Topical Meeting On Photonic Switching

TOPICAL MEETING ON PHOTONIC SWITCHING

Summaries of papers presented at the Photonic Switching Topical Meeting

March 18–20, 1987

Incline Village, Nevada

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TUESDAY, MARCH 17, 1987

LOWER LOBBY

6:00 PM-9:00 PM REGISTRATION/REFRESHMENTS

WEDNESDAY, MARCH 18, 1987

LOWER LOBBY

7:30 AM-6:00 PM REGISTRATION/SPEAKER CHECKIN

LOBBY

7:30 AM-8:30 AM CONTINENTAL BREAKFAST

PROSPECTOR/RUBICON ROOM

8:30 AM-11:40 AM
WA PLENARY SESSION: 1

8:30 AM
OPENING REMARKS
Peter W. Smith, *Meeting General Cochair*

8:50 AM
Linking Technology and Applications, Stewart D. Personick, *Meeting Program Cochair*

9:30 AM (Plenary Paper)
WA1 Overview of Switching Needs for 1990-2000 Plus, Eric Nussbaum, *Bell Communications Research, Inc.* Fiber optics and information services needs will drive new switch requirements. Necessary functional capabilities will include variable bandwidth assignment, high speed reconfigurability, modularity, and distributed intelligence capability. (p. 2)

LOBBY

10:20 AM-10:50 AM COFFEE BREAK

WEDNESDAY, MARCH 18, 1987—*Continued*

PROSPECTOR/RUBICON ROOM

10:50 AM (Plenary Paper)
WA2 Electronic Switching Technologies for Digital Logic, Robert W. Keyes, *IBM T.J. Watson Research Center.* Modern computers represent information as binary digits, the positions of switches. The great success of the transistor in providing these switches is described and projected through the coming decades. (p. 4)

11:40 AM-1:30 PM LUNCH BREAK

PROSPECTOR/RUBICON ROOM

1:30 PM-5:20 PM
WB Joint Photonic Switching and Optical Computing Plenary Session, T. Kenneth Gustafson, *National Science Foundation, Presider*

1:30 PM (Plenary Paper)
WB1 Photonic Switching Components: Current Status and Future Possibilities, John E. Midwinter, *University College London, U.K.* The range of components becoming available for routing signals in optical networks is vast and varied. We review their character and typical performance and point to the network characteristics they support. (p. 8)

2:20 PM (Plenary Paper)
WB2 Optical Digital Computers, Alan Huang, *AT&T Bell Laboratories.* (p. 9)

LOBBY

3:10 PM-3:40 PM COFFEE BREAK

PROSPECTOR/RUBICON ROOM

3:40 PM (Plenary Paper)
WB3 Optical Neural-Net Computer, Demetri Psaltis, *California Institute of Technology.* (p. 9)

4:30 PM (Plenary Paper)
WB4 Switching System/Network Architectural Possibilities, Tadahiko Yasui, Katsuaki Kikuchi, *NTT Electrical Communications Laboratories, Japan.* We describe the present status of optical switching technology and endeavors to enhance the advantages of optical switching systems. (p. 11)

5:20 PM BREAK

LAKESIDE ROOM

6:00 PM-8:00 PM CONFERENCE RECEPTION

THURSDAY, MARCH 19, 1987

LOWER LOBBY

8:00 AM–5:00 PM **REGISTRATION/SPEAKER CHECKIN**

LOBBY

8:00 AM–8:30 AM **CONTINENTAL BREAKFAST**

PROSPECTOR/RUBICON ROOM

8:30 AM–10:00 AM
ThA PHOTONIC SWITCHING SYSTEMS
H. Scott Hinton, *AT&T Bell Laboratories, Presider*

8:30 AM (Invited Paper)
ThA1 Switching Requirements for Broadband Integrated Services Digital Networks, O. Fundneider, *Siemens AG, F. R. Germany.* Introducing broadband services in integrated services digital networks has important impacts on switching technology. The architectural and technological aspects for broadband ISDN are discussed with respect to possible uses of optical switching. (p. 18)

