UPPSALA
UNIVERSITET

FREIA Report 2015/10
July 2015

DEPARTMENT OF PHYSICS AND ASTRONOMY
UPPSALA UNIVERSITY

RF Test of the Hélène Single Spoke Cavity

Han Li, Vitaliy Goryashko, Roger Ruber

Uppsala University, Uppsala, Sweden

Department of
Physics and Astronomy
Uppsala University
P.O. Box 516
SE – 751 20 Uppsala
Sweden

Papers in the FREIA Report Series are published on internet in PDF format.
Download from http://uu.diva-portal.org

RF Test of the Hélène Single Spoke Cavity

Han Li, Vitaliy Goryashko, Roger Ruber

Uppsala University, Uppsala, Sweden

Abstract

FREIA has developed a test stand based on a self-exited loop for demonstrating the performance of superconducting cavities at low power level. Before the arrival ESS double spoke cavities, a single spoke cavity Hélène from IPNO has undergone a cold test with FREIA SEL to check our test method, hardware set-up and cryo-system, etc. Similar test results as IPNO's previous test were obtained with the FREIA system. This report presents the details of the FREIA SEL setup and each measurement.

Table of Contents

1.Introduction **4**

2.SEL test stand **4**

3.Calibration procedure **5**

3.1 Using VNA de-embedding 6

3.2 Traditional calibration 7

4.Measurement of the resonance frequency **7**

5. Measurement of the Q factor vs. accelerating gradient 8

5.1 4K measurement 8

5.2 2K measurement 14

6. Measurement of the frequency shift vs. temperature 16

7. Measurement of the frequency sensitivity vs. helium pressure 17

8. Multipacting 18

9. Summary 19

Reference 19

1.Introduction

The FREIA laboratory (Facility for Research Instrumentation and Accelerator Development) is developing the RF system for ESS superconducting spoke cavities. This Project contains three phases: (1) test of the first RF source, (2) test of the prototype cavity and (3) test of the prototype cryomodule [1]. In the second phase, the bare spoke cavity will be tested at low power level to confirm its vertical test performance at IPNO. Then the spoke cavity with a RF power coupler will be tested at high power with the tetrode based RF system from phase 1. Since a Self-exited loop has a lot of advantages for testing high gradient, high-loaded Q cavities. FREIA develops a test stand based on a self-exited loop for demonstrating the performance of superconducting cavity at low power level. Before the ESS double spoke cavities, a single spoke cavity Hélène from IPNO has been undergone a cold test with FREIA SEL to check our test method, hardware set-up and cryo-system, etc. Similar test results as IPNO's previous test [2] were obtained with FREIA system.

2. SEL test stand

The concept of a self-exited loop (SEL) is presented by Jean Delayen in 1977, which could be defined as a high-gain, positive feedback loop that is unstable and operates at a limit cycle determined by a non-linear element. The principle of the SEL is shown in Figure 1[3].

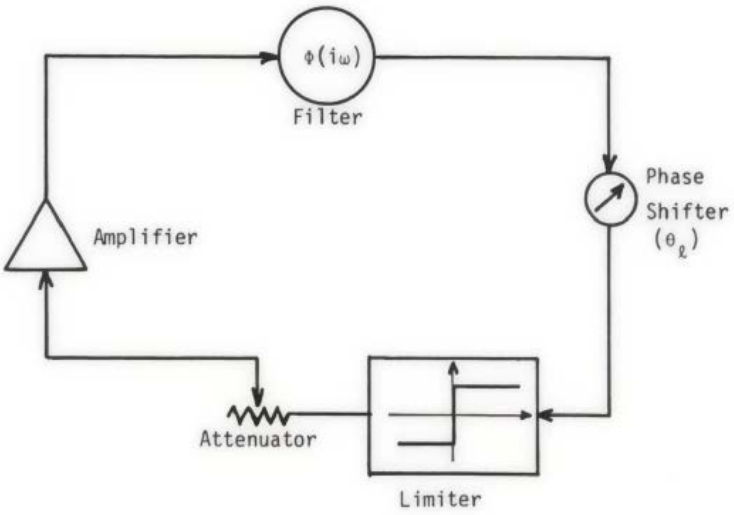


Figure 1: Block diagram of basic self-exited loop

With the SEL, the cavity, which is a narrowband filter, starts to oscillate by itself from the noise. Only two constraints apply: the total loop phase must be a multiple of 2π and the gain of this positive feedback loop must be greater than 1.

The SEL is found to be ideally suited for high gradient, high-loaded Q cavities operated in CW mode. Because the cavity field amplitude is unaffected by ponderomotive instability and there is no need for an external frequency source and frequency tracking feedback. The first SEL developed at FREIA is shown in Figure 2.

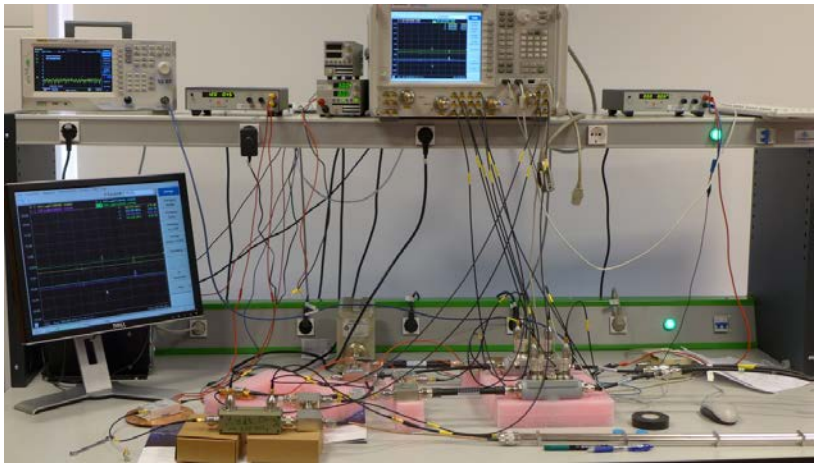


Figure 2: SEL setup at FREIA

So far, following are some key parameters of SEL at FREIA:

- The maximum power around 200W by combing two 100W amplifiers together;
- The maximum gain of the loop can reach 100dB;
- 40dB variable attenuation range depending on control voltage;
- 270 degree trombone phase shifter;
- A digital phase shifter is under development.

3. Calibration procedure

Calibration is the first and the most important step for an accurate measurement. Due to the attenuation of cables, especially cryo-cables, highly depends on operating temperature, all calibrations should be done when the cavity is fully cooled down. Following are two different calibration methods.

The block diagram of FREIA SEL is shown in Figure 3.

