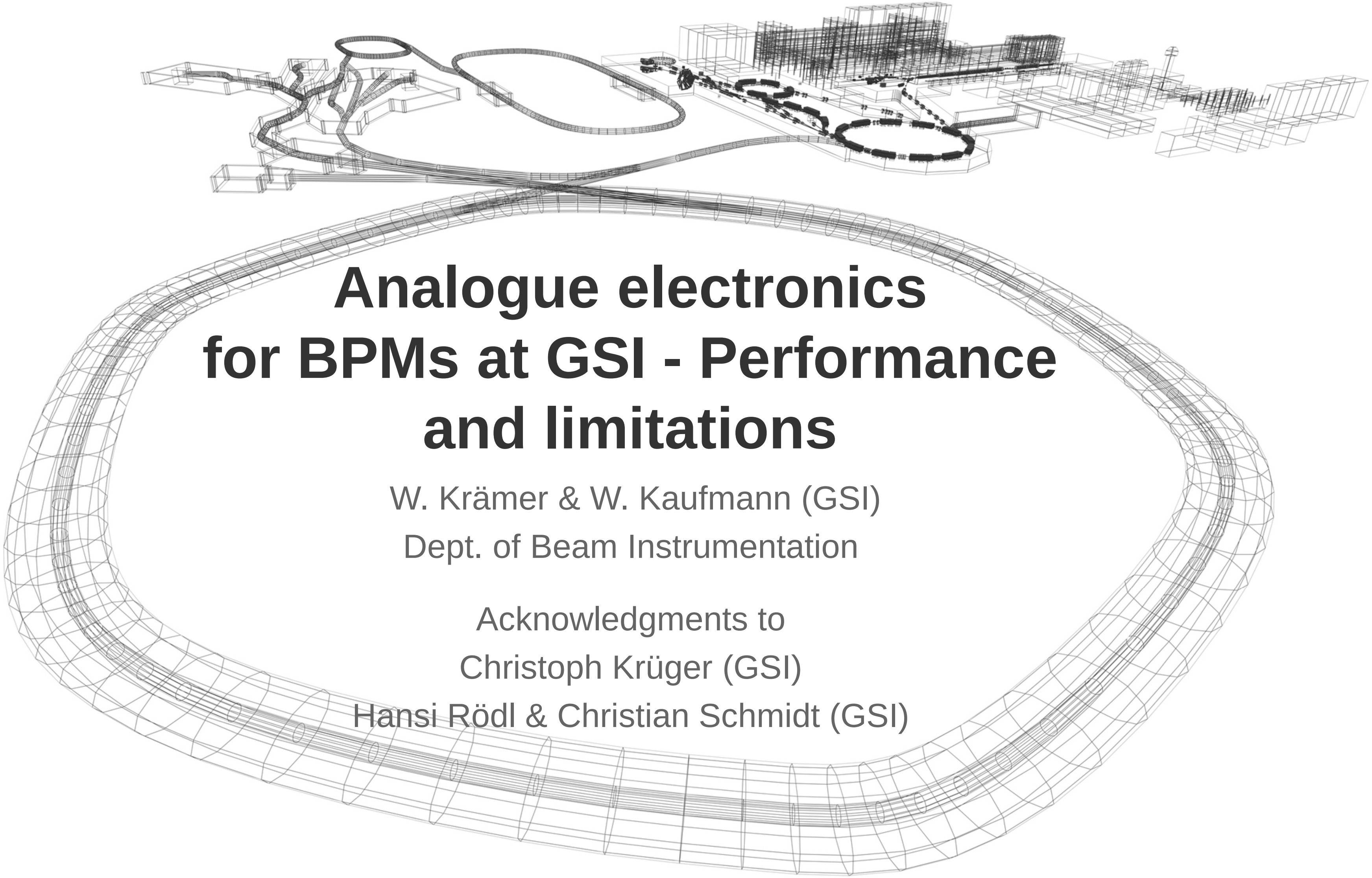
Joint ARIES Workshop on Electron and Hadron Synchrotrons
Barcelona, 12-14th November 2018



Analogue electronics for BPMs at GSI - Performance and limitations

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Dept. of Beam Instrumentation

Acknowledgments to
Christoph Krüger (GSI)
Hansi Rödl & Christian Schmidt (GSI)

Our Team – GSI beam diagnostics RF lab

You are invited to contact us, if there are any questions!

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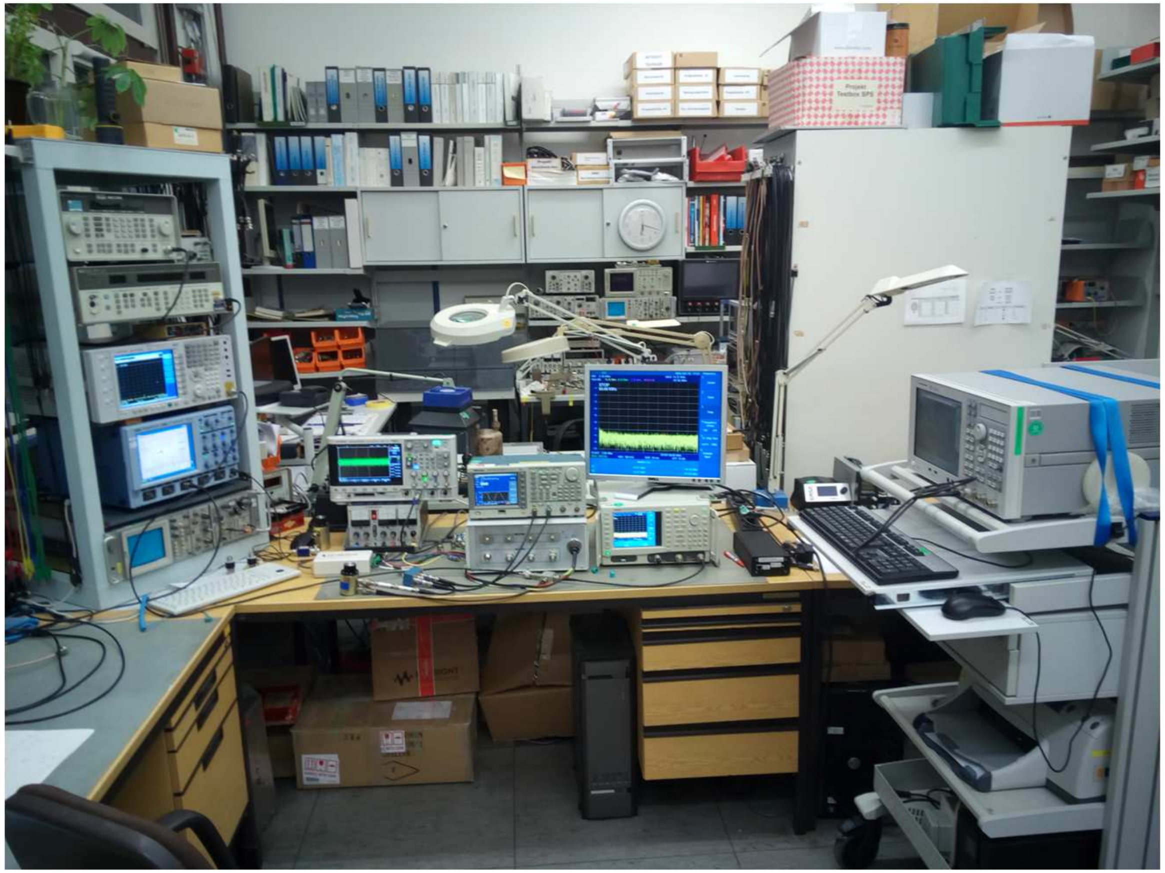


Overview

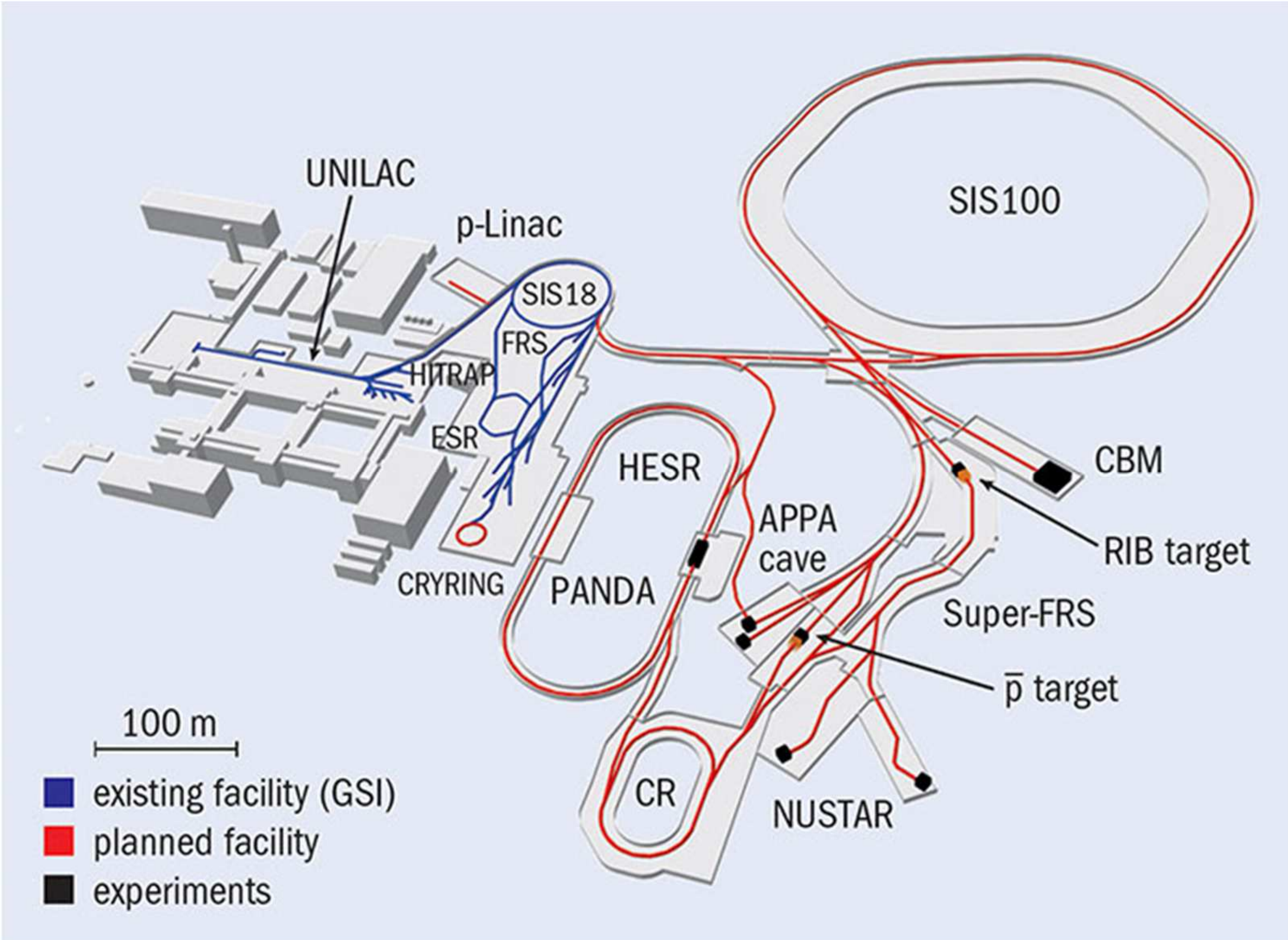
BPMs and amplifiers for Fair

- Cryring 9

- SIS100 84
- HESR 76
- HEBT 39
- SIS18 12
- ESR 12

  total 223

- p-Linac 15



3 different concepts for BPM pickup amplifiers

- Low energy synchrotron

Machine: Cryring
input impedance: 1 MΩ
Gain: 40 dB / 60 dB +/- 0.05 dB
Bandwidth: 10 kHz to 40 MHz
Output impedance: 50 Ω
Equivalent input noise: 2.3 nV / $\sqrt{\mathrm{Hz}}$

