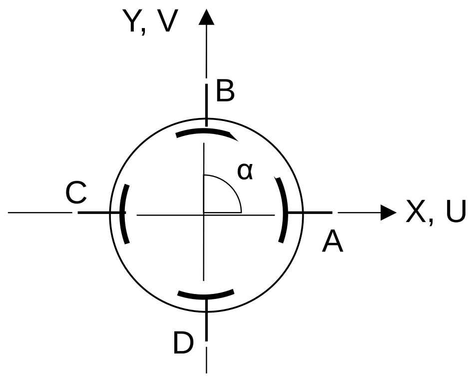



$\alpha = 90°$
$\beta \neq 0$
Note: α may be ≠ 90°. S-BPM is factory-set for equal X and Y gains, i.e., α= 90°

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

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

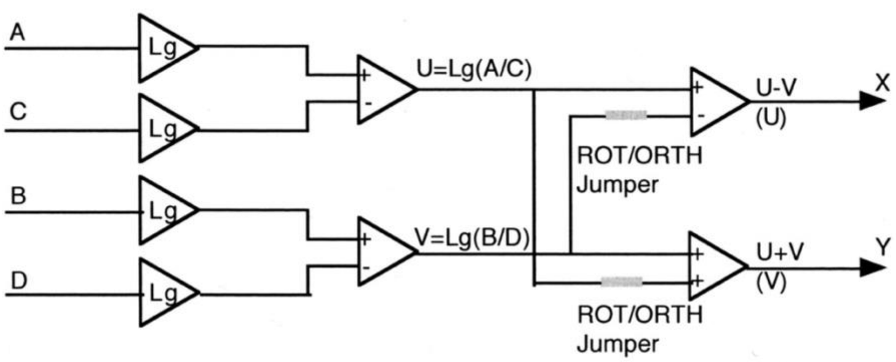
ORTHOGONAL PICKUPS




$\alpha = 90°$
$\beta = 0$

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

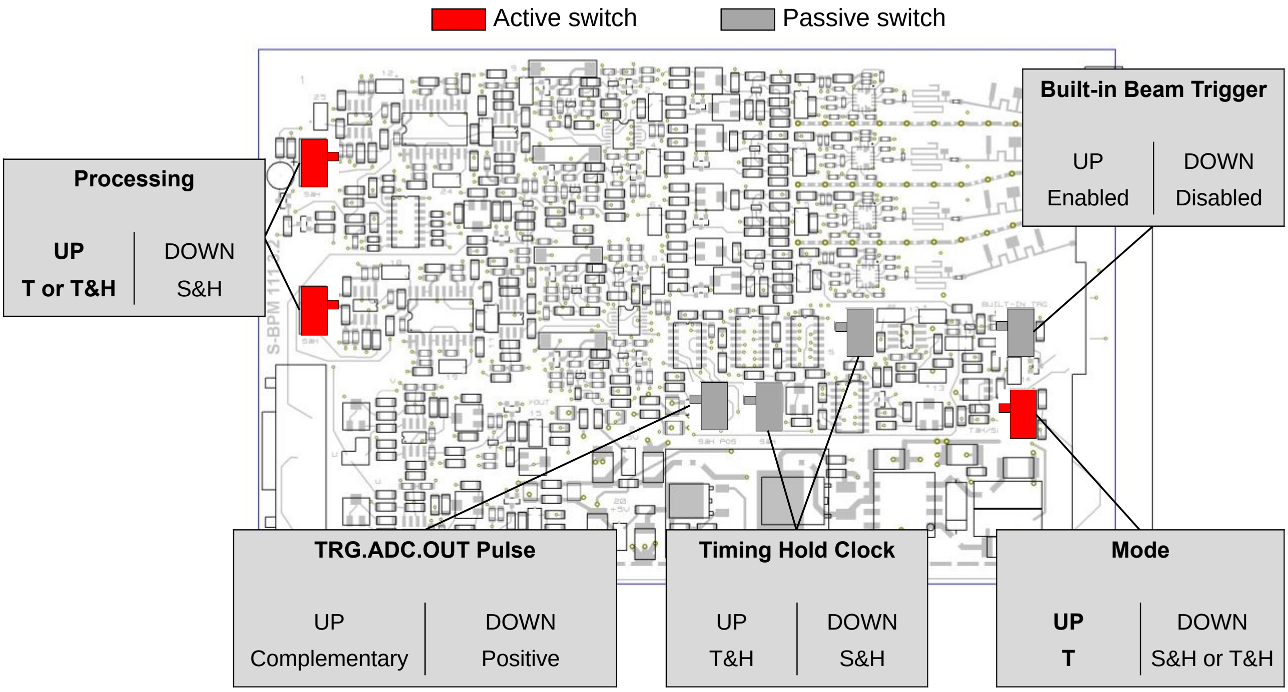
$X = K_x \cdot U$
$Y = K_y \cdot V$




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

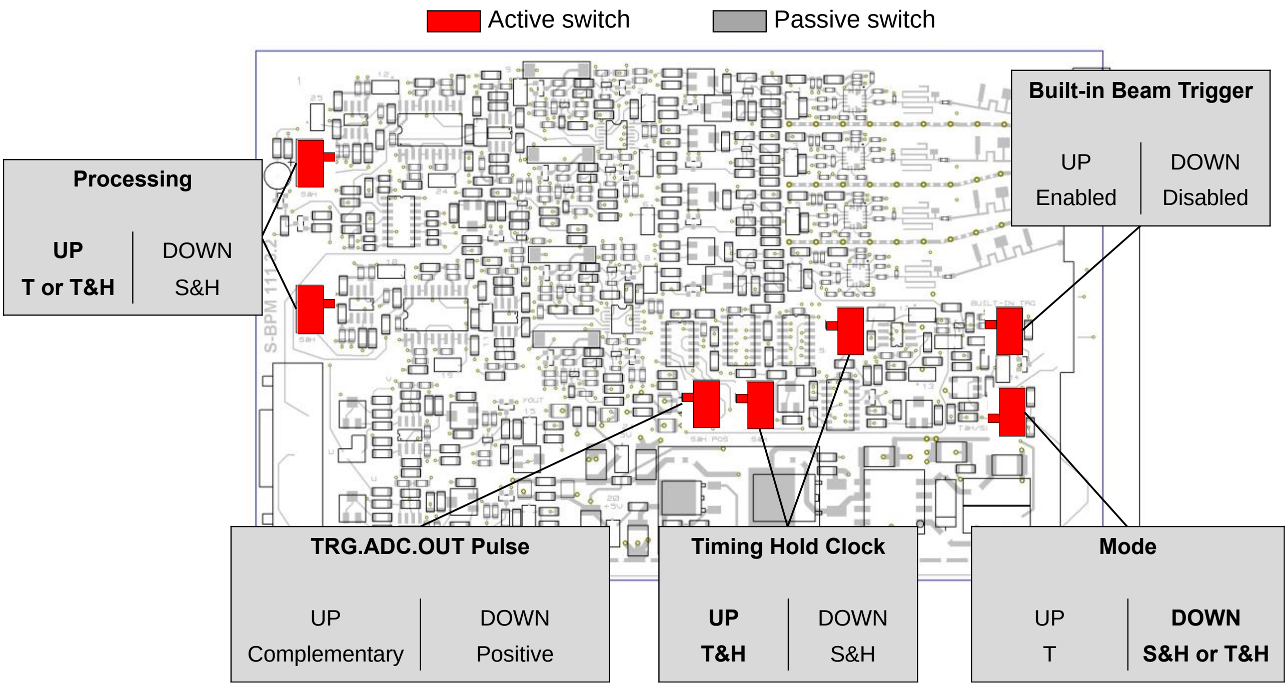
Set switches to: Mode: Track-Continuous (T) => UP
Processing: Track-Continuous (T) => UP
Timing: Inactive
Built-in Beam Trigger: not available in this mode
TRG.ADC.OUT Pulse: not available in this mode




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

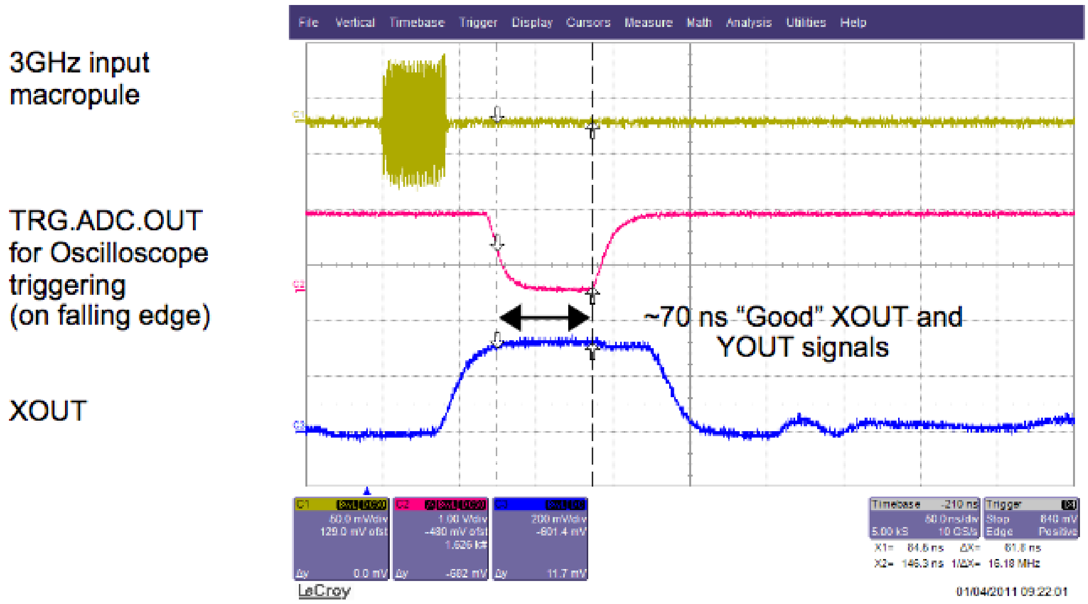
Set switches to: Mode: T&H => DOWN
Processing: T&H => UP
Timing Hold Clock: T&H => UP
Timing Trigger: Inhibition Trigger to avoid bad trigger during processing. 200ns in T&H mode => UP
Built-in Beam Trigger as desired. Disable for external trigger.
ADC Trigger Output Pulse as desired




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.

