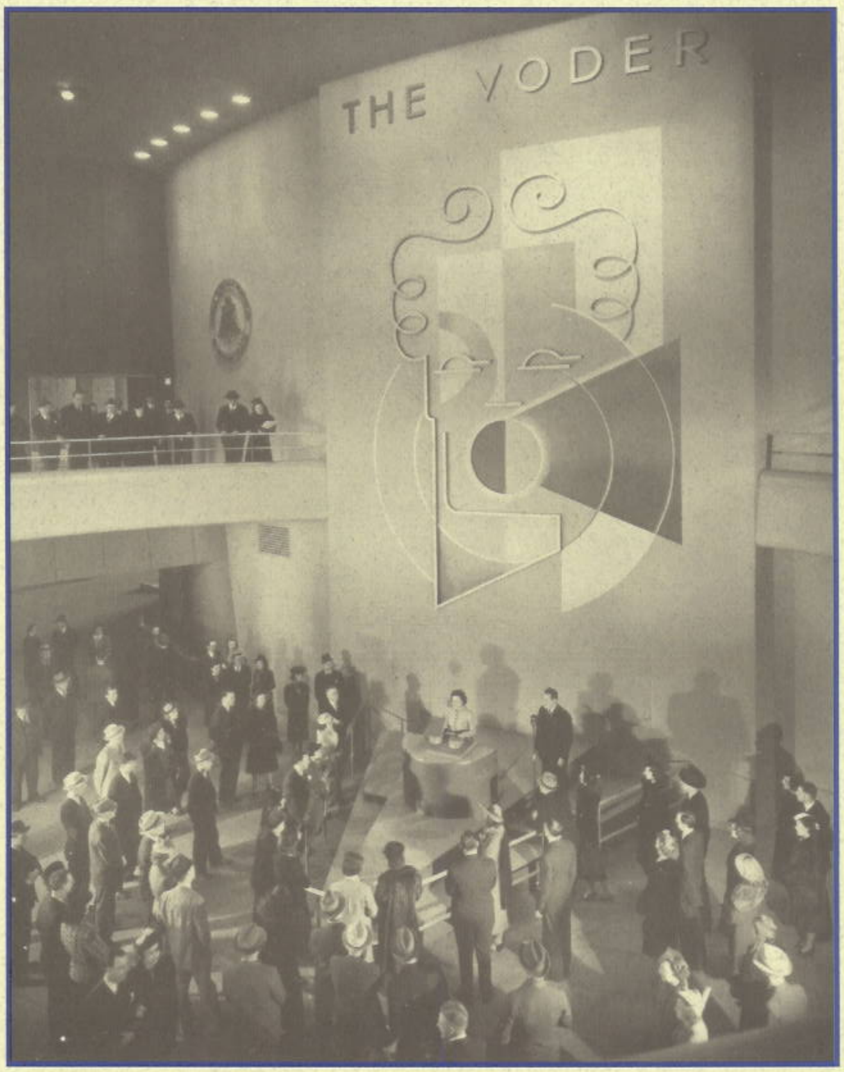
Fifty Years of Signal Processing:

The IEEE Signal Processing Society and its Technologies 1948–1998



The IEEE Signal Processing Society
1998

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Contents

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Preface

The IEEE Signal Processing Society is now 50 years old. When it began in 1948 as the Professional Group on Audio of the Institute of Radio Engineers, there was no discipline of signal processing. Over the next decades, as the IRE Professional Group on Audio evolved into the IEEE Signal Processing Society, it helped create the discipline of signal processing, which today is a vital and rapidly growing branch of engineering. The Society history, then, is an important part of the history of signal processing.

This booklet tells the story both of the technologies and the Society. The story is told chronologically. For each decade there are parallel narratives: the technology history on the left-hand side and the Society history on the right-hand side.

These are exciting stories. Signal processing technologies are today pervasive in communications, control systems, computing, and instrumentation. The Society history provides many examples of dedicated and unselfish service to the profession, as it shows how a professional organization adapted to rapid technological change, to the emergence of quite new technologies, and to changing social, political, and economic conditions. These are worthwhile things to know for today's and tomorrow's leaders of the Society, since the next 50 years are hardly likely to be any more settled than the last, and dedication, resourcefulness, and adaptability will certainly be required.

The material for this booklet comes from two monographs published in 1998 by the IEEE History Center at Rutgers University in New Brunswick, New Jersey: *Signal Processing: The Emergence of a Discipline, 1948 - 1998* and *The IEEE Signal Processing Society: Fifty Years of Service, 1948 - 1998*, both written by Frederik Nebeker. The excerpts from oral-history interviews included in this booklet come from interviews conducted by staff of the IEEE History Center. Many of them were part of a project, supported by the Signal Processing Society, to research the history of signal processing and of the Society. This booklet is also a product of that project.

The project has depended upon the help of a great many people—giving interviews, providing documentary materials, and reviewing drafts. The members of the Signal Processing Society's Ad-Hoc Committee for the History Project should be thanked by name: David C. Munson, Jr. (Chair), Dan E. Dudgeon, Tariq S. Durrani, Don E. Johnson, and H. Joel Trussell. Most of the former Society Presidents contributed, and, of these, Leo Beranek, William W. Lang, James L. Flanagan, Lawrence R. Rabiner, and Charles M. Rader gave oral-history interviews. Others who contributed interviews were Maurice Bellanger, James Cooley, Alfred Fettweis, Ben Gold, Thomas S. Huang, Fumitada Itakura, Thomas Kailath, James Kaiser, Bede Liu, Sanjit Mitra, Hans Georg Musmann, Alan Oppenheim, Enders Robinson, Manfred Schroeder, Hans Wilhelm Schuessler, Stan White, and Bernard Widrow. The professional staff of the Society, headed by Mercy Kowalczyk, gave invaluable assistance. Many others gave informal interviews, answered questions, offered advice, and helped in other ways.

This publication is dedicated to the thousands of volunteers, over a fifty-year period, who have contributed time, energy, ideas, and enthusiasm to nurturing an organization devoted to advancing the signal processing profession.

Frederik Nebeker
IEEE History Center

Any social institution is what its members make it! If its members do not care, if they let "the others" worry, let "the others" be the fools to work—then that institution, however great it might appear at the moment, is *doomed;* it will crumble and disappear. If, on the other hand, there are enough members who *actively* support the institution, who freely devote time and effort to its tasks and obligations, who share in the belief of a common goal and of common interests in higher achievements, then that institution will grow strong and prosper.

—Ernst Weber, first president of the IEEE (*Proceedings of the IRE,* vol. 39, 1951, p. 595)

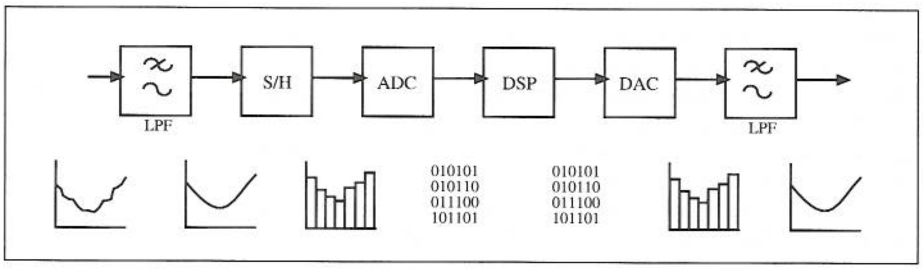
IEEE Signal Processing Society Meritorious Service Award

1970	Robert H. Rose II
1972	William Chapman and Frederick Van Veen
1973	Henry S. McDonald
1974	John J. Earshen
1975	William Chapman
1976	Lawrence Rabiner and Charles F. Teacher
1977	Howard D. Helms
1978	James F. Kaiser
1979	James Cooley and N. Rex Dixon
1980	Harvey Silverman and Charles F. Teacher
1981	Rao Yarlagadda
1982	Maurice Bellanger and Claude Gueguen
1983	Charles Rader
1984	William E. Collins
1985	Ronald Crochiere and N. Rex Dixon
1986	Jont B. Allen
1987	Hiroya Fujisaki
1988	Mos Kaveh
1989	John W. Woods
1990	Delores M. Etter
1991	Maureen P. Quirk
1992	John G. Ackenhusen
1993	Thomas H. Crystal
1994	David C. Munson, Jr.
1995	Panos Papamichalis
1996	James R. Deller
1997	Alan C. Bovik

What is Signal Processing?

Signal processing is an immense and diverse field. It is also a field that did not exist 50 years ago and one that remains mysterious, or quite unknown, to most people. Signal processing is not the transmission of signals, as through telephone wires or by radio waves, but the changes made to signals so as to improve transmission or use of the signals. Among the processes studied and devised by signal-processing engineers are filtering, coding, estimating, detecting, analyzing, recognizing, synthesizing, recording, and reproducing. Though signal processing concerns both analog and digital techniques, the field is increasingly dominated by digital techniques. Indeed, the emergence of digital techniques in the 1960s and 1970s played a large part in creating a community of engineers concerned with signal processing.

At the end of the 20th century, signal processing is a vital technology in many areas: communications, information processing, consumer electronics, control systems, radar and sonar, medical diagnosis, seismology, and scientific instrumentation generally. In addition to the wide range of application areas, there is a wide range of signal-processing tasks. Examples of these tasks are removing echo from telephone lines, scrambling cellular-phone conversations, controlling the suspension of an automobile so that it responds to road conditions, enabling satellite imaging systems to resolve tiny objects on the ground, and making internal organs stand out in CAT scans. That so many issues related to the processing of signals have arisen in recent decades and have assumed such economic importance is a result of the fact—and further confirms it—that ours is an Information Age.



The two rows show a typical signal-processing sequence, the upper row showing the signal-processing tasks and the lower row the signal changes. An analog signal passes through a low-pass filter, which removes all the frequency components of the signal above a certain frequency. The next step produces the staircase waveform: the input signal is sampled at particular points in time, and the sampled value is held constant until the next sampling. Then the heights are quantized, and each height may then be represented as a binary number. Next comes some digital-signal-processing task, such as enhancing certain features of the signal or compressing the information for transmission and de-compressing it after transmission. Then a reverse process recreates an analog waveform: digital-to-analog conversion produces a staircase waveform, which passes through a low-pass filter to remove high-frequency components, thus smoothing the waveform. (Redrawn after Figure 3.55 of Craig Marven and Gillian Ewers, A Simple Approach to Digital Signal Processing (New York: John Wiley & Sons, 1996).)

Signal processing has been one of the success stories of the last 50 years, both in terms of the way academic understanding of the discipline has been furthered and in terms of scientific results that have been converted into products that have changed the way we live.

— *Leonardo Chiariglione (IEEE Signal Processing Magazine, July 1997, p. 33)*

SPS Past President Don Johnson has called signal processing the "stealth technology." All of your friends know what "computing" is: they can touch their PCs and, with CD-ROMs and floppies, they can even touch the once-elusive software. They all know what "communications" is: it used to mean THE PHONE COMPANY, but now includes sizzling words like 'wireless' and cool tangibles like cell phones. But how many of your friends know what signal processing is? It's a key part of innumerable visible accomplishments, ranging from stunning Mars images to voice dialing (albeit audible rather than visible) and from ultrasound images to DVD. However, it often seems that only the people who actually work in signal processing think about who we are and what we do.

— *Leah H. Jamieson (IEEE Signal Processing Magazine, January 1998, p. 8)*

There appears to be general agreement that the year 1948 brought to a close the first phase of the development of PCM ... Perhaps all these contributions were overshadowed by a landmark publication ... [Oliver, Pierce, and Shannon's paper] explained the basic philosophy of PCM in terms of the previous work by Nyquist, but in a more usable form. It lucidly and compellingly presented the case for PCM and, as a result, influenced a generation of communications engineers.

— *Robert W. Lucky (in Sidney Millman, ed., A History of Engineering and Science in the Bell System: Communication Sciences (1925-1980) (1984), p. 412)*

Annus Mirabilis: 1948

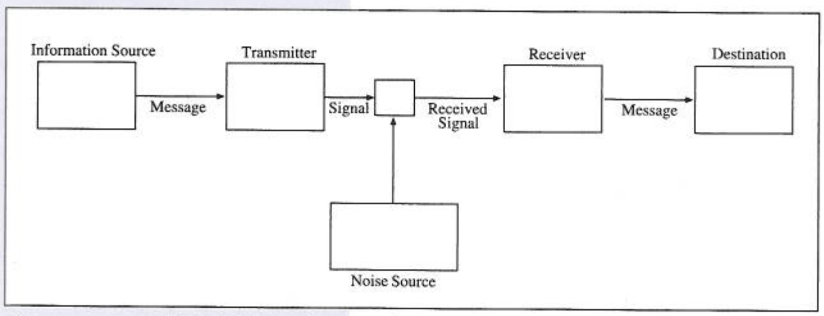
In the history of science the year 1666 is known as Isaac Newton's *annus mirabilis*. In that year that he wrote two papers on mechanics, "On violent Motion" and "The lawes of Motion", and a treatise on the new mathematics he had invented, which he called the method of fluxions and which we know today as calculus. Albert Einstein's *annus mirabilis* was 1905, when he published three classic papers that presented, respectively, the hypothesis of the quantum nature of light, the statistical physics of Brownian motion, and the special theory of relativity.

The year 1948 may be regarded as the *annus mirabilis* in the emergence of the discipline of signal processing. For in that year Claude Shannon published the epoch-making "A mathematical theory of communication"; Bernard Oliver, John Pierce, and Claude Shannon published the classic argument for the use of pulse-code modulation; modern digital methods of spectrum estimation were introduced; error-correcting codes were introduced; audio engineering achieved a new prominence; and the IEEE Signal Processing Society, albeit under a different name, was established. In addition, that year saw a demonstration of the first stored-program computer and the announcement of the invention of the transistor, heralding two new technologies that would later greatly stimulate signal processing.

The year 1948 stands out in any history of technology because it saw the publication of Claude Shannon's "A mathematical theory of communication." Robert Lucky has written, "I know of no greater work of genius in the annals of technological thought." Shannon, a researcher at Bell Telephone Laboratories, analyzed communication as the transmission of a message from a source through a channel to a receiver. He quantified this process, measuring the information source in bits per second, and found limits to the channel capacity. Perhaps the most celebrated result contained in the original paper is the proof that the capacity of a band-limited channel, in bits per second, equals the bandwidth times the logarithm (base 2) of the signal-to-noise ratio plus 1. Shannon, of course, was not alone in creating a discipline of information theory: he was much influenced by a 1928 paper by Ralph V.L. Hartley, beginning where Hartley left off, and by Norbert Wiener, who emphasized the statistical nature of communication. A number of other pioneers of the new discipline, including Dennis Gabor and Philip M. Woodward, made vital contributions.

Another landmark publication of 1948 was "The philosophy of PCM", written by Bernard M. Oliver, John R. Pierce, and Claude Shannon. Pulse-code modulation (PCM) is a means of transmitting information in the form of on-or-off pulses. PCM had been invented by Paul M. Rainey in 1926 and independently by Alan H. Reeves in 1937, but little noticed. Oliver, Pierce, and Shannon were so struck by its advantages that they "expected PCM to sweep the field of communications." This did not happen, even though their article was extremely influential. Over several decades, receiving boosts from the development of integrated-circuit technologies, the proliferation of computers, and the use of optical fiber for communications, PCM did indeed become widespread.

A dominant trend in many areas of technology in the second half of the 20th century has been the replacement of analog methods by digital methods. Besides the Oliver-Pierce-Shannon article, there were other signs of this trend in 1948. Because of the way most radar and sonar systems worked—both radiating and receiving pulses of electromagnetic radiation—many engineers during World War II dealt with discrete data. The work on fire control and other radar systems therefore generated a large literature on sampled-data control systems. One issue faced by radar engineers—and later by engineers in many other fields—was estimating a continuous spectrum, such as the power spectrum of a radar signal, on the basis



Shannon presented this depiction of a general communication system. (Redrawn after Figure 1 from Claude Shannon, "A mathematical theory of communication"(Bell System Technical Journal, vol. 27 (1948), pp. 379-423, 623-656).)

Annus Mirabilis: 1948

The IEEE, with more than 300,000 members in 150 nations, is the world's largest technical society. It is also one of the oldest, having begun as the American Institute of Electrical Engineers (AIEE) in 1884. Its other parent organization, the Institute of Radio Engineers (IRE), was founded in 1912, and the two merged in 1963. Over the last century the IEEE has grown steadily, as has its area of interest—electrical, electronic, and computing technologies. The scope of this interest has necessitated an internal IEEE structure: today 37 IEEE Societies, such as the Computer Society, the Communications Society, and the Power Engineering Society, represent particular areas of technology. The Signal Processing Society has a claim to being the oldest of these, and we may take up its story with the end of World War II.

Electronics, which exploits the passage of electrons through vacuum, gas, or semiconductor, came out of the war a much larger branch of engineering than it entered. Before 1939, radio was by far the largest area of electronics, though electron tubes were used also for long-distance telephony and carrier telephony, for sound movies, in phonographs and public-address systems, and in many instruments. During the war there arose new applications of electronics—such as radar, sonar, and computing—and earlier areas of application—such as communications, electronic navigation, instrumentation, and control systems—expanded enormously. Just after the war, industrial electronics emerged as a major field, and television and FM radio seemed poised for commercial success.

Oliver L. Angevine received a B.S. in electrical engineering from MIT in 1936 and then worked at the Stromberg-Carlson Company until 1951. He later joined a consulting firm that became Angevine Acoustical Consultants. Between 1989 and 1994 he did extensive work on the active cancellation of the hum of large transformers. In 1949 Angevine served as Chairman of the newly formed IRE Professional Group on Audio.

The burgeoning of electronics affected the American Institute of Electrical Engineers. Most of its members worked in electric power, industry applications, wired communications, or instrumentation, and these and the other fields of electrical engineering came increasingly to involve electronics. Indeed, by 1963, when the AIEE and the IRE merged, half of AIEE members were concerned with electronics.

The burgeoning of electronics affected the Institute of Radio Engineers even more. As its name suggests, it had a narrower focus than the AIEE. (It differed from the AIEE also in that, from its inception, it aimed to be a transnational organization, hence there was never an "American Institute of Radio Engineers.") Because it was often radio engineers who pioneered new areas of electronics, it was natural that the IRE represent the new areas. The IRE grew rapidly both in numbers and in technical areas during and after the war, and it became increasingly desirable that there be established groups of members in particular specialties. There had, indeed, already been specialized meetings of IRE engineers, such as of those interested in television.

On 7 October 1947 a committee named by the IRE Board of Directors recommended that "the Institute members belong to technical divisions called 'groups' according to the members' interests." The committee pointed out that radio engineering had grown so vast that engineers necessarily specialized, hence there was a demand for specialization in meetings and publications. It warned that if the IRE did not meet this demand, specialized groups would break off and form their own technical societies, just as the IRE itself was formed 35 years earlier.

The Board of Directors accepted this recommendation on 8 October and asked the committee to formulate detailed plans for what was called the Professional Group System. These plans were presented and approved at the meeting of the Board of Directors on 12 November. A Committee on Professional Groups was set up, and two people, Leo Beranek and Karl Kramer, represented a potential "Audio Group." On 3 February 1948

... I recall ... the Rochester Fall Meeting of the IRE back at the time when Peter Goldmark introduced the LP record. An engineer from Philco, who had had a hand in the design of the first commercial LP record player, was giving a paper on the design of the pick-up. As a demonstration he played the "Phonetic Punctuation" selection from the new Victor Borge record. At the time for questions, the first question was "What was the name of that record?"

— Frank H. Slaymaker (personal communication 25 February 1998)

After much lively discussion [at the meeting on 9 March 1950] it was moved and passed that the Audio Professional Group will treat audio in a professional sense. It was pointed out, however, that the professional interests of the radio engineer dealing with audio are closely related to the avocational interests of the serious hobbyist, and that there would be much of our work which would be both interesting and informative to those for whom audio is an avocation.

— *IRE Professional Group on Audio Newsletter,* no. 2, 9 June 1950, p. 1.

1948 **25 February: Communist coup in Czechoslovakia**

Enders Robinson: I came back to MIT in the fall of 1950, and I was in the Mathematics Department as a graduate research assistant. I was working under Norbert Wiener to find applications for his time-series analysis. As you know, Norbert Wiener was an eminent mathematician at MIT, and he worked in generalized harmonic analysis back in 1930. He always felt that people didn't realize that was probably his most important contribution. But during World War II, he worked on prediction theories for anti-aircraft fire control. He developed a theory—classified at the time—but published by MIT Press in 1949. We used the book when I was an undergraduate student there, so I was familiar with it. By 1950, we were ready to apply it. Meanwhile, Wiener had written another book called *Cybernetics* which was first published about 1948. That book was an instant success; he was the one that introduced the word cybernetics.

So Wiener was a celebrity by 1950, and my research assistantship depended on finding applications of his work. Another MIT mathematics professor, George Wadsworth, my graduate advisor, was working in weather prediction which he originally started during World War II; Wiener's classified book had come out, but it was too difficult mathematically to be applied as such. So Wadsworth asked Norman Levinson, who was another eminent mathematician at MIT, to take Wiener's book and to simplify it into numerical algorithms that he, Wadsworth, could use. Levinson published these papers in the Journal of Marthematics and Physics in 1947. They were added as apendices to Wierner's 1949 book, so Levinson's algorithms with Wierner's theory became the way to do this type of theing. We could then apply it to geophysics because seismic records are essentially noisy records.

of sampled data. In 1948 Maurice Bartlett in England, and the following year John Tukey in the United States, began developing the digital methods of spectrum estimation that have remained in use ever since.

One advantage of digital signals was made clear in 1948 by Richard W. Hamming's invention of error-correcting codes. Hamming proposed encoding a message in blocks of binary digits, with each block satisfying certain algebraic equations, so that if an error occurred in transmission (a **0** converted into a **1** or vice versa) the recipient could not only detect this, but also correct the error.

In June 1948 Bell Telephone Laboratories announced the invention of the transistor, a solid-state amplifying device. Even as a discrete component, its small size and low power requirements would in the 1950s and 1960s expand the realm of signal processing, and this effect was magnified manyfold when it later became possible to incorporate huge numbers of transistors on a single chip of silicon.

In 1948 there was a milestone in computer history also: on 21 June 1948 a small prototype computer, built at Manchester University, became the first operational stored-program electronic computer. Full-size stored-program computers were under construction in many places—the EDSAC by Maurice Wilkes at Cambridge University, the BINAC by Presper Eckert and John Mauchly at the University of Pennsylvania, John von Neumann's computer at the Institute for Advanced Study in Princeton, and others—but, as with the transistor, several years would pass before computers attained commercial success. Computers, too, would over the next decades have enormous influence on the development of signal processing.

Largely because of the impetus gained during World War II, communication and control engineering have reached a very high level of development today. Many perhaps do not realize that the present age is ready for a significant turn in the development toward far greater heights than we have ever anticipated.

— Norbert Wiener (Extrapolation, Interpolation, and Smoothing of Stationary Time Series With Engineering Applications (1949), p. v)

In this photograph Peter Goldmark demonstrates data compression: the small stack of LPs in the center contains the same music as the two large stacks of 78-rpm records. (CBS photo reproduced by permission.)

One of the biggest stories of the year was the commercial release of the new long-playing (LP) record. In September Peter Goldmark, head of CBS Laboratories, presented a paper to the Institute of Radio Engineers on "The Columbia Long-Playing Microgroove Recording System." In 1934 radio and phonograph salesmen had begun using the term 'high fidelity.' Though not defined precisely, it meant greater faithfulness in the sound coming from the radio or phonograph to the original sound. In the 1930s, however, it was little more than an advertising slogan, and there was even the belief among manufacturers that most people preferred the mellow sound and low fidelity of existing sets to the sharp sound of higher fidelity.

Many music enthusiasts, however, did not accept the quality of sound available from the radios and phonographs they could purchase and began experimenting with putting together their own sound systems. Some of them were amateur radio operators, and some of them had worked with communications, radar, or other electronics for the military in the war. They found that by judiciously combining amplifiers, pickups, turntables, receivers, speakers, and other components purchased from radio supply houses, whose supplies were augmented by surplus military equipment, they could achieve a much better sound. It was in 1947 and 1948 that this hi-fi movement began. What had been a hobby of a relatively small number of people at the end of World War II soon produced a multimillion-dollar component manufacturing business, with annual sales in the U.S. reaching $140 million in 1954.

Leo L. Beranek received a B.A. from Cornell College, Iowa in 1936. From then until 1946 he was associated with Harvard University, where he received an M.Sc. and a D.Sc. and became director of the Electro-Acoustics Laboratory and of the Systems Research Laboratory. In 1948 he co-founded the consulting firm of Bolt Beranek and Newman. The same year Beranek worked with a number of other engineers to establish the IRE Professional Group on Audio, and he served as Chairman from 1949 to 1951. From 1989 to 1994 he was President of the American Academy of Arts and Sciences.

the IRE Executive Committee changed the name of this potential Group to "Audio, Video, and Acoustic Group" and added Oliver L. Angevine to the Committee.

The Institute began publicizing the new Group System, and the IRE Executive Committee soon received its first petition for the formation of a Group. This was for the Audio Group (which had gone back to its original name), and on 2 June 1948 the Executive Committee approved the petition. It called for the establishment of a Group "concerned especially with the technology of communication at audio frequencies and with the audio frequency portion of radio systems."

The IRE Professional Group on Audio served as a model for Groups in other fields. In late 1949 there were already seven other Professional Groups: Antennas and Propagation, Broadcast and Television Receivers, Broadcast Transmission Systems, Circuit Theory, Nuclear Science, Quality Control, and Vehicular and Railroad Radio Communications. The Groups were given a large measure of autonomy, as they were authorized to organize sessions at IRE conferences and to hold their own meetings and conferences. The Groups published newsletters, occasional papers, and, before long, their own transactions.

At a meeting of the organizing committee of the Group on Audio on 7 March 1949, Oliver Angevine was named Chairman, though later that year, because of a change in his business, he resigned, and Leo Beranek became Chairman. In early 1950, for the first time, a Chairman was elected through a polling of members, and Beranek was elected.

The first activities of the Group were to organize sessions at conferences. In 1950 the Group began publishing a newsletter; it appeared four times in 1950 and began bimonthly publication the next year. On occasion, the Group also mailed technical papers to its members. The Professional Group encouraged the formation of local subsections; in early 1950 it was reported that in Boston an average of 250 members attended the monthly meetings, in Milwaukee an average of 150 members. Thus, in just a year and a half from the circulation of a petition for its formation, the IRE Professional Group on Audio was a vigorous organization acting at both national and local levels.

What was happening in 1948

movies people were watching:

- *Hamlet* with Laurence Olivier
- Walter Huston's *Treasure of the Sierra Madre*

TV shows people were watching:

- "Hopalong Cassidy"—the first of the TV Westerns, it began in 1948
- "The Howdy Doody Show"
- "Meet the Press"

music people were listening to:

- songs of Bing Crosby and Frank Sinatra

books people were reading:

- Alfred Kinsey's *Sexual Behavior of the Human Male*
- Norman Mailer's *The Naked and the Dead*
- B.F. Skinner's *Walden Two*

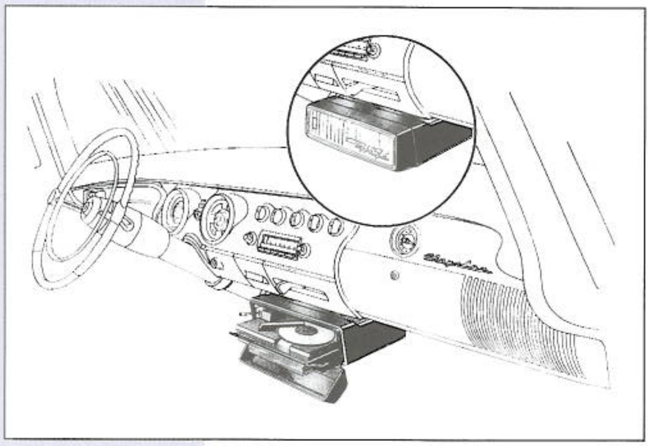
Leo Beranek: The audio group felt that loudspeakers and microphones and recording were related to radio. At least it was a branch of the radio work. They certainly had to have, in all radio broadcasting, loudspeakers and microphones. Recording was maybe more related to the movies, but it was moving into also being important in the broadcasting studios. So broadcasting belonged to radio. It didn't belong to electrical engineering. At that time, it was radio engineering.

