Technology Summaries for Microwave Theory and Techniques—1983

B.E. SPIELMAN, MEMBER, IEEE

Abstract—This paper consists of compendia of advances for the calendar year 1983 in four selected technical areas of interest to the microwave community. These four areas are: Hybrid MIC's, Microwave and Millimeter-Wave Solid-State Devices, Microwave Field Theory, and Microwave Systems.

INTRODUCTION

THIS CONTRIBUTION consists of compendia of advances for the calendar year 1983 in selected technical areas of interest to the IEEE MTT-S membership. The contributions contained in this collection of summaries were prepared through the Technical Committees of the IEEE MTT-S Administrative Committee (AdCom). These Technical Committees are constituted as Standing Committees of technical experts in various disciplines germaine to the MTT-S membership interests. Although prepared through these committees, the principal contributor(s) to each summary is (are) identified in conjunction with the respective summary along with the appropriate Technical Committee. The contributions are geared to the reader who is not expert in the particular technical area, but has sufficient background to understand commonly used technical technology for the specialty. Thereby, the reader may, from these summaries 1) gain a brief update on what is happening in areas other than his or her own specialty, and 2) access in a single source enough information to begin a more comprehensive study of the technology.

The intent is to provide technical summaries for selected technologies, as appropriate, each year. This year, summaries are provided for the areas of: Hybrid MIC's, Microwave and Millimeter-Wave Solid-State Devices, Microwave Field Theory, and Microwave Systems. In addition to the principal contributors identified for each summary, special thanks go to the Technical Committees responsible for providing these summaries. For the four summaries denoted, these committees are, respectively: MTT-6 (D. Maki, Chairman), MTT-7 (H. J. Kuno and M. Cohn, Co-Chairmen), MTT-15 (T. Itoh, Chairman), and MTT-16 (F. Ivanek, Chairman). Appreciation also goes to T. Itoh, Editor of these TRANSACTIONS, and his staff of reviewers for facilitating the timely and effective publication of these contributions.

Manuscript received May 18, 1984.
The author is with the U.S. Naval Research Laboratory, Washington, DC 20375. He is Chairman of the MTT-S AdCom Technical Committees.

ADVANCES IN HYBRID MIC'S

E. F. BILOHOUBEK, RCA LABORATORIES
COMMITTEE MTT-6

The general trend towards miniaturization and cost reduction that permeates many of today's electronic growth areas can clearly be seen also in hybrid MIC's. The emergence of miniature hybrid MIC's, increased integration of millimeter-wave components, and an abundance of dielectric resonator applications are good illustrations of the progress made this year.

Miniature hybrid MIC's that, in many cases, offer better performance than monolithic circuits while being comparable in size show great promise of becoming the preferred components for a variety of system applications. Current examples of this technology are miniature lumped-element amplifiers which use batch-processed multicircuit substrates to which active devices are added in the final process step [1]. Some companies produce such miniature amplifiers for low-power applications. For higher power and high-efficiency amplifiers, miniature beryllia circuits [2], or beryllia amplifier modules [3], are more appropriate. In either case, cost will be the ultimate factor in deciding which technology succeeds, as pointed out quite clearly by Pengelly in his article on "Hybird Versus Monolithic Microwave Circuits" [4].

Similar considerations apply to the millimeter-wave field. The monolithic approach may have its strongest justification at very high frequencies since circuits occupy little space and a large number of components could all be fabricated on the same substrate. Also, the dominant requirement for placing matching elements close to the active devices can best be fulfilled monolithically. Here again, however, cost will be the overriding factor and, as discussed in a timely article by R. Phaneul [5], small mass-producible millimeter-wave hybrid components are technically feasible now and probably provide a realistic solution to many military needs for the rest of the 1980's. Examples in this category are components for low probability of intercept and jam-resistance precision guided weapons [6] and both military and commercial communication links [7]–[10].

The trend towards miniaturization, especially at lower frequencies, is greatly helped by the application of dielectric resonators. This is another area that will be dominated by hybrids for many years to come. High-quality factor

0018-9480/84/1000-1372$01.00 ©1984 IEEE

circuits as needed for selective filtering or highly stable low-noise oscillators cannot be realized in monolithic technology. Active filters in the microwave range may be a possibility for some applications, but if low noise and large dynamic range are essential, dielectric resonators will dominate. A large number of publications [11]–[16] are devoted to the understanding, design, and application of dielectric resonators. Significant progress has been made in temperature stabilization of dielectric resonator-coupled oscillators [17], [18].

Last, but not least, the generation of high power with solid-state devices is still one of the most important challenges in the microwave/millimeter-wave field. Although many of the present combining structures rely on relatively large and bulky waveguide or resonator structures [19]–[22], other approaches (such as in-space power combining [23], [24] using the active array principle) show excellent promise for the highly efficient generation of high power from solid-state sources. Here, too, miniaturization and, ultimately, cost will be the deciding factors.

