IV-4. OPTIMAL DESIGN OF MATCHING NETWORKS FOR MICROWAVE TRANSISTOR AMPLIFIERS

Frank E. Emery, Michael O'Hagen, and S. D. Nolte

Texas Instruments, Inc., Dallas, Texas

The design of input and output matching networks for transistor microwave frequency amplifiers has been optimized by the use of an efficient computer program. Power amplifiers capable of 2.5 watts peak power output with a 400 MHz bandwidth at 2.25 GHz have been fabricated. The matching network problem was reduced to an equivalent non-linear programming problem by considering the filter elements as coordinates in an N-dimensional vector space. The optimal solution point in the vector space was found by the use of a "pattern search" routine which utilized randomly chosen orthogonal transformations of the search pattern to minimize an objective function. In this case, a suitable objective function was chosen to be the area under the curve of reflection coefficient versus frequency for the filter input. By use of multiple data input as many as six designs have been achieved in less than nine minutes on the 7044 computer.

Construction of transistor amplifiers at microwave frequencies involves the design of suitable matching networks. Power amplifiers are further complicated by non-linear operation to give efficiency as well as gain. The natural step to integrated microwave transistor amplifiers imposes a minimal size constraint upon the matching network design. Additional constraints such as transistor biasing networks and coupling capacitor dimensions must also be considered. The characterization techniques used to obtain the transistor input and output admittances have been previously described.[1/] The admittances generally cannot be ascribed to a simple equivalent circuit. The technique described in this paper allows networks, consisting of lossless transmission lines, to be designed to match the measured admittances over a broad range of frequencies. An extension of the technique to lumped parameter elements also has been made.

We have characterized either port of a transistor as an admittance for the purposes of this discussion. This admittance is generally a function of both power level and frequency; with the power level requirements chosen, the admittance is given in terms of frequency alone. By least squares curve fitting an admittance vs frequency function may be empirically described. In general, two such admittance functions are given to be matched to one another by the use of a suitable network. The case described below utilizes lossless transmission line elements to construct an admittance matching network over a broad band of frequencies.

The lossless line elements used are series sections, open stubs, and shorted stubs. Both the characteristic impedance and the individual line length are varied in the optimization procedure. A configuration of N elements thus describes the coordinates of a 2N vector space. By using one admittance as a load, the reflection coefficient between the transformed load admittance and the second (source) admittance may be calculated. Use of this function follows Fano.[2/] For a point in the vector space the reflection coefficient may be calculated as a function of frequency over the range of interest. Integrating the resulting reflection coefficient function from over this range results in an objective function to be minimized over the vector space.

A pattern search routine called "SPIDER" has been utilized to efficiently minimize the objective function. This routine avoids many local minima which exist in the objective function and seeks a global optimum. From the initial point a successful direction is determined by searching a fixed distance from the base point in a number of random orthogonal directions. If a successful direction is determined, a series of accelerating moves are made in this direction by a speed factor. If no successful direction is found with the current incremental values, then the increments are reduced. The exploratory moves are repeated with new increment values. Increments are successively reduced until the lower limit on the first variable is undercut which initiates an exit routine. The maximum number of iterations may be specified to cause a separate (possible non-optimal) exit. Figures 1 and 2 diagram the search routine program.[3,4,5]

At the present time the network configuration is at the discretion of the designer; an initial point must also be given to the program. Boundary values for the transmission line elements may also be specified by the designer. This approach has been tested by designing transistor microwave power amplifiers. Table I gives a sample configuration, starting values, and final values for a network matching the output impedance of an amplifier to a 50 Ω load. Figure 3 shows a computer plot of the reflection coefficient vs frequency curve achieved by the program. Figure 4 is a photograph of a 2.5 W peak power amplifier designed using the computer program; Figure 5 gives the frequency performance of the amplifier. The matching networks operate satisfactorily within the accuracy of the admittance measurements and the knowledge of the transmission line design parameters.

