Transmission Of Digital Information over Telephone Circuits

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The problems of transmission of digital data over commercial telephone lines are studied with particular attention to transmitting telephone numbers over a wide variety of circuits. The electrical characteristics of these lines and the noise present on them are major factors which influence the design of a reliable high-speed data transmission system. A system which takes account of these factors has been designed and tested. The results of tests indicate that it operates reliably on almost all message circuits at a rate of about 650 bits per second with signals occupying the band from 700 to 1,700 cycles.

INTRODUCTION

Transmission of digital information between central offices in the same or different cities is a basic process necessary to establishing a connection between subscribers. The existing methods of employing conventional dial pulses at the rate of about 10 pulses per second, or multifrequency pulsing at about 8 digits per second are adequate when used between existing central offices. When consideration is given to the application of electronic techniques to central office switching, it becomes apparent that higher signaling speeds are desirable if not necessary.

The work reported here was carried out several years ago with the objective of selecting a method for transmitting and receiving a short coded message about 10 decimal digits in length over commercial telephone lines. The equipment should be simple and reliable, and capable of application to any commercial circuit without adjustment of the terminal equipment or the circuit itself. Transmission of digits should be at the highest speed consistent with reliable operation. In the following pages we consider the limitations imposed by the characteristics of telephone circuits and how they influence the choice of a signaling method. We then describe a reliable system which is compatible with these limitations, and the results of tests of this system. Tests with some of the newer carrier systems are not included, since they were introduced after the completion of our work.

CHARACTERISTICS OF TELEPHONE CIRCUITS

Bell System circuits which are used for the transmission of speech comprise a variety of loaded, non-loaded and carrier circuits. The characteristics of these circuits differ widely, and while they do not impair speech transmission, they do affect the transmission of high-speed digital information. Circuits designed for special purposes, such as program transmission or telephoto, will not be considered.

Non-loaded voice-frequency circuits are ordinarily short, with attenuation increasing approximately as the square root of the frequency, and have no well defined upper cut-off frequency. As they present no serious obstacles to realizing our objectives, they will not be considered further.

Loaded voice-frequency circuits are used for both local and toll service, and have well defined upper cut-off frequencies. The attenuation characteristics of a number of typical circuits of this sort are shown in Fig. 1. In the case of local circuits, the upper cut-off frequency is set by the type of loading employed, and in toll circuits by the filters used in the four-wire terminating sets or two-wire repeaters. The terminating sets are designed to function as high-pass filters. Repeating coils also limit the low-frequency response. If we define the cut-off frequencies as the half-power points, or points at which the loss is 3 db, we see that a universal system is limited by these circuits to a band from about 300 to 2,000 cycles.

When we examine the attenuation characteristics of a number of typical carrier circuits shown in Fig. 2, we find the situation somewhat better at high frequencies and worse at low frequencies. The curves A-1 and A-2 are for the channel banks used in J, K, and L carrier systems. The approximate bandwidth between the limiting curves is from 400 to 2,600 cycles. The net band available for a universal system has now been reduced to 400 to 2,000 cycles. A further reduction to 400 to 1,700 cycles is necessary on two counts. The EB channel banks, or "emergency" circuits introduced during the war to provide two voice circuits over a single broadband carrier circuit have a band of from 400 to 1,700 cycles and an appreciable number of these circuits are still in use. Phase distortion, particularly at low frequencies, further limits the useful bandwidth even though EB circuits are excluded from consideration.

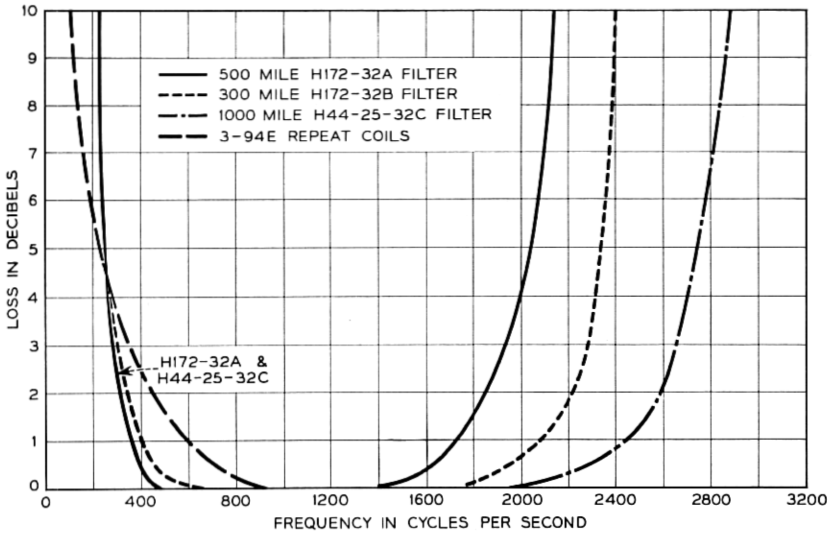

Fig. 1 — Transmission frequency characteristics of typical voice-frequency telephone circuits.