References

A. Miniature Hybrid Circuits

[1] J. Browne, "Miniature amplifier meets transistor size requirements," *Microwaves and RF*, pp. 114–119, July 1983.
[2] F. Sechi *et al.*, "Miniature beryllia circuits for *Ku*-band power amplifiers," in *MTT-Symp. Dig.*, June 1983, pp. 530–532.
[3] P. W. Wallace and A. A. Immorlica, "A two-watt 5–10 GHz miniature cascode amplifier design using BeO microwave integrated circuits," in *13th Eur. Microwave Conf.*, Sept. 1983, pp. 203–207.
[4] R. S. Pengelly, "Hybrid vs. monolithic microwave circuits—A matter of cost," *Microwave Syst. News*, vol. 13, no. 1, pp. 77–114, Jan. 1983.

B. Millimeter-Wave Hybrid Components

[5] R. Phaneuf, "A sensible approach to realizing mmW seeker systems," *Microwave J.*, pp. 109–112, June 1983.
[6] C. R. Seashore and D. R. Singh, "Mm-W ICs for precision guided weapons," *Microwave J.*, pp. 51–65, June 1983.
[7] T. H. Oxley *et al.*, "Dielectric guide *W*-band (75–110 GHz) receiver with partially integrated oscillator," in *MTT Symp. Dig.*, June 1983, pp. 287–289.
[8] R. S. Tahin, "*W*-band low noise integrated circuit crossbar and finline mixers with 20 GHz instantaneous RF bandwidth," in *MTT Symp. Dig.*, June 1983, pp. 290–292.
[9] Y. Tokumitsu *et al.*, "50-GHz IC components using alumina substrates," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31 pp. 121–128, Feb. 1983.
[10] W. Menzel and H. Callsen, "Integrated fin-line components and subsystems at 60 and 94 GHz," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 142–146, Feb. 1983.

C. Dielectric Resonator Applications

[11] A. P. S. Khanna *et al.*, "Dielectric resonator $HE_{11\delta+1}$ mode coupling to shielded microstrip line," in *MTT-Symp. Dig.*, June 1983, pp. 527–529.
[12] D. Maystre *et al.*, "Theoretical and experimental study of the resonant frequency of a cylindrical dielectric resonator," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 844–848, Oct. 1983.
[13] S. Yamashita and M. Makimoto, "Miniaturized coaxial resonator partially loaded with high-dielectric-constant microwave ceramics," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 697–703, Sept. 1983.
[14] Y. Shimoda *et al.*, "A proposal of a new dielectric resonator construction for MIC's," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 527–532, July 1983.
[15] A. Khanna and Y. Garault, "Determination of loaded, unloaded and external quality factors of a dielectric resonator coupled to a microstrip line," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 261–264, Mar. 1983.
[16] Y. Komatsu and Y. Murakami, "Coupling coefficient between microstrip line and dielectric resonator," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 34–40, Jan. 1983.
[17] T. Otobe *et al.*, "A low-drift oscillator stabilized by a highly sensitive discriminator," in *13th Eur. Microwave Conf.*, Sept. 1983, pp. 319–324.
[18] C. Tsironis and V. Pauker, "Temperature stabilization of GaAs MESFET oscillators using dielectric resonators," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 312–314, Mar. 1983.

D. Power Combining

[19] K. Chang and C. Sun, "Millimeter-wave power-combining techniques," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 91–106, Feb. 1983.
[20] M. Madihian and S. Mizushina, "A 3M-device cavity-type power combiner," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 731–735, Sept. 1983.
[21] K. Lee *et al.*, "A 250 KW solid state AN/SPS-40 radar transmitter," *Microwave J.*, pp. 93–103, July 1983.
[22] N. Okubo *et al.*, "A 6-GHz 80-W GaAs FET amplifier with TM-mode cavity power combiner," in *IEEE MTT-S Dig.*, June 1983, pp. 276–278.
[23] L. Wandinger and V. Nalbandian, "Millimeter-wave power combiner using quasi-optical techniques," *IEEE Trans. Microwave Theory Tech.*, MTT-31, pp. 189–193, Feb. 1983.
[24] H. Johnson *et al.*, "A lightweight active antenna array using miniature beryllia amplifiers," in *IEEE MTT-S Dig.*, pp. 477–478, June 1983.

Microwave and Millimeter-Wave Solid-State Devices

M. Cohn, Westinghouse

Committee MTT-7

1983 was another year of continued inexorable advances of various forms of FET's, primarily but not exclusively GaAs, to achieve higher power outputs, higher gains, lower noise figures, and higher frequencies. They have invaded the millimeter-wave spectrum, which has been a realm of two-terminal devices. These FET advances are rapidly being incorporated into monolithic microwave integrated circuits (MMIC's) formed on semi-insulating GaAs to achieve very wide bandwidth performance in addition to the previously cited device advances.

This year was also marked by the expanding use of GaAs for digital logic applications. During this year, GaAs was also used for the fabrication of p-i-n diodes, which is significant for the future development of high-speed switches, which in turn can result in lower insertion-loss phase shifters, attenuators, and transmit/receive switches in MMIC form.

A. Power Generation

1) Three-Terminal Devices: InP MISFET's with silicon dioxide as the gate insulator have achieved 3.5 W/mm of output power at 9 GHz. That power per unit of gate width is more than twice that of the best GaAs MESFET's [1]. MMIC power amplifier technology is typified by the paper by Tsukii *et al.* [2], in which a multistage GaAs FET produced an output power of 650 mW and a gain of 33 dB across the 8–18-GHz band.

