CHAPTER 1

ON THE SHOULDERS OF GIANTS

"*If I have seen further it is by standing on the shoulders of giants.*"
—Isaac Newton (1642–1727)

1.1 HE(A)DY STUFF

Hedy Lamarr (1914–2000), a celebrated movie actress from the Golden Age of Hollywood, once said, "Any girl can be glamorous. All she has to do is stand still and look stupid." Well, the very same Lamarr, in her spare time, co-invented—yes, I'm not kidding—a frequency-hopping radio-controlled system for guiding torpedoes. For

From ER to E.T.: How Electromagnetic Technologies Are Changing Our Lives, First Edition. Rajeev Bansal.

her invention, US Patent #2,292,387, granted in 1942, Hedy Lamarr finally received some long-overdue recognition. On March 12, 1997, at a San Francisco ceremony, her son accepted the Electronic Frontier Foundation Award, given to "Hedy Lamarr for her Contribution in Pioneering Electronics."

This bizarre sequence of events had its roots in pre-war Vienna, where, in 1933, the Austrian-born Hedy Lamarr married Fritz Mandl, a leading Austrian armaments manufacturer. Mandl's household was an institution in the Viennese society, attracting many dignitaries, including political and military leaders. Mandl was himself interested in control systems, and engaged in research in that field. Apparently, Hedy Lamarr also picked up a thing or two along the way. In 1937, their marriage broke up, and Lamarr emigrated to America and headed for Hollywood.

One day, in the summer of 1940, Hedy Lamarr and her Hollywood neighbor, George Antheil, an avant-garde composer, were playing the piano together, carrying on an improvised musical dialogue up and down the keyboard. They started talking about the war and Lamarr brought up the idea of frequency hopping, synchronized between the transmitter and the receiver, for secure (resistant to jamming) radio control of torpedoes. Antheil, drawing upon his experience with player pianos, suggested that the synchronized rapid frequency hopping that Lamarr had envisioned for the torpedo-control system could be implemented using perforated paper rolls, similar to player-piano rolls. In fact, by the time they applied for a patent in June 1941, their embodiment of the frequency-hopping technique used slotted paper rolls and utilized 88 frequencies, the exact number of keys on a piano. Their patent application also specified that the torpedo could be guided from above by a plane.

While their invention was granted a patent in 1942, it was an entirely different ball game when it came to convincing the US Navy that the device was practical for torpedo control. Ironically, Antheil's contribution of the player-piano mechanism as *one* possible implementation of Lamarr's frequency-hopping system apparently proved to be its undoing. Antheil later wrote, "In our patent Hedy and I attempted to better elucidate our mechanism by explaining that certain parts of it worked like the fundamental mechanism of a player piano. Here, undoubtedly, we made our mistake. The reverend and brass-headed gentlemen in Washington who examined our invention read no further than the words "player piano." "My God," I can see them saying, "we shall put a player piano in a torpedo." Amusing as Antheil's explanation is, it probably does not tell the whole story.

The Navy must have also realized the difficulties in setting up an electromagnetic communication link between a plane and a torpedo through the highly attenuating sea water (a problem that persists to this day) and, in particular, in equipping the torpedo with a suitable receiving antenna.

At any rate, discouraged by the Navy's attitude, Lamarr and Antheil did not pursue their invention further. Instead, Lamarr successfully used her charm to sell war bonds, raising millions of dollars for the war effort. In 1957, engineers at Sylvania Electronic Systems Division in Buffalo, New York, implemented secure radio communication via frequency hopping by replacing the piano rolls with electronic circuits. In 1962, 3 years after the Lamarr–Antheil patent had expired, ships equipped with secure military-communication systems, based on the frequency-hopping technique, were

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deployed during the Cuban missile crisis. Though Lamarr and Antheil never collected a penny from their pioneering work, their patent has been cited as the seminal work by subsequent patents in the area of frequency-hopping systems.

The bottom line is that Lamarr and Antheil were inventors ahead of their time. That is why it is particularly fitting that the 1997 Electronic Frontier Foundation Award finally recognized the vital role their patent eventually played in the modem development of secure communications.

[Compiled from reports in the *Chicago Tribune,* March 31, 1997, and the *American Heritage of Invention & Technology*, Spring 1997.]

(The original version of the column appeared in "AP-S turnstile," *IEEE Antennas and Propagation Magazine*, vol. 39, no. 3, p. 100, June 1997.)

NOTES

1. Many books are available about Hedy Lamarr and her inventions. See, for example, Richard Rhodes's *Hedy's Folly: The Life and Breakthrough Inventions of Hedy Lamarr, the Most Beautiful Woman in the World*, Vintage, 2012.
2. For more information about US Patent #2,292,387, consult: http://www.google.com/patents/US2292387 (accessed December 22, 2015).

1.2 FROM RUSSIA WITHOUT ENGLISH

The National Academy of Sciences recently published a biographical memoir [1] of Edward Leonard Ginzton (1915–1998). Ginzton's fundamental contributions to electronics and microwaves have been eulogized before, for example, when he was elected to the National Academy of Engineering (1965), or when he received the IEEE Medal of honor (1969). What Anthony Siegman, the author of this brief 35 page memoir, succeeds in doing is to present a multi-faceted portrait of Ginzton, who in Carolyn Caddes's words was "scientist, educator, business executive, environmentalist, and humanitarian [2]." Here are some highlights from Siegman's memoir.

Early Years

Ginzton, who was born in Ukraine, recalls his childhood education thus: "Since both of my parents participated as medical officers on the Eastern Front, my early childhood consisted of rapid migration with the tides of war, revolution, and other similar events. Until I was 8 we did not live in any one place for more than six months, and I was not exposed to formal education until I was 11." When Ginzton was 13, his family emigrated from Russian-controlled Manchuria to San Francisco. Ginzton, "knowing not a word of English," was placed in the first grade in the public schools. Four years later, Ginzton finished high school and entered UC Berkeley.

