CALIFORNIA STATE UNIVERSITY, NORTHRIDGE

TELEPHONIC COMMUNICATIONS SYSTEM FOR THE DEAF

A thesis submitted in partial satisfaction of requirements for the degree of Master of Science in

Engineering

by

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ABSTRACT

TELEPHONIC COMMUNICATIONS SYSTEM FOR THE DEAF

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A deaf person has as great a need to communicate by telephone as the hearing member of our society. Devices which are presently available on the market to meet this need are studied in detail. A set of system requirements which can best meet the human factors and technical aspects of such a device are developed, and these requirements are then used to develop a communications system.

CHAPTER 1

INTRODUCTION

There is a need for the deaf to utilize the telephone in communicating efficiently. A majority of the deaf presently depend on other persons to make their calls for them. Some deaf are equipped with reconditioned teletype machines or speech indicator devices. These devices and others presently available on the market are studied in detail in this thesis.

A set of system requirements was developed. It is felt that they will meet the majority of the human factor needs of the deaf and also meet the technical needs required for utilizing the telephone. These requirements were then used to develop a system.

A cost vs. function analysis was made, and it was determined that a portable, standard, low speed teletype would best meet all system requirements. Its operation is very similar to that of typing on a standard typewriter.

The only system requirements that may not be found on all terminals is the need for the terminal to operate in both the originate and answer modes of operation. This determines what frequencies are transmitted and received.

This feature then allows terminals to communicate with each other. The terminals themselves need not be identical as long as operation is possible in both modes of operation. Without this feature, terminals equipped for the originate mode could communicate only with terminals operating in the answer mode and vice versa.

Another method of transmission which had the same input and output devices but utilized tones of different frequencies rather than the standard FSK modem was also investigated. It was determined that the difference in device costs was not great, and the "General" method had the advantage of decreasing costs with the rapidly expanding computer entry device market.

CHAPTER 2

SYSTEM REQUIREMENTS FOR THE DEAF

This chapter describes a system guideline to meet the needs of the deaf. It also discusses equipment presently on the market, or under development, which can best meet these needs.

2.1 Deafness

Let us first define what we mean by the terms "deaf" or "deafness". The use of these words implies that the loss of hearing is so great that it makes everyday auditory communications impossible. In the strictest sense, the deaf person has no usable hearing - what hearing he may have is non-functional.[1]

It is most common for the average loss of hearing for pure tones within the "speech range" (500 to 2000 cps) to be used to indicate the severity of the hearing loss.[1]

Loss of 20 to 40 db	=	mild
Loss of 40 to 60 db	=	moderate
Loss of 60 to 80 db	=	severe
Loss of over 80 db	=	deaf

There are many forms and degrees of impaired hearing. They can be put into two main forms according to the parts of the ear affected. Conductive impairment is due to blocking of the physical sound waves in the external ear, the canal, the drum, or the middle ear structures as far as the inner ear. Perceptive impairment is a disturbance or a destruction of parts of the inner ear where the physical sound wave vibrations are converted into nerve impulses.[2]

Approximately one out of every ten persons in the United States has some degree of hearing impairment.[3] The Vocational Rehabilitation Administration estimates that there are about 250,000 deaf persons in the United States.[4] Some deaf persons cannot talk clearly, but many of them can speak well enough to be understood.

For the purpose of this thesis the following assumptions will be used:

a. "Deafness" will be defined as any loss of hearing which is great enough to prevent a person from using the telephone in a normal manner. This will not include the person who can make use of a hearing aid or speech amplifier to allow use of the telephone.

b. It will be assumed that the speech of a deaf person will, in at least 50% of the cases, not be adequate for talking over the telephone.

2.2 Proposed System Requirements for the Deaf

Discussions with the deaf and a literature search have resulted in the following design guidelines:

a. The cost of the device must not be prohibitive.

b. Ease of operation must be such that a deaf person of any age will be able to use the device. (It should be noted that by this we do not mean to say that a two-year old is expected to be able to operate the device, but only that no skills requiring extended training should be required.)

c. The system should be compatible with both the dial and touch-tone telephone systems.

d. The system should be portable or, at least, be easily transported.

2.3 Devices Presently on the Market

Table 2.1 indicates the equipment which is presently available on the market for deaf communications. This table also indicates the advantages and disadvantages of each piece of equipment. The devices which appear to have the most potential are discussed in the following paragraphs.

2.3.1 Speech Indicator - This device was first developed in 1964 by Hugh Moore and tested on an experimental basis in the field and at San Fernando Valley State College.[4] The testing was done under the direction of Dr. Ray Jones, Director of the Leadership Training Program at the college.[5]

The device is probably the simplest and least expensive of all the devices to be discussed. It consists of a magnetic pick-up coil which picks up the signal at the deaf person's receiver. The signal is then amplified and displayed on a simple meter movement. To use this device the deaf person must have a speaking voice which is clear enough to be understood over the telephone. The basic signals are:[6]

	Telephone Signal	Indication on Speech Indicator
a)	Dial tone	A steady signal
b)	Ring signal	A slow rhythmic signal
c)	Busy signal	A fast rhythmic signal
d)	Voice communication	Irregular signals

The basic responses are:

	Response	Signal
1.	"No" (one syllable)	Needle deflects once
2.	"Yes-Yes" (two syllables)	Needle deflects twice
3.	"Please Re-peat" (three syllables)	Needle deflects three times

If the deaf person is attempting to communicate with someone who does not have prior knowledge of the device or the code to be used, he must first give instructions on use of the device.

Example:

1. My name is ______________________.
2. I am a deaf person and cannot hear what you say.
3. I have a device that indicates to me when you say "No," "Yes-Yes", and "Please Re-peat."
4. Do you understand?

Various other types of signals and codes can be worked out and used.

Advantages:

1. Relatively inexpensive ($15.75).

2. Readily portable and usable on any standard telephone.
3. Only the deaf person needs to use the device.
4. Allows most deaf people a simple means of using the telephone.

Disadvantages:

1. Deaf person must be able to speak and be understood over the telephone.
2. Communication is slow for any type of message other than those requiring simple "yes" and "no" responses.

2.3.2 "Code-Com" Set - The Code-Com set is for people who are totally deaf, deaf and blind, or deaf and mute. It consists of a conventional telephone and a signal unit containing a light bulb, a vibrating disc, and a sending key.[7]

While a telephone ordinarily converts speech into electrical impulses which are transmitted and reconverted to speech at the receiver, the Code-Com set converts the transmitted signals into flashes of light and vibrations of the disc or sensor pad. Thus, a deaf or deaf and blind person can "read" simple messages by using a pre-arranged code such as Morse Code.

In a conventional telephone the transmitted electrical signals are reconverted to speech at the receiver. In the Code-Com set an electromagnetic transducer (reciever unit) converts these electrical signals into mechanical vibrations of the finger plate. A small bulb in the visual unit transforms the electrical signals into light flashes. In addition to human vocal sounds the set permits the user to identify a dial tone, a ringing tone at the other end of the line, a busy signal, "receiver-off-hook" clicks, and some background sounds in the vicinity of the telephone. The set also responds to changes in the amplitude of the signal. Thus, sound of higher amplitude can be felt as stronger vibrations of the finger plate.

A deaf person can use a simple question-and-answer system in addition to a pre-arranged code. After some practice with Morse Code, users were able to attain sending and receiving speeds of about <u>10 words per minute</u>.[7]

Field trials of the set have been conducted in Columbus in cooperation with the Ohio School for the Deaf and the Ohio Bell Telephone Company. The New York League of the Hard of Hearing, New York University, New York Telephone, Indiana School for the Deaf in Indianapolis, and Indiana Bell Telephone Company also have assisted in field trials.[7]

A deaf person can use a simple question-and-answer system in addition to a pre-arranged code. He advises a caller that he cannot hear but can recognize certain words from the light or vibration patterns they produce. He asks questions of the caller and instructs him to respond with "Yes," "Maybe," "No, no," or, if he doesn't understand, "Please repeat."[7]

The Code-Com set was developed by Bell Telephone Laboratories and is presently being made available in the Los Angeles area by Pacific Telephone. The monthly rate is approximately $3.00, with no installation charge.[8]

Despite the simplicity of this device, it does at least provide a means for the deaf to communicate with other telephone subscribers. The major shortcoming is that even with relatively well-trained participants, signaling speeds are slow. Although the deaf participant, being highly motivated, may acquire a high degree of proficiency in Morse Code signaling, the number of possible participants would be limited.[9]

Advantages:

1. Only the deaf person needs to use the device.
2. Relatively inexpensive.
3. Code key allows deaf person with poor speaking voice a means of signaling.
4. Codes can be received from any telephone anywhere.[10]

Disadvantages:

1. Both parties must know code.
2. Communication is slow.

2.3.3 Teletype - There are two different devices that can be used:

1. Teletypewriter exchange service (TWX)

A totally deaf person can send or receive messages by operating a TWX machine. It works much the same as a standard typewriter. The deaf person can send a message across the street or across the nation to any one of approximately 50,000 subscribers.[11]

To operate the TWX machine the deaf person first dials the number he wishes (only those persons having a TWX can be contacted), waits for an indication that the call is connected and then types the message.

The TWX works by decoding the typewritten message and sending it over special TWX lines to the TWX machine on the other end. The other TWX machine then decodes the message back and types it out.

Advantages:

1. Easy to send and receive - just like typing and reading typewritten copy.
2. Permanent copy of message is made.[10]
3. Fast.

Disadvantages

1. Not portable - must be used only where connected (requires special wires)

2. Can communicate only with people having same equipment.
3. Costly - must be obtained on a monthly rental or lease basis.
4. Equipment is large and bulky.

2. Teletypewriter

There are presently 250 deaf people in Los Angeles County, and 2,000 people throughout the United States who own teletype equipment. This teletypewriter equipment is donated by the Alexander Graham Bell Association for the Deaf. Maintenance is provided by deaf technicians through Teletypewriters for the Deaf, Inc.[12]

This equipment differs from the TWX equipment in that it uses regular telephone lines.

Communications can be carried on only with people who have similar equipment or with one of the commercial answering services which acts as a relay center.

Advantages:

Same as for TWX except--

1. Low cost for deaf person.

2. Equipment can be moved from location to location (does not require special lines).

Disadvantages:

1. Can communicate only with people having the same or similar equipment unless a telephone answering service or equivalent acts as an intermediary.[10]

2.3.4 Bell Experimental Coding Device - One experimental Bell Telephone device utilizes the tones generated by the touch-tone buttons to activate a visual display of the letters and numbers comprising the message.

The device as described by Bell Telephone operates in the following manner:[13]

In touch-tone dialing areas, pushbuttons generate pairs of tones which are sent over the telephone lines to control dialing and switching functions. When two telephones are connected over the telephone network, the touch-tone buttons will still generate tones, but will not interfere with normal switching functions.

Communicating with the experimental device consists of using the touch-tone pushbuttons to generate a sequence of letters, numbers, end-of-word, and end-of-sentence signals, one at a time, in the windows of a display device attached to the telephone.

The simple code utilizes the arrangement of the letters as they actually appear on the touch-tone dial. A, B, and C are sent using the 2 button; D, E, and F with the 3 button; and so on through the alphabet. Pushing the 2 button once indicates A, twice indicates B, and three times, C. A readout circuit (triggered by pushing the zero button) stores the signals until a letter is fully coded. Thus, in the code, A is 20, B is 220, and C is 2220.

Letters of the alphabet not used in dialing (Q and Z) are coded with the 1 button, with Q expressed as 10 and Z as 110. The 1 button is also used as a word separator (111) and to end a sentence (111,111). The 111 signal can also be used to erase signals stored in the readout circuit. When signaled to receive numbers, the receiving party presses a switch and a numerical display appears.

Visual outputs have been set for approximately 400 milliseconds duration, limiting the maximum speed of the device to 150 letters per minute, which compares well with acceptable rates in Morse Code.

As presently designed, the output device uses three off-the-shelf, 12-character windows for the visual display of letters and digits. The letters A through N, except I and J, appear in the left window. The center window shows the letters O through Z. Digits zero through 9 and letters I and J appear in the right window. Flashes of light in two lower windows indicate the end of a word or sentence and that the coding of a letter is in progress. All of these visual signals appear one at a time in sequence when properly activated, except the indicator for coding in progress, which remains on until the read-out circuit is triggered. (A display device could be designed to display all of the letters and numbers in one window).

In operation, tones from the touch-tone telephone arrive at the receiving end of the circuit and go into a touch-tone calling receiver. Output levels from this receiver serve as input signals to a bank of ten AND gate circuits that convert coded receiver outputs back to the digit that has been pushed by the sender.

This digit is sent into the visual display device, and A-Z decoder, attached to the base of the receiving telephone. Assuming that alphabetical readouts are desired, the receiving A-Z decoder, as well as the sender's A-Z decoder, are activated when the readout circuit is triggered, and supply control signals to suitable output letter projectors. For the system to present digits, the receiving party depresses a small button located over the right-hand display window. Operation of this button disconnects the A-Z decoder and signal processing is shifted to the presentation of consecutive digits. The button over the display window on the left reconnects the A-Z decoder.[13]

Experimental data obtained using the alpha-numeric display indicate that the best sender approached a transmission rate of 11 words per minute after less than two hours of training. The average transmission rate for all subjects with the alpha-numeric system approached 7 words per minute over the same training period.[9]

Some of the limitations of the above device are:

1. Operates only with a touch-tone system and, therefore, limits access to the equipment.
2. Moderate speed of transmission is not only limited by sending rate, but also because the visual output becomes strenuous for the eyes.

2.4 Conclusions

The lowest cost device is the Speech Indicator. However, this device is strictly limited in speed and requires a good understanding of some type of operating code to be properly used. Any lengthy type of conversation is highly impractical. Even with the above-mentioned limitations the cost of the device makes it attractive for at least basic "yes" or "no" type conversations. Since only the deaf person requires the device, only the deaf person needs one. The non-speaking deaf person could utilize the more costly Code-Com Set.

Next in order of importance is the decoding device presently in the development stages by Bell Telephone.

This device allows extended messages at a more rapid speed. The added cost of the device is not prohibitive and it only requires the deaf person to have the device. The major drawback of this unit appears to be the coding technique required in its use. While statistics have shown that the speed of a similar device is more rapid than the speech indicator, it does require a more advanced coding technique. This requirement appears to violate one of our ground rules in that a young child or non-technical person would probably find it very difficult to use the device.* It should be remembered that a hearing sender would not be as highly motivated as the deaf person.

A <u>teletype</u> kind of system appears to be the ideal solution with its major limitations being the need that both parties require a similar device, it is not easily portable, and it is relatively costly. These limitations do not really appear to be excessive since:

a) A large portion of the communications done by the deaf is with one another.

b) Family and friends could purchase the device as cost decreases.

---

*An interview with several middle-aged deaf persons with limited education has indicated a reluctance in the use of this device when they are the sender.

c) Systems specifically designed for deaf communications could be made more portable and less costly.

Direct emergency communications could still be a problem, but by calling a friend, or by utilizing an emergency calling service, the message could be relayed.[12]

Any system designed should attempt to meet the following human factor requirements (These requirements have been compiled from advantages and disadvantages of the equipment presently on the market, discussions with the deaf, and a literature search.):

a) Cost not prohibitive.

b) Operational skills not restrictive.

c) Compatible with all telephones.

d) Easily moved.

e) Not require the deaf person to speak.

f) The ideal system would require only the deaf person to use it (only the deaf person would have the device).

g) A comfortable operating speed is desired.

h) If the deaf person is required to transmit a message manually, a visual indication of the message is desired.

