Speaker's Corner

Births of Technologies Do Not Always Occur at Times of Invention or Discovery

■ **John M. Osepchuk**

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In recent years, there has been significant review of the origins and evolution of the microwave cavity magnetron, including a recent paper [1] by Blanchard and an entire conference [2] on this subject in the United Kingdom in 2010. One element of controversy is whether the United Kingdom deserves credit for the invention of the cavity magnetron in 1940 or whether the invention was the inevitable cumulative result of many studies and developments on the magnetron during 1920–1940. We believe that the British do deserve special credit for the birth of the cavity magnetron—where "birth" signifies the notable appearance and growth of a technology in the real world in terms of economics—e.g., financial expenditures, production numbers, and sales data. Analogous events occur in the history of the gyrotron and microwave ovens, for which credit is given to the Soviet Union and Amana Refrigeration, Inc., respectively. On the other hand, many technologies develop in the manner of evolution, i.e., with many steps by a variety of contributors. Despite the admitted ambiguities of inventorship and individual contributions, detailed historical studies are of great value not only to clarify the contributions of everyone involved but also because they are archives of many ideas, some of which failed to come to fruition in the past but might be revived with success years later because of the intervening progress in understanding the development and application of a technology over the decades.

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Digital Object Identifier 10.1109/MMM.2015.2405276
Date of publication: 3 April 2015

Review of Early Work on the Magnetron

In addition to the papers presented at the Cavity Magnetron Conference [2], there have been papers on this subject or related radars in *IEEE Antennas and Propagation Magazine* [3]–[6]. The most important reference to work before World War II is the encyclopedic review [7] by Harvey, who reviewed 168 papers on magnetrons between 1920 and 1940. They ranged from nonoscillating diode, negative-resistance type, and electron–cyclotron resonance type to traveling-wave resonance type or the cavity magnetron. In decreasing order of quantity, the papers were from the Union of Soviet Socialist Republics (USSR), which had the most papers on the subject, followed by Germany, Japan, the United Kingdom, France, Italy,

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Power amplifiers are often the most critical component of RF/microwave communications systems and consequently the focus of intense research to achieve increased linearity and power efficiency. New forms of power amplification are being developed to meet the needs of the wireless communication equipment industry and the world's demand for greater information transmission. PAWR will feature a number of archival session tracks on RF/microwave Power Amplifiers. Papers are now being solicited describing work in (but not limited to) the following areas of RF/microwave power amplifier technology:

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The Netherlands, and Sweden. This corresponds to the distribution of early historical papers at the Cavity Magnetron Conference [2], three of which came from the former USSR, and one each from France, The Netherlands, Germany, the United Kingdom, and Czechoslovakia. Reviews are missing of the work done in the United States by Kilgore [8] and in Japan by Nakajima [3], who also puts into perspective the German Wurzburg radar [9], which operated at 600 MHz—rather low for some radars and falsely linked [9] to the microwave oven.

Birth of the Cavity Magnetron

Many have credited the British for inventing the cavity magnetron [10]–[13]. Indeed, Buderi [13] titled his book *The Invention That Changed the World: The Story of Radar from War to Peace*, in which "an" is probably a more apt adjective than "the." In the past, complaints about this judgment have been countered by me [14] by pointing out that only after the work of Boot and Randall [15] did the magnetron have real impact in the real world, both economically and politically—including the Tizard mission to the United States and the superior allied radar that helped the war effort.

It is clear that the work in the United Kingdom cannot be aptly described as an invention or a step in an evolution. A better description is "birth," which triggered the tremendous work in the next 70+ years in the growth and decline of magnetrons in high-power radar applications [16] and also in the continuing applications in marine radar [17], [18], the microwave oven [19], and recent scientific exploration of the relativistic magnetron [20].

