INTRODUCTION

In this issue of the History Column we provide a brief review of the work of Hiroshi Inose, an outstanding contributor to the field of communications engineering, who passed away some eight years ago.

We noted some months ago, in introducing this series of History Columns, that we would be soliciting various types of papers of historical interest to our field. We have already published articles by original contributors to significant developments in the field, as well as articles involving subjects of great historical interest that occurred many years ago. We are continuing to solicit papers of this type and will be publishing them as soon as they are made available to us. The third type we will be publishing, of which the following article on Prof. Inose provides a fine example, consists of retrospective evaluations of the work of key individuals from throughout the world whose engineering activities during their lifetimes made a significant difference to our field, and, in turn, the world at large. By so honoring them, we honor all engineers who are currently involved in significantly improving worldwide communications.

DR. HIROSHI INOSE'S PIONEERING CONTRIBUTIONS TO DIGITAL SWITCHING SYSTEMS AND HIS OUTSTANDING LEADERSHIP IN INFORMATICS

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ABSTRACT

The idea of time slot interchange (TSI), the fundamental concept of implementing time switches in digital switching systems, was first conceived by Dr. Hiroshi Inose, then at the University of Tokyo, Japan, in 1957 while he was a visiting consultant at Bell Telephone Laboratories. The TSI collects each subscriber's pulse code modulation (PCM)-coded voice information to be stored into a small time interval (time slot), and then aligns multiple time slots on a common transmission bus to constitute a repetitive frame. The TSI enables any time slot to be interchanged with another time slot within a frame once the time slots in the frame are buffered in memories. Thus, TSI gives the time switch functionality equivalent to *N*-input by *N*-output space switch functionality.

He built a prototype digital time-division multiplexing (TDM) electronic switching system called CAMPUS, which is based on the TSI principle, using a magnetostrictive delay line as a memory device. TSI received little attention until the end of the 1960s because memory devices were very costly. However, with the rapid advancement of semiconductor technologies in the 1970s, the TSI scheme became more widespread. TSI was first commercially deployed in 1976 as the time switch of AT&T's no. 4 ESS, the world's first stored-program control time-division switching system. Since then, TSI has been used in almost all digital central office switching systems and digital private branch exchanges (PBXs).

Dr. Inose's contributions were not limited to research on such things as switching systems, PCM integrated communications, computer communications, and road traffic control systems; he was also actively involved in a number of Japanese governmental and international activities in the area of communications and information processing technologies. His final work was the establishment of the National Institute of Informatics (NII) in 2000, Japan's sole comprehensive academic institute in the field of informatics that seeks to advance integrated research and development activities in information-related fields.

DR. HIROSHI INOSE

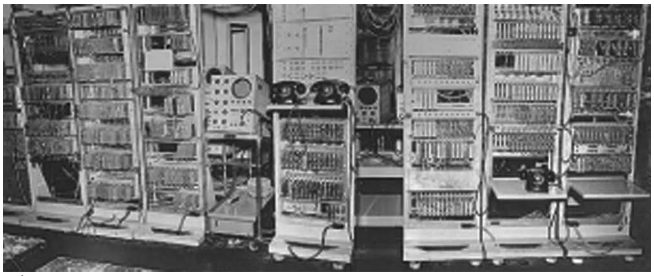
INTRODUCTION

The idea of TSI [1], the fundamental concept for implementing time switches in digital switching systems, was first conceived by Associate Professor Hiroshi Inose in 1957, when he was with the University of Tokyo, Japan, and a visiting consultant in the experimental ESSEX project at Bell Telephone Laboratories, Murray Hill, New Jersey.

Hiroshi lnose was born in Tokyo on January 5, 1927. He received B.E. and D.E. degrees from the University of Tokyo in 1948 and 1955, respectively. Dr. Inose was a professor of electronic engineering at the University of Tokyo from July 1961 to March 1987 and served as the dean of the Faculty of Engineering as well as the director of the Computer Center. He held the title of Professor Emeritus at the University of Tokyo until his untimely death October 11, 2000.