DEVICE	ADVANTAGES	DISADVANTAGES	COST
Speech Indicator	1. Relatively inexpensive. 2. Readily portable and usable on any standard telephone. 3. Only the deaf person needs to use the device. 4. Allows most deaf people a simple means of using the telephone.	1. Deaf person must be able to speak and be understood over the telephone. 2. Communication is slow for any type of message other than those requiring simple "Yes" or "No" responses.	$ 15.75
"Code-Com" Set	1. Only the deaf person needs to use the device. 2. Relatively inexpensive. 3. Code key allows deaf person with poor speaking voice a means of signaling. 4. Codes can be received from any telephone anywhere.	1. Both parties must know code. 2. Communication is slow.	$ 3.00 per month

Equipment Presently on the Market

Table 2.1

DEVICE	ADVANTAGES	DISADVANTAGES	COST
TWX	1. Easy to send and receive - just like typing and reading typewritten copy. 2. Permanent copy of message is made. 3. Fast.	1. Not portable - must be used only where connected (requires special lines). 2. Can communicate only with people having same equipment. 3. Costly - must be obtained on a monthly rental or lease basis. 4. Equipment is large and bulky.	Installation + Monthly.
Teletypewriter	Same as for TWX except... 1. Low cost for deaf person. 2. Equipment can be moved from location to location (does not require special lines).	1. Can communicate only with people having the same or similar equipment, unless a telephone answering service or equivalent acts as an intermediary.	$185.00 for deaf person.
Bell Experimental Decoding Device	1. Can be used by non-speaking deaf. 2. Messages of moderate length can be sent. 3. Portable. 4. Relatively low cost.	1. Coding technique required.	Under $400.00 in production quantities

CHAPTER 3

TELEPHONE SYSTEM REQUIREMENTS

The switched telephone network is a complex system. This chapter will describe the basic telephone network. It will also detail requirements and methods needed to transmit information over this network.

3.1 Basic Telephone Network

The nationwide Switched Telecommunications Network (also known as the Direct Distance Dialing Network or Switched Network) provides point to point voice bandwidth communications. The present network accommodates over 108 million terminals which include data sets, PBX's, and recording devices.[14]

The switched network is provided jointly by the Bell System and independent telephone companies. Although company ownership varies the structure and design, rules governing the network have been generally adopted throughout the telephone industry.[14]

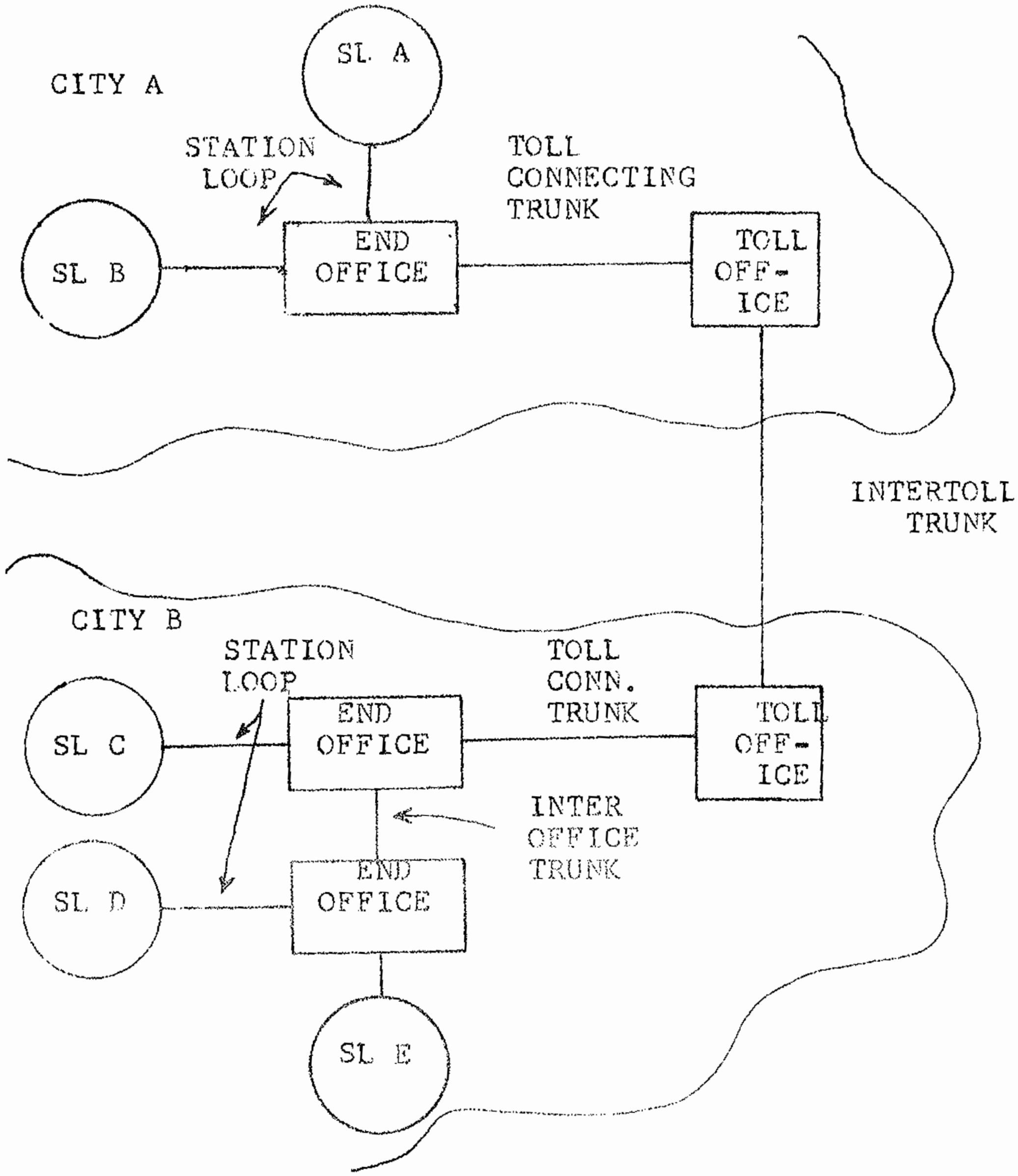
The telephone network is a complex arrangement of transmission, switching, signaling and terminal equipment.

The system provides the electrical transportation of customers' messages, and certain control signals, from one location to another. This transportation requires the identification and connection switching of independent transmission links to a continuous path from one terminal to another.[14]

The simplest connection involves voice frequency transmission between two stations through a single switching office. More complicated connections may involve many links in tandem, including several switching offices, and use both voice frequency transmission facilities and carrier systems. The transmission paths in the network may be divided into two categories, station loops and trunks. The station loop is normally a voice frequency facility using a telephone cable pair and is dedicated to the use of an individual station. The loop provides a two-way path between the customer's terminal equipment and the local central office (end office) and is used for ringing, dial pulse or touch-tone addressing, supervision and message transmission. While loops are dedicated to an individual customer, trunks are shared by many customers and provide transmission links between switching offices. Trunks may use either voice frequency facilities or carrier transmission systems and may be of either two-wire or four-wire design.[14]

In the simplest case, see Fig. 3.1, Station A wishes to communicate with Station B. In this case, where both stations are served by the same end office, the call would include only the two voice frequency station loops and the end office. A slightly more complex call might involve Station A wishing to reach Station C. Although both are in the same city they are served by different end offices and, in the example shown, the call must be completed over an interoffice trunk. Extending the complexity even further is a call from Station A to Station D located in a different city. In this example it is necessary to route the call through two toll offices via toll connecting trunks. These toll connecting trunks are used to connect end offices to the toll offices. Between the toll offices an intertoll trunk is used to complete the connection. The resulting connection consists of two loops, three trunks and four switching offices.

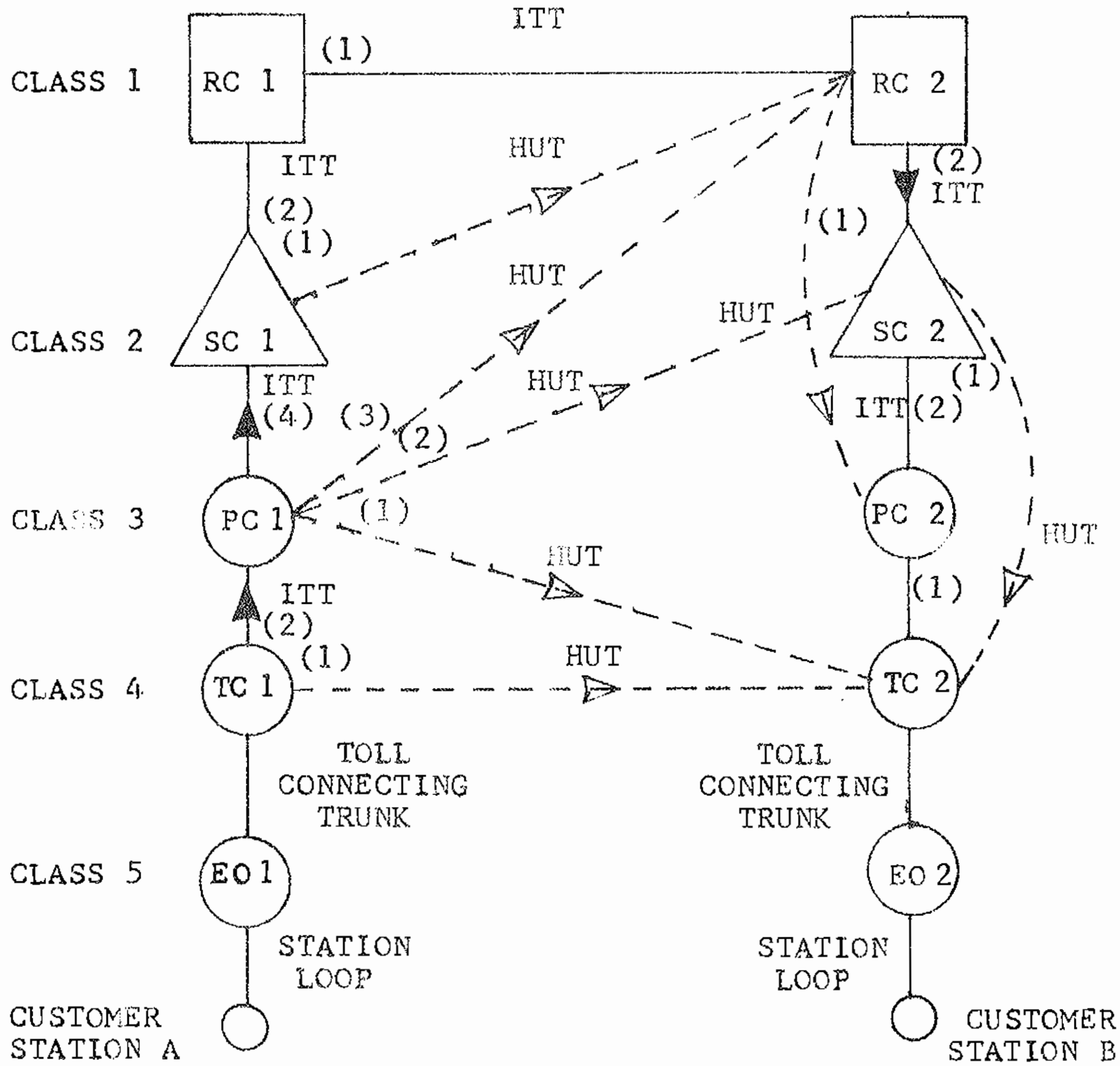
A call entering the network is always routed over the most direct available trunk. When the first choice high usage trunk group is busy, a call will be alternate routed to other trunk groups. In the example shown in Fig. 3.2 there are 13 possible routes for a call from Station A to Station B. Only when all high usage trunk groups are busy will a call be routed over the final



STATION LOCATION = SL

TELEPHONE ROUTING - SIMPLE CASE

FIGURE 3.1



NOTES:

1. Nos. in () indicate order of choice of rte. at ea. center for calls orig. at EO 1.
2. Dashed lines indicate high -usage groups.
3. ITT - Intertoll Trunk
4. HUT - High Usage Inter-toll Trunk
5. RC - Regional Center
6. SC - Sectional Center
7. TC - Toll Center
8. PC - Primary Center
9. EO - End Office

TELEPHONE ROUTING - COMPLEX CASE
FIGURE 3.2

trunk route. Most calls within the United States are completed over high usage trunks with the average number of trunks in a connection being 1.5. The probability of ever having to traverse all nine final trunks is estimated to be less than one in a million.[14]

Network signaling is used to identify the calling and called stations, to set up connections in the network, to identify the status (busy or idle) of lines and trunks, to provide charging information and to release connections. As an aid to understanding network operation, some of the basic signals used in performing the above functions are described. While these signals may be categorized in many ways, the three basic subdivisions of (1) supervisory, (2) address, and (3) audible tone signals will be used for this discussion.

Supervisory signals are normally used to indicate the status of lines, trunks and equipment. In the case of station lines, either an on-hook or off-hook signal is present. An on-hook condition represents a station not in use, such as a telephone with its handset on the switch-hook cradle. An off-book condition can be interpreted as a request for service and is also used to indicate that a line is busy.

Address signals indicating the destination of a call are used by both local and distant switching equipment to indicate the particular connections to be made. These include dial pulse or touch-tone signals on loops and interoffice dial pulse, single frequency, and multi-frequency signals sent over trunks.

Audible tones indicating call progress are provided for the user. They include dial tone, busy tones and ringing tones. A dial tone is provided to tell the customer that the equipment in his local central office is ready to receive address signals.

Busy signals used in the network are of two basic types: trunk or equipment busy, and station busy. The trunk or equipment busy signal is a fast (120 interruptions per minute) on-off tone signal indicating that all paths are busy at some point in the hierarchy. The station busy signal is a slower (60 interruptions per minute) on-off signal that indicates that the particular station called is in use.

Ringing signals are typically a two second on/four second off signal used to indicate to the called party that he has an incoming call. In addition, an audible ringing signal is sent back to the calling party to indicate that the call has been completed to the called station line and that the called station is being rung.[14]

3.2 Types of Network Signaling

D-C signals are used on station loops and on some voice frequency trunks. These may serve the supervisory and the address functions, or the supervisory function alone. In the case of station loops serving rotary dial (dial pulse) stations, differentiation between address and supervisory information is accomplished by timing. Supervisory on-hook/off-hook indications are represented by relatively long time intervals, while dial pulses, which occur at a nominal 10 pulses per second rate, are relatively short.

In-band a-c signals are transmitted within the voice frequency pass band and are of three basic types: touch-tone signals, multifrequency (MF) and single frequency (SF). Touch-tone signals, used for push button dialing, are sent over the local loop to the local central office for address signaling. These signals are converted at the central office to some other type of signal for local office control. Multi-frequency signaling, employing a two-out-of-five coding scheme in which two frequencies sent simultaneously represent a digit, is used for inter-office address signaling during call set up. Single frequency signals are used predominantly for trunk signaling and convey supervisory information. The present standard SF signaling system uses a frequency of 2600 Hz. Care must be taken to avoid interference with this signaling system.

Out-of-band a-c signals are used for signaling on some carrier systems. In these systems a single frequency signal above the voice band is used for both address and supervisory information, or for supervisory information alone. Because these signals are out-of-band there is no interference problem to concern the user.

One additional type of signaling scheme used is pulse code signaling on digital carrier systems. In these systems a given signaling condition is represented by the presence or absence of a particular pulse in the digital pulse stream. As with out-of-band a-c signaling, interference with the signaling functions is not a problem for the user.

