Switching Technology
(1925–1975)
A History of Engineering and Science in the Bell System

Switching Technology
(1925–1975)

Prepared by A. E. Joel, Jr. and Other Members of the Technical Staff, Bell Telephone Laboratories
G. E. Schindler, Jr., Editor.

Bell Telephone Laboratories, Incorporated
Credits for figures taken from other than Bell Laboratories sources appear on page 601.

Copyright ©1982
Bell Telephone Laboratories, Inc.
All rights reserved

First Printing, 1982
International Standard Book Number: 0-932764-02-9
Library of Congress Catalog Card Number: 82-072517
Printed in the United States of America
Contents

Foreword ............................................................... ix

Acknowledgments ......................................................... xiii

1. Setting and Scope .................................................. 1
   I. The Setting, 1.    II. Scope, 2.

2. State of the Art in 1925 ......................................... 7
   References, 9.


4. Introduction of Crossbar ........................................... 59
   I. Genesis of Crossbar in the Bell System, 59: The Coordinate Switching System, 61; Resumption of Work on the Crossbar Switch, 63; Switchboard Tandem Trunk Concentrator, 65; Other Apparatus Developments, 66.    II. Local Crossbar, 67: No. 1 Crossbar System, 68; Crossbar Tandem, 73; No. 2 Crossbar System, 76; Early Crossbar CDOs and PBXs, 78.    III. Toll Crossbar, 78.    References, 84.
5. The Better Understanding of Switching .................. 87

I. Early Research Contributions, 87. II. New System Ideas and Trades, 92: Automatic Ticketing, 92; Step-by-Step Senderization, 93; Higher Speed Step-by-Step, 93; Motorelay System, 93; The "Browser" Group, 94. III. Traffic Theory and Engineering, 95: Interoffice Networks, 96; Switching Center Networks, 100; Traffic Measurement (see also Chapter 11, section 3.4), 103; Other Traffic Activities, 107. IV. Other Theoretical Studies, 110. V. From Boolean Algebra to Switching Algebra and Synthesis, 111. VI. The Teaching of Switching, 112. VII. Documentation, 113. VIII. Improvements in System Reliability, 113. References, 116.

6. Preparing for Full Automation ......................... 121

I. The Switching Product Line of 1945, 121. II. Needs for Dial Service in the Smaller and Suburban Communities, 122. III. Nationwide Calling, 122: Operator Distance Dialing, 123; Nationwide Numbering Plan, 123. IV. Longer Distance Signaling, 128. V. Charge Recording Methods, 130: Automatic Ticketing, 130; Automatic Message Accounting, 135; Centralization of AMA, 142; Automatic Number Identification, 148. References, 153.

7. No. 5 Crossbar ............................................ 157


8. Direct Distance Dialing .................................. 173

I. Nationwide Planning, 173. II. No. 4A Crossbar, 180: No. 4A and 4M Crossbar, 180; Card Translator, 181; Cost Reduction and Capacity Improvements, 185; III. The Full Stature of Crossbar Tandem, 188: Centralized Automatic Message Accounting (CAMA), 188; Toll Features, 190. IV. Auxiliary Senders, 190. V. International DDD (IDDD), 192. References, 196.

9. Beginnings of Electronic Switching .................... 199

I. Early Applications of Electronics, 199. II. The Start of Systems Thinking, 200. III. Research System Experiments, 202. IV. The Start of Electronic Switching Development, 203: System Studies, 203; 1952—1954 Studies, 212; Exploratory Development, 214; Towards an Electronic Central Office—Pre-Morris, 225; Electronic PBX, 228; The Morris Field Trial,
10. The Complete Electronic Switching Family .......... 307


11. The Service and Feature Era .............................. 335

I. Introduction of New Services, 336: TOUCH-TONE* Service, 336; Wide Area Telephone Service (WATS), 342; INWATS, 343; Centrex (also see Chapter 13, section 3.1), 344; Automatic Identified Outward Dialing (AIOD) and Direct Inward Dialing (DID), 346; Data Services, 350; Emergency Service—911, 352; Coin Service, 355; Common-Control Switching Arrangement (CCSA), 358; Expanded DDD, 359; Automated Intercept Service, 359; Mechanization of Service Evaluation, 361; Switching for PICTUREPHONE* Visual Telephone Service, 362; Electronics in Local Electromechanical Switching, 363; Other New Services, 366. II. Growth of Service, 368: Unigauge, 368; Foreign Area Translation, 369; All Number Calling, 370; New Numbering Plan, 370; Local/ Tandum/Toll, 371; No. 5 Crossbar Route Translator, 372; Directory Assistance, 372; Charging, 378; Increased Crossbar System Capacity, 382; Party Lines and Concentrators, 382. III. Quality of Service, 385: DDD Improvements, 386; Main Distributing Frame (MDF), 388; Maintenance Improvement, 389; Traffic Measurement Systems, 400; New York Fire, 409. IV. New Features Made Possible by Electronic Switching, 411: Custom Calling Services, 411; Feature Growth, 412. References, 414.

