VLSI IN MILITARY COMMUNICATIONS

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The Electronic Battlefield and USLI

Modern survivability of military systems is based on advances in electronics components and digital computers. Actually electronics reaches into almost every segment of military operations, from satellite communications, to data processing, to "smart" missiles relying on processors, to routine administrative activities which utilize optical display and word processing, to every segment of primary and support mission areas. The scope of the use of electronics systems by the U.S. Air Force was susscintly stated by General Robert T. Marsh in the Air Force Magazine for July 1981 when he pointed out that "electronics systems represent about a third of the total value of Air Force weapons and equipment. Counting spares we own and maintain more than a quarter million black boxes and the Air Force will soon be supporting more than 40,000 computers ... within the total Fiscal 1982 requested funding of, $960 million for Air Force RDT&E technology base activities, approximately $270 million is for electronics and electronics related efforts - more than for weaponry ... more than for flight vehicles ... more than for propulsion and power ... at the heart of this galloping technology of course are the dramatic improvements in large scale integrated circuits (LSI) and very large scale integrated (circuits) microprocessors (VLSI) which give us all sorts of advantages in weight, volume, power and reliability. The end is nowhere in sight." This paper will provide a summary of how modern VLSI is being applied to military communications including how synergistic VLSI developments in the commerical and consumer marketplaces have influenced military systems, and the initiation and implementation of the Tri-service very-high-speed integrated circuit (VHSIC) program which is intended to overcome the high cost of relatively few specialized military systems by making it attractive for commercial manufacturers of VLSI chips to also produce widely applicable integrated circuit chips for military systems.

The Advent of VLSI

The beginning of microelectronics and its impact on miniaturization of electronics systems was not realized until the 1950's when the invention of the transistor in the late 1940's made possible thin film and thick film circuits using descrete transistors diodes and passive components. The 1960's saw the advent of the integrated circuit (IC) in which a single wafer of semi-conductor material contained the equivalent of a number of discrete transistors diodes resistors and capacitors to provide a complete function such as a complete digital logic gate or a flip-flop. This development continued into the 1970's which produced a third generation of circuit and system design approaches, resulting in more complex chips producing many functions; i.e. large scale integration (LSI). Perhaps the two most significant products of this third generation of integrated circuits and complexity were the calculator and the microprocessor.

A worldwide trend in the development of increasingly complex integrated circuits has brought the art of microelectronits to a fourth generation -- very large scale integrated circuits (VLSI) and very high speed integrated circuits (VHSIC's). In such complex integrated circuits, a single chip (IC) can contain the equivalent of almost 500,000 transistors, ex. The Hewlett Packard N-MOS single chip 32-bit processor contains 450,000 transistors on a 0.25 X 0.25 inch silicon die. IBM, using LSI has squeezed the main portion of its IBM/370 central processing unit onto a single chip of 4000 gates and 45000 transistors.

The Computer: The Triumph of VLSI

The computer was born more than thirty years ago using electron tubes to provide the limited number of functions capable of being addressed. The advent of the transistor initially appeared to be useful only to eliminate the enormous amount of filament power and heat dissapated by the electron tube computers. It was not until the middle-to-late 1950's that the transistorized computer made its debut in an art where only a few thousand operations of throughput was considered outstanding. The development of integrated circuits during the early 1960's gave way to many computer systems still in use today; re: the UNIVAC RMF 1230, which is used in many SCF installations.

The introduction of integrated circuits in the 1960's with as many as ten gates of logic power in a single 14-pin flatpack resulted in an order of magnitude jump in density and complexity over the "cordwood" packaging of the computers in the 1950's. The integrated circuit with parallel computer architecture was then used to obtain hundreds of thousands of operations per second. At the same time, costs decreased from several dollars per gate to as low as a dollar a gate.

This increase in computer complexity also impacted the traditional circuit designer resulting in the development of Computer Aided Design (CAD) systems to produce system designs containing many thousands of gates. Design automation (D/A) computer aids were developed to meet this challenge. Logic chips of ever-increasing function and density were produced throughout the 1970's, and produced computers with more than one hundred thousand gates of logic and many million words of memory. The characteristics of the transistor-transistor logic (TTL) circuitry allowed relatively unsophisticated simulation, data recording and test pattern generation support.

