FUNDAMENTALS OF DIGITAL TECHNIQUES AND SWITCHING

Contents

1. GENERAL

1.1 This section provides REA borrowers, consulting
     engineers, and other interested parties with
technical information for use in the design and construc-
tion of REA borrowers' telephone systems. It covers, in

particular, the study of digital technology as it applies
to digital switching systems. It also covers the basics
of digital switching in general.

   1.2 It is not the intention of this section to cover
        all aspects of digital technology in exhaustive
detail. The major facets of the technology will be
covered in such a manner that the reader will have a
basic understanding of digital techniques. Although no
particular digital switching system will be described
in detail, the major portions of a digital switch, in
general, will be explained.

2. DEFINITION OF DIGITAL

   2.1 The first step in understanding digital technology
        is being able to differentiate between analog and
digital signals. An ac or dc voltage or current signal
that varies smoothly or continuously is an analog signal.
These signals do not change abruptly or in incremental
steps.

   2.2 A series of pulses or rapidly changing voltage
        levels that vary in discrete steps or increments
is a digital signal. In other words, a digital signal
consists of voltage pulses that switch between fixed
levels. This off-on, up-down, fast switching character-
istic is fundamental of all digital signals.

   2.3 Examples of analog and digital signals are shown
        in Figure 1. Although all the digital signals in
Figure 1 are shown as two-level (binary), digital signals
may have more than two distinct states.

   2.4 It may prove useful at this point to list some
        examples of analog and digital devices. A radio's
volume control, a car's speedometer, a thermometer and a
compass all measure analog quantities. Examples of
devices that measure digital quantities are a television
set's VHF channel selector, and a car's odometer. Any
on-off switch is a digital device and so, of course, is
money. It is important to remember that analog variables
can be measured and displayed digitally.

3. ADVANTAGES OF DIGITAL TECHNIQUES

3.1 The use of digital techniques provides many advantages over analog methods. Reductions in size, weight and cost are among the major advantages. Other advantages are detailed in the following paragraphs.

3.11 Digital techniques produce more consistent accuracy. Greater precision and resolution in representing quantities and in making measurements are permitted through the use of digital techniques. The direct decimal display of data is not only more convenient, but the error of reading and interpreting analog meters or in setting analog dials is also eliminated. With digital measuring instruments, the reading will always be within $\pm$ one-half the value of the least significant digit being measured regardless of the operator.

3.12 A greater dynamic range is available with digital systems. The dynamic range is the difference between the upper and lower data values that a system or instrument can handle. Analog systems are limited because of component capabilities and noise to a range something less than 100,000 to 1. With digital techniques practically any desired dynamic range can be obtained.

3.13 Greater stability is provided by digital circuitry. Analog or linear circuits are subject to the effects of drift and component tolerance problems. Temperature and humidity affect resistor, capacitor and inductance values. Transistor biases vary, causing non-linear operation and distortion to occur. Component imperfections and ageing cause drift and resultant problems. Digital methods greatly minimize or completely eliminate such problems.

3.14 Many electronic processes can be fully automated if digital techniques are used. Special control circuitry or a digital computer can automatically set up, control and monitor many operations. Data is readily recorded, stored and displayed.

3.15 Digital equipment is relatively easy to design. Readily available digital integrated circuits make it so. Little or no breadboarding is required. In analog or linear circuits, breadboarding is mandatory to

ensure a workable circuit. Digital equipment can go from
paper design to finished product in a comparatively short
time.

   3.16 Digital methods permit new approaches to the
         solution of electronic equipment design. In
addition, design solutions impossible with analog tech-
niques are readily implemented with digital circuits.
Digital circuits make it possible to do some things that
have no analog equivalent. The microprocessor is an
example.

4. THE BINARY NUMBER SYSTEM

   4.1 The binary number system is most compatible with
        the pulses used in digital systems because only
two conditions are required to accommodate the two binary
digits, 1 and 0. No matter what number system is used
outside the digital system (for programming, readout,
etc.), the number is converted (coded) into binary form
for use within the system.

   4.2 Because the binary system uses only two distinct
        quantities, 1 and 0, working with digital systems
is rather simple. Manipulation of binary numbers is
relatively easy. Hardware representation of binary
quantities is also uncomplicated.

   4.3 It is useful to know how a decimal number is
        represented in the binary system. As in the
decimal system, the positional weights increase from
right to left; only in the binary system they increase
in ascending powers of 2 rather than 10. Thus, the
digit at the extreme right (the least significant digit)
has a weight of 2^0, or decimal 1. A digit immediately
to the left has a weight of 2^1, or decimal 2. The next
digit to the left has a weight of 2^2, or decimal 4, and
so forth.

   4.4 The binary number "1110" is equivalent to:

         (1×2^3) + (1×2^2) + (1×2^1) + (0×2^0), or

         (1×8) + (1×4) + (1×2) + (0×1) , or

            8   +   4   +   2   +   0   ,

or decimal 14. The binary number "1110" is read as

"one, one, one, zero," not "one thousand, one hundred and ten."

4.5 To illustrate the simplicity with which binary numbers can be manipulated, the following list shows the four rules of binary addition:

$$0 + 0 = 0$$
$$0 + 1 = 1$$
$$1 + 0 = 1$$
$$1 + 1 = 0 \text{ with a carry of } 1$$

Because there are only four elementary rules to remember, binary addition is much easier than decimal addition. Likewise, binary subtraction, multiplication and division are also very simple. Appendix A goes into binary arithmetic in more detail.

5. DIGITAL LOGIC CIRCUITS

5.1 All digital equipment, simple or complex, is constructed from just a few basic circuits. These circuits are called "logic elements." A logic element performs some specific function on binary data.

5.2 There are two basic types of digital logic circuits: decision-making and memory. Decision-making logic elements monitor binary inputs and produce outputs based on the input states and the operational characteristics of the logic elements. Memory elements are used to store binary data.

5.21 Decision-making circuits do exactly what their name implies - make decisions. The basic decision-making logic element is called a "gate." A gate has two or more binary inputs and one output.

5.22 While many simple logic functions can be implemented with a gate, generally gates are combined to form more sophisticated and complex decision-making logic networks called "combinational circuits." Most combinational circuits perform some unique logic function such as decoding, encoding, multiplexing, comparison or an arithmetic operation with binary numbers.

5.23 The other type of logic element is a memory
     circuit. The basic memory element is a bistable
storage device known as a "flip-flop." This circuit has
two stable states which can represent the two binary
numbers 1 and 0. The circuit can be placed in either
state so that it retains or remembers the bit stored
there. Most memory circuits store a single bit. Many
of these elements can be combined to store complete
binary numbers or words.

5.3 The three basic decision-making logic elements
    are the AND gate, the OR gate and the NOT gate
(inverter). All other digital logic elements and
circuits are variations or combinations of just these
three basic elements. Each of these elements receives
one or more binary inputs and generates a single binary
output.

5.31 The simplest form of digital logic circuit is
     the inverter, or NOT gate. The inverter is a
logic element whose output state is always opposite
its input state. The simplest and most widely used
form of logic inverter is the transistor switching
circuit. Figure 2A illustrates the NOT circuit. This
figure consists of three parts showing the symbolic
representation of the gate, the electronics involved
and a relay equivalent.

5.32 The AND gate is a logic element that has two or
     more inputs and a single output. The operation
of the gate is such that the output is a binary 1 if,
and only if, all inputs are binary 1. The simplest
form of AND gate is implemented with diodes and resis-
tors. A symbolic representation and schematic of an
AND gate is shown in Figure 2B.

5.33 Like the AND gate, the OR gate can have two or
     more inputs and one output. If any or all of
its inputs are binary 1, its output is binary 1. In
other words, the output is binary 0 only if all inputs
are binary 0. Again, the simplest implementation of
an OR gate uses diodes and resistors. An OR gate is
represented in Figure 3A.

5.4 While many circuits can be constructed with just
    the three basic digital logic elements - AND, OR
and NOT - most digital equipment is implemented with

special versions of these circuits known as "NAND" and
"NOR" gates. Such circuits are basically AND and OR
gates combined with an inverter.

5.41 The term "NAND" is a contraction of the expres-
sion "NOT-AND," i.e., an AND gate followed by
an inverter. The output is binary 0 if, and only if,
all inputs are binary 1. Figure 3B shows a NAND gate.

