Further Analysis of Errors Reported in "Capabilities of the Telephone Network for Data Transmission"

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(Manuscript received October 23, 1961)

The recorded error data from a field testing program reported on by Alexander, Gryb, and Nast have been further analyzed. New methods of analysis have given more information on the causes and nature of errors experienced by data in the switched telephone plant. The results obtained will enable workers in the field of error control to use the field test data more effectively. The ideas presented will be useful to designers of future field tests.

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I. INTRODUCTION

The purpose of this paper is to describe certain characteristics of errors affecting digital data in the switched telephone network. The present results are based on an analysis of error data recorded in a field testing program conducted by the Data Transmission Evaluation Task Force of the Bell System. These data are summarized in a previous paper by Alexander, Gryb, and Nast[1] which sets forth numerous conclusions about the telephone plant, based on the test program. The present paper reports the results of a sequence of statistical investigations which have made it possible to classify most of the errors into several populations. The effect of the test equipment on the time-distribution of errors is also discussed.

II. THE TASK FORCE TESTING PROGRAM

This section contains a description of those aspects of the test program which bear on the present discussion. Test calls were made by the Task Force over a wide variety of circuits. Both local and long distance calls were made over the switched telephone network and the performance of the circuits was recorded. Data concerning 1010 test calls were gathered and used for analysis. The test calls were of three categories: 10-minute calls at 600 bits/second, 10-minute calls at 1200 bits/second, and 30-minute calls at 1200 bits/second. Each of these categories was further subdivided into "Exchange Calls" which used no long distance switching facilities, "Short Haul Long Distance Calls" which were made over distances of less than 400 miles, and "Long Haul Long Distance Calls" which were made over distances of between 400 and 3000 miles.

The source of the transmitted data was a word generator which produced a sequence of marks and spaces repeating with a period of thirty bits. This word generator was used to drive an FM modulator. (The terms "mark" and "space" designate the two states of the FM channel. The convention here is that the lower of the two frequencies used is called mark and the higher is called space.) At the receiving end of the circuit, the FM signal was demodulated and compared with the output of another word generator identical to that at the transmitting end. When the output of the word generator at the receiving end agreed with the received signal, the bit was accepted as correct; when they differed, an error was noted. The two generators were kept in step by electronic clocks. The sequence of marks and spaces produced by the word generators was as follows:

SSSSMSSSSMMSMSSMMMMSMMMMSSMSSM.

The sequence of bits received correctly and bits received in error was recorded serially on a magnetic tape with two channels, as follows: The first channel contained only clock pulses, one pulse per bit. The second channel contained a pulse opposite the corresponding pulse in the first channel every time an error was noted, and was blank whenever no error occurred. The relative bit phase of the word generator, i.e., the position in the 30-bit word where the call began, was not recorded for any of the calls. The methods described below made it possible in most cases to determine whether a particular error changed a mark into a space or a space into a mark, and to determine which, if any, of the thirty positions in the test-generator word were most susceptible to errors.

The demodulator contained what is known as a zero-crossing detector, which counted the number of times the received signal crossed a neighborhood of zero. This detector delivered an output which was proportional to the number of zero crossings per unit time. A threshold was established and when fewer zero crossings were detected, a mark was scored; when more zero crossings were detected, a space was scored. Thus when no signal at all was received, the absence of signal was interpreted as a mark.

With a detector of this type, impulse noise would be more likely to add zero crossings to the received signal than to subtract them if the impulse noise were of higher frequency than the signal frequencies used in the tests. On the other hand, disturbances of lower frequency would tend to change spaces into marks by subtracting zero crossings. As it turned out, most errors caused by noise were mark-to-space errors, but the fact most important to our methods of analysis was that a single type of disturbance during a call caused one of the two types of error predominately. By a "single type of disturbance" we mean any statistically recognizable pattern of errors.

Much of the remainder of the discussion of this test program will depend on three of the properties of the system mentioned above, namely:

(1) a cyclic 30-bit word generator was used,
(2) any particular kind of disturbance on the line caused errors asymmetrically, i.e., either a majority of mark-to-space errors or a majority of space-to-mark errors,
(3) loss of signal caused all bits to be received as marks.

During some of the calls in the test program, the circuit was lost and a new attempt was made. On other occasions, the clock which kept the receiving word generator in phase got out of step, sometimes because of loss of signal. In either case, the error tape was erased and a new error recording was started from the beginning. Some of the calls encountered one or both of the above difficulties. Only the calls which were successfully completed were reported.