O.L. Angevine was with the Stromberg-Carlson Company. Angevine was very interested in the audio problem. I went to MIT in February of 1947 after the war and became a tenured professor there. I stayed at Harvard until 1947 in February on their faculty. And we were in communication with Angevine. We had our own section we'd set up. We called it the Audio Section. It was a Section of the Institute of Radio Engineers, and its main interest was audio. Angevine was interested in this out at Stromberg-Carlson. We communicated with each other, and we decided to communicate with the staff. We learned that there was talk going on already about the groups. They had appointed in October 7th, 1947 R.A. Heising as chairman of a planning committee, and he said that there were already six specialized meetings of radio engineers going on, mainly in broadcast engineering.

Our feeling was, in Cambridge at least, that audio was important enough in broadcasting that there at least ought to be activity in the field so that broadcast engineers could keep up to date. We didn't feel that IRE ought to drop that field and let it all go to the Acoustical Society, which was the only other one—there was no Audio Engineering Society then. We felt that this was an important thing to do, to keep our own members informed and to keep them active in the audio field. Well, at almost the same time the Audio Engineering Society was formed. The Audio Engineering Society decided to take over recording as their big thing, and in the process they took over broadcasting, really the audio part of broadcasting—the studios and the microphones and whatever they needed audio-wise, such as control panels and so on. So it turned out then that audio had a short life, really just until it became obvious that what was important was signal processing, and then that gradually took over.

Halcyon Days for Audio Engineering: The 1950s

Popular enthusiasm for higher quality sound made the 1950s an exciting time to be an audio engineer. Those concerned with disk recording made improvements associated with the new LPs and 45s, such as better recording, mastering, and processing techniques and a new lower-force pickup. Though accurate measurement of the features and performance of phonograph systems began in the 1920s, it was not until the mid 1950s that the industry adopted standardized tests of recording characteristics, making it easier for engineers to communicate and for listeners to judge the relative merits of different phonograph sets or components.


The Goldmark car phonograph was available in all 1956 cars manufactured by the Chrysler Corporation. (Chrysler Corporation image reproduced by permission.)

Two other areas of work by phonograph engineers in the 1950s were dictating machines and car phonographs. Phonograph recording for office dictation was a successful, and continually improved, technology from the late 19th century—Edison saw it as one of the most important uses of his invention—through the 1950s. Peter Goldmark and CBS Laboratories developed an automobile phonograph system in 1955 that was available in all 1956 Chrysler Corporation cars. There was, however, little public interest, which Goldmark attributed to apathetic marketing by Columbia and Chrysler. For this application, as with office dictation, a different technology—magnetic recording—came to the fore in the 1950s.

Magnetic recording, too, was part of the hi-fi movement. Ampex began to sell tape recorders in about 1948—these were, of course, reel-to-reel recorders—and went on to dominate the U.S. market. In 1954, when the difficulties of mass-producing them had been solved, pre-recorded tapes began to be sold, though they did not approach LPs in sales.

Continuing work on loudspeakers included efforts to achieve smoother frequency-response characteristics, more uniform directional patterns, lower nonlinear distortion, and superior response to transients. In the 1950s and 1960s the design of loudspeaker enclosures was put on a firm theoretical foundation; Leo Beranek's *Acoustics*, published in 1954, was a landmark. For public-address systems, there were new techniques to achieve desired directional patterns from individual loudspeakers and from loudspeaker arrays.

Hans Schuessler: The structures that you use for simulating transfer functions on an analog computer are precisely the same as you use for digital signal processing. The difference is that in the case of an analog computer you have just an integrator as the basic element. In DSP you have the delay element. In addition you need multipliers. In an analog case it's just a potentiometer; in the other case, it is a multiplier, a digital multiplier. The summation is done just with the integrated circuit—the integrator—it can be done easily: the structure is just the same. All the structures we have, we know for example the cascade structures, things like that, can be done and have been done, and I did it, back in the late '50s with analog means.

... [I used] the analog computer just to play with the potentiometers, shifting the poles and zeros around and looking at the impulse responses; and we found finally, as a hypothesis, that the minimum will be achieved if the frequency response in the stopband is of Chebyshev behavior, and the impulse response in the time domain dies out in a Chebyshev way as well. Somewhat like this.

Interviewer: Empirically determined?

Schuessler: Empirically. We could not prove it, but we found very good results just by playing with the analog computer. Again this hypothesis—not more—was a starting point for designing filters of this type on the digital computer.

Interviewer: Why did you move to a digital computer?

Schuessler: Well, finding let's say hundreds of examples just by playing around is one possibility, but it's not satisfying. In this case we have just the general rule, and developing the program to do that under certain constraints is by far better. And later on we have been told that these circuits—we published the results—have been really used in practice, which is somehow satisfying.

Halcyon Days for Audio Engineering: The 1950s

The 1950s saw the height of the hi-fi movement, and audio engineering made many advances. Stereo records were introduced in 1957. Tape recorders were sold in large numbers, and pre-recorded tapes began to be sold in 1954. Loudspeakers and microphones—including directional and wireless microphones—were improved. And there were important advances in speech-communication systems: telephony, radio broadcasting, public-address systems, and bandwidth-conserving systems.

These were all matters of interest to the Professional Group on Audio (PGA). It grew substantially in the 1950s, from 1126 members in 1950 to 4551 members in 1960. In this decade the electronics industry as a whole saw spectacular growth, and this was reflected in the growth of the IRE, whose membership tripled in the 1950s, reaching 90,000. The main activities of the Group on Audio remained publishing and organizing meetings and conference sessions.

In the first years the Group had two forms of publication: the newsletter and technical papers that were occasionally sent to members. Each paper had a cover page entitled 'Transactions of the IRE Professional Group on Audio.' In addition, the Group worked to place important papers in the *IRE Proceedings*, which appeared monthly. In March 1952 the newsletter and the occasional 'Transactions' were combined in a bimonthly publication. The following year this publication, adopting a format already in use by other IRE Professional Groups, became the *IRE Transactions on Audio*. Through this publication many papers on audio and electroacoustics achieved a worldwide distribution.

The *IRE Transactions* in the various technical fields met an important need in the 1950s as many new branches of electronics grew rapidly. By mid decade more pages were published annually in the various *IRE Transactions* that in the *IRE Proceedings*, and the latter assumed a new character, with many review articles and with many issues devoted to a single topic.

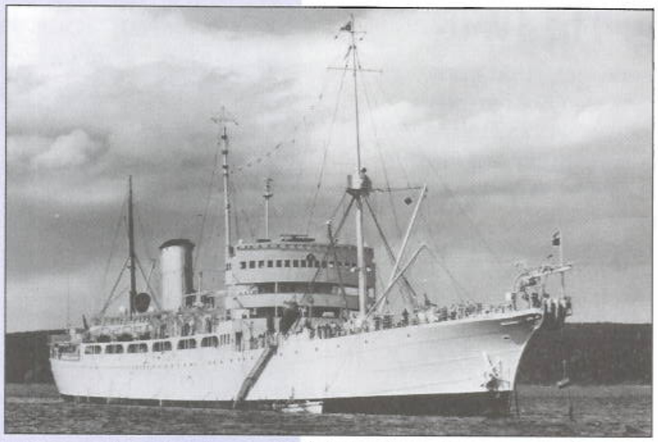
As befitted a Group concerned with magnetic recording, the PGA tried, in the early 1950s, a new form of publication in the distribution of tape-recorded talks. It was expected that many Sections and Chapters would want to present the recorded lectures at their meetings. The PGA formed a Tapescripts Committee (initially called the Recorded Papers Committee) "to act as a clearing house in the preparation and distribution of recorded papers." In 1954 nine recorded lectures were made available, and these were presented a total of 50 times. Some of these talks became multimedia presentations—this at a time before the word 'multimedia' existed. At a 1954 meeting of the Atlanta PGA Chapter, accompanying slides were shown while the tape recording was played. Those attending greatly approved of the performance, and thereafter the Tapescripts Committee provided slides with a number of the recorded lectures. By the end of the decade, however, interest in recorded talks had flagged.

The Group continued to organize sessions at professional meetings. For example, at the 1951 IRE National Convention there were two sessions on audio. One of the papers described an early example of automatic signal-analysis. This was a "speech silencer for radio receivers", which switched off the radio speaker after one or two syllables of speech and reactivated it when the speech stopped. One could thus listen to music without hearing commercials, except perhaps "singing commercials." The first PGA-sponsored session at a conference outside the United States was one at the Radio Fall Meeting held in Toronto in October 1951. In mid decade the Group was every year organizing a session for the major IRE conference on the West Coast (WESCON), a session at the National Electronics Conference in Chicago, and two or more sessions for the IRE National Convention in New York.

The Group was headed by a Chairman, elected each year by mail ballot. Leo Beranek was Chairman until mid 1951. The other chairmen who served during the decade are pictured.

Much of the work of the Group was carried out through committees. Though the list of committees changed almost every year, we may take the 1954 list as representa-

... I have tried to understand how the human auditory system works; Helmholtz's proposal that the ear behaves like a filter bank and Von Bekesy's experiments that verified this concept were great beacons for me.
— *Ben Gold, The Institute, June 1997, p. 13.*


The transatlantic telephone cable, laid by ship as shown, was put into operation in 1956. (Bell Labs photo reproduced by permission.)

In 1954 the Regency Company, using components made by Texas Instruments, manufactured the first transistor radio. Though pocket-sized, its performance was poor and its price was high ($49.95). In 1957 Sony (which until that year bore the name Tokyo Telecommunications Engineering Company) introduced a transistor radio (the TR-63) that set a new standard and attracted dozens of imitators. Soon, helped by the proliferation of all-rock radio stations, transistor radios became an essential part of the youth culture. Sony's transistor radios also helped establish a market for personal electronics, devices meant for a single user.

At about the same time as the introduction of the transistor radio came the celebration of the first transatlantic telephone cable. Though telegraph cables across the Atlantic date back to 1858, the necessity for telephony of using repeaters (that is, amplifiers) and the difficulty in designing ones that would work under water for a long period of time meant that until 1956 the only way to transmit a telephone signal from the United States to Europe was by radio.

So valuable were the undersea telephone channels that engineers devised a system,

James Flanagan: My thesis was on an automatic formant tracker which involved building a real-time spectrum analyzer. This was essentially a custom designed filter bank to do the spectrum analysis, an electromechanical scanner that would convert the spectral envelope into signals that could be analyzed, and then an electronic logic set that would attempt to identify the resonant peaks in that spectrum. Part of the thesis was then to evaluate how well that formant tracker did and how well one could synthesize speech from that information.

Interviewer: Was this actually built?

Flanagan: Yes, over about a 3-year period. It ended up being all vacuum tubes. This was before integrated circuits obviously, even before transistors. It must have been about four, or maybe five, 6-foot relay racks of electronic equipment, with lots of heat generated.

Interviewer: You said you started to drift into speech. Can you tell me about how that happened?

Ben Gold: Yes, I was interested in problems of this sort. I was 16 when I went to see the New York World's Fair. At the fair they had an exhibit of the Voder. It was fascinating. Here was a machine that kind of spoke. Not very well, but it spoke. I was more interested in some of the other things. There was an exhibit where if you won a lottery you could make a long distance call to anybody in the country through the Bell System, and everyone could listen in. I got a real kick out of that, but that didn't lead to anything later. The Voder, on the other hand, I always remembered.

Enders Robinson: So Professor Hurley obtained eight seismic records, like this one, so that I actually had the data in the fall of 1950 …. The first step was for me to hand-digitize these eight records by putting a T-square down with a scale and reading off the traces point-by-point, putting them in numerical form.

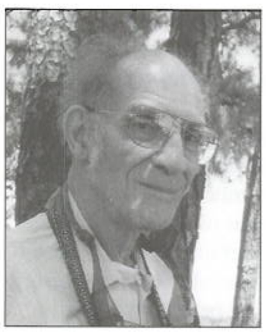
Interviewer: You probably had a pretty modest sample rate!

Robinson: Yes … it took a couple of days to do a record. And then you'd have to check to make sure.

Bernard Widrow: First of all, there was no field of digital signal processing at the time. There was no name for this stuff. We called it sampled data systems. There just was no formal structure of that type, and the field just wasn't established. The number of computers that existed in the whole world at that time you can practically count on the fingers of one hand. Actually it wasn't quite like that. MIT had a computer—it was an IBM. Today you would call it sort of a mainframe. I think it was an IBM 701, and it had a magnetic core memory in it, and it was just like a jewel.

Benjamin B. Bauer received the B.S. degree from Pratt Institute in Brooklyn in 1932 and the E.E. degree from the University of Cincinnati in 1937. In 1936 he joined Shure Brothers, manufacturers of electroacoustical devices in Evanston, Illinois; he became chief engineer in 1940 and vice president in 1950. In 1957 he joined CBS Laboratories in Stamford, Connecticut, where he became vice president in charge of audio, acoustics, and magnetics research. Bauer served as Chairman of the Professional Group on Audio from 1951 to 1952.

Marvin Camras earned B.Sc. and M.Sc. degrees from the Illinois Institute of Technology (earlier known as the Armour Institute of Technology). For most of his career he was researcher at the Armour Research Foundation and professor at the Illinois Institute of Technology. He is widely regarded as one of the most important developers of magnetic recording. From 1953 to 1954 he was chairman of the Professional Group on Audio; he served the Group also as editor of the Transactions from 1958 to 1963.



Vincent Salmon received a Ph.D. in theoretical physics from MIT in 1938. From 1939 to 1949 he worked at the Jensen Manufacturing Company in Chicago, where he was in charge of research and development. In 1949 he accepted a position at the Stanford Research Institute, where he worked until 1971. In that year he co-founded Industrial Health, Inc. From 1954 to 1955 he was chairman of the Professional Group on Audio.

Winston E. Kock received E.E. and M.S. degrees from the University of Cincinnati in 1932 and 1933 respectively, and a Ph.D. from the University of Berlin in 1935. From 1942 to 1956 he worked at Bell Labs, where he became Director of Acoustics Research. In 1956 he became chief scientist for the Bendix corporation. Kock served as Chairman of the Professional Group on Audio from 1955 to 1956.

Unfortunately, not enough young engineers are entering this field. Acoustics can hardly hold its own in attracting young men against the competition of atomic energy, computers, solid state devices and other disciplines which lately have become the subject of spectacular publicity. One of the important tasks confronting the PGA, in my opinion, is expansion of its activities among students for the purpose of encouragement and motivation of those with adequate mental and emotional equipment to enter the world of sound.

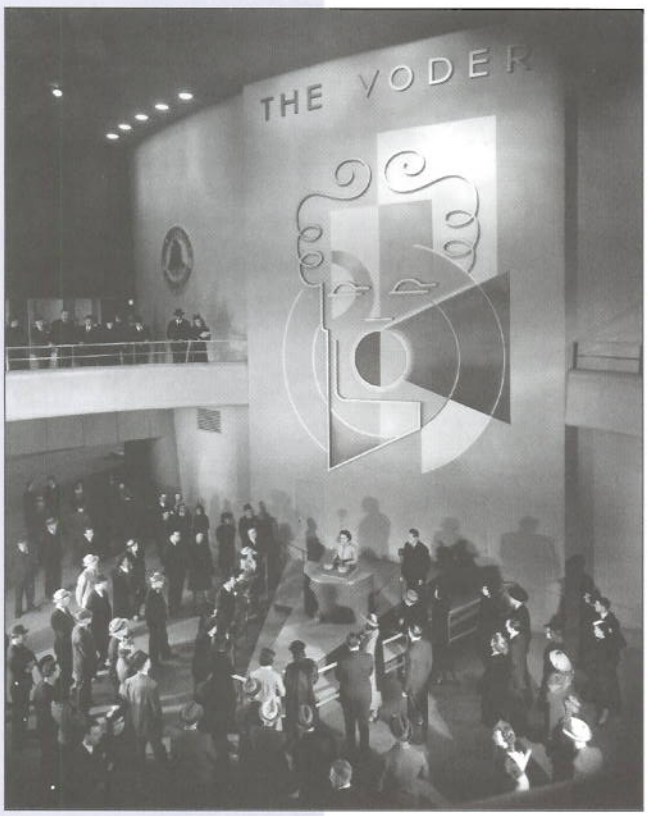
— Benjamin B. Bauer, *IRE Transactions on Audio,* vol. 3 (1955), p. 88.

1952 **4 November: Dwight Eisenhower elected U.S. President**

called time assignment speech interpolation (TASI), to take advantage of the pauses in speech during a telephone conversation. A person using the telephone talks, on average, less than 40 percent of the time. TASI, using speech detectors and fast electronic switches, could transmit parts of other telephone conversations during the pauses. A signaling and switching system at the receiving end ensured that a listener is always connected to the correct line. Put into service in 1960, TASI doubled the capacity of the cable and may be the first example of a commercial time-division switch.

For the telephone companies the most important way of increasing transmission capacity was the introduction of carrier telephony, or frequency-division multiplexing, which allowed many telephone signals to be sent over the same line, each within a particular bandwidth. The technique made heavy use of electron tubes, as oscillators, modulators, demodulators, and amplifiers. Also vital were wave filters, that is, circuits that passed only the frequencies within a specified range. Since these methods were standard in radio engineering, carrier telephony illustrates a general historical trend toward convergence of techniques of wire and wireless communications.

Karl Willy Wagner in Germany and George A. Campbell in the United States helped establish a theory of wave filters. The subject received great impetus from the work of Wilhelm Cauer, Sidney Darlington, and others. Cauer's 1926 dissertation on *The Realization of Impedances of Specified Frequency Dependence* was a landmark contribution to the systematic understanding of electrical filters.



At the 1939 New York World's Fair a speech synthesizer, the Voder, was demonstrated. It used hardware conceptually similar to the vocoder synthesizer, but the Voder was a human-controlled synthesizer. The operator worked at a keyboard, with a wrist bar to control the voicing parameter and a pedal for pitch control. (Bell Labs photo reproduced by permission.)

AT&T introduced carrier systems as early as 1918 and 1920, but the first system to be widely adopted was introduced in 1924. On a single pair of wires, three 2-way voice channels were carried at frequencies above the voice frequencies (in the 5 to 30 kHz range), thus quadrupling capacity. Continued improvements to carrier systems were made possible by the negative-feedback amplifier and by new electron tubes for use with higher frequencies (to 100 MHz and above). Coaxial cable, with much greater bandwidth, and, in the 1950s, microwave relay systems permitted carrier systems of higher capacity, such as the L-3 system bearing 1800 voice channels in one circuit.

A different approach to increasing transmission capacity was that taken by Homer Dudley at Bell Labs in the 1930s. He reasoned that speech is formed by modulating, with slowly changing vocal resonances, the sound produced by vocal sources, either the vocal cords or the turbulent airflow at constrictions in the vocal tract. The source could be characterized as either aperiodic (unvoiced sounds) or periodic (voiced sounds), and if it is periodic its frequency could be measured. The modulations of the speech spectrum could be measured by the relative energy in contiguous filter bands. This information might then be transmitted and the speech reconstituted at the receiver. The analysis-synthesis system, called the "vocoder", could achieve speech transmission with a 300-Hz bandwidth, while a traditional telephone channel required a bandwidth of 3000 Hz.

In the improvement of communications, as well as the audio technologies discussed earlier, electroacoustics played an important part. A science of electroacoustics requires the ability to measure the performance of transducers, amplifiers, and filters, both steady-state and transient response. A basic tool, the sound-level meter, was improved in the 1950s through the use of transistors and rugged condenser-microphones. Engineers specified protocols for measuring the characteristics of microphones and loudspeakers, such as directivity vs. frequency, linearity vs. level, and power-available efficiency vs. frequency.

1952 6 November: explosion by the U.S. of a hydrogen bomb

Daniel W. Martin received an A.B. degree from Georgetown College and M.S. and Ph.D. degrees from the University of Illinois. He then worked as an acoustical engineer for RCA Manufacturing Company from 1941 to 1949, when he joined the Baldwin Company in Cincinnati. He served as Chairman of the IRE Professional Group on Audio from 1956 to 1957.

Harry F. Olson attended the University of Iowa, where he received the B.E. degree in 1924, the M.S. degree in 1925, and the Ph.D. degree in 1928. Olson joined the Radio Corporation of America in 1928 and became head of the RCA Acoustical and Electromechanical Research Laboratory in Princeton, New Jersey. From 1957 to 1958 Olson was Chairman of the IRE Professional Group on Audio.

Frank H. Slaymaker earned the B.S. degree and later the E.E. degree from the University of Nebraska. He joined the Stromberg-Carlson Company in 1941, where he long remained, most of the time in the Research Department. His work, resulting in many publications and patents, concerned noise-reducing microphones, electronic carillons, ultrasonic transducers, and other topics. From 1958 to 1959 he was chairman of the Professional Group on Audio.

Alexander B. Bereskin earned the B.S. and M.S. degrees from the University of Cincinnati. He worked with the Commonwealth Manufacturing Company and the Cincinnati Gas and Electric Company before returning to the University of Cincinnati as Professor of Electrical Engineering. Much of his research concerned audio and video amplifiers. Bereskin served as Chairman of the Professional Group on Audio from 1959 to 1960.

Those of us who have served the PGA in various ways—as members of committees, as officers, or as participants in technical sessions—have found it to be a stimulating and rewarding experience. I especially treasure the friendships and the comradeship developed in this association as one of the important values beyond the measure of any conventional yardstick. In a very real sense I can say that the Professional Group on Audio has done much more for me than I have done for it.

— Benjamin B. Bauer, *IRE Transactions on Audio*, vol. 3 (1955), p. 88.

Accidentally, during the early 1940's, we discovered something .... We were monitoring a wire recording as it was being made, with a pickup head spaced a fraction of a second after the recording head. If the announcer wore the monitoring headphones, he immediately became speechless. ... One could beat the machine by blurting out brief phrases intermittently, with a pause after each burst to collect one's thoughts, or by speaking very slowly. ... There are differences among individuals in the degree of confusion or frustration generated by delayed listening. Women are less susceptible than men, which supports the theory that some of the more voluble talkers never got into the habit of listening even to themselves.

— Marvin Camras, *IRE Transactions on Audio*, vol. 7 (1959), p. 89.

ALICE was greeted by a courteous sales-technician as she entered the high-fidelity auditioning room. The courteous sales-technician nodded his head wisely and began his story. "In ancient times," he explained, "people used one loudspeaker and all the sound seemed to come from a hole in the wall. Now we call it monophony, which suggests such things as monogamy, monotony, monopoly, *et cetera*."

He continued, "Now I'd like to have you hear stereophonic sound with two loudspeakers." He pressed a button and a loud version of "Gaite Parisienne" issued from two speakers, one on each side of the room.

"Why must it be so loud?" exclaimed Alice.

"I've often wondered myself," said the courteous sales-technician. "Maybe that's what hi-fi means—that the volume must be high. It depends a lot on whether you are a demonstrator or a demonstratee. The demonstrators like it loud, and since they are the ones who own the set, it's usually played loud."

"You'll notice that the orchestra is now spread over the entire wall of the room," he went on.

To Alice, everything seemed to come mainly from one loudspeaker—the closer one. She wondered whether she would hurt the attendant's feelings by telling him. After all, he was so courteous. Finally she told him.

"I'm glad you mentioned it," he said, "You are supposed to stand on an imaginary line equally distant from both speakers."

— Marvin Camras, *IRE Transactions on Audio*, vol. 7 (1959), pp. 137-138.

A valuable application of electroacoustic transduction was the electronic artificial larynx developed in 1959 at Bell Labs and marketed by Western Electric; when pressed against the throat it supplied sound similar to that of the vocal cords.

Also related to electroacoustics are underwater acoustics and the design of sonar systems. In the first world war, hydrophones, or underwater microphones, were much used as a means of detecting submarines. To determine the direction of a sound, arrays of hydrophones were used, and they were steered either mechanically (repositioning the array) or—an early example of beamforming—electrically (using electrical compensators to introduce delays in the different hydrophone channels). Some hydrophones were equipped with electrical filters to improve the signal-to-noise ratio. The early systems were analog, but in 1960 V.C. Anderson showed how to steer a hydrophone array using digital shift registers to introduce the desired delays.

Radar was another area where digital signal processing was used in this period. One U.S. radar system, known as SAGE (Semi-Automatic Ground Environment), developed in the 1950s, did much to stimulate the development of both computer and communications technologies. When completed in 1963, SAGE consisted of 23 interconnected direction centers, each fed by the radar data from some hundred stations. All together there were 1.5 million miles of communications lines, and data were transferred in digital form. For this purpose, MIT and Bell Labs engineers developed the first high-speed modems (modulator-demodulators for sending digital signals over the analog telephone-lines), which were capable of transmitting 1600 bits per second. Related to the work on SAGE was the introduction in 1958 by AT&T of the Dataphone system, the first commercial modems specifically for transmitting computer data over phone lines.

Both sonar and radar involve processing weak signals in the presence of considerable noise, a challenge that occurs in many other areas as well, such as biomedical imaging and space communications. During World War II a number of people contributed to a mathematical theory of signals and noise, notably Norbert Wiener and Steven O. Rice. In 1950 James Lawson and George Uhlenbeck published the influential *Threshold Signals*, which discussed the relationship between the receiver filter and the output signal-to-noise ratio and gave a procedure for approximating the optimum filter.

Analysis of seismic data, like analysis of radar data, stimulated the development both of computing technology and signal-processing techniques. Texas Instruments, originally a manufacturer of seismic instruments used in petroleum exploration, began in 1956 to design a digital computer for processing seismic data. Signal-processing technique was advanced by, among others, Enders Robinson. In the early 1950s he showed how to derive the desired reflection signals from seismic data, carrying out one-dimensional deconvolution. The digitization and calculations were carried out by hand on a desk calculator; the deconvolution of 32 traces, each one 600 to 800 readings, took the entire summer of 1951. In the spring of 1952 Robinson and Howard Briscoe programmed the MIT Whirlwind digital computer to do the numerical filtering at high speed. A group at the Raytheon company contracted with MIT to do programming and computation tasks relating to the analysis of seismograms, and in March 1954 Raytheon offered to the industry at large what must have been the first commercial digital-signal-processing service.

At the end of the 1950s there occurred a technological advance that was to have an enormous impact on all of electronics and especially on the field of signal processing. Indeed, it may be argued that it was crucial to the emergence of a recognized field of signal processing. In February 1959 Jack Kilby of Texas Instruments filed a patent for the integrated circuit—a set of electronic components and their interconnections on a single slice of silicon or other semiconductor. Some six months later Robert Noyce and Jean Hoerni at Fairchild Semiconductor demonstrated the so-called planar process by which the components could be economically connected. Up to this time the transistor was not revolutionary: as a discrete component it was comparable in cost and performance with electron tubes. It was through the integrated circuit that the transistor revolutionized technology.

What was happening in the 1950's

movies people were watching:

- *The African Queen* with Humphrey Bogart and Katherine Hepburn
- *Ben-Hur* with Charleton Heston
- *The Bridge on the River Kwai*
- *Rebel Without a Cause* with James Dean

TV shows people were watching:

- "I Love Lucy"
- "Dragnet"
- "Leave It to Beaver"
- Westerns: "Gunsmoke", "Have Gun, Will Travel", "Wagon Train", and many more

music people were listening to:

- Leonard Bernstein's "West Side Story"
- songs of Elvis Presley

books people were reading:

- Norman Vincent Peale's *The Power of Positive Thinking*
- Jack Kerouac's *On the Road*
- J.D. Salinger's *The Catcher in the Rye*

1956 Hungarian revolt against Communist rule

Administrative Committee
Awards Committee
Chapters Committee
Editorial Committee
Finances Committee
Membership Committee
Program Committee
Tapescripts Committee

Classification of Subjects

1. IRE-PGA
   - 1.1 General
   - 1.2 Constitution and By-Laws
   - 1.3 National and Regional Meetings
   - 1.4 Chapters
   - 1.5 Membership
   - 1.6 TRANSACTIONS
   - 1.7 People
2. Bibliographies, Reviews, Standards, Tapescripts
   - 2.1 Bibliographies
   - 2.2 Reviews
   - 2.3 Standards
   - 2.4 Tapescripts
3. Sound Systems
   - 3.1 General
4. Microphones
   - 4.1 General
   - 4.2 Condenser
   - 4.3 Magnetic
   - 4.4 Crystal
   - 4.5 Moving—Coil
   - 4.6 Ribbon
   - 4.9 Special Microphones
5. Amplifiers
   - 5.1 General
   - 5.2 Preamplifiers and Voltage Amplifiers
   - 5.3 Power Amplifiers
   - 5.4 Frequency-Range Dividing Networks
   - 5.9 Special Amplifiers
6. Loudspeakers
   - 6.1 General
   - 6.2 Direct-Radiator Units
   - 6.3 Horn-Driver Units
   - 6.4 Horns, Enclosures, Baffles
   - 6.9 Special Types
7. Disc Recording and Reproduction
   - 7.1 General
   - 7.2 Discs
   - 7.3 Recording
   - 7.4 Pickups and Tone Arms
   - 7.5 Pre-emphasis and Postequalization
   - 7.9 Special Mechanical Recorders
8. Magnetic Recording and Reproduction
   - 8.1 General
   - 8.2 Tape and Wire
   - 8.3 Recording and Erasing
   - 8.4 Playback
   - 8.5 Pre-emphasis and Postequalization
   - 8.9 Special Magnetic Recorders
9. Acoustics
   - 9.1 General
   - 9.2 Room Acoustics
   - 9.3 Sound Waves and Vibrations
   - 9.4 Speech
   - 9.5 Music
   - 9.6 Hearing
10. Broadcast Audio
11. Audio Measuring Equipment and Techniques
12. Electronic Musical Instruments

This classification of subjects was used for the "IRE Professional Group on Audio combined index for 1954." (Reproduced by permission from IRE Transactions on Audio, vol. 2 (1954), p. 176.)

tive. The table shows the seven committees that reported to the Administrative Committee. At the beginning of the decade, to pay for the mailing of the newsletter and technical papers, the Group instituted an annual assessment of $2 for each member.