5.42 The term "NOR" is a contraction of the expres-
sion "NOT-OR," i.e., an OR gate followed by an
inverter. The output is a binary 1 if, and only if,
all inputs are binary 0. A NOR gate is depicted in
Figure 3C.

5.5 As previously mentioned, the basic memory or
storage device is a digital logic circuit called
a "flip-flop." A flip-flop is capable of storing a
single bit of binary data, either a binary 1 or binary
0. When the flip-flop is put into one of its two
stable states, it will remain there as long as power
is applied or until the state is changed. A flip-flop
is shown in Figure 4.

5.51 The S and R input leads of the flip-flop denote
the "set" and "reset" inputs. The outputs Q and
$\overline{Q}$ are the "normal" and "inverted" outputs, respectively.
The truth table at the bottom of Figure 4 shows the
output states of the flip-flop for various inputs. When
Q is binary 1, the flip-flop is set; and when $\overline{Q}$ is binary
1, the flip-flop is in the reset state. Under proper
operating conditions, $\overline{Q}$ will be the opposite of Q.
However, if S and R are both binary 0, both Q and $\overline{Q}$ will
be binary 1. Since this is an undefined state (neither
set nor reset), simultaneous zeros at S and R are not
permitted. For the flip-flop to be placed in the set
state, the S input must be binary 0 and the R input must
be binary 1. To reset the flip-flop, the S input must
be binary 1 and the R input must be binary 0. If both
S and R inputs are binary 1, the state of the flip-flop
will remain unchanged. This is shown by the X and $\overline{X}$ in
the truth table. X can be either a 1 or 0 depending
upon the previous state of the flip-flop.

5.6 All modern digital equipment is constructed with
integrated circuits. Digital integrated circuits
are building blocks which are used to construct digital
circuits. Previously, the designer of digital equipment

had to design not only the logic involved but also the
electronic circuits necessary to implement that logic.
With integrated circuits, the designer's job is primarily
that of selecting commercially available devices and
applying them to his specific application.

6. MICROPROCESSORS

 6.1 Many systems in use today, including digital
      telephone systems, use microprocessors as control
devices. Most microprocessors are used as the central
processing units (CPU) of digital computers. That is,
the microprocessor usually contains the arithmetic-logic
and control sections of a small scale digital computer.
Most microprocessors also contain a limited form of
input-output circuitry which permit them to communicate
with external equipment. To make the microprocessor a
complete microcomputer, external memory and input-output
devices must be added. See Figure 5. An external read-
only memory (ROM) is normally used to store the program
to be executed. Some read/write, random access memory
(RAM) may also be used. This type of memory is normally
used in digital switching systems to store the data base
information. The external input-output (I/O) circuitry
generally consists of registers and control gating that
buffer the flow of data into and out of the CPU.

 6.2 Microprocessors come in a wide variety of forms.
      The most popular microprocessor is the metal oxide
semiconductor large scale integrated (MOS LSI) circuit.
The entire CPU is contained on a single chip of silicon
and mounted in either a 16-, 24-, or 40-pin dual in-line
package. Such microprocessors are available with
standard word lengths of 4, 8 and 16 bits. Other more
sophisticated types of microprocessors are contained
within two or more integrated circuit packages. When
combined, they form a complete, small scale digital
computer.

 6.3 Microprocessors are employed primarily for dedicated
      functions. Rarely are they used to implement a
general purpose digital computer. The microprocessor
program is fixed and dedicated to a specific application
and stored in a read-only memory.

 6.4 There are two broad general applications for modern
      LSI microcomputers. They can be used as replace-
ments for minicomputers and as substitutes for random

hard-wired logic. Microcomputers have the advantages of smaller size, lower cost and lower power consumption.

6.41 The minicomputer was dedicated to control applications, and its programmable flexibility offered many benefits. But its cost was very high. Some microcomputers have nearly as much computing power and capability as a minicomputer and can replace the minicomputer in many systems.

6.42 Another common use for the microcomputer is as an alternative to standard hard-wired digital logic circuits. Equipment customarily constructed with logic gates, flip-flops, counters and other small and medium scale integrated circuits can often be implemented with a single microcomputer. All of the standard logic functions such as Boolean operations, counting and shifting can be readily carried out by the microcomputer through programming. The microcomputer will execute instructions and sort subroutines that perform the same logic functions. Many benefits result from using a microcomputer to replace hard-wired random logic systems. Some of these advantages are: (1) reduced development time and cost; (2) reduced manufacturing time and cost; (3) enhanced product capability; and (4) improved reliability.

6.43 It is important to remember that a microprocessor alone is not a microcomputer. The microcomputer, not the microprocessor, is the functionally useful system element. A microcomputer includes a microprocessor, program memory, data storage, input-output circuitry and other support devices.

7. MEMORY DEVICES

7.1 As was mentioned previously, memory must be added to a microprocessor to allow it to be useful. Memory is basically used to store program information and data in a microcomputer system.

7.2 Memory devices have four basic functions:

    a) data storage,
    b) decoding of address inputs to select a specific location,
    c) altering stored data at a selected location upon command, and
    d) outputing data from a selected location upon command.

7.3 Most microcomputer systems are dedicated to a
     specific task. Therefore, the microcomputer
program that defines the execution of the task will
not change often. It is common practice to separate
the program memory, which does not change, from the
data memory whose contents do change during execution.

7.4 Two basic kinds of memory devices are used in
     computer systems. These are designated "read-
only memory (ROM)" and "read/write memory (RAM)." RAM
denotes random access memory. Although read-only
memory is also random access, RAM is used to designate
read/write memories only.

7.5 Standard ROM is programmed during the semiconduc-
     tor manufacturing process. Transistors for each
bit of memory are either enabled or destroyed, depending
upon whether the location is to contain a 1 or a 0. As
mentioned previously, programs and data that do not
normally change can be stored in ROM. ROM is non-
volatile, i.e., the memory contents are not lost if
power is removed.

7.6 There are four basic types of semiconductor ROM:

     a) Masked ROM,
     b) Field Programmable ROM (PROM),
     c) Erasable/Programmable ROM (EPROM), and
     d) Electrically Alterable ROM (EAROM).

7.61 In masked ROM, the memory content is installed
      by the semiconductor manufacturer during the
final manufacturing process known as the "mask step."

7.62 Field programmable ROM is programmed by the user
      with special PROM programming hardware that burns
out fusible links within the device. The major disadvan-
tage in using PROM is that the programming device is
quite expensive.

7.63 The memory content in erasable/programmable ROM
      is installed by the user with special hardware
that injects electrons into the chip. The entire memory
can be erased by exposing the chip to intense ultraviolet
radiation which allows the injected electrons to leak
away.

7.64 In an electrically alterable ROM, memory content
       is installed by the user employing ordinary
memory write procedures similar to writing into a read/
write memory. In general, keyboards are used. The main
difference between an EAROM and an ordinary read/write
memory is timing. The read and write operations are
slower in EAROM.

7.7 Data memory, which contains information that
      normally changes during the operation of a system,
is stored in a read/write memory (RAM). RAM is volatile,
i.e., memory content is lost if power is removed. There
are two basic types of RAM - static and dynamic.

7.71 Static RAM stores data as the state of a flip-
       flop. One such flip-flop circuit is included
for each bit of memory. As long as power is applied to
the memory, the static RAM will retain its data.

7.72 Dynamic RAM stores data in the form of a charge
       in a MOS field effect transistor. This charge
will leak away in time and must be refreshed at regular
intervals. Since this refreshing requires additional
external circuitry, dynamic memory is not normally used
in smaller systems. However, in larger systems dynamic
RAM is desirable because many more bits can be stored in
one dynamic device.

8. ADVANTAGES OF DIGITAL SWITCHING

8.1 Digital technology has been used for quite some
      time in the telecommunications field. The first
electric telegraph whose messages were all digital was
proposed in the middle of the 18th century. The Morse
Code is a digital code. Telephony has also used digital
techniques for a long time, but only for signaling.
Dial pulses coming from the subscriber's set are a prime
example. The new portion of the technology is the use
of digital signals for the transmission of speech in the
telephone network. This development began in the early
1960's with the introduction of PCM transmission systems.
In the last few years digital switching systems have also
come into use.

8.2 The following paragraphs detail some of the advan-
      tages of using PCM and digital switching in the
telephone network.