III. THE EFFECT OF DROPOUTS

Rather early in the study it became obvious that, in some of the test calls, errors were caused not by noise but by loss or serious attenuation ("dropout") of the received signal, often for very short periods of time.

When this occurred, all bits were received as marks and errors were recorded only when the receiving word generator produced a space. When the receiving word generator produced a mark, the bit was recorded as being received correctly even though the mark that was received was completely independent of what was transmitted. The pattern of errors recorded during such a period was:

111101111001011000010000110110,

where a 0 stands for a bit accepted as correct, and a 1 stands for a recorded error. Thus, when the line was open or for some other reason no signal was being received during the tests, 16 errors were recorded for every 30 bits transmitted. The error rate observed during a dropout is evidently dependent on the proportion of spaces transmitted, which in many systems of error control differs widely from 16 out of 30; for instance, in the so-called 2/8 code, 2 marks and 6 spaces are sent in every block of 8 bits.

Computer programs were written by the author which could detect the pattern shown above in those cases where the dropout extended over more than about twelve bits. A dropout occurring in the first nine bit-positions of the test word would have caused eight errors, and, since the computer program was adjusted so as to find dropouts causing more than five errors, this dropout would be found. A dropout which covered the sixteenth through the twenty-fourth bit-positions would not be found, since it would have caused only one error and could not be distinguished from other error-producing effects. Because of the distinctive pattern of errors, the bit phase of the word generator could easily be determined in calls with long dropouts.

IV. THE EFFECTS OF NOISE

During some test calls, the nature of the disturbances on the transmission facilities was such that there were many more mark-to-space errors than space-to-mark errors. On other test calls, the reverse was true. A computer program was written by the author which made it possible to determine which calls were of these two types and to decide the bit phase of the word generator in those cases. The exact methods by which this was done are described in Section V.

In some calls, there were ten to twenty times as many mark-to-space errors as there were space-to-mark errors. In these calls, errors did not fall on all of the mark positions with even approximately equal frequency. Some mark positions were more vulnerable to errors than others, although the vulnerable positions were not always the same in different calls. In certain calls, the average number of errors on the four exposed mark positions (a single mark between spaces) exceeded by a factor of ten the average number of errors on the remaining mark positions.

V. METHODS OF DETERMINING BIT PHASE

Three different methods were used by the author to determine the bit phase of the word generator in the test calls. None of these was effective on calls with less than about fifty errors; in fact they occasionally failed on calls with as many as several hundred errors. However, the bit phase was determined for enough calls to account for somewhat more than 65 per cent of all the errors reported in the test program.

The first method was by far the simplest. The error data were visually scanned for the characteristic pattern of a dropout. In only a few calls were there long enough dropouts for this method to produce results.

The second method used the IBM 7090 computer to divide the sequence of good bits and bits in error into consecutive blocks of thirty bits each. The positions in these blocks were numbered from 1 to 30 and the number of errors corresponding to each numbered position was totaled over all of the blocks in the call. This produced a sequence of thirty numbers such as the one in Fig. 1, which is the result actually obtained for one of the test calls, Call No. 2330; this was a 30-minute Exchange Call at 1200 bits/second. This call had a total of 678 errors, and if the errors fell randomly at each bit position, then more than half of the thirty numbers in Fig. 1 would be expected to lie in the range 19–26 inclusive. This is far from being the case, since only three of them do so. About half of the numbers are surprisingly small and most of the rest are surprisingly large. There is a wide gap between the two collections of numbers. When the relative bit phase of the word generator in this call is assumed to be that of Fig. 2, which is correct, the numbers of errors corresponding to the fourteen bit-positions of the test generator word which are marks are:

25, 31, 20, 85, 27, 40, 28, 79, 46, 55, 43, 22, 66, 44

and the numbers of errors corresponding to the sixteen bit-positions which are spaces are:

9, 1, 11, 2, 3, 8, 2, 2, 6, 4, 7, 1, 1, 6, 4, 0.

It is difficult to ignore the fact that this choice of the relative bit phase of the word generator divides the thirty numbers in Fig. 1 into two dis-

9	25	31	20	85	1	27	40	28	79	11	2	46	3	8	55	2	2	6	4	43	7	1	1	6	22	66	4	44	0

Fig. 1 — Output of computer program for call No. 2330.

