**Scaling Factors**

**for the New Linac BPM Modules**

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# Positions

The old BPM electronics modules produced a voltage that was interpreted to be proportional to the ratio of the voltages from the plates, expressed in dB’s:

$$V\_{m}=k (20 log\_{10}\frac{V\_{1}}{V\_{2}})$$

Where:

* *Vm* is the voltage that the module produces
* k is a constant[[1]](#footnote-1)
	+ for the old Linac BPM modules (1988), this was 0.18 Volts/dB
	+ for the new BPM modules (1991), this was 0.092 Volts/dB
* *V1* and *V2* are the voltages from the opposite plates of the BPM

The new modules produce an integer value, *C*, which is equal to the difference of the plate voltages over their sum:

$$C=32768 \left(V\_{1}-V\_{2}\right)/\left(V\_{1}+V\_{2}\right)$$

Where:

* 32768 is the maximum count of a signed 16-bit word (215)
* *V1* and *V2* are the voltages from the opposite plates of the BPM

One can write down a series of factors for the new BPM system (where “DoS” means “diff/sum value” and “Val” means a unitless value from the BPM module readout, 32768 full scale):

Pcontrols *[mm]* = Kcontrols *[mm/Val]* \* Kelectronics *[Val/DoS]* \* KBPMResponse *[DoS/mm]* \*Preal *[mm]*

In a perfect world, the product of the three K constants will be 1.0.

Since the new modules calculate the difference-over-sum directly and the conversion to a control system voltage is trivial, one constant is unnecessary:

Pcontrols *[mm]* = Kcontrols *[mm/volts]* \* Kelectronics & BPM *[volts/mm]* \*Preal *[mm]*

Setting Pcontrols = Preal (an ideal world), we have:

Kcontrols *[mm/volts]* = 1 / Kelectronics & BPM *[volts/mm]*

There are two equations: One for the geometry of the LEL BPMs and one for the HEL BPMs. We shall refer to the constants on the right-hand side of this equation as KBL and KBH, for the LEL and the HEL BPM responses, respectively.

The measured BPM responses are[[2]](#footnote-2):

|  |  |  |
| --- | --- | --- |
| BPM | Value | Units |
| LEL  | 1.43 | dB/mm |
| HEL  | 1.89 | dB/mm |

As it turns out, EM oversaw the measurement of the response of the BPMs in 1988 (LEL) and in 1991 (HEL). These numbers are pulled from his log books from that time. These numbers are averages of the values of the individual BPMs. There was a range of values for these, but they varied only by a few percent.

# The Results

It is easy to convert these “dB/mm” measurements to “diff/sum”/mm values.

If you have ratio in dB, it is converted to a plain ratio in the normal way:

$$R= 10^{\left[\frac{dB }{20}\right]}$$

The ratio of two values, x and y, can be converted to a “diff/sum” with this functional form:

$$f\left(Z\right)∶= (Z-1)/(Z+1)$$

Where Z represents the ratio value. Plug in “x/y” for Z to see that this is right:

$$\frac{\frac{x}{y}-1}{\frac{x}{y}+ 1}≡\frac{x-y}{x+y}$$

Substitution gives us the answer we are looking for:

$$DoS=\frac{\left(10^{\left[\frac{dB }{20}\right]}-1\right)}{(10^{\left[\frac{dB }{20}\right]}+1)}$$

Plug in dB values of 1.43 and 1.89 (representing a 1 mm offset in the BPM) yields:

|  |  |  |
| --- | --- | --- |
| LEL | 0.08213 | “diff/sum value” per mm |
| HEL | 0.10847 |

Inverting these constants gives the value in mm:

|  |  |  |
| --- | --- | --- |
| LEL | 12.18 | mm |
| HEL | 9.225 |

The ACNET control system has various conversion equations from “raw volts” to engineering units. We use this one:

$$E= C\_{1}\frac{V}{C\_{2}}+C\_{3}$$

The values for C3 are beyond the scope of this note, so these will be set to zero.