The War Years

As Ginzton later noted modestly: "[During these] six years, I invented some 40 or 50 devices, some of which were relatively important." The Doppler radar techniques pioneered under Ginzton's supervision at Sperry provided the technical foundation of many sophisticated radars of later years. By the time the war ended, Ginzton had some 2000 people working under his direction.

The Stanford Years

Appointed an assistant professor of applied physics (rather than physics because of his EE credentials) at Stanford, Ginzton and his colleagues published "A Linear Electron Accelerator" in the February 1948 issue of the *Review of Scientific Instruments*, which led to the successful development of several generations of accelerators, the use of which was instrumental in at least six Nobel Prizes. Ginzton was also prescient in recognizing the potential application of these accelerators for radiation therapy for cancer; by the time of his death some 4000 of small medical accelerators were treating over 1 million patients annually.

The Varian Years

Varian Associates was established in 1948 with $22,000 of capital and six full-time employees. Ginzton was on the company's board from day one and remained on it till 1993. In 1959, when Russell Varian died suddenly, Ginzton was appointed CEO.

The McCarthy Era

Ginzton, who had shared a graduate-student office with Frank Oppenheimer (Robert's brother) in 1939, was caught up in the McCarthy maelstrom and lost his security clearance for a while. It required a massive legal effort by Stanford to get Ginzton's clearance back.

Community Leadership

Ginzton was an early champion of fair housing and clean air. He also founded and co-chaired (1968–1972) the Stanford Mid-Peninsula Urban Coalition, an organization to support the launch of minority-owned small businesses.

His Vision

Writing in 1956, Ginzton noted: "It is evident that the applications of present microwave knowledge will continue to grow, both in number and diversity; but despite the daily invention of novel applications, we must not become complacent. Every field of research has a finite half-life." Later in his life, he explained his philosophy to Caddes [2]: "Grow and become educated, but do not equate professional training with education. Try to learn how to think. Attempt to do what you want to do. Making a living is not enough."

ACKNOWLEDGMENT

I would like to thank my colleague Dr. Anthony DeMaria for bringing the Ginzton memoir to my attention.

REFERENCES

[1] A. E. Siegman, "Edward Leonard Ginzton (1915–1998)," *Biographical Memoirs*, vol. 88, National Academy of Sciences, Washington, D.C., 2006.

[2] C. Caddes, *Portraits of Success: Impressions of Silicon Valley Pioneers*, Tioga, Palo Alto, CA, 1986.

(The original version of the column appeared in "Microwave surfing," *IEEE Microwave Magazine*, vol. 7, no. 6, pp. 28–30, December 2006.)

1.3 ON THE SHOULDERS OF GIANTS

We know Maxwell's equations by heart but what do we know about Maxwell himself? Considering his preeminent position in the pantheon of leading scientists, there are relatively few biographies of Maxwell. The primary historical reference on Maxwell has been the 1882 biography written by Maxwell's long-time friend Lewis Campbell with help from William Garnett. Campbell's work received critical acclaim upon publication. "This volume will be heartily welcomed by all who knew Clerk Maxwell, and who cherish his memory, and lay the still wider circle of those who derive pleasure and new vigour from the study of the lives and work of the great men that have gone before them," noted the reviewer in *Nature* but it is no longer readily available. Fortunately, the full text of the 1882 biography is available on the web at https://www.sonnetsoftware.com/resources/maxwell-bio.html

Campbell's book, *The Life of James Clerk Maxwell*, has three parts: (1) a description of Maxwell's life, (2) an account of his scientific investigations, and (yes, I am not kidding) (3) a collection of Maxwell's poetry. Maxwell's poems cover the full spectrum from translations of Virgil's poetry to original poems on scientific issues. An example of the latter follows (I have omitted the middle section of the rather long poem as well as the accompanying figure and equations, which may be viewed at the website mentioned above):

A PROBLEM IN DYNAMICS (1854)

AN inextensible heavy chain

Lies on a smooth horizontal plane,

An impulsive force is applied at A,

Required the initial motion of K.

Let ds be the infinitesimal link,

Of which for the present we've only to think;

Let T be the tension, and T + dT

The same for the end that is nearest to B.

Let a be put, by a common convention,

For the angle at M 'twixt OX and the tension;

Let Vt and Vn be ds's velocities,

Of which Vt along and Vn across it is;

Then Vn/Vt the tangent will equal,

Of the angle of starting worked out in the sequel.

In working the problem the first thing of course is

To equate the impressed and effectual forces.

K is tugged by two tensions, whose difference dT

(1) Must equal the element's mass into Vt.

Vn must be due to the force perpendicular

To ds's direction, which shows the particular

Advantage of using da to serve at your

Pleasure to estimate ds's curvature.

For Vn into mass of a unit of chain

(2) Must equal the curvature into the strain.

Thus managing cause and effect to discriminate,

The student must fruitlessly try to eliminate,

And painfully learn, that in order to do it, he

Must find the Equation of Continuity.

…

From these two conditions we get three equations,

Which serve to determine the proper relations

Between the first impulse and each coefficient

In the form for the tension, and this is sufficient

To work out the problem, and then, if you choose,

You may turn it and twist it the Dons to amuse.

In 1884, an abridged second edition of the biography was published which included several previously unpublished scientific letters. I particularly enjoyed the following excerpt from a letter that Maxwell sent to Faraday in 1859:

> "*DEAR SIR—I am a candidate for the Chair of Natural Philosophy in the University of Edinburgh, which will soon be vacant by the appointment of Professor J. D. Forbes to St. Andrews. If you should be able, from your knowledge of the attention which I have paid to science, to recommend me to the notice of the Curators, it would be greatly in my favour, and I should be much indebted to you for such a certificate.*"

I don't know whether Faraday obliged with a glowing recommendation, but Maxwell didn't get the job!

