Vector Forum, A Branch of Kajfez Consulting
P.O.B. 757, University, MS 38677, USA

QZERO FOR WINDOWS

INSTRUCTIONS FOR USE

Installation

Create a folder named QZWIN (or another name of your choice) on your hard disk. In Windows 95 and 98 this is done by opening the Windows Explorer, clicking on C (or another letter of your choice), clicking on File, clicking on New, clicking on NEW Folder. You have to type the name (e.g. QZWIN) and press Enter. This will be called the first Explorer window.

Next, copy the entire contents of the diskette on this newly created folder. This can be done by using the Windows Explorer. Open the second Windows Explorer, reduce its size so that you can see both windows. In the second Window Explorer click on A (the location of the diskette). The list of files appears. Mark all the files by clicking on the first file, then move the mouse to the last file, press and hold the Shift key and click the right mouse button. All the selected files turn blue, because they must hold their breath until the user decides what to do with them. Drag the entire selection (with the mouse button still pressed) from the second window over to the first window and aim it over the folder QZWIN that you have created. The folder will also turn blue (becomes highlighted). Release the mouse button, folder gets back its healthy complexion, and the menu appears so that you can choose the option "COPY HERE."

The program is now ready to use. Remove the diskette, close the second Explorer (click on "x" in its right top corner), and double click the mouse on the file QZEROW.EXE. The dialog appears, and the program is ready to read your data. You may want to start experimenting with the program without reading instructions. If you cannot figure out something, the detailed instructions, including examples, can be found in the QZWINSTR.PDF file. The file opens with a double mouse click (providing your computer has Acrobat reader installed).

If you wish to create a shortcut icon, single click on QZEROW.EXE in your Explorer window, then go to "File," select the "Create the shortcut" menu. In the list of files a new file called "Shortcut to QZWIN " will appear with a yellow icon. Drag the icon somewhere in the open green area of Windows 95. Now, the Qzero for Windows can be activated by double-clicking on the icon, without the use of Explorer.

Purpose

QZERO for Windows is a tool to assist an experimentalist in the reflection-type measurement of the unloaded Q factor of a microwave or rf resonator. The purpose of the program QZERO for Windows is to process the measured data taken by a Network Analyzer in order to determine the loaded and unloaded Q factors of a resonator under test. The data should be taken in the vicinity of the loaded resonant frequency f_L, i.e. the frequency at which the absolute value of the input reflection coefficient S_{11} is minimum.

Principle of operation

The input reflection coefficient S_{11} of a resonator with high value of Q describes a circle on the complex plane when the operating frequency is swept across the resonator bandwidth. Such a Q-circle is clearly visible on a Smith-chart display of the Network Analyzer. The mathematical model used in the QZERO program is a linear fractional function as follows:

$$S_{11} = \frac{a_1 t + a_2}{a_3 t + 1} \tag{1}$$

The three complex coefficients a_1, a_2, and a_3 have to be computed for each particular measurement. The normalized frequency variable t is defined as follows

$$t = 2\frac{f - f_L}{f_L} \tag{2}$$

where f is the operating frequency and f_L is the loaded resonant frequency (the frequency with smallest value of $|S_{11}|$).

Typically, there will be some 20 or more measured data points, and there are only three unknown coefficients a_1, a_2, and a_3. The resulting overdetermined system of equations is solved in the least-square sense. Then, the loaded Q factor, Q_L, is obtained from the coefficient a_3, and the coupling coefficient κ is computed from the diameter of the Q circle. The details of the computational procedure can be found in the book *Q Factor*, which accompanies the QZERO program.

The program QZERO also computes the estimated standard deviations for the quantities of interest. It should be understood that those error estimates are obtained by assuming that the only source of error are random variations of the data. These error estimates do not take into account possible systematic errors of the equipment which generated the data.

How does the Window version of QZERO differ from the DOS version?