A monolithic distributed amplifier has achieved a power output of 250 mW over the 2–18-GHz band. This traveling-wave amplifier effectively adds the transconductance of many FET's, while not paralleling their input and output capacitance, thereby permitting the achievement of higher frequencies and wider bandwidths.

2) Two-Terminal Devices: See Millimeter-Wave Devices.

B. Devices for Low-Noise and Small-Signal Applications

Considerable interest was focused upon the high electron mobility transistor (HEMT). This device, which consists of a GaAs/GaAlAs heterostructure, offers the possibility of both lower noise and higher gain at a given frequency than conventional FET's having the same critical dimensions [4].

Progress also is continuing in the development of small-signal GaAs MMIC amplifiers.

In a paper by Imai *et al.* [5], a dc to 4-GHz amplifier achieves a 10-dB gain, a 7.2-dB noise figure, and a VSWR of less than 2.0. Nishiuma *et al.* [6] describe a 2.2-dB noise figure, 30–1700-MHz amplifier.

C. Devices for Signal Processing

GaAs p-i-n diodes with low forward resistance and high-Q reverse bias forward capacitance have been fabricated and used as high-speed switches [7].

D. Millimeter-Wave Devices

A significant development reported during 1983 [8] was that of distributed IMPATT diodes (DIMPATT's) made by MBE. These devices oscillate at a higher frequency than conventional IMPATT's of the same area, thereby providing higher power outputs at millimeter-wave frequences, e.g., 0.5 W at 50 GHz.

An integral packaging technique has been used to minimize parasitics for operation of double-drift GaAs diodes up to 109 GHz [9].

The achievement of gate lengths down to 0.25 μm has resulted in the demonstration of FET gains of about 5 dB from 55 to 62 GHz with a noise figure of about 7 dB at 60 GHz [10].

E. Devices for High-Speed Digital Logic

The high electron mobility transistor (HEMT) has been shown to be promising for high-speed, low power consumption digital logic applications [11]. The above paper describes master–slave flip–flop divide-by-two circuits which work at a maximum clock frequency of 8.9 GHz with 2.8-mW/gate power dissipation.

For digital applications, the achievement of 1K Random Access Memories fabricated on GaAs was another significant advance [12].

Even more impressive was the report of a GaAs 16×16 multiplier circuit [13]. This 3168-gate circuit, which performs multiplications in 10.5 ns, represents a benchmark in GaAs logic circuit performance.

REFERENCES

[1] M. Armand, D. V. Bui, J. Chevrier, and N. T. Linh, "High-power InP MISFETs," *Electron. Lett.*, vol. 19, no. 12, pp. 433–434, June 9, 1983.

[2] T. Tsukii, Y. Tajima, P. Miller, R. Mozzi, and E. Tong, "A 33-dB gain monolithic *X–Ku* band power amplifier module," in *1983 IEEE Int. Solid State Circuits Conf. Dig. Tech. Papers*, Feb. 1983, pp. 202–203.

[3] Y. Ayasli *et al.*, "2–20 GHz GaAs travelling wave power amplifier," in *Proc. IEEE 1983 Microwave and Millimeter Wave Monolithic Circuits Symp.*, pp. May 31–June 1, 1983, pp. 67–70.

[4] M. Niori and T. Saito, "A 20 GHz high electron mobility transistor amplifier for satellite communications," in *1983 IEEE Int. Solid State Circuits Conf. Dig. Tech. Papers*, Feb. 1983, pp. 198–199.

[5] U. Imai, H. Ito, K. Ohwada, and T. Sugeta, "Ultra-broad-band GaAs monolithic direct-coupled feedback amplifiers," *IEEE Electron Device Lett.*, vol. EDL-4, pp. 323–325, Sept. 1983.

[6] M. Nishiuma, S. Katsu, S. Nambu, M. Hagio, and G. Kano, "A 2.2 dB NF 30–1700 MHz feedback amplifier," in *1983 IEEE Int. Solid State Circuits Conf. Dig. Tech. Papers*, Feb. 1983, pp. 194–195.

[7] C. Barratt *et al.*, "New GaAs p-i-n diodes with lower dissipation loss, faster switching speed at lower drive power," in *1983 IEEE MTT-S Dig.*, pp. 507–509.

[8] B. Bayraktaroglu and H. D. Shih, "Millimeter-wave GaAs distributed IMPATT diodes," *IEEE Electron Device Lett.*, vol. EDL-4, pp. 393–395, Nov. 1983.

[9] B. Bayraktaroglu and H. D. Shih, "Integral packaging for millimeter-wave GaAs IMPATT diodes prepared by molecular beam epitaxy," *Electron. Lett.*, vol. 19, no. 9, pp. 327–329, Apr. 28, 1983.

[10] E. T. Watkins, J. M. Schellenberg, L. H. Hackett, H. Yamasaki, and M. Feng, "A 60 GHz GaAs FET amplifier," in *1983 IEEE MTT-S Dig.*, pp. 145–147.