Table I. Network Matching Output Impedance of an Amplifier to a 50 Ω Load

		Initial Value		Final Value	
Element No.		Y_o (mmhos)	l at 2.4 GHz (degrees)	Y_o (mmhos)	l at 2.4 GHz (degrees)
1	Series	15	45	12	14
2	Open Stub	15	45	20	62
3	Series	15	45	13	18
4	Shorted Stub	15	45	28	20
5	Series	15	45	23	15

ACKNOWLEDGEMENT OF SPONSORSHIP

Air Force Avionics Laboratory, Research and Technology Division
Air Force Systems Command, United States Air Force

Contract No. AF33(615)-2525

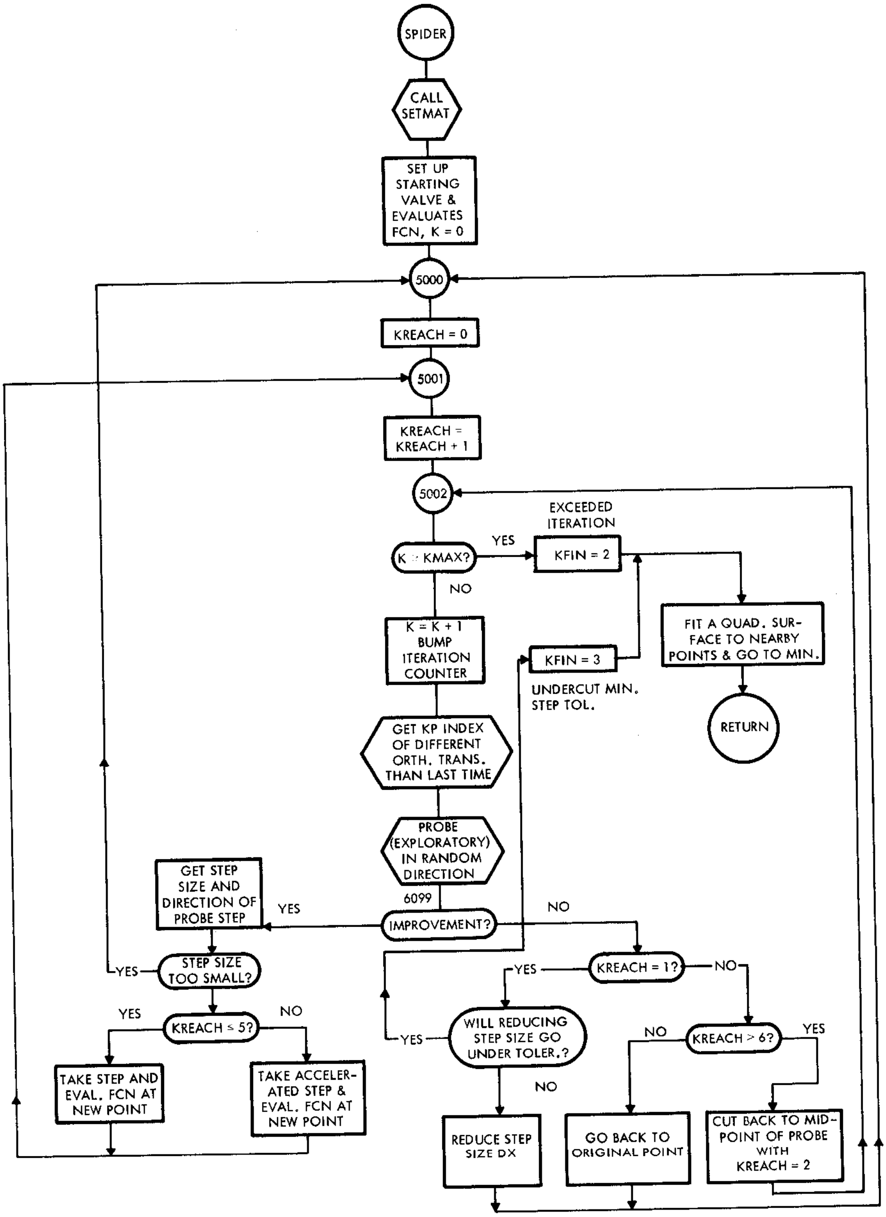


Figure 1. Spider Pattern Search Routine

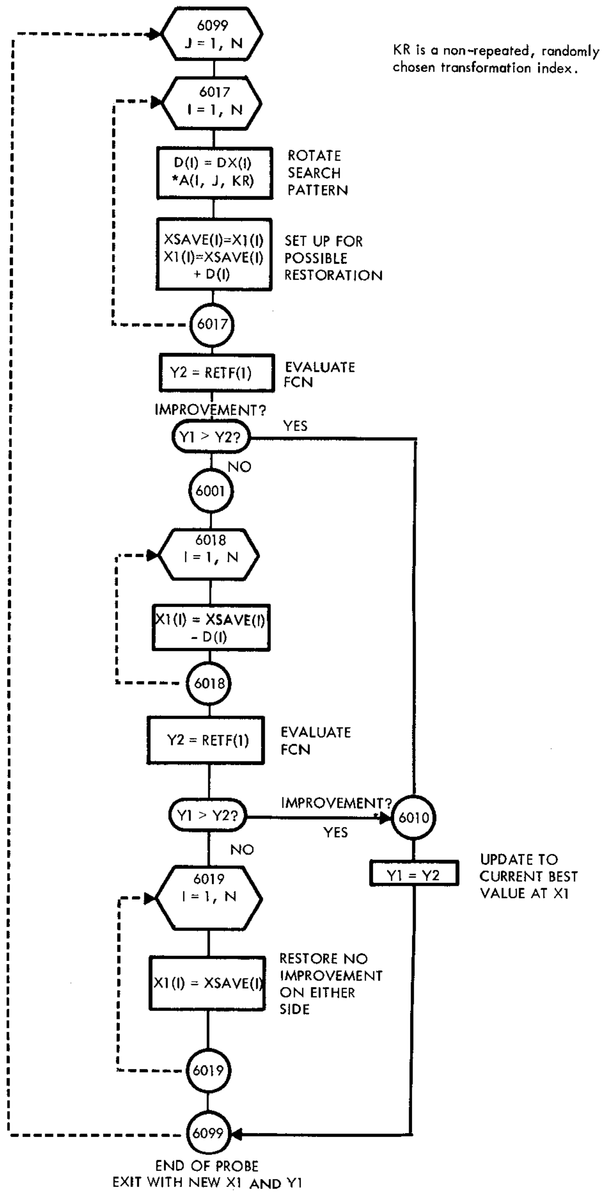


Figure 2. Search Routine Program

