Private Branch Exchange Systems and Applications

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Uyless Black,
Series Advisor

McGraw-Hill Series on Computer Communications

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McGraw-Hill, Inc.
New York San Francisco Washington, D.C. Auckland Bogotá
Caracas Lisbon London Madrid Mexico City Milan
Montreal New Delhi San Juan Singapore
Sydney Tokyo Toronto

Library of Congress Cataloging-in-Publication Data

Bush, Stanley E.
Private branch exchange systems and applications / Stanley E. Bush, Charles R. Parsons.
p. cm.—(McGraw-Hill series on computer communications)
Includes index.
ISBN 0-07-009706-2
1. Telephone—Private branch exchanges. I. Parsons, Charles R. II. Title. III. Series.
TK6397.B88 1993
621.385—dc20 93-2138
CIP

1 2 3 4 5 6 7 8 9 0 DOC/DOC 9 9 8 7 6 5 4 3

ISBN 0-07-009706-2

The sponsoring editor for this book was Stephen S. Chapman and the production supervisor was Donald F. Schmidt. It was set in Century Schoolbook by North Market Street Graphics.

Printed and bound by R. R. Donnelley & Sons Company.

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Preface

During the past 25 years, while the authors designed PBX systems and applications to run on them, very few books have been devoted to the explanation of the structure and the use of Private Branch Exchanges. Since PBX systems are a key element in the voice communication network of many companies of medium to large size, and since they provide access to the public network for many important data connections, they are a key asset that may be deployed and managed to facilitate the strategic plans of the enterprise. It is therefore surprising that they have received so little attention in print. Engineers, telecommunication managers, students, and sales personnel have had to rely on information from vendors, brief descriptions in books on other telecommunication subjects, or occasional articles in the trade magazines.

This book is aimed at fulfilling the needs of a broad cross section of telecommunications professionals who require more information about PBX system architecture and applications. It provides information about the technology, architecture, features, operation, and management of a modern PBX system. The material is presented in a practical way so that it may be directly applied in selecting and managing a PBX system or in building a network of PBX systems.

The original purpose of PBX systems was to reduce the number of wires necessary to provide telephone service to business enterprises. PBXs followed the development of the central offices available at the time with the only distinguishing characteristic being that of smaller size. Over the years PBXs have evolved into independent systems that are used to control private network voice and data communications and to access the public network. Modern PBX systems provide virtually hundreds of features to manage and control communications. The complexity of modern PBXs along with the divestiture of the Bell System have brought about a situation where the selection, operation, and maintenance of a PBX system is a reasonably complicated task.

This book is intended to help the telecommunications professional understand the operating characteristics and capabilities of today's

PBXs. You should find it useful in determining how best to manage your communication system with minimum risk while providing the required capability and flexibility at a reasonable cost. The book sets the stage for a discussion of modern PBXs by briefly discussing the history of PBX systems. It also provides tutorial material on the structure and operations of a PBX system. The first half of the book discusses the history, hardware, and architecture aspects of PBXs. The second half then discusses the features, operations, maintenance, and security issues associated with PBX systems. In addition, the book also constitutes a valuable reference source for evaluating PBX purchases and comparing vendor alternatives. It will help you match available PBX systems to your specified current needs, and it will help you select a system that will be flexible enough to remain viable over the time frame of your planning horizon.

This book may be used by anyone interested in the subject as a general introduction to the world of PBX systems. It can also be used as a general reference to answer questions about the architectural or feature differences among PBXs and the importance of such differences. It will be found useful by many in preparing Requests For Proposal. While this book is not intended as a textbook, it may be used in teaching telecommunications as a supplement to other texts that generally lack significant material on PBX systems and their uses.

Significant changes are about to take place in the PBX field. Systems will become more and more distributed and will incorporate new standard technologies such as ISDN, Frame Relay, and Asynchronous Transfer Mode. It is the authors' sincere hope that this book will help you track these trends so that you will be able to avoid being stuck with a "white elephant" or straying over the "bleeding edge" of PBX technology.

Acknowledgment

The authors would like to thank Dan Callahan who originally pointed out the need for a book on PBX architecture and applications. Dan started writing a few chapters before his booming consulting business swept him away from the project. We hope that this book at least resembles what he had in mind.

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1

Market Positioning

Introduction

While the telephone itself is now over 100 years old, the *PBX,* or *Private Branch Exchange,* came along much later. It grew out of the need to provide a switching system for a single customer. However, the first PBXs were simply smaller copies of the larger central office switches. Only after the arrival of automatic switching in the late 1920s and early 1930s was the PBX recognized as a separate product.