In the Linac, we normally use C2=10.0, which means C1 represents the “full scale” reading of the device. In the Linac control system, full scale is interpreted as 10.0 volts. That is, when the diff/sum raw reading is full scale, 32768, it will be interpreted as 10.0 volts. This cancels with the C2 in the denominator. Thus, the values of the constants C1 are:

|  |  |
| --- | --- |
| C1 (LEL) | 12.18 |
| C1 (HEL) | 9.225 |

**An aside:** A full scale reading on the BPMs with this conversion is 12.2 or 9.2 mm. This is not right; a BPM diff/sum “voltage” should roll off as the beam gets closer to one plate. *Future work!*

# 400 MeV Line BPMs

According to R. Webber[[3]](#footnote-3), the sensitivity of the Booster BPMs is

0.48 dB/mm (200 MHz beam)

According to Drennan[[4]](#footnote-4), this sensitivity is slightly different:

0.476 dB/mm

Plugging this into the formulae above yields:

0.02762 “diff/sum” per mm (0.02739, Drennan)

or

36.200 mm (full scale) (36.5 mm)

# Summary

Here is a summary table of all the BPMs, with their location and scaling factors:

|  |  |  |  |
| --- | --- | --- | --- |
| ACNET Name | Location | BPM Raw Scaling [dB/mm] | New Scaling *(Full Scale Value)* |
| L:BPH2OT | LEL Tank2 | 1.43 | 12.176 |
| L:BPV2OT | LEL Tank2 | 1.43 | 12.176 |
| L:BPHNTF | NTF? | 1.43? | 12.176 |
| L:BPH3IN | LEL Tank 3 | 1.43 | 12.176 |
| L:BPV3IN | LEL Tank 3 | 1.43 | 12.176 |
| L:BPH3OT | LEL Tank 3 | 1.43 | 12.176 |
| L:BPV3OT | LEL Tank 3 | 1.43 | 12.176 |
| L:BPH4IN | LEL Tank 4 | 1.43 | 12.176 |
| L:BPV4IN | LEL Tank 4 | 1.43 | 12.176 |
| L:UPHNTF | NTF? | 1.43? | 12.176 |
| L:UPVNTF | NTF? | 1.43? | 12.176 |
| L:BPH5IN | LEL Tank 5 | 1.43 | 12.176 |
| L:BPV5IN | LEL Tank 5 | 1.43 | 12.176 |
| L:BPH5OT | LEL Tank 5 | 1.43 | 12.176 |
| L:BPV5OT | LEL Tank 5 | 1.43 | 12.176 |
| L:D02BPH | HEL Transition | 1.89 | 9.228 |
| L:D02BPV | HEL Transition | 1.89 | 9.228 |
| L:D03BPH | HEL Transition | 1.89 | 9.228 |
| L:D03BPV | HEL Transition | 1.89 | 9.228 |
| L:D04BPH | HEL Transition | 1.89 | 9.228 |
| L:D04BPV | HEL Transition | 1.89 | 9.228 |
| L:D11BPH | HEL Module 1 | 1.89 | 9.228 |
| L:D11BPV | HEL Module 1 | 1.89 | 9.228 |
| L:D12BPH | HEL Module 1 | 1.89 | 9.228 |
| L:D12BPV | HEL Module 1 | 1.89 | 9.228 |
| L:D13BPH | HEL Module 1 | 1.89 | 9.228 |
| L:D13BPV | HEL Module 1 | 1.89 | 9.228 |
| L:D21BPH | HEL Module 2 | 1.89 | 9.228 |
| L:D21BPV | HEL Module 2 | 1.89 | 9.228 |
| L:D22BPV | HEL Module 2 | 1.89 | 9.228 |
| L:D22BPH | HEL Module 2 | 1.89 | 9.228 |
| L:D23BPV | HEL Module 2 | 1.89 | 9.228 |