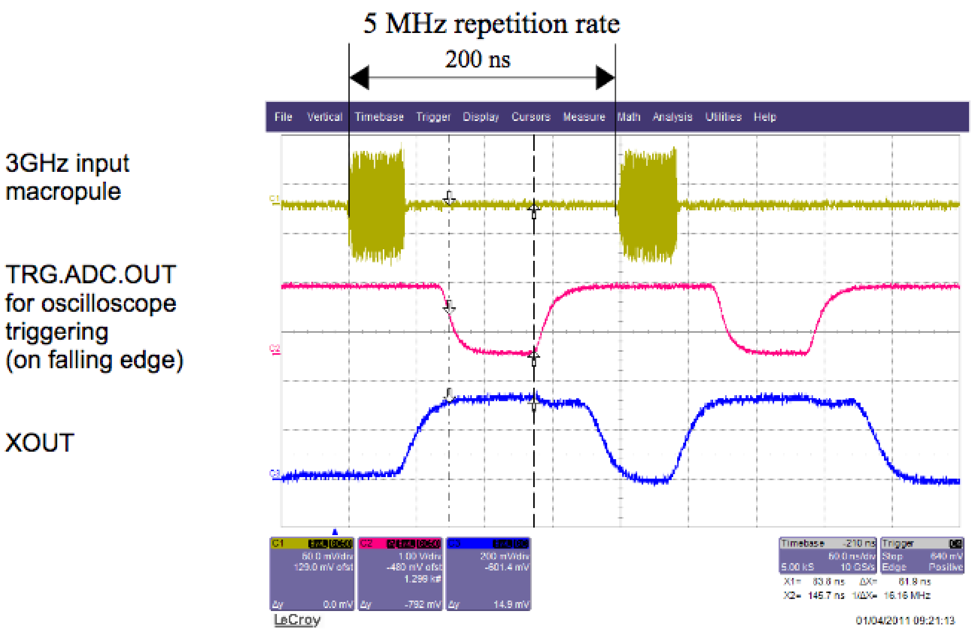
In Track & Hold Mode, the output signals timing looks like this:




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.

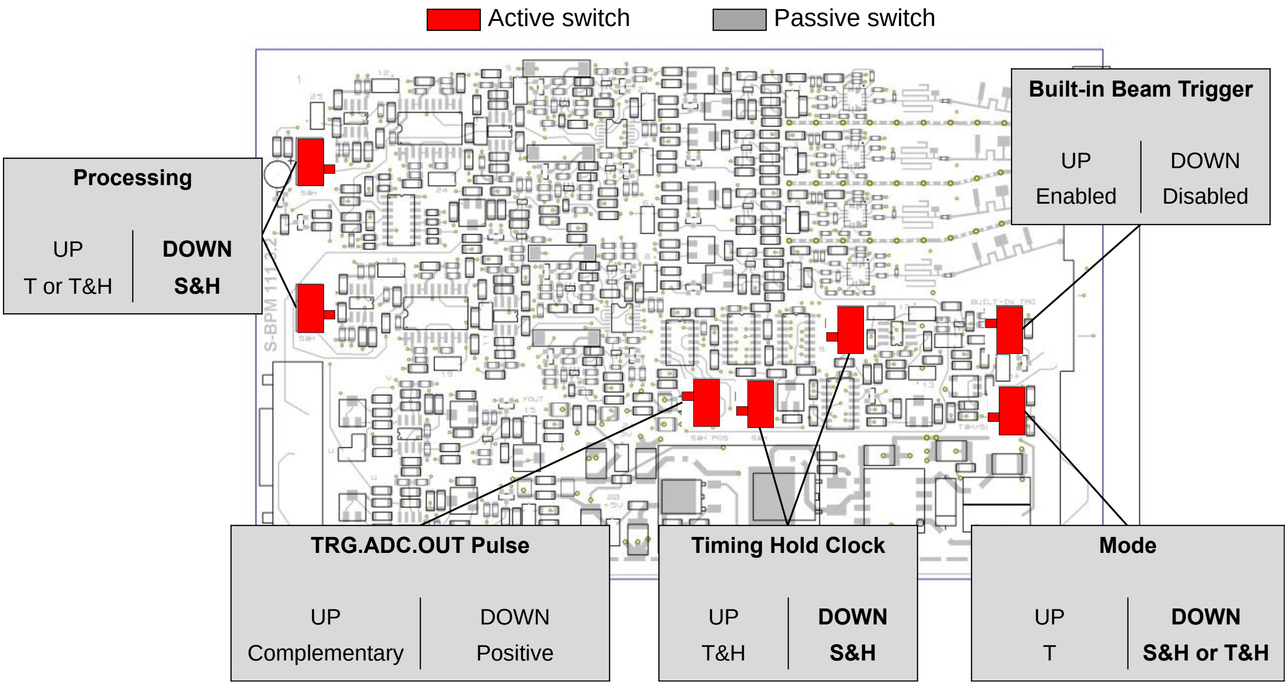
With 5MHz macropulse repetition rate, the output signals look like below:



## SAMPLE & HOLD MODE

Set switches to:

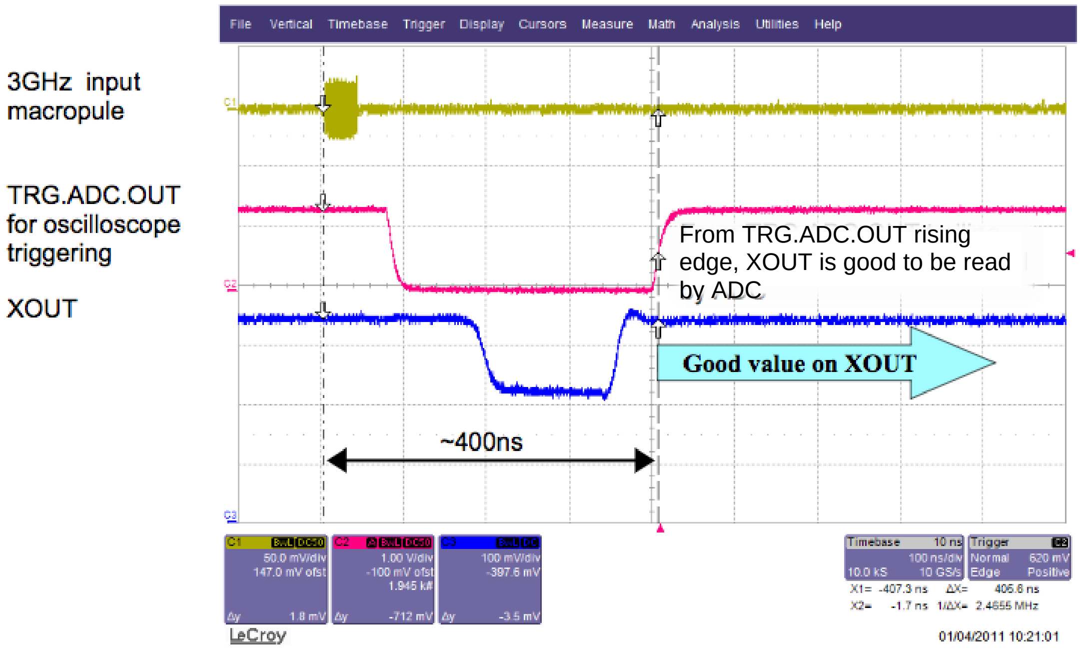
Mode: Sample&Hold => DOWN
Processing: Sample&Hold => DOWN
Timing Hold Clock: Sample&Hold => DOWN
Timing Trigger: Inhibition Trigger to avoid bad trigger during processing. 200µs in S&H mode => DOWN
Built-in Beam Trigger: As desired
ADC Trigger Output Edge: As desired




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.

