Microwaves—Science and Art

ERNST WEBER
Polytechnic Institute of Brooklyn

Engineering endeavor is generally recognized to be the *utilization of man's knowledge with ingenuity* for human welfare. Man's knowledge is science in all its branches; ingenuity s art, inventiveness, creative application. With the increased scope of scientific exploration and discovery, engineering at the advanced stages has naturally become "scientific engineering." Perhaps no field has experienced this development so strongly as "Microwave Theory and Techniques," as the area of our professional group is so aptly called.

The very origin of the concept and demonstration of microwaves attests to the necessary combination of these fundamental aspects. Though we consider the microwave art to be one of the youngest branches of radio engineering, its foundation goes back to radio's origin and, indeed, antedates it! Perhaps I might be permitted to recount briefly some historical data. We often refer to thinking in terms of electromagnetic phenomena as pre-Maxwell vs post-Maxwell, or as the period of belief in action-at-a-distance vs the period of the field concept. Actually, Faraday was responsible for the idea of the pervading electric and magnetic fields as Maxwell himself fully acknowledged, for example, in his essay "On Faraday's lines of force," published just 100 years ago in 1855. But Maxwell developed these ideas into his all-encompassing electromagnetic theory, *inventing theoretically the displacement current* as the necessary element for the existence of electromagnetic waves and at the same time postulating that these waves must propagate in free space with the speed of light.

Though many investigators were engaged in experimental exploration of electromagnetics, it remained for H. Hertz to demonstrate (1) an effect in dielectrics akin to currents in conductors, (2) the existence of electromagnetic waves, (3) the properties of these waves as akin to light waves; i.e., interference, refraction, reflection, and polarization. In every aspect, Hertz was an engineer-scientist. He studied Maxwell's writings and developed the first dipole-antenna solution, thus laying the theoretical foundation for the explanation of his experiments. He also invented the resonator detectors by means of which he demonstrated the standing waves in the laboratory and he designed the parabolic reflector for the shorter wavelengths down to 66 cm. He possessed sufficient engineering interest to compute the power requirements for continuous radiation of such short waves. The results of his experimentation in 1888 firmly established basic microwave techniques. However, because of lack of adequate sources of energy at these short wavelengths, radio telegraphy developed first, utilizing very low radio frequencies of the order of 10^5 cps.

Hertz's experiments in his own words make it appear "... that the hypothesis of the true (wave) nature of light which is connected with that theory (Maxwell's) now forces itself upon the mind with still stronger reason than before." Thus, the continuous field concept of Maxwell won a major victory and electromagnetic wave theory ranged itself side-by-side with the well-developed analytical mechanics. But whether we like it or not, we do have "fashions" in scientific theory and what is generally accepted today need not be popular tomorrow. Surely, demonstrable facts like meter indications, must be accepted by all as facts, but the interpretation by means of scientific theory need not be unique. Since we do not know the ultimate nature of things material, we must help ourselves with hypotheses and "models." We are, of course, free to choose the most appealing theory. As radio engineers, we have swung completely behind the Maxwell field concept and its supplementation by Poynting's vector for the power flow density. We need to keep an open mind, however, and reserve some sympathy for the power engineer when he has at least strong reservations in believing that the tremendous electric power transmission is just "guided" by the transmission line wires and "really" takes place in the air. Actually, one can construct different hypotheses concerning the distribution of energy-flow, as has been pointed out by J. Slepian.

This will bring me back to the statement in the first paragraph that our field, more than many others, needs "scientific engineers" for real progress. We can illustrate this most readily with the event accompanying the *rebirth of microwaves* at about 1930. It required the combination of the mathematical insight of J. R. Carson and the experimental inventiveness and skill of G. C. Southworth to present in one broad and classical contribution the feasibility of transmitting short electromagnetic waves through hollow pipes of metal. The mathematical development of the *mode concept* and its experimental verification have truly ushered in the age of microwave theory and techniques, prepared by Hertz' experiments and now come to fruition with the modern version of the *waveguide.*

Because with microwaves the linear dimensions of transmission equipment and components have become comparable to wavelength, most of the problems of analysis and design are of the type of diffraction phenomena, and belong to the most difficult class of problems in any field. Again this requires a knowledge of just what a measurement means, a knowledge of field distributions far beyond what we dreamt of before the advent of the modern waveguide. In order to make possible analysis and design on the basis of circuit concepts, at the beginning of World War II, the theoretical group at the Radiation Laboratory at M.I.T., notably J. Schwinger and N. Marcuvitz, adapted the perturbation methods of nuclear physics to these electromagnetic diffraction problems and evolved the "Wave Guide Handbook" which translates bounded field spaces into equivalent circuit elements of lower frequency theory. Coupled with the transmission mode concept, the microwave engineer has now gained a fair set of mathematical tools.

However, new challenges lie ahead. The development of semiconductor devices, of new magnetic and dielectric materials, will require a more thorough knowledge of solid-state physics than in the past. Obviously, this will stress even more the scientific basis of engineering and particularly stimulate new techniques unavailable to the pioneers in the field. Indeed, scientific engineering has no bounds as it delves for basic ideas and understanding into the unfathomed wells of science and with artful inventiveness bends this knowledge to the constant enrichment of our lives. To be sure, we must recognize that we only find what has been there, potentially, at all times. The unfoldment of the capabilities of the human mind in *re*-search, in *re*-discovery, and in *re*-creation is the most striking manifestation of the eternity of natural laws.