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Electronic Switching Network of the IBM 2750

Abstract: A description of the voice and data switching network of a fully electronic private automatic branch exchange (PABX) is given, including a description of the crosspoint device and its principles of operation. Some related circuity is described, including the terminal and service circuits, supervision circuits and a loss-compensation device.

Introduction

For over 15 years, space-division electronic switching systems have been considered as potential challengers of electromechanical systems. Fully electronic telephone exchanges using space- or time-division switching have appeared in the field and undergone practical trials.[1–6] Both solutions have their advantages and the choice must be made according to general application parameters. Generally, nonblocking traffic requirements favor a time-division approach; on the other hand, rates of transmission of digital data may make this approach impossible. A space-division network has a bandwidth well suited to data transmission, with low generated noise and low distortion and better crosstalk attenuation. A space-division network also is normally redundant and failure-tolerant to some degree. In consideration of all these factors, a space-division network was adopted for the IBM 2750 system.

The 2751 Switching Unit is the main component of the IBM 2750 system. It automatically connects or disconnects voice or data lines through its switching network by interpreting the signals received from users' telephone sets or from a connected IBM System/360.[7,8]

The 2751 consists essentially of 1) terminal circuits, which attach individual telephone lines and data terminals to the switching network; and 2) the switching network, which provides speech paths between telephone users and auxiliary functions such as operator connection, tone sending and multifrequency digit recognition.

The 2751 is constructed with electronic solid state circuitry. The switching network is of the space-division type and uses solid state crosspoints arranged in switching matrices; the technology used has led to a number of technical options for designing the whole system. It is well known that electronic devices cannot be used to lengthen the subscriber's line since they cannot handle the high voltages (sent or induced) existing on these lines; transformers thus provide electrical separation and impedance matching between the lines and the switching network. With transformers, one-wire switching becomes a natural choice leading to minimal volume and power dissipation, with the proviso that high crosstalk attenuation be ensured. By miniaturizing the switching network and paying special attention to the wiring arrangements, the required degree of crosstalk attenuation has been achieved in the present system.

The crosspoint switch

The set of objectives to be met by the switching device included very high reliability, high off/on impedance ratio, with very high blocking impedance, low control power, low power dissipation in the conducting state, smallest possible size, reproducibility and stability in operating characteristics.

A study was made of the various semiconductor devices available which met these requirements. Transistors need a permanent control capability when conducting; field-effect transistors present a relatively high and variable conducting impedance, and faithful reproduction of their characteristics is difficult to ensure. The thyristor was finally chosen as the switching device best suited to the application.

The crosspoint used in the 2751, shown in Fig. 1a, consists of three components integrated on the same chip of silicon—a thyristor, a resistor, and a diode, and is obtained through a planar epitaxial process;[9,10] eight

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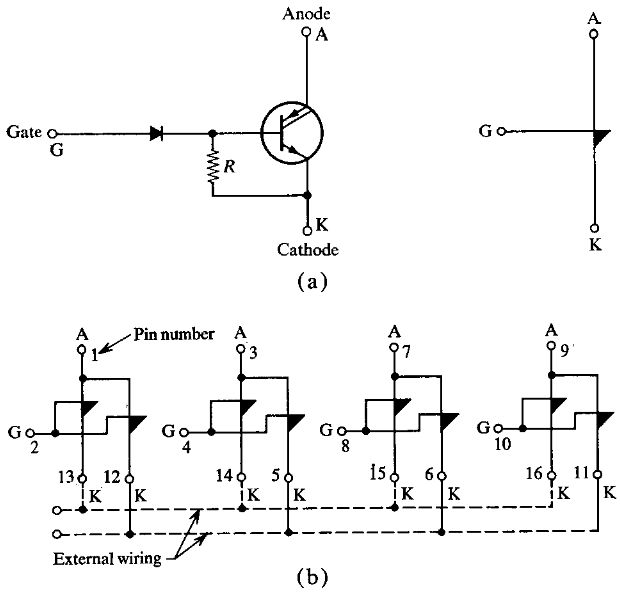


Figure 1 Crosspoint and module arrangement. (a) Symbolic representation of crosspoint. (b) 4 × 2 switching matrix.

crosspoints which can be arranged in a 4 × 2 matrix are packaged on a one-half-inch square, 16-pin module, indicated in Fig. 1b.

The miniaturization achieved with the integrated crosspoint is one of its significant advantages, since it permits economy in packaging and wiring and makes one-wire switching feasible.

• *Thyristor characteristics*

When no current is applied to the gate ($I_g = 0$), the thyristor has two stable states: OFF and ON. In the ON state, the crosspoint presents between anode (A) and cathode (K) a low dynamic impedance (6 ohms) with a high current capability (50 mA). In the OFF state, the crosspoint has a high impedance for voice frequencies ($C_{AK} = 3$ pF, $R \geq 30$ MΩ) with a breakdown voltage of over 35 V.[9–11]

The thyristor turns OFF after the anode-to-cathode current is interrupted during a period of time longer than the turn-off time. The thyristor can be switched from the OFF to the ON state by applying to the gate a current *pulse* i_G higher than a critical value i_{GT}. The thyristor will stay in the conducting state as long as the anode-to-cathode current is kept higher than the specified limit (holding current).

The resistor R connected between gate and cathode reduces and determines the triggering sensitivity of the crosspoint: R is so chosen as to make the shunted current i_0 ($i_0 = V_{GK}/R$) much higher than the triggering current i_G of the thyristor. The triggering current and the holding current of the crosspoint are thus defined by this resistor.

The crosspoint must continue to show satisfactory switching characteristics during the whole life of the machine, with total working reliability—no unwanted triggering must occur. Blocking characteristics and behavior under transient conditions have been thoroughly studied. The blocking resistance is specified to be higher than 30 MΩ during more than 100,000 hours; an 18-V positive step voltage (10-ns rise time) applied to the anode cannot trigger the device, as has been proved after a special study of the triggering conditions.[12–13]

In order to reduce the parallel losses to ground, gate-diode capacitance is reduced to only 2 pF and the admissible reverse voltage is larger than 35 V.

Description of the switching network

• *Traffic considerations*

The switching network is divided into three functional areas, as shown in Figs. 2 and 3: 1) the internal, or main, network, 2) the external network, and 3) the service network.

