

Software Tool for Broadband Matching

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ABSTRACT

In broadband antenna design, the Smith Chart technique for designing a matching network turns to be a tedious one due to the involvement of multiple frequencies and the varied behaviour of the elements at these frequencies.

Computational tool 'RFCAD' described in this paper can improve the efficiency of the design process. The Smith Chart based screen display leads to an intuitive approach to the design.

Initially the program reads frequencies and impedances of the antenna and displays these data in a Smith Chart. Then it enables the designer to build the matching network progressively by adding lumped and/or distributed passive elements. The GUI provides Edit Value and Insert/Delete Element functions. This facilitates a trial and error approach to optimise the design. VSWR, Mismatch Loss and Reflection Coefficient are displayed on screen to make this software a complete CAD tool.

This paper discusses the development, features and problems encountered in the development of the software, which was developed as a final year project at University of Moratuwa. The software was highly successful and currently being used in laboratory classes for the degree students.

1.0 INTRODUCTION

The merit of an antenna system, next to the merit of the antenna itself, depends on the efficiency of coupling between the feeder and the antenna. The standing wave ratio (SWR) at the interface determines the overall efficiency of the system. For single band applications, the antenna impedance can be calculated or measured, and an appropriate transmission line, with matching unit if necessary, can be used. In wide band applications the procedure is not as simple as in the single band case.

The antennas have their feed point impedance varying with the frequency of operation. A typical broadband system require an antenna with a limited SWR in a given bandwidth. Not very many antennas inherently has this property¹. A broadband matching network placed between the antenna and the feeder system can be used to achieve the desired performance.

The most general problem of broadbanding is that of synthesising a circuit to match one arbitrary impedance to another arbitrary impedance over a prescribed frequency range to be with in prescribed tolerance. Fortunately, the broadbanding problems found in practice involve impedances that are not completely arbitrary². A further simplification of broadbanding problem often occurs because, at least one of the impedances to be matched usually is the characteristic impedance of the transmission line, thus is either constant and resistive or nearly so.

The Smith Chart is a convenient graphical tool, which has been used for analysing and designing matching arrangements for antenna systems. It simplifies the process by avoiding tedious calculations. The results are obtained graphically with the help of geometrical constructions. In broadband matching design problems, the impedances as well as the values of matching elements varies with frequency. Hence this graphical method also becomes a complex one.

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Computational aids can improve the efficiency of design process. In designers point of view, he/she prefers to visualise the problem and the solution in the convenient and informative format of a Smith Chart. The objective of this paper is to introduce such a software tool for broadband matching circuit design; which was developed as a part of our final year project at Department of Electronic and Telecommunication Engineering, University of Moratuwa - Sri Lanka.

2.0 BROADBAND MATCHING DESIGN

In single frequency operation, when the antenna impedance is normalised to the characteristic impedance of the feeder and plotted on a Smith Chart, the centre point ($1+0j$) represents the perfect match. At this point the voltage standing wave ratio (VSWR) is unity. If the normalised antenna impedance is not $1+0j$ mismatch exists and a simple passive network can be design to match the two.

