January 30, 2009

Mr. Frederick B. Hubler wrote an article in the November/December 2008 edition of QEX, pages 23-29, "Broadband Impedance Matching". Mr. Hubler uses graphs in reference 2 of his article (my reference 2) to obtain g(i) values necessary for the prototype filter elements. I have found a way to obtain the g(i) values using a method and a computer program described in my reference 3. The compiled computer program and its C++ program listing are contained in a zip file I have provided as well as other supporting files which augment the work of Mr. Hubler in his QEX article.

I have been studying broadband impedance matching over the past several years. In that time, I have referred to a book by Thomas R. Cuthbert, Jr., "Circuit Design Using Personal Computers". Within this book is BASIC source code (Appendix B, Program B6-3) for a program which computes the g(i) values that my reference 2 (Mr. Hubler Ref. 2) provides in graphical form.

I have coded the BASIC source code found in Cuthbert's book in C++. The output of this program agrees with examples in Cuthbert's book as well as Table 2 in Mr. Hubler's QEX article (my Ref. 1).

The executable, Cuthbert_B6_3n.exe, is a DOS Windows Console Program. I have verified that it runs under Windows XP and Windows Vista. The program is compiled as a Win32 Console Application and so may run under earlier Windows operating systems. Source code is provided so readers are able to modify and compile as they wish. Outputs of the program are displayed at the console and written to both text and csv (comma separated variable) files.

The inputs to the program that are common for all types of inputs are:

Result File Name
Lower Band Edge Frequency (f1) (MHz)
Higher Band Edge Frequency (f2) (MHz)
N, number of resonate elements including load

Additionally, one of three different types of inputs is to be provided to the program:

1) Load Decrement
2) Load Parameters
3) Load Q

In the first type, the Load Decrement which is defined in Mr. Frederick Hubler's article is input into the program. In the second type, load parameters are input into the program and some simple calculations are performed to obtain the Load Decrement. Load parameters are also defined in Mr. Frederick Hubler's article. In the third type, load Q is input into the program as was done in the original "Program B6-3" found in the Thomas R. Cuthbert, Jr. text, and this is scaled by the Fractional Match Bandwidth within the program to obtain the Load Decrement.

The user is prompted to select between a series or parallel load realization. If the Load Parameter type of input is selected, then this selection causes the program to prompt for the appropriate load parameters (serial or parallel load). If Load Decrement or Load Q types of input are selected, then this selection causes the program to prompt for either Average Load Resistance or Average Load Conductance inputs.

In summary, the input selections follow this decision tree:

- For Load Decrement Input:
  - Enter Load Decrement
  - For Series Load Realization
    - Enter Average Load Resistance over Match Bandwidth (f1 to f2)
  - For Parallel Load Realization
    - Enter Average Load Conductance over Match Bandwidth (f1 to f2)
- For Load Parameters Input:
  - For Series Load Realization
    - Enter Average Load Resistance over Match Bandwidth (f1 to f2)
    - Enter Delta Bandwidth which is bandwidth in MHz used to calculate Delta Reactance
    - Enter Delta Reactance which is change in load series reactance over Delta Bandwidth
  - For Parallel Load Realization
    - Enter Average Load Conductance over Match Bandwidth (f1 to f2)
    - Enter Delta Bandwidth which is bandwidth in MHz used to calculate Delta Susceptance
    - Enter Delta Susceptance which is change in load parallel susceptance over Delta Bandwidth
- For Load Q Input:
  - Enter Load Q
  - For Series Load Realization
    - Enter Average Load Resistance over Match Bandwidth (f1 to f2)
  - For Parallel Load Realization

Enter Average Load Conductance over Match Bandwidth (f1 to f2)

The Series Load Realization uses Average Load Resistance to impedance scale the g(i) prototype values. Likewise, the Parallel Load Realization uses Average Load Conductance to admittance scale the g(i) prototype values.

