Commercial Applications of GaAs ICs

Jerry Gladstone

Hewlett-Packard Company
Microwave Technology Division
Santa Rosa, California 95403

Abstract

Applications for GaAs ICs in the commercial marketplace first emerged three years ago. Today they are part of many test and measurement instrumentation systems and essential elements in fiber optic communication systems. These applications as well as potential applications for the near future are reviewed in this paper. A simple market model is developed for categorizing commercial applications and some projections on the size of the market are presented.

Introduction

A little more than 14 years ago Van Tuyl and Liechti[1,2] reported the first successful gallium arsenide integrated circuit. This simple buffered FET logic gate (BFL) spawned an intense research and development effort at industrial facilities around the world. Rapid growth and progress, fueled by government research and development contract funds, naturally led to early applications in military systems. GaAs ICs found their way into many military applications including radar, electronic warfare and communication systems[3]. Commercial applications of GaAs IC technology took a little longer to realize -- the first commercial GaAs IC product delivered to end users is believed to be Pacific Monolithics' TVRO module introduced in March 1985[4]. In this paper the commercial applications of GaAs ICs are reviewed. It was not possible for this to be a comprehensive work as the market picture is changing very rapidly and certain types of information are difficult to obtain. Information gathered for this work drew heavily on the U.S. domestic GaAs IC manufacturers and focussed primarily on shipments in end product equipment or systems.

There are many possible GaAs technologies that can be integrated into circuits, but to date only those based on the MESFET have come to commercial realization. Depletion mode MESFET technology has been the workhorse of the GaAs IC field, and recently enhancement/depletion mode MESFET technology has become readily available. The advantages of GaAs for microwave applications are well known[5,6] and need not be repeated here. To the circuit designer, GaAs basically offers the advantages of speed (bandwidth and transition times), high input impedance devices, large voltage swings and the opportunity to integrate logic and analog microwave circuitry (for high speed signal processing). GaAs has many disadvantages including low transconductance, low output resistance, poor thermal conductivity and high price. These have left the technology pressured by the steady advances of silicon bipolar and MOS. But there are many applications for which GaAs is the best way to achieve the desired performance; let us explore a sampling of these commercial applications.

The Market

The commercial market for GaAs ICs can be divided into four segments: industrial, communications, computers and consumer. Each of these market segments can be split into three groups according to circuit type: analog, digital and mixed analog-digital. This partitioning serves as the framework for the market models used in this talk. Two market models are shown. The first represents known current production GaAs ICs which are being shipped in their end use product; this is figure 1. The second model is a combination of applications under development that are being supported with either custom GaAs ICs or production circuits from the merchant suppliers; this is figure 2.

	INDUSTRIAL	COMMUNICATIONS	COMPUTERS	CONSUMER
ANALOG	Instrumentation	Fiber Optic Systems		TVROs Cellular Telephones (?)
MIXED ANALOG-DIGITAL	Instrumentation	Fiber Optic Systems		
DIGITAL	Instrumentation	Fiber Optic Systems		

Figure 1: Market Model - ICs Shipping In End Use Products.

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	INDUSTRIAL	COMMUNICATIONS	COMPUTERS	CONSUMER
ANALOG	Instrumentation Radar Altimeters	Fiber Optic Systems Telephone Bypass DBS (Direct Broadcast Sat) NAVSAT GPS (Global Position Sat) NASA Search & Rescue MDS (Multiple Distribution System) MLS (Microwave Landing System) Phased Array Antennas		TVROs Cellular Telephones TVs, HI - RES TVs Auto Collision Avoidance Auto Radar Detectors Auto Antilock Brakes
MIXED ANALOG-DIGITAL	Instrumentation	Fiber Optic Systems	Networks	
DIGITAL	Instrumentation	Fiber Optic Systems	Supercomputers	

Figure 2: Market Model - ICs In Applications Under Development.