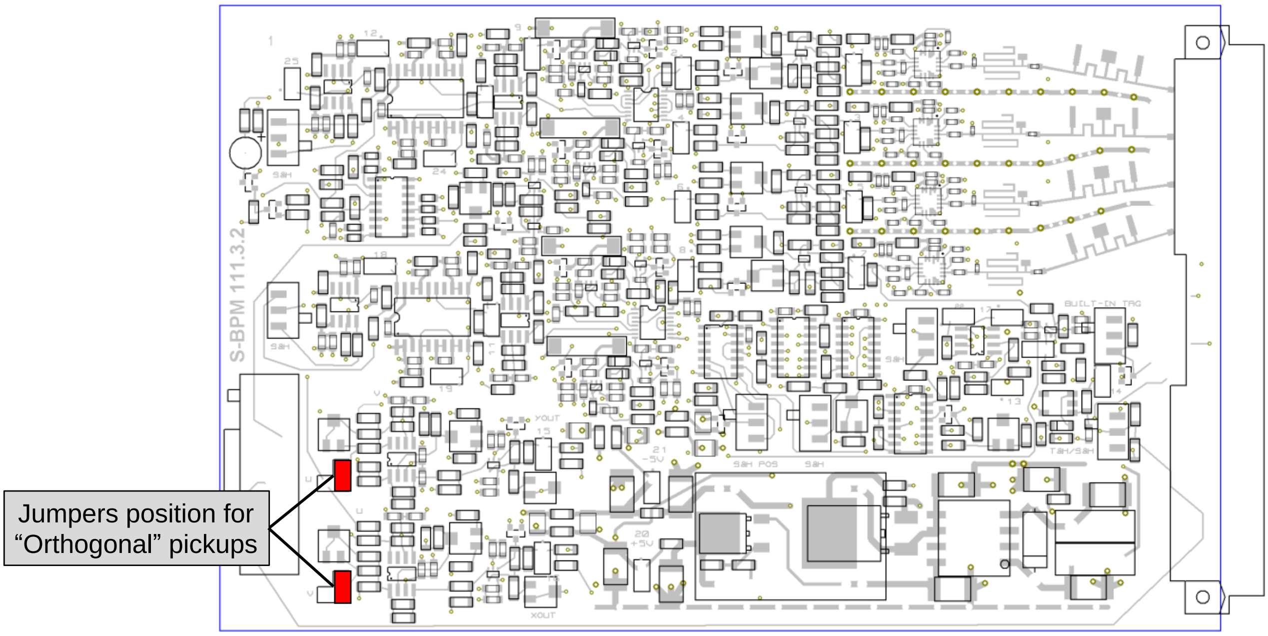
XOUT (and YOUT) are good to read by ADC at the time of TRG.ADC.OUT rising edge.
Note that TRG.ADC.OUT shape can be changed. See TRG.ADC.OUT description p.10.

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**

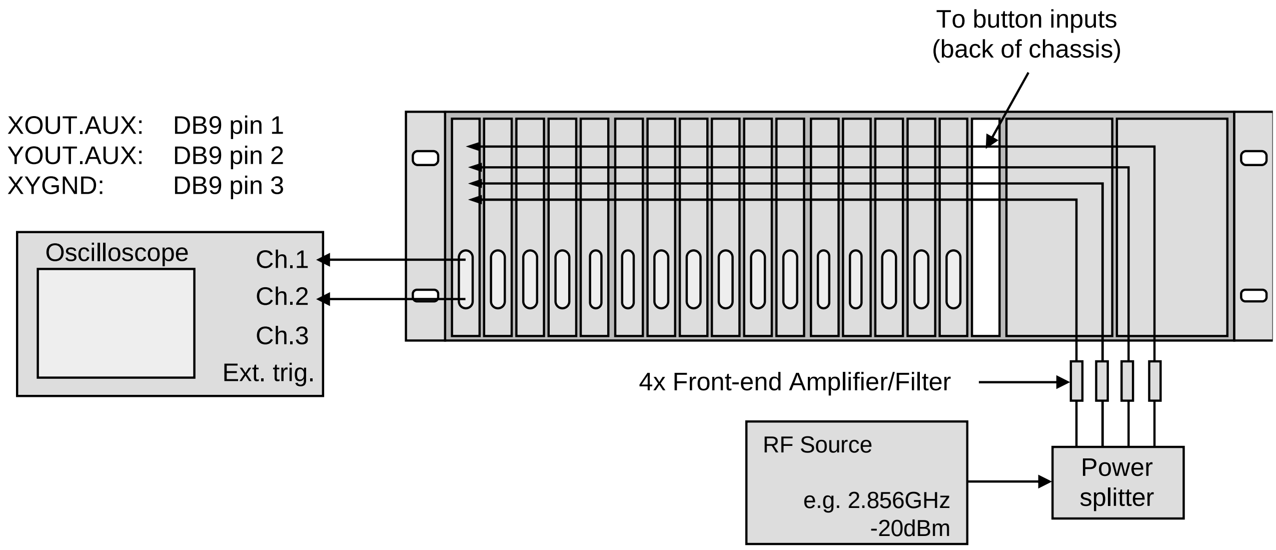
Track-Continuous mode can be used on CW beam or macropulse (burst) mode. A Quick Check is described for both modes, successively.

**For CW beams**

If you wish to use an S-BPM (whether 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.




To display X and Y signals, use an oscilloscope.
Attach the equipment together as shown above.

Oscilloscope setup:

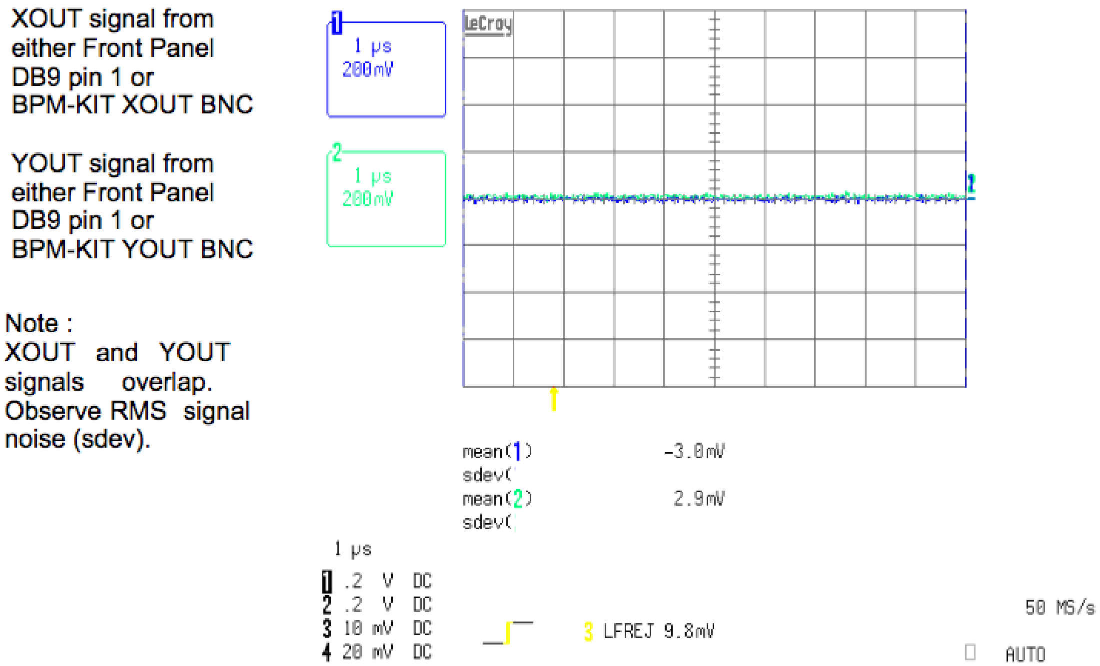
| | | | |
|---|---|---|---|
| Time base | 1 µs/div. | | |
| CH1 | 0.2 V/div. | DC-1 Mohm | XOUT |
| CH2 | 0.2 V/div. | DC-1 Mohm | YOUT |

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.

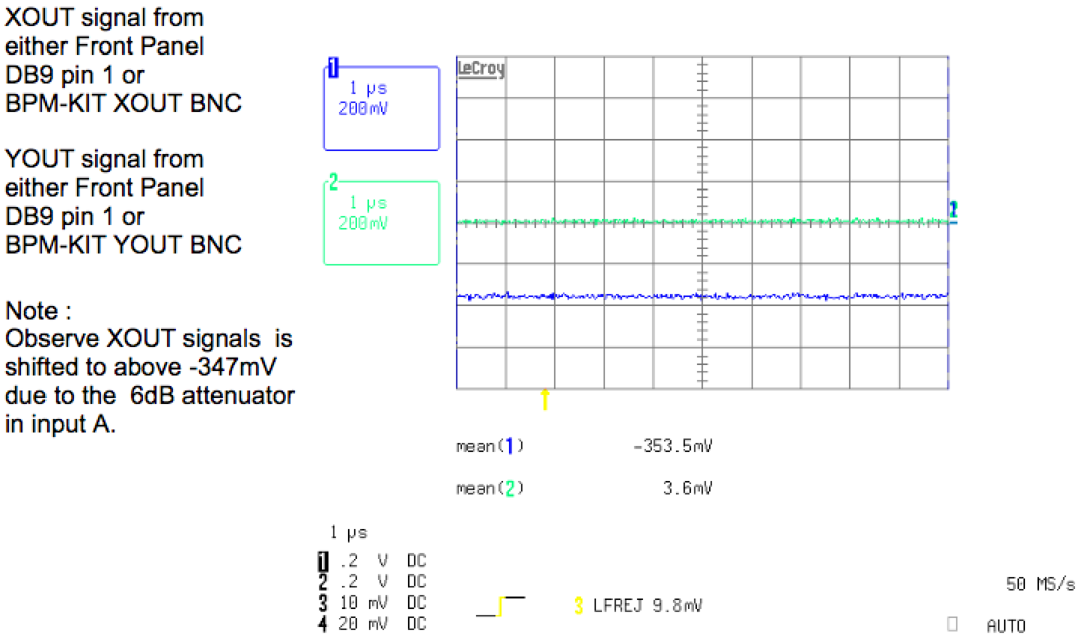



If the RF signals applied to all four S-FEFA inputs were exactly equal, and if the S-FEFA and S-BPM modules were perfect, the XOUT and YOUT voltages would be exactly 0 Volt. This is generally not the case, X and Y will be many 10s of millivolts off.