8.21   The transmission quality of a digital signal is
       practically independent of distance. A digital
signal is practically immune to interference. Regenera-
tion of digital signals is possible at points along a
transmission line with virtually no loss of quality.
This cannot be done with analog signals because the
noise as well as the signal is amplified. The digital
repeaters only have to determine whether the signal is
a "1" or "0." Once this is known, a fresh pulse is
transmitted. However, this determination is not always
correctly made and an incorrect pulse is sent. This is
known as a digital error. A digital error rate of no
more than 1 error pulse in 10^8 pulses excluding the
least significant bit is considered satisfactory in a
digital switching system.

8.22   Time division multiplexing allows an increase
       in capacity on cable pairs originally used for
single telephone channels.

8.23   PCM transmission used in combination with digital
       switching provides various economies. The termi-
nal cost is a large portion of the total cost of PCM
systems. The use of digital switching can substantially
reduce this cost where switching is performed directly on
the digital bit stream and no costly analog-to-digital
conversion is necessary in the central office.

8.24   The use of integrated circuitry has produced
       favorable cost levels and high reliability.

8.25   PCM transmission channels can provide integration
       of services. A PCM link can be used not only to
transmit speech, but also data, telex, encoded visual
information, etc.

8.26   New wide-band transmission media such as wave-
       guides and fiber optics are more suitable for
digital than analog transmission.

8.27   Considerably less floor space is required for a
       digital switching network as compared to an
electromechanical network. The overall floor space for
a digital office is approximately one-third of that
required for a step-by-step office.

8.28   Installation time is considerably shorter as
       compared to that required for electromechanical
systems.

9. ANALOG-TO-DIGITAL CONVERSION

9.1 A typical line to line call in a digital office is shown in Figure 6. The first step in this procedure is converting the analog signal into a digital signal. The steps involved are shown in Figure 7. The first step in this conversion is known as "sampling." The process of sampling entails taking instantaneous values of the analog signal at periodic time intervals. This sampled signal is a train of pulses whose envelope is the original analog signal.

9.2 The "Sampling Theorem" states that the sampled signal will contain all of the information contained in the original signal if the following conditions are met.

9.21 The original signal is band-limited, i.e., it has no frequency components in its spectrum beyond some frequency B.

9.22 The sampling rate is equal to or greater than twice B.

9.3 The speech spectrum between 300 and 3400 Hz is used in telephony. The speech signal is low pass filtered at 3400 Hz. This is the frequency B mentioned previously. A sampling rate of 8000 Hz is used in telephony. As this rate is somewhat higher than 2B, no information loss occurs.

9.4 The samples formed can assume any value in the amplitude range of the speech signal. For practical reasons these sample amplitudes must be rounded off. This rounding-off process is called "quantizing." All sample amplitudes between two marks on the scale are given the same quantized value. The number of quantized samples is discrete since there are a discrete number of intervals on the scale.

9.5 When the analog signal is reconstructed at the receiving end, there will always be a small difference between the received signal and the transmitted signal. This discrepancy is caused by the rounding-off process and is known as "quantizing distortion."

9.51 This quantizing distortion is independent of the
         sample amplitude. The same quantizing distor-
tion is produced by a quiet talker as a loud talker.
Therefore, relative to speech levels, the quiet talker
generates much more distortion percentagewise than the
loud talker. Statistically, it is also more probable
to have small amplitudes than large ones.

9.52 In order to obtain acceptable quantizing distor-
         tion over the range of the speech signal, it is
necessary to make the quantizing levels very small at
low speech amplitudes. This is known as "companding"
or "non-uniform coding." The most common coding proce-
dure involves the use of the "mu 255" Coding Law. Using
this law, the amplitude spectrum is divided into eight
intervals. Each interval is divided into 16 levels.
The level spacing increases by a factor of 2 from one
interval to the next higher. The eight intervals with
16 levels each produces 128 magnitudes including zero.
The total number of levels including positive and nega-
tive magnitudes is 255. The negative zero representation
is discarded. See paragraph 9.61.

9.53 The actual thresholds of quantization are usually
         represented halfway between the increments shown
in Figure 7. In other words, the quantized value three
includes signal magnitudes between 2½ and 3½. In a like
manner, the value 20 represents signals whose amplitudes
are between 19½ and 20½. The important thing to note is
that the maximum quantization error is $\pm$ one-half the
quantizing increment. Thus, the maximum error with 255
levels is $\pm$ one-half part in 255, or less than $\pm$ 0.2%.

9.54 The advantage of companding also can be seen from
         paragraph 9.53. Since the increments are smaller
at weaker amplitudes, the maximum possible error is also
smaller. As the increments increase, the possible error
also increases. However, companding keeps the percent
error fairly constant throughout the amplitude range.

9.6 The sampling and quantization processes form a
        digital representation of the original speech
signal. This representation is not, however, the best
form for transmission. Translation to a different form
of signal is required. This process is known as "encoding."
The sample values are normally encoded into binary form.

9.61 In paragraph 9.52 it was seen that 255 different
amplitude levels are possible - 127 positive,
127 negative, and zero (represented by 10000000). The
all-zero code is discarded so that frequent ones (pulses)
are available to update clocks. These quantized samples
are not in the best form for transmission because it
would be very difficult to build regenerator circuits to
distinguish between the 255 different amplitude levels.
A binary form of encoding is normally used. As mentioned
previously, a binary code has only two pulse levels, 1
and 0. Binary pulses are very attractive for transmission
because it is a rather simple matter to design regenerator
circuits to determine whether or not a pulse is present.
If a pulse is determined to be present, a perfect fresh
pulse can be generated and retransmitted.

9.62 In order to provide a distinct code for each of
the 255 quantized levels, eight bits of information
are necessary. A three-bit code is used for simplicity in
the example shown in Figure 7. The most significant bit
(left most bit) normally indicates whether the sample is
positive or negative and the remaining seven bits, the
magnitude of the sample. This eight-bit code group is
called a "PCM word."

9.7 There are two basic types of PCM digital systems in
use today - the 24-channel system and the 32-channel
system. The transmission rates, or the speed at which
data travels within the system, are different for these
two systems. The transmission rate for the 24-channel
system is the North American transmission standard of
1.544 megabits per second, and the transmission rate for
the 32-channel system is the CCITT transmission standard
of 2.048 megabits per second. These rates are calculated
as follow:

24-Channel System:

(8 bits/sample x 24 channels + 1 framing bit)
x 8000 samples/second = 1.544 megabits/second

32-Channel System:

(8 bits/sample x 32 channels) x 8000 samples/
second = 2.048 megabits/second

Inside the digital switch the switching rate can be higher
than these rates.

10. DIGITAL SWITCHING

10.1 The encoded data is transferred from one location to another by way of time slots on time-multiplexed buses. Figure 8 shows an example of such a bus. This figure shows that the first bit from each channel is placed on the bus, followed by the second bit from each channel and so forth until all bits have been multiplexed on the bus. The bus will carry bits at the internal switching rate of the digital switch. This is normally either 1.544 or 2.048 megabits per second although certain machines switch at faster rates. Both time and space switching are normally used to switch different time slots between different buses.

10.2 Figure 9 shows a simplified diagram of a time-space-time (TST) digital switching matrix or time slot interchange (TSI). For an explanation of how the switch operates, assume that a connection is to be established between input A and outlet F. The incoming call is assigned to incoming time slot 1. The called subscriber is assigned to outgoing time slot 2.

10.3 For switching to occur, the information in incoming time slot 1 must be transferred to outgoing time slot 2. For this to be accomplished, an internal time slot must be found that is idle on both sides of the space matrix. In this example, internal time slot 15 is found to be idle.

10.4 The information from input A is stored in memory until internal time slot 15 arrives. At this point, the data in incoming time slot 1 is transferred to internal time slot 15. The data is switched through the space matrix. The information is stored in memory until outgoing time slot 2 arrives. The information then is read into outgoing time slot 2. A path is thus created from A to F by this operation which is repeated once every frame.

10.5 At this point, however, there can be no conversation because a path has not yet been established from F to A. This second path can either be found independently of the first or the two paths can be established at the same time. When the two paths have been completed, two-way transmission is possible.

11. DIGITAL-TO-ANALOG CONVERSION

11.1 In order to convert from the digital signal back to the analog speech signal, three processes are normally used: regeneration, decoding and reconstruction.