In 1987, the total size of the commercial GaAs IC market was estimated to be $33.8 million according to figures compiled by Strategies Unlimited[7]. This is about 39% of the combined worldwide commercial and military market of $86.7 million. Figure 3 estimates that the commercial market will grow by more than a factor of five to $174.5 million in 1991 bringing it to a larger size than the entire military market. A major part of this growth is predicted to be in digital circuits for computer applications. A study of figure 3 reveals predicted growth factors of three to six for the various market segments over the next five years.

Let us review the four market segments with an emphasis on today's products and some projections for the future.

Industrial

The primary application for GaAs ICs in the industrial market segment is test and measurement instrumentation. All three types of circuits, analog, digital and mixed analog-digital, are currently being used in instruments being shipped today. Hewlett-Packard is utilizing GaAs ICs in instruments with eight separate systems currently in production, the first of which was shipped in August 1986. Anritsu has been shipping GaAs ICs for almost a year in their MP1601A 5 Gigabits/second and MP1604A 3 Gigabits/second Pulse Pattern Generators; Tektronix is reported (early 1988) to have GaAs ICs in two instruments almost ready for release.

The circuits used by Hewlett-Packard in their instrumentation cover most of the spectrum of possibilities. A 1 GHz 6-bit ADC system[8,9] that utilizes both a digital circuit -- clock control chip -- and a mixed analog-digital circuit -- sample-and-hold chip -- are used in the HP54111D Digitizing Oscilloscope that boasts a 1 Gigabit/second sampling rate. The clock control chip provides amplification and frequency division of the input 1 GHz clock signal, and performs the gating necessary to provide all system clock signals. This chip contains 400 active elements (252 transistors and 148 diodes) and is approximately 2.5 square millimeters. The sample-and-hold circuit, see figure 4, uses a two-rank S/H architecture with the first-rank S/H operating at 1 Gigasample/second and the second-rank samplers operating at 250 Megasamples/second. The sample-and-hold chip utilizes two main subcircuits: a diode bridge sampling gate and a source follower buffer. The sample-and-hold circuit uses 367 active elements (183 transistors and 184 diodes) and is approximately 2.5 square millimeters.

1987

	Industrial	Communications	Computer	Consumer	Total Commercial	Military U S & Europe	Total Market
Analog	3.8	5.6	0	2.5	11.9	35.0	46.9
Mixed Analog-Digital	1.5	0.8	0.5	0	2.2	4.9	7.1
Digital	2.9	1.8	15.0	0	19.7	13.0	32.7
Total	8.2	8.2	15.5	2.5	33.8	52.9	86.7

1991

	Industrial	Communications	Computer	Consumer	Total Commercial	Military U S & Europe	Total Market
Analog	11.0	38.0	3.0	7.0	59.0	82.0	141.0
Mixed Analog-Digital	6.5	5.0	3.0	1.0	15.5	10.0	25.0
Digital	10.0	8.0	80.0	2.0	100.0	38.0	138.0
Total	27.5	51.5	86.0	10.0	174.5	130.0	304.0

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Figure 3: Worldwide GaAs IC Market - Merchant And Captive (Millions Of Dollars Of Packged ICs).

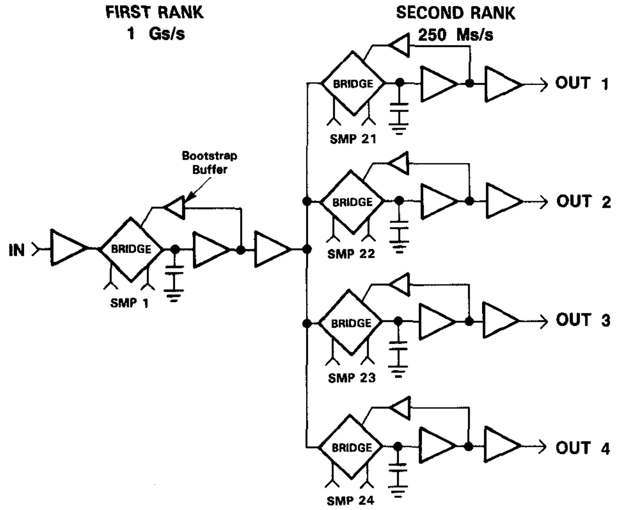

Figure 4: Block Diagram Of Hewlett-Packard's Two-Rank Sample-And-Hold Circuit.

