COMPUTER AIDED DESIGN OF RADIOFREQUENCY AND MICROWAVE CIRCUITS

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Abstract:

Radiofrequency and microwave CAD computer programs enabling for signal and yield analysis and circuit optimization have been developed. Program is used both in circuit design and student education.

1. Introduction

Recent advances in radiofrequency and microwave circuit design have been achieved as a result of both new manufacturing technologies and sophisticated design methods. Creativity of a microwave engineer gets drawn back heavily by an enormeous amount of calculations necessary to analyze a typical microwave circuit. Given a proper CAD package, a lot of this stuff may be taken away so that the engineer may devote his attention to the art of microwave engineering.

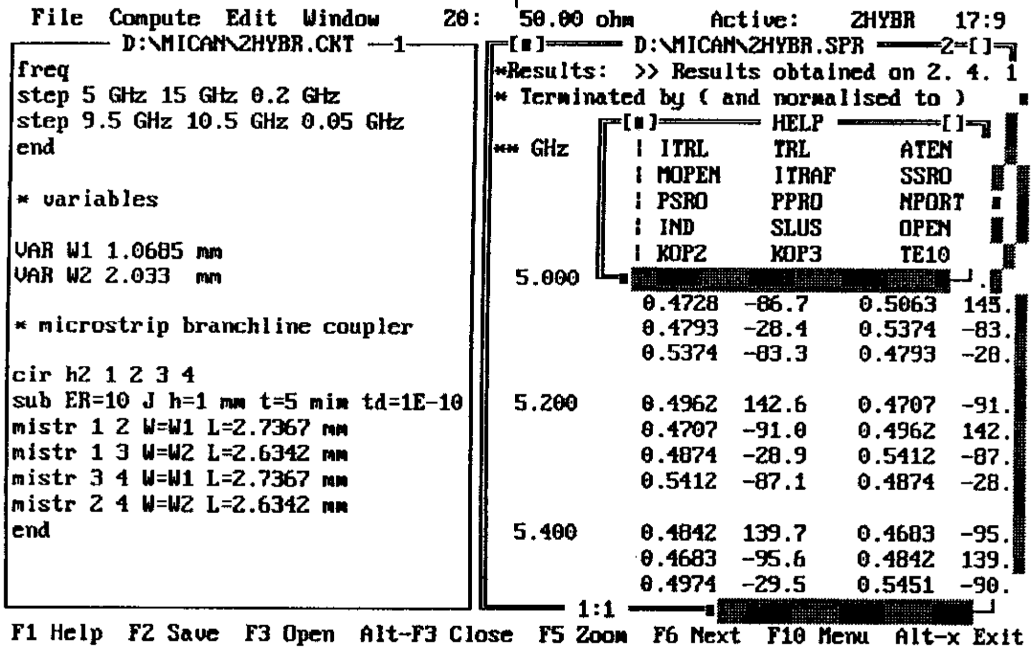
Due to trade restrictions and pricing, this kind of software is still nearly unavailable in Eastern Europe. Moreover, there is no vendor providing source code of the software, thus nearly no changes may be done in these programs. This is why developing our own computer code has been found of a great interest.

2. Short program description

The program consists of three main, relatively independent parts: Circuit analyzer/optimizer, planar transmission line analyser/synthesizer and interactive Smith chart. However independent, all these parts are able to interchange data so that results obtained while making use of the two latter ones are brought to the analysis/optimization program easily.

2a. Analyzer/optimizer

The analyzer is capable of analyzing linear circuits consisting of lumped and/or distributed elements (resistors, capacitors, inductors, voltage and current controlled sources, transformers, basic transmission lines and coupled transmission lines). Both ideal elements and physical models are included. Microstrip discontinuities include step in width, gap, tee and cross junction, open end and radial stub. Elements may be connected arbitrarily to form complex circuits.



```
freq
step 5 GHz 15 GHz 0.2 GHz
step 9.5 GHz 10.5 GHz 0.05 GHz
end

* variables

VAR W1 1.0685 mm
VAR W2 2.033  mm

* microstrip branchline coupler

cir h2 1 2 3 4
sub ER=10 J h=1 mm t=5 mim td=1E-10
mistr 1 2 W=W1 L=2.7367 mm
mistr 1 3 W=W2 L=2.6342 mm
mistr 3 4 W=W1 L=2.7367 mm
mistr 2 4 W=W2 L=2.6342 mm
end
```

```
*Results:  >> Results obtained on 2. 4. 1
* Terminated by ( and normalised to )

** GHz

  5.000
            0.4728  -86.7      0.5063  145.
            0.4793  -28.4      0.5374  -83.
            0.5374  -83.3      0.4793  -28.

  5.200     0.4962  142.6      0.4707  -91.
            0.4707  -91.0      0.4962  142.
            0.4874  -28.9      0.5412  -87.
            0.5412  -87.1      0.4874  -28.

  5.400     0.4842  139.7      0.4683  -95.
            0.4683  -95.6      0.4842  139.
            0.4974  -29.5      0.5451  -90.
```

Fig. 1.
A screen dump. Analyser/optimizer user interface.

