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JUNE 9-11, 1994/HONOLULU

1994 SYMPOSIUM ON VLSI CIRCUITS

DIGEST OF TECHNICAL PAPERS

1994 VLSI

CIRCUITS SYMPOSIUM
Honolulu

The IEEE Solid-State Circuits Council

IEEE

The Japan Society of Applied Physics

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FOREWORD

Welcome to Hawaii for the 1994 Symposium on VLSI Circuits

The Symposium on VLSI Circuits is sponsored by the IEEE Solid-State Circuits Council and the Japan Society of Applied Physics in cooperation with the Institute of Electronics, Information and Communication Engineers of Japan. The technical program of the eighth Circuits Symposium clearly attests to the fact that this meeting is now perceived as one of the major international forums for the discussion of important advances in VLSI circuit design. Contained herein are 58 papers selected from the 150 papers submitted to the Program Committee from 12 different countries around the world.

The Symposium features four invited talks spanning its entire scope. The talks cover the IRIDIUM Personal Communication System, ATM in Broadband-ISDN Communication Systems, Multichip Module Technologies, and Design Tradeoffs in Advanced Microprocessor Architectures. We expect lively discussions at our five evening rump sessions, which include a joint Circuits and Technology Session on Low Power/Low Voltage Technologies.

The contributed papers that make up the bulk of this conference represent significant advances in circuit design as applied to memories, processors, communication circuits, and analog and digital signal processing. Future design problems are clearly discussed and possible solutions are given. In addition, advanced solutions to the requirements of today are described. We expect the technical content of the program and the beauty of Hawaii to make the Symposium a worthwhile event for every attendee.

The excellent program owes much to the outstanding efforts of the Technical Program Committees, under the leadership of the Program Chairman, Kevin O'Connor, and Program Co-Chairman, Atsushi Iwata. The Committee members, leaders in the field of Circuit Design, have solicited strong papers and selected and organized them into attractive technical sessions.

Next year, the Symposium will be held in Kyoto, together with the Technology Symposium. We do hope you will attend.

June 1994

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Symposium Chairman

Akihiko Morino
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Session 11: Communication Circuits [Tapa II]

The IRIDIUM$^{TM/SM}$[1] Personal Communication System

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Abstract

Extensive use of VLSI technology allows the IRIDIUM Satellite System to be built at an affordable size and cost. The use of a new application specific integrated circuit (ASIC) methodology has improved development cycle times by a factor of two while simultaneously allowing the gate count per ASIC to increase by a factor of four.

Introduction

The goal of the IRIDIUM System is to make instant global communications a reality. At first thought, it would seem that we already have global communications. From the U.S., we can place calls to a vast number of domestic and international locations. However, there are many areas without telephone service, not only in emerging countries, but in developed nations as well. Consider that in Russia, with a population of 250 million, there are only 10 million telephones. In India, there are tens of thousands of villages without telephone service. There are some countries whose telephone system is so archaic that thunderstorms routinely disrupt service; some countries have service within their boundaries, yet lack the capability of international calling. Our mission of world-wide, world-class communications is decidedly a reach-out goal.

The system originally conceived utilized 77 satellites networked together orbiting the earth resembling the 77 electrons orbiting the nucleus in the atomic element iridium. In the years following the original system conception, several size, weight, performance and ctradeoffs have yielded the current design which uses 66 satellites. The satellites are networked together via cross-ostlinks, and with a system control facility, gateways, and subscriber units. The IRIDIUM System is overviewed in Figure 1.