9	25	31	20	85	1	27	40	28	79	11	2	46	3	8	55	2	2	6	4	43	7	1	1	6	22	66	4	44	0
S	M	M	M	M	S	M	M	M	M	S	S	M	S	S	M	S	S	S	S	M	S	S	S	S	M	M	S	M	S

Fig. 2 — Correct choice of word generator phase.

9	25	31	20	85	1	27	40	28	79	11	2	46	3	8	55	2	2	6	4	43	7	1	1	6	22	66	4	44	0
M	S	S	S	S	M	S	S	S	S	M	M	S	M	S	S	M	M	M	M	S	M	M	M	M	S	S	M	S	S

Fig. 3 — Incorrect choice of word generator phase.

tinct populations; the smallest number in the first list is 20 and the largest number in the second list is 11. Another (but erroneous) choice of the bit phase of the word generator is represented in Fig. 3. With this choice, the numbers of errors corresponding to marks are:

9, 1, 11, 2, 3, 2, 2, 6, 4, 7, 1, 1, 6, 4

and the numbers of errors corresponding to spaces are:

25, 31, 20, 85, 27, 40, 28, 79, 46, 8, 55, 43, 22, 66, 44, 0.

Two of the numbers in the second list (the 8 and the 0) seem to stand out as belonging more naturally to the first list.

Because of the pattern in Fig. 1 of four large numbers, then one small, then four large, followed after an interval of six bits by four small, then one large, then four small, the only choices of word-generator phase which make sense are those shown in Figs. 2 and 3. The choice between them is not difficult in this case. This pattern is repeated in dozens of calls; often it shows up even more clearly than in the example given here.

Calls in which there were numerous dropouts too short to be recognized by eye had an excess of space-to-mark errors. These calls were found and analyzed by the same method, but in this case high numbers corresponded to spaces.

These two methods failed to determine the bit phase in many calls which had very large numbers of errors. It was suspected that some of these calls had both short dropouts and, in addition, enough mark-to-space errors so that neither of the two kinds of error was in large excess. To handle this situation, a computer program was written which produced sequences of thirty numbers as above, but this time the first line included only the single errors, the second line included only the double errors, etc. Two examples of this presentation are given in Figs. 4 and 5. Now, errors caused by noise most commonly occurred one by one, and errors during a dropout occurred primarily in two's and four's as can be seen by reference to the test-generator word. Therefore the first line of this presentation could be scanned for any great preponderance of mark-to-space errors caused by noise, and the other lines could be scanned for evidence of short dropouts, which were also made more visible by this presentation. Many of the remaining calls succumbed to this double-barrelled attack. Fig. 4 gives an example of a call in which the errors were mostly due to dropouts, and Fig. 5 gives an example of a call in which the errors were mostly isolated mark-to-space errors.

3	1	1	2	1	2	0	1	3	2	2	(14)	2	1	3	4	2	1	2	(14)	2	1	0	3	3	1	3	2	4	3
0	0	0	1	1	0	0	2	2	1	0	0	0	(11)	1	0	0	0	0	1	0	0	1	0	(13)	0	1	(10)	1	2
0	2	1	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
(8)	0	0	0	0	(8)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	S	S	S	M	S	S	S	S	M	M	S	M	S	S	M	M	M	M	S	M	M	M	M	S	S	M	S	S	M

Fig. 4 — Output of second computer program for call No. 2249. The top line of this presentation contains the total number of isolated errors corresponding to each bit-position in the test word. The second line contains the total number of double errors corresponding to each position, with an entry made only once for each double error at the first of the two bit-positions it covers. That is, a double error on the first and second bit-positions would contribute 1 to the count in the first entry of the second line. Third and following lines are similar displays of triple errors, etc. In this, the circled entries constitute strong evidence of drop-outs.

2	3	2	1	31	0	4	1	0	21	6	0	24	0	1	17	7	4	11	0	11	7	4	6	0	0	22	0	1	26
0	0	0	2	2	0	0	0	1	5	1	0	1	0	0	6	1	5	1	1	9	1	2	0	0	0	0	0	0	1
0	0	0	1	0	0	0	0	1	2	0	0	0	0	0	1	1	0	0	0	5	1	0	0	0	0	1	0	0	1
0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	S	S	S	M	S	S	S	S	M	M	S	M	S	S	M	M	M	M	S	M	M	M	M	S	S	M	S	S	M

Fig. 5 — Output of second computer program for call No. 1607. In this call there is no evidence of any dropout, but the first line indicates many more isolated errors on the marks than on the spaces.

