Special Session in Honor of Professor Arthur A. Oliner

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A SPECIAL retrospective session in honor of Professor Arthur A. Oliner of Polytechnic University was held at the 1988 IEEE MTT-S International Microwave Symposium on Wednesday morning, May 25, 1988, at which many of Prof. Oliner's basic contributions to microwave theory and techniques were summarized in the context of their relevance to present-day needs. This was the first time a session of this type was held at a Microwave Symposium.

I. Organization of the Special Session

The special session was organized by Session Chairman Prof. Song-Tsuen Peng (New York Institute of Technology) with the enthusiastic support of the Symposium Steering Committee and the Technical Committee on Field Theory. The session was introduced by Jesse Taub (AIL Division of Eaton Corp.), Co-Chairman of the Symposium Technical Program Committee, who also described his personal experience in applying theoretical results published by Prof. Oliner to a complicated multiplexer problem in stripline, in order to stress that those theoretical results were of great practical value.

Following these introductory remarks, three formal technical talks were presented, by acknowledged experts in the respective areas, that constituted critiques of Prof. Oliner's contributions throughout his long and productive career. They summarized many of the accomplishments themselves, and indicated why they were valuable at the time and in what way they influence present-day activities. These talks were:

1) "Perspectives on Guided Wave Phenomena," by Prof. Tatsuo Itoh (University of Texas at Austin).
2) "Radiation from Open Waveguides and Leaky Wave Phenomena," by Dr. Felix K. Schwering (US Army CECOM, Ft. Monmouth, NJ).
3) "Microwave Integrated Circuit Discontinuities and Radiation," by Prof. Nicolaos G. Alexopoulos (University of California at Los Angeles).

Summaries of the three talks appeared in the Digest of the 1988 International Microwave Symposium (pp. 131–143).

After the technical talks, Dr. Kiyo Tomiyasu (General Electric Company, PA) paid a warm tribute to Prof. Oliner, a colleague and friend for over 35 years, and a fellow Microwave Career Award recipient and Honorary Life Member of the MTT Society. Prof. Peng then related several anecdotes about Prof. Oliner's hobbies and lifestyle, introduced Prof. Oliner's wife, Frieda, and then solicited comments from the audience. Presentations were made by Prof. Anthony B. Giordano (Polytechnic University), who has known Oliner for over 40 years, and by Prof. Paolo Lampariello (University of Rome, Italy), with whom he has been collaborating closely in research since 1980. The session ended after Prof. Oliner expressed his deep gratitude for the "many very kind remarks and the warmth behind them," and stated that the session had been "an immense privilege and honor" for him.

Arthur A. Oliner was born in Shanghai, China, in 1921. He received the B.A. degree at the age of 20 and the Ph.D. degree from Cornell University at the age of 24.

He stayed at the Polytechnic throughout his entire career, becoming full Professor in 1957, at the age of 36, then serving as Department Head from 1966 through 1973, and as Director of the Microwave Research Institute for 15 years, from 1967 through 1982. He was also a visiting Professor at various universities around the world: Walker-Ames Professor at the University of Washington, Seattle, 1964; Catholic University of Rio de Janeiro, Brazil, 1973; Tokyo Institute of Technology, Japan, 1978; Central China University of Science and Technology, Wuhan, China, 1980; University of Rome, Italy, 1982. Prof. Oliner has also interacted with industry: as a member of the Board of Directors of Merrimac Industries, 1962–present; as an expert witness in a patent case for General Microwave Corp., 1981; and as a consultant to industry since 1952, for IBM, Boeing, Raytheon, AIL, Hughes Aircraft Co., Kaiser Aluminum, Rockwell International, MIT Lincoln Lab., CBS Labs., Northrup Corp., etc.

Prof. Oliner was active in MTT affairs, being the National Chairman of MTT (before the position was called President) in 1959–1960, Chairman of the IEEE Committee on Antennas and Waveguides from 1959 to 1961, and the first MTT National Lecturer, in 1967–68. He is author, coauthor, or editor of three books and about 180 published papers, and he received prizes for two of them: the MTT Microwave Prize in 1967 and the Institution Premium of the British IEE, their highest award, in 1964. Among other distinctions he has received are a Guggenheim Fellowship in 1965–66, and the IEEE Centennial Medal in 1984. His most important recognitions are the Microwave Career Award, MTT's most prestigious award, in 1982, and his election in 1977 as an Honorary Life Member of the MTT Society, where he is now one of only six persons so honored.