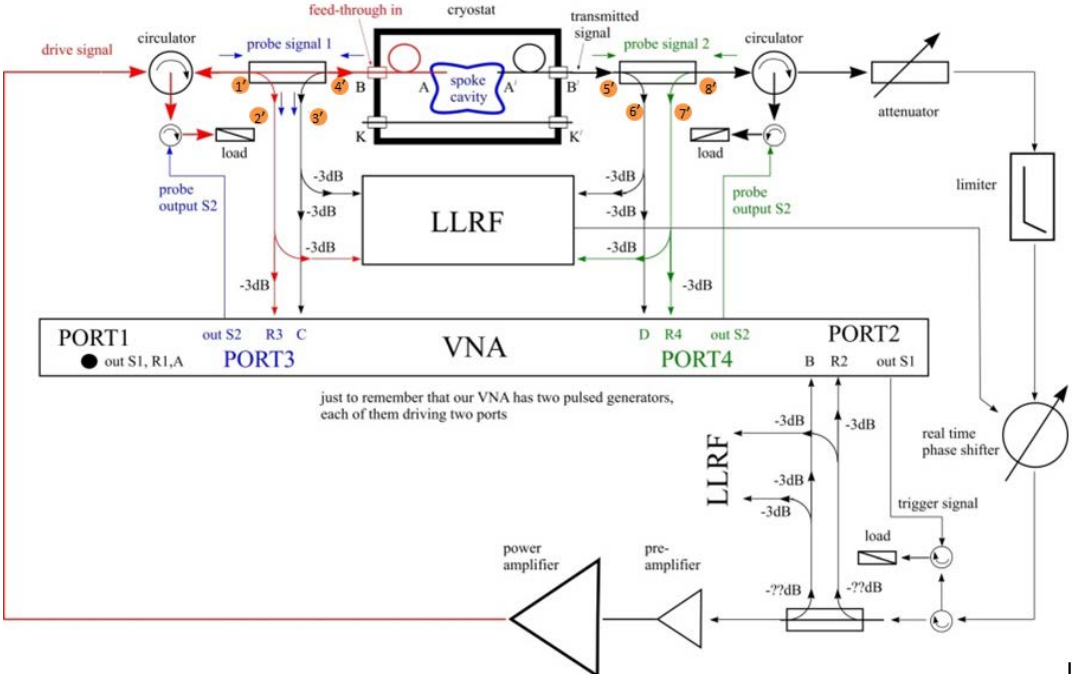


Figure 3: Block diagram of FREIA SEL

3.1 Using VNA de-embedding

Note that in this method a Vector Network Analyzer (VNA) is used as a receiver after source and receiver calibration. This way a direct power measurement is done from each antenna.

- Check all the components, in instance, circulator, amplifier, directional coupler, VNA works well separately and connect them together as Figure 3. Here, the front panel ports of VNA will be used. The reference receiver signal (R3) and measured signal (C) of VNA port 3 should be connected with forward directional coupler port 1' and port 2', while R4 and D ports connected with the port 6' and port 7'of transmitted directional coupler separately. Note that all RF outputs should connect into the loop with a circulator and load to protect the VNA from high level reflection.
  Actually, our VNA has two pulsed generator, each of them drive two ports. In order to avoid an unexpected coupling between two ports , it is better to choose two ports without sharing the same local source in VNA, like port 2and 3.
- Set VNA parameters, like frequency range, number of points, IF band width and average number. For an example, set center frequency as the cavity resonance frequency, 1MHz for frequency span, 100Hz for IF band width.
- Calibrate the power meter and set 352MHz as a measure frequency of channel A.
- Take the output of forward directional coupler (port 4') as the first reference plane. Carry out source and receiver calibration at this reference plane in order to get the absolute power measurement.
- Carry out two ports S parameter calibration by VNA at port 4' and port 5'.
- Measure cables by connecting with a through instead of the cavity. Get S parameters of the cable-cable system. Calculate the effect of each cable separately by transfer matrices (T matrices), and then convert to S matrices and finally implement the de-embedding in VNA [4].
  The reason why choose T matrices for calculating is because it is connects the 'input and output' that could be much easier to figure out the single effect of cable system. De-embedding procedure is done by matlab codes using equation (3.1) and (3.2).

$$T_{tot} = T_1 T_2 = T_2 \rightarrow T_{cable} = \sqrt{T} \tag{3.1}$$

$$\mathbf{S} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} = \begin{pmatrix} \frac{T_{21}}{T_{11}} & \frac{\det(T)}{T_{11}} \\ \frac{1}{T_{11}} & -\frac{T_{12}}{T_{11}} \end{pmatrix} \qquad \mathbf{T} = \begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix} = \begin{pmatrix} \frac{1}{S_{21}} & -\frac{S_{22}}{S_{21}} \\ \frac{S_{11}}{S_{21}} & -\frac{\det(S)}{S_{21}} \end{pmatrix} \tag{3.2}$$

- Redo the S parameter measurement, the S21 parameter should be around zero, the S11 parameter should be as small as possible. After de-embedding, the reference plane has been move to the end connector of cryo-cable. So the absolute power show in the VNA is the true power out from antenna.
- After VNA calibration, turn off the RF power of VNA and connect the loop to the cavity.

3.2 Traditional calibration

In this method, VNA will be used as an external source during the calibration procedure.

Assume that the attenuation from measure point to the antenna is consists of two parts: attenuation due to the directional coupler (calibrated factors of forward, reflected and transmitted signal are C_f, C_r and C_t respectively) and loss of signal cable connecting the SEL with the cryostat ($C_{cable_f}$and C_{cable_t}).

The calibration procedure is listed in detail below. All signals are shown in unit dBm. We define P_f, P_r and P_t as measure power, while P_F, P_R and P_T are true power from interface of antenna.

