ELENA Longitudinal Schottky diagnostics and intensity measurement expected performances

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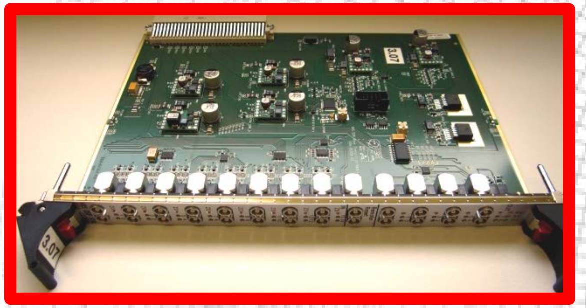
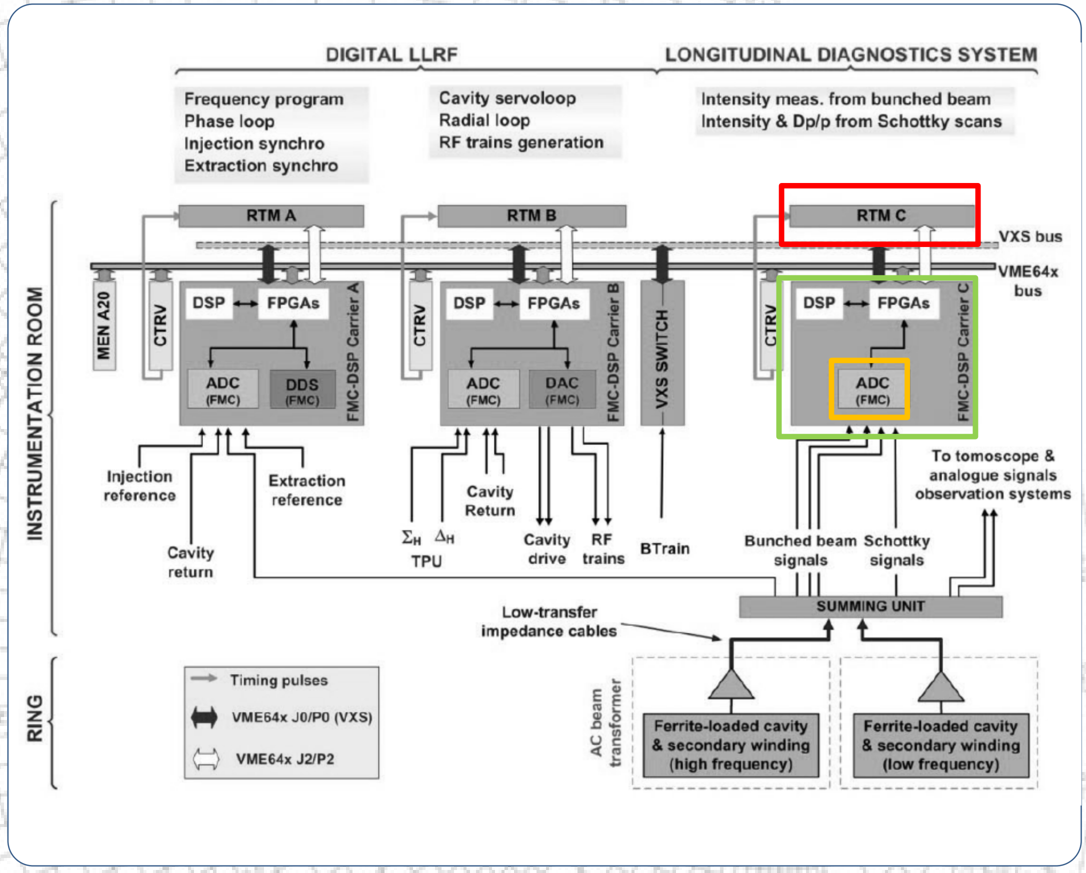
Overview

- Longitudinal processing hardware.
- ADC measured performances.
- Longitudinal PU system: overview.
- Beam transformer: Ferrite choices and measured characteristics of Q and magnetic permeability μ, expected performances.
- Simulated noise figures.
- Measured parameters in the manufactured transformers.
- Conclusion.

Longitudinal Processing HW

Longitudinal Processing Hardware





The longitudinal processing sub-system, is independent of the LLRF.

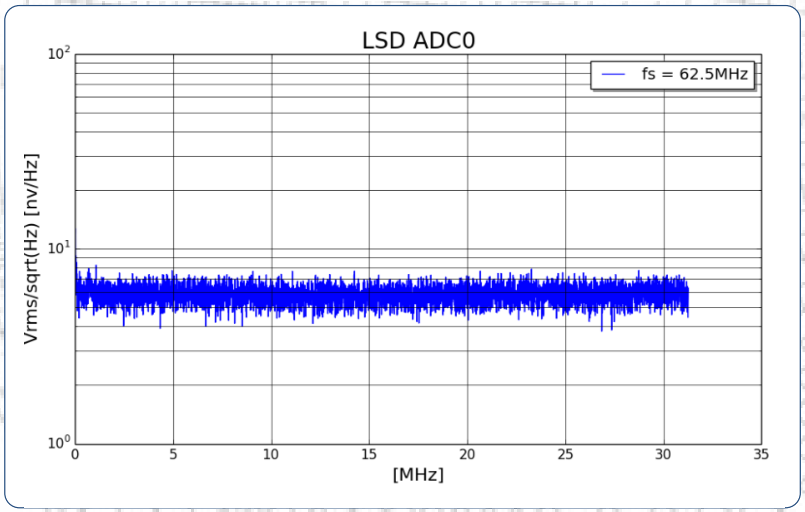
Calculations are made in an Virtex 5 FPGA (fast algorithms for integration + FFT) and DSP (slower and repetitive tasks).

ADC measured performances

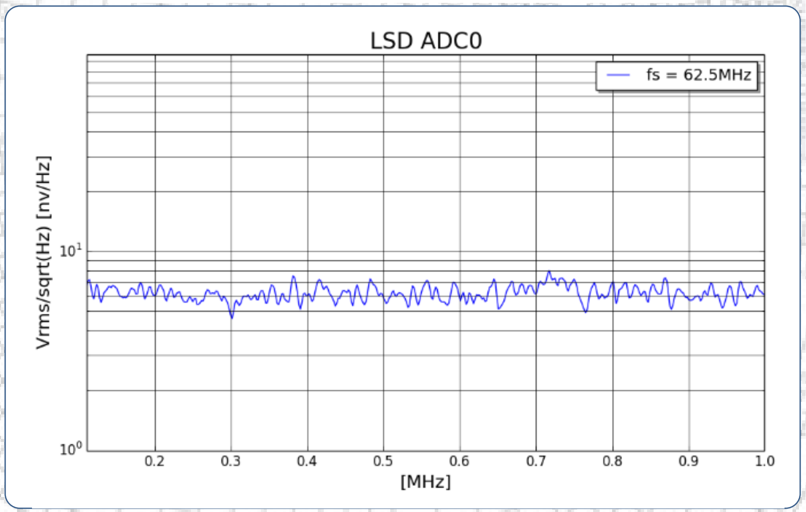
- ADC module developed for low noise longitudinal Schottky intensity measurements
- Measured performance:
  - Noise floor < 10 $nV/\sqrt{Hz}$ [more than 4 times (12dB) better than the noise floor level present at the output of the LNA, when in maximum gain (Zt = 20 $k\Omega$)]
- The same ADC module is used in the Orbit measurement system

Status:
A complete series has been produced, and is going to be tested once is received from the assembly company.

Measured wideband (62.5MHz) input referred noise LSD [nV/sqrtHz]

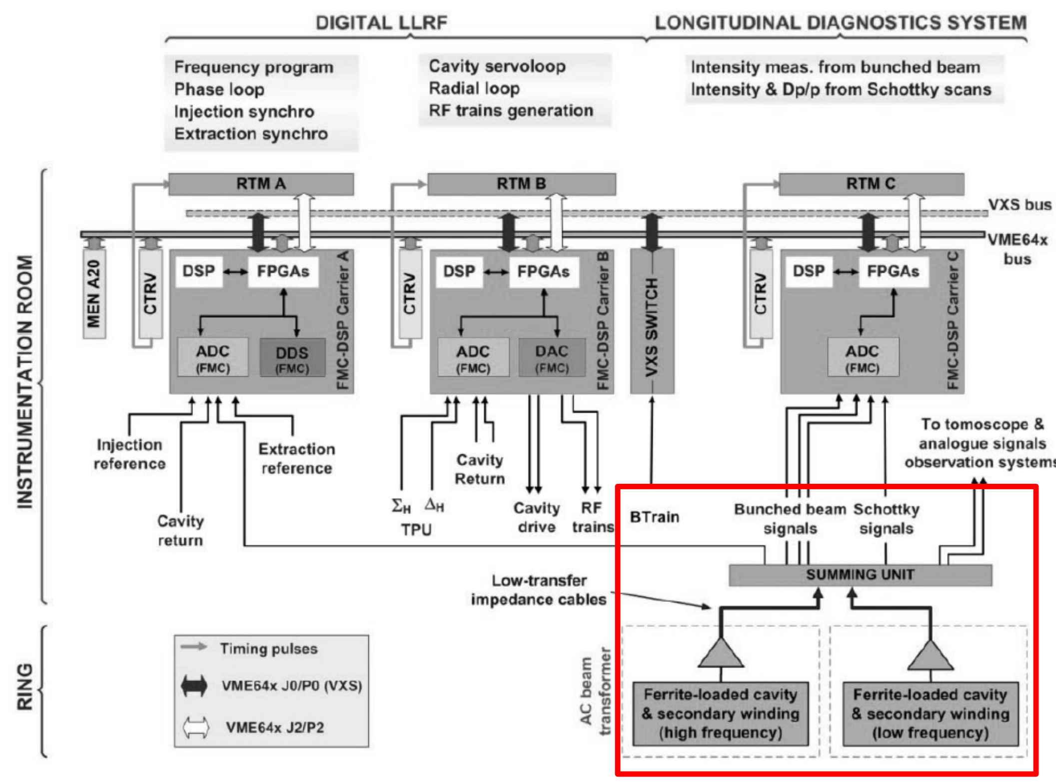


Measured 0.1 to 1MHz input referred noise LSD [nV/sqrtHz]

