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THE BRIDGE

The Magazine of IEEE-Eta Kappa Nu

Advancement of Technology **USING SLIDE RULES**

IEEE-Eta Kappa Nu

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THE BRIDGE

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2025 ISSUE 1 | Advancement of Technology Using Slide Rules

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Sean Bentley

2025 President,
IEEE-Eta Kappa Nu
Gamma Theta Chapter

Dear HKN Members,

Scholarship. Character. Attitude. As I prepared for my year as IEEE-Eta Kappa Nu President, I spent much time considering these words. They are prominent in our induction script and appear regularly in our written materials. We look for these qualities in our members, and they form the cornerstone of our organization. But what do they mean in practice, when we are going about our days, both in HKN activities and beyond?

Scholarship seems the most obvious, as we work to advance technology, particularly related to the fields of electrical and computer engineering. However, when taken with the other two, we must consider how these advances affect society and seek an ethical and beneficial approach to our scholarship. We must examine all data and evidence, and weigh factors beyond pure profits.

Similarly, the ideals of character and attitude must extend beyond our dealings with technology and into our interactions with all of society. We should strive to improve the greater good while simultaneously treating all individuals with respect and compassion. We are all busy and face a multitude of challenges in our lives, but the character and attitude within HKN members include selflessness and service. For humanity to advance, we must look beyond our differences and work together to solve complex problems.

With the confidence that advancing HKN means promoting these important ideals, I am very excited about the prospects for 2025. We are introducing a Regional Ambassadors program (led by Region 5-6 Governor Colleen Bailey) to increase the support for our university chapters. The new Chapter Advisor Recognition program will celebrate this important and often overlooked group within HKN. We are developing programs to increase our value to recent alums, including industry engagement partnerships. This is on top of our existing programs, conferences, and publications that aim to enrich the experiences of all our members.

I thank 2024 President Ryan Bales for his excellent leadership, which saw major growth in Eta Kappa Nu on several fronts. To all the HKN leadership, staff, and volunteers (at the national and chapter levels), I appreciate all you do to advance our mission. On a personal note, I thank two key individuals—2018 President Steve Watkins, a longtime mentor, friend, and example of the HKN ideals, and my wife Jin, my compass and reason for striving to always become better.

Having been an Eta Kappa Nu member for over three decades, I take this call to Scholarship, Character, and Attitude very seriously. I am honored and humbled to help guide our great organization in 2025. I view this as a partnership with all the members and volunteers, and as such, welcome hearing your suggestions or concerns at any time (bentley@ieee.org). This is our Eta Kappa Nu…let's move it forward together!

Dr. Hulya Kirkici

Xi Chapter

"Perhaps that is the reason, I still encourage my students not to use calculators heavily in their classes but to try to use the tools that they have learned in their mathematics classes."

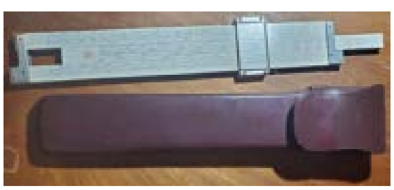


Fig. 1 Bulfin / Kirkici household slide rule.

THE BRIDGE, February 2025

Message from the Editor-in-Chief

Slide Rules: A Gateway to Advanced Computing

When the topic of "Slide Rules" was suggested for an upcoming issue of *THE BRIDG*E, I initially wondered if it would resonate with our readers. After all, most of us, including myself, have never used a slide rule and may not have fully considered its historical significance. I didn't grow up with smartphones, the internet, or even computers, but I am the child of multiplication tables and calculators – not far from the era of slide rules. Perhaps that is the reason, I still encourage my students not to use calculators heavily in their classes but to try to use the tools that they have learned in their mathematics classes.

Recently, I read an article titled "The Slide Rule: A Computing Device That Put a Man on the Moon" [1]. Of course, the 1960s and 1970s space programs led to many advanced technologies of today and had a lot of impact on technology that we normally understand and acknowledge, but not the slide rule! Later, I asked my family if we had a slide rule. Surprisingly, the other engineer in my household owned one and used it in college. Finally, I saw one, held it, and tried to use it (Figure 1). Its intricate functionality and the way one can calculate things are extremely difficult for those who haven't been trained to use it and for those who compute things easily with few keystrokes, these days.

In engineering and sciences, we often overlook the importance of tools such as the compass, protractor, triangle, etc., that we have used, and we still use starting from kindergarten. They have been here for centuries for us to use. Then why, one must ask, did that slide rule, a mechanical computing tool used for centuries, suddenly disappear from our classrooms, from engineering, from computing? The answer is that, just like any other disruptive technologies, the slide rule, the tool that has been the center of mathematics and computing, left the stage, and the "chips" and "digital" age came along with "electronic" calculators that took over the stage almost overnight [2]. Sometimes we forget where we are and what brought us here as a society.

Without irruptive technologies, none of today's technological advancements could have happened. After all, these technologies are developed for humanity, for us to have better lives, better health, better security, and a better community. The list goes on. However, we occasionally reflect on the past and recall the foundations upon which the technology we use today rests.

I am very thankful to the Guest Editor, Dr. Steve Watkins, for planting the initial idea, then working with the authors creating the content, *THE BRIDGE* Editorial Board enthusiastically agreeing to publish a special issue on slide rules, and the authors for writing the exceptional articles and content to make this issue a one of a kind. While reviewing the content in this issue, I truly enjoyed learning so much about slide rules, from the history of them to how they work. I hope you have the same experience as I had when you read this issue.

Furthermore, I thank the HKN Board and *THE BRIDGE* Editorial Board for giving me an opportunity to be the acting editor in chief of *THE BRIDGE* to see the production of this issue while a new editor in chief is appointed. With that, I am honored to welcome Burton Dicht, as the incoming editor-in-chief of *THE BRIDGE*. He has been with the IEEE family for a long time and has the wealth of knowledge to move the magazine to new heights. Thank you, Burt! We are so fortunate to have you to lead *THE BRIDGE* Editorial Board.

[1] https://www.npr.org/sections/ed/2014/10/22/356937347/the-slide-rule-a-computing-device-that-put-a-man-on-the-moon

[2] https://edtechmagazine.com/k12/article/2012/11/calculating-firsts-visual-history-calculators

Dr. Steve Watkins

Gamma Theta Chapter

"Invented over 400 years ago, slide rules were efficient tools for generations of scientists, engineers, technicians, and tradesmen."

THE BRIDGE, February 2025

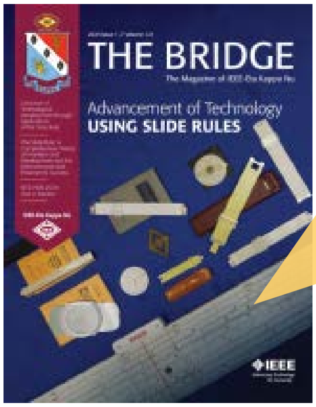
Intro from the Guest Editor

The theme of this issue of *THE BRIDGE* magazine is "Advancement of Technology using Slide Rules." Slide rules are elegant computing devices that resulted from the application of mathematical principles to practical needs in science and industry. Invented 400 years ago, slide rules were efficient tools for generations of scientists, engineers, technicians, and tradesmen. These tools were replaced upon the introduction of the electronic calculators in the 1970s. The application and versatility of slide rule approaches to computing are the subjects of our feature articles.

Our cover shows a collection of these tools from a pocket (6 inches) Pickett slide rule to the Post classroom demonstration model (77 inches). Our first feature shows the varied design and specialization of slide rules. The second feature describes the role of slide rules in the scientific and industrial revolutions that have created our modern world. Our history spotlight highlights the contribution of these handheld computing devices in the early space program. We have also compiled reminiscences and photographs from our IEEE membership; these are introduced on the next page and fully available at the IEEE-HKN website.

We thank everyone who contributed to this look at the past. In particular, we appreciate the feature authors for their efforts and expertise. They represent two organizations dedicated to preserving the history of slide rules - the Oughtred Society and the International Slide Rule Museum (ISRM).

ABOUT THE COVER



1. Pickett & Eckel Inc., Slide Rule Model N 3-T.
2. Gilson Slide Rule Co., Midget Circular Slide Rule.
3. Pickett & Eckel Inc., Slide Rule Eye-Saver Yellow Model N3-ES.
4. Keuffel & Esser Co., Slide Rule Model 4081-3.
5. Frederick Post Co., Duplex (Versatrig) Slide Rule Model 1450L with Post Veralog Slide Rule Instruction Text.
6. Pickett & Eckel Inc., Trig Slide Rule Eye-Saver Yellow Model N 200-ES.
7. Concise Co., Japan, Concise Circular Slide Rule No. 260.
8. Eugene Dietzgen Co., Phillips Slide Rule and Dietzgen Self Teaching Manual.
9. Kane Aero Co., Dead Reckoning Computer Model MK-6B.
10. Frederick Post Co., Demonstration Slide Rule, Versalog Model 1460.

Example Operations of a Slide Rule

The purpose of slide rules is to perform mathematical operations by positioning sliding scales. An adjustable cursor provides additional flexibility. The scales may relate to general calculations such as multiplication, division, and trigonometric functions or to specialized formulas such as aircraft ground speed and LC-circuit resonant frequency. For example, consider the operations of √2 and 1.4 x 3. Figure 1a shows a Post Versalog with the red-line cursor aligned with "2" on the D fundamental scale; the value of √2 = 1.41 is shown on the R1 scale. Figure 1b shows the beginning ("1") of the C fundamental scale aligned with "1.4" on the D fundamental scale with the cursor aligned with "3" on the C scale; the D scale reads 1.4 x 3 = 4.2. The latter operation uses the logarithmic scales for C and D to implement log(1.4 x 3) = log(1.4) + log(3) = Log(4.2).

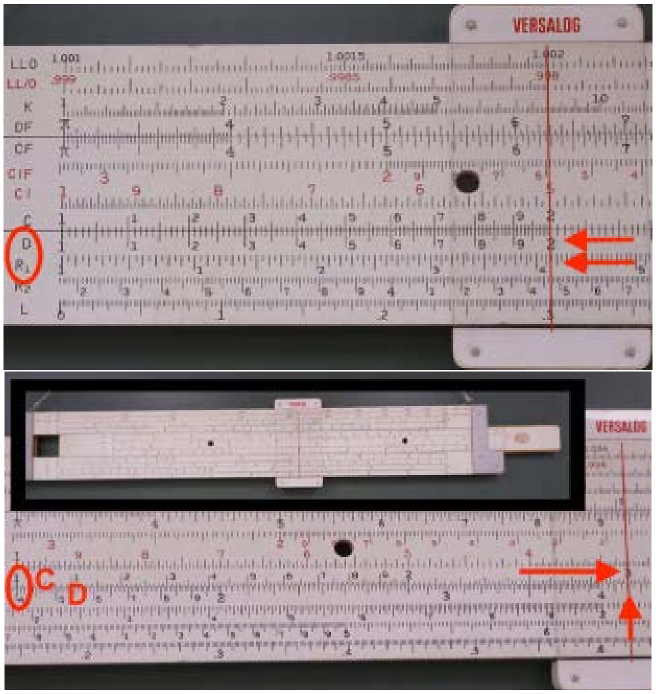


Fig. 1a. Cursor aligned for a square root (√2 = 1.41) using the D and R1 scales and Fig. 1b. Cursor aligned for a multiplication (1.4 x 3 = 4.2) using the D and C scales.

Slide Rules for Engineers: Contributions from IEEE Members

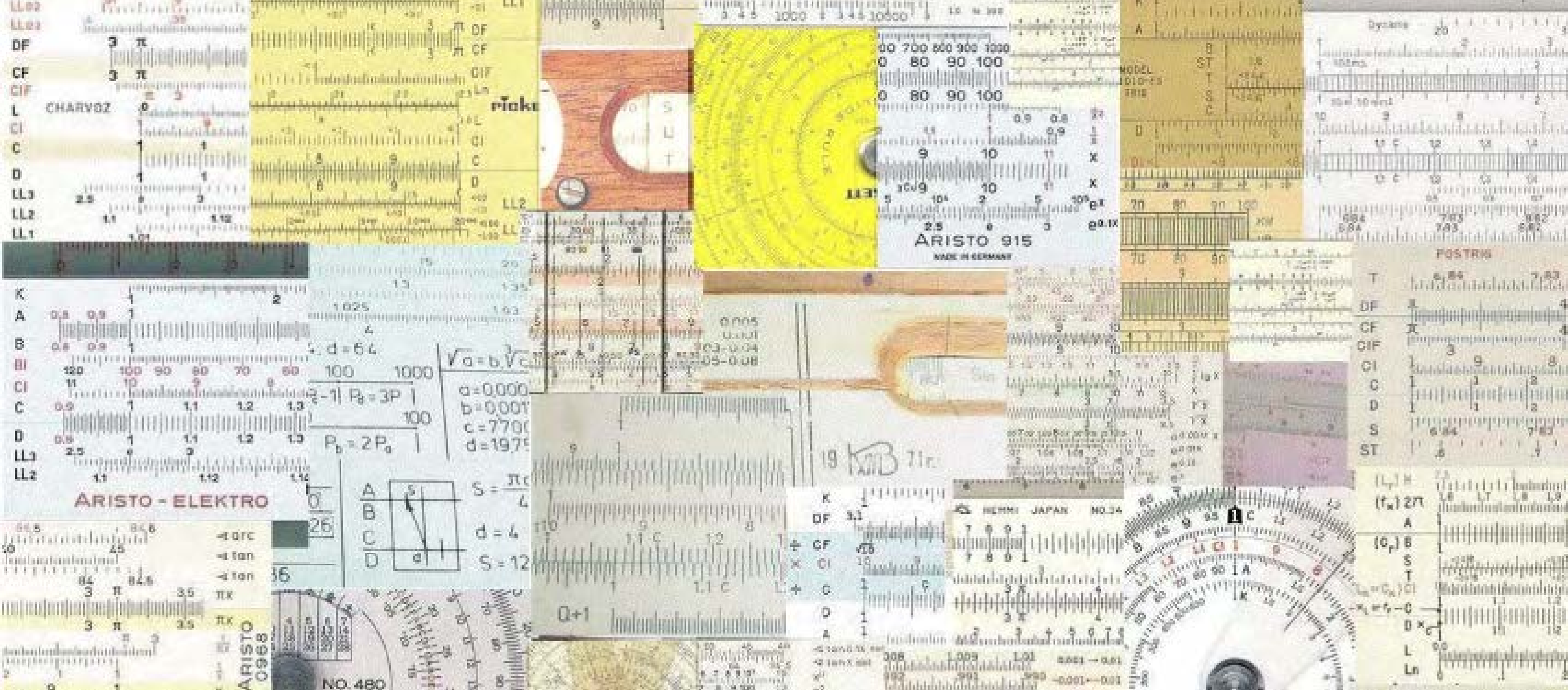
Before electronic calculators took their place, slide rules were a common tool for engineers. Many members across IEEE have strong memories of using these devices, and many have kept their personal slide rule or "slipstick." Here are some contributed images. See all of the photos and the associated comments on the IEEE-HKN website.

Xi Chapter of IEEE-HKN at Auburn University with teaching slide rules. Chair R. Mark Nelms and officers.

Aristo Slide Rule of Asad Madni, IEEE-HKN Eminent Member.

Pickett Slide Rule of Chuck Till, IEEE Life Member.

Circular slide rules of Robert L. Baber, Prof. Emeritus at McMaster University, Ontario, Canada.



Slide Rule Collage. Image Courtesy of the International Slide Rule Museum

Centuries of Technological Development through Applications of the Slide Rule

Mike Syphers

I. Introduction

The difficult task of multiplying and dividing numbers with several digits accurately by hand, particularly when many such operations are required for a particular calculation, was greatly mitigated with the invention of logarithms at the end of the 16th century by John Napier of Scotland. Rulers with logarithmic scales were created soon thereafter, most notably by Edmund Gunter of England. By sliding two equal-length logarithmic scales side by side, William Oughtred, also of England, showed how logarithms could be added and subtracted without the need for pen and paper, and thus in 1624 the slide rule was born [1].

Napier devised a scheme for which each natural number had another number — a logarithm — associated with it such that the sum of the logarithms of two numbers gave the logarithm of the product of the original two numbers. The tables of logarithms that he developed were of high precision, allowing for fairly accurate results of the multiplication of numbers of 5-6 digits each, with similarly precise results. His tables also contained the logarithms of values of trigonometric functions, which were important in navigation and in astronomy. But while cross-oceanic navigation often required such precision, many other applications can get by with much less. At first, logarithmic scales and slide rules were a curiosity of academic elites. But as they were easily portable and relatively simple to use, slide rules gradually began to find their way into a variety of applications through the introduction of special sets of scales and scale arrangements. With the simple movement of a slide, logarithms could be added to the rule to perform a multiplication or a division, greatly improving the speed and reliability of such computations in everyday situations.

One of the earliest special uses of slide rules — perhaps the earliest — was to compute the volumes of wine barrels. A special slide rule for this purpose was proposed by Oughtred himself in 1633 [2]. His new rule had a special non-linear scale in addition to the usual logarithmic scale, which, when used together, could compute the volume of a spherical barrel. Not unexpectedly, the main interest in such a quantity was to be able to assess tax on the barrel's alcoholic content. Fifty years later, in 1683, Thomas Everard, an excise officer in London, created a new rule with several slides containing a collection of special scales that could be used to compute a barrel's volume and the volume of its contents given certain measured dimensions, as well as computing the amount of malt barley in a rectangular wooden couching frame. By the mid-1700s, these so-called "gauging rules" were accompanied by other slide rules — "proofing rules" — for calculating the percentage of alcohol in the liquid (from hydrometer measurements) and for computing the actual tax to be assessed. The slide rule could do basic math operations like multiplication and division, squares, square roots, and on some models, reciprocals. However, even non-mathematicians could be trained to perform the required gauging calculations using the slide rule. An example of such a rule is shown in Figure 1.

[1] https://www.planetary.org/space-policy/nasa-budget

Fig. 1. An Everard-style Excise Tax Gauging Slide Rule, c. 1770, by Edward Roberts, London. Image courtesy of Nathen Zeldes.

In addition to gauging and excise tax collection, another discipline found good use of the early slide rule. In about 1677, Henry Coggeshall of England created a new type of ruler with a built-in slide that contained scale arrangements useful to the lumber industry. With tree diameters measured in inches and tree heights measured in feet, the logarithmic scales on the Coggeshall rule made it easy to figure out an area. Then, a length was multiplied by an area to get the volume of lumber that could be taken out.

