A MICROWAVE NETWORK OPTIMIZATION PROGRAM

J.W. Bandler
V.K. Jha
C.M. Kudsia
J.R. Popović

Abstract

The paper describes a fully-documented, comprehensive, user-oriented computer program package that will analyze and optimize certain electrical networks such as microwave filters and allpass networks. The package is written in FORTRAN IV.

Introduction

This paper completely describes a comprehensive, user-oriented computer program package that will analyze and optimize certain electrical networks. The organization of the package is such that the optimization of microwave filters including allpass networks is readily facilitated. In addition, the programs are organized on a modular approach so that future deletions or additions can be readily implemented by a user.

Brief Description

The package was originally developed on a CDC 6400 digital computer using batch processing. It is written in FORTRAN IV. It has also been tested and run on a time-sharing system. The package features some of the latest and most efficient methods of computer-aided design currently available. At the user's command, either the well-known Fletcher-Powell[1] method of minimizing unconstrained functions of many variables may be used, or the more recent method by Fletcher[2].

The package was designed to incorporate the adjoint network method of sensitivity evaluation to produce accurate first derivatives needed by these efficient gradient minimization methods. Many formulas published by Bandler and Seviora[3] are built into the package. Perturbation techniques are used to calculate group delay and group delay sensitivities with respect to variables since the small savings in computing time realized by using the adjoint network method do not appear to be worth the additional programming complexity.

State-of-the-art techniques in least pth approximation generalized for such tasks as filter design as proposed by Bandler and Charalambous[4] are incorporated. Thus, a variety of upper and lower response specifications as well as simple upper and lower desired bounds for variable parameters are catered for. Low values of p, e.g., 2, intermediately large values of p, e.g., 10 to 1,000, as well as extremely large values of p, e.g., 1,000,000 are optional to the user depending on how close to a minimax solution he wants to come.

The network to be optimized is assumed to be a cascade of two-port building blocks terminated in a unit normalized frequency-independent resistance at the source and a user-specified frequency-independent resistance at the load. Resistors, inductors, capacitors, lossless short-circuited and open-circuited transmission-line stubs, and series and parallel RLC resonant circuits can be called upon by the user and connected as series or shunt elements, in any order. Lossless transmission-lines as well as microwave allpass C- and D-sections can also be added at the user's command. As many upper and lower specifications on reflection coefficient, insertion loss and relative group delay as the user desires can be accommodated. Upper and lower bounds on all variables are user-specified.

Gradients are automatically checked before optimization. Responses before and after optimization are printed out. Much other useful information which can be used to check on the progress of the optimization process and to diagnose errors is printed out at the user's discretion.

Example 1

Design of Optimum Group Delay Equalizer

It is desired to use one microwave C-section to optimize a set of group delay specifications over a given band. Table I shows the given set of frequencies and corresponding group delay and also the starting and optimized values for the parameters and the corresponding total relative group delay. Observe that the starting point was the best result obtained by an existing program.

Example 2

High Power Output Filter

It is desired to meet or exceed the specifications shown in Table II for a six element filter consisting of series resonant circuits and shunt antiresonant circuits with unity terminations, using the slope reactance and susceptance, respectively, at 11,885.5 MHz as variables. The quality factors are to be 6,000. The normalized slope parameters are to be varied between 42 and 2,100. See Table III for the results.

Conclusions

Full details of the package and other test examples including an LC filter and transmission-line transformers are contained in an internal report of the Communications Research Laboratory of McMaster University[6]. At present, the package is limited to cascaded structures.

J.W. Bandler and J.R. Popović are with the Communications Research Laboratory, McMaster University, Hamilton, Ontario, Canada. V.K. Jha was with the Communications Research Laboratory, McMaster University, Hamilton, Ontario, Canada and is now with RCA Limited, St. Anne-de-Bellevue, Quebec, Canada. C.M. Kudsia is with RCA Limited, St. Anne-de-Bellevue, Quebec, Canada.

Acknowledgement

C. Charalambous, some of whose recent work is embodied in the package, is gratefully acknowledged.

References

[1] R. Fletcher and M.J.D. Powell, "A rapidly convergent descent method for minimization", Computer J., vol. 6, pp. 163-168, June 1963.