In the 1950s the interests of the Professional Group gradually expanded beyond particular audio technologies. In 1951 the newly elected Chairman, Benjamin Bauer, wrote, "The goal of the Group is to advance Audio Technology among Radio Engineers as part of the larger field of communications rather than to promote the narrow specialization which is all-too-prevalent today." The technical concerns of the Group in the early 1950s are shown in the figure, which is a classification of subjects used for an index to the IRE Transactions on Audio and the audio portion of the IRE Convention Record.

The audio technologies, such as amplifiers, loudspeakers, and magnetic recording, were the main interests of the Group. As the decade passed, other interests emerged, particularly in electroacoustics, measurement techniques, speech communications, and electronic music. Topics of some *Transactions* papers can suggest the increasing technical range of the Group: an acoustic lens, a wireless microphone, a device to make speech visible, a system for recording and reproducing television signals, impedance matching to transformers and filters, the phasing of microphones, determination of equal-loudness contours, speech bandwidth compression techniques, and the response and approximation of Gaussian filters.

In 1954 the Group instituted an awards program consisting of three annual awards. The highest honor was the IRE-PGA Achievement Award for "outstanding contributions to Audio Technology documented by papers in IRE publications." The table lists the winners of this award to the end of the decade. The two other awards were for outstanding papers that appeared in IRE publications: the IRE-PGA Senior Award could be given to an author of any age, the IRE-PGA Award could be given only to authors less than 30 years old. To encourage young people to pursue research, in 1956 the PGA established an annual Student Papers Competition in Audio. PGA members were also, of course, eligible for IRE Awards, such as the Medal of Honor, the Harry Diamond Memorial Award, the Morris N. Liebmann Memorial Award, and the Vladimir K. Zworykin Award. Peter Goldmark, a PGA member, won both the Liebmann and the Zworykin awards.

Achievement Award	
1954	Benjamin B. Bauer
1955	Harry F. Olson
1956	Henry E. Roys
1957	Marvin Camras
1958	Daniel W. Martin
1959	Alexander B. Bereskin and Peter C. Goldmark

This [the activity of the speech and signal processing people at MIT] was the first really impressive evidence to me of the importance of the FFT.

— *James Cooley ("How the FFT gained acceptance", IEEE Signal Processing Magazine, vol. 9 (1992), no. 1, pp. 10-13)*

Going Digital: The 1960s

Quite in contrast to the 1950s, the 1960s in the United States were turbulent: the civil rights movement, which had begun a decade earlier, had grown in strength; the anti-war movement escalated even more rapidly than U.S. military involvement in Vietnam; another movement too, the one for women's liberation, aroused great energies and passions; and there were the assassinations of John Kennedy, Robert Kennedy, and Martin Luther King. In Europe as well as the United States, youth were questioning the established order and demanding change or, in the case of the Hippies, "dropping out." Despite a decade of economic growth based in part on technical advances and of individual technological triumphs, such as the IBM 360 computer, the first heart transplants, and the Moon landing, there arose a widespread anti-technology sentiment.

Telephones were much in the news in the 1960s: the use of satellites to relay telephone signals (and a song entitled "Telstar" headed the popular music charts for three weeks in 1962); the introduction, and the storm of opposition to, All Number Calling (ending the use of letters, as in PE(nnsylvania) 6-5000); the "hot line," with a red telephone at each end, between Washington and Moscow, which was put into service in 1963; and the introduction the same year of Touch-Tone phones (which used a pair of tones rather than a sequence of pulses to signal a digit of a telephone number). A small cult, the "phone phreaks," became fascinated with telephone technology, and in the next decade many of them moved on to computing as a hobby. And in 1970 both overseas direct-dialing and Picture-Phone service began.

As we have seen, Bell Labs engineers from the 1920s on had been exploring ways to increase the capacity of the telephone system, and in late 1955 management decided to develop a pulse code modulation (PCM) system. There resulted the so-called T-1 carrier system, which was put into service in 1962 as the world's first common-carrier digital communications system. The speech waveform was sampled 8000 times per second to represent the usual 4000-Hz channel. The amplitude of each sample was described by seven binary digits, using nonlinear quantizing to cover better the wide dynamic range of speech, and an eighth bit was used for signaling. Voice was thus encoded at 64,000 bits per second. The system was designed to allow several conversions from analog to digital to analog, since digital lines would have to work with analog lines.

The Telstar communications satellite was launched in 1962. (Bell Labs photo reproduced by permission.)

Digital transmission speeded the adoption of digital electronic switching, which was introduced in France in 1970, with Platon, a time-division switching system, and in the Bell System in 1976. Indeed, there emerged a synergy of digital communication, digital switching, and computer-aided information processing in the telephone system. Here the unification of technologies reversed a historical trend of divergence between transmission and switching.

A 1968 ruling of the Federal Communications Commission had far-reaching effects. The Bell System had always forbidden direct attachment of non-Bell equipment to the telephone network, arguing that it might damage the network, but in 1968 the FCC ruled

Going Digital: The 1960s

The 1960s was a momentous decade in the history of the Signal Processing Society. There were organizational changes, notably the 1963 merger of the IRE and the AIEE to form the Institute of Electrical and Electronics Engineers (IEEE) and the continuing expansion of the field of interest of the Professional Group on Audio, reflected in its change of name in 1965 to 'Group on Audio and Electroacoustics.' Electronics and computing made great strides, due in part to the development of integrated circuits. Two more specific technological advances had the greatest long-term influence: the discovery of the fast Fourier transform and the realization that it was possible to process signals in the digital domain in much the same way they had been processed in the analog domain.

As already mentioned, electronics in the postwar world ramified into many new engineering specialties, and the Institute of Radio Engineers came to represent engineers in many fields other than radio. At the same time, electronic techniques were rapidly adopted by the traditional branches of electrical engineering, so that at the beginning of the 1960s, as already mentioned, half of the members of the American Institute of Electrical Engineers were concerned with electronics. In the 1950s a great many engineers belonged to both the IRE and the AIEE, and in the case of some technical specialties, such as aerospace applications and computing, there were corresponding entities in the IRE and the AIEE (called Professional Groups in the IRE and Technical Committees in the AIEE). And in a number of ways, the IRE and the AIEE were working together: in 1950 they authorized the formation of joint student branches so that students did not need to join two organizations (and by 1962 there were 130 joint student branches), and in 1952 they formed the Joint AIEE-IRE Coordination Committee to promote cooperation.

There were therefore good reasons for merging the two societies, and this occurred on 1 January 1963 with the formation of the Institute of Electrical and Electronics Engineers. The Professional Group system of the IRE was adopted in its essentials by the IEEE, and thus came into being the IEEE Professional Group on Audio. The expansion of the Group's interests led to a new name in 1965: the Group on Audio and Electroacoustics (G-AE).

Hugh S. Knowles received an A.B. degree from Columbia University in 1927. He worked for a number of companies, including the Jensen Manufacturing Company, where he was chief engineer from 1931 to 1950. From 1936 on he worked also as a consulting engineer. Knowles served as Chairman of the Professional Group on Audio from 1960 to 1961.

Cyril M. Harris received the B.A. and M.A. degrees from the University of California and the Ph.D. degree from MIT. From 1941 to 1945 he did war research at MIT, where he also worked as a teaching fellow. From 1945 to 1951 Harris was a research engineer at Bell Labs, and in 1952 he became a professor at Columbia University. He served as Chairman of the Professional Group on Audio from 1961 to 1962.

Many have characterized the emphasis of this Transactions on digital signal processing as a departure from the traditional grazing grounds of audio and electroacoustics. It may seem so at first glance, but in the light of the likely eventual impact of this exciting new tool, it is more probable that we are simply leapfrogging ahead to stake a solid claim in audio's future.

— Frederick Van Veen, *IEEE Transactions on Audio and Electroacoustics*, vol. 17 (1969), p. 65.

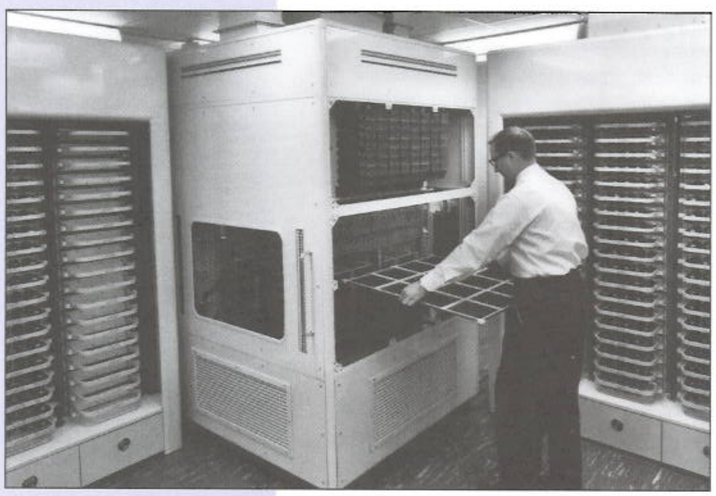
1960 first laser

James Flanagan: I think the whole area of digital signal processing, particularly digital filter design, was driven by the speech processing community. I made a mark here. Roger Golden and I did something called the phase vocoder in 1966. This required simulation of electrical filters. We had some infinite impulse response filters that approximated Bessel characteristics. We hadn't thought about finite impulse response filters very much then—they were developed a bit later—but we used them to good effect. The whole business of having to do filtration of signals, spectral analysis, and algorithmic operations on sampled data, of recognizing what happens when you square a signal or take a square root, or watching what happens to the bandwidth, this all drove the development of digital signal processing at that time. There might have been a parallel in image processing that I do not know about, but speech processing was a research activity that galvanized digital signal techniques.

Ben Gold: After a while we were able to test our own vocoder with our program pitch detector. It was slow: to analyze two seconds of speech took the computer about two minutes, 60 to 1 real time. So here is what we had to do. We had to take the speech down to the computer, run the speech in through the computer, run the pitch detector program, record, make our 2-track recording, and bring it upstairs to where the vocoder was. It was pretty slow. So we kept saying, "Wouldn't it be nice if we could program the vocoder on the computer?" So we went back to Bell Labs, and visited Jim Kaiser. There may have been other people there, but he's the one I remember. He said he knew how to build certain digital filters. That was just what we needed. We said, "My God, this is fantastic." We could actually build digital vocoders.

that people could buy and use the Carterphone, a device to link citizen-band radios and telephones. An important precedent for the Carterphone ruling was the case brought before the FCC in about 1960 by the Hushaphone Company. The Hushaphone was a mechanical device, invented by Leo Beranek, that attached to a telephone handset so that speech could not be overheard by other people in the room. After a lengthy hearing, the FCC ordered the Bell System to permit the use of Hushaphones. These rulings opened the gate to the design, manufacture, and marketing of a whole range of telephone-related equipment, such as modems, answering machines, and office communication systems.

The speed at which modems could operate was limited by the distortion of digital signals during transmission (since the shorter the duration of each bit, the more easily a 0 could be mistaken for a 1 or vice versa). To reduce distortion and thus increase the speed of modems, Robert Lucky, a young engineer at Bell Labs, designed an adaptive equalizer, which adjusted itself automatically to suit the particular call-path established. As a result, modems in the early 1970s could operate at 4800 bits per second (and, on dedicated lines, at 9600 bits per second). A similar advance, also made in the 1960s by Bell Labs engineers, was an adaptive echo canceller.



This is the Lincoln Lab TX-2 computer, which Ben Gold and Charles Rader used to perform numerical simulations of the performance of analog filters. The photograph shows Don Ellis removing one bit-plane from the 64K-word ferrite-core memory. (Lincoln Lab photo reproduced by permission.)

In the T-1 system described above, speech was transmitted at 64 kbps (kilobits per second). An invention made in 1967 by Bishnu Atal and Manfred Schroeder, called adaptive predictive coding or APC, permitted speech transmission of fair quality at just 4.8 kbps. Unlike the T-1 system, which (in digital form) transmitted the actual waveform, APC is, like the vocoder, a parameter-transmitting system: the voice signal is analyzed at the transmitter, parameters derived from this analysis are sent to the receiver, and there the voice signal is synthesized. The trade-off is a great deal of calculation at both transmitter and receiver for a low bit rate.

Carrying further the idea of APC, Atal invented linear predictive coding or LPC. While APC is a waveform synthesis technique used as a

Robert W. Benson received the B.S.E.E., M.S.E.E., and Ph.D. degrees from Washington University in St. Louis. From 1948 to 1954 he was a researcher at the Central Institute for the Deaf in St. Louis and from 1954 to 1960 at the Armour Research Foundation in Chicago. In 1960 Benson joined the faculty of Vanderbilt University. He served as Chairman of the Professional Group on Audio from 1962 to 1963.

Frank A. Comerci earned the B.S.E.E. degree from Newark College of Engineering in 1943, and from 1943 to 1946 he served the U.S. Army as Communications Officer, installing and maintaining cryptographic speech communications systems. In 1946 he joined Rangertone Corporation where he worked on the design of a magnetic tape recorder. In 1947 he began work at the Navy Material Laboratory in Brooklyn, where he headed the Acoustics and Communications Section from 1950 to 1959. Afterwards he worked at Audio Devices, Inc., in Glenbrook, Connecticut and then at the Magnetics Branch of Columbia Broadcasting System Laboratories in Stamford, Connecticut. Comerci served as Chair of the Group on Audio from 1963 to 1964.

William M. Ihde received the B.S. and M.S. degrees in electrical engineering from MIT in 1948. While in graduate school he studied under Leo Beranek, who was his thesis adviser. Ihde joined the General Radio Company in 1948 and in 1955 became manager of the Mid West District Office in Chicago for that company. He served the Group on Audio in many capacities, including as Chairman from 1964 to 1965.

Iden M. Kerney attended Harvard University, where he received a B.S. degree in communications engineering in 1923. From 1923 to 1934 he was employed by the Department of Development and Research of AT&T and from 1934 until his retirement in 1963 by Bell Labs. An active member of IRE and IEEE, Kerney served as Chair of the Group on Audio and Electroacoustics from 1965 to 1966.

Alan Oppenheim: ... I also remember that around the time I graduated I was talking to Tom Stockham, and I said, "It's kind of depressing that nobody is picking up on this stuff" and Tom said, "It's not depressing. Actually what's great is that we have this all to ourselves for a while until other people really discover it."

The FFT has probably been the most widely used tool in signal processing and its development in the mid-60's really started the DSP revolution.

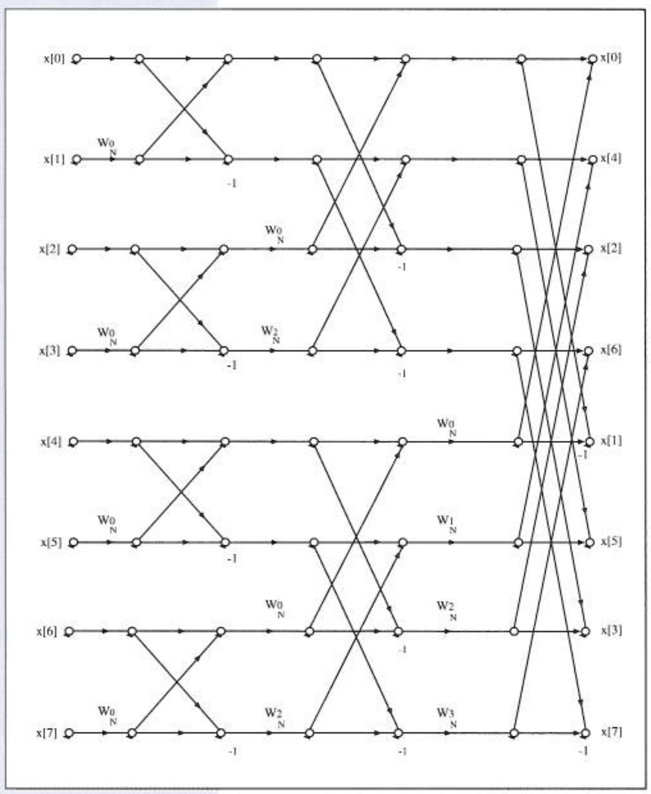
— *Gene Frantz and Panos Papamichalis ("Introduction to DSP solutions," Texas Instruments Technical Journal, vol. 13 (1996), no. 2, pp. 5-16)*

speech coder, LPC is a general method of speech analysis, which can be used for speech compression, speech recognition, speech synthesis, and other purposes. LPC, in a variety of forms, came to be widely used. In Japan at about the same time and independently, Fumitada Itakura and Shuzo Saito invented maximum likelihood analysis, and Itakura developed the PARCOR (partial correlation) method, which is essentially identical with LPC.

A great deal of calculation was required not only for the implementation of LPC and other coding schemes, but also for the research leading to such schemes. It was not just a coincidence that this happened in the 1960s, the decade in which computer technology became widely available. It became usual for universities and large businesses to have computers, and much more powerful ones, such as the IBM 360 introduced in 1964, became available. Perhaps even more important for advances in engineering were the so-called minicomputers, such as Digital Equipment Corporation's PDP-8, which first appeared in the 1960s. These machines had the speed of mainframes (though a shorter word-length), but were smaller and much less expensive. This permitted an epoch-making change: for the first time ever, many researchers could have their own computers.

At the forefront in the use of computers in research was MIT's Lincoln Laboratory, itself the site of much computer development. In 1962 or 1963 Ben Gold and Charles Rader, using Lincoln Lab's TX-2 computer, began to simulate the performance of wave (band-pass) filters numerically. Before then, a wave filter, such as might be used in a vocoder, was built from wires and components in order to be tested. At this stage, Gold and Rader thought of the computer only as a tool to speed up the design process for a device that would be implemented in analog hardware.

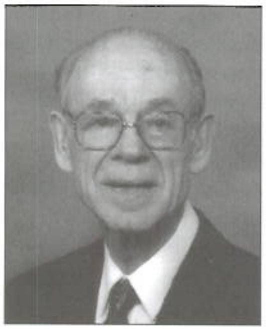
The 1960s was a time when numerical simulation was coming into use in many areas of science and engineering. Not only Gold and Rader, but others in the speech research community made early use of computers. For example, in 1964 A. Michael Noll used computer simulation to show that John Tukey's concept of the cepstrum (the Fourier transform of the logarithm of the amplitude spectrum) was well suited to solving the problem of pitch-extraction in a vocoder, and James L. Flanagan's classic *Speech Analysis: Synthesis and Perception*, published in 1965, describes many computer simulations. This was part of a general trend toward calculational approaches to science and engineering problems, especially numerical experimentation, which is the study of phenomena or systems by numerical simulation rather than by observation or manipulation of physical systems.



This is the structure of a 2-point, radix-2, decimation-in-frequency fast Fourier transform. (Redrawn after Figure 7 of Gene Frantz and Panos Papamichalis, "Introduction to DSP solutions" (Texas Instruments Technical Journal, vol. 13 (1996), no. 2, pp. 5-16).)

Thomas Huang: [In about 1960] image processing was so primitive then that we [the Image Processing Group at MIT, headed by Bill Schreiber] had to be concerned with equipment as well. We had to build our own scanner for digitizing images and reproducing them. We built one of the first image scanners in our lab using a CRT. I was using a Lincoln Lab prototype computer called the TX-0, probably the first transistorized computer. I had to program in assembly language. After digitizing each image we had to store the data on paper tape with punched holes. We fed that into the computer and then had to write the result on paper tape again. I remember an image of just 240 x 240 pixels took three rolls of tape.

1962 at MIT the Spacewar! computer game introduced



Donald E. Brinkerhoff earned B.S.E.E. and M.S.E.E. degrees from Purdue University. During World War II, after completing the Army Officers Electronics School at Harvard University and the MIT Radar School, he worked as an instructor in the M.I.T. Radar School. In 1945 he joined Delco Radio Division of General Motors; in 1952 became head of Acoustical Engineering and in 1962 Supervisor of Audio Systems Development. Brinkerhoff served on the Group's Administrative Committee through much of the 1960s and as President from 1966 to 1967.

William W. Lang received the B.S. degree from Iowa State University, the S.M. from MIT, and the Ph.D. from Iowa State. From 1949 to 1958 Lang worked for Bolt Beranek and Newman, as an instructor for the U.S. Naval Academy, and as a consultant for DuPont. He joined IBM in 1958, where he became head of the Acoustics Laboratory in Poughkeepsie, New York. He has played a major role in the development of international standards for environmental noise. Lang served as Chair of the Group on Audio and Electroacoustics from 1967 through 1968.

James L. Flanagan earned the B.S. degree from Mississippi State University. At MIT, where he studied under Leo Beranek, Dick Bolt, and Ken Stevens in the Acoustics Laboratory, he received the S.M. and Sc.D. degrees. Flanagan worked for 33 years at Bell Telephone Laboratories, where he headed the Speech and Auditory Research Department from 1961 to 1967 and the Acoustics Research Department from 1967 to 1985, when he became a Director of Research. After retiring from Bell Labs in 1990, Flanagan joined the faculty of Rutgers University, where he is Vice President for Research and Director of the Center for Computers Aids for Industrial Productivity. Flanagan was Chair of the Group on Audio and Electroacoustics in 1969 and 1970.

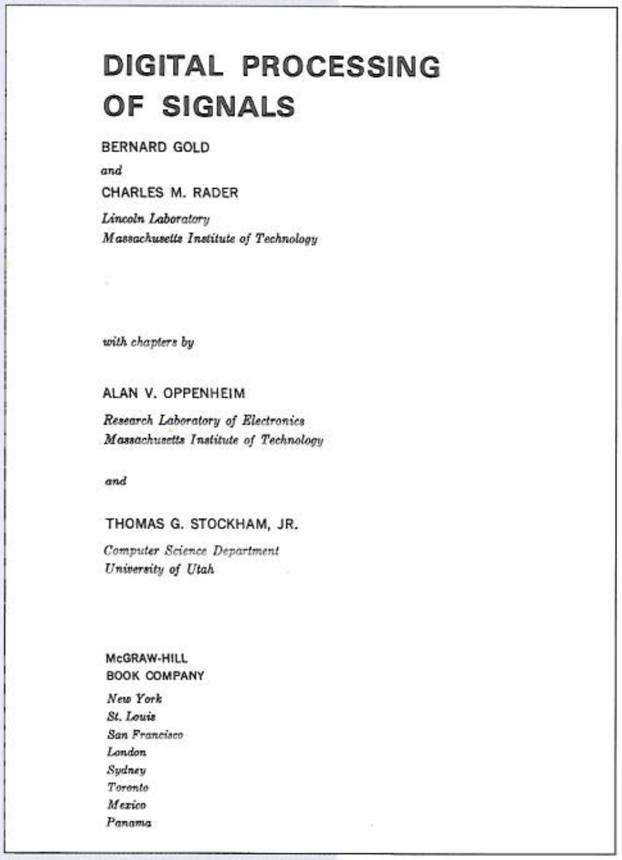
The organizational structure of the Group at the time of the merger was similar to what it had been a decade earlier, with six committees in addition to the Administrative Committee.

In September 1965 the editorship of the *Transactions* was put on a professional basis (as had occurred earlier with other *IEEE Transactions*), and Frederick Van Veen took over from Peter Tappan. This change brought with it an increase in the size of the *Transactions*, from 151 pages in 1965 to 546 pages in 1968. The increased publication costs were in large part responsible for an increase in G-AE dues, from $2 to $5 annually. The *Transactions*, since it included timely and G-AE information, also served as a newsletter. In 1967, however, the Group resumed publication of a separate newsletter.

Administrative Committee

Awards Committee
Chapters Committee
Constitution and Bylaws Committee
Editorial Committee
Finance Committee
Program Committee

The Group underwent momentous changes in scope in the 1960s because of two factors. First, the traditional fields of audio and electroacoustics were languishing within the IEEE, with most of the growth occurring in the Audio Engineering Society. Second, a completely new field of research, called digital signal processing, was emerging, but it



DIGITAL PROCESSING OF SIGNALS

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and
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with chapters by

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McGRAW-HILL
BOOK COMPANY
New York
St. Louis
San Francisco
London
Sydney
Toronto
Mexico
Panama

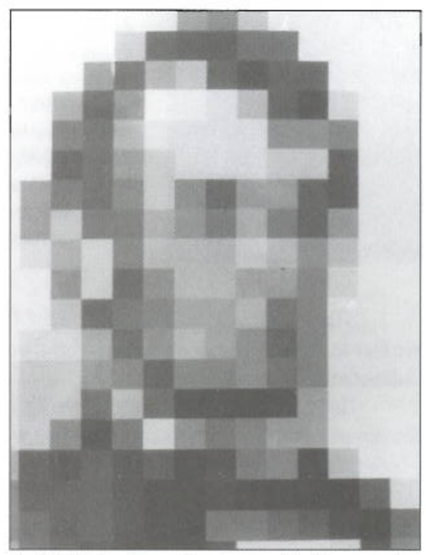
This is the title page of Gold and Rader's Digital Processing of Signals (1969), which was the first textbook on digital signal processing. (Reproduced by permission of McGraw Hill.)

As computers became widely used for simulation in the 1960s, there arose the idea, in a number of places, that the signal processing itself might be done by computer. As early as 1961 a computer was built specifically for digital signal processing. This was the TI187 transistorized computer built by Texas Instruments for analyzing seismic data, though not in real time. At Lincoln Lab, Gold and Rader used a computer as a vocoder, but the computer needed 10 seconds to process 1 second of speech. Also in the early 1960s, James Kaiser and R.M. Golden at Bell Labs began work to transfer "the extensive continuous filter art of the electrical engineer" from the analog to the digital domain.

Though 'filter' originally meant a device to select certain frequencies or ranges of frequencies from a signal, 'digital filter' soon acquired a very general definition: "a discrete time system which operates on an input sequence to produce an output sequence according to some computational algorithm." There emerged a field of digital-filter theory, which drew on the extensive earlier work done in classic circuit theory, numerical analysis, and more recently sampled-data systems. In the United States, James Kaiser, Enders Robinson, Sven Treitel, Ken Steiglitz, Ben Gold, Charles Rader, Alan Oppenheim, Lawrence Rabiner, and Thomas Stockham did important work in the 1960s. In Europe, Hans Wilhelm Schuessler, Anthony Constantinides, Vito Cappellini, and Fausto Pellandini were among the early contributors to digital-filter theory.

The rapid advances in computing technology in the 1960s promised to make this theory of practical importance. Mass production of integrated circuits began in 1962, when Fairchild and Texas Instruments sold a few thousand logic chips, and the capabilities of ICs grew rapidly.

Also in the mid 1960s, the discovery of a particular algorithm, the fast Fourier transform or FFT, incited a great deal more activity. The Fourier transform, named after the French mathematician Jean Baptiste Joseph, Baron de Fourier (1768-1830), is a mathematical procedure to convert a time-domain signal into a frequency-domain signal. It has been extensively used by communication engineers in studying noise, by physicists in solving partial differential equations, and by statisticians in studying statistical distributions. It can simplify the mathematics, and it also often makes the phenomenon of interest easier to understand.



At Bell Labs, Leon Harmon studied how much visual information is required for recognition of faces; his quantized portrait of Abraham Lincoln (with only 756 bits of information) became a popular image. (Bell Labs photo reproduced by permission.)