(The original version of the column appeared in "AP-S turnstile," *IEEE Antennas and Propagation Magazine*, vol. 41, no. 1, p. 116, February 1999.)

NOTE

1. For additional material on Maxwell and his famous equations, see Sections 4.1, 10.4, and 10.5.

1.4 DO-IT-YOURSELF EXECUTION?

An article by Niels Jonassen of the Technical University of Denmark (*Compliance Engineering*, January/February 1998) sparked my interest in Benjamin Franklin's technical writings. In July 1750, Franklin proposed the following experiment in a letter to his British friend P. Collison in London:

> "*To determine the question whether the clouds that contain lightning are electrified or not I would propose an experiment to be tried where it may be done conveniently. On top of some high tower or steeple place a kind of sentry box…big enough to contain a man and an electrical stand [an insulated platform]. From the middle of the stand let an iron rod rise and pass bending out of the door, and then upright twenty or thirty feet, pointed very sharp at the end. If the electrical stand be kept clean and dry, a man standing on it when clouds are passing low might be electrified and afford sparks, the rod drawing fire to him from the cloud.*"

An astonishing suggestion, indeed, from the inventor of the lightning rod, particularly when one considers the next statement in Benjamin Franklin's letter: "*If any danger to the man be apprehended (though I think there would be none*)…" Fortunately for Franklin, there was no suitable tower in Philadelphia, so he did not get a chance to try this "glow in the dark" experiment himself! However, his letter received a wide and enthusiastic audience in Europe. In May 1752, the French scientist d'Alibart carried out the experiment near Versailles and lived to tell the tale at the Academy of Sciences in Paris 3 days later. Soon after, the experiment was successfully duplicated in France again, in England, and in Belgium. Next year the Swedish physicist Georg Richman, working in Russia, installed "lightning chords" through the roof of his house with the chords ending above his desk so that he could observe the lightning phenomenon from the comfort of his chair. On July 26, 1753, the top of the lightning chords received a direct lightning strike and, in the memorable words of his colleague Lomonosov, Richman died a splendid death fulfilling a duty of his profession.

Meanwhile, back home in Philadelphia, Franklin, apparently unaware of the European experiments, "improved" on his original idea and thought of the famous kite experiment (which dispensed with the need for a tower). Sometime during the summer of 1752, the classic experiment was performed: sparks jumped from the metal key at the end of the electrified conducting kite string to Franklin's hand. No harm done! Since then a number of people have been killed imitating Benjamin Franklin. In the late nineteenth and the early twentieth centuries, large box kites carrying meteorological instruments were used by many US Weather Bureau stations. The kites used weighed 8 lb, carried a couple of pounds of instrumentation, and dragged a good deal of piano wire ("kite string") behind them. In one case, a man assisting in the flight was killed when the kite was struck by lightning [1].

REFERENCE

[1] M. Uman, *All About Lightning*, Dover, 1986.

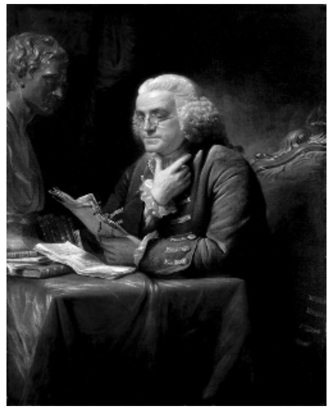
(The original version of the column appeared in "AP-S turnstile," *IEEE Antennas and Propagation Magazine*, vol. 40, no. 2, p. 102, April 1998.)

NOTES

1. A good biography of Ben Franklin is: W. Issacson, *Benjamin Franklin: An American Life*, Simon & Schuster, 2003.
2. A farmer and his cow are caught outdoors in a thunderstorm. A pine tree near them is struck by lightning. The cow is electrocuted but the farmer survives to tell the tale. How?
   (a) The cow presents a much larger capacitance than the farmer.
   (b) The cow happens to be a bit closer to the tree.
   (c) The cow's legs are too far apart.
   (d) It is a totally random occurrence.

   (c) The cow's legs are too far apart.
   The current from the lightning strike, which can be tens of thousands of amperes, passes into the earth at the base of the tree and spreads out radially in the top conducting layer of the ground. This sets up a potential gradient along the surface. The cow's foot near the tree will be at a much higher potential (depending on the ground resistance) than the foot farthest away from the tree. Clearly, a current will flow through the cow from one end to the other and could well be fatal.
   Source: R. Bansal, "Zapped: A pop quiz on electrostatics," *IEEE Potentials*, pp. 5–6, April/May 2000.
3. Textbook resources:
   (i) W. H. Hayt and J. A. Buck, *Engineering Electromagnetics*, 8th ed., McGraw-Hill, New York, 2012. Electrostatic fields are discussed in Chapters 2–6.
   (ii) F. T. Ulaby and U. Ravaioli, *Fundamentals of Applied Electromagnetics*, 7th ed., Prentice Hall, Upper Saddle River, NJ, 2015. Electrostatic fields are discussed in Chapter 4.

1.5 FRANKLIN: DID HE OR DIDN'T HE?



Benjamin Franklin's investigations [1] into electricity were discussed previously in Section 1.4. As all American children learn in school, Mr. Franklin showed that lightning was a form of electricity through his celebrated "kite experiment" sometime in 1752. Now a new book [2] by Tom Tucker poses the iconoclastic question: Did Benjamin Franklin *really* fly that kite?

