Requirements for a Remote Access Hybrid Computer Terminal Utilizing Common Grade Telephone Lines

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REQUIREMENTS FOR A REMOTE ACCESS HYBRID COMPUTER TERMINAL UTILIZING COMMON GRADE TELEPHONE LINES

BY

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B.S.MS., Stetson University, Deland, Florida 1965

RESEARCH REPORT

Submitted in partial fulfillment of the requirements for the degree of Master of Science in the Graduate Studies Program of Florida Technological University

Orlando, Florida
1974
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</table>
INTRODUCTION

The capabilities of digital computers has, for quite some time, been made available to remote users through the use of telephone lines, modulators/demodulators (MODEMS) and remote peripheral equipment. This process has made digital computers accessible to a greater number of users than could be serviced by those who could go to the location of the computer. This same capability has not been provided to those who require or would benefit from the use of analog or hybrid computers.

Briefly, a hybrid computer is an analog computer and a digital computer working together. This is accomplished by joining the two computers by means of a two way communication interface. Figure 1 shows a basic system. A more thorough description is not required for the purpose of this report.

---

**Figure 1.**—Hybrid computer system
Analog and hybrid computers are generally used to solve more specialized problems than stand alone digital computers. Therefore, their presence is also quite limited, with the total number of hybrid computer centers in the United States being approximately 50. This scarcity, and therefore low availability is compounded by the lack of remote access capability.

This lack of availability in itself suggests that remote access hybrid computation would be desirable and is made even more so by the fact that hybrid computers are capable of solving many problems much more efficiently than digital computers. Table 1 shows actual comparisons which document savings of up to a factor of 190. The data in this table are the results of a study done by the Martin Marietta Corporation on problems running on their IBM 360 digital and EAI 8400 Hybrid computer systems. In fact, there are applications, such as high frequency communication problems, which are essentially unsolvable on digital computers, due to the extreme time and cost, which hybrid computers can solve quite nicely.
TABLE 1
DIGITAL HYBRID COST COMPARISON

<table>
<thead>
<tr>
<th>MISSILE SYSTEM</th>
<th>TYPE PROBLEM</th>
<th>PROBLEM COMPLEXITY</th>
<th>DIGITAL COST/RUN</th>
<th>HYBRID COST/RUN</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>6 DOF Flight Test Analysis</td>
<td>3 or 4 Analog Bays and 1 Digital</td>
<td>$200.00</td>
<td>$5.34</td>
</tr>
<tr>
<td>B</td>
<td>3 DOF Terminal Phase</td>
<td>2 Analog Bays and 1 Digital</td>
<td>$1.40</td>
<td>$0.05</td>
</tr>
<tr>
<td>C</td>
<td>3 DOF Monte Carlo Tolerance Study</td>
<td>2 Analog Bays and 1 Digital</td>
<td>$6.00</td>
<td>$0.18</td>
</tr>
<tr>
<td>D</td>
<td>Satellite Lifetime Program</td>
<td>3 Analog Bays and 1 Digital</td>
<td>$5.71</td>
<td>$0.03</td>
</tr>
</tbody>
</table>

In addition to savings on existing applications, there are other factors which point to increased need for remote hybrid computing capabilities. One such factor is the, seemingly inevitable, new generation of analog computers which will include autopatch capability. This statement is made in light of the new government-backed program for several companies to develop such equipment. This equipment will surely lead to the capability of completely operating a hybrid simulation remotely. Another factor to consider is that the surface is just beginning to be scratched on many new hybrid applications such as digital communication receivers, biomedical simulation, voice intelligibility, cement manufacturing, diesel engine pollution and management decision modeling and training.

For this report, common grade telephone lines were chosen for the media for transmission of the required signals for a remote access
hybrid computer terminal. This choice was made on the basis of widespread availability and low cost. These characteristics of the common grade telephone line provide the remote access to a computer center from essentially any place where the necessary peripheral equipment is available. Also, the low cost goes hand-in-hand with the basic requirements of satisfying the hybrid computation need with the greatest economy and efficiency.
I. OBJECTIVES OF REPORT AND PROBLEM DEFINITION

The prime objective of this report is to consider the requirements and limitations of a remote access hybrid computer terminal using common grade telephone lines and to suggest methods of providing the requirements while overcoming the limitations. The assumptions for this report are:

1. The remote terminal will be connected to a hybrid computer facility which is designed to operate in full duplex mode to send and receive data.

2. Common grade telephone lines will be used for sending and receiving signals.

3. In an attempt to be most efficient and economical, one telephone line per remote terminal will be used, recognizing that increased capability would result from using multiple lines but that basically this is just an extension of the ability to use one line.