REFERENCES

1. "Microwave Power Generation and Amplification Using Transistors," A. J. Anderson, Harry F. Cooke, and Britton T. Vincent, Jr., 1965 NEREM Meeting.

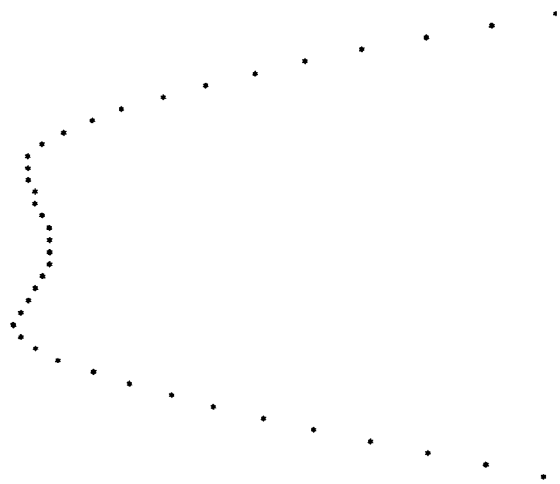
2. "Theoretical Limitations on Broadband Matching of Arbitrary Impedances," R. M. Fano, J. Franklin Inst., 249, pp. 57-83 and pp. 139-155.

3. "Direct Search Solution of Numerical and Statistical Problems," Robert Hooke and T. A. Jeaves, J. Assoc. Comp. Mach., 8.2, pp. 212-29, April, 1961.

4. "Recent Developments in 'Direct Search' Techniques," C. F. Wood, Westinghouse Research Laboratories Report 62-159-522-R1, July 1962.