Each area is designed for different conditions of traffic and presents a different blocking rate. Maximum traffic figures for the average busy hour are 0.18 Erlang* per extension for internal traffic and 0.7 Erlang per trunk for external traffic. The maximum service traffic is about 0.06 Erlang per extension or trunk; the average busy-hour service traffic depends on the service, typical figures being:

0.8 Erlang per switchboard operator
10 Erlangs for all tone senders
8 Erlangs for numeric multifrequency receivers
4.5 Erlangs for add-on circuits.

The grade of service offered by the 2751 can be expressed as the probability of not finding a network path during the busy hour; corresponding figures are:

1% between two extensions
0.5% between a trunk and an extension
0.2% between a trunk and an operator
0.1% between a trunk or extension and a given service.

If the traffic through the switching network exceeds by 15% the maximum traffic figures given, that is, if it reaches 0.21 Erlang per extension and 0.8 Erlang per trunk, the grades of service will be 10%, 5%, 2% and 1% respectively. All the traffic figures given above apply to the total traffic passing through the switching network, including voice and data calls.

• *General description*

Each network presents several switching stages, each stage being made up of a variable number of switching

* The Erlang is a unit of traffic density which is equivalent to 100 percent occupancy of one channel.

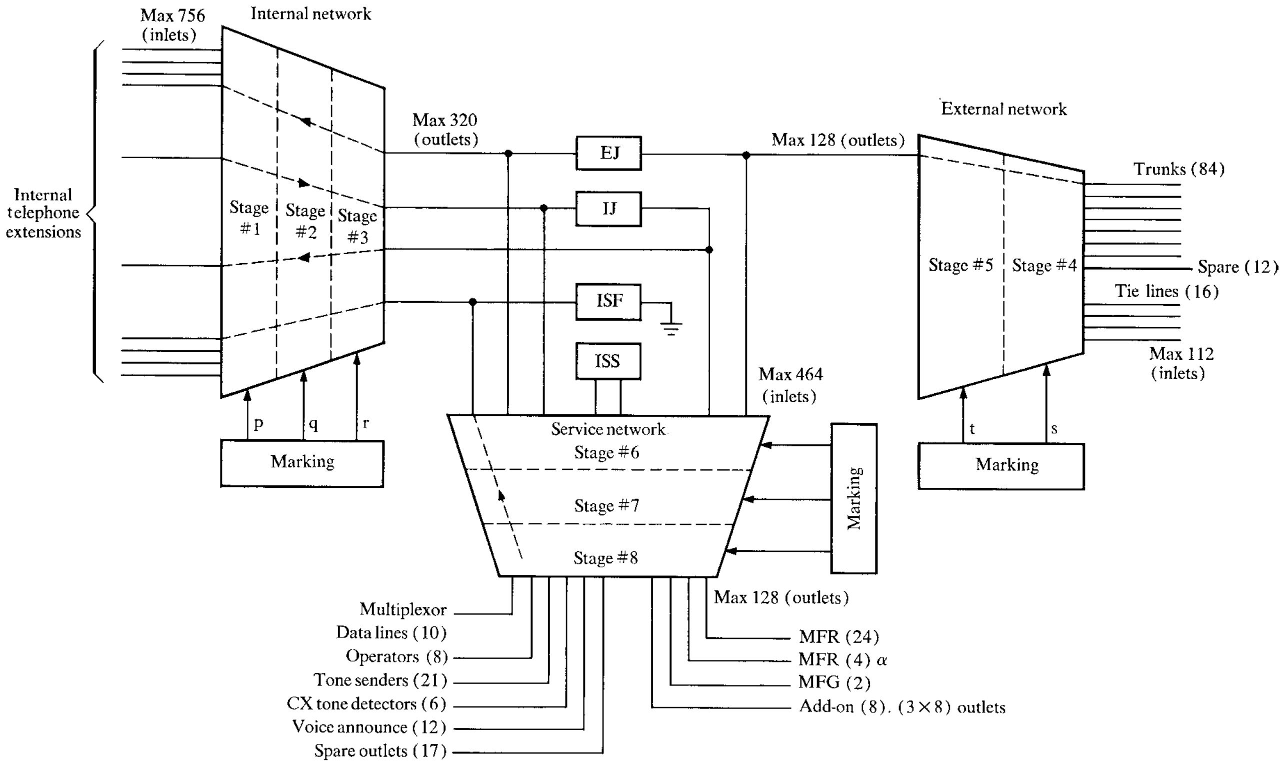


Figure 2 Switching network. (The symbol EJ is an external junctor; IJ, an internal junctor; ISF, an intermediate service feeder; and ISS, an interservice connector.)

crosspoints arranged in matrices. The number of stages, and the size and degree of concentration of the matrices in each stage, are the result of a trade-off between traffic requirements, acceptable blocking rates, and the number of crosspoints involved; the final choice of the 2751 switching network was facilitated through the use of simulation programs run on an IBM 7090.

The three networks are interconnected through several types of junctors, as shown in Fig. 3:

1) The internal junctor (IJ), which closes a path between two extensions through the internal network.
2) The external junctor (EJ), which closes a path between a trunk or tie-line and an extension through the internal and external networks.
3) The intermediate service feeder (ISF), which provides a connection between an extension and a service (tone generator, or operator, etc.).
4) The interservice connector (ISS), which interconnects two services through the service network.

• *Detailed organization of the networks*

The internal network is composed of three stages (1, 2 and 3) of crosspoint matrices. The first and second stages comprise up to 12 subgroups, each one corresponding to 64 extensions. Within each subgroup, the first and second stages intermix the 64 inlets and concentrate them on 32 outlets. The third stage intermixes the traffic of the subgroups.

The external network is composed of four identical groups. Each group is made up of two stages (4 and 5) of crosspoint matrices which mix the 32 inputs connected to the trunk or tie-line circuits with the 32 outputs connected to the external junctors.

The service network is composed of three stages (6, 7 and 8) of crosspoint matrices. Its basic part is composed of 232 inlets connected to 32 internal junctors (64 inlets), 64 external junctors (128 inlets), 32 intermediate service feeders (32 inlets), and 4 interservice connectors (8 inlets), and of 64 outlets connected to 64 service attachments.

• *Network modularity*

Modularity in switching and service networks is shown in Figs. 4(a) and 4(b).

Internal network. The basic network has 256 inputs (Group 1). Additional extensions can be added in groups of 256 inputs each (Groups 2 and 3) to give the maximum configuration of 768 inputs (Fig. 4a). The maximum number of outputs (internal junctors) is 96.

