Instruction for using the program Q0REFLv9.m

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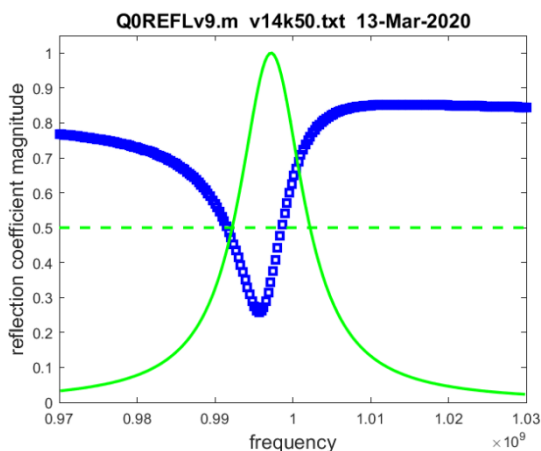
I. PRELIMINARIES

The purpose of the program Q0REFLv9 is to process the reflection coefficient data measured with a network analyzer, in order to accurately determine values of the loaded and unloaded Q factors of high-Q resonators. The data should be in the Touchstone RI format, consisting of three columns: frequency, real part of refl. coeff., and imag. part of refl. coeff.

Using Microsoft Windows File Explorer, create a new folder and name it "myQ0" or something similar. Copy the entire content of the "Q0v9" folder into myQ0 folder. Then open your Matlab® program and make sure that the active folder of Matlab is myQ0. This can be done by using "pathtool" and entering the name of myQ0 folder on top of the list and saving it. This way, all your input and output data will be available in this folder. I prefer the old Matlab version R2016a, because the graphics are easier to handle than in recent versions.

In the "current folder," on the left-hand of the default Matlab window, double-click on the "Q0REFLv9.m" name. The listing of the Q0REFLv9.m will appear in your Editor. In order to execute the program the first time, make sure that the "%" sign does not appear in front of the file name "deff={'v14k50.txt','n','n'};." All the remaining data file names should start with the "%" symbol, which in Matlab means: "this line is not executable." If and when you will want to use one of those input data, you will have to remove its "%" sign, and make sure that all others remain quarantined behind the "%" sign. Matlab's Editor has a convenient tool called "Comments" which makes it easy to enter or erase the "%" sign in front of the data files.

II. FIRST RUN

Start the program by clicking on the green triangle "run." The dialog window appears, containing 3 lines: 1) file name: v14k50.txt, 2) Stretching: y or n?: n, 3) Comment y or n?: n. Click OK, which means you agree with a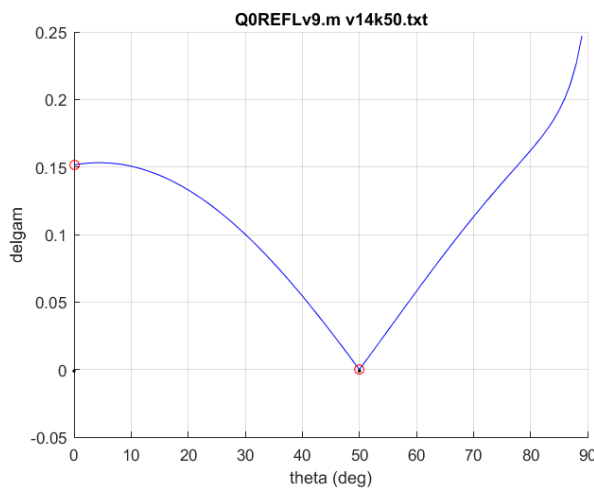ll three answers. The next prompt reads "Begin pruning." The display shows the blue data line, which is the magnitude of the measured reflection coefficient, and the green line which indicates the *rarity* of the data, namely the relative distance between two consecutive frequency data on the Smith chart. The horizontal dashed green line indicates where the rarity of data drops to one-half of the maximum. When the frequency is close to the resonance, the data move faster on the Smith chart, thus the rarity increases. The blue minimum indicates the location of the resonance, while the green maximum indicates about the same. Thus click OK and

use the mouse to choose the left and right pruning points where the two green lines intersect each other. Thus, you have decided to select only those measured points with the rarity larger than one-half of the maximum possible. For an accurate measurement, it is safe to have between 20 to 50 points inside the pruned region. If the program estimates that your unloaded resonant frequency is not inside the pruned region, it will stop further computation and give you a warning. In that case, you will have to start again, this time by choosing a wider pruning range, or even by changing your calibration of the network analyzer in order to increase the density of frequency points.

The next display shows a variable called "delgam" as a function of the line length "theta" expressed in degrees. This plot indicates that the program has processed the measured data and concluded that there are two possible values of theta where the delgam shows a minimum: one at 0°, and another at 50°. It is up to you to guess which one will result in a more accurate value of Q, so the program prompts you with: "Choose one minimum." Click OK and use the mouse to put the cross-hair on the red circle at 50°. The program works for a second, and finishes by displaying the Figure 5. That figure tells you how well the equivalent circuit has mimicked the measured data. The blue circles are the input data (after pruning), and the red dots are the equivalent circuit data. In this case, each red dot seems to have found the exact center of the corresponding blue circle. The overall uncertainty is estimated to be 0.11983%. Your display may show a slightly different value, depending on how many data points you have selected in the pruning procedure.