*Registered service mark of AT&T Co.
12. The Integrated Digital Toll Network .......... 421

I. No. 4 ESS—Integrated Transmission and Switching, 421. II. Maintenance and Administrative Techniques, 427. III. Common Channel Signaling, 430. IV. Stored-Program Controlled Network, 438. References, 440.

13. Private Branch Exchanges, Key Telephone Systems, and Special Systems ................. 443

I. Beginning the Second Half Century, 443. II. Continued Evolution of PBX Systems, 444: The Thirties, 444; The Forties—War and Post-War, 447; The Fifties—Improvement, Change, Innovation, 451; The Sixties—Solid State and Super Services, 455; The Seventies—Realization of the Electronic Promise, 479. III. Technology of Major PBX Service Innovations, 494: Centrex, 494; PBX Switchboard Innovations, 513; Innovations in Switching Features, 519; TOUCH-TONE® Calling and PICTUREPHONE® Visual Telephone Service, 528. IV. Key Telephone Systems, 537: Some Comparisons with PBX Systems, 537; Common Ancestry, 539; Divergence from PBX Technology, 539; Early Key Switching Systems, 540; The Key Telephone Systems Pattern Emerges, 543; Adding TOUCH-TONE Calling and PICTUREPHONE Visual Telephone Service to Key Telephone Systems, 549. V. Special Systems, 550: Telephone Answering Service, 553; Order-Taking Systems, 559; Systems for Dispatch and Emergency-Type Services, 566; Teletypewriter and Data Switching, 577; Switching of Network Facilities, 586. References, 590.

Abbreviations and Acronyms .................................. 595

Credits ............................................................. 601

Chronology ......................................................... 605

Index .................................................................... 617
Very soon after Alexander Graham Bell invented the telephone, it became obvious that it would be impractical to extend wires from every telephone to all other telephones. To conserve copper and dollars, wires had to converge on central points where individual telephone-to-telephone connections would be made. That is, calls had to be switched. Moreover, another basic concept of telephony also quickly emerged—namely, the trade-off between switching and transmission. The transmission costs of wire, cable, and associated plant could be optimized by having switching offices distributed to serve centers of population. The number of switching offices could be adjusted with changes in transmission costs. A classic and continuing problem of switching, therefore, is to design switching systems with capabilities that enable them to be sited at demographically advantageous points, so that total network costs are kept as low as possible. Also, for public telephony the need for compatibility in the presence of technological growth was established very early. Every item of equipment must function accurately and reliably with every other item of equipment in a network, no matter how spread out nationally or internationally. In addition, the network must absorb a continuous stream of innovations so as to bring the benefits of technology to its users as rapidly as possible.

In this book we see how these principles were applied during a significant period of technological change in Bell System history. The account begins in 1925, when various engineering and research groups of the Bell System were reorganized as Bell Telephone Laboratories. The nominal end point is 1975, which rounded out the first century of telephony.

As it turns out, however, 1975 is a reasonably good year to mark the end of one era of telephone switching and the beginning of another: the rapidly emerging new era of a digital, stored-program-controlled network. So, although we here concentrate primarily on the years 1925-1975, we have not hesitated to cover certain post-1975 developments started prior to 1976, when we knew them to be significant to current trends.
An earlier volume of this series \( (A \text{ History of Engineering and Science in the Bell System: The Early Years, 1875–1925}) \), describes how techniques born of necessity changed the telephone from a novelty to a useful instrument of personal communication and of commerce. Switching technology during this period was characterized by the introduction and improvements in manual switchboards. In the years covered by this volume, we see switching technology change from the final refinements in manual switching to work leading toward the introduction and complete take-over of automatic switching. In the process, the technology went through four successive phases: (1) indirect control, with switches requiring large mechanical motions, (2) common control, with switches requiring only very small motions, (3) stored-program control electronic switching, and, now (4) time division digital switching. At Bell Labs, each of these technologies moved from concepts to innovations, and the innovations were introduced to provide improved and expanded resources for the administration and operation of switching offices. The result has been high-quality and constantly improving telephone service and features, not only in the United States where the innovations were first employed, but throughout the world as these concepts were widely emulated.

The first practical automatic switching system was the step-by-step system, so-called because the switches move in step with, and under the direct control of, the telephone dial. With step-by-step, switch motions are limited by how fast (or slow) the customer dials, by how long it takes for the pulses representing each digit to be received and detected in the central office and, of course, by mechanical inertia. Switching innovation progressed to the first or indirect control phase, the panel system, separating the control of switch mechanisms from the dialing process. With panel, non-decimal power-driven switches of large capacity were introduced, and the independence of dial and switches permitted translation between the information dialed by the customer and the control needs of the system.

In the second phase, crossbar systems were designed and common control was first introduced. With common control the call-handling control was separated from the interconnection network and great improvements in flexibility were provided. Translations allowed complete flexibility in the assignment of lines and trunks, numbering plan and routing flexibility was provided, and the trunk network became more efficient and service again improved. In addition, the crossbar switches themselves introduced precious metal (platinum alloy) contacts into telephony which improved transmission performance. These relay-like contacts operated with very small motions and therefore with increased speed; this blended
nicely with the common control equipment that controlled their operation.

