BPM blocks offset calibration using Lamberson method

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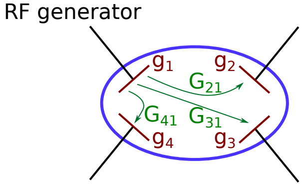
Outline

The Lambertson method



$$\frac{V_i}{V_j} = 2 \cdot 50 \cdot G_{ij} g_i g_j$$

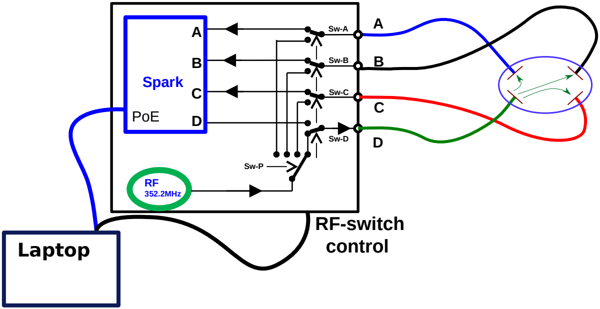
- V_i is the voltage at the button
- g_i is the gain (or sensitivity) associated with the button
- G_{ij} is the capacity coupling coefficient

Reference:

[1] *Calibration of position electrodes using external measurements* GR Lambertson - LSAP Note-5, Lawrence Berkeley Laboratory, 1987

The Lambertson method

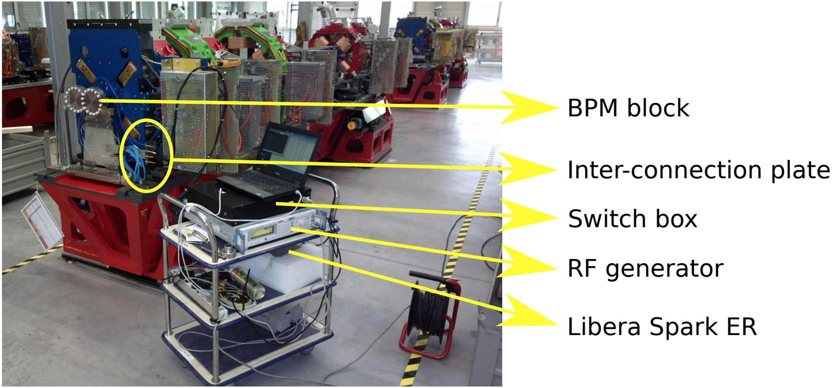
An home-made measurement setup:



- Stand-alone setup on a trolley (to go inside the tunnel).
- Automatically switches RF source on all 4 buttons.
- Measures the 3 others.

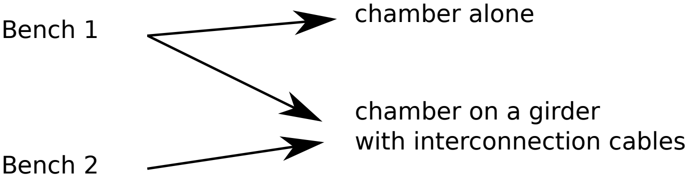
The Lambertson method

Measurement of all BPM blocks (c.f. DEELS2018 presentation Link)



Measurements and analysis

Up to now we have performed 1416 measurements (some were performed multiple times to test reproducibility).



Each measurement is associated with multiple parameters:

- Bench used
- Inter-connection cables present or not
- Length of inter-connection cables (short of long)
- BPM position in the cell
- BPM geometry (big or small)
- Chamber number
- Chamber ID

Measurements and analysis

A powerful tool for data analysis was necessary:
Python + Pandas + Jupyter was a perfect solution!