The delay distortion due to the non-linear phase characteristics of a number of typical limiting circuits is shown in Fig. 3. Since only the variation of delay with frequency is important, the curves have all been drawn to pass through the same point at a frequency of 1,000 cycles. The effect of this type of distortion depends upon the type of signal and the method of detection. The pulse distortion can be calculated,[1, 2] but it is difficult to relate pulse distortion to the performance of a particular system. We have experimentally determined that delay distortion about equal to 3 times the pulse length can be tolerated in a system of the type which we will describe below.* Inspection of Fig. 3 shows that for the delay distortion at the lower edge of the band to be equal to that at 1,700 cycles, we should fix the lower cut-off frequency at about 700 cycles. Application of the above rule of thumb indicates that pulses of about 3.9 ÷ 3 = 1.3 milliseconds could be transmitted with tolerable delay distortion. This corresponds to a data rate of about 750 bits per second, which we have experimentally found to be optimistically high for reliable operation.

The majority of carrier circuits in the Bell System employ single-side-

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* C. B. Feldman and A. C. Norwine have stated this result in an unpublished memorandum.

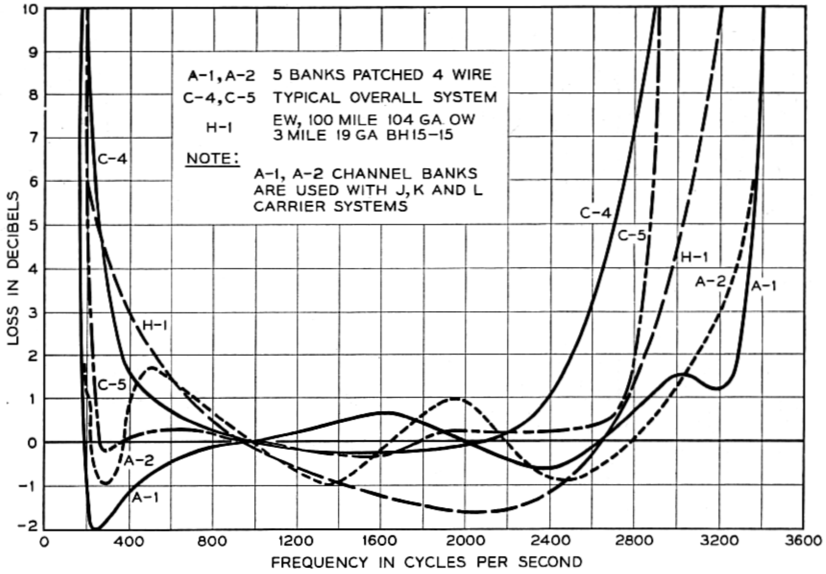

Fig. 2 — Transmission frequency characteristics of typical carrier telephone circuits.

band transmission with independent, non-synchronous carrier supplies for modulation and demodulation. The frequency difference is ordinarily only a few cycles per second, referred to the voice band, and has no noticeable effect on speech transmission. It is sufficiently great, however, to impose serious limitations on high-speed signaling. It can be shown that a signal $S(t)$ which is transmitted over such a circuit is received as

$$R(t) = S(t) \cos (\eta t + \epsilon) + Q(t) \sin (\eta t + \epsilon)$$

in which η and ϵ are respectively the radian frequency and phase difference between the two carriers. $Q(t)$ is the quadrature component which has the same amplitude spectrum as the original signal with the phases of all components shifted 90°. This shows that the structure of the received signal varies with time and this imposes another limitation on the type of signaling system which can be used. The envelope of the received signal is

$$\sqrt{S(t)^2 + Q(t)^2}$$

which is not a replica of the original signal, but is invariant with time.

Other limitations are imposed by noise, crosstalk, and echoes. The

CURVE	1000 ∿ DELAY	DESCRIPTION
1	58.64	3000 MILES 5 LINK K2 SYSTEM CHANNEL 12 PLUS 500 MILES OF 19-H-44 PLUS 6 PAIRS OF 4W TERMINAL SETS
2	53.30	1000 MILES OF 19-H-44 PLUS ONE PAIR OF 4W TERMINAL SETS
3	12.26	2000 MILES 3 LINK J2 SYSTEM CHANNEL 1 W-E JSA PLUS 3 PAIRS OF 4W TERMINAL SETS
4	22.70	200 MILES OF 19-H-174 PLUS ONE PAIR OF 4W TERMINAL SETS

