Microwaves—Present and Future

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Many of us are so immersed in the ever-narrowing branches of electrical engineering that it is difficult to take stock of the accomplishments in the field as a whole or to visualize the possibilities and limitations of future developments. For those of us engaged in teaching and research, and who expect to remain in the field, such an assessment is necessary if we are to guide our students properly and anticipate the probable roles of our own specialties. I will review briefly present-day microwave applications indicating some of the spectacular developments during the past twenty years and try to make an appraisal of potential limitations in microwave research *per se*, and point to a possible profitable avenue of research for the future.

Since 1940, microwave research has received a tremendous emphasis because of the obvious usefulness of this part of the electromagnetic spectrum for radar and communication systems. In the span of a relatively few years, microwave techniques have reached a high degree of development, although many practical unsolved problems remain in the specific requirements of commercial and military applications.

Current microwave applications, preponderantly supported by the military needs are necessarily governed by the "hide and seek" game imposed by international competition, as well as conflicting defense and offense objectives. Despite these general complications, the technology has already reached a high degree of perfection and future refinements will be governed only by their economic justification. For example, in radar applications, unlimited transmitter power at any wavelength can be made available and amplification of microwave signals at a noise level within a factor of 3 or 4 of perfection is now within reach as was recently demonstrated by traveling-wave tube research. Although much can be done to improve the reliability and the intelligence handling capacity of microwave communication systems, these are also a matter of economic justification as the technical solutions can be foreseen clearly. Further improvements in the range of communication systems, especially in the underdeveloped areas of the world, can be anticipated from the future development of forward-scatter techniques.

A number of new navigational systems, for both air and sea use, depend upon microwave developments. These range from the conceptually simple, but practically complicated, systems such as the instrument landing systems for airport traffic control and distance measuring equipment, to the imaginative devices which employ the Doppler effect to measure the ground speed of an aircraft and, by integration, its position. The basic principles for such systems have been thoroughly explored; it would seem to be only a matter of time before a new era in navigation accuracy is reached when these integrated systems are designed and developed to meet the various specific transportation service needs. For instance, it is easy to see that the Sage system, currently being installed for military use, has obvious extensions to commercial navigation for the location, control, and piloting of aircraft over the territorial limits of the United States.

Concurrently, microwaves, as a tool of basic research, have permeated a number of natural sciences. The spectroscopic research, so popular immediately after the end of World War II, has produced quantities of information about the molecular world, just as the knowledge of the atomic structure has resulted from the use of spectroscopy in the visual region. The early experiments were inspired by their intrinsic value, but today numerous applications are arising in other branches of physics, chemistry, and communications. For example, we are upon the threshold of new frequency and time standards, based upon the frequency of certain molecular transitions. Since these depend upon the interaction of a limited number of particles, the frequency can be expected to remain more constant than the period of the earth's rotation. These "atomic clocks" in turn, make other scientific experiments and applications feasible: one can think of repeating the Michelson-Morley experiment to test the theory of general relativity; the possibility also exists of using the Doppler effect to establish completely new types of navigation instruments.

Similarly, the microwave paramagnetic resonance phenomenon makes possible a clearer insight into the chemical bonding between the atoms in complicated molecules, an important topic in physics, chemistry, and other sciences. Microwave application of this technique in biological science may make possible observation of reactions of normal living organisms to environmental changes such as the effect of irradiation or drugs.

There are many other applications of microwaves, too numerous to mention here. To illustrate one possibility, consider their use in the linear electron accelerator. The power from a radar-type transmitter is made to flow simultaneously with electrons in specially designed disk-loaded waveguides; the acceleration of the electrons can be obtained without the use of high voltages. For example, an S band one megawatt source can produce 6 mev electrons in the distance of six feet, a one megawatt X band source can produce the same energy in two feet, and a 200 foot waveguide using 400 megawatts of S band power can produce one billion volts. The size and their relative simplicity make these machines practical for applications in industrial radiography, X ray and electron treatment of cancer, for the cold sterilization of food and drugs, and for other specialized applications. The high energy machines, such as the Stanford 220 foot accelerator, make many experiments in nuclear physics possible.

It is evident that the present microwave knowledge has created many applications undreamed of 20 years ago. The number of applications and their economic value will continue to grow, both in number and diversity, as components, techniques, and general know-how become universally available and understood. However, despite the daily invention of novel applications, we must not become complacent. From the history of scientific development, one can generalize that every new field of research has a finite half-life, perhaps not too different from 50 years. Thus, we must assume that research *per se* must come to an end. How soon? 10, 15, 20 years: certainly not much longer.

Keeping the importance of *basic research* in mind, those of us who have specialized in this field must anticipate either more prosaic engineering applications or a change to some other branch of science. Many will remain to explore and exploit the possibilities for which the foundation is now laid. Some will turn to the applications of microwaves in allied sciences, such as nuclear physics or biology.

Some will think of exploring the higher regions of frequency lying beyond the microwaves—to try to bridge the gap between the radio and infra-red radiation. For those of us who were educated at the time when conventional radio engineering was maturing into a sound branch of engineering, there is a parallel here. As the radio engineer sought higher and higher frequencies, the study and development of the microwave region was a natural evolution. Thus, the generation of submillimeter waves, lying in the wavelength range of 100–1000 Angstroms, or between 300 and 3000 kmc, appears as fascinating and promising today, as the microwave region appeared in 1936. Now, as then, there are many practical difficulties, challenging to the imagination and ingenuity of human skill but which offer, for the scientific adventurer, unknown rewards.