- High energy synchrotron

Machines: SIS100, SIS18, HESR, ESR, High energy beam lines
Bandwidth: 40 kHz to 55 MHz
Gain: -50 dB to +60 dB
Input / Output impedance: 50 Ω
Equivalent input noise: 1.6 nV / $\sqrt{\mathrm{Hz}}$

- Proton Linac

Machine: p-Linac
Bandwidth: 325 MHz to 3.25 GHz
Gain: 0 dB to +40 dB
Input / Output impedance: 50 Ω
Equivalent input noise: 1.4 nV / $\sqrt{\mathrm{Hz}}$

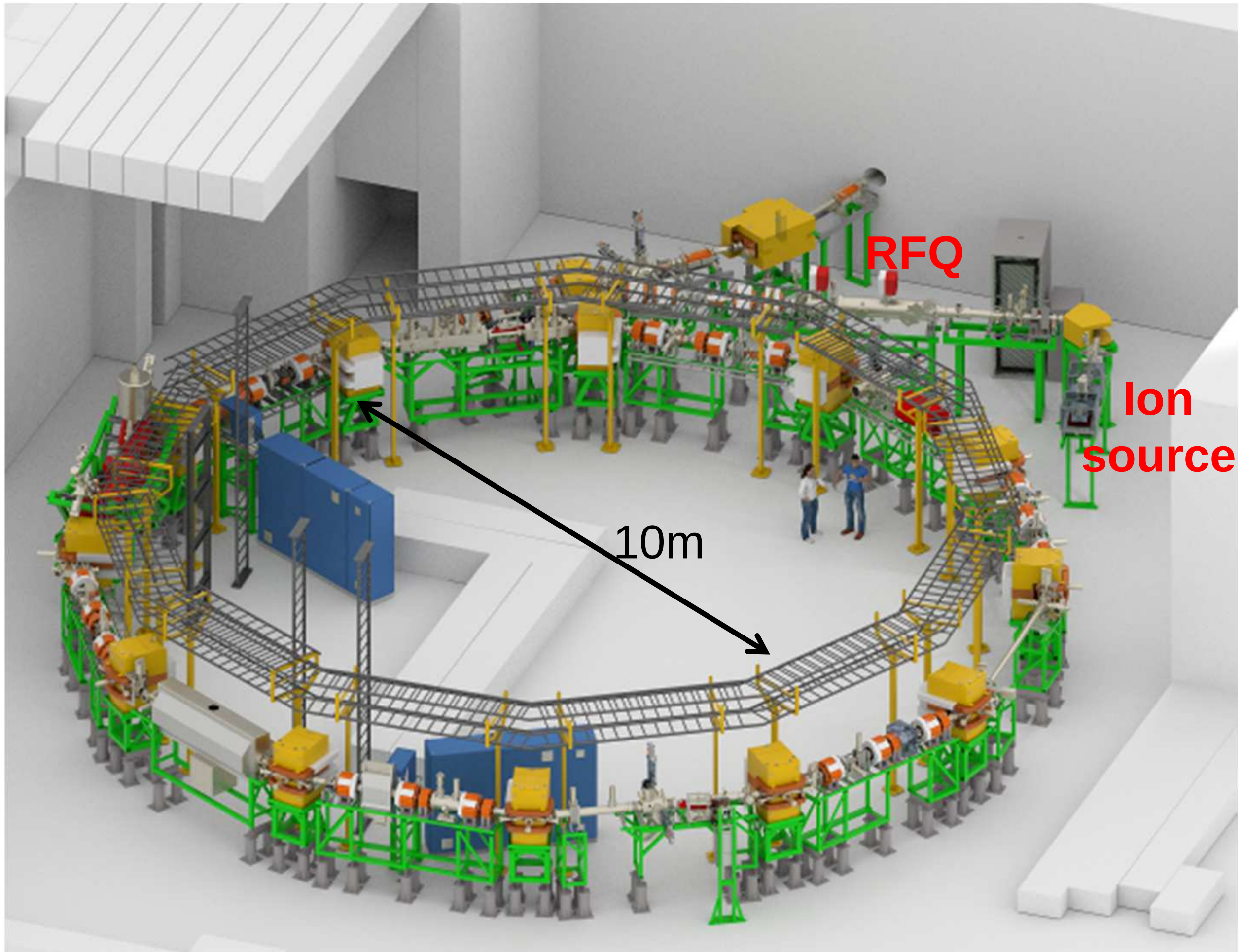
Low energy synchrotron – Cryamp

Cryring specs

- Dedicated 300 keV/u injector linac
- Injection possible with source potential 40 keV
- Beam current in the µA range
- RF frequency 100 kHz – 2 MHz

Cryamp application

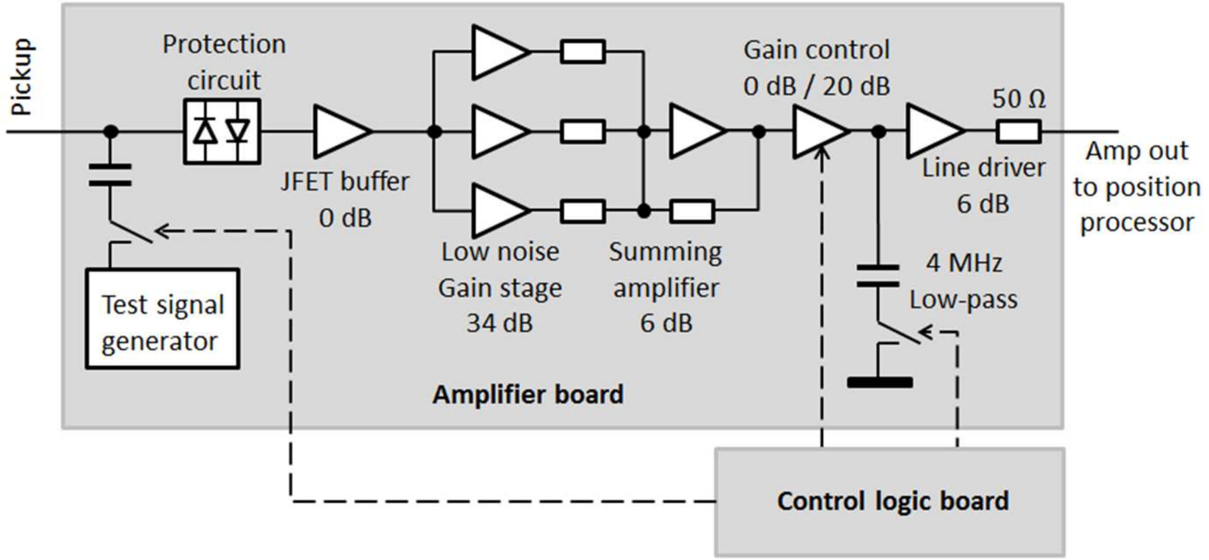
- Beam position measurement
- Integral bunch signals
- Relative beam current measurement
- Bunch shape monitoring



Low energy synchrotron – Cryamp

Design requirements

- Low noise architecture
- Fixed gain modes
- Gain accuracy through low tolerance components



Cryamp data

- Bandwidth: 10 kHz to 40 MHz
- Selectable low pass: 4 MHz
- Input impedance: 1 MΩ
- Output impedance: 50 Ω
- Output level into 50 Ω: 6 dBV
- Equivalent input noise: 2.3 nV / $\sqrt{\mathrm{Hz}}$
- Gain: 40 dB / 60 dB +/- 0.05 dB
- Pickup electrode biasing up to 200 Vdc (variant for cooler bpm)
- Internal test signal generator 125 kHz square wave

Low energy synchrotron – Cryamp

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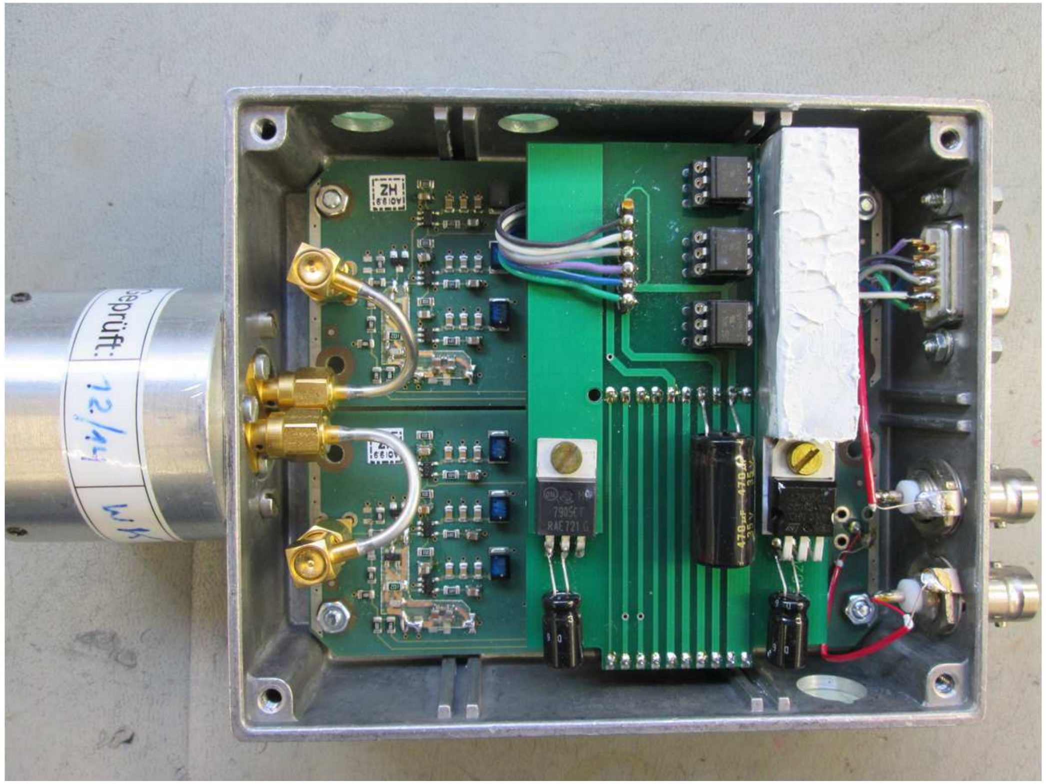

