BINARY DATA TRANSMISSION
GENERAL DESCRIPTION OF DATA AND ITS TERMINOLOGY

1. INTRODUCTION

1.01 This section is intended to give a general idea of what data transmission is and an acquaintance with some of the terms. There is a companion Section 972-055-100 which is a compendium of data terms and description of the various voice bandwidth data service offerings.

2. DATA TRANSMISSION

What Is Data Transmission?

2.01 "Data" is the plural of the old Latin word "datum" and means facts or information. The transmission of this information covers the entire communications field.

2.02 The transmission of data goes back many years. Primitive tribes have long used drums. The Indians used to transmit data by smoke signals. Later, semaphores, flags, cannons and heliographs were used. Still later came the telegraph, telephone and radio.

What Form Does Data Transmission Take?

2.03 The data with which this section is concerned will be in the form of ***binary digits. Binary*** means one of two; digit comes from the Latin "digitus," for finger, and has come to mean any one of the numerals from 0 to 9. In the data we are concerned with only two digits are used, "0" and "1." It has become convenient to refer to binary digits as ***bits,*** a combination of the first two letters in ***bi***nary and the last two in digi***ts.***

2.04 Table 1 compares binary numbers with decimal numbers. It is apparent from the data given in Table 1 that the representation of numerical quantities in the binary system involves the use of greater numbers of digits than are necessary to represent the same quantity in the decimal system. For example, the quantity, 1000, requires the use of 10 digits in the binary system and only 4 in the decimal system. On the other hand, the use of the decimal system requires the handling of 10 different symbols, i.e., 0, 1, 2, 3, 4, 5, 6, 7, 8, 9 while the use of the binary systems requires only two, 0 and 1. It can be seen, therefore, that if a binary man and a decimal man are to work an arithmetical problem in a comparable time the binary man must handle digits much faster than the decimal man.

2.05 We all have had some real experiences in helping our children with homework in arithmetic. From these experiences one gets the opinion that a good mathematician is one who has the ability to recognize and remember numerous symbols. Furthermore, out of these experiences one comes to the conclusion that the speed with which a person can make a repetitive computation depends primarily upon the number of digits that have to be handled in the operation—hence

DECIMAL NUMBERS VS BINARY NUMBERS

DECIMAL NUMBER	BINARY NUMBER	NO. OF DIGITS DECIMAL	NO. OF DIGITS BINARY
0	0	1	1
1	1	1	1
2	10	1	2
3	11	1	2
4	100	1	3
5	101	1	3
6	110	1	3
7	111	1	3
8	1,000	1	4
9	1,001	1	4
10	1,010	2	4
100	1,100,100	3	7
1,000	1,111,101,000	4	10
10,000	10,011,100,010,000	5	14
100,000	11,000,010,010,100,000	6	17
1,000,000	11,110,100,001,001,000,000	7	20

TABLE 1

the general use of number bases larger than 2. The opposite is true in the modern computer since these machines are limited in their capacity to recognize different symbols or digits. However, they can, very rapidly, handle large numbers of digits that they can recognize.

2.06 The limited digit recognition ability of modern computers stems largely from the limitation of their many electrical components. It is fairly easy to design and construct a computer which is capable of rapidly recognizing either of two conditions, however, as the number of conditions are increased beyond two the cost of the computer increases far in excess of a linear relationship for comparable speeds of operation. It is for this reason that most computers are designed on the basis of the binary system.

2.07 It is perhaps well to consider just how one sends information over a circuit by use of two digits, 0 and 1. This is where coding comes in. A typical example of coding is when you buzz for your secretary. Suppose you buzz once, (a mark) the secretary knows that this means "Please come in." If you buzz twice, (two marks) she understands that this means "Please pick up my telephone." This is, of course, a relatively simple code.

2.08 One of the earliest transmissions of data goes back to the Morse code. In this code the various characters require different lengths of time to transmit, varying from a single dot (mark) for the letter "E" up to longer characters such as "J" which consists of a dash (space), a dot, a dash and another dot. This code was worked out on the principle of assigning the simplest signals to the most used letters of the alphabet, the most complicated to the least used.

2.09 Another type of code used in the Bell System is the teletypewriter code. In its simplest form the characters in this code may be considered as consisting of 5 selecting unit intervals of time. Each group of selecting intervals is preceded by a "start" interval of one unit length and is followed by a "stop" interval of similar length (1.42 units long in most systems). The stop is always a mark and the start a space, with the character being represented by a combination of marks and spaces in the 5 time slots between. The various combinations of the 5 selecting intervals allow the possibility of $2^5 = 32$ basic characters. Two of these characters are used, however, to shift between upper and lower case type so that a total of up to 60 characters—letters, numbers, symbols, and operations — are feasible. Table 2 shows the standard teletypewriter code.