The optimizer allows for modifying variable values in order to achieve given goals. Any combination of scattering parameters and Rollet stability factor may become a goal.

In order to provide a means for cost optimizing, the program provides yield and worst case analysis. All elements, including measured sets of N-port scattering parameters, may be assumed varying according to Gauss, Simpson or equal density distributions.

Both circuit topologies and goals are entered in text mode. Each element is specified by its physical or electrical parameters (such as microstrip width, electrical length etc.) and terminal node numbers. An example of such a circuit description can be seen on Fig. 1.

The analyser has got a multiwindow text editor enabling for fast and convenient work. Results may be plotted in one to four separate windows, see Fig. 2. These plots may be invoked also during optimization so that the progress of the process is inspected and controlled instantly.

The program supports mouse, nevertheless may be operated also just from a keyboard. All control functions are accessed via pulldown menus. This user interface is completed with an interactive, hypertext help.

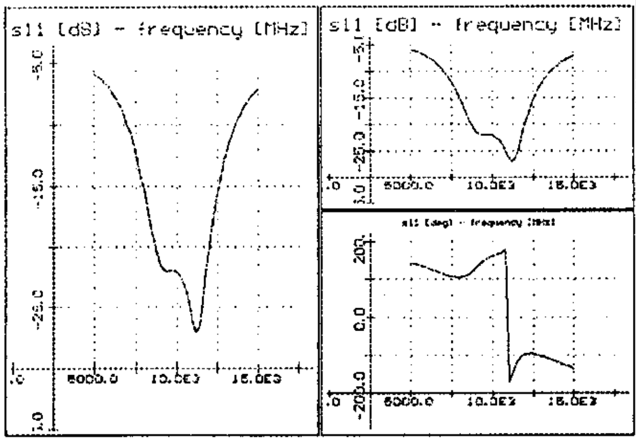
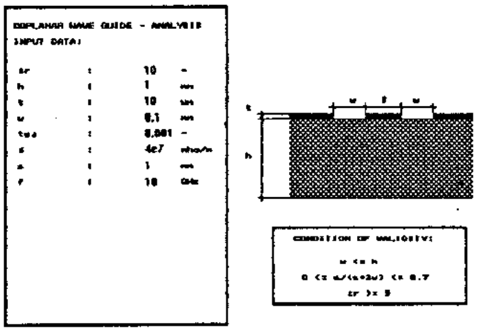


Fig. 2.
Screen dump. An example of output plots.

2b. Transmission line analyser/synthesizer

This is a user friendly programme for analysis and synthesis of the most used planar transmission lines. It is designed for an effective work with following lines. Microstrip line, strip line, slot line, coplanar waveguide line, coplanar strips line, coupled microstrip lines, coupled strip lines. Both in analysis and synthesis an appropriate sketch of the line with corresponding input and output data is displayed, see Fig. 3.

Analysis of the line may be done either on fixed frequency or in a graphic output. The parameters (characteristic impedance, wavelength, losses) are calculated on the chosen frequency or their frequency or the substrate parameters dependances are displayed.



```
COPLANAR WAVE GUIDE - ANALYSIS
INPUT DATA:

er     :    10      -
h      :    1       mm
t      :    10      um
w      :    0.1     mm
tgd    :    0.001   -
s      :    4e7     mho/m
s      :    1       mm
f      :    10      GHz
```

```
CONDITION OF VALIDITY:

w <= h
0 <= w/(w+2s) <= 0.7
er >= 9
```

Fig. 3.
Screen dump. Transmission lines analysis/synthesis user interface.

In synthesis the widths of strips or slots for desired characteristic impedances on a fixed frequency and specified substrate parameters can be obtained.

Data from synthesis may be immediately used in analysis.

The input data are checked with regard to the applied equations validity conditions.

