PROCEEDINGS OF THE IEEE THROUGH 100 YEARS: 1970–1979

I. INTRODUCTION

"Old time subscribers," noted G. Wade, Editor of the PROCEEDINGS OF THE IEEE, "will recognize that the basic character of the PROCEEDINGS in 1977 is quite different from that of 1947." The PROCEEDINGS had indeed evolved from publishing research papers of interest to radio engineers to a journal covering many more and diverse fields of interest. Starting in the 1950s, as more specialized Institute of Radio Engineers (IRE) publications emerged to respond to the needs of the new societies, the PROCEEDINGS had to shift its mission. It now strove "to bring to its many subscribers a balanced program of research papers of broad interest and tutorial papers of more general character" [1]. In each issue, the editors of the PROCEEDINGS tried to bring together in-depth overviews written by leaders in their fields, research results that would appeal to a large cross section of IEEE members, and technical tutorials to initiate the nonspecialist into a new hot area of R&D. The innovation of the Special Issue offered a more comprehensive coverage in a specific emerging area of technology that had broader general interest to IEEE's membership. The first Special Issue, which was on color television, appeared in October 1951. In the decades that followed, the popularity of these Special Issues grew, as did the frequency: from one or two per year in the 1950s to six per year in the 1970s.

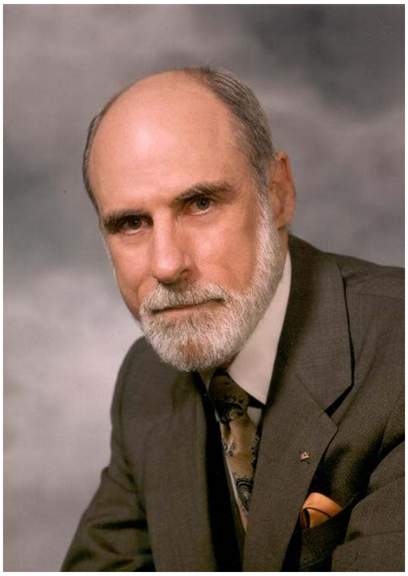

Fig. 1. *Vinton G. Cerf (courtesy of the IEEE History Center).*

The PROCEEDINGS by the 1970s had indeed evolved from publishing research papers of interest to radio engineers to a journal covering many more and diverse fields of interest.

The PROCEEDINGS Special Issues offer a wonderful window on to the important technological developments of the 1970s. For the reader's reference, the Appendix contains the complete list of topics that appeared as Special Issues during this decade. However, with 52 Special Issues, one cannot possibly provide a historical overview of all of them in one article, at least not without being overly superficial. Instead, as in History Center's coverage of previous decades, a selection of topics has been made that we hope will interest the reader. This paper will look at five of the important technical developments that received prominence in the pages of the PROCEEDINGS during the 1970s: cable television, data networks, multiplying bandwidth through optics, communications satellites, and the microprocessor. Not all the Special Issues, however, were of a technical nature. There were also two Special Issues dedicated to engineering education.

II. BANDWIDTH AND INTERACTIVITY THROUGH COAXIAL CABLE

In the late 1940s, using a coaxial cable and a large antenna, cable TV (CATV) brought service to areas outside the range of the television broadcasts found in large cities. In 1969, in response to the U.S. Federal Communications Commission's (FCC's) calls for comments on CATV regulations, Control Data Corporation (CDC) and the Industrial Electronics Division of the Electronics Industry Association (IED/EIA) proposed CATV technology

Digital Object Identifier: 10.1109/JPROC.2012.2200556

as the basis for a national broadband communications system. Titled "The Future of Broadband Communications," this joint submission regarded "such systems as being of national resource dimensions and the development of these resources as a national goal" [2]. CATV offered the possibility of two-way switching devices to facilitate the rapid exchange of data and information between the subscriber's unit and central switching mechanisms, data storage banks, and computers. "The potential for individual homes," explained one legal study of the regulatory issues surrounding CATV, "to function as virtual communications centers in which the subscriber could both send and receive information may very well abrogate McLuhan's fear that the media is becoming the message" [3, p. 328]. By the mid-1970s, the idea of CATV-based, two-way interactive services had led people to talk about the rise of the "wired city." One noted scholar on the political economy of communications identified cable TV as "one wing of a seismic structural change in the organizational makeup of the general telecommunications networking and broadcasting" [4]. The other wing of course was satellite communications, which will also be discussed in this article.

No sooner had the 1969 CDC and IED/EIA proposal been filed with the FCC, than Edward W. Herold, the Director of Technology for the RCA Corporation, a member of IEEE's Technical Activities Board (TAB) and IEEE Fellow, recommended that the PROCEEDINGS does a Special Issue on Cable Television. Seeing the potential of CATV, "TAB had already appointed an *ad hoc* advisory committee on cable television to explore the manner in which to best accommodate cable engineers and technicians with an identity of their own, within the framework of IEEE" [5, p. 961]. It was this *ad hoc* committee that then took up Herold's call for a Special Issue of the PROCEEDINGS on CATV. Because of the far reaching technical, political, and regulatory issues surrounding the emerging CATV debate, the editorial staff of the PROCEEDINGS worked very closely with the *ad hoc* committee to get the Special Issue out in half the time it would normally take. Quite a feat when one takes into account that all the papers were invited.

The 18 articles that comprised this issue did indeed meet the editors stated objectives: "to provide a basis for the enlargement of the technical issues confronting the industry, to indicate the state of the art of cable technology, to document some of the political interdictions to the development of the industry, and to flavor the issue with a few of the exciting future possibilities" [5, p. 961]. Not only did the technological advances in CATV, which allowed over 20 channels to be carried on one line, threaten the revenue streams for traditional television broadcasters in the large urban areas, but the bidirectional interactive potential of cable also put the CATV industry in potential collision course with the telephone industry. In their two articles in the PROCEEDINGS, Kenneth A. Cox [6], a Commissioner on the FCC, and E. Stratford Smith [7], the National Cable Association's first general counsel, did an excellent job in laying out the complex and often contentious regulatory issues that Congress and the FCC had to resolve in order to strike a fair balance between the ambitions of the CATV industry, the long accepted business model of television broadcasting, and the longer term interests of society.