TWO-WIRE VF PATCHING IS ASSUMED

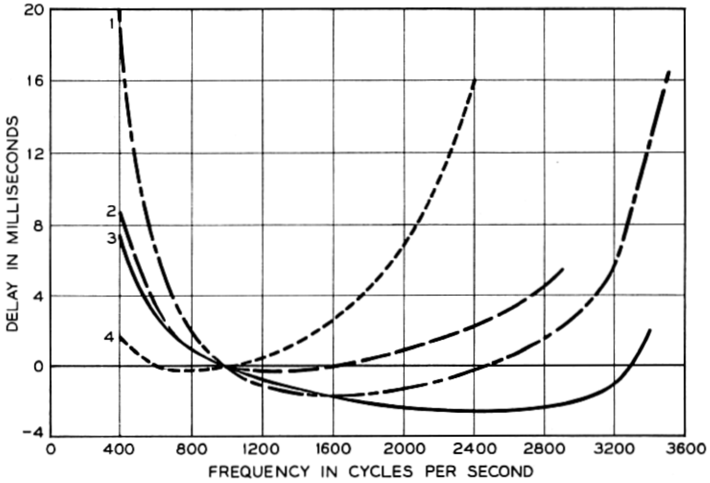

Fig. 3 — Delay distortion of typical maximum length telephone circuits.

amounts of the latter two are ordinarily small and have substantially no effect on the type of signaling system which will be described. They may be a factor in other, more vulnerable systems. We have found no adequate theoretical way of dealing with the effects of noise in a quantitative manner. In the case of thermal noise, an approximate treatment is possible, but departures from the idealized mathematical model render this treatment only approximate. The subject is best studied experimentally and will be discussed under "Results."

Another possible limitation is imposed by the use of compandors on some circuits. These devices compress the amplitude range of the signal at or near the transmitting end of the circuit and expand it, or restore it to normal, at the receiving end of the circuit. Multi-level signals might be expected to be vulnerable to this kind of treatment. The effects of compandors on relatively noise-free circuits have been studied experimentally and will be discussed under "Results."

CHOICE OF A SYSTEM

We have seen that the pass-bands of telephone systems restrict us to the use of signals whose frequency spectra lie between about 400 and 1,700 cycles, and that delay distortion considerations require that the lower limit be raised to about 700 cycles. This immediately rules out of consideration all methods of signaling which require transmission of a dc component. The obvious choice is to use a method which involves one or more modulated carrier frequencies. This is also attractive because envelope detection can be readily employed to avoid the difficulties encountered with non-synchronous carriers. Other methods which do not depend upon the precise structure of the signal within the pulse interval are possible, and have been considered both theoretically and experimentally. Such systems are generally more complex and no more reliable in the presence of noise than simple envelope detection of a modulated carrier.

The multifrequency signaling system[3] now in use for inter-toll signaling employs six carrier frequencies, in a two-out-of-five self-checking code. (Five of the frequencies are used to represent the ten decimal digits, the sixth frequency is required for supplementary signals.) For a given available frequency band, the rate at which information can be transmitted is in principle independent of the number of carrier frequencies employed. Actually there will be some reduction in speed with a multifrequency system due to wasted frequency space between bands. The amount of equipment required at the transmitting and receiving terminals increases with the number of carrier frequencies employed.

The effects of delay distortion are minimized in a multichannel system, such as voice-frequency telegraph, in which the available frequency band is divided into a number of bands each having substantially less distortion than the entire band. The average total delay in each of these narrow bands will differ from one band to another, and various parts of the message will be received at times which will differ with each type of circuit employed. In some types of systems, this may be of no importance, but generally speaking, it introduces additional complications in the equipment.

When signal elements consist of more than a single carrier frequency present at one time, care must be taken to avoid transient interference between channels. This can be adequately controlled by the use of transmitting filters, and timing in the receiver to inspect the signal after the transient has decayed to a negligible amplitude.

A system of this sort is vulnerable to "twist," or differences in attenuation of the different frequencies. Some sort of automatic volume control is required in the signal receiver, and some types accentuate the difference in amplitude of two or more frequencies applied to their inputs.

We have experimentally studied some multifrequency signaling systems and have found that they are somewhat more vulnerable to noise than a single frequency system. Multichannel systems are less vulnerable to some types of noise, but both multifrequency and multichannel systems are more complex equipment-wise than single frequency systems. We have been led to the conclusion that a single-frequency system employing envelope detection is to be preferred for high-speed systems.