[2] R. Fletcher, "A new approach to variable metric algorithms", Computer J., vol. 13, pp. 317-322, August 1970.

[3] J.W. Bandler and R.E. Seviora, "Current trends in network optimization", IEEE Trans. Microwave Theory and Techniques, vol. MTT-18, pp. 1159-1170, December 1970.

[4] J.W. Bandler and C. Charalambous, "Practical least pth optimization of networks", IEEE Trans. Microwave Theory and Techniques, vol. MTT-20,pp.834-840, 1972.

[5] C.M. Kudsia, "Synthesis of optimum reflection type microwave equalizers", RCA Review, vol. 31, pp. 571-595, September 1970.

[6] J.W. Bandler and V.K. Jha, "Network optimization computer program package", Communications Research Laboratory, McMaster University, Hamilton, Canada, CRL Internal Report Series No. CRL-5, November 1972.

TABLE II

FILTER SPECIFICATIONS

Frequency (MHz)	Specification (dB)	Type of specification
11,700	66	Lower
11,843-11,928	0*	Upper
12,038	31	Lower
12,080	41	Lower

* .85 dB was actually wanted but 0 was used for convenience in the program.

TABLE I

GROUP DELAY EQUALIZER DESIGN

USING THE FLETCHER METHOD

			Parameters		
	Value of p	Starting point	2	$10^{\dagger}$	10,000
	σ (see reference 5)	340	349.05	365.94	368.77
	d (see reference 5)	86	86.64	87.68	87.75
Frequency (MHz)	Given delay (nsec)		Total relative group delay (nsec)		
7,976	69.03	4.11	3.53	2.56*	2.49*
7,977	62.61	0.30	-0.19	-0.99	-1.04
7,978	58.03	-1.48	-1.85	-2.42*	-2.43*
7,979	54.79	-1.83	-2.04	-2.33	-2.29
7,980	52.52	-1.29	-1.32	-1.29	-1.19
7,981	50.79	-0.36	-0.23	0.14	0.29
7,982	49.98	0.56	0.83	1.48	1.69
7,983	49.49	1.09	1.44	2.26*	2.49*
7,984	49.49	1.08	1.44	2.26*	2.49*
7,985	49.97	0.54	0.82	1.46	1.67
7,986	50.95	-0.38	0.24	0.13	0.29
7,987	52.50	-1.32	-1.36	-1.33	-1.23
7,988	54.75	-1.89	-2.10	-2.39	-2.35
7,989	57.99	-1.54	-1.91	-2.48*	-2.49*
7,990	62.55	0.22	-0.27	-1.07	-1.12
7,991	68.94	4.01	3.43	2.46*	2.39*
	Maximum error	4.11	3.53	2.56	2.49
	Execution time (sec)	0	1/2	1-1/4	10

† Optimization for p=10 was started at the optimum for p=2.

* Extrema in the responses.

TABLE III

FILTER DESIGN USING THE FLETCHER METHOD

	Parameters		
Value of p	Starting point	2	1,000
B_1'	240	183.5	192.59
X_1'	420	300.2	280.87
B_2'	570	321.6	315.17
X_2'	460	318.9	315.17
B_3'	450	295.9	280.87
X_3'	210	179.7	192.59
Frequency (MHz)	Insertion Loss (dB)		
11,700	85.1	65.8	65.31
11,843	2.81	0.74	0.689
11,847	1.52	0.68	0.675
11,852	1.21	0.65	0.684
11,856	1.09	0.65	0.688
11,860	1.02	0.64	0.674
11,864	0.97	0.62	0.647
11,869	0.94	0.61	0.616
11,873	0.90	0.59	0.592
11,877	0.88	0.58	0.578
11,881	0.86	0.58	0.572
11,886	0.85	0.58	0.571
11,890	0.86	0.58	0.572
11,894	0.88	0.58	0.578
11,898	0.91	0.59	0.592
11,903	0.94	0.61	0.616
11,907	0.97	0.63	0.646
11,911	1.01	0.64	0.674
11,915	1.08	0.65	0.688
11,920	1.21	0.65	0.684
11,924	1.50	0.68	0.675
11,928	2.73	0.74	0.688
12,038	73.9	54.1	53.49
12,080	86.8	67.5	67.05
Execution time (min)	0	2/3	3