# STORED PROGRAM CONTROLLED TELEPHONE EXCHANGES

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This talk covers the historical development of telephone techniques, leading to the application of computer controlled exchanges. The structure and function of the programs used is described.

## 1 Introduction

A telephone engineer, who talks on an international seminar in Computing Science, has to face a serious risk of being misunderstood.

Not only is there the difference between theory (the scientific world) and practice (of the application-directed telephone-administration), but even more important is the difference in language between the fields of computer science and telecommunications. The terminology, the symbols, the diagrams and the units in which I shall express myself are quite different. Still worse is the situation that in both fields the same words can have different meanings; for example, the word digit, which means in telephony a figure out of a subscriber's number or an exchange code. The words number and code themselves are ambiguous in this context.

When I hope to reach at least some understanding in this circle then I base my optimism on the fact that at a certain time computers as well as telephone exchanges were based on the same building stone: The elctro-mechanical relay. This common ancestry of both fields leads one to expect that they are not too dissimilar.

## 2 Historical Development

The process of making a telephone call in a manual and an automatic exchange is elucidated in Figure 1. In this process we distinguish the use of signals (directed to a machine), tones (from machine to person) and speech (between persons). This combination of electrical and aural information-streams is characteristic of telephony. For machine to man or machine to machine communication via the switched telephone-network, this situation can give rise to difficulties (for example a free-tone in one country may be interpreted as a busy-tone in another country).

To get an impression of the technical development in automatic telephony the first patent for an automatic telephone exchange taken out by Almon B. Strowger in 1891 is shown in Figure 2. The first automatic exchanges were built following this principle. The telephone-dial was invented, and to split the impulse-series (digits) during the dialling, each selector had to be equipped with several relays. When the number of subscribers of a telephone service grew above the capacity of the selector, a more complicated connection network, consisting of several selector-stages became necessary. These so-called "step by step" systems had the property that the movements of the switches during call set-up were directly effected by the dial-pulses (a pulse for each step).

There were several drawbacks in these classical switching systems. The switching was slow, the equipment was voluminous, and complicated mechanical movements of the switches caused serious wear making a big maintenance staff necessary. The relays associated with the switches (the control equipment) had only to operate during call set-up and on disconnection, and stood idle most of the time.

The newer switching equipment needs less mechanical movements during the call set-up and disconnection process:

| | |
|---|---|
| Rotary selectors | only rotation of the wipers around the central axis |
| Crossbar-switches | small movements of horizontal and vertical bar to set one crosspoint |
| Relay-matrices | small movements of one relay armature |
| Reed-relay matrices | very small movements of the Reed-contact. |

The switching device became more simple and the control-functions became more centralized. Centralized <u>registers</u> which were connected to a caller to assemble and store the dialled digits were necessary. By means of another device, called a <u>marker</u>, this information was used to build up a speech path through the switches in the inter connection-network ("switchblock") of the exchange. <u>Registers</u> and <u>markers</u> were switched off during the call, and were available to set up other calls. The connection was watched by a junctor circuit, which caused the disconnection after call-termination.

A further centralization of control-functions was the introduction of an electronic number-analyzer, which translated the received digits into information necessary for steering of the selector-stages, for the choice of the tariff-class, for deciding whether all digits were received, and for the destination of the start-moment of setting up the speech-path in the switching network. The registers and markers could be simpler, and a great number of registers could make use of one number-analyzer, which contained the more complicated logical functions of the exchange.

Then the introduction of electronic memories as stores for subscribers' information (class of subscriber, subscribers' meters) was considered. In the United Kingdom magnetic drums were used for the translation-functions in S.T.D. (subscriber trunk dialling).

A logical next step was the introduction of the computer in the exchange to control and steer the switching network.

A general scheme of such a "stored program controlled" (S.P.C.) exchange consists of three main parts:

The speech-path network
The interface equipment
The central processor.

The first telephone exchange of this type was developed at the Bell Telephone Laboratories and put into service in 1965 in Succasunna (U.S.). Since then in several countries switching systems using this principle were developed. The idea of SPC-switching systems became the leading trend in exchange development. (In the PTT-network in the Netherlands we now have in operation three different types of SPC-exchanges for three different applications and developed by three different manufacturers.)

## 3 The Telephone Process in a SPC-Exchange

To give you some idea about the hardware construction of such a SPC-exchange Figure 3 shows a schematic drawing of a laboratory model that was built in our PTT-laboratories.

Information about the subscriber's status, namely, "on hook" or "off hook" is assembled by scanners which scan each subscriber's line every 250 milliseconds. The scan information for 16 subscribers' is assembled in one word and is compared with the former scan result for the same 16 subscribers. If a difference is found the information is sent to the processor, together with the numbers of the subscribers. This is, by the way, a matter of trade-off in exchange-design. In some early systems all scan information was directly sent to the processor and the control of the scanning process was also in the hands of the processor. This caused a considerable processor load. In later designs the scanners work autonomously, (but containing more hardware), so the traffic capacity of the processor was increased.

The same type of considerations apply for the dialling-information-receiver. Whether each individual pulse or each digit or the complete number is sent to the processor depends on available technology and the trade-off of price and load-values.

The process of establishing a telephone call and the disconnection can be split up in several parts. In a processor-controlled exchange, Figure 4, we will have a number of messages going to and from the central processor to the switching network.

In the preparation of the call first the exchange finds a new off-hook situation for the calling subscriber A, followed by the through-connection to a dial-information receiver. The dial-information receiver sends a dial tone to the calling subscriber A, and the exchange waits for further action.

In the dialling phase the information is received by the processor, and on completion of the number, the dial-information receiver is disconnected. The dialling phase is of course very time-critical, because here we have the risk of losing information.

The next phase is the through-connection to the called subscriber B. The transmission of a free-tone to A and of a ringing current to the bell of B, both sent by junctor BVS, is now beginning. The exchange waits for reaction from B.

When B lifts his handset the transmission of a free-tone and a ringing current stops. Conversation can take place. When both subscribers put down their handsents, this is discovered by junctors AVS and BVS and transmitted to the processor, releasing the switching network.

## 4 The Telephone Process as seen by the Central Processor

For a typical local exchange with a maximum of 15,000 subscribers we have a total traffic of about 100 Erlangs. In the busy hour, around 10 o'clock we have in such an exchange about 1000 different telephone processes going on. With a call duration of 120 seconds we find approximately 250 messages per second to and from the processor.