The straightforward calculation of a discrete Fourier transform of N points requires $4N^2$ multiplications. In 1965 James Cooley and John Tukey showed how to do the calculation with just $2N \log_2 N$ multiplications. Thus, even for a thousand-point transformation, the FFT reduces the calculation required by a factor of 200, and for larger sample sizes the reduction factor is much greater. Rabiner writes "... the algorithm remained a mathe-

1963 **the 7-bit American Standard Code for Information Interchange (ASCII) developed**

had no effective home within the IEEE where it could be nurtured and grown. Thanks to the foresight of William Lang, James Flanagan, and Reg Kaenel, and some members of the G-AE Subcommittee on Measurement Concepts (notably Charles Rader, James Kaiser, David Bergland, Kenneth Steiglitz, and Howard Helms), the G-AE energetically sought to become the home group for the emerging field of digital signal processing, as well as for the associated areas of speech and audio processing.

In order to achieve this goal, the Group leaders took several steps. They created a Technical Committee on Digital Signal Processing and invited leaders in the field to join. They set up a series of workshops on digital signal processing. They created a Technical Committee on Speech Communication and held special meetings on speech processing. They sponsored an influential session on DSP-based spectral analysis at the 1967 meeting of the Acoustical Society of America. And they promoted publications on DSP and speech processing in the *Transactions*.

A number of technical accomplishments stimulated the rapid growth of DSP and speech processing. First and foremost was the rediscovery of the fast Fourier transform (FFT) in 1965. There was the publication of key papers on digital filtering by James Kaiser and by Ben Gold and Charles Rader. There was the invention, independently by John Stockham and Howard Helms, of fast convolution, which firmly linked the FFT and methods of digital filtering and convolution. There was the discovery, independently by Bishnu Atal and Fumitada Itakura, of the technique of linear predictive coding. Each of these technical achievements revealed new horizons and contributed to the signal processing revolution of the following decades.

The biggest boost to the new field was the rediscovery, in the mid 1960s, of a particular algorithm, the fast Fourier transform (FFT). Engineers needed to learn about the new possibilities. William Lang and other G-AE leaders seized the opportunity, and the Audio and Electroacoustics Group, through workshops, conferences, and publications, came to play a central role in popularizing the FFT.

In the spring of 1966 the Group co-sponsored a special workshop on the FFT and spectral analysis, and in 1967 papers from this workshop were part of a special issue of the G-AE *Transactions*, which included a classic tutorial paper on the FFT written by members of the G-AE Subcommittee on Measurement Concepts. In 1968 the Group organized the first of the so-called Arden House Workshops; a hundred researchers exchanged ideas about the FFT, and many of the papers were published in a special issue of the G-AE *Transactions* in 1969. James Cooley has written of the Arden House Workshops, "These were unique in several respects. One was that they included people from many different disciplines .... Another thing that was unique was that work was really done. People got together to formulate and work out solutions to problems."

One of the reasons G-AE members were quick to adopt the FFT was its value in measuring the power spectra of stochastic processes, which was a concern of the G-AE Standards Committee. Since 1960 that committee had worked to improve practices for measuring power spectra of short-duration signals.

In the March 1970 issue of the *Transactions*, the editor Frederick Van Veen wrote the following:

> A Guest Editorial written by Bruce Bogert for our June 1967 issue began, "I suspect that one of the last places one might look for a discussion of digital frequency analysis would be in the *IEEE Transactions on Audio and Electroacoustics*." That milestone issue (our first special on the Fast Fourier Transform) was followed in

William Lang: Signal processing was spread over various different areas within the now IEEE, and so there was no real home for this great development [the FFT] that was coming down the pike. In '66, the logical home for this would have been the Acoustical Society of America, which basically covers all aspects of the science of sound.

... We held the meeting in Boston. It was a special half day session, and it was so popular that there were people—I can remember this—sitting on the floor in the auditorium. The auditorium was too small, and probably 150 people crammed into a space that would hold 100 comfortably. This was the first recognition that something that was really hot was coming. But the Acoustical Society was really not terribly interested, because this Society is basically an academic society.

... At that time the Group on Audio and Electroacoustics was struggling, and I mean struggling, because it inherited the background from the PGA. They didn't have much in the way of a publication, didn't have much of a program, and had no meeting of their own. The only meetings that they held were the IEEE international conventions which were usually held in New York once a year. The Group on Audio and Electroacoustics would sponsor a couple sessions at the international convention, and that was it.

Well, it turned out that we had an opportunity to go to Arden House. You've gotten the story, I think, of the Arden House workshops. The Group on Audio and Electroacoustics sponsored the first and second, and I guess there was a third, workshops on Fast Fourier Transform and Signal Processing. It is well documented in the IEEE transactions. I wasn't the editor, and I wasn't directly responsible, but I think this is what saved the Group on Audio and Electroacoustics from disappearing. I think that it was so weak in the mid-'60s that when it took over from the PGA it really wasn't going to last very long.

Technical Committees

- Audio Frequency Noise
- Digital Signal Processing
- Electroacoustic Transducers
- Speech Communication and Sensory Aids
- Underwater Acoustics

Try to imagine the signal processing profession without the FFT. Not easy is it? ... In a little more than N log N time, the FFT has helped to create a group of specialists who, without it, might be, for example, electrical engineers who actually knew something about electricity. To help spawn an entire field of engineering: Now that's hyper!

— *Jack Deller (IEEE Signal Processing Magazine, vol. 9 (1992), no. 1, p. 6)*

matical curiosity to most electrical engineers until an engineering interpretation was given to the procedure by Charlie Rader and Tom Stockham .... [They] constructed a Mason flow graph interpretation of the FFT from which a wide variety of the properties of the FFT, including bit reversal, in-place computation, twiddle factors, N $\log_2$N operation count, decomposition ideas etc., became clear."

In the 1960s the public was eager for photographs from space: as early as 1959 the Soviet Luna 1 had transmitted back a photograph of the previously unseen far side of the moon; in 1966 the U.S. Surveyor 1 soft-landed on the moon and sent back high-quality photographs of the Ocean of Storms; and later in 1966 the U.S. Lunar Orbiter 1 attracted even greater attention with photographs of the far side of the moon and of the earth from beyond the moon. In 1969 the public marveled at live television of the first steps onto the moon and at detailed pictures telemetered from Mars. These and other ventures into space posed great challenges for image coding, transmission, and reconstruction.

In science, imaging technology was advancing rapidly. Computerized tomography or CT scanning (reconstructing a 2- or 3-dimensional image of an object from the data from projections through the object) moved from conception to a practical device in 1971. One of the pioneers of CT scanning, Ronald Bracewell, helped develop another new imaging technology in the late 1960s: very-long-baseline interferometry for high-resolution astronomy and geodesy.

Radar imaging was improved by the application of signal-processing concepts; a milestone in this field was Fred E. Nathanson's 1969 book *Radar Design Principles: Signal Processing and the Environment*. Digital filters played a part in analyzing the reflected radar signals from Venus in the early 1960s. To process data from a pulse Doppler radar, Herbert Groginsky and George Works designed and built a hardwired FFT signal processor in 1969.

James Kaiser: That got me very interested in signal processing. Now, at the time I arrived at Bell Laboratories [ca. 1960], a change in the means of doing research in the speech area, in the coding area, was underway. Instead of the old way, which was to test an idea about a new way to do things by designing the electronics that embodied that idea and then running tests on that physical embodiment, we were starting to simulate the system—a compression system, an encoding system, whatever—on the general purpose digital computer. Then we would just run a test of the new idea, taking speech and running that through the simulated system and listening to the result. It was much faster and more versatile.

So I got much more interested in how you took continuous systems and got the discrete models necessary for the simulation. With my control background, I knew continuous systems and filter design quite well, and I tried to carry over some of the same ideas to the discrete world. A lot of it carries over as far as the recursive filters are concerned. These design techniques carry over directly via the different transform techniques, the Z transform, the bilinear Z transform, the matched Z transform, and so forth. But one feature of the digital systems is that it's very easy to build finite impulse response digital filters, whereas these are very difficult to build as continuous filters.

Bede Liu: With floating point arithmetics—without getting into detail—the errors are introduced through a slightly different mechanism. Well, the same mechanism, but in a different way, which makes the analysis very hard. Irwin Sandberg presented a very good paper at the Allerton Conference which pointed out the problem and ways to handle it. The approach he took was a deterministic approach. I guess you can call it classical error-analysis, or the numerical analysis approach.

I found it very interesting. I came back and talked to Toyohisa Kaneko [a graduate student] and said the proper way to look at the problem is through statistical probability. I said, "This is a very interesting paper, but the underlying problem is one of many, many small errors being introduced, and we should be able to analyze the problem using this probabilistic model." We talked about this for a little while, and a few days later Kaneko said, "Yes, everything carries through fine." So we wrote it up and sent the abstract to Allerton again for the '68 conference. One week before the conference he came in and he said, "No, it didn't work." Sure enough, it did not work; we overlooked something. We quickly tried to do a lot of things, and finally I was able to find a way to analyze the problem, which actually made the problem much more interesting. It got the result out. And that's my first work on digital filters.

September 1968 by a special issue on digital filters, a second special issue on FFT in June 1969, and many papers on digital signal processing scattered throughout the issues of the past three years. Today, this journal is one of the *first* places one would look for material on digital signal processing. Two more special issues scheduled for June and December will further establish our claim on this territory.

Achievement Award

1960 William B. Snow
1961 J. Ross Macdonald
1962 John K. Hilliard
1963 Donald F. Eldridge
1964 C. Dennis Mee
1965 Hermon Hosmer Scott
1966 no recipient
1967 Daniel von Recklinghausen
1968 Murlan S. Corrington
1969 Hugh S. Knowles

Van Veen goes on to say that digital signal processing became the province of the Group through the determined, relentless effort of a few leaders: "The driving force was unquestionably past G-AE Chairman Dr. William Lang, and accessories before and after the fact were Drs. James Flanagan and Reg Kaenel, our present Chairman and Vice Chairman [and others too]."

Following the Arden House Workshop, a Digital Signal Processing Technical Committee was established. This committee included most of the prominent researchers in the DSP field, including David Bergland, James Cooley, Howard Helms, Leland Jackson, James Kaiser, Alan Oppenheim, Larry Rabiner, Charles Rader, Ronald Schafer, Harvey Silverman, Ken Steiglitz, and Clifford Weinstein. It assumed responsibility for the subsequent Arden House Workshops, for workshops and sessions at other meetings, for a project to standardize terminology, for reviewing papers, and for various publications. Some of these activities, which were extremely influential, are described in the next chapter.

Even before the FFT-related activities, the field of interest of the Group was changing. In 1961 the PGA amended its constitution by adopting a revised statement of field of interest (Article 3, Section 1):

> The Field of Interest of the Group shall be the technology of communications at audio frequencies and of the audio-frequency portion of radio-frequency systems, including the acoustic terminations and room acoustics of such systems, and the recording and reproduction from recordings and shall include scientific, technical, industrial or other activities that contribute to this field, or utilize the techniques or products of this field, subject, as the art develops, to additions, subtractions, or other modifications directed or approved by the IRE Committee on Professional Groups.

The previous statement of field of interest was simply "recording and reproduction from recordings at audio frequencies." The new statement took account of the fact that recording, even when done for audio signals, was often at high frequency, and it also made room for the technical areas of speech communications and electroacoustics.

There were two organizations outside IEEE whose interests overlapped with those of the G-AE: the Acoustical Society of America and the Audio Engineering Society. The former was concerned principally with the science of acoustics (including electroacoustics), the latter with practical audio systems.

Bede Liu: Around that time, the Cooley-Tukey paper was published. There's really no inherent reason why digital filters and FFT should be tied together, no more than a lot of fields should be tied together. But a lot of people who were interested in FFT were also interested in digital filters. So after Cooley and Tukey's paper, a bunch of people organized a workshop called Arden House. I think that the push to publicize DSP really owes a lot to this group of people.

Alan Oppenheim: So Arden House was a happening, you know. There was tremendous excitement. The people who were there really sensed that there was something magic that was happening, and that it was an opportunity. In some sense, we had a tiger by the tail. There's another piece to it. Do you know how often there is the feeling that with the good ideas you have mined you've got to be really careful about what you say, because other people may run with it. So you have to be very protective. The spirit at Arden House was: "There is a gold mine here. There is more than enough for everybody! If I give away my five good ideas this morning, I'll have another five good ideas tonight, so I'm not worried about that." The excitement, the synergy, the spirit of collaboration, that was all really very, very strong at Arden House. And of course that kind of thing builds on itself. So there was definitely the feeling that something was really going on, and there was also the sense—it was clear with the Audio and Electroacoustics Group and the Digital Signal Processing Committee—that there was a tremendous amount of work to be done and that we all had to roll up our sleeves and put our shoulder to the wheel.

The field of signal processing was, even in the 1960s, wider still. There were studies of sound propagation in the ocean and of hydrophone arrays. Digital filters were used with missile data. A wide range of applications, often involving statistical, nonstationary, and multichannel data, served to broaden the range of theory and techniques brought into the field of signal processing. For example, Wiener filtering theory was extended to solve problems in missile tracking and guidance and in signal detection with radar, sonar, and multipath communications. Another example is the extension of Kalman filter theory for handling large or growing amounts of data in control systems and signal-detection systems; in these and other areas time-variant filters were needed. Closed-form solutions often had to give way to recursive numerical (computer-based) algorithms and time-variant implementations.

Hans Georg Musmann: During that time I worked on my thesis [in the early 1960s], I also built up a small computer with transistors — I had to connect the transistors of course by hand! I wanted to learn how computers work and operate. So, together with a colleague, I built up a small computer which could be operated by voice.

Interviewer: How was that done? Did you have any voice recognition techniques?

Musmann: Well, to a certain extent. I developed a very simple technique in which the voice is split up into frequency bands. Then I sampled the output of the frequency bands and used these patterns to distinguish between ten digits. Some commands, like "add in," or "subtract," or "multiply," and so on, were for operating the computer. …

Interviewer: Why did you choose to use voice input for that device?

Musmann: I thought it would be very nice to have a computer you can operate with voice. That is what you need still today!

Charles Rader: But the major thing is that if you wanted to try something out that involved changing a filter, changing the bandwidths, changing center frequency, etc., you had to build another one. That took a few weeks at best. So speech research, in effect, was being hampered by the need to actually build the hardware to try it out. And one of the thoughts that we had was if we could simulate the vocoder, instead of building it, it would speed the pace of research, because we thought, "Gee, programming things doesn't take any time." Nowadays people understand that that isn't true.

Hans Schuessler: But back in Germany in '64 we published a paper on the calculation of the impulse response of continuous networks by using the z-transformation. And that's just the type of work which has been done more or less at the same time at Bell Labs by Jim Kaiser. At that time they had a by far larger program to simulate continuous systems on a digital computer, calculating the impulse response and all that. But we were following at least the same idea. And what we did was just—you see it here—starting with a cascade connection of differences, we transformed this continuous system of second order or so into a digital one. And then we are in what we call now the IIR domain. And all these things have been done using the z-transformation and we ended up with transfer functions in the z-domain.

Interviewer: Can we talk about how you got involved with adaptive filtering?

Bernard Widrow: … I was thinking of trying to build a machine that would be brain-like, but it was just going to take too long. I'd had to do something that would have some practical value, but I still wanted to work in that field. So I got an idea, going back to sample data systems, of what today we would call a digital filter. A digital filter has parameters, it has coefficients. I got the idea to develop a mechanism that would vary the coefficients from the filter so that the filter could improve itself and become a better filter. In a sense a filter can learn to improve itself by acting as a filter, and I figured out a way to do this. I didn't have a brain, but I had a filter. I did not have a brain learning concepts and learning sophisticated things; I had a filter learning very simple things. But it was learning. It was something we could do even in those days, and it was something practical and something useful and something good for engineering, and that was my business.

What was happening in the 1960s

movies people were watching:
- *The Graduate* with Dustin Hoffman
- James Bond movies
- *Midnight Cowboy*

TV shows people were watching:
- "Twilight Zone"
- "Perry Mason"
- "The Beverly Hillbillies"
- "Mission Impossible"

music people were listening to:
- the Beatles and the Rolling Stones
- Motown
- Simon and Garfunkel's "Mrs. Robinson"

books people were reading:
- Rachel Carson's *Silent Spring*
- Joseph Heller's *Catch-22*
- Harper Lee's *To Kill a Mockingbird*

1967 5 June: start of the Six-Day War in the Near East

At the old World's Fair in Chicago, in 1933, Bell Telephone had an exhibit of speech scrambling set up with the microphone on one side of the room and the loudspeaker on the other side, so that the person at the mike could not hear what came out of the speaker. The procedure was to ask someone in the audience where he was from, and to pronounce the name of the home town into the microphone so as to amaze the spectators with the outcome. However, it was also the practice to refuse to use certain words. Being nosy, I got into a huddle with the Bell crew after the demonstration, and it seems that a few days before there had been a lady from Oshkosh. When Oshkosh was put in, some of the audience snickered, and some of the women blushed (remember this was over 26 years ago). The crew tried it afterwards and Oshkosh always came out ***kiss.

— Edward W. Logan, Jr., *IRE Transactions on Audio*, vol. 8 (1960), p. 1.

Look where you will in any industry and you will find the same lack of vision, the same mental inertia, the same preference for complacent peace over the brain sweat in learning (like old dogs) the new tricks of Progress. The deeper is their entrenchment, the more resistant is their determination to stick with what they have. Like the Colorado River in the Grand Canyon, their vision, if any they have, to far horizons is blocked by the results of their own past energies, and they cannot escape.

— Benjamin Miessner, *IRE Transactions on Audio*, vol. 9 (1961), p. 133.

The Acoustical Society was composed mainly of academics, and for most of them scientific understanding was the goal. G-AE, by contrast, was concerned with technologies, that is, with practical techniques and the scientific understanding of them. Differentiation from the Audio Engineering Society was harder, since the interests of the Audio Engineering Society were those that had been the main ones for the IRE Professional Group on Audio in the 1950s and had remained important to the G-AE in the mid 1960s. The interests of G-AE, however, had become much wider, while the Audio Engineering Society focused on the incremental improvement of particular systems.

The Group came to have greater and greater involvement with the speech processing community. In 1961, for example, it collaborated with the Acoustical Society in organizing a session, consisting of five papers, on speech compression systems. In 1969 there were five technical committees.

In 1965 the IEEE Technical Activities Board (TAB) came into existence with the mission of overseeing all IEEE technical activities above sectional and regional levels. The 35 Professional Technical Groups, now designated simply 'Groups', reported to TAB. The new TAB Chairman, Hendley Blackmon, suggested that the Technical Committees, which dealt mainly with standards, merge with the corresponding Groups, and in August 1965 the Audio and Electroacoustics Committee formally merged with the Audio Group, becoming the Group's Committee on Standards. Just before this occurred, the Group changed its name to Audio and Electroacoustics Group. The Standards Committee, headed at this time by William Lang, continued its vital work of reaching consensus on matters that would facilitate communication among engineers. Its documents, after approval by the IEEE Standards Committee, appeared as standards, test procedures, recommended practices, lists of definitions, or technical reports.

The Group continued to recognize outstanding work through its Achievement Award, renamed the Technical Achievement Award in 1967. Also in 1967 the Group created a special award, the Pioneer in Speech Communication Award, and presented it to Homer Dudley.

In the 1960s the Institute—and with it the Group on Audio and Electroacoustics—became more international. For example, in 1960 the Benelux Section of the IRE held an International Symposium on Data Transmission at Delft, The Netherlands. Concerned with the transmission of information in digital form, the Symposium considered such topics as types of codes, choice of modulation, and the behavior of links and networks under test. In 1967 a group of G-AE members began plans for what became the International Seminar on Digital Processing of Analog Signals, held in March 1970 in Zürich.

Sitting in the next room as I scrawl these words with my goosequill pen … is an old portable record-player, which cost like 60 bucks over 10 years ago and has never bust once. … I would never attempt to compete in the modern record-playing race. You do not simply play a record today. You have to take a two-year course at M.I.T. before they will sell you a really hip modern noise-maker. This machine cannot be bought whole, like an automobile. It must be put together, or other people's children sneer at your children. … Strictly between me and my flux density … I am going to lie down on my wire-wound L-pad and turn on Old Faithful again and play a little scratchy Bing Crosby. Old Faithful may not have much in the way of sound-pressure level characteristics … but it plays in the rain and can hit with men on base.

— Robert C. Ruark, *IRE Transactions on Audio*, vol. 11 (1963), p. 185 (originally published in the *Miami Herald*).

DSP comes of age: The 1970s

> Perhaps more than any other event, the introduction by Texas Instruments of a toy called "Speak-and-Spell" called the attention of the engineering world to synthetic speech. For less than $50 children could be given a toy that used synthesized speech to teach spelling in an entertaining way. I have no idea whether or not children thought that this was a big deal, but we engineers were electrified by what had happened.
>
> — *Robert W. Lucky (Silicon Dreams: Information, Man, and Machine (New York: St. Martin's Press, 1989), p. 213)*

Some historians have seen in the 1970s the beginning of the Third Industrial Revolution. The First Industrial Revolution, characterized by steam power and factory production, began in the late 18th century. The Second Industrial Revolution, characterized by electric power, the internal combustion engine, and telegraph and telephone communications, began in the late 19th century. The defining technology of the Third Industrial Revolution is the computer, particularly the microprocessor. Besides in computer technology itself, there were revolutionary changes in communications, instrumentation, and control systems, and all of these areas became much more important economically.

Many people would remember the 1970s for *détente*, highlighted by trips by President Nixon to China and the Soviet Union in 1972 and the Strategic Arms Limitation Treaty the same year. Even more memorable were the 1972 Watergate break-in (leading to Nixon's resignation in 1974); the 1973 oil embargo by the Arab oil-producing states; and the end of the Vietnam war in 1975.

Engineers may remember new aircraft (such as the Boeing 747, the Airbus, and the Concorde), the first pocket electronic-calculators, the blackout of New York City in 1977, and the beginning of bar codes and electronic scanners in supermarkets. In 1975 came the first personal computer, the Altair 8800, sold in kit form, and an assembled computer, the Apple II, was offered in 1977. In 1975 Sony and JVC began marketing video cassette recorders (JVC in VHS format, Sony in Betamax), and at about the same time Citizens Band radio burst into popularity. The 1970s was the first decade of video games (Pong appeared in 1972), of word processing (on typewriters with the capability of storing text), and of ATMs (automatic teller machines).

In the 1970s consumers began to be aware of digital signal processing. In Japan, the recordings of Nippon Columbia began to be digitally mastered in 1972. The same year in Britain, the BBC began using PCM for high-quality sound distribution for radio and television; and in its studios it began using an 8-track digital audio recorder with error correction. In 1975 Tom Stockham showed how DSP could improve historical recordings of Enrico Caruso, and digitally restored recordings began to appear the following year. In 1978 Texas Instruments introduced a toy called Speak & Spell. It taught a child to spell by pronouncing a word and indicating whether an attempted spelling was correct. Two things made the toy practical: an efficient algorithm for speech synthesis and inexpensive integrated circuits to carry out the algorithm. It contained a speech-synthesis chip, a read-only memory chip, tone generators, noise generators, and variable electrical filters. Speech was recreated, not synthesized de novo; the 165 words the toy could pronounce had been spoken by a human and then encoded by LPC (linear predictive coding) for efficient storage.

The Speak & Spell toy was introduced by Texas Instruments in 1978. (Texas Instruments photo reproduced by permission.)

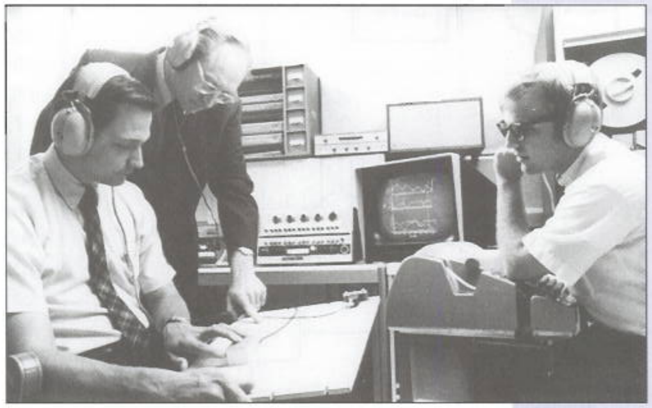
Among the many advances in speech processing during this decade should be mentioned adaptive differential pulse code modulation (ADPCM), suggested by James Flanagan in 1973. The idea was to exploit the fact that a small sample of speech can be predicted fairly accurately from preceding samples: place identical predictors at the transmitter and the receiver, and send only the difference between the actual sample and the prediction. In 1984 ADPCM was adopted as a new standard for encoding speech; it could, in 32 kbps, achieve the same quality of speech as the earlier standard could in 64 kbps. In 1976 Ronald Crochiere, Susan A. Webber, and Flanagan showed that one could achieve moderate savings in digital rate through sub-band coding (SBC), which divided the signal spectrum into bands and adaptively quantized each independently. In 1978 Larry Rabiner and Ron Schafer published the highly influential *Digital Processing of Speech Signals*, which showed how DSP pervaded the field of speech processing.

The use of satellites for telephony increased the need for reducing echo. The older technique, echo suppression, was replaced by echo cancellation, a technique that, instead of attenuating the echo, synthesizes it and sub-

1970 June: Conservatives win British election, Edward Heath becoming Prime Minister

DSP comes of age: The 1970s

The 1970s was a decade of advances in all the areas of interest to the IEEE Group. For speech processing, adaptive differential pulse code modulation, subband coding, and echo cancellation were introduced. The design of digital filters made great advances: transversal filters, multirate filters, filters for image processing, and many others. It was the decade of the first real-time DSP computer and the first use of integrated circuits for signal processing. The decade was an eventful one also for the IEEE Professional Group on Audio and Electroacoustics. Its growth in numbers (from 5299 members in 1970 to 8619 in 1980) was overshadowed by changes in emphasis in its technical areas, reflected in two name changes. By the end of the decade, digital signal processing was the principal concern of most of its members.



This November 1970 image shows (left to right) Ron Schafer, Jim Flanagan, and Larry Rabiner listening to speech synthesized by computer. All three of these people, it may be noted, served in the highest office of the IEEE Group on Audio and Electroacoustics. Flanagan writes, "... the computer in the background is a Honeywell DDP516. This was the first integrated circuits machine that we had in the laboratory. It was a 1MHz 16 bits with memory of 8K words (one-half of which was occupied by the Fortran II compiler). It had a card reader and an ASR33 teletype with 8-bit punched paper tape for input. If I remember correctly, the disk had a capacity of 700K words." (Bell Labs photo reproduced by permission.)

The organization of the Group changed only slightly from the previous decade, notably by the addition of an Advisory Board and of a European Activities Committee.

Administrative Committee
Advisory Board

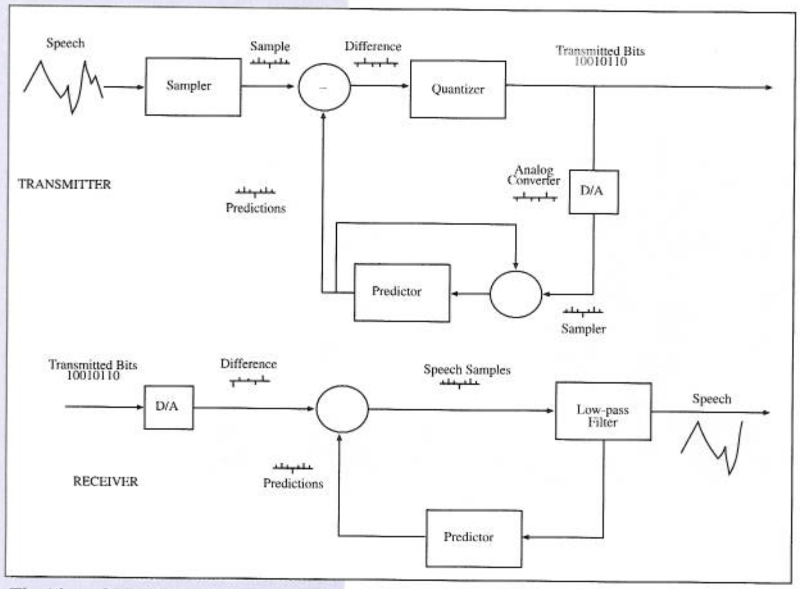
Awards Committee
Chapters Committee
Conferences and Meetings Committee
Constitution and Bylaws Committee
European Activities Committee
Membership Committee
Nominations Committee
Publications Committee

In the late 1960s and early 1970s as the Group vigorously promoted digital signal processing, it concerned itself less and less with audio engineering—in part because of the decline of the U.S. audio industry—and changed its name to the Acoustics, Speech, and Signal Processing Group in 1974. Most members felt that the new name better reflected the range of interests represented by the Group. In part, no doubt, to justify the new name, the February 1974 issue of the *Newsletter* contained the chart shown.

