Introduction to Exchange Systems

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A Wiley–Interscience Publication

JOHN WILEY & SONS

London · New York · Sydney · Toronto

Library of Congress Cataloging in Publication Data:

Flowers, Thomas Harold.
Introduction to exchange systems.

'A Wiley–Interscience publication.'
1. Telephone stations. I. Title.
TK6211.F54 621.385'4 76–13447

ISBN 0 471 01865 1

Typeset by Preface Ltd, Salisbury, Wiltshire and printed by Pitman Press, Bath

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FOREWORD

A telecommunications engineer is often forced to work within a unique set of constraints imposed by the existing network. The designer of a computer or an aircraft is restricted only by the laws of physics, the available materials and his own ingenuity. The railway engineer has to deal with additional restrictions imposed by factors such as rail gauge, track curvature and tunnel height. But in a public telecommunications network, virtually every piece of equipment has to be capable of interworking, directly or indirectly with every other piece of equipment in the network and this has, in the past, restricted the introduction of new technology, particularly in the switching field.

In the transmission field, the problems of technical advancement have not been so severe. This has come about partly because the fundamental technology (for example, coaxial cables) was often available in advance of the system requirement but mainly because the interfaces between different parts of the system were relatively simple and easily defined. Examples of such interface definitions are contained in the well-established series of transmission system recommendations produced by the International Telecommunications Union.

Switching, on the other hand, is essentially a branch of control automation, a comparatively new art. The early automatic switching systems, as partial replacements for the telephone operators, were in advance of their time and ingenious though these systems were, the implications of their adoption were not always fully understood. Thus, much of the system flexibility possible with a human operator was lost with the introduction of automation. Switching, because of its fundamentally interconnected nature, involves many interfaces and this has severely restricted the development of the network. Often it has been found that a new piece of switching equipment, based on technology different from that already existing in the network, would have to adapt to so many interfaces that the cost of its adoption became prohibitive.

The slow progress in the exploitation of new technology in switching equipment has been matched by a lack of suitable textbooks on switching. This book not only fulfils a need in providing a general treatise on switching but, more importantly, it explains in some detail how and why the switched telephone network has evolved from the operator controlled systems. Such information is invaluable for today's telecommunication engineers. The speed of advance of modern technology is such that any new system is almost certain to be obsolescent by the time it is connected into the network in significant quantities. The engineer is therefore forced to consider in greater depth the basic system philosophy before starting on the design of equipment. The analytical approach to operator-controlled and electromechanical switching systems adopted in the early chapters of the book will assist him in this approach. Moreover, for those engaged in the design of new equipment, a knowledge of the basic principles of existing electromechanical systems will enable a better appreciation of the interworking constraints to be gained.

The progress of technology in the late 1950s led to the realization that it was possible to design an electronic or semi-electronic switching system that was economically competitive with existing systems and at the same time permitted changes in operation to be made easily during the lifetime of the equipment. The particular developments were closely allied to the development of digital computers and the technique became known as 'stored program control'. The operation of the exchange could be changed or extended merely by loading a new program into the control processor and such could be made in exchanges all over the network within the space of a few minutes. The stored program control technique was a very powerful one but, as with any pioneering venture, the full implications of its use were not always realized by those who first designed exchanges based on this principle.

It is perhaps significant that during World War II the author of this book was engaged in the development of equipment that incorporated many of the concepts later used in the design of digital computers and stored program control systems. Much of his work such as the 'Colossus' project has only recently been cleared of security restrictions and it is now possible to appreciate the highly advanced thinking of people such as M.H. A. Newman, A. Turing and T.H. Flowers. From his early acquaintance with the fundamental concepts of stored program control, the author of this book has been able to recognize both the advantages and the limitations of the technique.

In the future, the prospect of using solid state devices for the switches as well as for the control has much to recommend it, in view of the high reliability of such components and the possibility of making substantial economies by using the switches in time-division. This approach has not so far gained widespread acceptance for public exchanges, not least because of the necessity for conforming to an overall transmission plan, which permits only a very small amount of attenuation within the exchange. The use of pulse code modulation to permit 'integrated' switching and transmission largely overcomes the transmission problem and appears to offer many advantages.

At the time of writing, the precise future of telecommunications switching is largely undetermined. The trend towards thinking of the overall telecommunications network rather than particular items of equipment will undoubtedly continue. Some measure of stored program control will probably continue to be applied in the control area but the extent to which stored program rather than wired logic control is used will depend mainly on economic factors. There is also likely to be a move away from metallic-contact switches and towards time-division multiplexing and solid-state components in the switching area. The opinions on the future development of switching systems expressed in this book may not receive general acceptance but at least the clear exposition of the comparative approaches will provide much food for thought.