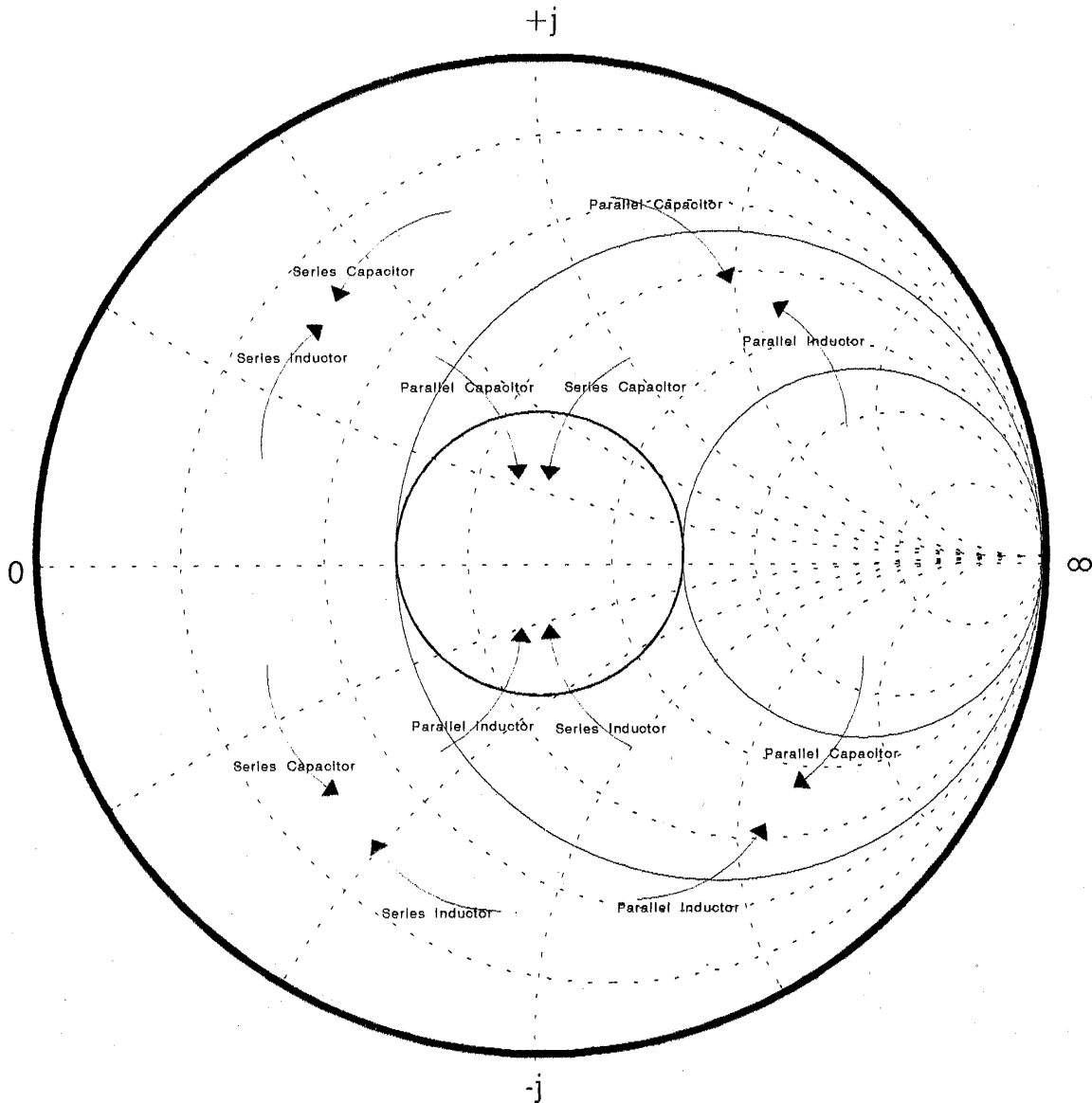


Figure 1: Impedance transformations due to passive elements [Impedance Chart]

For a broadband system it is not possible to perfectly match the antenna at all operating frequencies; instead an average match with minimum loss at required frequencies (or range) can be achieved by employing a proper matching network. Before embarking on designing such a network, a target VSWR below with the performance (mismatch loss) is acceptable, has to be defined. Matching can be achieved either using distributed, lumped or combination of both types of elements. By introducing passive elements such as capacitors, inductors, transmission line sections and stubs, the impedance points can be *moved* in a Smith Chart in desired direction. Figure 1 illustrates typical transformations due to adding passive elements. It should be noted that the relative degree of movement of each point will depend on the associated frequency of that point.

On a Smith Chart, as depicted in the figure, series reactance moves impedance values along lines of constant resistance circles. A series inductor moves the points in clockwise direction while a series capacitor moves them in counter-clockwise direction. Also a series inductor moves high frequency points farther than the low frequency points. In contrast, a series capacitor moves the lower frequency points farther than the higher frequency points.