A Private Branch Exchange is a switching system. The word exchange is simply an early term for a system that connects telephones to other telephones or to transmission facilities going to other switches. The second characteristic of a PBX is that it is private. Originally, this meant that the switch provided service for only one customer. It did not mean that the customer owned the switch. Until certain court decisions made in the late 1960s and early 1970s, the Bell System only leased equipment to customers. The word branch in PBX meant that the switch was separate and perhaps remote from the normal central office switches. Thus, a PBX is a small switching system, serving a single customer, which is distinct and possibly remote from the public switches in the network.

As a result of deregulation, customers may either purchase or lease a PBX. In addition, there are arrangements wherein one customer may own a PBX and lease some of the capacity to another customer. Also manufacturers, in order to distinguish their products from others, have added several letters to the acronym. PABX indicates that the PBX is automatic or controlled by dial pulses or push button signals rather than a human operator. EPABX designates an electronic version of an automatic private branch exchange. The acronym CBX stands for a computerized branch exchange. Each of these designations refers to some variation of the private switching systems known as PBXs. In this book, we will refer to PBX systems without added initials.

Very early in the history of the telephone, users discovered that it was inconvenient to have a different telephone connected to each other user. Before switching was invented, a manager may have had a telephone to call home and another to call the factory. Telephone switching systems have significantly reduced the cost and improved the convenience of connecting telephone calls. The first switch served only eight lines. It consisted of several manual switches which were used to connect one line to another. In addition, a telephone circuit allowed the operator of the switch to talk to the users who were referred to as subscribers. Because the switches were mounted on a wooden board, these primitive switching systems became known as switchboards. As the need for larger switching systems emerged, the switchboard evolved into a system of plugs and jacks. A person, called an operator or attendant, provided the intelligence to operate these cord switchboards, or *cord boards.* When a subscriber went off-hook requesting service, a small metal flag dropped next to the appropriate jack. On later cord boards a lighted lamp indicated the request for service. Usually some sound to alert the operator accompanied the visual indication. The operator inserted a plug (Fig. 1.1) attached to one end of a cord into the jack belonging to the subscriber requesting service. This established a connection to the operator's telephone circuit. The operator asked for the number and then plugged the other end of the cord into the appropriate jack to complete the connection. The operator alerted the called party by sending a ringing signal to their telephone. When the called party answered, the operator threw a switch that established the talking path. Visual and audible indications also indicated the completion of a call. The operator then removed the unneeded cords.

The earliest PBX systems were simply smaller cord boards. They worked in exactly the same way as the central office cord boards. If the

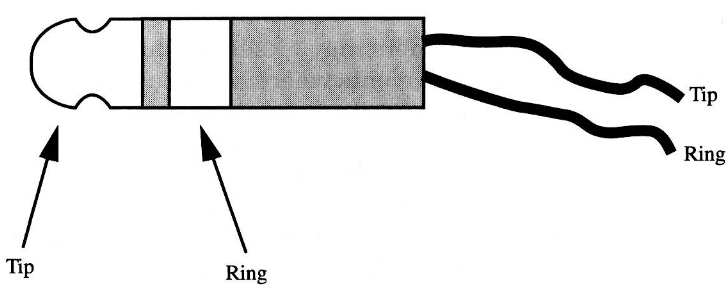

Figure 1.1 The components of a telephone plug.

subscriber wanted to customize the operation, he or she had only to tell the operator what was wanted. For example, if the customer wanted the operator to take messages for people who were busy on their line or away from their telephone, he or she simply told the operator to do so. Customizing features on modern PBX systems is considerably more difficult. These manual cord boards served well for many years. In fact, there were several in use even as late as the 1960s. It is likely that some small motel somewhere is using one today.

In the 1890s, Almon B. Strowger designed, patented, and constructed the first automatic switching system. Whether entirely true or not, the story is an interesting one. Strowger was an undertaker. The operator of the manual switching system in town was a relative of a competitor. Strowger suspected that she diverted calls to the relative unfairly. Whatever the reason, Strowger receives credit for the design that evolved into the step-by-step (SxS) switch. The basic switching mechanism has ten rows of ten contacts each. When wired together these switches form much larger switching systems. The first switch in the connection is called a line finder. When a telephone user goes off-hook, or lifts the receiver, the current flowing in the line and through the telephone creates an indication that service is required. This causes the line finder (Fig. 1.2) to step up and then across to make a connection to the line requesting service. At this point, dial tone is provided through the line finder to the telephone requesting service. When the calling party dials the first digit, the next switch in the connection, called a *selector,* steps up one row for each pulse in the digit. Thus, dialing a five causes the selector to step up five rows. The selector then hunts across the row looking for an idle switch to complete the next part of the connection. It skips any that are busy and stops at the first one that is idle. This next switch in the chain is also called a selector. If all selectors are busy, the calling party receives busy tone. If an idle selector is found, it handles the next digit in a manner similar to the first selector. That is, it steps up a number of rows corresponding to the number of pulses in the digit dialed. Then it hunts across the row to find an idle switch to complete the next part of the connection. Finally,