To backtrack a little bit, in July 1750, Franklin had proposed the following experiment in a letter to his British friend P. Collison in London [1, 3]:

> "*To determine the question whether the clouds that contain lightning are electrified or not I would propose an experiment to be tried where it may be done conveniently. On top of some high tower or steeple place a kind of sentry box…big enough to contain a man and an electrical stand [an insulated platform]. From the middle of the stand let an iron rod rise and pass bending out of the door, and then upright twenty or thirty feet, pointed very sharp at the end. If the electrical stand be kept clean and dry, a man standing on it when clouds are passing low might be electrified and afford sparks, the rod drawing fire to him from the cloud.*"

As pointed out in Section 1.4, fortunately for Franklin, there was no suitable tower in Philadelphia, so he did not get a chance to try this dangerous experiment *himself*! However, thanks to his letter, the experiment was carried out successfully several times in Europe. Meanwhile, back home in America, Franklin, apparently unaware of the European demonstrations, refined his original idea and thought of the famous kite experiment, which did not need a tower. Sometime during the summer of 1752, the classic experiment was performed: sparks jumped from the metal key at the end of the electrified conducting kite string to Franklin's hand. Or at least that is the way the story is conventionally told. Tucker, the author of *Bolt of Fate* [2], has his doubts though. He asks us to read carefully the account of the kite experiment Franklin published in the *Pennsylvania Gazette* [4]:

> *"The kite* ***is to be raised****, when a thundergust appears to be coming on, (which is very frequent in this country) and the person, who holds the string, must stand within a door,*

or window, or under some cover, so that the silk riband may not be wet… As soon as any of the thunder-clouds come over the kite, the pointed wire ***will draw*** *the electric fire from them; and the kite, with all the twine,* ***will be electrified****; and the loose filaments of the twine* ***will stand out*** *every way, and be attracted by the approaching finger. When the rain has wet the kite and twine, so that it can conduct the electric fire freely,* ***you will find*** *it stream out plentifully from the key on the approach of your knuckle… All the other electrical experiments [can] be performed, which are usually done by the help of a rubbed glass globe or tube, and thereby the sameness of the electric matter with that of lightning completely demonstrated" [emphasis added].*

Tucker was intrigued by the conditional spirit and the unusual future tenses used by Franklin in describing this experiment. He compared it with the reports of other experiments conducted by Franklin and found that the impersonal future-tense style used in the excerpt above was typical neither of the eighteenth century scientific reports in general nor of Franklin's own work in particular. In fact, according to Tucker, Franklin was usually very careful in describing exactly how, when, and where he did a particular experiment: "he gives specifics, he uses active voice, he offers diagrams, *he says he did it.*"

In another recent biography [5] of Benjamin Franklin, Issacson does not accept Tucker's analysis. He cites the great historian of science I. Bernard Cohen's books on Franklin's science. Cohen notes that the "kite experiment" was later reproduced by others and it was unlike Franklin to have just made up the account. Tucker, for his part, draws attention to a series of (nonscientific) hoaxes that Franklin pulled in his publishing career.

I would like to conclude this section by quoting from Gopnik [4], who points out that it was Franklin who edited Jefferson's draft to come up with the words "We hold these truths to be *self-evident*":

"The moral of the kite [story] is not that truth is relative. It is that nothing is self-evident.… We hold these truths as we hold the twine, believing, without being sure, that the tugs and shocks are what we think they are. We hold the string, and hope for the best. Often, there is no lightning. Sometimes, there is no kite."

REFERENCES

[1] R. Bansal, "AP-S turnstile: do-it-yourself electrocution?" *IEEE Antennas and Propagation Magazine*, vol. 40, no. 2, p. 102, April 1998.

[2] T. Tucker, *Bolt of Fate: Benjamin Franklin and His Electric Kite Hoax*" PublicAffairs, 2003.

[3] M. Uman, *All About Lightning*, Dover, 1986.

[4] A. Gopnik, "American Electric," *The New Yorker*, pp. 96–100, June 30, 2003.

[5] W. Issacson, *Benjamin Franklin: An American Life*, Simon & Schuster, 2003.

(The original version of the column appeared in "AP-S turnstile," *IEEE Antennas and Propagation Magazine*, vol. 45, no. 4, pp. 82–83, August 2003.)

NOTES

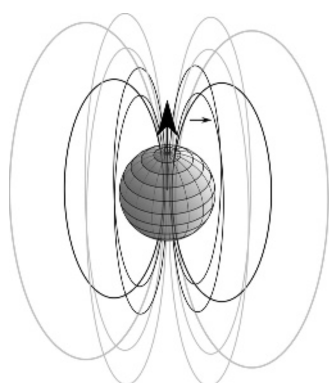
1. The electric charge delivered to the earth during a lightning strike is around
   (a) 1 nC
   (b) 1 C
   (c) 10^6 C
   (d) 10^{12} C

   (b) 1 C

   Since the electric filed is defined as the force exerted on a unit charge (1 C in the meter-kilogram-second, MKS, metric system), it is a common mistake to think that 1 C represents a tiny charge. Actually, the MKS unit of charge (named after Charles Coulomb) is way too large for most electrical engineering applications. Recall that a negative charge of 1 C will require almost 6×10^{18} electrons, hardly a "point charge" but rather the type of charge transfer that takes place during a violent phenomenon like a lightning strike.

   Source: R. Bansal, "Zapped: A pop quiz on electrostatics," *IEEE Potentials*, pp. 5–6, April/May 2000.
2. Textbook resources:
   (i) W. H. Hayt and J. A. Buck, *Engineering Electromagnetics*, 8th ed., McGraw-Hill, New York, 2012. Electrostatic fields are discussed in Chapters 2–6.
   (ii) F. T. Ulaby and U. Ravaioli, *Fundamentals of Applied Electromagnetics*, 7th ed., Prentice Hall, Upper Saddle River, NJ, 2015. Electrostatic fields are discussed in Chapter 4.
3. Reference [1] is included in this book as Section 1.4.