Following what is often referred to as the "computer depression of 1970-1971," an event occurred which changed the course of computer development; this was the advent of both the calculator and the microprocessor which with the use of alphanumerics for CRT display ushered in a new era of computer development which led to the introduction of VLSI in 1978. The advent of VLSI allows the design of systems consisting of millions and even tens of millions of logic gates. While the obvious increase in total system gates is a complexity increase, VLSI presents a challenge to the "business as usual" way of designing new electronic components. In the past the normal way to plunge into this new technology would be through custom designs, which would optimize chip area and eventually win acceptance in the marketplace as standard semiconductor products. Microprocessors and the new generation random access memories (RAM) ranging up to a quarter-megabit are examples of VLSI components designed in that way.

The computer of the 1980's using VLSI performs at a speed and with a capacity undreamed of only a decade ago; also, the computers of the 1960 required large equipments - sometimes as large as a room, to perform the same functions now possible in a computer system occupying only a cubic foot or two.

Each gate in a VLSI chip consists of three or four components. The VLSI chip will therefore contain 30,000 to half a million devices which require millions of interconnections to perform the desired function. The VLSI circuit design problem encountered in a single chip has not reached the order of a total large system design of only a few years ago. In order to design the VLSI chip with millions of interconnections, thousands of errors must be corrected by means of "softwires" on printed circuit (PC) cards. It is clear that new approaches are required for practical design of VLSI chips. The single limiting factor that is most evident today in the semiconductor industry is the lack of means for rapid low cost design of VLSI chips. Hence, the DoD VHSIC program which is designed to: (1) reduce the cost and schedule of VLSI design to approach the figures applicable to unit logic design, and (2) provide a means of obtaining the benefits of large volume (and therefore low unit cost) chip production.

VLSI and Consumer Products

LSI and VLSI require large production of chips to warrant the time and design cost per gate to render the manufacturing cost per gate at an economic level relative to the cost of TTL logic, for example consumer products such as digital watches, calculators, color tv sets, tv games, talking dolls, etc. address markets which can require millions of units thereby making the cost of developing appropriate LSI chips practical. As an example, modern color tv sets now use microprocessors and synthesizers-on-a-chip for toning, and indeed, the entire color tv circuit is accomplished by using a small set of complex integrated circuits. For such systems, an LSI integrated circuit can provide many complex functions at very low cost. For example, the NATIONAL LM1889 which is used for tv games and which inputs a baseband video and audio and develops a vestigial sideband video carrier with FM audio at channel 3 or 4 of a standard tv set, can be purchased for less than $8. Another example is the frequency synthesizer of a tv set or FM tuner which provides a local oscillator signal at UHF and VHF using one or two low cost chips - a far cry from the cost of many thousands of dollars of a commercial frequency synthesizer.

A new and expanding area of consumer products using VLSI and LSI is the home computer and the tele-text which are designed for home use and can be used to display, graph, word process, and develop and/or retrieve information. This has been a busy marketplace and the recent intention to compete in this area is indication of the automated home.

VLSI and LSI in commercial communications

LSI and VLSI chips are now the mainstay of commercial digital communications which is used, the world over, to replace convential analog telephone communications. LSI can be used to operate at digitized-voice data rates from 3.2 to 64 kilobits per second and LSI chips are now used to convert analog voice to whatever data rates are needed to enter a digital hierarchy for multiplexing with other voice channels to form a standard data stream in the hierarchy. 1.544 Mbps for example is used in both the AT&T digital hierarchy and military communications to transmit 24 digital-voice signals - each at 64 kbps. However, significant work has been done to reduce the number of data bits required to represent a voice with 30-32 kbps using delta modulation providing a reproduced voice of excellent quality, and a voice signal produced by a vocoder at 2400 bps now capable of producing a clear and recognizable voice. The same is true of video which formerly required almost 100 Mbps to represent a PCM digital version of a standard NTSC color TV signal. Such signals can be now produced with excellent quality with as few as 16-22 Mbps, and with quality satisfactory for teleconferencing to as low as 1.544 Mbps. Those important achievemnts in voice and video data rate reduction are a direct consequence of the use of LSI and VLSI chips. Other chips have been developed in the commercial world by INTELSAT, Comsat, AT&T, etc. to provide LSI and VLSI chips providing complete ViTerbi encoders and threshold decoders, modulators, PCM codec’s, SCPC channel units, frequency synthesizers. Of particular interest is the development of a digital canceller by AT&T for voice communication by satellite using almost 50000 transistors and gates on a single chip - a real triumph for VLSI which solved both a severe problem in the reduction in the time delay effects on voice communications by satellites, and rendered economic a circuit which would have cost almost $50,000 to manufacture by conventional means.