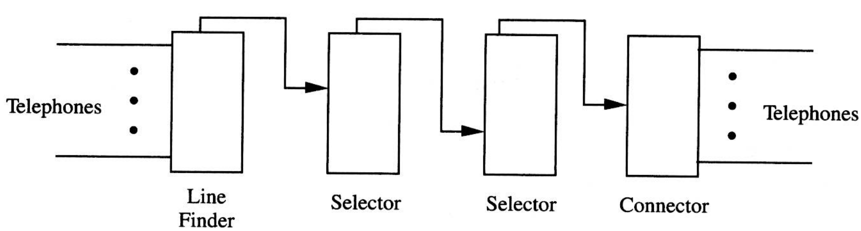

Figure 1.2 A step-by-step switching arrangement.

when there are only two digits left to dial, a connection has been established through a series of switches to the final switch called a *connector.* The connector steps up one row for each pulse in the next to last digit dialed and then waits for the final digit. The final digit causes the connector to step over one place for each pulse. The user of the subscriber line which is terminated on the connector at the point selected corresponds to the number dialed. Relays then apply ringing to the called line; when the called user answers, the connection is completed.

Step-by-step switching systems worked well and were inexpensive even though they did require some maintenance to keep everything properly adjusted. They brought with them some new terminology as well. One new term resulted from the method of making connections. Conversations are separated on different wire paths through the system. Switches which separate the connections physically are called *space-division switches.* The control is progressive, meaning that each switch handles only one digit and then passes the connection on to the next switch in line. This type of distributed control makes it impossible to select an alternate path through the system when all the paths to the next switching stage are busy. Idle paths may exist but cannot be used because there is no way to back up. Other limitations were not apparent for several years until new features such as call forwarding came along. It should be clear that a step-by-step switching system cannot route a call to some line other than the one corresponding to the number dialed. Even with these limitations, step-by-step switching systems served well for many years and many are still in place.

The Bell System offered a line of step-by-step PBX systems called the 701 series. These were the first private branch exchanges to provide automatic or dial service. They operated exactly as did their central office counterparts, only they were usually smaller. Many are still in use today. In fact, a uniquely designed 701-type PBX provided service to the White House for many years and was finally retired from service in 1987.

Common Control Systems

After World War II, research and development efforts modernized telephone switching systems. The new systems were smaller, less expensive, and provided more features. This resulted from two major changes in switch design. First, the basic switching component was improved. The new switch, called a *crossbar switch,* consisted of a metal frame which held five horizontal bars and ten vertical bars. Each horizontal bar had a set of spring-loaded metal fingers projecting to the rear toward each of the vertical bars. Each vertical bar when rotated operated a set of contacts located just above and below each horizontal bar. Thus there were ten sets of contacts on each vertical bar, and since there were also ten vertical bars, the entire switch housed 100 sets of contacts. However, when the vertical bar rotated, the contacts closed only if one of the metal fingers projecting from the horizontal bar was between the contacts and the rotating vertical bar. So a particular set of contacts closures could be initiated by first swinging a horizontal bar up or down. This put any of the spring-loaded fingers that were not in use between the vertical bars and the corresponding set of contacts. Then, rotating one of the vertical bars closed the appropriate contacts at the point where the fingers were in position. This connection stayed in place as long as the vertical bar remained in the rotated position, because the springs fingers were clamped between the vertical bar and the contacts. Each of the fingers not clamped to contacts by a vertical bar returned to the middle or unoperated position. At this point the horizontal bar was free to make other connections as required at other locations. The switch therefore had 10 independent input lines and 10 output lines. It provided the capability of connecting any input to any output for up to 10 connections at a time. Wiring these switches together in arrays formed a *switching matrix.* This switching mechanism is a space-division switch where each connection is set up on a separate metallic path.

The second major change was in the control mechanism used to operate the switching matrix. In the older manual systems the control, the operator, was completely independent from the switching mechanism, the cords. If the operator or attendant found a line to be busy they could establish a connection to some other line. This operation is a form of the modern feature call forwarding. Such an operation, as pointed out above, was not possible in a progressive control step-by-step switch. In the crossbar systems the control was separate from the switching matrix. This method was called *common control.* That is, the control system was common to the entire switching system and did not pertain to one switch only. The control element, called a *marker,* consisted of a set of relays wired in such a way that it preformed the necessary functions of establishing the proper connections (Fig. 1.3). The name marker comes from the method used to establish connections. The two ends of the connection were first electrically marked and then a connect command was issued. A set of registers assisted the marker by collecting the digits dialed. A translator converted the dialed digits to equipment numbers as required by the marker.