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

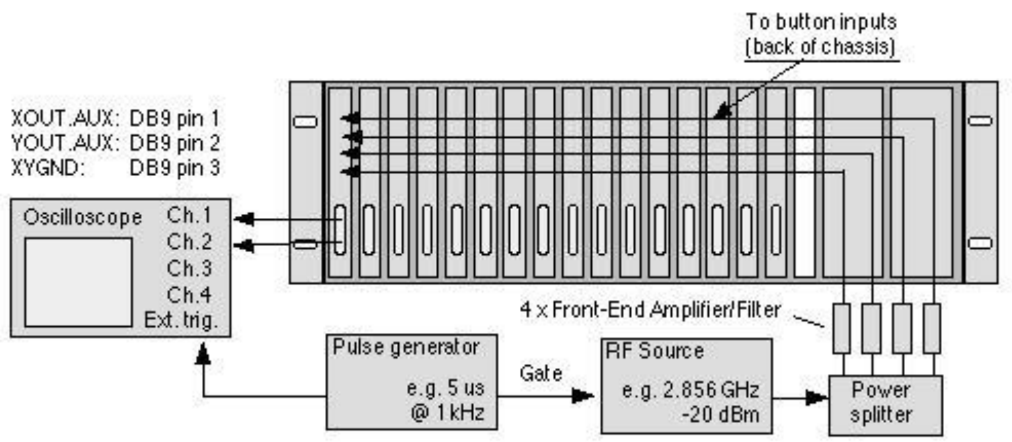



Further tests can be performed:

- 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.




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.

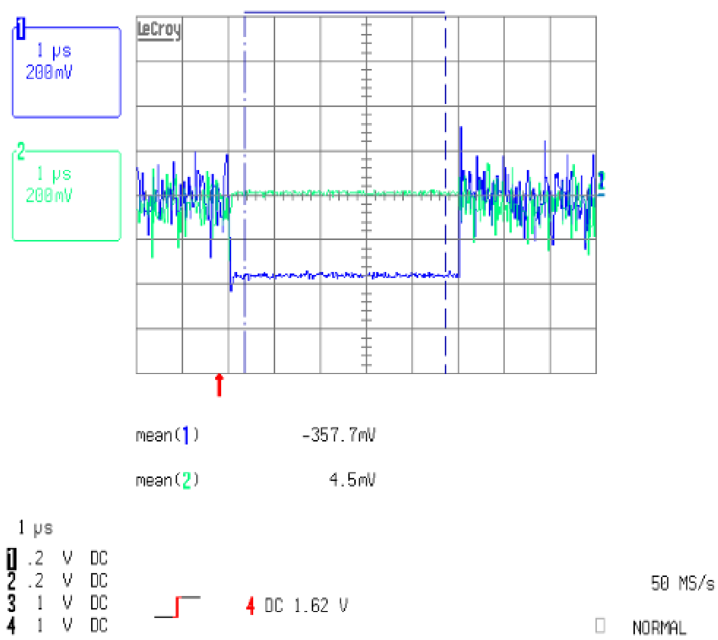
The following screen shot does not show the macropulse. It shows the S-BPM output signals XOUT and YOUT.

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.

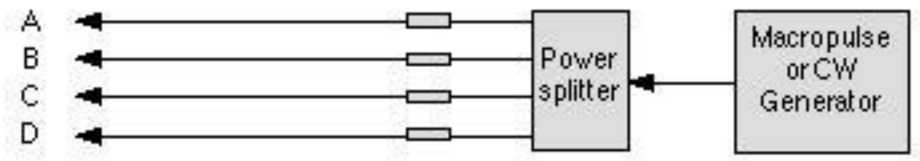


**Simulating beam position changes**

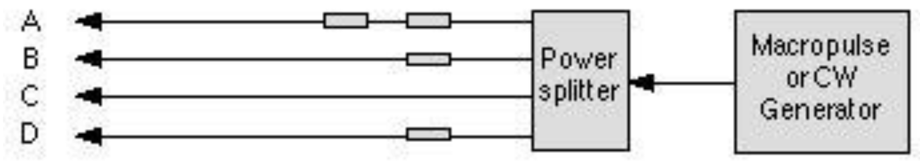
To simulate beam position changes, the input signal power is changed by 6 dB, 10 dB and 14 dB, hence simulating position changes up to 1/3 of BPM pickup radius.

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

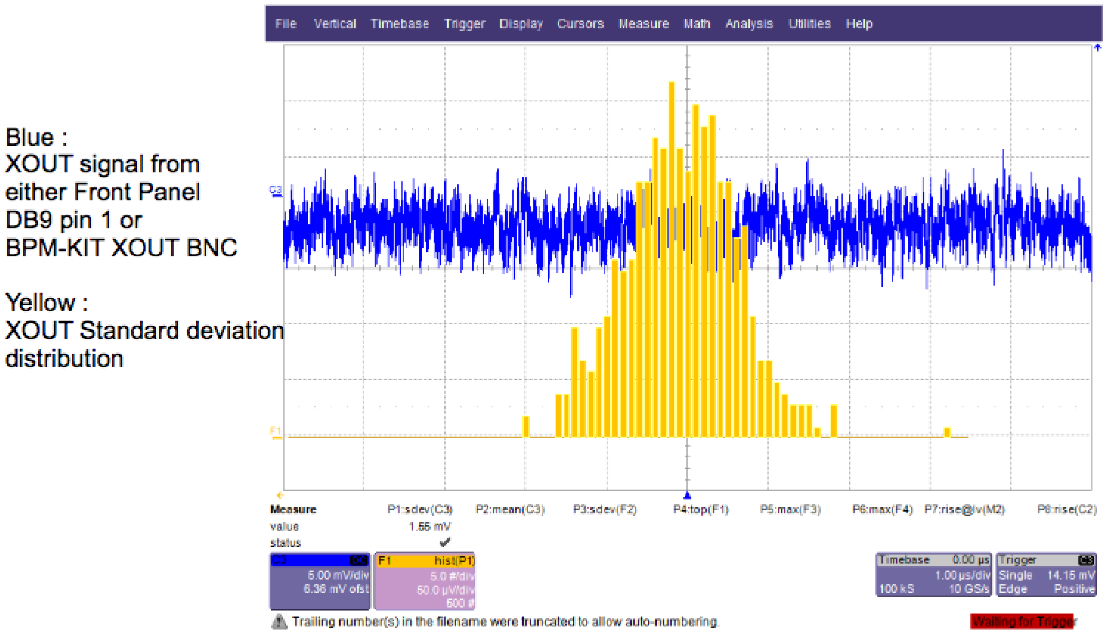
Where: β is the tilt angle of the pickup axes. Refer to AGREEMENT on AXES and SIGNS.