The HP8780A Vector Signal Generator -- a synthesizer capable of complex vector modulation -- utilizes an analog circuit that could be described as "precision" analog[10]. This amplifier, see figure 5, operates from 50 MHz to 3 GHz with 30 dB gain and 20 dB possible gain adjustment. The input is single ended, but it is converted to a differential topology at the first stage; the output is differential. It is considered a precision analog circuit as waveform symmetry, total gain, gain flatness and distortion are well controlled. A key design parameter was low distortion at 10 dBm output power levels. This chip utilizes 38 FETs and is 1 by 2 millimeters. A final example, this one a microwave analog circuit, is a 26.5 GHz traveling wave amplifier[11] that is used as a preamplifier in the HP71400A Lightwave Signal Analyzer. This amplifier has 9 dB gain, better than 10 dB return loss at input and output and a respectable noise figure over the entire frequency band (better than 6 dB 2-18 GHz). In this application the amplifier is used down to 100 KHz. The chip is 3 by 0.8 millimeters and employs 14 FETs.

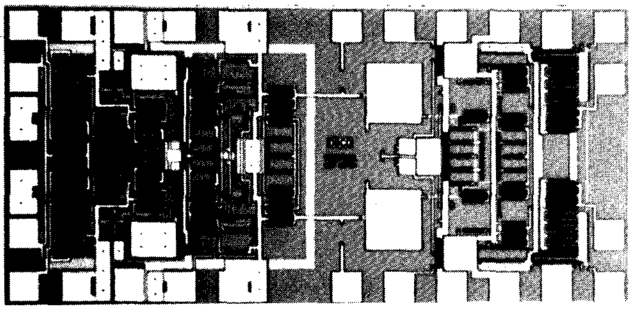

Figure 5: Hewlett-Packard's "Precision" 3 GHz Amplifier.

Numerous other circuit types are used in current and soon to be released HP instrumentation. These include many types of amplifiers, current switches, microwave switches, attenuators, mixers, modulators, frequency dividers, DACs and custom functions. Expect to see most instrument manufacturers, both large and small, turning to GaAs ICs in the next few years.

Communications

GaAs ICs find a natural home in communications applications. The first commercial use was in AT&T Communications' 1.7 Gigabits/second lightwave system which began production in November 1986. AT&T utilizes three different GaAs ICs in their fiber optic system, see figure 6; all SSI. The first circuit is a transimpedance preamplifier of about 30 transistors complexity that has a 4 GHz bandwidth at 1.5 Kohms impedance level. The chip includes a transimpedance stage (which converts input photodiode current to output voltage), two voltage gain stages, and an output buffer stage for driving low impedance transmission line loads. The second IC is a decision and regeneration circuit that has a bit error rate of $3x10^{-11}$ at -32 dBm signal levels. This circuit utilizes enhancement and depletion mode devices and consists of a high gain-bandwidth amplifer, D-type flip-flop, and complimentary 50 ohm output buffers. The final IC is a 50 milliampere laser driver circuit with a 20%-80% rise and fall time of 150 picoseconds. This circuit converts an input voltage signal at

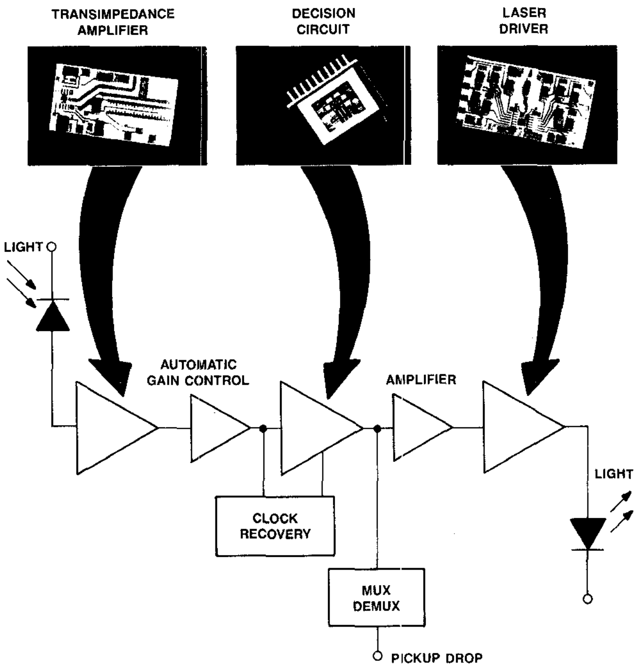

Figure 6: AT&T's Fiber Optic Lightwave Repeater. (Figure Courtesy OF AT&T)