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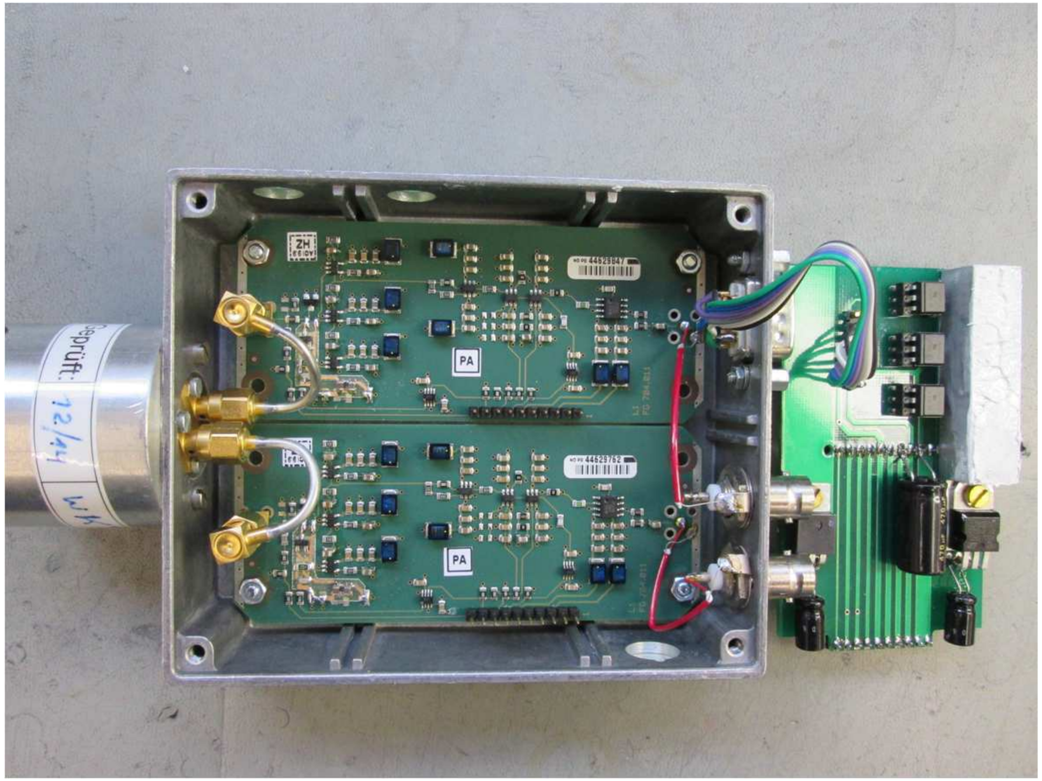

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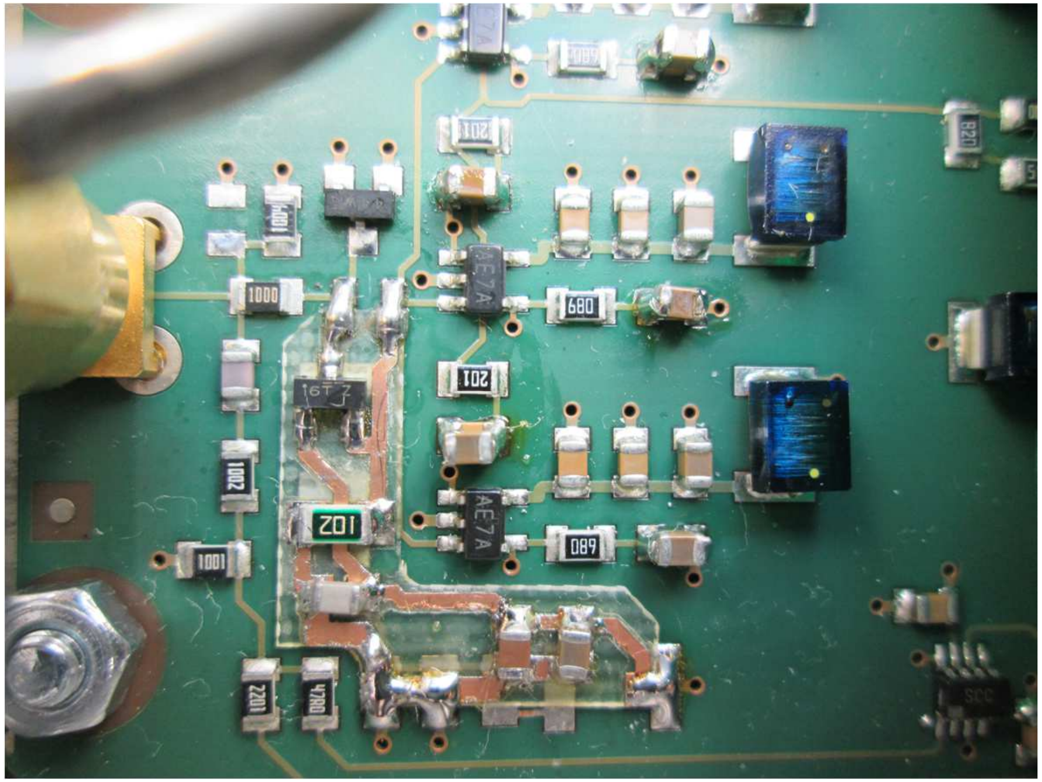
Low energy synchrotron – Cryamp



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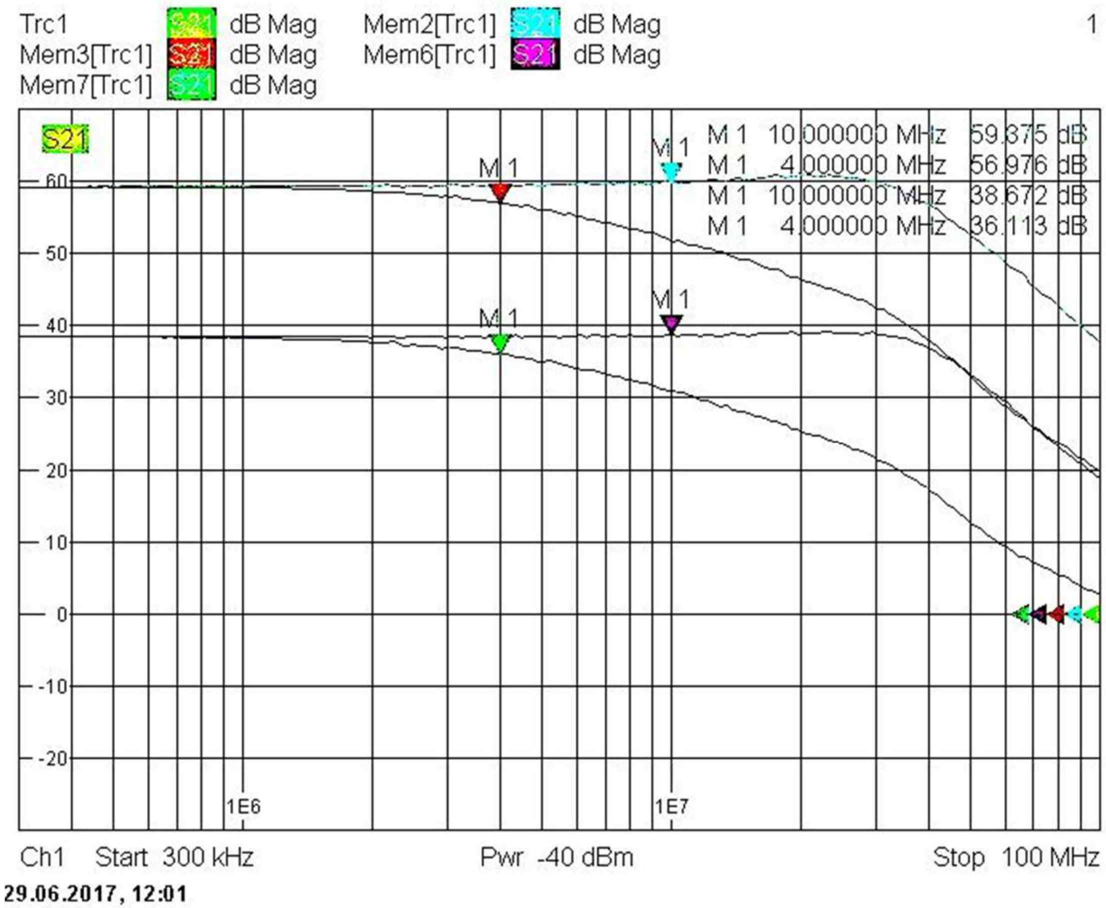
Low energy synchrotron – Cryamp

Frequency Response

- Forward transmission: $|S_{21}|$
- Measured with a R&S ZVB4 Network analyzer
- Shows operation in the 40 dB and 60 dB mode with internal low pass on and off



Low energy synchrotron – Cryamp

Noise performance of the Cryamp at 60 dB

- Measured with an ADVANTEST U3841 FFT spectrum analyzer

- Resolution bandwidth must be taken into account to derive the spectral noise voltage density

$$-60\frac{dBm}{10kHz} = -100\frac{dBm}{Hz}$$

$$-100\frac{dBm}{Hz} - 60dB = -160\frac{dBm}{Hz}$$

$$2.3\frac{nV}{\sqrt{Hz}} = \sqrt{50\,\Omega\,\frac{1\,mW}{Hz}10^{-16}}$$

Low energy synchrotron – Cryamp

Bunch signals in the time domain at 60 dB

- Measured with a Keysight DSOX2024A
- BPM sum signal as replacement for integrating current transformer for low currents ~10 nA
- BPM and ICT sense the bunces in this example

BPM
sum signal 60 dB

Integrating current
transformer 80 dB

Low energy synchrotron – Cryamp

Bunch signals in the time domain at 60 dB

- Measured with a Keysight DSOX2024A
- BPM sum signal as replacement for integrating current transformer for low currents ~10 nA
- Only the BPM detects the bunch in this example