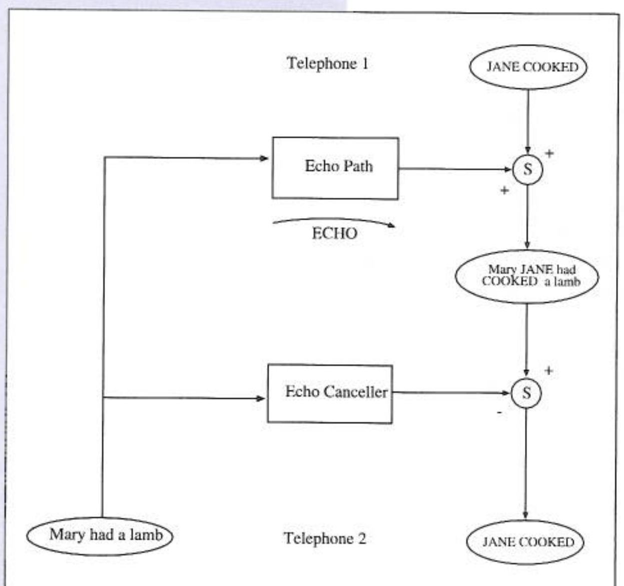
There soon followed another name change, which was a result of changed IEEE practice. In the early 1970s the largest IEEE Group, the Computer Group, asked for greater independence than was normally accorded a Group. IEEE therefore created Society status and set requirements on publications, meetings, other technical activities, membership, finances, and long-range planning in order for a Group to receive this status. It was thus regarded as a significant achievement when, on

Reginald A. Kaenel received the Diploma in Electrical Engineering and the Sc.D. degree from the Swiss Federal Institute of Technology in 1955 and 1958 respectively. He then joined Bell Telephone Laboratories, where he was concerned with data transmission over switched telephone circuits. From 1962 to 1964 he did systems engineering studies of spacecraft at Bellcomm in Washington, DC, and in 1964 he returned to Bell Labs. Kaenel served as President of the Group on Audio and Electroacoustics for 1971 and 1972 (the position was called Chair in 1971).

1970 **25 October: Communist China replaces Nationalist China (Taiwan) in the U.N.**



The idea of ADPCM (adaptive differential pulse code modulation) is to place identical predictors at transmitter and receiver, so that all that needs to be sent, in order to recreate the original speech, are the differences between the predicted speech samples and the actual samples. (Redrawn after figure on p. 247 of Robert W. Lucky, Silicon Dreams: Information, Man, and Machine (New York: St. Martin's Press, 1989).)



The echo canceler, placed at the near end of the line, does not block the echo, nor attenuate it. Instead, it synthesizes the echo and subtracts it, making the resultant signal free from echo. (Redrawn after figure on p. 31 of Charles W.K. Gritton and David W. Lin, "Echo cancellation algorithms" (IEEE ASSP Magazine, vol. 1 (1984), no. 2, pp. 30-38).)

tracts it from the total signal. Proposed by M. Mohan Sondhi in 1967, the process became commercially feasible with large-scale integration technologies of the late 1970s. The first single-chip echo-canceler was designed by Donald L. Duttweiler in 1979.

Speech processing researchers continued to innovate in digital-filter design, but the field was enlarged also by the work of researchers concerned with other types of signals. In 1969 Alfred Fettweis introduced a new type of digital filter, called the wave digital filter. A seminal advance was the algorithm created by James McClellan and Thomas Parks for the design of equiripple finite-impulse response (FIR) filters; Larry Rabiner further developed the Parks-McClellan algorithm and applied it to a number of different types of filter. Sidney Burrus and Thomas Parks showed how filters could be designed according to prescriptions in the time domain. In 1976 Alain Croisier, Daniel Esteban, and Claude Galand introduced quadrature mirror filters (QMFs). Sidney Darlington and Maurice Bellanger pioneered multirate filters. Bede Liu, Toyohisa Kaneko, Alan Oppenheim, Hans Wilhelm Schuessler, Clifford Weinstein, and others made important contributions in analyzing the accuracy of digital filters. Thomas Huang pioneered in developing filters for image processing. State-space methods and related mathematical techniques were developed, which were later introduced into fields such as filter design, array processing, image processing, and adaptive filtering. FFT theory was extended to finite fields and used in areas such as coding theory.

The concepts of probability theory and statistics had long been part of signal processing, as, for example, in Bernard Widrow's work in the 1950s on quantization noise. Throughout the 1960s, and later, Thomas Kailath and Enders Robinson published many papers that applied statistical theory, operator theory, and state-space techniques to a variety of different problems. In about 1970 the theory of Markov chains began to be applied to problems in speech processing, as in the work on speech recognition by James K. Baker and Fred Jelinek at IBM. By the mid 1980s this type of statistical pattern recognition had found a wide range of speech applications.

The 1970s saw the initiation of a great deal of work on facilitating communication between computers and people. At Bell Labs a system able to speak messages from a stored vocabulary was developed, and it found use in speaking the instructions for wiring telephone equipment (since the technician could work more rapidly and accurately if he did not need to look away from the work to read instructions). There was work on automatic speaker-recognition, either to identify speakers or to verify that a voice belongs to the person alleged. In the 1970s systems capable of high success rates were demonstrated, yet little practical use was found for automatic speaker-recognition, a situation which continued into the 1990s.

The challenge of automatic speech recognition was also taken up, the hope being

John V. Bouyoucos received A.B., S.M., and Ph.D. degrees in 1949, 1951, and 1955 respectively, all from Harvard University. An active member of the IEEE Group on Audio and Electroacoustics, he served as President in 1973. He was active also in the IEEE Group on Sonics and Ultrasonics.

Lawrence R. Rabiner attended MIT, where he received the S.B., S.M., and Ph.D. degrees, the last in 1967. From 1962 to 1964 he participated in the cooperative plan in electrical engineering at Bell Labs. He later joined Bell Labs, where he worked on speech communications and digital signal processing. He is currently Bell Labs Vice President for Speech and Image Processing Services Research. Long an active member of the Group on Acoustics, Speech, and Signal Processing, Rabiner served as President for 1974 and 1975.

Howard D. Helms received the B.S. and Ph.D. degrees from Princeton University in 1956 and 1961 respectively. He joined Bell Labs in 1961, where he was concerned with processing of signals in radar and sonar systems. He later worked at the Quality Assurance Center of Bell Labs, where he formulated procedures for assuring the quality of large time-division switching systems. A member of the Digital Signal Processing Technical Committee, Helms served also as President of the Society for 1976 and 1977.

Ronald W. Schafer received the B.Sc.E.E. and M.Sc.E.E. degrees from the University of Nebraska in 1961 and 1962 respectively and the Ph.D. degree from MIT in 1968. He then joined the Research Department at Bell Labs, where he worked on digital speech processing techniques. In 1974 he joined the faculty of the Georgia Institute of Technology, and he is now Regents Professor in the School of Electrical and Computer Engineering. Schafer served the Society as President for 1978 and 1979 and in many other capacities over many years.

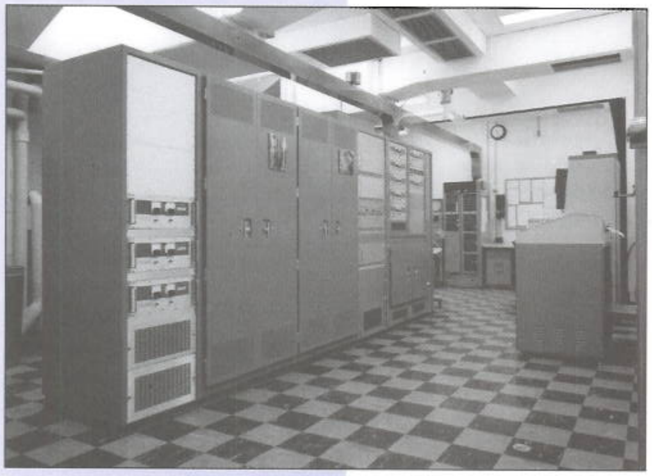
IS FOUR CHANNEL A QUADRIFIZZLE?

The development of four-channel home entertainment systems has been motivated by the marketplace and accomplished without a thorough engineering feasibility study.

... To the engineers and particularly the engineering managers responsible for audio equipment development, I send a plea to heed these words of Abraham Lincoln:

"If you once forfeit the confidence of your fellow citizens, you can never regain their respect and esteem. It is true that you may fool all of the people some of the time; you can even fool some of the people all of the time; but you can't fool all of the people all of the time."

— J. Robert Ashley, *Newsletter*, no. 38, December 1976, pp. 1-6.



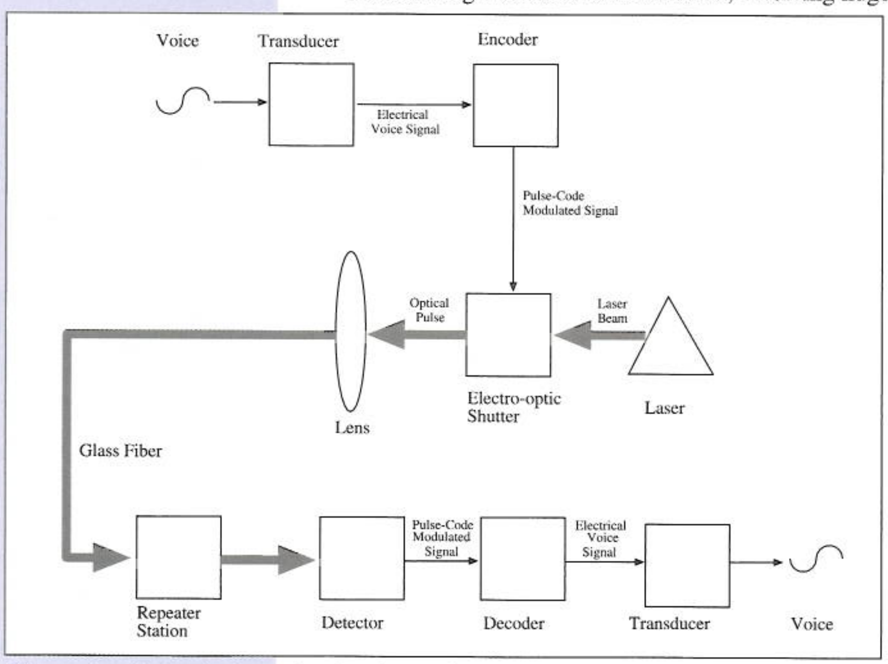
This photograph shows the Lincoln Fast Digital Processor (FDP), built under Charles Rader's direction at Lincoln Lab. (Lincoln Lab photo reproduced by permission.)

that people could dial a number by speaking it or even give oral instructions to computers. A landmark advance was Fumitada Itakura's introduction of a distance metric, between the utterance and templates of speech within the computer, that became widely used in the field. In the early 1970s researchers at Lincoln Lab began a line of work destined to assume great importance when they invented techniques for sending speech over packet networks.

The 1970s were a watershed in the history of signal processing for the development of signal-processing hardware. The decade opened with the completion of what may be the first real-time DSP computer: the Lincoln Fast Digital Processor (FDP). A special-purpose, parallel-processing computer, the FDP performed signal-processing tasks about a hundred times as fast as the general-purpose computers of the time. There followed in 1974 the Lincoln Digital Voice Terminal, a computer built to carry out a variety of speech-compression algorithms. A more powerful version, the Lincoln Digital Signal Processor (LDSP), was built in four copies and remained the main research tool for the Signal Processing Group at Lincoln Lab into the 1980s.

The future, however, belonged to single-chip signal processors. Throughout the 1960s integrated-circuit techniques advanced, and, in the form of calculators and watches, integrated circuits came into the hands and onto the wrists of a great many people. Going beyond a calculator chip (having hard-wired functions), Intel produced the first (programmable) microprocessor chip, the Intel 4004 in 1971. The following year Intel introduced the 8008, a microprocessor that operated on 8-bit, rather than 4-bit, words. Microprocessors were used in some DSP devices, such as the LPC vocoder, completed at Lincoln Lab in 1977. Because the usual signal-processing operations of filtering and transforming are calculation-intensive, involving huge numbers of multiplications, the introduction in 1976 by TRW of a 16-bit by 16-bit single-chip multiplier stimulated the development of real-time DSP machines.

Chips designed specifically for signal processing began to appear at the end of the decade. The Speak & Spell toy contained a speech synthesis chip (TMC0281), and, as mentioned above, in 1979 Bell Labs completed a fully-integrated single-chip adaptive echo-canceler. In February 1979 Intel introduced a single-chip DSP computer, the Intel 2920, but its lack of a hardware multiplier limited its speed, and its 9-bit analog-to-digital and digital-to-analog converters limited its accuracy. As the decade came to a close, a number of companies—AMI, AT&T, Intel, Matsushita, Motorola, NEC, and Texas Instruments—were working energetically to design and build single-chip DSPs. As we will see in the next



Fiber-optic cable is typically employed as shown. The analog signal is converted to electrical pulses, which control a shutter in front of a laser beam directed down the cable. En route the optical signal may be strengthened at repeater stations. At the receiving end, the optical pulses are converted to electrical pulses, from which is recovered the original analog signal. (Redrawn after figure on p. 51 of Britannica Yearbook of Science and the Future 1975 (Chicago: Encyclopaedia Britannica, 1974).)

1 January 1976, the ASSP Group became the ASSP Society. At the same time a new constitution and bylaws went into effect.

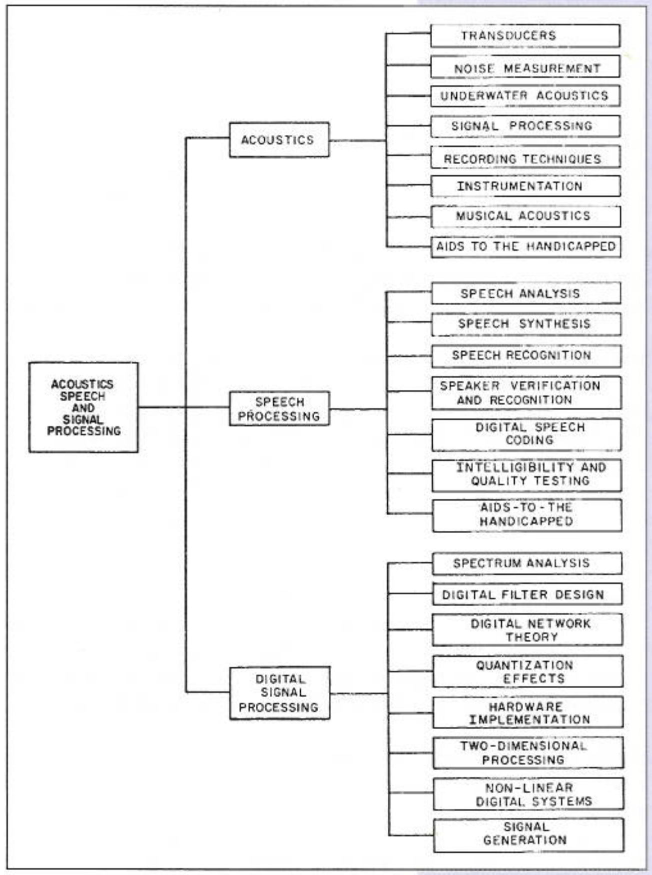
Along with growth in number of members (180,000 in 1978), the IEEE contained more and more technical Groups and Societies. There was concern that the diverse interests and concerns of these Groups and Societies might not be represented on the IEEE Board of Directors. So in the mid 1970s a Technical Division structure was created: the Groups and Societies were placed into seven Divisions—those in a Division having some commonality of technical interest—and each Division was represented on the IEEE Board of Directors by a Division Director. ASSP was placed in Division I, along with Circuits and Systems, Control Systems, and Information Theory.

The winners of the Technical Achievement Award in the 1970s are shown. In 1972 the Group presented the special award Pioneer in Speech Communication, which had been presented only once before, to Franklin S. Cooper for his work in synthesis as a tool for studies of speech patterns. In 1975 a new annual award, the Society Award, was instituted; it was regarded as a successor to the Pioneer in Speech Communication Award and as the Society's highest award.

As mentioned above, the Digital Signal Processing Committee was responsible for a wide range of activities. There were the Second, Third, and Fourth Arden House Workshops, held in 1970, 1972, and 1974 respectively. These workshops attracted researchers from around the world, and the proceedings made up three special issues of the transactions of the IEEE Group on Audio and Electroacoustics. Since DSP was a new field and its practitioners had quite different backgrounds, the terminology was not fixed, with different words being used for the same thing and the same word being used in slightly different ways. The DSP Committee helped to remedy this situation with the publication in 1972 of detailed recommendations for the use of some 200 terms.

The DSP Committee worked with IEEE Press to publish two volumes of reprints, since many of the important pioneering papers in DSP were otherwise hardly available. Another project of the DSP Committee was to publish a bibliography of the new field in 1972, and three years later it published a revised version, twice as large. In 1979 a DSP Committee project resulted in an influential book by IEEE Press of *Programs for Digital Signal Processing*, along with a magnetic tape containing 29 computer programs in machine-readable form.

Speech communication was another area of great activity. At the 1972 International Conference on Speech Communication and Processing, jointly sponsored by G-AE and the Air Force Cambridge Research Laboratories,



This chart appeared in the first issue of the Newsletter after the Group changed its name to Acoustics, Speech, and Signal Processing Group. At the time there were five Technical Committees: Digital Signal Processing, Digital Measurement of Noise, Electroacoustic Transducers, Speech Processing, and Underwater Acoustics.

Technical Achievement Award

1970	William W. Lang
1971	James L. Flanagan
1972	Ben Gold
1973	no recipient
1974	no recipient
1975	Bishnu S. Atal and James W. Cooley
1976	Alan V. Oppenheim and Charles M. Rader
1977	Augustine H. Gray, James F. Kaiser, and John D. Markel
1978	Lawrence R. Rabiner
1979	Ronald W. Schafer

Maurice Bellanger: The multirate filtering idea came from our work on delta modulation. Since our PCM channel bank had a per-channel digital filter, we had to minimize the number of multiplications. The multiplier was the most area-consuming operation. A second reason was that, in order to perform filtering in that context, we had to start from a high sampling rate. The final sampling rate is the regular PCM rate, 8 kilohertz, and we had to start from at least 32 kilohertz. So we tried to optimize the conversion from 32 kilohertz to 8 kilohertz using digital filters, and that's where the concept of multirate came in. We noticed that two half-band filters drastically reduced the number of multipliers, and thought that the concept could be applied in different fields. We gave some presentations of the concept within Philips, and it was used in other areas, not only for sample-rate reduction but also for sample-rate increase, which was called decimation and interpolation.

Interviewer: Has computer hardware development influenced the direction of the FFT algorithms?

James Cooley: Definitely. It gave some incentive for designing these nice scheduling algorithms for breaking the FFT into blocks and scheduling the blocks of calculation. Whole papers have been written just on the scheduling of data through hierarchical storage.

Alfred Fettweis: How can we do something in the digital domain, which is the equivalent of these resonant transfer filters? I tried first to do it on the basis of voltages and currents, and then realized that this is not feasible. Only with mediocre properties was it feasible. So I had to do something different. I therefore tried to directly convert the equations of resonant transfer filters, thus to transpose them into equations that would be realizable by digital algorithms involving multiplications, additions, and delays, that is, the kind of operations commonly available in digital signal processing. And that's how I discovered these wave digital filters. I first obtained them indeed by means of the resonant transfer. I never published how I did that. It was very much more complicated than the approach I did publish. I did not even mention in the papers—the first papers certainly not—that I had obtained the results from resonant transfer. But, in fact, I did. So the resonant transfer work was fundamental for getting to this signal processing method.

Fumitada Itakura: I continued my hobby of visiting mathematics libraries and accidentally found an interesting paper which transformed the autocorrelation function. It didn't say autocorrelation at all, but that a positive definite function could be expanded using line-spectrum type of transformation. The language was completely mathematical. But if I interpreted it in my engineering approach, the autocorrelation function could be expanded using minimum line-spectrum and the frequency and amplitude combination. That was the so-called LSP [line spectrum pair] theory. So I was quite lucky to find good mathematics—a very good mathematician paved the way for the speech scientist.

Thomas Kailath: Through a student from industry who came to us, we got interested in an area of antenna array processing. You have signals coming from different directions. You have an antenna array, and you have got to separate these signals. The traditional methods for doing that are really equivalent to taking the FFT of the data. It's a spatial FFT rather than a temporal FFT, but it's similar. If you have sinusoidal waveforms in noise, you would tend to get peaks of the FFT at the sinusoidal frequencies. Similarly, when you take the spatial FFT of signals coming from different directions, you tend to get peaks in those directions. This is non-parametric, and it doesn't take account of the fact, for example, that these are plane waves coming in, or that there are only two or three of them.

The FFT doesn't care about those things. You have numbers, you take the FFT. So, one of our students, Ralph Schmidt, said, "Well, even if you have no noise, that method can't solve the problem exactly. But, if you add the information that you believe there are only, say, three plane waves coming in from a few directions, then we can get an exact solution without noise. And with noise present, we can deduce an efficient algorithm that gives good estimates of the direction." That idea launched a new field of high-resolution model-based sensor array processing. And I had six or seven students work in that area. It was timely because those were the days of SDI, and that was one of the funding sources for this, because they were interested in determining the direction of incoming missiles.

What was happening in the 1970s

movies people were watching:

- Woody Allen's *Annie Hall*
- *The Godfather* with Marlon Brando
- *Saturday Night Fever*

TV shows people were watching:

- "All in the Family"
- "M*A*S*H"
- "Saturday Night Live"

music people were listening to:

- Bruce Springsteen
- disco music

books people were reading:

- Solzhenitsyn's *Gulag Archipelago*
- Richard Adams's *Watership Down*

chapter, success came in the early 1980s.

Just as in the previous decade, photographs from space caught the public attention in the 1970s. The Soviet Venera 7 sent back the first pictures from the surface of Venus in 1970; the U.S. Mariner 10 reached Mercury in 1973; and U.S. Viking 1 and 2, launched in 1975, sent back the first pictures from the surface of Mars the following year. There was also the radar mapping of Venus by the U.S. Magellan probe in 1980. Signal processing was involved in the encoding, reconstruction, and enhancement of these images, and it played a large part in all communications with satellites and space probes.

In the 1970s digital signal processing was increasingly applied to radar and sonar imaging. Researchers at ERIM and Lincoln Lab showed that DSP was useful in forming radar images of targets, determining speed of targets, and eliminating clutter. In the 1970s underwater acoustic systems reached a high level of performance, and the problem of separating and classifying signals came to the fore, as attention shifted from signal acquisition to signal processing. And there were important advances in geophysical signal processing, such as Richard Lacoss's work on adaptive filters for seismic applications.

Communications entered a new era in the 1970s with the development of fiber-optic technology. Light, because of its high frequency, promised great bandwidth for communications. Required, though, would be a controllable and intense source of light

114 papers were presented, and versions of many of them appeared in the June 1973 special issue of the *Transactions*. In 1974 the Group collaborated with Carnegie Mellon University in Pittsburgh in putting on a 5-day symposium on speech recognition, which resulted in, among other things, a special issue of the *Transactions* on that topic. In the 1970s IEEE Press also published four reprint volumes of papers on speech communications.

In 1976 the Society initiated its practice of holding an annual conference. Called the International Conference on Acoustics, Speech, and Signal Processing (ICASSP), it has been held every year since. In one sense ICASSP may be viewed as a continuation of the Arden House Workshops, since in 1974 it was decided not to continue the Workshops in the earlier form because the Group would be holding an annual meeting. (The Fifth Arden House Workshop in 1976 was quite different from its predecessors: it was focused on specific topics and emphasized discussion rather than presentation.)

At the end of the decade the Society held its first workshop on 2-dimensional digital signal processing (in Berkeley, California on 3 and 4 October 1979). This area was growing so rapidly that in 1981 the Society estab-

Pioneer in Speech Communication Award

1967	Homer W. Dudley
1972	Franklin S. Cooper

Society Award

1975	James L. Flanagan
1976	no recipient
1977	Henry S. McDonald
1978	Hans Wilhelm Schuessler
1979	Alan V. Oppenheim

The International Conference on Acoustics, Speech, and Signal Processing

12-14	April 1976	Philadelphia, Pennsylvania
8-11	May 1977	Hartford, Connecticut
10-12	April 1978	Tulsa, Oklahoma
2-4	April 1979	Washington, DC

James Kaiser: Following the [Arden House] workshop on the FFT in 1967, that group organized a technical committee on digital signal processing, which they asked me to join. That technical committee was Al Oppenheim, Larry Rabiner, and Ron Schafer, and a couple of other fellows from Bell Labs including Ron Crochiere, Leland Jackson, Howard Helms, and Dave Bergland. Al was up at MIT and Cliff Weinstein, Ben Gold, and Charlie Rader were at Lincoln Laboratory. Ken Steiglitz was there from Princeton, and then Jim Cooley and Harvey Silverman were there from IBM Yorktown Heights. There were also Russ Mersereau, Joe Fisher, and Steve Lerman. The committee was a very significant force in DSP. It got together every two months; two times in the United Engineering Center in New York, at the IEEE's offices up there on the tenth floor, and the third time it would be up in the Boston area, and then this cycle would be repeated. It was convenient because you could take the shuttle up to Boston for the day and return in the evening. It was at those meetings that we planned the IEEE press books, the program book, the selected papers on DSP books, and we planned the Arden House workshops—we organized and ran three workshops there that came about two years apart. We also did the normal technical committee work, which is reviewing the papers for the annual ICASSP. Moreover, when we'd get together we would interact with one another.

Lawrence Rabiner:It's probably the most productive committee [the technical committee for Digital Signal Processing] I've ever served on, focused and productive. We defined the technology and the field. We put out the key books. Even though committee members wrote a high percentage of the papers, every paper that got in the reprint books went through review after review. We would split hairs about whether this paper was better because it's more historic or this paper is better because it's more up to date and more factual. We were unbelievably careful. Probably we made mistakes. In hindsight, anyone's going to do that. But these are the events that built up the field.

Alan Oppenheim: We use ICASSP as the first platform to put ideas on the table, and then we publish them in appropriate places. … I would say ICASSP is probably, for this group, the typical way of starting to disseminate information.

Charles Rader: The annual conference [ICASSP] certainly had a huge influence, because it always had a substantial non-U.S. participation and many, many excellent papers.

Charles Rader: Another thing that happened around the same time—I mean, all these things kind of happened one on top of another—was that people became more and more interested in multidimensional signal processing. Processing pictures, for example. And multidimensional signal processing began to become more and more important. Eventually we created a separate committee to do multidimensional signal processing, along with one to do speech signal processing. Speech is more than signal processing. It has algorithms of trying to understand, and synthesize, and quality judgment, and so on. But a lot of signal processing ideas, including some of these linear predictive spectral estimation ideas were originated in the speech area. Two other areas that generated a lot of useful results were radar and seismic processing. So, the Society really helped bring these people together, exchanging concepts with one another.

1975 **20 November: Francisco Franco dies, ending 36 years of dictatorship in Spain** and a low-loss transmission medium. Rather suddenly, in about 1970, both of these became feasible: Corning Glass demonstrated highly transparent fibers, and Bell Laboratories demonstrated semiconductor lasers that could operate at room temperature. In 1977 fiber-optic telephone systems were put into service both by General Telephone & Electronics (in Santa Monica, California) and AT&T (in Chicago). Just over a decade later the first fiber-optic cable across the Atlantic went into service; its capacity exceeded all previous cables combined.

Hans Georg Musmann: At that time [in the mid 1970s] the problem was the digitization of a video signal, which is required for realizing such a visual communication system, and reducing the bit rate for moving images, which is almost three thousand times that of a speech signal. I always said our goal would be to cut down the bit rate of a video signal to that of a speech signal. Otherwise it's too expensive to use it.

Interviewer: The factor of three thousand is for television resolution?