Figure 2 shows an example of a folded timber slide rule from the 1800s. The brass slide has scales labeled B and C, with scale A directly above. All three of these are two-decade logarithmic scales that run from 1 to 10 to 100. Scale D, directly below the slide, is a single-decade logarithmic scale, but with an offset. It starts at 4 rather than 1, as do the other three scales, and ends at 40. As feet need to be converted to inches in these calculations, this layout places the "12" on the D scale near the center on the rule. The combination of this D scale and the two-decade scales A, B, and C allowed for direct computations of cross-sectional areas and volumes. These scales comprise a "Timber Rule," or "Carpenter's Rule," an instrument that remained in circulation until the late 1800s.

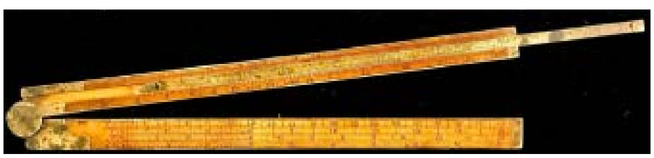


Fig. 2. A Carpenter's Rule, c. 1850, by Stanley, New Britain, Connecticut.

II. Enter the Engineers and Standardization

Developed in England, the early slide rules had typical lengths of about 12 to 24 inches. With accurate scales of this length, one can easily multiply 2- or 3-digit numbers and expect a result that is good to about 0.1-0.2%. The user must keep track of factors of ten in the calculations, however, as the slide rule only produces the digits of the final answer. And as with Oughtred's original examples, the A and B scales of Coggeshall's slide rule could be used to perform general calculations beyond those in the lumber industry.

The adjustment of scale B relative to scale A on the Coggeshall rule is equivalent to setting up a ratio; problems were thought of in these terms, as can be seen from the many early papers and books written about the slide rule. For example, the relationship "a: *b* as x: *c*" can be set by putting "*a*" on the A scale and "*b*" on the B scale opposite each other on the slide rule to set the ratio. All other numerical values opposite each other on these two scales will have the same ratio. Thus, with a ratio set to a/b, to solve for x = c (a/b), we find "*c*" on the B scale, and opposite *c* will be "*x*" on the A scale. To compute a two-factor multiplication, $x = a\ c$, we just let $b = 1$ and proceed as before. Having two decades that ran from 1 to 10 to 100 on each scale, all numerical combinations giving the same ratio would be visible at once.

The 1700s saw Carpenter's Rules become a staple within the lumber industry. But this was also the period of other significant technological growth, including the development of the steam engine. In the late 1700s, James Watt and Matthew Boulton were leaders in this new technology, and they began to create slide rules for their endeavors in the factories outside of Birmingham in an area dubbed as Soho [3]. While some of the slide rules they developed were special to their needs, the most popular of these so-called "Soho Rules" had a similar scale arrangement as the Carpenter's rule. Along with the same A, B, and C scales came a new variant of the D scale — a single-decade now running from 1 to 10. With this simple change, the square of any number on D could be found directly above on A. Hence, squares and square roots could be incorporated into many variants of general multiplication and division problems, which was important for the development of pistons and engines. In roughly 1810, Englishman Joshua Routledge invented a slide rule with the look of a Carpenter's rule but with the Soho scale arrangement, which became known as an Engineer's rule. By the mid-1800s, the most popular slide rule types being sold were Carpenter's and Soho/Engineer's rules, and the standard Gunter's rule with its single logarithmic scale for use in navigation.

The next major step in the standardization of slide rule scales came a few decades later. By 1800 slide rule manufacturing had made its way from Great Britain into France and Germany. In 1850 a young French military cadet, Lieutenant Victor Mayer Amédée Mannheim, patented a slide rule scale arrangement where the C scale of our previously discussed slide rules was replaced with a single-decade log scale — the D scale, but on the slide. This allowed for a much more robust set of calculations that could be performed involving squares and square roots, motivated by the desire to perform ballistics calculations.

In 1851, Mannheim patented a "cursor" for reading and comparing values on any of the four scales with greater ease. The French company Lenoir-Gravet began producing

Mannheim rules in the late 1850s. Mannheim's scales were good for artillery calculations, as envisioned by its inventor, and for many other more general applications. The Mannheim scale arrangement led to the rapid acceptance of the slide rule as a modern computing device. With its cursor for tying the various scales together, the slide rule user could quickly multiply, divide, take squares and square roots, and do so in a variety of circumstances and computational orders. Within years, if not months, the French Mannheim slide rules also had scales of logarithms, sines, and tangents of angles on the backs of their slides. This allowed for easy access to trig and exponentiation calculations when needed, giving them the same functionality as Napier's tables of logarithms. Mannheim's slide rule scales are shown in Figure 3. These scales would become a standard configuration on slide rules for the next 100 years with labels "A B C D" (top to bottom).

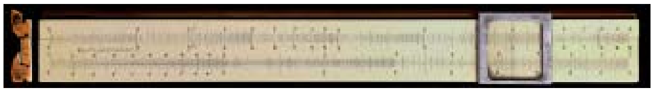


Fig. 3. A Mannheim Slide Rule, c. 1900, by Keuffel & Esser, New York.

III. The Need for Speed and Accuracy

After 250 years of development, improvements to the basic slide rule design and function began to develop very quickly, starting in the late 1800s. To get more accurate results, the slide rule could be made longer. Using single-decade scales with the same overall length, like those on the Mannheim, also led to better results.

There is the inevitable problem, however, that when the slide of a slide rule with single-decade scales is extended out beyond the end of the rule, the numerical results being sought can become "off-scale," requiring a re-adjustment of the slide. But a notable development was introduced by bridge engineers Edwin Thacher and his employee Edson Scofield. Thacher was designing bridges across major rivers in the United States and understood the need for greater accuracy in engineering calculations. In 1881 he invented and patented a very novel slide rule, an example of which is shown in Figure 4, that essentially divided a pair of logarithmic scales into multiple segments, yielding an 18-inch-long device with the accuracy of a 30-foot slide rule [4].

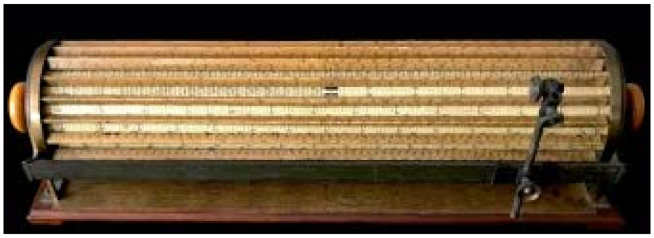


Fig. 4. Thacher's Calculating Instrument, 1907, by Keuffel and Esser, New York.

Thacher's patent also addressed the problem of results going off-scale. His new cylindrical slide rule contained a second identical set of scales offset from the first by half the cylinder's length. When a calculation was made, the answer was guaranteed to be found "on-scale" on one of the two scales, thus improving speed as well as accuracy.

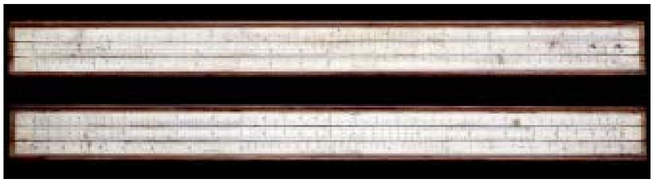


Fig. 5. Scofield Engineer's Slide Rule (front and back), 1901, sold by Eugene Dietzgen, Chicago.

Thacher and Scofield worked together to obtain a more general patent for such sets of scales, soon referred to as "folded scales." In 1901 they received a patent for a new "Engineer's Slide Rule," shown in Figure 5, with a variety of folded and inverted scales that enhanced both speed and accuracy of calculations [5].

The need for faster calculations increased as the development and proliferation of technologies in manufacturing and construction trades rapidly developed. Over the next fifty years, slide rule designs kept getting better by using arrangements of folded and inverted scales. This made multiplication and division faster and added more scales that made natural logarithms and easier exponential calculations possible. The slide rule became an essential tool for all engineering and scientific, as well as business and industrial disciplines.

IV. Applications for a Modern World

Even today, physicists refer to "modern physics" as the years beginning in about 1900 -- and this is also the time when the modern technical development of slide rules and their widespread general use began to take off. Table 1 shows a breakdown of three types of rules that developed. Manufacturers continued to produce slide rules with basic scales, mostly based on the successful Mannheim design, while they were also creating more advanced scale sets. In one direction, higher-end models provided additional scales to enhance computational speed and functionality in general computing. These would be similar in function to future so-called scientific calculators when compared to pocket calculators with only rudimentary operations. Basic slide rules might have 7-10 scales on them, while the advanced slide rules might have 20 to 30 or more.

Type of Slide Rule	Typical Functionality
Basic	Multiplication, division, squares, square roots; usually trig and common log functions; perhaps inverses and cubes — Mannheim was the standard.
Advanced	All above functions plus exponentials, natural logs, perhaps hyperbolic trig, special scales for rapid operation — akin to advanced scientific pocket calculator.
Specialty or "Programmed"	Special scales for specific calculations — akin to a programmable calculator or computer application.

Table 1. General types of slide rules according to functionality.

But in addition, new specialty slide rules beyond those in the lumber and gauging disciplines began to be designed at a fast pace for other fields within the first decade or so of the twentieth century. Chemists had rules for setting ratios of chemical compounds to perform quantitative analysis. Surveyors had "stadia" slide rules with additional trigonometric functions for creating topographical maps from their measurements. In the process of electrifying the world, electricians employed "electro" rules, which offered specific settings and scales for direct calculations of cable resistance and voltage drop calculations. Figure 6 shows a couple of examples.

Fig. 6. Top: Model 378 Electo slide rule, 1913, by Faber-Castell, Germany. Bottom: Model 33 Chemical slide rule, 1928, by Nestler, Germany.

And there were slide rule models for every circumstance in which a calculation needed to be performed: larger, higher-accuracy desktop models for the office; ruler-sized models in leather cases, some with belt loops for easier portability; and half-sized models for carrying in a suit coat pocket.

V. Advanced Specialty Slide Rules

According to the Oughtred Society, more than 90 new slide rule designs were recorded between 1900 and 1910, 20 times the average rate of the previous 100 years [6]. A good portion of this was due to the continued introduction of new specialty rules. The "spring design" slide rule is a prime example of a specialty rule, with examples dating back to the early 1940s. The equation for determining the deflection of a metal spring, for instance, can require about 5 multiplications or divisions, where one factor is also squared, and another is cubed. A designer attempting to develop the requirements of a particular spring for a particular application might need to perform extensive slide rule manipulations with a standard rule. So, slide rules like the ones in Figure 7 were created with double- and triple-log scales on a slide rule, some with multiple independent slides, that could be set to perform this specific calculation in one setting.

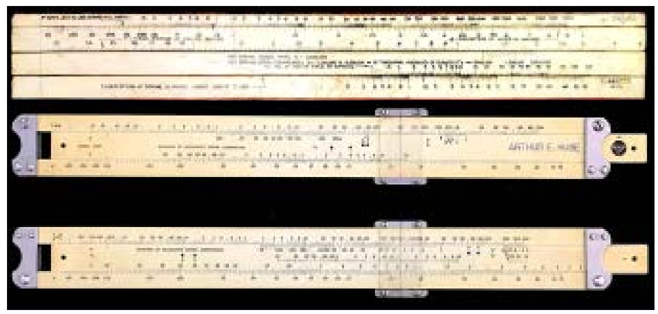


Fig. 7. Spring design slide rules. Top: Rule with 2 slides made by R. K. Baetzmann, 1941, Chicago. Bottom: Model 1025 (front and back),1952, by Pickett, Chicago

By inputting known parameters and seeking an acceptable outcome, combinations of remaining parameters that satisfy requirements could be readily scanned. Such rules might have scales that are less precise than a standard 10-inch slide rule, but ballpark estimates could be made rapidly, and then a more standard rule could be used for finalizing the design if required.

Similar slide rules were made for a wide variety of other disciplines. Some rules contained special arrangements of scales to improve the speed of repetitive calculations. Others contained scales of values for special functions required in calculations specific to a particular field or specialization. There were slide rules used for steel and concrete structure designs, like in Figure 8. Others for computing requirements of control valves and piping, and so on.

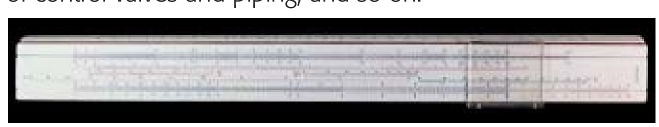


Fig. 8. The Model 3/11 slide rule, 1960, by Faber-Castell, Germany, used for calculations in the design of steel-reinforced concrete beams and structures.

There were special military slide rules developed for ballistics calculations, aviation and navigation calculations, aerial photography, and meteorology. Figure 9 displays an interesting slide rule used for computing the salinity of seawater versus depth based on electrical measurements along a cable dragged from a naval vessel [7].

Much of the design work necessary to create the circuitry of the early computers and calculators that eventually replaced the need for a slide rule was actually performed on …

Fig. 9. The Culbertson Salinity slide rule (front and back), 1955, by Kahl Scientific, El Cajon, California.

slide rules. Electrical and electronic circuitry involving high-frequency impedances required calculations best expressed in terms of "complex numbers" and required the evaluation of trigonometric functions with complex arguments. So-called "vector" slide rules, introduced in about 1930, consisted of scales of hyperbolic trig functions that could be used for such numerical evaluations. By the 1960s, there were "electronic" slide rules, some with not only the hyperbolic scales but also scales for straightforward computations involving reactive and capacitive impedances, resonant frequencies, stability criteria, surge impedances, relative gain, and so on. Figure 10 displays one such device that has well over 30 scales.

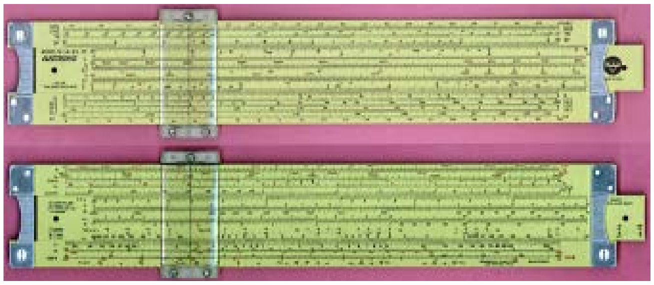


Fig. 10. The Model N16-ES Chan Street slide rule (front and back), 1960, by Pickett, Chicago. Image courtesy of International Slide Rule Museum (ISRM).

VI. The End of an Era

The Slide Rule: *b. 1624, d. 1976.* So, what areas of engineering used slide rules? The simple answer is, "All of them." Slide rules were used in the development of the electrical grid, bridges and buildings, automobiles and trains, particle accelerators, radios and TVs, planes and spacecraft, microchips, and data storage devices. Even as the early large-scale electrical computers were being developed, the slide rule was still the instrument that was always at hand or on the desk nearby. At the end of the slide rule's 350-year run, a list of popular, top-of-the-line advanced slide rule models — typically with 2-3 dozen scales each — included the Faber-Castell 2/83N, the Aristo 0969, the Keuffel & Esser (K&E) DeciLon, the Pickett N3 and N4, and the Post/Hemmi Versalog II, to give just a few examples. But when electronic calculators finally came to be of reasonable size and competitively priced in the mid-1970s, the worldwide sale and production of slide rules abruptly ended.

Today, the slide rule is primarily a collector's item. The $100 advanced slide rules of the 1970s (roughly $600-$800 in 2024 dollars) often can be found in antique stores or online for as little as $20-50 today. Not-so-common rules, often special rules, or perhaps the oldest models, can go for much more. The Oughtred Society website provides links to many collections, as well as information regarding the use and care of slide rules [8]. Only a very small number of companies still produce slide rules today. Most notably, Concise in Japan makes a limited number of models of general circular slide rules, as well as some specialty rules. Likewise, Mear Calculators in the UK makes slide rules primarily for specialized industrial calculations. And for those without access to a physical slide rule, virtual examples are also available [9].

While calculator apps on laptops, phones, and pads have replaced the calculators that replaced the slide rules, there are those who argue that computational conditions exist that still may be best pursued by a slide rule. When a slide rule is set up to perform a calculation, not only is the final answer found for the given input, but often other conditions that provide that same answer can be viewed simultaneously. Similarly, answers for a range of input values can often be viewed without having to move the slide again. This can be a useful property when trying to choose quickly between a variety of possible combinations of variables or when repeating a calculation with just a small change in one variable.

And, of course, no batteries are required.

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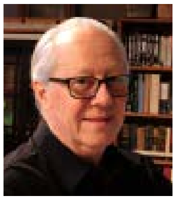

Mike Syphers retired in 2022 from his joint roles as Research Professor of Physics at Northern Illinois University and Senior Scientist at Fermi National Accelerator Laboratory (Fermilab). His career has been dedicated to the design and study of large-scale particle accelerators and charged particle beam transport systems, as well as to education in the field of particle beam physics. Mike is a Fellow of the American Physical Society, a member of the Oughtred Society and the UK Slide Rule Circle, and is an advisor to the International Slide Rule Museum. His website is http://followingtherules.info. The images are from his personal collection unless otherwise noted.

Everard's Slide Rule made by Isaac Carver Fecit in 1694

The Slide Rule: A Comprehensive History of Invention and Development and the Improvements that Powered its Success

Robert G. De Cesaris

I. Introduction

Simplifying complex calculations that required numerous multiplications and divisions to high accuracy became a burden in the late 16th century as astronomers sought detail to understand the movement of objects in the night sky and navigators took on treacherous journeys to map and claim new lands in the 'terra incognita' of the New World. Several mathematical shortcuts for complex calculations were developed with some success, but the discovery of logarithms revolutionized the simplicity of the calculations to a new level. In this article, we will discuss the tools that were invented to take calculating from merely counting to a new and beautiful understanding of numerical relationships. The invention of the logarithm represented a key fundamental development in this endeavor, and its quick adaptation to that most useful tool, the slide rule, became an important quantum leap for facilitating practical calculations to sufficient accuracy in numerous fields, especially in gauging, construction, navigation, and efficient steam and gasoline engine development. It became an essential tool in energizing the industrial revolution and in tackling modern engineering challenges that take us well into the 20th century. The development and proliferation of the slide rule is a fascinating topic; the many inventive and attractive designs continue to engender keen interest in their study, collection, and preservation. (Any figures or images not directly attributed in this article have been taken from the author's personal collection.)