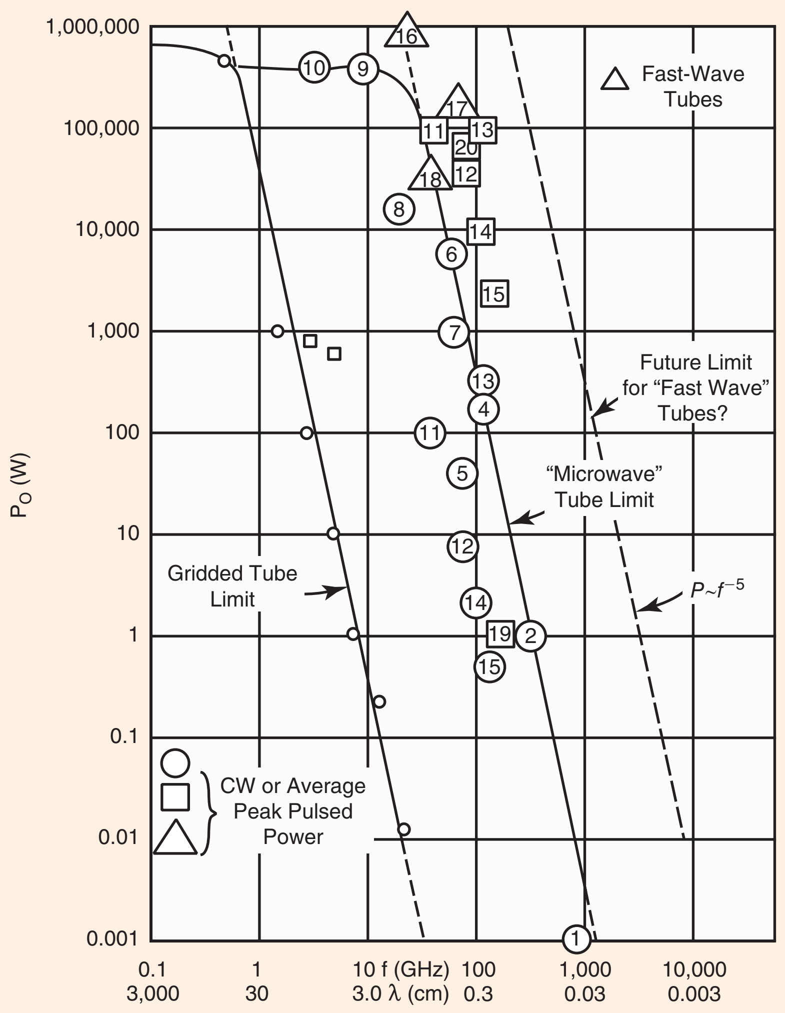

Figure 1. *Frontiers of microwave and mmWave power generation, 1968 [26].*

The History of the Gyrotron

There are some technologies that parallel the magnetron in terms of history. One example is the gyrotron, which today is perhaps the prime source of high power in the millimeter-wave (mmWave) part of the spectrum (i.e., 30–300 GHz). The principle of the gyrotron is the cyclotron resonance interaction of electrons with the E-field of electromagnetic waves in a waveguide—i.e., fast waves instead of the slow waves used in most microwave tubes, including the magnetron and the traveling-wave tube (TWT). Several mechanisms [21] can bunch the majority of electrons into a favorable phase for giving up rotational energy to the electromagnetic wave, including phase focusing by the B-field of the fast wave and relativistic effects which allow electrons to change their phase as they either give up energy (retarding phase) or absorb energy (accelerating phase).

One could argue that this interaction was recognized well before the birth of the gyrotron in the early 1970s. Indeed, measured power in a cyclotron-resonance mode of a magnetron was accomplished in 1936 by Cleeton and Williams [22]—in which phase sorting removes unfavorable electrons at the cathode or anode. Work with classical explanation before the 1970s was done with spiraling electron beams in waveguides [23] and in similar devices labeled the "electron–cyclotron maser" [24] for which relativistic or quantum-mechanical rationales applied in the 1970s. In the 1960s, however, there was still little penetration [25] into the mmWave region by any microwave tubes. At a Raytheon symposium in 1968, I [26] observed that gridded tubes and microwave tubes (with slow waves) both showed high-frequency limits that varied as $P \sim f^{-5}$, where P is power, per the theory of Elliott [27], and that only fast-wave tubes showed promise for a breakthrough, as shown in Figure 1.