9:00 AM
ThA2 Optical Broadband Communications Network Architecture Utilizing Wavelength-Division Switching Technologies, Syuji Suzuki, Kunio Nagashima, *NEC Corporation, Japan.* Wavelength synchronization is introduced in wavelength-division communications networks. A synchronized wavelength-division switching system, based on semiconductor optical integrated circuits, is also proposed. (p. 21)

9:15 AM
ThA3 Photonic Switching and Digital Cross-Connect Systems, Jonathan A. Nagel, *AT&T Bell Laboratories.* Wideband switches are being introduced into the network. This paper discusses their functions, general features, and potential applications for photonic switching technology. (p. 24)

9:30 AM
ThA4 Optical Switching in Coherent Lightwave Systems, M. Fujiwara, S. Suzuki, K. Emura, M. Kondo, K. Manome, I. Mito, K. Kaede, M. Shikada, M. Sakaguchi, *NEC Corporation, Japan.* Integration of optical switching networks and coherent transmission systems was studied. Space-division switching experiments in a 100-Mb/s optical FSK transmission system using closely spaced (< 5 GHz) transmitter wavelengths were carried out with a $LiNbO_3$ optical switch. (p. 27)

THURSDAY, MARCH 19, 1987—*Continued*

9:45 AM
ThA5 Photonic Switching Demonstration Display, J. R. Erickson, C. G. Hseih, R. F. Huisman, M. L. Larson, J. V. Tokar, G. A. Bogert, E. J. Murphy, R. T. Ku, *AT&T Bell Laboratories.* A switching demonstration display has been built to show the feasibility of routing digital video through a guided-wave photonic switch. (p. 30)

LOBBY

10:00 AM–10:30 AM **COFFEE BREAK**

PROSPECTOR/RUBICON ROOM

10:30 AM–12:00 M
ThB SWITCHING ARCHITECTURES
Alan R. Tedesco, *Bell Communications Research, Inc., Presider*

10:30 AM (Plenary Paper)
ThB1 Introduction to Switching Networks, Vaclave E. Benes, *AT&T Bell Laboratories and Columbia U.* We present a broad tutorial description of connecting network concepts and structures, divided into three categories: combinational, probalistic, and operational, each with suitable examples. (p. 34)

11:15 AM
ThB2 Deterministic and Statistic Circuit Assignment Architectures for Optical Switching Systems, A. de Bosio, C. De Bernardi, F. Melindo, *Centro Studie Laboratori Telecomunicazioni, Italy.* Two architectures are proposed: the first utilizes nonblocking networks operated with label-address techniques; the second uses blocking networks exploiting the wide band of the optical elements. (p. 35)

11:30 AM
ThB3 Dilated Networks for Photonic Switching, Krishnan Padmanabhan, Arun Netravali, *AT&T Bell Laboratories.* We present novel switches optimized for low crosstalk using directional couplers in $LiNbO_3$ as switch elements. The switch has a simple routing algorithm and an optimum number of elements. (p. 38)

11:45 AM
ThB4 Self-Routing Optical Switch with Optical Processing, P. R. Prucnal, D. J. Blumenthal, P. A. Perrier, *Columbia U.* The experimental demonstration of a self-routing optical switch, in which routing information is processed optically on a bit-by-bit basis, is presented. (p. 42)

12:00 M–1:30 PM **LUNCH BREAK**

PROSPECTOR/RUBICON ROOM

1:30 PM–3:00 PM
ThC PHOTONIC SWITCHES: 1
Rod C. Alferness, *AT&T Bell Laboratories, Presider*

1:30 PM (Invited Paper)
ThC1 Optoelectronic Hybrid Switching, R. I. MacDonald, *U. Regina, Canada.* The principles, performance and some possible uses of optoelectronic switching matrices are reviewed, and their advantages and disadvantages compared with other techniques of wideband switching are considered. (p. 46)