rates up to 3 Gigabits/second to an output pulse current that drives the laser; it contains three cascaded differential stages. Also in the lightwave communication systems area, NTT began upgrading a 400 Megabits/second fiber optic communications system to 1.6 Gigabits/second late in 1987 by utilizing GaAs 4:1 multiplexers and 1:4 demultiplexers purchased from NEC.

The future for GaAs ICs is extremely promising in the communications market segment with continued applications in fiber optic communication systems, and new applications in telephone bypass systems (14-15 GHz), MDS (Multiple Distribution Systems) as an alternative for remote cable installations and DBS (Direct Broadcast Satellites). Other applications under development include NAVSAT and GPS (Global Positioning Satellite) as well as a NASA Search and Rescue program for navigation and rescue, MLS (Microwave Landing System) for advanced commercial aircraft, and phased array antennas for communications satellites.

Computers

At present there does not appear to be any computer or computer-related equipment shipping with GaAs ICs. This situation will not persist too much longer considering the dozens of GaAs digital ICs in production (examples include flip-flops, various gates, counters, shift registers, microcontrollers, carry generators and even a 4-bit microprocessor) and available from many merchant GaAs houses[12] --- expect to start seeing GaAs ICs in computers and networking products in the future. The developers of the next generation supercomputers are turning to GaAs to enhance their performance. The CRAY™-3 is expected to be the first major computer system to be implemented with GaAs logic; it is reported to use approximately 48,000 logic chips and 40,000 memory chips[13].

Consumer

Pacific Monolithics' TVRO (TeleVision Receive Only) module allowed the first commercial end user delivery of a GaAs IC. Introduction was in March 1985 with production reaching a peak of greater than 2000 units per week by the end of 1985. The present market for TVRO's is estimated to be approximately 30,000 units per year. The PMI TVRO downconverter chip, see figure 7, includes RF amplification, a double-balanced mixer, LO buffer amplification, and IF amplification all on a chip of less than 1 square millimeter[14]. It has also been reported that Oki plans to sell a mobile phone which utilizes GaAs ICs for the entire RF section; introduction in the U.S. is planned for the near future.

The future for the consumer segment of the market could also include televisions, high-resolution televisions and applications in automobile collision avoidance systems, anti-lock brakes and radar detectors. The keys to securing future consumer applications are reducing prices and design cycle times.

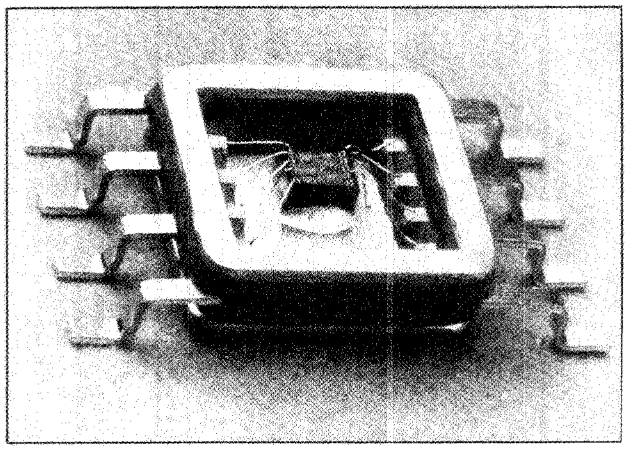

Figure 7: Pacific Monolithics' SMT Packaged TVRO Chip. (Photo Courtesy Of Pacific Monolithics)

Outlook for the Future

The GaAs ICs shipping in end user applications are all produced with depletion mode or enhancement/depletion mode MESFET technology. Some facilities are readying E/D & D processes offering two different pinch-off MESFETs. Newer technologies based on MODFETs and HBTs are also being investigated at laboratories around the world. These new technological capabilities along with emerging new integrated circuit design concepts should allow a large growth in the types of applications for GaAs ICs. As GaAs IC technology matures and improved design tools and testing techniques become available, GaAs ICs will benefit with lower prices, decreased design cycle times and increased levels of integration -- this will greatly enhance their appeal and utilization in the commercial marketplace.