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II. Some of Professor Oliner's Major Technical Contributions

A. Equivalent Circuits for Discontinuities in Stripline

In their talks, Profs. Itoh and Alexopoulos both described a basic and important technical contribution made by Prof. Oliner early in his career: equivalent circuits for discontinuities in strip transmission line. They pointed out that Prof. Oliner in 1955 introduced a simple waveguide model that effectively reduced the actual complex structure to a simple equivalent structure, and then employed Babinet's principle and other approaches to derive simple analytical results for a series of discontinuities. Prof. Alexopoulos commented that, since computers were not available then, "Prof. Oliner devised an ingenious approach that enabled him to develop equivalent circuits with simple closed-form expressions for all the practical discontinuities on the center strip, as well as slots in the outer walls of stripline."

These expressions compared very well with measurements, were widely used in industry, and have been quoted in handbooks. No one else had derived practical alternative expressions for those discontinuities during that whole period of the 1950's and 1960's. That same model was extended to microstrip line during the early 1970's by Prof. Ingo Wolff and his colleagues in West Germany, and used by them to obtain theoretical values for microstrip discontinuities.

Jesse Taub, in his introductory remarks, stated that early in his career at AIL he was assigned the formidable task of designing a frequency multiplexer in stripline, to operate from 8.0 to 10.5 GHz, consisting of 225 contiguous channels. Due to the enormous number of different design parameters, a design based on experimentation would have taken far too long, but by using a formula just published by Prof. Oliner in the "March 1955 classic issue on stripline" he was able to design the multiplexer successfully and to "beat the deadline gracefully." He added that the experience taught him, early in his career, "the power of using theory correctly."

That paper on equivalent circuits for discontinuities in stripline won the Microwave Prize for Prof. Oliner, as both Prof. Itoh and Prof. Alexopoulos indicated. As Dr. Tomiyasu pointed out, however, the prize was awarded in 1967, 12 years after the paper was published, and it is a unique case—the only time the prize was awarded retroactively. Dr. Tomiyasu also remarked that the paper has been highly praised by colleagues of Prof. Oliner; he quoted two of them, both famous in their own right and both recipients of the Microwave Career Award: Dr. Seymour B. Cohn, who called the work "a brilliant application of Babinet's principle," and Dr. Harold A. Wheeler, who further stated that Prof. Oliner "has made monumental contributions."

B. Waveguide-Fed Radiating Slots

Another early, important contribution was the analysis of radiating slots in the top wall of rectangular waveguide. This class of slots was, and still is, widely used in slot arrays. At that time, theoretical results were available only for the radiation conductance of half-wavelength slots, as Prof. Alexopoulos indicated. Prof. Oliner considered the stored power of the slots as well, and employed a variational formulation to derive simple closed-form expressions for both the susceptance and the conductance of the slots, both at and away from resonance. He also took into account the finite thickness of the slots, and he obtained very good agreement with various measurements.

Prof. Alexopoulos then read the following important tribute from Prof. Robert S. Elliott, the most prominent authority on slot array theory and design: "Prof. Oliner's work on this subject was a landmark accomplishment. His IRE paper in the AP Transactions in 1957 has been one of the truly seminal contributions to the theory of waveguide-fed slot antennas. Twenty years would pass before any significant improvement in his theory would be achieved. He has been one of our major creative pioneers in this field."

C. Wave Types Guided by Interfaces and Layers

Plasma layers were of great interest around 1960 because of various physical effects, such as blackout, caused by these layers on reentry vehicles. Together with Prof. Theodor Tamir, a colleague at the Polytechnic, Prof. Oliner examined in depth the types of wave that could be guided by plasma layers, and in the process discovered several wave types that were previously not known to exist on those layers. These were summarized by Prof. Itoh in his talk.

The first discovery (1962) was that *backward waves* are possible when the layers are overdense; it was the first time that backward waves were found on isotropic materials. Later, they found (1963) that *complex spectral waves* are also possible on a cross section that was filled partly by air and partly by the plasma layer, and they examined the frequency dependence, power circulation, and wavenumber-pairing properties of those waves. Today, such waves are found to be of potential importance in studies of discontinuities in finline and other guiding structures that contain dielectric material in part of the cross section. It has been observed that if the complex spectral waves are neglected, numerical results for the discontinuity susceptance may sometimes be in substantial error. A third wave type is the *leaky wave*, which is complex but nonspectral, and occurs on underdense plasma layers. These leaky waves were shown (1962) to explain some unusual radiation properties of slots on reentry vehicles.

These various studies led to a pair of comprehensive papers on wave types guided by interfaces and layers, published in 1963 in the *Proc. IEE* (Great Britain). Today those papers are considered classics and were awarded the Institution Premium, the highest award of the IEE, given to Americans for the first time.