A shunt reactance moves the points along circles of constant conductance. In practice constant conductance lines can be visualised by overlaying a reversed transparent Smith Chart on top of another, so that zero impedance of one chart is over the infinite impedance of the other. As depicted a parallel inductor moves points in counter-clockwise direction while a parallel capacitor in the opposite direction. A parallel inductor moves the lower frequency points farther than the higher frequency points and a parallel capacitor vis-à-vis.

3.0 DESIGN APPROACH

The first step in designing a broadband matching circuit is to choose the first network element. This element (and each succeeding element) may be a lumped or distributed component. The impedance characteristics of the broadband antenna as viewed through this element will be different to the impedance of the antenna itself.

The selection of the first element of the matching network is of primary importance. A proper selection provides a better opportunity for achieving the design objectives when the remaining elements are added. There exists a number of procedures for designing broadband matching network. The procedures are sometimes complicated and may not work in all cases. However the approach described above is straightforward and is usually successful¹. The degree of success in design is directly related to the experience and ingenuity of the individual designer. A trial and error approach can be effectively employed if a computational tool is available for quick transformation and plotting of points in a Smith Chart.

4.0 SOFTWARE TOOL RFCAD

RFCAD is a Smith Chart based software tool for broadband matching network design. To do the design the user has to input the frequencies of operations and the corresponding feed point impedances of the antenna at a sequential prompt. The impedances can be from practical measurements or a computer simulation such as Numerical Electromagnetic Code (NEC)³. The user has the facility to correct an erroneously entered data (if any). Alternatively the input data can be loaded from a disk file. Next he/she is prompted for the normalising impedance; the characteristic impedance of the transmission line. When these data are supplied the software will normalise and display it on a Smith Chart. Figure 2 shows a typical Smith Chart Display (SCD) before matching.

The points marked on the chart corresponds to the impedances of a half wave dipole tuned to 175.25 MHz at Band I and Band III television channels. Note that the three points corresponding to Band I are at a distance from the Band III points. The circle around the centre of the chart at VSWR=2 is the target VSWR for this design. The software facilitates the marking of a target VSWR circle at a desired value by simply clicking the VSWR button.

By clicking the mouse at any point on the chart area, normalised impedance, VSWR, mismatch loss and reflection coefficient at that point can be displayed. In addition if an impedance point is clicked the corresponding frequency of the point is also displayed. This feature makes the software a n excellent learning tool for a beginner.