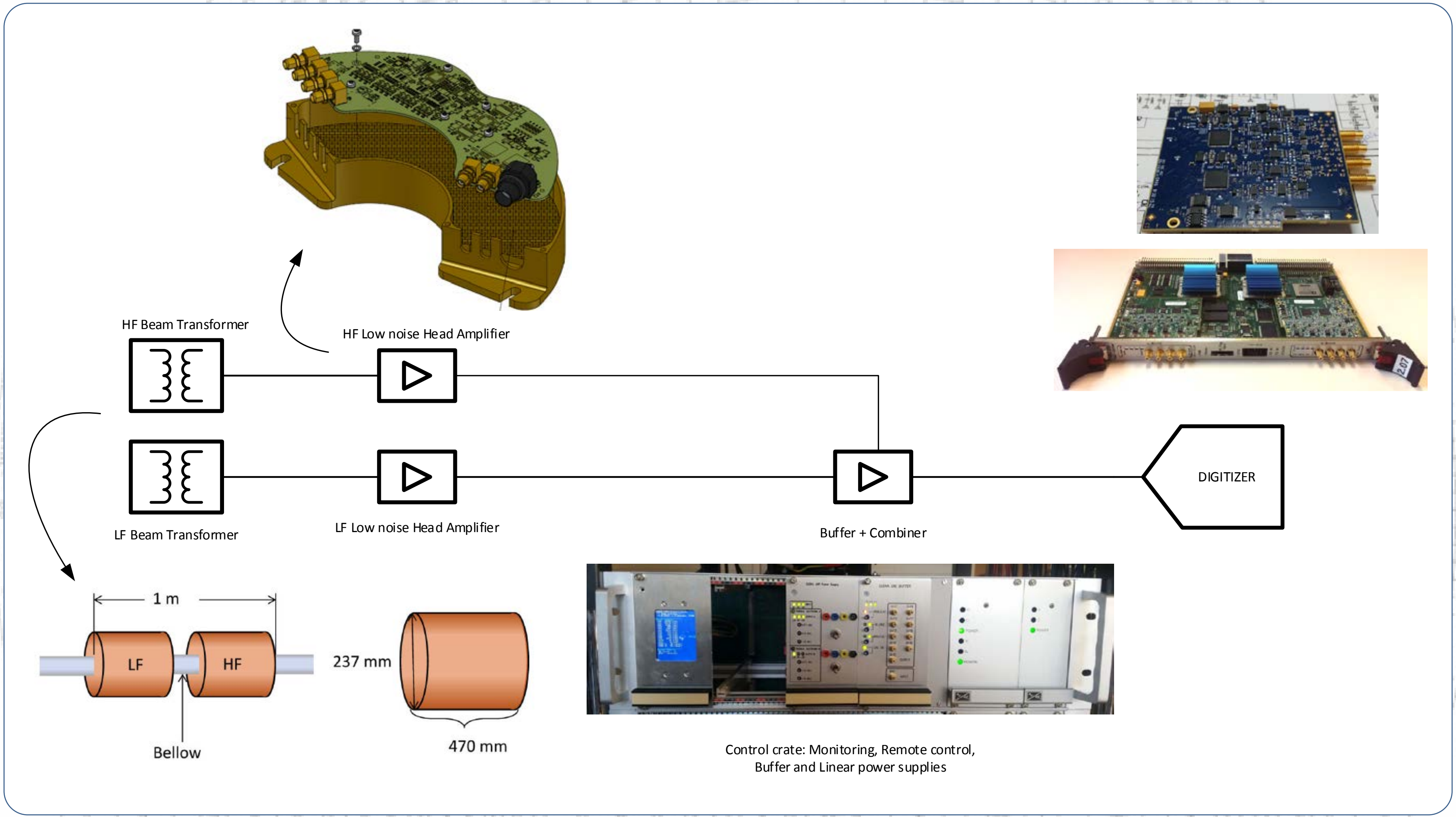


Longitudinal PU system

- Two LPU (Longitudinal Pick Up) are needed to cover the ELENA revolution frequency range.
- Each LPU unit has a low noise amplifier (LNA) to amplify the small signal level present at the output of the pick-up, to an adequate level to be distributed far away to the RF crates.
- One summing unit is needed to combine the signals coming from the high and low frequency LPU's, to give a flat frequency response over the whole bandwidth.

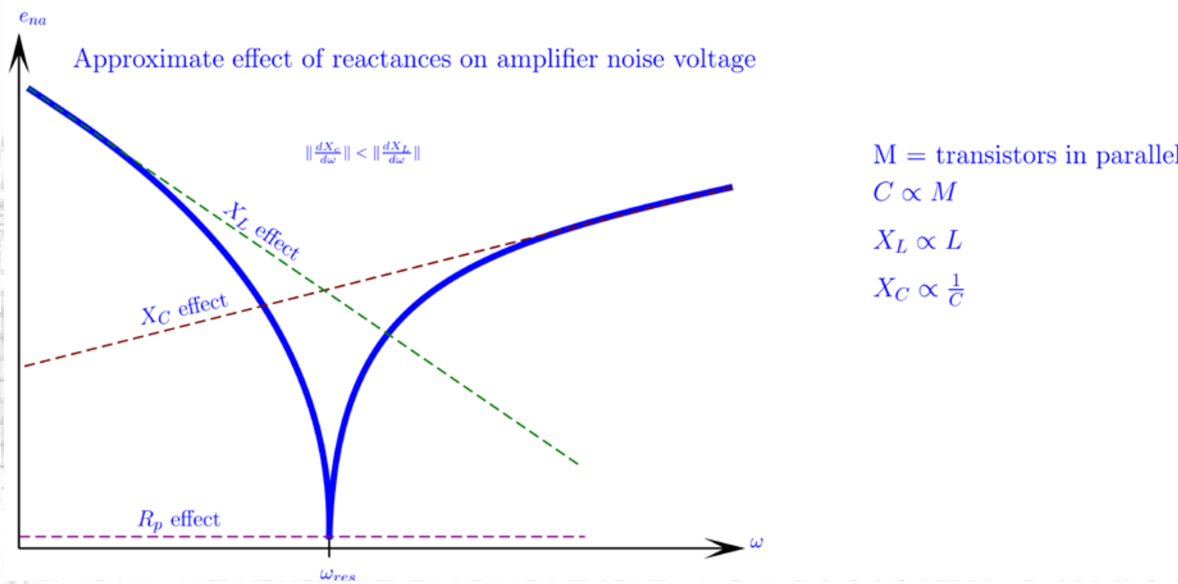


Overview of system components

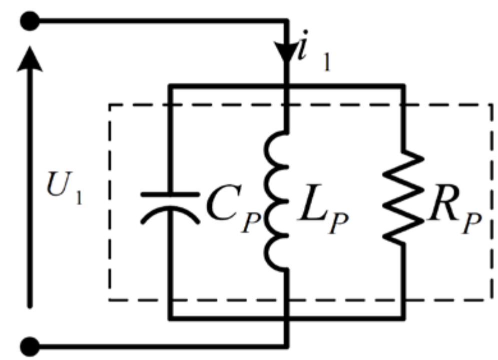


Beam transformer performances

- Amplifier noise sources: converted into equivalent input current noise.
- Amplifier total current noise: dominated by the amplifier input voltage noise, converted into noise by the transformer impedance. Current noise negligible for JFET input stage.
- Minimum equivalent input noise: bounded by the resonator loss (Rp = Shunt equivalent resistance)



- Low f noise tail: dominated by inductance (we require high Lp)
- High f noise tail: dominated by capacitance (Cp has to be kept as low as possible)



Beam transformer: parallel resonating structure

Noise characteristics determined –mainly- by the ferrite properties

Ferrite choices: measurements

3 Ferrite types where chosen for the longitudinal pick-ups:

- C2010: specific type for the high frequency (HF) unit, featuring high Q up to ~4.5MHz.
- CN20: specific type for the RING low frequency (LF) unit, featuring high permeability up to ~2MHz
- CN20X: slightly higher permeability than CN20. Is a 2nd batch that was needed to complete the transfer line pick-ups.

