EQUIVALENT CIRCUIT ANALYSIS OF MECHANO-ACOUSTIC STRUCTURES*

B. B. Bauer
Shure Brothers, Inc.
Chicago, Illinois

I. INTRODUCTION

To comprehend the new, the unknown, we often fall upon the old, the known. Thus, in the time of Volta and Ohm (circa 1800) many of the conceptions of electricity were based upon similarity with the older arts, i.e., hydraulics, mechanics and heat. Volta was among the first to recognize tbat the phenomena grouped under the name of galvanism were a manifestation of "electricity in motion" — as contrasted with the older electrical phenomena which represented "electricity in tension." Since there was no evidence of accumulation of electricity at any point in a circuit it followed that the current could be represented figuratively by the flow of an incompressible fluid along rigid and inextensible pipes. Ohm used Fourier's analyses of the conduction of heat to derive electrical laws and he was instrumental in developing the concepts of "current" and "electromotive force."[1] Thus since the earliest days of electrical theory, electro-motive force became endowed with the attributes akin to a mechanical force of hydraulic pressure, and electric current has been thought of as being of similar nature as mechanical velocity or the velocity of fluid flow. Undoubtedly, these classical concepts form the historical basis for equivalent circuit analysis as it is known today.

The early analogies became especially important during the end of the 19th century when ac electricity was still in its infancy while the theory of vibrations and sound had been already highly developed by Rayleigh and others. It was discovered that certain differential equations developed for use with vibrating mechanical bodies were equally applicable to electrical quantities. Rayleigh was among the first to bring the subject of alternating current electricity within the scope of acoustics and to prove that similar mathematical principles were applicable to both phenomena.[2]

Much has happened during the half century which followed Rayleigh's writings to change the relative technological positions of electricity, acoustics and mechanics. The improvement in electrical circuit elements, oscillators, amplifiers, oscillographs and meters — and indeed the perfection of the "analogy" computer — have made of the electrical network a most useful and flexible analytical tool. Therefore, we find an ever-increasing tendency to turn to the analogous electrical circuits for solution of mechanical, acoustical and other problems.

After having been introduced to a subject as old and venerable as this, the reader might wonder what there is new to be said about it. Surprisingly enough, the study of analogies has had a recent spurt in activity. New uses as well as limitations of analogies are being discovered almost daily. Complex physical organizations are being put into form manageable by analogies. Definitions and terminology are being brought in line with the new developments. The object of this paper is to attempt to give the reader a broad view of the subject to acquaint him with some of the new thinking regarding analogies.

II. THE EFP AND THE IFP ANALOGIES

The reader should be cautioned at this time that the traditional concept of similarity between voltage-force-pressure and current-velocity-fluid velocity is not the only one upon which a system of analogies can be based. During the past quarter century, through the efforts of Firestone[3] and others, it has become known that it is possible to establish another consistent system of analogies based upon certain mathematical similarities between electrical current, force, and pressure on the one hand, and voltage, velocity, and fluid flow on the other. The older "classical" analogy is currently being spoken of as the "voltage-force-pressure" analogy while the newer analogy (originally called "mobility" analogy by Firestone) is often referred to nowadays as the "current-force-pressure" analogy. For brevity we call them the EFP and the IFP analogies, respectively.

It seems feasible to apply either analogy about equally well to the solution of various problems, although it is generally recognized that the EFP analogy is the more advantageous with respect to acoustic devices and electrostatic (condenser, piezoelectric) transducers, while the IFP analogy is the more adaptable to mechanical devices and electromagnetic (magnetic, magnetostrictive) transducers. (Incidentally, equivalent circuits for transducers are a field in themselves and they are not treated here.) Almost everyone doing much equivalent circuit work eventually becomes conversant with both analogies. The casual user will avoid confusion by choosing a single analogy.

* Manuscript received June 1, 1954.

[1] Firestone, "A new analogy between mechanical and electrical systems," Jour. Acoust. Soc. Amer., vol. 4, pp. 239-267; 1933.

[2] Lord Rayleigh, "The Theory of Sound," Dover Publications, N.Y., vol. 1, p. 433, etc.; 1945.

[3] W. Dampier, "A History of Science," The MacMillan Company, N.Y., p. 232, etc., 1944.