On the technical side, the Special Issue offered the reader some intriguing examples of where CATV developments could go. Herold reminded the readers of the PROCEEDINGS that no changes to the 525 line, 4-MHz video bandwidth broadcast standards had been made when color was introduced in the early 1950s [8]. As a result, television broadcasting could not exploit the advantages of the larger picture tubes that were being produced by the end of the 1960s. Herold proposed an approach to use CATV to double the resolution of TV images [8]. In addition to higher quality TV reception, Herold pointed out that the higher resolutions brought by CATV "would open up new services, such as still pictures of text pages and easily readable small alphanumeric characters" [8, p. 1015]. William B. Gross, from General Electric, argued that a great potential for CATV lay outside the realm of TV broadcasting, in electronic mail. Transaction mail, according to Gross, was projected to be, by 1980, about 40% of all mail for an annual volume of 43.2 billion pieces. With data communications thrown in, Gross saw the revenue potential as $8.64 billion [9, p. 1003]. Gross urged the CATV industry to develop the technology needed to go after that market. He then proposed a CATV-based electronics mail system that not only was "more than competitive with the existing telecommunications infrastructure, but it also had the advantage of broadband information transfer not now available at a reasonable price" [9, p. 1012].

The broad technical and public interest in the concept of the "wired city" that arose at the start of the 1970s was also fueled by pioneering developments in data communications networks, which also received considerable prominence in the pages of the PROCEEDINGS.

III. INTEGRATING THE WORLD THROUGH DIGITAL DATA NETWORKS

"In 1968," Lawrence G. Roberts wrote in a 1978 issue of the PROCEEDINGS, "virtually all interactive data communications networks were circuit switched, the same as the telephone network. A decade later," Roberts reminded his audience, "packet switching had revolutionized data communications" [10, p. 1307]. So important was this rapidly emerging technology, that in 1978 the PROCEEDINGS devoted, for the first time, an entire issue to the subject. The guest editor for this issue was none other than Robert E. Kahn, whose accomplishments would later firmly place him as one the key pioneers in the early development of the Internet. Kahn and his coeditors underscored the remarkable growth of the technology during the 1970s. "Public and private packet networks have been built or are under development in over a dozen countries; the packet switching concept has been extended to virtually every type of communications media and is used over very short distances to those that span countries" [11, p. 1303]. They then went on to make the bold prediction that the day would come "when almost everyone in our society will have access to an all-electronic computer-based network for all his information needs" [11, p. 1303]. When one considers the far reaching penetration of packet switching technology into the lives of humans around the world, and the profound effect of packet switching on global cultural and political events, this 1978 prediction was an understatement to say the least.

For historians of technology and for engineers interested in history, the 1978 Special Issue on Packet Switching offers a wonderful overview of the developments as they were being experienced and understood at the time. Lawrence E. Roberts, who had been the project manager for ARPANET and who had also been the CEO of Telenet, the first packet switching network carrier, offered an excellent historical overview of the technical development of packet switching networks from their inception in the late 1960s through their rapid development in the 1970s [10]. In 1974, Vinton G. Cerf (Fig. 1) and Robert E. Kahn published their classic paper "A protocol for packet network intercommunications" [12]. Their paper became the cornerstone of the TCP/IP protocol that governs the global Internet. In this 1978 Special Issue, Cerf along with his coauthor Peter T. Kirstein give a firsthand account of the circumstances that brought TCP protocol into existence [13, p. 1387]. Their article also provides us, in the context of the late 1970s, an excellent summary of the key technical questions facing the growth of packet switching networks. "How can networks be interconnected so that packets can flow in a controllable way from one net to another? Should all computer systems on all nets be able to communicate with each other? What kinds of communication protocol standards are needed to support efficient and useful interconnection? Who should take responsibility for setting standards?" These were some of the crucial technical questions that Cerf and Kirstein tried to answer in their article. They also reminded the reader that the legal and political issues to be resolved will be equally complex: questions like "How is privacy to be protected? Should there be control over the kinds of data which move from one net to another?" Today, almost 35 years later, these questions are still being hotly debated.

Leonard Kleinrock (Fig. 2), another pioneer in the development of computer communications technology, who also played an important role in the early development or ARPANET, contributed an article to this Special Issue in which he extracted lessons learned from his decade-long participation in the development of packet switching networks [14]. True automatic resource sharing, Kleinrock told the readers of the Proceedings, is the next frontier of packet networks. But he cautioned:

> "We must continue to learn from our experience, and alas, that experience is often gained through mistakes observed rather than through clever prediction. . . . We must further be prepared to incorporate new technologies and new applications as they arise; we cannot depend upon "principles" as these principles become invalid in the face of changing technologies and applications."

In addition to the aforementioned articles there were many other technical contributions related to "protocols," "theoretical developments," and "advanced network concepts." But the full contextual value of this Special Issue for those interested in understanding the history of packet switching networks lies equally in the articles dealing with

Fig. 2. *Leonard Kleinrock (courtesy of the IEEE History Center).*

the political, legal, economic issues arising from the development of that technology. Stuart L. Mathison [15] wrote on the commercial and legal aspects, Israel Gitman and Howard Frank [16] analyzed the economics of future voice and data integration, and P. T. F. Kelly [17] examined the international dimension of public network standards. To Robert Kahn and his fellow editors' credit, they expressly included these broader topics in the Special Issue because they understood that technical development would be inextricably linked with political, economic, and regulatory changes.

Until the 1970s, cryptography had been the almost exclusive purview of the military and diplomats. With the emergence of public and private packet switched networks a broader interest in data security and privacy arose. From being an arcane subject known only to a few, cryptography started to interest a wider technical audience. In 1979, Whitfield Diffie and Martin E. Hellman (Fig. 3) offered the readers of the PROCEEDINGS an introductory, and technically comprehensive, tutorial on cryptography and its use in data networks [18]. In many ways, one could not think of two better authors for this tutorial. Three years earlier, Diffie and Hellman had published their groundbreaking paper that offered the first practical approach to public-key cryptography [19]. According to David Kahn, a noted historian of cryptology, the Diffie and Hellman paper, "was a dramatic breakthrough, for it had not occurred to anyone else in the long history of cryptology the deciphering key could be anything else than the inverse of the enciphering key" [20, p. 982]. It was this asymmetry that allowed packet switched networks to be secure. The use of cryptography had always been expensive. But the same advances in computer communications that had generated a need for security, as Diffie and Hellman pointed out in their tutorial, also made cryptographic techniques much cheaper. In reading this tutorial, one gets a good sense of the considerable development in public-key cryptography that took place during the 1970s.