The ESSEX project was a prototype telephone switching system that tried to handle switching and transmissions using PCM technology in a unified manner. At that time, the conventional approach for PCM-based switching systems was to simply align 24 PCM channels (equivalent to "time slots" in this example) for digitized voice signals in a repetitive frame and switch these time slots in a cyclic order. Consequently, if the time slot location in the frame associated with the specified input happened to coincide with the time slot location associated with the specified output, the switching from the input to the output could successfully be carried out. However, if the time slot location (e.g., #2 in the frame) associated with the specified input happened to be different from the time slot location (e.g., #4 in the frame) associated with the specified output, there was no way to switch from the input to the output. Dr. Inose recollected feeling that something was wrong with the conventional approach and that a solution must be found to solve this problem. The idea that ultimately led to the solution suddenly came to him on July 4, 1957, while watching the U.S. Independence Day fireworks and drinking a mug of beer with his colleagues on the roof of an apartment building near the Bell Telephone Laboratories. His solution was very simple: to temporarily store the data in a time slot, using some kind of memory storage, thus delaying the readout of the stored data until it was necessary. Thus, storing time slots made it possible to arbitrarily interchange any time slot in the frame from one to another. This was the invention of time slot interchange (TSI). In order to implement the TSI concept, a fixed number of time slots, each for an associated active telephone subscriber, are multiplexed into a single repetitive frame on a single common transmission bus. Then the incoming time slots in the frame are sequentially stored in the memory. If the order of the readout from the memory is changed from the order of writing into the memory in a controlled way, the desired time slot in a frame can be extracted in the output at an appropriate time. Thus, the TSI gives time switch functionality equivalent to N-input by N-output matrix space switch functionality.

TSI allowed switching and transmission functions to be really integrated in a unified manner using PCM technologies and the concept of a digital network to be constructed very economically [2]. This concept came true with the worldwide deployment of the integrated services digital network (ISDN) almost 30 years after TSI was invented.



The CAMPUS prototype system.

TSI PROTOTYPE IMPLEMENTATION AND WIDESPREAD DEPLOYMENT AS TIME SWITCHES

Immediately after his return to Japan in 1958, he started the Coded and Multiplexed Exchange Using Pulse Shift (CAMPUS) project at the University of Tokyo to create a prototype digital TDM electronic switching system based on the TSI principle. Bell Telephone Laboratories decided to entrust Prof. Inose with the research on TSI, initially giving him \$5000/year for his efforts and then \$10,000/year later on. These amounts of money were exceptionally large for universities in Japan in the 1950s and 1960s. Bell Telephone Laboratories' financial support continued for almost 20 years.

CAMPUS used a magnetostrictive delay line as a memory device. The magnetostrictive delay line could achieve a 1-μs delay for the 0.5 cm nickel-made delay-line length so that 20 taps were attached in series to the magnetostrictive delay line, with 0.5 cm intervals between adjacent taps. This constitutes a shift-register that can handle 20 time slots in a 20-μs frame, each with a 1-μs duration (time slot). As the nth tap is attached to the delay line output, any input time slot could be extracted as an output time slot from the nth tap with n delay unit times. Therefore, controlling when to extract the shifted input time slot from the delay line enables the ith time slot to arbitrarily be interchanged into the jth time slot, meaning the ith subscriber line can be connected to the jth subscriber line through the TSI-based time switch. A CAMPUS prototype system incorporating a 20-input by 20-output time switch with seven Electronic Industries Alliance (EIA) standard bays and one power supply bay was completed in 1962. Just before the completion of the system, Dr. H. E. Vaughan of Bell Telephone Laboratories and his colleagues visited the University of Tokyo to check on the CAMPUS prototype system and confirm the feasibility of the TSI principle. Based on the experiments and evaluation of the CAMPUS system, a patent application was jointly filed with Bell Telephone Laboratories to the U.S. Patent Office on April 27, 1960 and patented on March 9, 1965 [1]. Research papers were also published [3]. Professor Inose had a strong belief that the key idea should be created well before any others, be economical, and its feasibility should be confirmed through real construction or experimentation of the system. The CAMPUS project was one of the better examples that embodied his belief.

As TSI requires large memory capacity, it was criticized as costly and impractical until the end of the 1960s because memory devices were very costly. However, with the rapid advancement of semiconductor technologies in the 1970s, the TSI scheme was widely accepted due to decreasing cost and space. The TSI scheme was first commercially deployed as a time switch for the AT&T's no. 4 ESS, the world's first stored-program control time-division switching system, in 1976. Since then, TSI has been used in almost every digital central office switching system and digital private branch exchange (PBX) in the world. For example, one of the advanced switching nodes, NS8000 MHN-S, used in Nippon Telegraph and Telephone Corporation's (NTT's) telecommunication network in Japan incorporates a maximum of 64k-channel-based, 80k-input by 80k-output time-switch [4], using 16k-input by 16k-output time-switch large-scale integrations (LSIs) to accommodate over 23,000 ISDN subscribers.

In summary, it is amazing that such a simple but elegant TSI scheme has penetrated almost all time-division digital switching systems worldwide.