In the early 1970s, in the USSR, suddenly gyrotrons were developed [28], [29] with high power (as much as 22 kW) at mmWave frequencies of up to 300 GHz. Ample reference was given [29] by the Soviets to previous work [23], [24] at lower power and lower frequencies, but by giving a new name to their devices, they gave birth to a new technology

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based on new design techniques for injecting rotating beams of high rotating energy and techniques for focusing the generated power in controllable beams. Indeed, workers in the United States recognized [30] the justified use of the new name for this technology, and now on the Internet, it is stated that "the gyrotron was invented in the Soviet Union" [31].

History of the Microwave Oven

I have recorded and worked to maintain the veracity of the history of the microwave oven [32], [33] and have documented [19] the role of the magnetron in the microwave oven. It is generally acknowledged [34] that the microwave oven was invented by Percy Spencer of Raytheon Company during World War II. Yet, for many years thereafter, real-world applications were greatly limited in terms of bulk and cost for commercial (restaurant) use or consumers, e.g., approximately US$1,300 in the 1950s for a wall-mounted oven in the home. For over 20 years, first at Raytheon and then in Japan, the cooker magnetron slowly evolved, as shown in Figure 2, from a heavy 30-lb tube to a small tube (~2 lb).

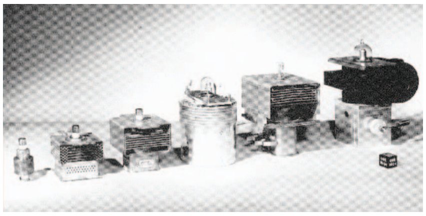

Figure 2. *The evolution of the cooker magnetron over the years from a heavy device to a small, lightweight device [19].*

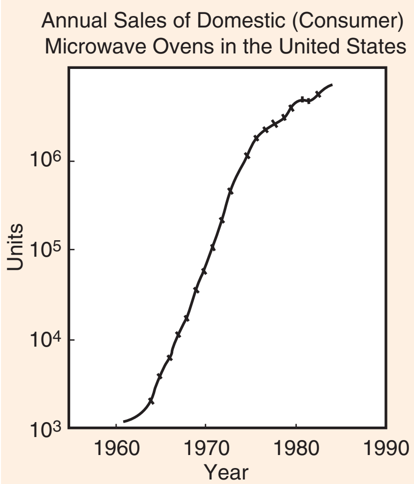

Figure 3. *An illustration of the birth of microwave ovens [32].*

Not shown in the photo is at least one important advance of unknown Japanese authorship [19] in the "filter-box" design, copied to this day. Sales of home ovens were insignificant until Raytheon acquired Amana Refrigeration in 1965, which had the know-how to design and market appliances for the home. In short order, they marketed a countertop design at the relatively low price of US$495 in 1967. As shown in Figure 3, U.S. sales of microwave ovens then showed logarithmic growth up to a current limit of about 10 million ovens per year. Clearly, the birth of the microwave oven did not occur at or shortly after its invention but only 25 years later after a period of evolution and injection of talent in the design and marketing of home appliances.

The Relation of Inventorship to the Birth of a Technology or Device

Inventorship is not always clear with regard to the birth of a new device or technology. Mouromtseff [35] explained, many years ago, that there is often ambiguity on authorship. He cited the example of radio transmission that had independent inventors—Popov in the USSR and Marconi in the Western world. Furthermore, the truth of inventorship can be obscured by the vagaries of patent litigation, as shown by the tragic history [36], over many years, of the inventor of FM radio, Major Armstrong, who committed suicide after 15 years of unsuccessful litigation against powerful interests—even though he is generally recognized as the true inventor in professional circles. Vigilance by the professional community is needed to correct false revisions of history—e.g., that the Nazis invented the microwave oven [33].