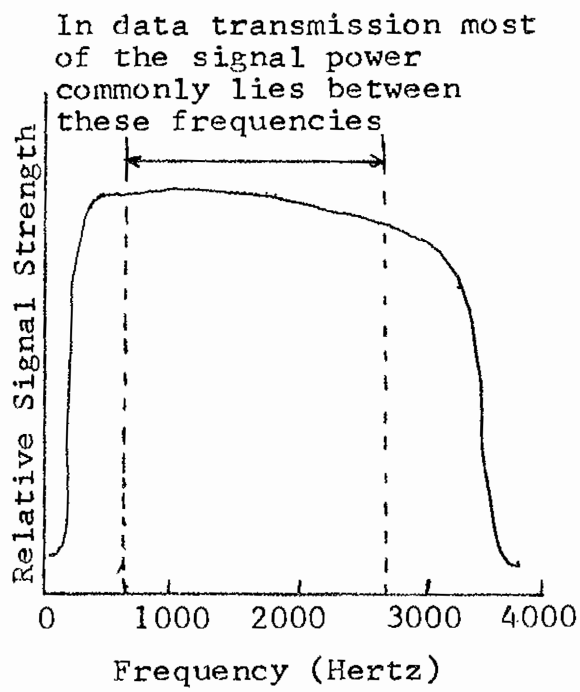
An important aspect of trunk signaling (both in-band and out-of-band) is that it is done on a link-by-link basis. This means that as a call progresses through the network it is established a link at a time and each trunk has its own associated signaling equipment. This feature makes the signaling function independent of the number of links in the connection.[14]

3.3 Transmission Factors

Optimum use of the telephone network for communications requires knowledge of the various factors affecting transmission. Some of these factors will be discussed in the following paragraphs.

3.3.1 Frequency Response and Bandwidth - Figure 3.3 shows the relative signal strength received on a typical telephone system.[15] Care must be taken that the data sent falls within the frequency range described. This will allow the data to be transmitted without severe distortion taking place.

Care must also be taken so that the data signals sent do not interfere with the telephone company signaling frequencies. To prevent this type of



FREQUENCY RESPONSE OF TYPICAL TELEPHONE SYSTEM

FIGURE 3.3

problem tariff regulations regulating customer-provided data transmission equipment limit the signal strength for both in-band (below 3995 HZ) and out-of-band (above 3995 HZ) transmission.[14]

The usable frequency range on the Bell System is 500 to 2100 HZ.[16]

3.3.2 Phase Delay - The phase of a signal is not transmitted linearly over the voice telephone lines. The signal is delayed more at some frequencies than at others. This is referred to as phase-frequency distortion or delay distortion.[16]

This type of distortion is a serious problem that must be considered for high speed data transmission, since it could create bits of information to be lost.

3.3.3 Noise - The following types of random noises can occur over the telephone lines. These are white noise, impulse noise, chatter from switchgear, cross talk, atmospheric noise, etc.[16]

Unfortunately the strength of these noises cannot be determined in advance for each line. The telephone does provide statistical data on the various types of noise.

By assuming a maximum noise level all equipment is designed to assure that the signal to noise ratio is adequate to allow transmission without the loss of data. For example: Modems are designed so that they are capable of receiving signals at -50dbm.[17]

3.3.4 Echo Suppressors - Echo suppressors are used in some four-wire trunks to control echo. The operation of these suppressors is important in data transmission because they normally limit transmission to one direction at a time (half-duplex). They will also have a definite operating time when the direction of transmission is reversed since it takes as long as 100 milliseconds for the suppressors to reverse their operation.[14]

Full duplex operation allows the transmission of data in both directions at the same time. This is accomplished by using different frequencies for the two directions of transmission. If it is desired to operate in this mode, the echo suppressors should be disabled to insure proper operation.

The echo suppressor may be disabled by the transmission of power in the 2010 to 2240 HZ band with no signal power outside this band. The minimum power level for disabling is 18db below the specified interface power level at the input to the Data Access arrangement, and the power must remain on for a minimum of 400 milliseconds.

Once the suppressor has been disabled, signal energy in the 300 to 3000 HZ band in either direction will keep it disabled. If power is interrupted for periods of greater than 100 milliseconds, the suppressor will be reactivated.[14]

3.4 Data Transmission

Due to the distortions produced within the telephone system, data, if in digital form or not within specified frequency limits, cannot be transmitted directly. This data must be converted to a form which can be transmitted over the telephone lines.[16] This means that the data must be converted into an analog signal falling within the ranges described in section 3.3.

In general, there are two methods of generating data for transmission over the telephone lines. The primary method is to transform the digital wave forms generated by computers, teletype machines, and other signaling devices into a modulated AC form (modulation). Modulation (and demodulation at the receiving end) takes place in a device called a data set or "modem". The modem takes the digital (DC) signal and converts it into an AC representation using FSK, ASK or PSK type modulation. Modems may be tied directly to the telephone lines (the telephone company requires special "safety" devices to be used in this case) or may be coupled to the telephone lines through an acoustic coupler.

The second method to be discussed is the Multi-Tone method of transmission. This method utilizes the generation of different frequencies to indicate the selected digit (no DC level signal is generated in this case).[18] While presently used primarily as a method of phone dialing, it can also be used, with some modification, as a method of transmitting data. This method is being used for the transmission of numeric numbers for credit card verification and bookkeeping. If care is taken so that the frequencies generated are within the telephone line range, it will not be necessary for a modem to be used. An acoustic coupler is all that would be required for transmission over the phone lines.

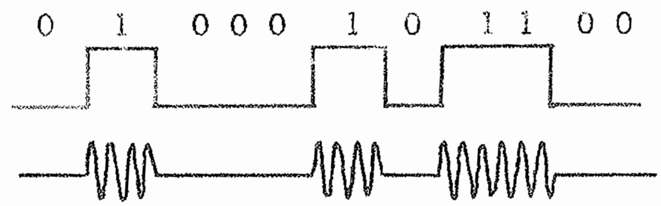
The methods of transmission described above will be covered in detail in the following paragraphs.

3.4.1 Modulation - In addition to making it possible to send signals with a DC component over channels that will not transmit direct current, (frequencies below 200 HZ are severely attennuated) modulation reduces the effects of noise and distortion, and it also increases the possible signaling speed.[16] The methods of modulation most often used will now be described.

<u>Amplitude Modulation</u> - amplitude shift keying (ASK), Fig. 3.4

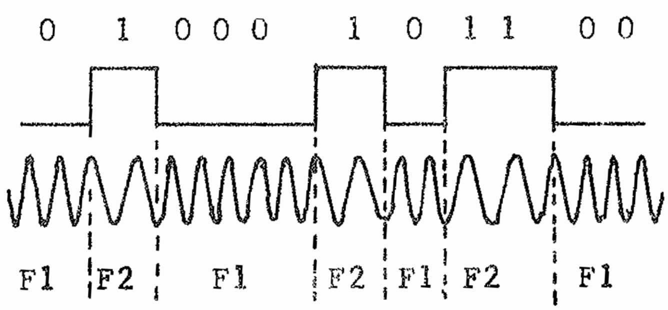
A digital "1" is represented by a high amplitude sine wave at the carrier frequency and a "0" is represented by a lower amplitude wave of the same frequency.

It is possible to use a waveform with more than two states as the modulating waveform.



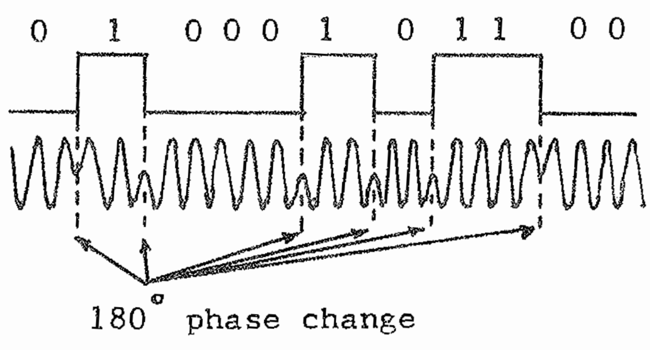
AMPLITUDE MODULATION

FIGURE 3.4



FREQUENCY MODULATION

FIGURE 3.5



PHASE MODULATION

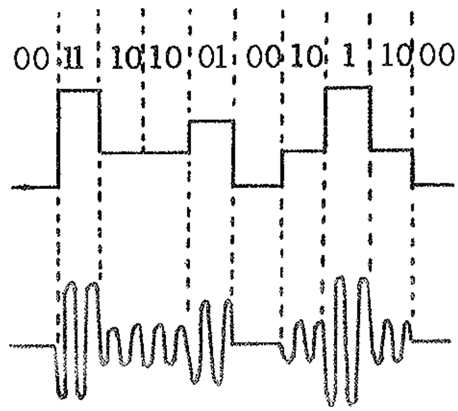
FIGURE 3.6

Fig. 3.7 shows amplitude modulation used to produce four possible states in the modulated waveform. The transmission rate that can be achieved approximately doubles by the use of this method, but it also increases its susceptibility to noise.[16] By its nature, amplitude modulation is already susceptible to noise. More than two states in the modulation waveform are, therefore, not normally used with amplitude modulation. They are, however, frequently used with phase modulation.

<u>Frequency Modulation</u>, frequency shift keying (FSK), Fig. 3.5

Instead of a digital "0" and "1" being represented by two different amplitudes, they are represented by two different frequencies.[16] Two or more different frequencies are transmitted within the communication channels bandwidth in order to convey two or more levels of information.[19]

Since amplitude excursions are unimportant for detecting a frequency moduled (FM) wave, FM modulation is relatively immune to disturbances that create errors in amplitude



FOUR STATE AMPLITUDE MODULATION

FIGURE 3.7

modulation (noise).[19]

The use of FSK limits a channels bit* carrying rate to about the frequency of the bandwidth. As data rates are kept below 1800 bits/second bandwidth conversion is not a problem.[19] FSK modulation is the type used for low and moderate speed transmission.

<u>Phase Modulation</u>, phase shift keying (PSK), Fig. 3.6

The "0" and the "1" are represented by sine wave carriers whose phase is altered to conform with the information being sent. In the simplest system the phases are 180 degrees apart. When more than two levels of information are carried additional phase differences are added. These added phase differences are usually in multiples of two and will make the difference between existing phase shifts smaller.

PSK, when complemented with amplitude modulation, can be used with very high speed systems.[19]

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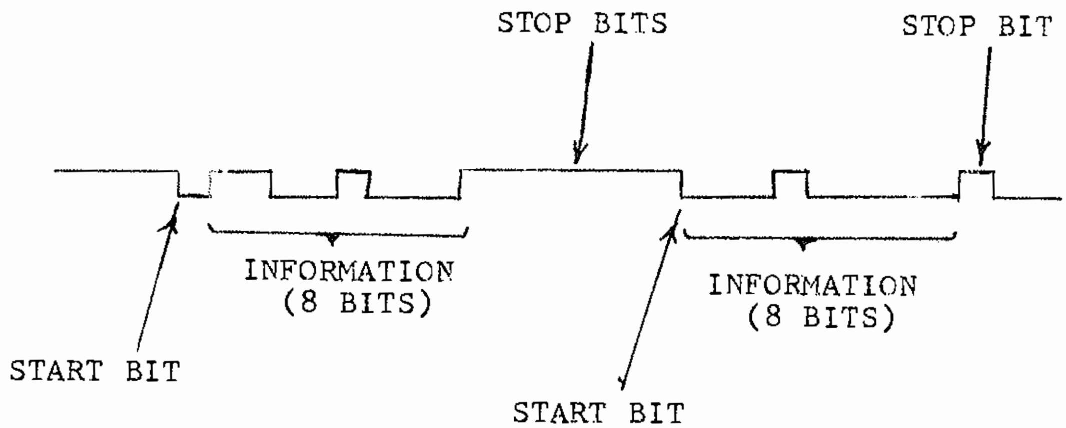
* See Appendix A for a discussion of "bits".

3.4.2 Transmission Modes - There are two transmission modes for sending data; synchronous and asynchronous.[19]

Asynchronous - This method is commonly called start-stop. The receiver operates on a character by character basis, starting at the beginning of a character, stopping at the end, and then starting once again at the beginning of the next character.[18] The characters (bits) do not have to be continuous in time, but may be transmitted as they become available.[20] This is possible since this method is insensitive to the time elapsed between characters. Each character contains all the required synchronization. This factor makes asynchronous transmission ideal for teletype terminals or other data entry devices which are not operated at a constant rate of speed.

In order for the receiver to properly recover the message, the bits are grouped into data characters (generally from 5 to 8 bits in length. Synchronizing start and stop elements are added to each character. Fig. 3.8[20]



ASYNCHRONOUS DATA TRANSMISSION

FIGURE 3.8

The start element is a single logic "0" (space) data bit placed at the front of each character. The stop element is a logic "1" (high or mark) that is added to the end of each character. The stop element is maintained until the start of the next character. There is no upper limit as to the length of a stop pulse, but there is a lower limit which is by the particular characteristic of the system used. Most modern systems use a 1.0 or 2.0 as a minimum data bit interval. The negative going transition of the start element defines the location of the data bits in one character. A clock source at the receiver is reset by this transition and is used to locate the center of each data bit.

The major advantage in asynchronous transmission is the simplification in transmission equipment which may be achieved since a clock signal need not be transmitted with the data. Note, however, that an independent clock source is still required at both the transmitter and receiver.[20]

The major disadvantage of asynchronous transmission is that a very large portion of the allowable communications channel bandwidth is taken up by the synchronizing start and stop pulses. Synchronous transmission requires a much smaller portion of BW for synchronization.

Asynchronous transmission is generally limited to 2K baud* over the telephone network.

<u>Synchronous</u> - This method feeds a continuous stream of data, which contains information immediately relevent to a message, along with some coding as to how the message is to be acquired and reconstructed.[19]

Synchronous data requires that a clock signal be transmitted with the data so that the location of the data bits can be determined for the receiver. A specific clock transition (rising or falling) marks the start of each data bit interval. Fig. 3.9[20]

Special synchronization data patterns are added to the start of the transmission so that

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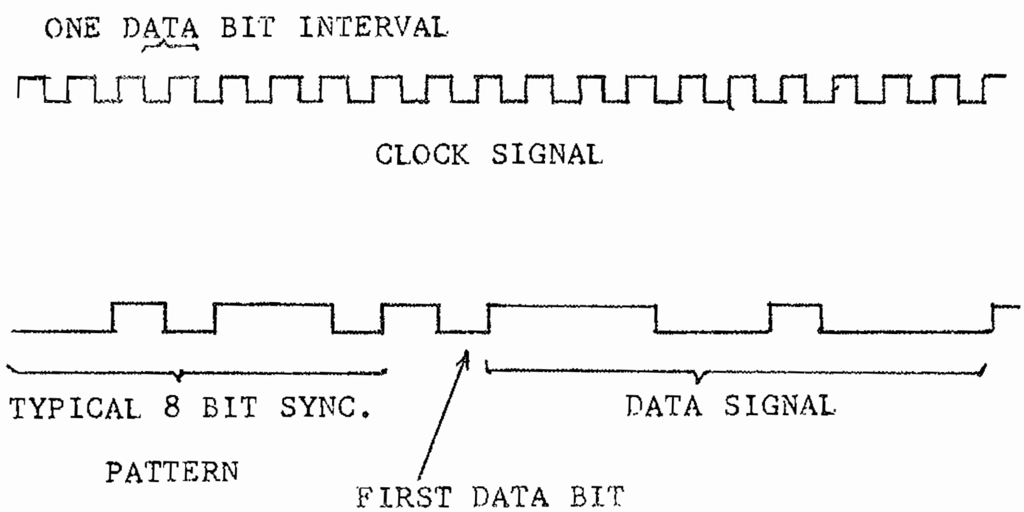
* See Appendix A



DATA SIGNAL

SYNCHRONOUS DATA TRANSMISSION

FIGURE 3.9

receiver can locate the first bit of the message. With synchronous transmission, each data bit must follow continuously after the synchronization word, since one data bit is assumed for every clock period.