We must now consider the relative merits of single sideband versus double sideband transmission. At first glance, we might consider that a single sideband system could transmit at twice the rate possible with a double sideband system. Since complete separation of sidebands is not possible when the base-band signal has a dc component it is necessary to transmit a vestigial sideband which occupies an appreciable portion of the available transmission band. Because of the effects of non-synchronous carrier systems, it is necessary that the transmitted signal be accompanied by some non-modulated carrier which is present at all times during signaling and which carries no information. Since the maximum power which can be applied to telephone circuits is limited, this results in forcing a reduction in the power of the information bearing signals, with a corresponding increase in vulnerability to noise. A vestigial sideband system requires a carefully designed filter with linear phase through the cut-off frequency as it is sensitive to delay distortion in the neighborhood of the carrier frequency.

A double sideband system requires no carrier during absence of signal, and because of the redundancy of the two sidebands, is less sensitive to amplitude and phase distortion. Considering the important case of negligible amplitude distortion, it has been shown[4] that the effective phase shift of the recovered signal is the average of the phase shift in each sideband or

$$\psi = \frac{(\varphi_+ - \varphi) + (\varphi - \varphi_-)}{2}$$

in which φ is the phase shift at the carrier frequency and φ_+ and φ_- the phase shifts in the upper and lower sidebands.

Although we have not attempted a quantitative evaluation of the relative merits of the two methods of transmission and have not made a direct experimental comparison between the two, the above considerations have led us to conclude that the double sideband system is best adapted to meet our objectives. We will restrict further discussion to such systems.

It is generally accepted that the maximum reliability in the presence of noise is obtained when a code is employed which consists of signal elements which are either present or absent. Higher signaling speeds can be obtained at the expense of noise impairment if multi-amplitude codes are employed. Since we are concerned with maximum reliability we consider only on-off types of signals.

When the complete message is short, the advantages of one code over another are not great, and the particular choice of code is usually fixed by the general objectives in view, or by equipment considerations. When information is received serially, it can be transmitted substantially as received, whereas if the message is coded as a unit, a delay equal to the length of the message is introduced in the coding process and again in the decoding process. We have elected to encode our message by decimal digits in two-out-of-five form to take advantage of the self-checking feature of this type of code.

It seems advisable to review some of the relations which must exist between carrier and sidebands if distortion is to be avoided. The carrier frequency must be higher than the highest frequency component of the base-band signal, and components of the base-band signal must not intrude upon the lower sideband. The base-band signal can be eliminated by balance in the modulator or by filtering if it is first modulated with a high-frequency carrier and then located at the desired point in the transmission band by a second process of modulation. If the carrier frequency is higher than twice the highest base-band frequency, there is no overlap and the base-band signal can be eliminated by a high pass filter. It is fortunate that the location and width of the available transmission band permit us to use the last method.

The maximum theoretical speed is obtained by postulating a signal which has a standard value at a sample point, say at the center of the signal interval and which is zero at the sample point of all other signal intervals. Since the locations of the zeroes are dependent on delay distortion, and since this differs from circuit to circuit, we cannot depend on this property to recognize the presence of a signal and a reduction in repetition rate is required. Even if the maximum speed could be obtained, the presence of noise would require that a lower rate be employed to insure reliable operation.

Ample operating margins are obtained with a pulse repetition rate equal to half the maximum theoretical rate. Higher rates can be used with increased vulnerability to noise. We believe that performance will be intolerably degraded if the repetition rate exceeds three-fourths of the maximum theoretical rate.

To minimize the effects of delay distortion, the frequency spectrum of the signal should be confined to the band in which the distortion is low. To minimize oscillations at the edges of a pulse, the cut-off should be gradual. These requirements are met by a Gaussian base-band pulse, since the frequency spectrum of such a pulse is also Gaussian. A single section low-pass filter with a nominal cut-off frequency equal to the reciprocal of twice the width of a rectangular pulse has a response to such a pulse which is a fair approximation to a Gaussian curve as shown in Fig. 4. A simple filter of this sort has been found satisfactory for this purpose. Somewhat better results have been obtained with empirically optimized pulse shapes generated by a capacitive commutator which is discussed below.

SYSTEM DESCRIPTION

A system which operates in accordance with the principles outlined above can be mechanized in many ways. One version, which was used in our experimental work, is shown in Fig. 5. The transmitter and receiver are connected to the ends of the chosen transmission facility, and the message is transmitted repetitively on a start-stop basis until a two-out-of-five check indicates that a plausible message has been received. The receiver then returns a stop signal to the transmitter and both are disconnected from the facility.

The message consists of a start and synchronize signal followed by an eight digit number, each digit of which is coded in two-out-of-five form. The number to be transmitted consists of 40 bits and is stored in a register in parallel form. It is removed from the register in serial form by a scanner and the pulses are shaped by a low-pass filter and applied to a modulator to produce double sideband carrier pulses for transmission over the line. The scanner shown in Fig. 5 consists of germanium diode gates controlled by vacuum tube ring counters.