II. The Gunter Scale

Edmund Gunter (1581 – 1626) was born in Hertfordshire, England, and attended Westminster School before entering Christ Church, Oxford, in 1599. He graduated in 1603 and remained at Oxford until 1615, when he received his divinity degree. In addition to being made Rector of St. George's Church in Southwark, he was named professor of astronomy at Gresham College, London, in 1619, remaining in this post until his death. In 1619, Gunter published his first set of logarithm tables, Canon Triangulorum, containing his recently calculated decimal logarithms of sines and tangents, along with Henry Briggs's initial base 10 logarithm table.

Fig. 1. Original Drawing of Gunter's Scale with Three Types of Logarithmic Scales [1]

At this point, Gunter decided to take a key step toward making logarithms faster and easier to use rather than having to deal with cumbersome tables. He understood that many simple navigational problems did not require extreme accuracy; he was also familiar with the use of dividers for making calculations using a sector. As seen in Figure 1, he devised a new set of scales that separated the numbers by logarithmic scale distances. These scales could be used to multiply and divide with the use of a set of dividers to add or subtract lengths with the final result being read on the same scale. He called his basic logarithmic scale the 'Line of Numbers' and also proposed adding logarithmic sine and tangent scales so that the important navigational 'Law of Sines' could be easily calculated. The basic scales became very popular for navigation, and over the next several decades, additional useful scales were readily added, resulting in the final form of a typical Gunter scale, as shown in Figure 2.

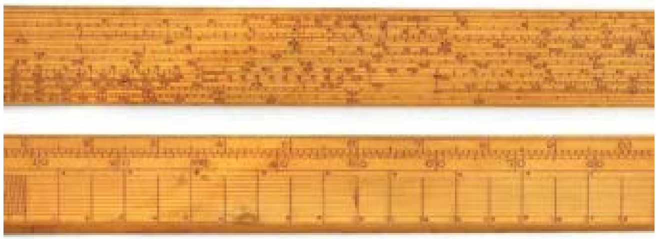

Fig. 2. Example of a Typical 19th Century 20-inch Gunter Scales with Gunter's Initial Scales and Numerous Others Added Later Proven Useful in Navigation

III. The Logarithmic Slide Rule

A. William Oughtred and the Controversy Over Invention

William Oughtred (1574 – 1660), born in Eton, England, on March 5, 1574, was an English mathematician and Anglican clergyman. He was educated at Eton College and at King's College, Cambridge, where he received both a bachelor's degree in 1596 and a master of arts degree in 1600. John Napier's discovery of logarithms directly led to Edmund Gunter's invention of the Gunter Scale, an analog tool containing logarithmic scales, his so-called "Line of Numbers," to be used with dividers. Reverend William Oughtred is credited with being the first to recognize that two equivalent Gunter scales, whether sliding against each other as straight scales or in circular form, could be used to perform direct multiplication and division. The actual invention of the slide rule cannot be pinpointed exactly, but it is believed to have been conceived by Oughtred between 1622 and 1628 based on his initial published book on the matter, *The Circles of Proportion and the Horizontall* Instrument, dated 1632 [2]. Figure 3 shows the title page of his seminal work.

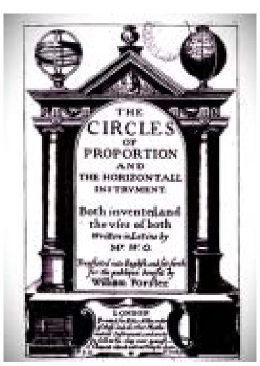

Fig. 3. Oughtred's 'The Circles of Proportion and the Horizontall Instrument' that Introduced the Slide Rule to the World (1632)

In his work, he refers to having conceived of his circle of proportions some years earlier, but without specifics as to the actual year of invention. Although Oughtred may have developed the linear form with two adjacent Gunter scales first, it was not until 1638 that an important letter was recently discovered in the Manuscripts Room at Cambridge University Library from Oughtred to Elias Allen, a well-known instrument maker of the time and also one who Oughtred employed for making his circular rule. That letter describes the linear slide rule and notes that he (Oughtred) 'would gladly see one of [the two parts of the instrument] made of brass when it is finished, which yet I have never done.' Along with the letter is a reverse print on paper of a two-foot-long rule, presumably inked by Allen after the rule had been completed as a demonstration to Oughtred. It was not uncommon at the time for instrument makers to produce reverse-printed records of instruments under construction that had taken a great deal of time and effort to engrave as a record of their work (Figure 4). No examples of the linear rule have survived, and very few examples of Oughtred's circular rule are known today. A few specimens are on display or housed in the archives of British museums, and one is currently on display at The Collection of Historical Scientific Instruments at the Putnam Gallery at Harvard University (Figure 5).

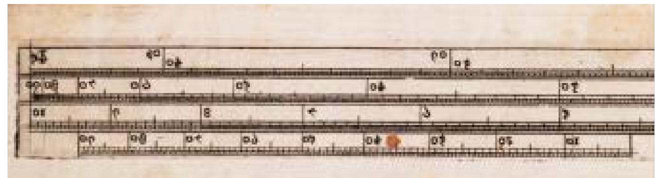

Fig. 4. Reverse Print by Elias Allen of Part of Oughtred's First Linear Slide Rule, from the Macclesfield Collection, Special Collections of the Cambridge University Library [Image by Boris Jardine and Cambridge University Library]

Fig. 5. An Early Example of Oughtred's 'Circle of Proportions,' by Elias Allen, c. 1633-1640 [Harvard University, Putnam Gallery]

Oughtred was noted for his generosity in assisting those interested in studying mathematics, and for more than five decades he tutored some of the better-known English mathematicians of the 17th century. In his writings, Oughtred routinely introduced his own notation and symbols in expressing mathematical concepts. Two symbols that he introduced are still widely used today, the 'x' for multiplication and the :: that is used to express proportions. Oughtred considered his slide rule tool for teaching mathematical concepts and did not pursue searching for other practical applications of the tool.

Oughtred became embroiled in a brittle controversy over priority with Richard Delamain (1600 – 1644), an English mathematician and a student of Oughtred, known for his works on sundials, when the latter published *Grammelogia or the Mathematicall Ring, extracted from the Logarythmes and projected Circular,* in 1631 [3]. Delamain published this small pamphlet, dedicated to King Charles I, in which he claimed to have invented the circular slide rule. An acrimonious controversy ensued with Oughtred striking back with his *Circles of Proportion and the Horizontall Instrument,* where he described his circular slide rule in great detail, defending his priority and reputation, and addressed the important issue of the proper rule of theory associated with the rule and with instruments in general, in the teaching of mathematics. Although Oughtred was successful in proving his priority, Delamain and his pamphlet did win royal favor and enabled his lucrative appointment as 'tutor to the king in mathematics.'

It is widely recognized today that William Oughtred was the sole inventor of both the linear and circular slide rules; however, this has not always been the case. Florian Cajori [3] best highlights the confusion and controversy in his book *A History of the Logarithmic Slide Rule and Allied Instruments,* initially published in 1909 and reprinted by Astragal Press in 1994. In the main text of his work, Cajori notes that Gunter's Line of Proportions (Gunter's scale) and the slide rule were often confused with one another. He initially concluded in his main text that based on all documentation known to him at the time, Gunter had invented the Gunter's scale, that Edmund Wingate (1596 – 1656), another English mathematician, had invented the linear slide rule in 1630, and that Oughtred had invented the circular form of the slide rule in 1632. Only after further extensive research of Wingate's numerous publications did Cajori conclude that none of Wingate's works indicated any invention of a slide rule but only referred repeatedly to numerous applications of Gunter's scale. Cajori added this as a key addendum to his book, concluding firmly that the invention of the linear slide rule is not due to Wingate, but that both forms of the rule are due solely to William Oughtred.

B. The Coggeshall, or Carpenter's Slide Rule, 1677

Oughtred primarily utilized the slide rule to assist in his teaching of mathematical principles and concepts. In 1677, Henry Coggeshall (1623 – 1690) recognized the potential of the sliding rule as a practical tool when he designed the Carpenter's slide rule, also known as the Coggeshall rule, to help calculate the surface area, volume, and other dimensions involved with harvesting timber. The basic rule consists of three scales, the outer two fixed in place with each other and the center scale, a slide. Coggeshall's initial description of the rule noted, 'Timber measure by a line of more ease, dispatch, and exactness, then any other way now in use… easy both to make and use' [3]. The design was improved twice, in 1682 and then again in 1722. Most versions bear the standard Coggeshall scales, namely, two two-cycle logarithmic scales, one on the fixed body portion, or stator, and one on the movable slide, running from 1 to 100, or from 1 to 10, twice. The final scale is located on the other stator, a single-cycle logarithmic scale running from 4 to 40; this is the 'Girt Line,' which is used for calculating the volume of timber; 'Girt' is one quarter of the circumference of the round log being measured.

A two-foot folding rule with two one-foot length scales connected by a hinge at one end became the most popular and useful shape. This is the version that most commonly survives today [4], an example of one is shown in Figure 6. This specific form was a small change to the widely used two-foot hinged linear folding rule of that time. This new form retained the traditional linear scale in inches on the reverse; the additional top leg with the Coggeshall scales provided additional computational capabilities, with the bottom leg containing other scales or tables that were relevant to the woodworking professional.

Fig. 6. A Typical Example of a Coggeshall, or Carpenter's Rule, that Can Be Commonly Found in Many Tool and Slide Rule Collections Today

C. The Everard Gauging Rule, 1683

Thomas Everard (1560 – 1633), an excise officer in Southampton, England, designed a slide rule specifically for gauging, that is, for calculating the excise tax owed on alcoholic beverages at ports of entry, malt houses, ale houses, taverns, inns, and wherever alcoholic beverages were imported, distilled, or sold to the public. This slide rule, in conjunction with other tools for measuring the volume and ullage (the amount by which a container falls short of being full) of casks and the concentration of alcohol in a beverage, was used throughout England by the end of the 17th century to collect this much-needed revenue. This was a time when England required a great deal of money to finance their new offshore empire, especially including shipbuilding and the payment of officers and soldiers. Beginning in 1643, England began an aggressive effort to collect taxes to support this effort. Taxes were due on many items, including all spirits, cider, soap, and vinegar, with additional items added as the need increased. Everard's design addressed facilitating these calculations for the tax on spirits and related items, and in 1684, he published a book that covered his new rule, S*tereometry Made Easie: or the Description and Use of a New Gauging-Rod or Sliding-Rule*… which he dedicated to Commissioners and Governors of His Majesty's Revenue of Excise. In his work, Everard went into detail on how one needed to find the true content of each cask and classified the different types of casks depending on the exact shape of the sides [5]. He first included the four most common cask varieties and illustrated each of the shapes in his book.

1st Variety: Middle Frustrum of a Spheroid
2nd Variety: Middle Frustrum of a Parabolic Spindle
3rd Variety: Middle Frustrum of two Parabolic Conoids
4th Variety: Middle Frustrum of two Cones

To be thorough, he also went on to describe additional shapes that were not as common. His initial rule was a four-sided rectangular rule of rectangular cross-section with the wider faces containing one slide each and the narrow faces having fixed scales. His gauging rule and its variations gained popularity, underwent alterations and improvements, and saw widespread use well into the 19th century. The lengths of the rules that were made for this purpose for the next two centuries came in sizes ranging from 6 inches to 24 inches. Also, as the rule was improved, the number of sides containing slides quickly moved from 2 to 3 to all 4, so that by the late 18th century, nearly all examples contained slides on all four sides of the rule. Figure 7 illustrates the diversity with which this most useful tool was developed for the collection of excise taxes on alcohol and for the intermediate processes related to the manufacturing of alcoholic beverages.

In summary, Everard's slide rule for excise officers yielded enormous success, with thousands of devices produced over the years. A significant number of these examples, particularly the later ones with four slides on each side, have survived. His design had the impact of standardizing the practice of calculating excise taxes and helped move the slide rule from a tool of mathematical teaching and inquiry to one of specialized practical application.

Fig. 7. A Variety of Everard Excise Rules of Various Lengths from the Late 17th to the Mid-19th Century

During the late 18th and early 19th centuries, perhaps influenced by the design of the Soho rule, invented in the 1770s, excise rule design gradually transitioned to flat, one-sided rules with two slides and then more prolifically to two-sided rules with two slides. This updated design generally contained similar scales with some updates and was also manufactured from 6 inches to 24 inches in length, with one known example measuring an impressive 36 inches long.

D. The 'Sliding Gunter' Rule, Mid-17th to 19th Century

There is no clear inventor of the sliding gunter, but it appears to be a rule that was gradually derived from the Gunter scales to enable navigational calculations without a divider. The sliding gunter is noted in a 1693 book by James Atkinson, *The Description and Use of the Gunter, Sliding Gunter, and Sector*, and later in the book he describes in detail 'The Use of Gunter's Scale, both single and sliding.' In 1703, T. Tuttel and J. Moxon, in their book *The Description and Use of Mathematical Instruments*, defined a sliding gunter 'as made of box[wood] with a middle piece that slides between two pieces, with Lines to answer Proportions by inspection, chiefly used by Mariners.' Examples of sliding gunters today are not common, but it is clear that these rules were made well into the mid-19th century, as shown in Figure 8, with numerous specialized scales for use in navigation.

Fig. 8. A Sliding Gunter with Logarithmic Sine and Tangent Scales on both Stator and Slide to Facilitate Calculations Dealing with Navigation

E. Soho Slide Rule (Engineer's Rule), 1770s; Routledge's Engineer's Rule, 1809

Slide rules in the 17th and early 18th centuries were very practical and designed for very specific purposes. It was not until the mid-to-late 18th century that its use extended to that of engineering; Soho slide rules are considered to be the first engineer's slide rule [6]. As early as 1827, John Farey wrote in A Treatise on the Steam Engine, 'The properties of the logarithmic lines upon a sliding rule are not very well known to practical engineers.' He also noted that these types of instruments had been in use for a long while among excise officers and carpenters to speed calculations. The slide rule was first used to build steam engines at the factory in Soho, England, which was started by Matthew Boulton and later joined by James Watt. This was the main event that led to the creation of a rule that could be used specifically in engineering. In turn, this rule led to the introduction of the slide rule to the general engineering community. In his treatise, Farey described this slide rule in great detail:

'The Soho sliding rules are made of boxwood, 10½ inches long, with one slider and four logarithmic lines on the front face; and at the back are tables of useful numbers, divisors, and factors for a variety of calculations. Sliding rules of this kind are called Soho rules, and they are so correctly divided by some of the best makers of mathematical instruments in London, that they are capable of performing ordinary calculations with sufficient accuracy for practice; and by means of tables at the back of the rule, most questions in mensuration may be readily solved.'

As can be seen from Figure 9, the scale arrangement is very simple, with the A scale on the top stator and the B

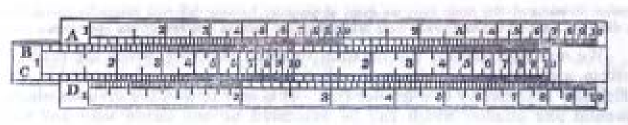

Fig. 9. The 'Soho Sliding Rule' as Depicted in John Farey's Work 'A Treatise on the Steam Engine'

and C scales from the slide being two-cycle logarithmic scales and the D scale on the bottom stator being of one cycle. From Farey's commentary, it is evident that this slide rule was very important in supplementing the design capabilities of Soho designers and technicians and in increasing their productivity. As a young man, James Watt had served as an apprentice instrument maker in London. After joining Boulton in 1775, he quickly recognized that a well-designed and very carefully calibrated slide rule could increase the productivity of the firm's technicians. He commissioned a few examples designed and produced by the reputable instrument maker John Jones that were more accurate and more precisely made than those made for Officers of the Excise. These rules were placed in the hands of his most trusted Soho technicians, where they were regarded as proprietary instruments that gave the company a competitive edge; hence, these rules were kept as a closely guarded company secret for years.

Jones's firm became W&S Jones when his sons William and Samuel assumed leadership of the company. Over the years, the Soho slide rule design eventually was featured in the W&S Jones catalogue, and by 1815, France, beginning with Étienne Lenoir, began producing precise boxwood slide rules based on the Soho design. The Soho design was extremely influential and ushered in a new era in the history of the slide rule. The very specific excise, carpenter's rule, Gunters, variations on sliding Gunters, and other complex rules were now joined by very large numbers of extremely simple and accurate instruments that could be applied to a very wide range of disciplines.

Lenoir and the successor companies Gravet-Lenoir and

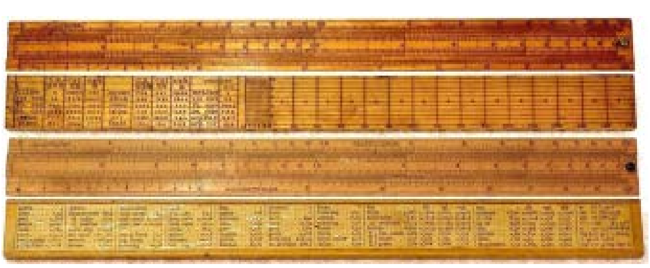

Fig. 10. Early Lenoir Slide Rules in Soho Form. Note Tables of Useful Data on Reverse Face. The Second Rule by Gravet-Lenoir Contains the Reverse Tables on Paper which Became the Standard for Engineering Soho and Mannheim Slide Rules

Tavernier-Gravet became one of the most important and prolific slide rule manufacturers by the mid-to-late 19th century; two examples of their early rules, which established a new standard for accuracy, are illustrated in Figure 10. In parallel to this development, a different form of this rule was invented by Joshua Routledge (1773 – 1829) of Yorkshire, England, a seller of iron goods, around 1809. He discussed this rule at length in his publication *Instructions for the Engineer's Improved Sliding Rule.* Routledge developed a design in physical form similar to the two-fold, two-foot Carpenter's rule with two one-foot length scales connected by a hinge at one end (Figure 11). For his rule, Routledge used the Soho scale arrangement for the top leg, which contained the slide rule, and then added a series of useful engineering data, constants, and factors to the bottom leg. The reverse of the rule was a standard linear measuring rule that extended to 24 inches when unfolded, exactly as on the Carpenter's rule of similar design. Other variations of this engineer's rule include a four-fold version, which is more compact and can be easily carried in a pocket.