2:00 PM
ThC2 Photonic Switching with Stripe Domains, E. J. Torok, J. A. Krawczak, G. L. Nelson, B. S. Fritz, W. A. Harvey, F. G. Hewitt, *Sperry Advanced Optics CTC.* This paper describes an all-optical crossbar switchboard for optical fibers. It is fast, solid state, nonblocking, latching, polarization insensitive, and can handle large numbers of fibers. (p. 49)

2:15 PM
ThC3 Single-Mode Fiber Switch with Simultaneous Loop-Back Feature, W. C. Young, L. Curtis, *Bell Communications Research, Inc.* A moving fiber-array switch providing a bypass function and a simultaneous loop-back circuit has been demonstrated. Fabricated with single-mode fibers the insertion losses for the bypass and on-line positions are 0.38 and 0.33 dB, respectively. (p. 52)

2:30 PM
ThC4 All-Fiber Routing Switch, S. R. Mallinson, J. V. Wright, C. A. Millar, *British Telecom Research Laboratories, U.K.* We report an optical crosspoint switch using a high-index waveguide sandwiched between two polished fiber coupler blocks. (p. 55)

2:45 PM
ThC5 All-Optical Switch for Signal Routing Between Fibers, C. R. Paton, S. D. Smith, A. C. Walker, *Heriot-Watt U., U.K.* An optically bistable nonlinear interference filter has been operated as a spatial switch to route an optical signal carrying video information between fibers. (p. 58)

LOBBY

3:00 PM–3:30 PM COFFEE BREAK

THURSDAY, MARCH 19, 1987—*Continued*

PROSPECTOR/RUBICON ROOM

3:30 PM–5:00 PM
ThD PHOTONIC SWITCHES: 2
Takakiyo Nakagami, *Fujitsu Laboratories, Ltd., Presider*

3:30 PM
ThD1 Monolithically Integrated Optical Gate 2 × 2 Matrix Switch using a GaAs/AlGaAs Multiple Quantum Well Structure, A. Ajisawa, M. Fujiwara, J. Shimizu, M. Sugimoto, M. Uchida, Y. Ohta, *NEC Corporation, Japan;* K. Asakawa, *Optoelectronics Joint Research Laboratories, Japan.* A 2 × 2 optical matrix switch, monolithically integrating multiple quantum well gate and optical circuits fabricated by a reactive ion beam etching method, is described. The switch size can be as small as 3 mm × 1.2 mm. Low crosstalk (20 dB at 9 V) is achieved. (p. 62)

3:45 PM
ThD2 Silicon Carrier-Enhanced Electrooptical Guided-Wave Switch, J. P. Lorenzo, R. A. Soref, *Rome Air Development Center.* An all-silicon 1.3-μm wavelength electrooptical switch is demonstrated for the first time. Partial 2 × 2 switching is observed during minority carrier interjection. (p. 65)

4:00 PM
ThD3 4 × 4 Ti:LiNbO$_3$ Switch Array with Full Broadcast Capability, G. A. Bogert, *AT&T Bell Laboratories.* We present a Ti:LiNbO$_3$ optical switch array which provides full broadcast capability. The architecture integrates directional couplers, *Y*-branches, and intersecting waveguides. The device operates at 13 V and exhibits measurement-limited crosstalk. (p. 68)

4:15 PM
ThD4 New Architecture for Large Integrated Optical Switch Arrays, P. J. Duthie, M. J. Wale, I. Bennion, *Plessey Research (Caswell), Ltd., U.K.* We propose a new reflective switch-array architecture and describe process-tolerant waveguide reflectors. Experimental results from a reduced 8 × 8 Ti:LiNbO$_3$ switch array are presented and used to derive practical maximum array sizes. (p. 71)

4:30 PM
ThD5 System Considerations for Lithium Niobate Photonic Switching Technology, W. A. Payne, H. Scott Hinton, *AT&T Bell Laboratories.* This paper discusses several components and system areas that require development prior to the successful implementation of lithium niobate technology for photonic switching. (p. 74)