3.4.3 Parallel or Serial - Digital data can be transmitted over communications lines in either serial or parallel mode.[16]

For parallel transmission, the channel is broken into (frequency multiplexed) many subchannels of narrower bandwidth. Each bit of a character is transmitted over a separate channel. The bit rate of each channel is reduced by a factor equal to the number of channels used. In serial transmission each bit of data is transmitted sequentially over a single channel.[19]

The stream of data is often divided into characters. Each character is composed of bits. The stream of information may then be sent either serial-by-character, serial-by-bit, parallel-by-character, or parallel-by-bit.

For parallel-by-bit transmission characters which are composed of six bits would require six separate communications paths with an extra one for control purposes. It may actually require seven separate wires. This would not be done over a long distance since costs would be greater than by other methods.[16]

Parallel transmission does have the advantage of not requiring circuitry to decide which bits are which in a character. Parallel wire transmission is often used, therefore, over short distances where the wires are laid down by the user.

Some machines are designed for parallel-by-bit transmission, but separate wires are not used to interconnect them. The bits travel simultaneously over the same wire, each bit using a different frequency band. This method is called frequency-division multiplexing.[16]

Most low and moderate speed transmission devices utilize serial transmission since it is less costly and can adequately handle the required data rates.

3.4.4 Channel Direction - In designing a data-processing system it is necessary to decide whether the line must transmit in one direction only or in both directions. If the latter, will the machines transmit in both directions at the same time?

Simplex lines transmit in one direction only.

Half-duplex lines can transmit in either direction, but only in one direction at once.

Full-duplex lines transmit in both directions at the same time. One full-duplex line is thus equivalent to two simplex or half-duplex lines used in opposite directions.

Many data transmission links use half-duplex lines. This allows control signals to be sent and two-way conversational transmission to occur.[16]

Most low speed computer terminals operate in the half-duplex mode.[19]

3.4.5 Codes - Since most data systems transmit binary information, it is necessary to structure an alphanumeric character set by arranging the zeros and ones so that each arrangement corresponds to a specific character.[19]

The number of bits (n) used for a given character determines the total number of code combinations in the code ($T=2^n$).[18] The total number of possible code combinations may or may not be used. In some codes not all combinations represent a character, and in other codes certain combinations are used for purposes other than sending data. An escape combination allows a large expansion in the total number of characters.[18]

There are presently several different binary codes being used:

Baudot Code is a telegraph code. Each character in this code is represented by five information bits. This permits $2^5=32$ possible code combinations to be transmitted. By using two of the combinations as a case-shift (escape) signal, Baudot is expanded to a 60-character combination. Table 3.1 shows the Baudot code.

● Denotes positive current

Code signals:							Lower case	Upper case			
Start	1	2	3	4	5	Stop		CCITT standard international telegraph alphabet No.2	U.S.A. teletype commercial keyboard	AT & T fractions keyboard	Weather keyboard
	●	●				●	A	—	—	—	↑
	●			●	●	●	B	?	?	$\frac{5}{8}$	⊕
		●	●	●		●	C	:	:	$\frac{1}{8}$	○
	●			●		●	D	Who are you?	$	$	↗
	●					●	E	3	3	3	3
	●		●	●		●	F	Note 1	!	$\frac{1}{4}$	→
		●		●	●	●	G	Note 1	&	&	↘
			●		●	●	H	Note 1	#		↓
		●	●			●	I	8	8	8	8
	●	●		●		●	J	Bell	Bell	'	↙
	●	●	●	●		●	K	(	(	$\frac{1}{2}$	←
		●			●	●	L	)	)	$\frac{3}{4}$	↖
			●	●	●	●	M	.	.	.	.
			●	●		●	N	,	,	$\frac{7}{8}$	⦷
				●	●	●	O	9	9	9	9
		●	●		●	●	P	0	0	0	∅
	●	●	●			●	Q	1	1	1	1
		●		●		●	R	4	4	4	4
	●		●			●	S	,	,	Bell	Bell
					●	●	T	5	5	5	5
	●	●	●			●	U	7	7	7	7
		●	●	●	●	●	V	=	;	$\frac{3}{8}$	⦶
	●	●			●	●	W	2	2	2	2
	●		●	●	●	●	X	/	/	/	/
	●		●		●	●	Y	6	6	6	6
	●				●	●	Z	+	"	"	+
						●	Blank				−
	●	●	●	●	●	●	Letters shift				↓
	●	●		●	●	●	Figures shift				↑
			●			●	Space				▪
				●		●	Carriage return				<
		●				●	Line feed				≡

Note 1 Not allocated internationally; available to each country for internal use.

Baudot 5-Bit Telegraphy Code [15]

Table 3.1

Indicated in Table 3.2 is the American Standard Code for Information Interchange (ASCII). This code has become the standard of the data-communications field. This code utilizes a seven-character identifying bits and is often supplemented with a parity-bit for error-checking purposes.

This code has several advantages over previous codes, such as the arrangement of the alphabetic portion to permit expansion to alphabets containing more than 26 letters.[18]

BCD, or binary coded decimal, is constructed of four bit blocks. This code is used primarily for internal machine coding and is not used widely for data transmission.

3.4.6 Errors - Errors in data transmission are generally caused by the transmitted signal being distorted by noise or line distortions. These distortions can cause the signal to be misinterpreted or can cause a loss of synchronization.

When important messages are sent, care must be taken that errors are minimized, and detected

BIT 4:	BIT 3:	BIT 2:	BIT 1:								
			BIT 7:	0	0	0	0	1	1	1	1
			BIT 6:	0	0	1	1	0	0	1	1
			BIT 5:	0	1	0	1	0	1	0	1
0	0	0	0	NULL	DC_0	b̸	0	@	P	UNASSIGNED	UNASSIGNED
0	0	0	1	SOM	DC_1	!	1	A	Q		
0	0	1	0	EOA	DC_2	"	2	B	R		
0	0	1	1	EOM	DC_3	#	3	C	S		
0	1	0	0	EOT	DC4 (STOP)	$	4	D	T		
0	1	0	1	WRU	ERR	%	5	E	U		
0	1	1	0	RU	SYNC	&	6	F	V		
0	1	1	1	BELL	LEM	' (APOS)	7	G	W		
1	0	0	0	FE_0	S_0	(	8	H	X		
1	0	0	1	HT / SK	S_1	)	9	I	Y		
1	0	1	0	LF	S_2	*	:	J	Z		
1	0	1	1	V_{TAB}	S_3	+	;	K	[		
1	1	0	0	FF	S_4	, (COMMA)	<	L	\		ACK
1	1	0	1	CR	S_5	—	=	M	]		①
1	1	1	0	SO	S_6	.	>	N	↑		ESC
1	1	1	1	SI	S_7	/	?	O	←		DEL

EXAMPLE: Character "R" is represented by 0100101

LEGEND:

NULL	Null/Idle	DC_0	Device control reserved for data link escape
SOM	Start of message	DC_1–DC_3	Device control
EOA	End of address	DC_4(Stop)	Device control (stop)
EOM	End of message	ERR	Error
EOT	End of transmission	SYNC	Synchronous idle
WRU	"Who are you ?"	LEM	Logical end of media
RU	"Are you...?"	S_0–S_7	Separator (information)
BELL	Audible signal	b̸	Word separator (space, normally nonprinting)
FE_0	Format effector	<	Less than
HT	Horizontal tabulation	>	Greater than
SK	Skip (punched card)	↑	Up arrow (Exponentiation)
LF	Line feed	←	Left arrow (Implies/Replaced by)
V_{TAB}	Vertical tabulation	\	Reverse slant
FF	Form feed	ACK	Acknowledge
CR	Carriage return	①	Unassigned control
SO	Shift out	ESC	Escape
SI	Shift in	DEL	Delete/Idle

The American Standard Code for Information Interchange (ASCII)[15]

Table 3.2

when present. Parity checking is one method locating errors.

3.4.7 Multitone Transmission - Another form of data transmission utilizes tones such as generated by a push-button telephone.

The Touch-Tone telephone was introduced by Bell System in 1963. This telephone contains eight oscillators which produce the following audible frequencies: 697, 770, 852, 941, 1209, 1336, 1477 and 1633 hertz.[16] When a button is pushed a combination of two discordant frequencies are produced. The frequency matrix for frequency generation is shown in Fig. 3.10. The Bell System 400 series data sets use the same eight frequencies plus others, and to these a data transmission device operating at 10 characters per second, or less, may be connected.

The data set utilizes a code in which two frequencies out of eight possible are transmitted at any one instant. This gives 16 possible combinations (2^4) that can be transmitted. This code provides some error detection in that a fault causing only one, or more than two, frequencies to be

"TOUCH-TONE" CALLING SYSTEM

		Nominal High Group Frequencies (Hz)			
		1209	1336	1477	1633
Nominal	697	1	2	3	Spare
Low Group	770	4	5	6	Spare
Frequencies	852	7	8	9	Spare
(Hz)	941	*	0	#	Spare

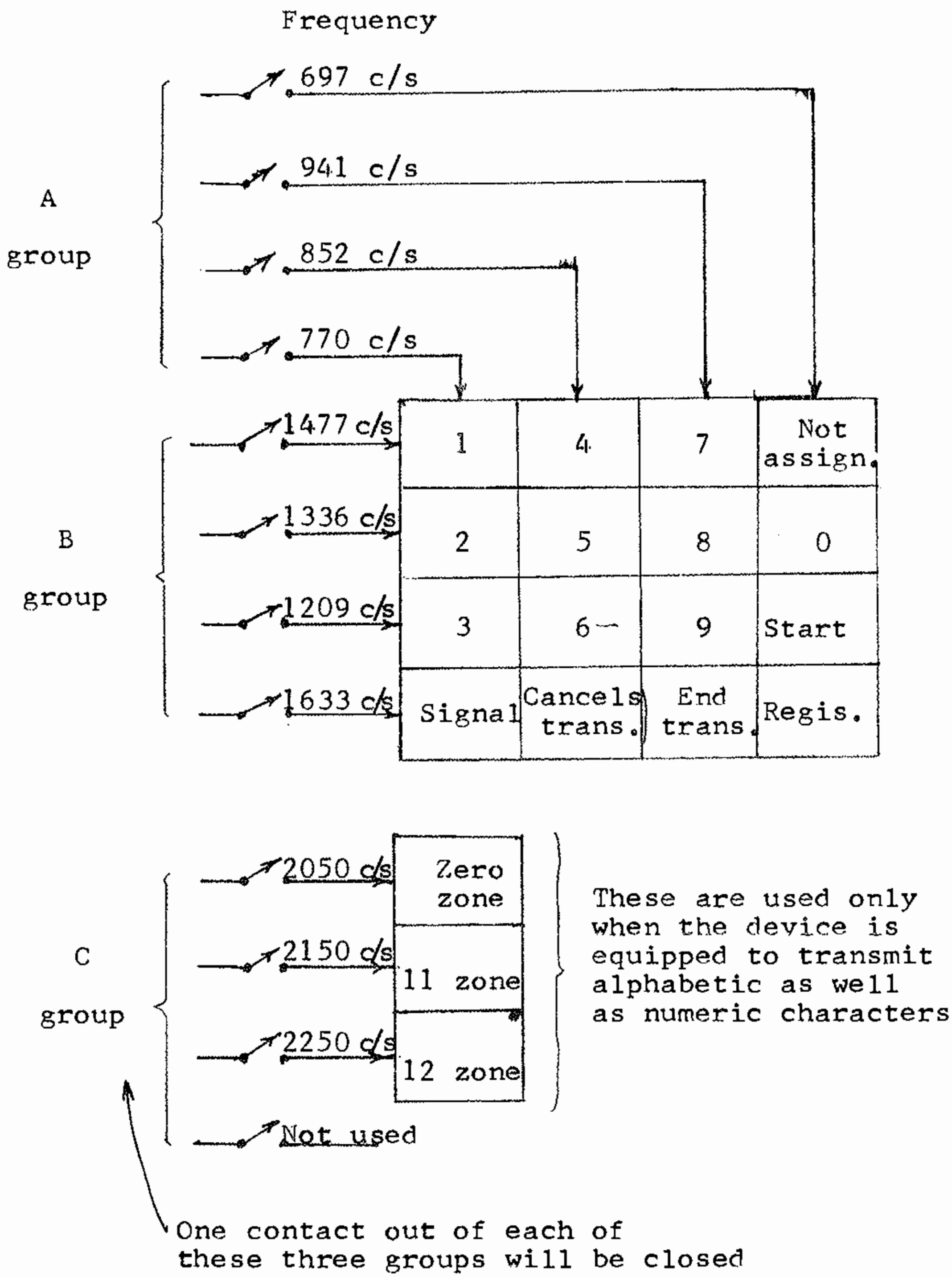
FIGURE 3.10

received will be noted as an error.

The 2-out-of-8 code as discussed above does not have enough combinations to transmit alphabetic data. The IBM 1001 data transmission device is able to transmit alphabetic data by the addition of three more frequencies. The coding remains the same as discussed above, but a third frequency can also be sent. The way that the characters are coded is shown in Fig. 3.11. The C-group frequencies are used when an alphabetic character is to be sent. The 12 "zone" combined with a digit gives the letters A to I. The 11 "zone" gives J to R, and the zero "zone", S to Z, and a special character composed of 0 and 1 punch.[16]

Multitone schemes may be developed which utilize other coding. Such schemes can utilize as many different frequencies as needed to meet specific applications.

The multitone method of transmission has the advantage of not requiring a modem for transmission, but it does require a tone decoder at the other end of the line to translate the generated tones into the desired alphanumeric data.



CODING USING 3 OUT OF 12 PARALLEL MULTIFREQUENCY TRANSMISSIONS

FIGURE 3.11

3.4.8 Modems and Acoustic Couplers - A modem (modulator-demodulator, or data set using Bell terminology) is a device capable of changing or converting (modulating) information-bearing signals from one form to another.[21] The modem is usually divided into two sections. The modulator portion converts the digital DC pulses, originated by computer or terminal equipment, into an analog signal acceptable for transmission over telephone lines. The demodulator reverses the process, converting the analog telephone signals back into a pulse train which is acceptable to the data terminal.[21]

Modems are available which operate at different speeds or data rate, expressed in bauds or bits-per-second (bps)*. For the purpose of this report we will concentrate on modems operating at 300 baud. This modem speed can be used on voice grade lines and the speed is adequate for data terminals which normally operate at 14.8 characters per second (teletype, etc.).[16]

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* See Appendix A

Modems operating at 300 baud normally operate asynchronous. These modems are usually associated with keyboard entry terminal devices where the time between information segments is random.[21]

Within this class of modems are the Bell System 113A, 101C, and equivalent modems using frequency shift keyed (FSK) modulation. The most commonly used is the Bell 103A and the 103A equivalents. Since the 103A can be used for full-duplex transmission on two wire lines, the data signals can be frequency division multiplexed. This is accomplished by the assignments of what Bell calls the Originate mode and Answer mode frequencies. These frequencies are as follows:

Originate	Mark = 1270HZ
	Space = 1070HZ
Answer	Mark = 2225HZ
	Space = 2025HZ

The Bell 103A has the capability to alternately operate in either mode. In typical operation the Originate mode is used in connection with a remote terminal for manual calling and the Answer mode is used in multiple installations at computer sights for automatic answering.[17] For terminal transmission (as would be required for deaf communication) it is recommended that the modem be capable of both sending and receiving in the originate or answer mode. This would then allow the modem to operate with any modem whether it is sending/receiving in the originate/answer mode.