2.10 A bit, then, is either a "0" or a "1." Going back to the Indians we could say "smoke" or "no smoke." In the original telegraph, the stylus tracing on the paper made "mark" or "space." These terms, marking and spacing, are still used in telegraphy today. They are also used to indicate the bits in data transmission, a "1" for marking and a "0" for spacing as illustrated in Table 1.

How Fast Is Data Transmission?

2.11 The Indian could consider himself lucky if he could transmit two bits per minute. Standard 100-speed teletypewriter systems can transmit about 75 bits per second. The data systems we are concerned with here are required to transmit hundreds of bits per second. One important source of these signals is the electronic computer. This has been labelled by some, the electronic brain. It really is only an electronic idiot since it can't do any original thinking. All it can recognize is "1" or "0"; yes or no; mark or space; off or on. It can recognize and make use of these bits of information at a very rapid rate.

How Is Speed Affected by the Telephone Line?

2.12 Telephone lines are limited in bandwidth. That is to say, there is a certain band of frequencies which the line will transmit but it will not transmit those higher or lower than the band. If you have bass and treble tone controls on your radio or hi-fi set you can demonstrate band limitation to yourself by turning these controls to their lowest point. The highs and lows will be reduced in volume and the set will sound mushy or distorted.

2.13 The effect of reducing bandwidth on data circuits can be compared to having a narrow bridge to drive a flock of sheep across. With

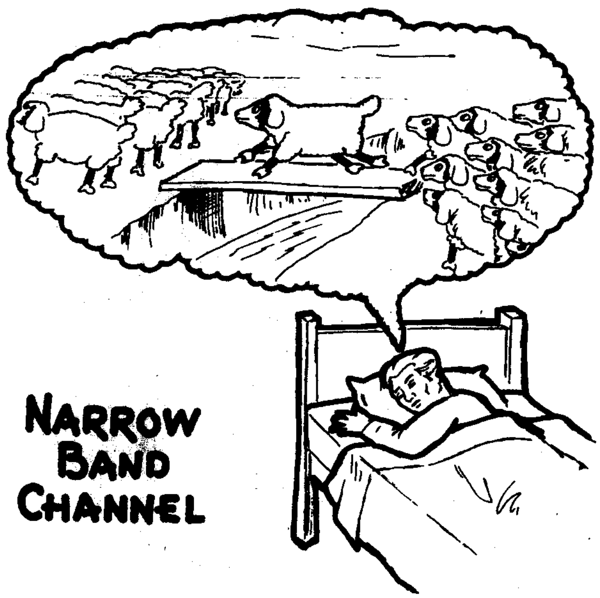
TELETYPEWRITER CODE

LOWER CASE	UPPER CASE	1	2	3	4	5
A	-	M	M	S	S	S
B	5/8	M	S	S	M	M
C	1/8	S	M	M	M	S
D	$	M	S	S	M	S
E	3	M	S	S	S	S
F	1/4	M	S	M	M	S
G	&	S	M	S	M	M
H	STOP	S	S	M	S	M
I	8	S	M	M	S	S
J	,	M	M	S	M	S
K	1/2	M	M	M	M	S

LOWER CASE	UPPER CASE	1	2	3	4	5
L	3/4	S	M	S	S	M
M	.	S	S	M	M	M
N	7/8	S	S	M	M	S
O	9	S	S	S	M	M
P	0	S	M	M	S	M
Q	1	M	M	M	S	M
R	4	S	M	S	M	S
S	BELL	M	S	M	S	S
T	5	S	S	S	S	M
U	7	M	M	M	S	S
V	3/8	S	M	M	M	M

LOWER CASE	UPPER CASE	1	2	3	4	5
W	2	M	M	S	S	M
X	/	M	S	M	M	M
Y	6	M	S	M	S	M
Z	"	M	S	S	S	M
LINE FEED		S	M	S	S	S
SPACE		S	S	M	S	S
CAR. RET.		S	S	S	M	S
LETTERS		M	M	M	M	M
FIGURES		M	M	S	M	M
BLANK		S	S	S	S	S

TABLE 2



the width of the flock restricted by the bridge it takes more time for a given number of sheep to pass. Likewise, a wide band circuit can handle bits at a higher rate than a narrow one.

How Is Data Applied to Telephone Circuits?

2.14 Data signals, when generated, may contain electrical energy components extending from zero frequency (dc) to several hundreds or thousands of cycles. Telephone circuits are band limited and cannot, as a rule, handle the extremely low frequencies perfectly. The data signals, then, are relocated in the spectrum to a band that can be readily transmitted. This process is called modulation. At the receiving end the reverse process, demodulation, converts the signal back to its original form. Modulation and demodulation may be performed by Telephone Company equipment or terminal equipment.