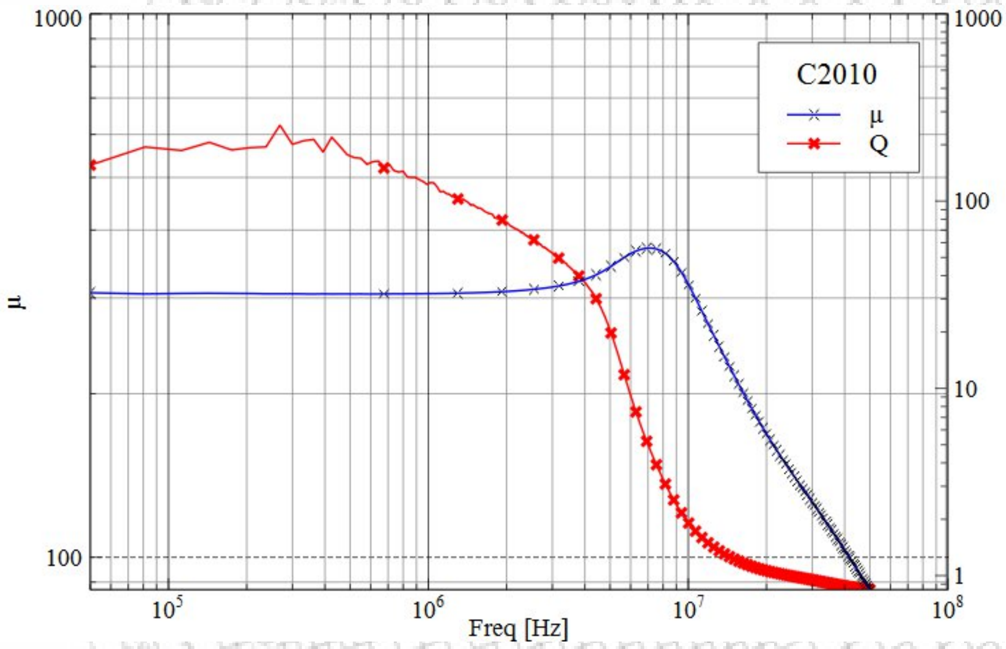
Different choices where made for the coil ratios, to improve the noise characteristics of the system:

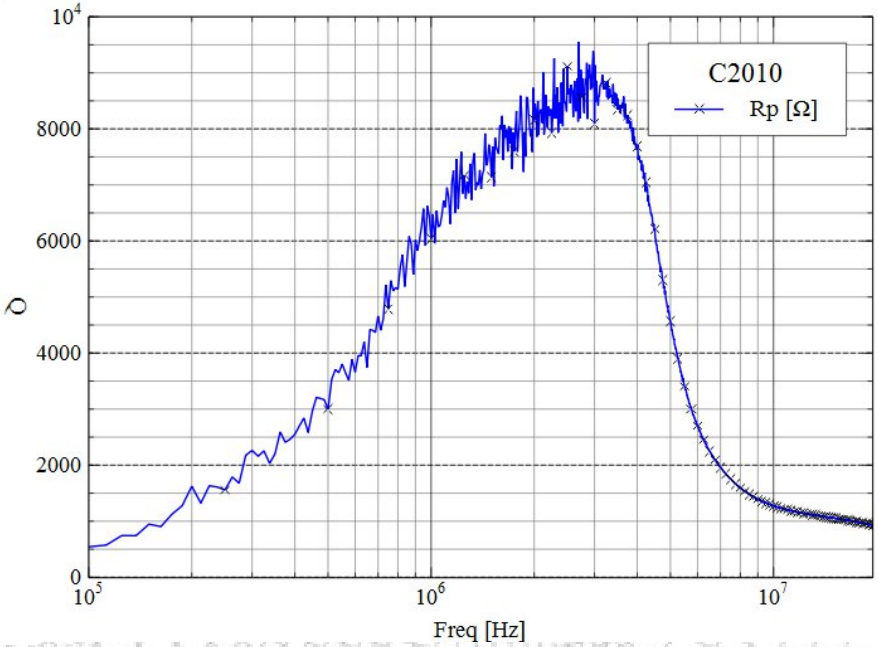
- Low frequency PU units (both sets: CN20 and CN20X): N = 5
- High frequency PU units: N = 2

HF (C2010) Fe Performance

Cavity inductance goes up to 9µH for a relative permeability µ=300

The peak measured equivalent shunt resistance (in the test cavity) is Rp = 9kΩ at 3 MHz, corresponding to an equivalent noise current *in_p* = 1.33pA/sqrtHz.

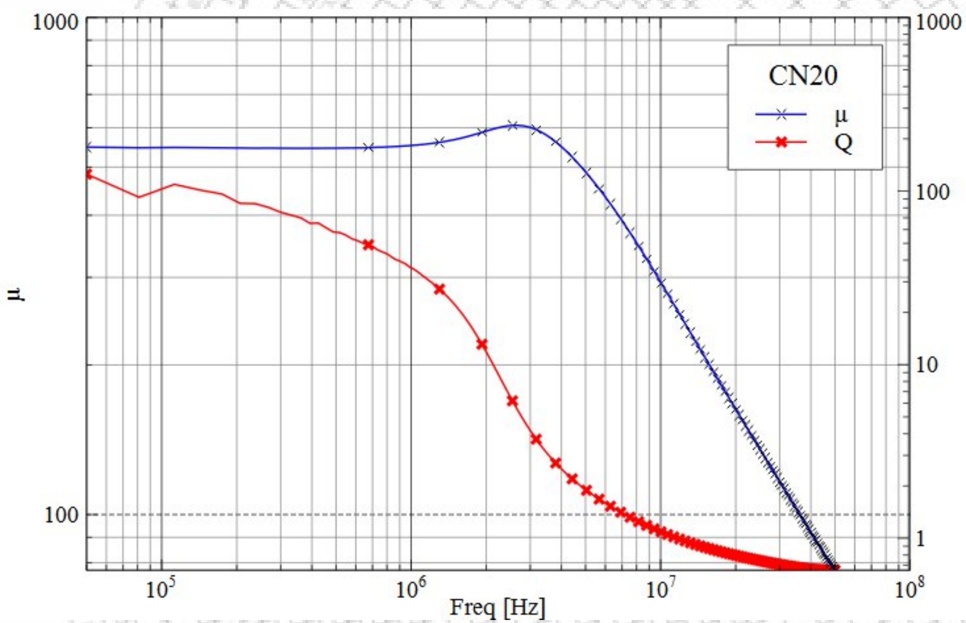


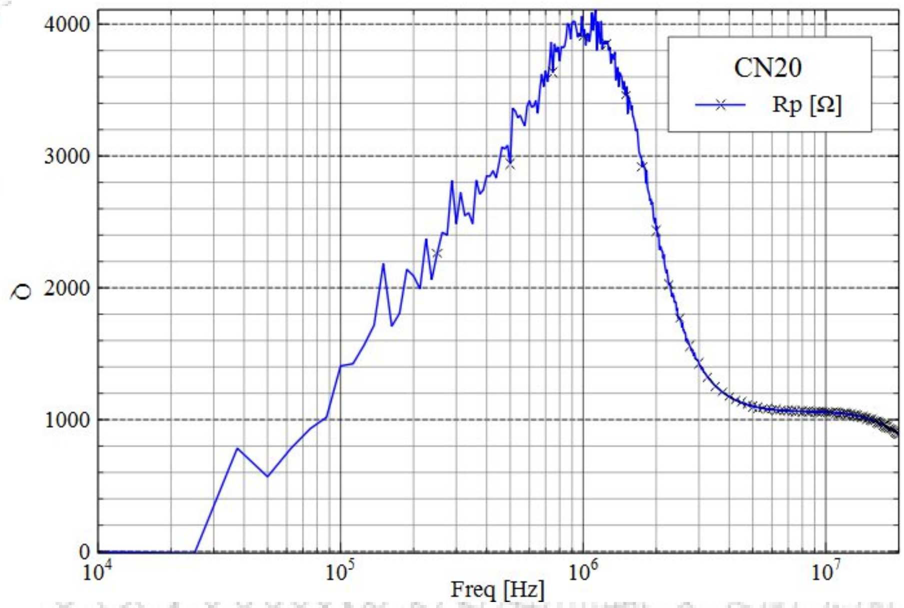


LF (CN20) Fe Performance

Cavity inductance goes up to 17μH for a relative permeability μ=550

The peak measured equivalent shunt resistance (in the test cavity) is Rp = 4kΩ at 1 MHz, corresponding to an equivalent noise current *in_p* = 2pA/sqrtHz.