To illustrate the requirements of a system intended to utilize a hybrid computer from a remote site, what is required to utilize a hybrid computer locally must first be determined. In general, one must first configure the system. This entails setup of the analog computers, set up of the digital computers, and proper setup of the hybrid interface. Once this is done, one needs to supply the necessary input and finally, receive the desired output. The three facets of the problem then are: (1) setup, (2) input, and (3) output.
For the digital computer part of the hybrid, all three of the required basic functions identified above may usually be satisfied by one device. Such devices which have both input and output capabilities are typewriters, and teletypes. There are others but these two can initiate input directly from human beings and supply output readily interpretable by human beings. Also these devices are readily available and not too expensive. The most versatile and fastest of these two devices is the teletype and one equipped with a cathode ray tube (CRT) display and hard copy unit is most flexible, allowing continuous plots, bar charts, diagrams, etc., in addition to normal alphanumerics. A CRT hard copy unit, that is, a unit which on local or remote command produces a paper copy of the contents of the screen, is most desirable for obvious reasons.

The requirements for interface setup and analog setup, input and output are not so easily met. The present state-of-the-art requires manual implementation of some setup and input functions. Without going into the details of why and explaining what is required of an on-site operator, let it be established that a man in the loop will be required for hybrid computation, at least at certain times for specific functions. This points out what a great advancement the next generation hybrid equipment will be if it possesses autopatch and other capabilities which eliminate this requirement. However, let it be noted that this man in the loop also provides a benefit, for having an expert work with the remote user can greatly increase the efficient use of the computing system.
This man in the loop however, also adds another requirement to the already established teletype and that is voice communication. Although the local expert and the remote user could communicate using the teletype, voice communication is so much more efficient between people that voice transmission will be deemed necessary.

Once analog and interface setup has been accomplished the necessary input for the analog and interface can essentially be handled entirely by the digital computer. So by giving the digital the proper input, it can in turn give the proper input to the analog and, having already provided for digital input in the teletype, the analog input has thus been satisfied also with the local expert satisfying any input requirement that the digital computer cannot satisfy.

Now we come to analog output which is a most important requirement. The main output device for an analog computer is the strip chart recorder. The strip chart recorder makes continuous X-Y recordings of any available parameter vs. time. Both the parameter amplitude scaling and the time base are selectable. Most recorders will handle up to four or eight channels of information and usually several recorders may be connected to each analog computer. The strip chart recorder is almost indispensable for analog computer utilization and is a most powerful analysis tool, so strip chart recording capability will be added to our requirement list.

It has now been established that (1) teletype, (2) voice, and (3) strip chart recording are requirements of a remote hybrid terminal. This list could be expanded to include many other capabilities which
would increase the power and flexibility of a remote terminal, however, the investigation will be limited to these basic items which are quite capable of utilizing a hybrid computer facility.

The problem has now evolved to the point that the three above mentioned signals are desired to be sent and received via a common grade telephone line. The final ingredient requiring investigation is the methods of transmitting and receiving these signals. These areas of interest will be discussed in the following chapters.

Figure 2 gives a pictorial representation of a remote hybrid terminal along with the hybrid computer center.
Figure 2.—Remote hybrid terminal and hybrid computer center
II. DESIGN CONSIDERATIONS

Voice Characteristics

In normal telephone use, the total frequency spectrum capability of the telephone line is dedicated to sending and receiving voice signals. However, in this application other signals, i.e. teletype and analog strip charts, must be sent in addition to voice. Therefore, the area of the telephone line spectrum which is dedicated to carrying voice must be limited but at the same time enough of the spectrum must be passed so as to have an intelligible voice signal.

The word "intelligible" is used here to mean easily understandable units of speech material which are complete and meaningful word phrases or sentences. Normal voice range may include frequencies as low as 100 Hz and as high as 2500 Hz but this wide range is not essential to have an intelligible signal.

Two tests were conducted to determine the required frequency spectrum for an intelligible voice signal. The first was a simple "listening" test which consisted of having five different people listen to both male and female voices which were processed through a low pass filter with cutoff frequencies of 800, 1000, and 1200 hertz (Hz). The consensus of opinion was that: (1) there was a definite deterioration of the voice when using the 800 Hz filter; (2) the 1000 Hz filter allowed good intelligibility; and (3) an improvement in intelligibility was noticed in the 1200 Hz filter over the 1000 Hz filter, but not a significant improvement.
The second test consisted of recording a phonetically balanced list of 50 words spoken by both a male and a female speaker. The term phonetically balanced implies a list chosen such that all speech sounds are represented approximately according to their frequency of occurrence in normal speech. The list of words used was obtained from "American Standard Method for Measurement of Monosyllabic Word Intelligibility." The list is given in Appendix A. The recording was then digitized at 8000 samples per second and input to a Discrete Fourier Transform program to produce the spectral mass function. The spectral mass plot will show us at what frequency we can filter the voice output without losing the dominant frequencies of the signal. The computer programs written to perform the test are listed in Appendix B.