Output Part 1 - Preliminary

The following three paragraphs describe how this program uses equations in reference 1 to calculate Load Decrement from the load parameters.

The Band Center Frequency (f0) is calculated from the inputs Lower Band Edge Frequency (f1) and Higher Band Edge Frequency (f2) using equation 1. Then the Fractional Match Bandwidth is calculated using equation 3.

When Series Load Realization is selected, the Reactance Slope Parameter is calculated from inputs Delta Reactance and Delta Bandwidth using equation 5. The Load Decrement follows from equation 7 with input Average Load Resistance.

When Parallel Load Realization is selected, the Susceptance Slope Parameter is calculated from inputs Delta Susceptance and Delta Bandwidth using equation 6. The Load Decrement follows from equation 8 with input Average Load Conductance.

The relation { (Load Decrement) = 1/ ((Load Q)(Fractional Match Bandwidth)) } is used to find Load Decrement or Load Q.

The data outputs of this section are:

Center Frequency (f0) (MHz) (actually geometric mean frequency)
{Square Root of (f1 * f2)}
Match Bandwidth (f2-f1) (MHz)
Fractional Match Bandwidth (wm) ((f2-f1)/f0)
For Series Load Parameter entry:
Reactance Slope Parameter
For Parallel Load Parameter entry:
Susceptance Slope Parameter
Load Q and/or Load Decrement depending upon input

Output Part 2 - Fano's Broadband-Matching Limitations;
Levy Matching;
Newton - Raphson Solution:

Fano's Broadband-Matching Limitations (Cuthbert {Ref. 3}, p. 189, Section 6.3) describes the best possible match over the match bandwidth.

Levy Matching (Cuthbert {Ref. 3}, p. 195, Section 6.3.3) minimizes the maximum reflection coefficient over the match bandwidth.

The Newton - Raphson Solution (Cuthbert {Ref. 3}, p. 125, Section 5.1.5; p. 196, Section 6.3.3) yields A and B which are then used to calculate the magnitude of the reflection coefficient minimum and maximum values. From these values the SWR and return loss minimum and maximum values are obtained.

The data outputs of this section are:

FV {program variable for measure of minimum in Newton - Raphson Solution }
IT {program variable that indicates number of iterations in Newton - Raphson Solution}
A {program variable for Newton - Raphson Solution}
B {program variable for Newton - Raphson Solution}
Magnitude of Reflection Coefficient Min and Max
Mismatch Loss Min and Max (dB)
Return Loss Min and Max (dB)
SWR Min and Max

Output Part 3 - Resistive Source with g(i) Prototype Values:

Green's Recursive Element Formula (Cuthbert {Ref. 3}, p. 200, Section 6.4) is used to compute g(i) for i = 2 to N+1. g(0) = 1 and g(1) = 1 / (Load Decrement).

Output Part 4 - Network Element Values Calculated:

Network Element Values Calculated using method described in Hubler {Ref. 1} p. 24 or Cuthbert {Ref. 3}, p. 205, Section 6.5.

The data outputs of this section are the Scaled Network Values:

Load Resistance derived from g(0)
L(1) (H)
C(1) (F)
…
L(N) (H)
C(N) (F)
Source Resistance derived from g(N+1)

The outputs from the program are written to two types of files which contain all information.

1) {Result File Name}.txt : Text file.
2) {Result File Name}.csv : Comma Separated Variable file.

The {Result File Name}.csv was created to allow a user to easily import data into a data spread sheet. The {Result File Name}.csv file can be imported into a MS Excel workbook by choosing the csv format for data import. Some of the entries do not display the full precision that the program output. These data entries can be reformatted to show desired precision within the Excel workbook.

Likewise, when the {Result File Name}.csv file is opened with MS Excel, some of the entries do not display the full precision that the program output and reformatting shows the desired precision. The {Result File Name}.csv file can be opened with a text editor and it will resemble the {Result File Name}.txt showing entries with expected precision.