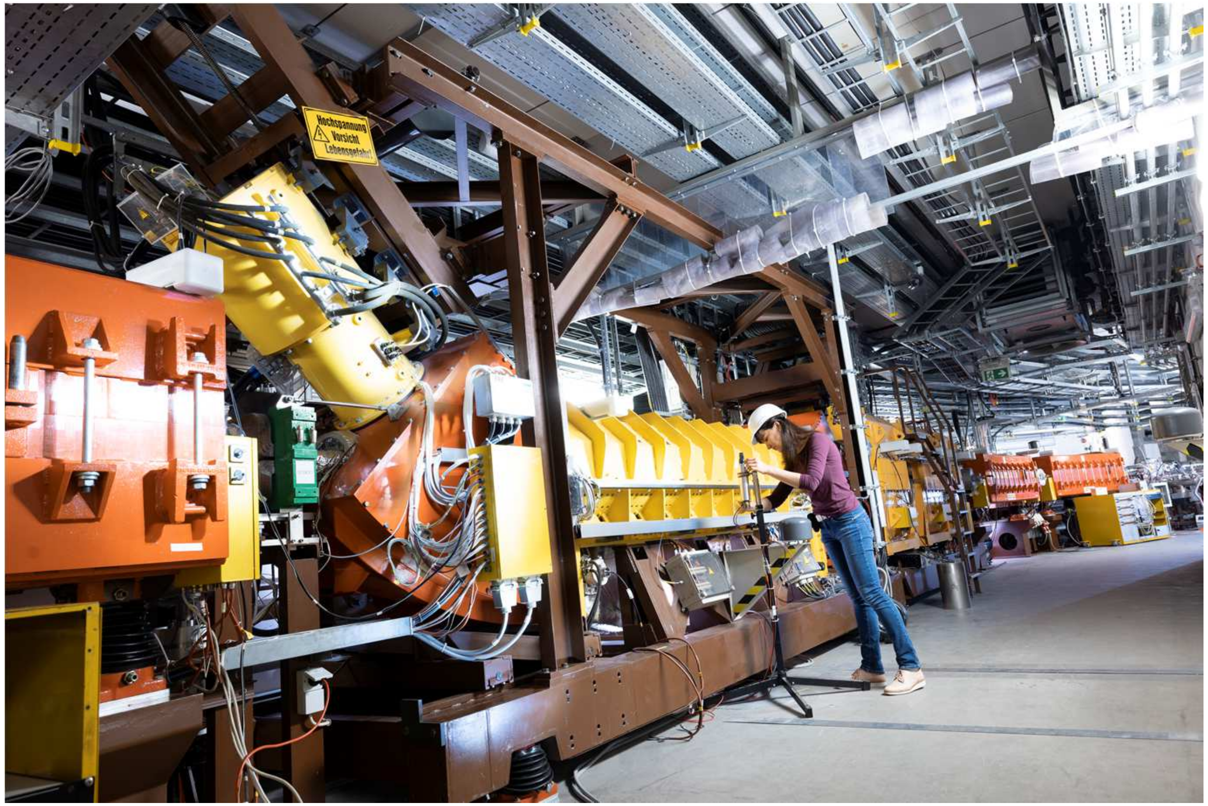
BPM
sum signal 60 dB

Integrating current transformer 80 dB

High energy synchrotron – Amplifier 110

SIS 18 specs

- 216 m circumference
- 18 Tm maximum rigidity
- 2 GeV/u maximum energy,
  depending on the element
- RF frequency
  800 kHz – 5.6 MHz



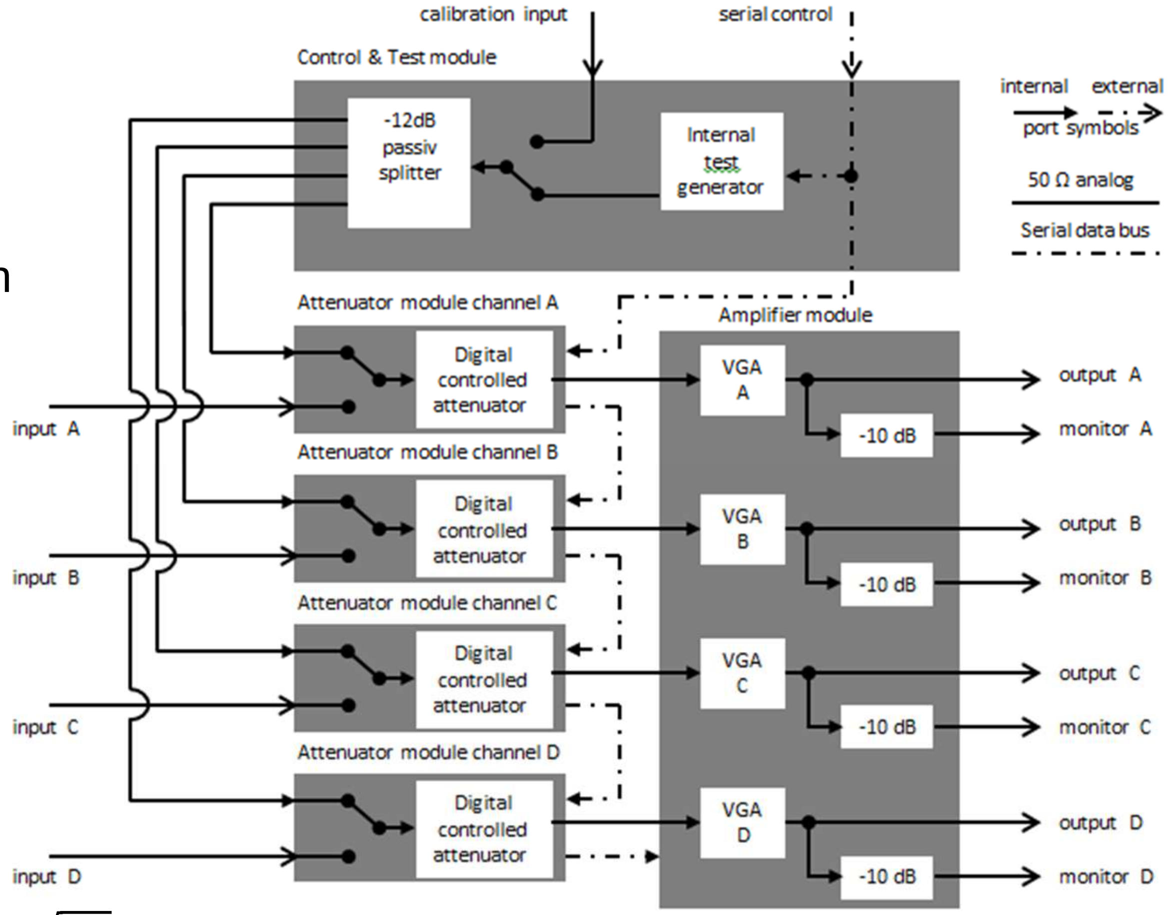
Amplifier 110 application

- Beam position
  measurement
- Closed orbit feedback
- Integral bunch signals
- Pickup tap with matching
  transformer

High energy synchrotron – Amplifier 110

Design requirements

- 110 dB Dynamic range
- Gain fine tuning through VGAs
- Automatic gain matching bench



Amplifier 110 Data

- Bandwidth: 40 kHz to 55 MHz
- Selectable low pass: 7 MHz
- Input impedance: 50 Ω
- Output impedance: 50 Ω
- Max output level: 6 dBV
- Equivalent input noise: 1.6 nV / $\sqrt{\text{Hz}}$
- Gain: -50 dB to 60 dB +/- 0.01 dB
- Internal test signal generator

High energy synchrotron – Amplifier 110

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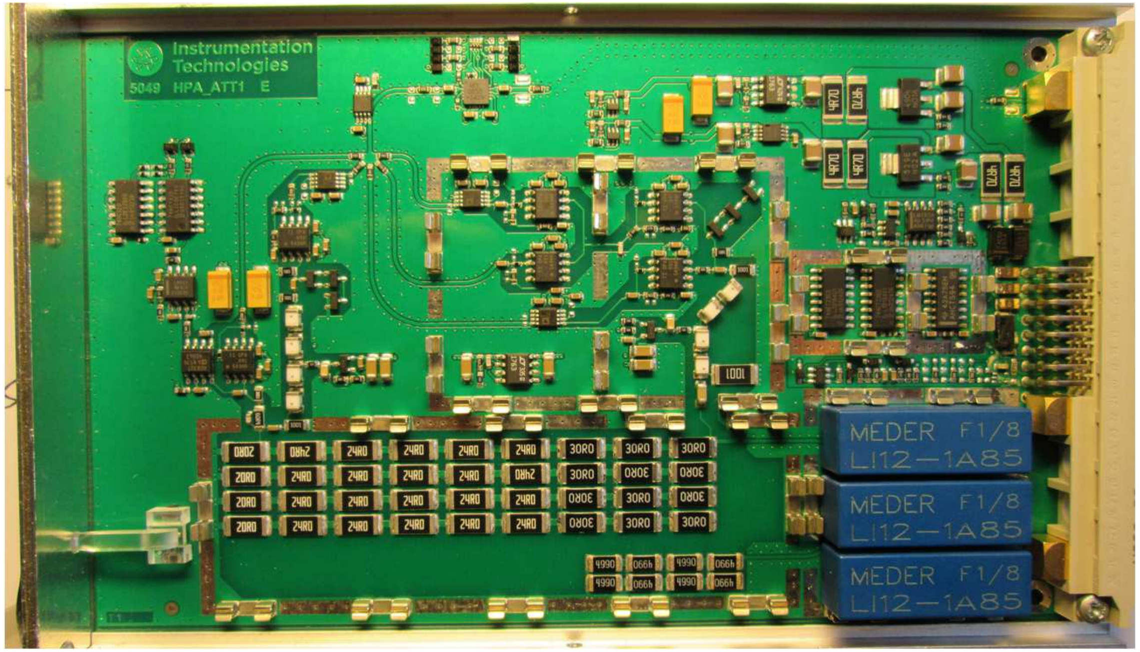

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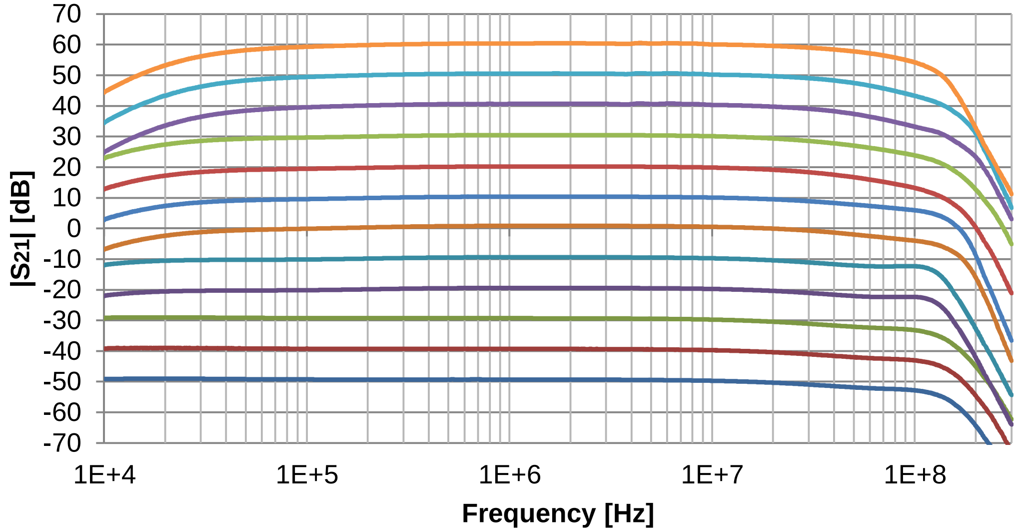
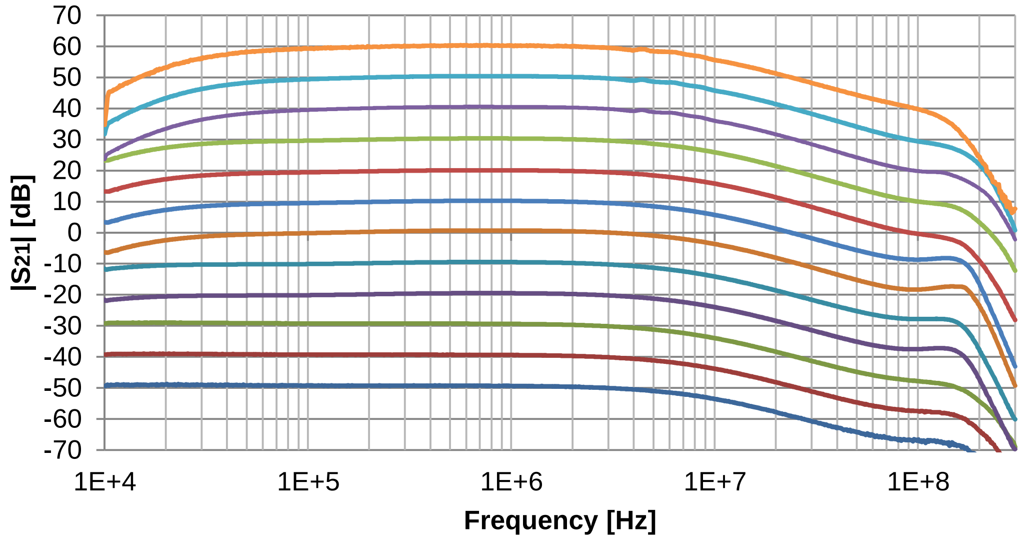
- Internal test signal generator