Figures 3, 4, and 5 show the resulting power spectrum density plots for the male speaker, female speaker, and the combined male and female speakers, respectively.
Figure 3.—Power spectrum density of male voice

Figure 4.—Power spectrum density of female voice
The plot of male voice spectrum shows that most of the power lies below 800 Hz. The plot of female voice spectrum shows a higher range of power with the last significant band of power around 1000 to 1100 Hz. The composite plot dictates that a maximum frequency of 1000 to 1200 Hz is required to pass the major portion of the power of speech.

Based on the results of the two tests and keeping in mind that the amount of the telephone capability used by voice should be minimized so that we may also send teletype and strip chart data and that a cutoff frequency is not absolute, that is frequencies above the cutoff do get passed but with increasingly less power as you get further from the cutoff frequency, a 1000 Hz filter should be chosen as a minimum and, if possible, choose a 1200 Hz low pass filter for the voice signal.

Figure 5.--Power spectrum density of combined male and female voice
Teletype Characteristics

The teletype or computer display terminal provides the capability to exchange information between a computer and people. As previously discussed, a computer display terminal which has a cathode ray storage tube, graphics capability in addition to alphanumerics, and a hard copy unit is desired. A terminal which meets these requirements and will be used as the basis for this research is a Tektronix 4012 computer display terminal.

The terminal sends information to and receives information from the computer by means of coded plus trains. These trains consist of binary voltage levels, with one level referred to as a mark and the other level as a space. A group of these marks and spaces represent a character such as alphabetic or numeric. Figure 6 shows a typical group of marks and spaces which are required to be transmitted to and from the computer and terminal. The voltage levels that represent the marks and spaces are arbitrary but they could be, for example, +20 volts for a mark and -20 volts for a space. The pulse width, \( \Delta t \), in seconds, is a function of the signaling speed.
These marks and spaces have a binary condition or a bi-stable quality, that is, either of two conditions may exist. In the binary numbering system, these two conditions are represented by the digits 0 and 1. These states have come to be known as "bits", short for binary digits. A bit basically carries information, that is it defines a previously unknown choice of 0 or 1, but in coded signals there are usually bits which do not carry information. These bits are used for special purposes such as parity check or character stop and start. So, looking at the above figure, there are seven character information bits plus four non-information bits for a total of eleven.

This distinction is important in defining the teletype signal to be transmitted and received on the telephone line. The important characteristics of the teletype signal which must be taken into account:
to transmit them over a telephone line are: (1) the signal is a set of

dc pulses with certain voltage levels for mark and space, and (2) the

frequency content of the signal.

The voltage levels are readily adjusted by gains and biases, so

the major consideration is the frequency content. The lower frequency

is 0 Hz or dc, for as Figure 7 shows, a continuously repeated space is

just a dc signal. To determine the upper frequency level we must

introduce a new term, baud.

![Diagram of dc Signal]

Figure 7.—A character represented by all spaces

Baud is the unit of signaling speed. The baud is found by
taking the reciprocal of the length, in seconds, of the shortest pulse
used in signaling a character. The difference between bit and baud
comes from the fact that there are non-information bits in the signal
and these may be longer or shorter in length than the information bits.
Therefore, the baud rate may be higher or lower than the bits per
second. Figure 8 shows the relationship between bauds and cycles.
This says that the highest frequency level of the teletype signal is one-half the baud rate.

Figure 8.—Relationship between baud and cycle

The Tektronix terminal is designed to operate at 110, 300, 600, 1200, 2400, 4800, or 9600 baud. This establishes a minimum frequency range of 55 Hz (0-55 Hz) for 110 baud half duplex teletype operation. As stated in the assumptions, full duplex operation is required for the computing system. Therefore, the system must be designed to send and receive two 0-55 Hz signals simultaneously as a minimum requirement. If a higher baud rate is desired, this will increase the frequency range of the signals. For example, 300 baud would require two 0-150 Hz signals.

Strip Chart Recording Characteristics

Analog computers represent physical quantities as voltages with the magnitude of the voltage corresponding in some known way to the
magnitude of the physical quantity. When an analog computer solves a problem some means of making a permanent record of the solution is required. This is accomplished by means of a strip chart recorder.

Figure 9 shows an example of a strip chart recorder output.

![Strip chart recorder output](image)

The recorded signal could, for example, represent the velocity of a car which starts at zero, increases to 60 ft./sec, and decreases back to zero. The time base marks off seconds but could be other units in place of time as so required and programmed.