The other growing uses of VLSI in commercial communications are becoming almost too numerous to mention but significant developments have been made in memory circuits which now make TDMA practical and economic in systems normally using SCPC channels, and in the development and manufacture of videotex terminals which allow retrieve and display of data stored in a computer memory.

VLSI in Military Communications

The computer system is the heart of military communications which includes internetting, data processing, survivable-communications, secure communications, speech processing, and Distributed Data Base Systems (DDBS). Survivability of communication networks, in particular is improved by redundancy of links and nodes, and by the ability of a computer to reconfigure a network. In the 1980’s, small powerful processors using VLSI will support low cost communication satellites, provide wide area distribution of communication services, and handle heavy processor loads required to achieve security objectives or develop data from or data systems for acquisition, updating, or retrieval.

Many ruggedized computer systems are now being developed based on the use of commercial computer systems and technology; for example, the military version of the DEC computer manufactured by NORDEN, the military version of the Eclipse computer manufactured by ROLM, or the ruggedized IBM Series I minicomputer. According to Col. P. Ulmen and S. Lipner writing in SIGNAL July 1981, “it would be shortsighted for government to place itself outside of commercial technology trends (in which a new generation occurs about every three years) and wasteful to compete with commercial industry for technology leadership; it is useful for government to sponsor certain hardware and software advances. The very high speed integrated circuit (VHSIC) program is an appropriate area where defense investments are accellerating technology developments.”

A peripheral of the computer system which has benefited from LSI and VLSI is the display system using either CRT or rugged plasma display systems. Here the man-machine interface is enhanced by displays which not only can display tabulated information, but also display this information in various colors (CRT only) to distinguish between various data or to display using curves or bar graphs or whatever is needed for data understanding.

Interestingly enough, it is the memory system of the computer which is not always benefiting from VLSI. After many years, a Winchester floppy disk or rigid disk memory still has a cost and data-storage advantage over the best of solid state memory systems.

Other areas where VLSI will make key impact is in the area of packet communications which enhance the survivability of a communications network by sending the data in packets, each with a preamble containing a destination code which in the era of VLSI codecs and matrix switches including store and forward systems, allows each packet to develop its own route to its destination followed by a verification of arrival returned to the sender. According to J. Rothfeder, writing in Electronic Design, August 6, 1981, "Both the Pentagon and Congress are emphasizing an effective system of command, control and communications (C^3) for the strategic Triad of land-based missiles, airborne bombers, nuclear submarines. Over the past few years, the Soviet Union's ability to disrupt the current U.S. strategic C^3 network -- which essentially consists of warning radars, satellites, airborne and fixed command posts, and message relay devices -- has grown disturbingly strong. In addition to ensuring that the Triad members remain in contact with command posts and each other directly before and during an enemy attack, C^3 is now expected to stay in operation after an attack."

"Much of the C^3 work at DARPA is in the development of more secure, more sophisticated and widerband communications networks. Special emphasis is being placed on computer communications technology, the use of lasers for strategic communications, and basic computer research."

"An installation plan is being developed for ARPANET, the packet-switched network slated for use at Strategic Air Command (SAC) headquarters. Along with this, a series of computer reconstruction plans is being implemented for SAC staff members to improve crisis management of computer compunciations, especially if the communications are severly disrupted in a nuclear attack. In addition. the communication range of packet radio network technology is being extended to provide automated data processing services for airborne use, such as in the airborne command post."

"The packet-communication technology program is also exploring computer-based methods for controlling, allocating, and accessing information through a variety of media, including mobile radio, boardcast satellites, coaxial and optical cable, and leased telephone circuits. The collections of networks are interconnected by small gateway computers. End-to-end security is a priority not only for these packet-swtiched networks but also for special applications such as multimedia systems and packet-switched voice."

Another area where VLSI will provide important functions; as codecs in transmitters and receivers of Fiberoptic systems to take advantage of both zero-RFI/EMI proof transmission capability and the light-weight wideband transmission paths between communications or data processing centers (es: TRI-TAC).

