Design Tool for Multi-nuclei RF Coil

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The main purpose of this script is to help investigating the overall performance of a novel decoupling strategy for multi-nuclei MRI coil. But it can also be used as general modeling tool for analyzing multi-nuclei coil performance in terms of matched impedance, NF and coil decoupling.

This modeling script analyze (1) the calculated NF of a chosen operational amplifier in non-inverting configuration, (2) (at different Larmor frequencies)matched impedance of an arbitrary RF coil with an arbitrary matching network with common components used in MRI coil making, (3) (at different Larmor frequencies)and the NF of OPA and decoupling coil based on the matching network optimized in the script.

An Example:

First, input a few parameters to start:

1. Open “Main_Function” to start.
2. For modeling OPA, entering two Resistance of non-inverting amplifier (Rf and Rg) and the input capacitance of the amplifier. These determine the NF/Gain of the OPA in general. (The default OPA programed in this script is LMH6629, and can be replaced by other OPA by changing the parameters of en and ei in sub-function “NF_Calculation_LMH6629_NonInverting”).

```
Rf = 200;
Rg = 10;
InputCap = 7e-12;
```

```
en = 0.69e-9;
in = 2.6e-12 ;
```

3. Measured/simulated RF coil impedance and frequency. (In this example, the measured OPA impedance is prepared as a file “Z_opa.mat”. But arbitrary measured or simulated amplifier impedance can be loaded here to replace the original file.)

```
% % input measured OPA impedance
data = load('Z_opa.mat').Final;
Freq = data(:,1);
Z_opa = data(:,2);
```

4. measured/simulated OPA input impedance and frequency. (In this example, the measured coil impedance is prepared as a file “Z_coil.mat”. But arbitrary measured or simulated coil impedance can be loaded here to replace the original file.)

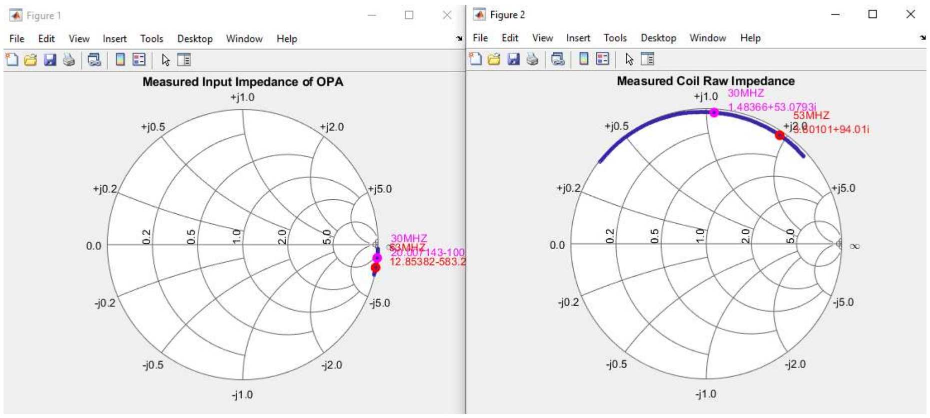
```
% % input measured Coil impedance
data = load('Z_coil.mat').Final;
Freq = data(:,1);
Z_coil = data(:,2);
```

5. Specify your frequency index in both main and all smithplot subfunction. (In this example, the impedance measurement was acquired using VNA4195A for 401 points between 10-70MHz, therefore measured impedance at 2H/30MHz and 23Na/53MHz is at the 139^{th} and 287^{th} points

in the matrix. If different measured impedance is loaded, the index need to be changed accordingly).

```
% frequency index is specified here Assuming at 4.7T
Freq_30MHZ_Index =  139; %2H 30.7192 MHZ
Freq_53MHZ_Index =  287;  %23Na
```