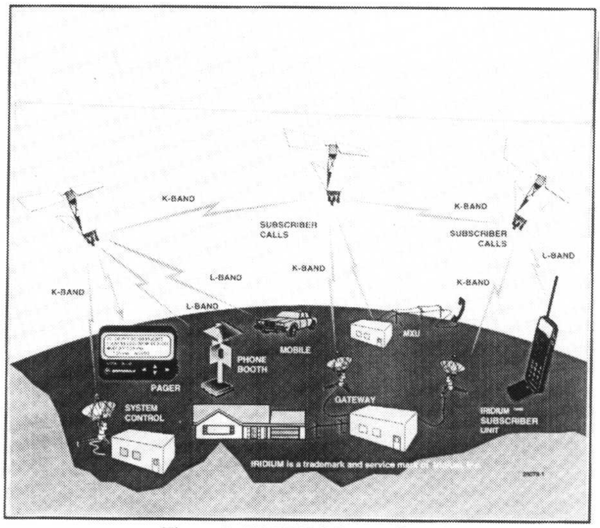

Figure 1 - IRIDIUM System Overview

We'll consider each element briefly and, no, we are not changing our name to dysprosium (the element with atomic number 66).

The Constellation

A network of orbiting satellites will be utilized to provide global coverage. We call this network a "constellation", analogous to natural constellations in space. The minimum number of satellites required for full-earth coverage depends on the altitude chosen. At higher altitudes fewer satellites are needed since they would be in "view" over a greater percentage of the earth. In fact, if the altitude were increased all the way to the geo-stationary level (35,786 Km), just three satellites would suffice. Unfortunately the

[1]IRIDIUM is a registered trademark and service mark of Iridium, Inc.

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Km), just three satellites would suffice. Unfortunately the complexity and size of each satellite increases as the required number of satellites decreases in order to maintain call capacity and link performance.

The satellite's antenna arrays get more complex at higher altitudes since the satellite must communicate directly with handheld telephone units having small, low gain antennas. Message-turnaround delays also increase with altitude which is undesirable. For geostationary satellites, the minimum delay would typically exceed 250ms., which is undesirable.

Conversely, lower altitudes require more, but simpler satellites. However, when considering lower and lower altitudes, a point is reached where the launch costs and logistics of more satellites becomes prohibitive. Also, the drag of the earth's atmosphere gets greater at lower altitudes which reduces orbital lifetime.

After considerable tradeoffs and optimizations, we have chosen an orbital altitude of nominally 780 kilometers, with 66 satellites configured in 6 polar orbital planes of 11 satellites each. The IRIDIUM Constellation is depicted in Figure 2.

The IRIDIUM System is being designed to use the principles of cellular telephony to provide reliable coverage from and to virtually any spot on earth. Three antennas on a satellite form a honeycomb pattern of 48 beams on the ground. As the satellites orbit the earth, the user would be handed-off from one beam to the next. Some handoffs would be intra-satellite, that is, within the 48-beam footprint of a single satellite. Once a user is within a boundary or edge beam of one satellite, the handoff will be inter-satellite. Instead of stationary cells and mobile users as in terrestrial cellular systems, the IRIDIUM System is designed to have relatively stationary users and mobile cells. Even the Concorde moves slowly compared to a satellite which orbits the earth in 100 minutes.

Figure 2 - The IRIDIUM Constellation

The satellites in the six orbits will converge as they approach the poles, and their beams will overlap. Some of the outer beams will be "turned off" to eliminate the overlap and to conserve power.

The satellites are networked together via 23 GHz crosslinks to allow the relay of calls. Each satellite will have four crosslinks, allowing each to communicate with the satellite immediately ahead and behind in its own plane, as well as to the nearest satellites in each of the two adjacent co-rotating planes.

The satellites will be small, each weighing only 700 Kg. Current plans call for production line assembly of satellites (yes, this is a new paradigm in manufacturing!), with the complete network of 66 satellites on orbit and operational in 1998.

System Control Facility

Obviously, there has to be ground control over the satellites. This will be performed in the System Control Facility (SCF), which is to manage the constellation by tracking telemetry and attitude control information for each satellite to keep it in its appropriate envelope within its orbit and by monitoring the electrical/power and other support subsystems. Also, the facility will manage the communications network, informing satellites if a node is down so as to re-route calls. Two System Control Facilities, geographically separated, will be built to help assure continuous operation.