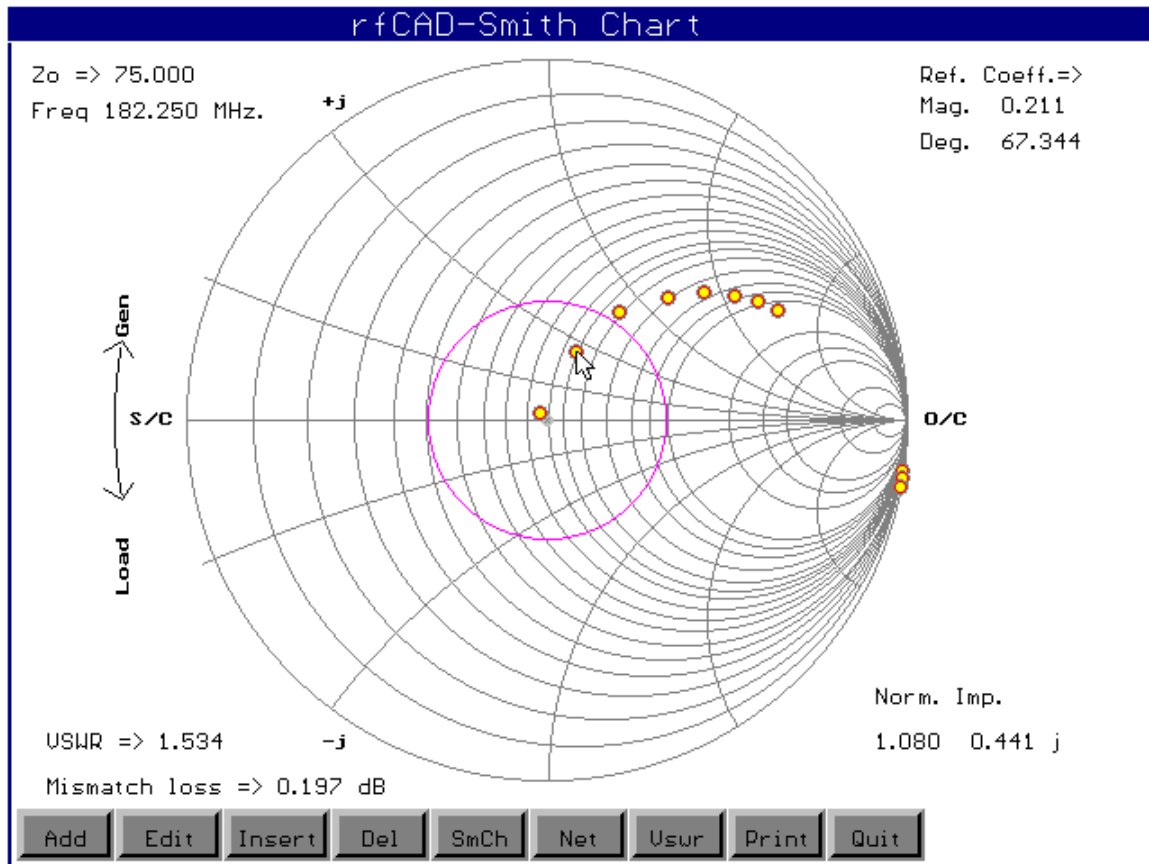


Figure 2: Smith Chart Display - Before Matching

The design of the network is carried out by the first four buttons on the bottom of the screen: Add, Edit, Insert and Del (for delete). By clicking the Add button a network element can be added to the circuit. The element could be an inductor, capacitor, short circuited stub (all in series or parallel to the line) or a transmission line section. The elements are numbered sequentially from the antenna towards the transmission line.

Edit button facilitates altering the value of a network element. The ability to alter the value of not only the last but any element, takes this software tool a giant step forward to the paper based Smith Chart. Once an alteration of element value is made, the SCD is updated instantly; whereas in a paper based chart such an alteration will involve re-doing the geometrical constructions. The Insert and Del buttons makes it possible to insert or remove a network element at the click of a button. Figure 3 shows the SCD after matching the impedances in figure 2.

