A Review of the Panel Discussion on Advances in Millimeter-Wave Subsystems—1990

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Abstract —**Advances in millimeter-wave subsystems formed the basis of a panel discussion at the 1990 International Microwave Symposium, in Dallas, Texas. Highlights from the state-of-the-art reviews and technology projections by the presenters are included. The panelists were from Europe, Japan, and the U.S. Additional references are listed, including papers written by panelists for this Special Issue.**

I. Introduction

On Tuesday evening, May 8, 1990, a panel discussion on advances in millimeter-wave subsystems was held as a session of the 1990 MTT-S International Microwave Symposium. The purpose of the discussion was to review the state of the art of millimeter-wave subsystem applications and the technologies currently used in these subsystems. Members of the panel were selected to represent a cross section of technologies and applications as well as to provide an overview of the current technologies used throughout the industry. Emphasis was placed on current and in-place construction techniques and on the way in which these techniques are being employed to produce multifunction systems. Panelists were asked to project future applications of new technologies, such as MMIC circuits, as well as to highlight some of the large-volume applications the new techniques can support.

This panel was unique in that it was an extension of a panel discussion at the Microwave Symposium held in St. Louis in June 1985 [1]. At that session, it was clear that hybrid waveguide and MIC type techniques with beam-lead diodes were the principal fabrication techniques employed. Only one panelist, J. Kuno of the Hughes Aircraft Company, discussed MMIC construction techniques. However, it was clear from four papers presented at the 1985 symposium that a very positive trend toward monolithic millimeter-wave circuits was under way [2]. By 1990, this trend had developed into a major industry thrust into millimeter-wave monolithic integrated circuits [3]. Another area that is emerging as a strong contender for future millimeter-wave applications is active quasi-optical techniques, where the use of MMIC components is expanding into single-chip subsystems involving both passive and active components [4].

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The panel in 1990 added another dimension to the number of millimeter-wave applications presented at the 1990 MTT-S Symposium. As in 1985, panel members were selected from Europe, Japan, and the U.S. Each panelist covered the applications currently being considered within his company and, where possible, covered the work of others within his own specialty area. The panel was organized by J. B. Horton, T. H. Oxley, and H. J. Kuno. The panel members were

- D. A. Williams (England, Marconi Electronic Devices)
- H. H. Meinel (Germany, Deutsche Aerospace AG)
- S. Kitazume (Japan, Nippon Electric Co.)
- G. Cachier (France, Thomson-CSF)
- M. Gupta (U.S., Hughes Aircraft Co.)
- S. Weinreb (U.S., Martin Marietta Labs)

with J. B. Horton (U.S., TRW Inc.) serving as moderator.

After the formal presentations, members of the audience were invited to give brief summaries of work on unique applications of millimeter-wave subsystems. Presentations were made by T. Best of TRW, L. Riley of JPL, and H.-L. Hung of COMSAT Laboratories. Brief descriptions of these presentations and of those of the panelists are contained here. Additional information is provided in papers included in this issue by three of the speakers: S. Kitazume, H. H. Meinel and D. A. Williams. Selected slides from the presentation material are included here to provide examples of the subsystems discussed during the session.

II. Overview

Interest in millimeter-wave subsystem applications has increased considerably since 1985, when a similar panel was held at the MTT-S Symposium, in St. Louis. The major applications in 1985 centered on military requirements and communications systems. In 1990, there is a major new thrust toward commercial applications, primarily in automobile traffic monitoring and traffic control. Hybrid construction involving waveguide and MIC components is still the mainstay for most applications. How-

REF	MFG	TYPE	GATE SIZE (μm)	Fmax (GHz)	NOISE CONSTANT (K/GHz)	REALIZABLE NF @ 44 GHz DB	REALIZABLE NF @ 60 GHz DB	REALIZABLE NF @ 94 GHz DB	COMMENTS
[a]	LINEAR MONO-LITHICS	InGaAs on GaAs	0.1 x 100	113	2.4	2.0	2.9	6.4	NON T-GATE MONOLITHIC
[b]	GE	InGaAs on GaAs	0.08 x 50	270	2.7	2.0	2.6	3.9	PLANAR DOPED
[c]	COMSAT	InGaAs on GaAs	0.35 x 60	107	7.1	4.1	5.6	11.4	MIMIC 2 STAGE
[d]	GE	InGaAs on InP	0.25	380	1.9	1.6	2.1	3.1	T-GATE
[e]	HAC	InGaAs on InP	0.2 x 50	173	0.9	1.0	1.4	2.4	

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[b] P. C. Chao, et al., "DC and Microwave Characteristics of Sub-0.1-um Gate-Length Planar-Doped Pseudomorphic HEMT's", IEEE Trans. Electron Dev., March, 1989.

