THE CIRCUIT IMPERATIVE IN BIOMEDICAL ENGINEERING EDUCATION

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Abstract:
The tools of circuit theory and practice are outlined as the imperative ones for filling a void in engineering education where the handling of living organisms, important to biomedical engineers, is by bypassed.

I. Introduction - The Void

Biomedical engineering offers advances to society some of which are beginning to be well publicized before the American public, for example via Public Television [1]. Indeed the recent and future advances recorded at the start of this decade [2] could be viewed as startling, especially when looked at in terms of the education received in the area by the average engineering undergraduate. For example, almost all hospitals in the Washington area have access to CAT (=computerized axial tomography) scanners while at the University of Maryland no course in biomedical engineering is required or integrated into the program of graduating BS engineers.

In general we find that graduate students at our university have been well aware of the importance of biomedical engineering as an area for valuable and stimulating study and research. For example at the University of Maryland in the two year period 1976-77 nine out of fifteen (that is, fully 60%) of the Electrical Engineering Ph.D.'s were awarded on biomedically motivated topics. Similar interest abounds in our undergraduate student body. Consequently, part of the problem of education in the biomedical engineering is to get the faculty and administration to recognize the field as having significant content. There is for sure a definite reluctance to accept the field which seems to be based upon more than the conservativeness of engineering educators. For example, biomedical engineering most often works at an interface with living organisms whereas engineers, and especially engineering educators, are by training most adept at handling inanimate objects. When it comes to handling living things they face a void in their education. Consequently, it appears to us of vital importance that this void be filled and through the use of classical engineering tools so that present faculty can participate in the ongoing revolution of ideas and techniques stemming from biomedical engineering.

II. Filling the Void

Our solution for filling this void is the application of the tools of circuit theory and practice to biomedical engineering problems. That is, rather than reeducate present faculty and administration to the handling of living objects, we propose adapting their already existing backgrounds in circuits to bring them and their students into contact with the field. In fact such a solution appears imperative for both the short term and long term progress of biomedical engineering. Short term because practice is quickly outrunning what is being taught and, hence, the academic world needs rapid measures, using existing manpower and facilities, to introduce even the most basic ideas most of which can be visualized through circuit concepts. And long term because electronic circuits provide the means for future advances in the field not only through instrumentation (VLSI [= very large scale integration] based) but also through direct control of biological processes, such as heart function, biofeedback, bone growth, nerve stimulation, etc. But there is an even more compelling reason for the deliberate attempt by the engineering academic community to merge circuit concepts and physiology. Electrical processes are absolutely essential for life itself, from the cellular level to the highest organism - the human. Moverover, the complexity of the involvement of the electrical processes in living matter increases extremely rapidly in higher organisms both because of the way the electrical processes take place and the reasons for which they take place. Most of these proceses are poorly, if at all, understood by the biologist and the physiologist because indeed they are complex and involve extremely large numbers of elements. But it is precisely in this area of coping with complexity and large numbers of elements that the circuits viewpoint has proven most successful in the last quarter of a century. Successful in two critical aspects: 1) in providing a dynamic vehicle of knowledge to explain experimentally found behavior and 2) in guiding thought to new ways of achieving a desired behavior (witness the latest and numerous commercial microcircuits). This last aspect of improving or finding an alternative (more desirable) natural behavior is the very essence of engineering. Thus, if biomedical engineering is to continue to be successful, at least in considering the living processes that involve electrical phenomena, it can only do so through circuit concepts; there is, as we see it, no alternative in sight. However, circuit concepts and methodology, as it is well known, go well beyond electrical and electronic methodology. The transition from circuit theory and engineering to system theory and engineering is a natural one and has become now the standard route through which thousands of engineers every year are presently graduated in our universities going into such careers as communication, computers, control, operations research, etc. At this time there is every indication that system approaches will influence greatly the very practice of medicine [3]. There is little doubt that today, and for the near future, technology is largely responsible for expanding the frontiers of medicine improving the quality of patient care and saving large numbers of lives that otherwise would have been lost [4]. The kind of technology, however, that is responsible for these achievements must be accompanied by a methodology which utilizes principles recognizing and taking into account key characteristics of living organs and systems [5]. To put it simply biomedical engineering is not simply the act of using, improving, designing or even inventing new instruments to help the biologist or the physician, etc., to do a better job [6]. It should be a profession whose aspirations go beyond instrumentation. Its ultimate objective should be to establish a group of professionals in our society responsible for engineering with living matter. This is of course a large order and it has many implications, a number of which are controversial at this time. There is general agreement, though, that humanity has arrived in an era where engineering with living organisms in a systematic way is encouraged, indeed expected, as an integral part of the advanced industrial societies. The view has even been expressed that the future of humanity rests with its ability to engineer with living matter. In any case the fact remains that ever increasing amounts of the technological resources of modern societies are being tunnelled to what are currently known (in a broad sense) as biological or medical purposes. Thus, in one way or another a group of specialists eventually will emerge to have primary responsibility for what we all understand to be the engineering aspects of this focused human endeavor. It is unthinkable that these engineers could function without having a deep appreciation of the fundamental aspects of living matter provided by the same overall framework which makes it possible for them to have an appreciation of these fundamental aspects of nonliving matter. Circuits (circuit theory and engineering) is the only engineering framework which can do that. We are aware that there are individuals within our engineering colleges that have doubts about the status of biomedical engineering as a subject to be taught in the traditional engineering departments at any level. The usual arguments are (not only voiced against biomedical engineering but against other nontraditional topics) that there is not sufficient technical content or engineering principles to warrant it. Nothing could be further from the truth. For at least, as far as circuits and biomedical engineering are concerned, those who have even a minimal working knowledge in both fields are profoundly aware that intellectually they stimulate one another [7] [8].