1.6 DE MAGNETE ("ON THE MAGNET")



Navigators all at sea

Don't eat onions for their tea

Not that they're at all emetic

They make the compass nonmagnetic

At the dawn of the twenty-first century, it may seem quaint that British naval helmsmen were once flogged if they were found to be in violation of the regulation [1] that "steersmen, and such as tend the Mariner's Card are forbidden to eat Onyons and Garlick, lest they make the index of the poles drunk." But such was indeed the sixteenth century world into which William Gilbert (1544–1603) was born. The year 2000 marked the 400th anniversary [2] of the publication of his pioneering treatise "De Magnete" (ix+246 pp, 7/6 (37.5 p) in London; 2 Thaler in Frankfurt; Published by Peter Short, London, 1600), which eventually helped dispel many nonsensical beliefs about magnetism. Predating Kepler's *Astronomia Nova* (1609), which described laws of planetary motion, and Galileo's *Sidereus Nuncius* (1610), which reported on his astronomical observations with the telescope, Gilbert's book on magnetism is considered by many to be the first scientific monograph written on modern principles. (Newton's *Principia* came much later in 1687.) Like a present-day doctoral dissertation, "De Magnete" [3] reviews previous work, describes Gilbert's experimental investigations and results, discusses his findings in a broader context, and finally provides speculations about future work [4].

William Gilbert was born in 1544 in Colchester (some 50 miles NE of London), where his father held the prestigious post of Recorder. Gilbert studied at St John's College, Cambridge, where he remained for 11 years until 1569, acquiring bachelor's and master's degrees, as well as his credentials as a physician. He settled in London to practice medicine and eventually became President of the Royal College of Physicians and Physician to Queen Elizabeth I. He died of bubonic plague in London in 1603 [4].

Gilbert's research on magnetism was really a hobby. Over a 20 year period (1581–1600), he conducted experiments in electrostatics (contributing to our vocabulary terms such as "electrick force") and in magnetostatics. For his work on geomagnetism, Gilbert constructed a spherical lodestone which he called terrella ("little earth"). Using small compass needles, he explored the magnetic field of his terrella and extrapolated his findings to the effect of the earth's magnetic field on the behavior of a magnetic compass. For example, to simulate the effects of proximity to landmasses, he carved out "oceans" from the terrella and found that the compass needles behaved differently near oceans and mountain ranges [4].

Gilbert supported the Copernican theory and also believed that the earth turned on its axis. However, he erroneously associated this planetary rotation with magnetism. The concept of a revolving earth was so heretical at the time that the continental copies of his book had the related pages expunged [4].

To celebrate Gilbert's contributions to magnetism, the American Geophysical Union, which publishes *Radio Science*, held a special session at its Spring 2000 meeting in Washington, D.C. The AGU journal *Eos* also published a belated (!) "book review" of "De Magnete," which is accessible online with a lot of other fascinating details about Gilbert's work and geomagnetism on a NASA website [4] maintained by Dr. David Stern.

If you fast forward the history of magnetism to the year 2000, you may wish to take note of some recent work on **nanomagnets** reported in the *Journal of Applied Physics* [5]. A cooled mixture of iron oxide, polystyrene, and methanol under the influence of a strong magnetic field behaves like a jarful of tiny compasses (nanomagnets). The Barcelona group, which did the work on nanomagnets, expects that they may someday lead to super-fast electronic switches and more efficient cores for power equipment. However, in making predictions about how soon nanomagnets may find real-life applications, it may be worthwhile to remember that it was almost 100 years after the publication of “De Magnete” before the flogging of British helmsmen with garlic-breath finally stopped.

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[1] B. Bolton, *Electromagnetism and its Applications*, VNR, New York, 1980.

[2] W. Leary, “Celebrating the Book That Ushered In the Age of Science”, *The New York Times* [Online]. Available: http://www.nytimes.com/2000/06/13/science/celebrating-the-book-that-ushered-in-the-age-of-science.html (accessed March 17, 2016).

[3] W. Gilbert, *De Magnete* (A reprint of Mottelay’s 1893 English translation), Dover, New York, 1991.

[4] D. Stern, “The Great Magnet, the Earth” [Online]. Available: http://www-spof.gsfc.nasa.gov/earthmag/demagint.htm (accessed March 17, 2016).

[5] “Nanomagnets: Lodestones on the Loose,” *The Economist* [Online]. Available: http://www.economist.com/node/348579 (accessed (March 17, 2016).

(The original version of the column appeared in “AP-S turnstile,” *IEEE Antennas and Propagation Magazine*, vol. 42, no. 5, pp. 110–111, October 2000.)

NOTES

1. Here is a very brief chronology of the *other* key figures in the history of electromagnetism:
   (i) Charles-Augustin de **Coulomb** (1736–1806): Coulomb’s law for the electrostatic force between charges
   (ii) Andre-Marie **Ampere** (1775–1836): Ampere’s law for the force between current-carrying wires
   (iii) Michael **Faraday** (1791–1867): Faraday’s law of electromagnetic induction
   (iv) James Clerk **Maxwell** (1831–1879): Maxwell’s equations for electromagnetism

2. Which produces the *largest* magnetic field?
   (a) An MRI (magnetic resonance imaging machine)
   (b) The earth
   (c) A 13 kV distribution line along the street
   (d) A 735 kV transmission line from a power generating station

   (a) An MRI (magnetic resonance imaging machine)

   MRI machines use very large static magnetic fields (more than ten thousand gauss) for diagnostic purposes. Among the remaining choices, the earth’s *static* (dc) magnetic flux density in air (about half a gauss) is roughly 200 times larger than the ac magnetic flux density from typical 60 Hz distribution lines. Lastly, since the magnetic field varies with the line *current,* a 13 kV distribution line may (in some situations) generate a larger magnetic field than a 735 kV transmission line [1 T (tesla) = 1 Wb/m^2 = 10,000 G (gauss)].

Source: R. Bansal, "Pop quiz: EMF and your health," *IEEE Potentials*, pp. 3–4, August/September 1997.