11.2 In the regeneration process, the distorted pulse train is replaced by reconstructed pulses. The regeneration circuit first determines whether a pulse is present or not. The pulses are then reshaped.

11.3 In the decoder circuit amplitude pulses are generated whose magnitudes are the same as the magnitudes of the quantized samples. After the pulse train has passed through the decoder, the original quantized samples are returned.

11.4 A low pass filter with a cut-off frequency of B Hz, normally 3400 Hz, is used to reconstruct the analog signal. The low pass filter eliminates any frequency components above B Hz. This leaves the spectrum of the original analog signal.

12. REMOTE SWITCHING TERMINALS (RST)

12.1 For many years subscriber concentrators have been used to serve groups of subscribers located at a distance from the central office. These concentrators are described in detail in REA TE&CM 340. Remote switching terminals serve the same purposes and have the same advantages as these concentrators. The basic difference is that RST's work on a direct digital basis into the host office. Therefore, channel banks are not required for analog-to-digital and digital-to-analog conversion. This leads to additional cost and space advantages not realized with line concentrators.

12.2 Under normal conditions the switching functions of the remote subscriber terminal are controlled by the host office processor. With the connecting span intact the subscribers served by the RST have all features, traffic capacity and special services available to all the other subscribers in the system.

12.3 When the span line is cut or otherwise out of service, an emergency switching option is available.

This option enables subscribers on the RST to talk to other subscribers on the same RST.

13.   THE ALL-DIGITAL NETWORK

13.1   Although many of the advantages of digital switching, in one degree or another, are with us today, its ultimate advantages will not be reached until the network becomes entirely digital, i.e., conversion from analog-to-digital and digital-to-analog takes place only at the subscriber set.

13.2   At this point the line circuit will be eliminated as will channel banks. This will bring about a large savings in cost and space.

13.3   Another point to keep in mind is that each time an analog-to-digital and digital-to-analog conversion is made, quantization noise is introduced. Therefore, the fewer conversions that are necessary, the less of a problem this noise becomes. With an all-digital network only one such conversion pair is necessary.

13.4   Although the all-digital network appears to be the ideal situation, it will be quite a number of years before it is realized. It will not occur until its economical advantages outweigh the cost of replacing the present-day network. The disadvantages of premature retirement of existing analog investment is the chief economic stumbling block in the path of the all-digital network.

APPENDIX A

Binary Arithmetic

1. GENERAL

1.1 The decimal number system is based on 10 distinct entities, 0 through 9. Using these 10 characters, any number can be depicted. On the other hand, any binary number can be written using only two characters - 0 and 1. This simplicity is the basic advantage of the binary system.

2. CONVERSION FROM DECIMAL TO BINARY

2.1 The positional weights of a binary number increase by a power of 2 for each bit from the least significant bit (LSB) to the most significant bit (MSB) (right to left). In other words, the LSB has a weight of 2^0, or decimal 1, and the MSB of an 8-bit number has a weight of 2^7, or decimal 128.

2.2 To convert a decimal number into a binary number, the following simple procedure can be used.

2.21 Divide the decimal number by 2. The remainder, either a 0 or a 1, is the least significant bit of the equivalent binary number.

2.22 Divide the result of the previous step by 2. The remainder is the binary digit to the left of the least significant bit.

2.23 Continue the above procedure until the result of the division by 2 is zero.

2.3 As an example of this procedure, convert 147 into its binary equivalent.

```
147 ÷ 2 = 73 with a remainder of 1 LSB
 73 ÷ 2 = 36 with a remainder of 1
 36 ÷ 2 = 18 with a remainder of 0
 18 ÷ 2 =  9 with a remainder of 0
  9 ÷ 2 =  4 with a remainder of 1
  4 ÷ 2 =  2 with a remainder of 0
  2 ÷ 2 =  1 with a remainder of 0
  1 ÷ 2 =  0 with a remainder of 1 MSB
```

Therefore, the decimal number "147" is equivalent to 10010011 in binary notation.

3. CONVERSION FROM BINARY TO DECIMAL

 3.1 In order to convert from binary to decimal, the
      positional weights for the various bits must be
kept in mind. To convert from binary to decimal, add
together the positional weights of each bit that is a 1.

 3.2 As an example, convert 10010011 into a decimal
      number.

Positional
  Weight   − 2^7=128 2^6=64 2^5=32 2^4=16 2^3=8 2^2=4 2^1=2 2^0=1

  Binary
  Number   −   1   0   0   1   0   0   1   1

      10010011 = 128 +16 + 2 + 1 = 147

4. BINARY ARITHMETIC

 4.1 A major advantage of using the binary number system
      in digital processes is the simplicity of manipulat-
ing binary numbers. In the following paragraphs the rules
for binary arithmetic will be given to illustrate this
simplicity.

 4.2 The rules for binary addition are:

         0 + 0 = 0 with no carry
         0 + 1 = 1 with no carry
         1 + 0 = 1 with no carry
         1 + 1 = 0 with a carry of 1

  4.21 As an example of binary addition, add the numbers
        22 and 27.

        +1 +1 +1 +1 ⟵────────── Carry
            1 0 1 1 0   22
            1 1 0 1 1   +27
        1   1 0 0 0 1   49

 4.3 Binary subtraction also has four simple rules. They
      are:

         0 − 0 = 0 with no borrow
         1 − 1 = 0 with no borrow
         1 − 0 = 1 with no borrow
         0 − 1 = 1 with a borrow of 1

4.31 As an example, subtract 13 from 27.

```
  -1 -1  ←───────────── Borrow
   1  1  0  1  1      27
   0  1  1  0  1     -13
   ─────────────     ───
   0  1  1  1  0      14
```

4.4 Multiplication of binary numbers has only three
     rules as follow:

$$0 \times 0 = 0$$
$$0 \times 1 = 0$$
$$1 \times 1 = 1$$

4.41 To illustrate binary multiplication, multiply
      9 times 2.

```
   1  0  0  1          9
      x  1  0         x2
   ──────────         ──
   0  0  0  0         18
1  0  0  1
──────────────
1  0  0  1  0
```

4.5 In binary division, only two rules are necessary.
     They are:

$$0 \div 1 = 0$$
$$1 \div 1 = 1$$

4.51 To illustrate binary division, divide 28 by 4.

```
                1 1 1                7
      1 0 0 )1 1 1 0 0        4 )28
            1 0 0
            ─────
              1 1 0
              1 0 0
              ─────
                1 0 0
                1 0 0
                ─────
```

APPENDIX B

Glossary

Analog Signal - Any ac or dc voltage or current that varies smoothly or continuously.

AND Gate - A logic circuit with two or more inputs and one output whose output is binary 1 if, and only if, all inputs are binary 1.

Binary Number System - A number system that uses only two distinct quantities, 1 and 0.

Bit - An abbreviation of "binary information digit" which represents a single character in a group, either a 1 or 0.

Buffer - A temporary storage facility used to interface between system elements whose data rates are different.

Central Processing Unit - The portion of a computer which controls the operation of the computer and manipulates the data being processed.

Companding - The process of compressing quantizing levels at low speech amplitudes at the transmitting end and expanding these levels at the receiving end. This is done to minimize quantizing distortion.

Concentrator - A switching unit located at a distance from a central office which allows a large number of subscribers to be connected to the central office over a much smaller number of trunks. The concentration ratio is normally on the order of 5 to 1.

Data Base Memory - The storage area of a computer controlled switching system which contains the specific information pertaining to that particular system such as subscriber directory numbers, trunk routes, etc.

Decoding - The process of converting the received
PCM code words into amplitude pulses which are the
same as the quantized samples at the transmitting
end.

Digital Signal - A series of pulses or rapidly
changing voltage levels that vary in discrete steps
or increments.

Encoding - The process of converting quantized
samples into PCM words.

Flip-Flop - A bistable memory device that can store
either a 1 or 0.

Instruction - A written statement, or the equivalent
computer - acceptable code, that tells the computer
to execute a specified single operation.

Integrated Circuit - A functional circuit whose
components and interconnecting "leads" are formed
on a single chip.

Inverter (NOT Circuit) - A logic circuit whose output
is always the opposite of its input.

Large Scale Integration (LSI) - Large functional
circuits made up of a hundred or more gate circuits
which form a complete system or instrument. Examples
are memories, computers and certain test instruments.

Logic Circuit - An electronic element which takes a
series of inputs and produces outputs according to
the specific function the element is designed to
perform.