[11] T. Mimura, K. Nishiuchi, M. Abe, A. Shbiatomi, and M. Kobayashi, "High electron mobility transistors of LSI circuits," in *Tech. Dig. 1983 IEEE Int. Electron Devices Meet.*, Dec. 1983.

[12] N. Yokoyama, T. Ohnishi, H. Onodera, T. Shinoke, A. Shibatomi, and H. Ishikawa, "A GaAs 1K static RAM using tungsten–silicide gate self-alignment technology," in *1983 IEEE Int. Solid State Circuits conf. Dig. Tech. Papers*, pp. 44–45, Feb. 1983.

[13] Y. Nakayama, K. Suyama, H. Shimizu, N. Yokoyama, and A. Shibatomi, "A GaAs 16×16 parallel multipler using self-alignment technology," in *1983 IEEE Int. Solid State Circuits Conf. Dig. Tech. Papers*, Feb. 1983, pp. 48–49.

MICROWAVE FIELD THEORY—1983

T. ITOH, UNIVERSITY OF TEXAS
R. H. JANSEN, UNIVERSITY OF DUISBURG
W. J. R. HOEFER, UNIVERSITY OF OTTAWA
F. SCHWERING, U.S. ARMY COMMUNICATIONS AND ELECTRONICS COMMAND
I. WOLFF, UNIVERSITY OF DUISBURG
E. YAMASHITA, UNIVERSITY OF ELECTRO-COMMUNICATIONS

COMMITTEE MTT-15

The noteworthy activities related to Microwave Field Theory can be decomposed in 1) printed lines and components, 2) dielectric waveguides and resonators, and 3) printed antennas. Only the papers describing the microwave application are reported in item 2). Obviously, there are many activities in optical fibers and waveguides not reported here. The write-up herein is edited by T. Itoh from contributions by R. H. Jansen, W. J. R. Hoefer, F. Schwering, I. Wolff, and E. Yamashita.

A. Numerical Characterization and Modeling of Printed Lines and Components

The quasi-static, as well as the frequency-dependent, characterization of printed microwave and millimeter-wave transmission lines by numerical methods is still of considerable interest. As far as the details of formulation, choice of expansion functions, definition of characteristic impedances, and computation of line loss is concerned, a certain maturity has evolved. Some agreement on how to treat this class of problems efficiently has been reached. The spectral-domain approach is preferred by many authors and is frequently used together with unbounded field and current density expansions, for example, in terms of Legendre polynomials. With most of the elementary configurations treated during recent years, work has shifted to the more involved transmission-line structures. These include the cases of uniaxial and multilayered anisotropic media [1], [2], finlines with magnetized ferrite substrate [3] and slow-wave MIS coplanar waveguides for MMIC applications [4]. From a mathematical point of view, a full-wave analysis of the open slot ring resonator using Galerkin's method in the Hankel transform domain [5] has to be mentioned here. Furthermore, microstrip analysis including surface-wave loss and radiation [6], as well as interesting applications of transmission-line techniques to the field of MMIC design [7], are characteristic to current developments.

Beyond this, progress and experience in numerical characterization which constitute three-dimensional electromagnetic problems become visible in several results published for printed circuit discontinuities and components. Mode-matching in terms of hybrid eigenmodes has been described for transverse finline discontinuities [8], and related E-plane filter design has been treated by several authors with differing degrees of complexity up to the CAD level [9], [10]. The full-wave analysis of asymmetrical series gaps in microstrip and suspended substrate lines has been reported using a nontransverse, unified spectral-domain approach [11]. Also, triangular and interacting rectangular microstrip resonators in a shielding waveguide configuration have been analyzed [12], [13]. A contribution by Lindell [14] illuminates a mathematical background for a wide class of methods which is frequently employed in printed waveguide and resonator analysis. This work drew some criticism and discussions [15]. In addition to the numerical work published, there is a clear tendency to include the modeling aspect for CAD purposes, either by the development of approximate analytical formulas from theoretical considerations and/or by matching them systematically to the available numerical results.

B. Dielectric Waveguides and Resonators

From the literature of the past year, it can be recognized that many authors have tried to find an alternative waveguide for the dielectric image line which does not have the disadvantages of the dielectric image line, e.g., the radiation at line discontinuities. Miao and Itoh published a paper on a hollow image guide [16] and Zhou and Itoh [17] described the theory of trapped dielectric image guides. Yoneyama *et al.* discussed the coupled and insulated nonradiative dielectric waveguides for millimeter-wave integrated-circuit applications [18], [19], and they proposed to use a higher order mode in this waveguide. A similar proposal is made by Trinh and Mittra [20], who described the theory and application of a suspended H-waveguide, but they used the fundamental E_{11} mode on this waveguide for millimeter-wave applications. Yamashita *et al.* [21] used the extended point-matching method for analyzing a multiple dielectric waveguide system.

Some papers deal with corrugated image guides which are important for filter and antenna applications. Schwering and Peng [22] described the effective dielectric constant and the leakage constant of corrugated dielectric image lines and their applications for antennas. Matthaei [23] discussed dielectric waveguide gratings in connection with filter applications, and Tsuji *et al.* [24], [25] described waveguiding characteristics and guided-wave experiments with dielectric corrugated waveguides.