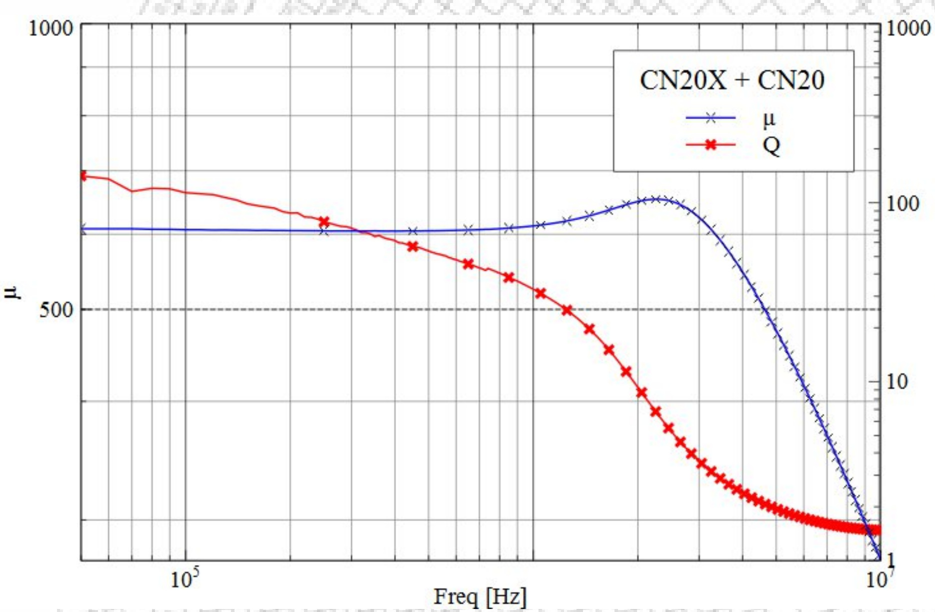


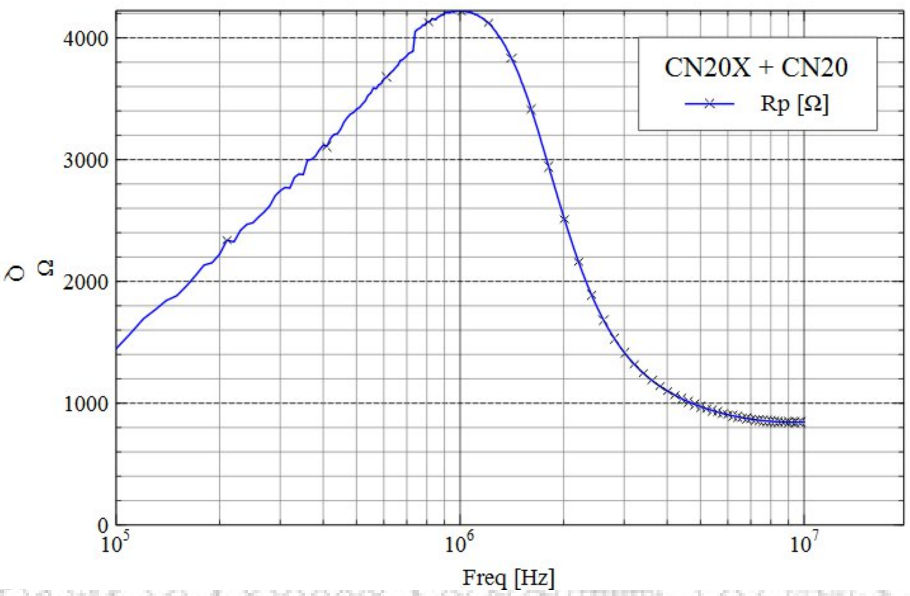


LF (CN20+CN20X combined) Fe Performance

Cavity inductance goes up to 20µH for a relative permeability µ=600

The peak measured equivalent shunt resistance (in the test cavity) is Rp = 4.2kΩ at 1 MHz, corresponding to an equivalent noise current *in_p* = 1.95pA/sqrtHz.

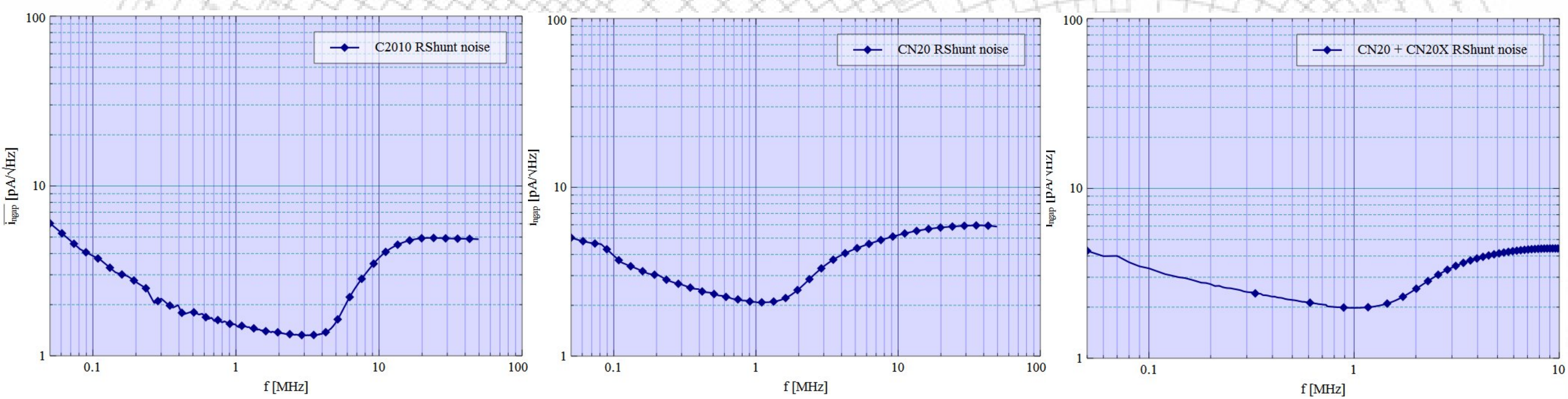




Expected performances: Rp noise at gap

The Rp (shunt) noise, is the minimum achievable noise given by the resonator losses

The figures shown, which are actual measurements taken with the test cavity, are the locus of the minimum noise points for all possible tuning frequencies.



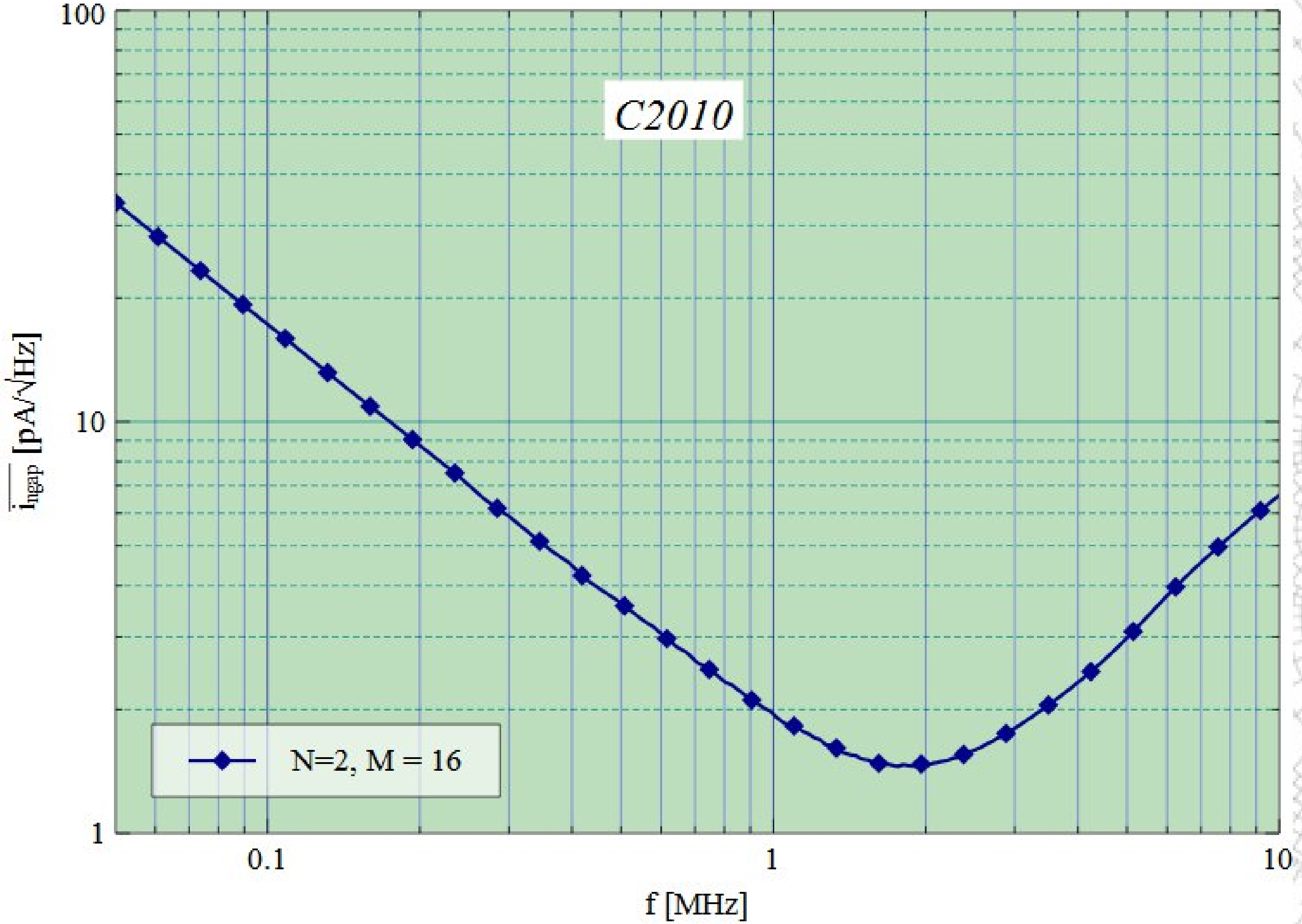
The optimum tune values (resonance point) for the pick-ups are:

- LF: 1MHz
- HF: 3.5MHz

However, as the amplifier input impedance is capacitive there is a trade-off between the actual total noise (Transformer + Amplifier) and the achievable tuning point.