(1) QZERO for Windows can do all the computation that QZERO for DOS can do. The results computed by the two programs are identical to each other. However, the printing of the Smith chart, containing the results of data processing, can be

done directly from the Windows environment. With a laser printer, the resolution is a good as the graphical display of the personal computer permits. Thus, such a plot can be incorporated in a word-processing document, or the printed copy can be used for an engineering or a scientific publication.

(2) In addition, QZERO for Windows can process the measured data of a two-port resonator. Such data consist of two files, namely S_{11} and S_{22}.

(3) Finally, the program can read directly the data file written by the HP8712 Network Analyzer.

Dialog controls

When QZERO for Windows is activated, the dialog window appears such as shown in Fig. 1. Through this dialog, the user specifies

- Was the resonator measured as a 1-port or as a 2-port?
- What type of input data format is used?
- If the input data are impedances, what is the characteristic impedance?
- Should the results of computation be written to an output file?
- How detailed should be the output file?
- What should be the name of the output file?

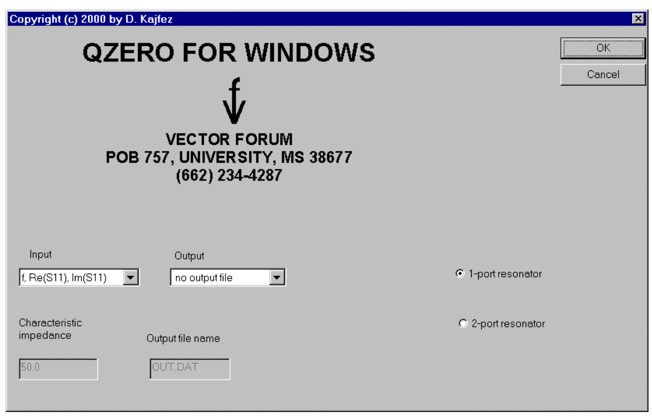

Fig. 1 Dialog window

The *input* format shown in Fig. 1 is specified as follows:

f, Re(S_{11}), Im(S_{11})

This means the data file consists of three columns of numbers, separated by commas or by blank spaces. The first column is the frequency at which the measurment is taken, and the next two columns contain the real and the imaginary parts of the input reflection coefficient. There may be up to 1601 rows of data (the largest possible number of points taken by the Network Analyzer). The input format shown is by the way the default format. Other possible formats are shown on the drop-down list of input data. For instance, the next format is

f, Re(Z_{in}), Im(Z_{in})

Again, there are three columns of data, the first one is frequency, the second and third are the real and the imaginary parts of the input impedance. If you select this format with a mouse click, it will appear in the top frame of the dialog input control. In this case, you must also specify the characteristic impedance at the input port of the resonator. First, you must click the OK button, then the default value 50.00 Ω will appear. If you are satisfied with this value, you do not have to do anything. Otherwise, drag the mouse over this value and type the new value of your choice.

Other possibilities of the input data format are the formats written directly by the Network Analyzer. At the time of this writing, the "spreadsheet" format is available. More formats compatible with various Network Analyzers may be added later???

The dialog box denoted *Output* controls whether the measured results should be saved in a file on the hard disk. The default value of this control is "no output file." This choice is appropriate when the user wants only to observe the results on the screen, but he does not want to save the results in a file. The other two selections are "short output" and "long output." After the user has selected one of these, he should press OK button. The dialog appears again, with the name out the output file highlighted in the box named "Output file name." The default name is OUT.DAT. The old output file will be every time overwritten with the new output, unless the user selects a different name. To change the name of the output data file, the user must drag the mouse over the default name, and type in the new name.

The two *radio buttons* are called "1-port resonator" and "2-port resonator." The 2-port measurement is a novelty that was not available in the original version of QZERO for DOS. By pressing this button, the user is expected to supply two different input data files: one measured at port 1 when the port 2 is terminated in 50 Ω load, and the other when port 2 is measured and the port 1 is terminated in a matched load 50 Ω.