From a software point of view the system presents itself as illustrated by Figure 5. Via the input/output bus system the central control unit has access to peripherals representing the telephone equipment in the switching network, and to other peripherals catering for the input and output of information for the maintenance and operation of the system (teleprinter, tape punch and tape reader).

To the central control unit the test points of the signal detectors and the drive points of the relays in the junctors appear as external memory blocks of 16-bit words from which the test point conditions may be read and into which the conditions of the relays may be written. The markers are units which can be given commands for connection build-up and release, and from which the command results may be read. The notion of time is represented by clock pulses. The memory has a word length of 16 bits and is used for the storage of programs as well as of data of the system. The size of the memory for a complete exchange of 15,000 subscribers is typically between 128K and 256K words. The lamp and key panel is used only when the system is started for the first time and for fault tracing.

As already mentioned, one of the optimization criteria of an S.P.C. exchange design is the trade-off between functions to be fulfilled by hardware in connecting section or by software in the processor. For scanning and for receiving dialling information we already see some differences in concepts. In small exchanges these functions are for the greater part fulfilled by the processor. For greater designs the processor capacity becomes a limiting factor, so these tasks are delegated to dedicated hardware.

Also the data about the situation in the switching network can, at every path search, be read at the testpoints of the network itself or be stored in the processor-memory. In the latter case a path-search is done more quickly at the expense of memory-space.

Subscribers can by systematically connected to the switching network in such a way that the subscriber's number gives directly the place where his line is connected. Alternatively there could be a full translation between place number and subscriber's number in the processor. The latter case gives full freedom for distributing subscribers' lines over the switching network, but costs both processor-time and memory-space.

The subscribers' meters can be implemented in the processor-memory and the metering-information can be put on a magnetic tape for later processing by an off-line computer.

5 Data List Structure

The subscriber's data, like his line-class, his tariff group, the list of his facilities, his meter, the status of his line(s), etc. will be stored in a list structure. In particular, his list of numbers for abbreviated dialling may take a considerable number of memory-words (for instance a 12-digit number takes 3 words of 16 bits). A total of 10 short numbers per subscriber would mean for a 15,000 line exchange a memory space of 450K words if we gave this feature to all subscribers.

For the construction of the subscriber's data list we shall consider two principles.

In the system of direct addressing, Figure 6, we can find the subscriber's half-word directly by shifting the telephone number one bit to the right and adding it to the begin-address of the list. From the 8 bits of the subscriber's half-word, one bit is reserved to indicate whether the other 7 bits are subscriber's data or whether they contain a reference X to a second list. On the address given by X we find a record of 4 words, of which the last word may be a further reference Y to a third list etc.

In the search method, Figure 7, we have only one or two bits per subscriber indicating whether the subscriber is a normal one or whether we should search further in the list of records for abnormal subscribers. Eventually a reference to a third list may be given.

Direct addressing is quicker but the search method needs less memory space. The choice between the different data structures is made depending on the expectation of the percentage of subscribers which wants special facilities.

## 6 Monitor Structure

In a typical real-time system, like a telephone exchange, the monitor or supervisor-function cannot control the input and output autonomously, but is instead subject to exacting time limits. These limits are due to the response time demands which the system must satisfy. The response time will in itself not make a system into a real-time process, but here we have two more characteristics for such a process:

When the system fails to satisfy the response time requirements the process will go out of control partially or completely beyond recovery.

The response time is of the order of time required to convert the input into the output.

Taking a closer look to the SPC-exchange we see the following characteristics and requirements which have a marked effect on the design of the monitor:

a) The shortest response time is of the order of 30 ms (minimum time that a digit is offered to the processor input).

b) The programs controlling the exchange are interdependent.

c) Telephoning is a stochastic process, in which for instance 0.1% of the calls offered may be allowed to be lost (contrary to accounting systems, where <u>all</u> traffic <u>must</u> be processed as a matter of principle).

d) The down-time of a telephone exchange should be very short (less than 5 hours in 40 years).

Because the system must satisfy the response time, time-limiting is necessary. This is introduced with clock pulses recurring every 10 ms., which thus forms the basic interval. During every basic interval common functions are carried out first (for example time limits for programs, scanning of test points, etc.).

Several events may coincide in a telephone-exchange, but the processor can only execute its instructions sequentially. The work for the processor is therefore divided into a number of priority levels.

The priority classification is an important feature of the software for SPC-exchanges. The control of a telephone exchange often requires 50-100 programs. These programs may be organized in different ways, for example

(i) They may be divided into a number of levels, programs having the same priority for corresponding levels.

(ii) They may be placed on a list: The position of a program on the list represents the priority of this program. In this case the control and information are transferred from one program to another.

The differences of priority classification give distinct differences in the programming of exchanges. In method (i) every priority-level has one work list and one save area, (Figure 8) where intermediate results may be dumped when a program must be interrupted temporarily. The monitor consults the work list and calls in the necessary programs. When the work list is empty the monitor moves to the work list of the next level of lower priority. In method (ii) each program must have its own save area and work list. Each program empties its own work list and ends with a jump to the next program. In this case the monitor functions are few and mainly consist in the handling of interrupts.

Comparing the two methods we see:

1. Method (i) requires more memory space for the complicated monitor program, but needs less save area and work list space.
2. Method (i) is more flexible with respect to the introduction of new programs and the re-arranging of the existing programs (standard interface to the monitor).

Looking at several SPC-exchange systems on the market we see an even greater difference in the way in which the monitor or supervision-function is realized. In some systems this function is implemented in hardware. In other systems the monitor can take as much as 35K of 16 bits-instruction-words.

## 7 Telephone Software

So far we have seen that the handling of scanning results, the interpretation of the received signalling, the call set-up and disconnect procedure, the handling of subscriber's data and the free path search, are tasks to be executed by the telephone programs. Another type of activity in the telephone switching process is the guarding of time-limits, for example subscribers taking too long to begin dialling or the recognition of signalling impulses on impulse duration.

A further important program package is the system assurance program. When the hardware or software has detected a fault, this program comes in at the highest priority level to make sure that prompt steps are taken to ensure uninterrupted telephone service. For this reason the central processing unit and the memory have been duplicated; the same precaution has been taken in other sections for all hardware that is common to more than 64-128 subscribers.