- Calibrate the power meter.
- Check all the components, in instance, circulator, amplifier, directional coupler, VNA works well separately and connect them together as Figure 3.
- Set VNA parameters, choose a frequency which is several MHz away from the cavity resonance frequency to assure cavity is detuned.
- Use the VNA port 3 RF output (0 dBm for example) to fed in forward directional coupler at port 1', connect a power meter to port 4'. Through the forward coupling path, get the forward coupled power Pf1 at port 2'and transmitted power P at port 4'. So the forward attenuation factor fulfill the relation

$$C_{f1}= P_{f1}-P \qquad (3.3)$$

Make port 4'open so that all signal reflects back to the load. Define a reflected coupled signal at port 3' as Pr2 and calculate the first part of reflect attenuation factor by equation (3.4).

$$C_{r1}= P_{r2}-P \qquad (3.4)$$

- Connect the coupler with cavity by power cables. Remeasure the reflected coupled signal P_{r3} at port 3' , which relates to the loss of forward power cables as

$$C_{cable_f}=(P_{r3}-P_{r2})/2 \qquad (3.5)$$

Finally, the measured power and the true power from the cavity have a relationship as:

$$P_F=P_f-C_{f1}+C_{cable_f} \qquad (3.6)$$

$$P_R=P_r-C_{r1}-C_{cable_f} \qquad (3.7)$$

- With the same method using an input source at port 8', we could figure out the transmitted attenuation factor.

$$C_{t1}= P_{t1}-P' \qquad (3.8)$$

$$C_{cable_t}=(P_{t3}-P_{t2})/2 \qquad (3.9)$$

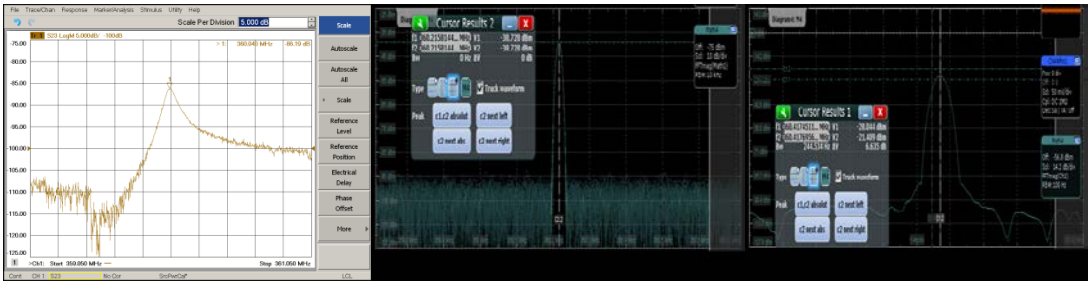
$$P_T=P_t-C_{t1}-C_{cable_t} \qquad (3.10)$$

Where, P_{t1} is coupled power measured at port 6' and P' is power meter value measured at port 5' while the transmitted directional coupler connects directly to a power meter. $P_{t2}$is the power value at port 6' while coupler connects with the cavity.

4.Measurement of the resonance frequency

Before the Q factor measurement, the resonance frequencies of Hélène in three different temperature situations have been studied.

Measurement results are shown in Figure 4 and table 1.



(a) (b) (c)

Figure 4: Resonance frequency of Hélène at different temperature. (a) room temperature; (b) 4K; (c)2K

Table 1 Resonance frequency of Hélène

Temperature	Resonance frequency	Measure method
300K	360.04MHz	VNA S parameter measurement
4K	360.215MHz	Self-exited loop
1.8K	360.417MHz	Self-exited loop

The resonance frequency of Hélène at room temperature is 360.04MHz, which is measured by S parameter sweeping. Note that the design external Q value of input and pick up antennas are 1.25E9 and 1E11, compare to Q0 factor of a normal conducting niobium cavity of order of 1E3, the transmitted signal is about 140dB weaker than input signal. It means by a normal VNA measurement it is impossible to find the resonance frequency. The typical noise background of a VNA is around -100dBm. In order to distinguish the resonance peak clearly, two amplifiers are added into the forward and transmitted side separately, and enlarge the transmitted signal from noise to -70dB.

With keeping a vacuum situation inside the cavity, the main reason of frequency shift from room temperature to 4K is a structure contraction due to material thermal expansion effect. According to niobium thermal expansion parameter [5], around 14% contraction of RF resonance volume which responds to 200KHz frequency increasing complete in the whole cooling procedure. Tracing and measuring the cavity frequency as a function of temperature could supply useful information of cavity behavior, which is presented in detail in [6].

Thermal contraction of cavity is almost done until 4K. From 4K to 2K, instead of contraction, pressure change in helium tank becomes the most sensitive factor to frequency shift. Pressure in helium tank decreases about one bar because of the temperature of liquid helium cooling down from 4.2K to 2K. A rough mechanical stability could be obtained from this processing and presented in detail in [7]. So from room temperature to 2K, the resonance frequency of cavity increases total 400KHz.

5. Measurement of the Q factor vs. accelerating gradient

5.1 4K measurement

To evaluate the performance of a SC cavity, we always measure the Q factor as a function of the accelerating field. When the cavity operates at its fundamental resonant frequency, through measuring the forward, reflected and transmitted signal, we can obtain coupling parameters of the antenna of each port simply through the equation below. Note that the resonance frequency is searched by adjusting a phase shifter in SEL.

$$\beta_t = \frac{Q_0}{Q_t} = \frac{P_t}{P_c} \tag{4.1}$$

$$\beta_e = \frac{Q_0}{Q_e} = \frac{P_e}{P_c} = \frac{\left(\sqrt{P_f} \pm \sqrt{P_r}\right)^2}{P_f - P_r - P_t} \tag{4.2}$$

Where, β_e and β_t are the coupling parameters of input coupler and transmitted antenna. Pe is considered as power coupled out and back to the input coupler and Pc is dissipated power in the cavity wall.

Since the external Q factor of transmitted antenna is designed much higher than the input coupler, we can ignore Pt when calculating β_e. So rewrite (4.2) as

$$\beta e = \frac{1+\Gamma}{1-\Gamma} \tag{4.3}$$

Where

$$\Gamma = \begin{cases} \sqrt{P_r/P_f} & \text{while } \beta_e \text{ is over coupled} \\ 0 & \text{while } \beta_e \text{ is critical coupled} \\ -\sqrt{P_r/P_f} & \text{while } \beta_e \text{ is under coupled} \end{cases}$$

To choose a corresponding formula, the first step is to carry out the coupling condition of the input coupler. Assume that the cavity is driven by rectangular pulses which are practically done by a waveform generator with a RF switch. The cavity responds differently to different coupling situations. As shown in Figure 5, through traces of transient signals, we can distinguish the coupling condition of the input coupler [6].