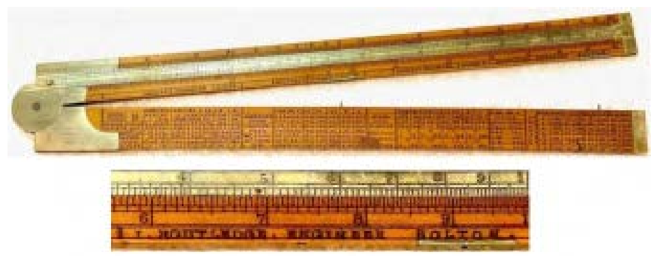

Fig. 11. Two-foot Folding Routledge's Engineer's Rule, Boxwood with German Silver Slide

F. The Mannheim Slide Rule, 1859

In 1859, a young lieutenant in the French artilley, Victor Mayer Amédée Mannheim (1831 – 1906) developed a new system of scales and introduced a metal cursor to enable easy transfer of readings from one scale to any other scale on that side of the rule. This novel arrangement also greatly facilitated continuous chained calculations by allowing the calculation to move back and forth between the slide and the cursor. This considerably increased the utility of the slide rule by speeding up calculations and by avoiding the necessity of writing down intermediate answers. The impact was so profound, and the transformation of slide rules to this model and its variants so complete, that Mannheim is considered the inventor of the modern slide rule. Mannheim's version of the slide rule quickly came to dominate the industry as the standard, and his version was imported in great numbers from France to other countries. As can be seen in Figure 12, the scale arrangement is of four scales: the A scale at the top of the stator and the B scale at the top edge of the slide are two-cycle logarithmic scales; the C scale at the bottom edge of the slide and the D scale on the bottom stator are one-cycle log scales. An improvement to the original design adds S, L, and T scales-that is, sine, logarithm, and tangent scales-to the back of the slide, which can be inserted with the reverse side showing and used with the A and D scales of the stator.

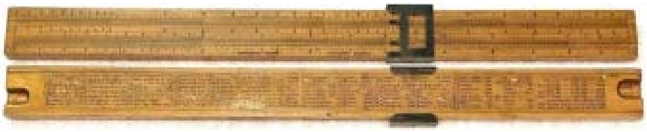

Fig. 12. An Early Example of a Mannheim Slide Rule by Tavernier-Gravet, 34 cm Length with Original Metal Cursor

After Mannheim's revolutionary improvement, the Mannheim slide rule was widely exported from France; eventually, it was copied by slide rule manufacturers throughout Europe and the United States and remained a fundamental scale configuration popular among scientists and engineers.

G. The Duplex Slide Rule Design, 1891

The next big breakthrough was made at Keuffel & Esser, in the United States, with William Cox's October 6, 1891 patent for an 'engineer's duplex slide rule,' which featured two sides and a two-sided cursor that could relate calculations to both sides of the slide rule (Figure 13). This significantly increased the number of scales available for simultaneous use in continuous calculations [7]. In his patent, William Cox notes that he is a subject of the Queen of Great Britain, residing in New York City of the United States, having invented a new and useful improvement in Engineers' slide rules, and goes on to specify the two-sided rule with a single two-sided cursor, which could relate scales on both sides to one another. This was of great benefit to Keuffel & Esser (K&E), who apparently had rights to his patent, as it provided a worthy competitor to the Mannheim set of scales for the engineer's slide rule. Very little is known of William Cox before he immigrated to New York, but his impact on K&E and their success is clear, establishing that company as one of the new premier manufacturers of engineering slide rules of all types.

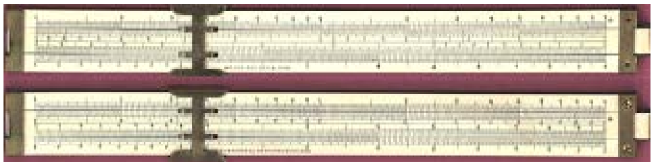

Fig. 13. Keuffel and Esser Cox Duplex, with Cursor Relating Calculations to Both Sides of the Rule

Both the Mannheim and Duplex slide rules and their variations were very important calculating tools, favored among engineers throughout the first three quarters of the 20th century, with Keuffel & Esser, Dietzgen, Faber (later Faber-Castell), Pickett, Hemmi, and many other manufacturers of slide rules all competing to provide the highest quality and accuracy at the most competitive cost. During the early 20th century, much easier-to-use glass cursors with single hairlines replaced the metal cursors on both the Mannheim and Duplex models. Although thousands of different specialized scales were introduced on hundreds of distinct models over the ensuing decades, the basic design of both types remained substantially unchanged throughout the duration of their manufacture.

After helping to power the Industrial Revolution, slide rules were used in architecture, steam, gasoline, and jet engine design; they were instrumental in building the Brooklyn Bridge and the Empire State Building and were even carried aboard the Apollo moon missions for use in routine calculations and, if needed, as a computer back-up.

Slide rule historians have estimated that over 40 million rules were produced in the 20th century alone, and it is well-known that many scale designs were developed over the years for very specific disciplines in areas such as surveying, artillery, steam, internal combustion, and jet engines, hydraulics, chemistry, electricity and electronics, radio engineering, and many other specialized fields. With the development of integrated circuits, electronic calculators became possible; at first, these were extremely power-hungry, expensive, and not intended for personal use. However, with the advent of the HP-35, introduced in 1972, so named because it had 35 keys, the world's first handheld portable calculator became a reality. The intense competition and rapid price reduction of the handheld electronic calculator resulted in one of the most dramatic displacements in the history of technology, rendering the slide rule that had been used by generations of scientists and engineers for decades for rapid computations as obsolete. Some very specialized slide rules, such as the E6B used in aviation and others for navigation, are still taught and used today for teaching the principles behind the calculations and as an ultimate backup in case of computer failure. Despite its rapid displacement by electronic calculators, the slide rule remains a key part of our technological history and will always be revered by scientists, engineers, and historians as an important tool that, in its time, was certainly instrumental in the advancement of science and engineering, and for many of the improvements in our lives over the last two centuries.

IV. Specialized Circular and Cylindrical Slide Rule Models and Early Rules of Historical Significance

A. Circular Slide Rules (Circular with Circular Scales, Circular with Spiral Scales)

As noted previously, some of the earliest slide rule designs were circular; with this form, one's calculation never runs off to the left or right of the rule, requiring a reset of the circular slide. In addition, for a given scale size, circular rules are more compact and easier to carry in a pocket. A circular rule of 3 inches in diameter would yield a scale on the circumference of ϖd, or approximately 10 inches, and could also accommodate additional sin and tan scales, or even a spiral scale for increased accuracy. Fowler's Calculators, Ltd., a Manchester-based company, was one of the most prominent manufacturers of circular slide rules. This company famously issued many dozens of different and often specialized circular models for well over 50 years. Since the late 19th century, many different pocket watch type slide rules, usually 2 to 4 inches in diameter, and larger circular models up to 8 inches in diameter with both circular and spiral scales, were manufactured throughout the US and Europe.

Two circular slide rules that do merit special attention are the Palmer's Computing Scale (Figure 14) and the Nystrom Calculator (Figure 15), both examples of the earliest slide rules that were manufactured in the United States. In early 1841, Aaron Palmer and George G. Smith, an engraver of printed plates, began work to develop and market an 'Endless Self Computing Scale' [8]. This slide rule, named 'Palmer's Computing Scale,' was copyrighted and printed on paper laminated to heavy cardboard with the edges decorated with a colored design, usually in red and gold or black and gold. The circular rule is 8½ inches in diameter with two circular single-cycle logarithmic scales, what we would call the C and D scales on a linear slide rule.

Fig. 14. The Palmer's Computing Scale, One of the First Slide Rules Manufactured in the US

During this time, sliding logarithmic scales were known in America, but to a very limited extent, mostly in the form of the two-foot folding Coggeshall and Routledge rules imported from England and sold in the US by tool vendors such as Belcher Brothers of New York and Stanley Rule & Level Company of Connecticut. In addition to the large rule, Palmer copyrighted several instruction booklets, some of which featured a miniature Palmer Rule attached to the inside back cover and named 'Palmer's Pocket Scale.'

Palmer's Computing Scale was continuously improved with the addition of new gauge points on the rule. John E. Fuller became associated with Palmer in 1844, and an additional Time Telegraph, copyrighted by Fuller in 1845, was added to the reverse of the Computing Scale. The Time Telegraph is a non-logarithmic scale used to determine the number of days between two dates and is again 8 ½ inches in diameter. By 1846, Fuller was the sole proprietor of the entire rule. In response to criticism that the rule was harmful to learning, Fuller responded:

'The idea that the employment of the (computing) telegraph will tend to weaken the mind by causing it to rely upon mere mechanism to make its number computations---I do not think the knowledge and use of this scale will be injurious to the young. So far from having an evil tendency on the knowledge of arithmetic…'

By 1848, an updated model was being made for the British market with a total of 67 gauge points; this final version includes the additional printing on the front of the rule 'or Pounds, Shillings, & Pence.' Interestingly, Palmer's rule was ahead of his time, and he considered his effort unsuccessful. General acceptance of the use of a slide rule in America did not occur until the late 1880s, a more than 40-year gap from the introduction of Palmer's Scale.

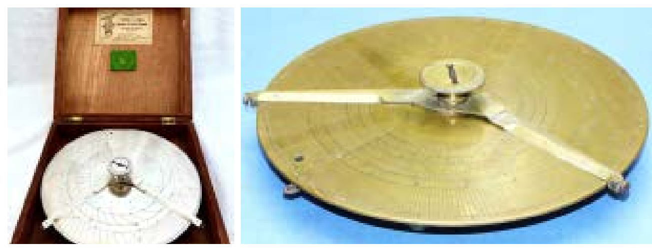
Fig. 15. Two of the Five Known Existing Examples of Nystrom's Calculator

The Nystrom Calculator is the first patented American slide rule [9]. John W. Nystrom (1825 – 1885) was a Swedish-American civil engineer, inventor, and author who served as an assistant secretary and chief engineer of the United States Navy during the American Civil War. He received several patents for inventions in steam propulsion, steam engines, navigation, refrigeration, and, of course, for his calculating machine. On March 4, 1851, he filed this invention as US Patent No. 7961. His patent model currently resides at the Smithsonian's National Museum of American History. Research indicates that less than 100 of these devices were ever sold, and less than a half dozen are known to exist today, including the patent model at the Smithsonian, one at the Arithmeum in Bonn, Germany, and one at the University of Mississippi Museum, in Oxford, Mississippi [9].

This calculator represents years of design effort by Nystrom, who began his work in the 1840s and first exhibited his invention at the Franklin Institute's annual fair in 1849, where it received the award of 'First Premium,' the Institute's highest award. Scientific American published an article of very high praise, extolling his invention as 'the most important one ever brought before the public.' Unfortunately, in spite of the high praise and accolades, the Nystrom Calculator was never accepted by the public, possibly due to the relatively high price of $15 to $20, quite a significant sum in the 1850s. Nystrom is also well-known for authoring a pocketbook of mathematical tables, Pocketbook of Mechanics and Engineering, that was reprinted over 20 times between 1854 and 1895 and was quite popular. In his later years, Nystrom took residence in Philadelphia and became active in the affairs of the Franklin Institute in that city. He died in Philadelphia in 1885, at the age of 61, his slide rule invention a commercial failure.

As noted earlier, moving forward 50 years, circular slide rules 2 to 4 inches in diameter with a pocket watch type design became very popular. These can be especially interesting as to composition and gearing; curiously, some models were made with sterling silver or gold cases for the 'most discerning gentleman' to convey a sense of status to the rest of the community. These pocket watch slide rules were most popular from the last quarter of the 19th century to the mid-20th century and were manufactured in a variety of materials and sizes, each with a distinct set of calculating scales and with a certain elegance that distinguished them from typical linear slide rules.

B. Cylindrical Slide Rules

a. Spiral Scale Models (Cylindrical with Helix Scales)

Spiral scale cylindrical slide rules are models that feature one or several scales that spiral around the cylinder in a helix, the scale(s) working their way from one end of the cylinder to the other. The Fuller Calculator (Figure 16), manufactured in England by W.F. Stanley, featured a single one-cycle spiral scale 500 inches in length (41.67 feet), giving an accuracy of 1 in 10000. It featured a relatively compact design for a logarithmic long-scale slide rule that was both practical to use as well as relatively cost-effective to produce in the late 19th and the 20th centuries. Nearly 13,800 examples were produced and sold by W.F. Stanley between 1878 and 1973, and the compact logarithmic helix design was subsequently used in many similar designs by Stanley and other calculating instrument makers. Numerous excellent articles have been written about the Fuller Calculator [10], [11], its variations [12], and its detailed history, including experimental models, prototypes, and its many transitions over time [13], to enable it to be easier to use and more cost-effective to produce.

Fig. 16. Fuller Calculator One-Cycle Spiral Scale of 500 Inches in Length

George Fuller (1829-1907), Professor of Engineering at Queen's College, Belfast, was granted Patent 1044 in May 1878 for his submission, *"Spiral Slide Rule for Working Arithmetical Calculation"* (see Figure 17). The Fuller Calculator is the epitome of a compact, yet extremely accurate, logarithmic calculating device that remained popular with scientists and engineers for nearly 100 years and was only discontinued with the advent of the inexpensive electronic calculator. W.F. Stanley produced several other very specialized calculators that were fundamentally based on the same principles, which, unlike the Fuller Calculator, were made in very small numbers due to their specialization and are highly sought after by collectors today. These include both the Barnard's Spiral Co-ordinate Slide Rule, designed by Henry Osmond Barnard (1869 – 1934) of which less than 110 examples are estimated to have been manufactured, with 17 known examples remaining today, and the Stanley-Whythe Complex Number Calculator, designed by David J. Whythe in 1960, of which less than 200 examples were manufactured.

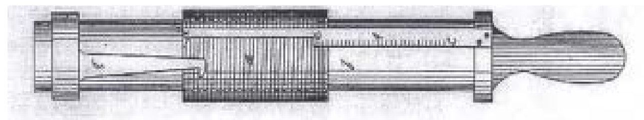

Fig. 17. Image from Patent 1044 "Spiral Slide Rule for Working Arithmetical Calculations," May 1878

b. Extended Linear Scale Models (Cylindrical with Segment Scales, Cylindrical Drum Models)

A typical 12-inch linear slide rule provides three significant figures plus a bit more with interpolation between marks for numbers that begin with 4 or less and two clean significant figures plus interpolation for those numbers that begin with 5 and above. This level of 2+ to 3-place accuracy was sufficient for most real-world applications. However, there were always some applications that required calculations to more significant places, and a slide rule with a longer logarithmic scale was the obvious answer. Several circular and spiral rules were developed with long scales, leading to the Fuller Calculator's spiral helix scale of 41.67 feet in 1878, patented by Professor George Fuller. This was quickly followed by the cylindrical segmented linear scale

Fig. 18. Thacher Calculator, Model 4013 with Magnifier and Detail of the Scale Arrangement

slide rule patented by Edwin Thacher (1839-1920) [14] in 1881 and offered by Keuffel & Esser, the first important development in slide rule long-scale technology in the US. As illustrated in Figure 18, Thacher broke two parallel one-cycle logarithmic calculating scales into 40 segments, each 18 inches long. The cylinder slides within a sleeve of 20 parallel rods, each triangular rod having two sections of the double scale, matching the two sections on the cylinder. The effective length of the Thacher slide rule scale is 30 feet; it can be read, with interpolation to 5 digits at the left index and 4 digits at the right index, an improvement of about 1.5 digits over a common 10-inch rule.

Other European makers followed with their versions of long scale calculators, including Nestler, Loga, Billeter, and others, with the longest scale length recorded being produced by Loga at 15 meters (49.2 feet). These rules were made for high-accuracy specialized applications and therefore in very limited numbers and are not as readily found today as is the more common linear slide rule.

C. Other Slide Rules of Historical Significance and Interest

a. Ivory Rule with Two Square Cross-section Slides, All Four Sides with Scales (1690- 1713)

This very early and interesting slide rule has a rectangular cross-section with scales on all four sides. The four-sided slides with square cross-section have scales that relate to the stators on the two narrow sides of the rule body, while the two wide sides contain fixed scales. To make things even more interesting, Figure 19 shows that this rule has scales for basic math problems like squares, cubes, and their roots, as well as scales for excise and gauging problems and barrel shapes, and fixed scales for navigation like you'd find on a better Gunter scale.

The Science Museum Collection in London houses a boxwood version of this rule, and their website features a photograph. The scales 'Frustrum of a Spheroid, 2 Form, 3 Form, and Frustrum of a Cone' are excise calculation terms, while the scales 'Meridian, Equal Parts: Degrees, Chords, Versed Sine (i.e., one minus the cosine of an angle), Sines, Tangents, and S · T (semi-tangent, or tan (x/2)) are all related to navigation.

Fig. 19. An Early Ivory Slide Rule with both Excise and Gunter (Navigation) Scales

b. John Suxspeach and his Catholic Organon, 1753

John Suxspeach, a schoolmaster from Middlesex, England, conceived of what must be the most complex and presumably complete slide rule ever developed and marketed for sale. Two well-researched papers by Peter Hopp cover the construction, patent, scales, and history of this fascinating rule [15]. In addition, at a count of no less than 86 total scales, covering the areas of gauging, navigation, mathematics, astronomy, dialing (using a sundial and astrolabe to determine position), and others, Suxspeach's invention originally included a telescope fitted into the middle of the octagonal slide within the rule. The body of the rule itself measures 12 inches long, 1¾ inches wide, and 1 inch deep and is very tightly inscribed with scales on both large sides (Figure 20). The octagonal slide, which aligns with the center of the main rule body, measures 7/8 inch at the outer diameter with, once again, tightly packed scales contained on all eight sides. Each narrow one-inch edge of the rule features a slide with scales on both sides. Suxspeach was granted Patent No. 676 for his Catholic Organon (i.e., meaning an all-inclusive instrument for acquiring knowledge) on 29 March 1753, the first patent ever granted on a slide rule [15]. Hopp's research indicates that perhaps up to 16 examples of this slide rule were manufactured over a period of approximately three years, with likely the first 13 examples made within the first year of manufacture. All currently known examples carry some form of maker's signature in Latin, as shown in Figure 20, either Ios or Iohn Suxspeach, Inventor. Ratcliff, followed by a date between 1st December 1752 and the last documented example (no rule, case only, numbered 16) in 1755, followed by Ben or Benjamin Parker fecit (the maker). Suxspeach also authored a book on his rule, *The Catholic-Organon, or Universal Sliding Foot-Rule. Of Great Use in the Practice of Arithmetic…. Invented by John Suxspeach.*

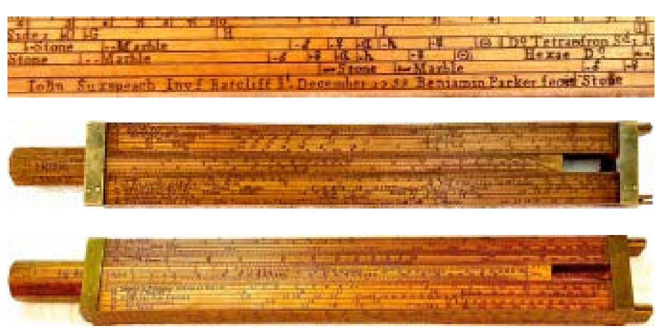

Fig. 20. John Suxspeach's Catholic Organon, Likely the Most Complex Slide Rule Ever Made

Based on current knowledge as of January 2025, of the 16 presumed Suxspeach rules that were manufactured, seven existing examples appear to have been positively identified. Four are housed in museum collections: Museum of the History of Science (MHS) in Oxford, Whipple Museum in Cambridge, Macleay Museum in Sydney, and the Arithmeum in Bonn. Private collections house two, one of which is the featured example in this article. In addition, one fresh example was discovered in Canberra, Australia, in February 2021 at the Green Shed, a reuse and recycling center, and was reported in the Canberra Times. The current location of this example is unknown.