In [51]:
```
alldata[alldata.ch_id == 'SR0112']
```

Out[51]:

	ch	ch_b	ch_id	datetime	meas	meas_on	bench	bpm	bpm_cell	bpm_geo	cable_length	0	1	
199	11	1	SR0112	2018-01-25 11:26:59	[[-0.6171674472892974, 0.1452740323208026, 0.1...	chamber	aloha	7	6	b	l	-0.000513	0.186444	0.15937
200	11	1	SR0112	2018-01-25 11:27:08	[[-0.6181674472892951, 0.14127403232080127, 0....	chamber	aloha	7	6	b	l	-0.005769	0.187198	0.15912
201	11	2	SR0112	2018-01-25 11:35:42	[[-0.7381674472892925, -0.16972596767919867, -...	chamber	aloha	8	6	b	l	-0.158011	-0.023585	-0.13183
202	11	2	SR0112	2018-01-25 11:35:50	[[-0.7351674472892924, -0.17172596767919757, -...	chamber	aloha	8	6	b	l	-0.156344	-0.029674	-0.12742
302	11	1	SR0112	2018-03-06 16:02:30	[[-0.7026079267037701, 0.11826369093466127, 0....	girder	aloha	7	6	b	l	-0.042220	0.126583	0.05141
303	11	1	SR0112	2018-03-06 16:02:37	[[-0.7036079267037749, 0.1342636909346595, 0.0...	girder	aloha	7	6	b	l	-0.040112	0.129453	0.05196
304	11	2	SR0112	2018-03-06 16:04:43	[[-0.6856079267037742, -0.3627363090653404, -0...	girder	aloha	8	6	b	l	-0.283932	-0.036198	-0.23215
305	11	2	SR0112	2018-03-06 16:04:49	[[-0.6836079267037718, -0.37973630906533984, -...	girder	aloha	8	6	b	l	-0.283603	-0.045101	-0.21609
1241	11	1	SR0112	2019-04-17 09:40:41	[[0.07867359249451056, 0.2170397704654583, 0.2...	tunnel	bonsai	7	6	b	l	0.054158	0.174700	0.18358
1242	11	2	SR0112	2019-04-17 09:47:58	[[-0.00016820501434722246, -0.1525316524165028...	tunnel	bonsai	8	6	b	l	-0.144123	0.007876	-0.05498
1250	11	1	SR0112	2019-04-17 10:26:06	[[-0.13131922131125862, 0.23266628504235243, 0...	tunnel	bonsai	7	6	b	l	0.040884	0.196691	0.19848

Figure: A screenshot of the Jupyter notebook for data analysis

Outline

The Lambertson method

Averages over many measurements (“big” geometry):

$$\mathbf{M} = \begin{pmatrix} -65\,\text{dBm} & -91.8\,\text{dBm} & -93.0\,\text{dBm} & -70.1\,\text{dBm} \\ -91.9\,\text{dBm} & -65\,\text{dBm} & -70.2\,\text{dBm} & -93.2\,\text{dBm} \\ -93.4\,\text{dBm} & -70.1\,\text{dBm} & -65\,\text{dBm} & -91.1\,\text{dBm} \\ -70.2\,\text{dBm} & -93.2\,\text{dBm} & -91.1\,\text{dBm} & -65\,\text{dBm} \end{pmatrix}$$

- row i: button i is used as emitter.
- Diagonal elements m_{ii} are proportional to RF generator's output power.
- This matrix should be symmetrical (theory), but is not despite calibration.
- Spark noise floor is ≈ 105 dBm. Some measurements are only 11 dB above noise floor.

The Lambertson method

Our implementation of the Lambertson method:
Normalise with RF generator's output power (to compensate for drifts):

$$m_{ij} \leftarrow m_{ij} - m_{ii}$$

Then remove the average for each element m_{ij}:

$$m_{ij} \leftarrow m_{ij} - \langle m_{ij} \rangle$$

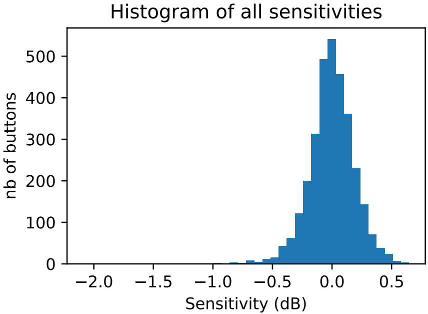
and compute buttons' sensitivity:

$$g_i = \left\langle \sqrt{\frac{m_{ni} m_{mi}}{m_{mn}}} \right\rangle \quad \text{for } (\mathrm{m} \neq \mathrm{i}), (\mathrm{n} \neq \mathrm{i}) \text{ and } (\mathrm{m} \neq \mathrm{n})$$

We get one value g_i for each button (what I call "sensitivity" of the button).
The g's are such that $m_{ij} = g_i g_j$.