What Is the Minimum Bandwidth Required?

2.15 According to theory, the maximum practical number of bits per second that can be transmitted with "simple" data terminal equipment is about equal to twice the number of cycles per second of bandwidth available. That is to say, for example, in a voice bandwidth transmission path basically capable of handling frequencies of a data signal from 1000 cycles per second to 2600 cycles per second (1600-cycle bandwidth) one could expect to transmit about 3200 bits per second. In practice, distortions in the modulation process and in the circuits limit the rate to somewhat less at the current state of the art. It is highly probable, however, that future developments, particularly in the area of "complex" data terminals, will permit this rate to be achieved or even exceeded (at a cost penalty, of course).

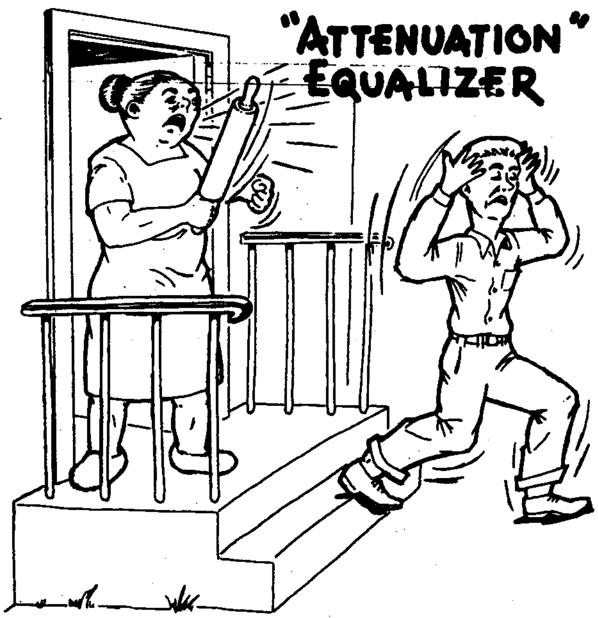
Is There a Direct Relation Between Information, Speed and Bandwidth?

2.16 We have seen that therc is a relationship between bandwidth and bits, or more accurately, signal elements per second. By spending a great deal more money for "complex" terminal equipment, more information than just a simple "on" or "off" can be sent in each signal element. Many systems, therefore, become a compromise between line and terminal costs. In addition, it is not possible to specify a telephone circuit in terms of bit rate because of the limitations due to modulation processes.

What Is All This Business About Delay and Attenuation?

2.17 Imagine that you are right in line with the starting gate at a horse race. All the nags are lined up straight as an arrow. As they run around the track some go faster than others. When they finish the race the bunch of horses no longer looks like a straight line across but like a random mob, with yours chasing all the rest. Electrical tones, like horses, don't all travel over a circuit at the same speed. This difference in speed is called delay distortion. If the terminal equipment demands that delay distortion be kept low, the circuits can be doctored up with delay equalizers.

2.18 Delay equalizers actually introduce delay or, in other words, slow up some of the tones so that they all reach the destination at the same time. This scheme would be the equivalent in the case cited above where the jockeys on the fastest nags reign them up or slow them down so that all arrive at the finish line at the same time.



2.19 Attenuation is just a two dollar word for loss. Just as your wife's voice sounds weaker as you get farther away from the house, signals over telephone lines become weaker with length. And if the different frequencies in the little woman's voice are attenuated at different rates she may not sound like the same girl from some distance. Note how different the Philadelphia Orchestra sounds over a cheap radio than in the concert hall.

2.20 Data signals may be distorted in a similar manner. Where this is important, attenuation equalizers are available to "flatten" the circuits. These attenuation equalizers flatten the circuits in a manner much similar to the reaction of the delay equalizers. In other words, they add loss to the low loss frequencies so that the loss throughout the transmitted band is the same for all frequencies. Of course, the same thing could be done by adding gain to the high loss frequencies. However, the former scheme is, in general, the more economical.

What Does the Company Have to Offer in the Line of Circuits Within the Voice Band?

2.21 Nobody wants to buy a pig in a poke. You shouldn't try to sell him one either. What follows in Section 972-055-100 is a presentation of the various grades of voice band services the Company is now offering. It would be pretty hard to include every need a user might dream up, but most of the more common are included. The section on definitions has been prepared so that you can use it as ready reference, so don't just stuff it in a desk drawer and forget it.

A Word About the Unusual

2.22 There will be times when a customer needs a channel that doesn't exactly fit the pattern. Don't let that throw you. Probably 90% of today's special services weren't even heard of twenty years ago. Someone had to be the first customer for every service in the business. Your engineers are on the payroll to help you in these cases. Use them. Don't wait too long after you hear about a special requirement.