With the maintenance and operation package, lines and junctors may be blocked and tested and data may be extracted from the memory and changed. For example, subscribers' meters may be read and service classes changed. Furthermore traffic records can be made, and faults may be removed by means of diagnostic and fault location programs.

With the system test package the system may be checked when it is to be brought into service for the first time or when it is expanded.

These last two packages need not be always available in the system. They can be on demand loaded into the free overlay area in the processor memory.

## 8 Processor Configurations

In some telephone systems a number of processors together function in a multi-processor-system, however, for the control of the exchange we will consider here only the more frequent and simpler case of duplicated processors.

The following configurations exist:

1. Active/Standby

The active processor carries the load, while the other remains in standby. In the case of cold stand by the standby processor is only switched in when necessary. In this case the standby processor has no updated memory, so all existing calls will be lost. In the case of hot stand by, the standby processor's memory is regularly updated. Fault detection is based on techniques which do not require duplex-operation.

2. Parallel Processing or Microsyncronization

The two processors and their memories are running synchronously and one or several registers and buses are matched. Hardware errors or failures are detected immediately and initiate test routines which determine the faulty processor. This unit is disabled and the load is carried by the remaining processor.

3. Load Sharing

Each of the processors takes a part of the telephony control process. The memories of both processors are regularly updated. At each clock interrupt, fault detection is carried out in each individual processor in addition to a regular check of one processor by the other. In case of a software failure the other processor will take over.

In comparison one can say that configuration 3 is not blocked by a software failure, but that hardware failures are detected (too) late. Configuration 2 can only find a software failure by a time-out. Hardware faults are detected immediately and can therefore be better traced. Configuration 1 seems to have no advantage over the other two.

One important feature in the double processor configuration is the access of the healthy processor to the control-wires of the sick one. In this case the healthy processor can handle all diagnosis-procedures that otherwise are executed by the repair man. So we can reach a saving of repair-time, and this gives a rise in the system reliability.

9 Centralized Maintenance and Supervision (BOA)

At the moment a system for regional centralization of maintenance and supervision is being developed in the Netherlands (Figure 9). Such regional centres can serve 300,000 subscribers or 100 SPC exchanges.

A service computer system is placed in the centre which fulfills several functions:

1. Continuously guards all connected exchanges.
2. Records and reacts to alarms.
3. Interfaces between several departments and exchanges.
4. Library for all overlay programs (for maintenance and testing).
5. Library for all load tapes of each of the exchanges.

6. Contains all "roll back" information in case of complete system failure.

7. Connection to the computer system for administrative purposes (ITCIS).

This BCA-system will be introduced in steps. In the telephone network we will have five layers with respect to control-functions.

<u>Difference and Similarities of Computer Applications for Telephone Exchange Control and for Mathematical and Administrative Purposes</u>

| | SPC-Exch. | Math. Comp. | Adm. Comp. |
|---|---|---|---|
| Processing speed | High | High | High |
| Number of processes | High | Low | High |
| Urgency | High | Low | High |
| Response time | Small | Not small | Not small |
| Purpose | Control of Hardware | Calculations | Processing of data |
| Character of Process | Taking Decisions | Exactitude | Information flow |
| System allowance | Important | Less important | Less important |
| Immediate processing | Necessary | Not necessary | Attractive |

## 10 The Future

Future developments include the development of the digital trunk-network and the development of new methods of presentation of functional specification, command languages for SPC-exchanges, a high level programming language for SPC-exchanges, and a compiler generating code no more than 5% longer than code produced by a skilled programmer. International studies are going on in this field, and I foresee a considerable growth in SPC exchanges.

Finally we consider how Computer Science graduates may contribute to Telephony. It is easier to teach programming to telephone engineers than vice-versa, but software men are better prepared to work in the following fields:

1. Development of monitors.
2. Development of compilers for new languages.

3. Help in the definition of the languages.
4. Assembly systems for load tapes (data & programs).
5. Simulation of systems.

Discussion

Following the presentation of his paper ir. Boesveld was questioned on the facilities that stored program exchanges could provide and he underlined some of the practical problems that these desirable features brought in their wake. For instance, if someone's calls were being automatically directed to you, and you answer the phone with your name and number, the caller is likely to say "sorry, wrong number" and try again. The whole process needs careful thought. Professor Galler wanted to be able to re-route his calls to a friend's house when he went to visit him at night. ir. Boesveld wondered if his friend wanted that as well - if so, the friend must give permission too. This underlines the complication of what is superficially a simple process. A doctor visiting a patient may wish his calls transferred to the patient's number, but the patient must be able to refuse. He had his rights when renting a telephone. One could wish for a wide distribution of such concern for the customers.

Professor Galler did get ir. Boesveld to agree that a problem of complexity was one thing, but it was not the telephone company's business to tell him, the customer, that he didn't want to use a certain proposed facility. That is the customer's business. However ir. Boesveld did note that investigations revealed that things that customers thought they wanted sometimes turned out not to be so desirable after all. For instance, with short numbers, a greater incidence of errors may arise.

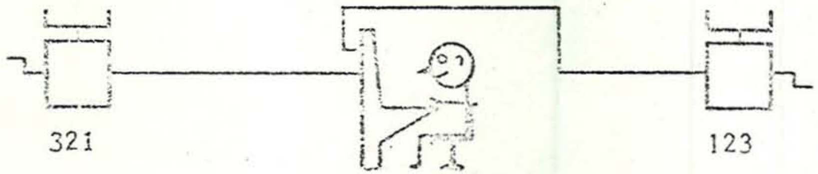
Professor Ercoli enquired if computers for telephone exchanges needed special attributes, or could, say, the PDP-11 range be used. ir. Boesveld said that ordinary machines were used in the laboratory where reliability mattered less, but for actual use, special machines were contructed with a lot of de-rating. For instance, no mechanical fans were used for cooling. The aim was for 40 years of trouble free operation. There is no problem as far as function is concerned. Some sort of time slicing is useful and can be added. Dr. Fraser commented that the design of PDP-11s was unsuitable in that if any device on the bus is powered off then the whole machine becomes inoperable. This is entirely unsatisfactory for use in a telephone exchange, and thoroughly unnecessary both functionally and economically. Bell Labs put several special reliability features in their computer exchanges. For instance all signals are reflected back to the sender for checking. There is a lot of unnecessary reinvention of the wheel going on in this area.