In addition to the known examples, MHS Oxford possesses a case marked 'J Suxspeach's 1755 Catholic Organon No. 16,' which does not contain any rules, thereby establishing the presumed upper bound of manufacture.

c. Peter Mark Roget (1779- 1869), and the Log-Log Scale, A Man Ahead of His Time

Peter Mark Roget was a British physician, scholar, and lexicographer who is best known for publishing the *Thesaurus of English Words and Phrases* in 1852, which has been continuously updated and is still published today as *Roget's Thesaurus*. What is not as well-known about Roget is that he also invented the log-log slide rule scale, shown in Figure 21, presenting his paper, 'Description of a New Instrument for Performing Mechanically the Involution and Evolution of Numbers' in the Transactions of the Royal Society (London). His paper was enthusiastically accepted, and he was elected a Fellow of the Royal Society in March 1815. Using his newly invented scale, any rational number could be taken to any rational number power, and roots could be similarly extracted without the tedium of logarithm tables.

Fig. 21. Roget's Log-Log Scale as Depicted in his Paper 'Description of a new instrument for performing mechanically the involution and evolution of numbers,' 1814

Recall that logarithms can evaluate the general expression $y = a^b$:

$$
\begin{aligned}
y &= a^b \\
\log(y) &= \log(a^b) \\
\log(y) &= b \times \log(a) \\
\log(\log(y)) &= \log(b) + \log(\log(a)) \\
y &= \log^{-1}\{\log^{-1}[\log(b) + \log(\log(a))]\}
\end{aligned}
$$

Therefore, with a slide rule and log-log scales, the problem of involution (that is, raising to powers) and evolution (extracting roots) becomes one of addition and subtraction when logarithms are applied twice. In this way, one can use a log-log scale in conjunction with a one-cycle log scale to perform involution and evolution. Unfortunately, despite being a novel concept, there were no practical applications in the early 19th century for incorporating a log-log scale into a slide rule. Therefore, after it surfaced in 1814, the concept was not implemented until approximately 90 years later, when Dennert & Pape in Germany and Keuffel & Esser in America manufactured some of the first commercially successful log-log slide rules for use in making sophisticated electrical, electrodynamic, thermodynamic, and other engineering calculations involving transient phenomena or requiring fractional roots. As the accuracy required for these calculations increased, the number of segmented log-log scales increased as well, so that by the 1950s, a typical

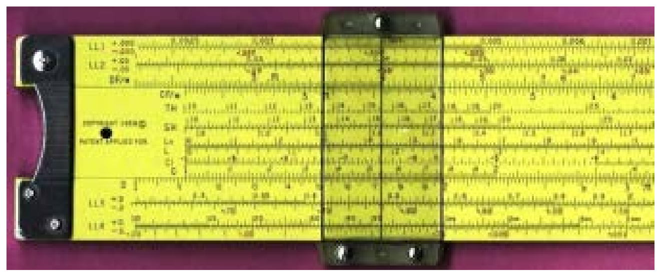

Fig. 22. Pickett Model N4-ES Vector Type Log-Log Duplex Slide Rule with Eight Log-Log Scales

log-log slide rule with scales for advanced applications contained between six and eight log-log scales, as can be seen in the Pickett rule shown in Figure 22.

V. Summary and Discussion

The invention of the logarithm ranks among one of the top mathematical achievements of the last thousand years and helped bring about the Scientific Revolution of the 17th century. It was immediately used to vastly simplify and facilitate the calculations that were required in astronomy to confirm the changing positions of the stars, the sun and the moon, as well as those of the planets. In 1620, Edmund Gunter invented a straight rule marked with trigonometric and logarithmic scales, which became an important navigational aid, and during that decade William Oughtred invented the linear slide rule and the circular logarithmic Circle of Proportions, the forerunners of all modern slide rules. Scientists developed specialized slide rules to calculate excise taxes and to measure the dimensions, surface area, and volume of timber, which became common tools. As the Industrial Revolution evolved, both general and specialized slide rules were developed and improved, resulting in thousands of distinct designs and hundreds of manufacturers that were used by scientists, engineers, and other technologists well into the second half of the 20th century.

The very technological revolution that the slide rule helped fuel eventually also set the expiration date for its demise. After 350 years of continuous improvement and development, the slide rule came to an abrupt end with the advent of handheld calculators in the 1970s, which were very simple to use and provided quick and accurate calculations. Nevertheless, the slide rule is still the undisputed champion when it comes to elegance and beauty in form and design. In this author's opinion, 350 years of technical ingenuity have also created some of humanity's most interesting and stunning works of art, a lasting testament that continues to flourish and be much appreciated and admired to this day.

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Robert G. De Cesaris retired as Director of Engineering with the Chipset and Graphics Group in 2023 after 36 years at Intel, working and then leading dozens of CPU, ASICs, Chipset, and Integrated Graphics Device and Platform research and development efforts. Bob has been president of the Oughtred Society since 2007, a group dedicated to the history, research, documentation, and preservation of slide rules and other mechanical calculating devices. He has arranged and led numerous meetings and conferences to further those goals. His collecting interests also include antique science and mathematics books and papers that cover significant scientific advances and innovation.

For those desiring further information, please visit www.oughtred.org for many additional resources on the history of slide rules and mechanical calculators and to access an extensive database of collections and relevant online links to assist with identification and research.

2024, Celebrating Our History While Looking to Our Future

Scholarship
- 24 Chapter Grants Awarded
- 48 Chapters in Coaching
- 8 New Chapters
- New Graduate Pitch Competition
- 2,419 Inductions, 12%
- 40 Key Chapters

Character
- 104,000 Service Hours
- 8,000+ STEM Hours
- 50 Grad./Alumni Mentoring Participants
- 18,000 hours w/IEEE Student Branches

Attitude
- 1,200+ Conference Attendees
- 2 New Eminent Members
- 87 Professional Inductees
- 4 Madni Family Scholarships
- 3 Professional Awards given
- 22 Outstanding Chapters
- 12th Apex Award for *THE BRIDGE*

120th Anniversary Highlights
- 120 Voices of HKN campaign
- HKN 120th Anniversary Coin
- 120th Anniversary Video
- 120th Anniversary infographic
- History timeline
- Nine 120th Anniversary Cakes
- Traveling HKN memorabilia exhibit
- 120th Anniversary Hackathon – close to 100 student involved.
- Founders Day Virtual Event
  - Fireside Chat with Vint Cerf and Bob Kahn
- Successful Social Media Campaign
- 120th Anniversary articles in the Institute, and the IEEE Foundation newsletter

Since 1904, HKN has been recognizing excellence in electrical and computer engineering and allied fields of interest. This past year offered the opportunity to look back on our proud past while building a bright future. From our explosive growth in the number of new chapters to our expansion of offerings to our graduate students, in 2024, HKN continued to build upon the solid foundation laid by our founders. Our successful year would not have been possible without the generosity of our donors, the tireless devotion of our volunteers, the support of our corporate and IEEE Society partners, the ambitious leadership of our Board of Governors, and the dedicated IEEE-HKN staff. Below are just the highlights of what made 2024 a historic year.

Eight New Chapters Were Welcomed into our Global Network in 2024!

2023 IEEE-HKN President Sampath Veeraraghavan (center) installs NuNu Chapter at the University of Dubai

We were thrilled to welcome 8 new university chapters into the IEEE-HKN family in 2024. These new chapters represent a diverse range of institutions and bring fresh energy and perspectives to our community, spreading the HKN ideals of scholarship, character, and attitude to new parts of the world. Congratulations to Hampton University in Hampton, Virginia; Obuda University in Budapest, Hungary; Texas State University in San Marcos, Texas; Polytechnic University of Puerto Rico in San Juan, Puerto Rico; Western New England University in Springfield, Massachusetts; Vardhaman College of Engineering in Hyderabad, India; Escuela Superior Politécnica del Litoral in Guayaquil, Ecuador; and the University of Dubai in Dubai, United Arab Emirates, on their installments."

Eta Chapter Welcomes Close to 100 New Members

Eight Professional Members being inducted at the 2024 June Board Series in Toronto, Canada

With six in-person ceremonies held around the world and three virtual ceremonies, HKN welcomed 87 new professional members into the Eta Chapter of the IEEE-HKN Board of Governors. These professionals were nominated for induction by HKN members because they embody the core values of Eta Kappa Nu, namely outstanding scholarship, impeccable character, and a dedication to lifelong learning and service. They have demonstrated significant leadership and service during their careers and will contribute their dedication and personal integrity by sharing their professional skills and personal time.

Many of the newly inducted members are dedicating their considerable talents to HKN by jumping right into service and joining HKN committees. A few newly inducted members are also exploring the possibility of forming new university chapters and helping reactivate dormant ones, and several have been connected with chapters in their local area to serve as mentors and event speakers.

In-person induction ceremonies were held throughout the year at:

- IEEE SoutheastCon, Atlanta, GA
- IEEE Region 5 Meeting, Springdale, AR
- IEEE Region 1&2 Meeting, Stamford, CT
- IEEE June Board Series, Toronto, Canada
- IEEE Oceans Conference, Halifax, Nova Scotia, Canada
- IEEE November Board Series, Dallas, TX

In addition, three virtual induction ceremonies were held to accommodate those members who were unable to attend in person. Several of the members inducted at December's virtual ceremony are AT&T and Nokia Bell Labs Fellows, having contributed significant research and innovation to our fields.

We are already planning several induction ceremonies for 2025. If you know a professional who embodies the attributes of HKN-Scholarship, Character, and Attitude, you can nominate him or her for the Eta Chapter here. With your help, 2025 will be another successful year for the Eta Chapter of HKN!

Two Nobel Prize Winning Scientists Elevated to HKN Eminent Members

On Tuesday, 17 September 2024, the HKN community gathered at the AT&T Museum & Science Technology Center in Middletown, NJ, to elevate **Dr. Robert Woodrow Wilson** and **Dr. Arno Penzias** to Eminent Member & Honorary Eminent Member, respectively. Dr. Wilson and Dr. Penzias are credited with discovering cosmic microwave radiation, which is considered strong evidence for the Big Bang theory of the universe's origin. Their discovery led to a Nobel Prize in 1978 in recognition of their outstanding contributions to advancing our understanding of the universe. IEEE Regions 1 and 2 sponsored the event in partnership with AT&T Labs and drew over 70 attendees to celebrate Dr. Wilson's

Dr. Robert Woodrow Wilson addressing the audience at his Eminent Member Elevation Ceremony

and Dr. Penzias's work. In 1950, Eta Kappa Nu established the Eminent Member recognition as the society's highest membership classification. It is to be conferred upon those select few whose attainments and contributions to society through leadership in the fields of electrical and computer engineering have resulted in significant benefits. to humankind.

HKN Celebrated its 120th Anniversary with First Ever Hackathon, Eminent Member Fireside Chat, and Cake-filled Alumni Gatherings

2024 marked the 120th anniversary of the founding of Eta Kappa Nu, which offered an opportunity to celebrate the rich history of our society while launching new initiatives. Alumni gatherings at IEEE meetings across the United States featured opportunities to reconnect and share their special Eta Kappa Nu memories over cake. Events were held at IEEE Region 3's SoutheastCon, the IEEE Life Members Conference, the IEEE Communication Society Conference, the IEEE Power & Energy Society General Meeting, and the IEEE World Forum on Public Safety Technology.

(left to right) IEEE-HKN Board Members, Colleen Bailey, Jim Jefferies, John McDonald, Karen Panetta, 2019 IEEE-HKN President and Evelyn Hirt, 2015 IEEE-HKN President. Photo taken at the IEEE Life Members Conference in Austin, TX

On Founders Day, 28 October 2024, the anniversary was also marked by a special virtual Fireside Chat featuring HKN Eminent Members Vint Cerf and Bob Kahn, known as the "Fathers of the Internet," who shared their recollections of their collaboration on building the architecture that created the internet. Dr. Karen Panetta, 2019 HKN President and Dean of the Graduate School of Engineering at Tufts University, hosted the event, which reached a worldwide audience of over 100 attendees.

The culmination of the first-ever IEEE-HKN Hackathon was also a part of the virtual celebration, with teams presenting their solutions to 16 IEEE professionals who judged their work. Students attending the 2023 Student Leadership Conference conceived of the Hackathon, which came to fruition after seven months of planning as a means of fostering international collaborations among chapters. The Hackathon Committee, led by Christian Winnigar, a Gamma Theta alum, was composed of 17 students who created mathematical and engineering problems around the theme of saving the eight founders of HKN. According to Serena Canavera, one of the event's organizers and 2025 HKN Student Governor, "Our founders, especially Maurice L. Carr, envisioned a society that would eventually become international, as it is today, more than a century into the future. To capture this spirit, our team combed through HKN's historical records, seeking insights into the visionary students who founded HKN. We imagined them facing various challenges, often misunderstood by school leaders who didn't yet see the value in an organization dedicated to the professional growth of young, bright, and philanthropic engineers."

The Hackathon succeeded in capturing the imagination of students around the world, with 62 students working in 12 teams. Test Equity awarded prizes to the top five teams. Hackathon promoted creativity, teamwork, and a greater awareness of the history of HKN while demonstrating its principles of scholarship, character, and attitude. Due to the enthusiastic response to the Hackathon, plans are already underway for another one in 2025.

To learn more about HKN's history, check out the timeline.

2024 Brings a Special Focus on Fulfilling the Needs of Graduate Students

Graduate students, always a key constituency for HKN, received even more attention through an expanded third round of graduate/alumni mentoring, special networking events, and a Graduate Pitch Competition.

The third round of the Graduate Student/Alumni Mentoring Program enjoyed a 300% growth rate since its inception, with 50 participants–31 mentees and 19 mentors paired in 2024. The 2024 program also included two virtual networking sessions, one held in March to kick off the program, which drew 31 participants, and one in August held in partnership with the HKN Alumni Committee with an additional 26 attendees. The Mentoring Program has been extremely meaningful to both its mentors and mentees. Patrick Nunally, a longtime mentor, said, "As I look back on the experience, it's been incredible. I have one young man completing his master's degree who has accepted an offer for the exact position in the same department with the exact same company (General Dynamics) that I had accepted coming out of school (40 years ago). Another young fellow is ready to launch his company. I've been working with him on his ideas, and he's already getting nibbles from investors, so he's getting ready to change the world."

A Graduate Pitch Competition was piloted in October as an addition to HKN's other graduate student offerings that include GradLab Podcasts and Graduate Student Research Spotlights in *THE BRIDGE* Magazine. The competition was introduced as a means to help graduate students practice their research presentation skills in a supportive, low-risk environment in preparation for other career- expanding opportunities like conference and dissertation presentations. In the pilot, eight graduate students presented their work to four judges.

The Graduate Student Subcommittee is committed to helping their fellow undergraduate students who are presenting a virtual panel session at the Pathways to Industry conference, "Paycheck vs. Fulfillment - Perspective on an Industry Career," as well as a special networking session where students could meet directly with the panelists and moderators. For TechX, the graduate students held an informal networking Resume Review Workshop that allowed 36 students to get expert advice from reviewers across industry, academia, and graduate programs. At the November Student Leadership Conference, members of the Graduate Student Subcommittee presented on how chapters can recruit graduate students, tabled, and handed out snacks, all visible reminders to students that graduation does not always have to mean an end to one's education.

THE BRIDGE Magazine Garnered its 12th Consecutive Apex Award for Publication Excellence

THE BRIDGE Magazine won its second APEX Grand Award for Publication Excellence in 2024. The October 2023 issue of *THE BRIDGE* received recognized for its special issue on "Humanitarian Technologies for a Sustainable Society." Congratulations to the issue's guest co-editors, Sampathkumar Veeraraghavan, 2023 IEEE-HKN President, and Dr. Mohamed Essaaidi, and to the 2023 Editor-in-Chief, Jason Hui. Less than ten percent of the more than 1100 entries received Grand Award recognition. It is the 11th year that *THE BRIDGE* and IEEE-HKN have been recognized and its second consecutive Grand Award win.

Growing HKN Social Media Presence Provides Platforms to Broaden Reach

Social media is an important means of connecting and growing our network and amplifying the great work of HKN. Due to the extraordinary efforts of Katie Brinker, chair of the Public Relations and Communications Committee, our PR and Communications Committee exceeded its 2024 goals by growing social media followers across our platforms by double digits, with LinkedIn increasing by 50% (3,845), Instagram increasing by 18% (1,016), and YouTube by a whopping 71% (711).

Part of the success of our social media is the creation of relevant and interesting content through the production of podcast episodes and the posting of sessions from

our virtual conferences, Pathways to Industry and TechX. In December, the HKN Alumni Committee, led by HKN Board Member Amy Jones, produced a well-received Career Conversations episode on *The Journey of Personal Discovery with Dr. Marcus A. Huggans*. In this episode, Dr. Marcus A. Huggans, an engineer and educator with over 20 years of experience in the STEM field, shares his insights from his impressive career, his passion for mentoring underrepresented students in STEM, and the importance of setting purpose-driven goals.

Everyone can help in these efforts in 2025 by liking and sharing content. Our social media supports all HKN initiatives—awards, conferences, chapter news, alumni, etc. - and tells stories of our impact in communities around the world.

