

Rabab Kreidieh Ward 

The Evolution of Women in Signal Processing and Science, Technology, Engineering, and Mathematics



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When I began writing this 75th anniversary article celebrating women in signal processing (SP), I reread the 1998 editorial titled “Fifty Years of Signal Processing: 1948–1998” [1]. At that time, IEEE had more than 300,000 members in 150 nations, the world’s largest professional technical Society. Within the IEEE umbrella, there were 37 IEEE Societies and technical groups, and the IEEE Signal Processing Society (SPS) was the oldest among its many Societies.

The 50th anniversary piece was a celebration of the major players in SP and the historic growth of the SPS. It featured many important scientists in SP and the SPS, including numerous blurbs, quotes, and personal recollections from male leaders in the SPS. The first nod to a woman inventor doesn’t occur until the 1970s, mentioning Susan A. Webber in the field of subband coding breakthroughs. Readers have to wait until the 1980s section to see the face and profile of an SPS woman member: Delores Etter, the Society’s first woman president, in 1988. Beneath her smiling photo and blurb, the piece acknowledges that, “As in most areas of science and engineering, there were relatively few women in SP until the last one or two decades, when their numbers increased markedly.” It mentions Marie Dolan and Carol McGonegal (who served on the Digital Signal Processing (DSP) Technical Committee (TC) in the 1970s), and various other women members of the SPS Board of Governors (BOG), starting with Edith L.R. Corliss (1973–1975). Leah Jamieson joined the BOG in 1981, Maureen Quirk in 1986, and Fay Boudreaux-Bartels in 1989, followed in the 1990s by Marcia A. Bush, Candice Kamm, Quirk, Sarah Rajala, Sally Wood, and Jamieson, who began her two-year term as Society president in 1998 (see Figure 1).

Jamieson is the second and final woman given a profile entry in that 55-page anniversary celebration piece, followed by a tip of the hat to Quirk and SPS Executive Director Mercy Kowalczyk, who were involved with revising the Society Constitution and Bylaws in 1993.

I know that during those 50 years, and in the 25 years since, great strides have been made by women to close the gender gap in society, at the SPS, and in science, technology, engineering,

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and mathematics (STEM). I know from personal experience that we have accomplished many firsts, despite many roadblocks. As a young woman living in Beirut in the 1960s, I had the highest grades in the country, but I couldn't study engineering at the American University of Beirut, so I had to go to Egypt for my engineering education, where approximately 18% of students were women. Soon after, I became the first women member of the Lebanese Professional Engineering Society. Later I completed my Ph.D. in electrical engineering at the University of California at Berkeley, and I was only the second woman to earn a Ph.D. there, in 1972; the first was an Egyptian named Kawthar Zaki.

In 1970, women accounted for 38% of the U.S. workforce; 8% were in STEM fields and only 3% were in engineering [2]. Like so many women, I couldn't find a job in academia that acknowledged my expertise. I was a sessional lecturer for two years at the University of British Columbia (UBC), and then I went abroad, had children, and eventually became the first woman in the engineering faculty at University of Zimbabwe. Later, in the early 1980s, I became the first woman engineering professor in BC, which made me Canada's first woman holding a Ph.D. to become professor of electrical engineering, and later, in 1998, to become Fellow of the Royal Society of Canada. At that time, most women I knew in science or engineering in Canada were appointed on short terms as sessional lecturers, so the majority of my colleagues and students were male.

Gradually, over time, more young women chose engineering, and some became established leaders in their fields, including Lina Karam, who was appointed in 2020 as the dean of engineering at the Lebanese American University in Lebanon. I was appointed as director of the Institute for Computing, Information and Cognitive Systems at the UBC, and later as its Natural Sciences and Engineering Research Coordinator and Advisor at UBC's Vice President (VP) Research Office. Some of my work has been licensed to U.S. and Canadian industries and has resulted in many accolades. Most notable are the IEEE Signal Processing Society Norbert Wiener Society Award, in 2008, and the R.A. MacLachlan Award, the highest award of the Association of Professional Engineers in BC, emphasizing significant technical contributions and leadership to engineering "that characterize the profession at its best."

In 2020, I became an international member of the National Academy of Engineering. This year, I am the recipient of the 2023 IEEE Fourier Award for Signal Processing. Among my various awards, the dearest to my heart and the one that I feel I deserve most, is the highly competitive Killam Senior Award for Excellence in Mentoring, which I received in 2013.

But sadly, today many women still face many of the challenges that I encountered decades ago. According to the IEEE-USA's 2022 Annual Salary Survey, the gap for IEEE women members grew in 2021, by almost US\$6,000, with the proportion of IEEE women engineers remaining at under 10%, the same number for the past decade [3]. The news from other data collection sources is similarly distressing. "As the demand for STEM talent increases, women's share of those jobs remain relatively flat," according to the 2020 Women in Stem Workforce Index, which found that in the United States, women hold only one in four STEM jobs [4]. Other troubling aspects of the Index include that the largest STEM occupation, computers and math, a field that has exploded in growth in the past decades, women's share of jobs actually decreased from 44% in 1990 to 27% in 2018, and women made up only 15% of the engineering and surveying workforce, the lowest representation among STEM workers. The STEM pay gap actually increased by 3% between 2010 and 2015 [5] and has flatlined since, at 27% in computers and math, 16% in engineering, and 26% in management positions [4], with women consistently underrepresented at the executive, high-level leadership level [2].

The situation is even more grim for U.S. women of color (WOC) in STEM [6]: 13% of STEM bachelor's degrees, 12% of master's degrees, 7% of doctorate degrees, and they represent only 4.8% of the workforce. Among science and engineering jobs, the numbers are even worse: 2.3% for Hispanic/Latina women, 2.5% for Black women, and 0.07% for indigent women.

I will provide more big-picture numbers later and also gender-specific statistics from the IEEE and the SPS, but first, on this 75th anniversary of the SPS, I want to celebrate and feature some of the many women SPS members who have worked so very hard to grow our Society, our research fields, and our world. I want you to hear their personal anecdotes, struggles, and victories. I want you to learn about the positive work



FIGURE 1. Women Presidents of SPS, from left: Delores Etter (1988–1989), Leah Jamieson (1998–1999), Rabab K. Ward (2016–2017), Athina Petropulu (2022–2023), and President-Elect Min Wu (2022–2023).

they're doing to encourage and support the next generation of brilliant women so that girls and young women from all walks of life, ethnicities, and cultural backgrounds have role models and heroes whose footprints they can follow, whose strides will encourage the next generations of women in SP and STEM to take great leaps and blaze their own trails in this world.