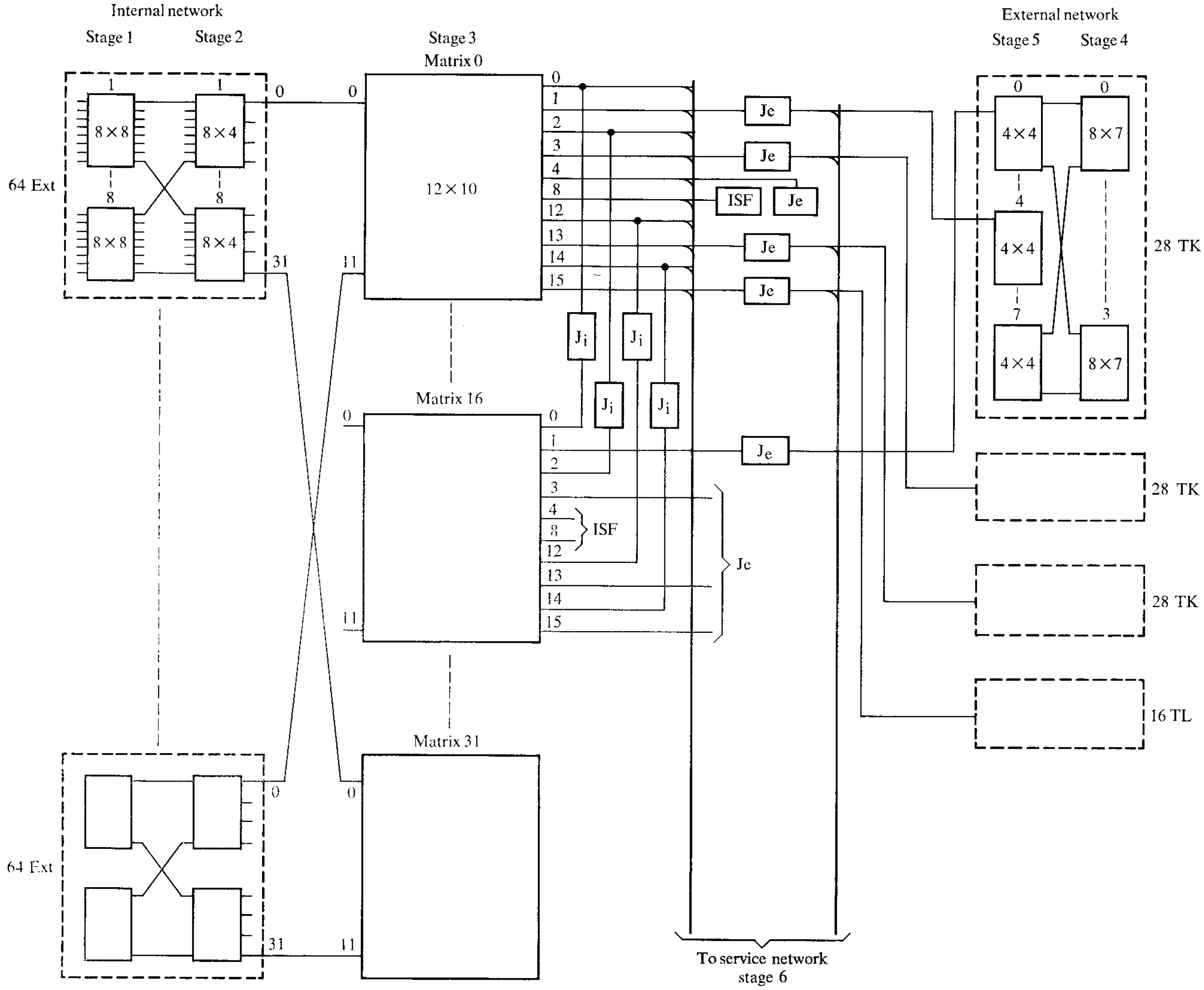


Figure 3 Junctor connections

External network. Four groups make up the external network; group 1, 2 and 3 are identical and comprise 32 inputs (trunk lines) each. Each group corresponds to 32 external junctors. The fourth group is designed to interface with tie-lines. Trunks may be incoming, outgoing, or both-way, and may be freely intermixed.

Service network. The structure of the service network is such that the number of inlets can be doubled by doubling the number of matrices at stages 6 and 7, and doubling the size of the stage-8 matrices. The number of outlets can be doubled by doubling the size of matrices at stage 7 and by doubling the number of stage-8 matrices.

The service network can thus be expanded in modular fashion by increasing either the number of its inlets (corresponding to the number of junctors) from 232 to 464 or the number of its outlets (corresponding to the number of services) from 64 to 128.

The number of services actually connected can vary widely, for example, from 2 to 8 operators, from 17 to 21 tone senders, from 0 to 24 multifrequency receivers, and from 0 to 8 add-on circuits.

- *Path marking procedure*

As shown in Fig. 5, any calling party can be connected to any one of N current sources J_A, and any called party to any one of N current sources J_B. A pair $J_A + J_B$ is permanently associated with an ac switch J_M controlling the continuity of the voice path between the calling and called parties; the transmission bridge so formed constitutes a junctor (Fig. 6).

Three steps are necessary to establish a conversation: 1) connect party A to J_A, 2) connect party B to J_B, 3) activate switch J_M to close the loop.

An extension-to-extension connection thus uses six crosspoints and one junctor. The switching network is