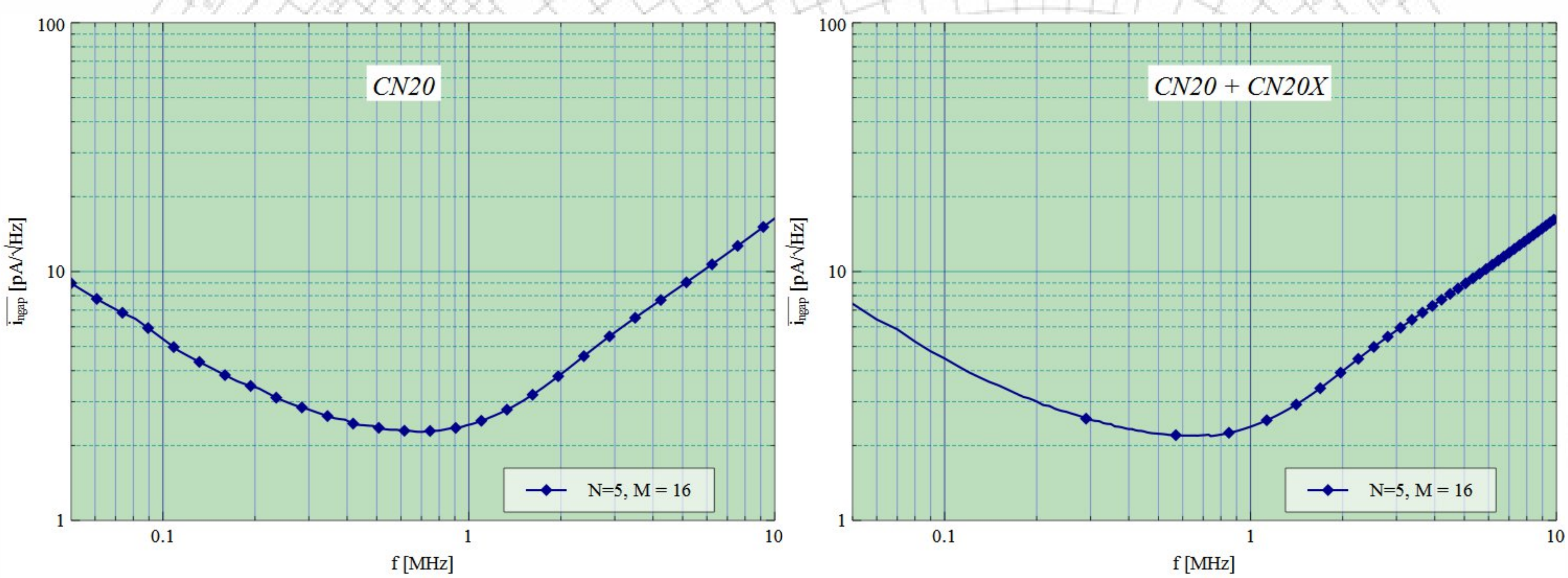
Expected performances: total noise at gap (Transformer + Amplifier)

HF Transformer.
Minimum noise density at ~2MHz: ~1.5 pA/sqrtHz.
High frequency noise: 7 pA/sqrtHz at ~10MHz



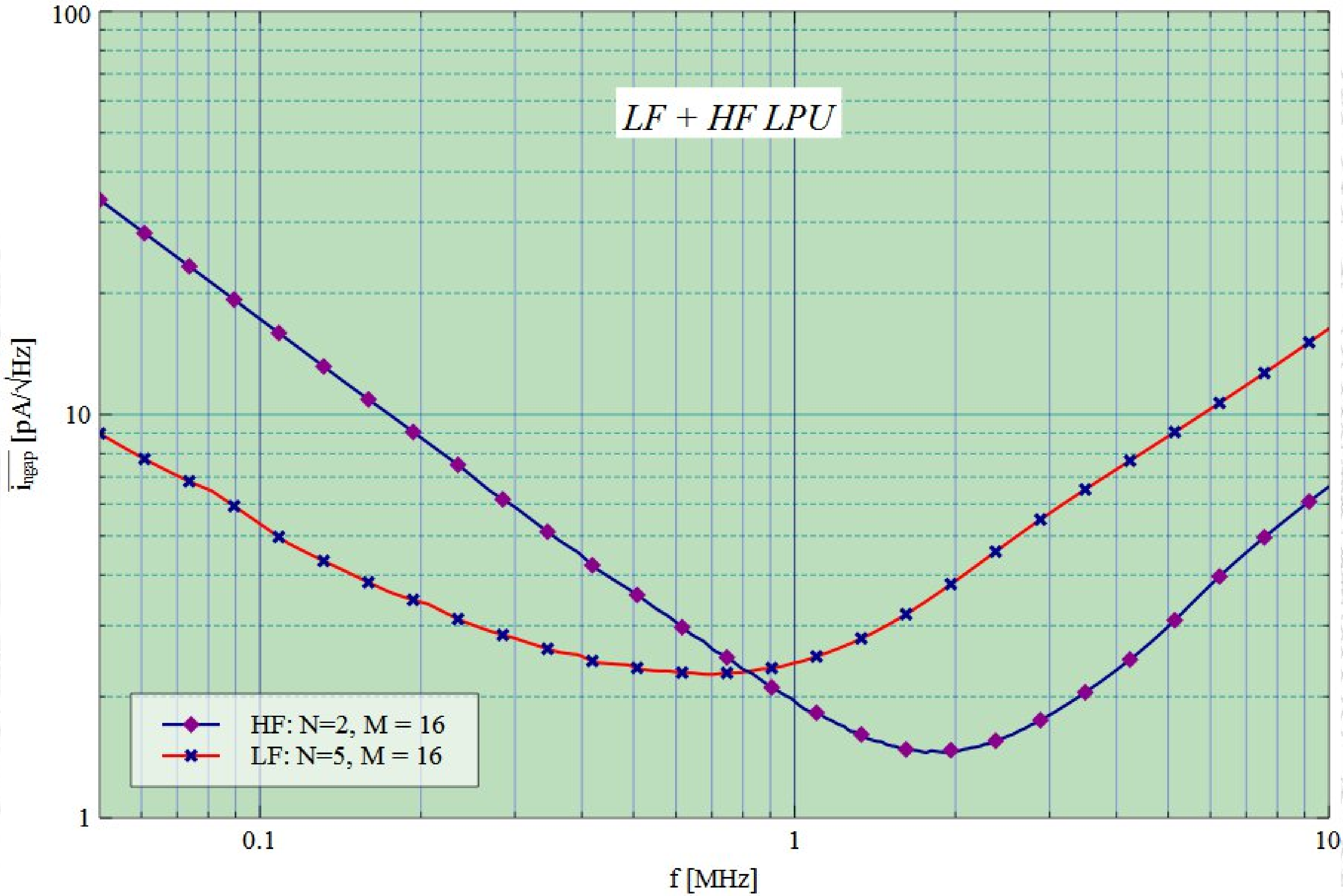
Expected performances: total noise at gap (Transformer + Amplifier)

LF Transformer, both Fe combinations.
Minimum noise density at ~650KHz: ~2.3 pA/sqrtHz.
Low frequency noise: 3.5 pA/sqrtHz at ~200KHz (slightly better for mixed ferrites, with 3 pA/sqrtHz)



Expected performances: total noise at gap (Transformer + Amplifier)