Musmann: Yes. Of course, you can use a smaller picture. That was also proposed later on. But even if you take an image one fourth as large, then you'll still have a factor of eight hundred or something like that. You can reduce the frame frequency from fifty hertz to ten hertz. Then you come down to a hundred times the rate of the speech signal. Nobody thought at that time that this compression factor could be achieved by coding. …

This indicated to me that if we wanted to create a visual communication system, we would have to cut down the bit rate for visual information to that of speech — or be close to it. Otherwise, nobody would be able to afford it. So we studied some techniques. And, in 1979, two years after the facsimile work, we demonstrated in the United States a transmission of moving images requiring just 64 kilobits per second. …

There was a big interest. The communications industry saw that it might be possible to transmit moving images via speech channels. But they were still hesitating, waiting to see if the problems with motion could be solved in the future. We transmitted mainly those parts of an image which had changed, and we took the other parts from the stored preceding image in the memory of the receiver.

Alan Oppenheim: The reason why it was so significant was that, prior to the Speak-and-Spell, you could basically think of digital signal processing as high-end, funded largely by the military or by high-end industry like the seismic industry, because it was expensive to do.

Lawrence Rabiner: People and companies jumped in: TI, Motorola, and Rockwell, jumped in really quickly. Academia jumped in really quickly. Al Oppenheim and Ron Schafer had a book out there that was focused on the academic audience. Ben Gold and I had another book out there with more of an engineering focus. Ben and Charlie [Rader] had this early book out, but it was, like all early books, a little too early. Even in '75, when the books came out, I think the first line stuff was pretty well-developed, and that was the real key. … There was a tremendous pent-up demand for this stuff. You can go out and do things with a computer, and after a while it became digital hardware and then it became real.

Charles Rader: Now, at the same time that I had found a way to express a Fourier transform as a convolution, a colleague of mine, by the name of Leo Bluestein, who was then at Sylvania, but who had actually shared an office with me a few years earlier when he was at Lincoln Lab, came around one day and said, "I've got this interesting result." He said, "I can do a Fourier transform where the number of points is a perfect square, and I have this algorithm." And his algorithm was not very interesting in itself, but part of the way through explaining the algorithm, he had done some manipulations to change a Fourier transform into a convolution, in still another way. It had nothing to do with number theory. It had to do with multiplying the input wave form by what engineers would call a chirp wave form. It was a sinusoid whose frequency increases continuously as time progresses. And then, if you would agree afterwards to un-multiply the Fourier transform by a chirp, what you found in the middle was you were convolved with a chirp. So, multiplication involved, post-multiplication to undo it, was another way of converting a Fourier transform to a convolution.

I said to him, "Leo, we can use the FFT to do convolutions, so forget about your clever little algorithm for doing the middle part. Let's use the FFT for that." The advantage of that was that the chirp algorithm would work for any length sequence, and so you could do any length sequence using any length FFT. That was the so-called chirp Z transform.

Manfred Schroeder: We were working on speech synthesis because by taking speech apart and synthesizing it again at the other end we could compress its bandwidth by a factor of 5 or more.

… [But] it was not just bandwidth compression. Another reason we were interested in speech synthesis was to read documents, as in reading machines for the blind. Optical scanners were already in existence in the '60s, but it was not easy to get speech from such devices. We wanted to do that, even if that was not immediate telephone business.

There was a beautiful application made by Western Electric, for the guys who wire these complicated circuits. Here's a complicated circuit-chart. In wiring it, they would often solder a wrong connection. So someone … wrote an automatic program that translated the wiring chart into a code that we translated into spoken instructions. The wiring man at Western Electric used earphones. He never had to turn his eyes off what he was doing. The earphones would tell him to connect the green wire to terminal 47, that kind of thing. That was, I think, the first application of synthetic speech within the Bell System.

1976 Kurzweil Reading Machine introduced

lished the Committee on Multidimensional Signal Processing, which became one of the most active Technical Committees. The second workshop in the series was held on 5 and 6 October 1981 in New Paltz, New York.

The ASSP Society, like IEEE in general, made increased efforts to become more international. In 1978 the Society President, Ron Schafer, wrote, "IEEE is an international organization in name, but in many ways I think we have failed to involve our colleagues overseas in the activities of the Society." As mentioned in Chapter 3, the Group was a principal sponsor of the First Zürich Seminar, held in 1970, and it continued in the 1970s to sponsor the biannual Zürich communications conferences (though it decided to cease sponsorship with the 1980 conference). The IEEE was one of three sponsors of the Conference on Digital Processing of Signals in Communications, held at the Loughborough University of Technology in England in 1977.

> Another collaboration that I have enjoyed is with Al Oppenheim. We wrote a textbook on digital signal processing which has just been published by Prentice-Hall. He wrote his part between ski runs in Grenoble, and I wrote mine in the wee hours of many nights back in New Jersey ….
>
> — Ronald W. Schafer, *Newsletter*, no. 32, February 1975, p. 7.
>
> After graduating, I accepted an engineering position at Motorola in Scottsdale, Arizona. I was hired as a circuit designer and worked on such things as receivers, broadband amplifier and phase-locked loop design. My first change in directions arose out of an instance where I saw one of the engineers spending two days tabulating numerical values corresponding to the Fourier series of … triangular pulses to look at radar side-lobe effects (keep in mind that this was 1965, just before the FFT revolution). I went rummaging through the company library and found a numerical analysis book which had the Goertzel algorithm for discrete Fourier transforms. Within a few hours, I had typed in the program and performed the triangular pulse analysis with computer printouts. My supervisor was sufficiently impressed that he allowed me to become more involved in computer simulation problems and less with circuit design.
>
> — John D. Markel, *Newsletter*, no. 35, November 1975, p. 8.
>
> In London I met Americans for the first time …. I later learned that almost all of my American friends were recipients of Fulbright, Guggenheim, or other equally meritorious awards …. … this exposure soon erased my mental image of Andy Hardy and replaced it with another, perhaps equally misleading, image. [In 1964] I nervously accepted an offer of employment from … Bell Telephone Laboratories …. Here again my statistically biased view of American university graduates was further reinforced in that all my peers were uniformly brilliant. In fact, so great was the cultural shock that I developed feelings of intellectual inadequacy that I thought only Woody Allen could experience.
>
> — Harry Levitt, *Newsletter*, no. 38, December 1976, p. 8.

The high cost of international travel limited attendance at conferences, and it limited participation in Society governance as well. Some earlier members of the AdCom were born and educated outside the United States, such as Peter Goldmark (Hungarian), Michel Copel (French), Reginald Kaenel (Swiss), and Hellmuth Etzold (German), but the first person to serve on the AdCom while residing most of the year outside the United States was Manfred Schroeder, and this was a special case in that Schroeder retained an affiliation with Bell Labs after his 1969 appointment as professor at Göttingen University. Another Bell Labs scientist, Gerhard Sessler, was a member of the AdCom from 1970 through 1972 and continued to serve the Group in several capacities after that, but ceased these activities when, in 1975, he accepted a German professorship.

In the late 1970s a group of European engineers and scientists, headed by Anthony Constantinides, established the European Association for Signal Processing (EURASIP) and the journal *Signal Processing*. Constantinides and some other founders of EURASIP were members of the ASSP Society, and from the beginning they sought cooperation and collaboration with the Society, planning a joint workshop in 1981 and a joint international conference in 1982.

On its own, the ASSP Society organized a workshop on DSP held from 9 to 11 September 1980 in L'Aquila, Italy. The increasing number of papers in the Society's *Transactions* written by authors outside the United States—46 percent of the papers in 1979, for example—led to the appointment of Ludwig Eggermont of Philips Research Laboratories in Eindhoven as Associate Editor. There was increasing involvement of Asian, especially Japanese, engineers and scientists in the activities of the Society. For example, in the last two years of the decade 15 papers written by Japanese appeared in *Transactions*.

1977 Deng Xiaoping begins modernization drive in China

Etched in silicon: The 1980s

In much of the world, the 1980s was the decade in which Japanese consumer electronics became commonplace: stereos, televisions, VCRs, camcorders, CD players, video games, the Walkman, "boom boxes," personal computers, fax machines, cellular phones, and many other products manufactured by Hitachi, JVC, Mitsubishi, NEC, Nintendo, Panasonic, Sanyo, Sony, Toshiba, and other companies. The Japanese economy had grown vigorously after World War II: output increased 9.5 percent a year in the 1950s and 10.5 percent a year in the 1960s. In the 1970s the Ministry of International Trade and Industry (MITI) led a reorganization of the economy away from steel, ships, and chemicals and toward electronics and precision machinery. This helped bring about the "second economic miracle" of the 1980s. Japanese companies pioneered many of the new electronic technologies, such as VCRs, videodisks, the Walkman, and compact disks, and the first commercial cellular-phone system anywhere in the world was the one put into service in Tokyo in 1979.

The burgeoning of consumer electronics owed much, of course, to the appeal of new products, such as personal computers and camcorders, and the new capabilities of already standard devices, such as stereo systems and telephones. Perhaps even more important was the success of manufacturers in providing more for the customer's dollar (or yen or mark). In the 1970s and 1980s, while the consumer price index in the United States tripled (that is, goods on average cost three times as much at the end of this period), the price of most consumer electronics products either remained constant or fell. Their 1990 cost in real terms, then, was one-third that of 1970.

The 1980s was also the decade in which personal computers became ubiquitous. When the decade opened, many people thought of personal computers as something for hobbyists only. In 1981 IBM introduced its personal computer, and its disk operating system (DOS) quickly became the industry standard. The next year appeared the first IBM-PC clone, made by Compaq. In 1983 came the mouse and pull-down menus, with Apple's (commercially unsuccessful) Lisa, and that same year the IBM PC-XT became the first personal computer with a built-in hard-disk drive. Apple introduced the Macintosh in 1984, and its user-friendliness was copied in Microsoft's Windows software, released in October 1985. The number of personal computers worldwide increased from 1.3 million in 1980 to 115 million in 1990. Computer software became a major industry, growing from annual sales of \$140 million in 1981 to \$1.6 billion three years later. In the late 1980s email became common as personal computers connected to networks such as the Internet.

One of the exciting new technologies at the start of the decade was videodisk, available in a variety of systems. They were of two types: systems in which an electrode sensed differences in capacitance, pioneered in the RCA VideoDisc, and systems with optically encoded information read by a laser, pioneered in Philips Laservision. None of these achieved great market success, though development of the latter type contributed to one of the most successful consumer products of all time, the CD player.

1983 was the year Philips and Sony, rival companies that collaborated in bringing the new technology to market, began selling CD players. Its technical features drew on several decades of advances in signal processing, using, for example, the type of error-correction coding invented by Irving S. Reed and Gustave Solomon in 1960 and incorporating a 16-bit analog-to-digital converter and digital filters of various sorts. Besides setting a new standard for audio fidelity—consumers now expect CD-quality sound from other products—this technology contributed to the devel-

The introduction of the compact disc ... has been universally hailed on at least two counts: it ushered in the age of digital audio, and it rescued the home audio business from a period of stagnation. The development, in the last few years of additional digital audio playback and recording devices, amplifiers and other components designed to process information digitally rather than in analog and even the advent of loudspeakers with digital inputs has virtually re-invented the home audio business and has had a profound effect on car, personal and portable stereo.

— Robert Heiblim (U.S. Consumer Electronics Industry in Review: 94 Edition (Washington, DC: Electronics Industries Association, 1994), pp. 47-48)

The IBM PC, introduced in 1981, rapidly became the industry standard. (IBM photo reproduced with permission.)

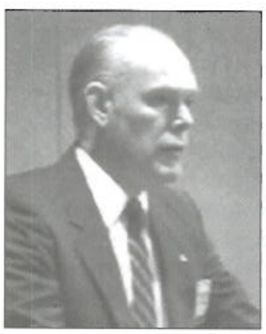
1980 4 November: Ronald Reagan elected U.S. President

Etched in silicon: The 1980s

Signal processing engineers will always remember the 1980s as the first decade of single-chip DSPs, which opened up many new areas of application for signal processing. They will also remember it as the decade of the CD player: for the first time, digital audio was in a standard consumer product. Not surprisingly then, the Acoustics, Speech, and Signal Processing Society grew steadily in the 1980s. Before the end of the decade membership reached 15,000, making the Society the fourth largest of IEEE's 36 Technical Societies.

This remarkable growth was a reflection of the overall growth of DSP and the substantial improvements in Society activities, brought about by the energy and vision of the volunteer leaders of the Society. It had become the practice for a person to serve two 1-year terms as President, so in 1985 the Society's Constitution was amended to provide for a 2-year term for the President.

Charles M. Rader received the B.E.E. and M.E.E. degrees from the Polytechnic Institute of Brooklyn in 1960 and 1961 respectively. He then joined the MIT Lincoln Laboratory, where he worked with Ben Gold on speech processing. In 1969 Gold and Rader published the landmark text Digital Processing of Signals. Rader is today Senior Staff Member at Lincoln Lab. An active member of the Society, he served as President for 1978 and 1979.



N. Rex Dixon received the B.A. degree from Western Michigan University and the M.A. degree from Indiana University. He then attended Stanford University, where in 1966 he received the Ph.D. degree in speech and hearing sciences and psychology. He worked as an advisory scientist at IBM research laboratories in San Jose, California, Research Triangle Park, North Carolina, and Yorktown Heights, New York. He also served on the faculties of several universities. Much of his research has concerned speech synthesis, speech recognition, and speaker verification. Active in the Society in several capacities, Dixon served as President for 1982 and 1983.

Ronald E. Crochiere received the B.S. degree from the Milwaukee School of Engineering and the M.A. degree from MIT in 1967 and 1968 respectively. He then joined the Raytheon Company, but returned to MIT in 1970 and in 1974 completed a Ph.D. on digital signal processing. In 1974 Crochiere joined the Acoustics Research Department of Bell Labs. Long an active member of the Society, he served as President for 1984 and 1985.

Serving as President of the ASSP Society is keeping me pretty busy. There are days when I can barely finish answering my mail. … a system designed for a well-defined purpose would be most efficient if only those parts which needed to communicate with one another were interfaced and if only the minimum necessary communication took place. To provide for redundancy, and to allow for new requirements to be met, most large systems have more than the minimum number of interfaces, and these interfaces carry more than the minimum amount of information. The IEEE design is clearly of this latter type: the cross-communication channels are both numerous and busy. I sometimes wonder how the Institute can function with so much communication, rather than suffering the equivalent of an epileptic fit. As President of ASSP it sometimes seems as if the system exists to send me mail.

— Charles M. Rader, *Newsletter*, no. 51, September 1980, p. 2.

Taken as a whole, the [ASSP Workshop on Speech Recognition held at Arden House in December 1985] demonstrated that speech recognition is an active but severely factional area of research. Each faction is like one of the proverbial blind men describing an elephant: each is able to obtain some knowledge of a different part of the anatomy, but no one has explored the whole animal. What is worse is that, since the factions come from different intellectual traditions, it is difficult for them to describe to each other that part of the elephant which they are examining. It is hoped that, if nothing else, this workshop reminded the participants of the need for interdisciplinary approaches.

— Stephen E. Levinson, *IEEE ASSP Magazine*, April 1985, p. 36.

Some weeks ago … I walked from the mail boxes back to my office with an inaugural copy of "The International Journal of Approximate Reasoning [Elsevier, New York, NY]." This journal about the manipulation of uncertain knowledge and data promised not only reports on the latest research in the area but also news of the activities of the North American Fuzzy Information Processing Society. But then a colleague saw what I had and remarked that I finally had found a journal that was pertinent to my style of thinking. "When you stop writing the ASSPS President's letter," he asked, "are you going to use your talents as editor of a section on almost-proven theorems?"

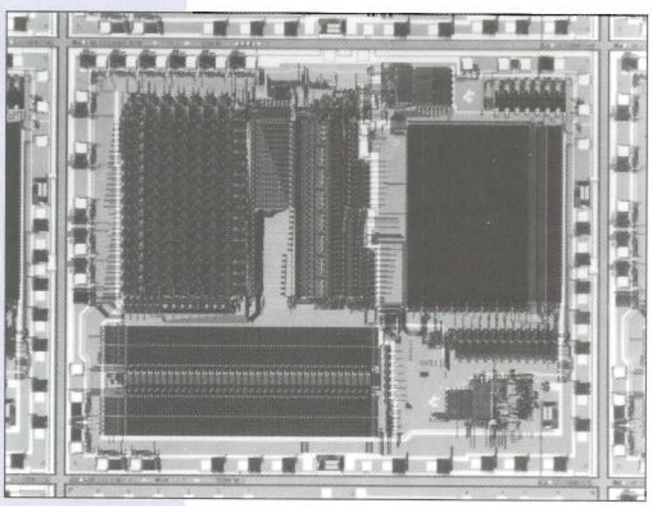
— Tom Crystal, *IEEE ASSP Magazine*, October 1987, p. 2.

opment of a variety of other optical storage media, such as the CD-ROM (Read Only Memory optical-disk for computers), which was introduced by Philips and Sony in 1984, and the Digital Versatile Disk (DVD), which began to be marketed in the late 1990s. Another form of digital audio, digital audio tapes, began to be marketed in the mid 1980s, but were slow in gaining popularity.

The CD player, which for every second of music performed prodigious computations, would not have been economically feasible before the era of integrated circuits and solid-state lasers, and no doubt the biggest story in signal processing in the 1980s was the design and production of integrated circuits, especially single-chip DSPs. It was, of course, possible to use general-purpose chips, but a chip designed specifically for signal-processing operations could do the job much faster. And for real-time signal processing, where a signal must be processed as fast as it arrives, speed is not just desirable, but requisite.

In the early 1980s there appeared quite a few single-chip DSPs. Particularly successful were the AMI S2811, the Intel 2920, the NEC muPD7720, and TMS32010 from Texas Instruments. The last named was the first in the highly successful and continuing TMS320 series. In 1984 AT&T began marketing DSPs with the DSP32, which was the first 32-bit floating-point DSP. Particularly successful in audio products was the Motorola 56000, introduced in 1985.

A great deal of attention was given to alternative ways of carrying out multiplication, such as cellular arrays, memory intensive policies, homomorphic systems, and modular arithmetic, which led in the late 1980s to the design of dedicated multiply, multiply/accumulate, and numeric processor chips. For algorithms involving trigonometric, logarithmic, or exponential functions, the CORDIC (COordinate Rotation DIgital Computer) algorithm received renewed attention as an alternative to the conventional multiply-and-add hardwares. Another alternative architecture that attracted interest in the 1980s was distributed arithmetic. Invented independently in about 1970 by Alain Croisier and colleagues in France and by Shalhav Zohar in the United States, distributed arithmetic is well suited to the usual sum-of-products computation. The 1980s also saw increased interest in various schemes of parallel computation. Parallel processing for the FFT had been developed in the mid 1970s, and in the 1980s considerable work on parallel processing led to the adoption of new algorithms.



This was the first single-chip DSP manufactured by Texas Instruments. (Texas instruments photo reproduced with permission.)

In the 1980s more attention than ever was given to image processing. Applications included videotex, fax machines, camcorders, radar, enhancement of satellite photos, and medical imaging. For example, CT (computerized tomography) scanners, introduced in the 1970s, became faster and more economical, and MRI (magnetic resonance imaging) scanners began to be used in hospitals in the early 1980s. Signal processing techniques were used also to make sonograms (diagnostic ultrasound images) more useful. In the mid 1980s black-and-white movies began to be colorized with the help of a video signal-processing system. Toward the end of the decade many VCRs contained digital memory circuits for generating still-frames and other special effects.

It was in the 1980s that the fax machine became common in offices. This resulted in part from more efficient coding, less expensive hardware, and the adoption of international standards. From 1980 to 1992 the cost of a digital fax machine fell by a factor of 30, and in the United States the market for fax machines grew from a half million units (annual sales) in 1985 to six million in 1991.

1982 Sony introduces the 3.5-inch diskette

Thomas H. Crystal attended MIT, from which he received B.S.E.E., M.S.E.E., and Sc.D. degrees, the last in 1966. As an undergraduate in the cooperative plan in electrical engineering and later as a doctoral candidate, he worked at Bell Labs, with Manfred Schroeder and then James Flanagan. Upon graduation he joined Signatron, Inc. where he worked in a variety of signal-processing areas. In 1972 he became a member of the technical staff of the IDA Center for Communications Research in Princeton, New Jersey. From 1990 to 1993 he was a program manager at DARPA. Crystal served the Society in many capacities, including as President for 1986 and 1987.

Delores M. Etter received the B.S. and M.S. degrees in mathematics from Wright State University in 1970 and 1972 respectively, and the Ph.D. degree in electrical engineering from the University of New Mexico in 1979. She was on the faculty at the University of New Mexico from 1979 to 1990 and since then at the University of Colorado, in both places as Professor of Electrical and Computer Engineering. Etter's many positions in the Society leadership include editor-in-chief of the magazine for 1986 and 1987, President of the Society for 1988 and 1989, and editor-in-chief of Transactions on Signal Processing from 1993 to 1995. She received the IEEE Fellow Award "For contributions to education through textbooks for engineering computing, and for technical leadership in the area of digital signal processing."

Delores M. Etter was the first woman to become President of the Society. As in most areas of science and engineering, there were relatively few women in signal processing until the last one or two decades, when their numbers increased markedly. Beginning in the 1970s, there were some papers in *Transactions* authored or co-authored by women, and Marie Dolan and Carol McGonegal served on the DSP Technical Committee in the 1970s. The first woman member of the Group's AdCom was Edith L.R. Corliss, who served from 1973 through 1975. Besides Delores Etter, three other women served on the AdCom in the 1980s: Leah Jamieson Siegel, Maureen Quirk, and Faye Boudreaux-Bartels, whose 3-year terms began in 1981, 1986, and 1989 respectively. In the 1990s women who have served on the AdCom (the Board of Governors after 1993) include Faye Boudreaux-Bartels, Marcia A. Bush, Leah H. Jamieson, Candice Kamm, Maureen Quirk, Sarah Rajala, and Sally Wood, and in 1998 Leah Jamieson began her 2-year term as Society President.

The growth of the Society's activities led to the establishment at the beginning of the decade of two major subcommittees of the AdCom: a Publications Board to oversee the Society's expanding program of publications, and a Conference Board to assist organizers of meetings, establish general policies, and make decisions about specific plans on behalf of the Society. Later in the decade a third Board was created when the Award Committee became the Awards Board.

Administrative Committee
Conference Board
Publications Board

Awards Committee
Chapters Committee
Constitution and Bylaws Committee
Membership Committee
Nominations Committee

There were also changes in the Technical Committees in order better to cover the technical scope of the Society. In the early 1980s three new Technical Committees were established—Multidimensional Signal Processing, VLSI for Signal Processing, and Spectral Estimation and Modeling—and by the end of 1987 an Audio and Electroacoustics Committee was formed. In the 1980s the

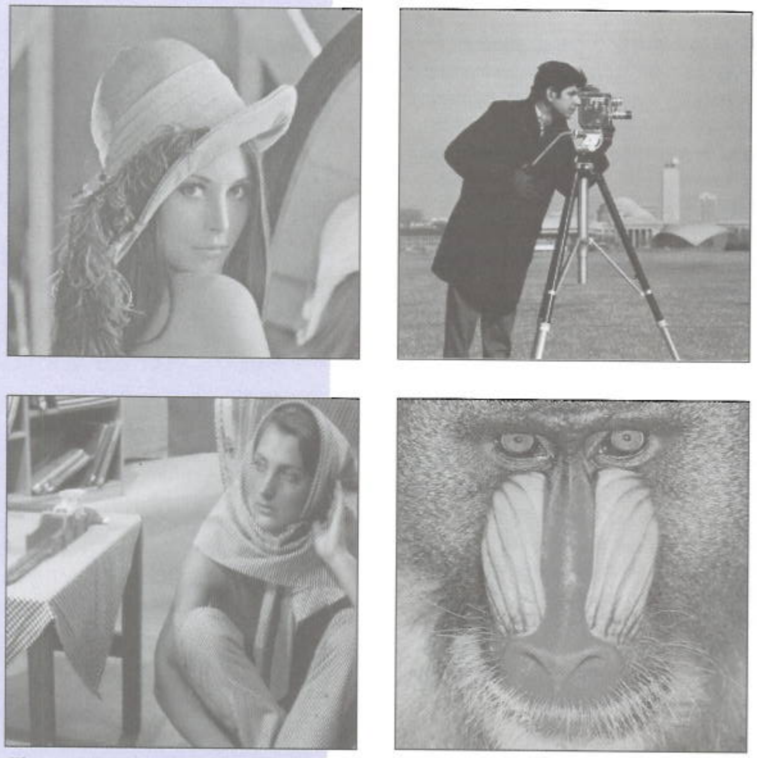
Bede Liu: In 1967 or so, I proposed to NASA a way to implement digital filters using delta modulation, without the multiplier, because in delta modulation, it is easy to do multiplication by one bit. That was not funded. But, two or three years later, I was working with Abe Peled [a graduate student] and I asked him to look at it again. He came back a couple of days later and said, "This is a great idea. It works." We continued working on it and he said, "Oh yeah, you can do this sort of thing; that will be very good." It is now the scheme most people call distributed arithmetic.

... It turned out some others thought of the same idea just around that time, maybe even a little bit ahead of us, but for some reason they did not receive wide publicity. Stan White at Rockwell was very interested in this. He dubbed the scheme the "Princeton Multiplier."

Lawrence Rabiner: I think the technology is so mature that it's second nature to everybody. Everyone you hire is absolutely steeped in the technology, knows it inside out, and uses it without thinking.

Interviewer: Did this maturing take place in the early 80s?

Rabiner: Probably in the early- to mid-'80s. When people come in now, they are just so good with it, it's just fundamental. It's being taught to undergraduates, throughout almost the entire world. People don't even think about it, it's like programming.



These are four common test images: Lena (or Lenna), the MIT cameraman, Stripes, and the mandrill. The last has been used especially in studying the processing of color images. (Lena image reproduced by permission of Playboy magazine.)

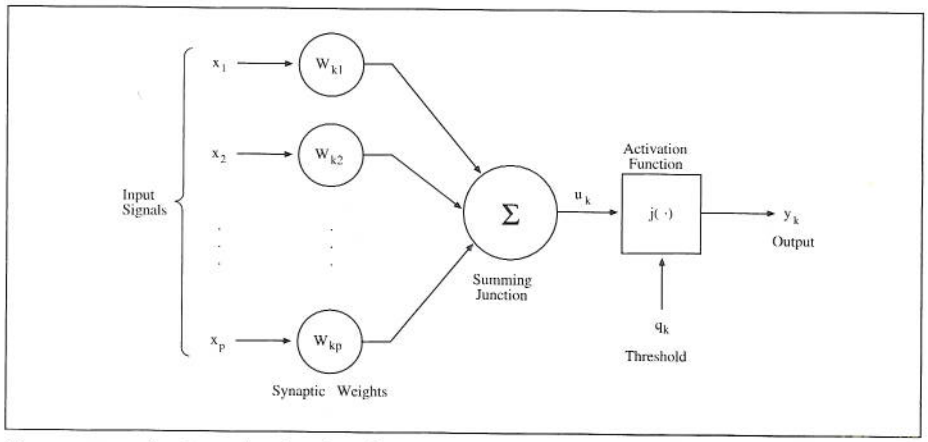
In the 1980s image processing became a recognized technical specialty. The first books on image coding—such as *Computer Techniques in Image Processing* by Harry Andrews, *Picture Bandwidth Compression* edited by Thomas Huang and Oleh Tretiak, and *Image Transmission Techniques* edited by William K. Pratt—appeared in the 1970s.

The improvement of image processing was facilitated by the use of common test images, which made it easier to compare the performance of different algorithms or image processing systems. These test images were chosen for their inclusion of a wide range of visual features such as textures, shadings, and colors. For the study of motion-picture systems there are standard video sequences. (Similarly, the speech-processing community has employed standard samples of speech.)

A major achievement of the 1980s was JPEG, the international standard for digitizing and compressing still pictures. The Joint Photographic Experts Group, under the auspices of the International Organization for Standardization and the International Electrotechnical Commission, elicited the views of experts from around the world and reached agreement on a standard that has been widely adopted. The success of JPEG inspired efforts to reach standards for moving images, which was achieved in the 1990s in the form of MPEG1 and MPEG2.

Automated image-recognition is one of the tasks signal-processing engineers have tackled. There are numerous contexts in which this would be useful, as in detecting missile-sites in aerial photographs, recognizing a person from a video image, or finding pictures of interest in a large photograph collection. It has, however, proved extremely difficult to write traditional computer-programs to analyze images. A different approach is to construct neural networks that can be trained to do the job.