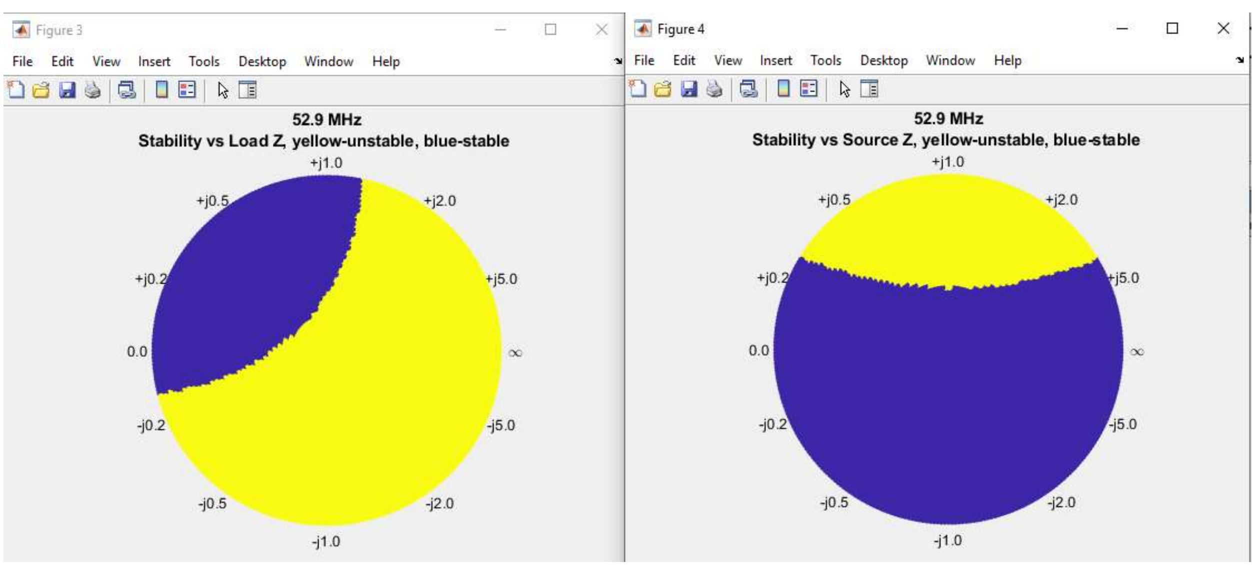
6. Then the loaded amplifier/coil impedance will be plotted on smitch chart according to the index.



7. (Optional) if the S parameter matrix of amplifier can be inputted here. Both input/output stability circle of the amplifier at the chosen frequency can be plotted. (In this example, 4 csv files named "Sxx_PwrOn" were loaded through the subfunction, other measured data can be loaded to replace the file in example. Btw, make sure you power up your amplifier when measuring S parameter, impedance quite different w/o DC biasing)

```
%% Input Sparameter Matrix and calcualte stability circle
% S-parameter measured by VNA4195A.
% S-para have be measured in linear |Gamma|/Phase mode#2,

% Read S para matrix
[Raw_S21,S11,S22,S21,S12] = Read_Sparameter('PwrOn');
%Calculate Stability Circle, ploted inside this function
[CL,RL,CS,RS] = Stability_Circle(Freq,markersize,Cres,Gammas,S11,S22,S21,S12,Freq_53MHZ_Index);
```



Now the coil/amplifier impedance has been inputted into the script, a matching network can be defined/optimized to interface the coil and amplifier.

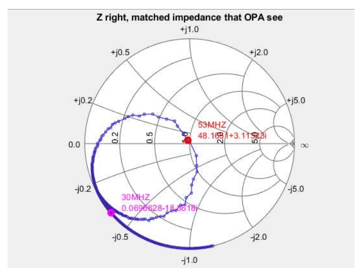
8. A matching network with common components can be defined in cascaded form, according to the table that programmed in this script. An example matching network with 3 components can be defined in the picture below. 6 common components can be used in this script: Type0-inductor, type1-capactior, type2-ideal transformer, type3-transmission line, type4-resistor, type5-LCC(C1 in series with C2||L3), type6-LCC [C1 || (C2 in series with L3]].

```
%Matching Network's matrix is defined here, every type is independent and
%can be cascaded.

%  Unit   |      Type      |  Config  |  addtional values  |
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%   1st   |       2nd      |   3rd    |    4th    |   5th    |
%   H     |       0-L      | 0-Series |     0     |    0     |
%   F     |       1-C      | 1-Shunt  |     0     |    0     |
% Z Ratio |      2-Tsfr    |  2-Tsfr  |     0     |    0     |
%   Z0    |       3-TL     |   3-TL   | Length(m) |    0     |
%   Ohm   |       4-R      |    0     |     0     |    0     |
%   C1-F  |   5-LCC_type1  |    0     |    C2-F   |   L-H    |
%   C1-F  |   6-LCC_Type2  |    0     |    C2-F   |   L-H    |
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%% Example %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%  [ seriec C(5pF) -> Ideal Transformer(1:4) -> shunt C(10pF) ]
% can be defined as:
% Components_Matrix = [
%                        [ 5e-12  1  0  0  0];
%                        [ 4      2  2  0  0];
%                        [ 10e-12 1  1  0  0];
%                         ];
```