2024 HKN Awardees at the IEEE November Meeting Series

Ryan Bales, 2024 IEEE-HKN President, presented the IEEE-HKN Awards on Friday, 22 November 2024, as part of the IEEE Educational Activities Awards Presentation Ceremony held during the IEEE Meeting Series in Dallas, TX, USA. Rabab Ward, the 2024 Vice President of IEEE Educational Activities, presided over the ceremony, which was attended by the IEEE President, members of the IEEE Board of Directors, and IEEE Officers. The following honorees received plaques and much-deserved gratitude for their inspiring contributions:

(left-right) Dr. Gina Adam, S.K. Ramesh, Dr. Andrea Goldsmith, Ron Jensen, Rabab Ward, Ryan Bales, Nancy Ostin, and Asad Madni

IEEE-HKN Asad M. Madni Outstanding Technical Achievement and Excellence Award: *Dr. Andrea Goldsmith*, Dean of Engineering and Applied Science, Princeton University, "for her pioneering work in wireless communications and information theory leading to the innovations which have shaped the performance of wireless networking and enabled fast, reliable wireless service around the world."

IEEE-HKN Distinguished Service Award: *Ronald Jensen*, 2021 IEEE-HKN President, "for continued service in leading and growing impactful IEEE-HKN programs and sustained dedication to mentoring future student leaders."

C. Holmes MacDonald Outstanding Teaching Award:
Dr. Gina Adam, Associate Professor in the department of electrical and computer engineering at George Washington University, "for contributions to nanoelectronics education and inclusion efforts in electrical and computer engineering."

Additional photos of the ceremony can be found here. The 2025 IEEE-HKN Awards cycle is now underway. If you know of a colleague who is making outstanding contributions and should be considered for one of the above awards, please learn more and submit a nomination here before 5 May 2025.

HKN Conferences Ready Students for their Future Careers

HKN once again hosted three conferences in 2024: Pathways to Industry, TechX, and the Student Leadership Conference, which drew a record number of participants. Each conference had a different focus, with Pathways to Industry held in February 2024, devoted to helping students and young professionals have the professional skills they need to secure internships and full-time jobs. The virtual conference, featuring engaging sessions like "From Rocket Science to Financial Planning: 5 Financial Insights I Wish I Knew in College" and an X-Factor Conversation with Bob Kahn, was filled with practical information as well as inspiring messages. HKN TechX followed in April, with a focus on ethical considerations in technology, and featured keynotes from Dr. Karen Panetta, who spoke about her groundbreaking work in artificial intelligence, and an X-Factor conversation with Dr. Sandra Magnus, NASA. Astronaut and HKN Eminent Member. "Responsible AI" will be the theme of the 2025 HKN TechX, which will take place from 9-11 April. You can register here.

Burton Dicht interviewing IEEE-HKN Eminent Member Sandra Magnus at 2024 TechX Conference

HKN conferences are made accessible and affordable to students through the financial support of our sponsors, donors, IEEE Society, and academic and industry partners who, in addition, share their wisdom and advice to guide the next generation of engineering leaders. Read about this year's SLC.

Inaugural Winners of Asad, Gowhartaj, and Jamal Madni Family Scholarships Awarded

Thanks to the generosity of Asad M. Madni and his family, a new scholarship was established in 2024 to support qualified undergraduate and graduate students pursuing a degree in the fields represented by IEEE-HKN and who are members of an active IEEE-HKN Chapter. The scholarship is another manifestation of the commitment of Dr. Asad Madni's family to education, having already established a scholarship at UCLA.

Asad Madni is an Eminent Member of HKN and winner of the Vladimir Karapetoff Outstanding Technical Achievement Award in recognition of his illustrious career as the president of BEI Technologies, where he led the development and commercialization of intelligent sensors, systems, and instrumentation, including the control system for the Hubble Space Telescope's Star Selector. Asad M. Madni is an adjunct professor of electrical and computer engineering at UCLA Henry Samueli School of Engineering and Applied Science. He was bestowed the IEEE Medal of Honor in 2022 and the John Fritz Medal in 2024. He established the IEEE-HKN Asad M. Madni Outstanding Technical Achievement and Excellence Award to recognize individuals who have distinguished him or herself with a career of meritorious achievement and innovation in electrical or computer sciences, engineering, or technology.

This year, four outstanding students were granted a $1,000 scholarship in recognition of their embodiment of HKN's principles of scholarship, character, and attitude:

Two Undergraduate Scholarships

- **Laura Floyd**, Mu Rho Chapter, Valparaiso University
- **Benjamin Nguyen**, Iota Phi Chapter, United States Military Academy

Two Graduate Scholarships

- **Hannaneh Hojaiji**, Iota Gamma Chapter, University of California, Los Angeles
- **India Elkhazin**, Zeta Lambda Chapter, Prairie View A&M University

Laura Floyd and Benjamin Nguyen were recognized for their achievements at the 2024 Student Leadership Conference held in November 2024. Laura's student profile can be found on here.

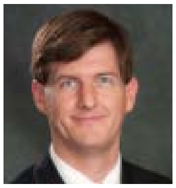
Applications for the 2025 Madni Family Scholarship are currently being accepted. To qualify for the Madni Scholarship, a student must be a U.S. citizen enrolled as a full-time student in electrical engineering or related fields at an accredited U.S. university or college. Further qualifications include being an inducted member of IEEE-HKN and having completed his or her third year in an IEEE-HKN field of interest. The award will be $1,000 per student to cover school expenses such as tuition, books, and fees. Applications will be accepted until 5 May 2025 and can be submitted here.

IEEE-HKN Welcomes 6 New Members of the Board of Governors for 2025

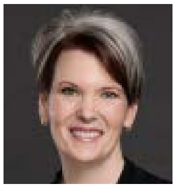
IEEE Eta Kappa Nu (IEEE-HKN) is excited to announce that the IEEE-Eta Kappa Nu (IEEE-HKN) Board of Governors confirmed the elections of six new members at its November 2024 Board meeting. The new governors' terms began on January 1, 2025.

Dr. Sean Bentley, *Gamma Theta Chapter,* will lead the honor society in 2025 as president. Dr. Bentley currently is an associate professor of physics at Adelphi University. He has previously served IEEE-HKN as the President-Elect in 2024, the Regions 1 & 2 Governor in 2018-2019, and the HKN Faculty Advisor Committee from 2018-2020. He is currently a member of *THE BRIDGE magazine* Editorial Board. His outstanding teaching contributions have been recognized by the American Association of Physics Teachers, who awarded him with the David Halliday and Robert Resnick Award for Excellence in Undergraduate Physics Teaching in 2022, as well as by Adelphi University, where he was awarded the Tenured Teaching Excellence Award in 2013.

Jim Jefferies, *Beta Psi Chapter,* was elected to serve as the 2025 president-elect. Jim Jefferies is a retired AT&T and Lucent Technologies executive who, in 33 years, rose from manufacturing engineer to vice president. He was responsible for teams that transferred glass technology from Bell Telephone Laboratories and developed fiber optic cables for AT&T. He also served as logistics vice president, responsible for worldwide supply chains, quality assurance, and export planning. He has led teams in major technology transfers, information technology transitions, and organizational change. More recently, he teamed with fellow Stanford Business School graduates in an entrepreneurial venture in San Francisco and served as Chief Operating Officer. He was the 2018 IEEE President and CEO and the 2015 President of IEEE-USA, supporting the globalization of its policy initiatives.



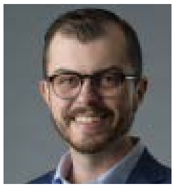
Dr. Ryan Bales, *Gamma Theta Chapter,* led the society as president in 2024 and will serve as its 2025 past president. He served as IEEE-HKN Governor At-Large from 2020 to 2022. Dr. Bales is a principal research engineer with the Georgia Tech Research Institute's Sensors and Electromagnetic Applications Lab and has 17 years of experience in applied research in embedded systems and electronic warfare. He has led the development of the digital signal processor for the Angry Kitten advanced electronic warfare program since its inception in 2011. He mentors junior engineers in the areas of embedded system design and signal processing and encourages service as part of their professional growth.



Melody Richardson, *Eta Chapter*, will serve as the Region 3-4 governor for a three-year term. Melody is a distinguished leader in the IEEE community, renowned for her dedication to education and outreach. She is the founder and coordinator of STEM on the MOVE, a segment of IEEE's MOVE Community Outreach program. Over 10,000 students worldwide have benefited from the engaging educational materials Melody has developed, including a custom STEM adventure book for children aged 5-11. Melody's efforts include mentoring university students, organizing workshops, and facilitating industry-academia partnerships. She is committed to equipping students with essential skills in networking, resume writing, and interview preparation, ensuring they are well-prepared for their professional careers.

Kathy Herring Hayashi, *Eta Chapter,* was elected to serve a three-year term as a governor at-large. Kathy has been involved in the semiconductor industry her entire career — developing, deploying, and analyzing advanced software tools used to create computer and mobile phone chips. She has led teams in semiconductor EDA software development for Qualcomm, Unisys, Cadence Design Systems, and Syntricity, a local startup. She has served as the IEEE Region 6 Director (Western Region of the United States) and as a member of the IEEE Board of Directors. She is a senior member of IEEE and IEEE-HKN.

Serena Canavero, *Mu Nu Chapter,* was elected to a one-year term as student governor. Serena holds a bachelor's degree in computer engineering from the Polytechnic University of Turin, Italy, graduating in the top 5% of her class. She is currently pursuing a master's degree in computer engineering at the Polytechnic University of Turin, where she ranks in the top 1% of her class. Notably, she developed a VR exposure therapy application in collaboration with the Department of Psychology to aid patients with social anxiety phobia. In 2023, Serena was elected president of the Mu Nu Chapter, where her visionary leadership and commitment to philanthropy brought about remarkable achievements.



Logan Wilcox, *Gamma Theta Chapter,* was elected to a one-year term as student governor. Logan is a Ph.D. candidate in electrical engineering at Missouri University of Science and Technology (Missouri S&T) with an anticipated graduation date of May 2027. He is also pursuing a graduate certificate in Explosives Engineering, with an anticipated completion date of May 2025. In May 2020, he received a B.S. in computer engineering from Missouri S&T and worked for 9 months as an associate engineer at Tech Electronics in St. Louis, MO. In recent years, he has concentrated his professional involvement on IEEE societies and mentoring within his local community. He holds the treasurer position at Gamma Theta, and this position allowed him the opportunity to ensure chapter success (financially) while also providing mentorship to other officers. His plans as a student governor of IEEE-HKN revolve around the idea of increasing engagement with recently graduated members.

HKN is looking forward to the expertise and energy that these new leaders will bring to our Board of Governors in the new year. We are looking forward to another productive year of collaboration!

Congratulations to the 40 Key Chapter Recipients for 2023-2024!

IEEE-HKN is excited to announce that 40 chapters have earned Key Chapter recognition for the 2023-2024 academic year! This recognition celebrates chapters that participate in activities identified as the best practices of successful chapters. Every chapter has the potential to earn Key Chapter recognition. Key Chapter banners were presented on 16 November 2024 during the Awards and Recognition Banquet at the Student Leadership Conference.

Congratulations to the members, officers, advisors, and department heads of the following chapters:

- Alpha, University of Illinois, Urbana-Champaign
- Beta, Purdue University
- Gamma, The Ohio State University
- Mu, University of California, Berkeley
- Beta Delta, University of Pittsburgh
- Beta Epsilon, University of Michigan
- Beta Eta, North Carolina State University
- Beta Mu, Georgia Institute of Technology
- Gamma Alpha, Manhattan University
- Gamma Gamma, Clarkson University
- Gamma Epsilon, Rutgers University
- Gamma Theta, Missouri University of Science and Technology
- Gamma Iota, University of Kansas
- Gamma Kappa, New Jersey Institute of Technology
- Gamma Mu, Texas A&M University
- Gamma Sigma, University of Utah
- Delta Omega, University of Hawaii, Manoa
- Epsilon Beta, Arizona State University
- Epsilon Delta, Tufts University
- Epsilon Zeta, University of Massachusetts Lowell
- Epsilon Eta, Rose-Hulman Institute of Technology
- Epsilon Mu, University of Texas at Arlington
- Epsilon Sigma, University of Florida
- Zeta Iota, Clemson University
- Theta Lambda, University of South Alabama
- Kappa Lambda, University of Memphis
- Kappa Xi, University of South Florida
- Kappa Upsilon, University of Texas, San Antonio
- Kappa Phi, University of North Carolina, Charlotte
- Kappa Psi, University of California, San Diego
- Lambda Zeta, University of North Texas
- Lambda Omega, National University of Singapore
- Mu Beta, Arab Academy for Science & Tech – Alexandria
- Mu Kappa, University of Queensland
- Mu Mu, Wentworth Institute of Technology
- Mu Nu, Politecnico Di Torino
- Nu Alpha, Universidad Nacional de Educacion a Distancia
- Nu Epsilon, Kennesaw State University
- Nu Eta, Sri Sairam Engineering College
- Nu Theta, Purdue University Northwest

Group photo of SLC attendees in the Embassy Suites Concord Golf Resort and Spa's lobby

The 2024 Student Leadership Conference draws Record Breaking Number of Students

The IEEE-HKN Student Leadership Conference (SLC) has become the most anticipated event of the year, not only for students but also for industry and IEEE Society Representatives, who enjoy the contagious energy of HKN students. Held on 15-17 November 2024 at the Embassy Suites Concord, North Carolina, this year's Student Leadership Conference had several new enhancements this year, including being held at a conference center as opposed to a college campus and a special "Find Your Technical Home" Pavillion where students had the opportunity to learn how to leverage IEEE Society membership to enhance their skills and to grow their careers. The Charlotte Section of the IEEE Young Professionals sponsored an after-party that promoted camaraderie and informal networking over games of foosball, cornhole, and giant Jenga.

Group photo of Gamma Theta Chapter attendees

Close to 350 attendees from 64 chapters all over the world participated in 5 workshops, 20 learning sessions, and two recruitment fairs. Session topics ranged from career development topics such as "Career Advancement Through Effective Communication" to more technical ones like "Quantum Computing: The Need for Engineers." The 2025 IEEE President Kathleen Kramer gave the keynote address at Saturday's lunch, and 2025 IEEE President-Elect Mary Ellen Randall also spoke to encourage students. The IEEE MOVE Truck was on hand all day, allowing students to witness firsthand how IEEE supports communities in times of natural disasters.

On Saturday evening, an awards dinner celebrated the achievements of HKN students and chapters with the awarding of the Madni Family Scholarships, Outstanding Student Awards, and Key Chapter Awards. The conference wrapped up on Sunday with 4 Region meetings where students shared best practices and made plans to continue collaborations beyond the conference. According to Serena Canavero, a computer engineering graduate student at the Politecnico in Turin, Italy, and 2025 IEEE-HKN Student Governor, "The SLC is a place where young, promising engineers come together to learn how to grow into their best professional selves. Here, we learn how to be ethical leaders, are enriched by international dialogue, and meet an incredible community of HKN colleagues from all over the world."

(l-r, Kathleen Kramer, 2025 IEEE President, 2024 Region Directors Eric Grigorian, Kathy Hayashi, Drew Lowery, and Mary Ellen Randall, 2025 IEEE President Elect)

Sponsorships from 40 companies, IEEE Societies, and graduate schools help to keep costs to attend affordable for students in addition to a generous grant from the Samueli Foundation. If you are interested in sponsorship opportunities, please contact Nancy Ostin at n.ostin@ieee.org. Plans are underway for next year's Student Leadership Conference with an announcement to be coming soon!

Founding Chapter President Supports the Newest Generation of HKN Students

In September 2024, Talmage De Lange, a founding member and inaugural chapter president of the Gamma Sigma Chapter, visited his alma mater, the University of Utah, to meet with current HKN members and ECE students. During his visit, he was given a tour of the university's ECE department. After the tour, students, faculty, and staff had the opportunity to talk with him regarding his storied career working on the F-14 Tomcat.

As the first chapter president, the department honored De Lange with a gavel, a modern membership certificate, and various gifts. Not only did De Lange enjoy the tour and meeting with current students and faculty, but the whole experience also benefited current HKN Chapter officers and students.

De Lange, along with a group of fellow students, founded the Gamma Sigma Chapter at the University of Utah 67 years ago on 16 January 1958.

After having been dormant for a number of years, four University of Utah students recently started working to revive the HKN community within their department, and De Lange received news of their efforts. The newly reactivated chapter is appreciative of the support and encouragement he has provided as their membership grows. Over a short span of only 12 months, Gamma Sigma Chapter has inducted 26 new members, completed nearly 300 hours of activity and service, and earned Key Chapter Recognition.

Gamma Sigma Chapter presents inaugural Chapter president with modern symbols of membership

According to newly inducted Gamma Sigma President Kyle Torson, "Joining the IEEE-HKN Gamma Sigma Chapter is a remarkable way for engineering students to acquire valuable experience, network with industry professionals, and enhance their overall resumes."

REFERENCES

https://www.ece.utah.edu/2024/01/11/bringing-back-ieee-eta-kappa-nu/

https://collections.lib.utah.edu/details?id=751470&q=eta+kappa+nu

Gamma Alpha Hosts Robot-Themed Halloween Fun

On 1 November 2024, Manhattan University hosted its annual Safe Halloween event, inviting children from the local community to enjoy a safe and festive trick-or-treating experience on campus. The event featured a variety of fun and educational activities while celebrating the Halloween spirit. The Gamma Alpha Chapter was thrilled to participate in this tradition, contributing to the evening with creative and interactive activities centered around this year's HKN-chosen theme: robots.

Gamma Alpha Students getting ready for local children

The chapter designed a maze-like activity with three engaging stations. At the first station, children answered basic questions about electrical and computer engineering and general science topics. Before moving on to the next station, they received candy, stickers, or erasers for their answers. This next activity involved a kid-friendly circuit troubleshooting challenge where participants identified and fixed simple issues, such as turning a switch on or ensuring power was running correctly. Finally, the third station provided entertainment with a glow-in-the-dark ring toss, where kids and parents tried their best to land glowing rings on a cone.

Parents and children enjoyed the thoughtfully crafted activities, which allowed learning and fun in equal measure. Gamma Alpha Chapter members took great pride in contributing to the local community while building stronger relationships within their organization. The chapter looks forward to continuing this tradition, creating even more creative and exciting activities for the next Safe Halloween event.

Couple Donates to IEEE-Eta Kappa Nu (IEEE-HKN) for their 50th Anniversary Celebration, Honoring their Connection to IEEE

(left to right) Shelly and Frank Chang with fellow HKN Eminent Member Ming Hseih

Dr. Mau-Chung Frank Chang, IEEE Life Fellow and IEEE-HKN Eminent Member, and his wife Shelly decided this past year to donate to the IEEE Foundation in celebration of their 50th wedding anniversary, honoring their beloved history with IEEE-Eta Kappa Nu (IEEE-HKN). Their gift was designated to create the IEEE-HKN M & L Chang Family Fund, which will provide long-term support to enable IEEE-HKN activities and programs to thrive in Asia-Pacific. Their generosity will make a lasting impact that encourages future generations from the region to discover the possibilities that can be found by being part of IEEE-HKN.

