Pre-amplifier Impedance Matching for Cryogenic BPMs

P. Kowina, M. Freimuth, K. Gütlich, W. Kaufmann, H. Rödl and J. Wiessmann,
Gesellschaft für Schwerionenforschung (GSI), Darmstadt, Germany
N. Sobel, F. Völklein,
RheinMain University of Applied Sciences, Wiesbaden, Germany

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Abstract

Beam Position Monitors (BPMs) for the FAIR fast-ramped super conducting synchrotron SIS100 will be installed inside the cryostats of quadrupole magnets. This contribution focuses on the coupling path between BPM electrodes and low noise amplifiers installed outside the cryostat. Matching transformers (MT) meet well the requirements of reflection free signal transfer through the relative long lines without loading the capacitive BPM by 50 Ohm. Two different transformers based on toroidal cores made out of Vitroperm-500F nanocrystalline were tested. The form of windings and circuit geometry were optimized to improve linearity allow for resonance-free transmission over a required frequency range from 0.1 MHz to 40 MHz. The MTs have to be balanced pair wise within 0.1 dB and the geometry of windings has to be mechanically stabilized using e.g. epoxy resin. A choice of different epoxy types and their suitability for cryogenic operation was tested in liquid Nitrogen.

Requirements for Impedance Matching

- BPMs with Matching Transformers (MT) installed in cryostats
- Beam parameters:
  - bunch lengths of several meters
  - bunch frequency: 0.5MHz – 2.7MHz
  - Beam intensity from 1e8 to 4e13 charges per spill
- Required bandwidth of matching transformer: 0.1 – 40 MHz
- Dynamic of the signal amplitude of 120 dB
  - ⇒ good control of saturation effects.
- MT have to be pair-wise matched within ±0.1dB
- MT have to be suitable for cryogenic conditions
- Suitability for cryostat insulation vacuum of 1e-7 mbar is mandatory

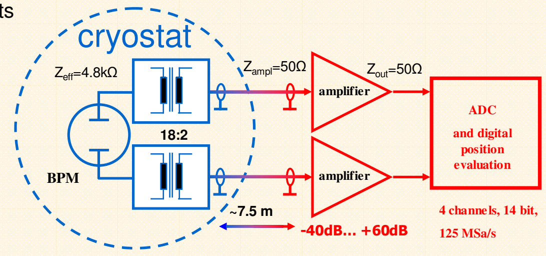

Figure 1:Schematic diagram of impedance matching by means of matching transformer.

$$Z_{eff} = (N_{pri} / N_{sec})^2 \cdot Z_{ampl}$$

Transfer function

- New and optimized design:
  - →Material: Vitroperm 500 F
  - →Winding ratio N_{pr}/N_{sec}=18 : 2
  - →Toroid dimensions:
    r_e = 20mm, r_i = 10.5mm, h = 10 mm
- Former design:
  - →Material: Vitroperm 500 F
  - →Winding ratio N_{pr}/N_{sec}=18 : 3
  - →Toroid dimensions:
    r_e = 8.6mm, r_i =5.9 mm, h = 7.4 mm
- Core saturation simulated by biasing the primary MT winding with a DC current via a BIAS-TEE

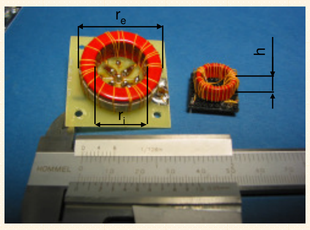

Figure 2: Matching transformers; New — optimized design (left) and former design (right).

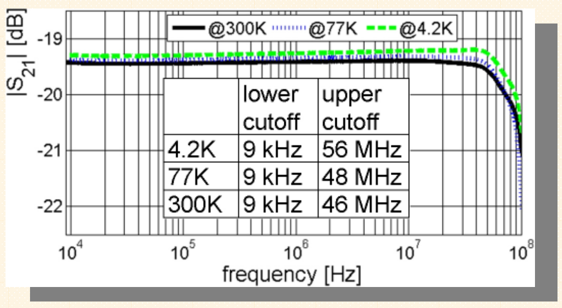

Figure 3: The transfer function of the optimized MT at different temperatures.

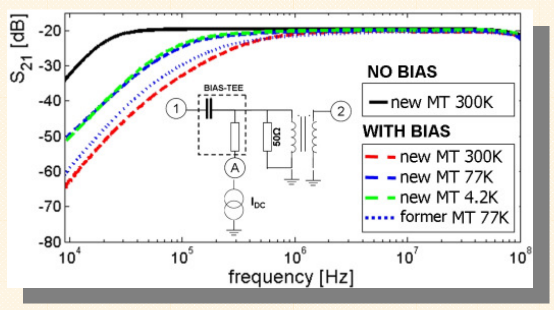

Figure 4: Saturation effects: The transfer functions measured with and without DC bias at different temperatures. The dashed lines show the transmission at a bias current of 450 mA which is equivalent to the highest expected BPM signal amplitude of 1.8 kV .