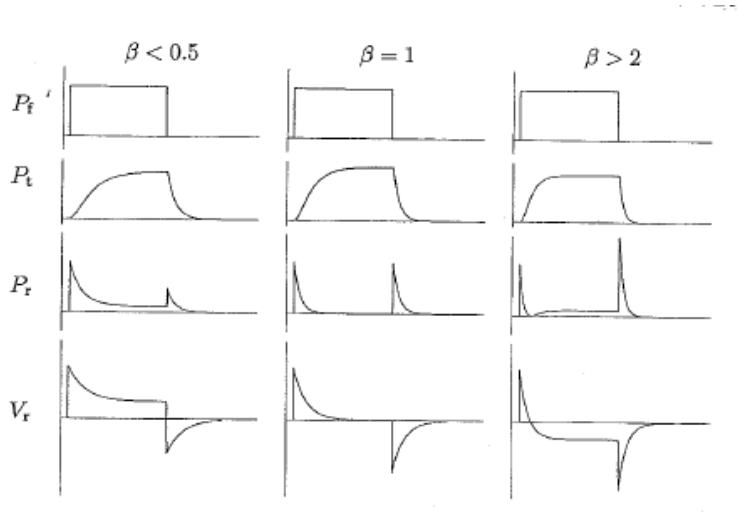


Figure 5: Rectangular drive pulses and their effects on the cavity for different coupling condition

Here, we choose measuring the transient reflection as it is much easier to read out the information. Figure 6 shows the measurement of Hélène. When the RF switch crisp turn on and off the loop, the reflect signal responds as a trace with two peaks. The first peak is proportional to Pr, the plateau is proportional to the Pr, and the second peak is proportion to the power coupled from the incident antenna (Pe). The ratios of Pe/Pf and Pr/Pf could find out the coupling situation from Figure 5. Hélène's response is same as the first situation, the second peak is smaller than the first peak, from which we can conclude that Hélène is under coupled at 4K. Recall equation (4.1) and (4.2), the calculated values of β_e and β_t are 0.867 and 0.00785, respectively.

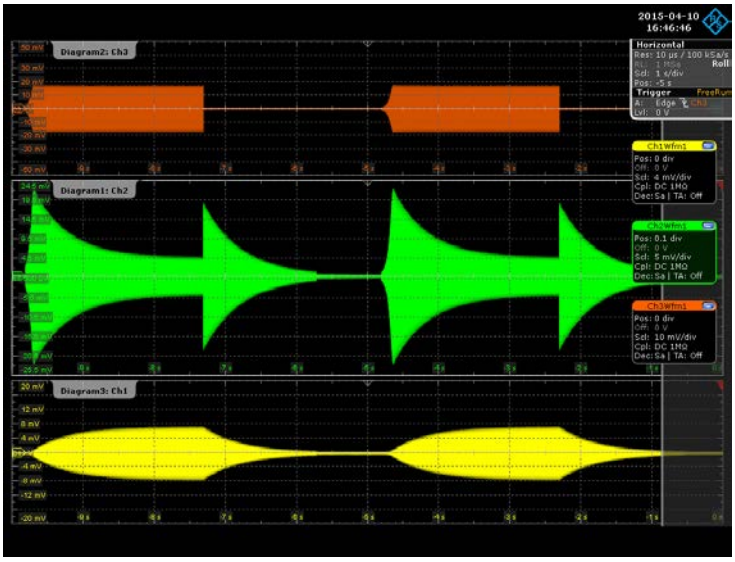


Figure 6: Transient trace of Helen under rectangular drive pulses at 4.2K.Where red, green and yellow signals are forward, reflected and transmitted voltage respectively

When the SEL loop signal has been cut off by a RF switch, the stored energy in the cavity thus decays exponentially with a constant decay time. As it is not easy to measure the whole natural decay time exactly in an exponential decay curve, we always measure the so called half-life decay time $\tau_{1/2}$, as Figure 7 shows, which fulfills the equation

$$U(t) = U_0 e^{-\frac{\omega \bullet t}{Q_L}} \qquad (4.4)$$

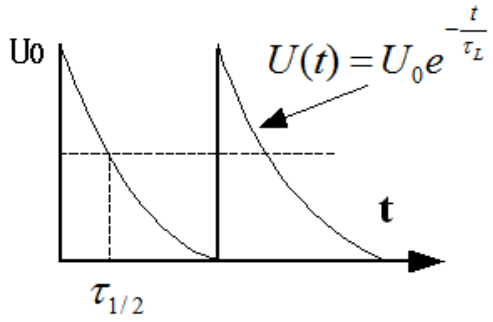


Figure 7: Stored energy decays as an exponential decay curve without RF input power

$$Q_L = \frac{\omega \cdot \tau_{1/2}}{\ln 2} \qquad (4.5)$$

From equation (4.5) the Q load factor can then be calculated directly by using resonance frequency and decay time. Note that the half-life decay time can be measured by using either transmitted or reflection signal. Both of them contain the same information of $\tau_{1/2}$,it could be a double check by getting the same $\tau_{1/2}$ value from these two independent signals measurement.

The stored energy only decays as a perfect exponential curve when there is no disturbance inside the cavity. We always measure the decay time at a very low field level, such as less than 1W dissipated power, in which field emission and multipacting is not usually occur.

The measurement results of Helen at 4.2K are shown in the figure 8 and table 2, only 2% deviation from transmitted and reflection measurement. And the value 174ms is used in the Q_L factor calculation.

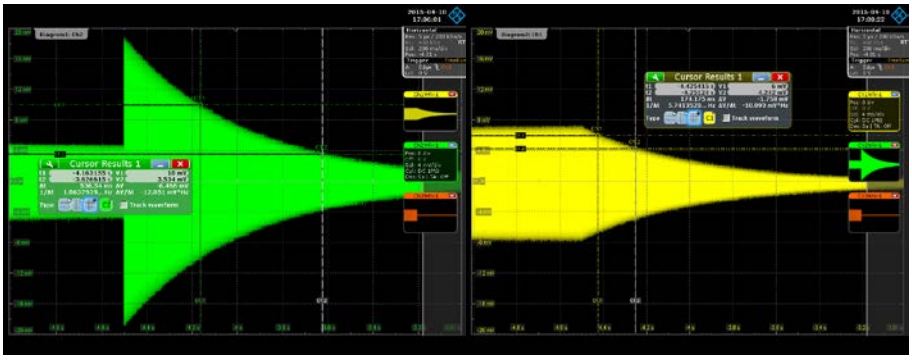


Figure 8: Decay time measurement from reflected signal (left) and transmitted signal (right)

Table 2 Decay time measurement at 4.2K

	Reflection measurement	Transmitted signal measurement
$\tau_{1/2}(4.2K)$	178ms	174ms

Once coupling parameter and Q_L are known, the Q_0 factor is obtained by

$$Q_0 = (1+\beta_e+\beta_t)\cdot Q_L \qquad (4.6)$$

And calculate the external Q factor of transmitted antenna easily for a later measurement via

$$Q_t = \varpi U / Pt \qquad (4.7)$$

$$Q_0 = \varpi U / Pt \qquad (4.8)$$

$$Q_t * P_t = Q_0 * P_c \qquad (4.9)$$

Table 3 shows the main measured data at Hélène's 4.2K test, the first Q_0 measured around 0.5W dissipate power , while Q_t equal to 1.36E11. Both of this values all closed to the design of the expectation.