When all the selections have been made and the OK button is pressed, the program will allow the user to browse through the folders and disks for selecting the input file(s) which have to be processed. If instead the Cancel button is pressed, the next prompt will verify whether the user wants to exit, and then he may either exit, or start all over from the beginning.

Example 1 (1-port, three measured S_{11} files)

The three cases of this example are shown in Figs. 67, 68, and 69 of the book *Q Factor*. The data files are called M4501.MEA, M450E8.MEA and M450D8K3.MEA. and they contain the real and imaginary parts of the input reflection coefficient. Use QZERO for Windows to process all three data files.
SOLUTION:
Start QZERO for Windows by either double-clicking on its shortcut, of from the Explorer by double clicking on the QZWIN.EXE file. When the dialog appears, click OK. Next, you see the subwindow entitled "Open: Select File for Unit 4" giving you the list of data

files to choose from. Unfortunately, the files we need are not shown, because only the files with the extension .TXT are showing. You must go to the box entitled “Files of type” and select “All Files (*.*).” Now, the measured files become visible and you click on M4501.MEA and then click the “Open” button. The program finishes the computations instantly and you will notice that two child windows have been created, one called “Graphic 1”, and the other called “PLOT 10.” Afterwards, the message box asks:

Load another input data?

One can process up to 40 data files in a single run of QZERO for Windows. The plots will be all cascaded in small windows, numbered from 10 up. Click on YES button and select the file M450E8.MEA. This file has only 7 points, as it contains only each eighth of the measured points. Finally, open the file M450D8K3.MEA. As explained in the book *Q Factor*, this file is obtained from an original set of 51 measured points by deleting the first 8 points, then keeping the next three, and again deleting eight, keeping three, etc. This is done to demonstrate the property of the QZERO program that the data do not have to be equidistant in frequency. Answer NO to the message about loading more data. The next message box comes:

Program terminated with exit code 0. Exit window?

Answer NO so that you have the opportunity to see what you’ve got. The situation is shown in Fig. 2.

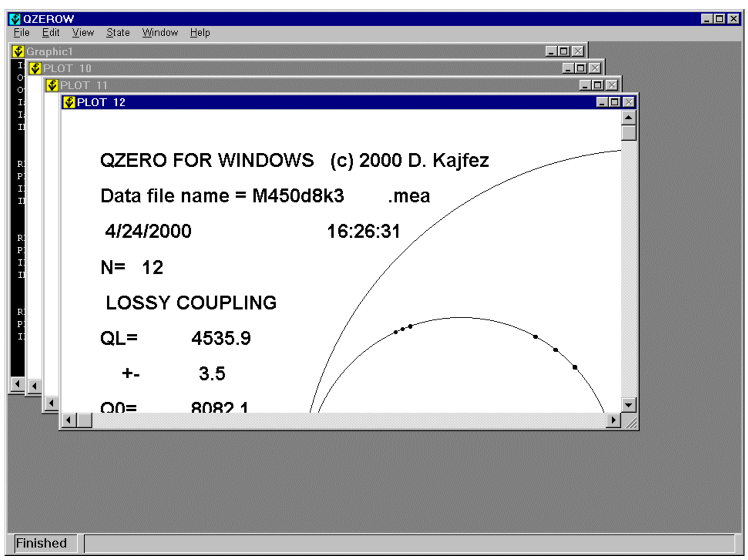

Fig. 2 Half-size windows

Only a part of the Smith chart of the third plot is visible. To see the full chart, the child windows must be made full size. The frame window (outside window) is called “QZEROW” and the child windows showing the Smith charts are called PLOT 10, PLOT 11, and PLOT 12.” These windows can be made full size by clicking on the ð symbol in their top right corners. When both the frame window and PLOT 12 are maximized, the full view looks like the one shown in Fig. 3. You may object that this is not really the full view, but when printed, it will be. It is possible to write the program so that the figure becomes smaller, but that would require a further sacrifice in resolution. The present size was selected as a compromise between a good visibility and a good resolution.