Women leaders and innovators at the SPS

Since I became a member of the Society in 1988, I've had the pleasure of meeting many fantastic women in STEM, including many of the women mentioned in the 50th anniversary publication. These women broke down gender barriers at the SPS level in academia and industry in all corners of the globe.

My involvement with the IEEE and the SPS has been crucial to my career success. To me, it was more than a professional home. I was exposed to new technical topics, and I have learned so much from my colleagues about strategic planning, creating common goals, embracing change, forging effective leadership and management, and the importance of rewards. Many of these colleagues are incredible women leaders.

Let's start with Etter, the first woman president of the SPS. She received a Ph.D. in electrical engineering from the University of New Mexico in 1979 and became a faculty member in the Department of Electrical and Computer Engineering (ECE) with a focus on speech recognition, software engineering, and adaptive SP [7]. She also worked at Sandia National Laboratories, working in seismic SP. In 1998, she became the Deputy Under Secretary of Defense for Science and Technology, overseeing the American Defense Science and Technology Program. She also ran the Defense Modeling and Simulation Office, the Department of Defense's high-energy laser research program, and was the principle U.S. representative at the North Atlantic Treaty Organization's Research and Technology Board.

In the 2000s, she joined the faculty of the U.S. Naval Academy, becoming the first Office of Naval Research Distinguished Chair in Science and Technology. She was also elected member of the National Academy of Engineering and was Assistant Secretary of the Navy for Research Development and Acquisitions, overseeing the purchases of military machinery and IT. The prestigious Dr. Delores M. Etter Top Scientists and Engineers Award is named for her.

I reached out to Etter to talk about the history of women in SP and her memories of those early years. She presented her first paper at an IEEE Asilomar Conference in 1978, and in 1979, she presented another paper at ICASSP. "I remember standing in the hall with the conference guide, trying to decide which of the parallel sessions to attend," she recalls. "I was wearing a brown linen suit with a white blouse with lace on the collar. I had my name tag clearly visible on the collar of my jacket to show my name and university affiliation. While I was standing there, another attendee walked up to me and handed me his coat. I took it, and then looked around to see why he handed it to me. Down the hall was a sign for coat check. I am sure that I was frowning as I handed him back his coat and pointed down the hall!"

Etter says that in those days there were few women attendees at SP conferences and SPS governance. "I wanted to help

provide more visibility to the other women," she says. Etter began volunteering in conference activities and "quickly realized that the SPS decisions were made by the Administrative Committee," which included no women, and "no members west of the Mississippi." That would change in 1983, thanks to Etter, who campaigned for a position on the BOG. "I was able to get on the ballot and get addresses for SPS members in California," she recalls. "I sent them a letter asking for their vote so that there would be broader representation geographically." Etter was elected to the BOG, and she began a decade of significant involvement with the SPS, including chairing many key committees, and as editor-in-chief (EIC) of *IEEE Signal Processing Society Magazine* (1986–1987) and *IEEE Transactions on Signal Processing (TSP)* (1993–1995.)

Jamieson is another trailblazer in SP and the SPS. After receiving her Ph.D. in electrical engineering and computer science (CS) at Princeton, she became a distinguished professor at Purdue and later dean of engineering, specializing in speech processing and parallel SP. In 2007, she became president of IEEE, and chair of both the Purdue and the National Global Women in Tech organizations.

Jamieson got her start at the SPS in the 1980s, volunteering. "There is no question that my experiences in the SPS contributed to many of my future successes," she acknowledges. "Several of my fondest memories as a member of the SPS are the people: new friendships, new colleagues, opportunities to work with some truly amazing people through my years on Acoustic Speech and Signal Processing (ASSP)/SPS committees and boards, and the truly wonderful SPS staff. My memorable experiences on the Board of Governors and as president included shoe shopping with SPS Executive Director Mercy Kowalczyk, something she said she didn't get to do with her other presidents. Colleagues in the Society offered me encouragement over many, many years."

Some of these colleagues were men, including Al Oppenheim and SPS Presidents Tariq Durrani (1994–1995) and Don Johnson (1996–1997). Jamieson went on to have numerous IEEE posts, including 2003 IEEE VP Technical Activities, 2005 IEEE VP Publications, 2007 IEEE president and CEO, and 2012–2016 president of the IEEE Foundation.

"I had my first experience with strategic planning when I was on the Board of Governors," she says. "As president of the IEEE Foundation, we developed a five-year 'Strategy for the Future.' Fostering collaboration became a central theme of much of my work at IEEE, and as dean of engineering."

As SPS president during the 50th anniversary of the SPS, Jamieson says, "I think we would have been hard-pressed to do an article about women in 1998." At that time, the climate for women in academia was described as "chilly" according to a 1996 book, *The Chilly Classroom Climate: A Guide to Improve the Education of Women*, coauthored by Bernice Resnick Sandler [8]. Known as the *godmother* of the 1972 U.S. educational amendment Title IX legislation prohibiting discrimination based on race, color, religion, gender, and national origin [9], her research on gender bias in academia documents women students' many hurdles, from hostility and

denigration, to the various ways that professors overlooked, ignored, and dismissed women students, from lack of eye contact and dialogue, to patronizing, simplistic responses to their questions or comments [10].

As the years passed, and research became increasingly collaborative, interdisciplinary and global, so did education research, with increased emphasis on teamwork, ethics training, and community outreach, including the IEEE program Engineering Projects in Community Service (EPICS), which Jamieson cofounded and directed. EPICS increased diversity, including that 33% of CS EPIC students were women, compared to only 11.5% nationally. These programs underline the need to connect girls and women in STEM to real-world, community-based issues and needs that will benefit the world. As IEEE grew, so too did its publishing output and global readership, strategic planning, global offices, and key messaging, including its 2010 core purpose of “Advancing Technology for Humanity.”