It is interesting that the phenomenon of "complex waves," which already had been discussed intensively in the 1960's, is described again in several papers. Katzier and Lange [26], Sherman and Hennessy [27], as well as Crombach [28], described aspects of this phenomenon.

A number of papers addressing exact theories for calculating the resonant frequency and the quality factor of dielectric resonators are evident [29]–[31]. Shimoda *et al.* [32] proposed a new dielectric resonator in MIC. Many other papers describe interesting theoretical aspects and applications of dielectric resonators.

Applications of dielectric guides in microwave and millimeter-wave techniques have been reported in the area of antennas [33]–[35], filters [36], and phase shifters [39], [40]. The paper by Chang [39], which describes a new technology for producing image-guide circuits using a laser-cutting technique, should be mentioned here, and the paper by Oxley *et al.* [40] gives some interesting aspects of integrated circuits using dielectric guides.

C. Microstrip Antenna Techniques

The most important recent contribution has been the development of a theory of microstrip antennas on electrically thick substrates. Such substrates become practical in the millimeter-wave region where they can be utilized to increase bandwidth and relax fabrication tolerances. A problem is the excitation of surface waves which reduces antenna efficiency and leads to pattern distortions. The theory was developed in two independent studies [41]–[44]. Results are in substantial agreement and provide substrate optimization criteria for both printed dipole and microstrip patch antennas. Bandwidths of 20 percent and greater can be obtained at efficiencies exceeding 50 percent.

The problem of devising efficient, easy-to-fabricate feed systems for microstrip arrays on thick substrates can be solved by using a dual-layer substrate where the radiating elements are printed on the upper layer and the feedlines on the lower layer, and coupling is effected electromagnetically [45], [46].

Studies on microstrip antennas on thin substrates have been concerned with nonstandard patch configurations, with ground screen and mutual coupling effects, and with microstrip array analysis. Major contributions include investigations on the annular ring antenna [47], [48], triangular patch antenna [49], and wraparound antenna [50], on coupling between patch antennas [51], on patch antenna array analysis [52], and on synthesis [53].

References

[1] H. Lee and V. K. Tripathi, "Spectral domain analysis of frequency-dependent propagation characteristics of planar structures on uniaxial medium," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-30, pp. 1188–1193, Aug. 1982.

[2] T. Kitazawa and Y. Hayashi, "Propagation characteristics of striplines with multilayered anisotropic media," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 429–433, June 1983.

[3] Y. Hayashi and R. Mittra, "An analytical investigation of finlines with magnetized ferrite substrate," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 495–498, June 1983.

[4] Y. Fukuoka, Y. C. Shih, and T. Itoh, "Analysis of a slow-wave coplanar waveguide for monolithic integrated circuits," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 567–573, July 1983.

[5] K. Kawano and H. Tomimuro, "Spectral domain analysis of an open slot ring resonator," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-30, pp. 1184–1187, Aug. 1982.

[6] J. Boukamp and R. H. Jansen, "Spectral domain investigation of surface wave excitation and radiation by microstrip lines and microstrip disk resonators," in *Proc. 13th Europ. Microwave Conf.*, (Nurnberg), Sept. 1983, pp. 721–726.

[7] D. Cahana, "A new transmission line approach for designing spiral microstrip inductors for microwave integrated circuits," in *IEEE MTT-Symp. Dig.*, (Boston), May 1983, pp. 245–247.

[8] H. El Hennawy and K. Shunemann, "Hybrid fin-line matching structures," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-30, pp. 2132–2139, Dec. 1982.

[9] R. Vahldieck, J. Bornemann, F. Arndt, and D. Grauerholz, "Optimized waveguide *E*-Plane metal insert filters for millimeter-wave applications," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 65–69, Jan. 1983.

[10] Y. C. Shih, T. Itoh, and L. Q. Bui, "Computer-aided design of millimeter-wave *E*-plane filters," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 135–142, Feb. 1983.

[11] N. H. L. Koster and R. H. Jansen, "The equivalent circuit of the asymmetrical series gap in microstrip and suspended substrate lines," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-30, pp. 1273–1279, Aug. 1982.

[12] A. K. Sharma and B. Bhat, "Analysis of triangular microstrip resonators," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-30, pp. 2029–2031, Nov. 1982.

[13] A. K. Sharma and B. Bhat, "Spectral domain analysis of interacting microstrip resonant structures," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 681–685, Aug. 1983.

[14] I. V. Lindell, "Variational methods for nonstandard eigenvalue problems in waveguide and resonator analysis," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-30, pp. 1194–1204, Aug. 1982.

[15] G. J. Gabriel, Comments on the above paper, *IEEE Trans. Microwave Theory Tech.*, vol. MTT-30, pp. 786–789, Sept. 1983.

[16] J.-F. Miao and T. Itoh, "Hollow image guide and overlaid image guide coupler," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-30, pp. 1826–1830, Nov. 1982.

[17] W. B. Zhou and T. Itoh, "Analysis of trapped image guides using effective dielectric constant and surface impedances," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-30, pp. 2163–2165, Dec. 1982.

[18] T. Yoneyama, M. Yamaguchi, and S. Nishida, "Bends in nonradiative dielectric waveguides," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-30, pp. 2146–2150, Dec. 1982.