3. Textbook resources:
   (i) W. H. Hayt and J. A. Buck, *Engineering Electromagnetics*, 8th ed., McGraw-Hill, New York, 2012. Magnetostatic fields are discussed in Chapter 7.
   (ii) F. T. Ulaby and U. Ravaioli, *Fundamentals of Applied Electromagnetics*, 7th ed., Prentice Hall, Upper Saddle River, NJ, 2015. Magnetostatic fields are discussed in Chapter 5.

1.7 A EUREKA MOMENT

Ten years ago, while I was in China accompanying my younger daughter on a high-school "field trip," I had the opportunity to experience the magnetic levitation technology firsthand when our group boarded the Shanghai Maglev Train [1] on the way to the Pudong International airport. Although the ride lasted only around 7 minutes, the 267mph top speed certainly provided an exhilarating experience. While many maglev transportation projects have been proposed over the years (e.g., a maglev link between Las Vegas and Disneyland [2]) and some have even reached the demonstration stage in the United States, for most people magnetic levitation remains a scientific curiosity, good enough for wowing students in a freshman physics laboratory with an inexpensive experimental kit such as [3], but with few realizable practical applications. More recently, a Harvard research group funded by the Bill and Melinda Gates Foundation came up with an ingenious way [4] to use the maglev technology for the on-the-go testing of the purity of food and water. And, amazingly, the device was expected to cost less than $50 (a big plus in the developing countries), even less than the price of a simple maglev demo kit such as the one from PASCO [3].

Everybody has heard about Archimedes's (287–212 BC) Eureka moment. The ancient Greek polymath had been asked by the king of Syracuse to determine whether a certain crown was made of pure gold. Archimedes realized that the density of the crown could be used as a simple test of purity. While the weight was easy to measure, the question was how to determine the volume of an irregularly shaped object. The story [5] is told that as Archimedes lowered himself into a bath he noticed that some of the water was displaced by his body and flowed over the edge of the tub. This was just the insight he needed to realize that the crown should not only weigh the right amount but should displace the same volume as an equal weight of pure gold. He was so excited by this idea that he reportedly ran naked through the streets shouting "Eureka" ("I have found it").

Fast forward to the twenty-first century and one finds that density measurement is still a handy way for determining the composition of many substances such as water (how much salt is there in irrigation water?) and milk (what is the fat content?). While sophisticated techniques exist for measuring the density, the required equipment is either too expensive or not portable enough. Professor George Whitesides's research group at Harvard described in a paper [6] published in the *Journal of Agricultural and Food Chemistry* "*a method and a sensor that use magnetic levitation (MagLev) to characterize samples of food and water on the basis of measurements of density. The sensor comprises two permanent NdFeB magnets positioned on top of each other in a configuration with like poles facing* [so that the magnetic field has its minimum at the center of the gap] *and a container filled with a solution of paramagnetic ions. Measurements of density are obtained by suspending a diamagnetic object* [e.g., a drop of milk or water] *in the container filled with the paramagnetic fluid, placing the container between the magnets, and measuring the vertical position of the suspended object* [with a vertically mounted ruler]. [A diamagnetic object will be pushed toward the center of the gap by the magnetic forces and below it by gravity, coming to an equilibrium point dependent on its density.] *MagLev was used to estimate the salinity of water, to compare a variety of vegetable oils on the basis of the ratio of polyunsaturated fat to monounsaturated fat, to compare the contents of fat in milk, cheese, and peanut butter, and to determine the density of grains.*" Archimedes would have been pleased.

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(The original version of the column appeared in “AP-S turnstile,” *IEEE Antennas and Propagation Magazine*, vol. 52, no. 3, pp. 174–175, June 2011.)

NOTE

1. Textbook resources:
   (i) W. H. Hayt and J. A. Buck, *Engineering Electromagnetics*, 8th ed., McGraw-Hill, New York, 2012. Magnetic forces are discussed in Chapter 8.
   (ii) F. T. Ulaby and U. Ravaioli, *Fundamentals of Applied Electromagnetics*, 7th ed., Prentice Hall, Upper Saddle River, NJ, 2015. Magnetic forces are discussed in Chapter 5.

1.8 AULD LANG SYNE

> *“‘Technological innovation’ is more than just invention. It is a process, often long and costly, of transforming new scientific knowledge into feasible technology, introducing it to use, and making its benefits available to the public. ‘Technical integration’ is intended to emphasize the more subtle flow of an intangible—engineering information and understanding. Not only has Bell Labs innovated, but it also showed the world technical integration of the innovations. The Bell System Technical Journal was a key enabler for this achievement”* [1].

Rod Alferness
Chief Scientist, Bell Labs

In July 1922, when the Information Department of the American Telephone and Telegraph Company printed no. 1, vol. 1 of the now-legendary *The Bell System Technical Journal* (50c. per copy; $1.50 per year), the field of electrical communication was still in its infancy. Most industries relied upon cut-and-try, rule-of-thumb methods for engineering development and the editorial board of the new journal, which included Edwin H. Colpitts of the Colpitts-oscillator fame, could only hope that “the time will undoubtedly come when every industry will recognize the aid it can derive from scientific research in some form as it now recognizes its dependence for motive power on steam or electricity rather than on muscular activity." The field of electrical communication was certainly leading the way in that direction and the editorial board proudly noted: "Electrical communication is credited with having organized a research laboratory prior to the first university course in electrical engineering" [2].

From July 1922 to December 1983 (when it ceased publication), *The Bell System Technical Journal* (*BSTJ*) published not only original research in the field of electrical communication but also reprints on [1] "important research and development work in the communication field generally so that the results of such work may be given greater publicity and become of greater value to communication engineers." The first issue included papers on high-power vacuum tubes, submarine cables (not fiber optic!), and the analysis of speech signals among others. The last issue (no. 10, vol. 62, December 1983) featured a special section devoted to the engineering behind single-sideband (SSB) microwave radio systems and, on the theoretical side, included a paper on an algebraic theory of relational databases [3]. But, it is the stuff that came in between those bookends that literally makes our communication world go round.