Table 3 Main measured data at Hélène's test

parameters	Value of 4.2(K)	Value of 2(K)	comment
$\tau_{1/2}(4.2K)$	174ms	347ms	Measure through reflation
Q_L	5.68E8	1.14E9	
Q_t	1.38E11	1.36E11	
Q_0	1.06E9	6.8E9	At 1MV/m

The decay time method just need to operate only once. As long as the first Q_0 and Q_t are figured out, then increase the input power, the corresponding Q_0 factor can be directly calculated as

$$Q_{02} = \frac{P_{t2} * P_{c1} * Q_{01}}{P_{t1} * P_{c2}} \tag{4.10}$$

Note that in a SEL, the driven signal comes from the noise background. So increase the field level means to decrease the loop attenuation, which is basically controlled by a voltage-control attenuator.

In Hélène's cold test, some multipacting (MP) barriers were encountered at low field level. In order to go through the MP, we set the lowest attenuation in order to get the highest gain to amplify a small driven signal as quickly as possible. Once the loop has gone through a MP barrier, reflection goes down and forward power is limited by limiters and the maximum amplifier output. As an example, about 44 dBm forward power into the cavity while using 50W amplifier in FREIA SEL. We first measure the performance at the maximum field. Then, increase the attenuation gradually until the transmitted power level is under the limitation of limiter and measure the Q_0 factor as a function of accelerating gradient in a reverse direction.

The corresponding field level is given by Q_t, P_t, the optimal βand the effective accelerating length βλ. The accelerating gradient is given by

$$E_{acc} = \frac{V}{L_{eff}} = \frac{\sqrt{R/Q_0 * Q_0 * P_c}}{\beta\lambda} = A\sqrt{Q_t * P_t} \tag{4.11}$$

Where, $A = \frac{\sqrt{R/Q_0}}{\beta\lambda}$

To avoid misunderstanding due to nonuniform definitions of the accelerating length, the field level also can be defined by the maximum surface electromagnetic field, as

$$Epk = K_1\sqrt{Q_t * P_t} \tag{4.12}$$

$$Bpk = K_2\sqrt{Q_t * P_t} \tag{4.13}$$

Table 4 lists the main design parameters of Hélène cavity.

Table 4 Main design parameters of Hélène cavity [7]

β_{opt}	0.2
R/Q_0	117(Ω)
E_{pk}/E_{acc}	6.56
B_{pk}/E_{acc}	13.4 $(mT/MV/m)$

So, field level of SC single spoke cavity Helen is calculated as

$$Eacc = 64.96\sqrt{Q_t * P_t}$$

$$Epk = 245.9\sqrt{Q_t * P_t}$$

$$Bpk = 870\sqrt{Q_t * P_t}$$

Measurement of the Q_0 factor is shown in figure 9. The maximum Q_0 factor is 1.06E9 at low field level. The maximum surface field E_{pk} reaches 26.4 (MV/m) and B_{pk} reaches 54 (mT/MV/m), which is limited by maximum power supply output. From figure 9, we could see that the Q factor decreases fast when increasing the input power, which indicates the cavity has Q disease when cooling down.

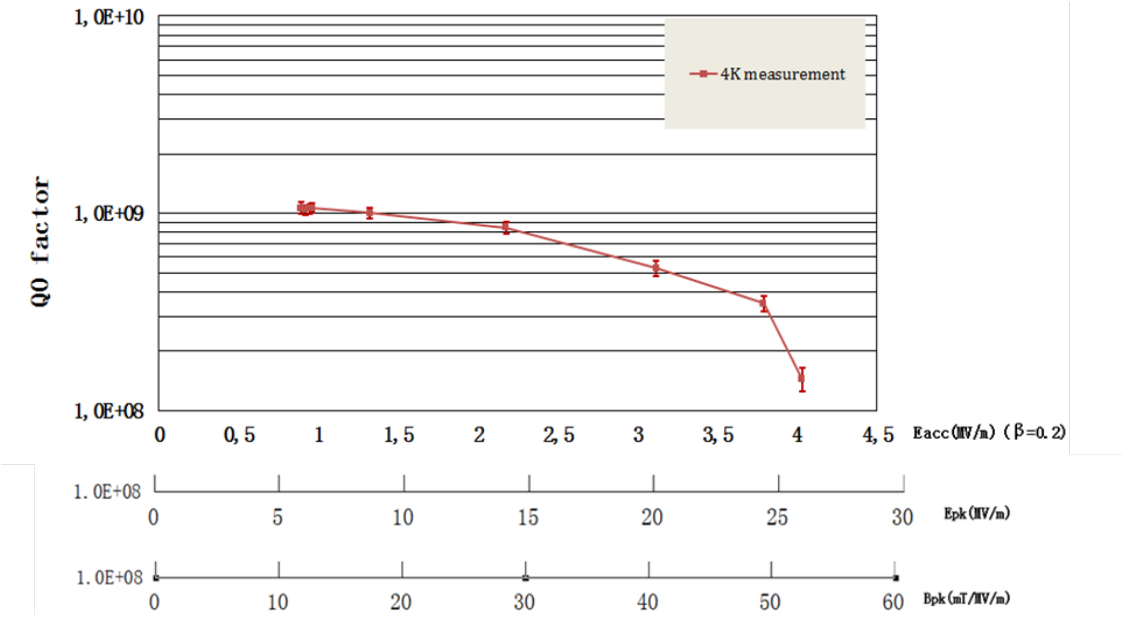


Figure 9: Results of Q factor as a function of field level at 4.2K

5.2 2K measurement

The 2K measurement was carried out by the same test method as 4K. When measure the cavity at 2K, we found out that the Q_0 factor improved about 6 times with respect to 4K performance, so the input coupler changes to over coupled condition, which is shown in the figure 10.