### 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.

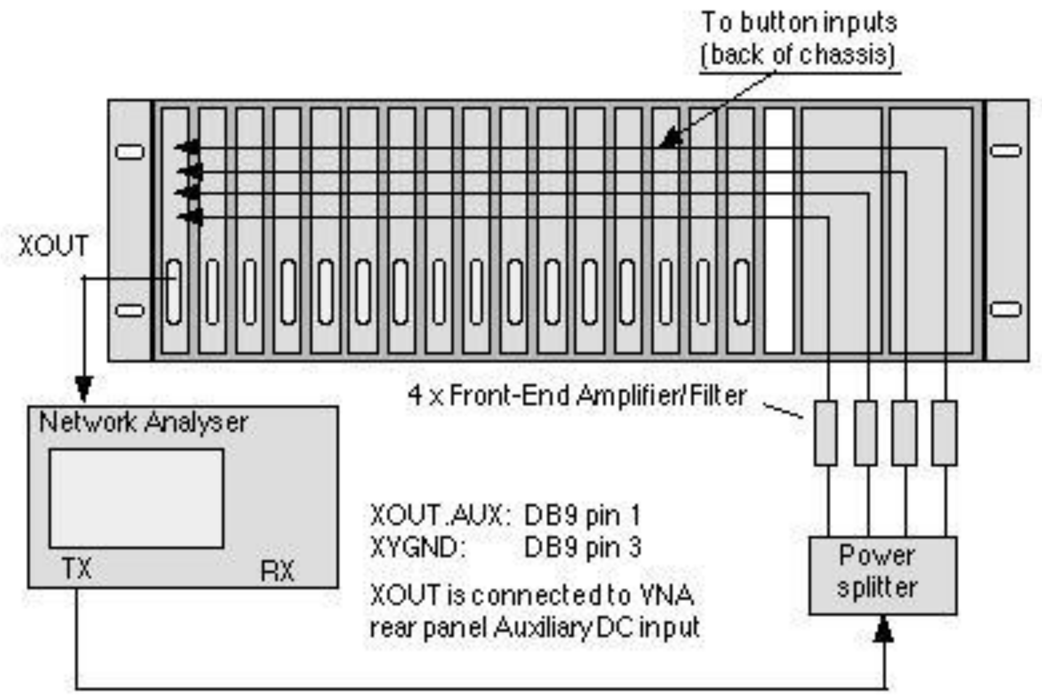
To translate this rms voltage noise in beam position resolution, let's assume a 25mm vacuum chamber radius and pickup electrodes width < vacuum chamber radius. In this case, a beam displacement by 1/6 of the pickup radius equals to 347mV.

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.

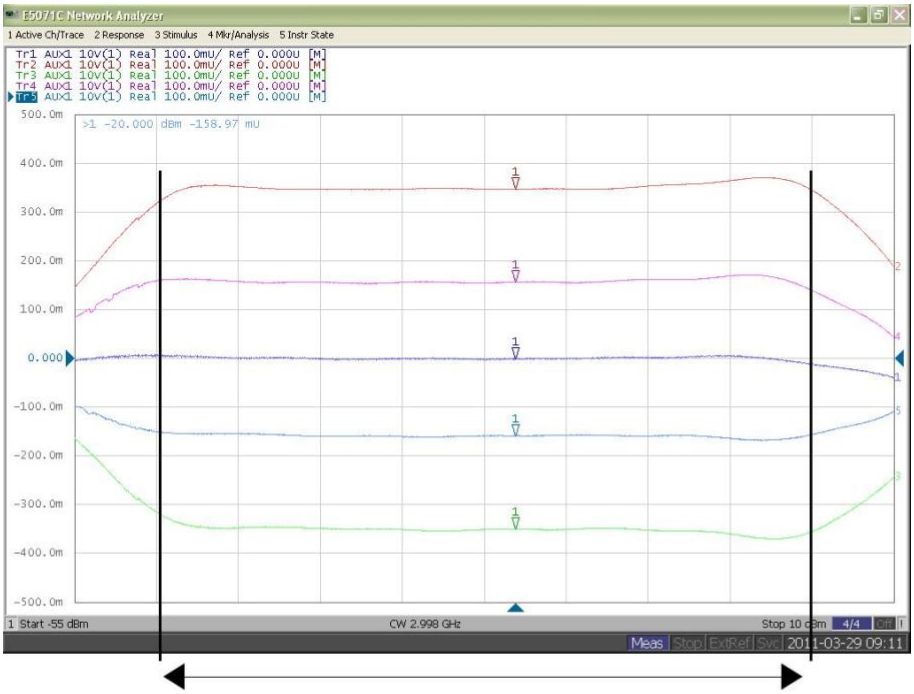
**Setup**




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).

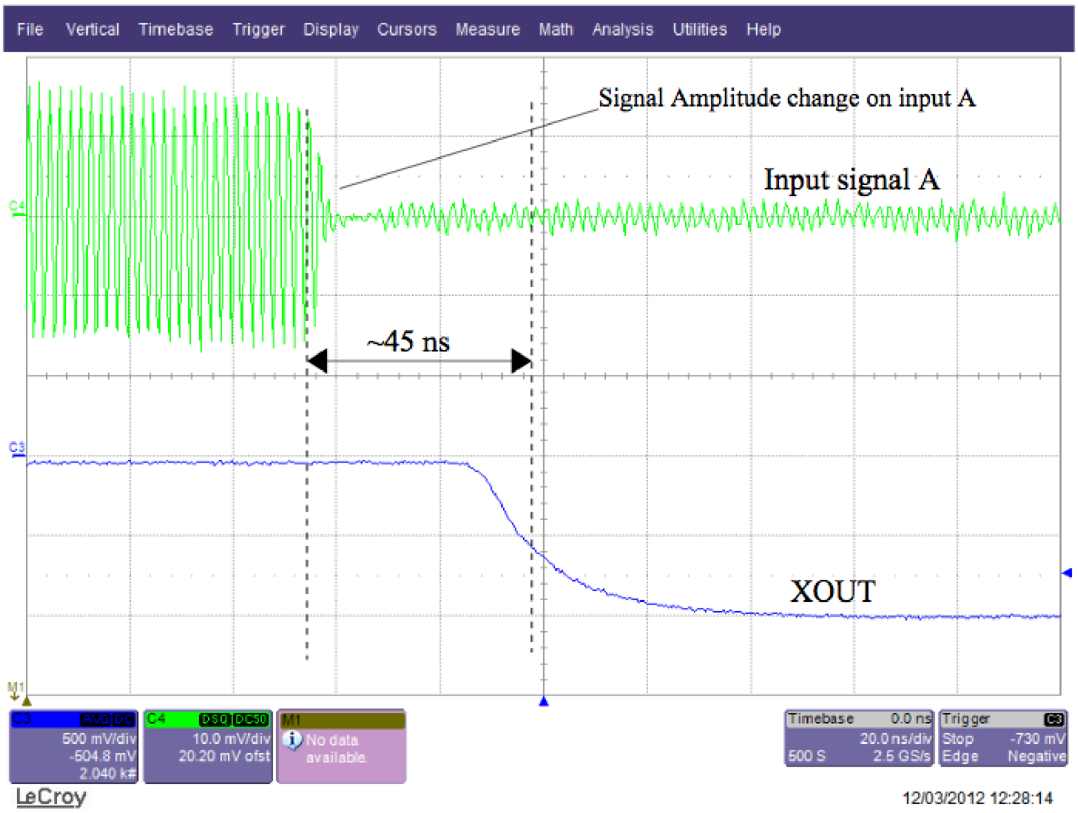
Note: -50 dBm is –approximately– the signal collected by a BPM electrode whose subtending angle is 45 degrees, passed by a 100-uA CW beam. Scale up the beam current lower limit if the electrode subtending angle is smaller.

**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:

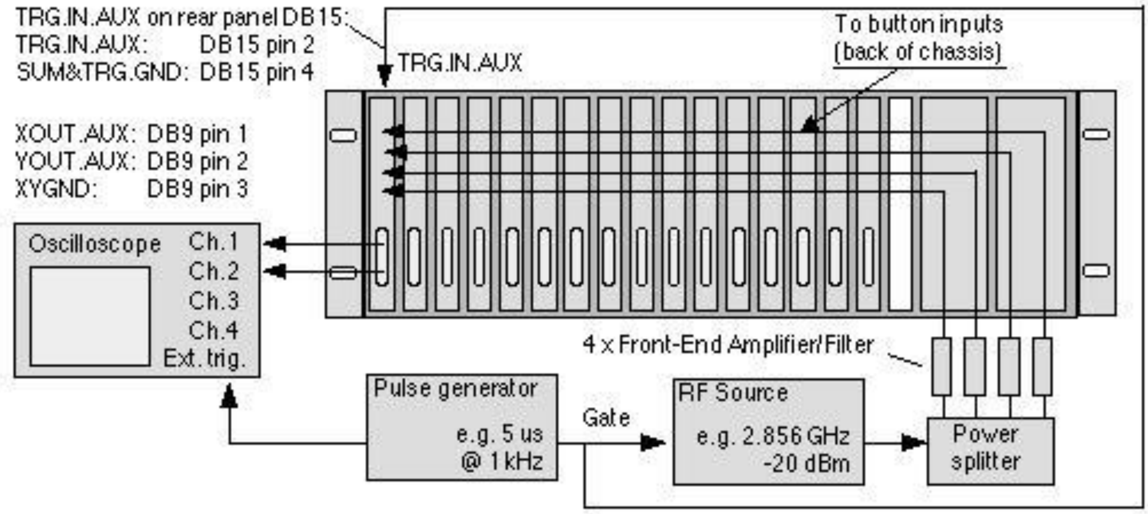
- Orthogonal pickups
- Built-in Beam Trigger
- Mode, Timing and Processing: S&H
- Built-in trigger: Disabled
- ADC Trigger output: Complementary.

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.