In cooperation with the IEEE, Alcatel-Lucent has recently made the entire *BSTJ* archive (1922–1983) available online [1] to the global research community. Yes, it has a "search" button and, yes, you can download pdf copies of the papers you would like to add to your own personal digital library. So whether you are looking for Shannon's seminal paper on the mathematical theory of communication or trying to trace the development of the cellular technology, you have just been handed the key to the candy store. Step right in and taste as many treats as you like. Bon appetit!

ACKNOWLEDGMENT

I would like to thank my colleague Dr. Anthony DeMaria, who first drew my attention to the online archives (1922–1983) of the *BSTJ*.

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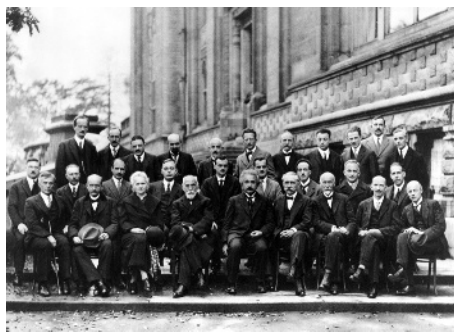
[3] "Table of contents," *The Bell System Technical Journal*, vol. 62, no. 10, December 1983. Also available online: http://ieeexplore.ieee.org/xpl/mostRecentIssue.jsp?punumber=6731005 (accessed July 31, 2015).

(The original version of the column appeared in "AP-S turnstile," *IEEE Antennas and Propagation Magazine*, vol. 52, no. 6, p. 138, December 2010.)

NOTES

1. Bell Labs, for a long time the research arm of AT&T, became part of Lucent in 1996. Lucent was acquired by Alcatel in 2006 and now (December 2015) it seems that Lucent-Alcatel is being acquired by Nokia.
2. To learn more about Bell Labs and its role in American innovation, see Jon Gertner's book *The Idea Factory: Bell Labs and the Great Age of American Innovation*, Penguin, 2013.

1.9 AS SINGULAR AS A DELTA FUNCTION?



> *"Even in college, as I studied electrical engineering, I never worried very deeply about such things. What exactly is an electric or magnetic field? A dangerously shallow knowledge of quantum electrodynamics has clouded the issue, and the more I read the less I understand"* [1].
>
> R. Lucky

I am sure that many readers of Lucky's column share his trepidations (as I do) when it comes to making sense of quantum electrodynamics. Even P. A. M. Dirac (1902–1984), who shared the Nobel Prize for physics with Schrödinger in 1933, might have commiserated. Dirac, who received his first undergraduate degree in electrical engineering, felt that the quantum world could not be described in words or represented as images. To draw its picture would be "*like a blind man sensing a snowflake. One touch and it's gone*" [2]. He remarked on this challenge even in his Nobel Banquet Speech [3] of December 10, 1933: "*But the physicist is at a disadvantage in this respect on account of the very specialized nature of his work, which cannot be made intelligible without an intensive preliminary course of study*."

Interestingly, in the same Nobel Banquet Speech, given during the Great Depression, Dirac expressed his belief that "*[t]here is in my opinion a great similarity between the problems provided by the mysterious behavior of the atom and those provided by the present economic paradoxes confronting the world. In both cases one is given a great many facts, which are expressible with numbers, and one has to* *find the underlying principles. The methods of theoretical physics should be applicable to all those branches of thought, in which the essential features are expressible with numbers.*" Clearly, in addition to anticipating antimatter particles, for example, a positron, Dirac was predicting the rise of the so-called "quants," the quantitative analysts (some of them trained as theoretical physicists) whose esoteric economic models might have precipitated (rather than solved, as Dirac had been hoping for) our recent "great recession." To quote another Nobel laureate (economics) Paul Krugman [4]: "*As I see it, the economics profession went astray because economists, as a group, mistook beauty, clad in impressive-looking mathematics, for truth.*"

Let me be clear: quantum electrodynamics did not (I repeat not) create our recent economic problems and, furthermore, it is perfectly safe to delve deeper into the subject. So where does an electrical engineer start? A case can be made to go back to Dirac's own papers and his seminal book on the theory of electrons. After all, as Freeman Dyson, who took Dirac's course at Cambridge University, testified [5]: "*The great papers of the other quantum pioneers were more ragged, less perfectly formed than Dirac's.* [Dirac's discoveries] *were like exquisitely carved marble statues falling out of the sky, one after another. He seemed to be able to conjure laws of nature from pure thought.*" Dyson's glowing recommendation notwithstanding, a more accessible source might well be *The Strangest Man*, a new biography of Dirac by G. Farmelo [6]. In addition to exploring the "hidden life" of Dirac, Farmelo places Dirac's work within the larger context of the developments in the twentieth century theoretical physics. Finally, even a cursory glance through the book will quickly reveal why the person who gave us the Dirac delta function might have been a true singularity himself.

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(The original version of the column appeared in "AP-S turnstile," *IEEE Antennas and Propagation Magazine*, vol. 51, no. 5, pp. 141–142, October 2009.)

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NOTE

1. Many online resources discuss the Dirac delta function. See for example: http://mathworld.wolfram.com/DeltaFunction.html (accessed December 22, 2015)

1.10 PUBLISH OR PERISH?

While doing research on the Nobel laureate P. A. M. Dirac (1902–1984) for Section 1.9, I came across some interesting bits in the history of science. Let me start with a quiz:

What do Newton, Dirac, and Hawking have in common?

(a) All of them received a Nobel Prize for their contributions to physics.

(b) All of them have the same initial for their first names.

(c) All of them made use of Maxwell's equations in their work.

(d) None of the above.