High energy synchrotron – Amplifier 110

Frequency Response

- Forward transmission: $|S_{21}|$
- Measured with an Agilent E5071C Network analyzer
- Shows operation in all modes from -50 dB to 60 dB





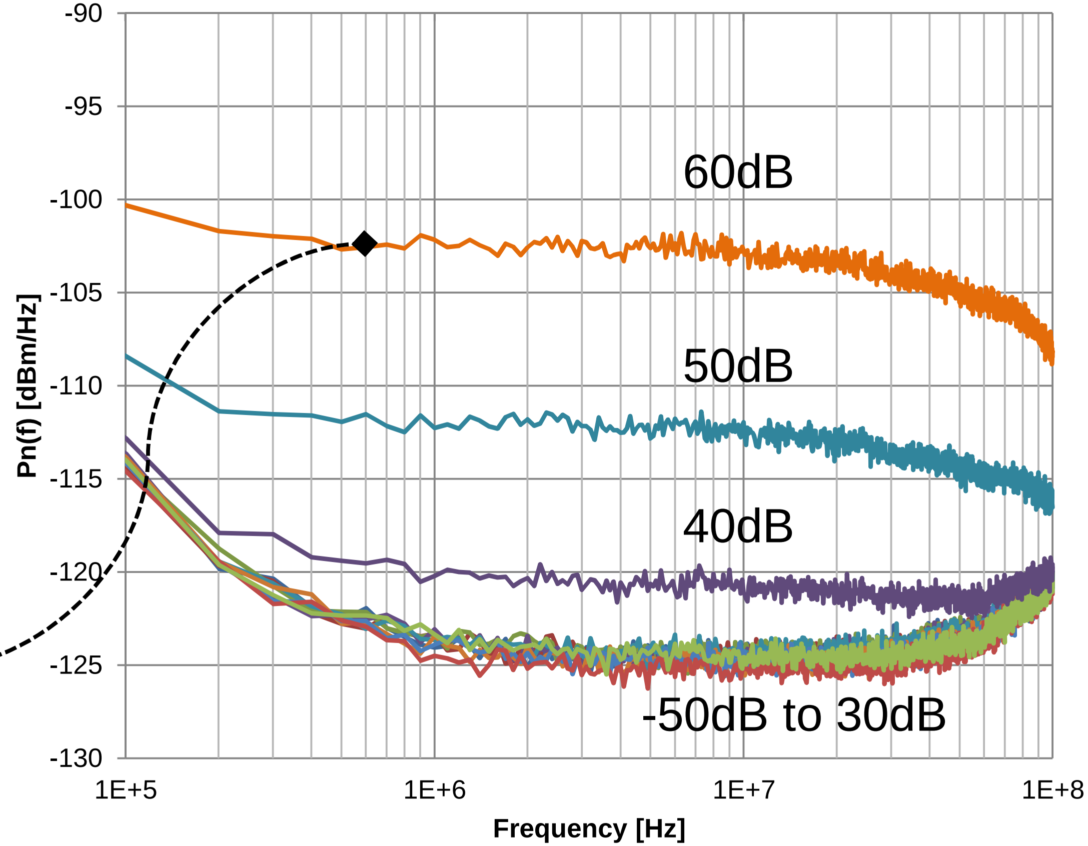
High energy synchrotron – Amplifier 110

Noise performance of the Amplifier 110

- Measured with an Agilent N9020A spectrum analyzer
- Shows output noise power density in all modes from -50 dB to 60 dB

$$-103\frac{dBm}{Hz} - 60dB = -163\frac{dBm}{Hz}$$

$$1.6\frac{nV}{\sqrt{Hz}} = \sqrt{50\,\Omega\,\frac{1\,mW}{Hz}10^{-16.3}}$$



High energy synchrotron – Amplifier 110

Noise performance of the Amplifier 110

- Measured with an Agilent N9020A spectrum analyzer
- Shows output noise power density with internal low pass filter

$$-103\,\frac{dBm}{Hz} - 60dB = -163\,\frac{dBm}{Hz}$$

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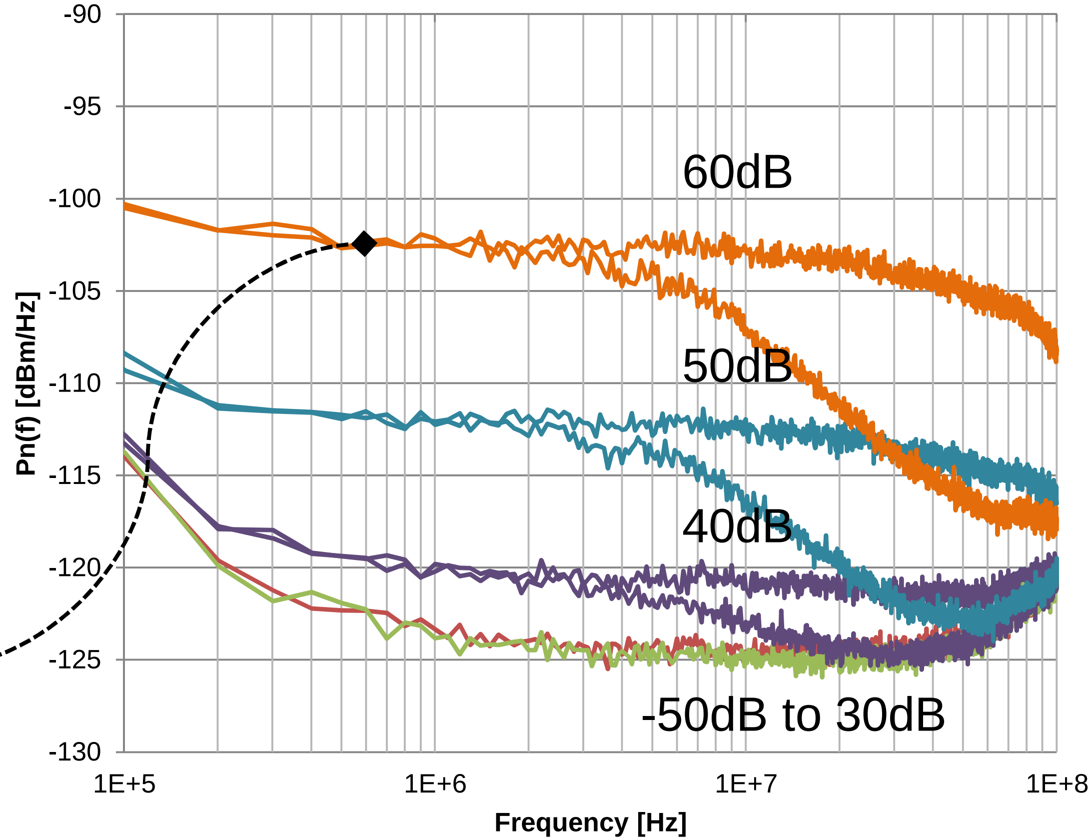
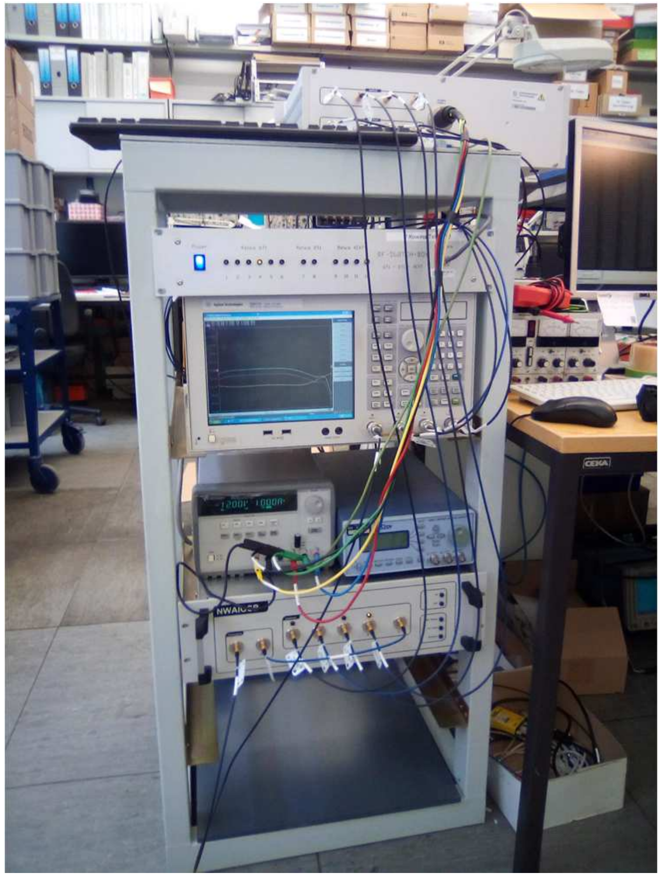
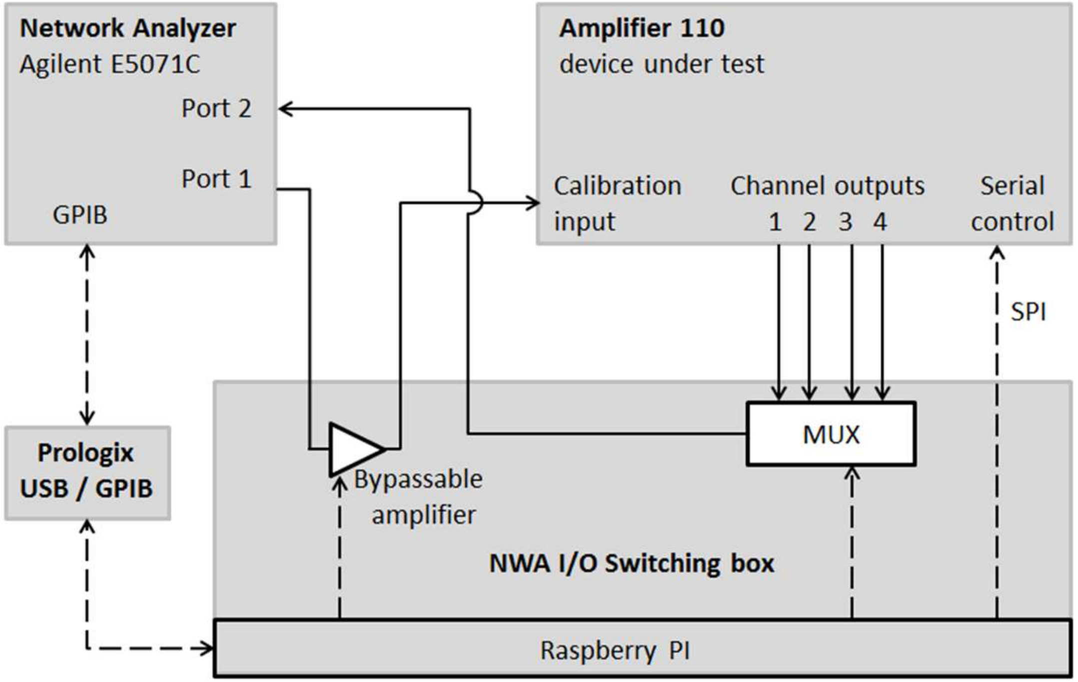