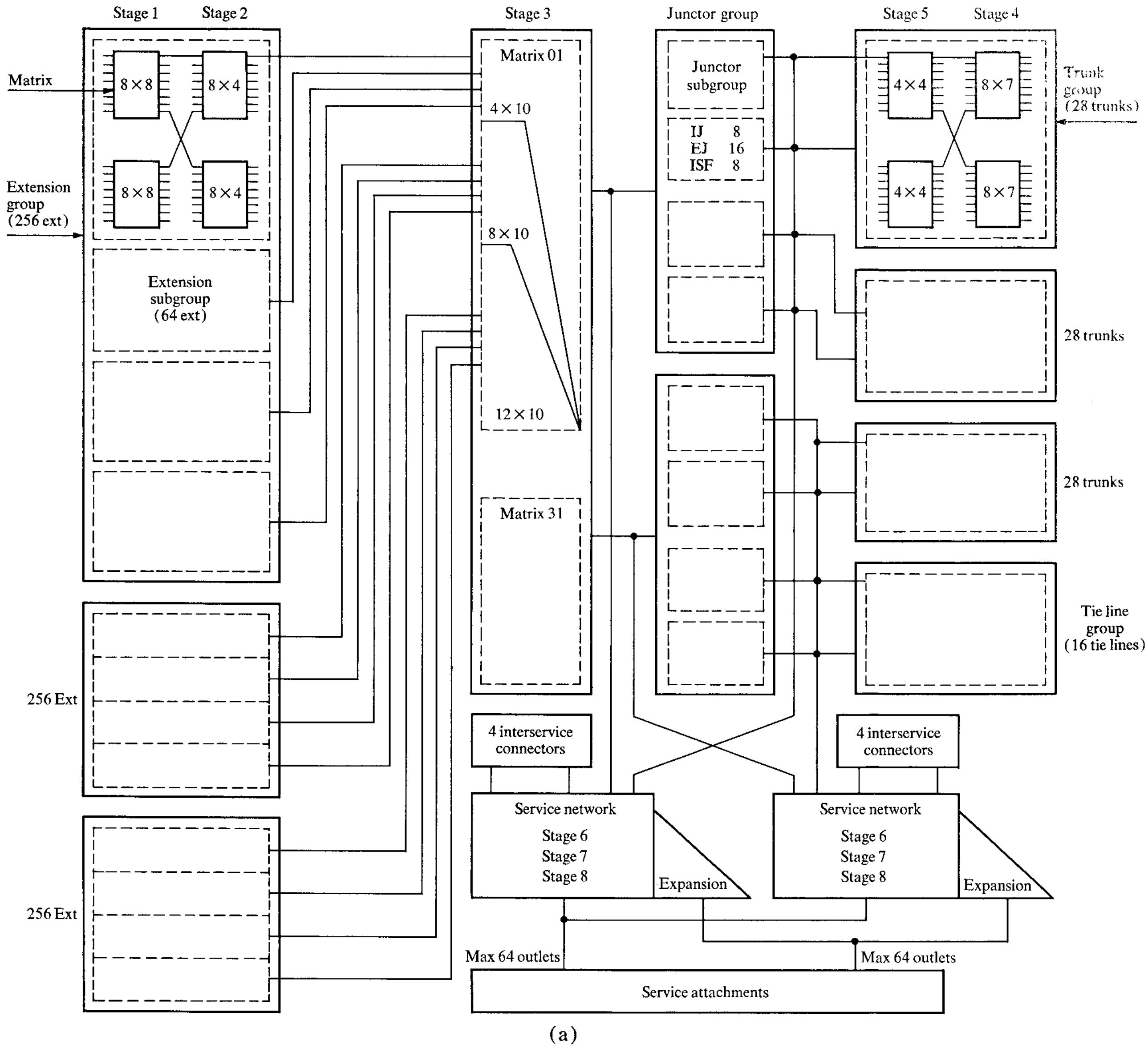
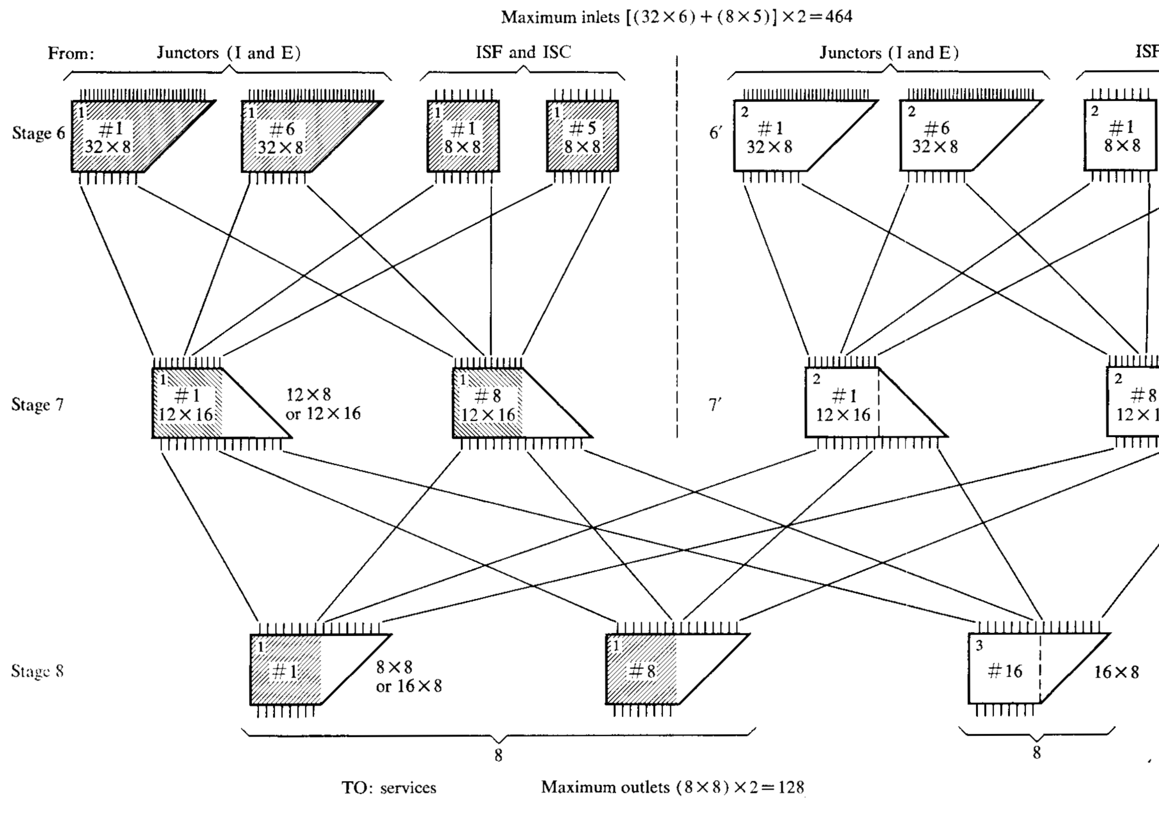


Figure 4 (a) Switching network modularity.

organized in such a way as to provide only one path between a party and a current source (J_A or J_B); in other words, all parameters of the path are fully defined by the addresses of the party and the chosen current source: these two addresses are sufficient to define fully the matrix that is involved at each stage, and the appropriate inlets and outlets; likewise, the links between successive matrices are clearly defined. This characteristic of the network is important, as it simplifies the path finding and path checking programs.[14]