Value of the History of Technology

The IEEE is a strong proponent of the value of history, which is evident in its History Center. Such histories help indicate the appropriate credit for contributions—whether inventorship, reduction to practice, or manufacturing. Such histories also can be a useful archive for facts and ideas with both technical and cultural values. Technically, the history may record many ideas that did not come to fruition, but later it is conceivable that intervening improvement in the understanding of a subject may enable an idea to become revived for useful development. Some possibilities in the field of microwave tubes have been listed in the past [19], [37]. Finally, the archives may include historical or societal events [38] in the background of technological development that is of considerable value to all. A moving example of this is found in the IEEE archives [5], [39], [40] of the historical development of the magnetron in the 1930s.

Conclusions

The birth of a technology is not necessarily equivalent to inventorship. The latter could be at birth, or it could be well before the birth with evolutionary developments after invention and even after birth. Producing good histories of technology can help us in assigning credit to pioneer workers in technology. Yet, as I said in 1984, each history, including mine, is "a" history and not "the" history [31]. It will help if historical accounts reflect a variety of perspectives, including different geographical locations and different occupations, e.g., engineering, science, industrial management, and governmental officials. Good histories will add to the stature of a profession and its journals.

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(continued on page 160)

Errata

Due to a production error, Figure 10 in "Submillimeter-Wave Radar," by Ken B. Cooper and Goutam Chattopadhyay [1] on page 63 of the December 2014 issue of *IEEE Microwave Magazine* was printed incorrectly. The correct figure is shown below. We apologize for this error and any confusion it may have caused.

Reference

[1] K. B. Cooper and G. Chattopadhyay, "Submillimeter–wave radar," *IEEE Microwave Mag.*, vol. 15, no. 7, pp. 51–67, 2014.