On the novel note that some manufacturers, other than the usual IBM, were coming in for criticism, Professor Page wound up the discussion.

# TELEPHONE EXCHANGE OPERATION

## MANUAL

A-SUBSCRIBER | OPERATOR+SWITCHBOARD | B-SUBSCRIBER

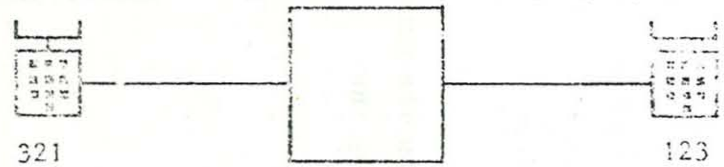



OPERATOR WATCHES SWITCHBOARD

| A-SUBSCRIBER | OPERATOR+SWITCHBOARD | B-SUBSCRIBER |
| --- | --- | --- |
| LIFTS HANDSET<br>ROTATES HANDLE →<br>OF GENERATOR | OPERATOR SEES SIGNAL<br>AND PUTS PLUG IN JACK 321 | |
| ← | "TELEPHONE<br>EXCHANGE" | |
| "GIVE ME SUBSCRIBER<br>NO. 123" → | | |
| ← | "A MOMENT<br>PLEASE" | |
| | OPERATOR PUTS OTHER<br>PLUG OF THE CORD IN JACK 123<br>OPERATOR ROTATES HANDLE<br>OF BELL-CURRENT GENERATOR → | RINGING<br>LIFTS HANDSET<br>← "HELLO" |
| | "SUBSCRIBER 321 IS CALLING YOU<br>A MOMENT PLEASE" → | |
| | MAKES THROUGH-CONNECTION<br>AND SAYS | |
| ← | "GO AHEAD" | → |
| CALL | OBSERVES THE GOOD START OF CALL<br>NOTES DOWN BEGINNING TIME<br>OF CALL AND NUMBER OF CALLING<br>SUBSCRIBER<br>WATCHES THE CALL | CALL |
| FINISHES CALL<br>PUTS HANDSET<br>DOWN<br>ROTATES HANDLE →<br>OF GENERATOR | OPERATOR SEES SIGNAL<br>REMOVES PLUGS<br>NOTES DOWN DURATION OF CALL | FINISHES CALL<br>PUTS HANDSET<br>DOWN<br>← ROTATES HANDLE<br>OF GENERATOR |

## AUTOMATIC

A-SUBSCRIBER | AUTOMATIC EXCHANGE | B-SUBSCRIBER




SCANNING OF SUBS.-LINES

| A-SUBSCRIBER | AUTOMATIC EXCHANGE | B-SUBSCRIBER |
| --- | --- | --- |
| LIFTS HANDSET → | CONNECTS INFORMATION RECEIVER | |
| DIALS 123 ⇄ | DIAL TONE | |
| | SWITCHES INFORMATION<br>RECEIVER OFF | |
| | SEARCHES FOR FREE<br>PATH IN THE EXCHANGE<br>BETWEEN 321 AND 123 | |
| | MAKES CONNECTION | |
| | ← SENDS<br>FREE TONE<br>(RINGING TONE)<br>SENDS →<br>RINGING CURRENT | RINGING |
| | | ← LIFTS HANDSET |
| CALL | STARTS: CALL-METERING | "HELLO"<br>CALL |
| FINISHES CALL<br>PUTS HANDSET →<br>DOWN | | FINISHES CALL<br>← PUTS HANDSET<br>DOWN |
| | DISCONNECTS<br>STOPS CALL-METERING | |

Figure 1

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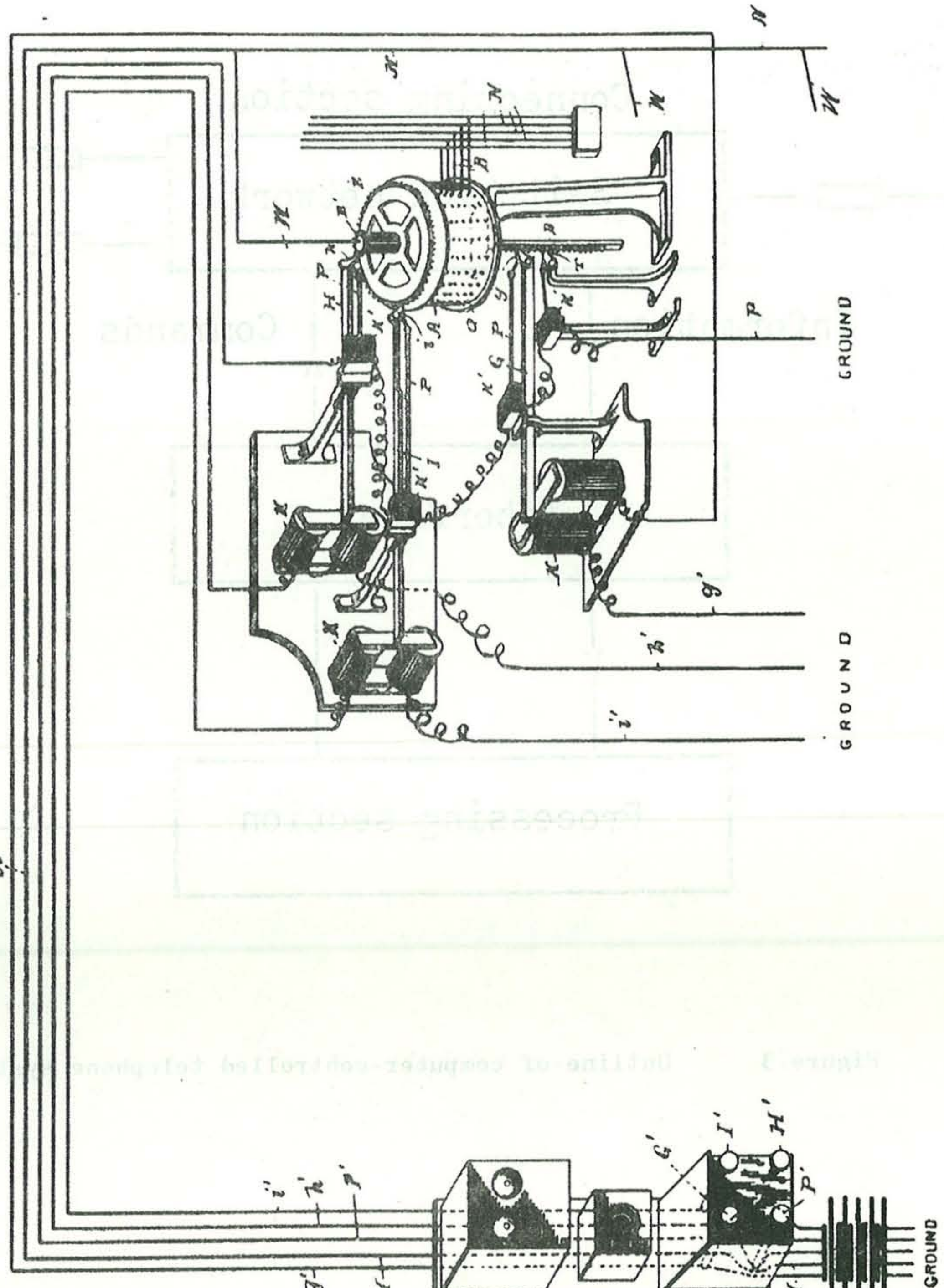
(No Model.) 3 Sheets—Sheet 1.