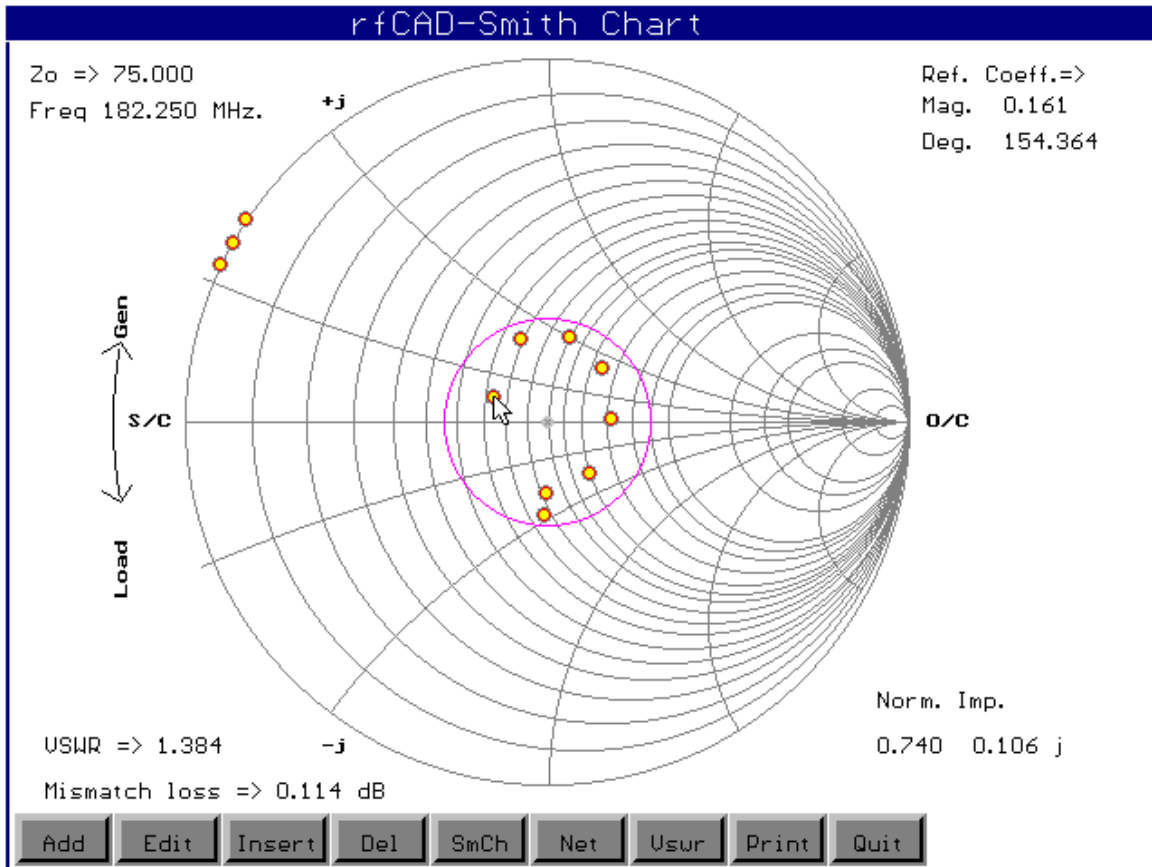


Figure 3: Smith Chart Display - After Matching

The SmCh (Smith Chart) and Net (Network) buttons toggles the display between the SCD and the network display. The network display shows the current network elements in the circuit. The Print button activates the printing services. The Smith Chart, the input data, the final results containing the normalised impedances, VSWR and Mismatch Loss at each frequencies after matching and the matching network can be obtained in the hard copy form. The designed network can be saved on a disk file and retrieved later.

5.0 SOFTWARE DEVELOPMENT

The software RFCAD has been developed in two phases. In the first phase the functionality of the software was developed and successfully demonstrated. The first version contained all the fundamental operations and calculations to design a broadband matching circuit.

5.1 Features in the First Version

It could read a set of impedance data from either keyboard or off a disk file, normalise them and plot them on a Smith Chart. The program accepts matching elements one by one and plot the impedances looking through the added elements. Only the latest element can be altered its value. For any reason, if the designer wants to alter the value of a previously entered element he/she has to go back to that state and re-enter the details of all the subsequent elements. There was no facility available to save the circuit and retrieve when continuing the previous work.

The user interface was mainly text based except for displaying the Smith Chart. The chart display contained the important parameters of a selected points such as frequency, normalised impedance,

VSWR, reflection coefficient, etc. Points could be selected to display these parameters through the cursor keys. The following elements could be added in designing a matching circuit:

1. Inductor (series/parallel)
2. Capacitor (series/parallel)
3. Transmission line section
4. Short circuited stub (series/parallel)

5.2 The Enhanced Version

The second phase of development was an effort to enhance the user interface and to provide extensive facilities to the designer. The initial idea of using Microsoft WindowsTM for the Graphical User Interface (GUI) was later given up due to the lack of development tools in the Department and the extensive learning time required adopting to the new platform. Instead we attempted to build our own graphical front end for this software using object oriented programming (OOP) techniques. The results of this effort was highly successful.