The measured points are indicated by black dots. It can be seen that the best-fit circle agrees well with each of the points. The three hollow points denote the center of the Q circle, and the points Γ_d and Γ_L (for the meaning of these two points see the book *Q Factor* p. 110, Fig. 58). On the left of the Smith chart one can read the important results, for instance Q_L = 4535.9 ± 3.5, Q_0 = 8002.1 ±9.0, etc. These results are identical with those from Fig. 69 in the book *Q Factor*.

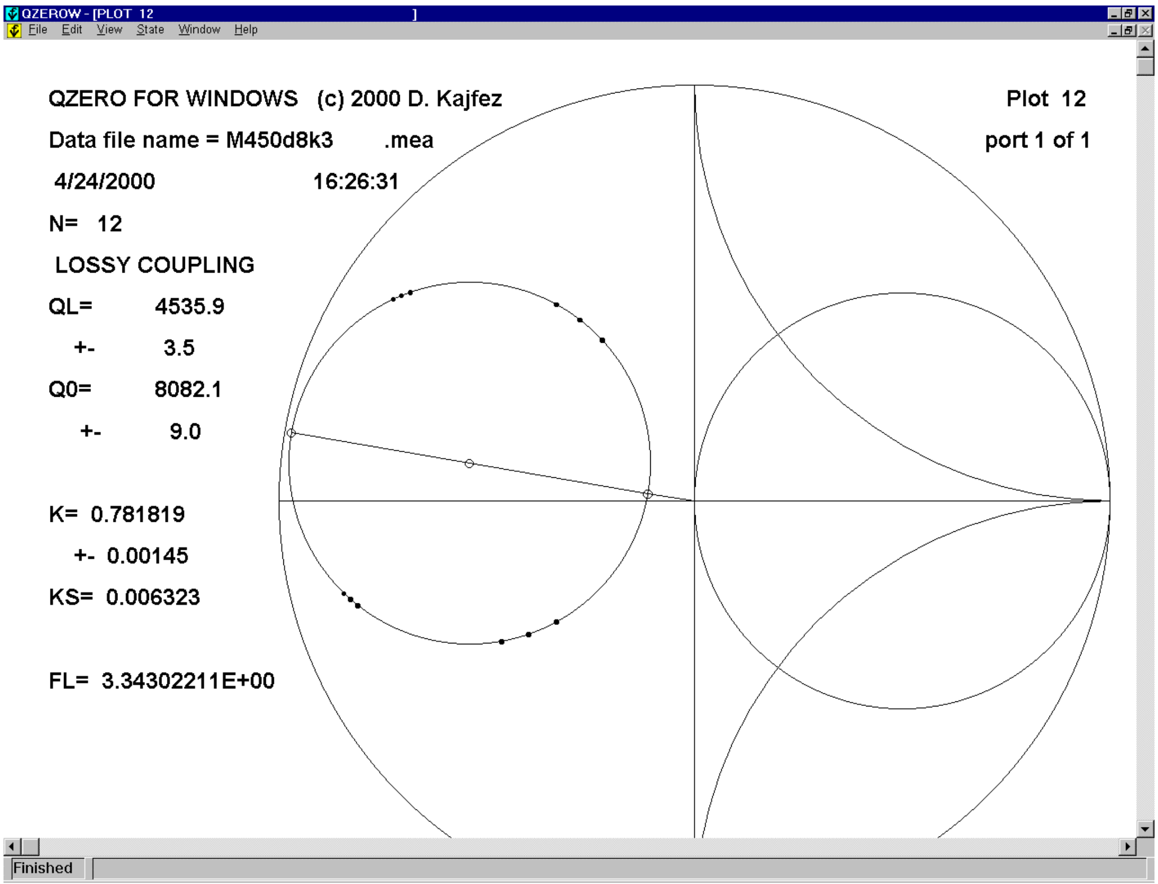

Fig. 3 Full size screen display

To see the first plot, minimize PLOT 12 by clicking the mouse on the "–" symbol in its top right corner and then maximize PLOT 10 by clicking on its "ð" symbol. The result is identical with Fig. 67 in the book *Q Factor*. These are the first 20 points of the total number of 51 measured points. The case demonstrates that even though the frequency scan covers only one skirt of the total response, the recovered value of the unloaded Q factor differs by less than one percent from the value 8003.8, obtained by using all 51 points (see Fig. 66 in the book *Q Factor*).