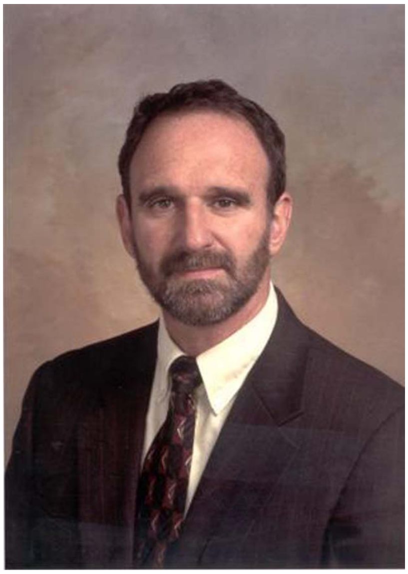

Fig. 3. *Martin E. Hellman (courtesy of the IEEE History Center).*

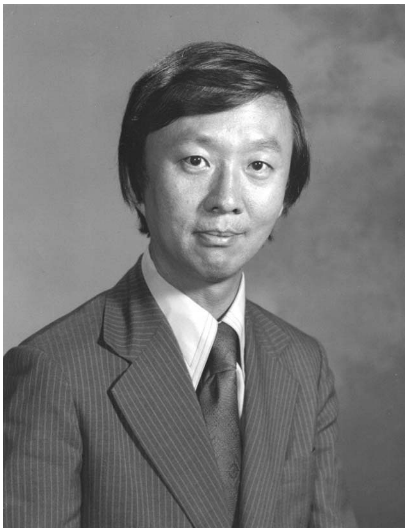

Fig. 4. *Charles C. Kao (courtesy of the IEEE History Center).*

IV. GREATER BANDWIDTH USING THE VISIBLE SPECTRUM

Optimizing bandwidth has always been a key focus of communications technologies. With the invention of the laser in the early 1960s, engineers and scientists started to dream of dramatic bandwidth increases. The 1966 landmark paper by Charles C. Kao (Fig. 4) and George A. Hockham [21], which addressed the idea of optical waveguides, provided a key theoretical foundation for this dream. But by the start of 1970s, optimism had given way to skepticism. Less than five years after the Kao and Hockham article, the value of optical communications was being seriously debated. Practical progress had proved elusive. The Bell Labs physicist and engineer, Rudolf Kompfner (Fig. 5), the key developer of the traveling wave tube, remarked "One could, by edict already today build an optical communication system; but it would be a very clumsy and inefficient affair. In order to have the same capacity as the wave guide, the optical art would have to be stretched beyond what is known" [22, p. 1410]. In an overview of the field in the PROCEEDINGS, Nilo Lindgren observed, "Today, after a decade of slow work, despite the development of many more types of lasers, of more powerful, more efficient, more extraordinary and reliable lasers, despite a growing spectrum of possible laser applications, it is hardly an exaggeration to say that there is, as yet, no practical optical communication

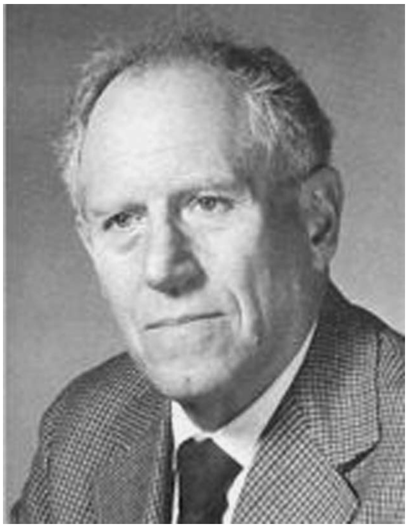

Fig. 5. *Rudolf Kompfner (courtesy of the IEEE History Center).*

system in existence" [22, p. 1410]. And yet, there were those who felt that enough progress was being made to sustain a belief in the long-term promise of optical communications.

In an attempt to "delineate some of the important problems that [had to] be resolved if communications at optical frequencies [were] to become practical and to present some objective criteria by which to judge the performance of such systems," in 1970, the PROCEEDINGS OF THE IEEE published a Special Issue on the subject [23]. Work in optical communications had been an interdisciplinary activity of physicists and engineers. The editors of this Special Issue reminded the theorists that they could not "assume that the important devices for building communication systems [were] just frequency scaled replicas of those existing at lower frequencies" [24, p. 1407]. At the same time, they cautioned the engineers not to assume that their past experiences at radio and microwave frequencies would necessarily be the guide to system design in the optical range. There was also concern about the ease with which communications engineers trained in, and conditioned to, microwave technology could make the transition to optical frequencies.

The 38 articles in the Special Issue explored the many facets that made up the two avenues in optical communications R&D: 1) line-of-sight, free-space transmission of laser light; and 2) transmitting laser light through optical waveguides. Despite all the challenges of attenuation in line-of-sight methods one article concluded that "the increasing sophistication of optical (and infrared) components and techniques, combined with rapidly expanding communication requirements, suggests that optical systems operating partly or entirely within the atmosphere may soon represent desirable solutions to real communications problems" [25, p. 1691]. The prospect of deep space travel was perhaps the primary impetus to develop practical free-space optical communication techniques. And yet, as Lindgren's survey article points out, a hindrance to the technical discussion of free-space methods was the absence of a real demonstration system. The National Aeronautics and Space Administration (NASA) "engineers for space missions were leaning over backwards precariously to make do with existing technology," which was microwave and millimeter wavelengths [22, p. 1416].

The most intense effort to develop optical communications technology was within telephony where optical waveguides were of keen interest [22, p. 1410]. The optical waveguides also suffered from serious attenuation issues. Kao and Hockham had specified a lower limit of 20-db/km loss for an effective optical waveguide. But as one author in 1970 Special Issue underscored, "the major drawback, however, at the present time is that the glass used in fiber optics is very lossy, amounting to a decibel per meter at the very best. In actuality, with present glasses, the losses would amount to thousands of decibels per mile, which makes the material clearly unsuitable for long-distance communication ... If pure enough fibers are successfully developed, dielectric waveguides might eventually be used between switching exchanges a few miles apart within cities and towns" [22, p. 1416]. Timing is everything. Within weeks of the Special Issue's publication, Corning demonstrated a fiber optic with 16-db/km losses [26]. In very short time, Corning lowered these losses considerably more. In the context of 1970, fiber optics were perceived as a telephony application of only a few miles. Today of course, fiber optic cables span the globe. Though the applicability of free-space optical communications has not had the dramatic successes of fiber optics, in the context of space travel, there is obviously still great interest.