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

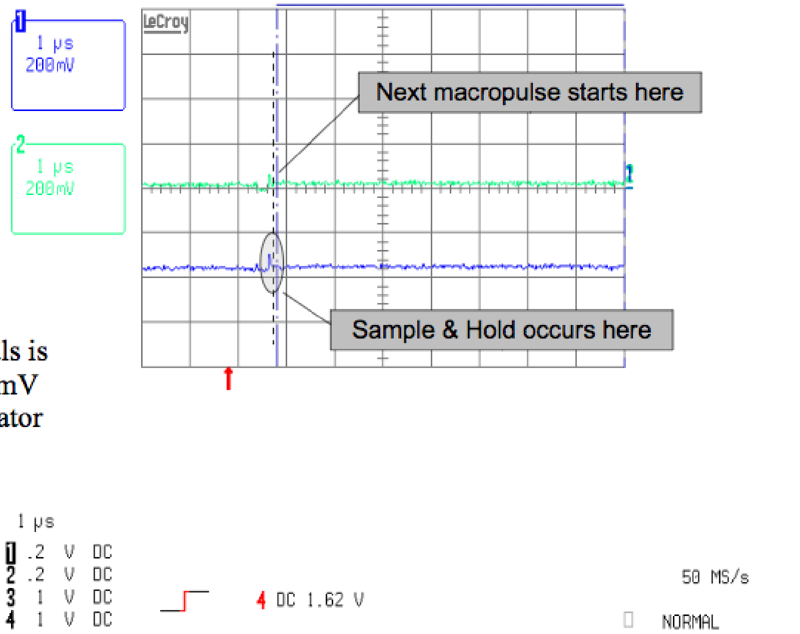
Note: Some oscilloscopes External trigger delay is not long enough to view the signal on the oscilloscope screen. When that is the case, add a cable delay line to delay the “Gate” of the RF source until the gated pulse is in the screen.

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

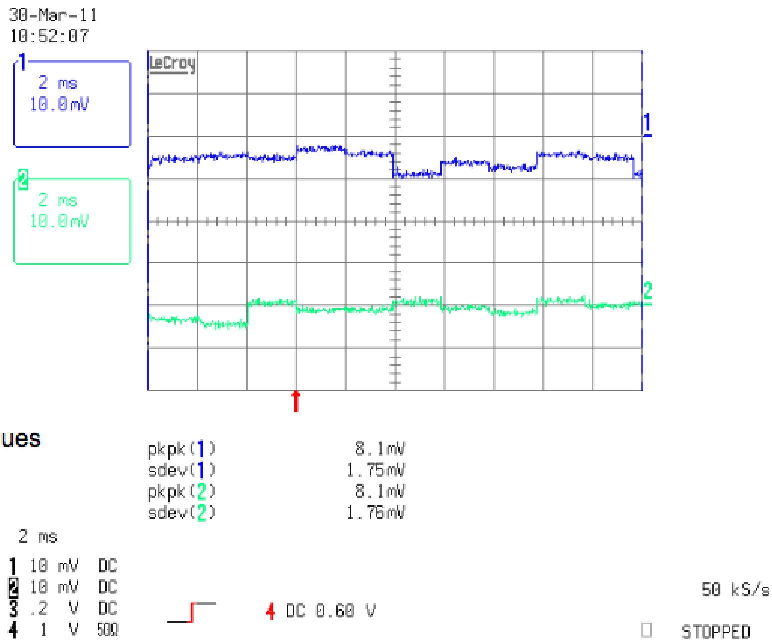
Note :
Observe XOUT signals is shifted to above -347mV due to the 6dB attenuator in input A.




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:

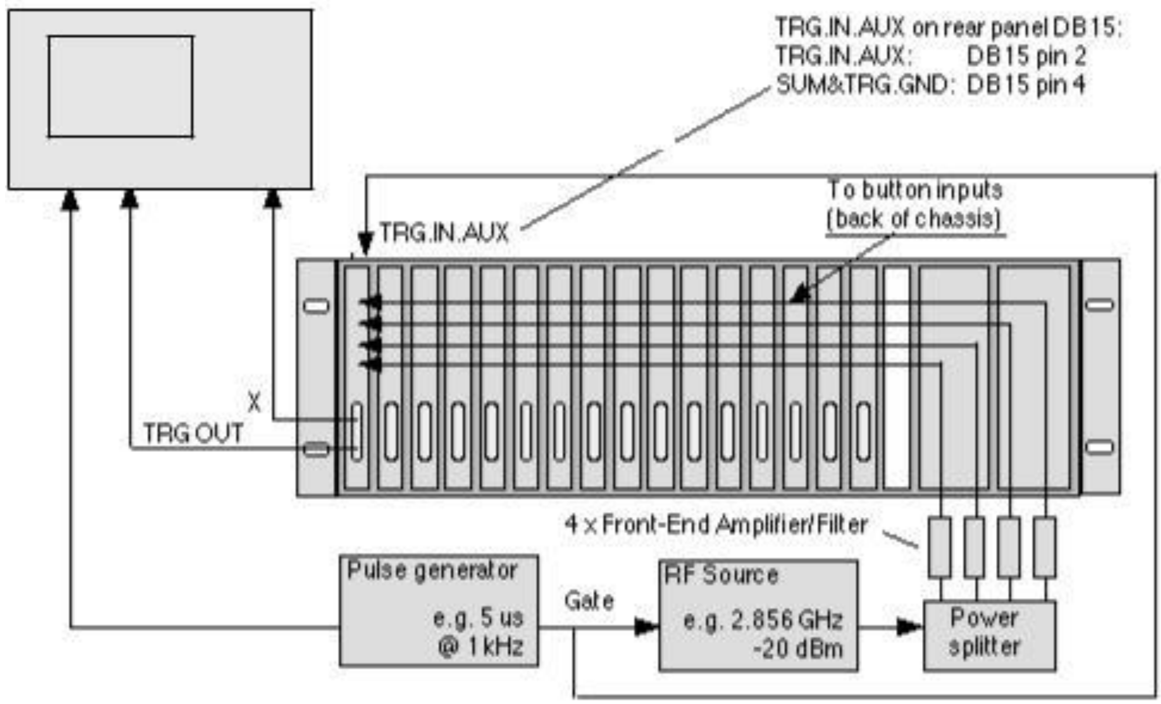
The pkpk() value is the macropulse-to-macropulse S-BPM peak-peak noise
The sdev() value is the macropulse-to-macropulse S-BPM rms noise or resolution.

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**




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

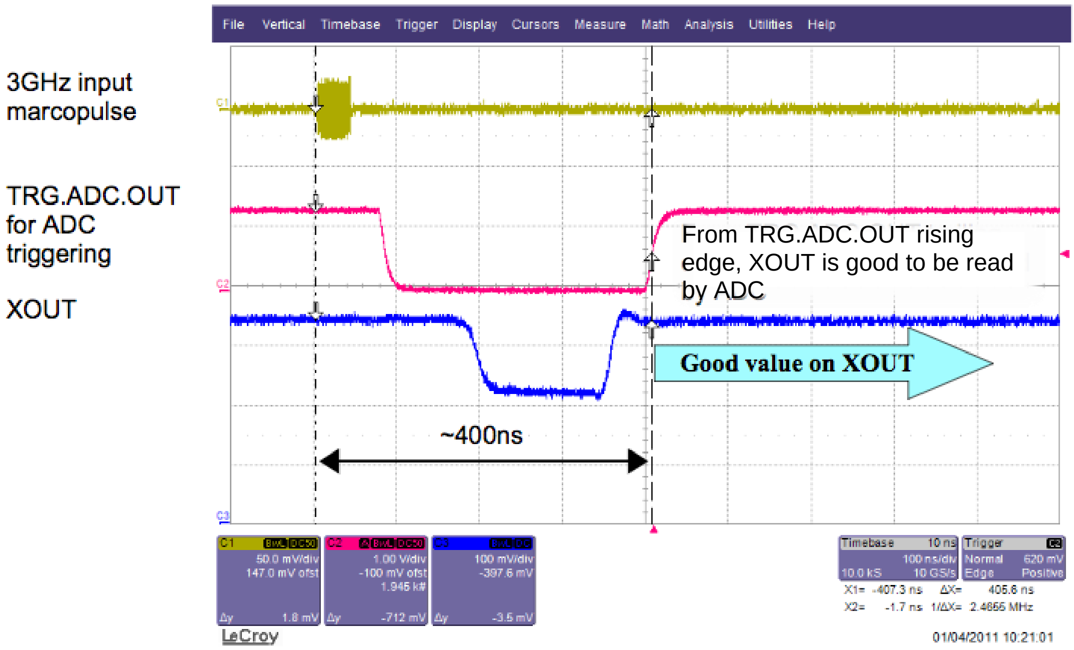
Observe the relative timing of
- CH1: input macropulse.
- CH2: output trigger TRG.ADC.OUT for the ADC on rear panel DB15 or front panel DB9 pin 9.
- CH3: X output XOUT.