Work on neural networks, which began in the 1940s, was motivated by the wish to emulate the way the human brain works. While a traditional computer consists of a central processing unit carrying out a specified set of operations sequentially, a neural net-



The neuron receives input signals and produces an output signal. For each input there is a weighting factor, and the activation of the neuron may be influenced by a threshold signal. (Redrawn after figure on p. 8 of Simon Haykin, Neural Networks: A Comprehensive Foundation (New York: Macmillan, 1994).)

1984 AT&T divests itself of operating companies

Society was not much involved with the setting of standards, and the Standards Committee was dissolved. There was, however, at least one Society standards project: the development of guidelines for evaluating speech recognizers.

The Society began activities in an important new area, VLSI for signal processing. In 1981 it co-sponsored, with the Communications Society, the First International Workshop on VLSI in Communications, held in Santa Barbara, California. In 1983 a Technical Committee on VLSI was established, and a workshop was organized biannually.

In 1987 the ASSP Society joined with nine other IEEE Societies to form the Neural Network Committee, whose immediate purpose was the organizing of an annual IEEE Conference on Neural Networks. In 1990 the Committee began publication of the quarterly *IEEE Transactions on Neural Networks*.

Society activities at the local level had declined in the 1970s and early 1980s, reaching a low point in 1985 when there were perhaps just a dozen active Chapters. Charles Rader then led an vigorous effort to reactivate existing Chapters and to establish new ones. (There arose a Catch-22 in dealing with inactive Chapters: disbanding a Chapter required, by IEEE rules, its cooperation, but when the AdCom wanted to disband one, it was no longer active so could not cooperate.) The Society AdCom provided funds for certain Chapter activities, and in 1986 it established a Distinguished Speakers Program. Every year three people were appointed as Distinguished Speakers, each agreeing to visit at least three Chapters in a 16-month term. Many of the Chapters, including the ones in Paris, Switzerland, Central Pennsylvania, and Dallas, held a number of full-scale workshops. In 1987 the number of active Chapters reached 28, and by the end of the decade there were 37 active Chapters, 12 of them outside the United States, including ones in Beijing, Finland, Korea, New South Wales, Spain, Tokyo, the United Kingdom, and Yugoslavia.

Technical Committees
Audio and Electroacoustics Committee
Digital Signal Processing Committee
Multidimensional Signal Processing Committee
Spectral Estimation and Modeling Committee
Speech Processing Committee
Underwater Acoustics Committee
VLSI for Signal Processing Committee

In 1986 the AdCom began considering changing the name of the Society to simply the Signal Processing Society. The main argument for the change was that image processing was a rapidly growing field, but it was not practical to add to an already long name. The change was controversial, but after polling the membership and receiving the approval of the IEEE Technical Activities Board and the IEEE Executive Committee, the Society became on 1 January 1990 the Signal Processing Society. The names of the Society publications reflected the new name with the first issues of 1991; it was decided not to change the name of the annual conference. The Society's new name did much to solidify its position as *the* IEEE Society for signal processing.

The cover of the first issue of the Society's magazine contained this depiction of the Society's technical areas.

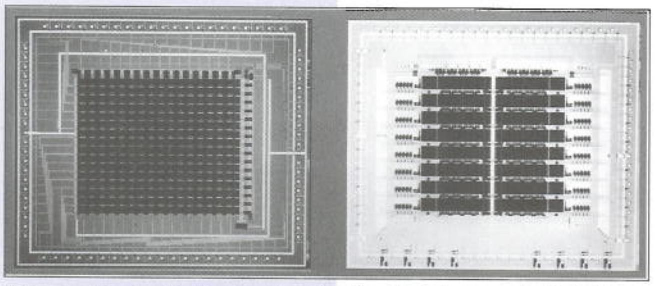
In the 1980s the Society increased its publication activities. The number of pages in Transactions increased from 477 in 1974 to more than 1600 in 1985, and in 1987 the *Transactions* began monthly publication. An important change occurred in 1984, when, at Larry Rabiner's suggestion, Pierce Wheeler, until then editor of the *Bell System Technical Journal*, became managing editor of *Transactions*. Together with his wife Barbara, Pierce Wheeler continued to manage Society *Transactions* for 13 years. At the end of this period, Monson Hayes, who served the Society as Chair of the Publications Board, said,

> "There are few names within the society that are as widely recognized as Pierce Wheeler. … As managing editor, he struggled with page budgets, worried about the length of the review process, handled incredible volumes of papers, finessed the publication schedule for papers, dealt with associate editors overbur-

Interviewer: Does one need to be careful in choosing where to publish a paper, particularly since there is so much overlap in fields?

Thomas Kailath: Yes. It can make a difference to the reception of a paper. I have tended to publish largely in IEEE journals. They are all carefully refereed which is an advantage. It slows down the publication process, but everyone profits, the writers and the readers.

1985 **Mikhail Gorbachev becomes leader of the USSR**



Two neural-network chips developed at Lincoln Laboratory in 1988. The one on the left is a perceptron classifier and the one on the right is a feature-map quantizer. (Lincoln Lab photo reproduced with permission.)

work consists of a large number of processing units working simultaneously and interconnected by multiple links. The basic unit, called a neuron, may have the structure shown in the figure.

Two milestone achievements of the 1950s were Frank Rosenblatt's perceptron (a simple neural network that decides which of two classes a given pattern belongs to) and Bernard Widrow's adaline (adaptive linear element). Engineering interest in neural networks flagged in the 1960s and 1970s, but was strongly revived in the 1980s. Among the causes were new algorithms, the new capability to implement neural networks in very-large-scale integrated (VLSI) circuits, and the belief that massive parallelism was needed for speech and image recognition. Some of the most important new algorithms appeared first in two landmark publications: John J. Hopfield's 1982 paper on recurrent networks, and a 2-volume text, edited by David E. Rumelhart and James L. McClelland and published in 1986, on parallel distributed processing. Quite a few potential applications of neural networks in automatic speech recognition, automatic target recognition, robotic vision, and other areas were shown to be at least feasible, if not yet practical.

The 1980s saw the evolution of the Integrated Services Digital Network (ISDN) from concept to large-scale implementation. The overall aim of ISDN was to maximize the capabilities of the public switched telephone network, allowing transmission of voice, data, and image on a single network. Digital transmission throughout, from subscriber to subscriber, would make this possible, and the standards adopted would be independent of the transmission medium or distance involved. Agreement on standards was reached through the International Telecommunication Union, with an important set of recommendations appearing in 1985. Among the areas of digital signal processing that were vital to ISDN were digital filters, adaptive filters, and signal analysis and recognition. In 1997 an ISDN line allowed a transmission rate of 64,000 bits per second.

Many advances in digital signal processing were stimulated by the satellite-communications business and by space programs. Packet-speech conferencing over a satellite network was demonstrated in 1982. Space communications relied on a whole range of DSP techniques, and NASA's Deep Space Network, arrays of antennas located around the world, continued to perform prodigies of signal extraction (the 1989 Voyager images of Neptune, for example, traveling across almost three billion miles of space).

James Kaiser: Think of the designer of elements of a communication system: he or she has what I call the big parts box next to his or her desk. The parts box has a couple of different compartments, labeled "cheapest element," "next cheapest element," and "most expensive element." Remember, economics is always the name of the game. The engineer is going to try to use as much of the cheap stuff as possible. Well, for continuous filters design, the cheapest thing was wire. That's the cheapest thing going. Next were resistors and capacitors. Inductors were fairly expensive. The most expensive thing, however, was gain. With the vacuum tube supplying gain, you had to provide the filament supply and the plate supply (called the "C+") and so on. Consequently, filters were implemented primarily out of RLCs. Oh, maybe a little later you could get some active filters using miniature tubes, but it was mainly RLCs. These components cost money, so the design techniques for continuous filters were set up so that you were always trying to get the filter of minimum order to meet your specifications. Minimum order meant a minimum number of parts.

When we got the integrated circuit, it was like somebody completely changed the rules. The cheapest thing around now was gain—supplied by the transistor. You could lay down the resistors, that was easy. Capacitors were fairly easy. Inductors were still pretty hard, but you didn't really need those. You could leave those out of an instrument. The most expensive thing around, however, was the interconnection—the wire! All of the sudden, the tables were completely turned around.

What was happening in the 1980s

movies people were watching:

- *Amadeus*
- *ET: The Extra Terrestrial*
- *Rainman*
- *A Room With a View*

TV shows people were watching:

- "The Cosby Show"
- "Dallas"
- "Saturday Night Live"

music people were listening to:

- Bobby McFerrin's "Don't Worry, Be Happy"

books people were reading:

- *In Search of Excellence* by Thomas Peters and Robert Waterman
- Garrison Keillor's *Lake Wobegon Days*

1986 explosion of the space shuttle ***Challenger***

Society Award	
1980	Lawrence R. Rabiner
1981	James F. Kaiser
1982	Ronald W. Schafer
1983	James W. Cooley
1984	Charles M. Rader
1985	Ben Gold
1986	Kenneth Steiglitz
1987	Thomas W. Parks
1988	John Makhoul
1989	Russ Mersereau

Technical Achievement Award	
1980	Thomas W. Parks
1981	Kenneth Steiglitz
1982	John Makhoul
1983	Leland B. Jackson
1984	Bede Liu
1985	C. Sidney Burrus
1986	James H. McClellan
1987	Jont B. Allen and Thomas S. Huang
1988	Thomas Kailath
1989	Benjamin Friedlander

dened with "too many papers," answered phone calls and letters from disappointed authors, and interfaced with Publication Board chairs."

Another change came in 1981 when the ASSP Society joined with three other Societies—Engineering in Medicine and Biology, Nuclear and Plasma Sciences, and Sonics and Ultrasonics—to establish a new quarterly journal, the *IEEE Transactions on Medical Imaging*, which began publication in 1982.

When Rao Yarlagadda became editor of the newsletter, it became a much more substantial publication, averaging 30 pages per issue during his 4-year editorship. Its success led to the establishment of a magazine in 1984, the *IEEE ASSP Magazine*. Modeled on the magazine of the Circuits and Systems Society, it was to take over the functions of the newsletter and to have refereed articles, principally overview articles and articles with a practical slant.

The Society continued to honor outstanding achievement. The winners of the two highest awards are listed in the tables.

ICASSP, the Society's annual international conference, became even more successful in the 1980s. Toward the end of the decade the budgets for ICASSPs were near $500,000, so they became a major business venture as well as a technical conference. The table lists the dates and sites of the ICASSPs of the 1980s.

For Society leaders, internationalism was an issue. In 1986 ASSP Society President Tom Crystal wrote

> … in the areas covered by our Society, internationalism has been a significant benefit. For example, speech analysis, coding, and recognition methods utilized for our own national benefit were invented and developed by engineers whose nationalities and countries-of-origin span the globe. What is personally more important for me in my promotion of ASSPS and IEEE transnationalism is the international fellowship of our Society.

The International Conference on Acoustics, Speech, and Signal Processing

9-11	April 1980	Denver, Colorado
30	March - 1 April 1981	Atlanta, Georgia
3-5	May 1982	Paris
14-16	April 1983	Boston, Massachusetts
19-21	March 1984	San Diego, California
26-29	March 1985	Tampa, Florida
8-11	April 1986	Tokyo
6-9	April 1987	Dallas, Texas
11-14	April 1988	New York
23-26	May 1989	Glasgow, Scotland

A large number of the Society's workshops took place outside the United States, and in 1983 four of the 16 members of the *Transactions* Editorial Board resided outside the U.S. The Society continued to lead the IEEE in becoming transnational: in 1987 29 percent of the Society membership resided outside the U.S., while that was true of only 9 percent of the IEEE membership as a whole. In 1989 about one-third of the Society members resided outside the U.S. The trend toward internationalism, for the Society and for IEEE as a whole, continued strongly in the 1990s.

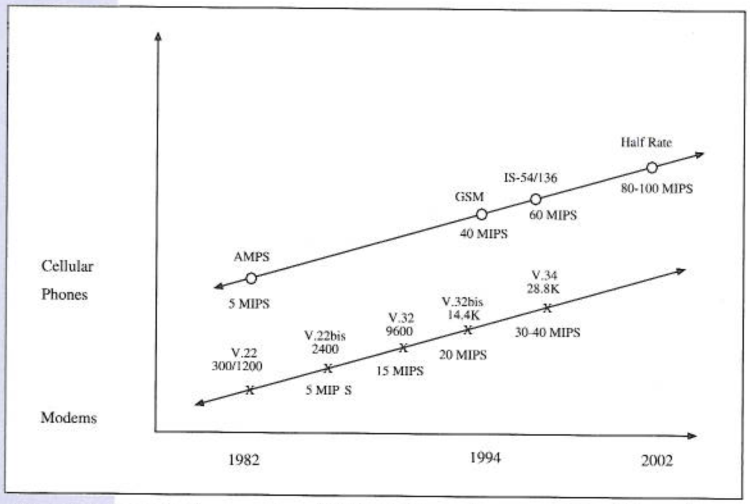
Breakout: The 1990s

The advantages of digital signals are so overwhelming that essentially all communication technologies are changing to this form.
—John G. Truxal (The Age of Electronic Messages (Cambridge, MA: MIT Press, 1990), p. 227)

The 1990s began a new era in international relations. The Cold War had dominated the years from 1945 to 1990, as that struggle between the superpowers was often superimposed on regional and local conflicts. In the 1990s it was economic relations—in an increasingly globalized marketplace—that took center stage. World trade had increased 10-fold from 1950 to the early 1990s, and in the mid 1990s there were some 37,000 multinational enterprises with some 200,000 foreign affiliates worldwide. One of the essential factors leading to this growth of international trade and multinational enterprise was the modern system of global communications that facilitated transnational operation.

The 1990s may be remembered as the decade the human race made its greatest strides toward interconnection. The worldwide telephone network continued to grow in extent, especially in the less industrially developed parts of the world, but rather unexpectedly it grew spectacularly in density, as it connected modems, pagers, cellular phones, fax machines, and the second and third telephones that many families found they wanted. To traditional broadcasting- and cable-television was added, for millions of people, television broadcast from satellites. Even more so than in previous decades, much of the world experienced through television the same events at the same time, such as the Persian Gulf War in 1991 and the funeral of Princess Diana in 1997. Added to this was the effect of the Internet, as personal computers, in addition to being stand-alone devices, became tools of access to this network, and millions of people all around the world viewed the same Web sites and joined in virtual communities concerned with almost any conceivable subject.

Signal processing played an important part in all of these changes. So it is not surprising that, after decades of steady growth and the cultivation of niche markets, signal processing achieved something of a breakout in the 1990s. In 1985 there were only three large commercial markets for DSP chips—speech coding, video compression, and modems—which, together, were a $50-million business. The growth of these three applications and the appearance of many new ones, such as cellular phones, sound boards, hard-disk drives, scientific instruments, and robotics resulted in a DSP business totaling $2.2 billion in 1995, as programmable and function-specific DSP achieved large markets.



This graph shows the increase since 1982 in DSP speeds, measured in millions of instructions per second (MIPS), for two applications, cellular phones and modems. (Redrawn after Figure 11 *of Gene Frantz and Panos Papamichalis, "Introduction to DSP solutions" (Texas Instruments Technical Journal, vol. 13 (1996), no. 2, pp. 5-16).)*

The breakout for signal processing came with continuing growth of the consumer electronics market. Some of the products that have become popular in the 1990s, besides those already mentioned, are multimedia PCs, laptop computers, scanners, projection TVs, widescreen TVs, broadcast satellite antennas, camcorders, digital cameras, fax machines, cordless telephones, and tapeless answering machines. Most of these products contained DSP chips, and signal processing thus provided a significant push to consumer electronics.

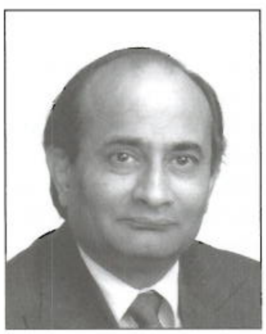
The advance of integrated circuit technology continued in the 1990s, as the density of components on chips continued to follow Moore's law, doubling every 18 months. An important benchmark was the Pentium chip, introduced in 1994, which contained five

Breakout: The 1990s

Signal processing technologies underwent an explosive growth in the 1990s, and the IEEE Signal Processing Society played a large role in this growth. The Society increased its membership, but much more significant was the increase in Society activities, especially in publications and conferences.

John G. Ackenhusen received five degrees from the University of Michigan: B.S., B.S.E., M.S., M.S.E., and Ph.D. He worked at Bell Laboratories, where in 1981 he became head of the Speech Recognition Group and in 1988 of the Signal Processing Systems Design Department. In 1991 he joined the Environmental Research Institute of Michigan (ERIM) to lead its Image and Signal Processing Laboratory. Ackenhusen has performed and directed research and development in real-time signal processing, both developing algorithms and designing computer architectures. Besides serving as President of the Signal Processing Society in 1990 and 1991, he was IEEE Division IX Director in 1994 and 1995.

David C. Munson, Jr. received the B.S. degree from the University of Delaware and the M.S., M.A., and Ph.D. degrees from Princeton University, the last in 1979. Since then he has been on the faculty of the University of Illinois at Urbana-Champaign. His research has concerned a variety of topics in signal and image processing, with an emphasis on computational imaging, especially synthetic aperture radar. For many years he has worked for the Society, including as President for 1992 and 1993 and as founding editor-in-chief of Transactions on Image Processing from 1992 through 1995.



Tariq S. Durrani received a bachelor of engineering degree from the Engineering University in Dhaka, before earning M.Sc. and Ph.D. degrees in electronics at the University of Southampton. Since 1982 Durrani has been professor at the University of Strathclyde, Scotland, where he is now head of the Signal Processing Division and director of the Centre for Parallel Signal Processing. His research has concerned spectral analysis, adaptive array processing, image processing, and neural networks. His many activities in the Signal Processing Society include the presidency in 1994 and 1995.

Don H. Johnson attended MIT, where he received the S.B. and S.M. degrees in 1970 and the Ph.D. degree in 1974. In 1977 he joined the faculty of Rice University in Houston, Texas, where he is currently Professor of Electrical & Computer Engineering and of Statistics. Johnson has served the Society in many capacities, including as President for 1996 and 1997. His research concerns statistical signal processing, particularly non-Gaussian problems.

"I have a confirmed reservation at this hotel, and I'm told you do not have a room for me," I said incredulously. "Yes, that's correct," he confirmed. "We're sorry." "You're *sorry*? But I have a confirmed *reservation*!" I repeated in utter frustration. The desk clerk knew what was coming. His boss was not The Manager for no reason. "Sir, there's something I must explain to you about the hotel business that apparently you don't understand." "What's that?" "Sir, a reservation means we reserve a room—*if we have one*."

— Jack Deller, *Signal Processing Magazine*, October 1991, p. 8.

It is a universally accepted fact that SP engineers are charming, good-looking, and well above average in almost every way, so it's not surprising that in matters of dating and romance, we are among the most desired of partners. However, this guy was taking advantage of this fact to a degree which made this midwesterner more than bit uncomfortable. This man had so many "girlfriends" that the "Peggys" alone had to be further categorized by an identifying alphabetic character. He seemed to favor "J-Peg" and "M-Peg" because he kept offering to show me images of them created on his workstation.

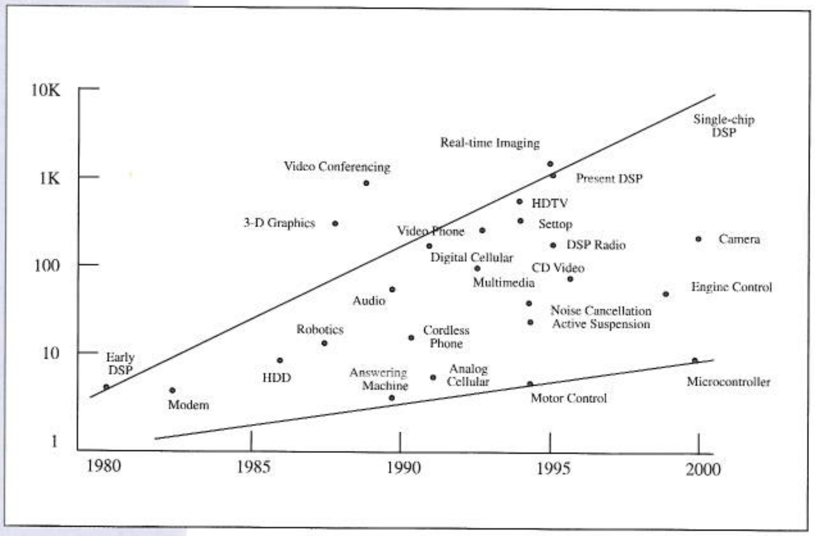
— Jack Deller, *Signal Processing Magazine*, October 1994, p. 4.

Whereas few undergraduates put much stock in the idea that the twisting and mixing prescribed by convolution is a reasonable way to compute an output from an input, even fewer of them would buy the notion that this mess could be untangled, or 'deconvolved', to recreate the input. ... we would completely lose our credibility with the first-time convolver by suggesting the possibility of 'blind' deconvolution.

— Larry Paarmann, *Signal Processing Magazine*, May 1996, p. 22.

1990 **2 August: Iraqi forces invade Kuwait** million transistors. DSP chips, too, attained greater component density, and the Texas Instruments DSP chip TMS320C805, introduced the same year as the Pentium, also contained five million transistors. There were also reductions in IC power dissipation, and it became common to include analog functions on a DSP chip.

Such advances, combined with mass production, brought down the cost of digital signal processing. In the 1990s it could be less than \$1 per MIPS (millions of instructions per second), while in the 1960s the machines capable of digital signal processing cost perhaps \$1000 per MIPS. This fact alone goes far in explaining the explosive growth of DSP applications. With IC technology, as with the consumer electronics market, signal processing gave as well as received: DSP applications are today as important as the computer industry in driving the technology of high-speed, low-power integrated circuits.



The two lines in this chart show the increase in speed (measured in millions of operations per second) for single-chip DSPs and microcontrollers respectively. New application areas are placed according to date and processing speed. (Redrawn after Figure 14 of Gene Frantz and Panos Papamichalis, "Introduction to DSP solutions" (Texas Instruments Technical Journal, vol. 13 (1996), no. 2, pp. 5-16).)

The lowered cost of calculation certainly opened new areas of application. So too did increased speed, especially with real-time signal processing. This resulted from faster ICs and, more importantly, better algorithms. The proliferation of applications led to a greater variety of DSP chips: in the late 1990s Motorola offered a compatible line of 16-, 24-, and 32-bit DSPs; Texas Instruments offered more than 150 DSPs, most notably those in its TMS320 family; and Lucent and many other manufacturers offered a great many more DSP chips.

Extremely important in the growth of DSP applications has been the availability of software support. Filter-design programs go back several decades, such as the Parks-McClellan program from the early 1970s, which has been perhaps the most widely used. More recently, two classes of software have been of great importance: code-generation tools and tools for system integration and debugging. The former allow a programmer to use a higher-level language. For example, the optimizing C-compiler produces assembly-language code that is nearly as efficient as the hand-assembled programs. The system integration and debugging tools, such as software simulators, hardware emulators, and system evaluation tools, have streamlined the development process.

It is a trite understatement to say that the SP field (or should we say fields?) is rapidly exploding. The half-lives of new SP technologies are ever-shorter and acronyms and jargon proliferate like genetic algorithms gone awry.

— Jack Deller (IEEE Signal Processing Magazine, vol. 11 (1994), no. 4, p. 4)

Among the many advances in communications in the 1990s were the rapid development of mobile communications, as cellular phones became commonplace. The transmission capacity of optical fiber continued to follow its own law of exponential increase: 10-fold every four years since 1975. By 1990 virtually all of the 140 largest metropolitan areas in the United States were connected by optical fiber. Videoconferencing did become easier, but is still not very much used.

There was also a continuing movement toward the digitization of communications and information storage. Digital cellular phones and PCS (Personal Communication Services), also digital, became popular. Digital standard television was introduced. Image scanners became common. They allowed the digitization of documents of all sorts, especially those with graphs, charts, diagrams, and pictures, and they were made more useful by the use of software for optical character recognition.

Until the 1990s telephone answering machines incorporated an analog tape

1991 Maastricht Treaty for integration of the European Community

Leah H. Jamieson received the B.S. degree in mathematics from MIT. From Princeton University she received the M.A. and M.S.E. degrees and the Ph.D. degree in electrical engineering and computer science. She is currently Professor at Purdue University. Her research includes the areas of speech processing, engineering education, and the design of parallel algorithms and software tools for signal-processing applications. Jamieson has been active in the Society on the Board of Governors and on many committees, and she is President for 1998 and 1999.

Early in the decade, because of the growth of Society activities, the AdCom began discussions with IEEE staff and volunteer leaders about creating a full-time Society staff, headed by a Chief Executive Officer. In 1992 John Ackenhusen noted these advantages: "Our Society will have an address, a telephone number, a repository and distributor of information, an advocate and birddog located within IEEE, and a continuous presence that transcends the temporary terms of officers and other volunteers." In March 1993 Mercy Kowalczyk, formerly Director of IEEE Corporate Services, became the new Executive Director of the Society.

Because the Society had grown and changed in other ways, major revisions of the Constitution and Bylaws were called for. A number of Society leaders, including Tom Crystal, Leah Jamieson, Maureen Quirk, and Sid Burrus, made substantial progress toward reaching an appropriate document. In 1993 Mercy Kowalczyk, working with the guidance of then President David Munson, brought the task to completion, and the new Constitution and Bylaws were approved by the AdCom in October 1983. Instead of an Administrative Committee consisting of the Society officers and nine members-at-large, the Society would be headed by a Board of Governors consisting of the Society officers and 12 members-at-large. Perhaps because any 20-person entity is likely to be cumbersome and unwieldy, the Board of Governors was soon being referred to as the BoG, and a smaller Executive Committee was created, which was empowered to meet and to act on Society matters between the twice-yearly meetings of the Board. There were some other changes to the Society organization.

Board of Governors
Awards Board
Conference Board
Publications Board

Chapters Committee
Education Committee
Finance Committee
Membership Committee
Nominations and Appointments Committee
Technical Directions Committee

In 1993 a revised statement of the Society's field of interest was approved: "The Signal Processing Society addresses the theory and application of filtering, coding, transmitting, estimating, detecting, analyzing, recognizing, synthesizing, recording, and reproducing signals by digital or analog devices or techniques. The term 'signal' includes audio, video, speech, image, communication, geophysical, sonar, radar, medical,

In 1996 the Society selected this logo, which was designed by Gabriel Thomas, at the time a graduate student in signal processing at the University of Texas, Austin.

Thomas Huang: One point I want to make again is that the trend now is for different fields to come together to work on interdisciplinary problems. Where I am at Beckman, I see several such interactions. One is signal processing, image processing, and computer vision coming together with computer graphics—in many applications you need analysis as well as synthesis, like in the modeling approach to video compression. The other interdisciplinary effort is in multi-modality, the merging of image analysis with speech in solving problems. So, I think we'll see more and more of these interdisciplinary efforts. In another example, we are getting into image video databases, so we have to work together with people in computer science, data structure, and information retrieval.

Interviewer: Isn't that a general trend, that digital signal processing is expanding its domain?

Bede Liu: Yes. People ask me, "What are you working on?" I say, "I'm doing digital signal processing," and I say it with such pride, and complacency. It's a little bit of the herd instinct. I belong to the blue tribe, which is better than the others. It's almost like computers. Computers now are so prevalent. They are almost every place. You say, "I work on computers," and it doesn't give that much information. Signal processing is getting to a point where it will be almost every place. It probably is unnecessary to toot the horn for signal processing—it's proven!

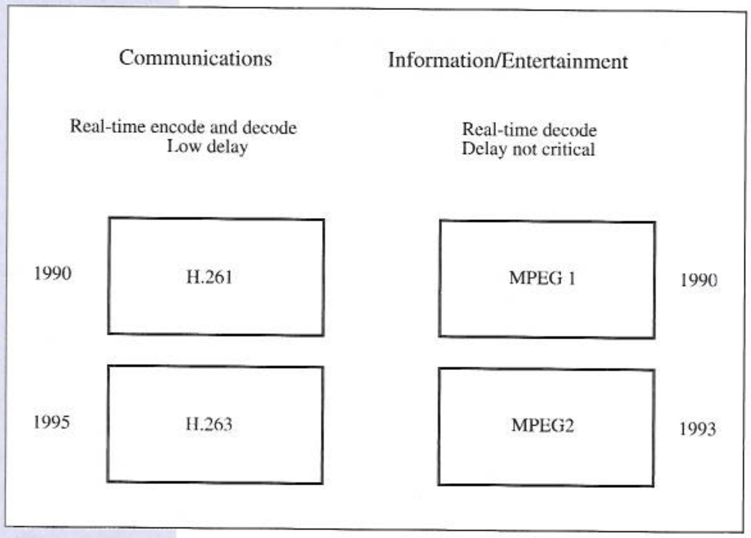
Researchers today working in this area [of multimedia signal processing] have the privilege of selecting the future direction of MMSP technologies, so what they are doing will deeply influence our future society. This means they bear a great responsibility for our future.

