

From Circuit Theory to System Theory*

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Summary—The past two decades have witnessed profound changes in the composition, functions and the level of complexity of electrical as well as electronic systems which are employed in modern technology. As a result, classical RLC network theory, which was the mainstay of electrical engineering at a time when RLC networks were the bread and butter of the electrical engineer, has been and is being increasingly relegated to the status of a specialized branch of a much broader discipline—system theory—which is concerned with systems of all types regardless of their physical identity and purpose.

This paper presents a brief survey of the evolution of system theory, together with an exposition of some of its main concepts, techniques and problems. The discussion is centered on the notion of state and emphasizes the role played by state-space techniques. The paper concludes with a brief statement of some of the key problems of system theory.

I. INTRODUCTION

THE past two decades have witnessed an evolution of classical circuit theory into a field of science whose domain of application far transcends the analysis and synthesis of RLC networks. The invention of the transistor, followed by the development of a variety of other solid-state devices, the trend toward microminiaturization and integrated electronics, the problems arising out of the analysis and design of large-scale communication networks, the increasingly important role played by time-varying, nonlinear and probabilistic circuits, the development of theories of neuroelectric networks, automata and finite state machines, the progress in our understanding of the processes of learning and adaptation, the advent of information theory, game theory and dynamic programming, and the formulation of the maximum principle by Pontryagin, have all combined to relegate classical circuit theory to the status of a specialized branch of a much broader scientific discipline—system theory—which, as the name implies, is concerned with all types of systems and not just electrical networks.

What is system theory? What are its principal problems and areas? What is its relationship to such relatively well-established fields as circuit theory, control theory, information theory, and operations research and systems engineering? These are some of the questions which are discussed in this paper, with no claim that the answers presented are in any way definitive. Technological and scientific progress is so rapid these days that hardly any assertion concerning the boundaries, content and directions of such a new field as system theory can be expected to have long-term validity.

The obvious inference that system theory deals with systems does not shed much light on it, since all branches of science are concerned with systems of one kind or another. The distinguishing characteristic of system theory is its generality and abstractness, its concern with the mathematical properties of systems and not their physical form. Thus, whether a system is electrical, mechanical or chemical in nature does not matter to a system theorist. What matters are the mathematical relations between the variables in terms of which the behavior of the system is described.¹

To understand this point clearly, we have to examine more closely the concept of a system. According to Webster's dictionary, a system is "... an aggregation or assemblage of objects united by some form of interaction or interdependence." In this sense, a set of particles exerting attraction on one another is a system; so is a group of human beings forming a society or an organization; so is a complex of interrelated industries; so is an electrical network; so is a large-scale digital computer, which represents the most advanced and sophisticated system devised by man; and so is practically any conceivable collection of interrelated entities of any nature. Indeed, there are few concepts in the domain of human knowledge that are as broad and all-pervasive as that of a system.

It has long been known that systems of widely different physical forms may in fact be governed by identical differential equations. For example, an electrical network may be characterized by the same equations as a mechanical system, in which case the two constitute analogs of one another. This, of course, is the principle behind analog computation.

While the analogies between certain types of systems have been exploited quite extensively in the past, the recognition that the same abstract "systems" notions are operating in various guises in many unrelated fields of science is a relatively recent development. It has been brought about, largely within the past two decades, by the great progress in our understanding of the behavior of both inanimate and animate systems—progress which resulted on the one hand from a vast expansion in the scientific and technological activities directed toward the development of highly complex systems for such purposes as automatic control, pattern recognition, data-processing, communication, and machine computation, and, on the other hand, by the attempts at

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¹ This and the following four paragraphs are reproduced with minor changes from an earlier article by the author: "System theory," *Columbia Engrg. Quart.*, vol. 8, pp. 16-19, 34; November, 1954.

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