In our view there are three stages of biomedical education:
1. The Beginning; where physiological concepts are tied with engineering ones
2. The Intermediate where anatomical laboratory experience is coupled to engineering techniques.
3. The Advanced where engineering design and research occur.

Looking at details relevant to each of these stages we see the almost unavoidable need for circuit concepts. For example at the Beginning stage a study of nerves, muscles and synapses should be included in any treatment. As is well recognized, this is best carried out through circuit analogies [9]. Since some of these analogs could be used to illustrate basic properties of circuits, our own suggestion is that problems using physiological analogies be included in the circuits courses presently required of all electrical engineering students. Too, because recent active circuits [10] have fascinating properties which can be nicely demonstrated in class on the oscilloscope illustrating also basic principles of electronic circuit design, we would suggest that in-class demonstrations or laboratory experiments could profitably be given using such circuits.

In the Intermediate stage typical experience in clinical engineering aspects has the engineer in contact, for instance, with ultrasonic testing of humans [2] where analysis of data relies upon analyzing acoustic wave equivalent circuits, or, as another example, patient monitoring for disease classification, prevention, and cure, which might well depend upon circuit theory of microprocessor networks [11] or the algorithmic theories [12] developed and taught through computer-aided circuit design. Perhaps of even more future importance will be experience with the many types of implantable circuits for in situ measurements and body function control.

As is being made clear to the public through the TV media [1], microprocessors are revolutionizing the field of aids to the handicapped (for example providing reading machines for the blind, talking devices for those with loss of voice, and revolutionary control of artificial limbs). This material serves as the starting point for the third Advanced stage (engineering design and research). Indeed biomedical engineering offers some of the deepest and most challenging problems for the engineering profession, as illustrated by the CAT scanner and developments to which it is leading, or by the example of microprocessor control of hospital patient monitoring. We believe that we are in an age of biomedical revolutions that continues and, for example, point to circuit developments leading to whole new classes of systems, such as "neural type systems" based upon circuit abstractions of physiological properties [13]. Almost all classically educated electrical engineers can participate in this revolution the importance of which is recognized by all forward looking college administrators. In fact biomedical engineering based on strong circuit foundations provides a rich fertile area for research and graduate studies at the international level [14].

III. Concluding Remarks

Biomedical Engineering has reached maturity and is now recognized as an important professional discipline which must be taught in the universities. Circuit theory and its methodology constitute essential educational vehicles with proper adaptation to accommodate living matter with no alternative in sight. In fact circuits thinking can be interwoven in all the three stages of biomedical engineering education.

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