D. Open Periodic Structures

Truly physical open periodic structures are difficult to analyze except numerically; in an attempt to obtain a full understanding in an era before computers were available, Prof. Oliner, working together with Polytechnic colleague Prof. Alexander Hessel, chose an idealized periodic surface, a sinusoidally modulated reactance surface, for which they were able to derive rigorous solutions. As a result, by examining the *rigorous solution* for an *idealized structure*, they were able to obtain an enormous amount of new information about this class of open periodic structures. In both of their talks, Prof. Itoh and Dr. Schwering referred to this group of studies.

The first contribution was to show that a surface wave guided by an open periodic surface would turn into a leaky wave when the frequency was raised sufficiently. The analysis described how the transition occurred, and it also provided the leakage rate. It was the first *rigorous* solution (1959) for leakage from *any* periodic structure and its derivation was included in the book (1962), *Radio Surface Waves*, by Profs. Harold M. Barlow and John Brown, then of University College, London.

Using the same idealized structure, they also derived the first *rigorous* solution for the *scattering* of a plane wave by any open periodic surface. This work led to a *completely new theory* (1965) of Wood's anomalies on optical gratings, which employed a *guided-wave* approach; the work actually had a much broader impact, far beyond Wood's anomalies, because it offered for the first time a correct and physically satisfying explanation for *all scattering resonances*. This guided-wave approach is now widely used by physicists as well.

Further studies on open periodic structures yielded insight into the mode-coupling regions of the k versus β diagram; the "radiation region" of that diagram was developed by Prof. Oliner in that period (1964) in a form that is now employed by everyone who uses that diagram for open periodic structures.

A completely new phase in the study of open periodic structures began about 1980, when Prof. Oliner collaborated with Prof. S. T. Peng as a result of an accurate solution Prof. Peng developed for the guidance of a surface wave at an oblique angle to a set of periodic grooves on a dielectric layer. These grooves, in contrast to metallic grooves, couple TE and TM modes, and the physical consequences become different and very interesting. Some of the new effects are that two extra stop bands are produced, anisotropy is introduced, the leakage at higher frequencies occurs at skew angles, and strong cross-polarization effects arise. These theoretical results, derived together with Dr. M. J. Shiau (now at TRW), were found to agree excellently (1983) with measurements furnished by Prof. R. Ulrich (University of Hamburg–Harburg, West Germany).

E. Antennas That Are Best Viewed as Waveguides: Phased Arrays

One of Prof. Oliner's strengths is his ability to examine certain classes of antennas by viewing them as waveguides in some basic sense. As a very important example, he introduced a totally new (waveguide) approach (1960) to the analysis of phased array antennas, which provided a systematic new analysis procedure as well as new physical insight. In terms of practical results, this work presented the first analysis that correctly took into account *all mutual coupling effects*, and showed what happened as a function of *scan angle* in both scan planes. These studies were discussed briefly by Dr. Schwering in his talk.

The waveguide approach employs a *unit cell* with phase-shift walls that change with scan angle; the whole array is thereby reduced to a *single waveguide*, where the junction with free space involves a transverse discontinuity between the feed waveguide and the outside periodic waveguide with phase-shift walls. The antenna is thus analyzed by using waveguide techniques.

This waveguide approach was later applied to a quite subtle but important problem in phased arrays known as blindness, whereby the array cannot radiate or receive at some angle. Prof. Oliner, working together with Profs. Hessel and Knittel (now at the MIT Lincoln Laboratory), were the first to present a correct explanation (1968) of this complex phenomenon.

This waveguide approach is presented in detail, with much additional material, in vol. II of R. C. Hansen's book *Microwave Scanning Antennas*, in ch. III by A. A. Oliner and R. G. Malech (1966). In 1970, Oliner was asked by DARPA (then ARPA) to run a four-day symposium at the Polytechnic and serve as General Chairman. The Proceedings of the highly successful symposium were published (1972) by Artech House under the title *Phased-Array Antennas*, with A. A. Oliner and G. H. Knittel as coeditors.

F. Antennas That Are Best Viewed as Waveguides: Leaky-Wave Antennas

This topic is one to which Prof. Oliner has made a large number of contributions both early in his career and also within the past decade. Dr. Schwering, who devoted most of his talk to those contributions, remarked "...what impressed me most was the unusual depth and clarity, and the very high scientific quality, of his publications."

During the 1950's there was a great amount of interest in leaky-wave antennas based on standard closed waveguides because of their structural simplicity and frequency-scan capability. At that time, Prof. Oliner developed a simple systematic transverse resonance procedure, treating the antenna as a *perturbed waveguide*, and derived expressions for the side or top discontinuities viewed transversely. A large number of leaky-wave structures in both rectangular waveguide (1959) and circular waveguide (1961) were analyzed with Leonard O. Goldstone, and in trough waveguide (1959) with Walter Rotman (at the Air Force Cambridge Research Laboratories, and now at the MIT Lincoln Laboratory). Those theoretical results were employed very successfully in the design of practical antennas.