The working of the switching network can be explained with an example showing an extension-to-extension connection, indicated in Fig. 7. Before any action, no current is flowing from A to J_A; all thyristors are in the OFF-state (blocked) with leakage currents in the nanoampere range; the current source J_A is blocked; all control leads are connected to ground (no marking voltage); and all gate diodes (Fig. 7) are reverse biased, all links being biased at +12 V. When the current source is set, a low impedance to ground is introduced at the output of the last matrix (cathode of T_3). One marking pulse driver per stage is also set: voltages V_1, V_2, V_3 are applied to the gate leads of T_1, T_2, T_3, through resistors. Thyristors T_1, T_2, T_3 are successively turned on and finally a voltage close



(b)

Figure 4 (b) Service network modularity. The basic service network is shaded.

to 24 V is applied to the path; current flow is limited by J_A and the ac impedance to ground is increased up to several hundred kilo-ohms. Now the current flowing from the +24 V supply through the transformer (or the limiters) keeps the three crosspoints conducting. The whole operation connecting A to J_A lasts less than 3 μs. The second half-path, B to J_B, is then set in the same way. Finally, the voice loop is closed by closing J_M, a diode switch with the following additional functions:

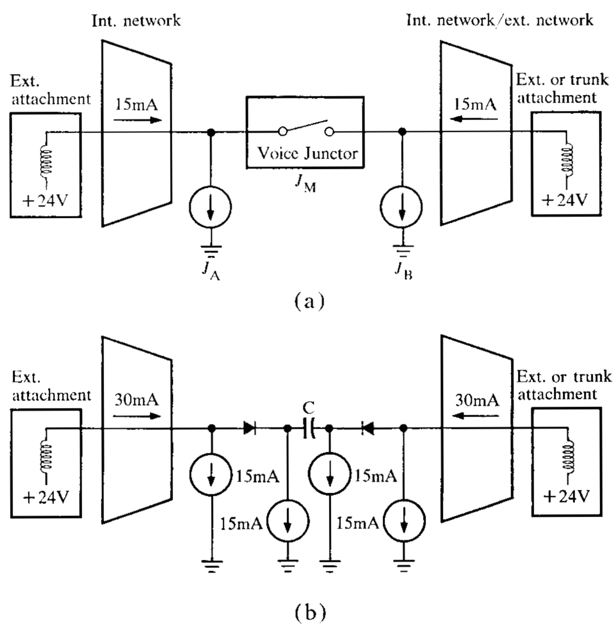
- separation of dc voltages,
- limitation of transient currents in the voice loop, giving unconditional stability to the path,
- provision of bidirectional amplification if necessary and compensation of the series loss in the switching network.

It is apparent from the foregoing that the physical connection of two users through the switching network is practically instantaneous.

- *Path unmarking procedure*

Two operations are necessary in path unmarking: open switch J_M, and block current sources J_A and J_B. All the

Figure 5 Path marking procedure, showing interconnection of two telephone terminals. a) Steps 1 and 2: both half-paths connecting the two terminals to both sides of a junctor are established. (b) Step 3: The voice junctor is set.



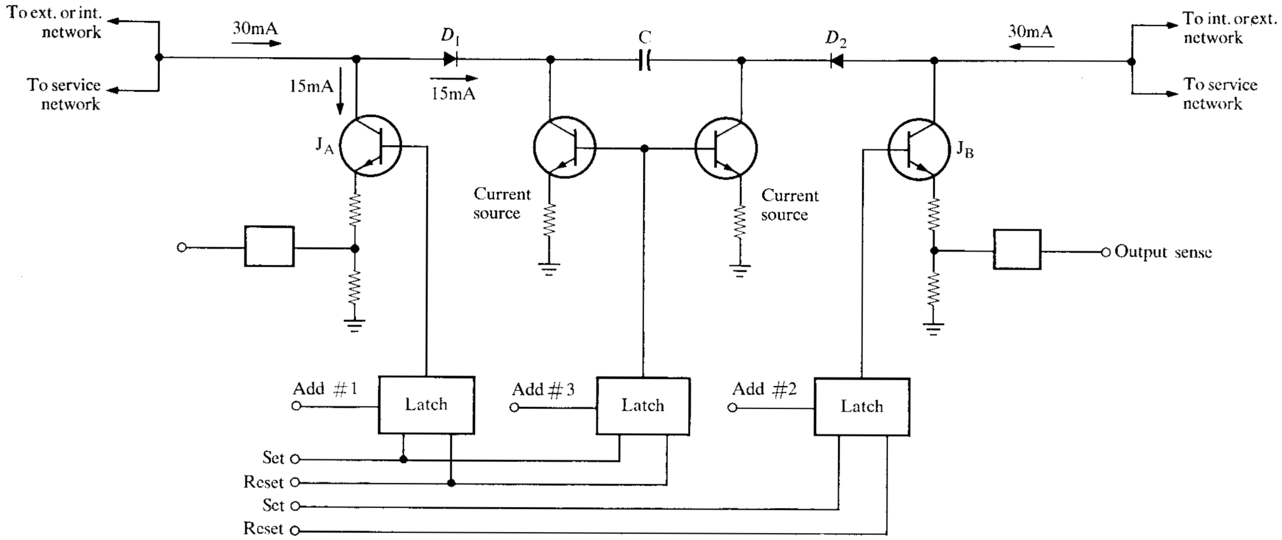
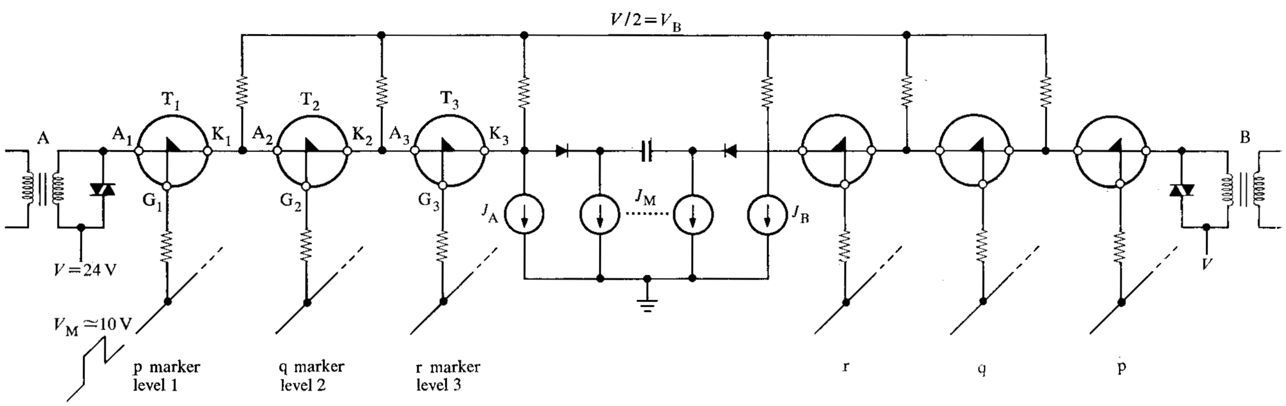


Figure 6 Junctor configuration.