THURSDAY, MARCH 19, 1987—*Continued*

4:45 PM
ThD6 High-Speed $\Delta\beta$-Reversal Directional Coupler Switch, R. C. Alferness, L. L. Buhl, S. K. Korotky, R. S. Tucker, *AT&T Bell Laboratories.* An optical directional coupler switch designed for low crosstalk operation for both switch states with multigigahertz toggle rates is described. Experimental and theoretical results are presented. (p. 77)

5:00 PM BREAK

PROSPECTOR/RUBICON ROOM

8:00 PM
ThE POSTDEADLINE PAPERS
John E. Midwinter, *University College London, Presider*

FRIDAY, MARCH 20, 1987

LOWER LOBBY

8:00 AM–5:00 PM REGISTRATION/SPEAKER CHECKIN

LOBBY

8:00 AM–8:30 AM CONTINENTAL BREAKFAST

PROSPECTOR/RUBICON ROOM

8:30 AM–10:00 AM
FA PHOTONIC DEVICES: 1
William J. Stewart, *Plessey Research (Caswell), Ltd., Presider*

8:30 AM (Invited Paper)
FA1 Photonic Switching Devices Based on Multiple Quantum Well Structures, D. A. B. Miller, *AT&T Laboratories.* Quantum well semiconductor structures can be used to make several different electrically and/or optically controlled modulators and switches. Physics and uses are reviewed. (p. 82)

9:00 AM
FA2 Room Temperature Excitonic Nonlinear Absorption in GaAs/AlGaAs Multiple Quantum Well Structures Grown by Metalorganic Chemical Vapor Deposition, H. C. Lee, A. Hariz, P. D. Dapkus, A. Kost, M. Kawase, E. Garmire, *U. Southern California.* A strong saturation effect of the excitonic absorption in GaAs/AlGaAs MQW structures grown by MOCVD has been achieved at room temperature, with low saturation intensity (249 W/cm²). (p. 85)

9:15 AM
FA3 Hard-Limiting Optoelectronic Logic Devices, P. Wheatley, M. Whitehead, P. J. Bradley, G. Parry, John E. Midwinter, *University College London, U.K.;* P. Mistry, M. A. Pate, J. S. Roberts, *U. Sheffield, U.K.* We report the first demonstration of a novel optoelectronic device for optical logic having an inverting characteristic that displays hard limiting and optical gain. (p. 88)

9:30 AM
FA4 Picosecond Optical Beam Coupling in Photorefractive GaAs, George C. Valley, Arthur L. Smirl, *Hughes Research Laboratories;* Klaus Bohnert, Thomas F. Boggess, *North Texas State U.* Picosecond optical beam coupling as a function of time delay is reported showing competition between photorefractive and free-carrier transient energy transfer and two-photon absorption. (p. 91)

9:45 AM
FA5 Nonlinear Optical Logic Etalon at Today's Fiber Communication Wavelengths, K. Tai, J. L. Jewell, W. T. Tsang, *AT&T Bell Laboratories.* We have constructed all-optical logic etalons operating in the 1.57-μm wavelength region using InGaAs/InP MQW structures. These etalons require several pJ switching energy, exhibit high on/off contrast with large on-state transmission and several ns recovery time, and have signal gain. (p. 94)

LOBBY

10:00 AM–10:30 AM COFFEE BREAK

PROSPECTOR/RUBICON ROOM

10:30 AM–12:00 M
FB HOLOGRAPHY AND BISTABILITY
Eric Spitz, *Thompson CSF, Presider*

10:30 AM (Invited Paper)
FB1 Wave Mixing in Nonlinear Photorefractive Materials; Applications to Dynamic Beam Switching and Deflection, Jean-Pierre Huignard, *Thomson-CSF, France.* Wave mixing in photorefractive crystals leads to new dynamic functions in optics. A review of the basic aspects of the beam interactions is presented as well as laboratory demonstrations of optically controlled beam deflection and switching devices. (p. 98)