Next, move the mouse to the top left corner and click on “File.” If you want to exit, click on “Exit,” and if you want a hard copy of the plot, click on “Print.” From the printer dialog you may select either Landscape size (for a full page plot), or the Portrait Size (for a somewhat smaller plot).

Reflection-type measurement of transmission cavities

When the cavity under test is a transmission cavity (a two-port), the precision measurement of the Q factor should be performed in two steps, as illustrated in Figs. 4a and 4b. In the first step, port 2 is terminated in a matched load, and the input reflection coefficient Γ_1 is measured at port 1. In the second step, the cavity is turned around, port 1 is terminated and the reflection coefficient Γ_2 is measured. In the Network Analyzer terminology, Γ_1 is called S_{11}, and Γ_2 is called S_{22}.

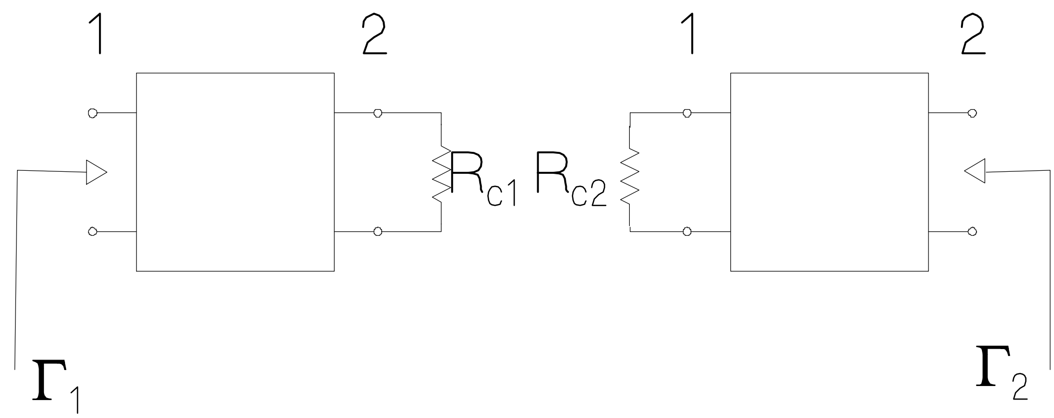

Fig. 4a Measuring port 1 Fig. 4b Measuring port 2

Program QZERO for Windows can process the two measured data files and evaluate the unloaded Q factor of the cavity, as well as the coupling coefficients of port 1 and of port 2. The principle of operation is based on a consecutive application of the QZERO procedure, obtaining the overall result as a weighted average of the two measurements.

When the measurement at port 1 is performed, as shown in Fig. 4a, the coupling coefficient at port 1 obtained by this method is denoted by κ_{m1} and the loaded Q is denoted by Q_{L1}. The true coupling coefficient κ_1 at port 1, which needs to be determined, is a quantity defined by

$$k_1 = \frac{P_{ex1}}{P_0} \tag{3}$$

Thus, the coupling coefficient is a ratio of power P_{ex1} dissipated in the external circuit connected to port 1 (assumed to be matched), and power P_0 dissipated inside the resonator. What is actually measured in the situation shown in Fig. 1a is the quantity

$$k_{m1} = \frac{P_{ex1}}{P_0 + P_{ex2}} = \frac{k_1}{1 + k_2} \tag{4}$$

because the power P_{ex2} dissipated in the external circuit at port 2 is also included in the measurement. Analogously, the measured coupling coefficient κ_{m2} at port 2, obtained in situation shown in Fig. 4b is