When a telephone requested service by going off-hook, an originating marker established a connection though the switching matrix to a *register.* The register provided dial tone and prepared to collect digits. The subscriber then dialed the desired number. When the register had collected a complete number it signaled a completing marker that it was

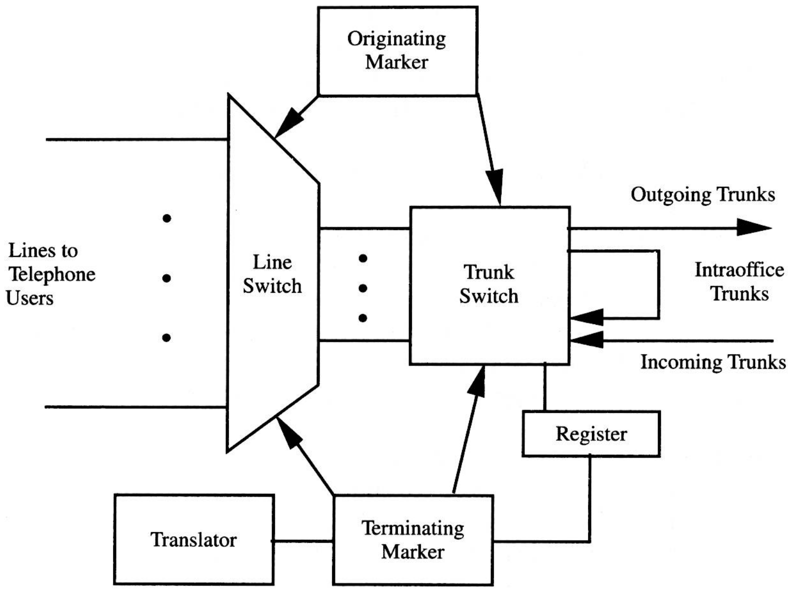

Figure 1.3 A simplified block diagram of a crossbar switch.

ready. The completing marker then made the final connection from the telephone connected to the register to the telephone represented by the number dialed and stored in the register. To do this, the completing marker enlisted the aid of the *translator*. The translator was capable of taking the actual dialed number as input and translating it into the equipment numbers needed for the connection. Thus, telephone numbers were no longer tied to the actual equipment which provided the connection. Changes were made by simply changing the information stored in the translator. There were many kinds of translators, but one frequently used consisted of a set of cards with holes punched in them. Some of the cards dropped depending on the actual number dialed. Light shining on the cards appeared at the output side of the translator where the holes line up. Changing the contents of the translator required punching new holes in a set of cards. This translation function and control independent of the switching matrix provided considerable flexibility in the way the system operated.

In the Bell System the 750 series of PBXs grew out of this technology. The common control of the 750 series systems allowed enhanced features such as dial access to conference circuits, digit translation to permit connection to a variety of special service circuits, and switched loops, more flexible connections, to the attendants.

The next phase in the evolution of switching systems came not as a result of a new architecture but as a function of technology. In the

1960s the transistor and evolving semiconductor technology made it possible to replace the relay marker with an electronic common control. This provided advantages in speed of operation, reduced initial cost, and lowered maintenance costs. In addition, where changing the program or the way in which the control operated required rewiring relays in the markers, the rewiring was much simpler in the electronic controls. In fact, features were changed by simply inserting diodes at appropriate spots in a suitably labeled matrix.

While this was going on, the switching matrix was also changing due to technological improvements. *Reed relays,* small metallic contacts in glass bottles, or semiconductor electronics replaced the crossbar switches. These networks provided the same matrix architecture as the crossbar switches did but they improved the speed of operation, lowered the initial and life cycle costs, and reduced the size and power consumption of the system.

These enhancements first appeared, as usual, in central office switching systems and later in PBX systems. In the 1960s the Bell System incorporated these technologies into the 800 series of PBX systems. These systems were smaller and more reliable than previous systems. It was easier to change options and features. In addition, it was possible to take advantage of the reductions in cost and size brought about in the semiconductor industry, at least for the system control circuits. On the other hand, reed relays wired together provided the switching network function. The circuits necessary to control the lines and trunks contained several relays and individual semiconductor parts. As a result, achieving maximum advantage from the semiconductor revolution required additional enhancements to PBX systems.

These changes also had their roots in the early 1960s with the development of switches based on computer control. In the Bell System the #1 ESS was the first electronic switching system or central office based on stored program control. A computer controlled the entire system. A memory system provided storage for the program which specified how the system should operate. Now, adding new features or changing old ones required only software changes. Also, changing options such as numbering, routing patterns, or restrictions was simply a matter of changing the translation software stored in the memory. Using a computer to control a switch was a major advance which allowed telephone switches to take advantage of many developments in the computer industry.

The other change required to take advantage of semiconductors in switching systems was the development of *time-division switching*. All previous systems up through the #1 ESS had space-division switching networks. That is, each telephone call existed on a separate physical