The two most important performance characteristics of modems are channel separation and receive level capability. Bell System studies indicate that in order to insure operation over a wide range of lines the modem must be capable of receiving signals at -50 dbm. A further complication can result when the modem is operated full duplex and operation requires the transmit and receive signals to be multiplexed onto the same telephone circuit. A direct measure of the filtering quality of the modem is its ability to separate these two signals. Typical channel separation is 60 db with 75 db indicating significantly improved filtering.[17]

A modem may be either hard-wired to the communications channel or tied to the channel acoustically. Acoustic coupling allows the modem to be used with any available telephone, but may be prone to ambient acoustic noise.

Hard-wired modems, unless provided by the telephone company, ust use a data-access unit to interface with the telephone lines. These devices are provided by the telephone company on a rental basis.[19]

An acoustic coupler allows the analog data, which has been generated by the modem or by multitone signaling devices, to be picked up directly by the telephone handset. This allows the data transmitting device to be made portable. A small terminal could be made to transmit from a public telephone (as long as a source of power is provided).

3.4.9 Input and Output Devices - There is presently on the market a wide variety of input and output devices. These units vary from fully self-contained units, units containing keyboard, printer, modem and tape punch, to individual components such as keyboards, modems, and tape printers. As an example let's look at today's methods of obtaining a keyboard.

A fabricated package that generates an encoded output can be purchased, or one can buy the keyboard matrix from a keyboard manufacturer and an encoder from an IC or hybrid manufacturer and put them together. The switches can also be purchased separately from numerous manufacturers, placed on custom designed boards and encoder added. If one's needs are enormous, one might even consider rolling one's own from raw materials.[21]

From the equipment that is available an engineer must make a decision on what to buy as a black box and what to custom design. This decision will, of course, depend upon the system requirements, but it must be kept in mind when deciding upon what direction the final system will take.

The equipment which is available is too numerous to be described in detail in this text. Equipment will be covered in more detail in the chapter covering system design.

3.5 Conclusions

As discussed in the previous sections on telephonic communications there are two basic system techniques which should be considered for a TCFTD (Telephonic Communications for the Deaf) system.

1. The "General" method of transmission is utilized by most low speed data entry devices presently on the market. These devices, in most cases, utilize the combination of the following transmission techniques.
   a) Serial
   b) Asynchronous
   c) ASCII code

   Since a TCFTD system is a slow speed device, being limited by the operators' terminal entry speed, the above described method would work very well. (Ex. Teletype 33 series with a Bell 103 series compatible acoustic coupler)

   Advantages:
   1. System components readily available on market place.
   2. Could be used for computer interface as well as terminal to terminal communications.
   3. Compatible with teletype systems presently in use by the deaf.

Disadvantages:

1. Due to the complexity of the system (ASCII coding, modem, clocking, etc.), the initial system cost is relatively high ($1,000+).

2. The multitone method of transmission similar to that utilized by the touch-tone type telephone.

   Advantages:

   1. System would not require a modem.
   2. System would not require as extensive coding, synchronization, and clocking as that required by the "standard" device.
   3. Possible lower device cost than the "General" method.
   4. "Touch-Tone" telephone could be utilized to transmit limited messages.

   Disadvantages:

   1. Not compatible with existing data entry devices.
   2. System components not all readily available on the market place.
   3. Not compatible with teletype units presently being used by the deaf.

It is felt that while the cost of the "General" type of system is presently high, it can and will be lowered in the future since the present market for data terminals is rapidly expanding. The price of these terminals will continue to decrease with the increased competition and utilization of advanced system integration.

A device which is built strictly for a TCFTD system, utilizing the multitone method, may be initially less expensive to build, due to reduced coding requirements and synchronization, but could not take advantage of the expanding computer data entry market.

It is not believed that the deaf population would create a large enough market to make the device significantly decrease in price.

From the above it can be seen that both systems have distinct advantages. Due to these advantages it is felt that no definitive decision can be made at this time as to which major system approach should be taken. Both systems must be studied in more detail. This is especially true of the multitone alphanumeric system for which very little design work has been done in the past.

The next chapter of this thesis will delve deeper into the system detail. After this has been done a more intelligent decision can be made as to the final system configuration.

CHAPTER 4

SYSTEM DESIGN

The preceding two chapters discussed the requirements for a Telephone Communications for the Deaf (TCFTD) system. Both the human factors and technical requirements were presented. This chapter will summarize these requirements and utilize them to develop overall system requirements.

4.1 Human Factor Requirements

4.1.1 A summary of the human factor requirements which were determined in Chapter 2 are presented below:

a) Cost not prohibitive.

b) Operational skills not restrictive.

c) Compatible with all telephones.

d) Easily moved.

e) Not require the deaf person to speak.

f) The ideal system would require only the deaf person to use it (only the deaf person would have the device).

g) A comfortable operating speed is desired.

h) If the deaf person is required to transmit a message manually, a visual indication of the message is desired.

4.1.2 Scenario of Ideal TCFTD - From the human factor requirements described above, and ideal TCFTD can be hypothesised. The following scenario will be used to demonstrate the use of an ideal TCFTD System.

A speaking person enters a telephone booth and dials (or uses touch-tone buttons). Mr. Smith's telephone will ring (Unknown to caller, Mr. Smith is deaf). This ring will activate a flashing light to indicate an incoming call. Mr. Smith will then throw a switch activating the following pre-corded message:

"You have reached 886-3460 home of the Smith family. We are deaf but are equipped to handle your call. Please respond in the following manner. If you are calling from a dial phone, dial the number 9 and wait for a response. (Mr. Smith will be able to sense the dialed 9 and send a message to the caller with further instructions.) If you are calling from a touch-tone phone, push the number 6 button and wait for a response." (Mr. Smith will be able to sense the touch-tone 6 and send a message to the caller with further instructions.) Once coding and decoding instructions have been successfully communicated the message may be completed.

4.1.3 Scenario Evaluation - The requirements of the system as described in the above scenario would cause the ideal TCFTD system to have the following major system requirements:

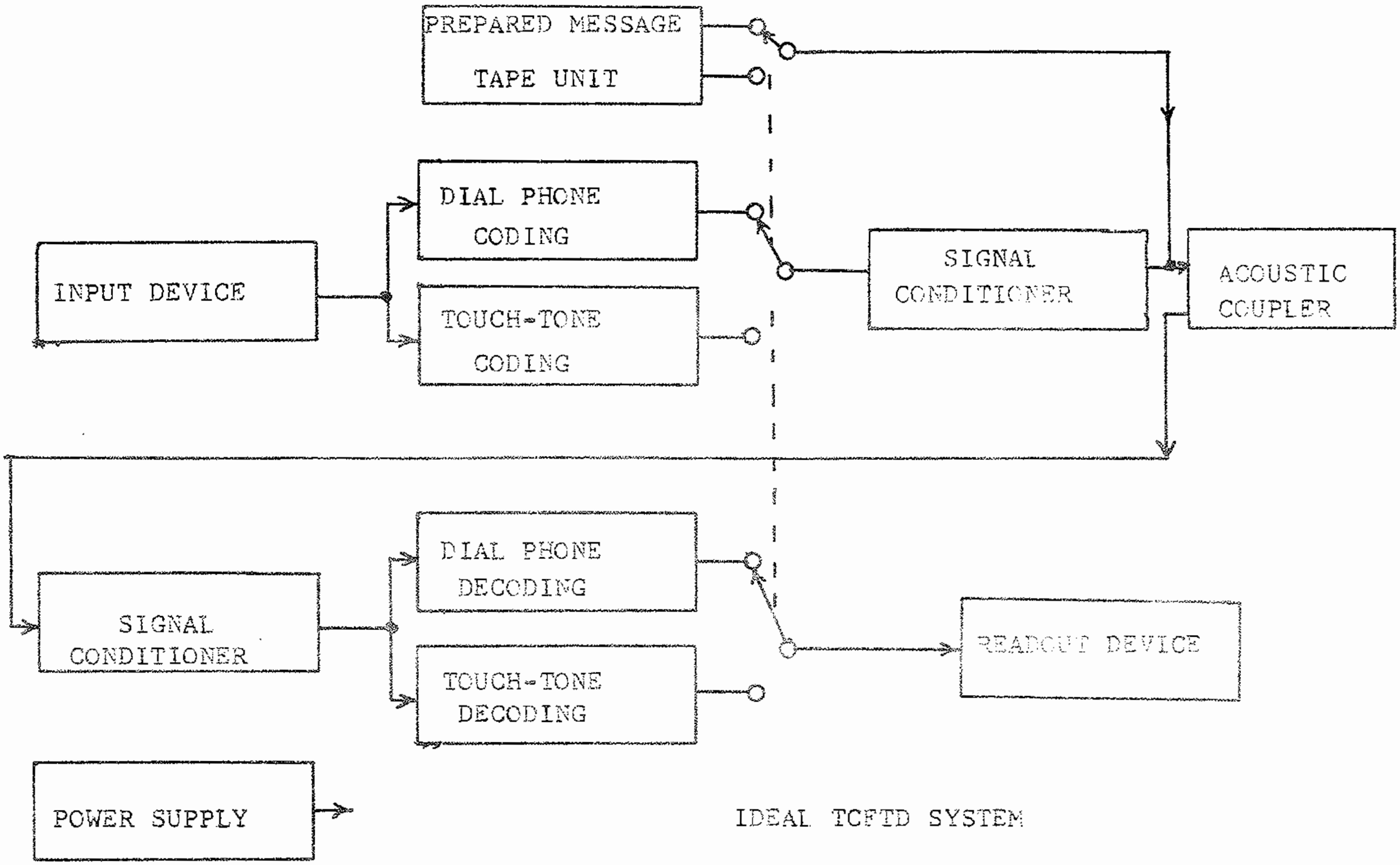
a) Detect, decode, and display a message from any type of telephone.

b) Initially respond with a message instructing the sender on the coding methods required to send a message.

c) Send a message, during a conversation, which can be received and decoded at any type of telephone without the need for any decoding device.

A block diagram of an ideal system meeting these requirements is shown in Fig. 4.1. This diagram does not include detailed system requirements, but is a general diagram meant to give the reader an idea as to the system complexity. Note that a method of coding and decoding must be devised which can convert the two different types of telephone devices (dial phone and tough-tone phone) into translatable messages.

Since the ideal system requires only the deaf



IDEAL TCFTD SYSTEM

FIGURE 4.1

person to have one, the hearing person must decode the tones or clicks he hears on the phone into the message which is being transmitted by the TCFTD system. When he wants to transmit, the speaking person must code the message so that it may be sent by dialing a special sequence of numbers or by pushing a sequence of touch-tone buttons.

Coding and decoding of this type would require operational skills to be learned and will cause transmission and reception to be done at a reduced speed.(1)

A stranger making a call to a deaf person would require a lot of patience and good learning ability to reach any kind of conversational speed in a short period of time.

(1) By utilizing the touch-tone telephone to transmit alphanumeric messages an average speed of 7 words per minute was approached for trained personnel - See section 2.3.4.

Combining the requirements for the ideal TCFTD system appears to cause a conflict in overall system requirements. The requirement that only the deaf person have a device conflicts with the requirements that operating skills not be prohibitive, and the desire for a comfortable operating speed. The requirement that the system operate from either a dial or touch-tone telephone adds to this conflict since two different methods of manual coding and decoding are likely to be required.

Because of these conflicting ideal system requirements, the author will devote the remainder of this thesis in the development of a system meeting all of the ideal system requirements <u>except</u> the need for only the deaf person to have the device (i.e., both parties would require devices). It is felt that conversation by deaf persons with strangers will be in the minority and that friends and relatives would be willing to spend the money required to purchase the required TCFTD system.

4.2 Technical Requirements

The technical requirements for <u>any</u> system utilizing the telephone was discussed in Chapter 3. It was determined that for a TCFTD system two methods of transmission could be used: The "General" method, which is presently being used by most low speed data entry devices on the market, and the Multitone method similar to that being used by the touch-tone.

4.3 System Requirements

The requirements and conclusions of the last three sections have been summarized and reduced into a set of system specifications. These specifications are presented in Tables 4.1 and 4.2 and will be used as a guideline for the design of a TCFTD system.

4.4 System Diagrams

The system requirements for the "General" Method can be achieved by the system shown in Fig. 4.2. This system will allow two terminals (both terminals need not be the same) to communicate with each other or may also be utilized for terminal/computer communications.

Table 4.1

System Specifications - "General" Method
1. ASCII code.
2. Originate/Answer modes desirable
3. Asynchronous
4. Serial transmission
5. Half duplex
6. Data rate of 10 characters per second minimum
7. Acoustically coupled
8. Visual indication of message while transmitting
9. Alphanumeric with period, space, and comma
10. Typewriter type entry device
11. Output device capable of showing the complete message before resetting
12. Lightweight
13. Operate with normal AC power or battery pack
14. Cost should be as low as possible

Table 4.2

System Specifications - Multitone Method	
1.	Asynchronous
2.	Multitone transmission
3.	Data rate of ten characters per second minimum
4.	Acoustically coupled
5.	Visual indication of message while transmitting
6.	Typewriter type entry device
7.	Output device capable of showing the complete message before resetting
8.	Alphabetic with period, space, and comma* (numeric desirable)
9.	Lightweight
10.	Operate with normal AC power or battery pack
11.	Cost should be as low as possible

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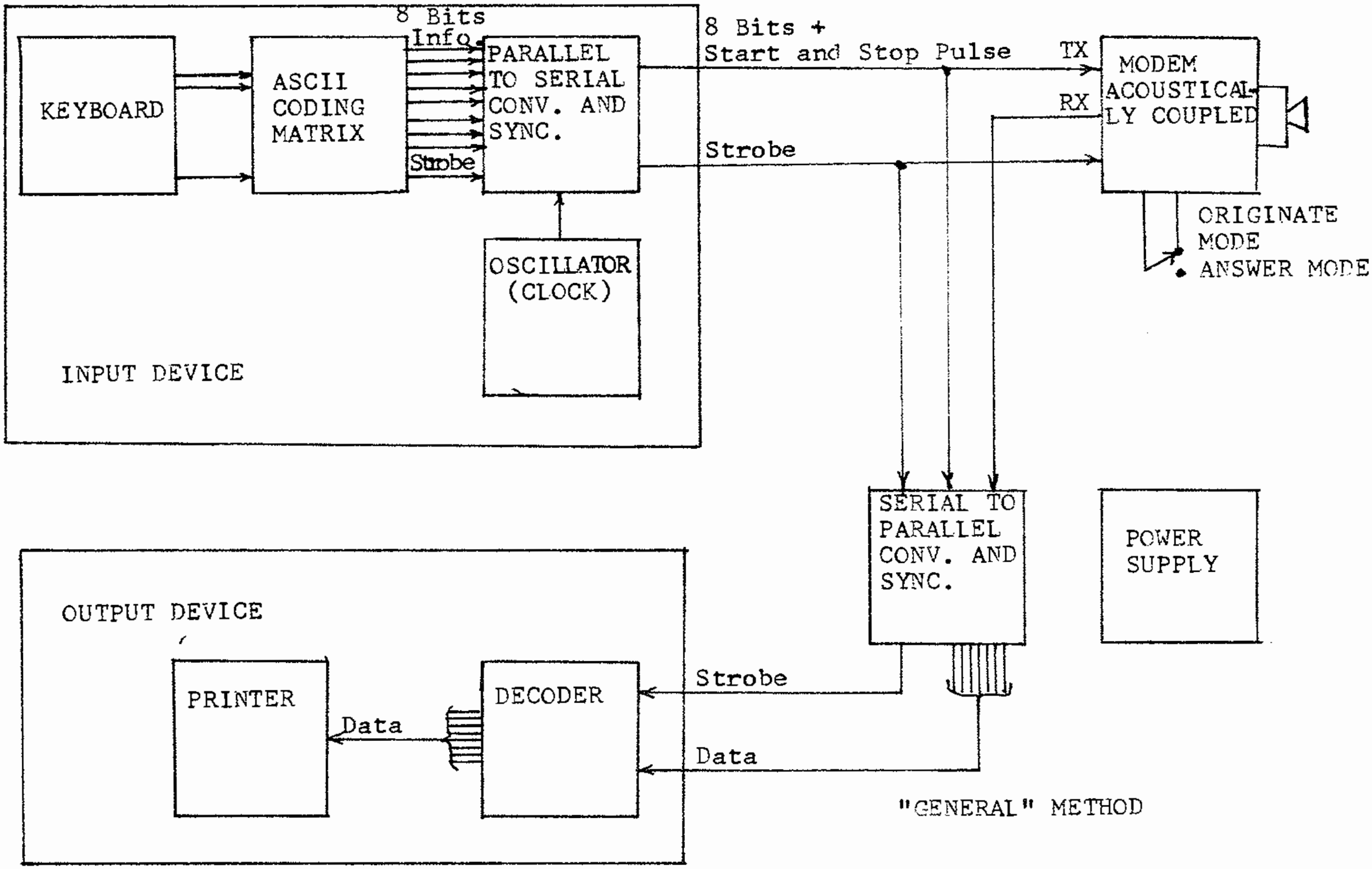
* Since this device is meant only for deaf communications there is no need for numeric characters. A deaf person can spell each number when necessary. This reduction in characters may allow the keyboard and decoding to be simplified.