[19] T. Yoneyama, N. Tozawa, and S. Nishida, "Coupling characteristics of nonradiative dielectric waveguides," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 648–653, Aug. 1983.

[20] T. N. Trinh and R Mittra, "Suspended H-waveguide and its millimeter wave applications," in *1983 IEEE MTT-S Symp. Dig.*, (Boston), pp. 305–308.

[21] E. Yamashita, Y. Nishino, and K. Atsuki, "Analysis of multiple dielectric waveguide systems with extended point-matching method," in *1983 IEEE MTT-S Symp. Dig.*, (Boston), pp. 119–121.

[22] F. K. Schwering and S. T. Peng, "Design of dielectric grating antennas for millimeter-wave applications," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 200–209, Feb. 1983.

[23] G. L. Matthaei, "A note concerning modes in dielectric waveguide grating antennas for filter applications," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 309–311, Mar. 1983.

[24] M. Tsuji, S. Matsumoto, H. Shigesawa, and K. Takiyama, "Guided-wave experiments with dielectric waveguides having finite periodic corrugation," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 337–343, Apr. 1983.

[25] M. Tsuji, H. Shigesawa, and K. Takiyama, "Wave-guiding characteristics of partially corrugated dielectric waveguides," in *1983 IEEE MTT-S Symp.*, (Boston), pp. 296–298.

[26] H. Katzier and F. J. K. Lange, "Grundlegende eigenschaften komplexer wellen am beispiel der geschirmten kreiszylindrischen dielektrischen leitung," *Arch. Elek. Übertragung.*, vol. 37, pp. 1–5, Jan./Feb. 1983.

[27] G. C. Sherman and C. H. Hennessy, "Complex TM modes in a generalized goubau line with arbitrary conductivities," *IEEE Trans. Antennas Propagat.*, vol. AP-31, pp. 553–562, July 1983.

[28] U. Crombach, "Complex waves on shielded lossless rectangular dielectric image guide," *Electron. Lett.*, vol. 19, no. 14, pp. 557–558, July 1983.

[29] M. Tsuji, H. Shigesawa, H. Aoki, and K. Takiyama, "Analytical and experimental considerations on the resonant frequency and the quality factor of dielectric resonators," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-30, pp. 1952–1957, Nov. 1982.

[30] M. Tsuji, H. Shigesawa, and K. Takiyama, "On the complex resonant frequency of open dielectric resonators," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 392–296, May 1983.

[31] R. de Smedt, "Dielectric resonator above an electric or magnetic wall," *Arch. Elek. Übertragung.*, vol. 37, pp. 6–14, Jan./Feb. 1983.

[32] Y. Shimoda, H. Tomimuro, and K. Onuki, "A proposal of a new dielectric resonator construction for MIC's," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 527–532, July 1983.

[33] R. E. Horn, H. Jacobs, K. L. Klohn, and E. Freibergs, "Single-frequency electronic-modulated analog line-scanning using a dielectric antenna," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-30, pp. 816–820, May 1982.

[34] C. Yao, S. E. Schwarz, and B. J. Blumenstock, "Monolithic integration of a dielectric millimeter-wave antenna and mixer diode: An embryonic millimeter-wave IC," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-30, pp. 1241–1246, Aug. 1982.

[35] K. Solbach and B. Adelseck, "Dielectric image line leaky-wave antenna for broadside radiation," *Electron. Lett.*, vol. 19, no. 16, pp. 640–641, Aug. 1983.

[36] G L. Matthaei, D. C. Park, Y. M. Kim, and D. L. Johnson, "Some dielectric-waveguide filter structures," in *1983 IEEE MTT-S Dig.*, (Boston), pp. 299–301.

[37] A. M. Vaucher, C. D. Striffler, and C. H. Lee, "Theory of optically-controlled millimeter-wave phase shifters," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 200–216, Feb. 1983.

[38] S. W. Yun and T. Itoh, "A novel distributed millimeter-wave isolator," in *Proc. 13th Eur. Microwave Conf.*, (Nurnberg), pp. 174–178.

[39] Y. W. Chang, "Millimeter-wave (*W*-band) quartz image guide Gunn oscillator," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 194–198, Feb. 1983.

[40] T. H. Oxley, J. Ondria, and P. L. Lowbridge, "Dielectric guide *W*-band (75–110 GHz) receiver with partially integrated oscillator," in *1983 IEEE MTT-S Symp. Dig.*, (Boston), pp. 287–301.

[41] N. G. Alexopoulos, P. B. Katehi, and D. B. Rutledge, "Substrate optimization for integrated circuit antennas," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 550–557, July 1983.

[42] P. B. Katehi and N. G. Alexopoulos, "On the effect of substrate thickness and permittivity on printed circuit dipole properties," *IEEE Trans. Antennas Propagat.*, vol. AP-31, pp. 34–39, Jan. 1983.