V. SPANNING THE GLOBE WITH COMMUNICATIONS SATELLITES

Satellite communications was another prominent subject in the pages of the PROCEEDINGS during the 1970s. In fact, the PROCEEDINGS dedicated two Special Issues on the subject over the decade, in 1971 and 1977 (Figs. 6 and 7) [27], [28]. The early 1960s saw a number of communication satellite "firsts." In 1945, Arthur C. Clarke, who later achieved great fame as a science fiction writer, proposed the notion of a geostationary communications satellite. On July 16, 1963, Syncom 2 became the first communications satellite in geosynchronous orbit. A year later, Syncom 3 became the first communications satellite in

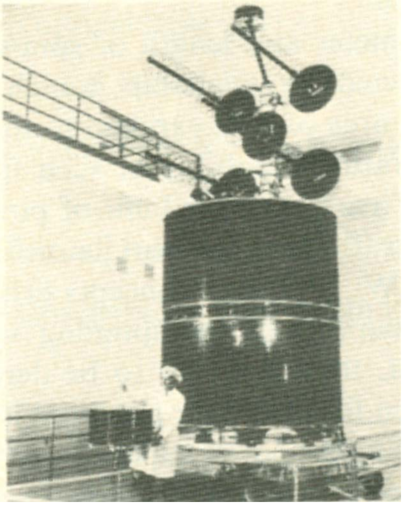

Fig. 6. *TACSAT I, built for SAMSO, launched in 1969 (from [54]).*

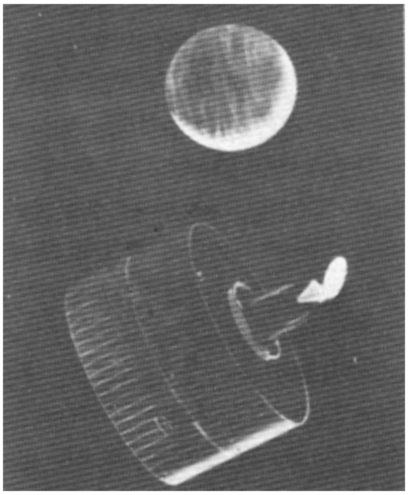

Fig. 7. *SKYNET I, built for the united kingdom under management of SAMSO, first launched in 1969 (from [54]).*

geostationary orbit.[1] The 1971 Special Issue of the PROCEEDINGS on communication satellites took stock of all the technical achievements of the 1960s and then addressed the future challenges. Of particular note was the realization that, with the increasing use of telecommunications satellites, frequency and geostationary orbit allocations were becoming scarce resources that required careful and technically informed international management. John L. Hult and Edward E. Reinhart examined this question along several technical fronts: efficient use of orbits and spectrum for sharing between satellite systems; frequency sharing between microwave-relay and satellite systems; frequency sharing between satellite and terrestrial systems for mobile and broadcast services; and spectrum demand of the implications for spectrum use [29]. The editor of the 1971 Special Issue, Walter E. Morrow, who was also a distinguished engineer in satellite communications, hoped that the issue would be of value to the International Telecommunications Union (ITU) in its upcoming 1972 deliberations on frequency and orbit allocations [30].

Throughout the 1960s, most satellite communications systems linked large fixed terminals. At the start of the 1970s, articles appeared in the PROCEEDINGS concerning the development of operational systems that would, for the first time, provide reliable communications to mobile platforms like aircraft, ships, and spacecraft. Sajjad H. Durrani and David W. Lipke examined the feasibility of relay satellite systems to provide real-time communications links between a spacecraft and the mission control center [31]. Irwin L. Lebow, Kenneth L. Jordan, Jr., and Paul R. Drouilhet, Jr. looked at the use of communications satellites for aircraft [32].

In 1977, six years after the first Special Issue on communications satellites, the second Special Issue on the same subject underscored the maturity of the industry. By 1977, INTELSAT, with 94 member countries, had emerged as the leading provider of international satellite communications. Eighty percent of the world's overseas communications traffic now went by satellite [33]. With this maturity, the management of frequency and orbit allocations became even more acute than it was at the start of the decade. "The number of communication satellites in service," observed David Withers in 1977, "have increased considerably in the past 2 or 3 years and the upward trend is accelerating" [34, p. 308]. He observed that in some part of the orbit, careful attention had to be paid to intersatellite interference when choosing the location for a new satellite in the 4- and 6-GHz bands. Congestion would, he argued, push technology to higher frequency bands. But Withers wondered if a point would be reached when there would not be room for further growth in the number geostationary slots. If that moment ever arrived, traffic priorities would have to be set.

Withers proposed a number of ways "... of stretching the satellite communications medium beyond the capacity of the geostationary orbit used in conventional ways" [34, p. 308]. Arguing that geostationary satellite networks, by their nature, operated in an interference environment, Michael C. Jeruchim, in his article entitled "A survey of interference problems and applications to geostationary satellite networks," reminded readers of the PROCEEDINGS that "a fairly extensive body of theory concerning interference already existed but many problems of importance still need[ed] to be solved" [35, p. 329]. In terms of predicting the future technical developments in satellite communications, Emeric Podraczky, Director of the Technical and Opeations Division of INTELSAT, concluded that technology would have to respond to the inevitable demand for greater frequency spectrum and orbital space. "The World Administrative Radio Conference in 1979," wrote Podraczky in 1977, "will have to define the spectrum range within which the growth of satellite communications will take place for years to come... Given proper choices of frequency spectrum, cost effective launch services and effective means of using the geostationary orbit, satellite communications should have a bright future and our IEEE Society can effectively contribute toward such developments" [36, p. 293].

VI. THE MICROPROCESSOR: THE DISRUPTIVE TECHNOLOGY THAT MOS BUILT

At the start of 1970s, a remarkable shift in transistor technology was getting underway. For most of the 1960s, integrated circuits (ICs) were built around bipolar transistors. During the same period, a competitor to bipolar had appeared. The metal–oxide–semiconductor (MOS), which worked on very different principles, offered the exciting prospect of much simpler, denser, lower cost, and less power-consuming ICs. And yet, by the end of the 1960s, the expected rapid and widespread implementation of MOS technology had not materialized. Lower speeds, continued reliability issues, and higher than expected costs all hampered the wider penetration of MOS into IC design. A solution to these problems appeared in 1968. That year while at Fairchild Semiconductor, Federico Faggin (Fig. 8) led a team that proved the feasibility of the silicon gate to MOS [37, p. 236], [38]. Surprisingly, Fairchild did not commit to the silicon gate. The newly formed Intel, on the other hand, boldly and very quickly embraced the silicon-gate concept. A number of difficult technical problems, however, still remained to be solved before the silicon gate could

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[1] A geostationary orbit, which is a special case of geosynchronous orbit, has a circular orbit with zero inclination, i.e. sits above the equator.