"GENERAL" METHOD

FIGURE 4.2

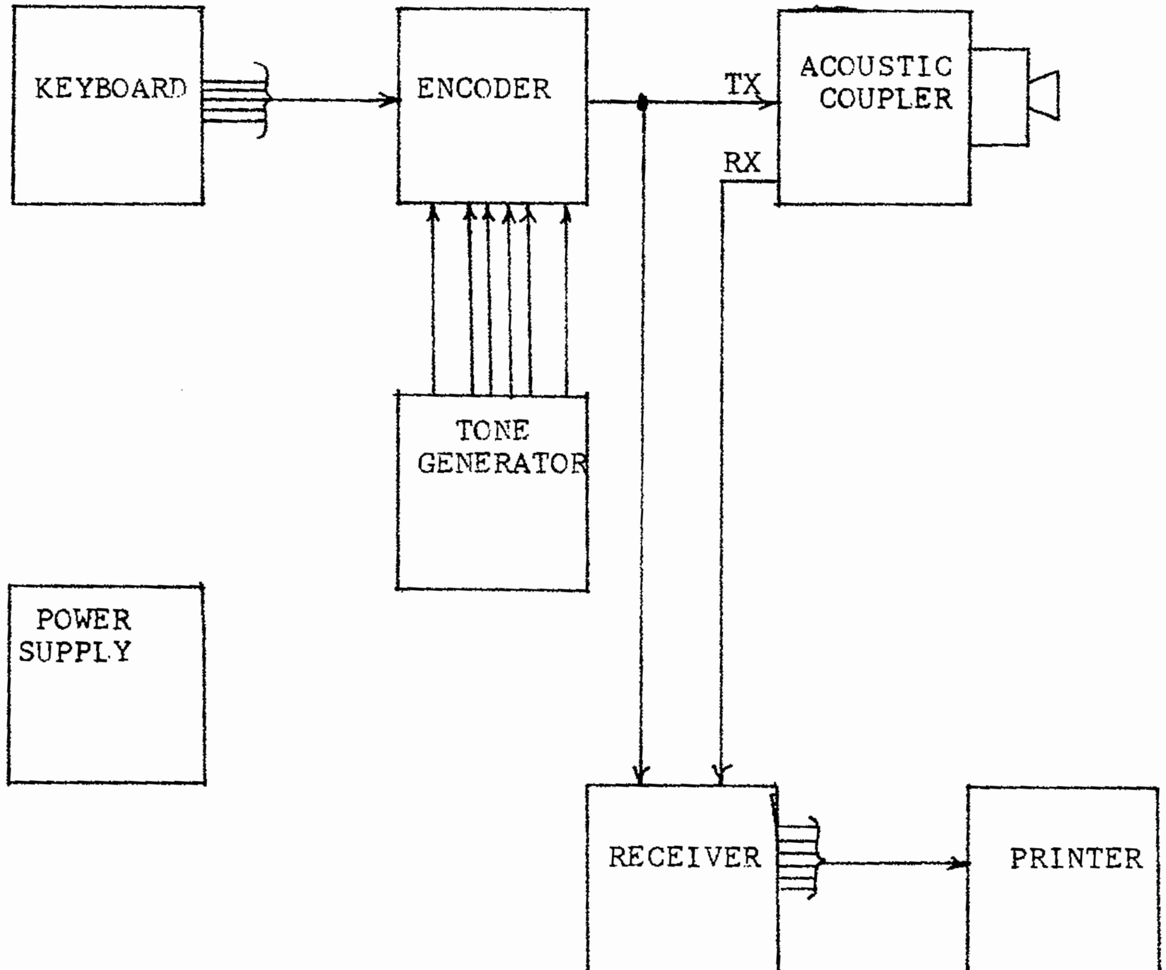
It is anticipated that this system will be constructed with off-the-shelf hardware. It must be determined at what system level hardware will be purchased, and what specific component types will best meet the electronic and physical requirements of Table 4.1.

Electronic requirements for the Multitone system can be achieved by the system shown in Figure 4.3. This system will allow two terminals of the same design to communicate with each other. This system will require that the majority of its components be designed since they are not readily available on the market.

In the sections to follow specific component blocks for each type of system will be specified. They will be selected from those on the market or, when necessary, they will be designed.

4.5 "General" Method

The simplest way of meeting the system requirements of the "General" Method is to purchase a complete terminal. These terminals are available in numerous sizes and shapes and have prices (100 up) varying from \$850 to greater than \$3000. Table 4.3 contains a listing of



MULTITONE SYSTEM

FIGURE 4.3

Table 4.3

Complete Terminals		
Type	Price ($) (100 up)	Comments
Dataline - 700	1,300	1) Completely portable (20 lbs) 2) full duplex only 3) originate mode only
Execuport - 300	3,490	1) Lightweight (35 lbs) 2) very quiet operation 3) originate mode only
Com Data Corp. 33KSR	915	1) Teletype Model 33 with modem
Comproport - 3500	1,000	1) Meets all specifications

Table 4.4

Entry Devices		
Type	Price ($) (100 up)	Comments
Unicluster 210-0175	114.95	1) Has internal clock and decoding
Cherry B70-4753	119	1) Has internal clock and decoding

some of the terminals which are presently available on the market.

These terminals meet most of the general system requirements of Table 4.1. The requirement that the terminal operate in both originate and answer mode is the one specification which is most often not present in the lower priced devices.

All the terminals contain the basic blocks shown in Figure 4.2 and summarized below:

1. Entry device (keyboard)
2. Encoder
3. Synchronization and Formating
4. Clock
5. Acoustically coupled modem
6. Decoder
7. Readout Device (printer)
8. Power Supply

These blocks may be purchased separately and assembled into a complete terminal.

Following is a discussion of the major components presently available:

4.5.1 Entry Device - Table 4.4 lists some of the entry devices presently available. Most of these devices closely resemble a typewriter keyboard. They contain full alphanumeric, symbols, and special keys.

Most keyboards contain built-in coding devices which generate ASCII coded symbols. These keyboards need only be connected to a specified source of power and, in some cases, a synchronizing clock.

A fully encoded keyboard with internal clock can be purchased for $119 in quantities of 100 (Cherry B70-4753).

4.5.2 Modems - Table 4.5 - Modems appear to be the most numerous of all computer peripherals. The requirements that it be acoustically coupled and meet the requirements of Table 4.1 narrows the field to a Bell 103F compatible modem.

The requirement for both the originate and answer mode of operation results in a machine costing approximately $50 more than one without this feature (Table 4.5). For a low cost, fixed position,

Table 4.5

Modems (Acoustic couple only)		
Type	Price($) (Unit Price)*	Comments
Omnitec 701A 702	 285 365	Originate only (O) Originate/Answer (O/A) 1) Enclosure included
Novation DC-102 DC-103	 315 415	O O/A 1) Enclosure included
Anderson Jackobson ADAC 242 ADC 300	 345 385 (rebuilt)	 O O/A
ComData Corp. #320 #310	 165 125	O/A O 1) PC board 2) Needs power supply
Communications Logic Inc. L-300G1ORG2 L-300A1ORA2	 107 190	1) O or A only 2) Power supply required 1) O or A only Built in power supply
Integrated Electronics Inc. 300A 300C PS	 272 320 85	 O O/A

*Approx. -10% for 100 lots

limited access device it may be possible to operate successfully with only the originate mode.

4.5.3 Readout Device - The two types of printers which meet system requirements are the strip printer and the page printer. The strip printer is more difficult to use when long complicated messages or equations are being sent, but is more than adequate for deaf communications.

Computer Terminal Systems, Inc. Model 004 with all the requirements costs $270. This was the lowest priced unit which could be found and still meet system requirements.

4.5.4 Parallel to Serial Converter and Synchronization - If the modem or keyboard purchased does not contain means of converting the parallel entry device (keyboard) data into the serial asynchronous format and adding synchronization it can be readily accomplished by auxiliary electronics.

Motorola has recently introduced such devices. When connected properly the MC2257 can convert parallel to serial and add synchronization in the transmitter. The MC2258 can convert serial to parallel information and add synchronization at the receiver.

These devices require only power and the proper clock frequency to operate as described above.

4.5.5 Power Supply - Power supplies are readily available which can meet any system requirement. The basic system requirements are those which convert line voltage into the DC voltages required for system operation and also supply adequate current to allow proper operation.

The minimum number of DC voltages required in the system is:

$\pm$15 VDC - op. amps and output device

+ 5 VDC - digital logic

All supplies should have fuses for protection, and over-voltage protection is desired.

The exact supply requirements would depend upon the system configuration decided upon, but due to the pricing policy of power supply companies it appears that a supply meeting all system requirements can be purchased for under $100.

4.5.6 Conclusions: The Comproport 3500 terminal appears to be the device that best meets all system requirements. This unit costs $1000. If components were assembled the lowest priced system meeting system requirements would be as follows:

Entry - Unicluster 210-0175	$115
Modem - Comdata 320	165
Power Supply	100
Readout - Computer Terminal, Inc. 004	275
Interface Electronics	100
Cabinet (in production quantities)	25
	$780

A complete system would cost $780 if assembled from off-the-shelf components. This price does not include the initial engineering costs which would be encountered during development.

The Com Data 33KSR unit costs $915. This unit is not easily moved, noisy, and operates only in the originate mode. O/A Modes are available at an added cost.

It would, therefore, appear that the Comproport terminal is the system which should be used for the "General" Method of operation.

4.6 Multitone Method

Before a detailed design of the Multitone system could be undertaken some basic system decisions had to be made. In the previous sections a system specification was generated along with a basic system block diagram. In general, we wanted to transmit multitone messages into an acoustically coupled telephone and decode these messages at the other end. The basic questions that had to be answered were:

1) What type of multitone coding should be used.
2) What frequencies should be used for transmission.
3) What type of filtering would be necessary.
4) Selection of input and output devices.

When these questions were answered, a more detailed system block diagram could be generated and, where necessary, a detailed circuit design undertaken.

The questions described above are answered in the following paragraphs.

4.6.1 Coding - As discussed previously it was decided that for a device which is to be used strictly by the deaf there is no need for a full alphanumeric keyboard. An alphabetic keyboard with a period, comma, and space is all that is required.

The standard ASCII coding scheme was decided upon (Table 4.6, see Table 3.2 for full ASCII). It is only necessary, however, to use six characters. The seventh character is not necessary since the required twenty-nine characters can be generated without it.

Using the ASCII code has the advantage that most readout devices will accept this code directly without the need for additional decoding. The decoding matrix is already built into the device.

By using this scheme a total of six frequencies will be required for transmission. There will be the need of transmitting a maximum of four, and a minimum of one, frequency at one time. It is felt

Table 4.6

ASC II CODE

	Frequency						
	1	2	3	4	5	6	7*
A	1	0	0	0	0	0	1
B	0	1	0	0	0	0	1
C	1	1	0	0	0	0	1
D	0	0	1	0	0	0	1
E	1	0	1	0	0	0	1
F	0	1	1	0	0	0	1
G	1	1	1	0	0	0	1
H	0	0	0	1	0	0	1
I	1	0	0	1	0	0	1
J	0	1	0	1	0	0	1
K	1	1	0	1	0	0	1
L	0	0	1	1	0	0	1
M	1	0	1	1	0	0	1
N	0	1	1	1	0	0	1
O	1	1	1	1	0	0	1
P	0	0	0	0	1	0	1
Q	1	0	0	0	1	0	1
R	0	1	0	0	1	0	1
S	1	1	0	0	1	0	1
T	0	0	1	0	1	0	1
U	1	0	1	0	1	0	1
V	0	1	1	0	1	0	1
W	1	1	1	0	1	0	1
X	0	0	0	1	1	0	1
Y	1	0	0	0	1	0	1
Z	0	1	0	1	1	0	1
0	0	0	0	0	1	1	0
1	1	0	0	0	1	1	0
2	0	1	0	0	1	1	0
3	1	1	0	0	1	1	0
4	0	0	1	0	1	1	0
5	1	0	1	0	1	1	0
6	0	1	1	0	1	1	0
7	1	1	1	0	1	1	0
8	0	0	0	1	1	1	0
9	1	0	0	1	1	1	0
SP	0	0	0	0	0	1	0
.	0	1	1	1	0	1	0
,	0	0	1	1	0	1	0

*Not necessary for coding.

that if adequate filtering is provided, there will not be any major problems with this coding scheme.

By studying the coding scheme decided upon it can be seen that transmission of numeric symbols can be accomplished without the need for additional frequencies. A full alphanumeric ASCII coding set can, therefore, be transmitted by the addition of the required data entry keys and some additional wiring. While this is not a system requirement it would certainly speed up transmission if a lot of numeric messages were being sent. The added cost vs. utility of this feature must be determined when the input entry device is decided upon.

4.6.2 Frequencies - To take advantage of equipment which is presently on the market, the logical choice of frequencies selected for multitone transmission would be those used in the touch-tone telephone system described in section 3.4.7 (Fig. 3.10). It was also felt that the research time and money spent by Bell Telephone in selecting these frequencies should be utilized. The limiting factors in frequency selection are:

1) Frequency response of the telephone system.
2) Sophistication of the filtering required to get required separation in the receiver section.

It should be noted that the minimum frequency separation in the touch-tone system (Fig. 3.10) is 268 HZ (1209-941). The touch-tone scheme allows the transmission of only 12 characters.

The coding (30 characters) scheme described in the previous section will have a minimum frequency separation of 73 HZ (770-697) if the Bell frequencies were used. This would mean that more sophisticated and expensive filtering would be required.

To reduce the filtering requirement at the receiver and allow band-pass filters which can be designed or purchased realistically, a slightly different frequency scheme was selected (Table 4.7).