Sensitivities

Combining all measurements, we get this graph:

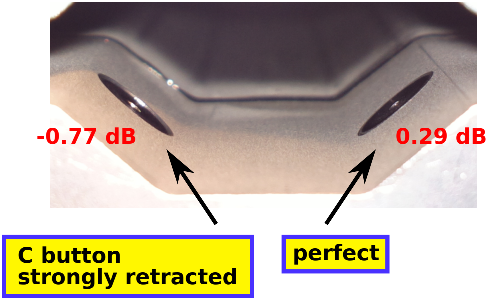


$\sigma = 0.2\,\mathrm{dB}$

Are we sure the dispersion of the results comes from BPM blocks, and not the measurement setup?

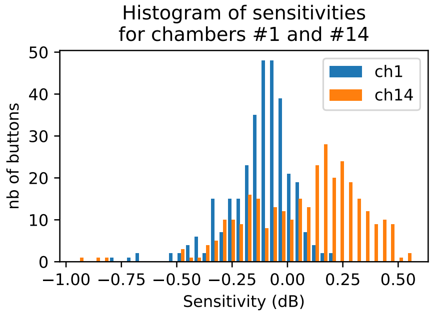
Sensitivities

Using measured sensitivities, we were able to find “black sheep” among BPM blocks. For instance, this BPM block with a retracted button:



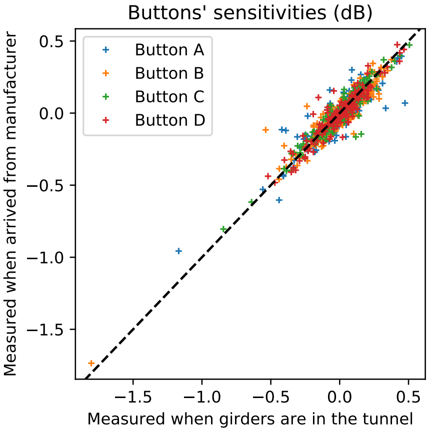
Sensitivities

Chamber #1 and #14 are very similar (from a mechanical point of view), but they are made by two different manufacturers.



Sensitivities

Combining the results from the 2 different measurement campains (≠ benches, ≠ bench operator, ≠ chamber configuration: naked chamber vs. chamber in the tunnel with interconnection cables):



One point on this graph is one button

→ clear correlation between the two measurements

Outline

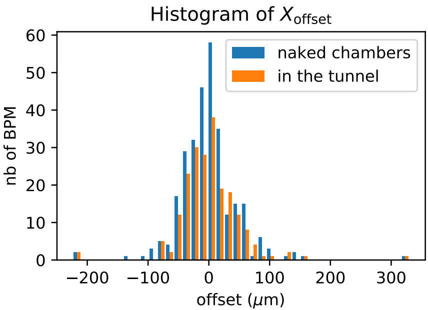
The Lambertson method

From the g's, we can calculate the offset for a centred beam:

$$
\begin{aligned}
X_{\mathrm{offset}} &= k_X \frac{g_A - g_B - g_C + g_D}{g_A + g_B + g_C + g_D} \\
Y_{\mathrm{offset}} &= \ldots \\
Q_{\mathrm{offset}} &= \ldots
\end{aligned}
$$

Sensitivities

Taking independently data from two measurement campaigns, we get the same histogram:

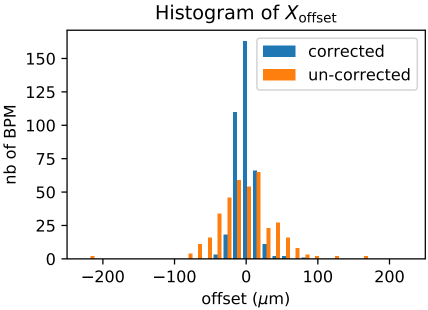


$$\sigma_{\text{chamber}} = 48.3\,\mu\text{m}$$
$$\sigma_{\text{tunnel}} = 49.1\,\mu\text{m}$$

But are individual values the same?