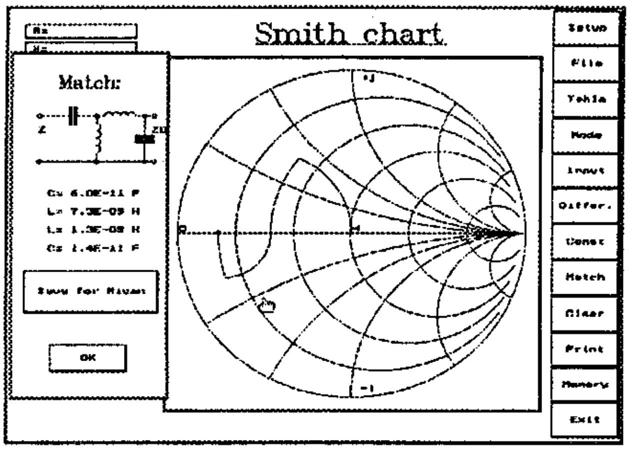
Synthetized dimensions of transmission lines may be brought easily into a separate window of the text editor so that they may be incorporated into analyzed circuits.

2c. Interactive Smith chart

The Smith chart is not just a way of graphic impedance representation, nor it is just a graphic aid for circuit synthesis. Radioengineers have evolved, say, a special way of "Smith chart thinking". This is why special care has been paid to it.

The Smith chart program enables for plotting impedances and assures fast and accurate conversion of plentiful parameters (SWR, impedances, admittances etc). Both normal and compressed charts are supported.

Matching circuits are designed instantly, see Fig. 4. These include lowpass, highpass and bandpass matching circuits that consist of lumped elements and/or transmission lines. All these designs are visualised in the Smith chart. Matching circuits are sketched. A special file, describing calculated matching circuits in a form readable by the analysis program, is generated.



```
C= 6.0E-11 F
L= 7.3E-09 H
L= 1.3E-08 H
C= 1.4E-11 F
```

Fig. 4.
Screen dump. Interactive Smith chart user interface.

3. Inside

The program may be seen from multiple points of view. While foregoing sentences have been depicted the program from a standpoint of the user, there are more viewing angles to mention. Different in nature they are of equal importance: a) microwave element characterization, b) circuit performance evaluation and c) program organization.

3a. Microwave element characterization

The program handles with a lot of microwave elements. Planar transmission lines may be concidered as the most important. All necessary equations for their evaluations were taken from [2] and [5].

a) Microstrip line.

The conductor thickness, dispersion and losses are involved. The used equations are valid for

$$0 < \frac{t}{h} \leq 0.2,$$

$$0.1 \leq \frac{w}{h} \leq 20,$$

$$\varepsilon_r \leq 16,$$

where t is the conductor thickness, h is the substrate thickness, w is the microstrip width, ε_r is the substrate relative permitivity.

Synthesis is performed by an iteration. The same formulas as in analysis are used.

b) Strip line.

The conductor thickness and losses are involved. The used formulas are valid for

$$\frac{w}{h} < 10,$$

where w is the strip width.

Synthesis is performed by an iteration. The same formulas as in analysis are used.

c) Slot line.

A zero conductor thickness and zero losses are supposed. The used formulas are valid for

$$0.01 \leq \frac{h}{\lambda_0} \leq \frac{0.25}{\sqrt{\varepsilon_r - 1}},$$

$$9.7 \leq \varepsilon_r \leq 20,$$

$$0.02 \leq \frac{w}{h} \leq 1,$$

where w is the slot width and λ_0 is the free space wavelength.

Synthesis is performed by an iteration. The same formulas as in analysis are used.

d) Coplanar waveguide line.

The conductor thickness and losses are involved. The formulas are valid for

$$\varepsilon_r \geq 9,$$

$$h \geq w,$$

$$0 \leq \frac{s}{(s + 2w)} \leq 0.7,$$

where s is the strip width and w is the slot width.

Synthesis for a desired s or w is performed by an iteration, formulas for analysis are used.

e) Coplanar strips line.

The strip thickness and losses are involved. The used formulas are valid for

$$\varepsilon_r \geq 9,$$

$$h \geq w,$$

$$0 \leq \frac{s}{(s + 2w)} \leq 0.7,$$

where s is the slot width and w is the strip width.

Synthesis for a desired s or w is performed by an iteration, formulas for analysis are used.

f) Coupled strip lines.

The strip thickness and losses are involved. The used formulas are valid for

$$\frac{t}{h} < 0.1,$$

$$\frac{w}{h} \geq 0.35,$$

where w is the strip width.

Synthesis is performed by optimitization for desired even and odd characteristic impedances.

g) Coupled microstrip lines.

The conductor thickness, dispersion and losses are involved. The formulas are valid for

$$0.2 \leq \frac{w}{h} \leq 2,$$

$$0.05 \leq \frac{s}{h} \leq 2,$$

$$\varepsilon_r > 1,$$

where w is the strip width and s is the slot width.