Yet despite many efforts, women engineers continue to experience a higher attrition rate in the workforce, lower pay scale, and many tensions between work and personal life responsibilities. Campus life is also still chilly. “Engineering students still tell the same ‘boys club’ stories,” Jamieson noted in her keynote talk at the 2021 ICASSP conference [11]: “Male lab partners who assume the woman will take notes while he does the experiments; women leading design teams whose members won’t pay attention to their leadership; unwanted sexual advances; faculty who shrug off concerns of women who come to them for help in dealing with these issues.”

Long-time SPS Member Quirk didn’t have such negative experiences at the professional level. “I found that male engineers were very supportive of women,” she says. “They never belittled researchers because they were women. Engineers are much more interested in people getting the answer rather than any attribute a person might have.” Quirk provided me with an amusing anecdote from 1984, the year she joined the ASSP Conference Board Committee, the first woman on that committee. At that time, she was working at the Jet Propulsion Laboratory in Pasadena, and attended a DSP workshop. “Tom Quatieri gave a talk about sinusoidal representation for speech,” she recalls of the event that included few women researchers. “He mentioned that it worked far better on women. I started clapping, then there was silence. After a moment, everyone started to laugh and clap. Later when I read his paper, he mentioned that the signal speech reconstruction method was ‘pronounced for low-pitched speakers.’” Two years later, Quirk was appointed SPS secretary until 1991; from 1993 until 1996, she was treasurer, then conference VP from 1997 until 2000.

Wood, another key woman member of the SPS starting in the 1980s, underlines the importance of networking and mentoring opportunities. In those days, “there were not many women in SPS, and we all knew each other,” she says. “When I got my B.S. degree, I was told that, in the United States, only 2% of practicing engineers were women. At the SPS, I benefited from informal mentoring from a number of more senior SPS members. As a Society, I think SPS serves its members well by having a broad range of professional activities and

venues for engagement. SPS is an intellectually vibrant and collegial community, which attracts so many women.”

As a professor of ECE, and current associate dean for graduate studies at the Santa Clara University School of Engineering, Wood became an IEEE Distinguished Lecturer (DL) in 2003. She says that her proudest moments include serving as SPS VP of Awards, and becoming an IEEE Fellow.

Another important factor in the growing number of women in our field is that the SPS and the IEEE grew its membership at the global level, attracting many new members from around the world, including Asia, the Middle East, and Europe. I have met many incredible SPS women colleagues from all parts of the world, and I can only mention some of them here whom I have served with on different SPS committees: Urbashi Mitra, Sheila Hemami, Yan Sun, Tulay Adali, Bhuvana Ramabhadran and Behnaz Ghoraani from the United States, Deepa Kundur, Z. Jane Wang, Octavia Dobre, and Mahsa Pourazad from Canada, Roxana Saint-Nom from Argentina, Hong (Vicky) Zhao from China, Helen Meng and Pascal Fung from Hong Kong, Anubha Gupta from India, and Maria Sabrina Greco, Christine Guillemot, Isabel Trancoso, and Josiane Zerubia from Europe.

Zerubia is the first woman from outside North America whom I have served with on the SPS BOG. She has been active member of the SPS for more than 25 years. As director of research at Center INRIA since 1989, she has headed many labs and groups, including Scene Analysis and Symbolic Image Processing, Variational and Stochastic Models for Image Processing, Models of spatio-temporal structure for high-resolution image processing, and AI and Remote Sensing on board for the New Space. A Fellow since 2003, Zerubia acknowledges, “It is not always easy to be a successful woman in SP and scientific fields. Male and female colleagues could try to push you down. The only way to survive is to work harder and to always get better results.” Zerubia also credits the work of her male counterparts who “strongly supported” women members, including former SPS Presidents Jose Moura and Ali Sayed. “My vision for the future for women in SP is that we need to encourage young ladies to choose to learn math and physics at a young age [and give them opportunities] to learn SP at university. We also need role models in SP. Mine are Rabab Ward and Jelena Kovačević.”

Kovačević is a specialist in wavelet theory and biomedical imaging and a long-time advocate of women in STEM [12]. She grew up in the former Yugoslavia and credits her parents for putting her on the path to a career in math, providing her “infinite confidence” that she could do anything she wanted in life. She attended Columbia University and was one of only a handful of women Ph.D. students in the electrical engineering department, from where she graduated in 1991. That decade, she worked at Bell Labs in New Jersey and cofounded xWaveforms. In both academia and industry, “I did hear an occasional, ‘She got the job because she is a woman,’ comment and ignored it,” she says. But once she became the department head of ECE at Carnegie Mellon in 2014, she learned that only 21% of undergrads in her department were women. She listened to “heart-wrenching” stories from women students about the

hardships they faced simply because of their gender. “I educated myself. I attended a leadership academy for women at Carnegie Mellon. I read articles. I discovered that gender bias in STEM fields abounds. Even though we know that diversity, in gender and race, makes us smarter, better people.” She took action at the departmental level. “We completely revamped our faculty-hiring process, educated faculty on unconscious bias, had broad and inclusive search committees, and published our search procedures,” she says. “We also hosted prominent career-building workshops and events like Rising Stars in EECS (electrical engineering computer science), and Judith Resnik Year of Women in ECE.” Within three years, the number of women undergraduate students grew to 27%. The department included five women junior faculty members, growing the number of women staff members to 18%. In 2018, Kovačević became dean of New York University’s Tandon School of Engineering, the first woman to head the school since it was founded in 1854.

Kovačević has been an active member of the SPS for more than 30 years, former EIC of *IEEE Transactions in Image Processing*, former member-at-large of the BOG, and winner of an IEEE SPS Technical Achievement Award, which she counts among her proudest career moments. “We still have a lot of work to do on campus and after graduation,” she says. “Many women go to Silicon Valley, which isn’t welcoming to women. We need to make this a wider conversation: that gender equality in STEM is also a social issue that everyone needs to change, so that all parents; educators; and employers; all the elders in our culture, advocate for equality so that all children can follow their passions to have opportunities to fail and learn and succeed.”

As a long-time professor, I appreciate the importance of growing the number of professional women faculty members in academia. And many other women SPS members have the same goal, including our current SPS President Athina Petropulu.