11:00 AM
FB2 Design and Construction of Holographic Optical Elements for Photonic Switching Applications, M. R. Taghizadeh, I. R. Redmond, A. C. Walker, S. D. Smith, *Heriot-Watt U., U.K.* We report the simultaneous operation of a 2-D array of all-optically bistable switches in ZnSe nonlinear interference filter using a dichromated gelatin holographic array generator. (p. 104)

11:15 AM
FB3 Optical Threshold Mechanism using a Fiber Coupled Phase-Conjugate Mirror, Ram Yahalom, Aharon Agranat, Amnon Yariv, *California Institute of Technology.* We describe a new optical phenomenon in which the phase conjugate power of mutually incoherent light beams is determined by their relative input power. Its potential as a threshold mechanism is briefly discussed. (p. 107)

FRIDAY, MARCH 20, 1987—*Continued*

11:30 AM
FB4 Computational Properties of Nonlinear Optical Devices, Michael E. Prise, Norbert Streibl, Maralene M. Downs, *AT&T Bell Laboratories.* We derive the relationships between the optical properties of devices (transmission and contrast) and their potential computational properties (fan-in and fan-out), when used in an optical digital computer. The required accuracy of intensity levels in the system is discussed. (p. 110)

11:45 AM
FB5 Operating Curves for Optical Bistable Devices, P. Wheatley, John E. Midwinter, *University College London, U.K.* A method of presenting the steady state and dynamic responses of optical bistable devices is explained; it can be used to show the capabilities of such devices and their suitability for sequential logic. (p. 113)

12:00 M LUNCH BREAK

PROSPECTOR/RUBICON ROOM

1:30 PM–3:00 PM
FC PHOTONIC DEVICES: 2
W. Jack Tomlinson, *Bell Communications Research, Inc., Presider*

1:30 PM (Invited Paper)
FC1 Optical Amplifiers for Photonic Switches, R. M. Jopson, G. Eisenstein, *AT&T Bell Laboratories.* Optical amplifiers will play an important role in photonic switches. We describe the basic properties and limitations of practical optical amplifiers. (p. 116)

2:00 PM
FC2 170-ps Fast Switching Response in Bistable Laser Diodes with Electrically Controlled Saturable Absorber, Akihisa Tomita, Shunsuke Ohkouchi, Akira Suzuki, *NEC Corporation, Japan.* Fast switching in a bistable laser diode was achieved by controlling the carrier density electrically through the loss section electrode. The turn-off time was reduced to 170 ps. (p. 119)

2:15 PM
FC3 Organic Materials for Nonlinear Optics, R. D. Small, J. E. Sohn, K. D. Singer, M. G. Kuzyk, *AT&T Engineering Research Center.* Organic and polymeric materials are discussed in the context of nonlinear optics, including our development of doped poled polymer glasses for use in nonlinear optics. (p. 123)

2:30 PM
FC4 Physical and Optical Properties of Cd(Se,S) Microcrystallites in Glass, D. W. Hall, N. F. Borrelli, *Corning Glass Works.* Commercially available filters and experimental glasses containing Cd(Se,S) microcrystallites are studied using x-ray diffraction, TEM, wet-chemical analysis, photoluminescence, and linear and nonlinear absorption measurements. (p. 125)

2:45 PM
FC5 Dynamics of Photonic Switching in Indium Antimonide, H. A. MacKenzie, J. Young, H. A. Al-Attar, *Heriot-Watt U., U.K.* Results are presented which characterize both the dynamic switching and noise dependence of single bistable channels and the transfer of switching in adjacent channels. (p. 128)

LOBBY

3:00 PM–3:30 PM COFFEE BREAK

PROSPECTOR/RUBICON ROOM

3:30 PM–5:00 PM
FD TIME-DIVISION SWITCHING
Flavio Melindo, *CSELT, Presider*

3:30 PM (Invited Paper)
FD1 Photonic Time-Division Switching Technology, Hirokazu Goto, *NEC Corporation, Japan.* The principles and present state of optical time-division switching technology are described. Further studies aimed at the achievement of large-capacity switching systems are also discussed. (p. 132)