— Ryohei Nakatsu (IEEE Signal Processing Magazine, vol. 14 (1997), no. 4, p. 36)

recorder. In the mid 1990s digital telephone answering devices (DTADs) began to claim a large share of the market. DTADs offer many advantages, such as message manipulation capability (skip, save, selective delete, and so on), increased reliability (not having the tape recording and reading mechanism), and the ability to add value-enhancing features (such as caller-ID, full-duplex speakerphone, and speech recognition) with small addition to the unit cost. DTADs are, needless to say, highly dependent upon DSP technology.

As we have already seen, digital means have gradually displaced analog means for recording, processing, transmission, and reproduction of audio. In the 1990s two new standards, MPEG1 and MPEG2 (discussed further below) made efficient coding of audio widely used, as they allowed CD-like quality with six-to-one or twelve-to-one compression ratios. In the early and mid 1990s the film industry switched from analog to digital formats. In the 1990s there has been much work on microphone arrays, especially for teleconferencing, such as self-steering arrays (that electronically aim at the person speaking at that moment) and adaptive beamforming (in which the beamforming program adjusts its parameters on the basis of received data). Also notable has been work on recording and reproducing a 3-dimensional sound-field, and on DSP-assisted loudspeakers (which have built-in digital filters to correct for the shortcomings of speaker performance).

In the 1990s image processing became an even more prominent branch of signal processing. Since video in uncompressed form requires great bandwidth, effective means of image compression are required for many transmission and storage technologies to be practical. Here, as with many other areas of DSP, international standards have been vital to rapid technological and commercial development. As a standard for videophones the International Telecommunications Union developed H.261; approved in 1990, it was intended for use on ISDN lines at 64 kbps or a multiple of that rate. For lower bit-rates, H.263 was defined in 1995. The Moving Pictures Expert Group (MPEG) reached agreement in 1990 on a standard for CD video and audio, known as MPEG1, then went on to define a more general syntax that could be used for broadcast video. MPEG2, adopted in 1993, can apply to digital standard television, digital high-definition television, and the DVD (digital versatile disk). MPEG4, still under development, will apply to video coding at low bit-rates, such as are typical for Internet connections.



Four important standards for video compression, along with their dates of adoption, are shown. (Redrawn after Figure 2, with dates of adoption added, of Karen Oehler, Raj Talluri, Yuji Itoh, and Fritz Whittington, "Digital video compression" (Texas Instruments Technical Journal, vol. 13, no. 2 (March-April 1996), pp. 27-40).)

MPEG2 has been a great achievement from several points of view. At its meetings, which began in 1990, hundreds of experts from around the world contributed their knowledge and opinions. It became a very broad standard: it includes MPEG1 as a subset, and its original goal of defining coding for standard digital television expanded to include HDTV, thus obviating the planned MPEG3. The standard was reached swiftly, as MPEG was meant to be an anticipatory standard. And it has been of enormous commercial importance: it has been adopted for direct-broadcast and cable television, and it is the core of the so-called Grand Alliance standard for HDTV. The driving force behind MPEG has been Leonardo Chiariglione of the Centro Studi e Laboratori Telecomunicazioni SpA (CSELT) in Turin, Italy. In 1996 the U.S. broadcasting industry awarded MPEG, along with JPEG, an Emmy.

The 1990s have been years of rapid change for television. On 3 June 1989 Japan

1992 3 November: Bill Clinton elected U.S. President

Technical Committees
Audio and Electroacoustics
Design and Implementation of Signal Processing Systems
Digital Signal Processing
Image and Multidimensional Signal Processing
Multimedia Signal Processing
Neural Networks for Signal Processing
Speech Processing
Statistical Signal and Array Processing
Underwater Acoustics

musical, and other signals." In 1996 the Society also adopted a logo; it became a registered mark in 1997.

In mid decade the Technical Committee on VLSI for Signal Processing changed its name to the Committee on the Design and Implementation of Signal Processing Systems to reflect the wider scope of the committee's activities (including the embedded software and the design methodologies). Its workshop became annual—rather than biannual as in the 1980s—and changed its name in 1997 to Workshop on Signal Processing Systems. Almost all of these workshops resulted in an edited volume *VLSI Signal Processing* published by IEEE Press; ten of these influential books had been published by 1998.

In 1996 the Society established a new Technical Committee, for Multimedia Signal Processing, with the objective of promoting SP research for technologies that process multiple signal sources (speech, music, text, image, and video) and to bring together engineers from the communications, computer, and networking communities. It soon organized its first workshop, held 23-25 June 1997 in Princeton, New Jersey, and began work toward establishing a *Transactions*.

The growth of Society publications and meetings strained existing procedures, and in 1990 a New Technology Directions Committee, chaired by David Munson, was formed to consider "options for increasing the focus of the Society on the individual needs of a diversity of members while growing in response to an ever-broadening field." One such option was specialization in Society publications.

In 1982 the Society published about 1000 pages in *Transactions.* In 1986 the page total was 1687, and in 1991 it reached 2749. This was about the largest number of pages annually that could be accommodated in one *Transactions.* Another, and more serious problem, was that Society members working in image processing were in many cases sending their work elsewhere because the Society had no journal focused on image processing. The proposal to establish a second Society *Transactions*, the quarterly *IEEE Transactions on Image Processing*, met with considerable opposition from other IEEE Societies, some seeing it as an intrusion on their territory and some arguing that it was not necessary. David Munson led the fight to win approval for the new journal, and when it was established in 1992 he was named Editor-in-Chief. The journal was an immediate success, and it quickly moved from quarterly to monthly publication.

At the same time the Society began considering establishing a transactions on speech processing and a special type of transactions for the rapid publication of research results in all the technical areas of the Society (later called *Signal Processing Letters*). The *Transactions on Speech and Audio Processing* began publication in 1993, and *Signal Processing Letters* the following year. These publications were "unbundled" from Society membership, so that each member received, besides the magazine (which all received), only those publications he or she wanted (and was willing to pay a small amount extra for). With continuing specialization in publications and conferences, it was hoped that *Signal Processing Letters* would, as Munson put it, "be the 'glue' of our society, where a

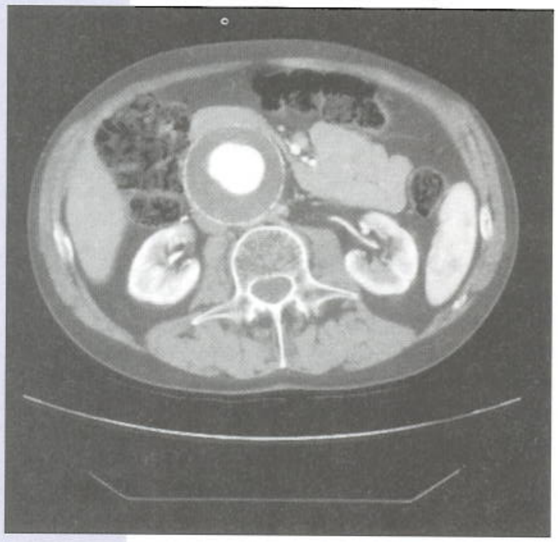
I feel very fortunate that people like Ben Gold, Charlie Rader, and Richard Lacoss are at [Lincoln] Lab where I can see them every week. It kind of brings the technology alive for me to hear about how some of the ideas we take for granted today had to be developed, tested, and proven with the '60s technology. It makes me realize that my job is to try and be creative enough to conceive and develop the ideas that will be taken for granted in the '20s (that's 2020s) with the paltry technology of the '90s.

— Dan Dudgeon, *Signal Processing Magazine*, July 1996, p. 12.

In the first half of this century, what engineers dreamed about doing was limited by hardware: vacuum tubes and RLC circuits. In the second half, digital computers made algorithm and computational speed the only limitations. Digital signal processing took off in the mid-1960s, when computer availability, the rediscovery of the fast Fourier transform by Jim Cooley and John Tukey, and the publication of the book by Ben Gold and Charlie Rader occurred within a few short years. During this period and years thereafter, algorithms drove applications. ... So many applications were around that finding one was easy because the underlying technology had many obvious advantages. While exceptions do exist (wavelets, for example), the field largely no longer works that way. Take it as a sign of a mature (but not ancient) field that applications drive new algorithms.

— Don H. Johnson, *Signal Processing Magazine*, November 1996, p. 12.

initiated broadcasting of HDTV programs; although the source signal is defined in a digital format, the transmission is analog. It now appears that Japan, like the rest of the world, will adopt fully digital HDTV. Digital satellite systems, broadcasting television directly to homes, have rapidly become a large business; in 1996 more than three million direct-to-home systems were sold in the United States. Digital cable television began to be available in some areas. In the United States since 1993 new television sets with 13-inch or larger screens have contained captioning decoders. And though 4-channel sound had failed to gain consumer acceptance when it was introduced under the name 'quadraphonic sound' in 1969, multichannel audio did succeed in the 1990s in the form of "surround sound" or "home-theater" systems.



This example of computed tomography is an abdominal section produced by CT fan-beam reconstruction. (Reproduced by permission from IEEE Signal Processing Magazine, March 1997, p. 56.)

Another area of application of DSP has been digital photography. By 1997 almost every major camera manufacturer was offering digital cameras, which allow editing and enhancement of images in the cameras themselves and easy transfer of images to business and home computers. Techniques of digital image enhancement include contrast enhancement, edge sharpening, pseudo-color enhancement (because the human eye discriminates many more colors than it does shades of gray), and removal of the effects of degrading phenomena (such as lens aberration), and such techniques have been of great importance in science, being used by archeologists, astronomers, ecologists, geologists, meteorologists, oceanographers, and others. Work on multispectral image compression has been important for satellite sensing systems, since such systems are constrained by downlink communications bandwidth.

The 1990s have seen the widespread application of signal processing in medical imaging, such as x-ray computed tomography, positron-emission tomography, electrical impedance tomography, optical imaging, cardiac electrical imaging, magnetic resonance imaging, ultrasound imaging. Image restoration techniques were important in processing images from the Hubble Space Telescope.

The field of signal processing has continued to make heavy use of computers, and in the 1990s it became common for computers to assist with analytical, as well as numerical problems, through symbolic processing and object-oriented programming. In the 1990s the debt was more than repaid in the way DSP enhanced the performance of personal computers and workstations. Indeed, Leonardo Chiariglione has argued that the signal processing field and the data processing field are converging, as programmable signal-processors have become common and as computers use complex signal processing for input, output, and storage. For example, in the 1990s DSP chips became a standard part of hard-disk drives and CD-ROM drives, being used to control the disk and the reading head. At first it took a dozen DSP chips to run a disk drive. The number was reduced by half in the late 1990s, and manufacturers now aim at being able to run a disk drive with a single chip.

This is one of many instances of the use of DSP in control systems. Much more prominent have been the enhancements to computer interfaces, notably in the multimedia computers of the 1990s, where DSP chips handle audio and visual information quickly, taking over this task from the main microprocessor. People have begun using voice-recognition software for computer control. And signal processing has played a central part in the growth of the Internet and the World Wide Web, as high-speed modems and data-compression techniques vastly expand the possibilities of interconnected computers.

In the 1990s there has been increased interest in neural networks for signal processing. They have proved useful for interference rejection in wireless communications.

member working on any single aspect of signal processing can be exposed to concise treatments of new ideas from other areas."

In 1994 Society President Tariq Durrani reported that the splitting of the *Transactions* was a success: "It has led to increased circulations, an increase in the total number of pages now published in Transaction form by the Society, a cutback on the backlog of publications, and a continually increasing rate of quality submissions." The Society also co-sponsored four other *IEEE Transactions*, ones on Evolutionary Computation, Fuzzy Logic, Medical Imaging, and Neural Networks. In addition, the Society produced and marketed video courses on particular topics in signal processing (based on tutorials prepared for Society conferences).

Signal Processing Magazine, extremely well received by the members, became a major signal-processing journal, as some of its papers came to be among the most cited in the field. In 1995 it went from quarterly to bimonthly publication. Jack Deller, editor-in-chief for six years, was the person most responsible for this great success. Society President Don Johnson wrote, "It is impossible to express the degree of sincere thanks I feel for Jack Deller's editorship … Because of him magazine articles have improved in quality and timeliness, and the magazine has become a major voice of signal processing ideas."

The Society made a number of steps toward electronic publishing. In 1992 the Image and Multidimensional Signal Processing Technical Committee initiated an electronic newsletter. Proceedings of ICASSP were made available on CD-ROM beginning in 1993. In 1996 Ahmed Tewfik, Mos Kaveh, Don Johnson, and other Society leaders began working with IEEE Publications staff to provide Web access to SPS journals, and this began in 1997 when *Signal Processing Letters* was one of the first IEEE publications to be made available online. The next year all Society *Transactions*, as well as *Letters*, were available online. In 1997 Richard Cox, SPS Vice President for Publications, began working toward the goal of having the algorithms and data associated with an article available online so that a reader could judge algorithms directly, even applying them to other data sets.

Recognition of achievement in signal processing remained an important activity of the Society. The winners of the Society's two highest awards in the 1990s are listed in the tables.

As always, the Society participated in IEEE awards, including Fellow status. In 1997 the IEEE established a new Institute honor, the IEEE Jack S. Kilby Signal Processing Medal. The idea for this medal came from Tariq Durrani and Panos Papamichalis, who secured the sponsorship of Texas Instruments. The first Kilby Signal Processing Medal was given jointly to Bernard Gold and Charles S. Rader. In 1998 Thomas G. Stockham, Jr.

Society Award

1990	Thomas Kailath
1991	Thomas S. Huang
1992	Bishnu S. Atal
1993	Robert M. Gray
1994	C. Sidney Burrus
1995	James H. McClellan
1996	Fumitada Itakura
1997	Frederick Jelinek

Technical Achievement Award

1990	Robert W. Broderson
1991	Richard A. Roberts
1992	Sun-Yuan Kung
1993	David G. Messerschmitt and John W. Woods
1994	Thomas P. Barnwell, III, and Louis L. Scharf
1995	Teuvo Kohonen and Sanjit K. Mitra
1996	Murat Kunt and Petre Stoica
1997	Robert M. Gray and Boaz Porat

The International Conference on Acoustics, Speech, and Signal Processing

3-6	April 1990	Albuquerque, New Mexico
14-17	May 1991	Toronto, Ontario
23-26	March 1992	San Francisco, California
27-30	April 1993	Minneapolis, Minnesota
18-22	April 1994	Adelaide, South Australia
9-12	May 1995	Detroit, Michigan
7-10	May 1996	Atlanta, Georgia
21-24	April 1997	Munich
12-15	May 1998	Seattle, Washington
14-19	March 1999	Phoenix, Arizona

Mark J.T. Smith (right), an IEEE Fellow, Georgia Tech professor, and author of many papers on signal processing, was twice a member of the U.S. Olympic Fencing Team (in 1980 and 1984). In 1996, shortly after ICASSP was held in Atlanta, Smith was part of the chain of torchbearers taking the Olympic flame to the site of the summer 1996 Games. He was at the time a member of the Society's Board of Governors. (Reproduced by permission from IEEE Signal Processing Magazine, November 1996, p. 20.)

Fortunately, there will always be signals that need to be processed; advances in technology will continue to offer new opportunities for sophisticated systems; and this, in turn, energizes creativity in algorithm development and refinement for practical systems. Frankly, I don't ever see an end to this cycle.

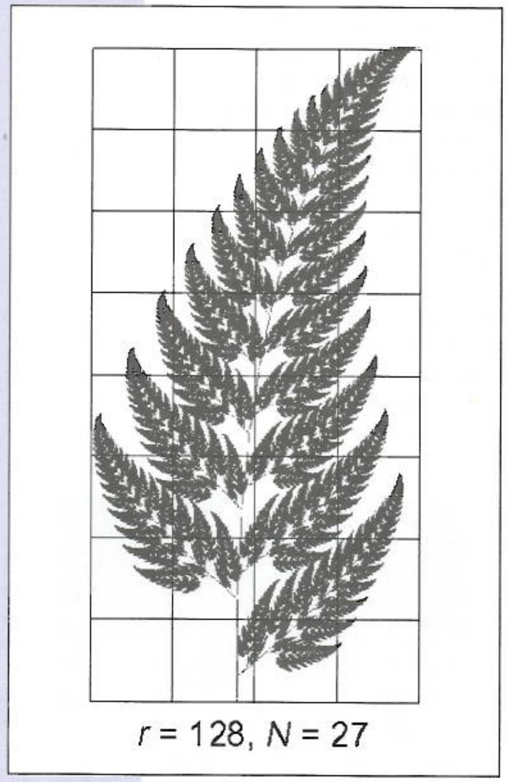
— Alan V. Oppenheim (RLE Currents, vol. 2 (1989), no. 2, p. 10)

Neural networks for aircraft control and for automobile-engine control are being developed. Neural network techniques have helped in image restoration and, because of their highly parallel nature, led to efficient VLSI architectures for image restoration.

Among the most exciting developments of the past decade have been the application by SP engineers of the concepts of fractals, chaos, and wavelets. Fractals are objects in geometry that have non-integral dimension. Fractal coding has been extensively applied in image compression.

In physics, a chaotic system is a mathematically defined system that evolves in a seemingly random way, neither approaching a steady state nor cycling through a sequence of states. Recently, chaotic models have been employed in signal processing. For example, Simon Haykin modeled sea clutter (that is, the radar backscattering from an ocean surface) as a chaotic process in order to build a neural network for use in canceling sea clutter.

Wavelets are a mathematical decomposition technique, which may be viewed as an extension of Fourier analysis. The theory underwent considerable development in the mid 1980s, and it was soon applied to digital signal processing by Ingrid Daubechies and Stefan Mallat. Besides stimulating some new approaches to signal processing, wavelet theory provides a unified framework for techniques already developed for particular SP applications. Among the areas where wavelets have been successfully applied are image processing, speech processing, data compression, subband coding, multiresolution analysis, and wideband correlation processing.



A fractal that has found application in signal processing is Barnsley's fern.

There have been other new departures for signal processing in the 1990s. One example is work, which has led to commercial application, on so-called fuzzy algorithms, which use fuzzy logic. This type of logic, invented by Lotfi Zadeh in the 1960s, is based on the concept of a fuzzy set, for which membership is expressed in varying degrees. Another example is work on so-called genetic algorithms, which use a searching process modeled on the laws of genetics and natural selection. Genetic algorithms have been applied as an optimization tool in many areas of signal processing. The widespread use of object-oriented programming for DSP might also be mentioned.

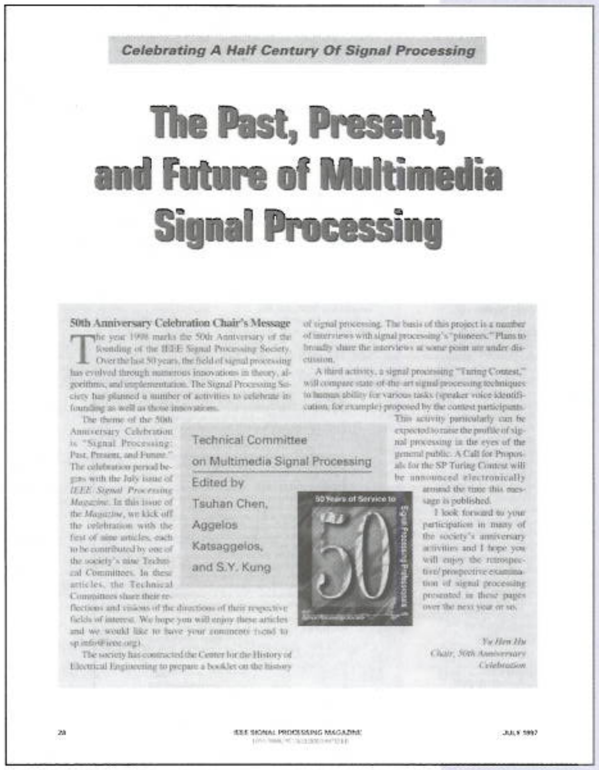
A sign of the fecundity of signal processing is its growth into other areas of engineering, such as control systems, imaging systems, and instrumentation. Indeed, the wide applicability of its concepts and techniques is eroding boundaries between disciplines. Information theory, coding theory, communication theory, and neural network theory are all closely related to signal processing theory.

Ours is an information age. Much of the economy and a large part of an individual's experience depend upon electronically-mediated information flows. Even more broadly, the rapid pace and global scope of all of modern life—economy, politics, entertainment, science—depend on electronic communications. And virtually all of these information flows involve the work of signal-processing engineers. What's more, no longer is signal processing an obscure technical specialty. In the 1990s, Stephen Hawking (a physicist who, because of a neuromotor disease, is able to talk only through a voice synthesizer) and tapeless answering machines call attention to speech synthesis. Advertisers tout the number of pixels in images from digital cameras. People using the Internet discuss modem rates and data compression. And widely available computer software allows anyone to manipulate music or enhance images. In short, after 50 years of development, signal processing has taken on a large and prominent role in modern life.

received the award. The U.S. National Medal of Science and the National Medal of Technology are the nation's highest honor for scientific and technological achievement. At least four Society members (two of them former Society Presidents) have received these medals: in 1990 Marvin Camras received the National Medal of Technology; in 1996 James Flanagan received the National Medal of Science; and in 1997 Ray Dolby and Robert E. Kahn each received the National Medal of Technology.

ICASSP maintained its excellent tradition. In the 1990s, three of them took place outside the United States, and ICASSP2000 is scheduled to take place in Istanbul.

Alan Bovik and David Munson, with the strong support of the Image and Multidimensional Signal Processing Technical Committee, worked to establish a second major international conference series, the International Conference on Image Processing (ICIP). Though there was considerable opposition to establishing a second major conference, many people felt that ICASSP had become too big and that a major annual conference devoted to the rapidly growing field of image processing would help to focus research. The first and subsequent ICIPs have been highly successful and have raised the Society's profile in image and video processing.



Celebrating A Half Century Of Signal Processing

The Past, Present, and Future of Multimedia Signal Processing

Technical Committee on Multimedia Signal Processing

Edited by Tsuhan Chen, Aggelos Katsaggelos, and S.Y. Kung

This is the first page of the first of nine articles on the occasion of the Society's 50th anniversary.

The Society continued its efforts to become transnational. Of the 20,000 members in 1995, 58 percent resided in the United States, 19 percent in Europe, 15 percent in the Pacific Rim nations, 5 percent in Canada, and 3 percent in Central and South America. In 1997 of the 40 Associate Editors of the Society *Transactions*, 17 lived outside the United States (eight in Europe, one in the Near East, five in the Far East, two in Australia, and one in South America). Four of the ICASSPs listed above took place or will take place outside the U.S., and the other major SPS conference, ICIP, went outside the U.S. in 1996 and will do so again in 1999 and 2000.

The 50th anniversary of the Society in 1998 is being celebrated in a number of ways. An Anniversary Ad Hoc Committee was formed, with Yu Hen Hu as Chair. Under his direction, each of the Society's technical committees arranged for the writing of retrospective and prospective views of its technical area, and these were published serially in *Signal Processing Magazine* beginning in July 1997. The IEEE History Center was commissioned to conduct a series of oral-history interviews with signal-processing pioneers, to prepare edited transcripts of these interviews, and to write a booklet on the history of the Society. A birthday celebration was organized for ICASSP 98 and for ICIP 98.

International Conference on Image Processing

13-16	November 1994	Austin, Texas
22-25	October 1995	Washington, D.C.
16-19	September 1996	Lausanne, Switzerland
26-29	October 1997	Santa Barbara, California
4-7	October 1998	Chicago, Illinois
25-28	October 1999	Kobe, Japan

1995 19 April: bomb explodes outside a Federal office building in Oklahoma City

What was happening in the 1990s

movies people were watching:

- *Forrest Gump*
- *Jurassic Park*
- *Lion King*
- *Pulp Fiction*

TV shows people were watching:

- "The Oprah Winfrey Show"
- "Seinfeld"
- "The X Files"

music people were listening to:

- (and dancing to) the Macarena
- Spice Girls

books people were reading:

- Robert James Waller's *Bridges of Madison County*
- Stephen Covey's *The 7 Habits of Highly Effective People*

Maurice Bellanger: We feel indeed that in Europe we have always had some excellent laboratories, certainly at the same level. We had, for example, excellent background in mathematics and in the basics, which prepared the young people to develop these techniques. The advantage of being in the U.S. is certainly the availability of the technology, which undoubtedly came at that time from U.S. companies, particularly California companies. Another difference is that in Europe the students and engineers are not forced to publish. It's perfectly feasible to present a thesis without having published internationally. Local publication and local appreciation may be enough. There is also the language issue, so there are a number of reasons why the signal processing field might appear more developed in the U.S. than in Europe, but I don't think that's the case. We could draw a history of European contributions to signal processing quite easily.

Thomas Huang: The Fourier Transform spreads things all over. If you have a small object in the image, its Fourier transform is spread over the whole frequency domain. So, it has advantages and disadvantages. If you want to search for the object, you cannot do it in frequency domain because it's spread all over. Also, if you make mistakes or have errors in the frequency domain, they are spread all over the image. On the other hand, the wavelet transform is concentrated in both frequency and in the spatial domain. The transform domain has several different layers with different frequencies in the components. In each layer, the original object remains concentrated, not spread out.

One application for image representation is in retrieval. You want to retrieve images, but in the meantime you want to represent the image in your database in an efficient way. So, you want to compress, but still be able to retrieve different objects. If you use the Fourier Transform you have to decompress before you can search for your object, but if you're in the wavelet representation, you can search for objects directly (although this is not completely done yet).

Thomas Kailath: Here is an example of signal processing in our semiconductor work. We heat a wafer to 1,000 degrees very fast in a chamber with hot halogen lamps. How do you measure the temperature? You can't touch the wafer with a probe, because it pollutes the wafer. You've got to be indirect. So what you say is there's radiation coming off the wafer. If you can count the number of photons, then that's related to the temperature by Planck's law, which says how many photons are emitted at a given temperature. However, the number of photons is random, so you get a count that's random. You're interested in something else, which is the temperature of that wafer as it changes in form. You've got to infer knowledge about one signal, which is not observable, from another signal, which is observable. Both of these are random (in the latter case, because of the errors in measurement), but there's some dependence between them, some statistical dependence. That's signal processing in its fundamental or generic form. It's extracting information from signals for other purposes.

James Kaiser: I also want to stress again this is an engineering agenda versus science agenda issue. It has become so easy to do so much computation using computers that people will press keys on the keyboard without thinking what they are doing. I think that there has got to be a resurgence of work on the scientific end of things. It's so easy to generate a tremendous amount of garbage that you've got to understand what it is you're doing. So it is very important that we get back to basic understanding, get a much better grounding of what science underlies the phenomenon we are looking at. We have got to be able to do that. I mean, this world is not an ideal world. It's time-varying and nonlinear. That's the first message.

The next message is that the young people—or anybody, really—who are using these tools have got to thoroughly understand what assumptions underlie the tool that they are using. That will tell them what they can expect to get out. You want to know what the guts of the filter are so you can know what you have filtered out and what will pass through that filter. You've got to know that—issues such as quantization, and, even more so, linearity versus nonlinearity.

Charles Rader: Back somewhere before the '80s, I was thinking in the terms of leaving the laboratory and becoming a professor somewhere, and when you do that, they like you to give a talk. I put together a talk on the field of digital signal processing. And I was able to put on one sheet of paper a set of topics and connect them all together with lines, showing what had led to what and what was related to what. I don't think anybody can do that anymore. First of all, if you tried to put it all on one piece of paper, no matter how big, there would be so many lines crossing one another that you couldn't follow it.

Hans Schuessler: Well, for me the theoretical core was and still is the essential point. As an engineer, I am lucky that all of this can be applied. And the influence is to be seen not only in industrial regions, but for the public as well. The first application was a compact disc for music. It was done already 15 years ago, somewhat more. As an engineer I am glad about that. But the main reason for me to be interested and to still work on signal processing is just the intellectual core in it.

The IEEE Signal Processing Society

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