Fig. 8. *Federico Faggin (courtesy of the IEEE History Center).*

be the basis of a viable product. Committed to this new approach to MOS, Intel devoted the time and resources to move it into production [39]. In unleashing the full potential of MOS technology, the silicon gate set the stage for a truly revolutionary breakthrough of the 1970s—the microprocessor.

It is no surprise that Intel, having already perfected the production silicon-gate ICs, was well placed to pioneer the microprocessor. It is also no coincidence that Federico Faggin, who had moved from Fairchild to Intel in 1970, was chosen to spearhead the development of the world's first microprocessor—the 4004. Today, Intel is synonymous with the microprocessor, but, at the start, this new device was not a priority. Faggin later recalled that, in the beginning, “both Vadasz and Grove (Fig. 9), my boss's boss, considered my project a diversion dreamed up by the marketing guys to make some money while waiting for the memory business—the real mission of Intel—to mature” [38, p. 12]. Yet, it did not take long before Intel's management grasped its potential. In 1976, writing for the PROCEEDINGS, Gordon E. Moore, cofounder of Intel and then its President, proclaimed: “The effect of the microprocessor on the electronics industry is revolutionary.” Elaborating further, Moore wrote:

> “The previous interface between component supplier and user is altered with significant qualitative changes in the tasks each performs. Certainly, the new product capability and flexibility imparted by microcomputers will also have a profound effect on society outside the electronics industry, but the first impact of the revolution is upon the structure of the electronics industry itself. . . . It has a revolutionary impact on the technology that spawned it. The appearance and acceptance of the microprocessor approach to the realization of logic functions has had a major influence on the direction that technology development is taking. . . . It would be easy to conclude in retrospect from a superficial view of the evolution of integrated-circuit complexity that the microprocessor was an obvious product as soon as the achievable circuit complexity was sufficient to realize such a function in a single integrated structure. . . .

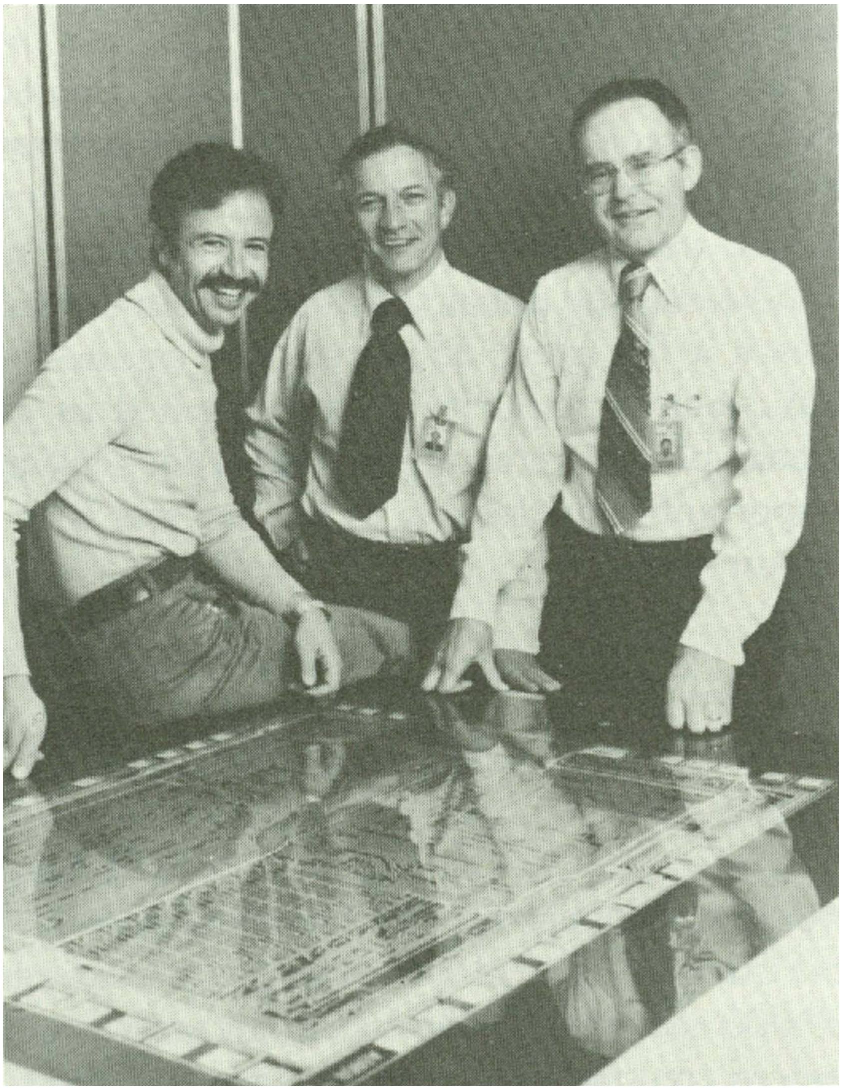

Fig. 9. *Andrew Grove, Robert Noyce, and Gordon E. Moore, the founders of Intel Corporation (from [55]).*

> In fact, revolutionary products seldom follow such a logical path in their origin, and, from my view, this is not how the microcomputer came into being. . . . My view (which I admit is that of a technologist) is that the characteristics that evolved in the technology forced the product-development directions" [40, p. 837].

Even Moore, in his reference to microcomputers, could not have foreseen the far reaching disruptive nature of the microprocessor that was about to undermine the established computer industry. At the start of the 1970s, "Big Iron" and minicomputers were the technological and business models for computation. The moment the microprocessor appeared, a new found interest in portable computers appeared at the margins. In 1971, Kenbak-1, first personal computer advertised for sale, appeared in *Scientific American*. Very quickly a host of microcomputers appeared: Micral, the earliest nonkit PC; Altair 8800 PC; Tandem 16; Apple I and Apple II' Radio Shack's Tandy computer; and Atari's game playing microcomputer, to name but a few.

In line with its practice of keeping IEEE members abreast of important technological developments, in 1976, the PROCEEDINGS offered a Special Issue on the Microprocessor and Its Applications. Articles were presented under four headings: technology; architecture; software and systems development; and applications [41]. Moore's paper offered a "unique perspective, from the insider's vantage point, on the technological development leading to the birth of the first microprocessor" [42, p. 835]. For those interested in the history of the microprocessor, Moore's narrative is a glimpse into his thinking as he was living through the events. The other articles span the many technical issues arising from the design, reliability, testing, and manufacturing of microprocessors.