Medium Scale Integration (MSI) - Functional circuits
consisting of 12 or more gates which form a complete
functional operating network such as a decoder,
counter or multiplexer.

Memory - An organized collection of storage elements
into which units of information consisting of binary
digits can be stored and from which this information
can later be retrieved.

Microcomputer - An electronic device, consisting of
a microprocessor, program memory, data memory and
input-output circuitry, capable of accepting, storing
and arithmetically manipulating data.

Microprocessor - An electronic circuit contained on a
single chip of silicon which performs the arithmetic-
logic and control operations of a digital microcomputer.

NAND Gate - A logic circuit electrically equivalent
to an AND gate followed by an inverter. The output is
binary 0 if, and only if, all the inputs are binary 1.

Non-Volatile Memory - A storage element whose contents
are not destroyed if power is lost.

NOR Gate - A logic circuit electrically equivalent to
an OR gate followed by an inverter. The output is
binary 1 if, and only if, all inputs are binary 0.

OR Gate - A logic circuit with two or more inputs and
one output whose output is binary 1, if any or all
inputs are binary 1.

PCM (Pulse Code Modulation) - A time division modula-
tion technique in which analog signals are sampled at
periodic intervals and the values observed are
represented by a coded arrangement of eight pulses.

PCM Word - An eight-bit code group representing a
specific quantized level.

Program Memory - The storage area of a computer which
contains the instructions that tell the computer what
operations to perform.

Quantizing - The rounding off process whereby all samples whose amplitudes fall into one specific interval are given the same output amplitude.

Quantizing Distortion - The difference between the analog speech signal on the receiving side and the corresponding signal on the transmitting side due to the rounding off of speech samples.

RAM (Random Access Memory) - A storage element which may be written into or read out from at any point in time and at any memory address.

Regeneration - The process of replacing distorted pulses with reconstructed pulses.

Remote Switching Terminal (RST) - A digital switching unit located at a distance from its host digital central office which allows a large number of subscribers to be connected to the central office by means of a smaller number of trunks. Analog-to-digital conversion takes place at the RST, and switching is accomplished on a direct digital basis at the central office.

ROM (Read-Only Memory) - A nonvolatile, nonalterable storage element which has been preinterconnected or programmed to perform a particular set of functions.

Sampling - The process of taking instantaneous values of an analog signal at periodic time intervals.

Small Scale Integration (SSI) - Amplifier or gate circuits that perform a single basic function. Examples are AND gates, OR gates, flip-flops, etc.

Space Matrix - An array of crosspoints separated in space. In modern systems every inlet has access to every outlet by means of separate paths.

Subroutine - A portion of a computer program which performs one specific function.

Time Division Multiplexing (TDM) - The merging of several bit streams into a composite signal for transmission over a single communication channel.

Time Matrix - A series of memory devices which are used to switch data from many different sources onto a single bus and vice versa. Altering the positions of information from the various sources effectively switches the data.

Time Slot - The time interval which is assigned to carry one bit of information.

Time Slot Interchange - The functional element of a digital system which performs the switching operations.

Truth Table - A table or chart used to show the relationships between inputs and outputs for logic circuits.

Volatile Memory - A storage element whose contents are destroyed when power is removed.

ANALOG SIGNALS

SINE WAVE

POSITIVE DC VOLTAGE

RANDOM AC VOLTAGE

DIGITAL SIGNALS

+5
OV

OV
-6

+3
-3
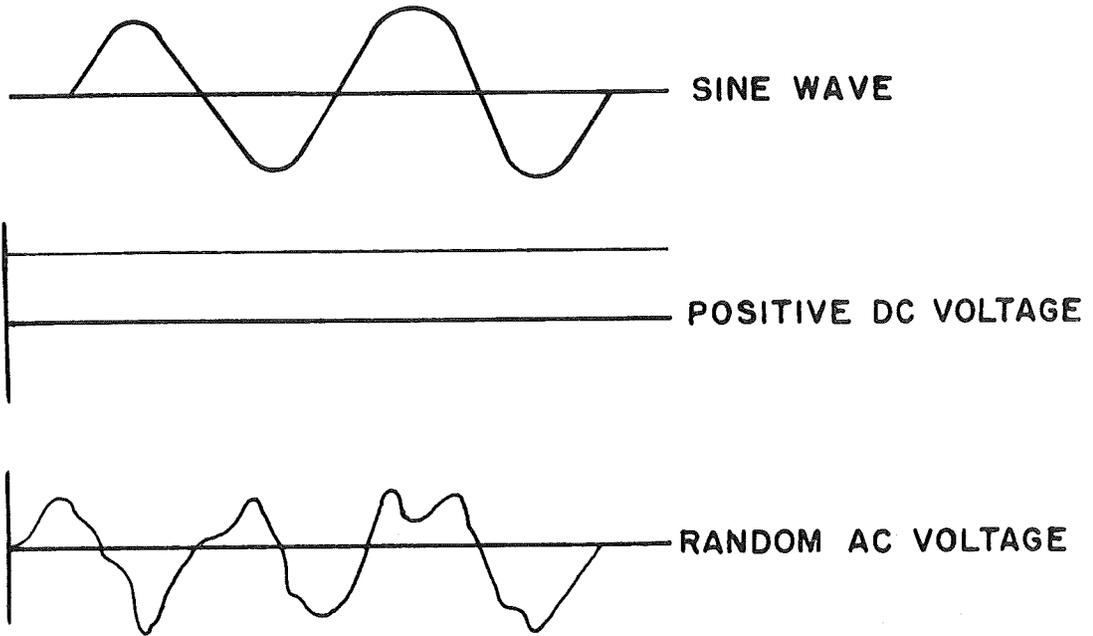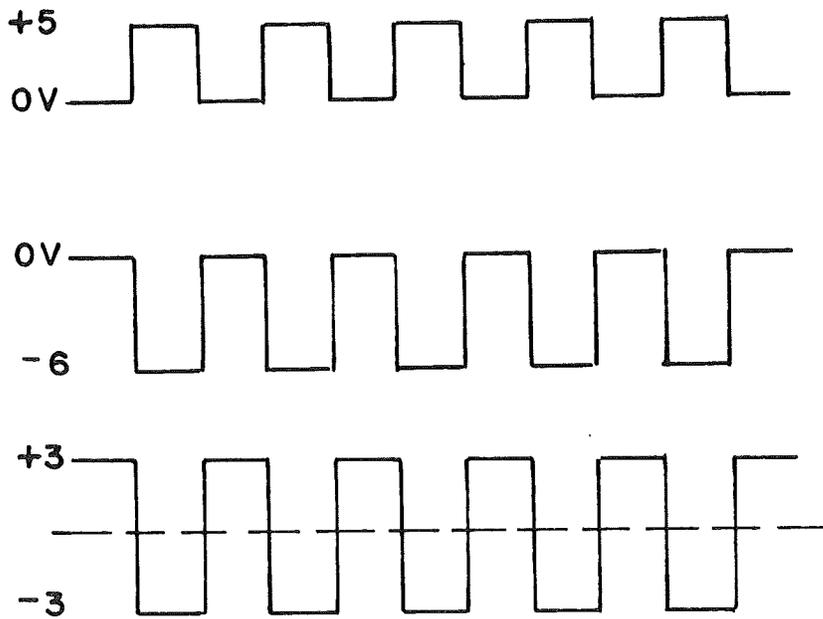
FIGURE - 1

INVERTER
(NOT GATE)
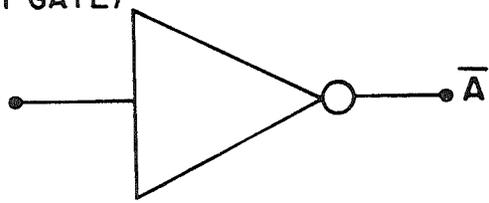
A	$\overline{A}$
0	1
1	0
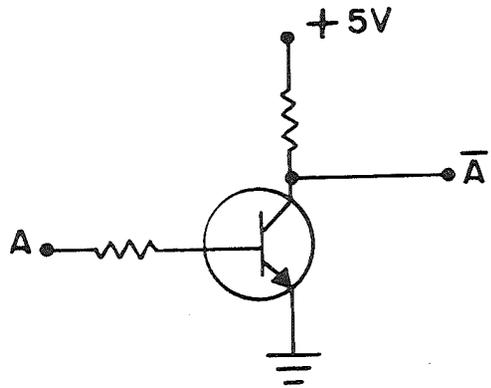
AND GATE
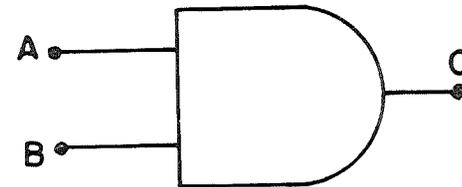
A	B	C
0	0	0
0	1	0
1	0	0
1	1	1

$+5V$

$\overline{A}$

A

$+12$

A

B

C

(N.C.)