In section 3.3.4 echo suppression was described. To disable the echo suppressor it is necessary to transmit power in the 2010 to 2240 HZ range for a minimum of 400 milliseconds. An upper frequency of

Table 4.7

Multitone Frequency Scheme	
No.	Frequency (HZ)
1	697
2	852
3	1094
4	1336
5	1633
6	2100

2100 HZ was selected. This frequency will allow the echo suppressor to be disabled (transmitted a space, this will also be utilized as the call frequency) and still be within the upper frequency limits of the telephone network.

All but one of the remaining frequencies were selected from the standard touch-tone scheme. The frequency 1094 HZ was selected because of the large frequency gap between 852 HZ and 1336 HZ (484 HZ) would allow adequate filtering.

4.6.3 Input Device - The minimum input device required was a grouping of 29 reed relay type switches which would provide a switch closure when each specific key is pressed. No "roll over" encoding or timing circuitry is required. Any transmission error will be immediately apparent and will not cause any major problem other than the incorrect spelling of a word or the reduction of sending speed.

Switch lines are connected directly to a FET switching matrix. This matrix controls the output of six oscillators. The combination of frequencies transmitted is determined by the matrix connections.

The connection of the FET matrix is in accordance with the coding scheme described in the previous section.

The cost of a complete keyboard of this type is approximately $75. The additional price for the 10 additional (numeric) keys is approximately $20. A keyboard meeting all minimum system requirements costs less than $100.

A fully encoded keyboard (7 bit output, 55 Key ASCII code) with "N" key roll-over and internal timing costs $119 in lots of 100 (Cherry B70-4753 or Unicluster 210-0175).

While encoding, roll-over and internal timing are not required for system operation, they make the design simpler (only 6 lines are required to connect the keyboard to FET matrix). The deaf person will have an easier time learning system operation since the keyboard is similar to that of a regular typewriter. It is felt that these added features are worth the additional $19.

4.6.4 Output Device - The type of output device selected was determined primarily by:

1) Need for a presentation which would not require the user to perform any decoding
2) Low cost
3) Minimal amount of auxiliary electronics
4) Low power consumption.

As a result of these requirements a strip printer was decided upon. Specifically, the type of printer decided upon contains a continuously rotating character wheel behind the paper and a solenoid actuated hammer in front of the paper. The paper is pressure sensitive and when struck by the hammer a permanent letter is printed.

The lowest price printer of this type (the lowest price for any print-out type device), complete with all the required electronics is manufactured by Computer Terminal Systems, Inc. and costs approximately $265 in lots of 100.

An additional feature of this device is that it is operated from +12VDC rather than the +36V required by most printers of this type. This feature allows power supply requirements to be simplified.

The printer was found to be the most costly and also the most complicated piece of equipment required in the system.

4.7 Design of Multitone System

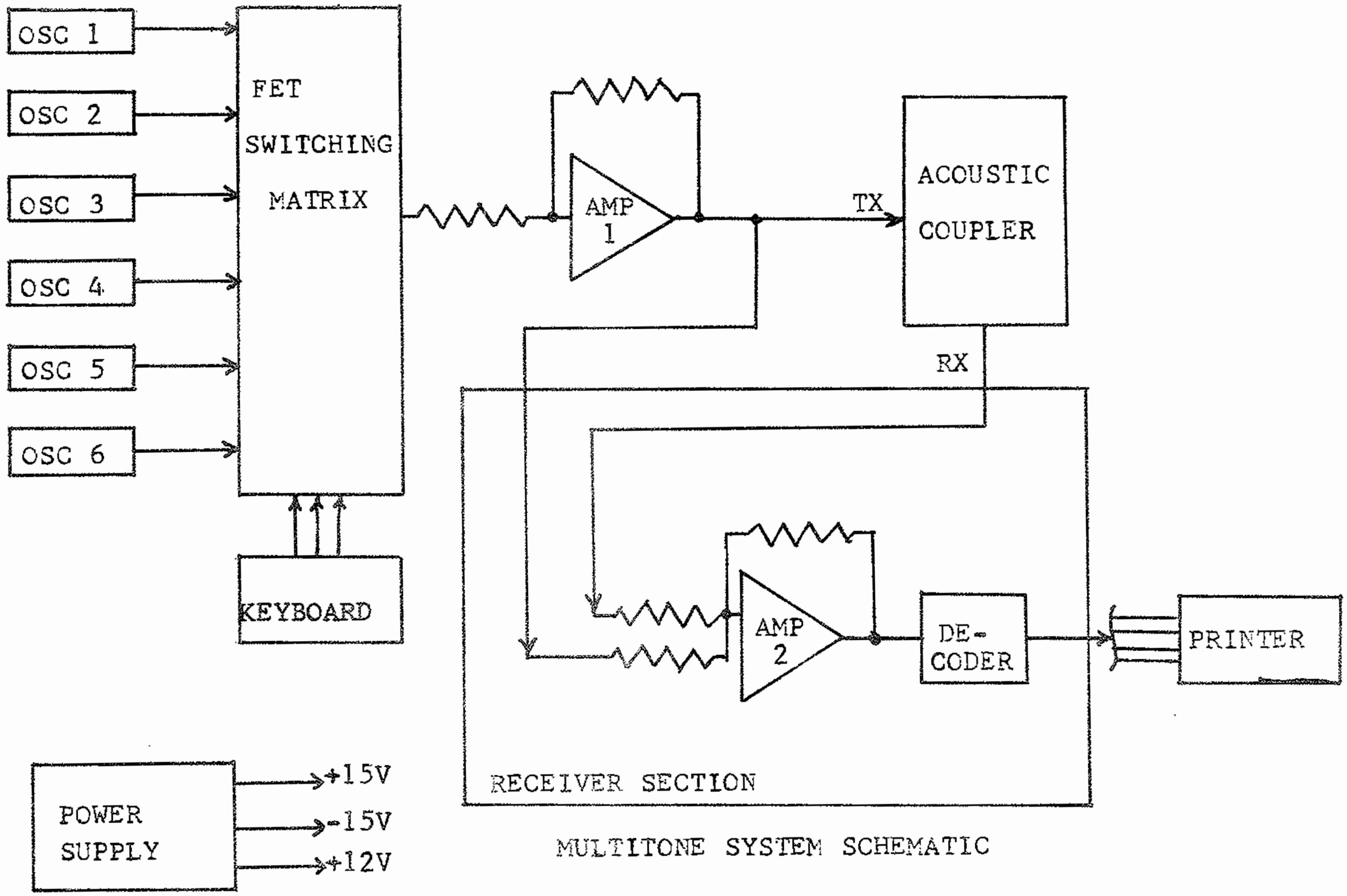
A detailed block diagram incorporating the results of section 4.6 is shown in Fig. 4.4.

Detailed design requirements for each of the following functions must now be determined:

1) Oscillators
2) FET Matrix
3) Receiver Section
4) Amplifiers
5) Pulse Forming Network

4.7.1 Oscillator - Six oscillators are required and will operate at the frequencies shown in Table 4.7.

To insure proper circuit operation these oscillators must have good frequency and amplitude



MULTITONE SYSTEM SCHEMATIC

FIGURE 4.4

stability. Distortion is not very critical in this application since only the second harmonic is within the detection range. The worst case second harmonic distortion that can be tolerated is calculated for the 697 HZ tone which has a second harmonic of 1394 HZ. This is within 58HZ of the 1336HZ adjoining tone. So an oscillator with a -20db second harmonic (not very difficult to achieve) would have an attenuation of -20db at the receiver. This is an attenuation of ten and should be adequate.

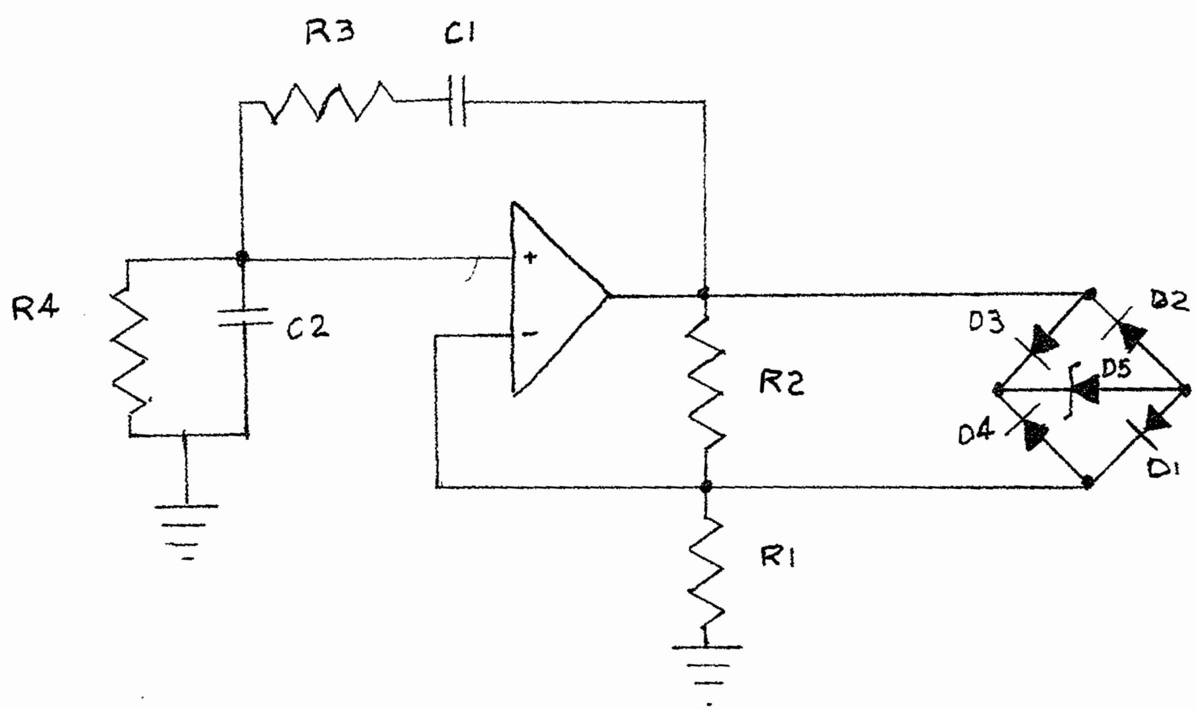
Oscillator requirements are:

1) .5% Frequency accuracy
2) 1% Frequency stability 25°C - 75°C
3) 1% Amplitude stability 25°C - 75°C

A design meeting the above requirements is shown in Figure 4.5. This circuit is a wein-bridge oscillator utilizing a single zener diode and diode bridge to maintain stability. The oscillation frequency of this circuit is determined by:

$$f = \frac{1}{2\pi RC} \qquad R = R3 = R4, \quad C = C1 = C2$$

To assure that oscillation will start at turn-on R2 = 2.1 R1. This makes the overall loop gain



OSCILLATOR

FIGURE 4.5

slightly greater than unity until the diodes act to limit the output amplitude.[22]

4.7.2 FET Switching - The FET switches are used to couple the desired oscillator to the buffer amplifier, which then drives the acoustic coupler. The output of the keyboard drives the FET's with a +5v true logic level corresponding to the desired ASCII coding.

FET requirements are:

1) ON @ VIN = +5 VDC
   OFF @ VIN = 0 VDC
2) 6 Channels
3) VCC = $\pm$15 VDC
4) R_{ON} = 300 ohms

An inverter consisting of 2 triple Or gates may be connected between the keyboard and FET's. This type circuit inverts the keyboard logic level and drives the FET's, if required.

The FET switches are 2 triple Intensil 1H5014 analog switches. These FET's are on with a maximum R_{ON} of 100 ohms when the gate level is at OV, and off when the gate is $\geqq$ +4.5VDC.

4.7.3 Receiver Section - The receiver section may be built using one of two basic methods. Both methods will now be presented.

<u>Method 1</u> - Filtering & Pulse Forming (Figure 4.6)

Filtering:

Appendix B gives the detailed calculations for all the band-pass filters required specifications. These specifications are summarized in Table 4.8. Note that the frequencies vs. Q requirements are not excessive and should, therefore, allow filters to be purchased at a moderate cost.

The basic requirements used in the determination of filter specifications were:

1) Center frequencies as determined in previous section.
2) Minimum attenuation of the center frequency of one filter to the adjoining filter is -40db.
3) Attenuation must not be greater than -3db within the specified pass band.

Table 4.8

Required Filter Responses:

Gain = 0 $\pm$ .5 db

fo*	BW -3db	BW -40db	Q
697	31	310	22.5
852	31	310	27.5
1094	47.6	476	23
1336	48.4	484	27.7
1633	59.4	594	28.5
2100	93.4	934	22.5

fo = Center Frequency

BW = Bandwidth

Q = fo/BW

* All numbers are in HZ

A second order (2 Pole-Pair) Butterworth filter will meet the design requirements.[23]

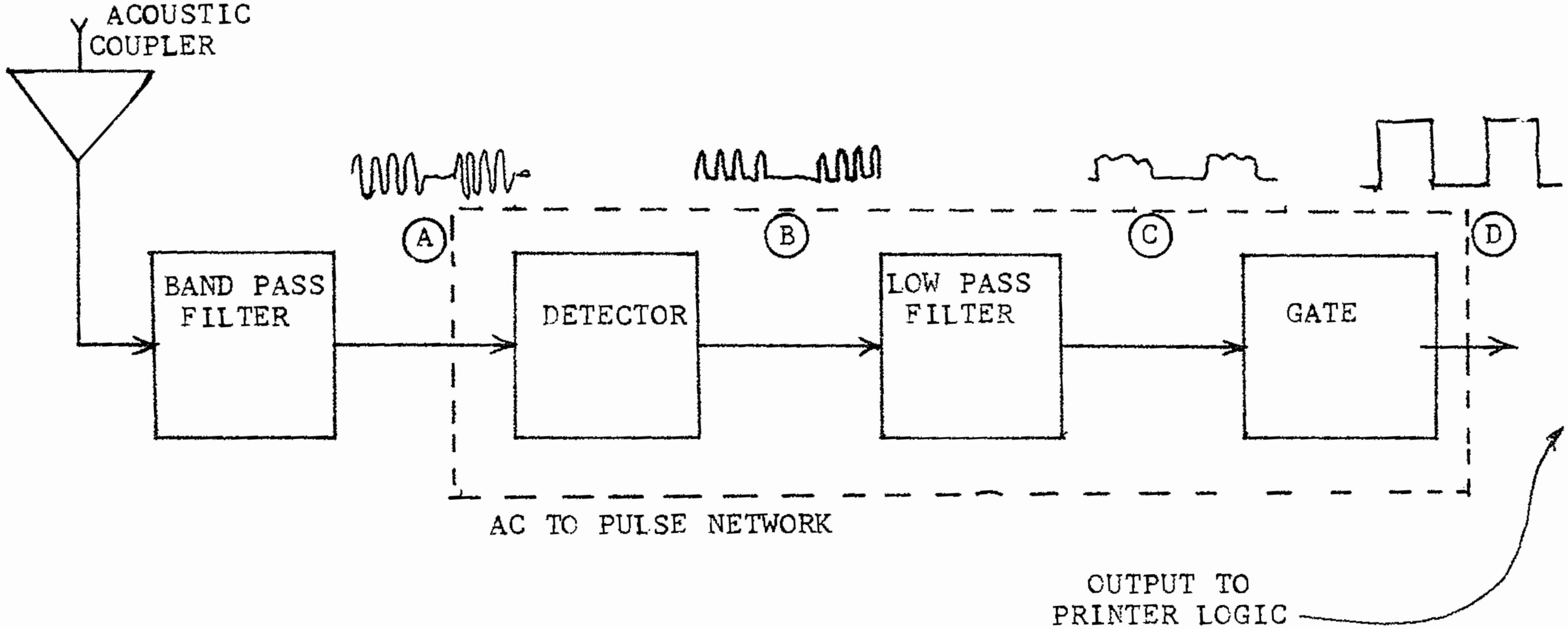
AC to Pulse Network

The purpose of this circuit is to convert the AC signal which the bandpass filter allows to pass (filters will pass only those frequencies which fall within the specified filter bandwidths) into a DC level. The DC level will be converted into a pulse compatible with the printer input logic circuitry.