The signal is a time varying dc voltage which may contain frequency components from 0 Hz to many hundreds of Hz. However, the strip chart recorder has a full width frequency limit of approximately 50 Hz. So this establishes the maximum range of analog signals which we will need to transmit. Again the voltage levels are easily adjusted by gains and biases before sending and after receiving.
Telephone Line Characteristics

The reasons for choosing common grade telephone lines as the media for transmission were noted earlier. Now the characteristics of this media must be examined, for these characteristics define the limitations within which the system must be designed.

There are many transmission impairments which may affect data transmission. The most common of these impairments is distortion. Distortion occurs when attenuation or delay varies as a function of frequency. Attenuation refers to a loss of amplitude or power and delay refers to a time shift in the signal. Table 2 lists end office to end office frequency response data. This data represents attenuation distortions relative to 1000 Hz with positive values representing more loss. The loss due to local loops which must be added to this data is typically less than 10 dB at 1000 Hz and approximately 3 dB difference between 600 and 2750 Hz. The data in Tables 2 and 3 is taken directly from Bell System Data Communications PUB 41005, "Data Communications Using the Switched Telecommunications Network".

Table 3 gives the delay distortion for end office to end office respective to 1700 Hz when delay distortion is at a minimum. The local loop delay distortion is insignificant when compared to this data and, therefore, may be ignored.

Another impairment is nonlinearities which are caused by certain transmission techniques used by the telephone company. These include suppression in amplifiers, non-linear elements in companders, and foldover distortion and quantizing in pulse code modulated (PCM)
TABLE 2

FREQUENCY RESPONSE IN dB RELATIVE TO 1000 Hz

<table>
<thead>
<tr>
<th>Frequency Hz</th>
<th>Short Mean</th>
<th>Short Std. Dev.</th>
<th>Medium Mean</th>
<th>Medium Std. Dev.</th>
<th>Long Mean</th>
<th>Long Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>200*</td>
<td>11.4</td>
<td>5.1</td>
<td>13.7</td>
<td>4.5</td>
<td>12.4</td>
<td>5.0</td>
</tr>
<tr>
<td>250</td>
<td>6.4</td>
<td>2.7</td>
<td>8.0</td>
<td>3.7</td>
<td>6.8</td>
<td>3.1</td>
</tr>
<tr>
<td>300</td>
<td>4.0</td>
<td>1.9</td>
<td>4.8</td>
<td>2.8</td>
<td>4.0</td>
<td>2.1</td>
</tr>
<tr>
<td>400</td>
<td>2.2</td>
<td>1.4</td>
<td>2.8</td>
<td>2.2</td>
<td>2.0</td>
<td>1.4</td>
</tr>
<tr>
<td>600</td>
<td>0.9</td>
<td>0.9</td>
<td>1.6</td>
<td>1.9</td>
<td>1.2</td>
<td>0.8</td>
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<tr>
<td>800</td>
<td>0.4</td>
<td>0.5</td>
<td>0.7</td>
<td>0.5</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>1200</td>
<td>0.1</td>
<td>0.3</td>
<td>-0.3</td>
<td>0.4</td>
<td>-0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>1400</td>
<td>0.0</td>
<td>0.6</td>
<td>-0.3</td>
<td>0.6</td>
<td>-0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>1700</td>
<td>0.3</td>
<td>0.9</td>
<td>0.1</td>
<td>0.8</td>
<td>0.2</td>
<td>0.8</td>
</tr>
<tr>
<td>2000</td>
<td>0.8</td>
<td>1.1</td>
<td>0.8</td>
<td>1.1</td>
<td>0.7</td>
<td>1.0</td>
</tr>
<tr>
<td>2300</td>
<td>1.4</td>
<td>1.3</td>
<td>1.4</td>
<td>1.4</td>
<td>1.7</td>
<td>1.4</td>
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<td>2450</td>
<td>1.8</td>
<td>1.5</td>
<td>2.0</td>
<td>1.6</td>
<td>2.4</td>
<td>1.7</td>
</tr>
<tr>
<td>2750</td>
<td>3.5</td>
<td>2.5</td>
<td>4.1</td>
<td>2.2</td>
<td>4.7</td>
<td>2.3</td>
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<tr>
<td>2850</td>
<td>4.4</td>
<td>3.0</td>
<td>5.4</td>
<td>2.6</td>
<td>6.1</td>
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<td>3000</td>
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<td>4.1</td>
<td>8.1</td>
<td>3.6</td>
<td>9.2</td>
<td>4.3</td>
</tr>
<tr>
<td>3100</td>
<td>9.0</td>
<td>5.9</td>
<td>10.6</td>
<td>4.7</td>
<td>11.6</td>
<td>5.2</td>
</tr>
<tr>
<td>3200*</td>
<td>12.9</td>
<td>8.0</td>
<td>14.7</td>
<td>6.8</td>
<td>15.2</td>
<td>6.6</td>
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<td>3300*</td>
<td>17.6</td>
<td>10.0</td>
<td>20.0</td>
<td>8.0</td>
<td>19.8</td>
<td>7.6</td>
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<tr>
<td>3400*</td>
<td>21.2</td>
<td>9.8</td>
<td>24.4</td>
<td>6.4</td>
<td>25.1</td>
<td>6.1</td>
</tr>
</tbody>
</table>

