of 100 MHz–30 GHz, the microwave attenuation is about 19 dB. The results of this study are applicable to any transparent glass coated with any thin metallic film.

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REFERENCES

[1] H. A. Lasitter, "Low-frequency-shielding effectiveness of conductive glass," *IEEE Trans. Electromagn. Compat.*, vol. EMC-6, pp. 17–30, July 1964.
[2] Genisco Test Rep. TR 10670, Feb. 1968.
[3] D. E. Gray, Ed., *American Institute of Physics Handbook*, 3rd ed. New York: McGraw-Hill, 1972, pp. 6-119–6-121.
[4] ——, *American Institute of Physics Handbook*, 3rd ed. New York: McGraw-Hill, 1972, p. 6–138.
[5] K. Fuchs, "The conductivity of thin film metallic films according to the electron theory of metals," *Proc. Cambridge Phil. Soc.*, vol. 30, p. 100, 1938.
[6] E. H. Sondheimer, "The mean-free path of electrons in metals," *Advan. Phys.*, vol. 1, p. 1, 1952.
[7] C. Kittel, *Introduction to Solid State Physics*, 2nd ed. New York: Wiley, 1962.
[8] *ITT Reference Data for Radio Engineers*, 5th ed., 1972.
[9] *Sierracin Intrex—Electrically Conductive Film Components*, Sierracin Corp., Sylmar, Calif., 1974.
[10] C. S. Vasaka, "Problems in shielding electrical and electronic equipments," U. S. Naval Air Development Center, Johnsville, Pa., Rep. NADC-EL-N5507, June 1955.
[11] S. A. Schelkunoff, *Electromagnetic Waves*. New York: Van Nostrand, 1943, pp. 83 and 226.
[12] E. I. Hawthorne, "Electromagnetic shielding with transparent coated glass," *Proc. IRE*, vol. 42, pp. 548–553, Mar. 1954.

Computer Program Descriptions

NOVA (Network Optimization Via Adjoints)

PURPOSE: Least pth optimization of reflection coefficients and/or transducer gain of two-port microwave networks.

LANGUAGE: Fortran IV; 1145 cards, including comments.

AUTHORS: D. L. Herrick was with the Department of Electrical Engineering, University of Maine at Orono, Orono, Me. 04473. He is now with the Department of Electrical Engineering, Montana State University, Bozeman, Mont. 59715. J. C. Field is with the Department of Electrical Engineering, University of Maine at Orono, Orono, Me. 04473.

AVAILABILITY: ASIS/NAPS Document No. 02628. This document includes a program listing, flow charts, and user's guide including examples illustrating input data format. A deck may be obtained from J. C. Field, price furnished upon request.

DESCRIPTION: NOVA employs a least pth objective function [1] based on the following network responses: (1) input reflection coefficient, (2) output reflection coefficient, (3) transducer gain, or (4) a weighted combination of the first three responses. This objective function is minimized by the Fletcher–Powell algorithm [2], which was selected for its rapid, second-order convergence. The response gradients required by Fletcher–Powell are evaluated by means of adjoint network techniques [3].

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See NAPS document No. 02628 for 63 pages of supplementary material. Order from ASIS/NAPS c/o Microfiche Publications, 440 Park Ave. S., New York, N. Y., 10016. Remit in advance for each NAPS accession number, $9.95 for photocopies, $1.50 for microfiche. Outside of the U. S. and Canada, postage is $2.00 for a photocopy or $.50 for a microfiche. Make checks payable to Microfiche Publications.

The allowed network configuration for NOVA is a cascade arrangement of two-port circuit elements, with the possibility of a single parallel path.

Seven basic types of circuit elements are available. They include transmission lines, open- and short-circuited shunt stubs, resistors, capacitors, and inductors. The distributed elements may be lossy or lossless, the amount of loss being specified in decibels per wavelength. Additionally, a general two-port element type is provided. This element is characterized by its measured S parameters and is useful for representing transistors or any element for which experimental data must be used. With the exception of the general element, the user may select which of the network parameters are to be varied during optimization. Since the general element is represented empirically, it is never optimized.

To avoid using excessive computer storage, a maximum of 30 network parameters and 30 frequency points were selected for NOVA. Larger networks may be accommodated by simply redimensioning the appropriate arrays. Most of the input data is in NAMELIST format to help identify each variable on a data card. The program is presently running on an IBM SYS370/145 computer and requires $42K_8$ of core.