As an alternative, a capacitive commutator was used to perform the

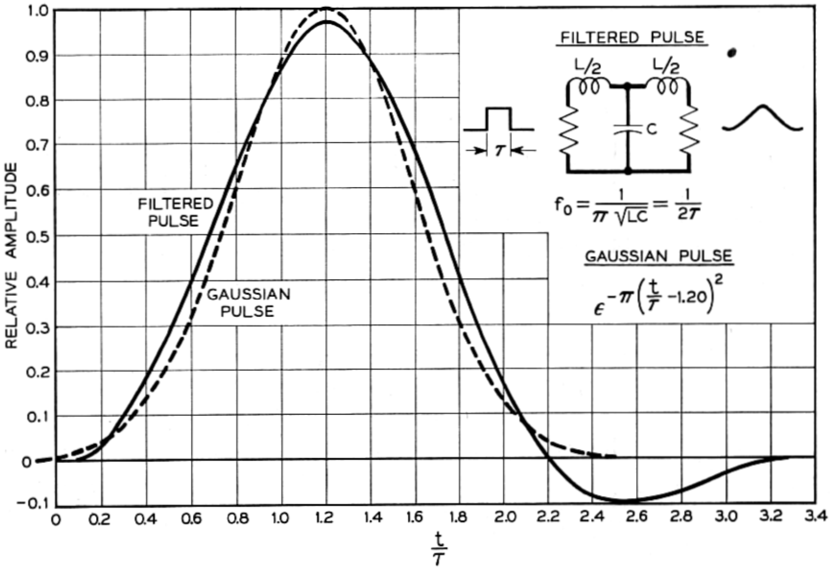

Fig. 4 — Filtered rectangular pulse and Gaussian pulse.

functions of the scanner, low-pass filter, and modulator. This device consists of two glass discs about three inches in diameter, one stationary and the other rotated just out of contact. Carrier frequency is applied to conducting segments, painted on the stationary disc, in accordance with the coded signal. The signals appear in sequence on one conducting segment on the rotating plate, which is coupled to the stationary plate with capacitive slip rings. The shape of the resulting pulses is determined by the size and shape of the scanning segment.

The received signals enter an automatic volume control circuit which amplifies and delivers signals to an envelope detector at substantially constant amplitude, over a 30-db range of inputs. The detected signal is then filtered and sliced. The start circuit recognizes the start signal and starts a start-stop oscillator upon the arrival of the synchronize pulse. The digit pulses are directed to the register by means which involve coincidence between sliced signal pulses, bit sampling pulses, and digit gating pulses.

We have employed vacuum tubes and germanium diodes as the basic circuit elements. There are many well known methods of implementing the various functions with these or other components, and consequently, we will omit detailed circuit considerations.

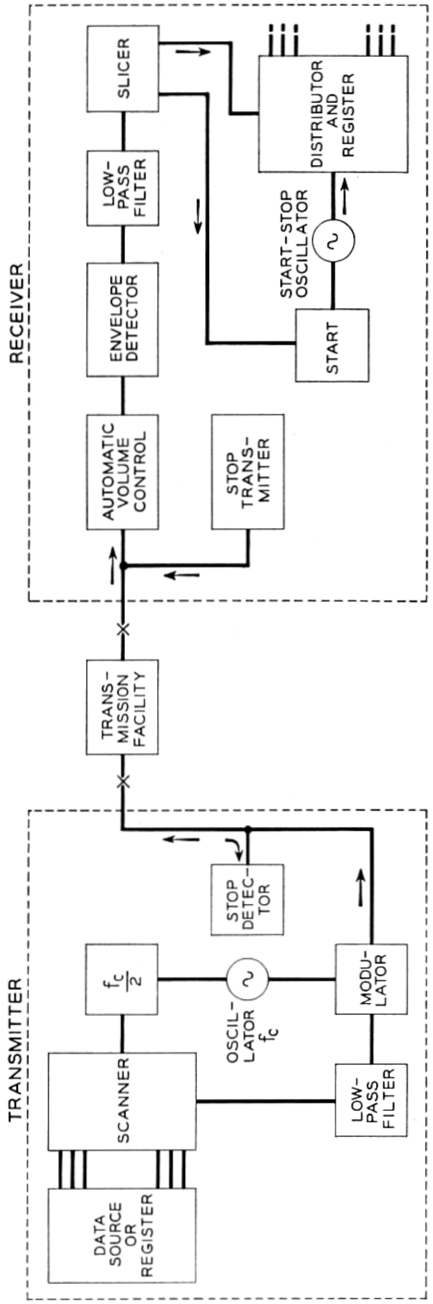

Fig. 5 — Block diagram of signaling system.