*Distortion values at these frequencies are at least as great as shown.
**TABLE  3**

ENVELOPE DELAY DISTORTION IN µSEC WITH RESPECT TO 1700 Hz

<table>
<thead>
<tr>
<th>Frequency Hz</th>
<th>Short</th>
<th>Medium</th>
<th>Long</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Std. Dev.</td>
<td>Mean</td>
</tr>
<tr>
<td>200*</td>
<td>4580</td>
<td>2461</td>
<td>7526</td>
</tr>
<tr>
<td>250*</td>
<td>3384</td>
<td>1727</td>
<td>5866</td>
</tr>
<tr>
<td>300</td>
<td>2816</td>
<td>1407</td>
<td>4884</td>
</tr>
<tr>
<td>400</td>
<td>1695</td>
<td>930</td>
<td>3413</td>
</tr>
<tr>
<td>600</td>
<td>656</td>
<td>430</td>
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<td>800</td>
<td>290</td>
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<td>2000</td>
<td>50</td>
<td>62</td>
<td>36</td>
</tr>
<tr>
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<td>152</td>
<td>122</td>
<td>226</td>
</tr>
<tr>
<td>2450</td>
<td>248</td>
<td>159</td>
<td>363</td>
</tr>
<tr>
<td>2750</td>
<td>485</td>
<td>276</td>
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<tr>
<td>3400*</td>
<td>1935</td>
<td>1277</td>
<td>4040</td>
</tr>
</tbody>
</table>

*A significant percentage of connections were not measurable at these frequencies.*
systems. Data systems with line speeds less than 2400 baud are usually unaffected by the nonlinearities normally encountered. If high baud rates are to be used, one must limit the power outside the 0 to 4000 Hz baud and avoid designs which generate high signal levels at certain input frequencies within this band to avoid the nonlinear distortion caused by PCM systems. Also, amplitude modulation should not be used for data transmission since the design of the companders used in the telephone system does not allow them to follow rapid changes in signal power.

Due to impedance irregularities along a transmission line or at its end, a portion of the originating signal is reflected back to the originating end. This phenomenon is commonly called echo. In fact the echo towards the originating end may itself be reflected back towards the receiving end. The first echo is not a problem for data transmission since the sending station is not trying to receive signals at the same frequency as it transmits. The secondary echo could be a problem if the delay and amplitude of this signal is sufficiently high but normally it is not. In fact, the real problem to data transmission is not the echo itself but the suppression of the echo by the telephone company to produce a higher quality of voice transmission. On long distance trunks when a signal in one direction is sensed a high loss is inserted in the return line to prevent transmission in the other direction, thereby eliminating the echo. This feature prohibits rapid changes in direction of transmission and prevents full duplex operation which is required for this application. Fortunately, a provision for disabling the echo suppressors is provided. The disabling occurs when
power in the 2010 to 2240 Hz band is transmitted with no significant power outside the band for at least 400 milliseconds. After being activated, the echo suppressor disable continues to operate as long as there is uninterrupted signal power in the 300 to 3000 Hz band in either direction of transmission.

In general, noise is not a significant problem in data transmission over the Direct Distance Dialing (DDD) telephone system. The received signal to noise ratio is high enough so that the noise does not interfere with signal detection. However, impulse noise can cause unsatisfactory performance. Impulse noise is characterized by relatively short bursts of high amplitude. Most impulse noise originates in switching equipment. At this time, most switching systems are adequate for data transmission, however, there are a few switching systems which are not satisfactory for data transmission. When this condition is encountered, the problem may be circumvented by use of a remote exchange line to connect to a different switching system. The course of action to follow, to insure that the local loop, including switching systems, is adequate for the desired data transmission, is to use a Data Access Arrangement (DAA) service. The DAA, when leased from the telephone company for a nominal fee, will be engineered to meet data transmission objectives.

The local loop conditioning provided by the DAA is available in three types. These three types provide combinations of manual and automatic operation in addition to different levels of conditioning determined by the type of data transmission desired.
A final consideration is transmission path. Due to automatic switching equipment, consecutive calls between two given stations may be connected by very different paths. The different paths may cause considerable variation in transmission characteristics. If an unsatisfactory connection is made due to this problem, the only alternative, using the switched network, is to replace the call. Other factors being satisfactory, this should correct the problem.