Sensitivities

Now, using one measurement campaign to correct the offset measured during the second campaign:

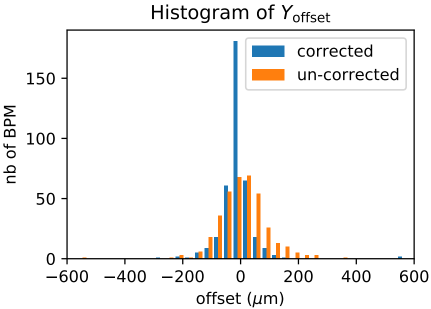


$$\sigma_{X,\mathrm{un-corr}} = 45.9\,\mu\mathrm{m}$$
$$\sigma_{X,\mathrm{corr}} = 13.5\,\mu\mathrm{m}$$

We are able to reduce BPM horizontal offset by a factor 3.4.

Sensitivities

Vertical plane:



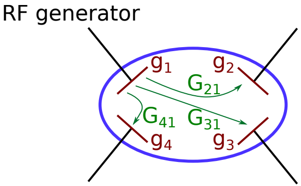
$$\sigma_{Y,\mathrm{un-corr}} = 100.1\,\mu\mathrm{m}$$
$$\sigma_{Y,\mathrm{corr}} = 62.2\,\mu\mathrm{m}$$

Correction in the vertical plan is not as good as in the horizontal plane. Reason?

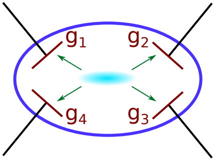
Outline

On the method itself

- My personal questioning:



With beam:

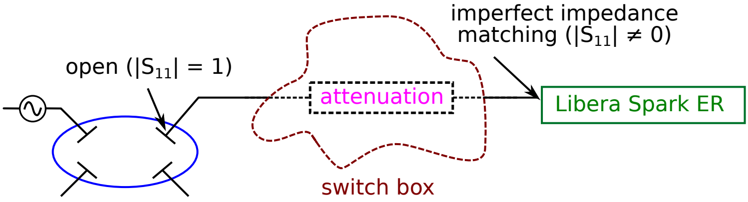


Are sensitivities the same in these two different situations?

- Subtracting the mean value for every measured value hides a possible systematic offset.

Impedance mismatch issue

If we focus on one measurement channel:



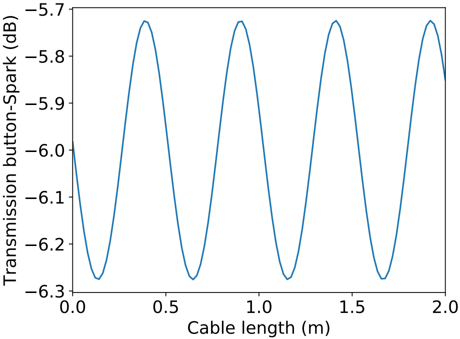
- Reflexion at Spark input was measured to be in the range $[-18\,\mathrm{dB}\ ,\ -22\ \mathrm{dB}]$.

Due to imperfect impedance matching at both ends, the transmission from buttons to the Spark depends on cable lengths.

Impedance mismatch issue

Calculation with:

- Spark $|S_{11}| = -20\,\mathrm{dB}$
- attenuation in the switch box: -6 dB



Transmission vary significantly with cable lengths!

Impedance mismatch issue

Possible solutions to this problem:

- Add attenuation in the switch box
  $\rightarrow$ difficult: already at the detection limit of the Spark.
  and RF source at max power
- Always perform measurements with same Spark and cables.
  $\rightarrow$ this is what we did.
- Circulators?

External effects

We can think of other sources of errors:

- Inter-connection cables are not perfectly of the same length.
- Temperature drifts of equipments.
- Measurement can depends on exact bending of cables
  $\rightarrow$ this effect is unfortunately not negligible.

Outline

Conclusion

- Lamberston method requires a carefuly designed setup (weak signals + impedance mismatch).
- It was successful in finding retracted buttons.
- We found a good agreement between different measurement campaigns.
- We intend to use the calculated offsets for the first turns (until beam-based aligment).

But:

- Our implementation of the method does not address systematic errors (e.g. all buttons A with reduced sensitivity).
- Impedance mismatch can also produce strong offsets in a regular BPM measurement (talk for DEELS2020?).

Acknowledgements

Diagnostics group technicians (benches fabrication + measurement campaigns):

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