Introduction to Special Issue on Emerging Commercial and Consumer Circuits, Systems, and Their Applications

WELCOME to the exciting new world of commercial and consumer applications of RF, microwave, and millimeter-wave circuits and systems. The re-birth of "wireless" communication has given a new meaning and a purpose for the traditionally defense-oriented microwave and millimeter-wave technologies. This explosive growth of emerging applications is taking place primarily in the following areas (see Fig. 1):

- Cellular\Cordless\PCS\PCN
- Wireless Local Area Networks (WLAN's)
- Satellite Communications
- Automotive Electronics

The cellular telephone networks are typically designed to handle large area (~ 30 miles) mobile applications, whereas cordless phone systems coverage is confined to a much smaller area (a few feet). The first cellular systems used analog FM modulated signals and were limited in capacity by the allocated frequency band and the channel spacing of the users. Digital cellular telephone networks using encoded digital modulation schemes offer greater user capacity, improved spectral efficiency, enhanced voice quality and recognition, and security. PCS (personal communication services) and PCN (personal communication networks) operating around 1.8–2.0 GHz will not only offer baseline voice service, but also messaging, voice-mail, data-base access, and on-line services using lower-cost microcells and picocells. It is a collection of different services sharing licensing, regulation, and inter-portability standards. Selective subsets of the PCS frequency band are still being auctioned by the Federal Communication Commission (FCC). Table I(a) and (b) provide a synopsis of analog and digital cellular and cordless telephone networks. A summary of the frequency allocation for the broadband PCS spectrum is given in Table II.

Satellite communication is finding applications in navigation, broadcast satellite television, and the proposed multibillion dollar combined investments in satellite phone services. The Global Positioning System (GPS) is a comprehensive all-weather, global, highly accurate three-dimensional (latitude, longitude, and altitude) navigation system. The total system consists of a constellation of space satellites that transmit signals continually on two frequencies, $L1 = 1575.42$ MHz and $L2 = 1227.6$ MHz, a network of ground facilities for satellite monitoring telemetry, tracking, controlling, navigation message generation, and user receivers that convert satellite signals to position and navigation information. GPS receivers have been developed using Silicon and GaAs MMIC's. Direct

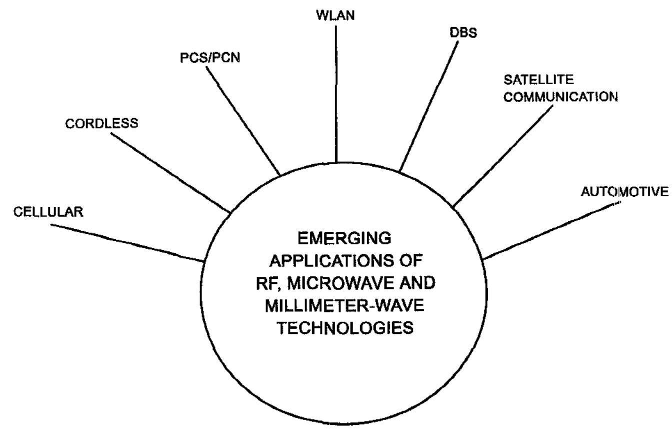

Fig. 1. Emerging applications of RF, microwave, and millimeter-wave technologies.

Broadcast Satellite (DBS) systems are finally making home deliveries as a powerful alternative to cable television. PRIMESTAR, a Ku-band fixed satellite service provider, requires 3–4 ft.-diameter satellite dishes. DirecTV, a subsidiary of GM Hughes Electronics designed to beam as many as 150 channels of digital programming directly to any home in the United States via satellite, is being presently sold under the RCA brand name. The RCA digital satellite system includes an 18-in. satellite dish, a digital receiver/decoder, and a remote control. At the heart of the receiver of the broadcast satellite systems is a 12-GHz GaAs MMIC frequency downconverter.

The proponents of satellite communications were not content with only navigation and television applications. Companies and individuals have invested multimillions to over billions of dollars to launch satellite phone systems capable of providing voice, data, fax, two-way paging, and video conferencing worldwide. Table III describes the nature, cost, and sponsors of the proposed systems. By launching the first satellite on April 7, 1995, American Mobile Satellite Corporation becomes the only company offering satellite-based phone systems in the United States.

