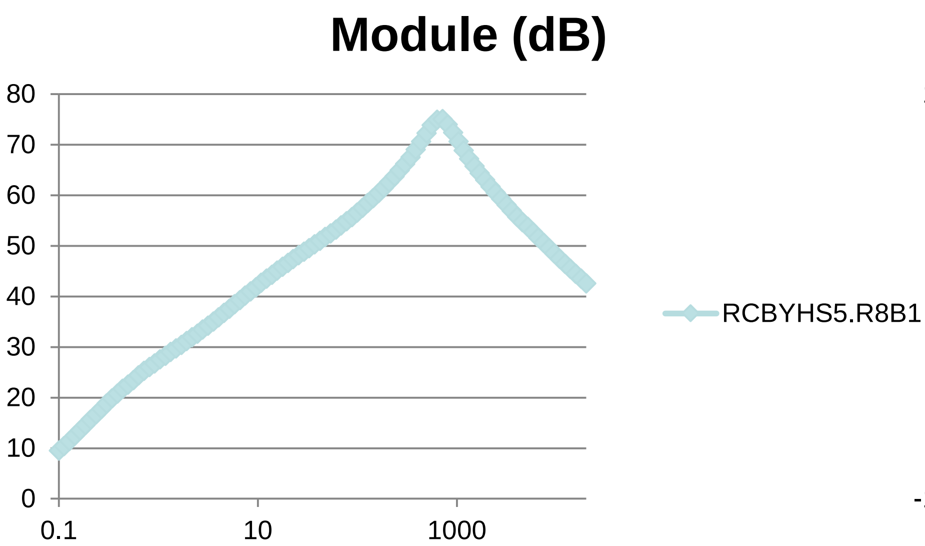
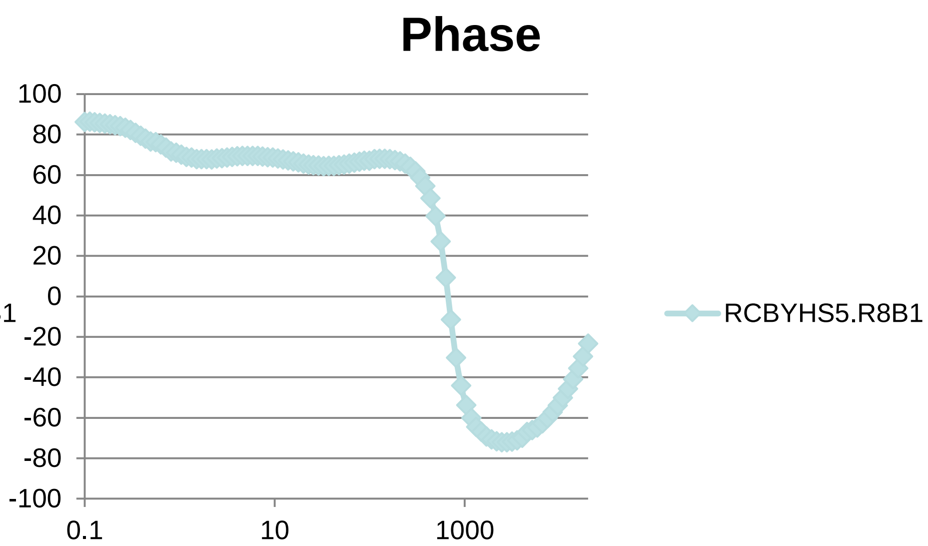
Circuit modeling & synthesis

- Starting from a measured transfer function, the idea is, in the first step, to do a curve fit in Matlab.