The three basic circuits which perform the above conversion are:

1) Detector
2) Low Pass Filter
3) Driver (Switch)

A block diagram of the AC to Pulse network is shown in Figure 4.6. The detector input section is a half wave rectifier formed by a single diode which allows only the positive half cycle of the AC input (A) signal to pass through (B) and, therefore, acts as a detector



RECEIVER SECTION METHOD-1

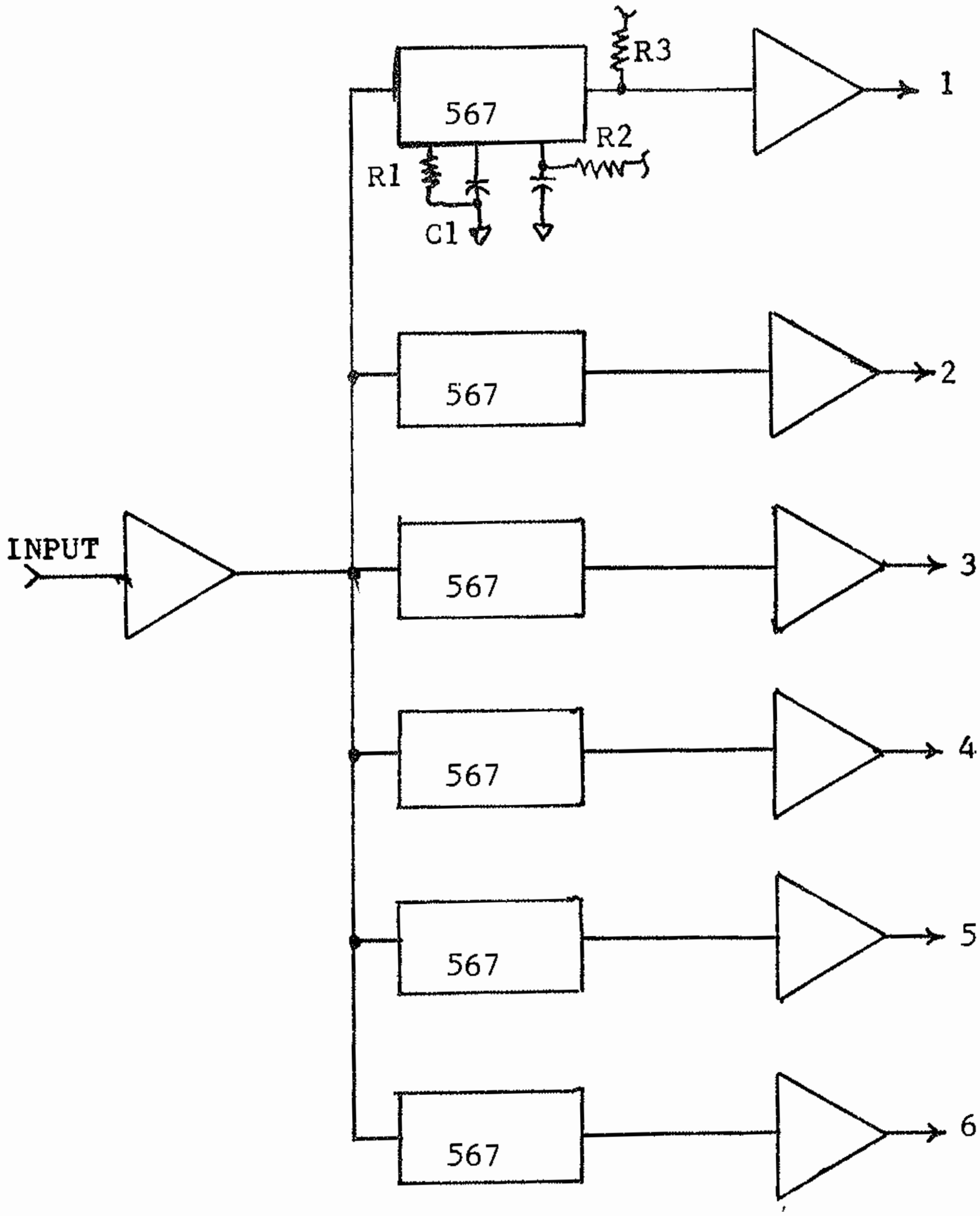
FIGURE 4.6

circuit. The half wave signal is filtered by an active low pass filter. This circuit filters out the majority of the ripple, thus smoothing the signal so that its shape follows the envelope of the AC input signal (C). This signal will then be squared up and its amplitude shifted by a driver gate (D).

Method 2 - Tone Decoder (Figure 4.7)

This circuit utilizes a monolithic phase locked loop (PLL) as a tone decoder. The 567 series is made especially for tone decoder applications. Each decoder is tuned to the desired center frequency (Table 4.7) by adjusting R1 and C1. Resistor R2 reduces the bandwidth (capture range) of each circuit to approximatley 8%.[24] This reduced bandwidth allows enough separation between input frequencies to insure proper operation (circuit is acting like a band-pass filter).

When a signal tone is present at the input, within a frequency band corresponding to the capture range of the PLL, the output level will



RECEIVER SECTION METHOD-2

FIGURE 4.7

switch. The output of each PLL is connected to an inverter which senses the change of input level and converts it to the proper logic level to drive the output device (strip printer).

The receiver section using Method 1 would cost approximately $212 and $57 using Method 2. The major difference in these prices is the elimination of the bandpass filter requirement with Method 2. The filter elimination also reduces the complexity of the system. Method 2 should be used in the system.

4.7.4 Pricing - The pricing of the Multitone Method system would be as follows (engineering time for proto development not included):

Entry	$115
Read Out	275
Power Supply	75
Electronics	97
Cabinet	25
Acoustic Coupler (no electronics)	25
	$612

4.7.5 Conclusions - The Multitone Method can be built at an approximate cost of $600. The required electronics, printer and keyboard are the major items setting the cost of the device, with the keyboard and printer remaining at a relatively high price level even in large production runs. All other items will probably be reduced in price with large production runs.

CHAPTER 5

CONCLUSIONS

Two different sets of system requirements meeting both the majority human factor needs of the deaf and technical requirements of the telephone system were developed in Chapter 4. From these requirements two communications systems were developed.

An ideal TCFTD system was also considered, but due to conflicting requirements, it was decided that this thesis would concentrate on the development of a system which required both conversing parties to have the device.

The "General" method system, section 4.5, utilizes a standard low-speed teletype system. A system of this type can be purchased for \$1000 complete, or can be assembled from components for approximately \$780. While the cost of this system is presently high, prices are rapidly decreasing due to the expanding requirements for computer entry devices. This system is electrically compatible with those devices furnished by the Alexander Graham Bell Institute, free of charge, to the deaf. Only the relatives of the deaf need to purchase a complete unit. The deaf, as long as the Institute can supply the units, or until costs decrease, would only be required to adapt the unit for an acoustically coupled modem which can operate in both the originate and answer modes.

The multitone system, section 4.6, is similar to a teletype. It, however, utilizes a transmission scheme using tone conversion rather than a modem. This system is not compatible with the standard teletype. The Multitone system can be built at a cost of $612. This price does not include development costs.

Table 5.1 summarizes the advantages of the "General" vs. Multitone method. As a result of this comparison, it is concluded that the multitone method is not economically feasible to build. This is because a general purpose terminal in quantity can be purchased at a price very close to that required for the Multitone method. The reason for this is that the price for the Input Device, Output Device, Power Supply and Case remain the same while the price of the required electronics is about the same as that required for a commercial modem and interface electronics. The price of the Multitone system could probably be reduced in large production runs, but since the "General" method is more versatile, it would not be worthwhile to develop the Multitone method.

A portable, low speed, teletype utilizing the "General" method of transmission is recommended as the best device to meet the needs of "A Telephonic Communications System for the Deaf."

Table 5.1

"General" vs. Multitone Method

<u>"GENERAL" METHOD</u>

Unit Cost: $1000 complete
$ 780 components

Advantages:

1. Systems and system components are readily available on the market place and are rapidly decreasing in price.

2. Could be used for computer interface as well as terminal-to-terminal communications.

3. Compatible with teletype system presently used by the deaf.

Disadvantages:

1. The system is more complex than required for deaf communications.

<u>MULTITONE METHOD</u>

Unit Cost: $612 (does not include development costs)

Advantages:

1. System is less complex than the "General" method. It does not require a modem or extensive coding, synchronization and clocking.

2. Lower cost

Table 5.1 (continued)

Disadvantages:

1. Not compatible with teletype units presently being used by the deaf.

2. Not compatible with existing data entry devices.

3. Due to usage for deaf communications only, pricing is not likely to reduce rapidly.

4. System must undergo development cycle before becoming available on the market.

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APPENDIX A

The rate data transmitted is usually measured in bauds. Baud represents a basic rate of transmission in pulses per second and is defined to be the reciprocal of the shortest signal element (usually one data bit an interval).[19] The amount of information that can be packed into each baud is represented by the number of bits per baud.[19]

Example 1:

Each character is 11 data bit in length, and 15 characters are transmitted per second. The shortest signal element is:[20]

$$\frac{\text{seconds}}{\text{15 characters}} \times \frac{\text{character}}{\text{11 data bits}} = 6.06 \frac{\text{Msec}}{\text{data bits}} \text{ or}$$

$$\frac{\text{data bits}}{\text{6.06 Msec}} = \underline{165} \text{ baud}$$

However, only 10 bits of information (8 data, 1 short, and 1 stop)* are transmitted every 66.6 Msec, the bit rate

$$\frac{\text{10 bits}}{\text{66.6 Msec}} = 150 \frac{\text{bit}}{\text{sec}}$$

It should be noted that it is the variable stop rate in asynchronous transmission that can make baud rate differ from the bit rate.[20]

*Even though the stop pulse lasts for two data intervals, it is still only considered one bit of information.

APPENDIX A (continued)

Example 2:

Each asynchronous ASCII character is 1 bit in length, and has a start bit and 2 stop bits. It, therefore, has a total of 10 data bits. If 30 characters are transmitted per second, number of baud is equal to:

$$\frac{30 \text{ characters}}{\text{second}} \times \frac{10 \text{ data bits}}{\text{character}} = 300 \text{ data } \frac{\text{bits}}{\text{second}}$$

$$= \underline{300 \text{ baud}}$$

APPENDIX B

FILTER CALCULATIONS

1. f_G = $\underline{697}$ Hz = Geometric Center

$f_{H(-40db)}$ = $\underline{852}$ Hz = High Frequency

$BW_{(-40db)}$ = (852 - 697)2 = 155(2) = $\underline{310}$ Hz = Bandwidth

$f_{L(-40db)}$ = 852 - 310 = $\underline{542}$ Hz = Low Frequency

Let $BW_{(-40db)}$ be 10X $BW_{(-3db)}$:

$BW_{(-3db)}$ = $\underline{31}$ Hz

$$Q_{Filter} = \frac{f_G}{BW_{(-3db)}} = \frac{697}{31} = 22.5$$

$$f_{H(-3db)} = \frac{BW}{2} + \sqrt{\left[\frac{BW}{2}\right]^2 + (f_G)^2} =$$

$$\frac{31}{2} + \sqrt{\left(\frac{31}{2}\right)^2 + (697)^2} = \underline{712}\ \text{Hz}$$

$$f_{L(-3db)} = f_{H(-3db)} - BW_{(-3db)} = 712.1 - 31 = \underline{681.1}\ \text{Hz}$$

2. f_G = $\underline{852}$ Hz

$f_{L(-40)}$ = $\underline{697}$ Hz

$BW_{(-40)}$ = (852 - 697)2 = 155(2) = $\underline{310}$ Hz

$f_{H(-40)}$ = 697 + 310 = $\underline{1007}$ Hz

Let:

$BW_{(-3db)}$ = $\underline{31.0}$ Hz

$$Q_{Filter} = \frac{852}{31} = 27.5$$

$$f_{H(-3db)} = 15.5 + \sqrt{240 + (852)^2} = \underline{867.5}\ \text{Hz}$$

$$f_{L(-3db)} = 867.5 - 31 = \underline{836.5}\ \text{Hz}$$

3. $f_G = \underline{1094}$ Hz

$f_{H(-40)} = \underline{1336}$ Hz

$BW_{(-40)} = (1336 - 1094)2 = 242(2) = \underline{484}$ Hz

$f_{L(-40)} = 1336 - 484 = \underline{852}$ Hz

Let:

$BW_{(-3db)} = \underline{48.4}$ Hz

$$Q_{\text{Filter}} = \frac{1094}{4.4} = 22.7 \cong 23$$

$$f_{H(-3db)} = \frac{48.4}{2} + \sqrt{\left(\frac{4.4}{2}\right)^2 + (1094)^2} = \underline{1123} \text{ Hz}$$

$f_{L(-3db)} = 1123 - 48.4 = \underline{1075}$

4. $f_G = \underline{1336}$ Hz

$f_{L(-40db)} = \underline{1094}$ Hz

$BW_{(-40db)} = (1336 - 1094)2 = (242)2 = \underline{484}$ Hz

$f_{H(-40db)} = 1094 + 484 = \underline{1578}$ Hz

Let:

$BW_{(-3db)} = \underline{48.4}$ Hz

$$Q_{\text{Filter}} = \frac{1336}{48.4} = 27.7$$

$$f_{H(-3db)} = \frac{48.4}{2} + \sqrt{\left(\frac{48.4}{2}\right)^2 + (1336)^2} = \underline{1360.2} \text{ Hz}$$

$f_{L(-3db)} = 1360.2 - 48.4 = \underline{1311.8}$ Hz

5. $f_G = \underline{1633}$ Hz

$f_{L(-40db)} = \underline{1336}$ Hz

$BW_{(-40db)} = (1633 - 1336)2 = 297(2) = \underline{594}$ Hz

$f_{H(-40db)} = 1336 + 594 = \underline{1930}$ Hz

Let:

$BW_{(-3db)} = \underline{59.4}$ Hz

$Q_{Filter} = \frac{1633}{59.4} = \underline{27.5}$

$f_{H(-3db)} = \frac{59.4}{2} + \sqrt{(\frac{59.4}{2})^2 + (1633)^2} = \underline{1662.7}$ Hz

$f_{L(-3db)} = 1662.7 - 59.4 = \underline{1603.3}$ Hz

6. $f_G = \underline{2100}$ Hz

$f_{L(-40db)} = \underline{1633}$ Hz

$BW_{(-40db)} = (2100 - 1633)2 = (467)2 = \underline{934}$ Hz

$f_{H(-40db)} = 1633 + 934 = \underline{2567}$ Hz

Let:

$BW_{(-3db)} = \underline{93.4}$ Hz

$Q_{Filter} = \frac{2100}{93.4} = \underline{22.5}$

$f_{H(-3db)} = \frac{93.4}{2}$ Hz $+ \sqrt{(\frac{93.4}{2})^2 + (2100)^2} = \underline{2146.7}$ Hz

$f_{L(-3db)} = 2146.7 - 93.4 = \underline{2053.3}$ Hz