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This Week's Citation Classic

Director S W & Rohrer R A. The generalized adjoint network and network sensitivities. *IEEE Trans. Circuit Theory* **CT-16**:318-23, 1969. [Dept. Electrical Engineering and Computer Sci. and Electronics Res. Lab., Univ. California, Berkeley, CA]

It has been established that the adjoint network and network sensitivities play important roles in automated network design algorithms. The present paper derives a related adjoint network representation and sensitivity coefficients for networks containing a very broad class of elements: those that admit a parametric representation. A brief discussion is given as to how these results may be exploited in a general automated network design scheme. [The *SCI*® indicates that this paper has been cited over 95 times since 1969.]

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"During the mid-1960s there was considerable growth in interest in the use of the computer for electronic circuit design. One of the more popular approaches proposed for this purpose involved formulating the circuit design problem as an optimization problem which could be solved by using the recently developed nonlinear programming algorithm due to Fletcher and Powell.[1] However, this approach was potentially computationally expensive because it required evaluation of the gradient of a performance function with respect to each of the designable parameters of the network. Since the performance function is an implicit function of the designable parameters, evaluation of the gradient seemed to require the use of perturbation, which, in effect, would require one additional circuit simulation for each designable circuit element. Unfortunately, circuit simulations were themselves computationally expensive (due in part to the lack of good sparse matrix techniques and stiffly stable numerical integration schemes which were developed during the latter part of the 1960s and early 1970s). Therefore, for the nonlinear programming approach to circuit design to be computationally feasible, a better technique for gradient evaluation was needed.

"The contribution in this paper was the development of a simple scheme which could be used to compute all of the gradients using only one additional circuit simulation. Derivation of this method was based upon a previously little used theorem due to Tellegen which was first published in 1952.[2] Use of Tellegen's theorem led us to define the concept of an adjoint network, which, as we discovered many years later, could be viewed as the generalization of a concept known as the transposed network, first introduced by Bordewijk in 1957.[3] (Because of the limited distribution of the journal in which Bordewijk published his results, they were not widely known until the early 1970s.) It is interesting to note that today, 12 years after publication of this paper, even though it is widely recognized that the adjoint network concept itself is somewhat superfluous, i.e., it is not needed in order to gain the efficiency in the computation of the gradients, it is still being used to derive new results.[4]

"This paper describes work which was done while I was a PhD student at the University of California, Berkeley, under the direction of my coauthor, Ron Rohrer. Furthermore, the contributions described in this paper are a direct result of some previous work that Ron had published in 1965 which was aimed at the optimal design of transmission lines.[5]

"Among the reasons for the popularity of this paper are, I feel, that it presented a solution to a meaningful problem, and due to the use of Tellegen's theorem, the solution was easily understandable to many readers. Further, and probably most important of all, it was published at the right time in a journal that had a fairly large readership. In 1969, this paper was selected to receive the Best Paper Award from the IEEE Professional Group on Circuit Theory (now the Circuits and Systems Society)."

1. **Fletcher R & Powell M J D.** A rapidly convergent descent method for minimization. *Computer 1.* **6**:163-8, 1963.
2. **Tellegen B D H.** A general network theorem with applications. *Philips Res. Rep.* **7**:259-69, 1952.
3. **Bordewijk J L.** Interreciprocity applied to electrical networks. *Appl. Sci. Res.* **6**:1-24, 1956.
4. **Vandewalle J, De Man H & Rabaey J.** The adjoint switched capacitor network and its applications. *Proc. IEEE Int. Symp. Circuits Syst.* **3**:1031-4, 1980.
5. **Rohrer R A, Resh J A &** Hoyt R A. Distributed network synthesis for a class of integrated circuits. *IEEE Int. Convention Rec.* **7**:100-12, 1965.