Synthesis is performed by optimitization for desired even and odd characteristic impedances.

3b. Circuit performance evaluation

A variety of evaluation methods can be found in literature. We have chosen two ones: The subnetwork growth method [2, 3] and Sigorski method.

The former deals with scattering parameters. It is based upon successive circuit simplification. Two ports are eliminated in each step. The fastest solution is obtained if such two ports are chosen that resulting multiports have as little ports as possible. Finally, all ports, except inputs and outputs, are eliminated. This algorithm is both fast and simple.

The later method deals with admittance matrices. It is very general, but involves matrix inversion. It is slower, thus recommended for simple circuits only.

In order to optimize circuit parameters, an error (criterion) function must be set up. Two error function types are available: least squares and minimax.

A nongradient optimization method has been chosen. The algorithm is based on [1], with some improvements taken from [4]. This method proved to be relatively insensitive to local minimum problems. On the other hand, it does not exhibit convergence as fast as gradient-based methods.

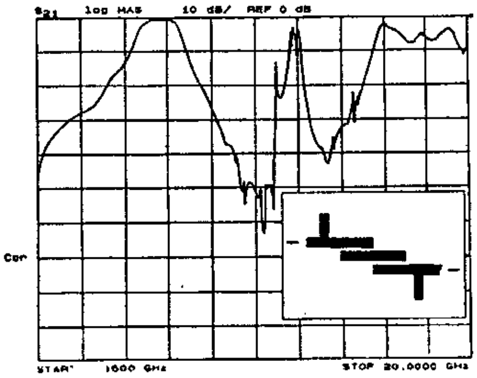


Fig. 5. Measured transmission of a microstrip coupled line bandpass filter. By courtesy of TESLA.

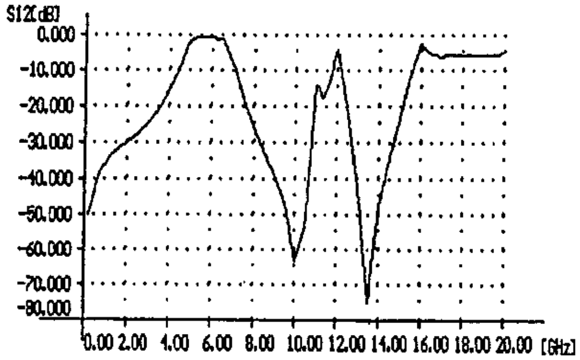


Fig. 6. Calculated transmission of the same microstrip filter.

Yield analysis simulates manufacture process. Parameters of a number of circuits with randomly chosen variable values are calculated. The results are plotted for each variable. This kind of analysis gives a better insight into the circuit behavior than an ordinary sensitivity calculus method.

3c. Program organization

A special arrangement has been chosen in order to fit the program into limited PC memory. It has been divided into separate parts, each one of them performing just one task. Each part is a completely executable program. A short resident part controls program execution and enables data interchange between other programs. The advantage of this solution over standard single overlaid program is found in that no overlay buffer is needed.

4. Conclusion

Radiofrequency and microwave CAD package has been developed. Computed results were found to be in a good agreement with measured data, see Fig. 5. and 6.

This software has been found easy-to use both in radiofrequency circuit design and student courses. As the source code is available, adding new elements and features makes no problems.

5. References.

[1] Box, M. J.: A New Method of Constrained Optimization and a Comparison with Other Methods. Computer Journal, Vol. 8(42),1965

[2] Gupta K.C., Garg R., Chadha R., "Computer Aided Design of Microwave Circuits", Artech House, Dedham, 1981.

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[5] Gupta K. C., Garg R., Bahl I. J., "Microstrip Lines and Slotlines", Artech House, Dedham, 1979.

About authors:

Zbyněk Škvor graduated from the Czech Technical University in Prague, Faculty of Electrical Engineering in 1985. He is with the department of electromagnetic field of this faculty, where he is teaching electromagnetic field theory, microwaves and radiofrequency CAD. He published papers on microwave hyperthermia, computer interfacing, radiofrequency circuits and glass melting. He is IEEE Czechoslovakia Section treasurer and IEE Czech Centre Secretary/treasurer.

Karel Hoffmann graduated from the Czech Technical University in Prague, Faculty of Electrical Engineering in 1974 and the second degree received in 1981. He is with the department of electromagnetic field of the Faculty of Electrical Engineering of CTU. His research activity is focused on microwave circuits, microwave components modelling, correction methods for precise microwave measurement, microwave CAD.

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