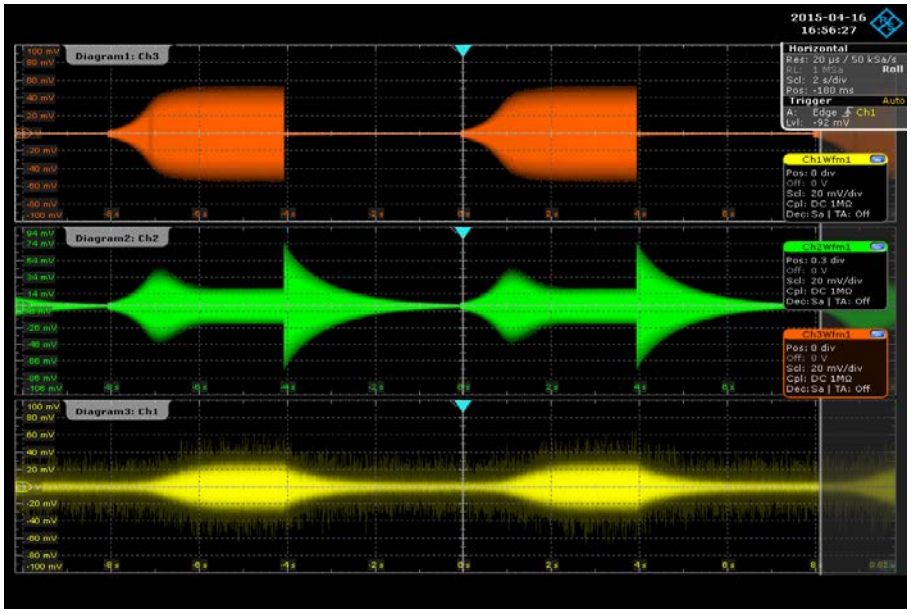


Figure 10: Transient trace of Helen under rectangular drive pulses at 2K.Where red, green and yellow signals are forward, reflected and transmitted voltage respectively

Decay time measure by reflection is shown in Figure 11. Related measured values are listed in table 3.

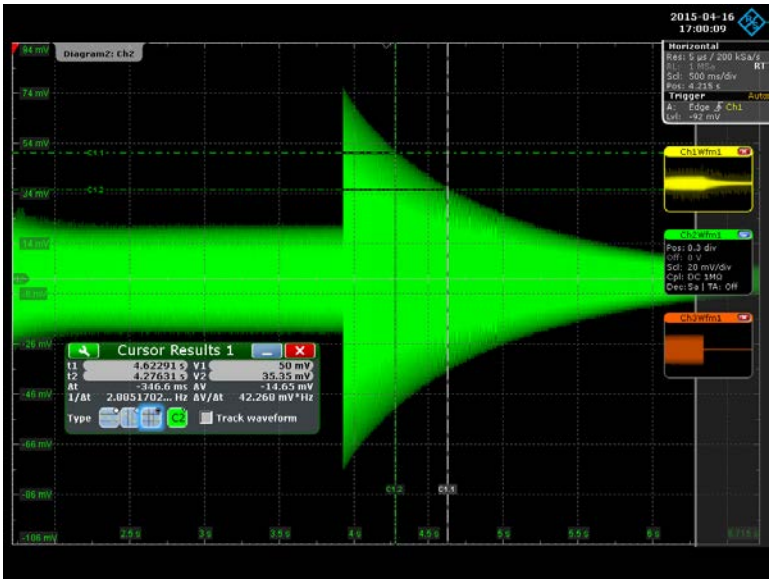


Figure 11: Half-life decay time measurement at 2K

Finally, the Q factor as a function of field level at 2K is given in Figure 12. By calculating the error bar of the measurement, the external quality factor of pick up antenna Q_t at 4 K has 5.5% uncertainty. The same measurement of Q_t at 2 K is found to have 5.6% uncertainty.

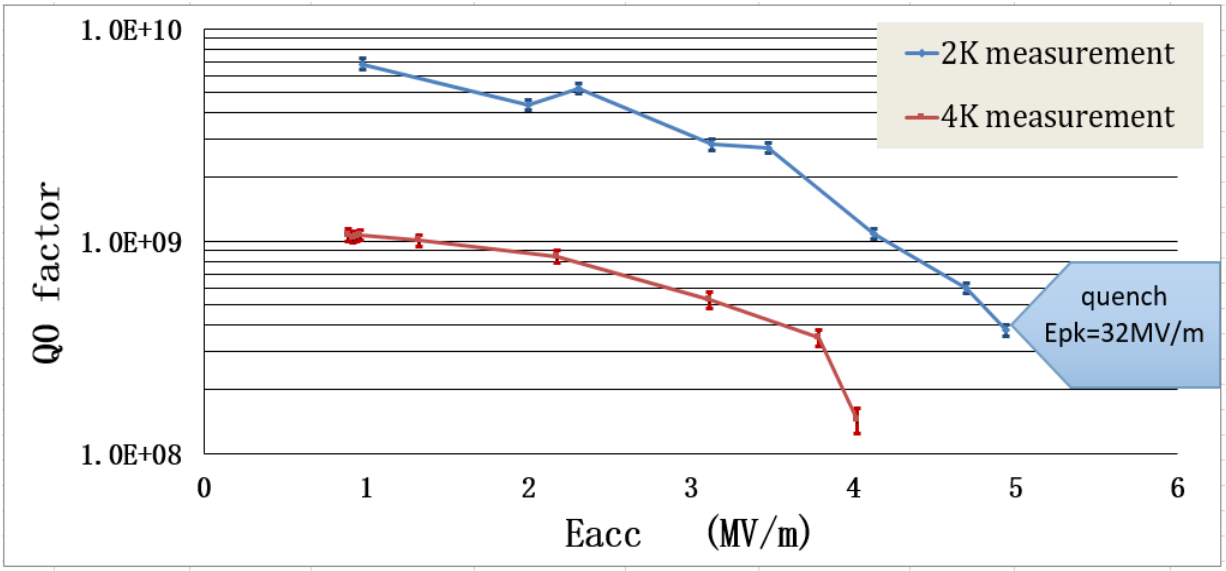


Figure 12: Results of Q factor as a function of field level at 2K

In 2K measurement, we encounter a thermal quench at E_{acc}=4.9(MV/m), corresponding peak surface electromagnetic field E_{peak}=32MV/m, B_{peak}=66MV/m. The quench traces for forward, reflected and transmitted power are shown in figure 13. In a SEL, when the cavity encounter a thermal quench, the dissipate power at the cavity wall drives a normal conducting surface region and Q_0 factor goes down quickly. The power of signal that runs in the loop also goes down due to the unmatched coupling of cavity, which means the dissipated power on the cavity wall becomes much smaller and less heat is generated. Once the field level is low enough, the cavity cools down and turns to superconducting situation again. So the loop signal increases again until the next thermal quench. The process seems like a Q switch turning on and off regularly [8].