TESTS

The system has been tested in the laboratory and on commercial toll circuits in the Long Lines network. The test set-up is shown in Fig. 6. A number selected for transmission was manually set in a comparator and compared with the number actually received. If the two numbers agreed, an "OK" call was counted. If the two-out-of-five check indicated an implausible received number, a re-cycle was recorded and the transmission was repeated until a check was finally obtained. If a plausible but incorrect number was received, an error was recorded. A call was considered mutilated if either a re-cycle or an error was recorded. A number was transmitted at least 100 times for each test condition, and many more observations were made when the mutilation rate was low.

Laboratory tests were made with facilities which included artificial non-loaded lines, carrier terminals, and compandors. One of the carrier terminals was modified so that the frequency difference between carriers at the modulator and demodulator could be varied continuously from 0 to 20 cycles per second. Various band-pass filters were inserted in the transmission facility. Tests were also made over representative commercial telephone circuits and over a number of such circuits in cascade.

The effects of noise were studied by introducing different types of interference through a hybrid circuit. The majority of these tests were made with thermal noise but other tests were made with pulsed thermal noise, contact noise and single frequency tones.

We shall not attempt to characterize all the different types of interference which we employed. The properties of thermal noise are well known and need no description. Since impulse noise has not been studied

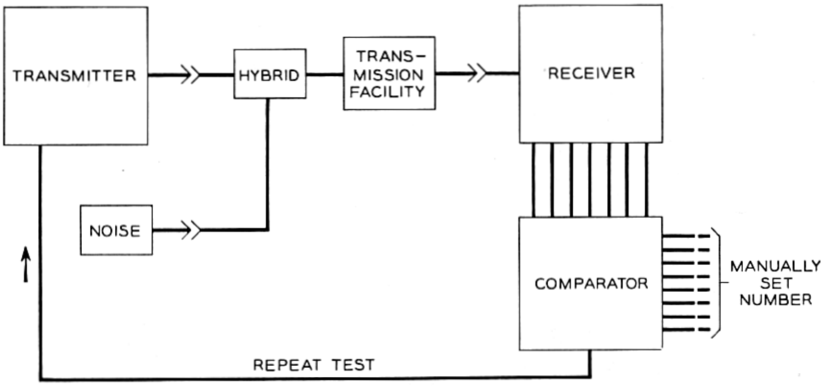

Fig. 6 — Block diagram of test set-up.

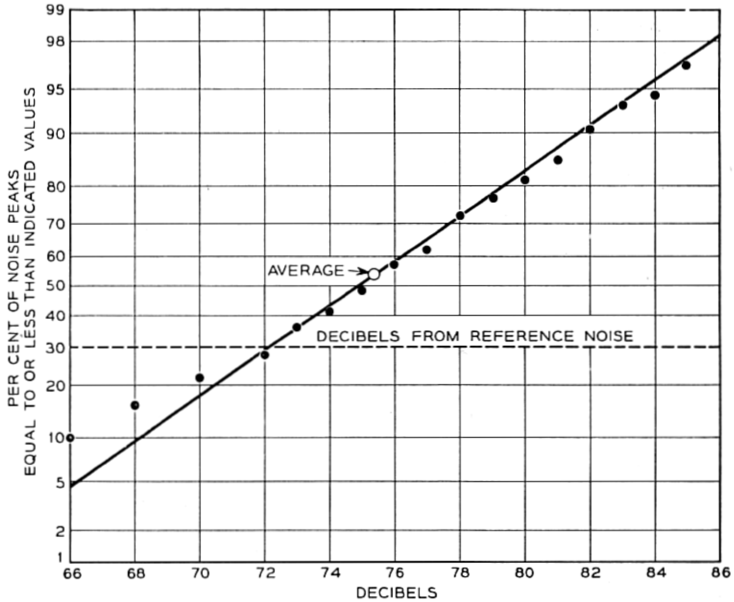

Fig. 7 — Distribution of recorded contact noise peaks. Measured with a 2B noise meter.

extensively, we will discuss the properties of a single sample of recorded contact noise which was employed in our test.

The noise peak voltages were measured with a recording peak voltmeter which could resolve peaks with durations of the order of a millisecond or less. Measurements were also made with a 2B noise meter which is a standard Bell System instrument.[5] Because of the relatively long time constant of this meter, a short peak is measured with an apparent amplitude which is much less than the true amplitude, and this difference will depend upon the duration of the peak. Comparison of the peak voltage measurements with those made with the 2B noise meter showed a reasonable correlation between the two distributions, with a correlation coefficient of 0.78. A short noise peak equal in amplitude to the amplitude of a 0 dbm sine wave is measured by the 2B set as approximately 66 db above reference noise, or on the average the 2B set will measure short noise peaks as if they were about 24 db less than their true amplitude.