Gateways

An IRIDIUM Gateway, shown in the Systems Overview of Figure 1, is designed to interconnect the IRIDIUM Constellation with the Public Switched Telephone Network (PSTN). The Gateway is intended to handle call set-up, caller location, and collection of the necessary data to support billing. Caller location is necessary because, an IRIDIUM Subscriber who resides in Phoenix could carry and operate the unit in Singapore or Tel Aviv, or any other location with an operating license.

Gateways, through their incorporated switch and other interface electronics, are designed to interconnect the IRIDIUM Network to the world's PSTN. In this manner, calls could not only be placed between two IRIDIUM Subscribers, but also between an IRIDIUM Subscriber and a PSTN telephone.

In the current design, the Gateways would typically employ a minimum of three 3.3 meter tracking dish antennas that are separated by around 30 Km. At least two dishes are needed because as a satellite disappears over the horizon another will have appeared at a different location above the horizon, and the handover from one to another is to be virtually instantaneous. Most Gateways are planned to have at least three tracking dishes to help ensure the availability of the communications link during maintenance activities.

The antenna separation would provide optional communication paths for avoidance of rain/thunderstorm cells during adverse weather conditions. It also would provide an option to avoid "looking" into the sun; a source of considerable radio noise. These options would reduce the amount of link margin (and peak transmitter power) required to maintain communication during these potentially detrimental conditions.

Subscriber Units

Subscriber units will be offered in a variety of shapes and sizes. Initial development includes the individual portable/handheld unit, the mobile unit which can be installed in an automobile or boat, the transportable unit that can be moved between remote fixed locations, and a variety of paging products. The current concept for an individual handheld unit is illustrated in Figure 3.

Motorola has plans to manufacture dual-mode, handheld subscriber units which will be compatible with both terrestrial cellular systems as well as the IRIDIUM System. Where the terrestrial system is available at home or as a roamer, the user could use the terrestrial cellular system. Where a terrestrial cellular system is not available, and an IRIDIUM Service is authorized, an IRIDIUM dial tone should be available.

The portable/handheld unit is currently designed to operate for 24 hours on a single recharge in a combination of standby (able to receive a "ring" indicating an incoming call) and active modes. The system is now being designed to be operated with subscriber unit transmit power levels comparable to those of handheld cellular telephones.

The Communications Network

The IRIDIUM System is often viewed as a space system (for obvious reasons), but, when you consider the functional objective, it isn't a space system. Fundamentally, the IRIDIUM System is a personal communications system that happens to have some of its infrastructure located in space. This subtle distinction is of paramount importance to our engineering team. The emphasis has always been on the personal communications device, the *handset*, which could be easily carried in a pocket, which will operate on rechargeable batteries, and which will operate in environments typical of today's cellular telephones. The inclusion of satellites in this system is not of much concern to those who will buy and use the handsets. They do not generally care whether there are telephone poles, undersea cables, microwave towers, or satellites involved in their

Figure 3 - The IRIDIUM Subscriber Unit

calls. They care about the voice quality, the availability of a dial tone, the cost, and the convenience of reliable service. The system is currently designed to support voice, transparent data, and compatible facsimile services.

The IRIDIUM System would employ communication links in two portions of the spectrum. The up/down links between the satellites and the subscriber units would operate within the 1610.0 - 1626.5 MHz region of L-Band. This band was allocated for satellite-based personal communications at the 1992 World Administrative Radio Conference (WARC) in Torremolinos, Spain.

The satellite crosslinks, as well as the up/down feeder links to the gateways, are designed for operation in the 20 - 30 GHz region of K-band. Licenses are required for operation in each Country; some are pending now.

ASIC Methodology

The satellite payload electronics extensively utilizes large gate count ASIC circuitry to achieve very high density packaging and low cost manufacturing. The entire spacecraft is manufactured using surface mount components and assembled on highly automated robotic manufacturing lines.