The correct answer, as you must have guessed, is (d). So what is the common thread linking these justly celebrated physicists? They all occupied (at different times, of course) the Lucasian Chair of Mathematics at Cambridge University in England. Many readers may know that Maxwell (1831–1879) also taught at Cambridge University but he was *not* associated with the Lucasian Chair. Rather, in 1871, he became the first Professor of Experimental Physics and directed the newly created Cavendish Laboratory [1].

According to Reference [2], the Lucasian Chair of Mathematics was deeded in December 1663 at Cambridge University, England, as a result of a gift from Henry Lucas, Member of the Parliament (MP) for the university. The first holder of the Lucasian Chair was Isaac Barrow (1630–1677), who made fundamental theoretical contributions to geometrical optics. "… Barrow was required to lecture once a week during the term and to submit annually at least ten of these lectures to the vice-chancellor for deposit in the university library for public use." A strict publication requirement, if ever there was any! He was followed by Sir Isaac Newton as the second holder of the chair and then some 300 years later by Stephen Hawking, who occupied the chair for thirty years (1979–2009), retiring from the chair on 1 October, 2009 at the age of 67 (as required by the university rules). The next holder (2009–2013) of the chair was Michael Green, a co-founder of string theory [3].

Many holders of this prestigious academic chair have made important contributions to the field of electromagnetics. Here are some names one would readily recognize from graduate textbooks in the field:

- George Airy (1801–1892): Airy function
- George Stokes (1819–1903): Stokes' theorem
- Joseph Larmor (1857–1942): Larmor precession

As one would expect, holders of the Lucasian Chair have been prolific contributors to the scientific literature. For example, Airy's published papers have been counted at 377 in addition to another 141 official reports and addresses [2]. But to every rule, there must be an exception. Thus we come to the interesting case of Joshua King (1798–1857), who held the Lucasian Chair just before George Stokes. To quote from Joshua King's obituary [4]:

> "*His great mathematical power, however, did not lead him in the path of original investigation: with the exception of a short paper, containing 'A new demonstration of the Parallelogram of Forces,' read before the Cambridge Philosophical Society April 14, 1823, and published in Vol II of the Society's Transactions, we are not aware that he has left behind him any contribution to mathematical science*."

Joshua King might have published little but at least he still enjoyed an enormous reputation at Cambridge throughout his tenure as the Lucasian Chair. Dirac was not so lucky. As noted in Reference [5], his last years as a Lucasian Chair were a bit of a trial:

> "*In post-war Cambridge, although still the Lucasian Professor, he was an irrelevance. They even took away his departmental parking space. Sick of such slights, Manci* [his wife] *persuaded him to accept an Eminent Professorship at Florida State University, where he became a revered curiosity.*"

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[2] For information on the Lucasian chair, a valuable resource is: http://www-history.mcs.st-and.ac.uk/Societies/Lucasian.html (accessed December 22, 2015).

[3] The news of Michael Green's appointment to the Lucasian Chair is at: http://www.guardian.co.uk/science/2009/oct/20/stephen-hawking-michael-green-cambridge (accessed December 22, 2015).

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DID YOU KNOW?

A FUN QUIZ (I)

Crème de la Crème

As a clutch of new science books [1] readily demonstrates, there is a lot of uncertainty not only about the current status of physics but also (Heisenberg's principle notwithstanding) about how fast the field is progressing (some would even say regressing). To be sure, there have been exciting developments [1] such as the experimental discovery of the Higgs boson, which completes the so-called Standard Model of particle physics, and the impressive new satellite data about the cosmic microwave background (CMB), which leads us ever closer to a deep understanding of the conditions prevailing in the early (i.e., shortly after the Big Bang) universe. Yet, when it comes to the "Holy Grail," namely a grand theory that would unify the Standard Model with Einstein's theory of general relativity, physicists seem to be as much at a loss now as they were nearly a generation ago. In his new book [2] *Farewell to Reality: How Modern Physics Has Betrayed the Search for Scientific Truth*, Jim Baggott complains bitterly about theoretical developments such as string theory, calling them "fairytale physics," since they have not been accompanied by actual experimental evidence or even testable predictions.

As Niels Bohr once quipped, "prediction is very difficult, especially if it is about the future." Perhaps, we can look in the rear-view mirror of history and agree more easily who the greatest contributors to physics have been before the current malaise set in. That was the task that the editors of *The Guardian* recently set for themselves when they looked for a list of the 10 best physicists [3]. To add to the fun, I have presented the list compiled by *The Guardian* in the format of a mini game show (think Jeopardy!). The answers appear at the bottom of this section.

1. Who supposedly received his inspiration about gravity from a falling piece of fruit?
2. Which Danish physicist came up with the modern idea of an atom, with a nucleus surrounded by revolving electrons?
3. Which Italian physicist got into trouble with the Vatican for his scientific theories?
4. Who came up with the famous equation for the equivalence of mass and energy?
5. Who discovered the theory of electromagnetism?

From ER to E.T.: How Electromagnetic Technologies Are Changing Our Lives, First Edition. Rajeev Bansal.

6. Who discovered electromagnetic induction?
7. Who was the first woman to win a Nobel Prize?
8. Whose “diagrams” are used to illustrate quantum electrodynamic interactions?
9. After whom was the element rutherfordium named?
10. Who predicted the existence of antimatter but turned down a knighthood because he did not want people using his first name?

One of (only?) the chief virtues of offering such a list is to get a conversation going among the readers. *The Guardian* not only anticipated such a debate but actually encouraged it by asking readers to submit their own choices. Many obliged and sent in what they considered serious omissions: Archimedes, Tesla, Planck, Heisenberg, Schrodinger, Lord Kelvin, Boltzmann, Pauli, ______ (you may enter your choices here)!

ANSWERS

1. Isaac Newton
2. Niels Bohr
3. Galileo Galilei
4. Albert Einstein
5. James Clerk Maxwell
6. Michael Faraday
7. Marie Curie
8. Richard Feynman
9. Ernest Rutherford
10. Paul Dirac

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