9. As another example, to match/tune this coil to around 50Ω at 23Na/53MHz, a two-capacitor matching network (37pF series and 215.3pF shunt) can be define, and the matched impedance of the coil can be plotted as below:

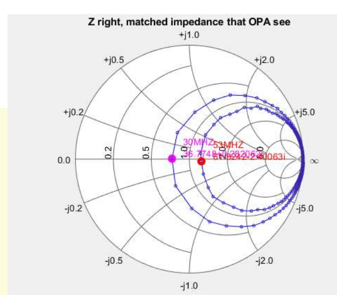
```
%% Regular 50 MN for 53MHz
Element_1 = [ 37e-12 1 0 0]; %series C
Element_2 = [ 215.3e-12 1 1 0]; %shunt C
Components_Matrix = [
                     Element_1;
                     Element_2;
                      ];
```



10. In this script, a matching network of LCC and transformer is used to tune/match this coil at both 2H/30MHz and 23Na/53MHz (different matching networks can be investigated if for other purposes). And the matched impedance is plotted as below:

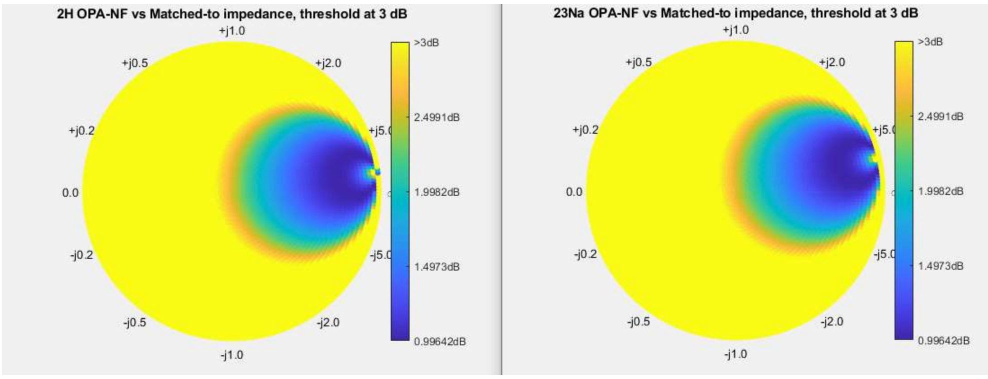
```
LCC_1 = [ 59.3e-12 5 0 181e-12 81e-9]; %series LCC
Tsfr = [15 2 2 0 0]; %transformer

Components_Matrix = [
                     LCC_1;
                     Tsfr;
                      ];
```



11. The calculated NF map of OPA vs matched impedance at different frequencies are plotted here to provide a visual guidance of where the optimal NF impedance is at .This is calculated

according the OPA parameters inputted earlier. (The NF map is threshold above 3dB, so that yellow area means the NF is higher than 3dB. And the impedance area with NF below 3dB is plotted according to the color bar).



12. With the defined matching network involved, the NF of OPA at the matched impedance and the decoupling of coil are also calculated and shown in command window.

```
NF_2H =

    3.1519


NF_23Na =

    2.2315


Decoupling_2H =

  -27.0829


Decoupling_23Na =

  -14.7409
```

13. Based on the calculated NF and decoupling, the matching network can be iterated/optimized. Different coil and OPA can also be investigated.

Further extension of modeling RF LNA

In this script, operational amplifier is used as an example. However, other RF LNA can also be modeled if further extension can be added to this script. Common RF LNA usually come with a touch stone file (.s2p file) from the manufacturer that contains its S-parameter matrix and noise parameters. Using the updated version of 2022A RF toolbox of MATLAB, .s2p file can be loaded into this script with the function "zparameters" and "noise Parameters". The manufacturer-measured S-parameter matrix of the device (therefore input impedance from S11) can be imported using the function "zparameters" and replaced with the OPA input impedance measurement in the example (with frequency and index properly re-selected). And the manufacturer-measured noise parameters of the device can be imported using the function “noiseParameters” and replaced the NF modeling of the OPA.