RESULTS

Preliminary tests were conducted over representative toll circuits to determine the optimum location of the carrier frequency. This depends upon the type of circuit, but the best compromise appeared to be in the neighborhood of 1,200 cycles. With this choice optimum results were obtained with sidebands symmetrically located about the carrier frequency and occupying the band from 700 to 1,700 cycles. Both 1,000- and 1,200-cycle carrier frequencies were employed in many of our tests.

Laboratory tests using representative lengths of artificial non-loaded cable showed adequate margins. The maximum "twist" in the signaling band was 10 db. No attempt was made to determine the maximum twist that could be tolerated.

From one to four "K" carrier links caused no observable degradation in signaling performance. Frequency differences between the carriers of up to 20 cycles, and continuous variations, did not affect performance at signaling speeds of 100 to 150 digits per second, or 500 to 600 bits per second.

From one to four compandors were inserted in a relatively noise free transmission path with no effect on reliable transmission of pulses. We believe that two properties of the messages contribute to this result. The start pulse, which is long compared to a single bit, prepares the compandor for the signal bits, which follow it. The compandor is then held at a more or less fixed setting, since the use of a two-out-of-five code insures that there will be no long interval between pulses.

Recordings of babble or crosstalk between channels of EB carrier circuits were used to show that cases of this type of interference, which were bad by telephone standards, had no effect on reliable signaling.

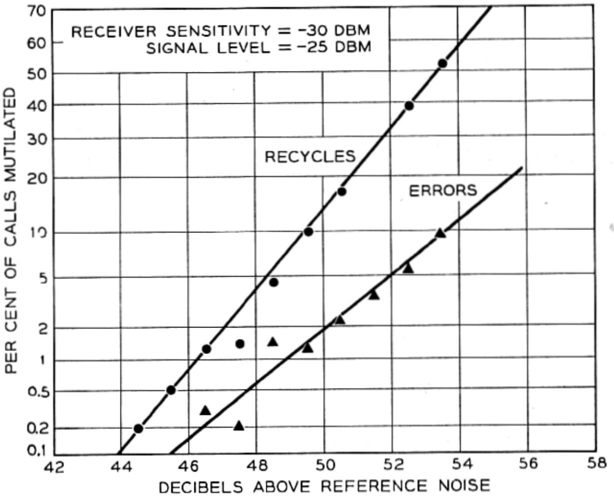

Fig. 8 — Per cent of mutilated calls versus thermal noise power.

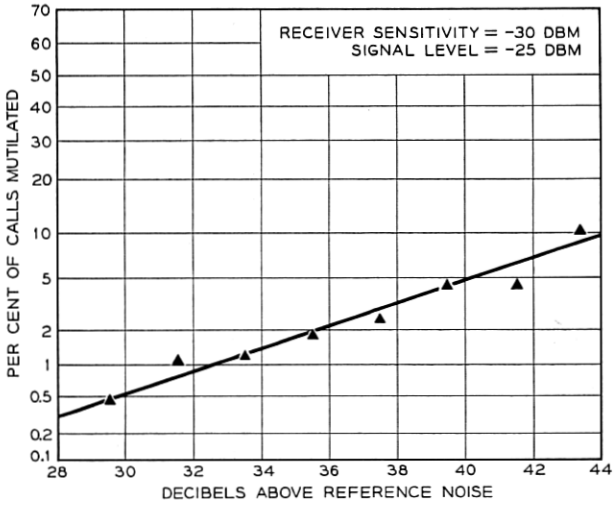

Fig. 9 — Per cent of mutilated calls versus recorded contact noise power.

The effect of thermal noise on the reliability of signaling is shown in Fig. 8. In these tests the peak of the received signal was equal to the peak of a −25 dbm sine wave. The receiver was set to just operate on a 5 db weaker signal, or −30 dbm. A 500 to 1,500 band-pass filter was ahead of the receiver and the carrier frequency was 1,000 cycles. An eight digit number was transmitted but mutilations were recorded for only the first three digits. It is interesting to note that the self-checking code provides a substantial but not perfect check on mutilated signals. Mutilation of two or more of the bits representing a decimal digit causes the failures. The effect of noise at a low level is ordinarily to add a false signal element, or to nullify a true one. Either of these will be detected by the self-checking feature. At higher noise levels there is an increasing tendency to have both effects occur within a single digit. Since the mutilated digits contain two signal elements, one of which is incorrect, the self-checking circuits will fail to detect the error. Since Bell System Standards require that message circuit noise shall be less than 26 db from reference noise at the zero level point, it is clear that the system has ample margin against thermal noise.

Similar data for impulse noise having the peak distribution shown on Fig. 7 are shown in Fig. 9, with errors and re-cycles combined into a single curve. The noise values shown are taken as the value at the 30 per cent point of the distribution curve as indicated above. The margin against noise mutilation for this type of noise is much less than for thermal noise, but reasonably satisfactory performance for telephone signaling is to be expected when circuit noise meets Bell System Standards.