In introducing the articles on "applications," the Guest Editors for this issue, William W. Lattin and Paul M. Russo, reminded readers that "the frontiers of potential applications are not so much limited by technology as by the designer's imagination" [42, p. 835]. Imaginations were indeed fertile. Within two years, in 1978, the PROCEEDINGS had to publish a second Special Issue on the microprocessor, but this time dedicated to applications [43]. As this second issue demonstrated, interest in microprocessor applications had, within less than two years, penetrated into a wide ranging number of human activities. The availability of cheap, reliable, and very compact computational power was about to revolutionize consumer electronics. With the microprocessor came the concept of intelligent consumer products. In one paper, a group of engineers from RCA Laboratories surveyed progress in intelligent microwave ovens, washing machines, color televisions, turntables, video games, and automobiles [44]. Of particular note is their discussion on the microprocessor's impact on CATV. The growth of the "wired city," noted the authors, had been slowed down "by technical problems in two-way transmission and the high costs of putting specialized control centers in consumer homes" [44, p. 133].

The focus of the article was on programmable video games and in particular the RCA Studio II. In the beginning, the microcomputer seemed to be an answer looking for a question. Still rooted in the paradigms of computers in business and scientific settings, the marketers of microcomputers often tried to come up with data processing applications in the home as a way to convince consumers to buy microcomputers. However, as the last 30 years have shown, what the mass consumer market was really ready to pay for were communications and entertainment applications. In the RCA Studio II product, RCA Laboratories understood this marketing reality. "The marketing philosophy adopted for the initial RCA offerings in the consumer market," explained the authors, "is to concentrate on high-volume consumer entertainment applications (starting with programmable video games) and to make technical spin off applications for the educational and hobby markets" [44, p. 138]. RCA's interest in programmable video games started in the early 1970s with flexible recreational educational device (FRED). RCA Laboratories designed a microprocessor (COSMAC) specifically for FRED. In response to the rapidly evolving state semiconductor of semiconductor technology in the early 1970s, FRED went through six generations to produce the Studio II product. The challenge in commercialization Studio II was to design a product that would allow quick entry into the market. The authors understood that "any microprocessor-based consumer product [had] almost unlimited possible functions and "bell and whistles" that [could] be built in. . . . However, to enter the market quickly and cost-effectively the initial minimum viable system required can be obtained only by severe self discipline by the system designer" [44, p. 139].

The automobile, as John Marley wrote in the PROCEEDINGS, held out special opportunities and challenges for the microprocessor. The automobile offered an instant mass market for the microprocessor industry. "The very high volume," proclaimed Marley, "assures that the 'brain chip' will be available at very low cost-similar to the history of the semiconductors in the shirt pocket calculator" [45, p. 142]. Marley also underscored the important technical challenges facing the introduction of the microprocessor into the automobile: high-volume economics, stringent long-term reliability, high speed, continuous real-time performance, hostile electrical and physical environments, and adaptability (without a keyboard in every car). One also had to consider "the methods of creating and installing the instruction programming, the degree of design flexibility, the categories of tasks which can be done efficiently, the integration of the entire computer on a single chip, and the physical form factor in packaging" [45, p. 142]. There was also the matter of creating the associated transducers, actuators, and cabling that would supply the real-time inputs to and from the microprocessor. Another exciting aspect of introducing the microprocessor into the automobile was the display of information which would require the design of electronic instrument panel clusters and greater attention to the driver interface. With the large-scale introduction of the microprocessor into the automobile still a few years away, Marley's article offers a comprehensive overview of all the design issues that automotive engineers faced, in the context of 1978, as they experimented with the idea.

The two articles by Dan C. Stanzione [46] and Donald K. Melvin [47] give detailed accounts on the way microprocessor technology diffused into the into the telephone switching system during the 1970s. Victor Klig's paper is a comprehensive overview of the significant advances in applying the microprocessor to biomedical applications [48]. Klig's review looked at blood pressure monitoring, electroencephalography (EEG) processors, limb prosthetics, and physiological monitor for cardiac catheterization. Klig also identified the automation of blood and tissue assays and urine analysis as blood test analyses important future applications. Such automation promised considerable economic savings. The challenge with such automation was the handling and interpreting the large volumes of information. "New methods of presenting useful information for the enlightenment or stimulation of the biomedical and engineering communities," concluded Klig, "will have to be found" [48, p. 159]. Greater utility, added Klig, would also require a greater degree of standardization of the human interface to the biomedical instruments.

VII. ENGINEERING EDUCATION: THE CHALLENGES GOING FORWARD

The tumultuous times of the late 1960s continued into the 1970s. Protests over the Vietnam War were tearing American society apart. There was a general pessimism as to where technological change was leading humanity. Stagflation and the first oil crisis led many to question the energy-intensive trajectory of western industrialism. Universities had become fertile grounds where accepted wisdom was being challenged (Fig. 10). The time honored role of the university education was being challenged from within. A new generation of students and faculty members wanted to reexamine the educational process. To what extent did a university education prepare men and women to tackle all the dire problems facing society? How could education benefit humanity? Engineering education was crucial to answering these questions.

In describing the context of the day, the President of the IEEE's Education Society, Warren B. Boast, used the memorable lines from Charles Dickens' *A Tale of Two Cities*: "It was the best of times, it was the worst of times, it was the age of wisdom, it was the age of foolishness." Boast wanted to make the point that Dickens was writing about "times" preceding the French Revolution when great changes were in the air. It was a time when for some the future only held out uncertainty while for others it held out hope. "Present times," Boast continued:

> "are no exception . . . The glimmer of hope for the future is education, because without knowledge and understanding which come with education, the reasoning and planning which can provide the stable future can never occur. The interface between scientific-engineering technology and the organic world, including man himself, is being stressed to the breaking