“I have to admit that in the first few years I felt isolated at SPS conferences,” says the 1991 Ph.D. graduate of ECE from Northeastern University. “After I got involved as a volunteer (through a TC membership first), I started having a network, which made a big difference. Women in SP (WISP) is a great opportunity to feel part of a community. I am very proud to have been EIC of *IEEE TSP* and SPS VP Conferences. While there has been progress, women still do not get as many nominations for awards and recognition [(DL and distinguished industry speakers (DISs)]. Women represent untapped capital. If we make them feel included and comfortable, they will unfold their talents and the field of SP will be so much richer.”

Petropulu is a distinguished professor at Rutgers ECE, and she’s active on many levels at IEEE and the SPS, including as IEEE Technical Activities Board member, and a former BOG member-at-large at the SPS. She has won numerous awards, including the Barry Carlton Best Paper Award at the IEEE Aerospace and Electronic Systems Society, where she served as a DL in 2019. While president-elect at the SPS, Petropulu received approval for a new faculty diversity-building workshop she conceived and named *Promoting Diversity in Signal Processing (PROGRESS)* [13]. This workshop was inspired

by iRedefine, a program she spearheaded, as president of the Electrical and Computer Engineering Department Head Association. “The idea is to motivate and prepare women and underrepresented minorities to consider academia,” she says. Between 2017 and 2018, iRedefine helped 36.6% of the 66 student participants get academic jobs. “We all see that there are very few women faculty,” says Petropulu. “China has over 50% female students, but still very few faculty. Who is going to inspire those women to become leaders when they hit the job market? Companies recognize the value of diversity and have the means (high salaries) to lure women. But academia does not offer high salaries. How can it compete with industry for the best? At PROGRESS, we provide information on how to put together application materials, CVs (curriculum vitae), give mock interviews, and also professional training on how to negotiate. Since PROGRESS is for all the world, we have panels focusing on different countries.”

PROGRESS attracted 202 students at its start in conjunction with ICIP 2020. It’s now an ongoing SPS workshop at ICASSP and ICIP conferences and some mentoring teleconferences. Panel members represented a diverse group of global academic leaders from Beirut to Bangalore, to Buenos Aires and Hong Kong. The exit surveys for their first workshop showed that interest in pursuing professional academia more than doubled [14].

Piya Pal, one of our younger senior members of the SPS, agrees that mentorship is a key factor for women in STEM. “SPS has a lot of activities planned during conferences, which are very encouraging for young people,” she says. “But I think the real work happens behind the scenes through forming personal relationships between a mentor and a mentee.” Born in Calcutta, Pal did her Ph.D. at the California Institute of Technology (Caltech) in 2013 and is now an assistant professor at the University of California, San Diego’s Jacobs School of Engineering. “Encouragement from the [SPS] community and the visibility of my work at an early stage played an important role for my career development,” she acknowledges. Student paper awards were essential for her early career; her doctoral thesis was awarded the 2014 Charles and Ellen Wilts Prize for Outstanding Thesis in Electrical Engineering at Caltech. “I was also honored to receive the Early Career Technical Achievement Award from the SPS and the U.S. PECASE Award for my works on sparse sampling techniques,” she says.

On the challenges for women in STEM, Pal acknowledges that “people (both men and women) can jump to quick conclusions (which are often wrong) about another person’s work, and this is usually due to lack of proper technical understanding, or sometimes even due to deep-rooted biases. When faced with these situations, I have always tried my best to fight back purely on a technical basis and not let my personal emotions get in the way toward establishing the scientific truth.”

Women in the SPS: Challenges and opportunities

Many key women and men at the SPS have spent decades working very hard to open doors for women in SP. Yet many recent stats show that progress for women in STEM has plateaued over the past decade, particularly in leadership in academia

and industry, and for WOC. I would like to now turn the spotlight on IEEE and the SPS to check our progress in the past 25 years and discuss new hurdles and opportunities.

When I became president-elect of the SPS in 2014, my priorities included growing the number of women involved in SP, inspiring our young members to get involved with the SPS, and ultimately seek out fruitful careers in SP and all STEM fields. Since the start of my involvement in the SPS in 1998, I have found it to be very supportive of diversity, and its presidents take special care and consideration of the various methods for cultivating and advancing women's participation in our Society. It has been an honor to continue these endeavors, both as president and a senior member of the SPS. In the past decade, I have had many lively discussions about this topic with Past Presidents Mostafa Kaveh, Jose Moura, Ray Liu, Alex Acero, Ali Sayed, and Ahmed Tewfik. As the SPS shared my goal to increase its women members, we looked at ways to enhance women members' experiences at the SPS. Senior women members know from personal experience that diversity, networking, and mentorships are crucial to both personal success

and the vitality of any organization, and we wanted to grow these opportunities. The WISP Subcommittee was approved by the SPS BOG in May 2014, with the leadership of Kostas Plataniotis, the SPS VP Membership at that time. That year, we started holding the WISP luncheon at all major SPS conferences, including ICASSP, ICIP, and GlobalSip. These luncheons, which also welcomed male SPS members, featured women speakers discussing ways to build and advance women's careers so that everyone can benefit and thrive. These luncheons were well attended, especially by newcomers. I loved attending them, seeing colleagues, meeting new people, and participating in discussions with speakers and panelists.

When I was president in 2017, and under the support and direction of Nikos Sidiropoulos, the WISP Subcommittee was elevated to the committee level, directly reporting to the SPS Membership Board. (The chairs of WISP thus far include Antonia Papandreou-Suppappola, Namrata Vaswani, and currently, Celia Shahnaz.) Initially, the WISP Committee focused on the luncheons, and they have since become active in hosting other events, including International Women's Day.

IEEE Signal Processing Society Member Quotes

It was not always easy to break into the field and to make friends. In the beginning, it could be lonely as the only woman on a committee or in the room. Luckily, that problem does not exist anymore as more women are joining the IEEE Signal Processing Society (SPS). It brings diversity into the Society and generally, into the field. I have always felt supported during the Women in Signal Processing (WISP) meetings at the major conferences. I met fantastic colleagues, shared experiences, and made some of my best friends. Being able to mentor younger colleagues was always an inspiration. But there are still not enough awards given to women who would richly deserve them. New awards can be created. Similarly for keynotes, there should be a push to have more women speaking. My vision for the future for women in signal processing? Equity. —*Sabine Süssstrunk*, IEEE Fellow; head of the Image and Visual Representation Lab, and director of the Digital Humanities Institute (2015–2020) at Ecole polytechnique fédérale de Lausanne; member of the Executive Committee of Swiss National Science Foundation.