High energy synchrotron – Amplifier 110

Automatic gain matching bench for the Amplifier 110





High energy synchrotron – Amplifier 110

Automatic gain matching bench for the Amplifier 110

- Basic principle for finding optimal VGA settings based on S-parameter comparison

$$I = \int_{f_1}^{f_2} \left| \left|\underline{S}_{21Ref}(f)\right|_{dB} - \left|\underline{S}_{21Measure}(f)\right|_{dB} \right| df$$

$$= \int_{f_1}^{f_2} \left| \Delta_{|\underline{S}_{21}|dB}(f) \right| df$$

- In the case of perfect matching the integral equates zero

- Numeric approximation of the integral through a sum

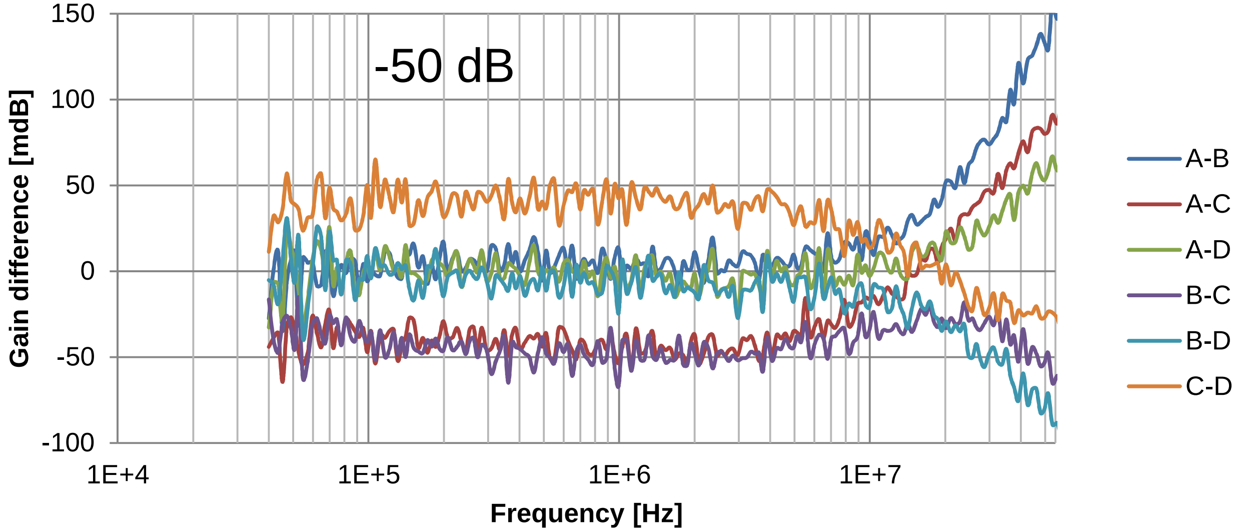
$$I \approx \sum_{n=0}^{N-1} \left| \left|\underline{S}_{21Ref}(n)\right|_{dB} - \left|\underline{S}_{21Measure}(n)\right|_{dB} \right|$$

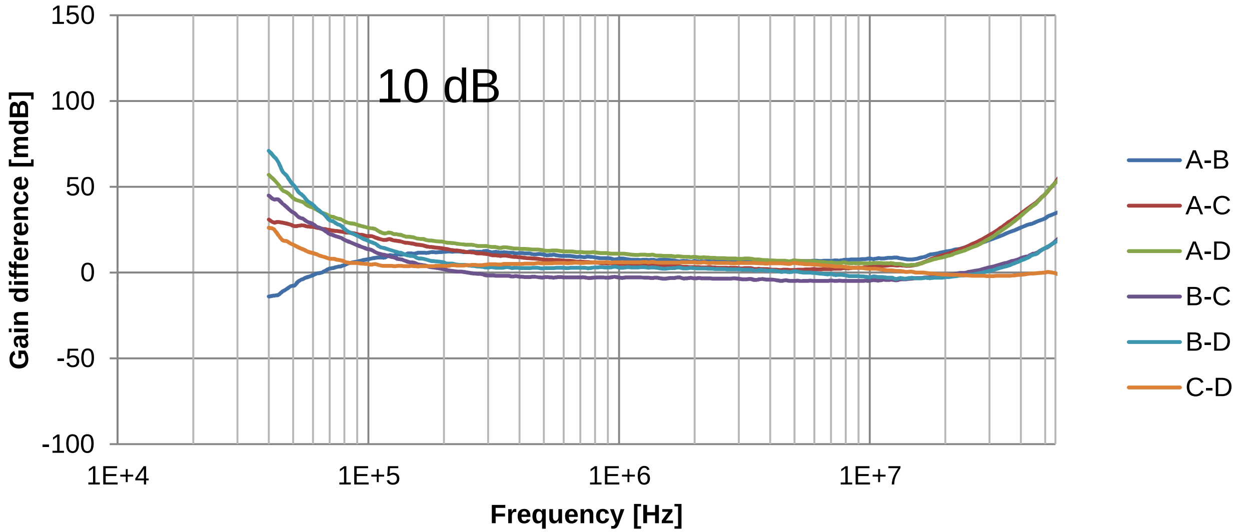
$$= \sum_{n=0}^{N-1} \left| \Delta_{|\underline{S}_{21}|dB}(n) \right|$$

High energy synchrotron – Amplifier 110

Gain differences over frequency between channels, after calibration

- Mismatch is in the $10^{-3}\,dB = 1\,mdB$ range
- Noise is a challenge for the calibration routine





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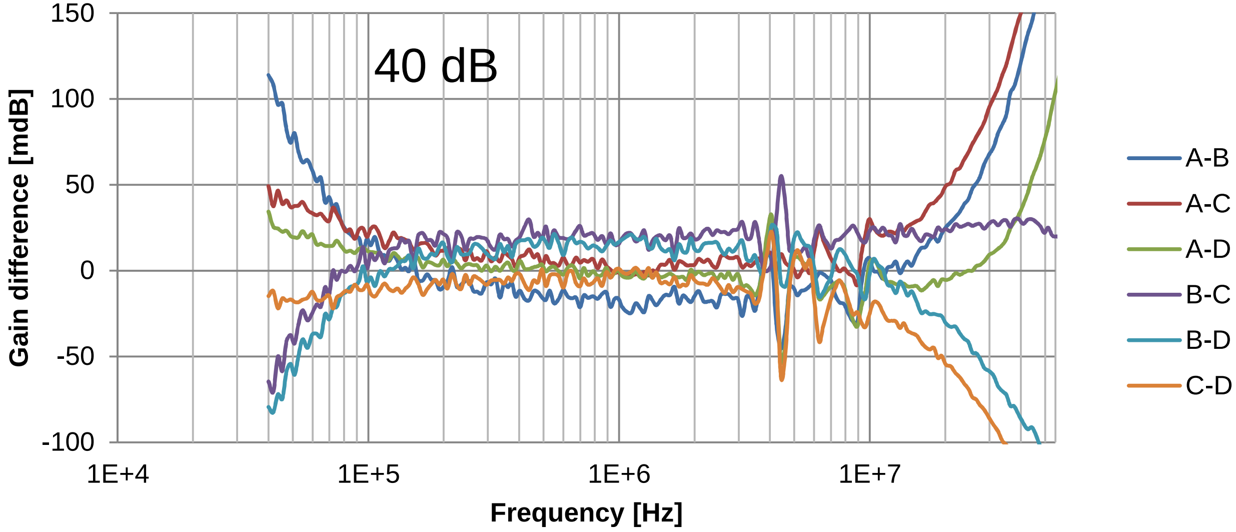
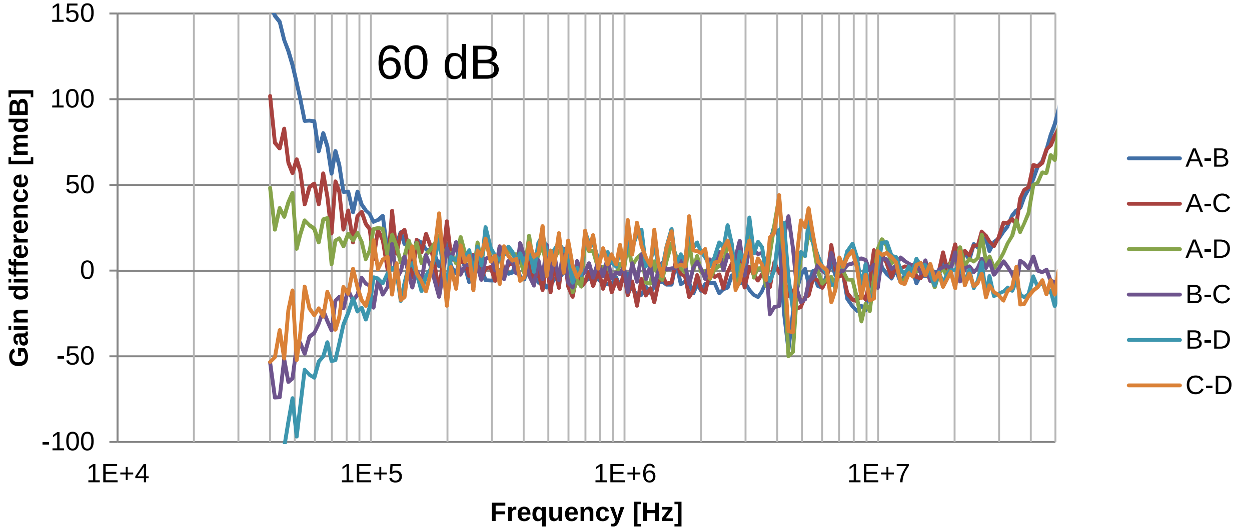