[43] D. M. Pozar, "Considerations for millimeter wave printed

antennas," *IEEE Trans. Antennas Propagat.*, vol. AP-31, pp. 740–747, Sept. 1983.
[44] D. M. Pozar, "Input impedance and mutual coupling of rectangular microstrip antennas," *IEEE Trans. Antennas Propagat.*, vol. AP-30, pp. 1191–1196, Nov. 1983.
[45] J. Rivera and T. Itoh, "Analysis of an electromagnetically coupled patch antenna," in *1983 Int. IEEE/AP-S Symp. Dig.*, (Houston, TX), May 1983, pp. 170–173.
[46] A. Sabban, "A new broadband stacked two-layer microstrip antenna," in *1983 Int. IEEE/AP-S Symp. Dig.*, (Houston, TX), May 1983, pp. 63–66.
[47] W. C. Chew, "A broad-band annular-ring microstrip antenna," *IEEE Trans. Antennas Propagat.*, vol. AP-30, pp. 918–922, Sept. 1982.
[48] K. F. Lee and J. S. Dahele, "Mode characteristics of annular-ring and circular-disk microstrip antennas with and without air-gaps," in *1983 Int. IEEE/AP-S Symp. Dig.*, (Houston, TX) May 1983, pp. 55–58.
[49] E. F. Kuester and D. C. Chang, "A geometrical theory for the resonant frequencies and *Q*-factors of some triangular microstrip patch antennas," *IEEE Trans. Antennas Propagat.*, vol. AP-31, pp. 27–34, Jan. 1983.
[50] S. B. De Assis Fonseco and A. J. Giarola, "Analysis of wraparound antennas using dyadic Green's functions," *IEEE Trans. Antennas Propagat.*, vol. AP-31, pp. 248–253, Mar. 1983.
[51] C. M. Krowne, "Dielectric and width effect on *H*-plane and *E*-plane coupling between rectangular microstrip antennas," *IEEE Trans. Antennas Propagat.*, vol. AP-31, pp. 39–47, Jan. 1983.
[52] C.-C. Liu, J. Shmoys, and A. Hessel, "*E*-plane performance tradeoffs in two-dimensional microstrip-patch element phased arrays," *IEEE Trans. Antennas Propagat.*, vol. AP-30, pp. 1201–1206, Nov. 1982.
[53] B. B. Jones, F. Y. M. Chow, and A. W. Seeto, "The synthesis of shaped patterns with series-fed microstrip patch arrays," *IEEE Trans. Antennas Propagat.*, vol. AP-30, pp. 1206–1212, Nov. 1982.

Microwave Systems—1983

J. B. Horton, TRW

Committee MTT-16

Progress in microwave systems in 1983 has been evolutionary in nature. Some of the key advances in microwave systems for both commercial and military applications are included here.

Systems applications of new technology in satellite communications were highlighted in special issues of the *IEEE Journal on Selected Areas of Communications* and the *AIAA Aerospace America* [1], [2]. Work in this area has continued in the United Sates, Europe, and Japan to expand satellite communications services in the 6/4, 8/7, 14/12, 30/20, and 44/20-GHz bands. Frequency bands through 30 GHz are being actively developed for commercial communications [3]. Above 30 GHz, military applications are being investigated.

In commercial communications systems, increased circuit loading, lower unit cost, digital connectivity, and exploitation of higher radio frequencies continue to be major driving forces in the development of commercial communication hardware. Microwave, millimeter-wave, and optical-fiber systems are benefiting from higher levels of component integration in microstrip, finline, and semiconductor chip technologies, as well as from material advances.

In the microwave region, digital information densities of 4.5 bits/s/Hz have been achieved [4] at 6 GHz both in the U.S. and Japan using bit rates of 135 Mb/s with 64 QAM signalling. The required transmitter linearities are obtained by predistorting traveling-wave tube amplifiers operating about 10-dB below saturation. At 4 GHz, 5 W solid-state (GaAs FET) power amplifier linearities of about 80 dB-Hz have been achieved [5]. High levels of circuit integration are particularly evident in cost-sensitive direct-broadcast satellite receivers which require low-noise amplifiers: single-chip devices with noise figures (associated gains) of 2.5(9.5) dB, 2.8(16) dB, and 3.4(20) dB at 23 GHz, as well as 2.9(6.1) dB at 18 GHz, have been reported [6]. Integration of mixers with IF circuit components [7] offers further improvements.

In the millimeter-wave region [8], alumina has been introduced as substrate material for integrated circuits; cost-effective finline structures find increasing use in integrated circuit and subsystem designs. Improved receiver designs [9] at 55, 100, and 205 GHz achieved noise figures of 5 dB(DSB), 7.0 dB(SSB), and 9.5 dB(SSB) with conversion losses of 2.9 dB(DSB), 7.2 dB, and 7.1 dB, respectively.

High-speed digital transmission over optical fibers has led to the development of undersea cable systems [1] in the U.K. (called "NL1"), the U.S. (called "SL"), and in Japan (developed by KDD), all operating near 1.3 μm over single-mode fibers at bit rates of 280 Mb/s. Fiber loss reductions allow repeater spacings of 30 to 50 km.