Finally, it is worth noting that many Third World countries are in a unique situation with regard to their public telecommunications networks. Since they do not have the severe restrictions imposed by the necessity for interworking with a highly developed but obsolescent network, they can configure their own network almost without restriction to suit their national requirements both now and in the future. This they can do in the full knowledge both of modern technology and of the earlier, and often restricting, course of development of telecommunications networks in highly industrialized countries. This book will help engineers in Third World countries to gain such knowledge and so help them towards the realization of a highly effective telecommunications network.

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PREFACE

To be introduced to exchange systems through principles and generalizations, as in this work, instead of through particular systems which is the way that many engineers come to learn the subject, leads, I believe, to a better understanding not only of the subject in general but also of particular systems when they come to be studied. Every system in practice inevitably includes some feature based on arbitrary decision by an administration or designer or is forced by local conditions, a fact which generally needs some knowledge broader than just that of the system itself to recognize. I hope and believe that many already in telecommunications will find interest in the book but being an introduction, I have had to keep students and newcomers very much in mind. For that reason I have endeavoured to make it complete in itself and to be comprehensible without any prior knowledge of exchange systems or having to refer to other works: this explains why no references are given and terms and conventions particular to exchange switching are defined and explained as they occur in the text.

I gratefully acknowledge much helpful criticism and advice which I have received during the preparation of the manuscript, from numerous colleagues and friends in the industry.

London, January, 1976. T. H. FLOWERS

ABBREVIATIONS

a.d.c.	advise duration and charge
conc.	concentrator
c.o.s.	class of service
d	data
d.d.i.	direct dialling-in
d.l.	data link
d.l.j.n.	data link junction number
DM	driving magnet
dm	contacts operated by DM
d.n.	directory number
e.l.	exchange line
e.n.	equipment number
e.n.c.	equipment number, calling
e.n.t.	equipment number, terminating
e.n.f.	equipment number, file
e.n.s.	equipment number, switch
f.d.m.	frequency division multiplex
i.b.	international barred
i.c.	incoming
i.c.j.	incoming junction
i.c.r.	incoming junction register
i.d.f.	intermediate distribution frame
i.f.s.	interface switch
i.j.	incoming junctor
i.s.	incoming service
j.n.	junction number
l.d.b.	long distance barred
l.j.	local junctor

m	message
m-d	data message
M	memory, data store
md	memory, data store
m.d.f.	main distribution frame
MK	mark
Mk	stored mark
mk	mark
n.u.	number unobtainable
o	operational data
o.b.	outgoing barred
o.g.	outgoing
o.g.j.	outgoing junction
o.j.	outgoing junctor
o.o.s.	one-only selector
o.r.	originating register
or.j.	originating junctor
P	logic part of processor
p.a.b.x.	private automatic branch exchange
p.a.m.	pulse amplitude modulated
p.a.x.	private automatic exchange
p.b.x.	private branch exchange
p.c.m.	pulse code modulated
pk	park
p.m.b.x.	private manual branch exchange
p.m.x.	private manual exchange
pr	subscriber as processor
prX	processor X
r.t.	ring tone
s	signal
s-d	data signal
s.j.	service junctor
sm	signal-message
s.o.	service observation
s.p.	semi-permanent (store)
SPC	stored program control
s.s.o.	special service observation
s.v.i.	service interception
sw	switch

temp.	temporary (store)
t.d.m.	time division multiplex
t.j.	terminating junctor
t.o.s.	temporarily out of service
t.s.	time switch

CONTENTS

Chapter One
INTRODUCTION

1.1 Object and Scope

Humans communicate with one another using their five senses. The conditions and maximum distances over which communication is possible are limited by natural laws and the construction of the human body. Communication surmounting unnatural conditions or distances is telecommunicated, which means that the communication must be transmitted for at least part of the distance between the communicating parties in a form different from its natural form. Electric transmission is the most flexible and widely used form and the only one here to be considered. Electric transmission first used for the sending of written messages by telegraph, was later applied to messages spoken on the telephone. Public services require the destinations of the messages to be variable from the sending points, which implies some form of switching. Public telegraph services developed a kind of switching now called message switching and telephone services have a different kind called circuit switching. Now and more particularly in the future, message and circuit switching of information telecommunicated in a wide variety of forms is or will be required, and some of the forms and the quantities of information to be transmitted cannot be clearly foreseen at present. It is important that the whole problem be appreciated by system and exchange designers but the whole problem being outside the scope of one publication, this work is limited to circuit switching and almost entirely to telephone circuit switching.