VI. METHODS OF FINDING SHORT DROPOUTS

Even though the last method mentioned was able to reveal short dropouts in a call, it gave no indication of their exact lengths or where they were located in the call. Another computer program was written which went bit-by-bit through each call of known bit phase, and counted up how many marks had been received out of the previous thirty bits. If no errors were recorded in the previous thirty bits this number was at all times 14. If mark-to-space errors were occurring, the number was less than 14. But, if a dropout occurred, even over a few bits, the number rose dramatically and made it clear where the dropout probably began and ended. By this method, combined with visual inspection of the original data, every dropout which caused more than five errors in any call of the test program was found, except for the remote possibility that during a dropout noise simulated the transmitted word.

Another interesting phenomenon was discovered by means of these computations; namely, that often there was a dropout during which a few spaces would be received, but there was no correlation between these spaces and the spaces actually sent by the transmitter. This indicates that on occasion, even when the line was open, there was enough noise received to simulate a space, so that some bits which were recorded as correct in the field trials were actually the result of two potential errors in the same bit-position whose effects cancelled. Short periods of time during which the transmitted signal was absent, but during which impulse noise caused several spaces to be received, are not classified as dropouts, since the resulting error patterns are not distinctive.

VII. ANALYSIS OF THE DROPOUTS

In the test calls, a total of 58 dropouts extended over more than 12 bits, and these were analyzed. Of these, none were in Exchange Calls, 3 were in Short Haul Calls, contributing 110 errors, and the remaining 55 were in Long Haul Calls, contributing 3400 errors. The longest dropout was 1129 bits long (approximately 1 second). It is estimated that dropouts lasting 12 bits or less contributed at least 1500 additional errors.

In addition to those discussed above, many dropouts occurred during the tests and were not reported because these dropouts caused a loss of synchronization between the transmitting and receiving word generators or were long enough to cause the test personnel to terminate the call. The recording of errors in these cases was abandoned and a new recording started.

It is difficult, therefore, on the basis of the reported data, to specify quantitatively the contribution of dropouts to the total error rate. This contribution was negligible in the case of Exchange Calls and Short Haul Calls. In Long Haul Calls, dropouts were a major source of error. Even after the omission of records of many dropouts, as explained above, about 10 per cent of all Long Haul Calls had one or more dropouts, and these dropouts contributed over 20 per cent of the errors in Long Haul Calls.

Since there were no dropouts in the final data on Exchange Calls, and only negligible ones for Short Haul Calls, and since a very large number of calls were made in these categories, it seems safe to assume that the causes for dropouts lay in long-distance transmission or switching facilities, or at least that these facilities formed an essential link in the chain of causes leading to a dropout.

VIII. ANALYSIS OF ERRORS DUE TO NOISE

There were 36 calls in which the bit phase of the word generator was established and in which there were no errors that could be attributed to dropouts. In these calls, the number of mark-to-space errors was slightly more than four times as great as the number of space-to-mark errors. This statement, though true, is somewhat misleading, because this was just the kind of call in which the bit phase was easy to determine. It is certain that none of the remaining calls with more than about 50 errors has any such discrepancy between the two kinds of error, or else its bit phase would have been determined. What can be deduced is that some transmission paths favored this kind of error very much.

In some calls, an abnormally high number of errors fell on those bit positions which corresponded to single marks between spaces; in others, an abnormally high number fell on the positions corresponding to marks immediately preceding spaces. These effects may have been caused by conditions on the line, such as high delay distortion; or they may have been caused by characteristics of the test equipment, as illustrated in Section IX.

IX. THE CASE OF CALL NO. 2390

Call No. 2390 was a 30-minute Long Haul Call at 1200 bits/second with 4565 errors. This call had more errors than any other call in the test program. In spite of the large number of errors, the three methods described did not reveal the bit phase of the word generator in this call. Therefore, the pattern of errors in the call was subjected to close scrutiny. It was discovered that the sequence of good bits and bits in error at the end of the call was precisely that which would be recorded if the receiving word generator were one bit out of step with the transmitting word generator. Somewhat further back in the call the pattern corresponded to the two generators being two bits out of step. This was traced back through the call step by step until finally a place was reached where the two word generators were out of step by fifteen bits. By this time, several thousand errors had been accounted for. The search was not carried beyond this point.

Evidently the bulk of the errors in Call No. 2390 were caused by a failure of the terminal equipment to keep in step. These 4565 errors make up 12 per cent of the errors observed during the entire testing program and 17 per cent of those observed in Long Haul Calls.