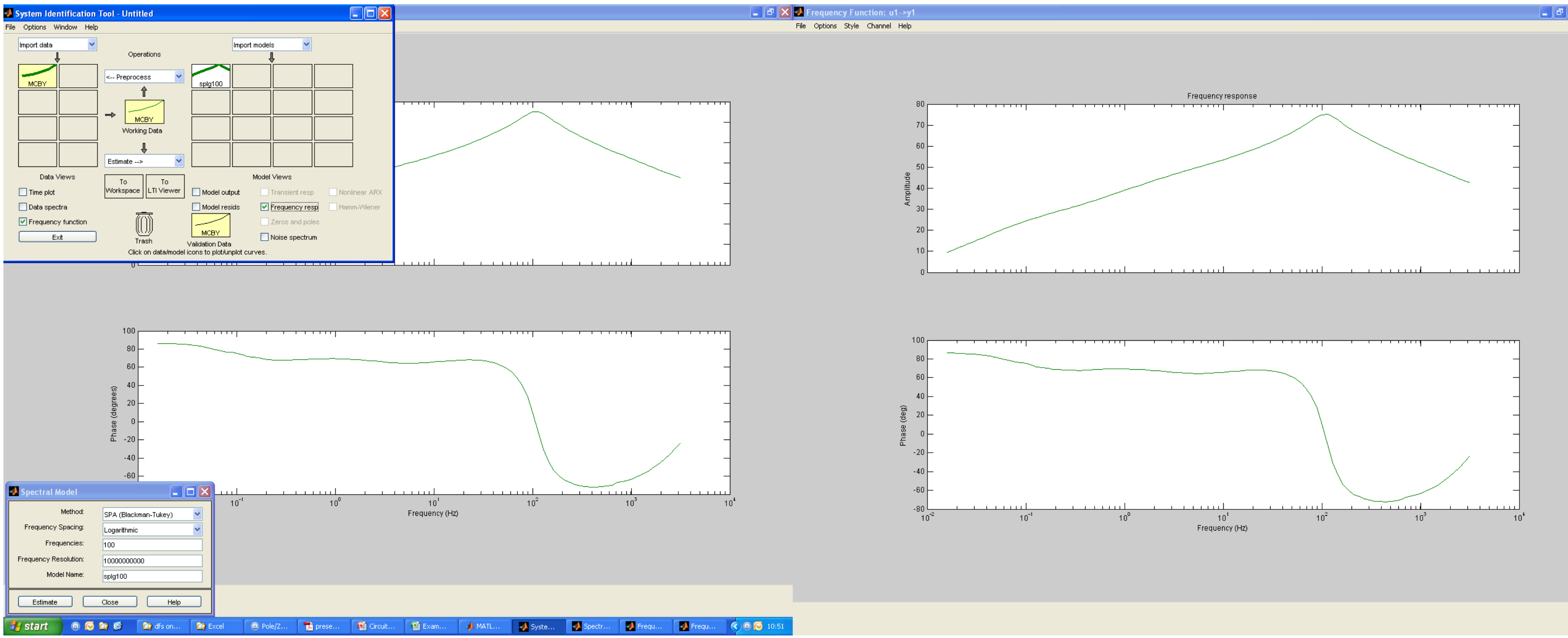
- Examples of TFM at cold, in the tunnel:





Modeling

➔ Curve fit in Matlab, using the system identification toolbox.



Modeling

- ➔ Transformation of the estimated model to the state space model. It’s done using the “pem” command in Matlab, and specifying the maximum order of the polynomials.

```
>> tfm = pem (splg100,6)
State-space model:     dx/dt = A x(t) + B u(t) + K e(t)
                        y(t) = C x(t) + D u(t) + e(t)

A =
                  x1           x2           x3           x4           x5
       x1     17.041        -1734         1660       3085.8      -4190.2
       x2     118.72      -898.65      -7257.8      -1261.1        28563
       x3      28.61      -327.48       7901.9        11045       -36200
       x4     7.6264       394.98       6666.8       4544.1       -52160
       x5      11.94       18.513      -2000.5      -2489.2        14066
       x6      3.576       329.16       5347.7       3630.7       -44449

                  x6
       x1     4052.1
       x2    -5353.1
       x3      19151
       x4      13738
       x5     -14585
       x6      13039

B =
                  u1
       x1  3.1564e+006
       x2 -3.8195e+006
       x3   4.475e+006
       x4   2.594e+005
       x5  4.4941e+005
       x6 -3.1336e+005

C =
                  x1           x2           x3           x4           x5
       y1     22.556       51.944       55.376      -58.702      -249.98

                  x6
       y1    -28.423

D =
                  u1
       y1          0

K =
                  y1
       x1          0
```