II. FIGURES

Figure 1 shows the results of the pruning operation: the blue dots are the data which were used for processing the information, and the red dots indicate the ignored part of the input data file. There is no visible noise on the data, because this is an artificial data file used to validate the functioning of the program.

Figure 2. As mentioned above, this figure displays which minimum has been selected for processing. In this particular case, the first minimum, occurring at 0°, has been rightfully ignored. Depending on what data you are working on, it may happen that several minima will be created between 0 and 90 degrees, and you might try each of them, to find out which circuit model gives the best agreement with the measured data.

Figure 3 shows a pruned part of the Q-circle at port 0 of the equivalent circuit. For successful data processing, the center of the Q-circle should be located on the horizontal axis of the Smith chart. An incorrect guess of the value theta may result in a tilted Q-circle, which immediately tells you that you cannot trust the results that follow.

If you zoom-in on the location where the Q-circle crosses the real axis, you will notice an interpolated red point, between the two nearest "measured" points. This red point is the best estimate for the unloaded resonant frequency f_0.
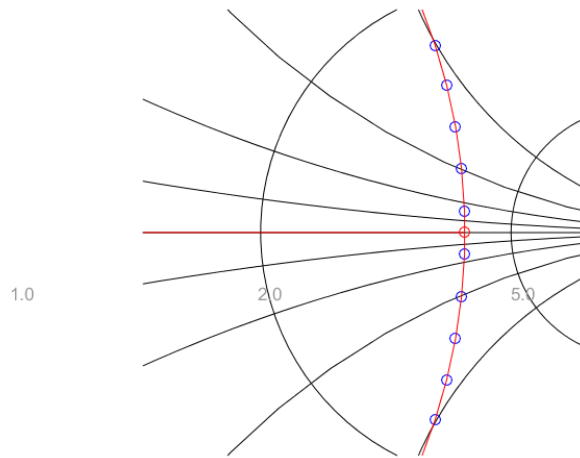
Figure 4 is a summary of the a-posteriori data processing. It displays the "measured" point in blue circles and the processed points in red lines. The detuned reflection coefficient, the center of the Q-circle, and the loaded reflection coefficient are shown with red dots, connected by a straight line, which indicates the diameter of a Q-circle. The heavy red point indicates the unloaded resonant frequency. All the data are referenced to port 1 of the equivalent circuit.

To the left of the Smith chart, the resulting values for the loaded Q, unloaded Q, and their estimated uncertainties are printed out. But the value of the unloaded resonant frequency is printed without quoting its uncertainty, because we do not know how to do that yet. But since we know that the unloaded resonant frequency for the validation data was f_0 = 1.0 GHz, it is reassuring to find that the recovered value of f_0 turns out to be accurate to the first 8 digits.

Figure 5 is a check of how good the overall agreement is between the measured data (blue circles) and the reflection coefficient computed from the equivalent circuit (red dots). For the example shown, each computed red point has found the center of the "measured" blue circle.
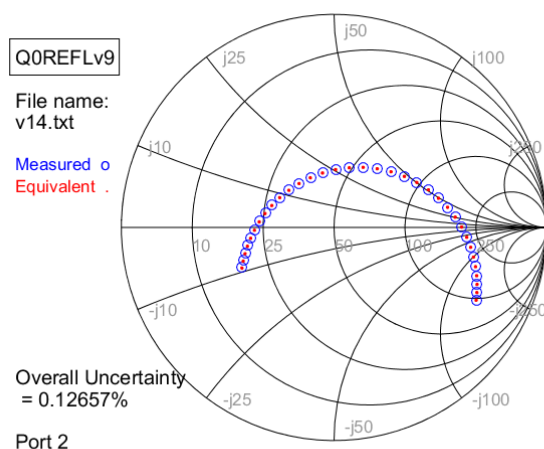
You may ask: the overall uncertainty is expressed in percent of what? The answer is: the radius of the Smith chart is taken to be a standard for the distance. Therefore, the fact that the overall uncertainty equals 0.13% means that, within the pruned region, most departures between

measured and equivalent points are smaller than 0.13% of the Smith chart radius.