Combined LF + HF LPU in the ring: the optimal cross-over frequency is ~800KHz

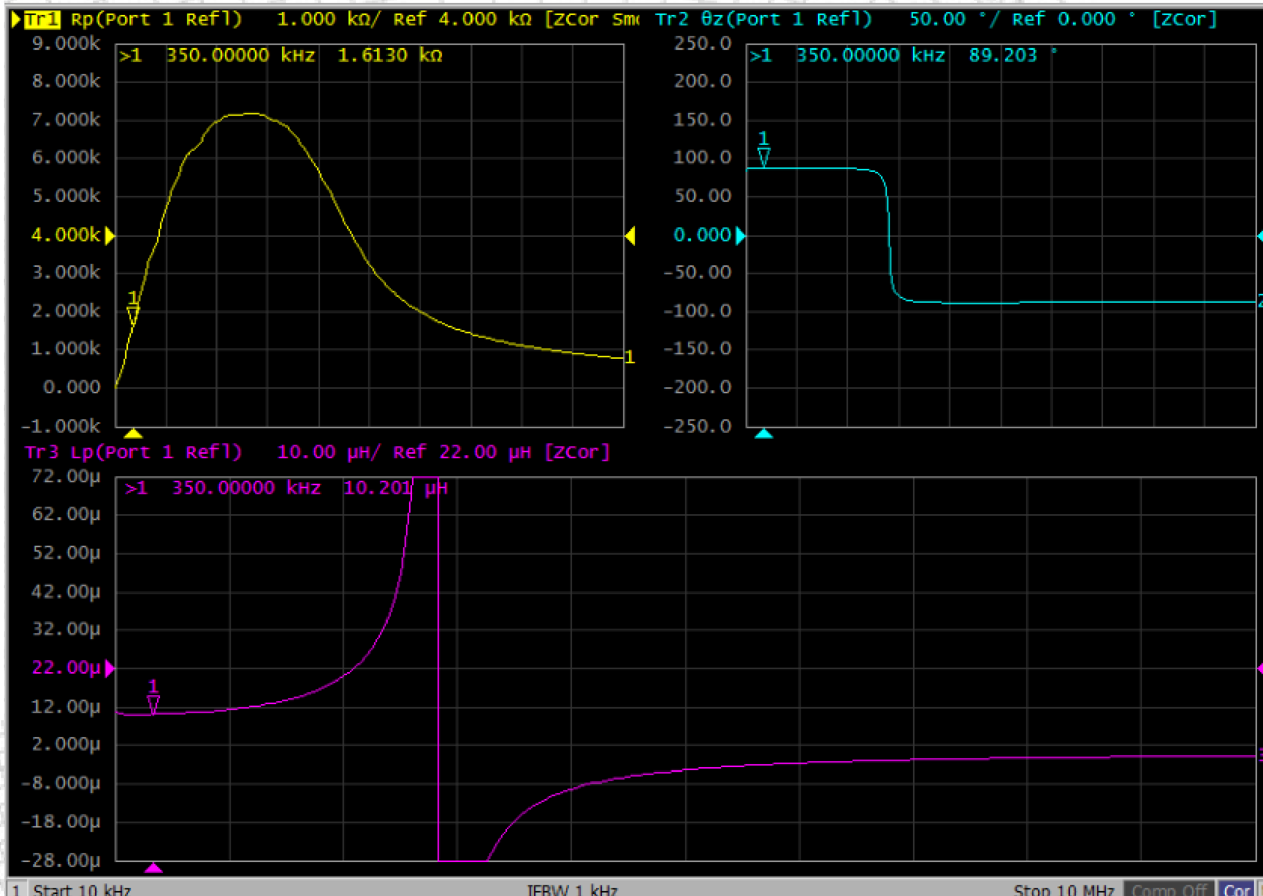


Expected performances: measured impedance in final units

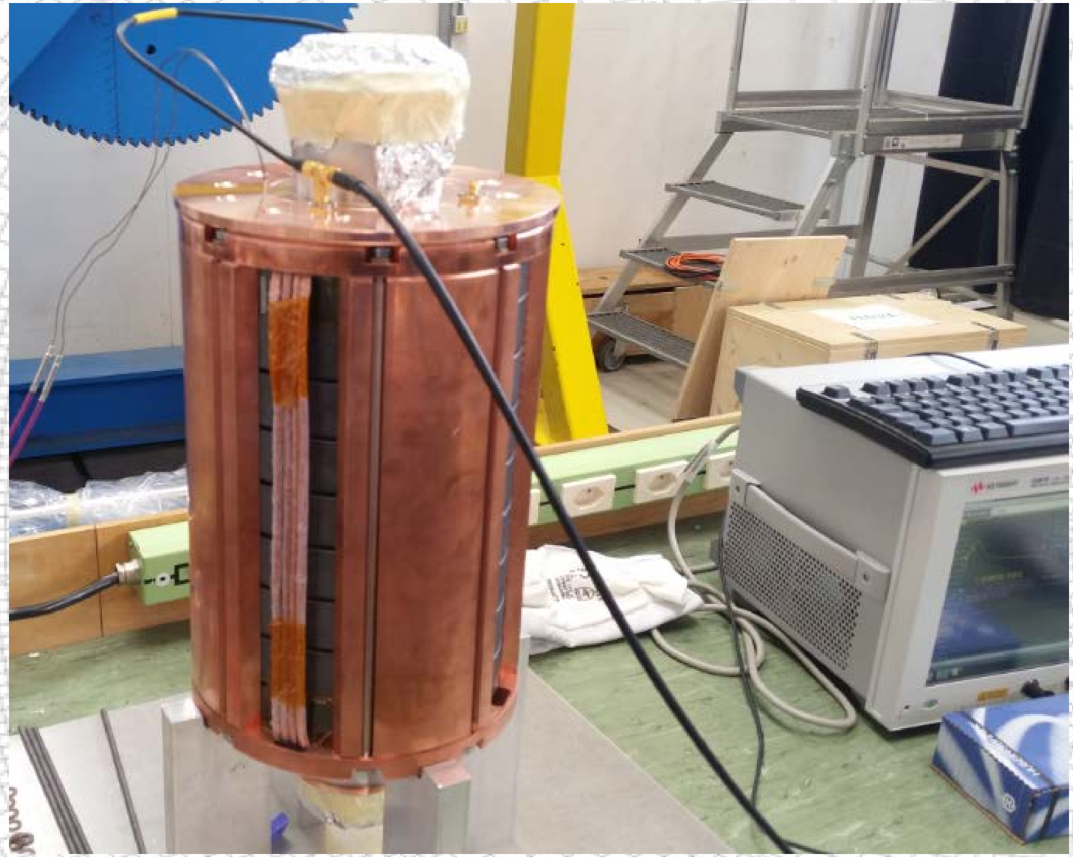
HF LPU after cavity was welded:

- Impedance measured in Primary coil (gap) with secondary's in parallel.
- Measured Rp at gap = ~7kΩ [9kΩ with ferrite alone in test cavity]. Reduction factor = 1.3 (possibly due conductive losses in ferrites in close contact with copper walls?..)
- Measured Lp at gap = ~10µH [9µH in test cavity] (reduced stray inductance?..)

With the actual measured Rp, the minimum noise is expected to be 1.5 pA/sqrtHz instead of 1.33 pA/sqrtHz, or a factor 1.14



Expected performances: measured impedance in final units

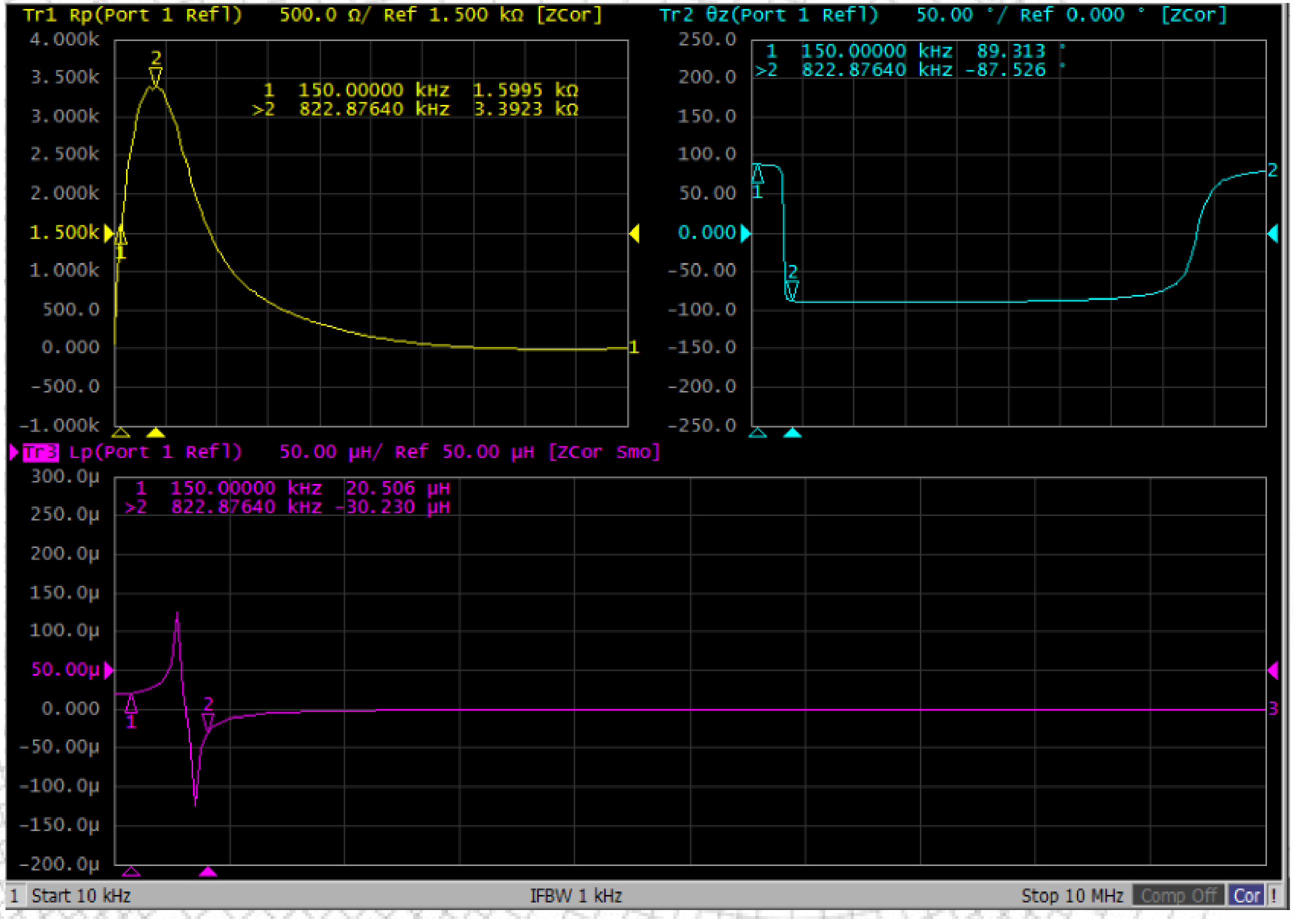


Expected performances: measured impedance in final units

LF LPU (CN20 + CN20X) after cavity was welded:

- Impedance measured in Primary coil (gap) with secondary's in parallel.
- Measured Rp at gap = ~3.4kΩ [4.2kΩ with ferrite alone in test cavity]. Reduction factor = 1.2 (possibly due conductive losses in ferrites in close contact with copper walls?..)
- Measured Lp at gap = ~20µH [17µH in test cavity] (reduced stray inductance?..)

With the actual measured Rp, the minimum noise is expected to be 2.2 pA/sqrtHz instead of 1.95 pA/sqrtHz, or a factor 1.13



Conclusions

- Predicted noise levels are better than the intended ones for the LF transformer (2.3 pA/sqrtHz vs 3.5 pA/sqrtHz (see F. Pedersen presentations from 2012), while the performance of the HF transformer is as good as expected.

- Measurements taken during transformer assembly shown that the actual shunt resistance (Rp) values are slightly lower than expected, which will certainly produce an increment in the noise levels with a factor of ~sqrt(1.13) (nearly 7% more noise) in both cases (HF + LF).