Operational radar systems at low microwave frequencies, e.g., AWACS [10] represent the integration of many diverse microwave components. Key among these are the high-power klystron transmitter and the waveguide face antenna. At higher frequencies (10 GHz), newer technologies involving active antenna array elements [11] are being developed to provide forthcoming radar systems with solid-state power sources. Two approaches to generating the needed power are being considered: the enclosed power combiner circuitry [12] and the distributed active array [11]. The active array is lightweight because the distributed active elements combine their power in space rather than bulky combining circuits. Beryllium oxide (BeO) technology is being applied to the solid-state element substrates because BeO possesses the thermal conductivity of aluminum and its thermal expansion matches GaAs.

Millimeter-wave (MMW) radar development centered at 35 and 94 GHz is primarily keyed to missile guidance requiring rugged, lightweight, and small components. MMW developments using finline circuitry has allowed fabrication of a 94-GHz dual-channel receiver [13] for use in a coherent radar system with polarization diversity. The planar circuitry allowed integration of an attenuator, balanced mixer, LO power divider, and IF filter in one split block assembly.

In contrast to conventional radar and communication systems, electronic warfare systems require wide bandwidth and fast tuning rates to maximize their probability of intercept or their ability to lock-on for jamming activities. Some of the recent advances affecting these systems include a heterodyne voltage-controlled oscillator (VCO) with a 2–8-GHz output frequency and a maximum frequency deviation from a straight line of less than ± 25

MHz without a linearizer circuit [14]. By using silicon hyperabrupt tuning diodes, the post tuning drift was minimized. A second VCO design incorporating a BeO substrate and flip-chip FET provided 15–16-GHz output with power levels exceeding 35 mW and moderate noise performance on a substrate size of 3.5 × 5 mm [15].

A broad-band *W*-band (75–110-GHz) downconverter suitable for a radar warning receiver application has been built using dielectric guide for the quadrature coupler needed to combine the MMW and LO frequencies. Transitions into waveguide and microstrip are used for the RF/LO and single-ended mixer ports, respectively. A Gunn oscillator is used as the LO [16].

REFERENCES

[1] *IEEE J. on Selected Areas in Communications*, vol. SAC-1, no. 3, Apr. 1983.

[2] Communications: Special Section, *AIAA Aerospace America*, pp. 61–63, Mar. 1984.

[3] D. Santarpia and J. Bagwell, "Status of NASA's multibeam communications technology program," in *EASCON '83 Proc.*, (Wash. DC), Sept. 1983.

[4] *Int. Communications Conf.*, Boston, MA, June 1983, Session F2.

[5] *IEEE MTT-S Int. Microwave Symp.*, (Boston, MA), Digest Paper T3, May 1983.

[6] Joint Special Papers on Monolithic Microwave ICs, *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 1065 ff, Dec. 1983.

[7] Joint Special Issue on Monolithic Microwave ICs, *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 1 ff, Jan. 1983.

[8] Special Issue on Millimeter Waves, *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 89ff, Feb. 1983.

[9] *IEEE MTT-S Int. Microwave Symp.*, (Boston, MA), May 1983, Digest Papers U4, I2, C4.

[10] W. A. Skillman, "Microwave technology—Key to AWACS' success," in *1983 Int. Microwave Symp. Dig.*, (Boston, MA), Paper 01, session handout.

[11] H. C. Johnson, M. Oz, R. E. Marx, J. Rosen, and E. Mykietyn, "A lightweight active antenna array using miniature Beryllia amplifiers," in *1983 Int. Microwave Symp. Dig.*, (Boston, MA), Paper 07, pp. 477–478.

[12] J. McClymonds, "A 16.5 watt, 20 GHz IMPATT diode power combiner," in *1983 Int. Microwave Symp. Dig.*, (Boston, MA), Paper P2, pp. 484–486.

[13] W. Menzel, H. Callsen, and K. Solbach, "An integrated receiver front end for a 94 GHz dual polarization radar," in *1983 Eur. Microwave Conf. Proc.*, (Nürnberg, W. Germany), pp. 142–147.

[14] R. G. Winch, "The heterodyne VCO," in *1983 Int. Microwave Symp. Dig.*, (Boston MA), Paper 06, pp. 475–476.

[15] F. Sechi, M. Oz, P. Jozwiak, and E. Mykietyn, "*Ku*-band VCO using miniature Beryllia circuit technology," in *1983 Eur. Microwave Conf. Proc.*, (Nürnberg, W. Germany), pp. 208–212.

[16] T. H. Oxley, J. Ondria, P. L. Lowbridge, N. Williams, R. A. Gelsthorpe, and S. Gibbs, "Dielectric guide *W*-band (75–110 GHz) receiver with partially integrated oscillator," in *1983 Int. Microwave Symp. Dig.*, (Boston, MA), Paper I1, pp. 287–289.

Barry E. Spielman (M'71) was born in Chicago, IL, on October 29, 1942. He received the B.S.E.E. degree from the Illinois Institute of Technology, Chicago, in 1964, the M.S.E.E. degree from Pennsylvania State University, University Park, in 1967, and the Ph.D. degree from Syracuse University, Syracuse, NY, in 1971.

From 1964 to 1967, he served as a Research Assistant in the Ionosphere Research Laboratory of the Pennsylvania State University. While studying at Syracuse University, he was employed as an Instructor and Research Assistant. Since 1970, he has been employed at the Naval Research Laboratory, where he is currently the Head of the Solid State Circuits Section and Acting Head of the Microwave Technology Branch.