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)



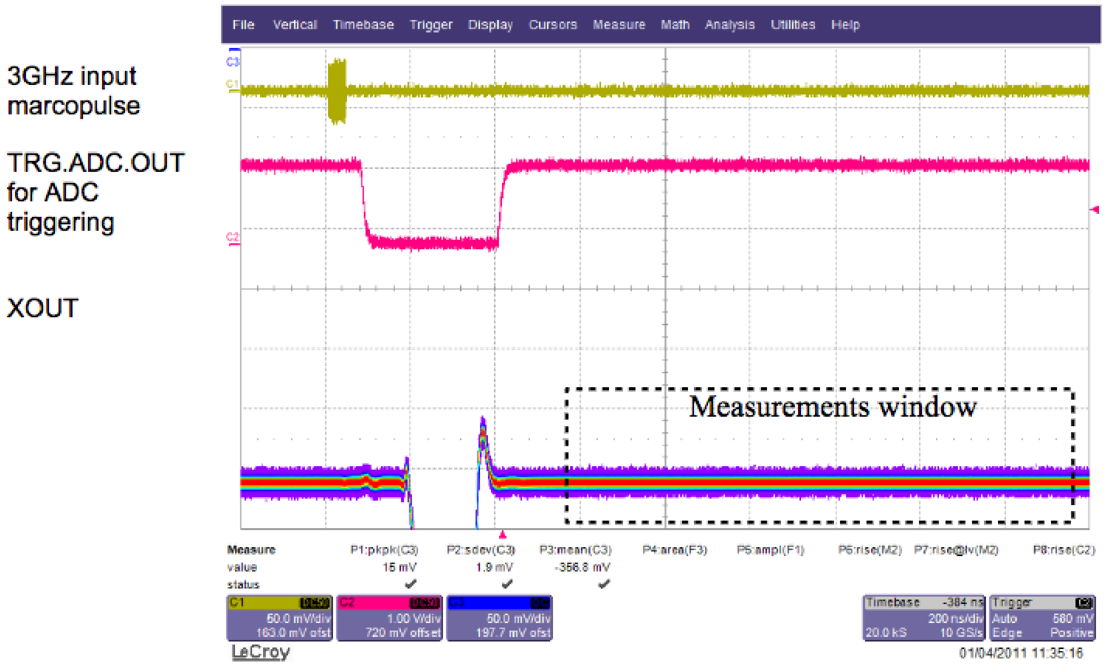

Rising edge of TRG.ADC.OUT occurs about 400ns after TRG.IN.AUX was applied to S-BPM.

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.

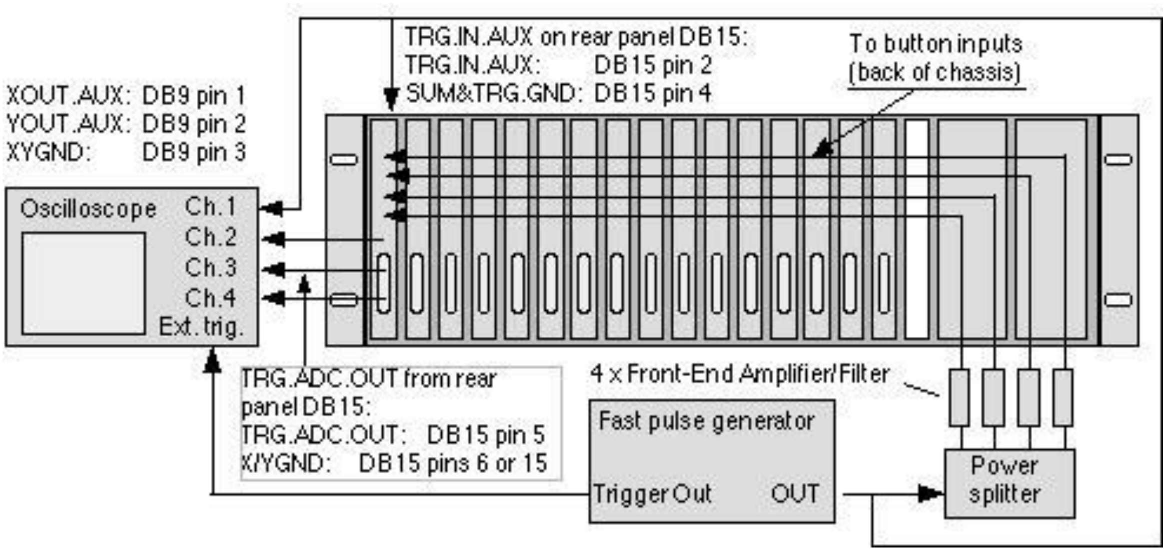
**For single pulse beam**

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.




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.

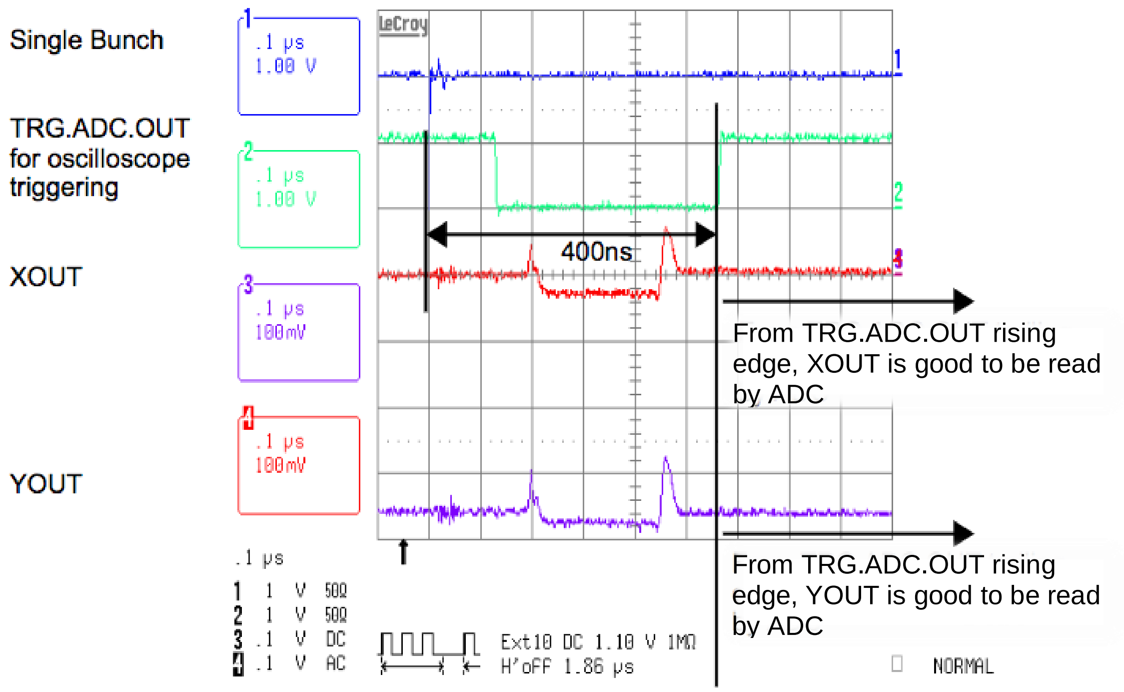
This 50V pulse, after splitting in an inductive-type 4-way splitter (-7 dB) is about equivalent to a 500-pC bunch seen by four pickups of 5 pf capacitance and subtending angle = 45 degrees.

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.



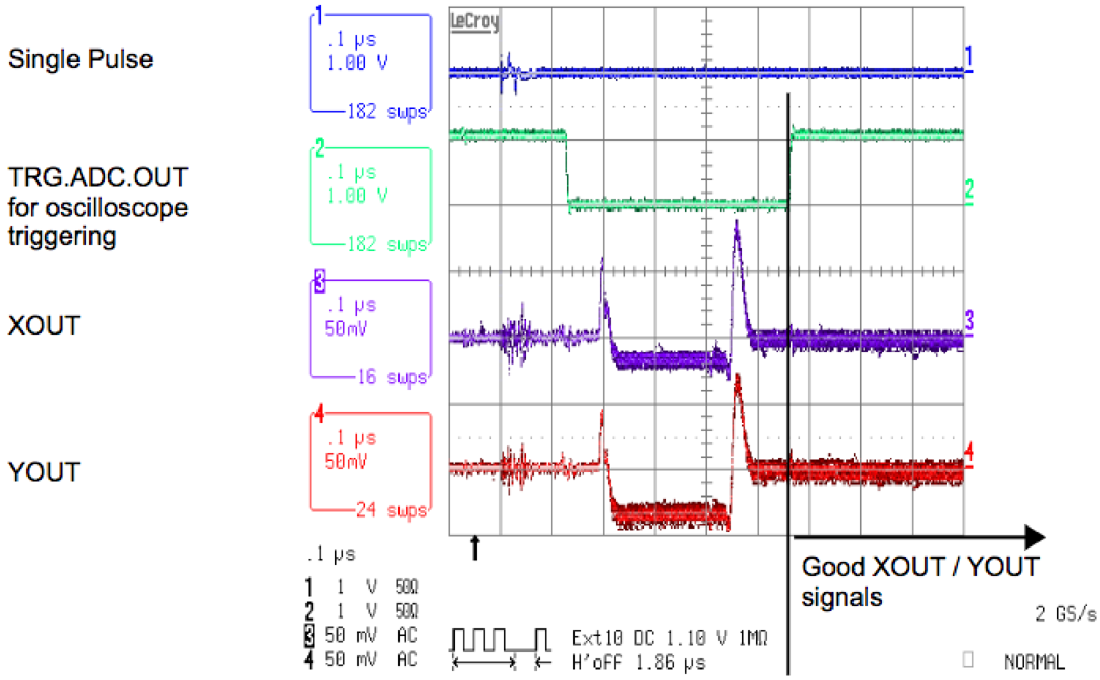

Rising edge of TRG.ADC.OUT occurs about 400ns from the time when TRG.IN.AUX was applied to S-BPM.