Examining Table 2, frequencies from 600 to 2300 Hz can be used without experiencing excessive attenuation of the signal. Table 3 shows the envelope delay distortion to be minimal in this range also. In general, envelope delay distortion is not a problem for data rates below 300 baud. Thus, it has been determined that the band from 600 to 2300 Hz may be used for transmitting our teletype and strip chart signals.

Transmitter and Receiver Techniques and Characteristics

The signals which must be transmitted to and from a remote site have been defined in the previous sections. The transmission medium has also been defined. In this section methods of transmitting and receiving these signals will be examined.

The voice, strip chart and teletype signals which must be transmitted can be called baseband signals. If all baseband signals were just combined and transmitted there is no way to recover the individual signals after receiving them since all the signals contain some of the same frequencies. Also, those parts of the baseband
signals lying outside of the band pass range of the telephone line would be lost.

The voice signal may, of course, be transmitted directly since the band pass of the telephone line is sufficient for the frequencies of the voice signal. The analog signal, 0-50 Hz, and teletype signal, 0-55 Hz for 110 baud, lie entirely below the minimum telephone limit. These signals must be relocated into the band pass area, 600-2300 Hz, before transmission by modulation and recaptured after reception by demodulation.

Modulation is the technique of modifying one signal called the carrier as a function of another signal called the baseband. This modified carrier is then transmitted and after received, the baseband is recovered by demodulation. Carriers in the 600-2300 Hz range should be chosen for the analog and teletype signals.

There are three basic types of modulation, they are amplitude, frequency and phase modulation. As discussed in the section on telephone characteristics, common grade telephone lines are not suited for amplitude modulation because of the characteristics of the compandors found in the telephone network. Phase modulation techniques provide higher baud rates than frequency modulation but are also more complicated and expensive. Also, the objective is to send several different signals not to send one signal at a high baud rate. Frequency modulation systems are reasonably simple and inexpensive, provide good performance and versatility and is the most widely used technique for low speed data transmission. For these reasons, the attention will be focused on this technique.
Frequency modulation is the technique of changing the frequency of the carrier signal from some reference frequency, called the center frequency, as a linear function of the phaseband signal. Figure 10 shows an example of frequency modulation.

![Baseband Signal](image1)

![Unmodulated Carrier](image2)

![Modulated Carrier](image3)

Figure 10.—Example of frequency modulation

State-of-the-art techniques in frequency modulation dictate that certain criteria be observed to assure that the baseband signal can be transmitted and recovered accurately. One of these is that the bandwidth, that is the maximum range of the carrier around the center frequency, be at least twice the maximum frequency of the baseband signal. Another requirement is that the bandwidth of the carrier divided by the center frequency be no less than four percent.

Since several signals are being sent at the same time some form of multiplexing must be used. Multiplexing is combining the signals
before transmission and separating these signals once they are received. Frequency division multiplexing accomplishes this by assigning each carrier a slot on the frequency spectrum with no overlapping of signals. These signals are then summed together and transmitted. When this total signal is received, it is passed through bandpass filters, that is, devices which accept as input signals which contain many frequencies but output only that portion of the total signal which falls within certain frequency limits. These bandpass filters are tuned to those slots of the frequency spectrum where the carriers were assigned.

State-of-the-art filter design requires that center frequencies of adjacent slots be separated by two times the bandwidth of the widest carrier slot. This is done to guarantee that all frequencies outside of the slot are reduced in strength by the filter to a level where they do not interfere with the desired signal. Bandpass slots must be separated two and one-half to three times their bandwidth from low pass filter cutoff frequencies since low pass filters have less steep rolloff characteristics.

Special Considerations

The major requirements and limitations have now been defined. These provide a framework within which the system must be designed. A few other problems which must be considered in the design will now be noted.

One problem in that the telephone system limits the power which may be transmitted through a line. This power limitation works out to
be approximately .35 volts into a 600 ohm resistance at the originating phone. This limitation requires that we provide a gain adjustment on the output amplifier of our multiplexer.

Another problem is that of voice feedback to the sending station. When one person talks the voice is not only received by the party at the other end but it is also picked up by his own receiver. To combat this problem of having your own voice amplified and played back at you, a local voice nulling circuit must be employed. Figure 11 shows a schematic of one technique for solving this problem. The talkers voice, in addition to being transmitted, is inverted and summed with his received signal thereby nulling out his own voice.