# A. B. STROWGER.

## AUTOMATIC TELEPHONE EXCHANGE.

No. 447,918. Patented Mar. 10, 1891.




*Witnesses.*

R. A. Balderson
A. M. Strowger

*Inventor*

Almon B. Strowger

Figure 2

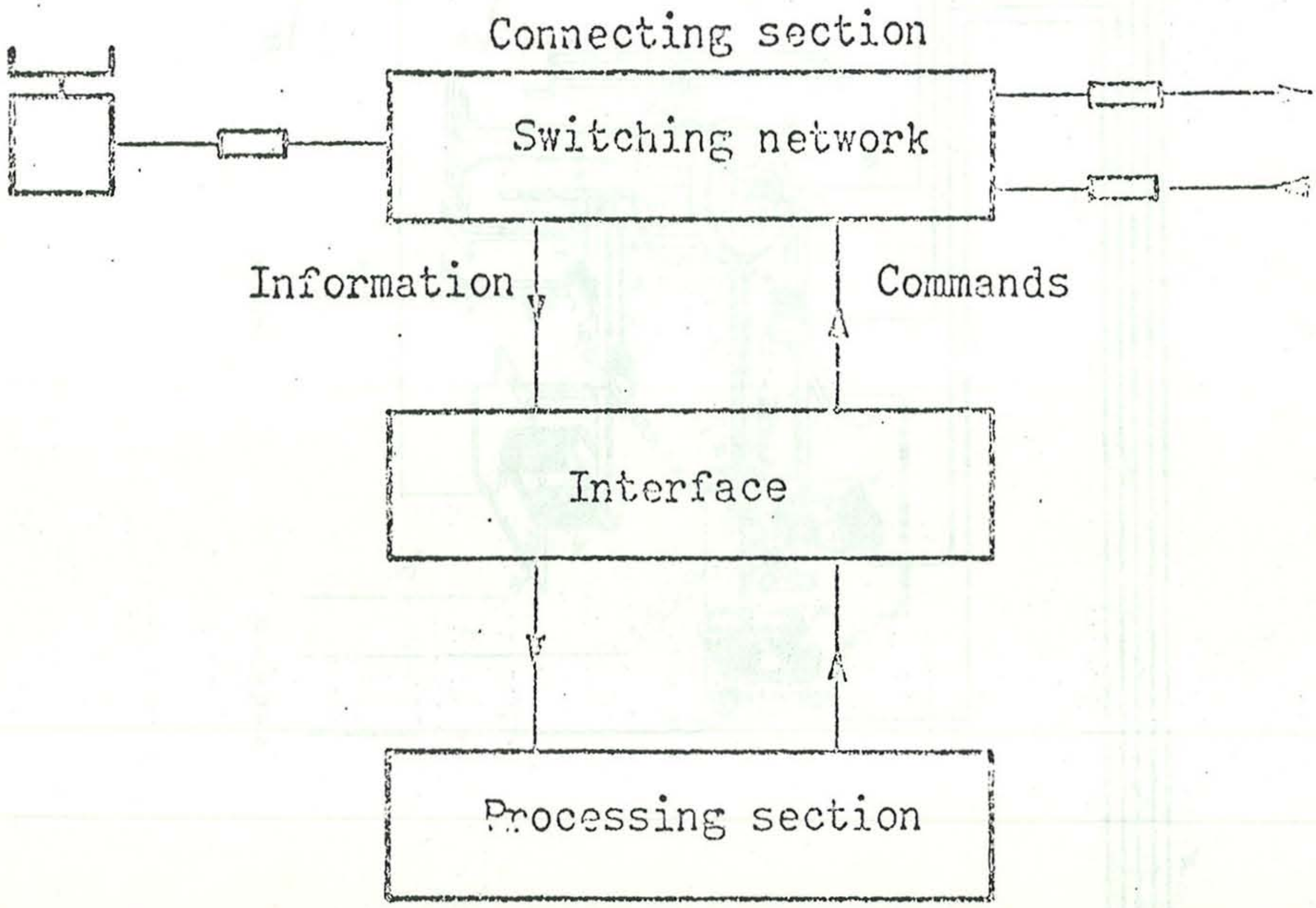
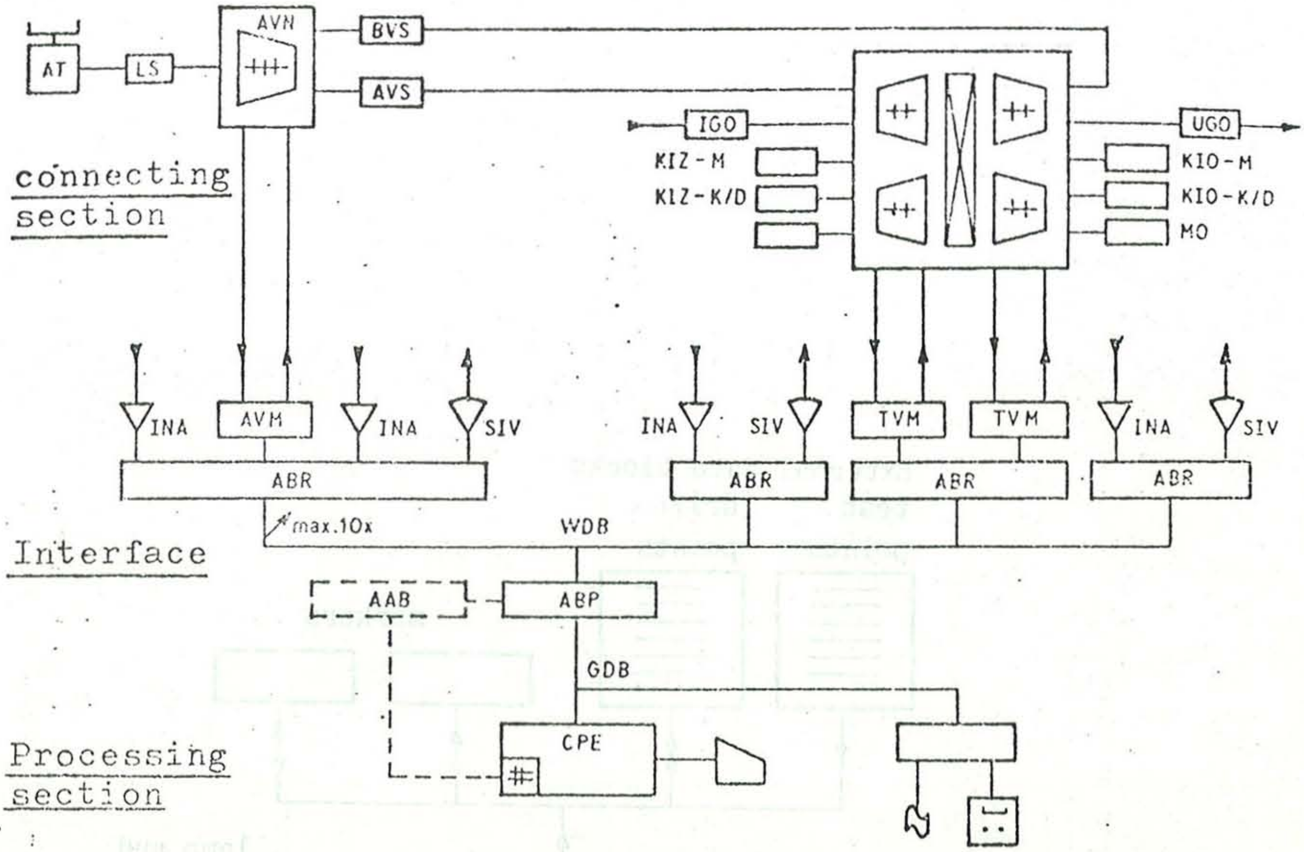