Some of my proudest moments are my paper awards, the successful conferences I organized, and the pride of having improved the *IEEE Signal Processing Letters* performance. I can see a new generation of thought leaders and pioneers. —*Anna Scaglione*, IEEE Fellow; Cornell University, member of the SPS Board of Governors BOG (2011–2013), editor-in-chief of *IEEE Signal Processing Letters* (2012–2013).

Just around the time I got my Ph.D., my advisor decided to leave his tenured faculty position and left academia. I

was an academic orphan. My Ph.D. was in adaptive filtering and I was thinking that neural networks with a statistical connection could be a fruitful research direction. Hence, I decided to make it to the NNSP workshop, which in 1993 was held in a small town in Greece. That trip indeed helped shape my career. I found a vibrant and friendly community with NNSP (now MLSP) TC, which I also chaired (2003–2005 and 2021–2013). The interactions within this and then the broader SPS community provided important support. That is why, when serving as Vice President (VP) Technical Directions, I worked on multiple initiatives to reach out to young professionals to help them connect easily with our technical activities within the SPS, and find a community that nurtures them. —*Tülay Adalı*, IEEE Fellow; distinguished university professor, University of Maryland Baltimore County; SPS VP Technical Directions (2019–2021); chair of the IEEE Brain Initiative.

Luckily, I have had great mentorship through the years that supported my growth. SPS has dedicated women in signal processing committees and arranges dedicated events at major conferences to help female students, which are commendable. However, it is often hard to measure if such events have led to sustained impacts on women's careers. It is wonderful to see many of our senior women are taking up leadership positions in SPS, which for sure will inspire more to follow, leading to broader and more diverse participation in our community across all races, genders, and demographic areas. —*Yuejie Chi*, Carnegie Mellon University; IEEE SPS Distinguished Lecturer (2022–2023); IEEE Information Theory Society Goldsmith Lecturer (2021).

A healthy portion of the time is devoted to networking, allowing me to meet many new women members from all parts of the world, and learn about their country-specific challenges and situations. Many women wanted to know how they could start volunteering at the SPS. A woman from China was surprised that in North America, we had so many initiatives to encourage women to go into STEM, saying that in her country there are now many women engineering students and professional engineers, and that women are encouraged to do what they like to do. Women in some Arab countries said that approximately half of engineering students are women, although they face challenges getting employment in some fields, and so, some women start their own businesses or work in a related profession. A Canadian resident from Mexico said that women students in Mexico are very optimistic about getting into engineering programs at university, but they have fewer career prospects as male engineers tend to prefer hiring male graduates. I learned that there were many variations from one region to the next, even among neighboring countries.

The SPS has also spearheaded an informal event for senior women faculty members that began in 2018 at ICASSP, thanks to Yonina Eldar. “It is important to have a more intimate forum than the WISP luncheons, where senior colleagues can network and also discuss issues having to do with more advanced stages of our careers,” says Eldar. “It’s an informal women’s gathering with the goal of celebrating each other’s success and enjoying each other’s company, and of course creating a supportive network.” The event has since become an ICASSP tradition.

The SPS still holds the networking luncheons at ICASSP/ICIP, although during the peak of the COVID-19 pandemic, all events were held virtually. In general, the pandemic has caused many setbacks in academia, when women in STEM identified loss of mentoring and networking as a significant issue, with a years-long impact on their educations and careers [15]. It shows just how important these networking opportunities are for women in our field.

Recent SPS statistics provide some evidence that our various programs have benefited women in SP, particularly at the student level. But there’s certainly much room for improvement.

I have attended the Women in Signal Processing events at ICASSP, whenever possible, both as a student and later as a professor. I can meet with my friends and professors from all over the world, make new contacts within the community, and discuss relevant and timely issues that women in STEM (science, technology, engineering, and math) fields may face. However, it is not usually clear how to get involved into SPS activities other than attending those events. SPS is a large community, and it is easy to feel lost. —*Tanaya Guha*, University of Glasgow; honorary associate professor, University of Warwick; chair, IEEE Women in Engineering (WIE) Vancouver Section, IEEE Multimedia Systems and Applications TC (2021–2024); presently, Editorial Board member, *Nature Scientific Reports*.

As a daughter and a wife, I always face the expectations to take care of my aging parents and my own family. I moved back and forth to balance my research career and family duties. Now I am self-employed to do independent research in my field while taking care of my families. I hope I can have free access to IEEE e-library from home without having to physically visit a university in the future, which is important for a self-employed woman researcher. Women in signal processing can advance technologies to improve the quality of human life if they are inventive and persevering. —*Huiqun Deng*, IEEE Senior Member; self-employed.

The lack of women in most forums pushes you toward a male mentality. To overcome that, I try to be present in different representative bodies so I can influence and invite women on board, or help them to gain visibility. WISP is

the best tool and must keep on growing in members and visibility in many different activities, which should be organized for women and men. —*Ana Perez-Neira*, IEEE Fellow; Universitat Politècnica de Catalunya; SPS VP Conferences (2021–2023), general chair ICASSP 2020 (with more than 15,000 virtual attendees).

You always need to do much more than a man to be recognized. I did more. Women still need to fight to break the glass ceiling, but their competencies are better recognized and this also encourages young women to pursue a career in SP. The SPS is an international organization, so the recognition is more objective than in local and small professional committees. The international recognition helps in supporting our local recognition and professional career promotion. My fondest experience at SPS is chairing ICIP 2014 in Paris. —*Beatrice Pesquet*, IEEE Fellow; Télécom ParisTech; SPS BOG member (2017–2019), chair of SPS Image, Video, and Multidimensional Signal Processing (IVMSP) technical committee, and of SPS International Conference on Image Processing (ICIP) IDSP TCs.

I had to overcome shyness early in my career due to few women at conferences. Women’s meetings at conferences are motivating. More advertising and events with successful women in the field would be interesting as well as financial support for young and promising researchers, and help from more experienced colleagues. —*Mariane Petraglia*, IEEE Senior Member; Federal University of Rio de Janeiro, Professional Trajectory Award Recipient; IEEE WIE Unicamp, Brazil (2015).