![Figure 11.—Technique for nulling voice feedback](image)

Another consideration involves teletype operation. Providing remote teletype operation has been discussed but it is also desirable for the local expert to have access to the computer system via teletype. It is desirable for both local expert and remote user to be able to
input to the system and receive output. This will allow the expert to monitor the users direction and allow the expert to instruct and demonstrate directly. Both receiving the computer output is not a problem since both may be tied to the computer data signal. Both may not be tied simultaneously to the computer input, so a switch must be provided at the computer center to select the remote or local teletype for computer input.

The computer interface must also be considered. Only data is required to be sent over the telephone line but additional signals, beside data in and data out, are required for the computer to work properly. These additional signals are ground, clear to send and character ready. The detail as to what these signals are and how they are generated will not be discussed since they, along with their interface connector, are standardized (Electrical Industry Association document RS232-C) and the techniques envolved are well known as all computer data sets must provide them.

A final consideration is the required interraction of the three signals, teletype, voice and stripchart data. The teletype is used for both input and output, both during setup and an actual computer run, therefore teletype capability must be provided at all times. Voice is required during setup but not during an actual run. Stripchart data is transmitted only during an actual run. This says that voice and stripchart data are not required simultaneously. This, in turn, says a voice- stripchart switch may be installed which will give teletype and voice in one position and stripchart data in the other position.
This will allow a wider bandwidth for sending voice or stripchart data compared to trying to allow transmission of all three signals at all times.
III. SUMMARY AND CONCLUSION

A summary of the major considerations of the previous chapter follows:

(1) One thousand to 1200 Hz requirement for voice signal

(2) Two teletype signals, each 55 Hz minimum

(3) Fifty Hz maximum for each stripchart channel, as many as possible

(4) Six hundred to 2300 Hz band for data, 2010 to 2240 Hz echo suppressor disabling signal

(5) Carrier signals require a bandwidth of twice the highest frequency of their associated base band and a bandwidth at least .04 times their center frequency

(6) The multiplexer requires a twice the bandwidth separation between center frequencies of two bandpass slots and a two and one-half to three times the bandwidth separation of a band pass slot from the cutoff frequency of a low pass slot.

(7) Special consideration noted in last section of previous chapter.

The following two diagrams show the recommended design to satisfy items (1) through (6) above. Figure 12 is the voice teletype frequency allocation. Figure 13 is the stripchart data - teletype frequency allocation.
Figure 12.—Voice - teletype frequency allocation

Figure 13.—Stripchart data - teletype frequency allocation
Figure 12 shows that the voice signal low pass cutoff has been placed at 1200 Hz. To minimize interference, the two teletype signals were placed near the high end of the telephone band pass range but the 2200 Hz maximum signal is still on the conservative side of our 2300 Hz design limit. The 150 Hz bandwidth of our teletype channels is greater than the required minimum of 110 Hz for a 110 baud signal. The separation of the two teletype channels is set at the required twice the bandwidth figure of 300 Hz. The separation of the lower teletype channel and the voice rolloff frequency is 625 Hz, greater than the required 450 Hz separation. The 150 Hz bandwidth of the teletype channels exceeds the required minimum of .04 times their center frequency or 85 Hz worst case. Notice that the higher frequency teletype channel lies totally and exclusively in the 2010 to 2240 Hz echo suppressor disabling signal range and may therefore be used as a disabler when required.

In Figure 13, the teletype channels are, of course, located the same as Figure 12. The placement of the stripchart channels can start no lower than the 600 Hz lower design limit and may be placed no higher than the required separation from the lower teletype channel which is two times 150 Hz or 300 Hz. This makes the upper limit 1825 Hz minus 300 Hz or 1525 Hz. Therefore the stripchart data allocation has a range of 600 to 1525 Hz. Due to the bandwidth and separation requirements there is a tradeoff in the bandwidth of each stripchart channel and the total number of channels which can be allocated in this range. It was decided to reduce the maximum stripsignal frequency from the
recorder limit of 50 Hz to 30 Hz since this upper range is seldom used anyway and this reduction will allow eight channels of stripchart data in the 600 to 1525 Hz range if assigned as shown in Figure 13. This allocation meets the required separation of channels and the minimum bandwidth to center frequency requirement, worst case.