STRONG LEADERSHIP FOR A LARGE AND COMPLEX SOCIETY STRIVING FOR EXCELLENCE

Dr. Inose's contributions were not limited to only time-division digital switching, but widely covered many areas ranging from technology to social science, such as switching, PCM integrated communications, mutually synchronized systems, coding, digital transmissions, computer communications, road traffic control, automatic diagnosis, databases, natural language processing, electronic circuits, information technology and society, and science and technology policies. Among these achievements, the coding research includes the invention of the Δ-Σ code modulation scheme [5] in 1961 as a byproduct of the CAMPUS project.

In the area of road traffic control, many cities throughout the world suffered from heavy traffic congestion in the 1950s. This is because too many automobiles made it difficult for computers to control traffic, and real roads were too complicated to analyze. Therefore, no effective control means existed at that time. Dr. Inose solved this problem by introducing a macroscopic traffic model and applied his research results to the development of the Tokyo road traffic control system, which included thousands of traffic signals and automobile detectors [6, 7]. Later, this system became the standard model and was widely deployed in many other cities in Japan.

Moreover, he promoted the development of a computer communications network, N-1, to connect seven interuniversity computer centers in the late 1960s [8]. The N-1 network has now led to SINET3 [9], a Japanese academic backbone network with a maximum 40-Gb/s bandwidth, which is used to connect over 700 universities and research institutions throughout Japan to the Internet.

Along with these research efforts, Dr. Inose gradually expanded his professional activities into giving opinions and advice on information technologies and governmental policies. He contributed to:

- Various governmental decisions on national policies through many government-relevant committees
- International activities in the OECD by publishing papers and giving presentations on the relations between information technologies and society [10]
- Science and technology policies [11]

Because of the above research and social contributions, he was awarded numerous prizes, including the Second Marconi International Fellowship in 1976, the IEEE International Communication Prize in 1982, the Order of Culture from the Japanese Government in 1991, the Alexander Graham Bell Medal in 1994, and the IEEE Third Millennium Medal in 2000. As for his activities in academic societies, he was elected Vice President of the IEEE Communications Society in 1980, President of the Information Processing Society in Japan (IPSJ) in 1981, and President of the Institute of Electronics and Communication Engineers (IECE at that time and now IEICE) in 1985.

Dr. Inose continued to have a long-term objective of contributing to the development of academic fields and improving people's lives, cultures, and industries by promoting information-related researches and an academic information infrastructure. In order to achieve this objective, he promoted a plan devoted to establishing the National Institute of Informatics (NII) that seeks to advance integrated research and development activities in information-related fields. These activities range from theoretical concepts to applications, and from science and technology to humanities and social science. His dream was realized by establishing the NII and being inaugurated as the first Director General of NII in April 2000. On October 11, 2000 just after the opening ceremony of NII on October 6, he suddenly passed away at the age of 73. Many condolences were expressed to his family from people all over the world who were impressed by Dr. Inose's dedicated passion and his widely recognized leadership in progress in the information technology field.

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BIOGRAPHIES

MASAO SAKAUCHI [M] is a director general of the National Institute of Informatics, Japan, and a professor in the Institute of Industrial Science at the University of Tokyo. He received a B.Sc. degree in electrical engineering from the University of Tokyo in 1969, and M.S. and Ph.D. degrees in electronics engineering from the University of Tokyo in 1971 and 1975, respectively. He has acted as the general chairman and program chairman of 10 international conferences and workshops, including the IEEE International Workshop on Machine Vision and Machine Intelligence (1987), IAPR, and IEEE International Conference on Document Analysis and Recognition (1993), IEEE International Conference of Multimedia Processing and Systems (1996), and Intelligent Transportation Systems Conference (1999). He has authored more than 407 refereed papers in the research fields of multimedia databases, multimedia systems, image processing and understanding spatial data structures, geographical information systems, and fault-tolerant computing.

SHIGEKI YAMADA [SM] is a professor and director of the Research and Development Center for Academic Networks, National Institute of Informatics, Japan. He received his B.E., M.E., and Ph.D. degrees in electronic engineering from Hokkaido University in 1972, 1974, and 1991, respectively. He worked in the NTT laboratories from 1974 to 1999, where he was involved in the R&D of NTT's D10 stored-program control analog switching system, D60/D70 digital switching systems, network-wide distributed systems, and distributed network architecture. From 1981 to 1982 he was a visiting scientist in the Computer Science Department, University of California, Los Angeles. He moved to NII in 1999, where he is involved in the design and deployment of the Japanese academic network, SINET3. His current research interests include future network architecture, and ubiquitous and mobile networks. He has authored more than 80 refereed papers, and holds three U.S. patents in the research fields of switching systems and networks. He is a member of IEICE and IPSJ.