Figure 3 Outline of computer-controlled telephone system




| | |
|---|---|
| AAB | autonomous tester control (with direct memory access |
| ABP | bus system - processor interface |
| ABR | bus system - peripherals interface |
| AT | subscriber's telephone |
| AVM | Line Link marker |
| AVN | Line Link block |
| AVS | A-junctor (calling end) |
| BVS | B-junctor (called end) |
| CPE | central control unit |
| GDB | d.c. Data Channel |
| IGO | incoming d.c. relay set |
| INA | tester |
| KIO-D/K | push-button/dial information receiver |
| KIO-M | MFC signalling receiver |
| KIZ-D/K | push-button/dial information transmitter |
| KIZ-M | MFC signalling transmitter |
| LS | line circuit |
| MO | recording relay set |
| SIV | driver |
| TVM | transit marker |
| TVN | transit block |
| UGO | outgoing d.c. relay set |
| WDB | a.c. Control Channel |

Figure 4 Model of semi-electronic telephone system

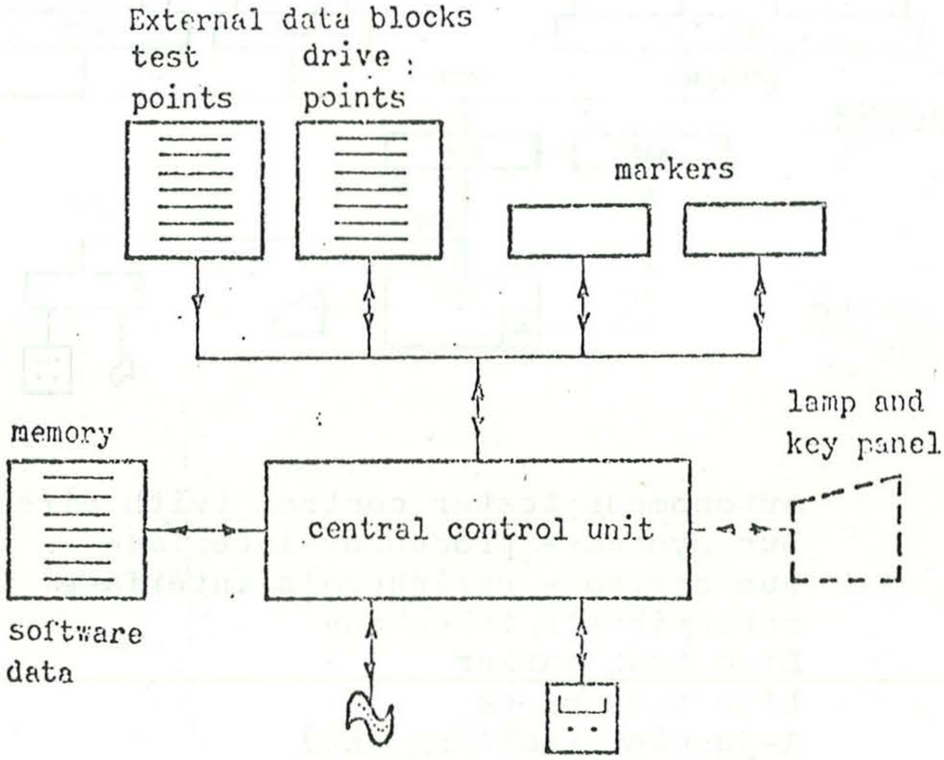
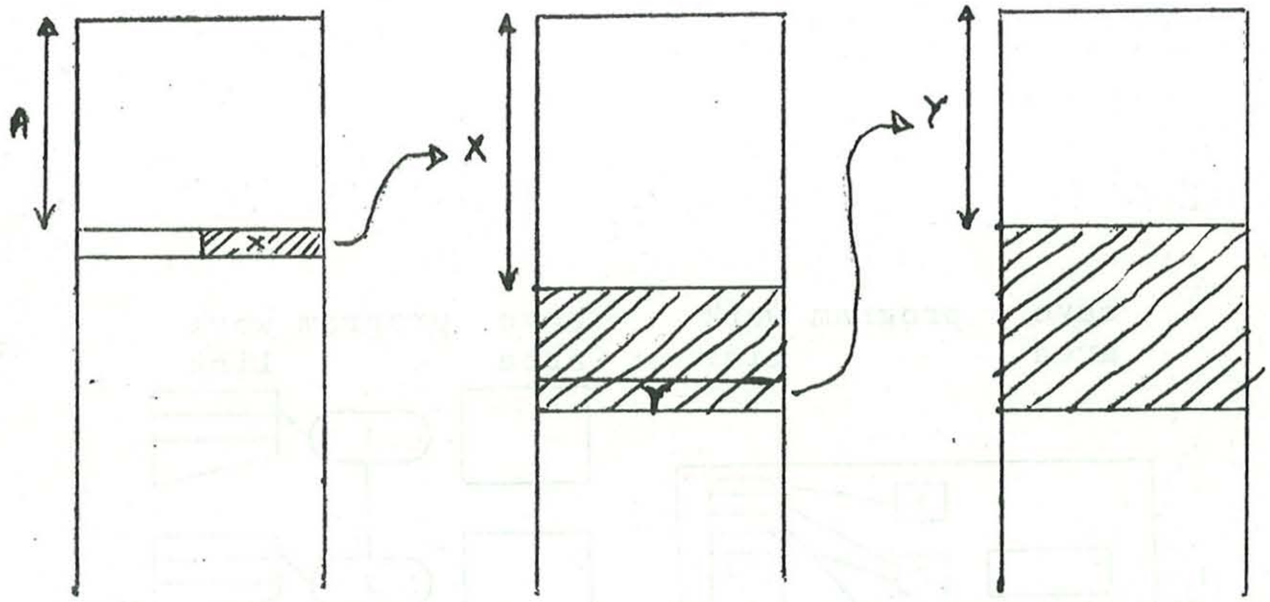