This design well provides the essentials for remote hybrid computing. It does so within the limitations of one common grade telephone line and the state-of-the-art techniques for frequency modulation and multiplexer design. The techniques used are well known, relatively inexpensive and reliable. This design and related concepts certainly show the feasibility of opening the world of hybrid computation to the remote user and is a step towards a better utilization of the limited availability but powerful computational capability of hybrid computers.
## APPENDIX A

**Phonetically Balanced Word List**

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APPENDIX B

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**Computer Programs:**

```c
PROGRAM TO CREATE VOICE POWER SPECTRUM PLOTS FROM VOICE DATA INPUT TAPE

COMMON /ARRAY1/W(5)/ARRAY2/X(5)/ARRAY3/B(8000)/ARRAY4/
   *A(8820), C(8000)
EXTENDED TITLE(6)
EXTENDED XANOT(9), YANOT(25)
DATA B/8000=0,0/
DATA XANOT/1HF, 1HR, 1HE, 1HQ, 1HU, 1HE, 1HN, 1HC, 1HY/
DATA YANOT/1HF, 1HR, 1HA, 1HC, 1HT, 1HI, 1HO, 1HN, 1H , 1HO, 
   *1HF, 1H , 1HA, 1HV, 1HE, 1HR, 1HA, 1HG, 1HE, 1H , 1HP, 1H0, 1HW, 
   *1HE, 1HR/
DATA TITLE/1H1, 1H0, 1H1, 1H1, 1H1, 1H1, 1H2/
K=0
L=0
GO TO 10
5 CONTINUE
K=0
CALL REPTP
10 CONTINUE
CALL REDTP
CALL PK32F7(A(21), 8000)

ASSEMBLY

```

```c
XST X2SV, 2
XCS =4000, 2
REP ECA A+4021, 2
EST C+4000, 2
EROT 16
EST C+8000, 2
XJT REP, 2, 1
XCS =8000, 2
CON RM /C+8000, 2
LDAE =0
CA C+8000, 2
EST C+8000, 2
XJT CON, 2, 1
XCA X2SV, 2
J 20S
X2SV BSS 1
```
FORTRAN

20 CONTINUE
DO 30 I=1,4000
M=2*I-1
N=2*I
B(M)=B(M)*C(I)
B(N)=B(N)*C(I*4000)
30 CONTINUE
K=K+1
IF(K,NE,50) GO TO 10
CALL FURY(8000,3)
L=L+1
40 CALL PLOTS(13,,10,,0,1)
CALL PLOT(1,,1,,=3,0)
CALL SCALE(B(1),8,0,4001,1,10,0)
CALL LINEWT(-1)
CALL AXIS(0,0,XANOT=9,10,0,0,400,10,0)
CALL AXIS(0,0,YANOT,25,8,0,90,B(4002),B(4003),10,0)
A(1)=0,0
A(2)=1,0
A(4002)=0,0
A(4003)=400,
DO 100 I=3,4001
A(I)=A(I-1)+1,0
100 CONTINUE
CALL LINECC(A(1),B(1),4001,1,0,0)
CALL PLOT(10,0,3,0)
CALL PLOT(10,8,2,0)
CALL PLOT(0,8,2,0)
CALL LINEWT(0)
DD=1,0
DO 555 I=1,9
CALL PLOT(DD,0,3,0)
CALL PLOT(DD,8,2,0)
555 DD=DD+1.
EE=1,
DO 556 I=1,7
CALL PLOT(0,EE,3,0)
CALL PLOT(10,EE,2,0)
556 EE=EE+1.
M=(L-1)*2+1
CALL SYMBOL(5,8,5,2625,TITLE(M),0,2)
CALL PLOT(0,0,999,0)
IF(L,EQ,3) GO TO 101
IF(L,EQ,2) GO TO 102
WRITE(9,300) (B(I),I=1,4001)
300 FORMAT((F20,7))
DO 301 I=1,8000
301 B(I)=0,0
REWIND 9
K=0
GO TO 10
102 L=L+1
READ(9,300) (A(I),I=1,4001)
DO 103 J=1,4001
B(J)=B(J)+A(J)
103 CONTINUE
GO TO 40
101 CALL NTRAN(3,9,0,0,0,0)
ENDFILE 3
REWIND 3
CALL EXIT
END

1 C SUBROUTINE TO READ AND
2 C REPOSITION INPUT TAPE
3 C
4 REDTP REL
5 ENTRY REPTP
6 COMMON ARRAY4
7 A BSS 6820
8 C BSS 8000
9 RESUME
10 PZE **
11 IOW ,RDB
12 ARG PNTR1,,GU1
13 J 0,6
14 PNTR1 ARG A,,4020
15 REPTP PZE **
16 IOW ,REP
17 ARG PNTR4,,GU1
18 J 0,6
19 PNTR4 DATA 1/0
20 END

20
SUBROUTINE TO REARRANGE WORD

FORM FROM INPUT TAPE FORM TO
FORM REQUIRED FOR PROGRAM USE

CALL PK32F7(IADC,SIZE)
CALL PK32T7(IADC,SIZE)
ENTRY PK32T7,PK32F7

PK32T7
REL

CALL PK32F7(IADC,SIZE)
RETURN

GET SIZE

PACK TO LHW

PACK FROM LHW

PACK FROM RHW

RETURN
SELECTED BIBLIOGRAPHY