- ➔ Transformation from the state space model to the Laplace transform

```
>> tfm_Laplace = tf (tfm)

Transfer function from input "u1" to output "y1":

 1.942e006 s^5 - 1.2e010 s^4 - 1.362e014 s^3 + 2.65e016 s^2 - 1.438e019 s

                                                                 + 4.078e017

--------------------------------------------------------------------------------
s^6 - 3.867e004 s^5 - 5.551e008 s^4 + 1.743e012 s^3 + 2.636e015 s^2 + 5.847e017 s

                                                                 + 1.057e020
```

Synthesis: Continued fractions decomposition

- Once we get to the Laplace transform, we start the synthesis of the circuit.

- The method used is the continued fractions decomposition: through polynomial divisions, a Laplace transform could be expressed as:

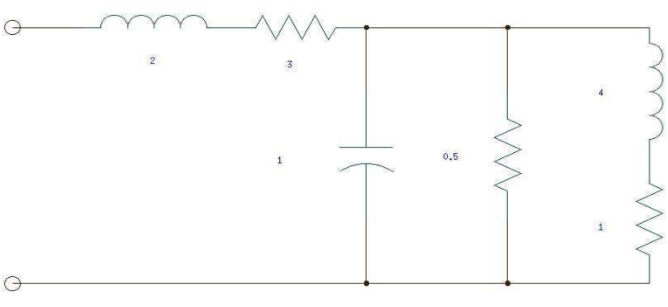
$$Z = Z_0 + \cfrac{1}{Y_1 + \cfrac{1}{Z_2 + \cfrac{1}{Y_3 + \dots}}}$$

- Example:

$$Z = \frac{8s^3 + 30s^2 + 37s + 10}{4s^2 + 9s + 3} \qquad Z = 2s + 3 + \frac{4s + 1}{4s^2 + 9s + 3} \qquad Z = 2s + 3 + \cfrac{1}{\cfrac{4s^2 + 9s + 3}{4s + 1}}$$

$$Z = 2s + 3 + \cfrac{1}{s + 2 + \cfrac{1}{4s + 1}}$$

- This corresponds to ((1Ohm in series with 4 H) in parallel with 0.5 Ohm and 1 F) in series with 3 Ohm and 2 H



Synthesis: Continued fractions decomposition

- Practical example with the real Laplace transform of the measured MCBY:

$$H(s) = \frac{1.942\times10^{006}s^{5} - 1.2\times10^{010}s^{4} - 1.362\times10^{014}s^{3} + 2.65\times10^{016}s^{2} - 1.438\times10^{019}s + 4.078\times10^{017}}{s^{6} - 3.867\times10^{004}s^{5} - 5.551\times10^{008}s^{4} + 1.743\times10^{012}s^{3} + 2.636\times10^{015}s^{2} + 5.847\times10^{017}s + 1.057\times10^{020}}$$

- First division:

$$H(s) = \frac{1}{5{,}15\times10^{-07}s - 0.0167 + \dfrac{-6.86\times10^{08}s^{4} - 5.49\times10^{11}s^{3} + 3.09\times10^{15}s^{2} + 3.44\times10^{17}s + 1.06\times10^{20}}{1.942e^{006}s^{5} - 1.2e^{010}s^{4} - 1.362e^{014}s^{3} + 2.65e^{016}s^{2} - 1.438e^{019}s + 4.078e^{017}}}$$

- Z0=0, Y1=5.15^-7-0.0167
- We have found a negative value for a component (R=-0.0167!!!!). This is the main disadvantage of this method.
- Even if it’s mathematically correct, and could be simulated in Pspice giving good results, some people couldn’t accept it, because it doesn’t have a physical meaning.