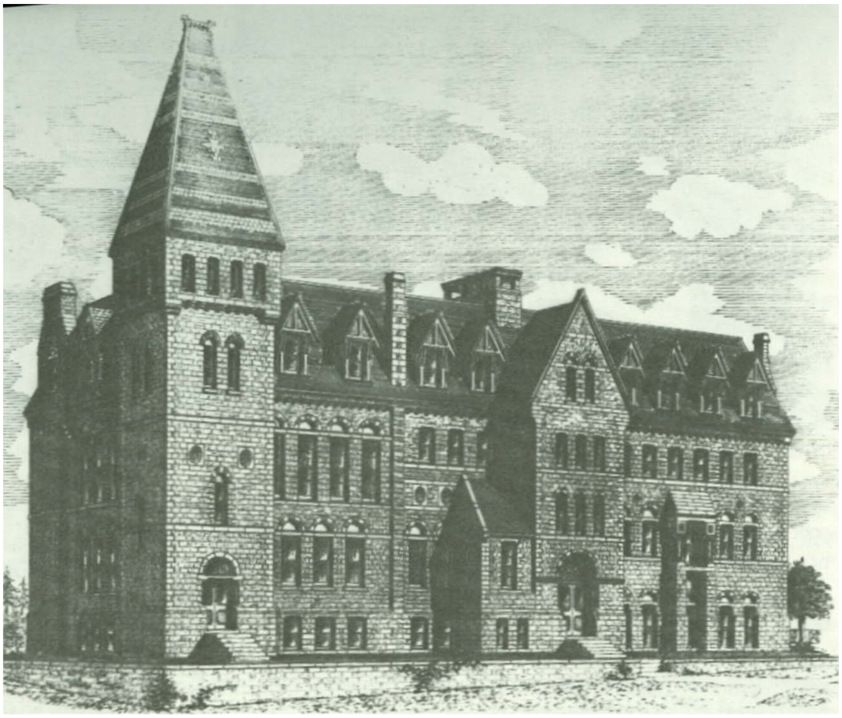

Fig. 10. *The Cornell program was first housed in the Physical and Chemical Laboratory, which was renamed Franklin Hall—in honor of The First American Electrician—at the end of the 1880s (from [55]).*

> point through overloading the organic world with waste products of the technological world. Good priorities, which we as individuals and as groups of people assign to our lives either individually or as nations, can be orderly established only with knowledge and understanding which comes with education" [49].

In 1971, the PROCEEDINGS explored the challenges of engineering education in a Special Issue. In introducing the issue, John R. Whinnery, who later went on to win the IEEE Medal of Honor and the National Medal of Science, wrote: "It will be news to none of the readers that higher education in general and engineering education in particular are undergoing the most sweeping set of changes of our generation." He went on to explain:

> "Some of the changes are forced upon us by shifts in the patterns of financial support and by the changing job market for engineers. Others are happening by choice as we understand better the role of technology in society and strive to educate engineers for the 'new priorities.' Both sources of change provide opportunities for a better educational system if we are wise in making the right choices."

The Special Issue's 24 articles on education offered a wide range of perspectives on "making the right choices" (Fig. 11). Several authors feared that engineering education was forgetting the fundamental and immutable purpose of engineering: designing useful systems for humanity. Robert Spence, from Imperial College, London, U.K., lamented that engineering freshman curricula in most universities exhibited a remarkable paucity of "engineering flavor" [50]. Instead the freshman curriculum was a diet rich in the "basic" or "fundamental" courses of mathematics, physics, and chemistry. Even engineering subjects like fluid mechanics were so presented as to leave students uninterested or unable to appreciate engineering's close connection to designing for society. For Spence, this state of affairs reflected the fact that "engineering education [had] been unduly influenced by attitudes more appropriate to the natural sciences. It should instead acknowledge the ultimate concern of the engineer for design rather than analysis, for systems rather than constituent components, and for value to the community in place of mere increase of knowledge" [50, p. 920].

In his paper, "The major problems facing engineering education," which offers an excellent historical overview covering seven decades of debates on engineering education, Eric A. Walker underscored the recurring nature of some of these challenges to education [51]. Spence's concern over the dominance of science in the education of engineers is one. Walker reminded readers that in 1932, the newly established Engineer's Council for Professional Development (ECPD) in the United States, stressed that the engineer's university education be rooted in the needs of society and a curriculum that advanced "the distinguishing characteristic of the engineer—[the]

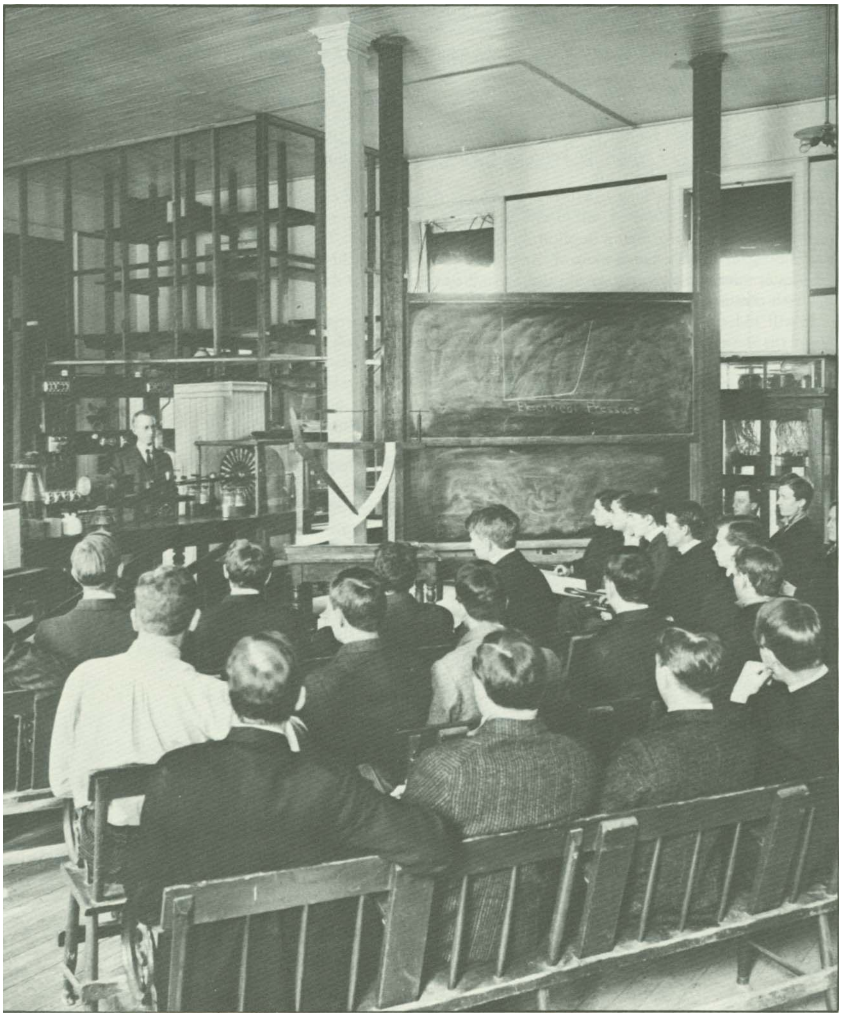

Fig. 11. *Harris Ryan instructing a few of the many hundreds of Cornell students he trained in his 16 years on the faculty (from [55]).*

ability to design" [51, p. 825]. Then, in the mid-1950s, with the appearance of the Grinter Report, there was an intense push to broaden and deepen the basic science content throughout the engineering curriculum [52]. "And in the ensuing modification of engineering programs to include more science," Walker notes that "[the] idea of the professional engineer as the creative designer was almost completely lost" [51, p. 825]. The resulting emphasis on science in the engineering was so pervasive that, by the start of the 1970s, there was reaction to it. "Engineering literature," wrote Walker, "began to emphasize the need for distinguishing the engineer from the scientist, for restoring to him his traditional role of innovator—of creative agent in the process of translating the forces and materials of nature into useful goods and services. . . . The wheel had come full circle; but in its revolution the dilemma had gained new momentum" [51, p. 826].