In January 1995, the U.S. Federal Communications Commission (FCC) granted licenses to proceed with Globalstar, Iridium, and Odyssey. These systems offer similar services including handheld telephone communications similar to the cellular services currently offered. Table IV shows some of the system operation parameters and user service information. The design and operation parameters for each system are a challenge to the space industry, and because of the experience

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TABLE I
SYNOPSIS OF (a) ANALOG (b) DIGITAL CELLULAR AND CORDLESS PHONE SERVICES

	ANALOG CELLULAR TELEPHONES			ANALOG CORDLESS TELEPHONES		
STANDARD	AMPS Advanced Mobile Phone Service	TACS Total Access Communication System	NMT Nordic Mobile Telephone	CTO Cordless Telephone O	JCT Japanese Cordless Telephone	CTI/CTI+ Cordless Telephone 1
Mobile Frequency Range (MHz)	Rx: 869-894 Tx: 824-849	ETACS: Rx: 916-949 Tx: 871-904 NTACS: Rx: 860-870 Tx: 915-925	NMT-450: Rx: 463-468 Tx: 453-458 NMT-900: Rx. 935-960 Tx: 890-915	2/48 (U.K.) 26/41 (France) 30/39 (Australia) 31/40 (The Netherlands, Spain) 46/49 (China, S. Korea, Taiwan, USA) 48/74 (China)	254/380	CTI: 915/960 CTI+: 887/932
Multiple Access Method	FDMA	FDMA	FDMA	FDMA	FDMA	FDMA
Duplex Method	FDD	FDD	FDD	FDD	FDD	FDD
Number of Channels	832	ETACS: 1000 NTACS: 400	NMT-450 200 NMT-900: 1999	10, 12, 15 or 20	89	CTI: 40 CTI+: 80
Channel Spacing	30 kHz	ETACS: 25 kHz NTACS: 12.5 kHz	NMT-450: 25 kHz NMT-900: 12.5 kHz	40 kHz	12.5 kHz	25 kHz
Modulation	FM	FM	FM	FM	FM	FM
Bit Rate	n/a	n/a	n/a	n/a	n/a	n/a

(a)

	DIGITAL CELLULAR TELEPHONES				DIGITAL CORDLESS TELEPHONES/PCN			
STANDARD	IS-54 North American Digital Cellular	IS-95 North American Digital Cellular	GSM Global System for Mobile Communications	PDC Personal Digital Cellular	CT2/CT2+ Cordless Telephone 2	DECT Digital European Cordless Telephone	PHS Personal Handy Phone System	DCS 1800
Mobile Frequency Range (MHz)	Rx: 869-894 Tx: 824-849	Rx: 869-894 Tx: 824-849	Rx: 935-960 Tx: 890-915	Rx: 810-826 Tx: 940-956 Rx 1429-1453 Tx: 1477-1501	CT2: 864/868 CT2+ 930/931 940/941	1880-1990	1895-1907	Rx: 1805-1880 Tx: 1710-1785
Multiple Access Method	TDMA/FDM	CDMA/FDM	TDMA/FDM	TDMA/FDM	TDMA/FDM	TDMA/FDM	TDMA/FDM	TDMA/FDM
Duplex Method	FDD	FDD	FDD	FDD	TDD	TDD	TDD	FDD
Number of Channels	832 (3 users/channel)	20 (798 users/channel)	124 (8 users/channel)	1600 (3 users/channel)	40	10 (12 users/channel)	300 (4 users/channel)	750 (16 users/channel)
Channel Spacing	30 kHz	1250 kHz	200 kHz	25 kHz	100 kHz	1.728 MHz	300 kHz	200 kHz
Modulation	$\pi/4$ DQPSK	BPSK/OQPSK	GMSK (0.3 Gaussian Filter)	$\pi/4$ DQPSK	GFSK (0 5 Gaussian Filter)	GFSK (0.5 Gaussian Filter)	$\pi/4$ DQPSK	GMSK (0.3 Gaussian Filter)
Bit Rate	48.6 kb/s	1 2288 Mb/s	270 833 kb/s	42 kb/s	72 kb/s	1.152 Mb/s	384 kb/s	270.833 kb/s

(b)

and technologies available in the space industry, they probably can be realized by the dates projected. But the ultimate success of each system will depend upon the user acceptance (convenience) of the service and the cost, referenced to existing telephone services.