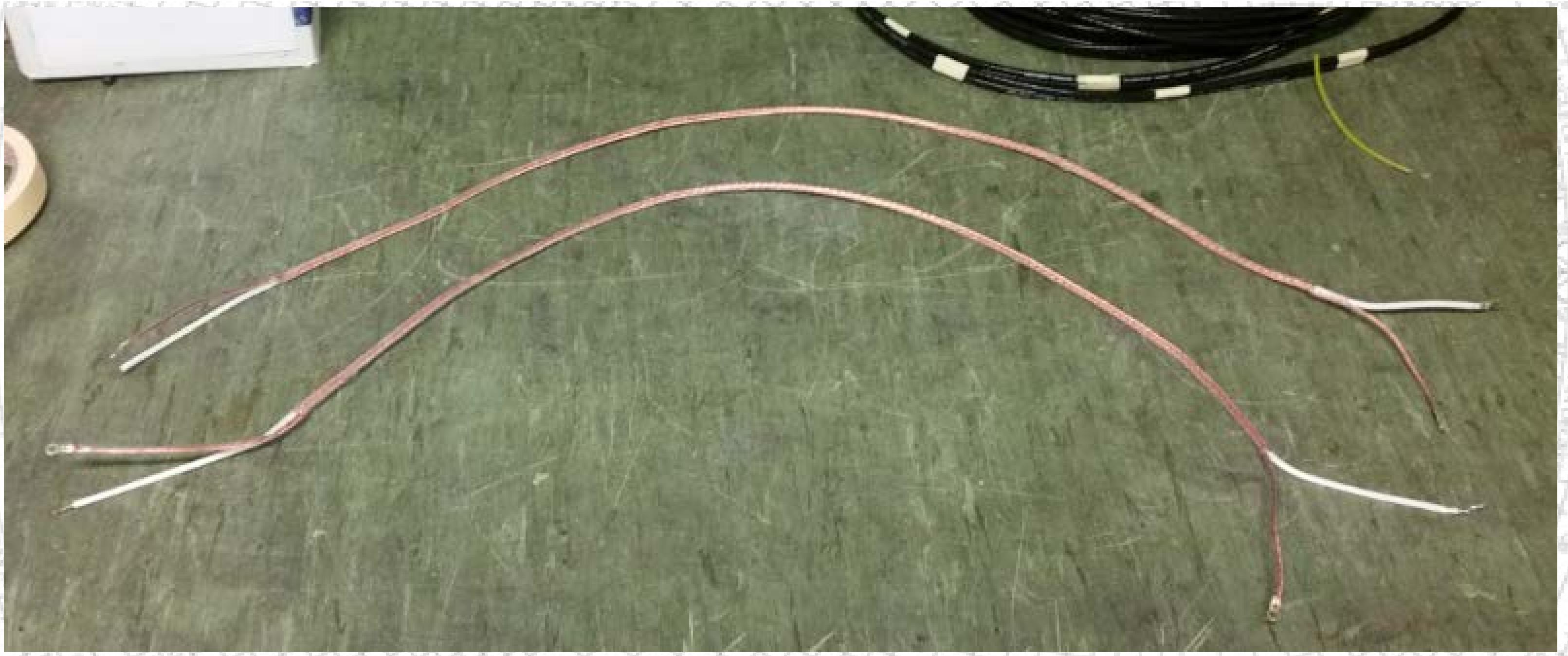
- The simulation codes provided an accurate prediction of the behaviour of the noise figures, as measured in the lab set-up, but did not predict the observed effects in the welded cavities. More factors had to be taken into account, and a better physical model is required.

- With the observed results, the combined CN20 + CN20X LF transformer (which has a slightly better noise figure) is mounted in the ring, as the extra inductance does not benefice by a substatial factor the required transient response for the transformers installed in the transfer lines.

Back-Up slides

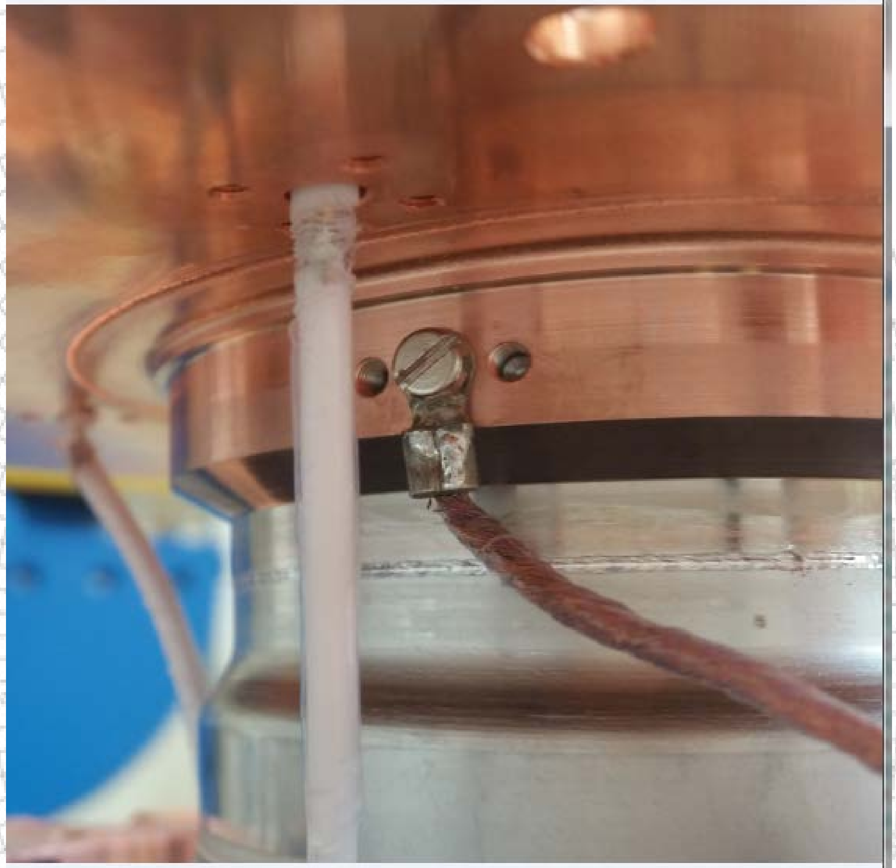
Production

- Coils:
  - Made with PTFE coaxial (Belden 89259), with FEP jacket removed and replaced by a PTFE shrink sleeve.
  - PTFE core thermal stability assessed at 250 deg. Celsius (meltdown starts at 300 deg. C.)
  - Shrink sleeves stable up to 250 deg. C.

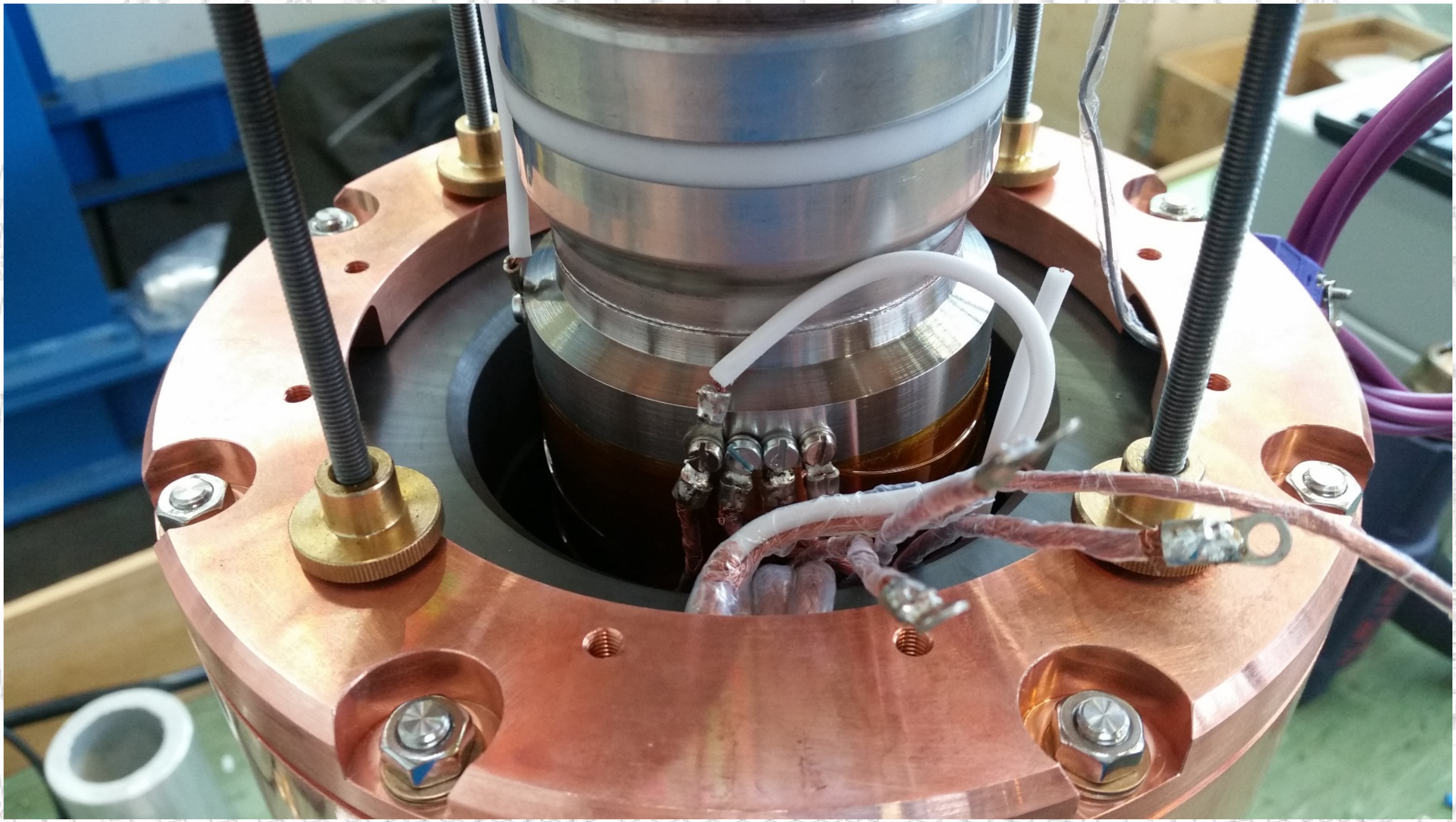


Production

- Coils:
  - Terminals: crimped solder lugs with high melting point tin (Sn96Ag4, stable up to 220 deg. C, melt down starting at 250 deg. C.)
  - Connectors: cable is turned around terminal, and then is soldered with Sn96Ag4. A PTFE thermal shrink sleeve is also used, to guarantee mechanical stability between 220 deg. C and 250 deg. C., avoiding wire to escape (very difficult fault to fix in a welded cavity like this!).