Dr. Chang is the Wintek Chair in Electrical Engineering and a distinguished professor at the University of California, Los Angeles (UCLA). Throughout his career, his research has focused on developing high-speed semiconductor devices and integrated circuits for radio, radar, imagers, spectrometers, and interconnect System-on-Chip applications. He found his passion for investigating semiconductor devices and circuits while studying physics as an undergraduate at National Taiwan University in Taipei, Taiwan.

"I enjoyed applying what I learned to create sensors and radios," recalls Dr. Chang. "Because of that, I decided to pursue my advanced studies in electrical and computer engineering."

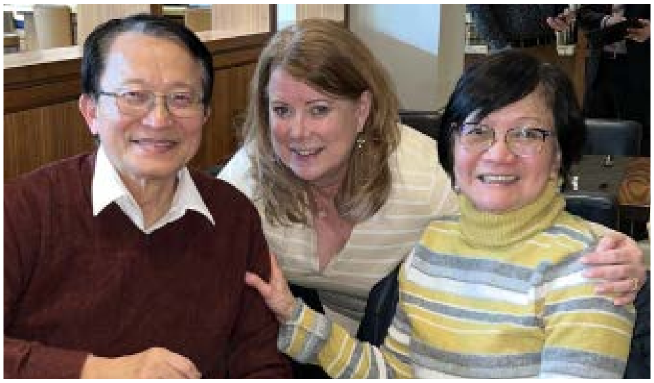
He would go on to earn his MS in Material Science and Engineering from National Tsing Hua University in Hsinchu, Taiwan, before completing his PhD in Electrical Engineering at National Chiao Tung University in Taipei and Hsinchu, Taiwan.

From 1983 to 1997, he was the assistant director and department manager of the High-Speed Electronics Laboratory at the Rockwell International Science Center (now Teledyne Scientific & Imaging). He joined UCLA in 1997, where he first became involved with IEEE-Eta Kappa Nu (IEEE-HKN). While serving as the electrical engineering department chair, he was deeply impressed by students and faculty who selflessly devoted their time to nurturing engineering leadership and community.

"IEEE-HKN has been one of the most effective organizations with emphasis on nurturing engineering students' readiness and competency in pursuing the advancing future engineering society," states Dr. Chang. "The engineering landscape has greatly expanded due to fast development in all fronts of sensing, imaging, communications, and AI related computations. This demonstrates how important it is that we continue to nurture and educate our next generation of pioneers and leaders globally."

Dr. Chang has pioneered System-on-Chip development for both high-speed and high-frequency system applications. He invented the multiband, reconfigurable RF-Interconnects for both inter-CPU cores and inter-CPU/memory communications. He and his students were the first to demonstrate CMOS active and passive imagers at 100-180 GHz. His lab also pioneered the development of self-healing 57- 64 GHz radio-on-a-chip (DARPA's HEALICS program) with embedded sensors, actuators, and self-diagnosis/curing capabilities. He also invented the Digitally Controlled Artificial Dielectric (DiCAD) embedded in CMOS technologies to vary transmission-line permittivity in real-time (up to 20X in practice). This makes it possible to make reconfigurable multiband/mode radios in (sub)-mm-wave frequency bands.

His UCLA lab also realized the first CMOS Frequency Synthesizer for Terahertz operation (PLL at 560 GHz) and devised the first tri-color CMOS active imager at 180-500 GHz based on a time-encoded digital regenerative receiver and the first 3-dimensional SAR imaging radar with sub-centimeter range resolution at 144 GHz. More recently, his lab has devised a Reconfigurable Convolution Neuron Network (RCNN) Accelerator for AIoT applications, spun



Frank and Shelly Chang with Nancy Ostin (Center) Director of IEEE-HKN

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Kathleen A. Kramer

Professor of Electrical Engineering, University of San Diego
Chapter of Induction: Eta Chapter

"...I am so glad that I, along with three of my students, had this unique opportunity to learn from practitioners and to be inspired by the HKN community."

Kathleen A. Kramer, 2025 IEEE President & CEO, is a professor of electrical engineering at the University of San Diego in California. She worked to develop new engineering programs as a founding member of the faculty and eventually became the chair of electrical engineering, then serving as Director of Engineering (2004-2013). She received her B.S. degree in electrical engineering magna cum laude with a second major in physics from Loyola Marymount University and her M.S. and Ph.D. degrees in electrical engineering from the California Institute of Technology.

Kramer has also been a member of the technical staff at several companies, including ViaSat, Hewlett Packard, and Bell Communications Research. She is a fellow of ABET and a leader in the development of accreditation criteria for cybersecurity and for mechatronics and robotics. As a new faculty member, she helped found the Kappa Eta chapter of HKN at the University of San Diego.

Attendees of the 2024 Student Leadership Conference (SLC) were treated to a keynote speech by then IEEE President-Elect, Kathleen Kramer, where she laid out her vision for a ***"One IEEE"*** —a vision that enables strategic investments and public imperatives while preparing students for success by connecting academia and industry with local and global IEEE student communities throughout their career journey. Students found her leadership, commitment, and passion for fostering technical knowledge inspiring. The feeling was mutual, as she reflected on her first SLC attendance as her favorite IEEE-HKN memory, stating:

"The experience from these three days tops the charts. I am so glad that I, along with three of my students, had this unique opportunity to learn from practitioners and to be inspired by the HKN community."

Kramer also draws inspiration from Lisa Su, CEO of AMD, who was recently named "CEO of the Year" by TIME Magazine. She admires her collaborative and transformational leadership, which fuels her own commitments as the 2025 IEEE President and CEO.

Her father, Henry Kramer, was a key influence in her decision to pursue engineering. The space program recruited him into programming while he was studying mathematics at the University of Washington. Recognizing her own aptitude for math and physics, he encouraged her to explore engineering. Reflecting on her early academic journey, Kramer shared:

"At the time, I was attending an all-girls high school and really hadn't any notion that engineering and physics weren't seen as typical options for girls."

She initially chose electrical engineering (EE) without fully knowing what it entailed but eventually double-majored in physics, becoming her university's first female physics major. While deciding between graduate school and an industry career, she ultimately chose to pursue a Ph.D. at Caltech—largely because EE applications were due first. She humorously noted:

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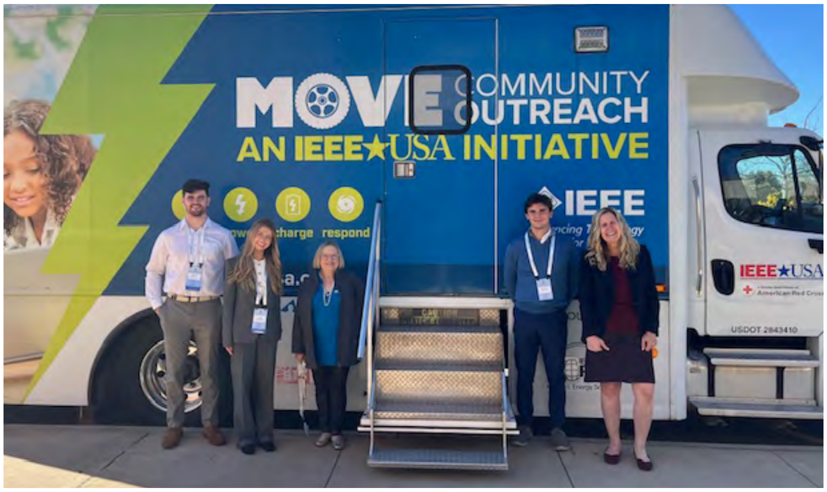


Kathleen Kramer (right) pictured with students and Mary Ellen Randall (center) in front of IEEE's MOVE Truck

Laura Floyd is a super senior at Valparaiso University in Northwest Indiana. She is studying electrical engineering and physics, as well as secondary education and German. She spent a year in Reutlingen, Germany, taking some of her engineering electives in German at the Hochschule Reutlingen and working at Bosch GmbH. She recently completed a senior capstone project combining electrical engineering, physics, and secondary education. In this project, she developed the equipment and educational materials to introduce students to radio astronomy through a lab activity observing the hydrogen line in the Milky Way Galaxy. She is currently student teaching at Wheeler High School, and she will graduate in the spring of 2025. Outside of academic pursuits, she also enjoys singing in choir. After graduation, she will start her career at Northrop Grumman. She is passionate about astronomy and radio communications, and she hopes to work on satellite communication systems.Always looking to challenge himself to expand his knowledge, he states, "If I had more time, I would like to explore new destinations, satisfying my desire to travel. And I have at least 20 books that I still can't find time to read!"

Laura Floyd

Electrical Engineering, Physics, Secondary Education, German Valparaiso University, Valparaiso, IN; HKN Student Chapter President, 2024 Madni Family Scholarship Recipient

As one of the inaugural recipients of the Madni Family Scholarship, Laura Floyd has always stood out from her peers, embodying HKN's characteristics of scholarship, character, and attitude. Her experiences in high school led her to pursue electrical engineering—her participation in a program called HUNCH (High School Students United with NASA to Create Hardware), where she designed solutions to everyday challenges astronauts face on the International Space Station, and earning her amateur radio license as part of a radio astronomy science fair project she was working on, which, according to Laura, *"exposed me to many electrical engineering topics I'm using today in both my degree and career. These two experiences were instrumental in inspiring me to pursue electrical engineering."*

These early experiences channeled her passion for physics and astronomy into engineering, which she loves, stating, *"Engineering draws from every field imaginable, from physics and mathematics to biology and social sciences; we use our experience with how the world works to inform and inspire our designs."* However, the open-endedness of engineering can be a source of frustration for her since it makes it difficult to know when a project is complete. According to Laura, *"Sometimes, you put a lot of effort into an idea only to find out later that it wasn't feasible. Or you spend a lot of time on one solution to a problem, which limits the amount of time you have left when you do find the correct path. Also, like other creative endeavors, there is always 'one more thing' you can do to improve a project. This can make it hard to acknowledge when a project should be considered complete, even if it's not perfect."*

Laura credits her mentor, Florence Gold—who oversaw the HUNCH program at her school and holds a doctorate in education—for inspiring and encouraging her to pursue secondary education alongside her technical degree. However, she wants to pursue a career in industry before turning to education, adding, *"Some of the best engineering professors I've had were people who spent some time in the industry first. They bring a real-life perspective that is incredibly valuable in the classroom."* Eventually, she would like to be a role model for the next generation to pursue engineering.

Laura envisions the next ten years for engineering, like other fields, to be constantly evolving, making it necessary to ***"develop the skills to learn new skills," but hopes "that the innovations that we are starting to see today will help us more effectively do routine work, so that we can focus our creative energy on the challenges that require our higher-order critical thinking and problem-solving skills."*** She advises today's electrical engineering students to *"find an area of interest within the field. Electrical engineering is a huge field, and I think some people fall into the trap of worrying that it's not right for them, just because they find one topic/class boring, difficult, or unnecessary."* Electrical engineering plays a role in almost all industries, plus academia, opening many different career paths, so Laura asserts that the key is ***"tying what you're passionate about together with the place you feel you can make a difference."***

Laura is following her own advice and is already making a difference to the next generation of engineers through her leadership, commitment, and service activities.

IEEE History Center

Michael Geselowitz

Towards the end of the 19th century, with the emergence of an electric light and power industry to complement the established telegraphy industry, the field of electrical engineering began to take off. The first departments of electrical engineering separated from physics departments in the 1880s, and by the turn of the century, they could be found throughout the United States, as well as the developed world. Tau Beta Pi, a general engineering honor society, had been founded at Lehigh University in 1885.

Fig. 1. HKN President Clyde M. Hyde presents the Outstanding Young Electrical Engineer Award Bowl to the 1966 winner, Dr. Morton H. Lewin of RCA Laboratories.

In 1904, a group of electrical engineering students at the University of Illinois at Urbana-Champaign decided that their numbers were strong enough to establish their own honor society, and Eta Kappa Nu, or HKN, was born. What followed was an exciting and distinguished history (the full history can be found here on the Engineering & Technology History Wiki website, or ETHW). For example, in 1908, Eta Kappa Nu began to publish a magazine, originally called The Electric Field and now known as *THE BRIDGE*! In 1936, HKN introduced the Outstanding Young Electrical Engineer Award (now the Outstanding Young Professional Award), with the winners' names engraved on a brass bowl. Figure 1 shows the presentation for 1966. In 1941, HKN established an eminent member category. Then, in 2009, it merged with IEEE, the world's largest engineering association, to become IEEE-HKN. But who keeps track of this history?

For IEEE (formally the Institute of Electrical and Electronics Engineers), the HKN merger was not its first. In fact, IEEE was formed in 1963 from the merger of two engineering associations, the American Institute of Electrical Engineers (AIEE, 1884) and the Institute of Radio Engineers (IRE, 1912). From its inception, IEEE was the world's largest technical association. Recognizing the responsibilities associated with this status, IEEE established an IEEE History Committee to preserve and promote the history of IEEE, its members, their professions, and related sciences and technologies.

In 1980, in preparation for its centennial in 1984 (as dated to the founding of AIEE) and in recognition of the continued growth in importance of its fields of interest, IEEE established a staff IEEE History Center to develop and maintain an IEEE Archive and to work with the History Committee to carry out their joint mission. The Center supports the activities of the Committee, primarily awarding recognitions, while the Committee provides guidance and oversight to the historical activities of the Center.

The longstanding, close relationship between IEEE and HKN made the IEEE-HKN merger possible. Since HKN lacked the capacity for historic preservation, the IEEE History Center became its de facto archive. For example, for many years between honor ceremonies, the HKN Bowl, which is now on display at IEEE's Corporate Office in New York City, was kept in the IEEE Archive. After the merger, the IEEE History Center became, in effect, the official historian for HKN.

The recognitions bestowed by the IEEE History Committee include the IEEE Middleton Book Prize, the IEEE Life Member History Fellowship, and, most notably, IEEE Milestone status. The IEEE Milestone Program recognizes achievements in IEEE's fields of interest that are at least 25 years old, have benefited humanity, and have had widespread geographic importance. Milestones can be sponsored by any organizational unit. Successful proposals are forwarded by the History Committee to the IEEE Board of Directors for final approval, after which a bronze plaque with an appropriate citation is dedicated at the site of the event. For instance, the milestone in Figure 2 recognizes the HP-35 electronic calculator for its pioneering technology that replaced the slide rule as an engineering tool.

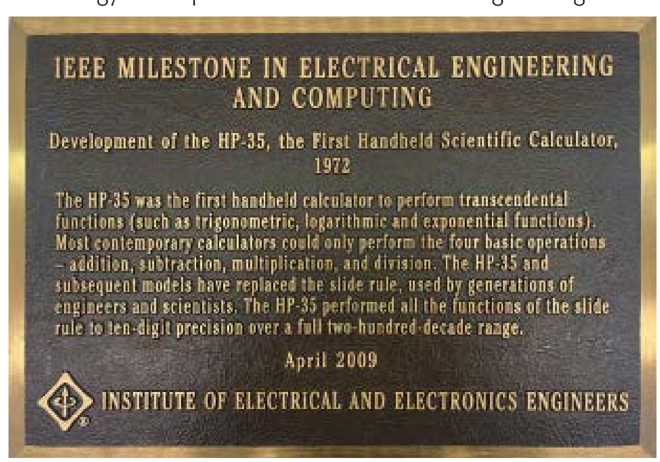


Fig. 2. IEEE Milestone Plaque for the First Handheld Scientific Calculator.

The IEEE History Center, as mentioned, maintains the IEEE Archives. It also develops and maintains a collection of oral histories of prominent engineers, currently at over 900. The processed oral history transcripts are made available as part of the historical documentation of IEEE and its technologies. The History Center also operates the IEEE REACH Program, which provides free, online, open educational resources to help pre-university educators bring the history of technology into their classrooms.

Most recently, the History Center has established the IEEE Global Museum, which promotes an understanding of electrotechnology and its impact upon society by bringing museum-quality traveling exhibits to IEEE members and the public. The initial major exhibit, on the first IEEE Medal of Honor winner E. Howard Armstrong (an Honorary Eminent member of HKN), is currently on display at the National Museum of Industrial History in Bethlehem, PA, USA.

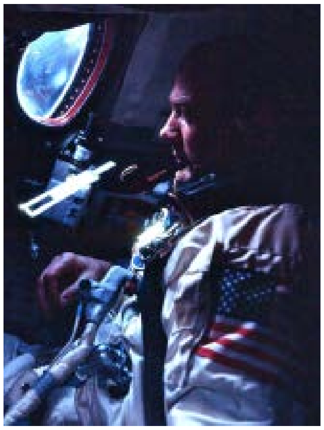
Most importantly, the History Center developed and maintains (now on behalf of a consortium of eleven engineering associations) the ETHW mentioned above. The site includes all the History Centers' historical content, including archival material, IEEE Milestone information, and oral histories, plus a wealth of articles on technology history and IEEE history. Thanks to the merger, this includes IEEE-HKN history; scanned back issues of *THE BRIDGE* are also available there.

To learn more about the activities of the IEEE History Center, the IEEE History Committee, and how HKN members can participate in those activities, visit the Center on the IEEE web pages or email ieee-history@ieee.org.

From Logarithms to Lunar Landings: How Slide Rules Contributed to the Apollo Program

Burton Dicht, Eta Chapter

The Apollo program showcased cutting-edge technology to fulfill President Kennedy's bold challenge of landing humans on the Moon and returning them safely to Earth. The mighty Saturn V rocket, the sophisticated Apollo Command/Service Module, and the spider-like Lunar Module stand as enduring symbols of this extraordinary achievement. In a previous issue of *THE BRIDGE* [(Guiding Apollo to the Moon, 2023 Issue 1/Volume 119)](), we explored one of the program's groundbreaking innovations: the Apollo Guidance Computer (AGC), a marvel of engineering that laid the foundation for modern computing.



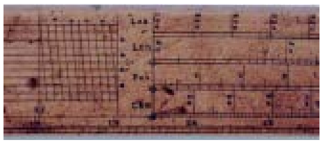
Astronaut Buzz Aldrin with a slide rule on the Gemini 12 mission in 1966 (Image Credit: NASA)

Looking back, it is easy to surmise that every calculation required to get astronauts to the Moon and back relied solely on advanced electronics and precise programming. Yet, amid the complexity of computers and spacecraft systems, astronauts and engineers relied on an analog tool with roots in centuries-old mathematics—the slide rule. With its sliding scales and logarithmic precision, this simple device was far from obsolete. In fact, it became an indispensable backup on some of the most ambitious exploration missions in human history.