[c] G. M. Metze, et al., "60-GHz Pseudomorphic-MODFET Low-Noise MMIC Amplifiers", IEEE Trans. Electron Dev., April, 1989.

[d] K. H. G. Duh, et al., "High-Performance InP-Based HEMT Millimeter-Wave Low-Noise Amplifiers", 1989 IEEE MTT-S Digest, pp. 805-808.

[e] S. Vaughn, et al., "High Performance V-Band Low-Noise Amplifiers", 1989 IEEE MTT-S Digest, pp. 801-804.

51-40

Fig. 1. State-of-the-art millimeter-wave low-noise devices.

ever, monolithic microwave integrated circuits (MMIC's) are being used throughout many subsystems, and there is little doubt that monolithic technologies, constructed primarily on gallium arsenide substrate material, will find more applications, although silicon monolithic circuits were reported by two panelists. The one near-term application that can foster high-volume MMIC applications is traffic control. Examples of automobile subsystems being developed were provided by H. H. Meinel and S. Kitazume. A second application, phased array antennas, continues to attract strong engineering interest, but does not offer large-volume production at this time.

The most comprehensive discussion of devices was presented by S. Weinreb. He reported on low-noise devices in the 40 to 94 GHz region. Fig. 1 shows the chart presented at the panel. Additional information can be obtained in references [a] through [e] listed in the figure. Weinreb stressed the need for efficient packaging techniques, the need to reduce interconnections, and the need for techniques to integrate diodes/transistors on chip. Efficient direct coupling from chip to millimeter-wave waveguide is still a major concern for subsystem applications. As an example of high-level monolithic integration, he showed a planar-array construction from Rutledge *et al.* [5]. One basic need stressed by Weinreb is a coaxial connector that operates up to 100 GHz, which is approximately twice the frequency for current connectors [6].

S. Kitazume provided an in-depth background on millimeter-wave technology and applications developed in Japan over the last 20 years. A paper covering his presentation materials is included in this special issue. Engineers

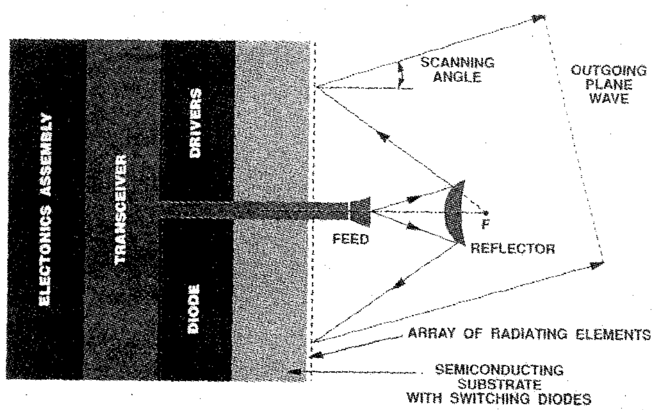

Fig. 2. Millimeter-wave phased array.

in Japan have used millimeter-wave technology in more systems applications than elsewhere, particularly in communications. An interesting recent application is the 60 GHz automobile traffic control system. Device development in Japan continues to be impressive, and predictions are for a steady improvement. Currently, MMIC circuits are being developed for 30 GHz applications and are expected to go to higher frequencies in the near future. If low production costs can be realized, the 60 GHz automobile control system is a good candidate for high-volume production. The clear impression from Kitazume's presentation is that Japan is in the millimeter-wave business to stay, with a broad base of research from devices to systems to help realize the potential applications.