To illustrate program usage, an example involving the design of a 1–2-GHz amplifier is included. The goal was to achieve a flat 14-dB transducer gain over the 1–2-GHz range. The configuration of the amplifier is shown in Fig. 1, and the initial parameter values are

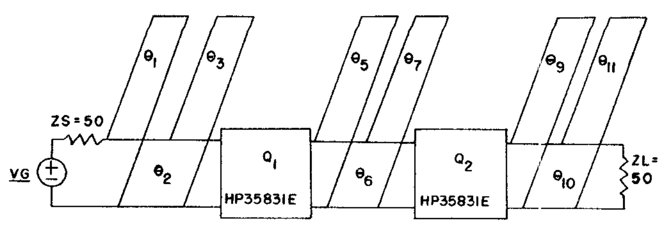

Fig. 1.

TABLE I

Element Number	Initial Electrical Length (Degrees)	Final Electrical Length (Degrees)
1	100.	49.139
2	100.	97.149
3	100.	74.658
4 (Transistor)	----	-------
5	100.	75.566
6	100.	133.061
7	100.	88.435
8 (Transistor)	----	-------
9	100.	60.446
10	100.	137.678
11	100.	63.337

Note: Initial and final element lengths for the 1–2 GHz amplifier.

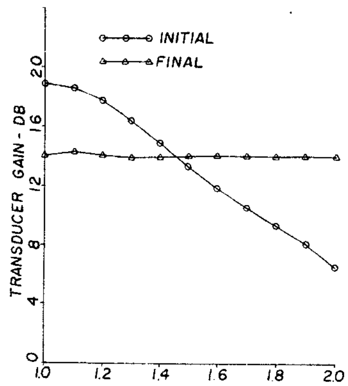

Fig. 2.

shown in Table I. All transmission line impedances were fixed at 50 Ω and only line lengths were allowed to vary. A value of $p = 4$ was selected for the least pth objective function. The frequency points were chosen as: 1.00, 1.25, 1.50, 1.75, and 2.00 GHz. The S parameters for the HP35831E transistors were obtained from the manufacturer's specifications.

After fifteen iterations or about 122 s of computer time, the program converged to the final parameter values given in Table I. Fig. 2 shows the frequency response of both initial and final designs. In order to obtain smooth curves, the responses at additional frequency points were calculated using MECAP [4]. The optimized response is 14 dB + 0.315 dB, −0.100 dB over the octave bandwidth.

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REFERENCES

[1] J. W. Bandler, "Optimization methods for computer-aided design," *IEEE Trans. Microwave Theory Tech.* (*Special Issue on Computer-Oriented Microwave Practices*), vol. MTT-17, pp. 533–552, Aug. 1969.

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

[3] J. W. Bandler and R. E. Seviora, "Current trends in network optimization," *IEEE Trans. Microwave Theory Tech.* (*1970 Symp. Issue*), vol. MTT-18, pp. 1159–1170, Dec. 1970.

[4] J. C. Field and D. L. Herrick, "MECAP—An analysis program for microwave engineering courses," *IEEE Trans. Educ.* (Short Notes), vol. E-17, pp. 198–201, Nov. 1974.

[5] V. G. Gelnovatch and I. L. Chase, "DEMON—an optimal seeking computer program for the design of microwave circuits," *IEEE J. of Solid-State Circuits*, (Special ISSCC Issue on Solid-State Microwave Circuits), vol. SC-5, pp. 303–309, Dec. 1970.

[6] D. A. Calahan, *Computer-Aided Network Design* (preliminary edition). New York: McGraw-Hill, 1968, p. 291.

Contributors

Chung-Kwang Chou (S'72) was born in Chung-King, China, on May 11, 1947. He received the B.S.E.E. degree from the National Taiwan University, Republic of China, and the M.S. degree in electrical engineering from Washington University, St. Louis, Mo., in 1968, and 1971, respectively. He is currently studying electrical engineering and physiology toward the Ph.D. degree at the University of Washington, Seattle.

Since 1971 he has been involved in the research of microwave biological effects on the nervous system with the Department of Rehabilitation Medicine at the University of Washington. His research interests include bioengineering and physiology, especially the biological effects and medical applications of EM energy.

Mr. Chou is a member of Tau Beta Pi and Sigma Xi.

Kenneth R. Courtney received the B.S. degree in biochemistry from Washington State University, Pullman, the M.S. degree in physiology, and the Ph.D. degree in biophysics, both from the University of Washington, Seattle, in 1967, 1968, and 1974, respectively.

He was an Instructor at Centralia College from 1969 to 1970 and was later with the Department of Rehabilitation Medicine, University of Washington. He is presently working as a Research Associate at the University of Colorado Medical Center, Boulder, on problems related to nerve and synapse regeneration in amphibian autonomic ganglia. His major research interest is the electrophysiological study of factors determining the stability of nervous tissues.