IV. STRETCHING

Sometimes, the measured data contain thousands of frequency points, showing perhaps several sharp resonances, and it becomes difficult to accurately select the pruning range. In order to see better what is going on at one specific resonant frequency, we would like to stretch certain part of the frequency scale over a wider portion of the graphical display. This can be accomplished by answering "y" to the second dialog line question "stretch: y or n." As the next example, let us investigate the measured data file FD-40.mea. In the listing of the Q0REFLv9.m program, insert the "%" symbol in front of the data file that you have been using previously, and remove the "%" symbol in front of the FD-40.mea data line. Also, on the same line, make sure that the answer to the dialog question "stretching: y or n?" is 'y'. Start the program by clicking on the green triangle called "run."
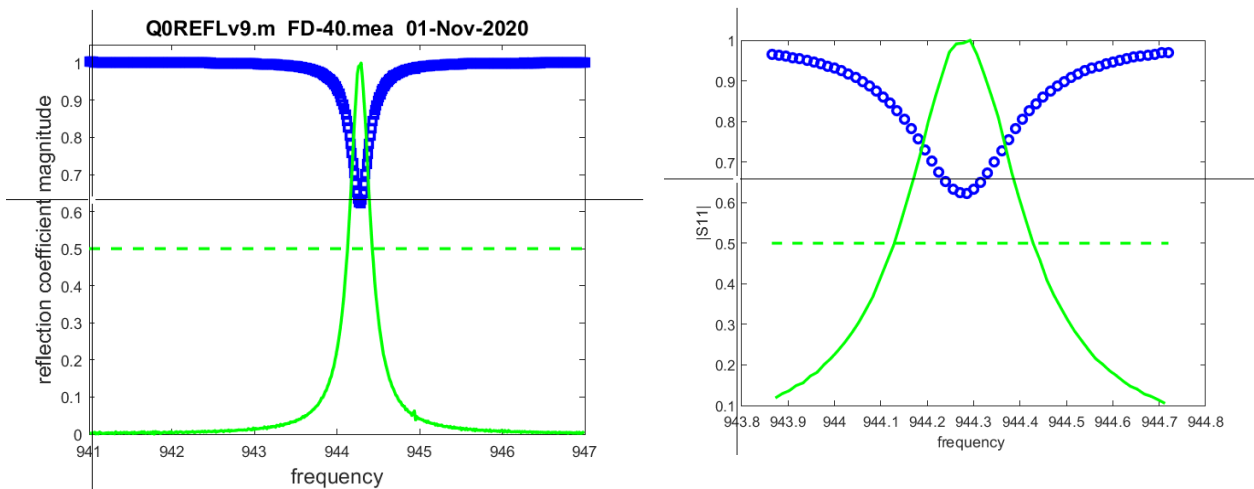
The prompt "start stretching" appears on the display which shows a resonance somewhere between 944 and 945 MHz. Click OK, and then OK again, then use the cross-hair mouse indicator on the left flank of the green rarity line at about the 0.1 level and click, then on the right flank at about the same level and click. Immediately, the resonance is stretched, and you can conveniently choose the 0.5 level at the left and right sides of the pruning bandwidth. Afterwards, you see the delgam function of theta again, and the prompt is: "choose one minimum." Select the lower one at 73°. My result for the overall uncertainty is 0.038652%, what is yours?

V. SAVING THE RESULTS

When you want to save the results of your Q factor measurement, this can be done by answering the question "Comment: y or n?" (the third line of the dialog box) with "y." This will allow you to write a comment for characterizing the measurement, something like: "validation file, overcoupled case." Remember to go to the Command Window of Matlab and type your

comment (followed by Enter), otherwise the programming will not continue. The comment and the data will be written into the file called "resultsv9.txt," and it will look like following:

```
**********************************************************************
 Q0REFLv9   v14k50.txt   yr 2020 month  3 day 13 hour 16 min 48 sec 12
  comment: validation data, overcoupled case
          QL          dQL         kappa       dkappa           Q0          dQ0
 +1.0000e+02 +2.8503e-04 +2.0000e+00 +2.6474e-03 +3.0000e+02 +8.0388e-04
          rs           xs  OveUncPerc           fL        f0corr
 +2.0000e-01 -1.0000e+00 +0.00114407 +9.9466e+08 +1.00000003e+09
```

Every processed and commented set of results will be added to the same file. When you think the file has become too long and you do not need these data, you should erase them.

At the beginning of the QREFL9.m program, lines 28 to 38 contain several input data. Only the FD-40.mea line of data represents an actual measured result, the remaining lines are the validation files for checking the proper functioning of the program. The names of the data contain the letter k (for angle), the letter n (for noise), and the letter p (for decimal point). For instance, the file name v14k50n1.txt is an overcoupled case with the transmission line length theta=50°, and with an added noise of 1%. All v14 data are overcoupled cases, and all v13 data are undercoupled cases. When you will be using your own measured data, put the % sign in front of the v14k50.txt file, and insert your line of data in the program listing

If you do not want to change anything in the program listing, you can run the program as it is, and in the first dialog box replace the name "v14k50.txt" with the name of your data file. I avoid naming my data files with the ".dat" extension, because Matlab grabs and re-formats them, so that I cannot recognize and use them anymore.

References
[1] D. Kajfez, "A-posteriori estimation of random uncertainty for the reflection type Q-factor measurement," *ACES Journal,* Vol. 35, No. 10, pp.1105-1112, October 2020. Open access at: http://aces.socieaty.org/newsletter.php
[2] D. Kajfez, *Q Factor Measurements Using Matlab Ⓡ*, Boston, MA, USA: Artech House 2011.