A new ASIC design methodology was developed that integrates several computer aided design (CAD) tools together that share common data bases and automatically convert from system level behavioral modeling to Very High -level Descriptive Language (VHDL). Our ASIC manufacturing foundry then converts the VHDL descriptions to gate level and device level implementations and automatically places and routes these complex circuits.

The current payload electronics design is comprised of almost 200 ASIC circuits made up of 14 different ASIC types and up to 200K gates per ASIC. See Table 1. The total design encompassed over 1.4 million gates of new logic designed in less than 12 months time. This represented a new benchmark within Motorola.

Table 1

ASIC Usage in the IRIDIUM Satellite

Subsystem	ASIC Types	ASICs per Satellite	Total Gates
L-Band	5	87	560K
K-Band	2	16	160K
Processor	7	75	720K

L-Band Links

Satellite L-Band phased arrays form the 48 spot beams to receive and transmit to the hand held telephone units. On board the satellite, hundreds of digital modems process the subscriber unit signals. Extensive use of ASIC circuitry and Digital Signal Processing (DSP) make the L-Band Link size and power achievable for the spacecraft.

The 48 beams provide Spatial Division Multiple Access (SDMA), which, when combined with Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA), allow a great degree of dynamic reallocation of capacity by geographical location in response to demands for service. The combination of SDMA, TDMA & FDMA also result in very efficient spectral use.

K-Band Links

The intersatellite links network all the satellites together in a manner that allows many choices for the phone messages to be routed. On board the satellite, extensive use of Microwave Monolithic Integrated Circuits (MMIC) and digital modems built in ASICs are planned to allow the satellite to achieve its low power and small size.

On-Board Processor

The satellites are an active part of the message routing network, due to six on-board computers and extensive use of ASIC circuitry which connects the processors together with high speed memory, the modems and the antennas on the satellite.

Summary

The IRIDIUM Communications System is designed to be a global, digital, satellite-based, personal communications system primarily intended to provide low-density, portable service via handheld subscriber units, employing low-profile antennas. Calls can be made and received anywhere in the world with a personal, pocket-size, portable unit. A constellation of small, "smart" satellites will be internetted to form the network's backbone. Small, battery-powered, cellular-telephone-like user units would communicate directly with the satellites. Terrestrial Gateways interface the satellite network with the Public Switched Telephone Network. The system is intended to complement the terrestrial telephone network in densely populated areas by providing a similar service everywhere else in the world.

The IRIDIUM System is intended to be much more than a satellite system, much more than a radio, much more than a telephone system, much more than the technologies that allow it to be built. The IRIDIUM System is a vision -- a realizable vision -- for a worldwide portable, personal communications system -- a vision whose greatest realization, like the telephone of a century ago, extends beyond today's imagination. The rest of the story still remains to be written.

Subscribers to IRIDIUM Service will be widespread and varied. An international business person with a portable unit in a coat pocket could have easy access to the home office, and the head of a large multinational corporation could quickly call any colleagues, whether they are at home or traveling, on the earth's surface or in the air, anywhere in the world. The mountain climber, skier, or recreational sailor could continue to communicate with family, friends, or business associates. Developing countries without a telephone infra-structure could have subsidized, solar-powered, centrally-located telephone "booths" in every village. Land and sea mining operations could have continuous worldwide service. And, areas experiencing natural disasters could maintain a reliable communications linkage to the rest of the world.

ATM in B-ISDN Communication Systems and VLSI Realization

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ABSTRACT

Asynchronous Transfer Mode (ATM) is considered to be the key technology for realizing B–ISDN.
This paper discusses VLSI trends and the application of VLSIs to realize an ATM switching node system for B-ISDN.
The concept of VLSI realization as related to ATM switching under QOS control, virtual channel handling, usage parameter control, and OAM is addressed in addition to analyzing the required hardware amount.
Finally, VLSI requirements and the future ATM switching system image as suggested by expected VLSI developments are introduced.