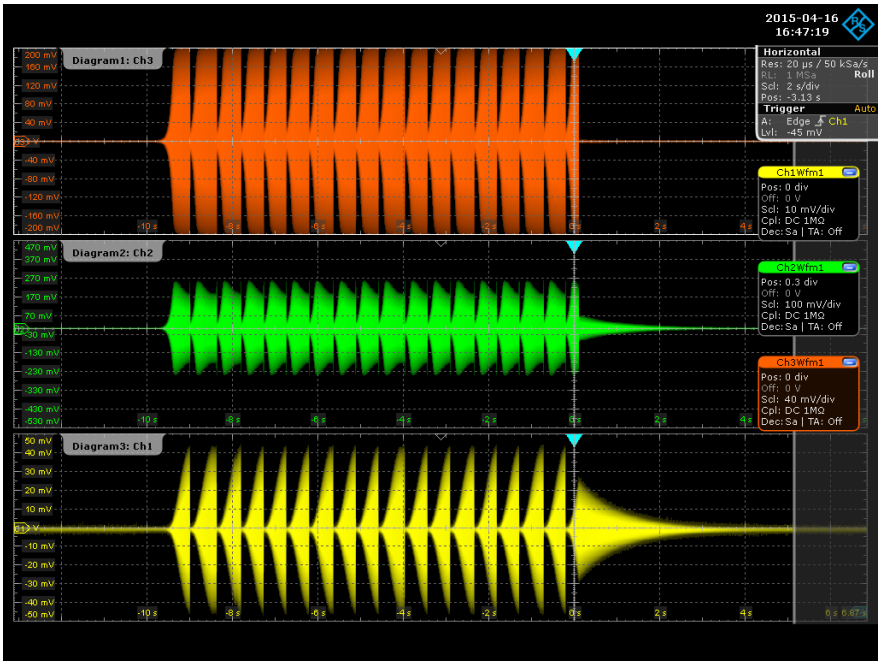


Figure 13: Transient trace of Helen under Q switch at 2K.Where red, green and yellow signals are forward, reflected and transmitted voltage respectively

6. Measurement of the frequency shift vs. temperature

When the temperature of cavity wall changes, for example, undergoing a cooling procedure, the cavity volume changes due to the material thermal expansion effect. Measuring frequency shift as a function of cavity temperature, could supply useful information of cavity behaviour.

Helium pressure is approximate equal to one atmosphere at 4.2K. Let us assume the pressure in helium tank does not change much during cooling down from room temperature to 4.2K. Tracking the resonance frequency of cavity, we can directly obtain the cavity behaviour and frequency shift. According to the niobium thermal expansion property, 80% of the structure contraction has completed when the cavity is cooled down to 80K.

Note that the cavity is super under coupled when it's temperature is higher than dozens of Kelvin. We use amplifiers to enlarge forward and transmitted signal if necessary. On the other hand, the cavity should go through the hundred Kelvin region quickly in order to avoid so-called Q disease effect. It means measuring the cavity frequency as a function of temperature during warming up will be more accurate than during a cooling down procedure.

Figure 14 shows the cavity frequency as a function of temperature when Helen cools down to 4.2K. About 200K shift from room temperature to 4.2K as measurement. Unfortunately, we did not repeat the same measurement when Helen warmed up.

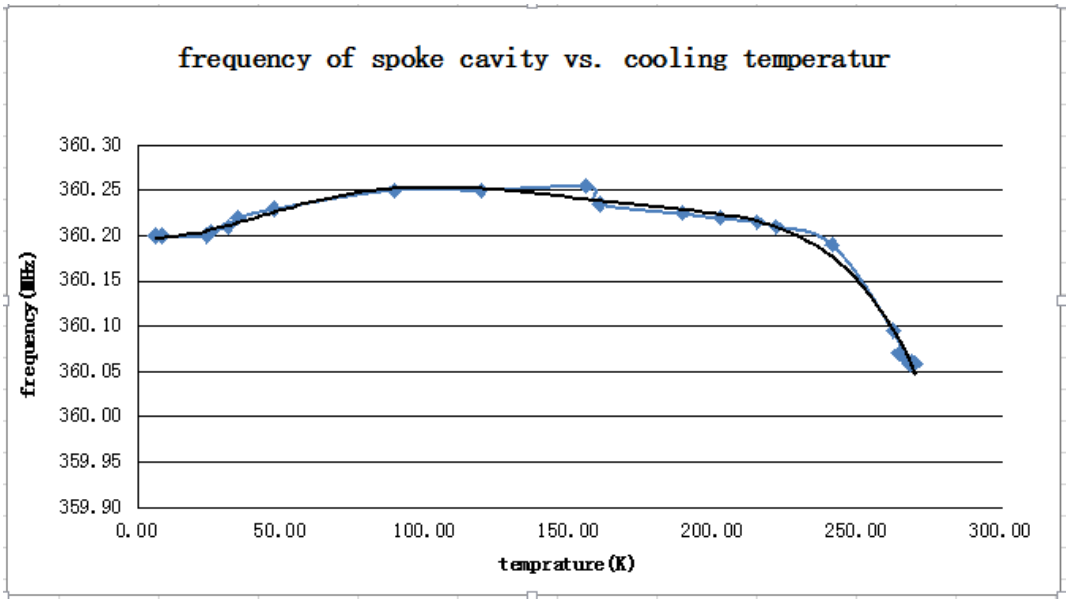


Figure 14: Cavity frequency as a function of temperature from 300K to 4.2K

7. Measurement of the frequency sensitivity vs. helium pressure

Fluctuation of pressure in the helium tank will cause a changeable volume of SC Spoke cavity. Large resonance frequency fluctuation will make a higher requirement to the LLRF control system, especially to the fast piezo tuning system. Measuring frequency sensitivity as a function of helium pressure, could supply very useful information about the mechanical stability of the cavity.

There are several ways to carry out cavity mechanical stability measurements. One direct way is to measure the frequency shift while monitoring transient pressure at the same time, which requires a stable field level. Another simple way is to measure resonance frequency shift when cooling down from 4.2K to 1.8K. As we know, the helium pressure is roughly one atmosphere at 4.2K while only 1638 Pa at 1.8K. The frequency sensitivity can be figure out by equation (7.1).

$$frequency \quad sensitivity \quad (Hz/mbar) = \frac{f(4.2K) - f(1.8K)}{pressure(4.2K) - pressure(1.8K)} \qquad (7.1)$$

Note that the mechanical contraction from 4K to 2K is very small, thus frequency shift cause by temperature can be ignored. Just a small and stable RF input power is used to track the cavity resonance frequency.

Figure 15 shows how the helium pressure and resonant frequency of the cavities drift over a certain period. Here the cavity vessel is fixed on a table by four points inside the cryostat and Hélène is tested without a tuning system.

