RECOLLECTIONS ON MICROWAVE THEORY

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1.Introductory Comments

The following is a somewhat personal retrospective and anecdotal recollection of just a small part of MIT Radiation Laboratory World War 2 activities, namely that facet which contributed to the development of the theory of the propagation of microwaves in waveguides. In 1941 I had been doing graduate work with my advisor Dr. Ernst Weber at the Bklyn Polytechnic Institute on some perplexing aspects of the Sommerfeld problem of electromagnetic propagation over the earth. One Saturday shortly after Pearl Harbor, F.W.Loomis and I.Rabi visited the Polytechnic to inspect Dr. Weber's laboratory and to discuss the possiblity of a cooperative program between the Rad Lab program and Poly; on Sunday with only a few clothes I was on a train heading for Cambridge and the Radiation laboratory. On Monday I was sent to Ed Purcell's group and he soon assigned me the task of understanding the effects of discontinuities in waveguides. This was then a minor effort of the group members who were concerned with uderstanding and designing 3 cm systems using magnetron sources, TR boxes, waveguide structures, and parabolic antennas. Many who worked in Purcell's group stayed for a short time to become familiar with microwave techniques and then passed on to groups more directly concerned with real radar systems.

In 1941-2 magnetrons and klystrons were in an early stage of development. Accurate power measurement devices were not readily available and calibration techniques were not very sophisticated. The quick "standard" technique to detect whether power was coming down a guide was first to place your hand at the end of the guide to sense for microwave warming, if not the cheek was used, and for greater sensitivity the eye was the last resort. Standing wave detectors were also in an early stage and not particularly accurate for experimental checks of theoretical calculations which were the concern of a number of individuals in George Uhlenbeck's theory group.

In 1942 microwave theory of waveguides was just a minor branch of electromagnetic theory applied to a special geometry and frequency range. EM theory had a well developed background of publications dating back to J.C.Maxwell's classic book on Electricity and Magnetism of 1873. Stratton's famous 1941 text on electromagnetic theory provided an up to date state of the field and was extensively used. Prior to 1942 there was even a goodly number of publications on guided waves by Rayleigh, Sommerfeld, Hondros and Debye, Southworth, Barrow, Chu, and Schelkunoff, to mention but a few. But not all of these works were completely known and appreciated by many of us at Rad lab. A somewhat amusing anecdote apropos of this observation relates to a Rad Lab seminar lecture by an eminent nuclear physicist on effects of small obstacles and apertures in waveguides, followed a week later by a talk on the same subject by another physicist. The latter opened his talk by derisively tossing a report by the previous speaker on a lecture table and acerbicly stating that if people would only read the literature they would not be wasting time and paper by repeating the work of others. He was referring to an 1897 Lord Rayleigh paper which did contain many results of the previous speaker but most of us were then unaware of the extent of Rayleigh's work. Also during the period 1941-46 there was a good deal of not generally appreciated theoretical microwave research in other countries and laboratories, for example: Booker in Great Britain, Vainshtein in the Soviet Union, Whinnery, et alia in this country. A far more extensive survey of microwave field theory that goes beyond the purpose of the Rad lab activity sketched herein is covered in a September 1984 review by A.Oliner in the IEEE Transactions on Microwave Theory and Techniques.

2. Radiation Laboratory Microwave Theory

A quantum jump in the evolution of microwave theory at the Rad Lab was associated with the arrival of Julian Schwinger about 1943. Bob Marshak and I had rented a house in Cambridge and invited Frank Carlson of the Theory group and Dave Falkoff, one of Bob's students, to join us. Schwinger, then in his early twenties and already well known to Bob and others for his work in quantum theory, arrived in Cambridge one hot summer day and having no place to stay was invited by Bob to use the house's only empty space, a hot attic room. Julian's working pattern was to work at night and sleep during the day, whence he had to endure the heat of the summer sun and sleep in very sketchy attire. My task was to awake him around 7P.M., take him to dinner and then to the Lab. This was a personally rewarding task that lasted a number of years and led to many interesting discussions in which I learned many field theoretical techniques and in return I explained network and transmission line engineering techniques to Schwinger. Schwinger, interacting with members of the Theory group, very quickly began to introduce integral equation and Green function methods to solve elegantly many of the capacitive and inductive waveguide discontinuity problems of interest to those involved in the microwave "plumbing" necessary in the design and tuning of waveguide structures used in radar systems. The detailed and sophisticated field theory used to obtain practical results was relatively abstruse but the final results were cast in terms familiar to engineers.

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In this context, I remember the day Zacharias, who was concerned with overall system research, dropped in for a chat and commented on the fact that although Schwinger's theoretical techniques were not generally understood, the engineering presentation in network terms of the final results gave workers a physical and conceptual feel that expedited experimental solutions of many microwave design problems.

Frank Carlson, Albert Heins, Harold Levine, Paul Marcus, Dave Saxon, and others were strongly influenced by Schwinger's analytical methods and contributed significantly to the solution of numerous waveguide discontinuity problems later reported in the Waveguide Handbook. Schwinger was urged to lecture, during daytime hours, on novel variational and equivalent static integral equation techniques geared to numerical calculation of impedance and scattering parameters of more and more complex classes of discontinuity problems. Numerical work was then done on mechanical calculators and one can speculate on what the pace of development of microwave theory would have been if modern electronic computers were available. Bifurcations in waveguides posed a difficult analytical problem for which existing methods of solution were not applicable. One morning I found a night time note on my desk which read "A New Era Dawns". Schwinger had evolved a novel application of Wiener-Hopf techniques which opened up the solution of a new class of diffraction problems in open and closed waveguides. These efforts stimulated others in the accurate design of many devices such as multi-port waveguide directional couplers, etc.. Bob Dicke's use of scattering matrices and related symmetry principles ought to be noted in this connection. The list of Rad Lab individuals who contributed to the development of microwave theory is too lengthy to recall and acknowledge in this short account. One has only to look at the Rad Lab Series of books to note the efforts of so many that I have not mentioned.

3. Summary Comments

This brief plucking of remembrances of the past would not be complete without a comment on the germinative effects of Rad Lab contributions after its close in 1946. The many industrial companies, research laboratories, and academic research programs that sprouted in the microwave field subsequent to World War II are a tribute to the impact of the MIT Radiation Laboratory and its unusual administration. The subsequent development of optical and acoustical waveguides, and currently of electron guides in mesoscopic systems also owes much to the early microwave work at the Rad lab. To those of us who were members of the Rad Lab it was an unforgetable experience of esprit and collective dedication to a national effort that ought to provide a model for administrative planning of other, not necessarily war time, national efforts.