The marketplace is also expected to grow significantly over the next few years. Increasing realization of their performance, cost and reliability advantages will guarantee a healthy growth for GaAs ICs in test and measurement instrumentation systems. The virtual explosion in personal and commercial communication systems, and the trend toward high-tech electronics in automobiles both provide sizable new market opportunities for GaAs ICs. And of course, the quest for high-speed computers and supercomputers represents one of the most significant market potentials for GaAs ICs. Surely, the conjectured five-fold increase in the commercial GaAs IC market over the next five years, as forecast in figure 3, promises an exciting future for the GaAs IC.

Summary

In the three years since the first commercial GaAs IC was used in an end product the market has grown slowly and at times unsteadily. The next five years should see more rapid and sustained growth in the utilization of ICs in commercial products as the dozens of current developments reach the marketplace.

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References

[1] R.L. Van Tuyl and C.A. Liechti, "High Speed Integrated Logic with GaAs MESFETs", in ISSCC Dig. Tech. Papers, February 1974, pp. 114-115.

[2] R.L. Van Tuyl and C.A. Liechti, "Gallium Arsenide Digital Integrated Circuits", Technical Report AFAL-TR-74-40, Air Force Avionics Lab., Contract F33615-73-C-1242, March 1974.

[3] For an in depth report on the military GaAs IC market see "Military Markets for GaAs ICs", Strategies Unlimited, September 1987.

[4] Private communication with Frank Russell, Pacific Monolithics.

[5] R.A. Pucel, "Design Considerations for Monolithic Microwave Circuits", IEEE Trans. Microwave Theory Tech., vol. MTT-29, No. 6, June 1981, pp. 513-534.

[6] E.W. Mehal and R.W. Wacker, "GaAs Integrated Microwave Circuits", IEEE Trans. Microwave Theory Tech., vol. MTT-16, No. 7, July 1968, pp. 451-454.

[7] Report to be published by Strategies Unlimited, Mountain View, California, approximately Spring 1988.

[8] J. Corcoran, K. Poulton and T. Hornak, "A 1 GHz 6-bit ADC System", in ISSCC Dig. Tech. Papers, February 1987, pp. 102-103, 358-360.

[9] K. Poulton, J.J. Corcoran and T. Hornak, "A 1-GHz 6-bit ADC System", IEEE Journal of Solid-State Circuits, Vol. SC-22, No.6, December 1987, pp. 962-969.

[10] W.M. Kelly, M.J. Woodward, E.B. Rodal, P.A. Szente and J.D. McVey, "Vector Modulator, Output Amplifier, and Multiplier Chain Assemblies for a Vector Signal Generator", Hewlett-Packard Journal, Vol. 39, No. 11, December 1987, pp. 48-52.

[11] J. Orr, "A Stable 2-26.5 GHz Two-Stage Dual-Gate Distributed MMIC Amplifier", in IEEE MTT-S International Microwave Symposium Digest, June 1986, pp. 817-820.

[12] For example Vitesse Electronics, TriQuint Semiconductor, Gigabit Logic, and Harris Microwave Semiconductor all offer digital GaAs ICs as production parts.

[13] D. Keifer and J. Heightly, "CRAY-3: A GaAs Implemented Supercomputer System", in Tech. Dig. GaAs IC Symposium, October 1987, pp. 3-6. CRAY™ is a registered trademark of Cray Research, Inc.

[14] J. Browne, "GaAs MMIC subsystems downconvert 8-GHz signals", Microvaves & RF, Vol. 25, No. 7, July 1986, pp. 131-133.