There are three aspects of exchange design which are interrelated but still identifiably separate. System design is the first. Telecommunication being required over an area too large to be served by one exchange, many exchanges are used with telecommunication between them in a network called a system. The area covered is commonly an entire country by a national system. System design comprises exchanges in networks, the exchanges and their interconnection, and both telecommunication and switching. Exchange system design comprises exchanges in networks, the principles on which they operate and the services which the exchanges provide. Basic change to a national or an exchange system once it is established is usually difficult and expensive but it occurs infrequently. The second aspect, that of apparatus design, is concerned with components and sometimes their mechanical but more often their electrical interconnection, the electrical interconnection of components also being known as circuit design. Apparatus design to satisfy the requirements of a system can change as new components and techniques become available, usually without difficulty if the system does not change and mostly as new equipment required for growth and replacement of existing plant. Traffic design, the third aspect, is concerned with quantities of apparatus needed in exchanges to carry the traffic expected to occur. Traffic design is thus individual to exchanges and changes as the traffic changes usually because of natural growth. The principal concern of this work is exchange systems: the salient points of telecommunication and of apparatus design are outlined but traffic design is mentioned only as it affects system and apparatus design.

Because choices exist for the apparatus to be used for its mode of operation even within the limits of one system, apparatus and traffic designs are possible in great variety and many exist and are or have in the past been in commercial production. To acquaint the reader with the details of present or past designs of exchanges is not an objective which is pursued nor is it essential to the main objective, that of promoting an understanding of why and how exchanges come to be designed in the ways now known and may be designed in the future to satisfy the needs of public communication services however they may develop. Existing practices are nevertheless useful to illustrate facts, problems and theories and are used for those purposes. Thus the subject of exchange systems is no more than introduced but presented in broad perspective as a sound basis for the detailed study of known systems and the design of future systems.

1.2 Messages and Transmission

A message is an intelligent communication between men, between machines or between a man and a machine. It may not be intelligible to the men or machines involved, they may be passing the message for those to whom it is intelligible, but that it is sense and not nonsense is obvious to them. The essential parts of the communication are the originator of the message, the message transmission and the message recipient.

The electric telegraph made possible the rapid transmission over great distances of written messages comprising the letters of the alphabet and some other characters which in the written order constituted a message meaningful to the originator and to the recipient and will be termed the message proper. To a telegraphist concerned in sending a message over distance, the message was a series of symbols drawn from a set of *N* symbols, namely letters and figures, which he had to send in the order written, to another telegraphist to write down so as to re-create the message proper. Between the two telegraphists was an electrical circuit for message transmission and what could be sent, transmitted and recognized at the receiving end were electrical states, originally current and no current, and continuous current in one or other of the two possible directions of transmission. The sending telegraphist, using his hand to operate a mechanical key with contacts to control the electrical states to be transmitted, coded the *N*-symbols of the message proper into the dots, dashes and spaces of the Morse alphabet to transmit a message which the receiving telegraphist read from the movements of a galvanometer needle or from the sound emitted by a sounder. In more general terms, the *N*-symbol message was transduced by a transmitter, the telegraphist and his key, to a transmitted message comprising two electrical states and time, the transmitted message being transduced by a receiver, the galvanometer and telegraphist, back to the message proper. The transmission was not limited to two states, in fact Alexander Graham Bell was experimenting with a method of telegraphy using more than two states when he accidentally discovered the telephone. He was plucking tuned reeds to make them vibrate at their own natural frequencies and thus to generate currents which at the receiving end caused similar reeds to vibrate and be heard. Hence in the general case the transmitted message comprises n electrical states and is known for that reason as n-state digital or merely digital transmission. In Table 1.1 the components of the first electrical telecommunication system, the telegraph service, are shown.

Table 1.1 Telecommunication system components

Message proper	Transmitter-transducer	Transmitted message	Receiver-transducer	Message proper
Telegraph— written N-symbols digital	telegraphist— hand—key	n-state digital	galvanometer— eye— telegraphist	written N-symbols digital
Telephone— sound analogue	microphone	analogue	ear-phone	sound analogue

Telegraphed messages designated telegrams were the first but are now only one class of digital message which telecommunication systems are or will be required to transmit. In all cases there is a message proper comprising *N*-symbols to be transduced, including being coded, by a man or machine transmitter to a transmitted message of electrical n-states which are transmitted over an electrical circuit commonly referred to as a line independently of its construction, to a receiver which transduces and decodes the electrical states back to the *N*-symbols in a form which is comprehensible to the recipient, man or machine. The coding between the N and the n depends on their relative quantities and existences. If $N = n$ a simple one-for-one code may be used and the states may be transmitted independently of time. For example, ten press-buttons may be used to send the ten decimal digits by pressing one button at a time and with each button arranged to transmit a different frequency. A receiver will recognize the digit being sent by the received frequency, and the length of time which it is sent is not important provided that it is long enough for the receiver to recognize it. If N is not equal to n, each member of the larger group has to be represented by a combination of the members of, or by a timed sequence of the members of, the smaller group. If N