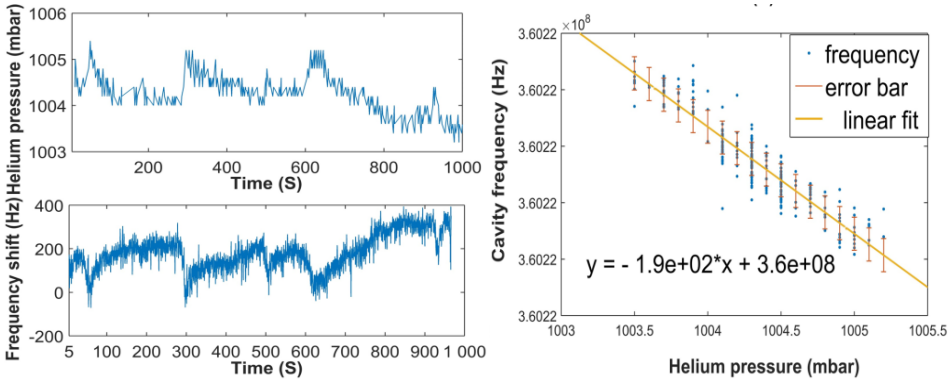


Figure 15: Left (top) and left (middle) graphs are the helium fluctuation and frequency shift, respectively, pressure sensitivity of Hélène (right).

In the measurement we determined Hélène's pressure sensitivity to be -190 Hz/mbar. On the other hand, the resonance frequency of Hélène is 360.215MHz at 4.2K while 360.417MHz at 1.8K (table 1). Recall the equation (7.1), frequency sensitivity (or mechanical stability) of Helen is about 200 Hz/mbar. These results are consistent with each other.

8. Multipacting

Multipacting barrier is one of the most harmful effects in spoke cavity. When Multipacting happens, a large number of electrons collide with cavity wall and absorb the RF power so that it becomes impossible to increase the electromagnetic field by increasing the input power.

By using our SEL, there are several ways to help us to identify if there is a multipacting inside the cavity:

- S33 parameter increase fast;
- forward, reflect and transmit signal fluctuate obviously or even decrease suddenly, as shown in Figure 16;
- the spectrum of loop signal is jumping during the Multipacting, as shown in Figure 17;
- decrease the loop attenuation, could not increase the transmitted signal;,
- can detect an X-ray from the radiation doses meter (maybe have the field-emission at the same time)

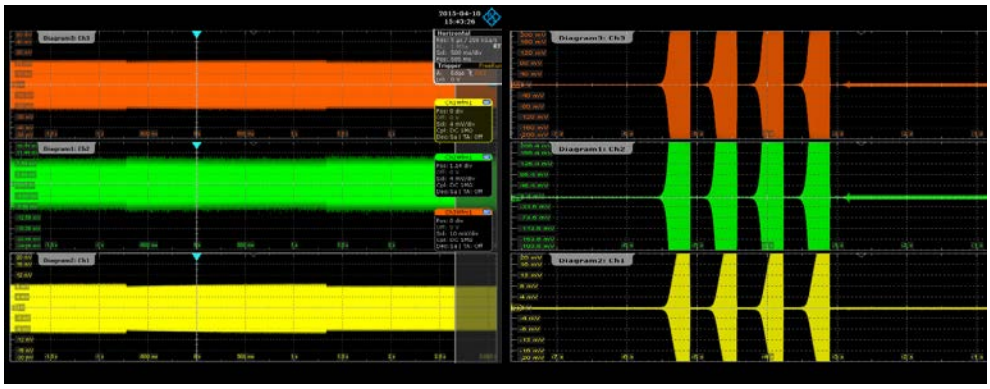


Figure 16: Transient signals fluctuate obviously under MP in a SEL

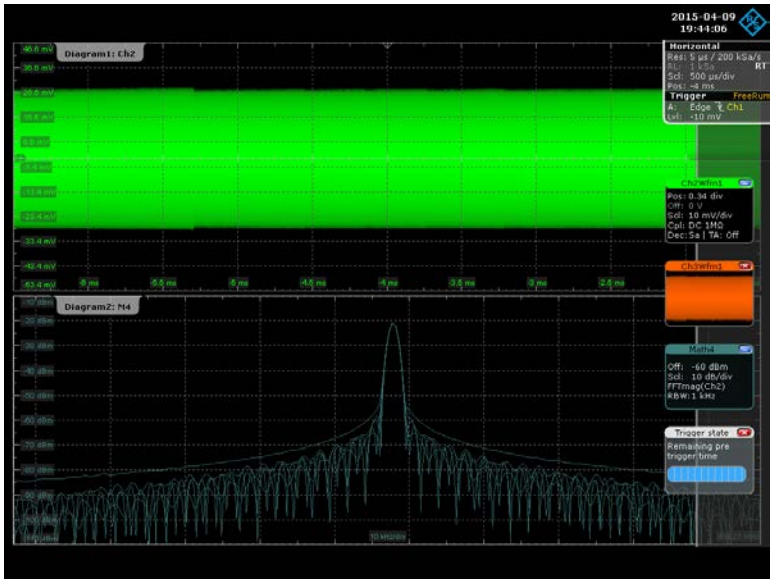


Figure 17: Spectrum jumping under MP in a SEL

In order to go through the MP, we set several amplifier and limiter in series to get as high gain as possible. For FREIA SEL, the maximum gain so far can reach 100dB. Once the loop has gone through a MP barrier, reflection goes down and forward power is limited by the maximum amplifier output. All signals are stable.

9. Summary

The first step of a test stand based on a self-exited loop has developed at FREIA. A single spoke cavity Hélène from IPNO is used to check and develop our test method, hardware set-up and cryo-system, etc. Similar test results as IPNO's previous test were obtained with the FREIA system, which means FREIA SEL has already manage cold test of superconducting cavities at low power level. From the study of FREIA SEL, update of amplifier is needed to get higher incident power to overcome the field emission and MP barriers, and meet thermal quench point of the cavity. Also in the next step, we will focus on the integrating of all test data into one interface.

Reference

[1]Roger Ruber et al., Uppsala test facility project plan. Uppsala University, FREIA report 2013/03.

[2]G. Olry et al., Development of spoke cavities for the EURISOL and EUROTRANS projects. 12th International Workshop on RF superconducting, Jul 2005, Ithaca, United States. 441, pp.201-204.

[3] Jean Delayen. Self-exited loop.Jefferson lab LLRF workshop. 25-27, April, 2001

[4] Harald Nicander. Deembedding. Uppsala University, internal memo.19, March, 2015

[5] Material properties for engineering analyses of SRF cavities. Fermilab specification:5500.000-ES-371110

[6] Hasan Padamsee et al., RF superconductivity for accelerators. P158

[7] G.Olry et al., Development of spoke cavities for the EURISOL and EUROTRANS projects. 12th International workshop on RF Superconductivity, Jul 2005, Ithaca, United States.441,pp.201-204

[8] Hasan Padamsee et al., RF superconductivity for accelerators. P200-201