$$k_{m2} = \frac{P_{ex2}}{P_0 + P_{ex1}} = \frac{k_2}{1 + k_1} \tag{5}$$

Solving (4) and (5), we obtain the desired actual coupling coefficients in terms of the measured coupling coefficients:

$$k_1 = k_{m1} \frac{1 + k_{m2}}{1 - k_{m1} k_{m2}} \tag{6}$$

$$k_2 = k_{m2} \frac{1 + k_{m1}}{1 - k_{m1} k_{m2}} \tag{7}$$

The desired unloaded Q of the cavity is then obtained from

$$Q_0 = Q_L \left(1 + k_1 + k_2\right) \tag{8}$$

Ideally, the loaded Q factor measured at port 1 should be identical with the one measured at port 2, because the twoport is passive and reciprocal. In practice, one observes a slight difference between the two results, and the average of the two should yield the most probable value. The difference between the two results also provides a good measure of the overall uncertainty of measured results.

Example 2 (2-port resonator)

The measured results obtained with the Network Analyzer Model HP8712C are stored on a diskette in the ASCII format “Lotus 123.” The file names are TRAC0.PRN and TRAC1.PRN. Process the data, plot the Smith chart displays and write a short output file.

SOLUTION:

Start QZERO for Windows, click “2-port” button, and select “Input” to be “HP: ASCII Lotus 123” and “Output” to be “short output.” Click “OK” button. As the characteristic impedance should stay 50 Ω and the output file name should remain OUT.DAT, click the “OK” button again. On the “Files of type” select “All Files (*.*)” and then click on TRAC0.PRN and “Open.” Next, you must select for the second time “Files of type” to be “All Files (*.*),” and this time open the file TRACE1.PRN. By the way, this tells you that next time you have a chance to baptize a data file, better choose its extension to be “TXT,” so you have to do less clicking with your mouse when feeding it to the program.

Both files have been entered, say “NO” to further files and “NO” to “Exit Window?”, and the program creates three cascaded windows, one for text, and two for graphics. In order to print the graphic windows, the frame window and the child window must be maximized and then printed with a “File” and “Print” menus on the left top corner. The printed results are shown in Figs. 5 and 6. The two plots are identified to be “Port 1 of 2” and “Port 2 of 2”. The two loaded Q factors are 805.8 and 816.7, thus differing from each other by 1.3 percent. The difference is probably caused by less than perfect calibration of the network analyzer and the connecting cable.