| L:D23BPH | HEL Module 2 | 1.89 | 9.228 |
| L:D31BPH | HEL Module 3 | 1.89 | 9.228 |
| L:D31BPV | HEL Module 3 | 1.89 | 9.228 |
| L:D32BPV | HEL Module 3 | 1.89 | 9.228 |
| L:D32BPH | HEL Module 3 | 1.89 | 9.228 |
| L:D33BPH | HEL Module 3 | 1.89 | 9.228 |
| L:D33BPV | HEL Module 3 | 1.89 | 9.228 |
| L:D34BPH | HEL Module 3 | 1.89 | 9.228 |
| L:D34BPV | HEL Module 3 | 1.89 | 9.228 |
| L:D41BPH | HEL Module 4 | 1.89 | 9.228 |
| L:D41BPV | HEL Module 4 | 1.89 | 9.228 |
| L:D42BPV | HEL Module 4 | 1.89 | 9.228 |
| L:D42BPH | HEL Module 4 | 1.89 | 9.228 |
| L:D43BPH | HEL Module 4 | 1.89 | 9.228 |
| L:D43BPV | HEL Module 4 | 1.89 | 9.228 |
| L:D44BPH | HEL Module 4 | 1.89 | 9.228 |
| L:D44BPV | HEL Module 4 | 1.89 | 9.228 |
| L:D51BPH | HEL Module 5 | 1.89 | 9.228 |
| L:D51BPV | HEL Module 5 | 1.89 | 9.228 |
| L:D52BPV | HEL Module 5 | 1.89 | 9.228 |
| L:D52BPH | HEL Module 5 | 1.89 | 9.228 |
| L:D53BPH | HEL Module 5 | 1.89 | 9.228 |
| L:D53BPV | HEL Module 5 | 1.89 | 9.228 |
| L:D54BPH | HEL Module 5 | 1.89 | 9.228 |
| L:D54BPV | HEL Module 5 | 1.89 | 9.228 |
| L:D61BPH | HEL Module 6 | 1.89 | 9.228 |
| L:D61BPV | HEL Module 6 | 1.89 | 9.228 |
| L:D62BPV | HEL Module 6 | 1.89 | 9.228 |
| L:D62BPH | HEL Module 6 | 1.89 | 9.228 |
| L:D63BPV | HEL Module 6 | 1.89 | 9.228 |
| L:D63BPH | HEL Module 6 | 1.89 | 9.228 |
| L:D64BPH | HEL Module 6 | 1.89 | 9.228 |
| L:D64BPV | HEL Module 6 | 1.89 | 9.228 |
| L:D71BPH | HEL Module 7 | 1.89 | 9.228 |
| L:D71BPV | HEL Module 7 | 1.89 | 9.228 |
| L:D72BPH | HEL Module 7 | 1.89 | 9.228 |
| L:D72BPV | HEL Module 7 | 1.89 | 9.228 |
| L:D73BPH | HEL Module 7 | 1.89 | 9.228 |
| L:D73BPV | HEL Module 7 | 1.89 | 9.228 |
| L:D74BPH | 400 MeV Straight | 1.89 | 9.228 |
| L:D74BPV | 400 MeV Straight | 1.89 | 9.228 |
| L:BPH201 | 400 MeV Straight | 0.476 | 36.504 |
| L:BPH202 | 400 MeV Before Spect | 0.476 | 36.504 |
| L:BPH203 | 400 MeV Beyond Spect | 0.476 | 36.504 |
| L:BPH204 | 400 MeV Momentum | 0.476 | 36.504 |
| L:BPV201 | 400 MeV Straight | 0.476 | 36.504 |
| L:BPV202 | 400 MeV Straight | 0.476 | 36.504 |
| L:BPV203 | 400 MeV Beyond Spect | 0.476 | 36.504 |
| L:BPV204 | 400 MeV Momentum | 0.476 | 36.504 |
| B:HPQ1 | 400 MeV Straight | 1.8 | 9.686 |
| B:VPQ1 | 400 MeV Straight | 1.8 | 9.686 |
| B:HPQ2 | 400 MeV Straight | 0.476 | 36.504 |
| B:VPQ2 | 400 MeV Straight | 0.476 | 36.504 |
| B:HPLAM | 400 MeV to Booster | 0.479 | 36.276 |
| B:VPLAM | 400 MeV to Booster | 0.479 | 36.276 |
| B:HPQ3 | 400 MeV to Booster | 0.476 | 36.504 |
| B:VPQ3 | 400 MeV to Booster | 0.476 | 36.504 |
| B:HPQ4 | 400 MeV to Booster | 0.476 | 36.504 |