Figure 5 Telephone system from a software point of view

DIRECT ADDRESSING:




ADDRESS A IS DIRECTLY GIVEN BY SUBSCRIBER'S NUMBER

Figure 6

SEARCH METHOD;

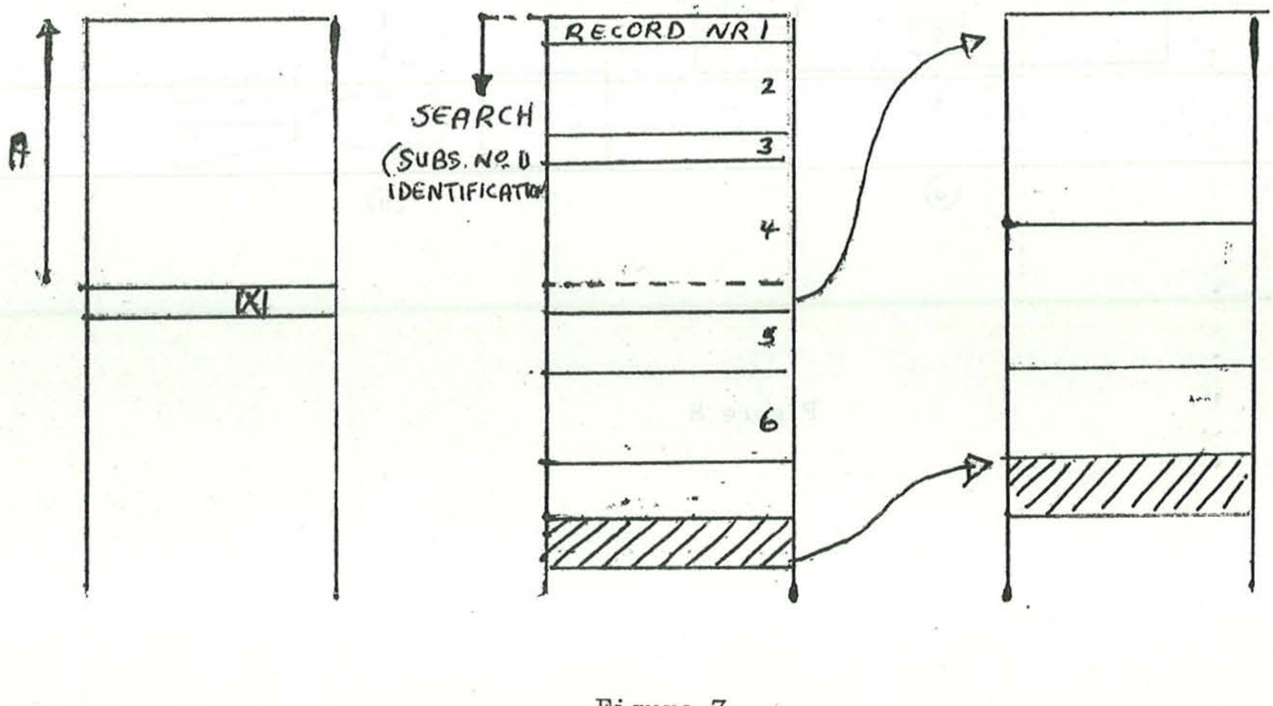
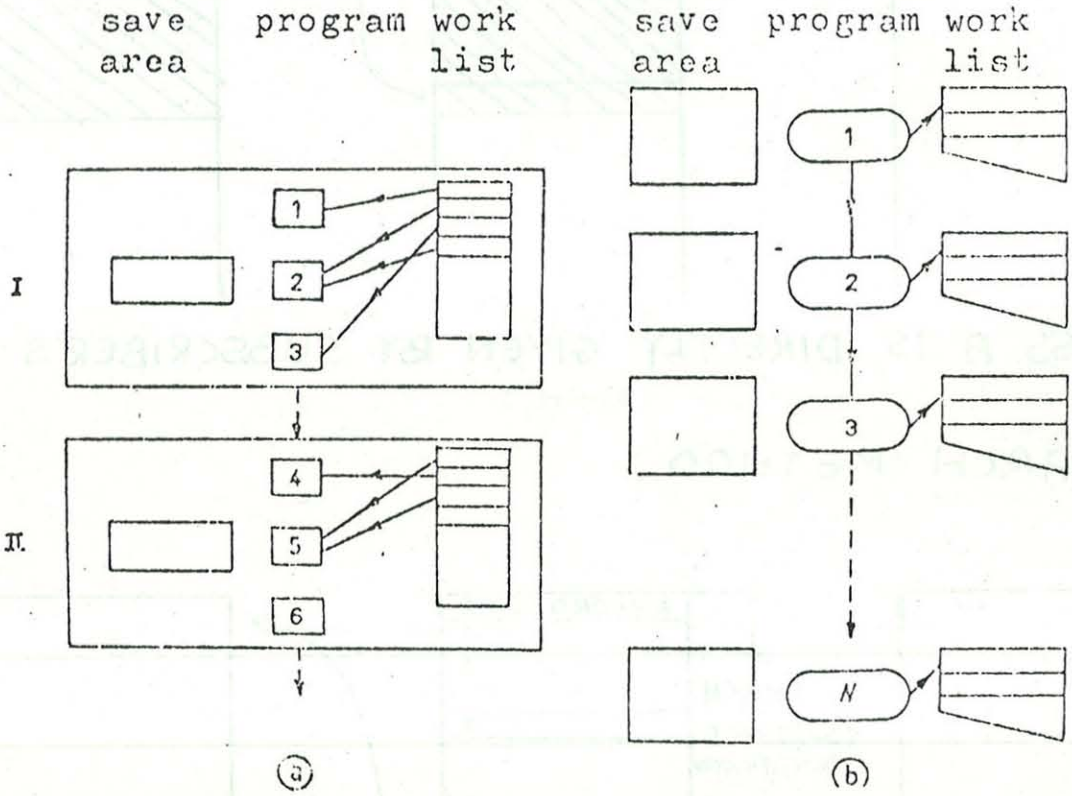