It does not seem justified to let these pseudo-errors contribute to the reported error rate on the telephone network. And it is certain that this call should not be used in a study of error control or of the burst structure of errors, since not only the pattern of errors but the errors themselves were caused by the nature of the test equipment and not by the characteristics of the telephone plant.

X. SOME SPECIAL RESULTS

During Call No. 1568, a Long Haul Call at 1200 bits/second, the field test personnel noted that four bursts of errors which caused a total of about 400 errors coincided with audible multifrequency keypulses. A direct inspection of these errors failed to reveal much regularity in the pattern of errors within the bursts. After the bit phase of the word generator in this call was determined, the sequence of received marks and spaces was inspected. During the four keypulses, the received signal conformed to the following four patterns, respectively:

M M M S S S M M M S S S M M M S S S
M M M M M S M M M M M S M M M M M S
M M S M M S M M S M M S M M S M M S
M M M M S S M M M M S S M M M M S S

with occasional errors superimposed, presumably arising from noise. These patterns have periods of 6, 6, 3, and 6 bits, respectively, which correspond to frequencies of 200, 200, 400, and 200 cps. These frequencies may be related to the fact that the two tones transmitted simultaneously during an MF pulse are always separated by a multiple of 200 cps.

In parts of some calls, remarkably many errors were separated by exactly 57 good bits. On investigation, these all turned out to be calls at 1200 bits/second which terminated in a few particular step-by-step central offices. Most probably, these errors were caused by some switching mechanism in the telephone plant which, when it operates, produces a 21-cps disturbance.

In Call No. 1420, a Long Haul Call at 1200 bits/second, there were four long dropouts and their lengths were 301, 302, 329, and 337 bits. The closeness of lengths of these four dropouts suggests that all of them had the same cause.

In Call No. 2429, a Long Haul Call at 1200 bits/second, there were eight long dropouts and their lengths were 33, 33, 67, 67, 94, 95, 97, and 126 bits. All of these lengths are close to being multiples of 32 bits, again suggesting a common source of the dropouts.

XI. THE ROLE OF THE TEST WORD

The choice of a cyclic word generator as the source of the transmitted data did not affect the measurement of error rate significantly. However, its characteristics were strongly reflected in the final error recordings because of the considerable contribution of dropouts to the total error rate. The fact that the length of the test word was 30, a number with many small factors, again did not affect the measurement of error rate; but if the data were used in simulation experiments — for example, to test an error-detecting code whose length was a divisor of the number 30 — the results could be biased by this choice of length of test word.

After the bit phase of many of the calls was revealed by analysis of the error recordings, it was possible to resolve the following questions:

(1) whether any particular error changed a mark into a space or the reverse,

(2) which, if any, of the 30 bit-positions were most susceptible to errors,

(3) to what extent errors were caused by dropouts, and

(4) the contribution of terminal-equipment malfunction to the observed error rate.

Using the bit phase to study the distribution of errors among the 30 bit-positions of the test word, it was discovered that the most vulnerable positions were different in different calls. It would be instructive to be able to compare these differences in vulnerability with the measured characteristics of the transmission medium. There were a number of calls in the series for which almost all of the errors fell on a single bit-position in the test word. It is not known either why this occurred or which bit position was affected, since it is impossible to determine the bit phase for such calls.

XII. RELATION TO ERROR-CONTROL SCHEMES

One of the results of this study is the knowledge that with the modulation scheme used in the testing program, the mark-to-space and space-to-mark errors were not evenly mixed with each other. For a long period of time the mark-to-space variety was more abundant by a large factor, owing to noise; at other times the reverse was true, because of dropouts, interfering tones, and the like. An error-detecting code which counts the number of marks per block is much more efficient in this situation than when mark-to-space errors and space-to-mark errors are well mixed.

For example, in the 2/8 code, which has been suggested for error detection, bits are transmitted in blocks of eight, and in every block there are exactly two marks and six spaces. A received block with more or less than two marks is detected as an error. This scheme will always detect an error condition if a single error occurs in a block. If a block contains two errors (which is likely because of the burst character of the errors) then an error condition will be detected if both errors are in the same direction but not if they are in opposite directions. Assuming that the two kinds of error are well mixed and that sent marks are four times as likely to be in error as sent spaces, we find that a double error in a block will be detected only 39 per cent of the time. The truth is that, because of the lack of mixing, a double error in a block would be detected over 90 per cent of the time by this code. During a dropout the situation is even more striking. A message using this code would experience a bit-error rate of 75 per cent during a dropout but *every one of these errors would be detected*. The relative advantage of this code and of other codes of this type would go unnoticed if the codes were evaluated by a direct simulation using the field test data.