4:00 PM
FD2 A 1.5-Gb/s Time-Multiplexed Photonic Switching Experiment, J. R. Erickson, R. A. Nordin, W. A. Payne, M. T. Ratajack, *AT&T Bell Laboratories.* We describe a time-multiplexed photonic switch that routes 45-Mb/s channels which are block multiplexed to 1.5 Gb/s. The switch is nonblocking and capable of broadcasting. (p. 135)

4:15 PM
FD3 4-Gb/s Optical Time-Division Multiplexed System Experiments using Ti:LiNbO$_3$ Switch/Modulators, R. S. Tucker, S. K. Korotky, G. Eisenstein, U. Koren, G. Raybon, J. J. Veselka, L. L. Buhl, B. L. Kasper, R. C. Alferness, *AT&T Bell Laboratories.* We demonstrate the use of high-speed Ti:LiNbO$_3$ switch/modulators in a 4-Gb/s optical time-division multiplexed fiber transmission system based on mode-locked semiconductor lasers. (p. 138)

FRIDAY, MARCH 20, 1987—*Continued*

4:30 PM
FD4 Optimizing Photonic Variable-Integer-Delay Circuits, Richard A. Thompson, *AT&T Bell Laboratories.* For three different structures, we investigate the total number of photonic switches and the number of switches through which a photonic signal must pass. (p. 141)

4:45 PM
FD5 Photonic Switch Architecture utilizing Code Division Multiplexing, T. S. Rzeszewski, A. L. Lentine, *AT&T Bell Laboratories.* Code-division multiplexing is a means of making a multiplicity of input channels orthogonal, so that any input to a code division (CD) switch can be switched to any output. This type of switch is nonblocking and has inherent broadcast capability. A photonic implementation of a CD switch and combinations of CD with time, space and wavelength division switching are discussed. (p. 144)

5:00 PM CLOSING REMARKS

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WEDNESDAY, MARCH 18, 1987

PROSPECTOR/RUBICON ROOM

8:30 AM–11:40 AM

WA1–2

PLENARY SESSION: 1

Overview of Switching Needs for 1990-2000+

E. Nussbaum
435 South Street, Room 2A-213
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Morristown, NJ 07960

Summary

Research and development underway 30 years ago brought about today's world of stored program controlled digital switching. The confluence of three key elements was the trigger for this new era in switching--the transistor, the basic concepts of stored program controlled computing, and the techniques of digital communication in the form of PCM. Today, roughly one quarter of the world's 400 million telephone lines are served by central offices deploying most of these technologies. Though stored program gave these switches considerable new flexibility for customer features and allowed great strides in automation and simplification of maintenance and operations, the new technology was primarily deployed as a one-for-one cost reduction element for its electromechanical predecessors in the existing network--effectively a replacement vehicle between existing mainframes.

Today the prime technological driving force in the network is, of course, fiber optics. Along with that has come an enormous increase in the speed capability of the driving electronics, allowing for high speed data interchange and digital encoding of all information up to and including full motion video. These elements, together with the associated progress in computing power and storage capabilities, are the foundation of the so-called information age in which all forms of information are transmitted, stored, and processed electronically, be they voice, data, image, or video. To meet these "information age" needs, the next generation of switch, unlike previous generations in electronic switches, will require major new functionality in the switching network and its control, and most probably a redefinition of the role of the switch in the conventional telephony hierarchy. Some specific characteristics required to meet the needs in this new era include:

A. Capability for switching high bandwidths measured into the hundreds of Mb/s as opposed to the 64 kb/s standard rate prevalent to date.

B. Dynamic bandwidth assignment capabilities to allow a user to "dial up" the amount of bandwidth needed for the occasion, be it a low bandwidth interactive data transfer, or speech, or a high speed burst of data for bulk loading, or "continuous high speed data" such as full motion video.

C. Non-symmetric bandwidth capabilities allowing a user to have differing upstream and downstream channel capabilities as required, since users will often be using communication nets to access remote data bases with a query that is very brief compared to the response data supplied.