As an IEEE Fellow, a former president of Pennsylvania State University, and the Vice President of Technology and Science, for ALCOA, Walker was well positioned to understand the tensions in the engineer's education. Later, in 1995, Walker was awarded William E. Sayle II Award for Achievement in Education. In his paper, Walker underscored a fundamental constraint up against which in the undergraduate engineering curriculum was pushing very hard: time. To respond to the need for more basic sciences, to the importance of creative design of useful products as the defining feature of engineering, and to the desire to give students an awareness of the societal challenges to which they must apply their skills, engineering curricula were being stretched very tight. Perhaps, Walker suggested, this was the time to make education a cooperative effort between the universities, industry, and the professional societies. Walker argued that industry would have to take a far more active role in the education process. Universities would have to be far more flexible. At issue was the legal power of universities to be accredited and grant degrees. But Walker cautioned that these privileges might not remain the sole property of universities. He believed that proprietary organizations, subsidiaries of industry, or industry-owned organizations would, in the near future, be accredited. Walker went on to suggest an intriguing partition of responsibilities in undergraduate engineering education: private sector organizations could offer the courses while the universities oversaw final examinations and conferred the degree. This scheme, he hoped, would "give a tremendous impetus to teaching by industry." The reader may find some resemblance in Walker's suggestion with the present day growth of the online education industry. As for the role of engineering societies in the cooperative venture in education, in 1971, they were doing very little in this direction. But their participation was vital if "the standards of engineering education [were] to be maintained and if there [were] to be a professional element in the practice of engineering" [51, p. 827]. Walker called for the engineering societies to take the lead to set up a consortium between industry and universities that could create an engineering education system to meet the needs of the 1980s.

So important was the issue of the engineer's education in the 1970s that the PROCEEDINGS put out a second Special Issue on the subject in 1978. Many of the themes in the 1971 Special Issue reappeared in the 1978 issue. For example, in his editorial to the 1978 issue, Lyle D. Feisel, the President of the Education Society, comes back to the tension in the engineering curriculum between science-based training and engineering as creative design. "There is," wrote Feisel, "a long-standing debate, recently intensified, on the appropriate design of the system of engineering education. Competing designs range from the one extreme that reminds one of the classical scientific education, with emphasis on theory and research and little contact with the principles of design, to the other extreme which would eliminate most basic sciences and concentrate on design, leaning heavily on experiential learning and practice-oriented activity" [53]. Feisel called for a balanced approach, one that took the best from both. But he warned that "as the 1980's draw nearer, there is a danger of the adversary mode dominating as engineering education is modified to deal with the problems of the new decade" [53, p. 821]. His fear was that "industry" would be pitted against "academe." "Engineers in academe," wrote Feisel, "must remember that the principal goal of the education system is to train and educate engineers for entry into the profession and for productive employment by industry. At the same time, engineers in industry must remember that the only source of new engineers is through the universities" [53, p. 821]. Cooperation was in order and "IEEE provided the best mechanism for such cooperation." The conduit for this cooperation would be the IEEE Education Group and the IEEE TRANSACTIONS ON EDUCATION.

All readers of the PROCEEDINGS interested in the future of engineering education should take a glance at the 1971 and 1978 Special Issues on Engineering Education. Within the pages of these issues are excellent historical overviews that may put current debates in perspective. Perhaps these issues can inform current debates by reminding us about the problems that are long-standing and those that are new. If there are fundamental problems that keep resurfacing from generation to generation, then it behooves all those interested in improving the quality of education in the next generation of engineers to ask, "why?" ■

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APPENDIX SPECIAL ISSUES IN THE PROCEEDINGS OF THE IEEE DURING THE 1970s

1970

January	Computers in Industrial, Process Control.
March	Air Traffic Control.
May	Detection Theory.
July	Cable Television.
October	Optical Communication.

1971

February	Satellite Communications.
April	Atomic and Molecular Plasmas.
June	Engineering Education.
August	Microwave Semiconductors.
October	Thick and Thin Films for Electronics Applications.

1972

January	Computers in Design.
February	LEDs.
May	Time and Frequency.
July	Digital Picture Processing.
October	Digital Pattern Recognition.
November	Computer Communications.

1973

January	Applications of Superconductivity.
May	Ground Transportation for the Eighties.
July	New Materials for Display Devices.
September	Radio and Radar Astronomy.
November	Minicomputers.

1974

January	Industrial, Scientific, and Medical Applications of Microwaves.
February	Reliability of Semiconductor Devices.
April	Computer Graphics.
July	Computers in the Power Industry.
September	Effects and uses of Energetic Radiation in Electronic Materials.
November	Rays and Beams.

1975

January	Infrared Technology for Remote Sensing.
March	Social Systems Engineering: An Introduction.
April	Digital Signal Processing.
June	Interactive Computer Systems.
August	Large Capacity Digital Storage Systems.
October	Laboratory Automation.

1976

January	Recent Trends in System in System Theory.
April	Man-Machine Communications by Voice.
May	Surface Acoustic Waves.
June	Microprocessor Technology and Applications.
September	Two Centuries in Retrospect.

1977

January	Optical Computing.
March	Satellite Communications.
May	Biological Signal Processing and Analysis.
June	Multidimensional Systems.
September	Telecommunications Circuit Switching.

1978

February	Microprocessor Applications.
April	Electromagnetic Measurement Science.
August	Education.
October	Fault-Tolerant Digital Systems: Is HAL Going to Join Us Before 2001?
November	Packet Communication Networks.

1979

January	Miniaturized Filters.
May	Pattern Recognition and Image Processing.
July	Electromagnetic Theory to Geophysical Exploration.
September	Technology and Health Care Issue: Introduction.

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