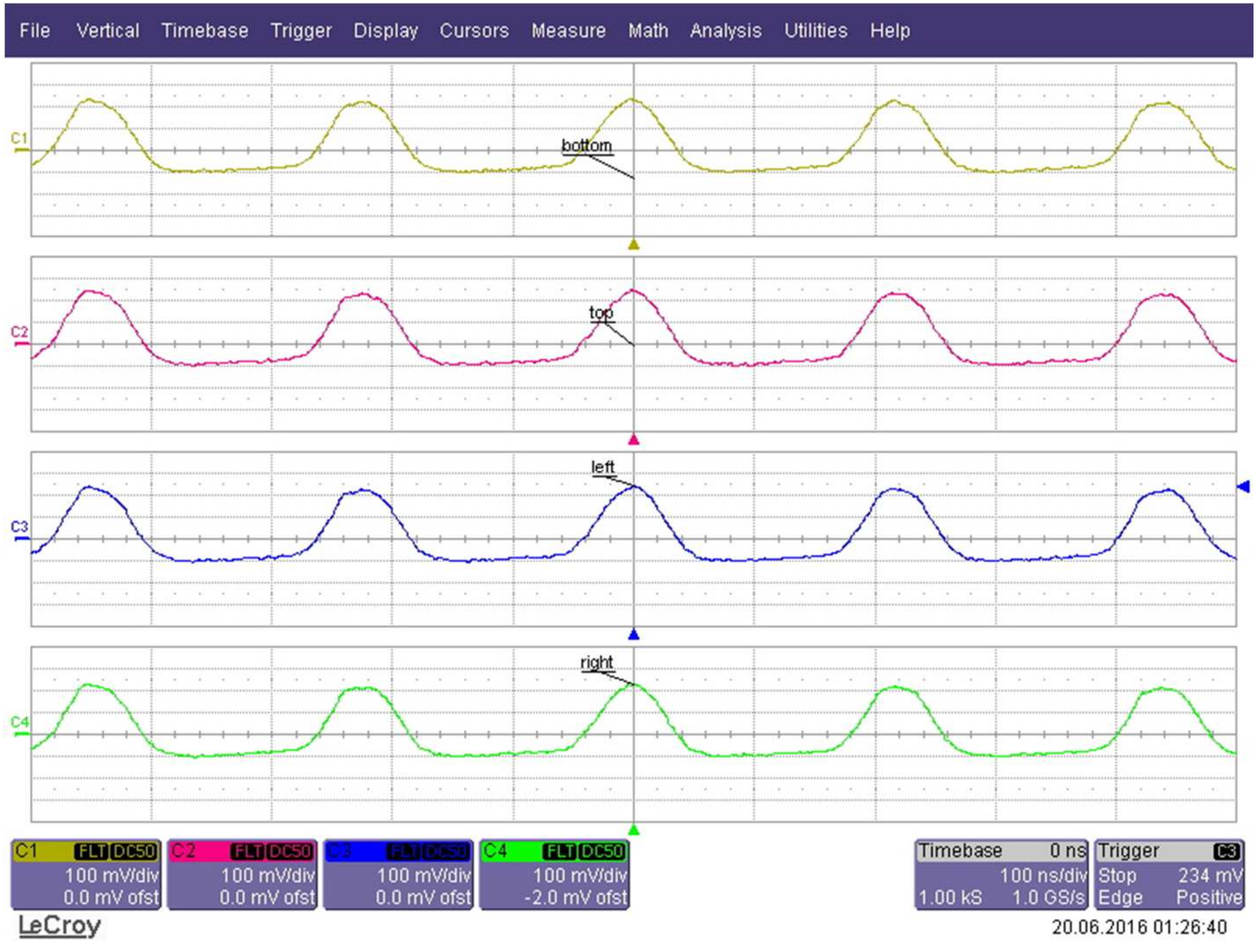


High energy synchrotron – Amplifier 110

SIS 18 Bunch signals

In the time domain

- Measured with a LeCroy Wave Runner 6200A DSO
- 2.2 mA beam current
- Amplifier 110 set to 30 dB amplification

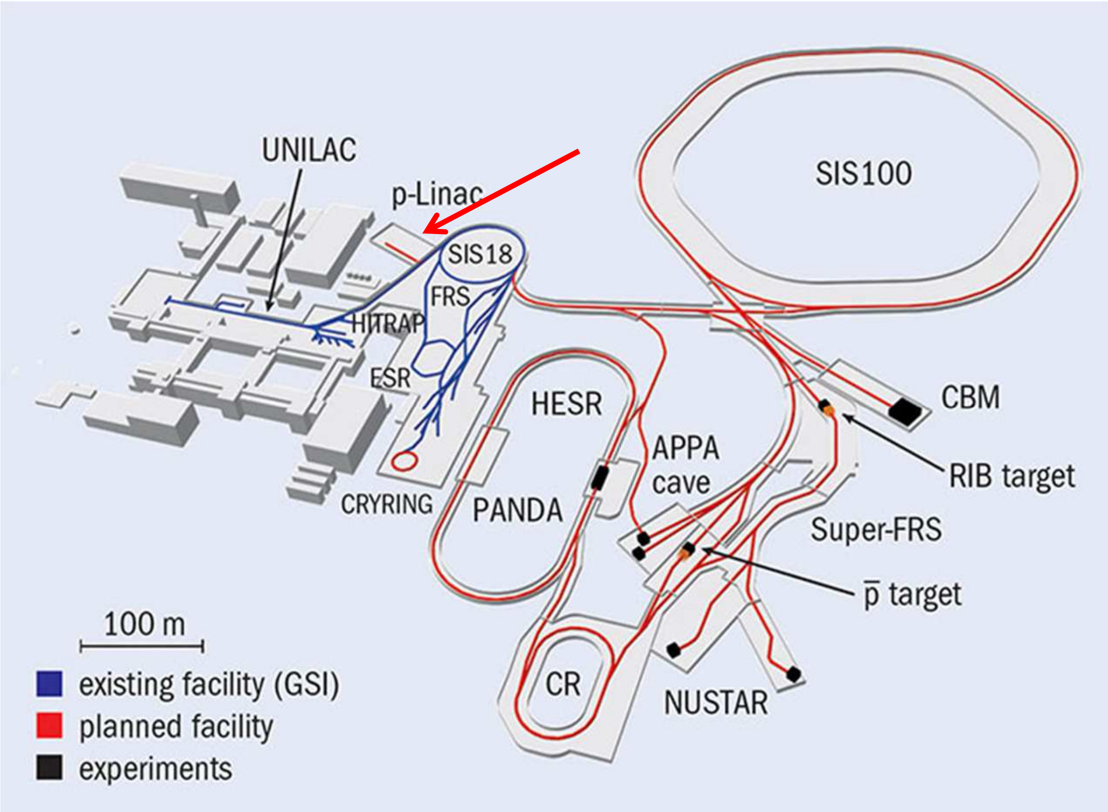


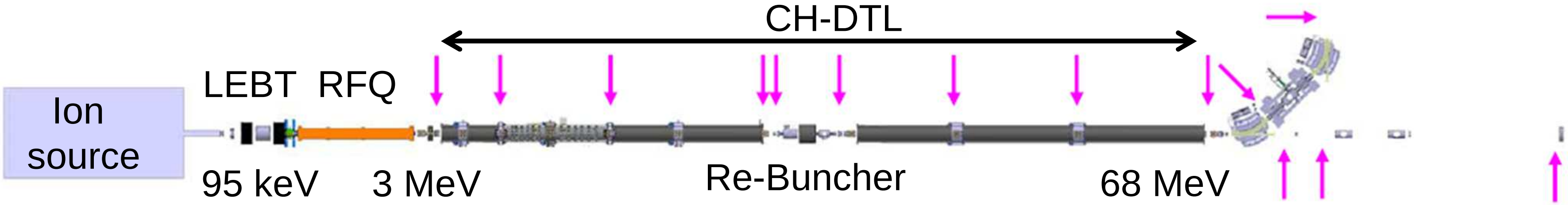
p-Linac specs

- 325 MHz RF frequency
- 68 MeV/u energy
- 70 mA nominal beam current
- 30 µs makropulse time
- 250 ps bunch length

p-Linac Amplifier application

- Beam position measurement
- Time of flight measurement
- differentiated bunch signals