D. A very fast switching reconfigurability, be it fast circuit or high speed packet switching, to allow multiple routing paths for the multimedia mix of traffic necessary to meet the information needs described above.

E. Broadcast or multipoint capability to more readily allow the use of telecommunications networks for conferencing, narrowcasting, and even full fledged broadcasting (as in cable TV).

F. New topological structures that distinguish the function of switching individual channels within a whole facility at some points in a hierarchy, while switching larger "hunks" elsewhere in the hierarchy, driven by the dramatic change in the cost ratio of switching and transmission with the advent of fiber optic transmission systems.

G. Increased reliance on distributed intelligence and control to separate physical control of switching configurations from the geographic constraint of the associated controller, and instead allow for a

network of "data bases" interconnected at high speeds (again using a fiber optic technology) to control an entire network in a far more efficient and flexible manner.

Put together these factors all indicate the next generation of switch is unlikely to be a one-for-one physical and functional replacement from today's switching technology. The combination of technological and service triggers will instead help redefine the structure of the entire network and the nature of the services it can provide.

For optical switching to play a major role in this next generation of communication networks it must fulfill the requirements of the vast majority of the aforementioned points. To do so, it must compete with steadily improving costs and performance of silicon and the coming GaAs alternatives. To meet the functionality requirement in large scale networks, optical switches will have to be able to individually and rapidly switch the multiple channels of information and signaling emanating from each fiber, provide the capability for individual buffering and reconfiguration of bits for digital network interfaces and synchronization, and perform optical regeneration if information is to be kept in an all optical domain over large geographic areas. The limitations of performing these functions at the electronic level are primarily the cost of the E/O interfaces required, and of the extensive multiplex and demultiplexing necessary to separate and isolate channels. At the performance level the limitations occur when speeds of more than several hundred Mb/s per second are to be switched. The future of optical switching as a ubiquitous technology to move us towards all optical domain networks depends on its ability to meet these functional needs and to compete economically with the electronic alternatives.

It seems likely that to achieve that will require a total rethinking of traditional network structures and elements into a form that bears little relationship to the current partition of transmission, switching and control elements. Probable earlier steps to introduce more optics into switching might include its use in such areas as: a) lower functionality (cross connect) switching at limited high level points in the network and b) hybrid optoelectronic structures performing relatively simple high speed functions (e.g. multiplexing) combined with more conventional electronic implementation of complex lower speed functions. Modular structures to allow such technology upgrades are an important overall consideration in new switch and network architectures.

Overview of Electronic Switching Technologies for Digital Logic

Robert W. Keyes

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Yorktown Heights, NY 10598

Modern computation depends on the representation of information in digital form. "Digital" means that there are a discrete set of signal values. All contemporary electronic logic uses just two digits, binary representation of information. There are two recognizable signal values. A binary unit of information is known as a bit. It can be represented by the position of a switch of the familiar ON-OFF type. The state of the switch or the signal is also conveniently represented by a 0 or a 1.

- Why Switches? -

One might wonder: why digital? The answer is well-known, although not always well-remembered. Although representation of information by a continuous signal that can have an infinite number of values can represent an infinite amount of information, the ability to use this capacity is limited by noise and the accuracy of measuring instruments. Digital representation means that only a discrete set of standard signal values must be distinguished. Arbitrary accuracy in the representation can be obtained by the use of enough digits.

One might further ask: why binary? The answer lies in the requirement that the signal values that represent the digits must be well-separated; the digits must be recognizable in spite of attenuation and distortion suffered in transmission from one place to another and in spite of the imperfections of sending and receiving devices. The clearest separation is afforded by using only two signal values. It is also easy to make physical devices with two clearly distinguishable physical states, e.g., there is or is not a magnetic bubble at a certain location, a ferromagnetic torus has two low energy states, a relay contact is either open or closed. Obviously other number systems could be used. Some have been investigated, but none has led to machines with the reliability, accuracy, and speed of binary digital computers. Thus the state of the art of computation is closely related to the state of development of electronic on-off switches.