By the year 2003, it is projected that there will be over 167.5 million U.S. subscribers for wireless phone services, from satellite to cellular and paging, according to Personal Communications Industry Association.

The wireless local area network (WLAN) concept is becoming increasingly popular. It provides greater flexibility and lower cost compared to the existing wired local area networks for communications. It offers users the freedom to move about the workplace without the restrictions of wired LAN

TABLE II
SUMMARY OF THE MAIN PCS FREQUENCY SERVICES (FCC ALLOCATES 120 MHz FOR LICENSED SERVICES)

Channel Block	Frequency (MHz)	Service Area
A (30 MHz)	1,850-1,865/1,930-1,945	Major trading areas
B (30 MHz)	1,865-1,880/1,945-1,960	Major trading areas
C (20 MHz)	1,880-1,890/1,960-1,970	Basic trading areas
D (10 MHz)	2,130-2,135/2,180-2,185	Basic trading areas
E (10 MHz)	2,135-2,140/2,185-2,190	Basic trading areas
F (10 MHz)	2,140-2,145/2,190-2,195	Basic trading areas
G (10 MHz)	2,145-2,150/2,195-2,200	Basic trading areas

Source: Federal Communications Commission

TABLE III
SATELLITE COMMUNICATION SYSTEMS THAT ARE UNDER DEVELOPMENT OR HAVE BEEN PROPOSED

	Globalstar	Teledesic	Iridium	American Mobile Satellite Corp.	Spaceway	Odyssey
Headquarters:	Palo Alto, CA	Kirkland, WA	Washington, DC	Reston, VA	El Segundo, CA	Redondo Beach, CA
Investors:	Loral Corp., Qualcomm, Alcatel (France), Dacom Corp. (S. Korea), and Deutsche Aerospace (Germany) and others.	Startup company backed with funding from William Gates, chairman of Microsoft, and Craig McCaw, chairman of McCaw Cellular.	Motorola, Sprint, STET (Italy), Bell Canada, DDI (Japan).	Hughes Communications, McCaw Cellular, Mtel, Singapore Telecomm.	Wholly owned and operated by Hughes Communications.	TRW, Teleglobe of Canada
Cost to build:	$1.8 billion	$9 billion	$3.4 billion	$550 million	$660 million	$1.3 billion
Startup:	1998	2001	1998	Satellite launched April 7, 1995	1998	1998
Description:	Worldwide voice, data, fax and paging services using 48 low-earth-orbit satellites.	A worldwide network of 840 satellites will offer voice, data, fax and two-way video communications.	66 satellites will offer worldwide voice, data, fax and paging services.	Satellite network will provide voice, data, fax and two-way messaging throughout North America, targeting customers in regions not served by cellular systems.	Dual-satellite system offering voice, data and two-way videoconferencing in North America.	12 satellite system offering voice, data and fax services

Sources: The Washington Post, March 25, 1994, and The Wall Street Journal, January 18, 1993

outlets. The IEEE's 802.11 working group on wireless LAN's has assumed the existence of three types of physical layers for traditional shared-medium LAN structures: infrared light, direct-sequence (DS) spread-spectrum radio, and frequency-hopping (FH) spread-spectrum radio. The latter two methods use three unlicensed frequency bands set aside by FCC for industrial, scientific, and medical (ISM) applications. Fig. 2 summarizes the different frequency bands allocated by the FCC for WLAN applications.