Production

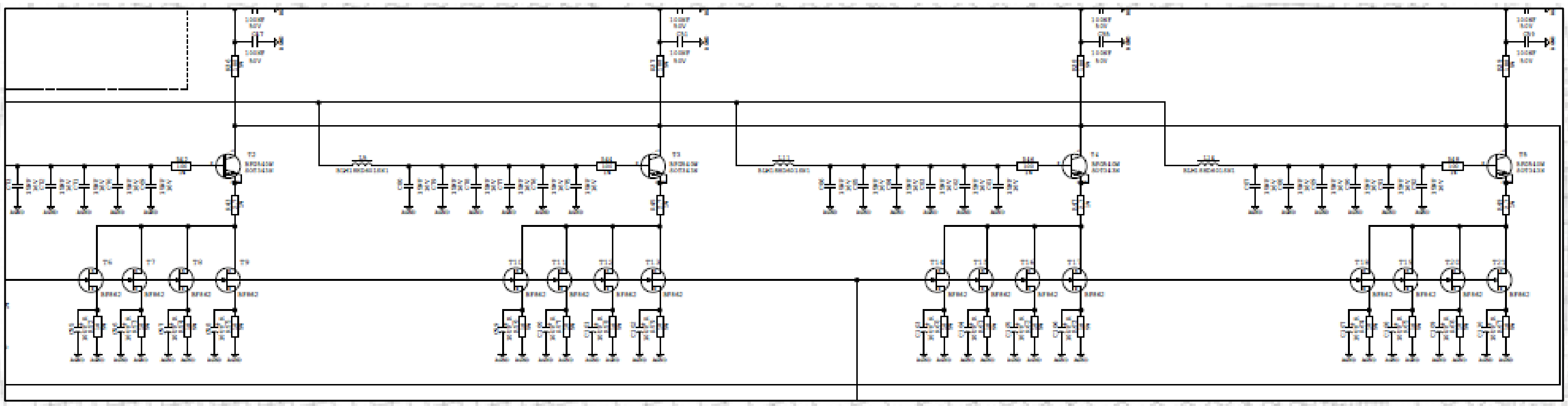


LNA

The LNA (head low noise amplifier), is an active feedback transimpedance amplifier, with paralleled input JFET transistors, to lower the total voltage noise.

It is a modified version of the AD design, with improved noise and bandwidth.

There are two versions, which are optimized to work in closed loop with the beam transformer types: HF and LF.



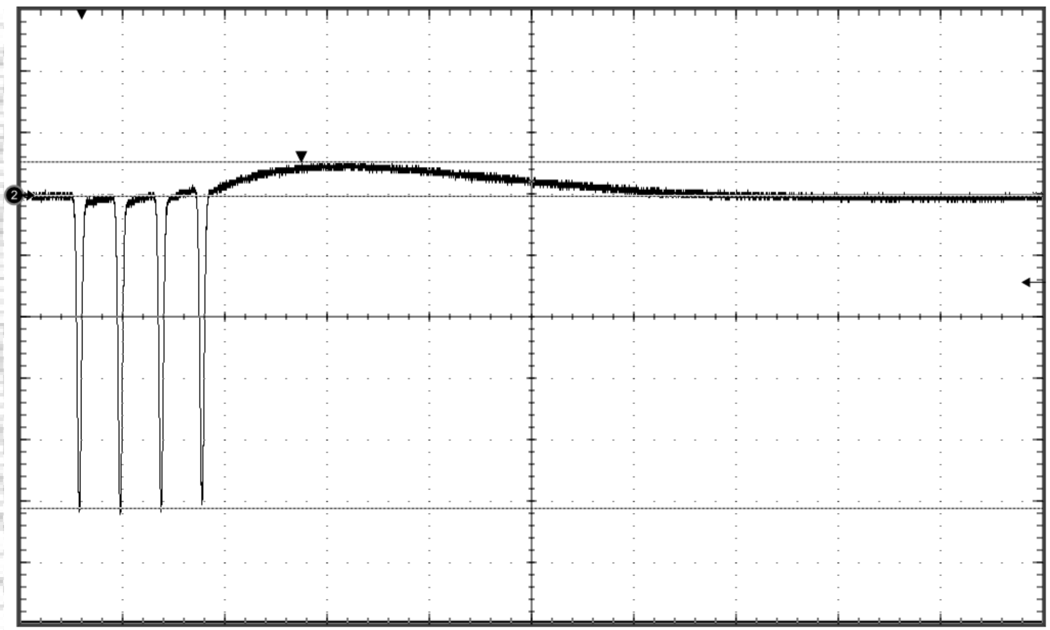
It has two selectable transimpedance gains: 4 kΩ and 20 kΩ, and features a wide output dynamic range > ±10V

LNA

The LF (low frequency) version, has to provide a fast time response to avoid baseline distortion due AC coupling.

It has been optimized to provide a proper response (within 1% error in baseline), during extraction at harmonic 4.

The figure shows the measured response of the prototype amplifier, working in closed loop with the LF pick-up (test cavity):



	Value	Mean	Min	Max	St Dev	Count	Info
C2 Freq	499.7kHz	499.66689k	499.7k	499.7k	0.0	1.0	
C2 +Ovrsht*	11.02%	11.023622	11.02	11.02	0.0	1.0	

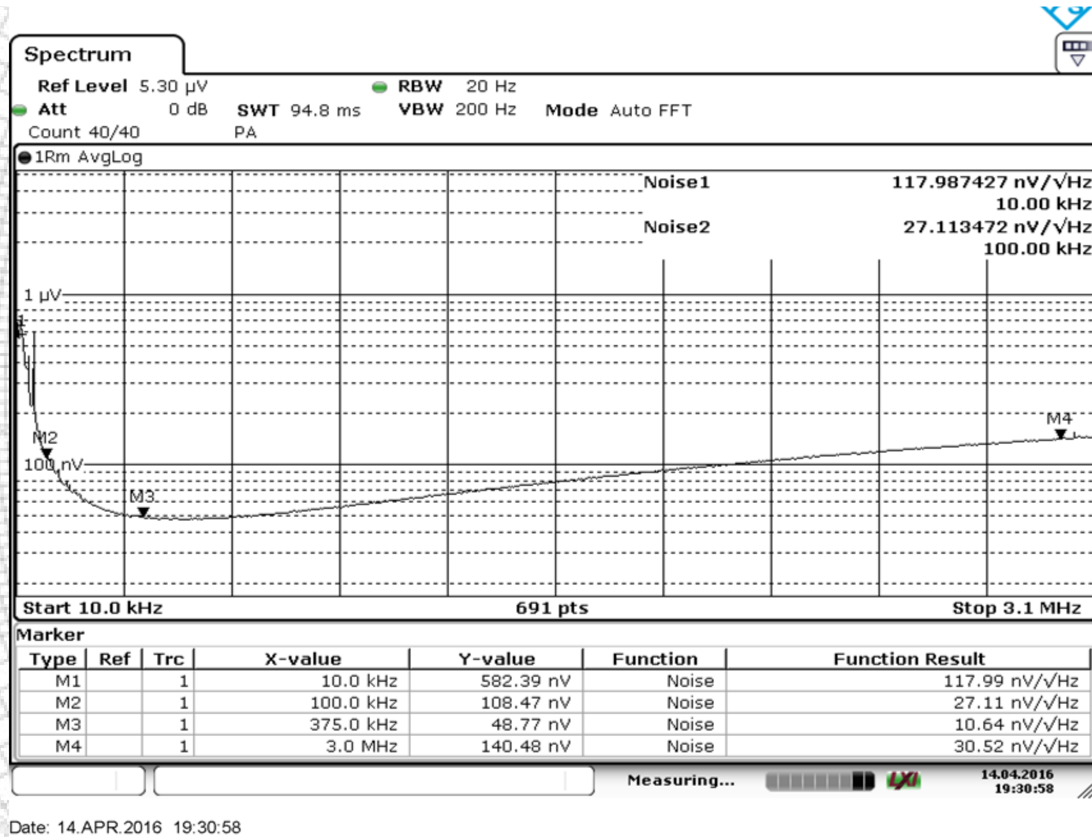
LNA

The LF amplifier provides a 2nd order response at low frequencies, delaying the undershoot outside of the bunch window. This is accomplished by tuning the feedback network, placing a pole-zero pair between the origin AC coupling zero, and the damped resonator lower pole, getting the effect of a gain 'bump' with flat phase before the frequency of the 4th harmonic:

LNA

The LF (low frequency) version has been tested for noise levels in the laboratory (the HF version could not be measured, as the cavity resulted too noisy [need of a welded cavity], but the loop stability and gain levels could be assessed).

The obtained noise levels are slightly over the predicted noise (10.6nV/sqrtHz/4kΩ = 2.65 pA/sqrtHz instead of 2.3 pA/sqrtHz from simulations).



Type	Ref	Trc	X-value	Y-value	Function	Function Result
M1		1	10.0 kHz	582.39 nV	Noise	117.99 nV/√Hz
M2		1	100.0 kHz	108.47 nV	Noise	27.11 nV/√Hz
M3		1	375.0 kHz	48.77 nV	Noise	10.64 nV/√Hz
M4		1	3.0 MHz	140.48 nV	Noise	30.52 nV/√Hz