While complete records are scarce, it is believed that at least one slide rule—and possibly two (one in the Command Module and another in the Lunar Module)—were carried on each of the first five Moon landing missions. [1] What practical purpose did this analog tool serve, given the advanced technology available to the astronauts? In high-stakes missions where every second counted, the slide rule offered something even the AGC could not: simplicity and a reliable backup for performing critical calculations.

The Apollo astronauts faced multiple scenarios where the slide rule could prove indispensable. If issues arose with the guidance, navigation, and control systems, addressing them would have required precise mathematical calculations—likely performed with a slide rule—to measure and adjust the spacecraft's position, attitude, trajectory, and propulsion system. Similarly, a malfunction in the stability and control system, which managed spacecraft rotation, translation, and thrust maneuvers, might have necessitated the use of a slide rule for troubleshooting and recalibration. Even challenges with the propulsion system, such as achieving the exact 50-50 mixture of unsymmetrical dimethylhydrazine and hydrazine fuel, might have called for manual calculations using a slide rule to ensure accuracy and mission success. [2]

The origins of the slide rule trace back to the 17th century, beginning with John Napier's development of logarithms in 1614. Napier introduced logarithmic tables, which, while groundbreaking, were cumbersome to read and use. In 1620, Edmund Gunter, a professor of astronomy at Gresham College in London, placed logarithmic scales on a standard ruler, creating what became known as "Gunter's Scale." [3] While not a slide rule in the modern sense—it lacked sliding parts—this innovation paved the way for the tool's development.



Gunter's Scale
Image Credit: whipplemuseum.cam.ac.uk

Two men are credited with inventing the slide rule as we know it, a tool that would remain integral to science, engineering, and mathematics for more than 340 years. In 1622, Anglican minister William Oughtred devised a method using two logarithmic scales that slid against one another, allowing for direct multiplication and division. Oughtred also conceptualized a circular slide rule in 1632. Around the same time, in 1630, English mathematician Edmund Wingate published his own concepts for a slide rule. [3]

The slide rule continued to evolve, reaching a significant milestone in 1859 when French artillery lieutenant Amédée Mannheim introduced the movable cursor and created the modern slide rule. As advances in mathematics, science, engineering, and technology progressed, the slide rule became an essential tool for calculations. By the 1920s, it had achieved its final form, cementing its place as an indispensable instrument for scientists and engineers. [4]

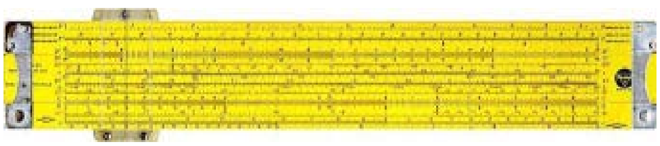
The first aeronautical E6B slide rule in 1937 Image Credit: nicolamarras.it

The evolution of slide rules in aviation and aerospace engineering paralleled the rapid advancements in flight technology during the mid-20th century. These analog calculators became indispensable tools for engineers and pilots alike, playing a crucial role in various aspects of aircraft design and flight operations. Developed in the 1930s, the E6B aeronautical slide rule quickly became an essential instrument for pilots in the cockpit. Its versatility in performing critical flight calculations made it a standard piece of equipment, and remarkably, it remains in use in small aircraft today by private pilots. [5]

Kelly Johnson (r) from Lockheed, designer of the SR-71 with slide rule
Image credit: sliderulemuseum.com

The slide rule's significance in aerospace engineering was exemplified by its pivotal role in the development of several iconic aircraft. The Boeing B-52 Stratofortress, a long-range nuclear bomber jet designed in the 1950s, was primarily engineered using slide rules. [4] Similarly, these analog calculators aided in the design of the legendary Mach 3+ SR-71 Blackbird, one of the most famous aircraft ever created. [5]

As the Space Age dawned, slide rules found their way into NASA's arsenal of tools. Norman Chaffee, a former NASA engineer who joined the Johnson Space Center (then the Manned Spacecraft Center) in 1962, succinctly captured their importance: "We went to the moon with slide rules. I didn't even have my first full-function calculator until 1972." [6] The Apollo program, culminating in the historic moon landing of 1969, relied heavily on slide rules for various calculations both on Earth and in space.



Pickett Company's 5-inch metal "N600-ES" model. Image Credit: sliderulemuseum.com

For the Apollo missions, NASA selected the Pickett Company's 5-inch metal "N600-ES" model, a popular choice among engineers, scientists, and students of the era. NASA employed this slide rule on five Apollo missions, requiring no modifications for its use in space. Pickett capitalized on this prestigious association in their marketing materials. [7]

Slide rule use in Mission Control depicted in the movie Apollo 13
Image Credit: Universal Pictures

The National Air and Space Museum (NASM) has preserved several historically significant slide rules, including one carried by Apollo 13 astronauts during their perilous 1970 mission. The museum also displays the well-worn slide rule of Dr. Wernher von Braun, the father of the Saturn V rocket and director of the Marshall Spaceflight Center [8].

By the final lunar mission in December 1972, electronic pocket calculators were beginning to supplant slide rules in industry. The Apollo-Soyuz mission in 1975, the last to use Apollo hardware, saw the crew carrying a Hewlett-Packard pocket calculator that surpassed the computational power of the on-board Apollo Guidance Computer [8]. The historical significance of these analog devices is further evidenced by the 2007 auction of Buzz Aldrin's Pickett N600-ES slide rule, carried on Apollo 11, which fetched $77,000. [9]

Pickett company promotional piece highlighting their slide rules were used on five Apollo missions
Image credit: Pickett Company and sliderulemuseum.com

While the critical guidance and navigation calculations for the Apollo missions were performed by onboard computers and large Earth-based systems, slide rules served as vital backup tools for the astronauts. Even in the emerging digital age of Apollo, these humble analog devices demonstrated their enduring utility, proving that sometimes the simplest tools can play a pivotal role in humanity's greatest achievements.

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Lessons learned from our friend Dr. Arthur Winston

Karen Panetta, IEEE Fellow

Dr. Arthur Winston was a long-time IEEE-HKN champion and IEEE volunteer. In 2004, he became the IEEE President. Arthur always focused on mentoring young people and was responsible for connecting me to IEEE-HKN. He was so proud of me when I became IEEE-HKN President in 2019. While I can tell you many stories of the years I spent working with Arthur, I thought it would be better to share the lessons I learned from him and perhaps only one story to put it all into context.

Arthur Winston (center) with Dr. Karen Panetta (right) and Sampathkumar Veeraraghavan (left)

Arthur taught me that there are only two things people don't like. They don't like the way things are and they don't like change. It is very easy to complain about the way things are and expect others to step forward to fix it, but it takes tremendous courage, enormous energy, and infinite resilience to make the change happen. Arthur was an architect for change. Not only did he establish the blueprint to take on grand challenges, but he also led the charge to execute those plans. We don't do this expecting to get promoted or to make money, because change is often met with a tsunami of resistance that gives us a reputation of a rebel warrior rather than celebrating and supporting us as pioneers. We take on these challenges because it is the right thing to do.

There are two examples that immediately come to mind that demonstrate Arthur's profound impact. The first is his contributions to IEEE Women in Engineering (WIE).

Arthur was a proponent of diversity and inclusion long before this topic was on most organizations' radars. He also knew that simply giving a group of underrepresented individuals a space and budget to go off and "solve the problem" on their own was not a viable or sustainable approach to address social challenges. Arthur knew that it took a community-both men and women- who wanted to support the advancement and inclusion of everyone to bring about positive change.

Let me share a story of how my involvement with Arthur and the evolution of IEEE WIE came about. Arthur and I worked together at Tufts University. He was the Executive Director of the Tufts Gordon Institute for Engineering Management, while I was an assistant professor in the Department of Electrical and Computer Engineering and the Computer Science Department. Arthur was also a member of our department.

There was a bus leaving for a department outing. Arthur prided himself on being very punctual, but I was always running late. Thus, I was the last one to get on the bus. There was only one seat left, and fortunately for me, it was next to Arthur.

That bus ride changed my life. Arthur and I discussed what it would take to get young women interested in pursuing engineering, and by the time we got off the bus, Arthur had asked me to provide him with a position statement about all the topics I discussed and proposed to him.

Two months later, I was informed that I was selected to be the new IEEE Women in Engineering Committee Chair, a position reporting to the IEEE Board of Directors and a role with high expectations that I would lead this global organization into a thriving community.

I secured my first passport and found myself on a plane to Paris, France, to meet the IEEE WIE Committee members.

In all honesty, the committee members were totally perplexed about how a woman from Boston, who had no prior experience on the WIE committee and never traveled beyond the U.S., could possibly lead and help the organization flourish. I had already developed a thriving Nerd Girls STEM outreach program that was gaining international recognition. Despite processing the necessary knowledge and leadership skills, I felt completely unfamiliar to the IEEE WIE Committee.

I appreciated their honesty, but I also endured some brutal commentary from a vocal individual about how I arrived to become the leader of IEEE WIE and had my abilities questioned. Behind the scenes, Arthur must have strongly advocated for me because he knew IEEE WIE needed a disruptive innovator who could bring synergy and global cooperation to the organization. He trusted and believed in me, and there was no way I would let him down. I committed to myself that failure was not an option, and a mediocre performance was not acceptable. I tuned out the "noise" and set out to work.

During that time, Arthur introduced me to my IEEE WIE Committee Chair predecessor, MaryEllen Randall, now the IEEE President-Elect, for support. She was one of my strongest advocates, helping to quell the anguish of some of my skeptics. MaryEllen has continued to be among the most collegial individuals I have ever worked with. I am so grateful that Arthur connected us.

The synergistic transition of power and cooperation between MaryEllen and myself should be a model for nations' leaders to follow! Furthermore, my most vocal skeptics turned into allies and were instrumental in helping me implement new strategies that changed the organization's trajectory.

As IEEE WIE grew, it became evident that we needed more staff support. I was told that I needed to put in a request and a proposal to hire new staff.

Together, MaryEllen and I put forward a proposal that came back with a definitive response, which was "No."

I was confident we put forward a compelling proposal and thought I now had to live with the decision.

I received a call from Arthur, who said, *"I heard you are not going to attend the IEEE Board meeting and present your proposal to the IEEE Finance Committee. Why not?"*

I replied, *"That's because they already denied the proposal and said no."*

Arthur laughed and responded, *"Karen, in IEEE, 'no' doesn't mean 'no.'"*

I got on a plane and headed across the country to present to the IEEE Finance Committee, a committee that had a reputation for eating their own young. I was terrified.

I presented the proposal and recall Past IEEE Treasurer, Joseph Lillie, who was chairing the committee, working out the numbers so that our request could be granted.

That support enabled IEEE WIE to expand and flourish.

Incidentally, it took me 20 more years to get over my fear of the IEEE Finance Committee. I decided to take the bull by the horns and joined the committee in 2024. They are not as scary as I envisioned and are extremely brilliant and data-driven individuals.

Arthur was so proud of me for conquering my fear, and I remained appreciative that he entrusted my stewardship to Joe Lillie as I ventured into what I thought back then was the lion's den.

IEEE WIE has become the largest international affinity group supporting women in technology. It has more male members than any other technical women's professional organization. Because IEEE WIE has grown to become a thriving international community, it is often referred to as "WE," reflecting the true collaborative spirit of its membership. Arthur was one of the first male members, and he was also the recipient of the first IEEE WIE mentorship recognition awards. He was also the first male to receive an award from IEEE WIE.

The second example of Arthur's impact is when the US Department of State had restrictions on the dissemination of technical and scientific research. Arthur knew that a global economy could not be achieved if people worldwide were not allowed to participate and be educated in the latest technological advancements. He knew international collaboration and the inclusion of diverse perspectives inspired the most impactful innovations.

Arthur did not stand on the sidelines expecting others to address and solve this issue. Rather, he stepped into action and led the charge to have the restrictions lifted.

Imagine what our world would have been like if such restrictions were not removed. Healthcare technologies that have saved billions of lives would not have been created or disseminated, and the millions of new business ventures that have lifted underserved populations from poverty would have surely been further excluded from participating.

When Arthur's son called me to inform me of Arthur's passing, I was distraught, and rather than me consoling his son as I should have, his son was consoling me. When I ended the call, my husband reminded me that while I was sad and would always miss Arthur, I should recognize all the time and effort I spend educating underrepresented groups of individuals, promoting outreach and education as a viable path to make dreams come true, and my own reputation for being a disruptive innovator. These are exactly the traits that Arthur exhibited throughout his lifetime. Furthermore, the wonderful individuals I have met in IEEE through Arthur have remained my steadfast collaborators.

Arthur was my role model and mentor, and I am honored that I have become exactly what he architected in his blueprints for me and the countless others he has mentored.

What I realized most was that Arthur's life mission and efforts were never solely about engineering technologies. They were about mutual respect for all people and the inclusion of all individuals through collaboration. This is Arthur Winston's legacy, and I hope to continue to be a vehicle to continue his legacy.

Arthur loved IEEE, and his family has requested that any remembrances for Arthur be donated to the IEEE Foundation.

continued from [page 34]

off an Edge-AI startup company, Kneron, in San Diego, and won the 2021 IEEE Transactions on Circuits and Systems Darlington Best Paper Award.

Dr. Chang was also recognized with the IEEE/RSE James Clerk Maxwell Medal (2023) for his seminal contributions to the heterojunction technology and realizations of (sub)-mm-Wave System-on-Chip with unprecedented bandwidth and reconfigurability. Additionally, he received the 2018 HKN Karapetoff Outstanding Technical Achievement Award.

Throughout his work, Dr. Chang has been a champion of cross-disciplinary collaboration because he believes that to prevail in an ever-increasingly complex and competitive future, "the next generation of pioneers must learn how to work together harmoniously and effectively." He believes IEEE-HKN is an organization that can help foster this teamwork and contributes to the IEEE Foundation to support this ongoing initiative.

"As an UCLA ECE Department chair, I observed that HKN members of UCLA Chapter devote their time selflessly to help other students in preparing for exams when they themselves are also busy in taking the same exams," explains Dr. Chang.

Dr. Chang and his wife hope others will support IEEE-HKN. Learn more about how to join them in financially supporting the work of IEEE-HKN by visiting the [Support IEEE-HKN webpage].

continued from [page 38]

"After receiving encouraging responses, I decided not to make the additional extra effort to keep all my options open. This was an uncareful but ultimately wonderful decision."

Kramer loves engineering for numerous reasons, stating that *"I love that I am:*

1) Always learning and challenging my mind;

2) Solving hard problems that need to be solved and helping others to do this with me;

3) Part of a greater force for innovation that is successful only by working with many others;

4) Helping many others to better succeed in advancing their own professional and academic success."

However, she cautions that *"careers in technology, science, and innovation across IEEE's fields of interest, both for industry and academics, have become increasingly challenging to maintain. The demands and expectations for even our most expert contributors are dynamic, and the space for opportunities is very dynamic."* She sees future opportunities for IEEE to be a force for supporting professionals throughout their careers, ensuring they stay in the field, and advancing technology for humanity.

Her most important lesson that she learned as an engineer has been "***to build your own lasting self-confidence, durable professional 'grit.'"*** She encourages students to build their own portfolio of skills and experiences and help others do the same as they navigate their own career journeys. She also recommends that students seek out challenges and opportunities, knowing that *"high-caliber, high-impact work doesn't happen in just one attempt, even with effort."* She further counsels that *"recognizing failure is inevitable but should be instructive and to expect that no matter how you plan and try, at least three tries will be necessary."*

Kramer strongly supports the mission and impact of IEEE-HKN on its members and the profession. She sees IEEE-HKN's greatest opportunity in the coming years as its leadership role in shaping the next generation of innovators. She ties this to one of her strategic priorities as the 2025 IEEE President & CEO: to connect our next generation to industry success, stating that ***"IEEE-HKN provides a high-impact opportunity for the whole institute to learn from."***

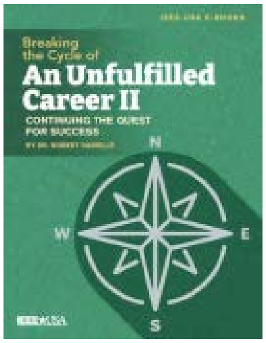
Free Offerings from IEEE-USA for IEEE Members

Georgia C. Stelluto

IEEE-USA's New, Free January E-Book:

Breaking the Cycle of an Unfulfilled Career II – Continuing the Quest for Success

IEEE-USA's Free New January E-Book for Members Continues the Quest for Success



Have you ever felt stagnant in your career, had a bully in the workplace target you, or faced a new boss who offered great promise but ended up hurting the organization? Dr. Robert Danielle's new e-book on *Breaking the Cycle of an Unfulfilled Career II: Continuing the Quest For Success* looks at these situations, and others, that might make a motivated, high-performing employee lose their edge, or even leave a company.

The second in this series, this e-book is for the reader who sees a lack of advancement opportunities, feels their potential is not being recognized, or whose career has become stagnant. Danielle points out that it is not uncommon for employees to find themselves in such situations, noting that the U.S. Bureau of Labor Statistics has reported 42 percent of employees feel blocked in their professional growth.

Members—Download your free January e-book from IEEE-USA by going to: https://ieeeusa.org/product/breaking-the-cycle-of-an-unfulfilled-career-2/

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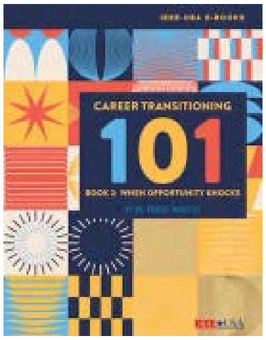
To read the full article, go to: https://insight.ieeeusa.org/articles/new-ieee-usa-e-book-offers-strategies-to-get-your-career-back-on-track/



IEEE-USA'S Free, New January Audiobook: *Career Transitioning 101: Book 2, When Opportunity Knocks*

IEEE-USA's Free, New January Audiobook Goes Beyond Luck to Make Opportunities Happen

Have you ever known people who seem to be just plain lucky? In IEEE-USA's new audiobook, *Career Transitioning 101: Book 2, When Opportunity Knocks,* author Dr. Robert Danielle speculates more often than not, that lucky people have taken steps to prepare themselves to identify and seize the moments. In this audiobook, Danielle gives tips, anecdotes, and advice on how to lay the groundwork for such opportunities.

The new January audiobook is available free from the IEEE-USA Shop.

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