Automotive electronics is another growth area offering a myriad of real opportunities across the entire frequency spectrum. Applications for microwave and millimeter-wave technologies in automobiles are being actively pursued in Europe by Daimler Benz, Volkswagen, Siemens, and Thomson, while Toyota, Matsushita, and NEC are involved heavily in Japan. In the U.S., General Motors, Ford, and Chrysler are developing prototype systems. Near obstacle detection (NOD), collision warning and avoidance radar, sensors, vehicle identification,

TABLE IV
PROPOSED SPACEBORNE PHONE SYSTEMS

SYSTEM	IRIDIUM (Motorola)	ODYSSEY (TRW)	GLOBAR STAR (Loral and Qualcomm)
No. of satellites	66	12	48
Class	LEO	MEO	LEO
Lifetime in years	5	15	7.5
Orbit altitude (km)	781	10,354	1390
Orientation	Circular	Circular	Circular
Initial geographical coverage	Global	CONUS Offshore U. S. Europe Asia/Pacific	CONUS
Service Markets	Cellular like voice Mobile FAX Paging Messaging Data transfer	Cellular like voice Mobile FAX Paging Messaging Data transfer	Cellular like voice Mobile FAX Paging Messaging Data transfer
Voice cost/minute	$3.00	$0.65	$0.30
User terminal types	Handheld Vehicular Transportable	Handheld Vehicular Transportable	Handheld Vehicular Transportable
Estimated cost	$3000	$250-500	$500-700
Wattage	0.4	0.5	1
Uplink bands	L-band (1616.5-1625.5 MHz)	L-band (1610.0-1626.5 MHz)	L-band (1610.0-1626.5 MHz)
Downlink bands	L-band	S-band (2483.5-2500 MHz)	S-band (2483.5-2500 MHz)
Methods of access	FDMA	CDMA	CDMA
Projected operational dates	1998	Mid 1998	Mid 1998

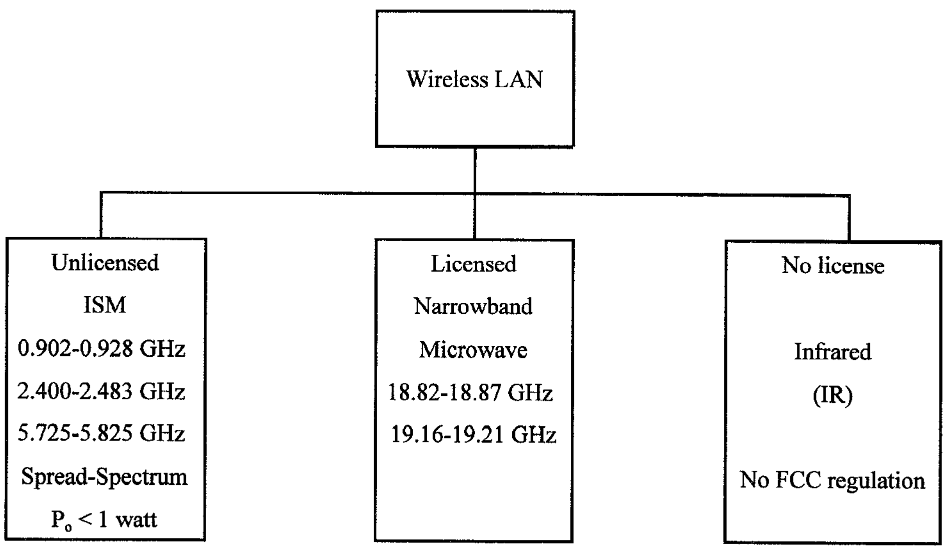

Fig. 2. Frequency bands for WLAN applications.

traffic management, electronic navigation, intelligent highways, etc. are just a few of these applications.

This special issue contains 16 papers related to the emerging field of commercial and consumer circuits and systems. The topics included are mostly oriented toward microwave technologies, although it is clearly evident that microwave subsystems and systems involving other related technologies are dominating the applications. Digital technology, antenna design, miniature designs of traditional microwave components, optical interfaces, packaging, and long-life battery technology are some of the emerging technologies that are required to make microwave systems attractive and sellable in the consumer market. The papers included in this issue were selected from manuscripts that were submitted or invited and are representative of the types of systems and technologies now being developed for the consumer market.