Applications in Germany were summarized by H. H. Meinel, who presented applications through 94 GHz,

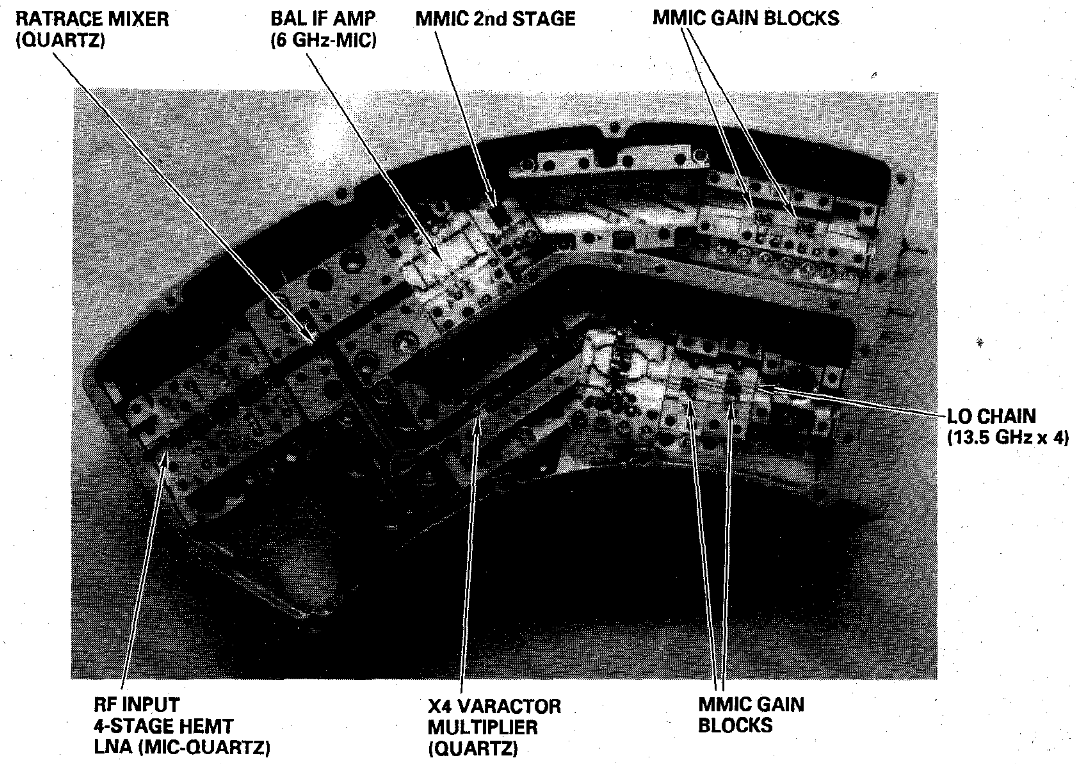

Fig. 3. 60 GHz Down-converter hybrid construction.

based mostly on the finline construction technique. Details of these applications are contained in Meinel's paper in this special issue. Meinel stressed that two approaches are currently being pursued in developing applications: 1) cost-driven technology and 2) performance-driven technology. Examples were given of both. The cost-driven application is a 61 GHz traffic control system, the AEG Verkehrs Erfassungs System. Seeker front ends at 94 GHz make up the performance-driven application. MMIC circuit applications are in future plans, but hybrid construction is still the dominant fabrication technique, particularly in the seeker application, where military users put high physical stress on the components. One unique application reported is a silicon-based MMIC transmitting element operating at 73 GHz.

D. Williams's presentation included applications of microstrip technology up to 220 GHz. His paper in this issue covers the large number of components currently being used for subsystem design. The approach used involves creating a library of proven designs and, through computer-aided design techniques, integrating these components in subsystem design. Applications are mostly military, where performance is the major concern, although reduction in cost is a key factor. The example presented was an FMCW radar front end that must withstand large physical stress. Predictions are that with the component library techniques, MIC components can be applied to systems and manufactured at relatively low costs, particularly in cases where robustness is a major design parameter.