The following files and folders are included in the main zipped folder:

Readme.pdf	This document in PDF format.
Cuthbert_B6_3n._xe	DOS Windows Console Program executable which needs to be renamed to Cuthbert_B6_3n.exe. Refer to Note 4 for renaming executable Cuthbert_B6_3n._xe. Rev: n, January 30, 2009.
Cuthbert_B6_3n.cpp	DOS Windows Console Program C++ source file. Rev: n, January 30, 2009.
Interpolated 4.xls	Impedance Data for Shakespeare Model 390-1MGB (Excel 97 – 2003 Workbook) Original Data 8 to 10 MHz Band interpolated by MATLAB 16 to 20 MHz Band interpolated by MATLAB 25 to 30 MHz Band interpolated by MATLAB
Series Load	Folder which contains following folders. Each folder has design data.
Hubler_T1_N1_Series_Load	Folder for Hubler QEX Article, Table 1, N = 1 Result File Text format Result File Comma Separated Variable format Schematic in gif file SWR graph in gif file Return Loss in gif file
Hubler_T1_N2_Series_Load	Folder for Hubler QEX Article, Table 1, N = 2 Same files as above but with N = 2
Hubler_T1_N3_Series_Load	Folder for Hubler QEX Article, Table 1, N = 3 Same files as above but with N = 3
Hubler_T1_N4_Series_Load	Folder for Hubler QEX Article, Table 1, N = 4 Same files as above but with N = 4

Parallel Load	Folder which contains following folders/file. Each folder has design data. The parallel load data has been calculated to produce the same Load Decrement as in the series load data.
Hubler_T1_N1_Parallel_Load	Folder for Hubler QEX Article, Table 1, N = 1 (Parallel load with same Load Decrement as series load data.) Result File Text format Result File Comma Separated Variable format Schematic in gif file SWR graph in gif file Return Loss in gif file
Hubler_T1_N2_Parallel_Load	Folder for Hubler QEX Article, Table 1, N = 2 Same files as above but with N = 2
Hubler_T1_N3_Parallel_Load	Folder for Hubler QEX Article, Table 1, N = 3 Same files as above but with N = 3
Hubler_T1_N4_Parallel_Load	Folder for Hubler QEX Article, Table 1, N = 4 Same files as above but with N = 4
Parallel Load Design.xls	Excel file describing how parallel load was designed to relate to series load having same load decrement. (Excel 97 – 2003 Workbook)

Notes:

1) (Load Decrement) = 1/ ((Q)(Fractional Match Bandwidth))
   (Q) = 1/ ((Load Decrement) (Fractional Match Bandwidth))
   These equations are used to replace Q with Load Decrement in original Cuthbert B6-3 program.
2) The parameters FV, IT, A, and B are used internal to the program and can be found in the original BASIC program which is in commented text at the end of the C++ source file.
3) Cuthbert_B6_3n._xe DOS Windows Console Program executable which needs to be renamed to Cuthbert_B6_3n.exe. This is because executable files (*.exe) cannot be sent by email.
4) Unzip the attached zipped folder. To rename Cuthbert_B6_3n._xe to Cuthbert_B6_3n.exe, open Tools menu on folder Toolbar. Click Folder Options… . Click View tab. Uncheck "Hide extensions for known file types". Click OK. Rename file Cuthbert_B6_3n._xe to Cuthbert_B6_3n.exe.
5) I am sorry, but as of yet I have not yet figured out how to remove "Valid digital signature" warning which appears after starting up Cuthbert_B6_3n.exe. If you have trust issues you may be able to run all files through a virus scan.

References:

1) Frederick B. Hubler, "Broadband Impedance Matching", ARRL QEX, November/December 2008.

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2) G. Matthaei, L. Young, and E.M.T. Jones, "Microwave Filters, Impedance Matching Networks, and Coupling Structures", Artech House, 1980.

3) Thomas R. Cuthbert, Jr., "Circuit Design Using Personal Computers", John Wiley & Sons, 1983.

Sincerely,

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