An ad hoc committee chaired by Mari Ostendorf was tasked with collecting statistics and information about women IEEE Members in the field of SP and how they fare in awards and in leadership roles. Besides Ostendorf, the ad hoc committee also included Petropulu, Beatrice Pesquet-Popescu, and Eve Riskin.

In September 2016, I received their report. It was an illuminating read, highlighting that women made up only 9.4% of SPS members and 10.6% of IEEE Members, and although 10% of SPS fellows were women, reflecting their substantial technical achievements, since 1990, only 2.2% of SPS major (nonservice) awards were earned by women.

“Our primary findings are that women in the SPS are grossly underrepresented in technical achievement-related awards (Society, technical achievement, education) relative to their percentage representation in the Society, which is itself low relative to representation in IEEE overall ... the trends are consistent with those for the major IEEE awards, where the numbers are significant. The representation of women among plenary speakers at the SPS flagship conferences also appears to be unreasonably low ...” [16]

The committee found that the single biggest issue was related to the nomination process. Women members were nominated at much lower level than their male counterparts. This

Women in Science, Technology, Engineering, and Mathematics by the Numbers

In 1970, women accounted for 38% of the U.S. workforce, but only 8% of science, technology, engineering, and mathematics (STEM) occupations, and 3% of engineering jobs. By 2019, the proportion of women had reached 48% of the U.S. workforce and 27% of the STEM workforce. Yet in the computer and engineering fields, the largest among STEM occupations at 80%, women represented only about a quarter of the computer workforce and 15% of engineering occupations [2].

A 2020 global snapshot of women in engineering (WIE) jobs found that women’s representation ranged from 11% in Brazil, to 14% in the United Kingdom, to 20% in India [21]. In the European Union, women account for only 32% of the high-tech workforce [22].

Gender pay gap

Women typically earn less than their male counterparts in all fields, including STEM. Among the 70 STEM occupations in the U.S. Census Bureau, women earned more than men in only one STEM field (computer network architects) [2].

According to 2020 data on workers aged 35–44, women in the United States earned 30% less than men, and that pay gap increased with age. In STEM occupations, in 2019, women earned US\$0.816 for every dollar that men earned [6]. In the United Kingdom, the pay gap for women engineers is 11%, and by the age of 35, 57% drop out of the profession despite the fact that the country has a shortage in the field [23].

The leaky pipeline

The pipeline starts leaking during childhood [6]. A 2019 U.S. study asked school kids to draw a scientist. Only 28% depicted a woman scientist. The majority of boys drew male characters, and girls did the same twice as often as the girls who depicted a woman scientist. Another 2019 U.S. meta-analysis of gender stereotypes in science [24] found that although 70% of girls aged six drew a woman, only 25% of girls aged 16 chose to depict a woman. When students reach middle school, boys are more than twice as likely as girls to

choose science or engineering careers, according to 2019 research.

Almost 50% of U.S. women in science and engineering majors switch to non-STEM faculties, compared to 33% of men. Fifty-seven percent of Bachelor of Arts (BA) recipients are women, but only 39% are STEM degrees, with the lion’s share in biological sciences, math and statistics, and physical sciences. Only 19% of BAs given to women were in computer sciences, and 21% in engineering [National Science Foundation (NSF) 2017–2019].

Additionally, U.S. women in STEM receive only 44.3% of master’s degrees and 41% of doctorate degrees, and 36% are postdoctoral fellows. Yet only 29% are employed in STEM fields. In engineering, only 13% of working engineers are women, earning 10% less than male counterparts [25], and as many as one in four of them will quit this profession after the age of 30.

The situation is much more grim for undergraduate U.S. women of color (WOC) in STEM, with 5% Asian, 5% Hispanic/Latina, 3% Black, and 0.16% identifying as American Indigenous. WOC represent roughly 17% of undergraduates, but only 9% are in STEM. WOC also receive only 12% of master’s degrees and 7% of doctorate degrees and make up only 5% of the STEM workforce [6].

Academia

As of 2019, women are only 34.5% of faculty at academic institutions, and fewer than 3.5% are Hispanic, Black, or Indigenous. Twenty-eight percent of tenured STEM faculty are women, and less than 3% are Hispanic, Black, or Indigenous.

Career crunch

According to 2019 U.S. NSF statistics, women represent 52% of the college-educated workforce, but only 29% of workers in science and engineering. In computer sciences, it’s 25%, and in engineering, we were only 16% of the workforce. In general, the disparity in income for STEM occupations is 16%, with the highest gender wage gaps among health care, physical scientists, and computer occupations [26]. As mentioned previously, the situation with

is a crucial aspect of career success: when women were nominated, the success rate almost doubled.

This research suggested that women have to make much bigger strides than men in the same field, which is consistent with other gender-specific literature in this field. Unconscious bias is a culprit, which has repeatedly been linked to the gender divide. Research in academia has found that a CV with a male's name gets a higher rating [17], and in academic fellowship applications, women with competence matched to their male counterparts, such as publication volume and impact, were given significantly lower scores [18]. Even recommendation letters for women medical faculty members resulted in lower reviews [19].

WOC is even worse. In the science and engineering workforce, Hispanic/Latinas, Black women, and Indigenous women count for only 2.3, 2.5, and 0.07%, respectively.

Leadership

Among U.S. government labs and research centers, 86% of the directors are white men while only 5% are women, and no WOC are represented at the director level. Only 26% of STEM-related leadership positions are held by women, including 3% of WOC. Between 2013 and 2019, women counted for only 8% of CEOs at biotechnology and initial public offering companies [6].

Science academies

Globally, women represent 33% of researchers, but only 12% of members of national science academies [27]. A 2021 Gender Insight report found that women memberships in National Academies included highs of 25% in Mexico and Canada, 19% in Malaysia and the United States, 15% in Brazil, 11% in Singapore, 10% in the United Kingdom, and 9% in India [21].

R&D

According to the United Nations Educational, Scientific and Cultural Organization, Central Asia has the highest number of women in R&D at 48.5%, followed by 45.8% in Latin America and the Caribbean, and 40.9% in Arab States [21].