A useful technique in studying error-control methods is the construction of mathematical models of the occurrence of errors. Several such models have been constructed using the field test data,[2,3] and have been used to study the effectiveness of error-control procedures.[4] To test the validity of such models and to evaluate the parameters used in the models, it is necessary to study the manner in which errors are distributed in time, e.g., to what extent they occur in bursts. One way of doing this is to determine the distribution of lengths of runs of consecutive errors and the distribution of lengths of runs of good bits between errors.[2] Because of the structure of the test generator word, every run of consecutive errors in the field test data during a dropout had length 1, 2, or 4 and every run of consecutive good bits during a dropout had length 1, 2, or 4. These distributions of run lengths depended only on the choice of test-generator word. Also, repetitive patterns of errors in Long Haul

Calls were often produced by causes other than dropouts. For instance, the single event described in Section IX contributed 17 per cent of all the errors in these calls, and occasions (described in Section X) when the signal was overridden by tones contributed about another 10 per cent. Thus, including dropouts, about half the errors in Long Haul Calls occurred in repetitive patterns, and these patterns reflected the nature of the test equipment and the modulation scheme rather than that of the telephone plant.

Also, when short spikes of impulse noise caused bits to be received as spaces regardless of what was transmitted, errors were recorded in the field test data only when the occurrence of a spike of noise coincided with a transmitted mark. Those which coincided with transmitted spaces were not recorded as errors. Therefore, the mean length of runs of good bits in the data is about twice the mean distance between spikes of impulse noise. If the mark-counting code described above were tested against these data, it would appear to experience twice as many errors as it would have experienced if it had been used on a real-life channel.

XIII. CONCLUSIONS

With no knowledge of the bit phase of the word generator, the only error statistics which could be reliably deduced from the field test data were the error rates themselves. With the recovery of the bit phase, the proportion of mark-to-space errors could be determined, dropouts were revealed, and certain malfunctions of the test equipment were discovered. Now a considerable amount of additional information is available about the causes and nature of errors experienced by data in the switched telephone network. This information makes the existing data more useful for simulation and analysis.

The analysis reported in this paper confirms some results of Ref. 1 and modifies some others. It is unrelated to most of the material discussed in Ref. 1. Specifically:

(1) The subject matter of this paper has no bearing on Figures 1–25 of Ref. 1.

(2) The reported error rates and the distributions of error rates by classes of calls are essentially as indicated in Figures 26–29 of Ref. 1.

(3) The time distribution of errors over large blocks (e.g., more than 50–100 bits), as shown in the right-hand portions of Figures 30, 31, 32, 34, 36, and 38 of Ref. 1, is not changed.

(4) The validity of the time distribution of errors over very short blocks, (e.g., 2–10 bits), as represented in Figures 33, 35, 37, 39

and the left-hand portions of Figures 30, 31, 32, 34, 36, and 38 of Ref. 1, has not been confirmed.

(5) The problem mentioned in (4) throws doubt on the data used to construct Figures 40–43 of Ref. 1.

The results whose validity is questioned in (4) and (5) follow from arbitrary choices made in designing the field tests. The effects of such choices are considerable and hard to evaluate. It is therefore difficult to assess the nature and extent of the changes that should be made in the figures named in (4) and (5).

Because line dropouts (and the loss of word-generator synchronization in one call) contributed significantly to the error rate, the choice of the test word influenced the time distribution of errors, as noted in (4) above. This must be considered in evaluating schemes for error correction and detection.

In most of the calls with high error rates not caused by dropouts, the errors had a distinct tendency to change marks into spaces. This also must be considered in evaluating error-control schemes.

It must also be borne in mind that the property of receiving all bits as marks in the absence of signal and the property that impulse noise usually changes marks into spaces are *not* themselves characteristics of the telephone plant, but are dependent on the particular devices used for modulation and demodulation (Ref. 1, pp. 435–6). The important point is that the methods and point of view of this paper can be applied to data obtained with any system of modulation. One cannot hope to devise a good method of controlling errors without a deep knowledge of the nature of the errors and of how the terminal equipment is affected by them.

XIV. ACKNOWLEDGMENTS

The author is indebted to R. M. Gryb and G. J. McAllister for their cooperation in making the field test data available, and to Eric Wolman for technical advice.

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