| B:VPQ4 | 400 MeV to Booster | 0.476 | 36.504 |
| B:HPQ5 | 400 MeV to Booster | 0.476 | 36.504 |
| B:VPQ5 | 400 MeV to Booster | 0.476 | 36.504 |
| B:HPQ6 | 400 MeV to Booster | 0.476 | 36.504 |
| B:VPQ6 | 400 MeV to Booster | 0.476 | 36.504 |
| B:HPQ7 | 400 MeV to Booster | 0.476 | 36.504 |
| B:VPQ7 | 400 MeV to Booster | 0.476 | 36.504 |
| B:HPQ8 | 400 MeV to Booster | 0.476 | 36.504 |
| B:VPQ8 | 400 MeV to Booster | 0.476 | 36.504 |
| B:HPQ9 | 400 MeV to Booster | 0.476 | 36.504 |
| B:VPQ9 | 400 MeV to Booster | 0.476 | 36.504 |
| B:HPQ10 | 400 MeV to Booster | 0.476 | 36.504 |
| B:VPQ10 | 400 MeV to Booster | 0.476 | 36.504 |
| B:VPQ11 | 400 MeV to Booster | 0.476 | 36.504 |
| B:HPQ12 | 400 MeV to Booster | 0.476 | 36.504 |
| B:VPQ12 | 400 MeV to Booster | 0.476 | 36.504 |
| B:HPDEB | 400 MeV to Booster | 0.476 | 36.504 |
| B:VPDEB | 400 MeV to Booster | 0.476 | 36.504 |
| B:HPQ13 | 400 MeV to Booster | 0.476 | 36.504 |
| B:VPQ13 | 400 MeV to Booster | 0.476 | 36.504 |
| B:HPQ15 | 400 MeV to Booster | 0.476 | 36.504 |
| B:VPQ15 | 400 MeV to Booster | 0.476 | 36.504 |
| B:HPQ16 | 400 MeV to Booster | 0.476 | 36.504 |
| B:VPQ16 | 400 MeV to Booster | 0.476 | 36.504 |
| B:HPQ17 | 400 MeV to Booster | 0.476 | 36.504 |
| B:VPQ17 | 400 MeV to Booster | 0.476 | 36.504 |
| B:HPINJ ? | 400 MeV to Booster | 0.476 | 36.504 |
| B:VPINJ ? | 400 MeV to Booster | 0.476 | 36.504 |
| B:HPFOIL | 400 MeV to Booster | 0.436 | 39.852 |
| B:VPFOIL | 400 MeV to Booster | 0.436 | 39.852 |
| B:HPH23 | 400 MeV to Booster | 0.476 | 36.504 |
| B:VPH23 | 400 MeV to Booster | 0.476 | 36.504 |
| B:HPL1D | 400 MeV to Booster | 0.5 | 34.753 |
| B:VPL1D | 400 MeV to Booster | 0.5 | 34.753 |
| B:HPS01 | 400 MeV to Booster | 0.5 | 34.753 |
| B:VPS01 | 400 MeV to Booster | 0.5 | 34.753 |
| B:HPL1U | 400 MeV to Booster | 0.679 | 25.597 |
| B:VPL1U | 400 MeV to Booster | 0.679 | 25.597 |
| B:HPS24 ? | 400 MeV to Booster | 0.5 | 34.753 |
| B:VPS24 ? | 400 MeV to Booster | 0.5 | 34.753 |

1. These numbers were given to me by R. Webber in 1988 and 1991, and can be found in my log books from the time: “Studies log book #2”, page 42 (August 26, 1993), and “BPMs and Trims”, page 41 (March 11, 1988). [↑](#footnote-ref-1)
2. “Studies log book #2,” page 38 (October 17, 1991) and “BPMs and Trims” logbook, page 41 (March 11, 1988) [↑](#footnote-ref-2)
3. <https://beamdocs.fnal.gov/AD-private/DocDB/ShowDocument?docid=2085>, by Bob Webber. [↑](#footnote-ref-3)
4. <https://beamdocs.fnal.gov/AD-private/DocDB/ShowDocument?docid=3801>, by Craig Drennan [↑](#footnote-ref-4)