Figure 7



save area
program
work list
I
II
1
2
3
4
5
6
(a)
save area
program
work list
1
2
3
N
(b)


Figure 8

## DATA NETWORK
## FOR BoA-COMPUTER SYSTEM

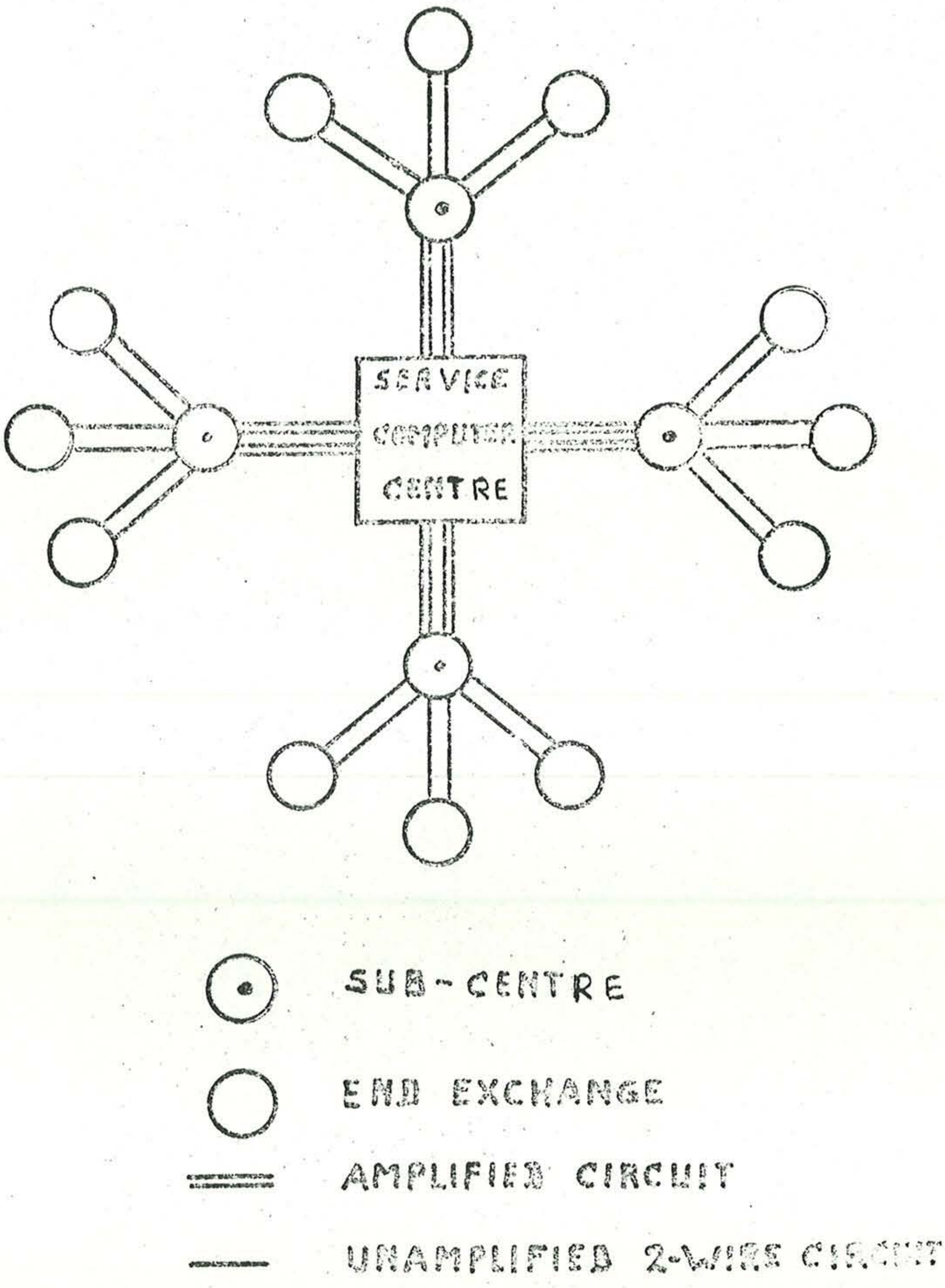



Figure 9