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.

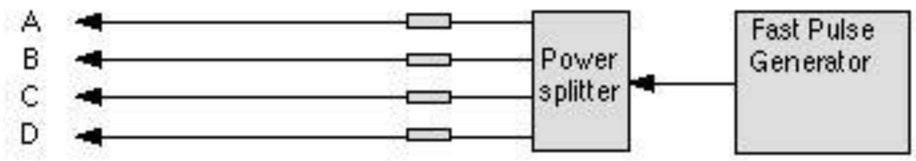
**Simulating beam position changes**

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.

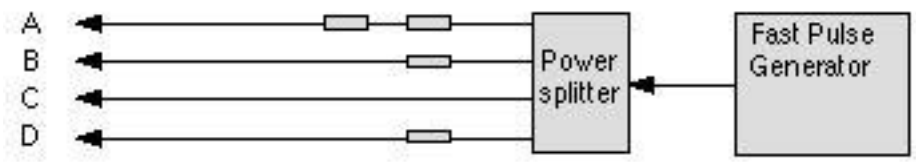
If an inductive-type 4-way splitter is used, the pulse generator output amplitude should be about 50V with risetime < 160ps. If a resistive-type pickup is used, 100V is required.

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

### Output signals for ADC

| | |
|---|---|
| XOUT | X displacement. Bipolar signal up to ±2V<br>(0 Volt represents pickup center)<br>Output impedance: 100 Ω |
| YOUT | Y displacement. Bipolar signal up to ±2V<br>(0 Volt represents pickup center)<br>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<br>Signal range 0...+2V<br>Output impedance: 100 Ω |
| TRG.ADC.OUT | Trigger for external ADC<br>TTL pos./comp. Pulse<br>(See QUICK CHECK: Sample&Hold Mode -and- Track&Hold Mode)<br>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<br>(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<br>50 Ω, positive edge > 0.4 V |
| TRG.GATE | Input for gating the beam trigger<br>TTL, High-Low-High<br>High state inhibits Built-in Beam Trigger<br>Low state (default state) allows Built-in Beam Trigger. |
| SUM&TRG.GND | Ground for TRG.IN.AUX -and- TRG.GATE. |

**External Controls**

| | |
|---|---|
| TRACK.CONTINUOUS | TTL signal. To set Track-Continuous mode.<br>High state (default) sets Track&Hold mode.<br>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

| Function | Signal | 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 |
| **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.

## 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<br>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<br>Model 75 SX 15-15 |

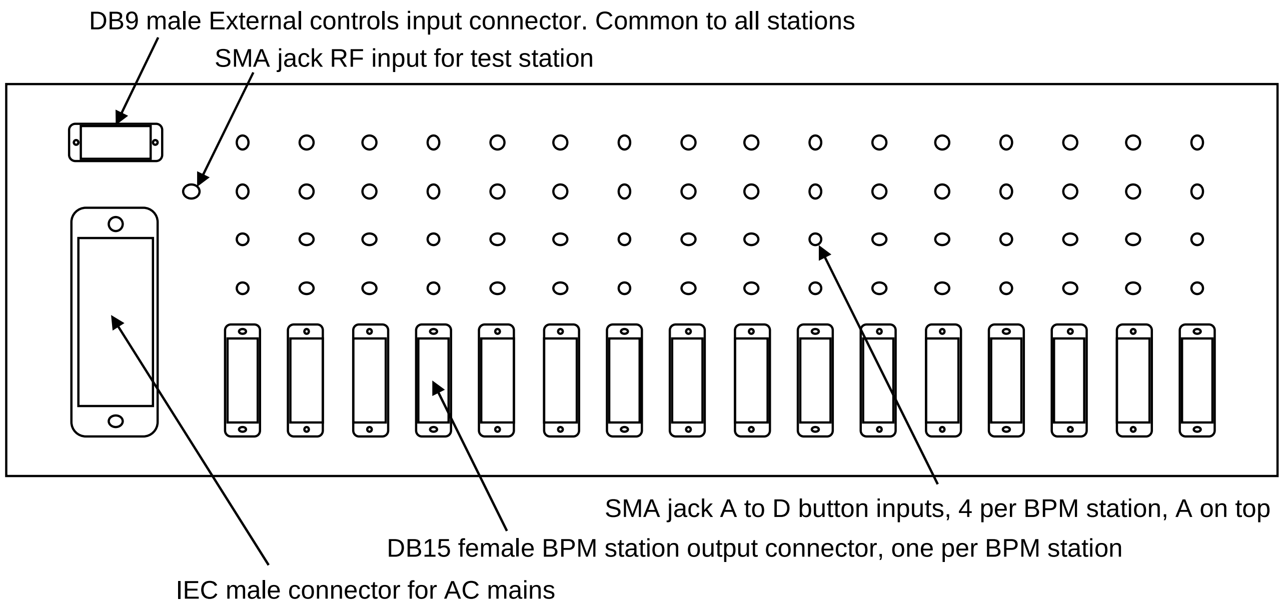
**BPM Chassis BPM-RFC/X**

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

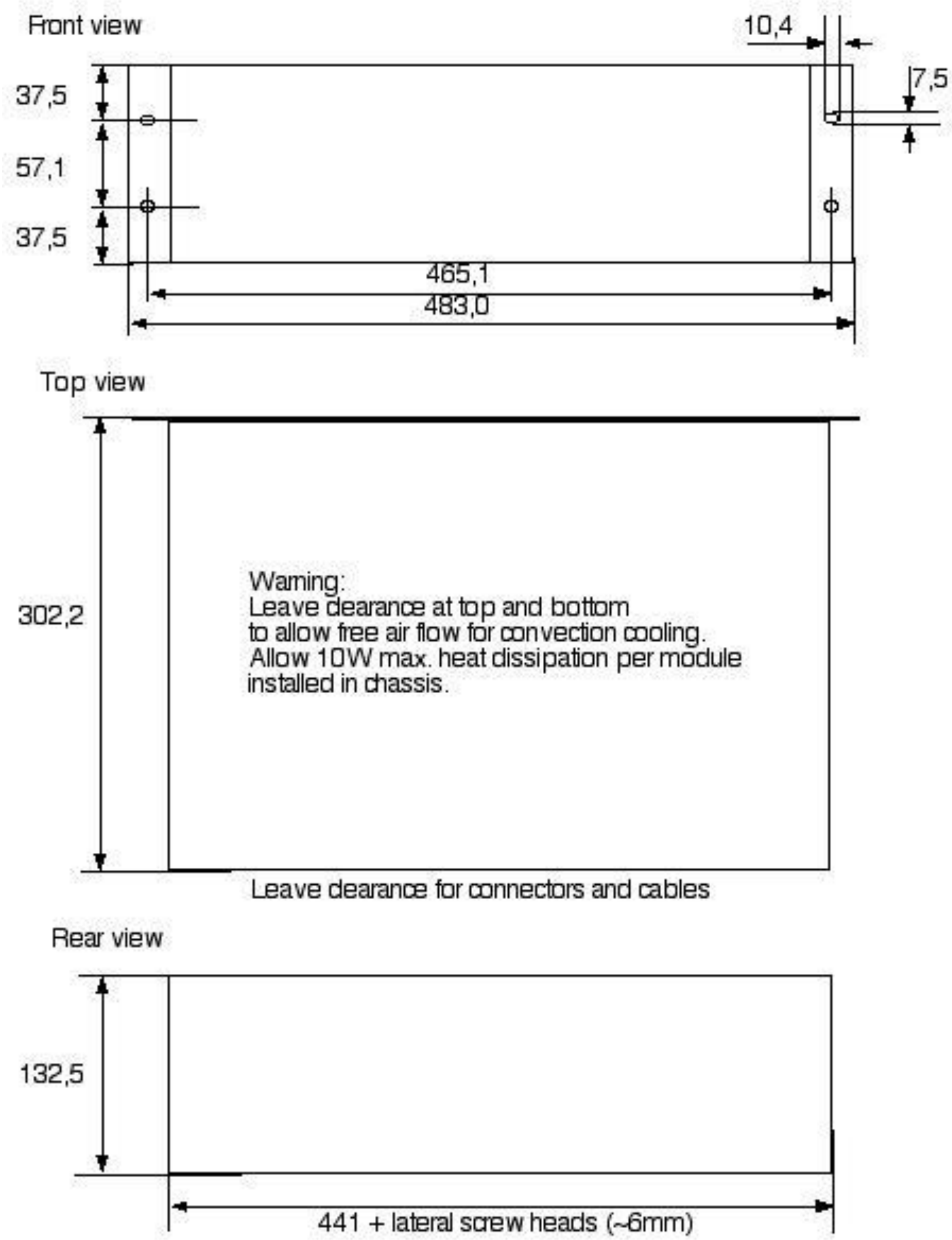
The BPM-RFC/X is available equipped for 1 up to 16 BPM stations. X being the number of stations.

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**



More information and latest manuals revisions can be found on our website

**www.bergoz.com**

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