In the case of thermal noise, the maximum peak voltage that we have observed is about five times the r.m.s. voltage, or a difference of 14 db. R.m.s. noise 14 db below the just operate point of the receiver, $-30 - 14 = -44$ dbm should rarely cause a mutilation. Since a sine wave at -90 dbm will indicate reference noise on a 2B noise meter, the tolerable amount of noise is approximately $90 - 44 = 46$ db above reference noise. This figure is consistent with the data of Fig. 8.

Peak voltage measurements of the recorded contact noise show that the actual peaks are about 24 db greater than those measured by the 2B set. We would expect satisfactory operation with impulsive noise about 24 db lower than with thermal noise, or $46 - 24 = 22$ db above reference noise, which is in approximate agreement with Fig. 9.

The system was tested on nine representative toll circuits and four circuits composed of several voice circuits in tandem to produce conditions of far greater severity than would ever be encountered on com-

TABLE I — SUMMARY OF TOLL LINE TESTS

Test	Circuit Loop	Miles Approx.	Facilities	Per cent Re-cylces			
				100 D.P.S.		150 D.P.S.	
				Cap Com	Elec	Cap Com	Elec
1	NY-St. Louis	1,880	“EB” A on “K” Carrier	0	0	0	0
2	NY-St. Louis	1,880	“EB” B on “K” Carrier	0	0	0	6.2
3	1 + 2	3,760	1 + 2	0	0	0	7.6
4	NY-Knoxville	890	“K” + “C” Carrier +4W 19-H-44	0.2	0	0	11.7
5	NY-Jacksonville	2,010	“K” + “L” Carrier	0	0	0	8.2
6	NY-San Francisco	5,950	4 “K” Carrier 2 “K + L” + “L” Carrier	0	0	0	0
7	NY-San Francisco	5,950	“EB” on “K” Carrier “A” and “B” Banks	0	0	0	0.2
8	6 + 7	11,900	6 + 7	0	67	4.2	51
9	NY-Harrisburg	355	4W 19-H-25	0	0	0	.7
10	8 + 9	12,255	8 + 9	0	47	0.2	N.O.
11	6 + 9	6,305	6 + 9	0	0	0	26*
12	NY-Albany	310	2W 16-H-44	0	0	0	0
13	NY-New Haven	156	2W 19-H-174	0	0.3	0	0

N.O.—This condition not operable.
* One error recorded on this condition.

TABLE II — SUMMARY OF OPERATING RANGES IN TOLL LINE TESTS

Test	Range, db in Attenuator			
	100 D.P.S.		150 D.P.S.	
	Cap Com	Elec	Cap Com	Elec
1	0–29	0–31.5	0–26.5	1–24
2	1–32	0–33	4–31	26–32
3	0–27	0–28	4–26	26–27
4	0–31	0–32	0–31	22–30
5	0–33	0–33	0–32	6–31
6	0–33	3–32	5–32	31–33
7	2–35	3–36	4–33	17–34
8	4–35	28	15–34	35
9	0–25	0–27	0–24	0–23
10	0–30	0–31	5–29	*
11	0–26	0–27	1–21	25–26
12	0–25	0–26	0–23	0–24
13	0–14	0–16	0–13	0–15

* In this case circuit was inoperable. In some cases above where one limit is zero, it is probably that the range was considerably greater than indicated above since the normal operating range at 100 digits per second is about 32 db.

mercial circuits. "N" and "O" carrier were not in use at the time of the tests.

Tests were made at two speeds, 100 decimal digits per second and 150 decimal digits per second with an electronic transmitter and with a capacitive scanner. A 500-cycle low-pass filter was used with the electronic transmitter at both signaling speeds. No filter was required with the capacitive commutator. An attenuator preceding the receiver was varied to determine the range of attenuation over which the system would operate satisfactorily. The results are shown in Tables I and II. These tests indicate that a signaling speed of 750 bits per second or higher might be realized. We consider this to be an optimistic conclusion because of the favorable noise conditions during the tests. We believe that signals can be transmitted reliably at about 650 bits per second.

CONCLUSIONS

One of the fundamental limitations on pulse signaling is the phase distortion inherent on all commercial telephone circuits. Without phase equalization and with signals transmitted in a single band, the practical location of this band is from about 700 to 1,700 cycles. Methods of signaling which depend upon recognition of the precise structure of the signal are not practical because of the variable phase shift introduced by non-synchronous carriers of most carrier systems. The envelope of a signal modulated carrier is not dependent upon this type of phase shift. A signaling system which transmits pulses of a 1,200-cycle carrier frequency and employs envelope detection has been found to be reliable at signaling speeds of about 650 bits per second. This system operates with adequate margin over substantially all commercial telephone circuits that were in use at the time the tests were made.

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