After World War II, the transistor and bulk electronic memory created tremendous new potentials for switching, and many exploratory developments were undertaken at Bell Labs to convert them into realities. The result was the third and entirely new approach to switching systems design—stored-program control—and switching took its place at the frontiers of the new electronic technology in terms of sophisticated hardware and software, systems architectures, complexity and size. The relationship to computers is obvious, but the switching system designs were unique. In real time, electronic switching systems process telephone calls with an objective of two hours downtime in 40 years, or about one-thousandth of one percent, compared to the one percent performance of a typical commercial computer. Now more than 50 percent of Bell System calls are switched using stored-program techniques.

The fourth era of switching technology, and the one currently in progress, is a period of further extending digital techniques into switching to encompass the interface with transmission as well and, indeed, to require the engineering of switching systems and transmission terminals carrying digital signals as single, integrated entities. The Bell System was the first to combine stored-program control and time division digital switching. Furthermore, a new high-speed digital signaling technique, known as common channel interoffice signaling (CCIS), was introduced in 1976 and soon will be serving 50 percent of all toll calls.

Thus the foundation for future high-efficiency, low-cost telecommunications has been established. The new era of integrated digital switching and transmission will continue to extend service beyond the telephone to include more complex terminals and all forms of information—voice, data, and video. The advantages are greatly expanded services, new services, new and more powerful operational and management techniques, and sophisticated measurement and maintenance arrangements. And the network will continue to grow, both domestically with the cooperation of the independent telephone manufacturing and operating companies and internationally with the cooperation of foreign administrations.

In all probability, the next fifty years will see changes take place even more rapidly than those of the first fifty years of Bell Laboratories and the first 100 years of the telephone. While telecommunication switching technology and its application will continue to play important roles, the technical and managerial expertise of Bell System people will be the most important ingredient in insuring this progress.
The contributions of many Bell System people are acknowledged in this book, but it is important to recognize that, as the technology has become more sophisticated, it has taken ever larger teams of designers and managers to convert inventions into developed and engineerable systems and, therefore, individual contributions are not as easily identified. This book is dedicated to the generations of engineers who made these accomplishments possible.

On a personal note, it has been my pleasure to share with many colleagues in this, one of the great technological adventures of the twentieth century. By whatever measure—complexity, numbers of people, development costs, investment, or telephone traffic processed—this adventure is a huge one. The greatest satisfactions, however, come not from designing something big but from seeing the human achievements involved when individuals tackle and solve some of engineering's most challenging problems.

W. O. Fleckenstein
Vice President, Switching Systems
April 1982
Acknowledgments

Although I was the principal author of Chapters 1 through 12, a major Chapter (13) devoted to the development of PBXs and other customer-premises switching systems was prepared by Charles Breen who, prior to his retirement from Bell Laboratories, was associated for many years with the engineering of these systems. Other contributors to the customer-premises switching chapter were George M. Anderson, PBXs from 1970 to 1975, and Frank M. Fen- ton, key systems from 1970 to 1975. Frank F. Taylor prepared sections IV, V, and VI of Chapter 9, and was most helpful in editing the entire manuscript. Walter S. Hayward reviewed and contributed to section III of Chapter 5, and sections III and IV of Chapter 11. I would also like to acknowledge the considerable help of Janet Edwards, who keyboarded the manuscript and its numerous revisions into the Bell Labs UNIX* system word processor, Ruth L. Stumm, who searched diligently for illustrations and helped with proofreading, Terry Getz, who prepared the illustrations for publication, and Arlene M. Dagostino who took the words and illustrations and made them into a book.

One could not prepare a book of this type without continuously monitoring and collecting data over a period of time. My wife, Rhoda, provided much encouragement, and my secretary, Frances Anderson has been most patient, participating in this process as well as typing all of the original manuscript drafts. All contributors thank George E. Schindler, Jr., our editor and mentor, whose encouragement and continuous help were important to the creation of this history.

In this book, readers should note that numbers of installations and entities refer only to the period covered by this history. Such numbers will in many cases be different when updated through recent years.

*UNIX is a trademark of Bell Laboratories.
Over many years, during which colleagues have provided insight into the developments with which they were engaged, I was privileged to observe their progress, reflect on these activities, and now to record in this volume the events as I recall them. The subjects covered have been chosen from a larger set. There are always questions of history that one cannot anticipate even in a most comprehensive volume. I hope readers will find the material included here interesting to peruse and useful for reference. A thorough reading should provide an understanding of how the research and development activities of Bell Laboratories during its first 50 years have made available the switching techniques and technology for serving the nationwide network during a critical period of its growth.

Amos E. Joel, Jr.
The Mulberry office switchboards (originating in the background and terminating in the foreground) used with the first panel switching equipment in Newark, New Jersey in 1915. Although manual and semiautomatic switching were to remain in use for many years, it became apparent that full automatic switching and high-capacity transmission systems were the path to more and better telephone services. To reach that goal, manual systems had to be adapted to work compatibly with the new automatic systems. Moreover, telephone devices, logic circuits, numbering and routing plans, and administration and maintenance techniques all grew in complexity and ability to handle large amounts of local and toll traffic.