And the prize goes to

Between 1901 and 2019 there were 616 Nobel Laureates in Physics, Science and Medicine. Only 19 of these prize winners were women. According to one study of National Institutes of Health funding between 2006 and 2017, women as first-time principal investigators received US\$40,000 less than male counterparts [6].

Blatant discrimination

According to a 2018 National Academies of Sciences, Engineering and Medicine survey, 50% of women in STEM academia experience sexual harassment. Another 2018 study found that half of women in STEM jobs experienced discrimination, 9% higher than their non-STEM

The ad hoc committee report acknowledges that, "People tend to hire others who have similar backgrounds to theirs, and the same trends seem to hold in SPS nominations for awards and invited talks. Recognizing unconscious biases is a critical step to reducing their impact on judgments. In addition, the reality of these biases means that boards need to be proactive about building a diverse candidate pool, in nominations for awards but also for lecturers, TCs, and board members."

Although IEEE and the SPS had various policies in place to provide gender balance among editors and TCs, the committee found no similar policies for nominees. They underlined the need for specific methods to bridge the gender gap: in leadership

counterparts. A whopping 70% of women in STEM report that they are routinely the target of biases and microaggressions related to their merits and competence. Even more chilling, 90% of STEM workers that do report sexual misconduct experience some form of retaliation [6].

COVID-19: A disturbing new normal

A 2021 report by the U.S. National Academies of Science, Engineering and Medicine found that women in STEM "face a myriad of systemic inequities" and "disproportionate hardships," suggesting "that the disruptions caused by the COVID-19 pandemic endangered the engagement, experience, and retention of women in academic STEM, and may roll back some of the achievement gains made by women in the academy to date" [28]. These hardships include loss of work-life boundaries; reduced productivity; isolation from networks, communities, and mentorships; increased issues with setting work-life boundaries, due in part to home childcare responsibilities; and psychological issues, ranging from burnout and sleep problems, to anxiety and depression. The report found that these various pandemic-related issues have been more pronounced for WOC [29].

The benefits of closing the gender gap

The European Institute for Gender Equality found that decreasing the gender gap in STEM fields could result in more than one million jobs, grow gross domestic product of the European Union by up to €820 billion by 2050, and potentially close the gender wage gap [30].

In other research about healthy workplace dynamics, research has consistently found that workers, and their organizations, thrive in environments that provide workers with three basic needs: autonomy, competence, and interconnectedness [31]. Psychological safety is another key factor that breeds inclusiveness, trust, and mutual respect, particularly when provided by leaders and executives. Google's Project Aristotle crunched the numbers among its teams, looking at numerous factors, and finding that psychological safety was the one key factor for successful teams [32].

Women SPS EICs	4	2	3	4	0	1	0	1	0	0	0	0	0	0
Total SPS EICs in time frame	16	17	11	12	4	7	3	2	1	2	1	3	1	2
Percentage of women SPS EICs	25%	11.76%	27.27%	33.33%	0%	14.29%	0%	50%	0%	0%	0%	0%	0%	0%
Women SPS TC chairs	4	5	4	5	1	1	0	0	0	0	—	—	—	—
Total SPS TC chairs in time frame	34	31	31	26	22	19	16	14	9	5	—	—	—	—
Percentage of women SPS TC chairs	11.76%	16.13%	12.9%	19.23%	4.55%	5.26%	0%	0%	0%	0%	—	—	—	—
Women SPS DLs	5	6	2	2	0	1	1	0	—	—	—	—	—	—
Total SPS DLs	26	26	25	28	28	18	14	3	—	—	—	—	—	—
Percentage of women SPS DLs	19.23%	23.08%	8%	7.14%	0%	5.56%	7.14%	0%	—	—	—	—	—	—
Women SPS DISs *	1	—	—	—	—	—	—	—	—	—	—	—	—	—
Total SPS DISs	20	—	—	—	—	—	—	—	—	—	—	—	—	—
Percentage of women SPS DISs	5%	—	—	—	—	—	—	—	—	—	—	—	—	—

training activities, by annually tracking the percentage of women in all aspects of Society membership activities, including major awards nominees and winners, paper awards and DLs, and by making meaningful policy changes to address any gender gaps.

The committee also recommended training programs to address unconscious biases in leadership training, methods for reducing the number of “all-male nomination slates,” and including more male members among the WISP Committee to increase and diversify the pool of nominators. A silver lining among all this data was that as of 2016, SPS women student membership had grown to 21.8% of the total student members. But the number of graduate women students was lower (16.5%), and women also represented less than 10% of nonstudent members. “As expected, the membership statistics show a leaky pipeline,” the report acknowledges, citing a “particularly big drop from graduate student members to members.” Unfortunately, this trend has not changed since. In 2021, although women student undergraduate memberships had risen to 31% of the total student numbers, for the graduate students it was 16.3%, and the number of nonstudent members was 9%.

Whatever the specific causes, this “leaky pipeline” dilemma is ubiquitous in STEM gender research, which has often found that after postsecondary graduation, we tend to lose far too many talented, bright women to other fields. In STEM and at the IEEE and SPS levels, there’s a pressing need to retain women members in IEEE, the SPS, and in academia, research, and industry.

Recent IEEE statistics from 2020 found that since 1993, the percentage of IEEE (and also SPS) women members increased from 6 to 13%. And since 2009, the proportion of women IEEE Fellows has doubled, from 3 to 6%, and SPS membership has also grown from 5 to 9%.

We recently gathered new statistics on women senior membership numbers, award recipients, women BOG members, and other important statistics on women in leadership roles at IEEE and the SPS. The SPS-compiled data included only the Society Awards and not the Paper Awards. We found that the number of women SPS fellows more than doubled since 2016, to 208. The number of women SPS award recipients during the last five-year interval (2017–2021) remained the same as the previous five-year period at five, representing 12% of total SPS awardees. But the number of awards increased in the last five-year period to nine awards, up from four between 2012 and 2016, when 18.5% of recipients were women. The original four awards were

- 1) the Carl Friedrich Gauss Education Award (formerly the Education Award)
- 2) the Claude Shannon–Harry Nyquist Technical Achievement Award (formerly the Technical Achievement Award)
- 3) the IEEE Signal Processing Society Norbert Wiener Award (formerly the Society Award)
- 4) the Leo L. Beranek Meritorious Service Award (formerly the Meritorious Service Award).