$\overline{A}$

A

FIGURE-2A

A

B

C

FIGURE-2B

OR GATE

A	B	C
0	0	0
0	1	1
1	0	1
1	1	1

FIGURE-3A

NAND GATE

A	B	C
0	0	1
0	1	1
1	0	1
1	1	0

FIGURE-3B

NOR GATE

A	B	C
0	0	1
0	1	0
1	0	0
1	1	0
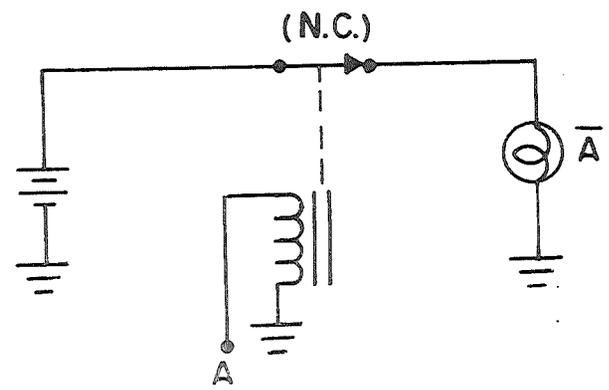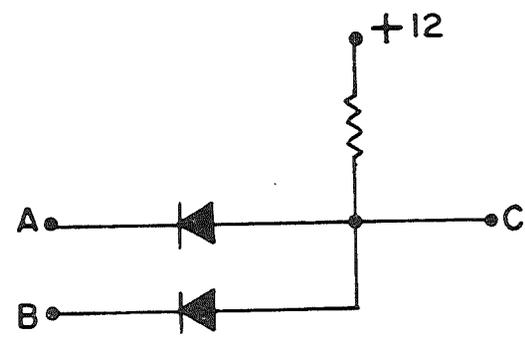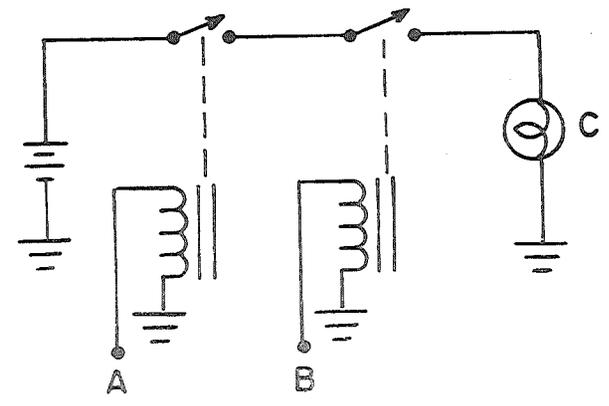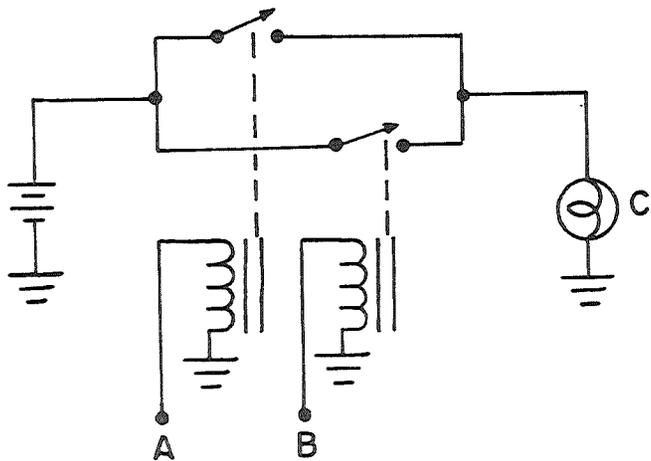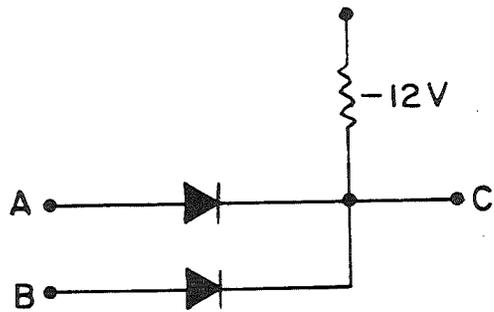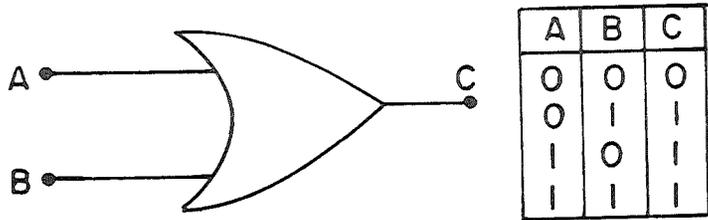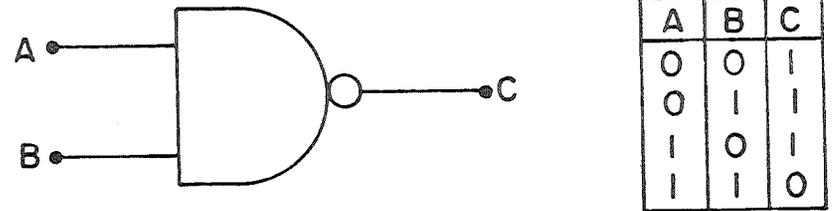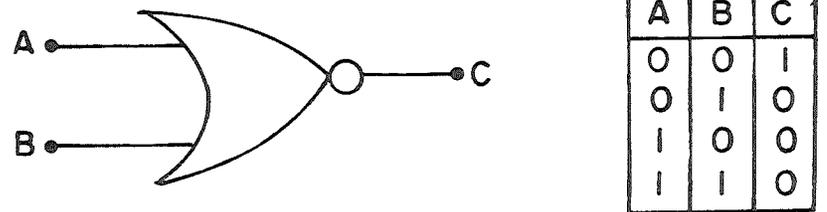
FIGURE-3C

FLIP-FLOP
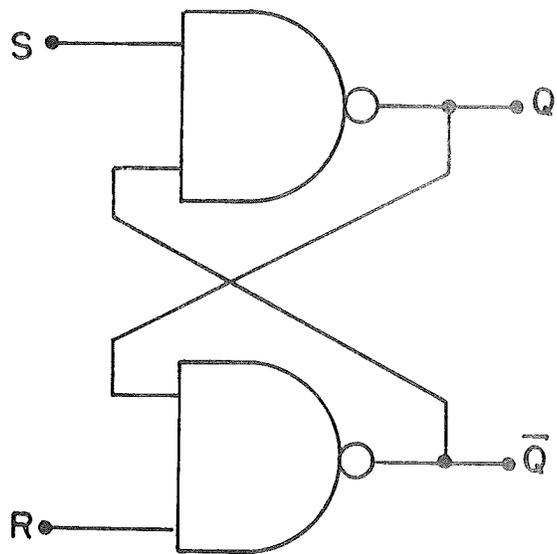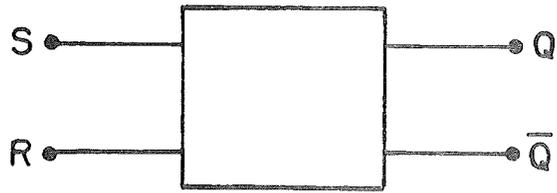
S	R	Q	$\overline{Q}$
0	0	1	1
0	1	1	0
1	0	0	1
1	1	X	$\overline{X}$