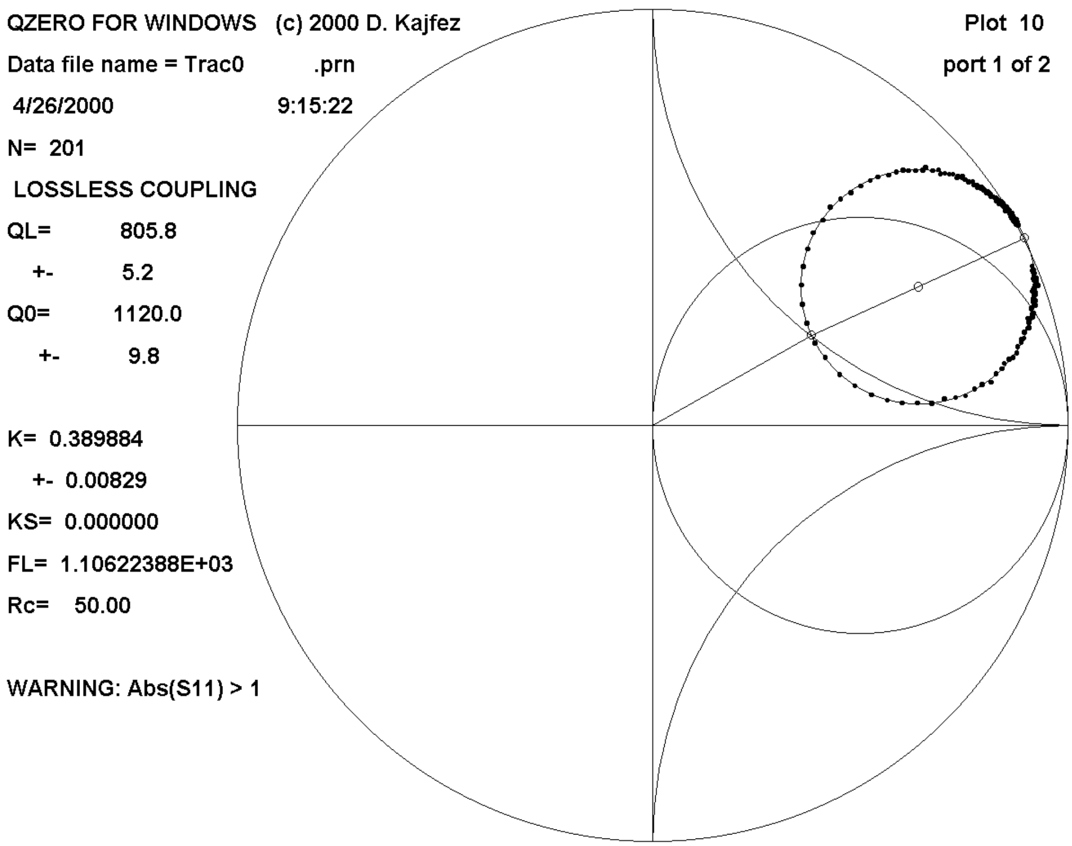

Fig. 5 Port 1 measurement results

In both figures, one can notice a slight noise superimposed on the data. In addition, some of the points in Fig. 5 fall outside of the Smith chart perimeter, which triggered the warning message. Namely, passive circuits cannot have the absolute value of a reflection coefficient to be larger than unity