The new awards are

- 1) the Industrial Innovation Award, established in 2015
- 2) the Amar G. Bose Industrial Leader Award, also established in 2015

- 3) the Meritorious Regional/Chapter Service Award was introduced in 2017
- 4) the Pierre-Simon Laplace Early Career Technical Achievement Award began in 2019
- 5) the Meritorious Regional Distinguished Teacher Award was introduced in 2020.

For the 2012–2016 time frame, two women received the Claude Shannon–Harry Nyquist Technical Achievement Award: Eldar (2013) and Kovačević (2016). Three women received the Leo L. Beranek Meritorious Service Award: Petropulu (2012), yours truly (2013), and Min Wu in 2015. Between 2017 and 2021, two women received the Pierre-Simon Laplace Early Career Technical Achievement Award: Yuejie Chi (2019) and Piya Pal (2020). Tara Sainath was given the IEEE SPS Industrial Innovation Award in 2021. The Leo L. Beranek Meritorious Service Award was given to Ostendorf (2017), Helen Meng (2019) and in 2022 to Tulay Adali.

Among the IEEE-level SPS-related awards given to women, in 2011, Ingrid Daubechies received the IEEE Jack S. Kilby Signal Processing Medal, and Julia Hirschberg was given the James L. Flanagan Speech and Audio Processing Technical Field Award. In 2012, this award was given to Janet Baker (and her husband James Baker), and in 2018, to Ostendorf. I received the 2023 IEEE Fourier Award for Signal Processing.

On the IEEE leadership level, IEEE has had four women presidents: Jamieson, Martha Sloan, and since 2017, Karen Bartleson and Kathy Land. Karen Panetta served as an IEEE Women in Engineering (WIE) chair (2007–2009), and Shahnaz is presently the IEEE WIE chair-elect. Hemami was IEEE VP Publications Services and Products (2012–2016), and Evangelia Micheli-Tzanakou was IEEE VP Education (2007–2011). In 2022, I was elected as the 2023 IEEE VP Education.

In the SPS, the number of women in the SPS BOG increased to 16 in the last five years, and women make up four of the 34 SPS TC chairs and four of the 16 SPS EICs. Among SPS DLs, five of 26 are women, but only one woman (Dilek Hakkani-Tur) is among the 20 SPS DISs. The latter award was established in 2018.

Some of these numbers are certainly a dramatic improvement from earlier decades; there were no women EICs until the 1980s, no women TC chairs before the 1990s, only two women fellows until the mid-1980s, and no women IEEE-level SPS awards recipients before 2007 (see Table 1).

Women SPS members and women in STEM fields have made many great strides, despite the inequities that they continue to face. Many of my women colleagues share a cause for optimism and celebration, in large part thanks to the participation of women members and leaders in the field. We have more than 900 IEEE WIE groups worldwide and both an IEEE and a Technical Activities Board Diversity and Inclusion Committee, while almost all IEEE Societies and Councils have women or equity, diversity, and inclusion committees or subcommittees, and there are many other women-focused committees. We also have an IEEE conferences Code of Conduct, with a zero “tolerance for discrimination, harassment, or bullying in any form at IEEE-related events.”

Diversity is a key aspect of any healthy ecosystem, in nature and the cultural institutions we nurture. Wu, our current SPS president-elect, is an ideal leader for continuing to grow our diversity. “Through many volunteer roles, I have gained experiences, broadened my horizon, developed leadership skills, and made friends and formed comradeships around the world,” says the specialist in information forensics and security and multimedia SP. “Being an SPS member for about 25 years (starting as a student member in graduate school), I couldn’t have foreseen that two decades later, I would contribute directly to blazing a trail to diversify the leadership of SPS,” she says, acknowledging that she has “overcome the twists and turns” in her career including “many forms of implicit bias and double-standard treatment.” Currently the associate dean for graduate programs at the University of Maryland’s A. James Clark School of Engineering, Wu was born and raised in China, did her Bachelor of Science at Tsinghua University in Beijing, and her Ph.D. in electrical engineering at Princeton University. She offered some sage advice that has helped her overcome institutional and cultural gender biases. “Quietly biting our lips won’t help in the long run, nor lead to the greater good,” she said. “Get support and sounding boards from mentors and supportive colleagues. I have received broad support from members around the world, including many whom I have worked with over the years in various capacities. Take strides in doing good work, technical work and serving the community. Continue inclusive excellence, for more women as well as other underrepresented groups. Nurture a big heart and fair mind for the greater good and work with male colleagues to build a strong, vibrant community full of positive energy.”

As a girl, I was fascinated and gripped by Marie Curie and her incredible achievements. She said, “Life is not easy for any of us, but what of that? We must have perseverance, and above all, confidence in ourselves” [20].

She was my idol and I used to dream that one day, I would also do great things. As a young girl, I did not know exactly what my own great thing would be, but I had much confidence that I would be able to do it. That’s thanks in large part to my mother, who taught me and my siblings that with hard work, we could do anything we wanted and reach any goals we set for ourselves, no matter how high we set those goals. This self-confidence was my savior as I certainly faced many obstacles. But whenever I came up against a closed door, I looked for another door to open.

We need to nurture and cultivate that confidence. We need to start with children, encouraging young girls and young women to follow their passions. I believe that more of us women leaders should visit elementary and secondary schools and talk to students, girls and also boys about the beauty of invention, the mysteries of the universe, the fact that engineering can solve so many of our social and environmental problems and advance technology for all of humanity. It is interesting that there has been a healthy increase in women students studying health-related engineering, and many biomedical strides and inventions have been made by experts

in SP to help foster a better life for humanity, to literally help save lives.

In every country, and all cultures, we still have a lot to do, and a long way to go, to bridge the gender divide, fix the leaky pipeline, and rise above the recent plateaus in the gender wage gap, the number of women in engineering and CS professions, and among women in leadership positions in academia and industry. Women, and men, need to continue to actively participate in closing these gender gaps; by mentoring girls and young women and providing them with opportunities to succeed at all levels of society; by giving them the chance to make mistakes, and rewarding them when they do succeed; by pushing beyond our own cultural limitations and internal biases to recognize their talents, no matter their gender, color, and ethnicity; by helping women open their own doors—in academia, industry, and all aspects of life.

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