FIGURE - 4

SCHEMATIC DIAGRAM OF TYPICAL MICROCOMPUTER
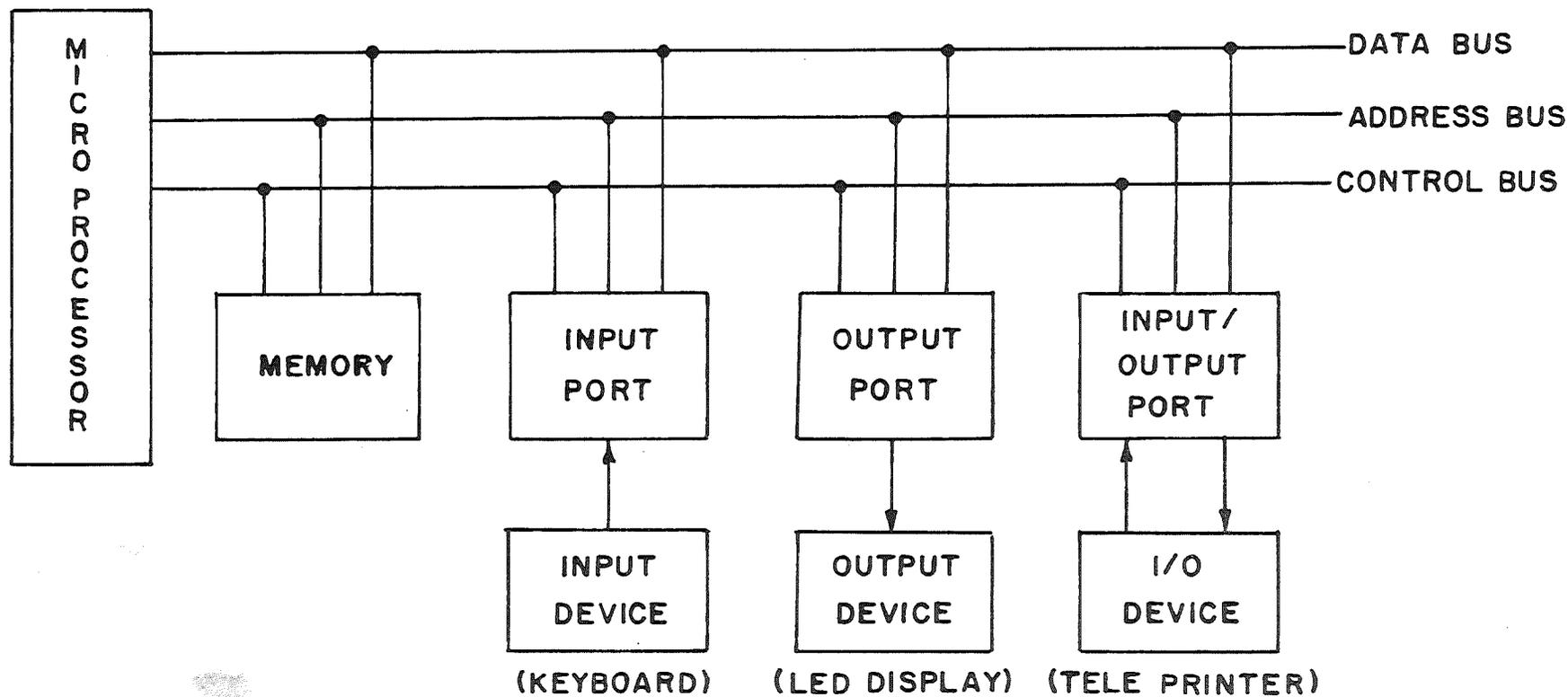
FIGURE-5

TYPICAL LINE-TO-LINE CALL THROUGH DIGITAL CENTRAL OFFICE
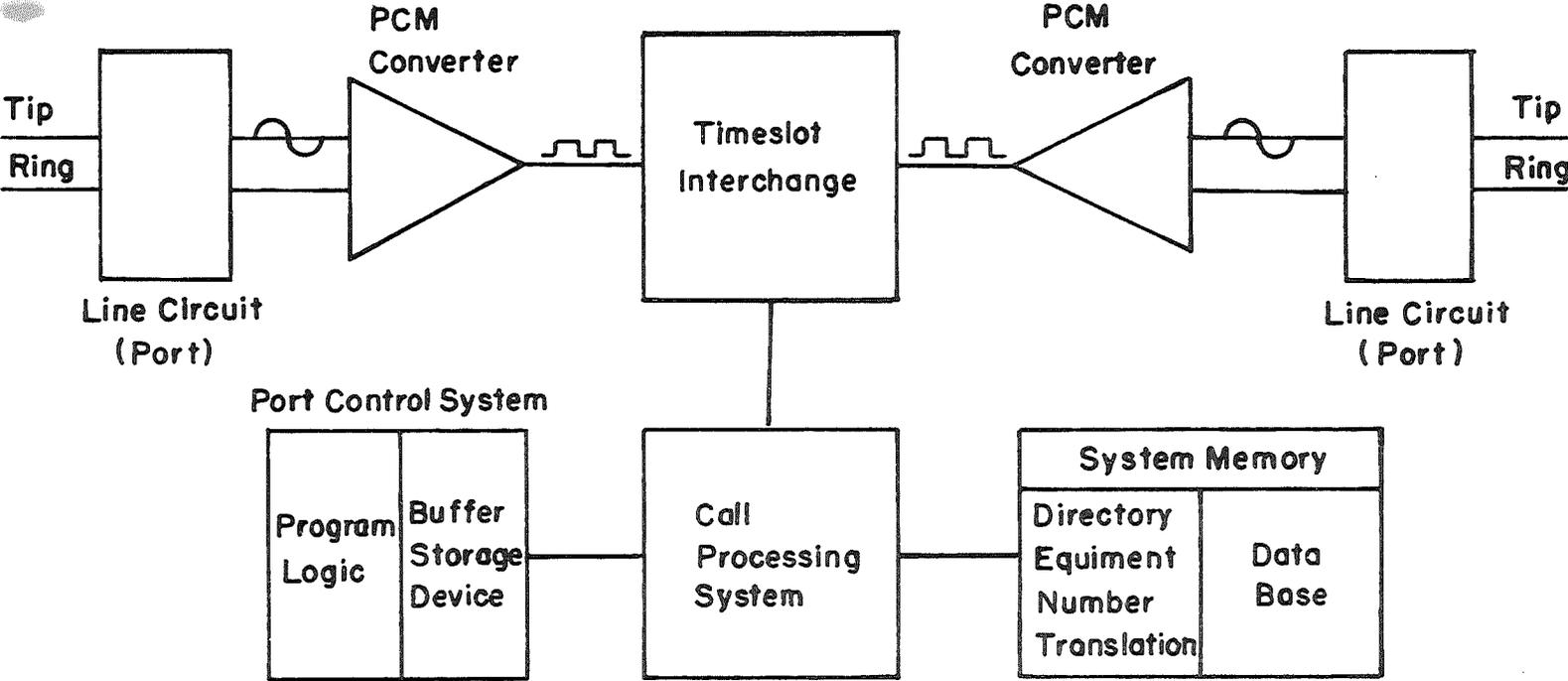
FIGURE -6

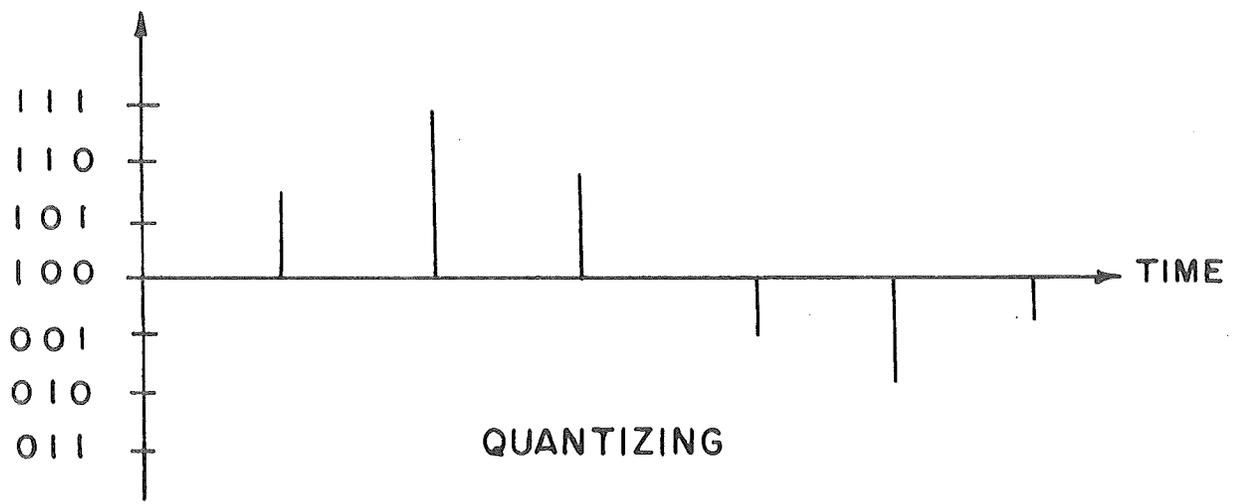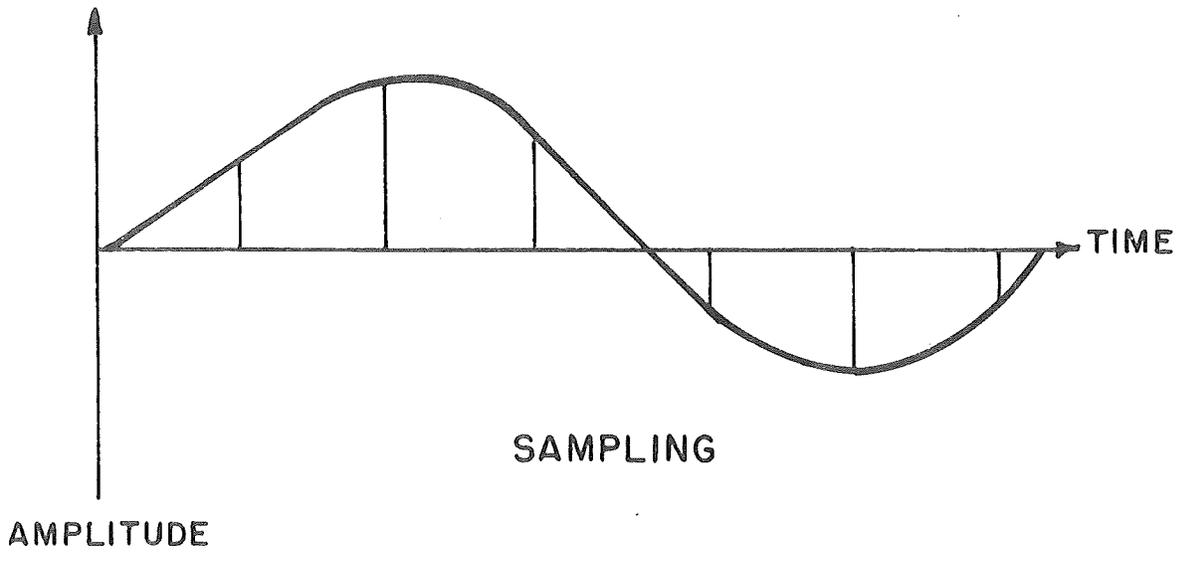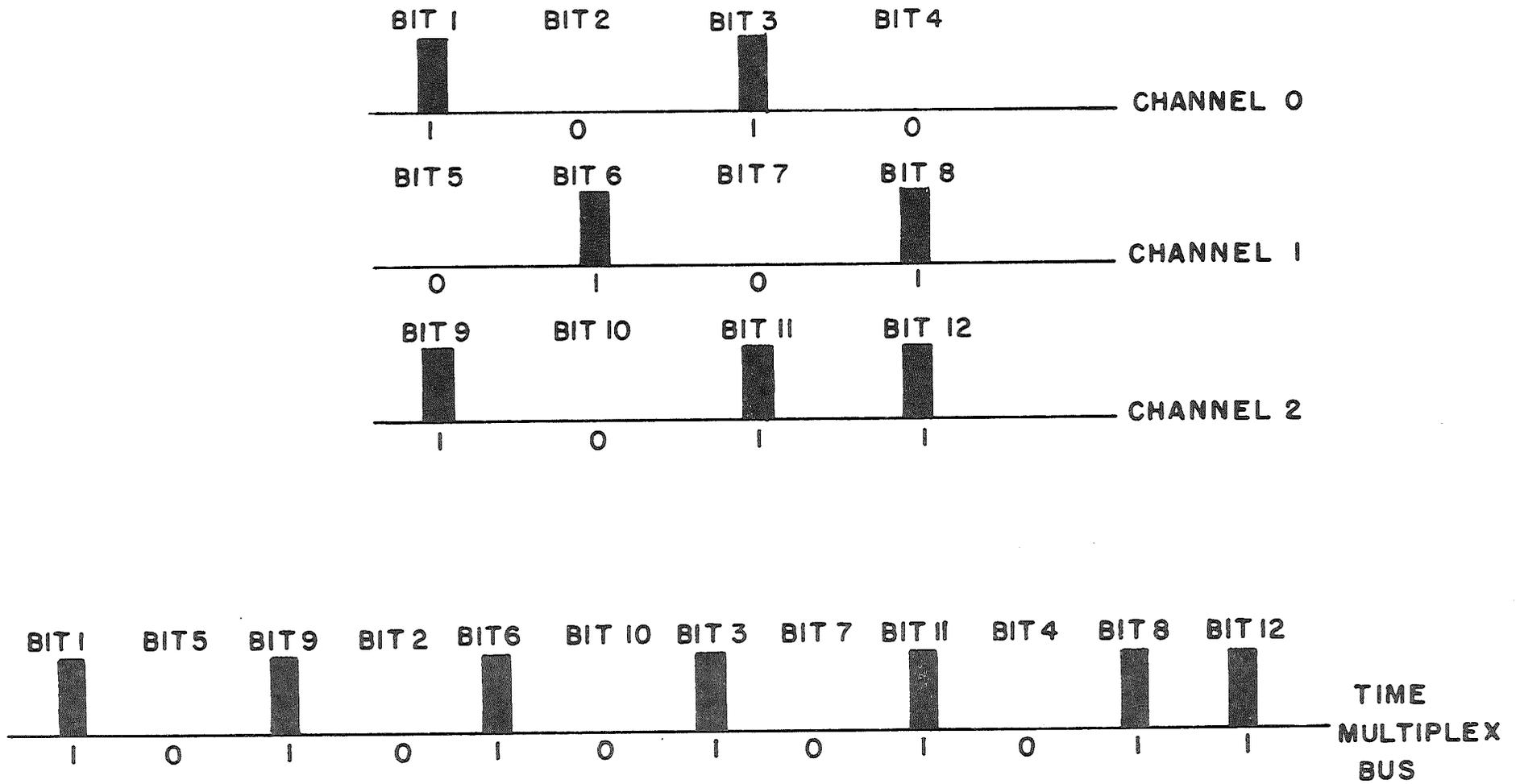# ANALOG-TO-DIGITAL