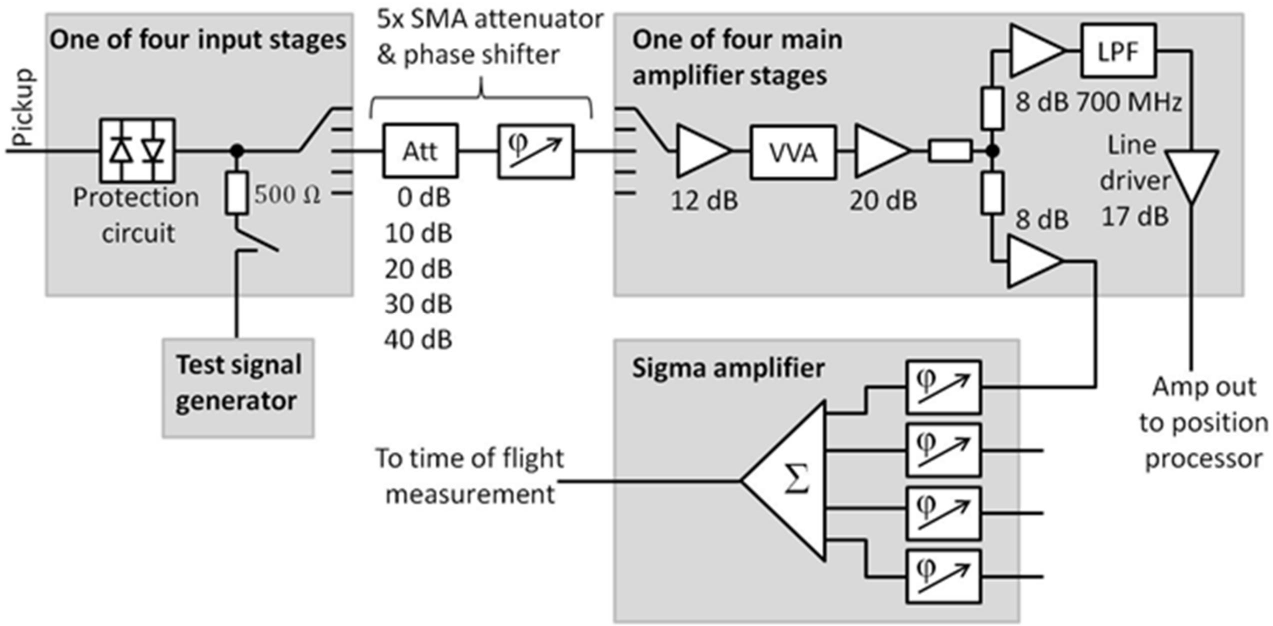




Proton Linac – p-Linac Amplifier

Design requirements

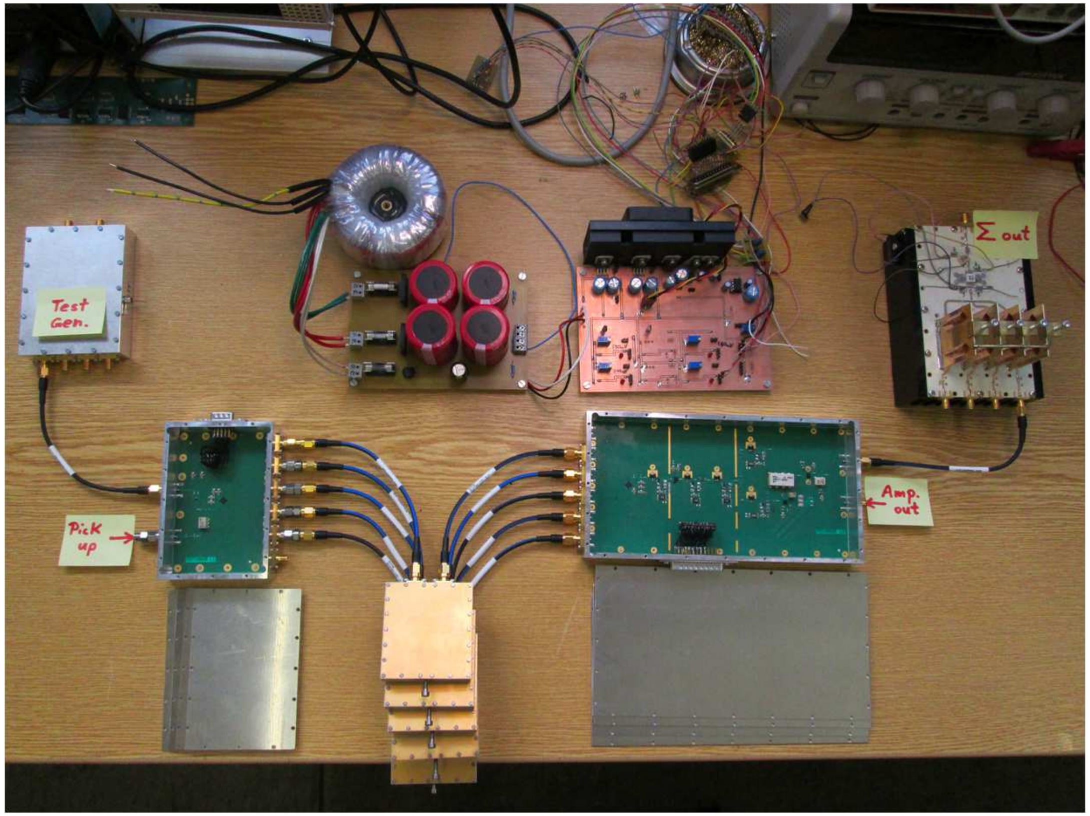
- Broad band architecture
- 0.1° phase accuracy @ 325 MHz
- Delay matching through phase shifters



p-Linac Amplifier Data

- Bandwidth: 325 MHz to 3.25 GHz
- Input impedance: 50 Ω
- Output impedance: 50 Ω
- Equivalent input noise: 1.3nV / $\sqrt{\text{Hz}}$
- Gain: 0 dB to 40 dB +/- 0.1 dB
- internal test signal generator

Proton Linac – p-Linac Amplifier



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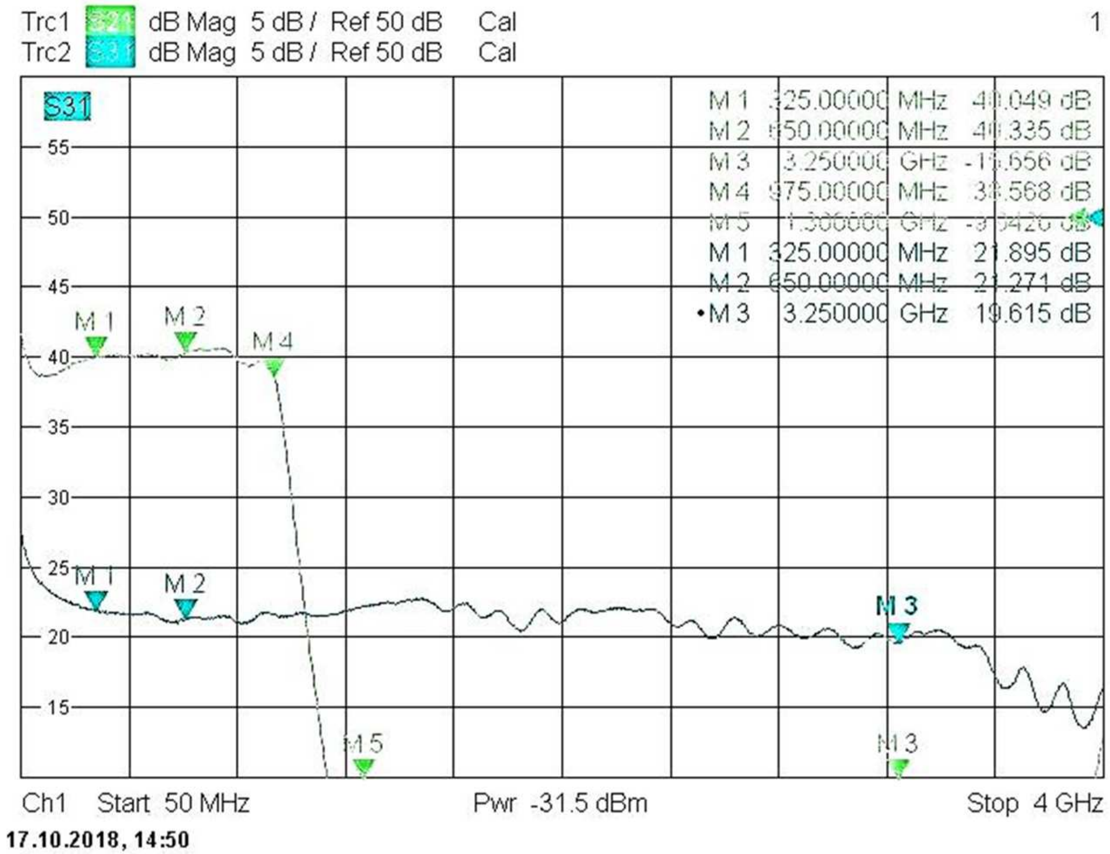
Proton Linac – p-Linac Amplifier

Frequency Response

- Forward transmission: $|S_{21}|$
- Measured with a R&S ZVB4 Network analyzer
- Shows the transmission through the two different outputs



Proton Linac – p-Linac Amplifier

Noise performance of the p-Linac amp at 40 dB

- Measured with an ADVANTEST U3841 FFT spectrum analyzer
- Resolution bandwidth must be taken into account to derive the spectral noise voltage density

$$-63.9\frac{dBm}{1MHz} = -123.9\frac{dBm}{Hz}$$

$$-123.9\frac{dBm}{Hz} - 40dB = -163.9\frac{dBm}{Hz}$$

$$1.4\frac{nV}{\sqrt{Hz}} = \sqrt{50\Omega\ \frac{1\ mW}{Hz}\ 10^{-16.39}}$$

Proton Linac – p-Linac Amplifier

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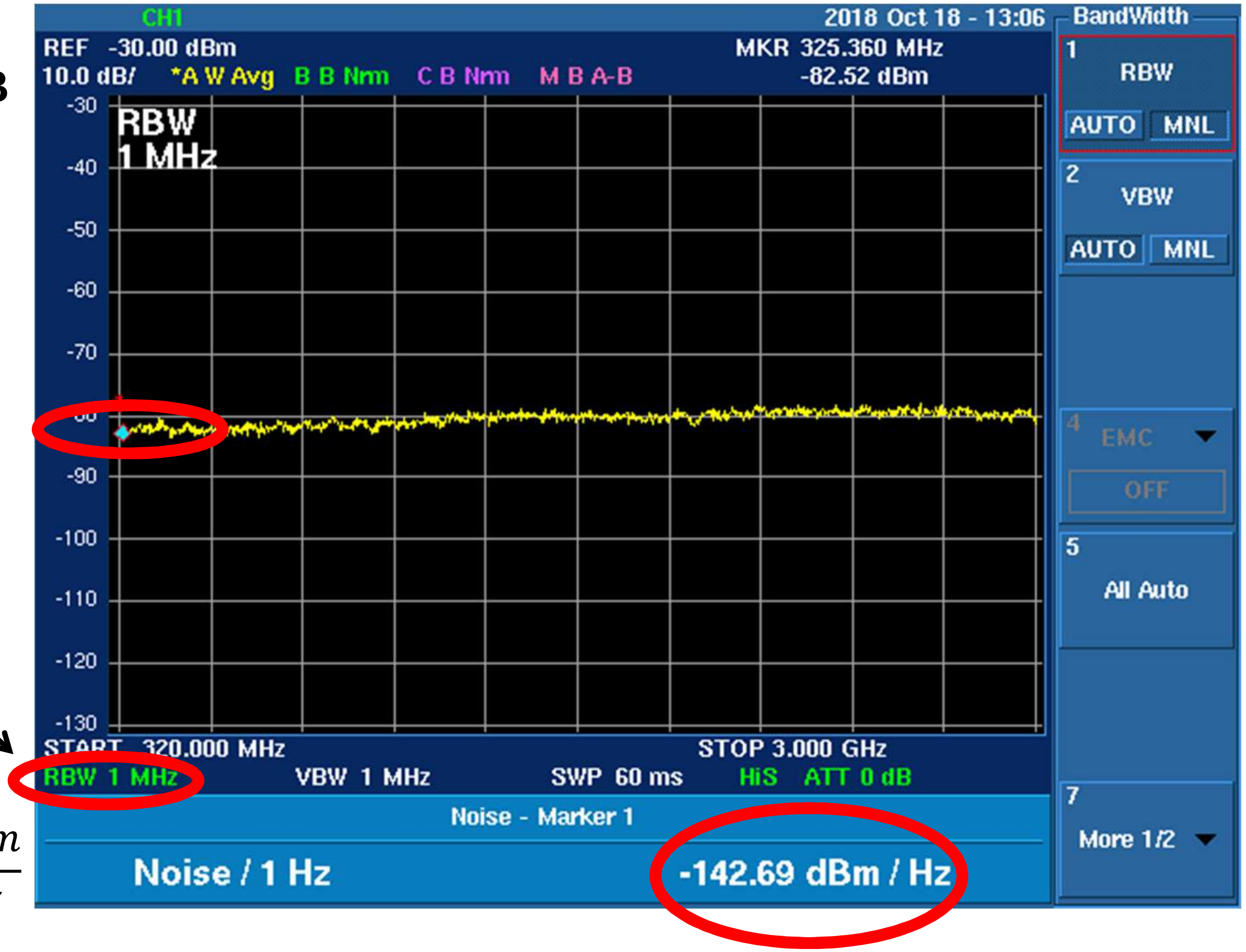

$$-82.5\frac{dBm}{1MHz} = -142.5\frac{dBm}{Hz}$$

$$-142.5\frac{dBm}{Hz} - 22dB = -164.5\frac{dBm}{Hz}$$

$$1.3\frac{nV}{\sqrt{Hz}} = \sqrt{50\Omega\,\frac{1\,mW}{Hz}10^{-16.45}}$$

Summary

- In house design was necessary due to special requirements
- High input impedance was needed for the Cryamp
- Large dynamic range for the high energy synchrotron amplifiers
- All three amplifiers are low noise designs
- Good gain flatness
- Fully remote controlled
- Internal test generators for gain drift check
- Recently brought in operation (Cryamp & Amplifier 110)

Outlook

- Further testing during the beam time in February 2019
- Completion of the p-Linac amplifier
- Thank you!!!