- The Transistor -

Although many physical phenomena of a switching character are known, large digital systems have only been realized with three: relays, vacuum tubes, and transistors. These three types of devices depend on essentially the same mode of operation, which, though simple and familiar, also is sometimes forgotten. One of the two signal values applied to an input terminal establishes a connection between an output terminal and one of the power supply leads. The other input signal value opens this connection and permits the output to assume the value of the other power supply lead. Thus the values of the output are determined by power supply voltages distributed throughout the system.

Although relays and vacuum tubes have been used to construct large systems, they were rapidly displaced by transistors not long after the invention of the latter device. The transistor fitted the needs of systems containing thousands of logic gates for devices of low cost, high reliability and low power dissipation extremely well. Furthermore, the transistor turned out to have almost unlimited potential for miniaturization; the pace of improvements in all aspects of transistor performance stagger the imagination and defy all suggestions of problems that seem to limit the technology. The experience of the past two decades lends confidence to the extrapolation of current trends to a considerable distance into the future.

- The Future -

The themes that have characterized transistor development through the past two decades have been integration and miniaturization, the latter being an essential element of the former. These directions have been the key to low cost, low power, and high reliability, and, in addition, have led to high speed through reduction of capacitances and of the distances between elements. The history of miniaturization and integration can be projected to provide a basis for a picture of the chips of the future. Such projections will be presented. The picture obtained differs so dramatically from the chips of today that the forecast is hard to accept. Yet progress has continued in the face of similar doubts in the past.

Quite a few effects inhibit progress to smaller dimensions and higher levels of integration. New fabrication techniques offering finer resolution, more accurate alignment, and greater control must be developed. Electric fields increase, accelerating the deleterious effects of hot electrons. High-speed systems demand large currents; current densities increase with miniaturization. The high current densities cause electromigration, increase the losses at contacts, and affect the operation of devices.

Integration poses its own set of problems. Highly integrated chips in high-speed systems consume large amounts of power that must be supplied through miniaturized contacts to the chip and removed by elaborate cooling means. Increasing off-chip communication capacity is also needed by increasingly integrated chips that are part of a large system. Even chips that constitute a self-contained system use increasing word lengths that need more off-chip contacts. The amount of wire necessary to provide communication on a chip also increases rapidly with increasing levels of integration.

Digital switching is used in a variety of information-handling products, such as memories, microprocessors, and high-speed gate arrays, each filling some niche in a cost-functionality space. Attack on each usually proceeds simultaneously on several technical fronts, as the existence of several types of transistor and their flexibility in fitting into a wide variety of circuit configurations offers many options. Bipolar transistors and field-effect transistors, NMOS and CMOS, silicon and gallium arsenide constantly compete for a place in applications. Limitations of one technology may provide opportunities for another.

The speed of switching devices and comparisons of speed among devices attract large amounts of attention. Speed can be measured at various levels. A single device can be selected and tuned to demonstrate high speed switching. This is more difficult in an integrated ring oscillator, where ten or twenty devices must all operate simultaneously. Large load capacitances that must be charged and possible variability among devices must additionally be taken into account in functional units of useful size. Speed in a large mainframe computer is dependent not only on the properties of switching devices but on the ingenuity of engineers in supplying power and removing heat at high densities and in providing a compact network of interconnections among chips. The large numbers of components demand attention to economic considerations. The significance of simple measures of speed to performance in complex applications is often obscure.

- Conclusion -

The difficulties that one sees in realizing the extrapolations of transistor switches into the future are the challenges that the scientists and engineers who will be responsible for implementing the technologies of the future will have to face. History provides reason to believe that the challenges will be successfully met.

WEDNESDAY, MARCH 18, 1987

PROSPECTOR/RUBICON ROOM

1:30 PM–5:20 PM

WB1–4

JOINT PHOTONIC SWITCHING AND OPTICAL COMPUTING PLENARY SESSION

T. Kenneth Gustafson, National Science Foundation
Presider