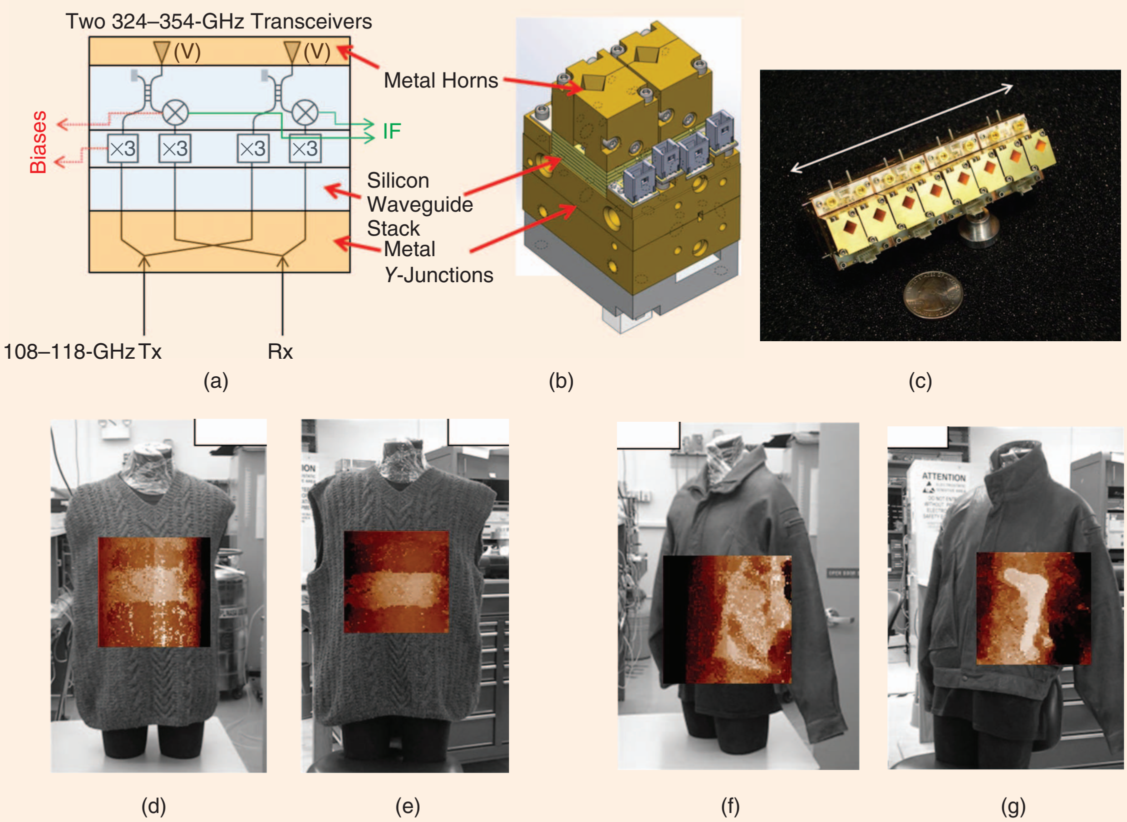

Figure 10. *(a) A schematic diagram of the 340-GHz transceiver array's two-element unit cell. The orange color represents metal waveguide blocks while the green is a stack of micromachined and gold-plated silicon wafers containing waveguide transitions, diode device pockets, and a hybrid coupler. (b) A CAD model indicating the parts of this array element. (c) A fully assembled eight-element 340-GHz transceiver array. Head-to-head comparison of (d) 680-GHz and (e) 340-GHz radar imaging (the latter using an element of the new array) for a thin bomb belt behind a heavy knit wool sweater. The same comparison of (f) 680-GHz and (g) 340-GHz radar imagine of a handgun in the pocket of a thick leather jacket. The superior penetration of the 340-GHz radar is evident.*

Digital Object Identifier 10.1109/MMM.2015.2409491
Date of publication: 3 April 2015

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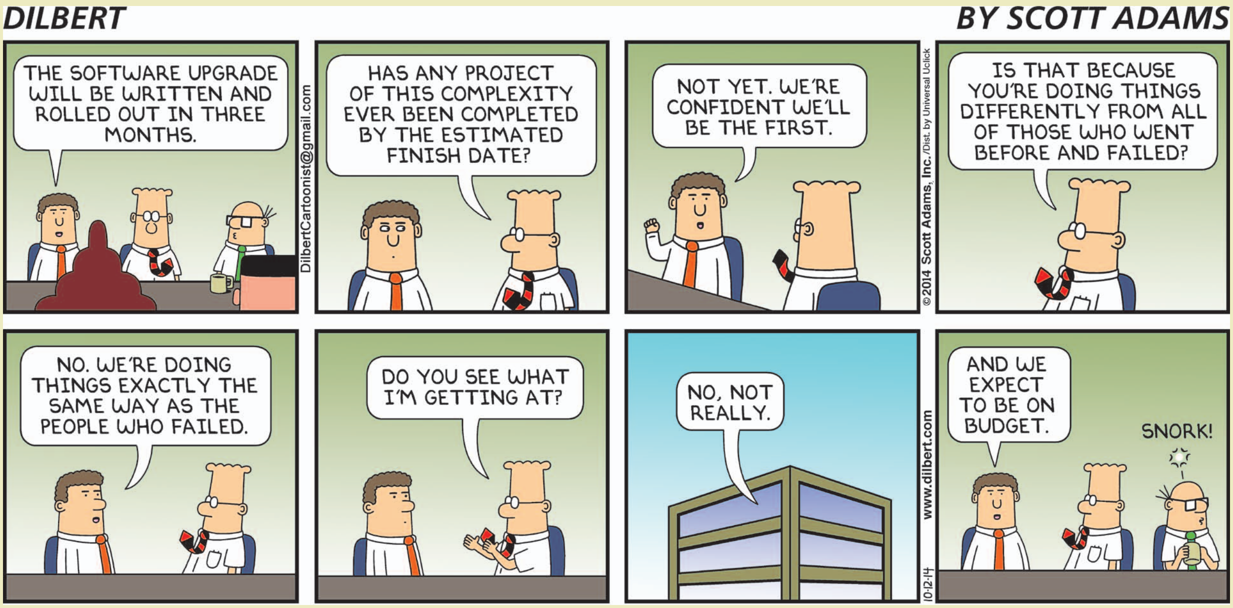

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Speaker's Corner *(continued from page 155)*

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