1. Introduction

Enhancing ISDN(Integrated Services Digital Networks) capability to achieve broadband capacity will significantly advance the telecommunication world. In recent years, broadband ISDN(B-ISDN) has been adopted as the vehicle with which to provide a wide variety of communication services.
Asynchronous Transfer Mode (ATM) has been widely studied and is recognized as the key technology for implementing B-ISDN. Fig.1 shows possible network services, required transmission speeds, and expected transitions in B-ISDN demands towards the year 2010. The essential functional requirements for B-ISDN services are assumed to be the capability to handle
<1>multi-media traffic from voice to video,
<2>multi-rate traffic from low speed to ultra high speeds, and<3>multi-cast traffic.
ATM has been standardized by ITU-T (International Telecommunication Union - Telecommunication Standardization Sector, formerly CCITT) as the transfer mode for B-ISDN.
Most service specifications, including signaling for B-ISDN, will be finalized by the end of 1994 by ITU-T except the signaling for VBR connection, multi-point connection, bandwidth negotiation and so on.
As the first step in realizing B-ISDN, experimental ATM switching systems and corresponding transmission systems have been built and tested, and some key LSI components have already been developed(1)~(5).
In ATM networks, information such as voice, data, normal video, and super high definition video, is divided into fixed length (53 byte) data blocks, called cells, and these cells are non-periodically transmitted through the networks. This information transfer method realizes the very flexible allocation of transmission capacity.
Furthermore, it will integrate communication technologies and computer technologies so that true multi-media communication services will be achieved. Attractive communication services such as video on demand, tele-pathology, visual telephony and virtual reality can be realized by making full use of the ATM technology.
For implementing practical ATM systems, the requirements shown in Table 1 should be taken into consideration.
ATM systems for B-ISDN should handle various QOS parameters such as cell delay and loss ratio in a multi-media environment.
For example, real time applications such as visual telephony and TV conferencing have strict delay requirements and signals must be delivered within a specified period of time. Other applications such as remote medical examination and network computing have strict cell loss ratio requirements and must be delivered reliably.
Satisfying the above mentioned basic requirements with

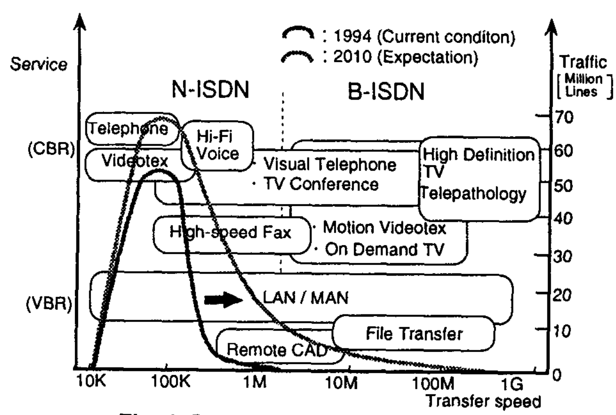

Fig. 1 Broadband network services

Table 1. Basic requirements for the practical ATM system

Item	Requirements	
	Initial stage	Mature stage
(1) Transmission speed (a) Subcriber line (b) Trunk line	(a) ~150Mb/s (b) ~150M/600Mb/s	(a) ~600Mb/s (b) ~10Gb/s
(2) Switching capacity	~several tens thousands of 150 Mb/s lines	~several thousands of 150 Mb/s lines
(3) Switching performance (a) Delay (b) Cell loss rate	(a) < 1 m sec (b) < 10^{-6} ~ 10^{-10}	(a) < several hundred μ sec (b) < 10^{-11}
(4) Virtual channels／line	~several thousands of vertual channels／line	~hundreds thousands of virtual channels／line
(5) Qos classes	one	many
(6) Application	· point to point · CBR	· point to point／multi cast · CBR／VBR

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