The program was developed as a multi-file software using the 'project' feature in the Turbo C++TM Integrated Development Environment (IDE). The software was divided into the following modules:

1. Main computational & Control module (`rfcad.cpp`)
2. Class definitions and data structures (`win_obj.h/win_obj.cpp`)
3. General purpose routines (`utility.h/utility.cpp`)
4. Mouse interface (`mouse.h/mouse.cpp`)
5. Button utilities (`butt.h/butt.cpp`)
6. Smith Chart utilities (`smith.h/smith.cpp`)

Most of the drawbacks in the first version were eliminated in the new version. It has a WindowsTM like fully graphical interfaces. Point and click features were added for easy operation. The Edit, Insert and Delete functions were introduced. The VSWR marker, Save and Load for the network file and hard copy output facility were newly incorporated into the software.

Several steps were taken to make the software rigid against user errors. Illegal option selections are rejected with appropriate messages on screen. User input is buffered to certain extent such that typing alphabets in place of numbers and vis-à-vis are not accepted. File related errors are also buffered with appropriate messages. Several bugs were detected and corrected in the testing stages. However a 100% error free software is an ideal target and cannot be guaranteed even in a professional software product.

5.3 Problems encountered

RFCAD has a total graphical user interface (GUI). All the inputs and outputs are in graphics mode. The Turbo C++TM does not provide any standard function to take inputs in the graphic mode. We had to write our own routines to accept characters from keyboard, echo them on graphic screen and to draw the cursor in the appropriate position.

5.4 Future developments

Currently RFCAD supports only passive components. A further development could be to add active elements such, as transistors in s-parameter model⁴. This will make the package a total RF design software. The input (impedance vs. frequency) file format can be made compatible with an antenna simulator such as NEC³ and the output (network) file format can be standardised with a circuit simulator such as SPICE⁵. This file compatibility will add a professional touch to the software as a product.

6.0 OBSERVATION

When designing a broadband matching network the difficulty of achieving the prescribed tolerance of match, increases with the required bandwidth. The difficulty increases with the electrical length of the transmission line (if present) between the antenna and matching network.

A matching circuit should have as few elements as possible to minimise the losses. When the number of components is high the stray effects of the leads etc. will severely affect the performance of the circuit. Figure 4 gives the mismatch loss vs. VSWR curve. Both mismatch loss and VSWR are available in package.

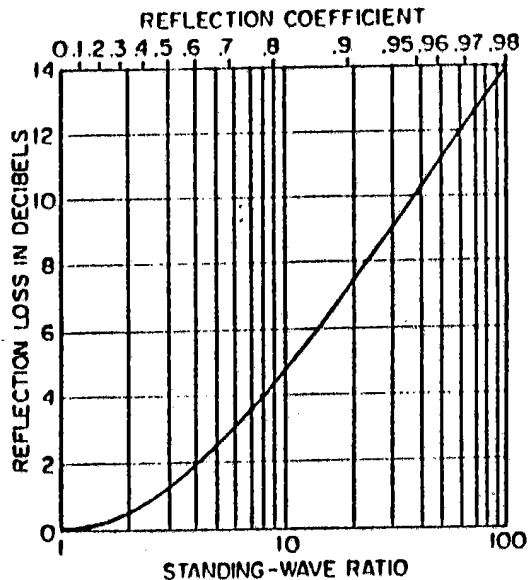


Figure 4: Mismatch loss Vs. VSWR

7.0 CONCLUSIONS

The software RFCAD package discussed in this paper extends the capabilities of the familiar Smith Chart technique. Complex multi-frequency problems can be handled with ease with this computational tool. The integrated Smith Chart Display enhances the designers vision of the state of the problem as well as solution during the design process. In addition to being a power full CAD tool, it can also be used as a learning tool for students learning transmission line theory and matching design. When the suggestions given in section 5.4 are implemented this programme will become a professional Software product.

8.0 REFERENCES

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