One of the best examples of the application of MMIC technology was presented by G. Cachier. Fig. 2 shows a schematic diagram for a W-band front end which involves most of the components and subsystem technologies for an antenna subsystem. Note that a Cassegrain design is used, with a dual feed control system. Approximately 2500 dipole radiating elements with dual polarization are used. The dipoles are directly connected to p-i-n diodes, which provide 2 bit phase control. The elements are constructed using monolithic high-resistivity silicon wafers. The wafer contains the dipoles and diodes, and is metallized on the back side to create the dipoles. Digital logic drivers are fabricated on a second wafer. This application is unique in several ways and we look forward to more information about the development progress.

The presentation by M. Gupta centered on the design and selection of a frequency for automotive radar. This was an in-depth discussion of the trade-offs involved in application of the radar. The frequency range considered was 10 to 60 GHz. More information is expected as the subsystem is developed.

Short presentations from members of the audience were presented by

H.-L. Hung, COMSAT Laboratories
T. Best, TRW, Electronic Systems Group
L. Riley, NASA, Jet Propulsion Laboratory

H.-L. Hung discussed recent results on MMIC circuits at 30 and 60 GHz. Applications are for the COMSAT systems and they dealt with multichip components as well

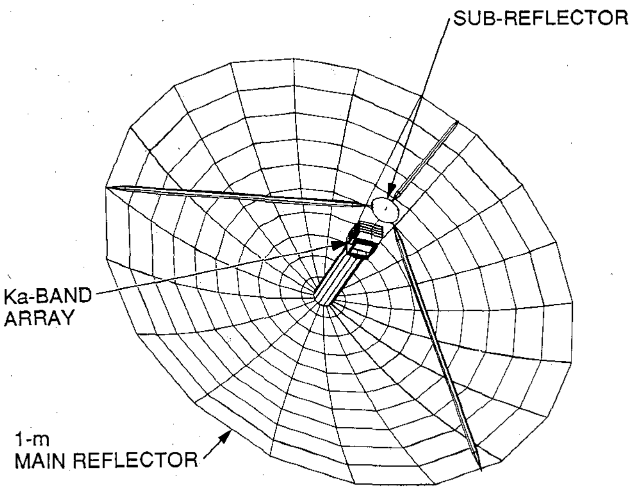

Fig. 4. Ka-band array feed with Cassegrain antenna.

as recent single-chip performance results. These results were for breadboard units, and more information is expected later as development progresses.

T. Best discussed the design and construction of the 60 GHz down-converter shown in Fig. 3. [7]. The unit contains a mix of circuit types, including a low-noise amplifier, mixer, and power amplifier in the LO chain and IF gain blocks in the output. The unit gain is 55 dB RF-to-IF, with a 5 dB noise figure. The unit weighs 250 g and uses less than 5 W of dc power. MMIC chip amplifiers were used in the LO and IF channels. Plans for the next generation of the down-converter are for an all-MMIC version including the 60 GHz low-noise amplifiers. More information is expected as this work continues.

L. Riley presented a brief review of the progress on a Ka-band array feed designed for a Cassegrain antenna [8]. Fig. 4 shows the subsystem design. The array feed subsystem will use 21 elements and is dual frequency (34 GHz up-link, 32 GHz down-link); it will contain 63 MMIC chips in the array, two MMIC chips in the preamp, and 21 VLSI chips for control. Total output power is 4 W at 34 GHz, with 350 mW per element. This is a fairly complicated subsystem, with power combining and phase shifters and with MMIC chips throughout the unit. Currently, hybrid integration techniques are being used (one five-element array has been breadboarded) with Duroid used for the radiating elements and alumina used for interconnections. This development is still in the early stages; more information is expected as development progresses.

III. Conclusions

In reviewing the progress made in the last five years in millimeter-wave applications, the types of applications still involve small quantities for military, communications, special interests such as intrusion radar and traffic control systems, and a large number of areas where short wavelength and propagation characteristics provide some special features. For the material presented in this session and papers presented at the 1990 IEEE MTT-S Symposium, the number of millimeter-wave applications appears to have tripled since 1985. It is clear that applications will continue to grow, particularly in the traffic control area. Two countries, Germany and Japan, have taken major steps to develop a 60 GHz traffic control system. This application could offer the one truly high-volume, low-cost application, possibly using MMIC subsystems. Does this mean that we are about to create a new household word? The future driver would climb into his car, turn on the *millimeter-wave*, set the route computer, and be on his/her way.

Acknowledgment

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