The first paper, by Meinel, is partly historical, but it provides a summary of how millimeter wave technology has transitioned from the military market to the consumer market and has assumed a dominant role in commercial applications. Next, Stiller *et al.*describe a 79-GHz transmitter with an integrated antenna for automotive application. This is followed by a paper describing a 94-GHz automotive radar using a low-cost GaAs transceiver chip (Chang *et al.*). Next, Gauthier *et al.* provide a unique design of a 90-GHz potentially low-cost receiver, including the antenna, for an as yet unspecified application. The final paper in this first series of applications shows an X-band application for a noncontact identification transponder, where packaging is clearly a major concern (Pobanz and Itoh). This first series of five papers illustrates some of the typical design and development efforts using traditional military technologies that have been used for consumer applications.

The next group of three papers involves communications applications. Bacon and Filtzer describe a series of X-band chips designed for the direct-broadcast-system (DBS) market where cost is a major design factor. Nakagawa *et al.* next describe a 2-GHz low-cost broadband tuner and newly developed MMIC chips for use with video distribution systems using optical fiber networks. This is for fiber-to-the-home systems. In the third paper of this series, Hatsuda describes a Ku-band package communication ultra-small aperture terminal being considered for remote areas in Japan; the services provided include health and patient monitoring via satellite.

The next set of papers involves special purpose applications, and system design includes the special use as well as the low-cost aspect. Vincent and Van der Merwe describe an X-band search and rescue radar transponder designed for low-cost, high-volume production. The purpose of this system is to increase the radar cross-section of vessels in distress at sea. Next, Freitag *et al.* describe the successful design of a 4-W GaAs X-band MMIC power amplifier and the application of this amplifier to generate a 180-W transmitter for a wind shear detection system. Over 75 transmitters have been produced and are in use in commercial MODAR wind shear detection systems. In a third application of this type of consumer application, Battiboia *et al.* describe an X-band radar for indoor burglar alarms. In addition to the low cost requirement, the intrusion alarm meets international frequency assignment and maximum radiated field strength requirements.

The last series of papers for the special issue involves special component designs for consumer applications. High on the list of related technologies is digital circuits and their application in microwave systems. Feher and Mehdi provide an in-depth discussion of digital modulation and how the choice of modulation technique affects system efficiency. This paper is based on a recent book by Feher and contains an extensive list of references on recently enacted standards for cellular telephones. Next, McGrath *et al.* describe an L-band GaAs chip set for a personal handiphone system. The paper explains critical issues related to chip performance and radio system standards requirements for a mobile telephone system in Japan. Next, Nakatsugawa *et al.* describe an L-band LNA having low power consumption for mobile communications systems. This design features low voltage and low current, which help reduce the battery size and weight for the handsets. Hunter *et al.* next provide design details on miniature filters using ceramic material with high dielectric constants for 2-GHz designs and Fin-line designs for 12 GHz. Applications are for mobile communications handsets and microwave fixed links. The last paper of this series deals with phased array antennas. Telikepalli *et al.* describe a phased array antenna for mobile communications terminals using the INMARSAT satellite communications system.

This Special Issue is the first of its kind that deals with emerging commercial and consumer circuits, systems and applications of RF, microwave, and millimeter-wave frequencies. We hope that the readers will find this issue very useful. We would like to thank all authors for their hard work in preparing quality manuscripts and for promptly responding to reviewer's suggestions and comments. Special thanks to Ms. Jackie Cellini of Westinghouse for providing excellent administrative help. We would also like to express our gratitude to the MTT-S ADCOM for approving this special issue, MTT-6 and MTT-16 Technical Committees for sponsoring the issue, and Drs. Dan Masse and Bob Trew for their guidance, support, and encouragement. A large number of expert reviewers listed below are acknowledged for their timely effort in critically reviewing the manuscripts.