CONVERSION

SAMPLING

AMPLITUDE

QUANTIZING

CODING
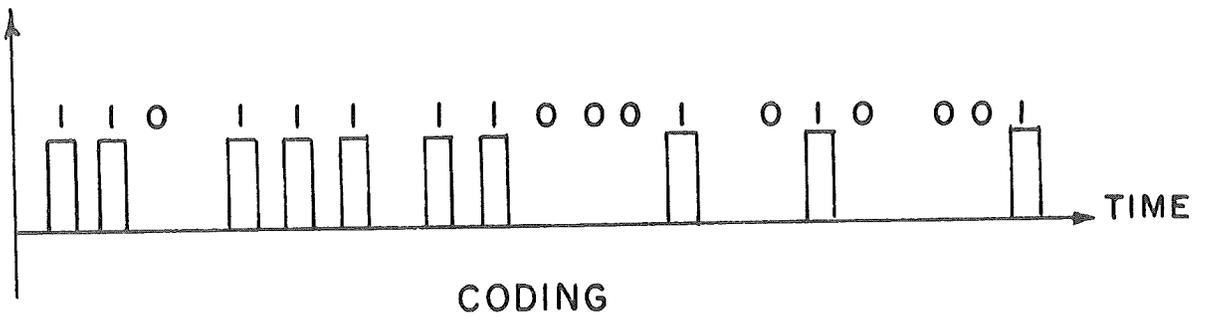
FIGURE-7

TIME MULTIPLEXING

FIGURE- 8

DIGITAL SWITCHING MATRIX

INCOMING
TIME SLOTS

INTERNAL
TIME SLOTS

OUTGOING
TIME SLOTS

A

B

C

15

15

D

E

F

SPACE

TIME

TIME

FIGURE-9