5. Optimum Seeking Methods, Douglas Wilde, Prentice-Hall, Inc., Englewood Cliffs, N. J., 1964.

FRECUENCY	REFLECTION COEFFICIENT
2.000000	0.196957E-00
2.012500	0.177050E-00
2.025000	0.158185E-00
2.037500	0.140364E-00
2.050000	0.123597E-00
2.062500	0.107903E-00
2.075000	0.933149E-01
2.087500	0.798842E-01
2.100000	0.676895E-01
2.112500	0.568494E-01
2.125000	0.475374E-01
2.137500	0.399919E-01
2.150000	0.344860E-01
2.162500	0.312011E-01
2.175000	0.300194E-01
2.187500	0.304425E-01
2.200000	0.317850E-01
2.212500	0.334309E-01
2.225000	0.349385E-01
2.237500	0.360260E-01
2.250000	0.365276E-01
2.262500	0.363611E-01
2.275000	0.355122E-01
2.287500	0.340377E-01
2.300000	0.320888E-01
2.312500	0.299602E-01
2.325000	0.281650E-01
2.337500	0.274788E-01
2.350000	0.287817E-01
2.362500	0.326265E-01
2.375000	0.389803E-01
2.387500	0.474605E-01
2.400000	0.576532E-01
2.412500	0.692303E-01
2.425000	0.819439E-01
2.437500	0.955989E-01
2.450000	0.110030E-00
2.462500	0.125089E-00
2.475000	0.140637E-00
2.487500	0.156546E-00
2.500000	0.172692E-00



THIS AMAZING FEAT HAS BEEN ACCOMPLISHED IN 100 ITERATIONS

Figure 3. Reflection Coefficient vs Frequency

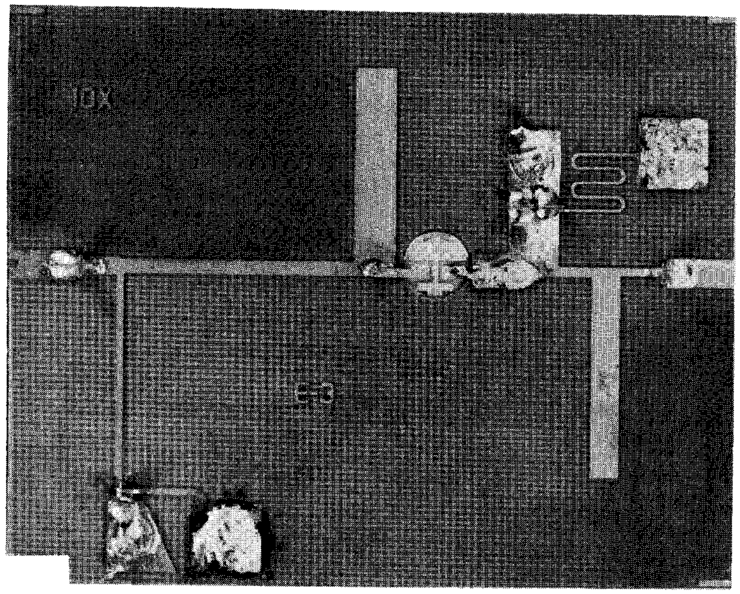


Figure 4. Peak Power Amplifier (2.5 W)

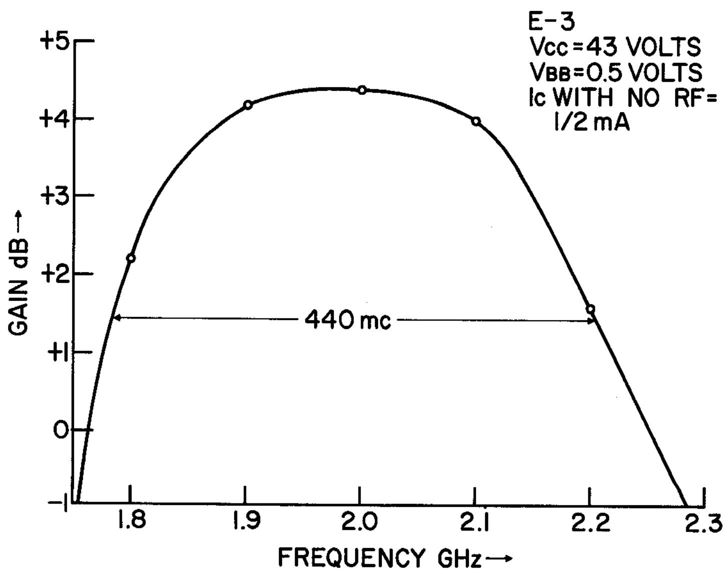


Figure 5. Frequency Performance of Amplifier