Military communications will also benefit from the computer-control and moniter of a complex of equipment interconnected by the parallel bus IEEE 488 system, now subscribed to by more than 150 equipment manufacturers. The IEEE 488 parallel bus system - and the serial RS-232 system-interconnect all equipments with an IEEE bus controller which monitors and controls all equipments, and in addition to increasing the quality and reliability of all data developed, also reduces the manpower requirements - a significant contribution to life cycle cost reduction.

<u>The DoD VHSIC Program</u>

The VHSIC program, sponsored by the Defense Dept., is one of the most ambitious collaborations of government and private industry. It is aimed at stimulating and speeding up the development of IC device technology. VHSIC addresses several key military issues of the 1980's, two of the most important being:

- The U.S. military establishment should gain and maintain a qualitative arms lead over its adversaries to compensate for a numerical inferiority.

- The military should afford complex functions in small packages that can easily be replaced or repaired, for a reduction in required logistics and operator skills.

The $160-million Phase 1 of VHSIC, whose contracts were signed March 7, 1980, is a six-year phase involving six prime contractors: i.e., Texas Instruments (Army) with concentration on bipolar technology; Hughes (Army) with CMOS/SOS hybrid/custom design; TRW (Navy) with bulk CMOs and bipolar coverage; IBM (Navy) with NMOS and customized macrocell architecture; Honeywell (A.F.) with bipolar technology; and Westinghouse (A.F.) with bulk C-MOS coverage and single-chip sets.

The basic VHSIC objective is to push improvements in military systems performance through improvements in IC designs and processes, which -- in the main -- boils to achieving micron and submicron line geometries. There are two parts to the VHSIC Phase 1 program. The first part involves the development of IC devices with 1.25 µm line widths while second part of the Phase 1 program involves the development of devices with line widths of just 0.5 micrometers.

Throughput capacity, in gate-Hz, is one measure of the capability VHSIC devices are expected to attain. Throughput capacity is a parameter that is derived from multiplying the number of gates on an IC chip by the chip's clock frequency. Microprocessors have throughput capacities on the order of 10^{10} gate-Hz, while such military systems as the AIM-54 Phoenix seeker processor and the UYK20 standard computer have throughput rates of 10^{11} and 10^{12} gate-Hz, respectively. Weapons systems are being planned with even higher systems throughput capacities of 10^{13} gate-Hz and more. Such throughput rates require that IC pattern definitions be at least 1 in size and smaller, otherwise, total system weights and power-dissipation levels could become too prohibitive. (Electronic Desigh, August 6, 1981).

The outcome of the VHSIC program will be one in which nearly every future computer and communications system component will benefit. Packet radios for the Army and other services will have VHSIC chips at the design foundation. High-performance imaging and phased-array radars are expected to proliferate as more and more VHSIC chips are used in such systems to make them smaller and less expensive. Even the foot soldier will benefit, as portable JTIDS (Joint Tactical Information Distribution Systems) packages, powered by batteries and carryable on one's back, become readily available thanks to VHSI chips.

Gallium Arsenide VLSI

Low frequency and baseband functions using VLSI will use CMOS or N-MOS. For frequencies at UHF and above, and data rates into the megabit range, Gallium Arsenide (GaAs) VLSI will be used. Monolithic GaAs technology is on the verge of engulfing the microwave industry and radically changing the nature of the business. The US military has gradually increased funding of monolithic GaAs research, and now many millions of dollars of government funding support US-based research. Efforts in Europe are intensifying on monolithic GaAs design and the Japanese reportedly have 26 organizations working on monolithic receiver front ends alone.

A major impetus for research on this technology is the cost savings that can be realized by producing microwave circuits monolithically. Complete circuits deposited on a semiconductor chip need no tuning; in fact, most can't be tuned. Hence, microwave circuits could be mass-produced monolithically without the time-consuming and costly tweaking that is required now. Also, subsystems defined on a chip could open up new block-diagram approaches for system designers who work on equipment that ranges from test-and-measurement hardware to space-based radar. The reduced size and power consumption of monolithic GaAs circuits Is particularly beneficial for space applications.

Approaches to monolithic circuit design are as varied as the personalities of the designers, and there is disagreement as to which designs will ultimately lead to GaAs very-large-scale integration (VLSI, or 10,000 gates/chip), if GaAs VLSI is indeed ever achieved. Research efforts can be separated into three general areas: analog low-noise, analog high-power, and digital circuits. And, as monolithic GaAs power amplifiers, low-noise receivers, and A/D converters become commonplace, the analog and digital worlds will merge on GaAs wafers.