Figure 7 Path marking [with switching path OFF, $I(t) = 0$; with switching path ON, $I(t) = 15$ mA].



crosspoints of the voice path are turned off by the second operation.

Voltages at points K_1, K_2, K_3 (see Fig. 7) drop to +12 V; thus, marking pulses cannot trigger the thyristors, V_1, V_2, V_3 being lower than +12V.

Terminal and service circuits

The terminal units attached to the 2751 through extension lines can be telephone sets, data sets or any other voice frequency devices; attachment to the 2751 is through twisted pair wiring.

- *Extension line circuit*

The standard extension line circuit provides the following functions (Fig. 8):

- Call signal emission and control (ring circuit)
- Direct current feeding of the extension line
- Off-hook detection
- Rotary dialing detection
- Switching network current detection
- Level limitation and transient voltage elimination.

The extension line circuit is made up basically of a line transformer and of some associated circuitry intended for signalling or current feeding purposes.

The need for a line transformer at the network interface arises mainly 1) to terminate the balanced to ground telephone lines, and 2) to provide for dc isolation between the switching network and the telephone line.

The line transformer incidentally offers fair protection against longitudinal induced noise and lightning surges.

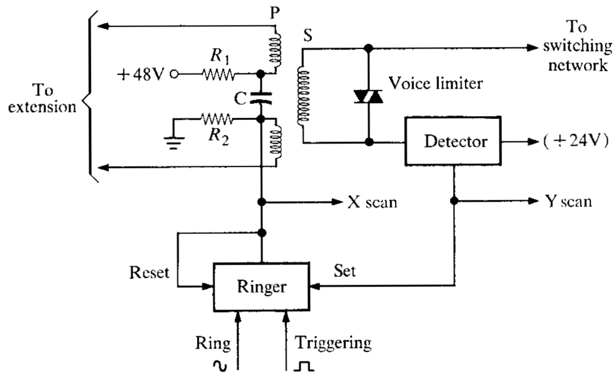


Figure 8 Extension circuit.

To obtain compact extension-circuit packaging, a small volume line transformer providing efficient primary-to-secondary insulation and low leakage inductance was required. A 36 × 22 mm ferrite-pot transformer was therefore developed.

Compensation for the insertion loss due to the transformer is easily provided by placing a negative-resistance converter in the junctors. It is a relatively simple matter to compensate for *either* parallel *or* series losses; since we had other series losses in the crosspoints and cabling, we chose to compensate for series losses and to reduce parallel losses as much as possible. At the cost of increased series loss, a reduction of the transformer volume can be obtained, the limiting factor being an uncertainty on the exact value of the serial resistances which prevents precise compensation.

Particular attention was paid to winding interleaving to obtain low leakage inductance and good symmetry to ground. These two characteristics are not fully compatible; an acceptable compromise is a symmetry factor of 60 dB at 800 Hz and a leakage inductance of 10 mH. Such a value permits compact packaging of the line circuits without any magnetic shielding between neighboring transformers; an important cause of crosstalk is thus almost completely eliminated.

• *Trunk line circuit*

Like the extension line circuit, the trunk line circuit is made of a line transformer, allowing the connection of a public network line to the 2751. The standard trunk circuit performs the following functions:

- Call signal detection
- Loop holding and dialing
- Current adjustment
- Charge metering
- Line termination
- Switching network current detection
- Level limitation.

The standard trunk circuit is designed to satisfy the PTT interface requirements of all European countries in which the product is to be marketed. In addition, a special direct inward dialing trunk circuit has been developed for use in those countries where direct inward dialing is authorized by PTT, e.g., in Germany.

• *Service circuits*

Voice exchanges between two telephone users are routed through the internal and/or external networks of the 2751. The establishment, pursuit and termination of such calls, however, cannot be carried out without switchboard operator intervention or the help of certain auxiliary signalling or signal-recognition functions such as sending tone wavetrains to users, recognizing tones sent by the public exchanges (CX's), recognizing multifrequency signals sent from multifrequency (MF) sets.

These functions are known as *services*, and circuits to accomplish them are connected to permanently assigned service network outlets; the service network enables the required service to be connected to any extension or trunk line.

The following list shows the maximum number of each type of service:

Numeric multifrequency receivers (MFR's)	24
Tone signal senders	21
Operators	8
Alphanumeric MFR's	4
Multifrequency generators	2
CX tone detectors	6

Multifrequency receiver (MFR). The MFR's recognize signals sent to the 2751 in multifrequency parallel form and decode them into digital form for processing by the control unit. There are two distinct types of MFR's, numeric and alphanumeric. Connection to the 2751 network, scanning methods used and packaging are common to both types.

Numeric multifrequency receivers detect numbering signals emitted from a push-button terminal, using the code recommended by the CCITT Study Group XI for Telephone Signaling (Contribution XI-121), and send the corresponding digital information to the control unit. The whole device performs the following functions:[15]

1) Detection and recognition of coded frequency pairs,
2) protection against: voice interference, digit repetition during prolonged depression of one key, lack of one frequency at the beginning of the emission, random brief disappearance of one frequency during confirmation, and
3) detection of failures occurring in the address or command decoders, and in drivers or detectors.

The MFR can accept a transmission rate of up to 12 characters per second.

Tone signal sender. All the tones required by the system are derived from a common 425-Hz tone bus which feeds a set of tone signal senders attached to the service network; these send appropriate tone patterns readily recognizable by the user, under the control of the operational program.

Operator telephone set attachment. An independent attachment circuit connects each operator telephone set to the service network; to control this type of connection, a service network address identifies each operator. An intrusion tone can be superimposed on a conversation to indicate to a telephone user the presence of an operator on the line.