During the past decade Prof. Oliner continued his work on leaky-wave antennas in a new context, in response to new challenges in the *millimeter-wave* range. Because of the higher guide losses in that range, he selected low-loss open waveguides, particularly groove guide and NRD guide, as the basic structures to perturb, and he devised new methods to control the leakage rate. Because of the smaller wavelengths and the associated fabrication difficulties, he also proposed and analyzed antennas of simple configuration. As a result, as Dr. Schwering pointed out, these new structures are "truly novel, with no microwave counterparts."

Most of these investigations were conducted together with Prof. Paolo Lampariello (University of Rome, Italy) and Prof. Hiroshi Shigesawa (Doshisha University, Kyoto, Japan). Many of these new antennas have been described in two chapters on millimeter-wave antennas, intended for inclusion in two handbooks, on which Dr. Schwering and Prof. Oliner have recently collaborated.

G. Undesired Leakage Effects in Microwave Integrated Circuits

The subject of Prof. Oliner's most recent work, as pointed out by both Prof. Itoh and Prof. Alexopoulos, is the vitally important one of undesired leakage effects in microwave and millimeter-wave integrated circuits, in MMIC configurations, and in high-speed circuits. The cross talk and coupling that results can ruin the performance of a complex, high-density circuit unless the leakage effects are understood and controlled.

A basic study that was preliminary to this subject was performed in collaboration with Prof. Peng, and published as a pair of invited papers in a special issue of the MTT TRANSACTIONS on guided waves (1981). This study showed that unexpected leakage in surface-wave form can be obtained under certain circumstances from a class of *dielectric strip waveguides* because of TE–TM coupling at the sides of the strip. Such structures had customarily been analyzed approximately by using the effective dielectric constant (edc) method, which gave good numerical values for the guide wavelength but could not predict any leakage. This study showed that the edc method was the zero-order approximation of a rigorous mode-matching procedure.

In his talk, Prof. Itoh paid special attention to that study and used it to illustrate a general point. He stressed that many microwave engineers tend to apply some approximate analytical method to a specific problem to obtain numerical results without bothering to examine whether or not they fully understand the underlying physical behavior. By proceeding in that way, they may "miss some hidden effect." He then asserted that this indeed happened to him when he applied the edc method "blindly" to the inverted strip guide (which he invented), without appreciating its limitations. The "hidden effect" in that case was the leakage from uniform dielectric waveguides, together with an associated resonance effect.

The approach in which one first examines the basic physical behavior, Prof. Itoh continued, is relevant to Prof. Oliner's more recent work on undesired and often unexpected leakage effects in MIC guides such as microstrip line, slot line, and coplanar waveguide. The first analysis along these lines (1986) was his detailed investigation, made together with Dr. Kun Sam Lee (now at Texas Instruments, Dallas), of the properties of higher modes of microstrip line, which were shown to be strongly leaky over a small frequency range just above cutoff. Both Dr. Schwering and Prof. Alexopoulos also pointed out how Prof. Oliner applied this information to create a new leaky-wave antenna by simply employing a uniform length of microstrip line but feeding it in its first higher mode. The most recent results (1988) concern leakage effects in ordinary and conductor-backed slot line and coplanar waveguide, for lines of both finite and infinite width. These latest studies are being conducted together with Prof. Shigesawa of Japan and his colleague, Dr. M. Tsuji. It should be noted that all these leakage effects are in addition to the leakage produced by conversion into surface waves (and space waves if relevant) at various discontinuities.

H. Other Contributions

It is not possible to include all the important contributions mentioned by the speakers. Among the omitted topics are some listed by Prof. Itoh under open periodic structures, a study discussed by Dr. Schwering of metal-strip-loaded dielectric image guide antennas (conducted together with Prof. Peng and Prof. Marco Guglielmi of Polytechnic University), and a new leaky wave interpretation (together with Prof. David Jackson of the University of Houston) of high-gain radiation from a dipole in a special layered configuration first identified and analyzed by Prof. Alexopoulos and Prof. Jackson, and described in Prof. Alexopoulos' talk.

All of Prof. Oliner's contributions to several major areas have been omitted completely; these areas include precision microwave measurement methods, integrated optics, and surface acoustic waves, corresponding to almost 40 papers out of his approximately 180 publications. In this excluded category there is also a book, *Acoustic Surface Waves* (1978), which he edited and to which he contributed two chapters.