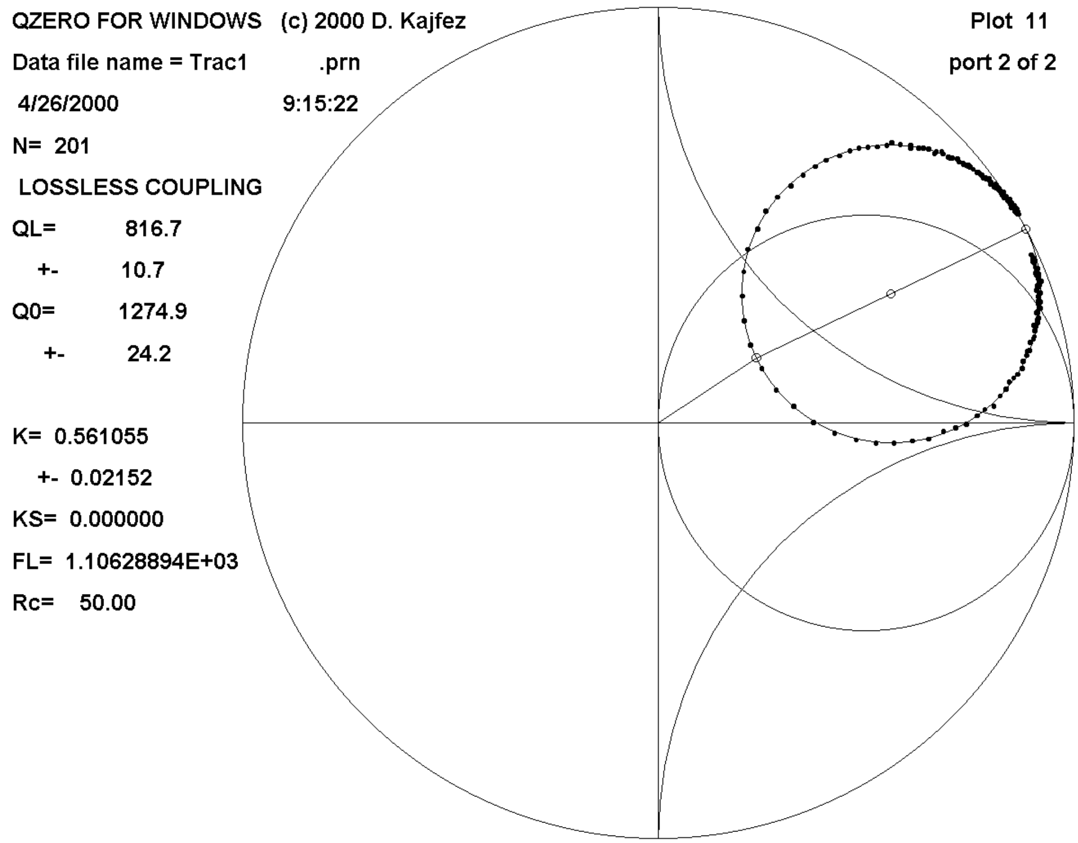

Fig. 6 Port 2 measurement results

The output file OUT.DAT is shown in Fig. 7. The "Port 1 Analysis" and the "Port 2 Analysis" display the apparent values of the coupling coefficient (i.e. the ones denoted by subscript *m* in equations (4) to (7)). Also the values of Q_0 are the apparent values, since the resonator is in each measurement loaded by a 50 Ω resistance according to Fig. 4. The true values of the coupling coefficients and the unloaded Q factor are given under the title "Weighted Averages." They have been obtained from the apparent values with the use of equations (6) to (8).

```
 **************** QZERO FOR WINDOWS ****************
 **          Copyright (c) 2000 D. Kajfez           **
 ***************************************************

  4/26/2000                                  9:15:21

 2-PORT RESONATOR

 PORT 1 DATA FILE = Trac0           .prn

 PORT 2 DATA FILE = Trac1           .prn

 CORRESPONDING PLOTS #  10 AND #  11

**************** PORT 1 ANALYSIS

 NUMBER OF POINTS =   201

 LOSSLESS COUPLING

WARNING: ABS(S11) =   1.002624 (>1.0 !)

 QL =       805.8 +-        5.2

 Q0 =      1120.0 +-        9.8

  K =    0.389884 +-   0.008287

 KS =    0.000000

 FL =     1106.223877

**************** PORT 2 ANALYSIS

 NUMBER OF POINTS =   201

 LOSSLESS COUPLING

 QL =       816.7 +-       10.7

 Q0 =      1274.9 +-       24.2

  K =    0.561055 +-   0.021522

 KS =    0.000000

 FL =     1106.288940
```

Fig. 7 Short output

It is important to note the following advantages of the described measurement procedure for two-port resonators:

- The procedure fully characterizes the transmission cavity, including the loaded and unloaded Q factors, and the coupling coefficients for each of the two ports.
- The measurement provides the values of both input and output coupling coefficients, which can be entirely different from each other. In the widely used transmission-type measurement of the Q factor (also called the insertion loss method), this information is not available. Instead, one must postulate the equality of the input and output coupling coefficients in order to determine the unloaded Q factor.
- The resulting Q factors and coupling coefficients are accompanied by the uncertainty estimates. This has been made possible by data processing of many more measured points than the number of unknowns to be determined. In addition to these random errors, the difference between the loaded Q factors measured at the opposite ports constitutes an estimate of the systematic errors.

The disadvantage of the described procedure is that two separate measurements must be performed, and each stored in a data file to be fed to the program. Thus, the procedure is not suitable for production tests. However, such a procedure is useful in a research environment, when precision is of utmost importance.

Availability

The program QZERO for Windows is sold together with the book *Q Factor* (Vector Forum 1994), which includes also the DOS software and instructions for its use.

The order form is on the following page.

Please do not send orders by an e-mail. On the other hand, the author would appreciate any e-mail comments or questions on the use of the program at the following address:

eedarko@olemiss.edu