Network control

The inputs to the switching system are the events occurring on the attached telephone lines, which the 2751 then has to translate into machine-intelligible language. The accompanying paper on 2750 programs[14] explains this.

Two operational functions are fundamental: *scanning* and *marking*.

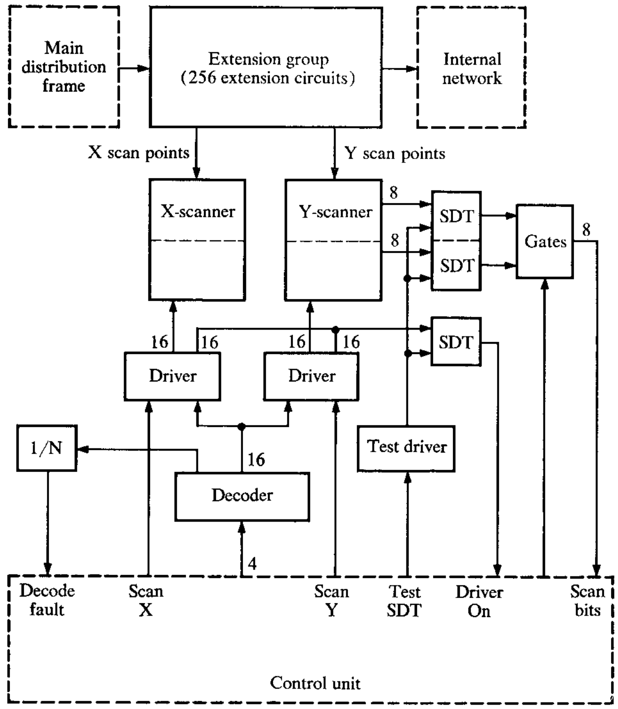


Figure 9 Extension circuit organization.

- *Scanning*

The 2751 must detect

- extension call requests,
- extension call endings,
- public network call requests,
- digits dialed on rotary sets,
- digits dialed on pushbutton sets,
- operator key codes and
- digits received from the public network.

This information is detected by periodically scanning the terminal circuits, the multifrequency receivers and the operator keys.

- *Marking*

Information collected in the scanning phase is interpreted by the network control program and in most cases leads to the connection of two terminal circuits. The operation is briefly described below.

Each interstage link in the 2751 network has a different address. The control program defines those links which have to be selected to establish the required voice path through the network, then turns a given junctor on and sends a marking command and the selected link addresses to the control unit. This command activates the marking pulse generators (or markers), one per matrix stage.

The control program keeps a permanent record of the state of the switching network by continuously updating the occupancy tables of all links and junctors. With the help of this network image, the program is able to compute a free path to establish a specific connection, e.g., extension to extension, extension to trunk, extension to service.

Each time a new half-path is established between a terminal circuit and a junctor, a current must flow from the selected terminal circuit towards the selected junctor; indications from current sensors placed at both ends of the half path are collected by the scanner; the links and junctors are listed BUSY in the network tables. When a path is freed, its components are also freed in the tables, and correct execution of the operation is controlled through the current sensors.

As we have seen, scanning and marking both involve the use of scanners. An example of scanner organization is shown in Fig. 9. The 2751 contains several scanners, one for each area of the machine; typical of them are the terminal circuit scanners, which collect the statuses appearing at the switching network inlets, and the junctor scanner, which collects the statuses of the junctor current sources. Each scanner contains fault-detecting circuits which continuously verify its correct operation.

Transmission characteristics

In the 2750, two main transmission problems arise: *insertion loss* and *crosstalk*.

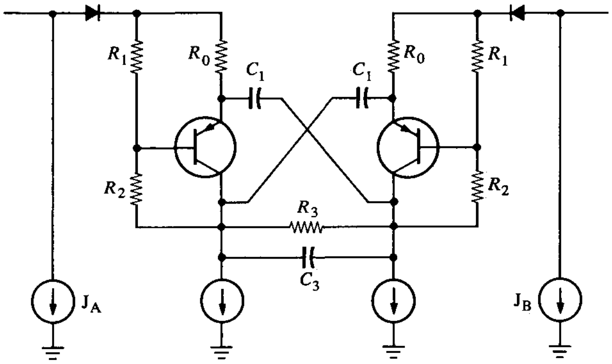


Figure 10 Negative impedance converter.

Insertion loss problems occur because the solid state device presents a finite impedance to voice signals; moreover, line transformers introduce non-negligible insertion losses.

Crosstalk problems are due mostly to the choice of one-wire switching which in turn introduces high crosstalk coupling in the sections of wiring unbalanced to ground. Two-wire switching would avoid this but would also be more costly.

• *Insertion loss*

The 2750 specifications are in accordance with tight PTT requirements, namely:

Insertion loss, in dB, at	300 Hz < 1.7
	800 Hz < 1.3
	3400 Hz < 1.3

The design aim has been to guarantee an internal attenuation of $+0.8$ dB $\pm$ 0.4 dB at 800 Hz, during the whole operating life of the machine.

Serial losses, in ohms, are distributed as follows:

Two line transformers (primary)	100
Two line transformers (secondary)	30
Six crosspoints	36
Wiring	24
Feeders + dc detector	155

The total equivalent serial resistance relative to a 600-Ω load is 447 Ω.

Such serial losses alone would lead to an insertion loss of 2.7 dB. Parallel losses are estimated to be 8 kΩ, which correspond to an equivalent serial loss of 45 Ω or 0.35 dB.

Since parallel losses are only 10% of series losses, it is sufficient to compensate only for the series losses. The ideal point to introduce a compensating device is the junctor because of its central and symmetrical position in the internal transmission loop.

Figure 5 shows the network elements involved in a telephone call between extension users. Figure 6 shows the operating principle of a junctor. Current sources are used to close the diode switch.

The amplifier and its feeder are shown in detail in Fig. 10.

A compensating device and two transistors replace the coupling capacitor C of Figure 6. The same current sources are used in this case to supply current to the amplifier.

It can be seen that this negative impedance converter is relatively simple and can be designed for very small size; it does not impair the junctor-card packaging density.

A computer simulation was used to analyze the various influencing parameters. The computer program, written in FORTRAN IV, includes the behavior with frequency of the negative impedance converter, and calculates the best, the nominal and the worst cases of insertion loss through the 2751. Computed results were in very good agreement with experimental ones. Both showed that although insertion loss specifications are very tight, they can be met with careful design and good accuracy on components.