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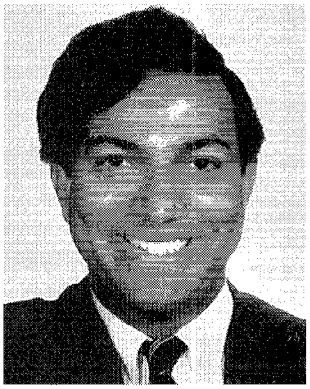
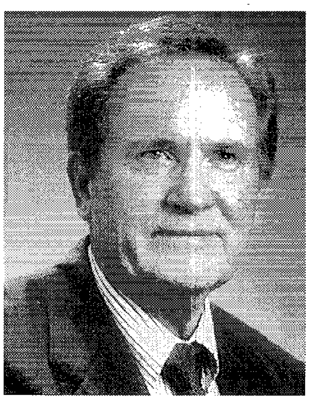


Fazal Ali (SM'90), a disciple of the late Prof. Fred Rosenbaum, received the B.S. in physics and applied mathematics (double major), B.S.E.E., and M.S.E.E. degrees from Washington University in St. Louis, MO. He is currently engaged in Ph.D. research work.

He has been involved in the design and development of GaAs MMIC's for the last 12 years. He joined the Advanced Technology Division of Westinghouse in 1992. In his present position as an advisory engineer, he has been involved in the design and development of HBT power MMIC's and MESFET-based circuits and providing technical leadership in the commercial applications of MMIC's. Before joining Westinghouse, he worked at Pacific Monolithics for (approx.) seven years as Manager of MMIC product development and senior member of technical staff. His MMIC design and product background using MESFET, PHEMT, and HBT technologies include gain blocks, LNA's, phase shifters, switches, attenuators, passive components, mixers, frequency converters (up/down/image-reject), oscillators, multifunction MMIC Transceivers, and MMIC-based sub-systems. He has also served as Program Manager and Principal Investigator on several customer funded R&D projects. Prior to Pacific Monolithics, he worked at Avantek on the design of MMIC distributed amplifiers. He introduced and taught the first graduate course in GaAs MMIC design as an Adjunct Professor at U.C. Berkeley and Santa Clara University from 1986–1991. He has authored/co-authored over 50 technical publications, five invited presentations and edited, co-edited and co-authored three books on GaAs IC technology: *HEMTs and HBTs: Devices, Fabrication and Circuits* (Artech House, 1991), *Advanced GaAs MMIC Technology* (MEPL, London, 1989) and *Microwave and Millimeter-Wave Heterostructure Transistors and Their Applications* (Artech House, 1989). He holds five U.S. patents and 15 disclosures in MMIC design techniques.

Mr. Ali received the 1993 Westinghouse Corporate Signature Award of Excellence for contributions to HBT Power MMIC's, the 1994 Award of Excellence for contributions to control circuits and several special performance awards. He is a member of Eta Kappa Nu, Tau Beta Pi, Omnicron Delta Kappa (leadership Honor Society). He serves on the editorial review board of the IEEE TRANSACTION ON MICROWAVE THEORY AND TECHNIQUES and IEEE MICROWAVE AND GUIDED WAVE LETTERS. He is very active in the Microwave Theory and Techniques Society and serves on the Technical Program Committee of the IEEE International Microwave Symposium and GaAs IC Symposium. He is presently the Chairman of MTT-6 Technical Committee on Microwave and Millimeter-Wave Integrated Circuits of the MTT-S ADCOM.



John B. Horton (S'55–M'57–SM'68–F'86–LF'94) received the B.E.E. degree from the George Washington Univesity and the M.S.E.E. degree from the University of Pennsylvania.

He is a licensed professional engineer in New Jersey. He is currently a project manager, System Engineering, in TRW's System and Electronics Group, Redondo Beach, CA. He is currently on special assignment for new business in satellite communications systems. His experience includes work on the Navy EHF Satcom Program, the NASA 30/20 Ghz System Study, TDRSS, seveal military satellite systems, Shuttle Payload Studies, missile guidance, and airborne and large ground-based radars. His current projects involve new trends in communications, including digital signal transmission, multimedia services, and personal communications.

Mr. Horton is a member of AIAA. He served on the IEEE Microwave Theory and Techniques Society (MTT) Administrative Committee from 1969–1979 and was President of the society in 1973. He is currently Associate Editor for Microwave Systems and Applications for the IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES and a member of the MTT-16 Technical Committee on Microwave Systems.