Synthesis: Foster cells

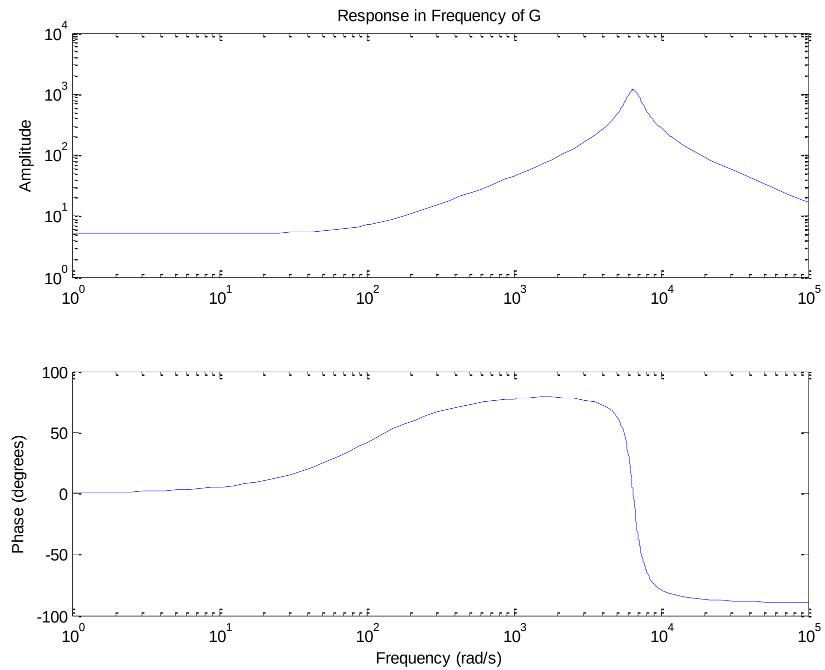
- Alternative way to find the final circuit is Foster's method.
- There are two different methods that will result in both LC circuits:
  - Foster 1: Impedance
  - Foster 2: Admitance
- It seems that is possible to get positive values for all the components, but is NOT guaranteed in all the cases.
- Two matlab scripts (one for each method) are giving automatically the values of the components.

Synthesis: Foster cells

- Practical example with a third order TF from a MCBY

```
G <1x1 tf>

Transfer function:
1.688e006 s^2 + 3.211e009 s + 3.464e011
----------------------------------------
s^3 + 3061 s^2 + 4.456e007 s + 6.758e010
```



- We apply the first script to the TF:

```
>> foster1 (num,den)
Impedancia: Numerador Par, Denominador Impar
Grado del Numerador menor que Grado del Denominador
Condensador de valor -9.05681e-005 en serie
Bobina de valor 0.0402402 y condensador de valor 5.85951e-007 en paralelo
-----------------------------------------------------------------
```

- As we find a negative value for a component, we apply the second method:

```
>> foster2 (num,den)
Admitancia: Numerador Impar, Denominador Par
Grado del Numerador mayor que Grado del Denominador
Condensador de valor 5.92417e-007 en paralelo
Bobina de valor 0.176474 y condensador de valor 1.7736e-006 en serie
----------------------------------------------------------------------
```

- By now, this method has been tested with several TF, and always one of the solutions is giving all positive values. Anyway, as I said, taking in account the theory behind Foster’s method, the positive values are not guaranteed.

Step response

- In parallel with this, it was suggested to see if it’s possible to model the magnet from a step response, due to the difficulties of doing a TFM with high current in a 13kA circuit.

- With a step response, we should get a second order model as maximum. This could lead us to miss part of the behavior, specially at high frequency.
  In the other hand, it could be perfectly enough (depending on the precision needed) and the setup for the measurement with current is much easier.

- A little mock-up is already done to compare the model coming from the step response and the model coming from the frequency response of a commercial inductance.

Missing points

- Still missing points:
  - Do the schematics with these components in Pspice, and check that the response in frequency is acceptable.
  - Test the scripts to know if we are going to get any negative value that we couldn’t avoid.
  - Compare the results of step response and frequency response models.

- Hopefully, they should be ready for the next meeting.