Cryogenic Test of MT Encapsulations

- 4 samples prepared for each epoxy type
- Each sample was tested in 10 thermal cycles in LN_2
- Epoxy constituents mixed with precision of 10^{-3} (0.1g)
- Admixture of Antifoam 88 used to reduce the surface tension and to remove air bubbles from epoxy material
- Encapsulations after filling kept 10 min. in a 0.1 mbar vacuum for outgassing

Table 1: Epoxy resins used in encapsulations under tests.

Main constituent	Second constituents	Total Thermal contraction* ΔL / L [%] 395 K to 4 K
Stycast 2850 FT	Catalyst 24 LV B	1.2
Stycast 2850 KT	Catalyst 24 LV B	----
Stycast 2850 GT	Catalyst 24 LV B	0.42
Araldite CW 299-3	Araldite CW 299-1	1.06
Stycast 1266 A	Stycast 1266	1.15

*Values of total thermal contraction ΔL / L are taken from: G. Ventura and L. Risegari, "The art of cryogenic", ISBN:978-0-08-044479-6 and CA. Swenson, Rev Sci Instrum (1997;68), p1312.

Figure 5: Matching transformers non-encapsulated and encapsulated in epoxy (from left top to down bottom). The order is the same as in Table 1.

Figure 6: Samples that survived cryogenic tests: Stycast 2850 KT (left) and Stycast 2850 KT (right).

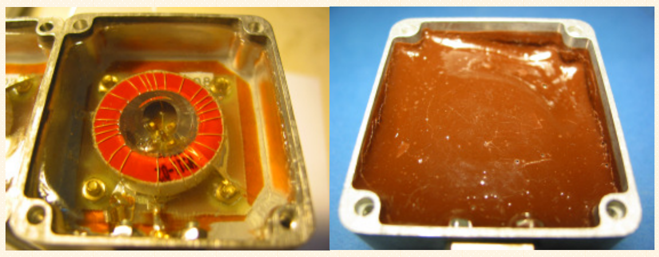

Figure 7: Materials those structure was destroyed during the thermal cycling: Stycast 1266 A/B (left), Araldite CW 299 (right) and Stycast 2850 FT (not shown).

Figure 8: Cryogenic test of encapsulation samples. Extension out of semi-rigid cables used to slow down the cooling. Otherwise shock cooling would generate additional stress in epoxy and toroid material.

Outgassing of Epoxy Materials

- Outgassing is driven by two processes: desorption from surface and diffusion from bulk material.
- Outgassing data (Fig.9) fit by beans of Non-linear Least-square with function:

$$f(x) = a \cdot \exp(-\frac{t}{\tau_1}) + b \cdot \exp(-\frac{t}{\tau_2})$$

τ_1 – desorption coefficient
τ_2 – diffusion coefficient
a, b - coefficients of normalization

- Samples: 1mm thick plates with area of 5 x 10cm²
- Measurement time: ~50 days / sample
- After 100 h outgassing rate reach 3,6e-8 mbar * l / s / cm²
- Constituents of outgassing analyzed by a mass spectrometer; no organic contamination found (Fig. 10)
  - ⇒ Stycast 2850 GT is suitable for insulation vacuum of 1e-7 mbar.

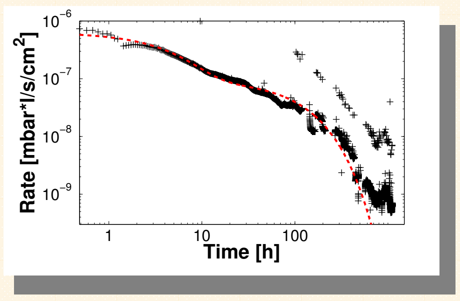

Figure 9: Outgassing rate for Stycast 2850 GT. Parameters of non-linear least square fit:
τ_1 = 4.55 h, τ_2 = 114.9 h, a = 5.37e-7, b = 9.5e-9

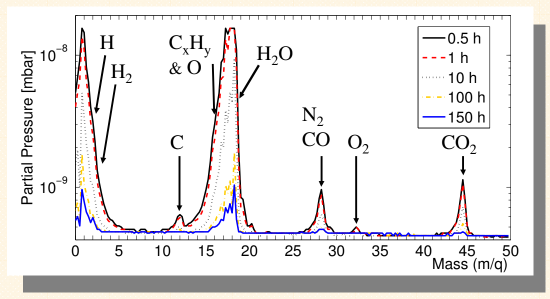

Figure 10: Mass spectrum of the constituents of the outgassing flux for Stycast 2850 GT. Spectrum is dominated by water vapors. No indication of an organic contamination is observed.

Acknowledgment

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Conclusions and perspective

- It is shown, that the optimized matching transformers are able to transmit BPM signals in the required frequency range also at cryogenic temperatures.
- To minimize the offset of the BPM position determination the MTs have to be pair-wise balanced within ± 0,1 dB.
- Geometry of windings has to be stabilized in encapsulation out of epoxy resign.
- Total thermal contraction of Stycast 2850 GT and Stycast 2850 KT match the contraction of toroid material
- Stycast 2850 GT is suitable for the insulation vacuum and its.
- For a complete prove of the cryogenic suitability of the encapsulation further tests in temperature of LHe are required.