The large number of different impedance conditions in telephony demanded a careful study of stability. Our main concern was that in no case should the 2751 become an amplifier. By itself, the negative impedance converter is open-circuit stable and short-circuit unstable. When it is placed in the network, two cases of instability are likely to occur: at low frequency, when the line transformers begin to introduce important parallel losses, and at high frequency, when parallel losses are created by the cabling capacitance to ground. Stability criteria were met by designing a line transformer with relatively high primary inductance (refer to the section "Extension line circuit," p. 422) and by reducing the conversion factor of the negative impedance converter above 100 kHz.

• *Crosstalk problem*

Let us recall the definition of crosstalk in telephony. Consider two communication lines, each input and output being terminated in the line characteristic impedance. If a generator sends V_1 on one line, a level V_2 is received at one end of the second line. The ratio V_2 to V_1 expressed in dB is the crosstalk ratio. According as the receiving end is near or far, so the crosstalk is near-end (NE) or far-end (FE). The crosstalk effect is different from the noise effect, crosstalk being intelligible, whereas noise is not.

With one-wire electronic switching, crosstalk has three main origins: 1) blocking impedance of the crosspoints, 2) wire coupling (electrostatic and electromagnetic coupling), and 3) impedance of the common reference plane.

1) Off-state crosspoints in the common matrices contribute to the crosstalk by their leakage resistance and capacitance in parallel; since the switching network is biased at a dc voltage different from ground and as the parallel impedance of a link to ground is much lower than the OFF impedance of the crosspoint, only four crosspoints contribute to this kind of crosstalk because in the 2751 network there can only be two crossings of the two considered voice paths, in the worst case.

The effect of the leakage resistance is normally negligible, and the crosspoint capacitances may be included in the wiring capacitance.

2) Wire coupling covers many items, namely, electromagnetic coupling of line transformers, of the wiring from the line transformers to the junctors, and conversation-to-conversation capacitance (which includes capacitance of four crosspoints in the off-state) and wire-to-wire capacitance.

All these items may be separately evaluated; for example, a great part of the wiring is made of flat cables whose characteristics are well known. Then all effects can be added, giving a total mutual inductance M and a total capacitance C.

The crosstalk voltage due to M and C is

$$j\omega \frac{M}{2} I, \tag{1}$$

where $I =$ ac current in the disturbing voice path, and

$$j\omega C \frac{Z_0}{2} \frac{V_1}{2}, \tag{2}$$

where $Z_0 =$ telephone line impedance (600 Ω) seen through the line transformer.

3) Since we have a one-wire switching network, all voice currents have a common return path, which is the distribution plane connecting all secondary windings of the line transformers.

The crosstalk voltage due to distribution coupling is

$$\rho \frac{I}{2}, \tag{3}$$

where $\rho =$ impedance of the common reference plane.

After summation of these three elementary effects, near-end crosstalk voltage is given by

$$V_{\mathrm{NE}} = j\omega \frac{V_1}{2} \frac{Z_0}{2} \left(C + \frac{M}{Z_0^2} + \frac{\rho}{j\omega Z_0^2} \right) \tag{4}$$

and far-end crosstalk voltage by

$$V_{\mathrm{FE}} = j\omega \frac{V_1}{2} \frac{Z_0}{2} \left(C - \frac{M}{Z_0^2} - \frac{\rho}{j\omega Z_0^2} \right). \tag{5}$$

This scheme, although simplified, gave good results in evaluating crosstalk in the upper frequency band (800 to 3400 Hz). However, since crosstalk was a critical problem in our one-wire switching network and since several attempts at electronic switching had failed for this reason, a more thorough investigation was undertaken.

• *Simulation of crosstalk in a one-wire electronic switching network*

First, equivalent circuits were derived from systematic evaluations and measurements of cable parameters, of crosspoint off-impedance (capacitance and resistance), and of internal common impedance of 24-V and 48-V sources. Effects of disturbed circuits on disturbing circuits were neglected in view of the small induced voltages and high values of coupling impedances.

Then all voltages due to capacitive coupling, inductive coupling, coupling through the common impedance of the +24-V distribution, and coupling through the impedance of +48-V power supply, were separately computed and algebraically added.

In this way, worst-case values of crosstalk attenuation could be calculated at various frequencies, at near-end and far-end terminals. The worst case values found were

>8.5 nepers, or 74.0 dB at 300 Hz,
>9.5 nepers, or 82.5 dB at 800 Hz,
>8.0 nepers, or 69.4 dB at 3400 Hz.

These values, which correspond to very special configurations of the voice paths, *and* to worst case, end-of-life components, are not normally encountered during the whole operating life of the 2750, and never on new machines. It would seem also that larger switching networks could be built without impairing crosstalk attenuation.

Conclusion

With the 2750, IBM has introduced an electronic system embodying solid state circuitry for control and switching. Exhaustive studies and experiments indicate that the semiconductor latching switch is a most attractive device for electronic switching.

The advantages of the electronic switch are well known: lack of mechanical wear, robustness, high reliability and long life, high speed properties, very low control power, microelectronic size, low mass production cost, etc. Apart from these universal advantages, however, the electronic switch is particularly suitable for voice and data switching systems construction, as the following considerations show.

One-wire switching should by no means be considered a limitation of the semiconductor switch, since it could serve equally well in two- or four-wire switching systems.

Again, the need for loss compensation may lead to the wrong conclusion that the weak point of a semiconductor switch is transmission loss. While it is true that its resistance is higher than that of a metallic contact, this resistance is not a determining factor when the several losses in a 2751 are considered. Present electromechanical systems do not require loss compensation, because they use large components everywhere; such components are not suitable for electronic switching systems. In fact, transmission loss is the price to be paid for component miniaturization. Printed circuits, high density wiring, small coils and capacitors imply higher series resistances, which became tolerable after we had developed an efficient bidirectional amplifier.

To sum up, the most significant advantage of the integrated electronic switch when applied to the industrial production of PABX's of the type described above is that switching networks of tens of thousands of crosspoints can be encompassed in a very small volume, permitting one-wire switching with unimpaired transmission quality. This is a most important consideration, since one-wire switching reduces the size of the network and therefore its cost.

Acknowledgments

The design and development of this switching network have required a large scale cooperative effort. It is therefore impossible to acknowledge all contributions individually, but the author would especially like to thank J. Garcia and W. Youdale of La Gaude for their help in selecting the information and organizing this paper.

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Received January 31, 1969